# Online adaptation of robots controlled by nanowire networks: A preliminary study


Paolo Baldini, Michele Braccini, Andrea Roli
p.baldini@unibo.it m.braccini@unibo.it andrea.roli@unibo.it

University of Bologna


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Good morning to everyone, my name is Paolo Baldini and I'm here to present a preliminary study that I conducted with Andrea Roli and Michele Braccini about the online adaptation of robots controlled by nanowire networks.

# Motivations and goals

Behavioural adaptation





Motivations and goals
Behavioural adaptation

Starting from the motivations, one frontier in robotics aims to endow the robots with the ability to adapt to changing contexts and environments, allowing to keep carrying on the work also when the initial conditions under which the system was developed changed. This may be the case of a warehouse that has been reorganized, or more extremely a space-robot that have to adapt to unknown environmental conditions. Basically, we want the robots to behave like biological beings, adapting and surviving in different ecological niches.

# Motivations and goals

Behaviour {
- Control system & logic
- Robot physical structure
- Working environment





Motivations and goals
Behaviour { Control system & logic, Robot physical structure, Working environment

Nevertheless, before talking about adaptation, we have to define what the behaviour is. This is the visible result that arise from a system-environment interaction where, in case of a robot, the system is composed by the control system / logic and its physical structure.

# Motivations and goals

Behaviour $\begin{cases} \text{Control system \& logic} \\ \text{Robot physical structure} \\ \text{Working environment} \end{cases}$ Phenotype $\begin{cases} \text{Genotype} \\ \text{Environment} \end{cases}$





Motivations and goals
Behaviour Control system & logic Robot physical structure Working environment Phenotype Genotype Environment

This relationship is the same that we see between genotype and phenotype, where the second depends on the first and on the environment.

Due to this relationship, talking about behavioural adaptation is for us equivalent to talk about phenotypic plasticity.

# Requirements

- Driving strategies;
- Online adaptive methodologies;
- Suitable control systems.





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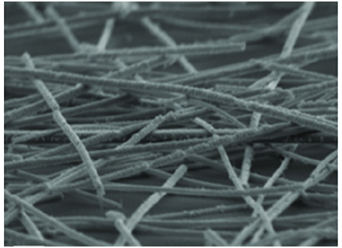
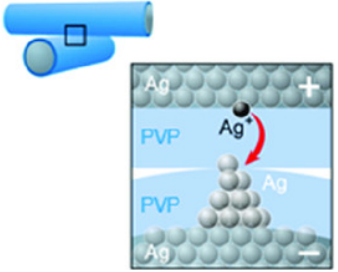
- Online adaptive methodologies;
- Suitable control systems.

In order to achieve adaptation, the first thing that we need is to define a driving force (or strategy) that represents the robot goal. This is a self-evaluated performance that will act as a selective pressure, and drive the changes that are performed by the adaptive mechanism. This has to act on the robotic control system (i.e., the genotype), without modifying it. Additionally, the design of the mechanism has to consider the intrinsic characteristics of the controller (e.g., a graph based system). Therefore, before defining the adaptive mechanism, we have first to select the robotic control structure.

# Nanowire networks

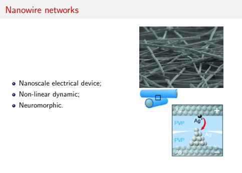
- Nanoscale electrical device;
- Non-linear dynamic;
- Neuromorphic.







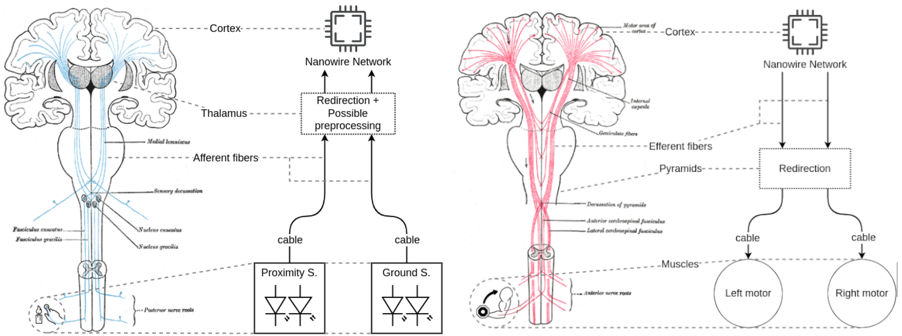



We decided to use a novel electrical device with non-linear dynamics: the Nanowire Network.

