Lab 6: Collective Decision in Sensor/Actuator Networks

This laboratory requires the following equipment:

- Webots simulation software (Linux)
- One MICAz radio node module per group of 4 students
- One full e-puck kit per student: an e-puck robot with battery, a communication board, a speaker board and a Bluetooth dongle
- One white arena per group of two students

The laboratory duration is up to five hours. The TAs will leave after 3 hours, but if you want to continue, talk to the TA about returning the hardware later. We encourage you to take notes during the course of this laboratory to aid in the exams. A solution will be posted a few days after the lab session.

Office hours

Additional assistance outside the lab period (office hours) can be requested using the **dis-ta@groupes.epfl.ch** mailing list.

Information

In the following text you will find several exercises and questions.

- The notation $\mathbf{S_x}$ means that the question can be solved using only additional simulation or an experimental manipulation.
- The notation $\mathbf{Q_x}$ means that the question can be answered theoretically, without any simulation; if you decide to write a report, your answers to these questions should be submitted in your report. The length of answers should be approximately **two sentences** unless otherwise noted.
- The notation $\mathbf{I_x}$ means that the problem has to be solved by implementing a piece of code and performing a simulation.
- The notation $\mathbf{B_x}$ means that the question is optional and should be answered if you have enough time at your disposal.

1 Introduction

This lab is focused on collective decision algorithms. In Part 1 you will experiment with a simple collective decision making algorithm using real e-puck robots and in Part 2 you will study a similar algorithm in a Webots simulation. Before starting, you need to get familiar with the major modules of the systems explained below.

1.1 MICAz Mote

The MICAz is an off-the-shelf platform commonly used for deploying a wireless sensor network (WSN). It operates in the 2.4GHz range, and is IEEE 802.15.4 compliant. TinyOS (http://www.tinyos.net/), while originally designed for the MICA family, has been adopted by several other devices as well. Other features include:

- IEEE 802.15.4/ZigBee compliant RF transceiver
- 2.4 to 2.4835 GHz, a globally compatible ISM band
- 250 kbps data rate
- Runs TinyOS 2.1
- Has a wide range of available sensor boards, data acquisition boards, etc.

In this lab we will use MicaZ Motes to increase the range of communications between e-puck robots.

1.2 e-puck Communication Module

The e-puck robots in this lab will be capable of wireless communication via a radio board (see *Figure 1-1*). This board uses the same Zigbee protocol as the sensor motes, allowing e-pucks to communicate with motes, as well as with each other. The communication range of the board can be adjusted from approximately 10 centimeters to 5 meters. We will use only short range (~ 15 cm) radio communication with the e-pucks in this lab.

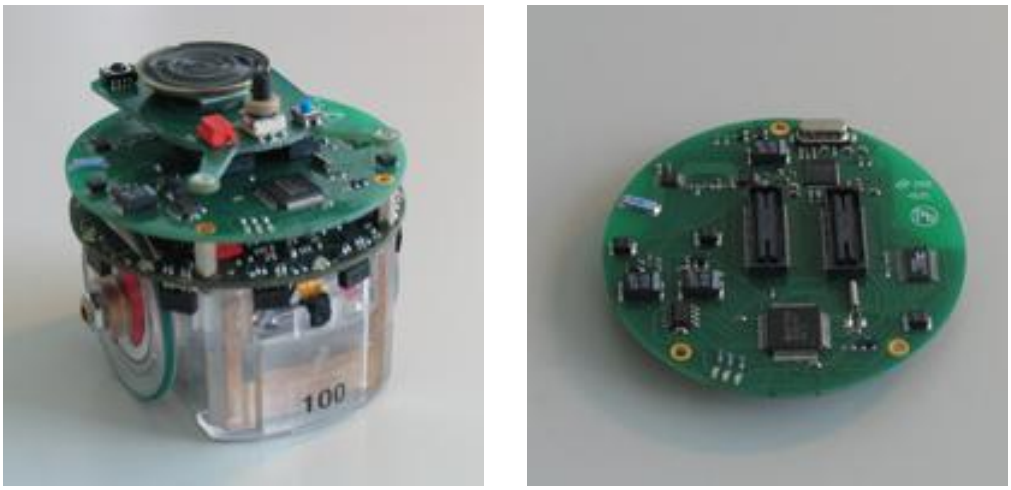


Figure 1-1: e-puck Robot with Radio Module

1.3 Collective Decision

Collectively taking a decision is equivalent to solving a discrete consensus problem where the possible choice set is pre-established. The final choice is then the result of the consensus process, similar to the case of continuous consensus problem. One difficulty with distributed intelligent systems is that there is no central arbiter to make global decisions. For example, how does a hive of bees decide where to construct a new nest, or a cockroach society pick a shelter? To address this challenge, the multi-unit system must use an effective method for making a collective decision. In distributed robotics, this usually is accomplished by each robot forming an opinion

on the issue, and varying that opinion over time based on the interactions it has with other members of the system, until the entire swarm or network converges on a single opinion. Often the interactions within the distributed intelligent system are very limited, making rapid convergence difficult.

