

# TOPOS 2: Spiking Neural Networks for Bipedal Walking in Humanoid Robots

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**Abstract.** This work analyses the state of the art in the field of Evolutionary Robotics and marks the path we select in the design of evolutionary strategies. The aim of this text is to describe the lines that we are going to follow in the foreseeable future. Our goal is to create through evolution the neural network that couples with a complex humanoid robot body. For us the problems of a non-structured environment and of Evolutionary Robotics need a sub-symbolic connexionist approach based in *Nouvelle AI* that can cope with the coupling among sensorimotor, neural and environment parts. We also describe the tools we choose to accomplish this task.

**Keywords:** Evolutionary Robotics, Spiking Neural Networks, Artificial Life, sub-symbolic, small-world topologies, CUDA

## 1 Introduction

Current computer power brings us the opportunity to search for new paths in Robotics but most of the research is based on the classical Artificial Intelligence paradigm, which relies on a top-down human design. Sometimes the problems are too complex to solve them by hand. The alternative is to build systems with a strong bio-inspired bottom-up structure, to let the evolutionary algorithms to select the appropriate links and relations among the basic parts, taking into account new theories in the field of graphs and networks. In this work we propose a system to exploit the computer power and get not-so-simple behaviours from very low-level primitives with the aim to obtain a truly scalable system.

Evolutionary Robotics [1] has its roots in Artificial Intelligence [2, 3], Artificial Life [4], evolutionary strategies [5, 6], and in neural networks [7].

## 2 State of the art

Our recent work [8–10] describes the state of the art in Evolutionary Robotics. ER is a type of Behaviour-based Robotics and hence there are two forms of understanding: the classical approach to robotics and the line defined by Rodney

Brooks to avoid the problems caused by the use of representations. Ronald Arkin depicts these ideas as a continuum in a spectrum. The Spectrum of Robot Control [11] represents the range of robot control strategies from a deliberative symbolic, classic AI, high level cognitive approach for a structured environment and a reactive, sub-symbolic, *Nouvelle AI* connexionist based system that can cope and couple with a non-structured environment. The latter is more suitable for an embodied and situated robot controller since it applies the Symbol Grounding Hypothesis, and the former excludes the connection between the world and the system [12] because the designer has to set symbol primitives to *represent* the atomic stimuli.

Embodiment and situatedness are two ideas that we have to take into account if we want to get a robot for a non-structured environment, because the information that the robot needs is closely related to the filtering that the body and sensors physically do. There is a coevolution between the neural system and the shape and function of the sensors. The body as a whole determines and modifies the given response to a stimulus.

Evolutionary Robotics is a young discipline that has followed this approach achieving complex behaviours that emerge from simple interactions among the parts of the system. Nevertheless, there are two problems that have to be addressed in order to obtain more powerful robots: morphogenesis and scalability. First attempts of morphogenesis were a simple and direct expression of the robot parameters and neural weights from the genetic information to the actual controller and the physical robot. This is not a scalable system. Genetic Algorithms cannot find the correct relations among the values that shape the individual. Instead of this, the evolutionary algorithm has to set as an individual the set of parameters of a dynamical system whose final result is the robot. In our opinion, this is the way to develop a body and sensorimotor structure coupled with the topology of the neural network, that can be parametrized and evolved.

In other words, if the environment is complex and it only can be described in a non-linear form, the robot and its evolution has to be equally complex, as a new born child that has to learn to coordinate vision, proprioception and environment. The whole mechanism has to be scalable to allow the growing of the robot capabilities to quantitatively more complex ones.

Some authors have created new models of neural networks, more bio-inspired and with a rich dynamics, time delays and interesting effects on computational capabilities [7, 13–15]. There has been also a lot of exciting new work on network topologies [16–18] that has been applied to Neural Networks but in a theoretical level to study their properties [19, 20]. As a clue on how the neuroscience could change with these theories, in [20] we can read:

*“Our results suggest that mammalian cortical networks, by virtue of being both small-world and topographically organized, seem particularly well-suited to information processing through polychronization.”*

It is clear that an experiment in Evolutionary Robotics could help to the progress in these areas.

