Adaptive Locomotive Behaviors of a Biped Robot: Patterns Generation and Classification

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- Primitive Pattern Classification
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Objectives

• Generate different **motion patterns** for walking as well as oscillation.

Complex tasks (running, obstacle avoidance, …) require more than just oscillatory movements.

• Provide the ability to switch between intrinsic behaviors to enable the robot to react **quickly** against environmental changes.

Related Work

Locomotion

Biological studies of animals suggest that animals' locomotion is mainly generated at the spinal cord, by a combination of a central pattern generator (CPG) and reflexes receiving adjustment signals from a cerebrum, cerebellum and the brain.

[Orlovsky et al 1999] [McCrea et al 2008] [Graham 1911]

These studies were taken into account in robot's locomotion gait in order to implement such mechanism, especially on legged robots.

[Ijspeert 2008] [Taga et al 1991] [Kimura at al 1999] [Morimoto et al 2008] [Endo et al 2008]

Biologically inspired walking mechanism for legged robot does **not require** a perfect knowledge of the robot's dynamics.

Neural oscillators

Different models of neural oscillators are widely used to generate rhythmic motion. Such oscillations generated by two mutually inhibiting neurons are described in a set of differential equations (e.g. Matsuoka).

[Matsuoka 1985]

Related Work

[Rowat & Selverston] proposed a model of rhythmic neuron that can **generate different types of patterns** such as oscillatory ones.

The different behaviors in the activity of this neuron can be used in robot's locomotion to achieve different tasks as well as walking.

Locomotion Patterns

Complex task, like walking, hopping, running, and obstacle avoidance, require correct synchronization and **switching between patterns**.

[Lacquaniti et al 2007]

In action learning approach, where learning always occurs in the space of parameters, there is a **limitation** to learn complex tasks, due to the dimension of this space which can drastically increases.

Dynamic Movement Primitives which are used to generate discrete and rhythmic movements are stored in **motion library**. *[Schaal et al 2009]*

Proposed Approach

Instead of learning in the space of parameters, learning can be occur inside a new space called **patterns' space**.

Our work aims to produce a biological inspired neural controller for biped walking, based on **CPG with a rhythmic neuron** proposed by Rowat and Selverston.

According to the environment changes, the **adaptation of the neurons behavior** will be shown.

Therefore, a new space for patterns allowing intrinsic behaviors of a joint motion will be proposed.

Primitives Patterns Generation

Neuron Model (rhythm generator)

The membrane currents of the neuron are separated into two classes, fast and slow, according to their time responses.

$$\tau_m . \frac{dV}{dt} = -(fast(V,\sigma_f) + q - i_{inj})$$

$$\tau_s . \frac{dq}{dt} = -q + q_\infty(V)$$

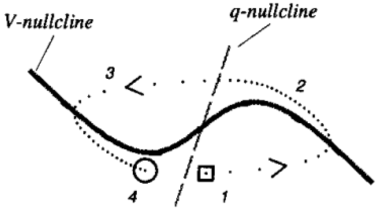
$$q_\infty(V) = \sigma_s(V - E_s)$$

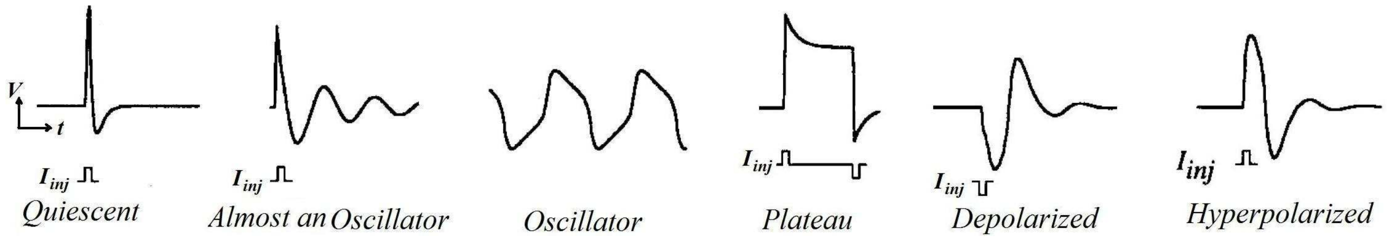
$$fast(V,\sigma_f) = V - A_f . tanh((\sigma_f / A_f)V)$$

σ_f : The dimensionless shape parameter for current-voltage curve

σ_s : The slope of the steady state value of the lumped slow current.

$$\sigma_f = \frac{g_{Ca}}{g_L} \quad \sigma_s = \frac{g_K}{g_L}$$





[Rowat & Selverston 1991]