This is a graph-like structure composed of nanometric wires. It is a memristive device, meaning that its internal state depends on its recent history. More specifically, the strength of the connection between the wires depends on their previous stimulation. This is similar to what happens in Hebbian learning, with the connection between neurons that activate together becoming stronger. Because of this property, we can say that the device is neuromorphic.

# Robotic architecture

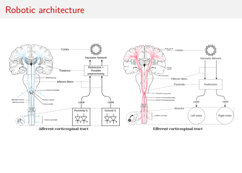



Afferent corticospinal tract

Efferent corticospinal tract





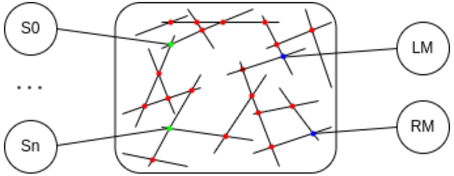



The nanowire network represents the genotype and is therefore not modifiable. In order to exploit its capabilities, we decided to use a variant of the Reservoir Computing architecture, a framework for the use of highly dynamic immutable systems for computation. This is modified in order to be used online. The resulting model gains inspiration from biology, representing the corticospinal tract. The idea is that the sensory inputs are forwarded to specific points of the network, influencing the "reasoning" of the robot.

Accordingly, the motion commands are taken from specific points and used to control the actuators.

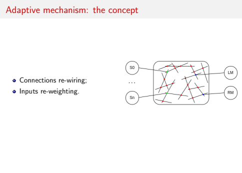
# Adaptive mechanism: the concept

- Connections re-wiring;
- Inputs re-weighting.



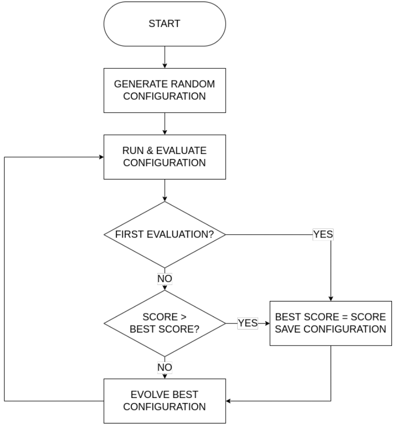




As mentioned, the main point of the adaptive mechanism is the modification of the behaviour through the reconnection of the inputs to different point of the network. Nevertheless, we also decided to apply a weighting to the incoming signals. This helped in accentuate the perception of not very sensible sensors, and in attenuate sensible ones. Additionally, it allowed the system to give more importance to specific inputs, and to ignore others. For the outputs, this helped in calibrate the control signal.

# Adaptive mechanism: the algorithm



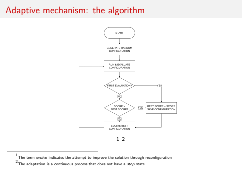

1 2

[1] The term *evolve* indicates the attempt to improve the solution through reconfiguration

[2] The adaptation is a continuous process that does not have a *stop* state

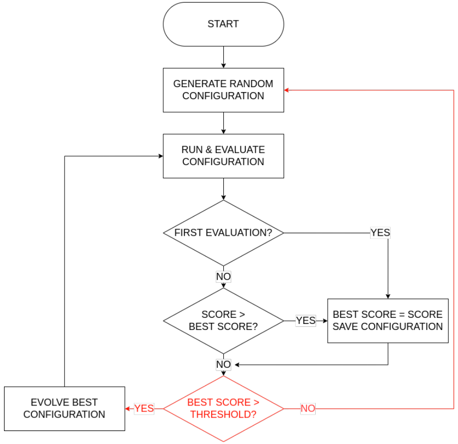






The described concept is performed continuously during the robot life, and allows to optimize a configuration thanks to some lesser changes in connections and weigths. The algorithm starts from a random configuration (i.e., a set of connections and weight), and evaluates it during a fixed period of time. If the resulting performance is the best until now, it is saved together with the configuration, that is subsequently adapted; otherwise the precedent best configuration is evolved again differently. The cycle continuously repeats, guaranteeing the solution to improve.

