Spike timing dependent plasticity (STDP)

to make robot navigation intelligent

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This is not a success report

but

a guideline of our ongoing project

or

a report of what we are currently planning.

To start with
a benchmark to know
if what we are planning will work or not.

Benchmark will be

Path Planning

or

Robot Navigation

$\Downarrow$ where

the aim is usually to minimize the route from start to goal, but...

Task of minimizing navigation on its own is not so difficult

$$\Downarrow$$

A-star, Genetic Algorithm, Reinforcement Learning, Neural Network, Ant Colony Optimization, etc...

Genetic Algorithm (GA)

$\Downarrow$

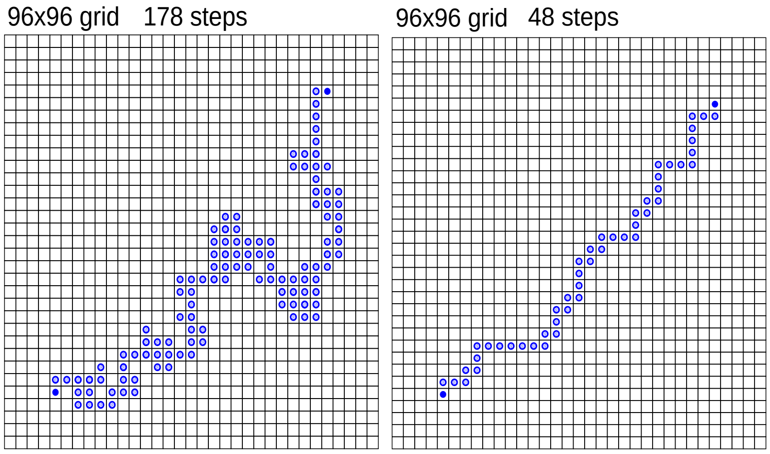
Agent decides actions following its chromosome

e.g.

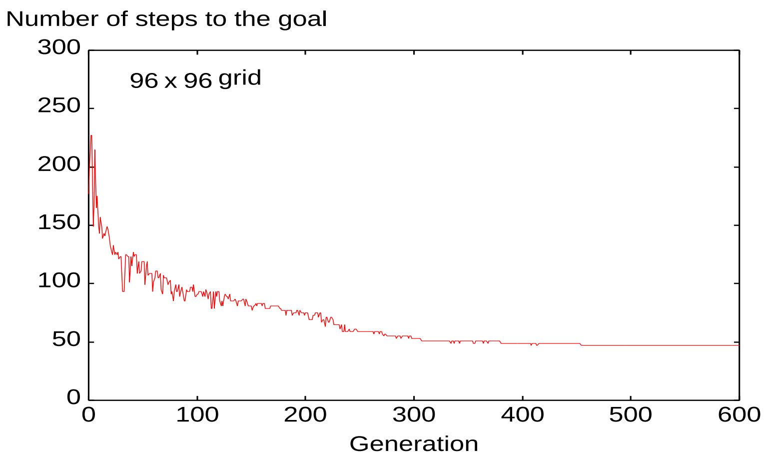
with chromosomes like
(4 1 1 2 1 3 2 3 3 4 2 1 3 4 3 2 3 3 2 1 1 3 2 1 3 ...)

indicates the agent a route to be followed

Random walk evolved to be minimized



Task was easy



Let's extend it

From Minimization to Maximization

$\Downarrow$ i.e.

We don't care goal points but to maximize an exploration

A Camel in a Desert

The 52nd problem

in the

"Propositiones ad acuendos inventes" (in Latin)

by

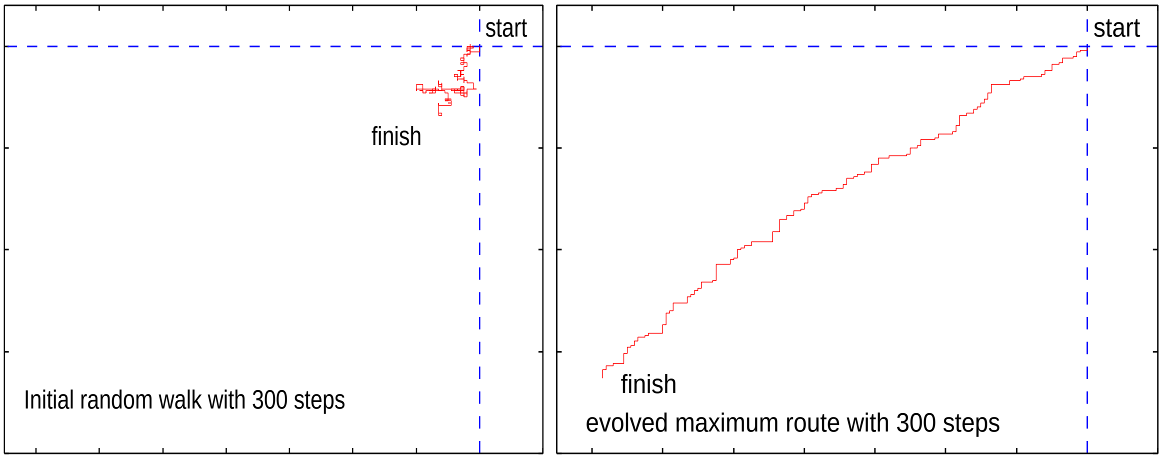
Alcuin of York (732–804)