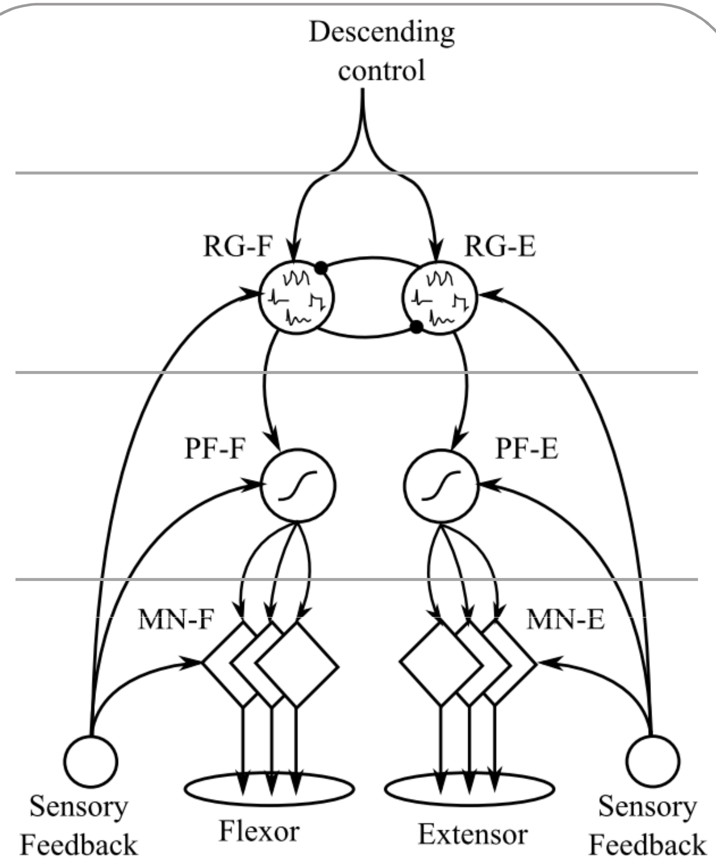
Primitives Patterns Generation

Central Pattern Generator

The locomotion and rhythmic movements in mammals are organized by oscillatory spinal cord circuits called CPGs. *[McCrea & Rybak 2008]*

Experimental studies show that the rhythmic patterns in cat limbs can be generated in the **absence of descending control** from higher centers and sensory feedback.

Each joint appears to have its own CPG, which can be coupled to the CPG of another joint in order to achieve complex movements



Three level Central Pattern Generator for one joint.

CPG with three levels: Rhythm Generator (RG), Pattern Formation (PF), and MotorNeuron (MN) level.

Sensory neuron model:

$$\rho_i = \left(1+e^{\alpha(\theta-\varphi)}\right)^{-1}$$

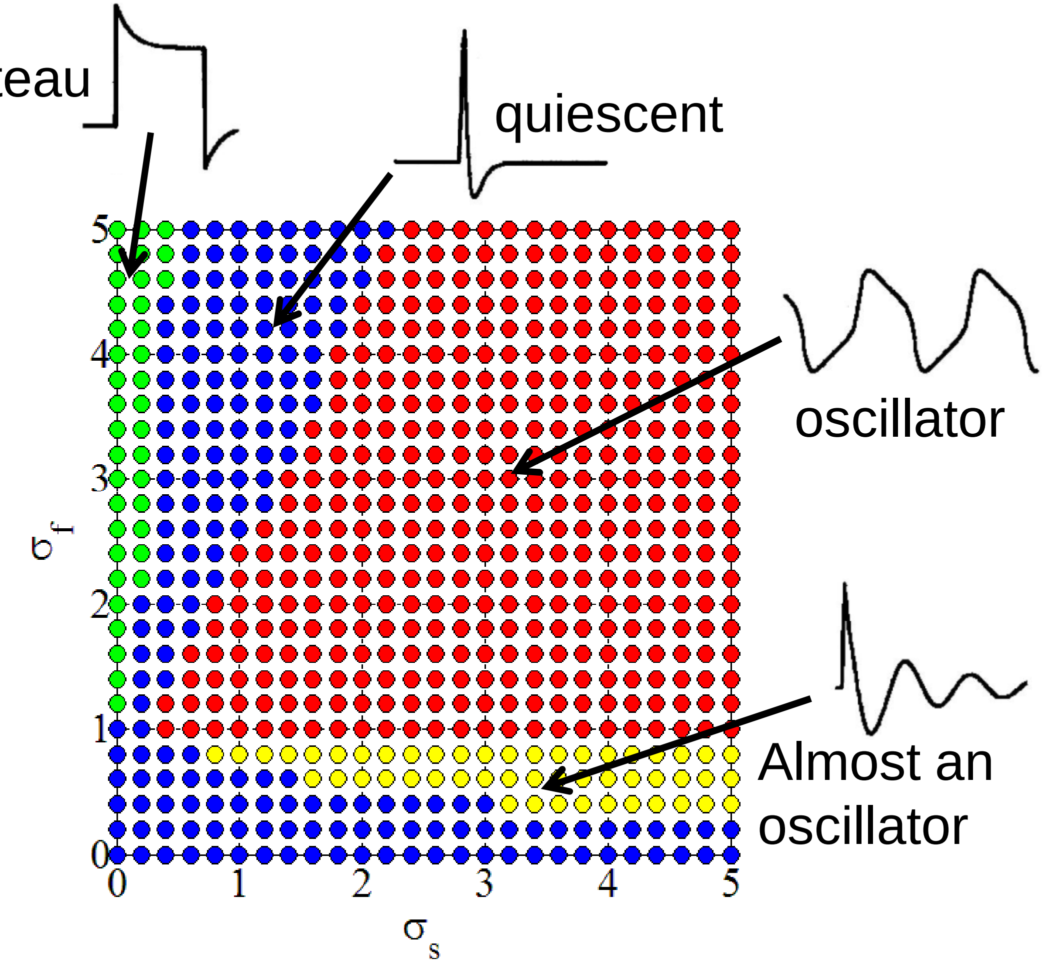
Where:

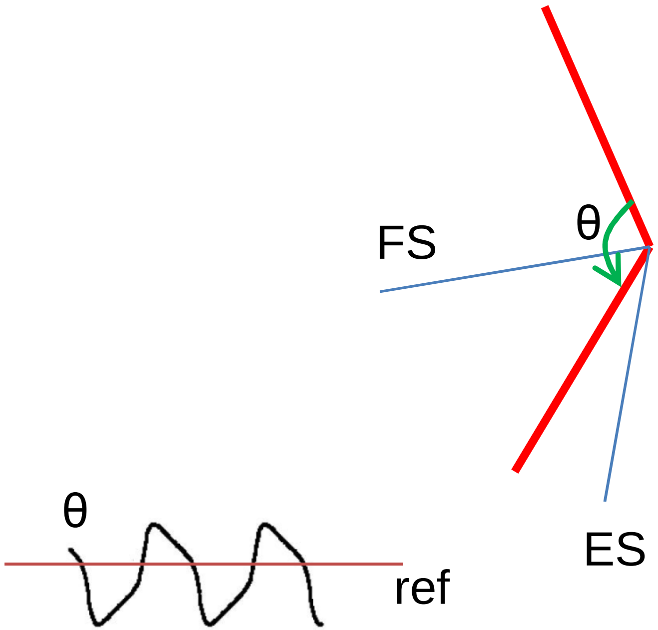
ρ	Neuron Activity
α	Dynamic
θ	Amplitude
φ	Neuron Input

Primitives Patterns Generation

Observed Behaviours of a Joint

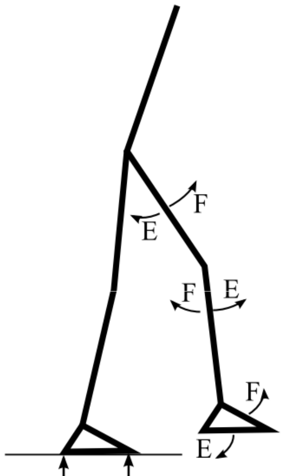
The different behaviours observed on the joint for the same injected current i_{inj} .

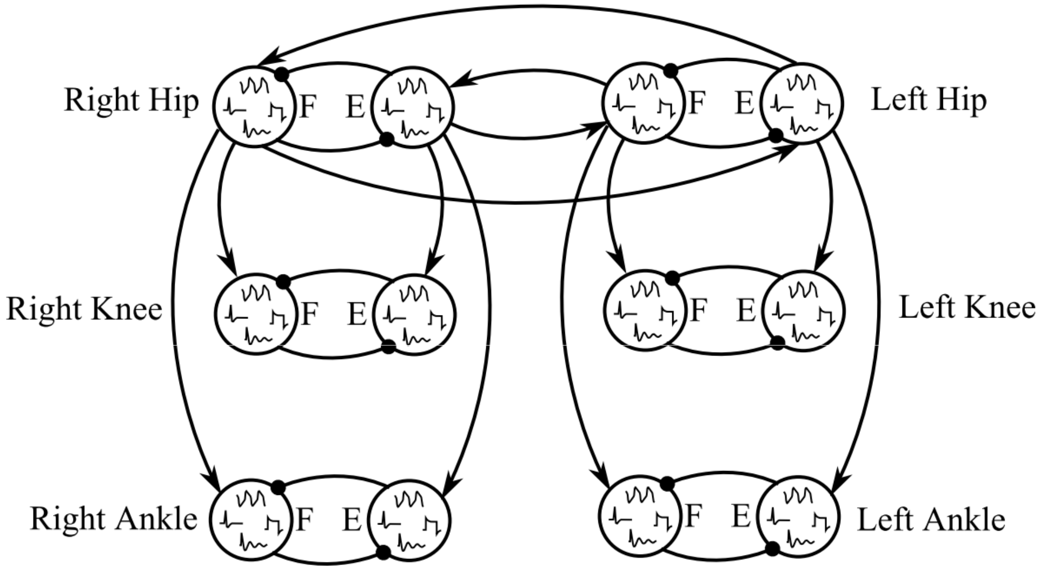




Primitives Patterns Generation

Coupling circuitry for biped locomotion:



