# From Dynamic Hebbian Learning for Oscillators to Adaptive Central Pattern Generators

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For the last two decades, models of Central Pattern Generators (CPGs) are increasingly used to control the locomotion of autonomous robots, from humanoids to multi-legged insect-like robots. CPGs are mainly modelled by means of coupled nonlinear oscillators. Really complex phase patterns result from these couplings and therefore, make these systems interesting for modelling gaits of animals and for controlling robots. However, in most cases the design of such CPGs is quite difficult since the different parameters and coupling constants have to be tuned by hand.

Indeed, the values of several parameters usually need to be adjusted, such as the parameters controlling the frequency of the oscillations. In previous contributions, we showed that by converting the parameter controlling the frequency of an oscillator into a dynamical system (i.e. a new state variable in the system), the oscillators were able to adapt their frequency to the frequency of any periodic or pseudo-periodic input signal (cf. fig.). Such a mechanism is useful for adapting the frequency of the oscillator to the natural frequency of a mechanical system or to the frequency of some sensory feedback.

Moreover, the form of the adaptive rule we introduced is really simple and is always the same for every kind of oscillator. We called this adaptation mechanism *Dynamic Hebbian Learning* since it is a correlation-based learning rule.

The interest of such an adaptive rule is that it is part of the dynamical system, all the learning is embedded in the dynamics of the system. We do not need any supervisor or any external optimization, as the learning system is a closed system.

Furthermore, we analytically proved the global convergence of the learning to the desired frequency, for any signal that can be written as a Fourier series. Thus, within this framework, constructing adaptive oscillators such as Hopf, Van der Pol, Rayleigh, Fitzhugh-Nagumo oscillators or Rössler strange attractor is straightforward. In other contributions, we already showed how simple adaptive controllers could be built with our adaptive mechanism to control simple robots with spring actuators.

In this contribution, we will show how we can extend this general framework to build adaptive CPGs modelled as coupled adaptive oscillators. We show that with such adaptation capabilities, the CPGs are able to learn any desired periodic pattern. The parameters of the CPG are dynamically adapted by the system and no external optimization is required.

We will show that our adaptive CPGs can learn the shape and phase relations of multi-dimensional periodic inputs. As a matter of fact, the adaptive CPG learns a periodic input pattern and after convergence, if the input signal disappears, the pattern stays encoded as a structurally stable limit cycle in the system of coupled oscillators. The learning is successful even if the pattern to learn is noisy or if its period is not well-defined. Encoding patterns, or trajectories, as limit cycles is of great interest for controlling robots because the system is robust to external perturbations and can easily integrate sensory inputs. The method we present here can therefore easily be used to design robust CPG-based controllers for the locomotion of robots.