# Adaptive mechanism: the algorithm

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[1] The term *evolve* indicates the attempt to improve the solution through reconfiguration

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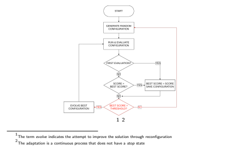
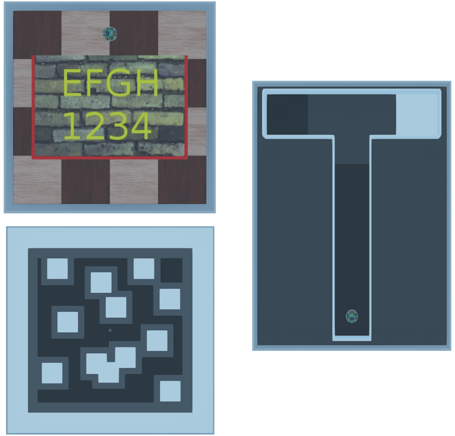


Nevertheless, during the experiments we noticed that the optimization converges faster if some really bad configurations are discarded, and new random one generated. Therefore, we decided to insert a threshold value, allowing the system to find good enough solutions before starting with the adaptation. This little change allowed the robot to adapt faster, and to run the experiments in a much shorter time.

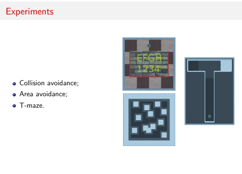
# Experiments

- Collision avoidance;
- Area avoidance;
- T-maze.







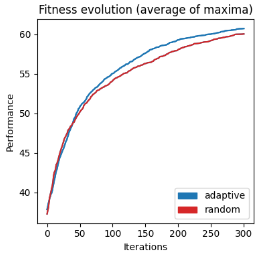

The experiments consisted in the adaptation to three tasks in three different simulated environments.

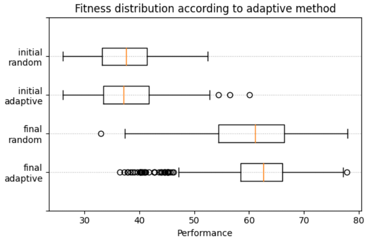
The first consisted in a collision avoidance, where the robot was asked to avoid obstacles while continuing on a straight line. The second is the area avoidance, where the obstacles become virtual. This test also used only one sensor, showing that it is possible to obtain a wandering behaviour and still avoiding obstacles with a very limited system. The third required the robot to reach the correct end point in a T-shaped maze, where the goal destination depends on the color of the floor at the start of the run. This task was executed differently from the others. Indeed, the control system run continuously and never reset, while the robot is kidnapped at the start of each trial. This change was decided in order to more easily evaluate the ability of the adaptive mechanism to exploit the network memory through a fine tuning.

In all the tasks the configurations are tested online, meaning that the state of the controller is never reset at the start of a new evaluation. With the T-maze task as an exception, also the robot position is ever reset.

# Results

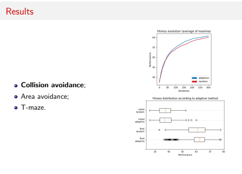
- **Collision avoidance**;
- Area avoidance;
- T-maze.