1.4 Hybrid Networks

When using simple hardware devices such as miniature robots and sensor nodes, units tend to be limited in their capabilities. Often tasks will require a functionality which is not available to a single type of device. In these cases, it can be helpful to use a **hybrid network**, which is composed of two or more types of devices working in tandem. In this way, very simple units can be combined to accomplish more complex tasks.

1.5 Radio Communication in Webots

A plugin module has been developed for Webots which will allow the simulation of realistic radio communication within a Webots world, using libraries from the NS3 network simulation architecture (http://www.nsnam.org/). Note that as these libraries only exist for Linux, it will **not** be possible to use the plugin in Windows.

2 Part 1: Collective Decision with real hardware

2.1 Wireless Sensor Networks as Distributed Intelligent Systems

One type of multi-unit system in which we can potentially apply the principles of distributed intelligence is a wireless sensor network. Note the similarities between a distributed, networked robotic system and a wireless sensor network: in fact, both systems can be seen as specific instances of a broader category of "sensor and actuator networks", or according to a recent labeling adopted by the research community we could classify them as instances of "distributed cyber-physical systems".

2.2 Collective Decision in Real World Hybrid Networks

We are going to try a collective decision with real hardware. To do this, you have to **team up with another student**. Your team should have 2 e-pucks, each equipped with a communication board.
Start your computer with Linux and plug in the Bluetooth dongle.

Download the lab code from Moodle: lab06.tar.gz and unpack it into Lab06 directory:

```
$ tar xvzf lab06.tar.gz
```

You will also need to download the e-puck development environment onto your computer. Copy these files in your "Lab06" directory by doing the following ("Lab06" is the directory you just uncompressed which contains the "Code" folder):

a) Download (clone) the necessary files from the e-puck git repository into your "Lab06" folder by going into "Lab06" and typing:

```
$ git clone https://disalgit.epfl.ch/epuck/epuck.git
```

The download might take a few minutes.

b) Inside the *epuck/EpuckDevelopmentTree/* directory, you will find a *library/* and a *program/* directory. In order to use the e-puck library code that you just downloaded, it must be compiled. Do this by going to the *library/* directory and executing *make*:

```
$ cd epuck/EpuckDevelopmentTree/library
$ make
```

Open a new terminal, compile and program your e-pucks with the provided controller using the following commands:

```
cd lab06/Code/collectivedecision
make
```

Turn on the robot and upload your code (replace ## in the following command with your epuck ID).

```
epuckupload -f collectivedecision.hex ##
```

As soon as dots appear on your screen (`$ .....`) press the blue reset button on the robot. This will start writing the program to the e-puck memory. Now stars will appear on your screen, indicating that the robot is being programmed (`$ .......**********`). When no more stars appear, the robot has finished programming.

When the robot is programmed, we need to calibrate its infra-red (IR) sensors. Make sure the robot is turned off. Then set the selector switch on the top such that the arrow is pointing to the rear of the robot. This puts the robot into calibration mode. Put the robot in a spot where it is at least 30 cm away from any obstacle. Turn it on and make sure you remove your hands. The red LEDs will blink briefly while the IR sensors are being calibrated. When the red LEDs turn off and on again and stay on, the IR sensors are calibrated and the calibration information is stored in the non-volatile memory. This means that you only have to do this calibration once for each robot. Turn the robot off and change the selector switch so that the arrow points to the front of the e-puck.

Now use the supplied walls to build a quadratic arena in which you will be running the e-pucks in the upcoming experiments. When you switch on or reset your e-pucks, they will randomly choose either right wall following (state R) or left wall following (state L). The collective decision algorithm then works as follows: each e-puck listens for messages during time $t=1s$ and counts the number of left wall follow messages (n_L) and right wall follow messages (n_R) that it receives. If the majority of received messages coincides with its own state, it keeps that state—otherwise, it changes the state with probability $p=0.5$. Right afterwards, the e-puck locally broadcasts a message with its own state (independent of whether the state was changed or not). Note that such messages are received by e-pucks in the vicinity (~ 15 cm) only.

Note that the e-pucks are not synchronized with each other. (You can neglect the case where two e-pucks simultaneously transmit their state, as it is very improbable.)

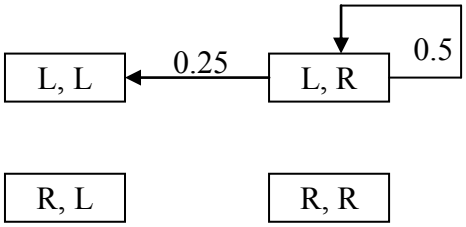
Q_1(5): Switch on your e-pucks and put them in different corners of the arena. Can you observe collective decision? About how much time does it take until both e-pucks are in the same state?

