1 Exam format and allowed material

- You must bring your student ID in order to take the exam. You must write only your SCIPER number on all the exam answer sheets and on the assignment (not your name).
- As mentioned on the SIE control form available on Moodle, the exam is open book, i.e. all printed/written material is allowed (e.g., books, lecture notes, exercises, solutions, personal notes). Electronic devices are not allowed, except for a simple calculator, as explained below.
- You will need a calculator, but it has to be non-programmable and non-graphing. If you have any doubts about whether your calculator is allowed, please write us an e-mail mentioning the exact model number.
- You must write your answers in black or blue pen. Answers in pencil will not be graded.
- The assignment will be available in English only, and must be answered in English. Note that we do not grade on grammar as long as the point is clear.
- All answers must be written on the provided answer sheets. If you are running out of space, you can ask for extra paper or use your own sheets of paper, but not the assignment sheets (answers on the assignment sheets will not be taken into account; you should only add your SCIPER number there). Do not forget to add your SCIPER number on each answer sheet that you hand in.
- General recommendation: the printed/written material that you will bring with you may be helpful in case of emergency, if you forget some concept and/or detail, but you will not have enough time to read all the slides related to each question. Also, most questions will test your understanding of the concepts transmitted in the course material – the answers are not explicitly written in the slides.
- You will have 3 h time.
- Your assignment will have four parts with corresponding problem sets to solve; their focus will be as follows:
    1. Machine-Learning and Metaheuristics
    2. Coordination and Division of Labor
    3. Multi-level Modeling
    4. Platforms, Localization and Distributed sensing
- A problem set could involve solving a specific problem with a sequence of tightly coupled questions related to the problem or a mixed series of qualitative and quantitative questions loosely coupled among them.
- The assignment will distribute 120 points but we will grade over 100 (i.e. it will be sufficient to make 100 points to get a full score). Each part will distribute 30 points.

2 Literature to be considered for the examination

- **Lecture notes**: all.
- **Reading material**:

All papers and book chapters distributed will help you to better understand the lecture slides. In particular, primary reading documents should be carefully read by the students in view of the exam preparation. Secondary reading are at disposal of the students for better understanding of the concepts explained in the lecture but they do not represent independent examination material.

3 Typical questions and problem sets

Here below is a series of potential problem sets you could be asked to solve and questions you could be asked to answer organized again per part. Keep in mind this is not an exhaustive list! However, it should give you a quite precise idea about what to expect during the exam.

3.1 Machine-Learning and Metaheuristics

Keywords: ACO, PSO, ABC; application to networking (e.g., routing), robotics (e.g., control design and optimization), operational research (e.g., TSP)

- Problem example: given a TSP problem (weighted graph), generate a solution using the desirability only, using the pheromones only, with/without elitism, with/without local search, with/without one of the rules of ACS, etc. -> you will have to crunch out a series of cities the ant(s) have gone through with their distances.
- Problem example: you get a control architecture with a certain number of parameters and you are asked to encode the problem properly using a PSO (how many particles, inertia, etc.), strategy (noise-resistant, public/private, heterogeneous/homogeneous …).
- Problem example: you get a series of candidate solutions in a population and you are asked to calculate its diversity using the social entropy and a standard Euclidian distance, the specialization, etc.
- How does PSO work? You could be asked to elaborate your explanations using vectors in a 2 dimensional space, point out specific differences, etc.
- What are the differences between AS and ACS? How do they work? You could be asked to elaborate your explanations on a simple example graph.
- What are the differences between AntNet and ABC? How do they work? You could be asked to elaborate your explanations on a simple example graph.
- What do you need to do for dealing with noisy fitness/performance function? You could be asked to follow a specific particle path with a noise resistant and a regular algorithm or illustrate your answer with pseudocode.
- What is the credit assignment problem in collective systems? Can you give examples (possibly based on lecture case studies) on which this problem will arise?

3.2 Coordination and Division of Labor

Keywords: stigmergy; self-organization; collective decisions; self-assembly, self-aggregation; trail-laying/following mechanisms; ant networks and bridge *experiments; Reynolds rules; graph-based distributed control; flocking and formations; threshold-based algorithms; market-based algorithms*