If this knowledge could be applied to Evolutionary Robotics, within the described framework the so called small-world networks and their algorithms could give us the tools to tackle both problems, morphogenesis and scalability. With these ideas, through simple algorithms the net would grow and connect to form the sensorimotor loop, parametrized with the help of the evolutionary strategies.

The lines that Di Paolo [21] marks as the future of Evolutionary Robotics are on one hand, more and more high-level cognitive behaviours, and on the other hand, experiments as a synthetic biology:

*“The purpose of work in ER is less centred on trying to obtain more ‘cognitively’ complex performance —a goal that has not been abandoned— and more on understanding other dimensions of adaptation and the role of different kinds of underlying mechanisms. The design and study of novel integrated systems of this sort may well be one way for evolutionary robotics to contribute useful information back to biology, especially neuroscience, in the proximate future.”*

Both objectives could merge and obtain complex cognitive mechanisms based on the last discoveries in neuroscience, with the help of graph theory and new methods of describing, building and connecting the body and the control of the robot.

### 3 Objectives

After the critical analysis of the situation in Evolutionary Robotics we can describe the main goal that we want to achieve. We want to build mechanisms to get an advance in complex sensorimotor behaviours (as bipedal walking of a humanoid robot) in a completely sub-symbolic connexionist system, that is, the designer deals with neuron definitions, without setting architectures, hierarchies, or at least not directly, but through bio-inspired developmental algorithms. Nevertheless, the current works based on human designed behaviours implement the analytic approaches of the classic AI [22]. These ones are obviously interesting but lack a synthetic framework like the one described. The work we propose is ambitious within the constraints of the theoretical proposal.

For this task we need a big spiking neural network to connect to simulated muscles as a proprioceptive and motor system in a humanoid robot with tens of degrees of freedom. The neural network has to have thousands of neurons because it is easier to extract and set the correct information for each joint, and this topology also has to reflect the somatotopic arrangement (spatial organisation that maintains the body topology within the brain [23]) and to show a small-world connectivity [24].

So this development would give a step further in the fields of morphogenesis, scalability, robotic neuroscience and globally in Evolutionary Robotics. The interaction between the body and the growing network could be the way of emerging a meaningful structure of the neural network in the previously described framework and consequently at least a partial solution to the problems that usually arise when building new robots using evolution.

## 4 Tools

The first thing we need is a simulation of a humanoid robot. The need of a simulation is because it is much easier and cheaper to apply evolutionary strategies in simulation due to the available computational power and the lack of damages in the robot. After a search we choose SimSpark simulator [25], the one used in RoboCup 3D Soccer Simulation League. The reasons are that is free software, it uses the Open Dynamics Engine (ODE) for simulating physics as velocity, inertia and friction, rigid body dynamics and collisions. It has a model of a Nao-like robot with a lot of sensors and 22 degrees of freedom (see fig. 1).