Q_2(15): With just two e-pucks, the system can be in one of four possible states, as shown in the graph below. The system (consisting of 2 e-pucks) has 4 states:

State S1: Robot 1: L , Robot 2: R
State S2: Robot 1: L , Robot 2: L
State S3: Robot 1: R , Robot 2: R
State S4: Robot 1: R , Robot 2: L

Each time one of the e-pucks takes a decision after having received a message from the other e-puck, the system state may change.

Transitions (between the states) happen when an event occurs. The events are the messages communicated between the robots. The e-pucks send messages every one second. Right before sending a message the e-puck makes a decision and probably changes its own state. Complete the graph with all possible transitions. What are their probabilities? *Hint:* looking at the code may help figuring out the transition diagram.



Q_3(10): Which system states are stable (absorbing states) according to the graph? (Stable states are states which the system doesn't leave, once it has reached them.)

Team up with another group now. You should have 4 e-pucks and 1 MICAz sensor node in your team. The ID number (labeled "M##") of the MICAz that you have is the group ID that it is programmed with. In order to have all the 4 e-pucks communicate through the MICAz node to each other, you need to **set a common group ID in the file *lab06/Code/collectivedecision/collectivedecision.c***. Open the file and change 00 in:

```
#define   GROUP_ID  0x00
```

to the MICAz's group ID.

Compile and reprogram all four e-pucks with your modified code. Place the MICAz outside (between) your two arenas with e-pucks still inside them. The e-pucks

can then occasionally communicate with the MICAz, which can relay messages between the two arenas; hence forming a backbone network between the e-pucks. Note that while e-pucks are configured to send messages within a range of about 15 cm only, the range can be extended with the MICAz acting as a relay. It has enough transmission power to send messages across the whole room. This is why we need the team number to distinguish between different teams: the MICAz simply discards all messages that do not have the same team number. Messages that are not discarded are re-sent.

Q_4(5): Switch on the MICAz and reset the e-pucks. Do you observe collective decision making? How long does it take now?

Q_5(5): Now you will intentionally try to influence the decision. Turn the selector switch of **one** e-puck to either 90° left or 90° right, for fixed left or right wall following, respectively. (If the dial is in an invalid state, all the LEDs will be turned on.) What happens now? Why?

3 Part 2: Collective Decision in Webots

We are now going to work with e-puck robots in Webots endowed with a simulated copy of the radio module, which leverages the NS3 radio communication plug-in [1]. The collective decision algorithm is very similar to the one in part 2.

Q_6(5): Open the world *collective_decision.wbt,* compile the controllers and run the simulation. This world contains 10 robots with random initial wall following states. Observe the default settings for broadcast frequency, and opinion change probability in the controller code. Does a collective decision happen now? If so, how long does it take? (Note: You may want to run this in fast mode. If the robots stick together, either manually move one of them or re-start the simulation.)

I_7(5): Try changing the opinion change probability (OPCHANGE_PROB) of the robots. What happens for very low probabilities (e.g. 0.01)? What happens for very high probabilities (e.g. 0.99)? Why?

I_8(5): Increase the decision interval (DECISION_INTERVAL) to *t=2s*. How does this affect the time until a collective decision happens? What happens if you increase it to *t=20s*? Why?

I_9(5): Open the *collective_decision.wbt* world file in a text editor and change the transmitter power of the radio of all the robots (txPower) from -10 dBm to +20dBm (a much larger value). Note that there are 10 robots and you need to do this for all of them. Revert the simulation. What happens now? Why?

A scalable approach to solving this discrete consensus problem might be for the robots to use a threshold-based algorithm, like the one previously deployed for task allocation purposes, for deciding whether to change their current state. Assume that all robots occasionally broadcast the state which they are in (either “L” or “R”) and that your robot therefore always knows n_L, the number of robots in state “L” and n_R the number of robots in state “R” within its communication range.

Q_{10}(10): What would be a sensible value for the stimulus s? What would be a sensible value for the threshold θ? Please indicate s and θ in terms of n_L and n_R.

Q_{11}(15): Describe (**do not** implement!) an algorithm with the following two stable states:

- 10 robots doing left wall following, 5 robots doing right wall following
- 10 robots doing right wall following, 5 robots doing left wall following

The system must converge towards these states. You can assume that each robot has a unique ID in the range 1 – 15 and that robots don't fail/crash. (In addition, you can assume that each robot receives an infinite number of messages from all other robots in any infinitely long time interval. In other words: there is enough randomness in the system so that e-pucks meet with each other from time to time.)
Hint: This is equivalent to having all 15 robots doing left wall following, with exactly 5 of them also playing a sound on their speaker.

Q_{12}(15): How would you have to extend your algorithm if the 15 robots had unique IDs in the range 1 – 200 (with some numbers left out)?

References:

Llatser I., Jornod G., A. Festag A., Mansolino D., Navarro I., and Martinoli A., "Simulation of Cooperative Automated Driving by Bidirectional Coupling of Vehicle and Network Simulators," *Proc. of the IEEE Intelligent Vehicles Symposium,* June 2017, Redondo Beach, USA, pp. 1881-1886.