- Problem example: given a group of perfectly holonomic vehicles with the position and a graph-based distributed control law based on the Laplacian of the connection graph, illustrate graphically the evolution of agents' trajectory, calculate various properties of the resulting connection graph at various instant of time.
- Problem example: given a trajectory, derive the kinematic equations $\xi_I(t)$ of the movement of a differential wheeled robot moving on this trajectory. Now consider a group of robots that need to keep a given formation in which the leader follows this trajectory. What information would the follower robots need in order to be able to keep the formation? Give a minimalistic set of sensors that would be able to provide this information. Justify your choice.
- Problem example: consider a group of robots that need to reach a collective decision. Given a (set of) steady state(s) towards which the system should converge, how would you have to program the behavior of the robots to reach it? How would you need to modify you strategy to reach a different given outcome of the system?
- Problem example: given a task allocation scenario, decide whether a market-based or a threshold-based strategy would be more suitable. Justify your choice and encode the problem for the chosen strategy (what is the stimulus, threshold, local/global objective functions etc.)
- Problem example: given a series of tasks (with precise locations in a 2D space) to solve and a set of robots (with also precise location in a 2D space), derive the resulting robot-to-task allocation under specific conditions (e.g., different series for presenting tasks, bundles) and algorithms class (threshold-based or market-based).
- Problem example: consider a group of virtual or real ants, a multi-path bridge with specific lengths, a food source, and a nest (or multiple food sources in an open space with specific distances and a nest); what will be the final chosen route according to specific ant behavior (deterministic, probabilistic, specific values)? How much time it will take (probabilistic estimation)?
- Problem example: given a system of ODE representing the evolution of worker allocation to given given task(s) as well as the demand evolution associated to the task(s), carry out a steady state analysis and analyze the stationary agent allocation and demand level.
- Problem example: caste a given scenario (multi-tasks, multi-agents) into a market-based solution; define utility functions; calculate the resulting allocation on a simple numerical example.
- What are the differences between formation and flocking? Do you know a simple algorithm able to maintain the formation of a group of robots? (formulate with pseudo-code). Do you know a simple algorithm able to maintain a flock of robots? (formulate your answer with pseudo-code). What sensing/communication/computation capabilities do you need for running them? Which one will be more expensive in terms of sensing/communication/computation?
- What are the key ingredients of self-organization? Identify the key ingredients of self-organization in a given experiment we saw in the course and give supporting rationale.

3.3 Multi-Level Modeling

Keywords: submicroscopic models (e.g. Webots), microscopic models (e.g. multi-agent); macroscopic models (e.g., mean field); modeling assumptions; differences between modeling levels; linear and nonlinear models; parameter calibration; steady state analysis

- Problem example: given an arena of a certain area, a certain number of robots, a certain number of behaviors, formulate a macroscopic model for capturing the system dynamics; carry out a steady state analysis for specific parameters
- Problem example: given an arena of a certain area, a certain number of robots, a certain number of behaviors, formulate a PFSM and illustrate in details with rationale your choices for modeling at the various levels (explicit parameters represented, spatiality handling, etc.).
- Problem example: simplified models of obstacle avoidance, robot self-aggregation, object aggregation, stick-pulling from the papers as a start; we will change various details and ask you to reformulate the equations at macroscopic level, carry out a steady state analysis, and compare results with the original model.
- Clarify various sources of errors in going up with abstraction (physical -> sub-microscopic -> microscopic-> macroscopic) with the typical implementation we saw in the course (real miniature robots -> Webots -> multi-agent non spatial -> mean-field ODE).

3.4 Platforms, Localization and Distributed Sensing

Keywords: sensors and actuators; controller classes (e.g., proximal, distal); control architectures (e.g., Braitenberg, ANN, behavior-based such as motor-schemas); odometry; feature-based localization; sensor networks principles and applications; mobile and robotic sensor networks; energy management and power consumption in sensor networks;

- Problem example: given time series of speed on both wheels, calculate where the robot will be using odometry (without slip, with slip, with some parameter having special values, etc.); knowing the initial state, compute the covariance matrix that reflects the positioning uncertainty after a specific set of movements; combine odometry with a distance sensor measurement and explain graphically localization accuracy.
- Problem example: given a robotic platform with a certain perception-actuation configuration, a given task to solve, formulate a proximal (e.g., Braitenberg architecture) and a distal (e.g., behavior-based) control solution; outline number of parameters to be found and propose solutions for reducing the overhead for finding the parameters for each architecture type (reducing their number, other techniques).

- Problem example: given a mission for a robotic platform, propose a control architecture based on the motor-schema framework with specific control laws for each motor-schema and appropriate sensory suites.
- Problem example: calculate energy budget for communication, computation, sensing in a sensor network given a specific sensing task.
- Problem example: propose energy-saving control laws for a specific simple example of field; illustrate the dynamic of message sending at specific events/instances of the field.
- Problem example: given a certain field to sense, propose a concrete deployment strategy for a sensor network (number of nodes, node locations) given specific limitations of the sensor node in sensing, communication, and computation.
- Problem example: given a certain static/mobile/robotic sensor network deployment with some assumptions on it sampling strategy determine its state after a given number of time steps; calculate its performance; calculate the network's temporal and/or spatial resolution.
- Classify a list of sensors into the appropriate bin (exteroceptive/proprioceptive, active/passive) and add rationale for your choice.
- Classify a list of vehicle as holonomic/non-holonomic and add rationale for your choice.
- Analyze the response of a specific sensor: resolution, bandwidth, range, linearity, accuracy, precision, etc.
- What are the main research issues/challenges in sensor networks? What are the main application domains so far? What are the typical problems encountered in the deployment of WSN in the field?