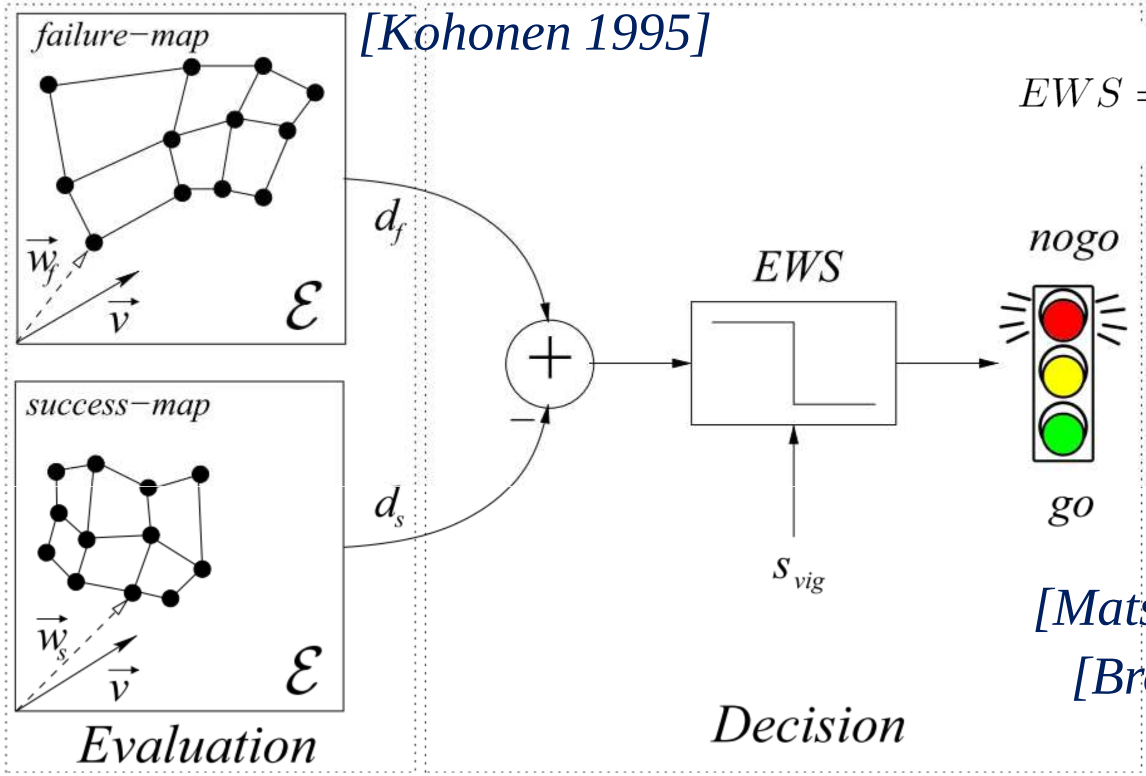


2D simulated biped
22kg
1m20

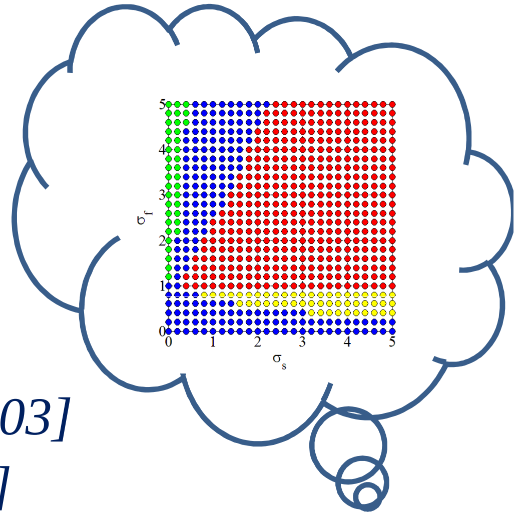
Neural Representation of Patterns

Experience-based learning mechanism. ***[Nassour et al IROS 2009]***

[Kohonen 1995]



$$EWS = \begin{cases} 0 & (go) \quad if(d_f - d_s) > s_{vig} \\ 1 & (nogo) \quad otherwise. \end{cases}$$



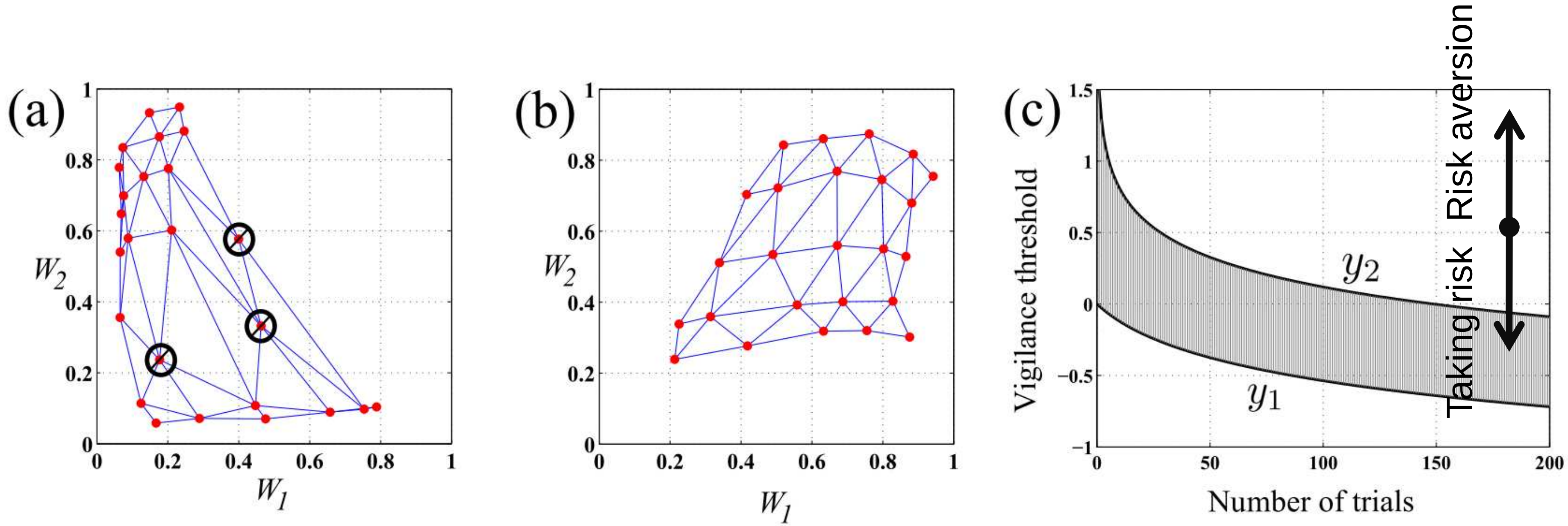
[Matsumoto 2003]
[Brown 2005]