Can a camel maximize its exploration in a desert surviving with grains on his back?

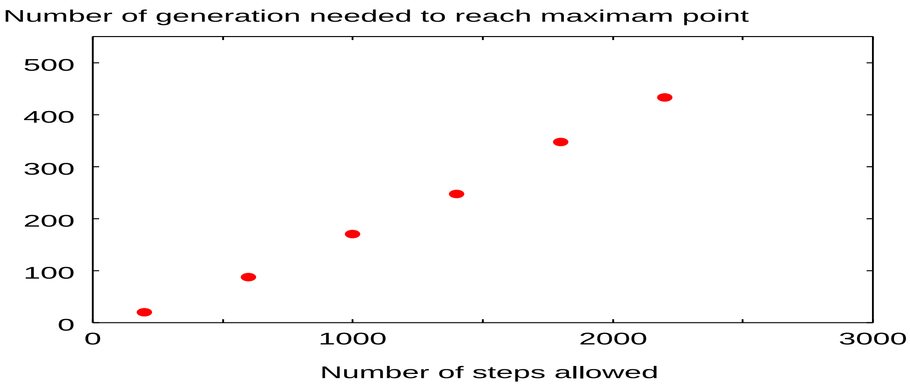
Modern version: From Camel to Jeep in a Desert

Can a jeep maximize its exploration in a desert with a tank of fuel?

Still it's not so difficult by GA for example



Task was rather easier



The complexity is $O(N)$

Why not extend it further

Let's make it return to the point it started

$$\Downarrow$$

while also maximizing an exploration

Planet Land-rover Problem

From A (start) to B (goal) minimizing its route

$\Downarrow$

From A to A maximizing its route

(This is our proposal here as a benchmark)

Can the rover return to the base with its exploration being maximum spending a limited energy given when it started?

Much more demanding

$\Downarrow$

Taking GA as an example, what might be a fitness?

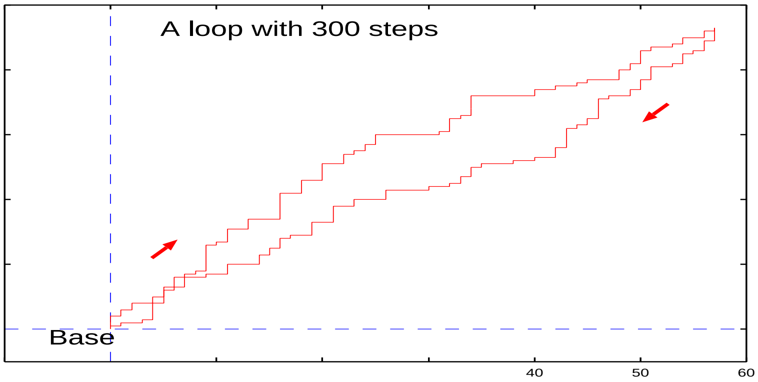
e.g.

$\{$*total length*$\}$ *&* $\{$*how often it has crossed previous route?*$\}$

with

Multi Objective GA (MOGA)

A Heuristic create such a route



What heuristic do you guess?

Topic of today's talk:

What is intelligence?

$\Downarrow$

Intelligence should be spontaneous, flexible, or unpredictable more or less

Stolle et al. (2002)

"... every day we might be cooking a different breakfast, but the kitchen layout is the same from day to day."

“I beg your pardon?”

Intelligent people try a different explanation for an easier understanding

while

others repeat the expression, maybe with a bigger voice

What if your canary stop singing?

Legendary three strategies in Japan.

(1) Just wait until she sings again.

(2) Try something so that she sings again.