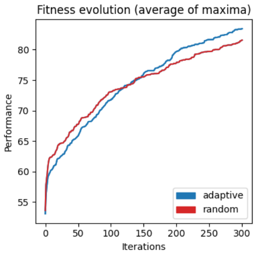



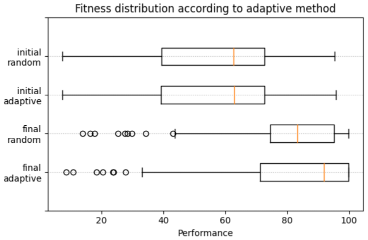

The result seems to confirm the validity of the mechanism, allowing the robot to obtain better scored in all the tasks.

In the Collision Avoidance, the results difference is not impressive, mostly due to the low complexity of the task and on the highly redundant signals from the sensors. Nevertheless, we can clearly see an improvement.

# Results

- Collision avoidance;
- **Area avoidance**;
- T-maze.




Results
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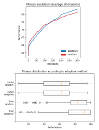
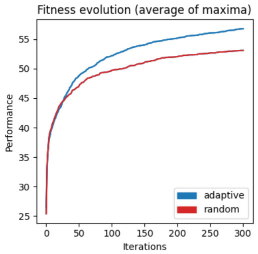
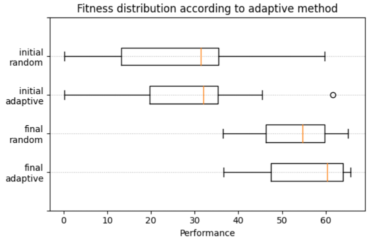


In the Area Avoidance, the improvement is more evident, especially in the performance distribution. This is due to the more fine-tuning required. Nevertheless, the good results of the random methodology may be acknowledged to the low number of sensors involved: just one. This cause the effectiveness of the mechanism to be limited to the optimization of the input weight.

# Results

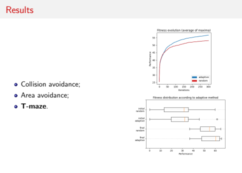
- Collision avoidance;
- Area avoidance;
- **T-maze**.





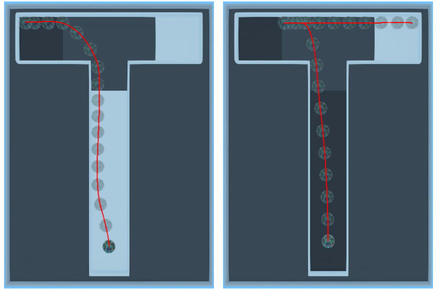


Finally, the T-maze task sees the highest improvement. This is due to the increasing complexity, requiring a finer tuning. This strongly suggests that the adaptation might become essential in more complex tasks.

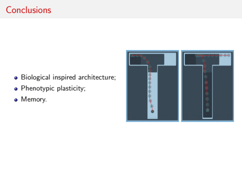
# Conclusions

- Biological inspired architecture;
- Phenotypic plasticity;
- Memory.










Concluding, we endowed the robot with a biological inspired architecture and adaptive mechanism. We showed that they may be used to generate different behaviours from a single control system, and that their use may help in completing complex tasks. Additionally, we demonstrated the capability of the adaptive mechanism to exploit the intrinsic memory of the nanowire networks, opening the way for more complex tasks.

# Future works

- Test of more complex tasks;
- Modulated adaptivity;
- Early individuation of bad configurations;
- Hardware adaptive mechanisms;
- Nano- and micro- bots for real-life tasks;
- Others. . .





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- Test of more complex tasks;
- Modulated adaptivity;
- Early individuation of bad configurations;
- Hardware adaptive mechanisms;
- Nano- and micro- bots for real-life tasks;
- Others. . .

Future works include the test of more complex tasks, like the ability to escape from a longer maze. The adaptation may also be modulated, allowing it to be more aggressive in early stages of the run or with low performances. An early identification and discard of bad configurations may also result in a valid improvement of the adaptive mechanism, allowing a faster adaptation and a higher resistance to faults. Other paths include the creation of small adaptable robot and the design of possible hardware implementation of the adaptive techniques. An example is the use of self-assembling wires to connect the sensors to the network.