w_f :Weight of the winner in failure map v : random vector
w_s :Weight of the winner in success map.
d_f :distance between v and w_f .
d_s :distance between v and w_s.
Ɛ : space of parameters
s_{vig} :threshold of vigilance.
EWS : Early Warning System.

Neural Representation of Patterns

The biped learns walking with a proposed coupling circuitry shown previously.

(a) Failure map, represents failed patterns.
(b) Success map, represents successful patterns.
(c) Vigilance threshold in function of trials to represent the risk tendency.

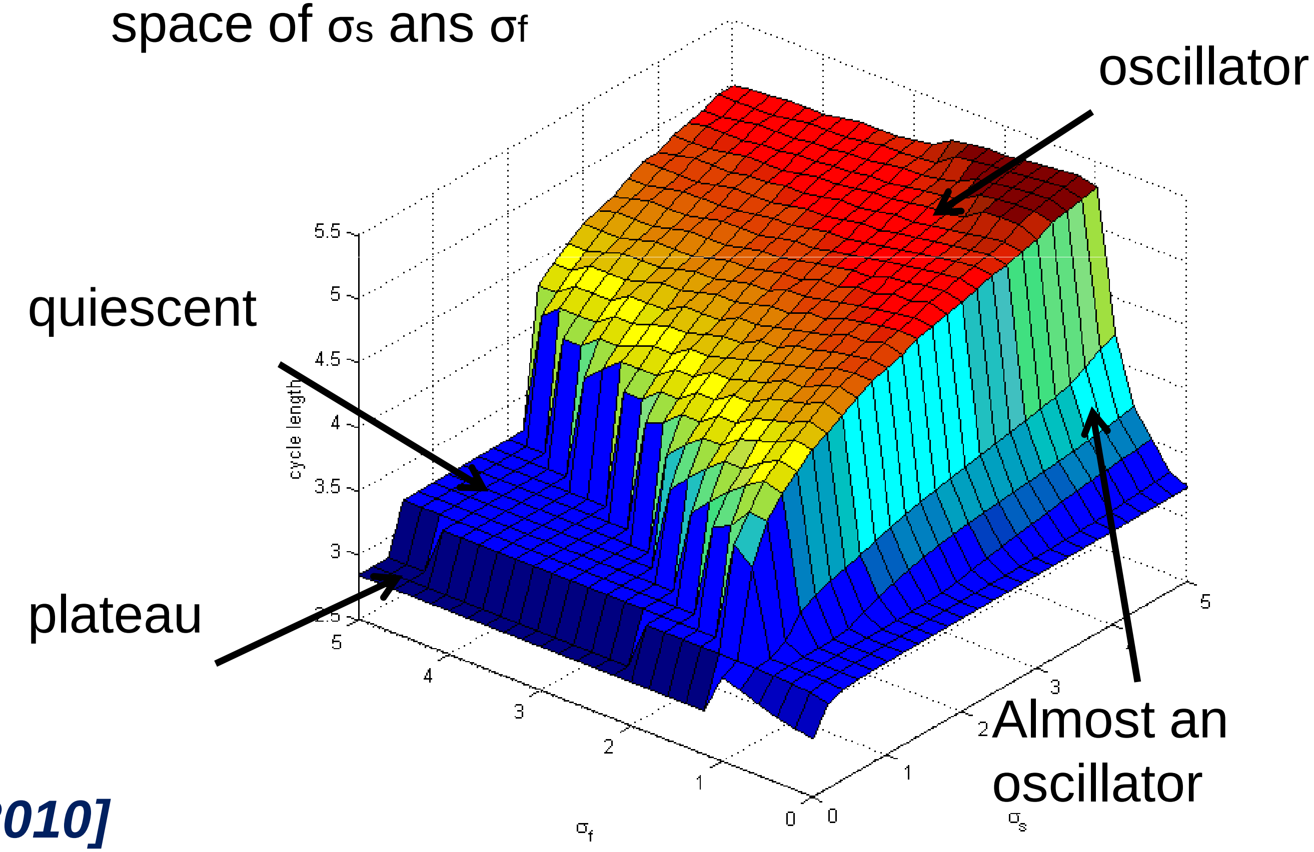


Primitive Pattern Classification

Reduce dimensionality by introducing patterns axis.
An energy based classification of the patterns is carried out:

$$\mathcal{E} = \int_{t_0}^{t_f} \dot{\theta}^2 \, dt$$

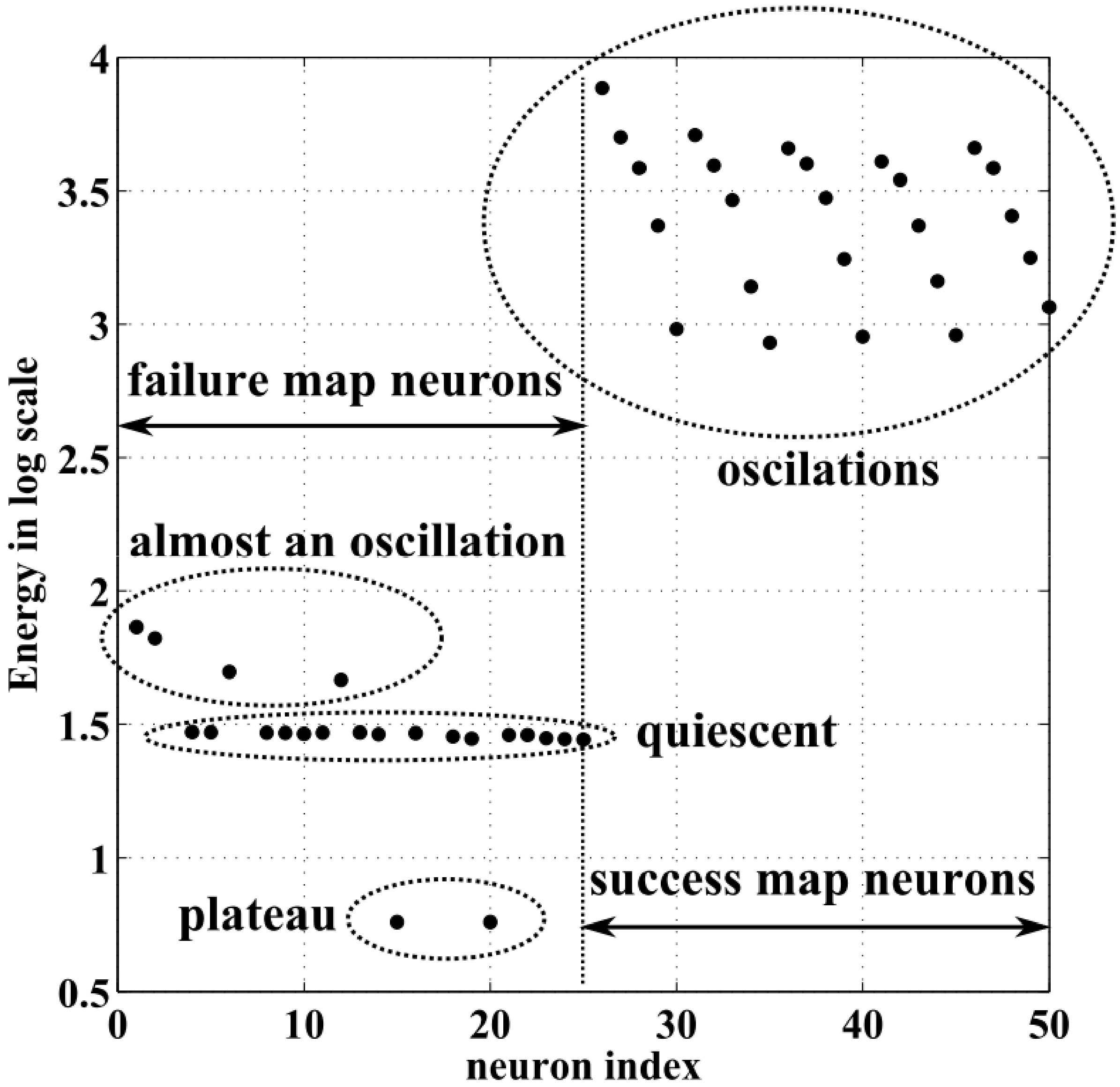
The energy based metric patterns for the space of σs ans σf



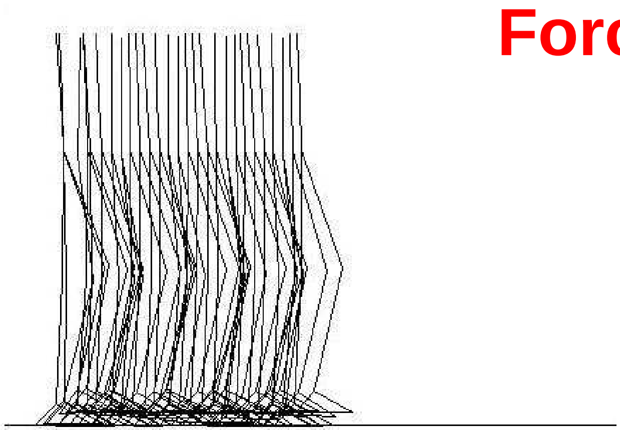
[Nassour et al ISAB 2010]

Primitive Pattern Classification

The energy based metric patterns for the success and failure neuron.