(3) Kill her if she doesn't sing any more?

To be intelligent,
action should be different more or less
even in an exactly identical situation

Performance is not intelligent

if we use

deterministic A-star, GA, NN with fixed weights?

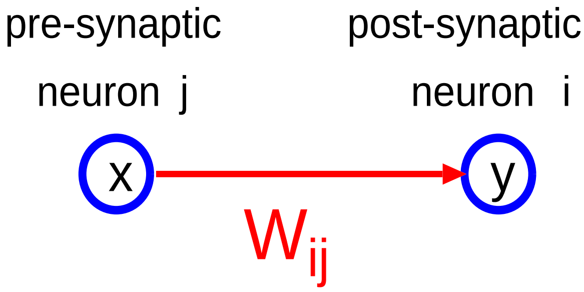
Let's make a learning occur during behaviors

$$\Downarrow$$

Evolution of Learning

A notation

Hebbian Learning of NN



$$w_{ij}(t+1) = w_{ij}(t) + \eta x_j(t) y_i(t) \quad (x_j, y_i \in [0,1])$$

Floreano's approach (2000)

$$\Downarrow$$

Modification of w_{ij} during exploration

with either one of four Hebbian and Hebbian-like rules

Hebbian learning

$$\Delta w = (1 - w)xy \qquad (1)$$

Hebbian type learning

Weaken if the post-synaptic is active, while the pre-synaptic is not

$$\Delta w = w(-1 + x)y + (1 - w)xy \tag{2}$$

Weaken if the pre-synaptic is active, while the post-synaptic is not

$$\Delta w = wx(-1 + y) + (1 - w)xy \tag{3}$$

And

Strengthen if the two have similar activity and weaken otherwise.

$$\Delta w = \begin{cases} (1-w)F(x,y) & \text{if} \quad F(x,y) > 0 \\ wF(x,y) & \text{otherwise} \end{cases} \tag{4}$$

where

$$F(x,y) = \tanh(4(1-|x-y|)-2)$$

Evolution of leaning

Which rule and what parameter's value should be assigned to each of the synapses?

$$\Downarrow$$

Evolution leads the combination to the optimum.

Stanley's implementation (2003)

$$\Delta w = \begin{cases} \eta_1(1-w)xy + \eta_2 wx(y-1) & \text{for excitatory neuron} \\ -\eta_1(1-w)xy + \eta_2(1-w)x(1-y) & \text{for inhibitory neuron} \end{cases}$$

$$\Downarrow$$

Evolution is on (η_1, η_2) of each synaptic weight

Their result

Starting with random weights every time anew
the weights are modified step by step by the rule it learned

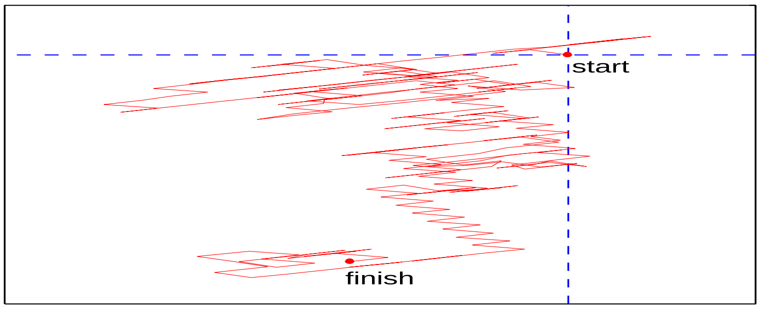
$\Downarrow$

Every run is different depending on the initial random weights

More general learning (Durr et al. 2008)

$$\Delta w = \eta(Axy + Bx + Cy + D)$$

An example of exploration by a recurrent NN with random weights



Can it learn so that path will finish at the start point?

Our Aim

$\Downarrow$

Learning should occur during a random exploration

with a spiking neural network to seek its biological plausibility

Learning by STDP

(Spiking neuron's version of Hebbian Learning)

$$\Downarrow$$

The topic is still open!

Meunier et al. (2005)

$$\Downarrow$$

"Up to now, nobody has been able to show how it is possible to learn with STDP..."