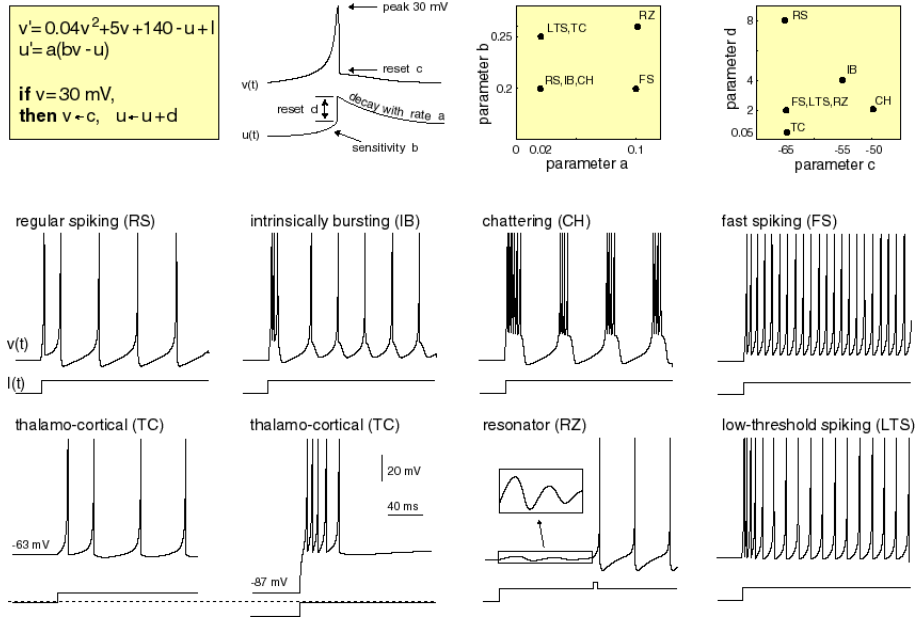


**Fig. 1.** A Nao-like humanoid robot in the SimSpark simulation.

A software that helps to use SimSpark is the `libbats` library [26], which also it is free software (GPL). This library deals with some common operations that we do not need to change from the usual way and let us to read and set joint angles easily.

We also need a fast simulation of a spiking neural network. We select the Izhikevich model [14]. The reasons to pick out this one are explained in [27]. In short, this model is one of the fastest and also it has most of the necessary characteristics. The formulas that rule the neuron dynamics are the following (eq. 1).

$$\begin{aligned}
 \dot{v}_i &= 0.04v_i^2 + 5v_i + 140 - u_i + I \\
 \dot{u}_i &= a(bv_i - u_i) \\
 \text{if } v_i &\geq 30\text{mV} \\
 v_i &\leftarrow c \\
 u_i &\leftarrow u_i + d
 \end{aligned} \tag{1}$$



**Fig. 2.** Some of the neuron dynamics in the Izhikevich model, from [14].

The robot controllers for the SimSpark are written in C++, so we can run them at high speed, but the neural networks are fully “parallelisable”, that is, they are matrix calculus that can be done in parallel. Nowadays, we have powerful rendering graphical processor units (GPU) that are designed to calculate at each processing core the colour, brightness and shadows for each pixel in a 3D scene. There are programs that allow to send non-graphical computing to GPU to perform general-purpose computing. In this case the hardware and software pack that we have chosen is CUDA [28]. It is a mature technology and it is demonstrated that can be 26 times faster than a common CPU software when simulating a neural network based on the Izhikevich model [29, 30].

The design of the *fitness functions* is always a problem in Evolutionary Robotics. We have to design an experiment in which a function has to tell how

good is a robot (one of the possible solutions of a problem subject to evolution) in order to select or discard the parameters that define the robot. In this case it is easy to design the experiment thanks to the problem that we want to work, the bipedal locomotion. The fitness value can be calculated as the covered distance in a fixed time. It could be also added a value related to the time that the robot has maintained the standing position while walking.

## 5 Conclusions

In this work we have set the basis for a search of new techniques in Robotics. We continue our previous in Evolutionary Robotics, remarking the bio-inspired bottom-up structure, and adding new works on graphs to permit evolutionary strategies to build the neural controller of the robots that fits with a complex humanoid robot body.

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## Modifications

REVISION 1 RECOMENDATION ACCEPT SUBJECT TO REVISION COMMENT The proposed line of work sounds interesting, although some results would make it a more relevant contribution. I suggest reviewing the bibliography's format (capital letters and web pages that could be substituted for books, i.e. CUDA) and would also suggest avoiding the spanish word for free software licenses (libre) because it is unnecessary.

REVISION 2 RECOMENDATION ACCEPT SUBJECT TO REVISION COMMENT The paper focus is on presenting a proposal of work without actually providing any results. As such, it has some interest, but it does require a more extensive review of who is doing something similar and evaluating their results in order to justify the project the authors are presenting. I would suggest they improve this aspect. Additionally, a thorough revision of the use of English would be required, as there are some quite awkward expressions in the paper, there are even expressions in Spanish like software libre which should probably be "open source" or "free software".

Please modify the paper following the guidance on the required revisions. Include as a final page of the paper a commentary describing the changes you have made to the paper, and the way in which these changes satisfy the requirements of the reviewers.

### Modifications:

1. Bibliography format and links revised.
2. The expression "software libre" removed.
3. Added Ref. 22 as a part of the state of the art in bipedal walking. It is clear that the conexionist approach is not taken into account in Robotics nor in bipedal walking, and as a basic scientific need it has to be studied.
4. Since this work is a non-trivial task as the evolutionary systems are unpredictable, currently we do not have conclusive results to publish, but we think that the analysis can be interesting *per se*. See section Objectives.