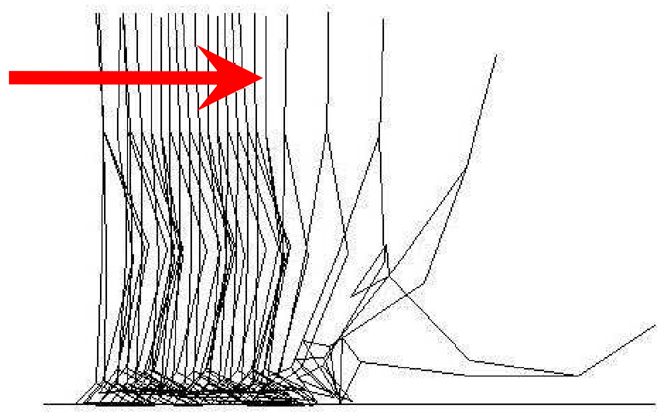


Example in switching pattern in case of perturbation



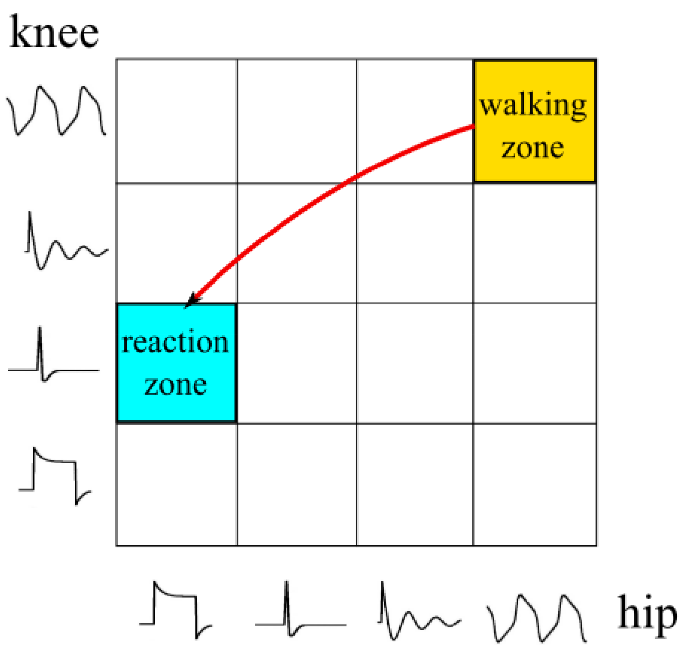
Walking without perturbation.

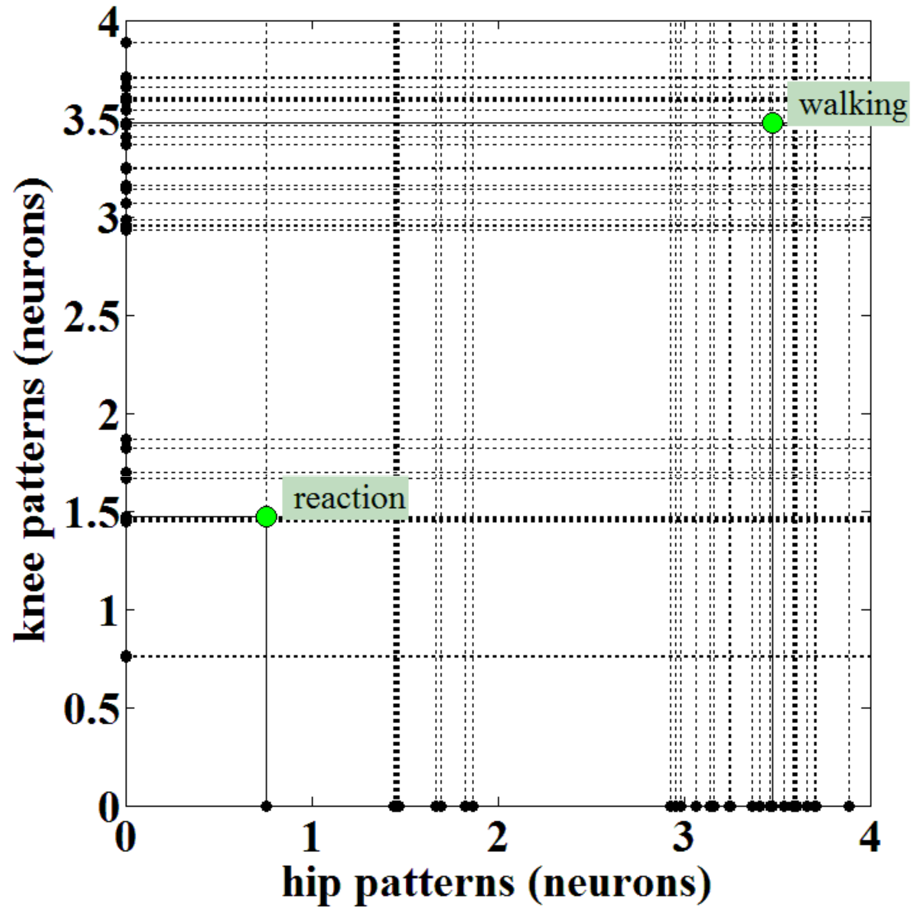
Force



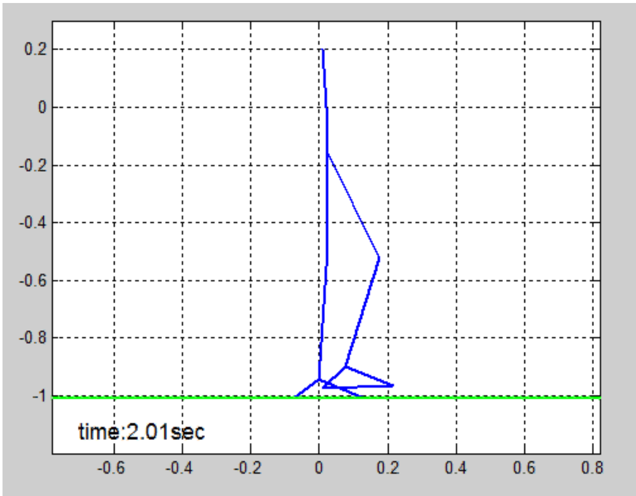
Falling due to the perturbation.

