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ANNarchy: a code generation approach to neural simulations on parallel hardware

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Neuro-computational models allow to investigate the functioning of the brain by creating biologically realistic neural networks which explain and predict experimental observations. Researchers in computational neuroscience face several problems: 1) models can comprise millions of neurons and synapses, so the simulations can be slow, 2) models are described by complex differential equations, which can be hard to solve numerically using low-level code, 3) researchers need to exchange and integrate different models, which therefore need a common code base.

Several neural simulators exist to solve these problems (Brian, NEURON, NEST, Auryn…) but are mainly limited to a small class of neural models, the spiking point-neuron, which exchanges information through discrete events called spikes (Fig. 1). In the SpaceCog project, we need to integrate different neuro-computational models using both spiking neurons and rate-coded neurons, which exchange an instantaneous firing rate. An additional difficulty is that there exists a variety of parallel hardware (shared-memory, distributed or GPU-based systems) which have different requirements in terms of programming: a neural simulator optimized for an architecture will likely perform poorly on another.

Code generation is a promising approach to solve all these problems: a neuro-computational model can be described in high-level language such as Python, but the simulator generates entirely a low-level code that is optimized for the underlying parallel hardware. We present here the ANNarchy (Artificial Neural Networks architect) neural simulator, which relies on this principle.

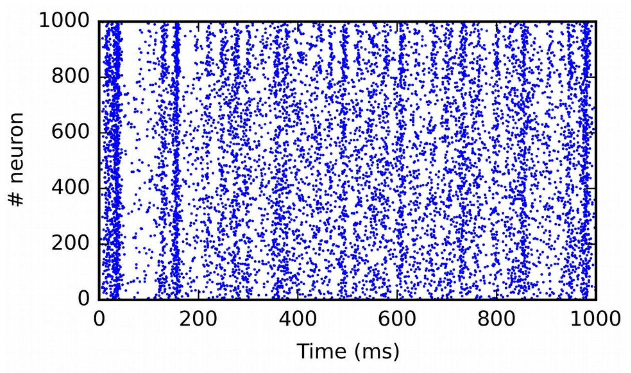

Fig. 1: Raster plot obtained for a pulse-coupled network of 1000 spiking neurons using ANNarchy. Each dot indicates the emission of a spike.

The definition of neuron and synapse models can be specified using an equation-oriented mathematical description. This information is used to generate C++ code that will efficiently perform the simulation on the chosen parallel hardware (currently multi-core system or GPU). Several numerical methods are available to transform ordinary differential equations into an efficient C++ code. Tools are provided to record and analyse the activity of the network during the simulatin. The parallel performance of the simulator already compares positively to alternative solutions. It is now used in the SpaceCog project to integrate the different models and perform efficient parallel simulations.