Farries et al. (2007)

$$\Downarrow$$

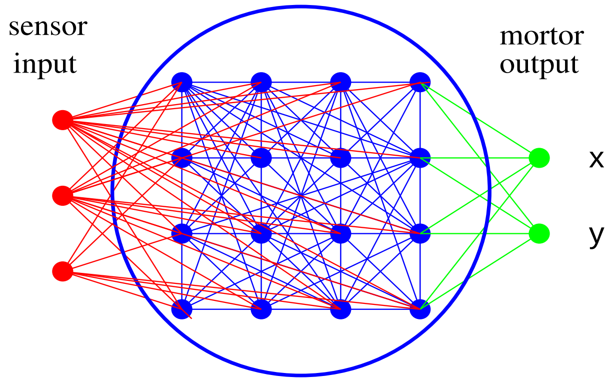
"Although synaptic plasticity is widely believed to be a major component of learning, it is unclear how STDP itself could serve as a mechanism for general purpose learning."

Still the method is not so fruitful

but

Why not challenge?

Architecture we are planning

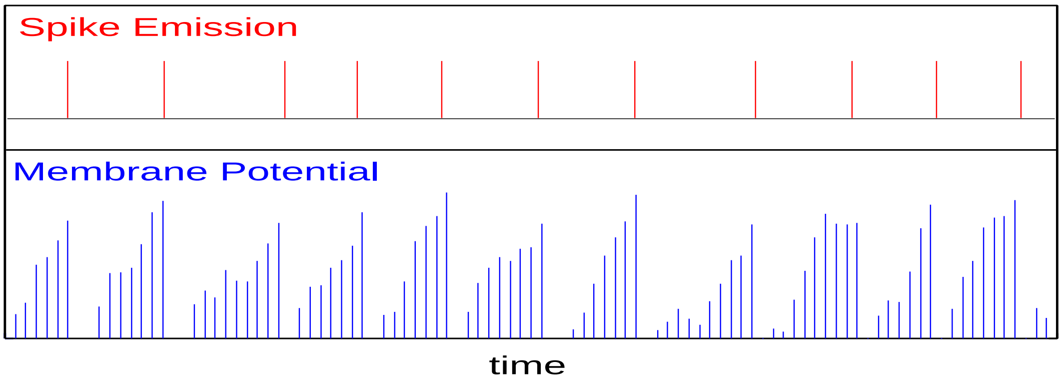


$\Downarrow$ a.k.a.

Echo State Network, Liquid State Network or Reservoir Computing

Integrate-and-Fire Model

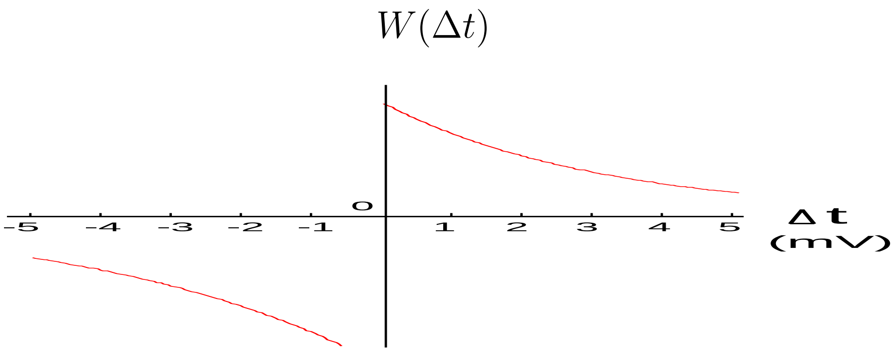
$$u_i(t) = u_r + (u_i(t-\delta t) - u_r)\exp(-\delta t/\tau) + \sum_j w_{ij} f_j(t-\delta t)$$



What is STDP?

$$W(\Delta t) = \begin{cases} A_+ \exp(-\Delta t/\tau_+) & \text{if} \quad \Delta t \geq 0 \\ -A_- \exp(-\Delta t/\tau_-) & \text{if} \quad \Delta t < 0 \end{cases}$$

where $\qquad \Delta t = t_{post} - t_{pre}$



In short

potentiation occurs when a pre-synaptic neuron fires
shortly before a post-synaptic neuron

and

depression occurs when the post-synaptic neuron fires shortly after.