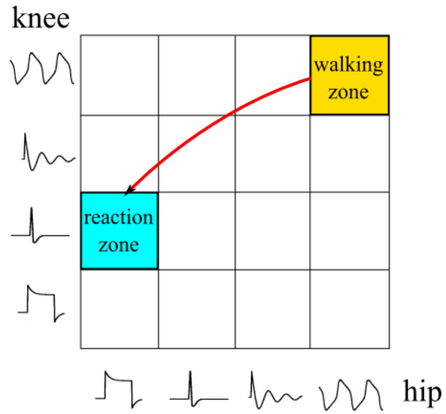
Example in switching pattern in case of perturbation

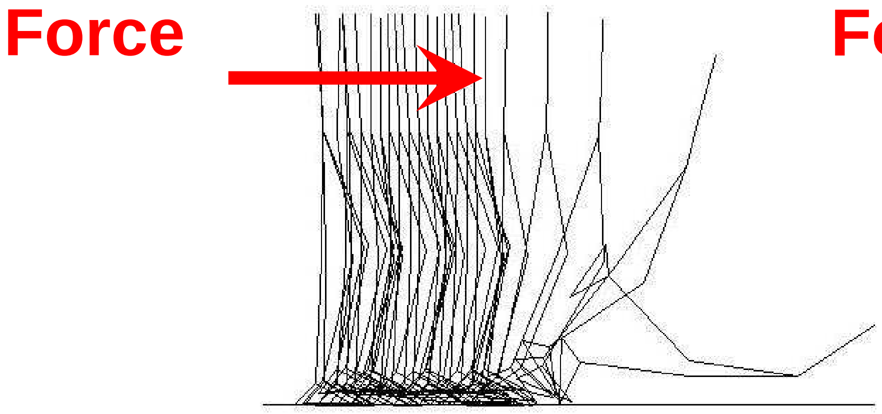


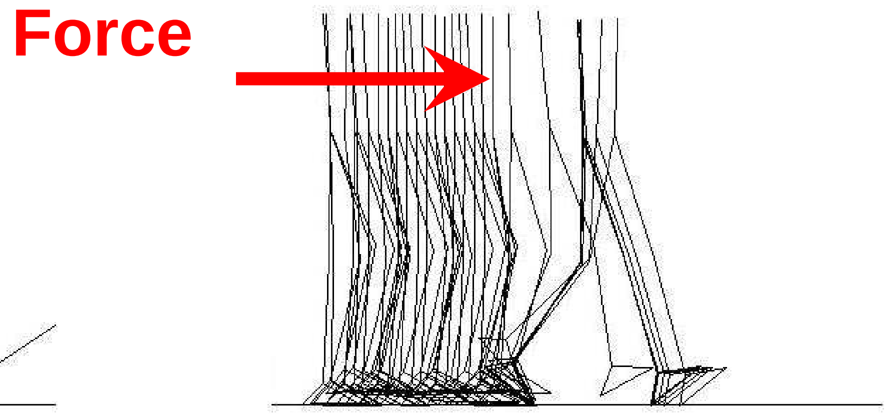


Example in switching pattern in case of perturbation









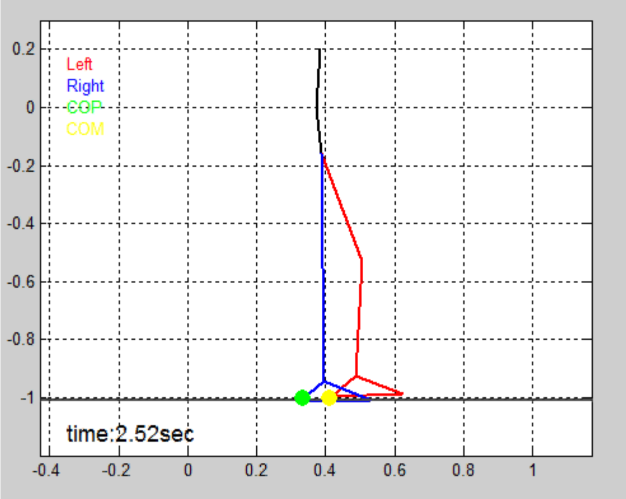
Falling due to the perturbation.

Successful walking with **adaptation** to the perturbation.

Conclusion & Future Work

The behavior in rhythm generator neurons brings adaptation to face external perturbations.
Reducing the dimensionality by energy based metric.
Establishing a space of patterns for the hip, and the knee joints.

Learning to achieve more complicated reactions.
Learning patterns will replaces learning parameters.
Apply the proposed adaptation mechanism to a humanoid prototype under development.



Thank you !

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