1 Exam format

The oral exam will take place in English; therefore, the presentation and follow-up discussion will involve questions and answers in English.
No time for preparing previously assigned questions is foreseen: the student will enter the examination room when called in and will start the exam. The exam will in total last roughly 18 minutes: 3 minutes for presenting the own contribution to the course project with the help of slides and a beamer, 3 minutes to answer questions about the presented slides or the whole course project, and 12 minutes for discussing two topics of the course, each of them involving questions and answers (Q&A) for 6 minutes. For the course project, the leadership for the Q&A session will be taken by one of the Teaching Assistants (TA) while the main instructor will be responsible for the session related to the course topics. As in any other oral exam, a neutral observer will be there to ensure the exam fairness.
The students will be asked to argue technically and document their answers with the help of pen and paper (we are expecting as precise as possible answers with plots, algorithmic formulations, equations, and so on). The written paper will be kept as exam record. As the whole Q&A session (on course project and course topics) will take place around a table, all the participants must wear **protection masks**, according to the EPFL regulations for the current pandemic period. We will take care of disinfecting the discussion place and used objects, from one student to the other, to the extent possible.

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 is at disposal of the students for better understanding of the concepts explained in the lecture but they do not represent independent examination material.
  Sometimes, even in primary reading, not all aspects of a paper are covered in detail. Please check out lecture slides for guidance. In particular, we will certainly not pull out a paper and ask you to explain what is the exact meaning of a given formula or so but we are expecting that the formalism covered in the slides is clear for you and you can reconstruct it. The exercises will be treated in the same way of the reading material: they should have helped you to better digest the lecture content but we will certainly not ask specific questions related to a lab assignment or solution if not covered explicitly in the lecture as well.

3 Typical potential questions

Here below is a series of potential questions you could be asked to answer organized per main topic seen in the lecture. 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 Metaheuristic Optimization

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

- What are the differences between AS and ACS? How do they work? Can you write the pseudocode of the algorithm? You could be asked to elaborate your explanations on a simple example graph.
- What are the differences between AntNet and ABC? And those between ACS and AntNet? You could be asked to elaborate your explanations on a simple example graph.
- What is the TSP problem? Why is it difficult? How does an ant choose its next path? How does the elitism mechanism work? How can be local search combined with the metaheuristic principles? What are the advantages of each of the two components?
- How does PSO work? Can you write the pseudocode of the algorithm? How do you choose the meta parameters of the algorithm (e.g., particle numbers, neighborhood type, etc.) as a function of the fitness landscape? You could be asked to elaborate your explanations using vectors in a 2-dimensional space, point out specific differences, etc.
- What do you need to do for dealing with noisy fitness/performance function? How many techniques you know for handling a noisy performance evaluations? What are advantages and drawbacks of each of these variants? Can you illustrate with a flowchart or pseudocode one of these variants?
- What type of adaptation strategies do you know? What are the key 3 criteria/axes to classify these strategies? Can you illustrate with one specific example how they can be applied?
- 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? Do you know possible methods for solving the credit assignment problem in a collective system?
- How does a simple in-line search algorithm work? How many variants do you know? What are advantages and drawbacks of such simple algorithm?
- What is specialization and what is diversity? How can you measure them? What is social entropy? Can you illustrate how it works with an example seen in the course? Do you know an alternative method to measure diversity?

3.2 Coordination and Division of Labor

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

- 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.
- What are the differences between qualitative and quantitative stigmergy? Can you illustrate them with some examples?
- What are the bridge experiments discussed in the course? Why do they work? What happen in case a source of food or a branch is added later? Why certain ant species do get stuck when a shorter branch is added at later time? What happen if we have more than two paths on the bridge or more than two sources of food to choose from?
- 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?
- How many and what are the Reynolds rules? How do they work? What happens if you leave one of them out?
- Can you explain how a continuous consensus control law is working? Can you do an example in 1D or 2D? What is the Laplacian of a network? You could be asked to calculate the Laplacian for a small graph. What localization information you need to run a Laplacian control law? Can you give two different localization strategies needed to implement a Laplacian control law on a multi-robot system? How can you achieve different formation topologies in the context of a Laplacian control law?
- How do threshold-based algorithms work? How do market-based algorithms work? Can you explain with an example? How are tasks defined typically in one of the other class of algorithms?
- For a given problem, can you define the stimulus, threshold or the local/global objective functions? Can you write the macroscopic equation for a single-task two-caste system? Can you formulate different demand evolutions?
- How many variants of threshold-based and market-based algorithms do you know? Can you explain with an example these variants?

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

- Can you 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).
- 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; can you calculate some parameters as a function of other in stationary conditions? How?
- Can you illustrate how the stick-pulling experiment was modeled in its essence (simplified model)? Is this a linear or nonlinear model? What metrics were used for evaluating the performance of the team?
- Can you illustrate how the seed-assembling experiment was modeled? Is this a linear or nonlinear model? What were the modeling difficulties of such case study? What metrics were used for evaluating the performance of the team?

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; power consumption and mobility in sensor networks.

- What classification axes for sensors do you know? Can you give examples in each of the category and explain how these specific sensors work?
- What performance metrics do you know for a sensor? What is the difference between accuracy and precision? How do you calculate them?
- 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?
- What are the key principles for designing a simple, robust and energetically efficient algorithm to gather environmental data with a sensor network?
- What is a Braitenberg vehicle? How does it work?
- What is the difference between proximal and distal controller? Examples?
- Can you tell me how you would build a controller for obstacle avoidance?
- What is the kinematic forward model of a vehicle? How does look like the one for a differential-drive wheel robot? What's useful for? Can you mathematically formulate a kinematic forward model for a differential wheeled vehicle?
- What is odometry? How does it work? What are the assumptions for good odometry? What is the difference between an odometry based on wheel encoders vs. accelerometers? Can you explain the effect of wheel slip on wheel-based odometry?
- What indoor positioning techniques do you know? What main classification axes for positioning systems do you know? Can you give some examples?
- What does it mean feature-based navigation? What is a Kalman filter? What is it good for? Can you explain how it works mathematically in 1D?