It's too basic to be applied to a real simulation

Reward-modulated STDP Learning
(Florian 2007)

$$w_{ij}(t+\delta t) = w_{ij}(t) + \gamma r(t+\delta t)\zeta_{ij}(t)$$

where

$$\zeta_{ij}(t) = P^{+}_{ij}(t) f_i(t) + P^{-}_{ij}(t) f_i(t)$$

$$P^{+}_{ij}(t) = P^{+}_{ij}(t-\delta t)\exp(-\delta t/\tau_{+}) + A_{+} f_j(t)$$

$$P^{-}_{ij}(t) = P^{-}_{ij}(t-\delta t)\exp(-\delta t/\tau_{-}) + A_{-} f_j(t)$$

Reinforcement Learning (RL)

What an agent learns is a *policy*

and

policy is how to select an *action* in a given *situation (state)*

maximizing

total *rewards* the agent occasionary will receive from the environment

Policy indicates agent which action should be chosen in any possible situation

$\Downarrow$

While in GA

Agent decides actions following its chromosome

in RL

Agent decides actions following its policy it has already learned

However

our world is with no obstacle, no wall, no corridor, only one goal

$\Downarrow$

Everywhere no reward except for one point (goal)

$\Downarrow$

A needle in a Haystack

(Rewards are not likely to be encountered by a random exploration)

We have not succeeded yet

Nevertheless

we think of
a further extension of the benchmark
as a bigger challenge

$\Downarrow$

What if the rover carries containers for fuel?

Jeep Problem

Where jeep explore is 1-D desert

Jeep can unload its fuels anywhere in the desert

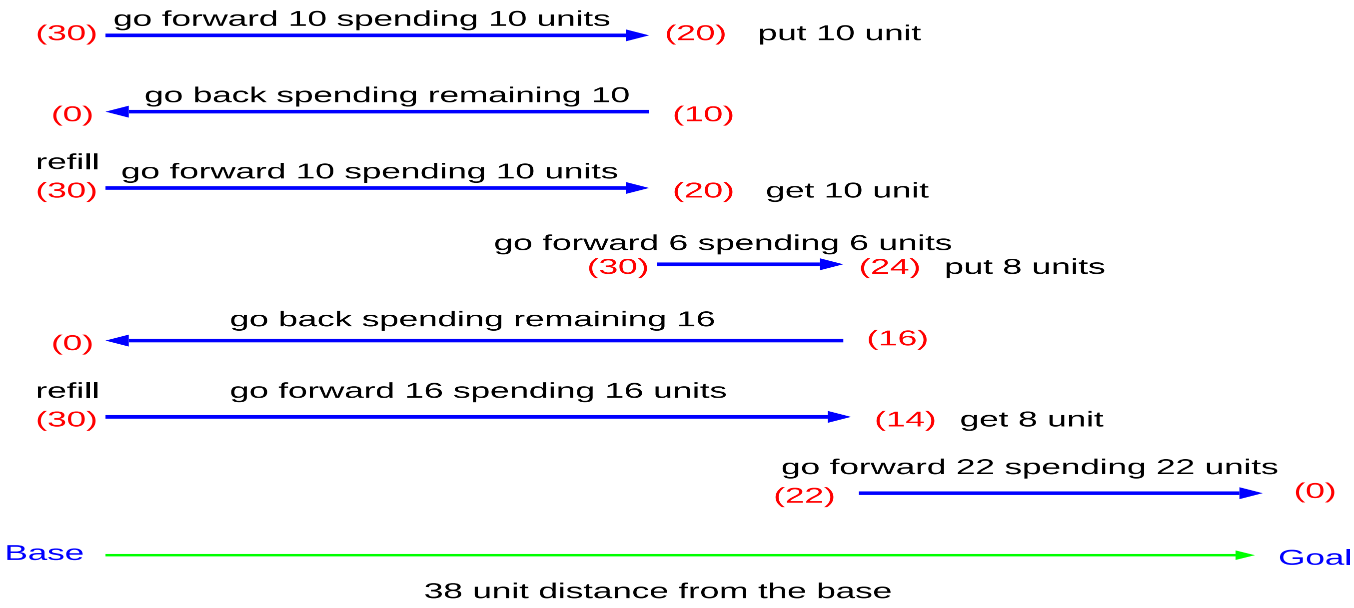
Fuels can be filled only at the base

Jeep can go back to the base n times to re-fill its tank

$\Downarrow$ thus

The jeep should maximize its penetration

An example of a success



Let's give the rover the same condition

$\Downarrow$

A very tough benchmark, and
an infinitely large number of solutions (when it's in 2-D)

$\Downarrow$

Good as a benchmark to check our intelligence of

a different action in a same environment

Let me conclude

To claim artificial NN to be intelligent

a different action more or less should be made under identical situation.

$\Downarrow$

We want to, or we are going to realize it
by
Spiking NN with learning by STDP

also

to be more biologically plausible.

SONY's AIBO

can excellently learn but still repeats same action in the same situation

Hoping collaborations

to design

an agent like real human intelligence

Thank You!