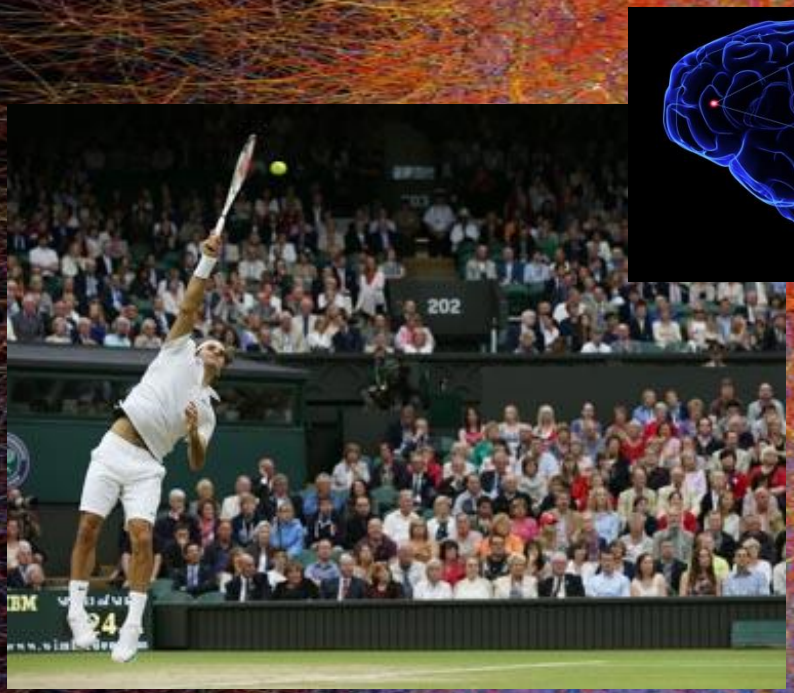
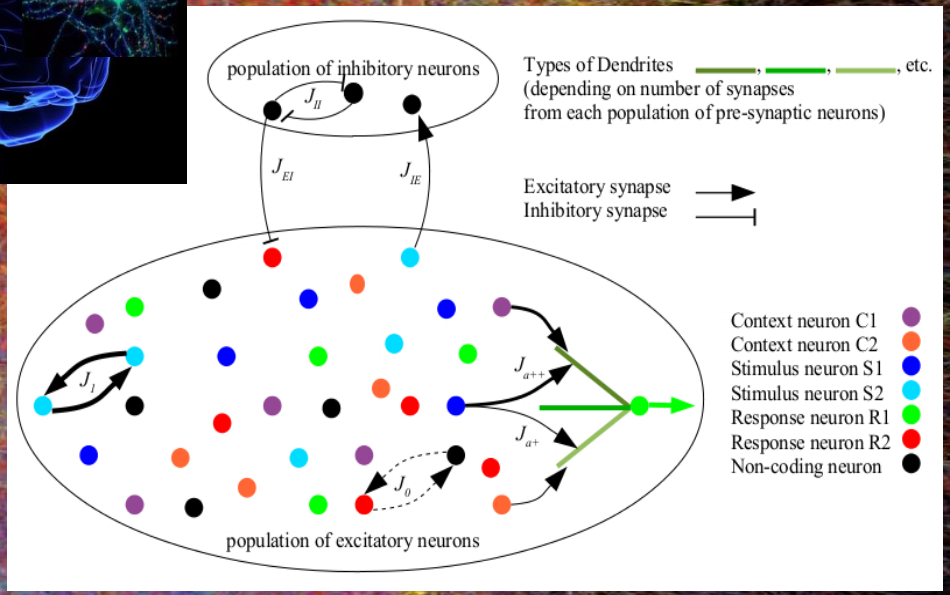
Learning and processing of non-linearly separable combinations: from dendrites to behavior

Frédéric Lavigne, Francis Avnaïm and Laurent Dumercy





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We are gratefull to Nicolas Brunel for fruitful discussions
Lavigne, Avnaïm, Dumercy (2014). Frontiers Cog. Sci.

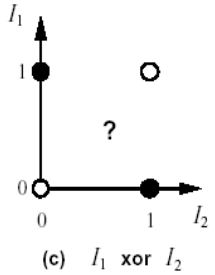
On-line processing of XOR combinations

Context: stroke	**Stimulus:** racket forehand side	**Response:** Backspin or topspin rotation of the ball
forehand	**upward**	**slice**
forehand	**downward**	**lift**
backhand	**upward**	**lift**
backhand	**downward**	**slice**

responses cannot be selected based on any single stimulus,

but only based on their combinations

Input1	input2	ouput
0	0	0
0	1	1
1	0	1
1	1	0



(c) I_1 xor I_2

How non-linearly separable problems are learned by the brain?

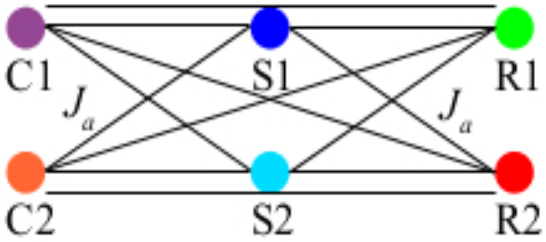
Failure of hebbian learning of XOR combinations

context	*stimulus*	→	*response*
C1	*S1*	→	*R1*
C1	*S2*	→	*R2*
C2	*S1*	→	*R2*
C2	*S2*	→	*R1*

Triadic XOR combinations

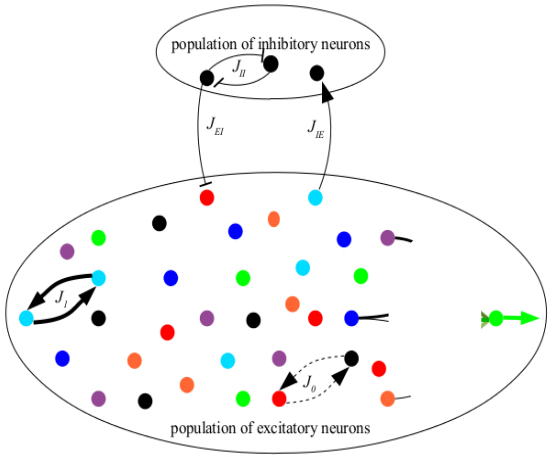
→ $a_{ij}=q^{+}\xi_i\xi_j$ →

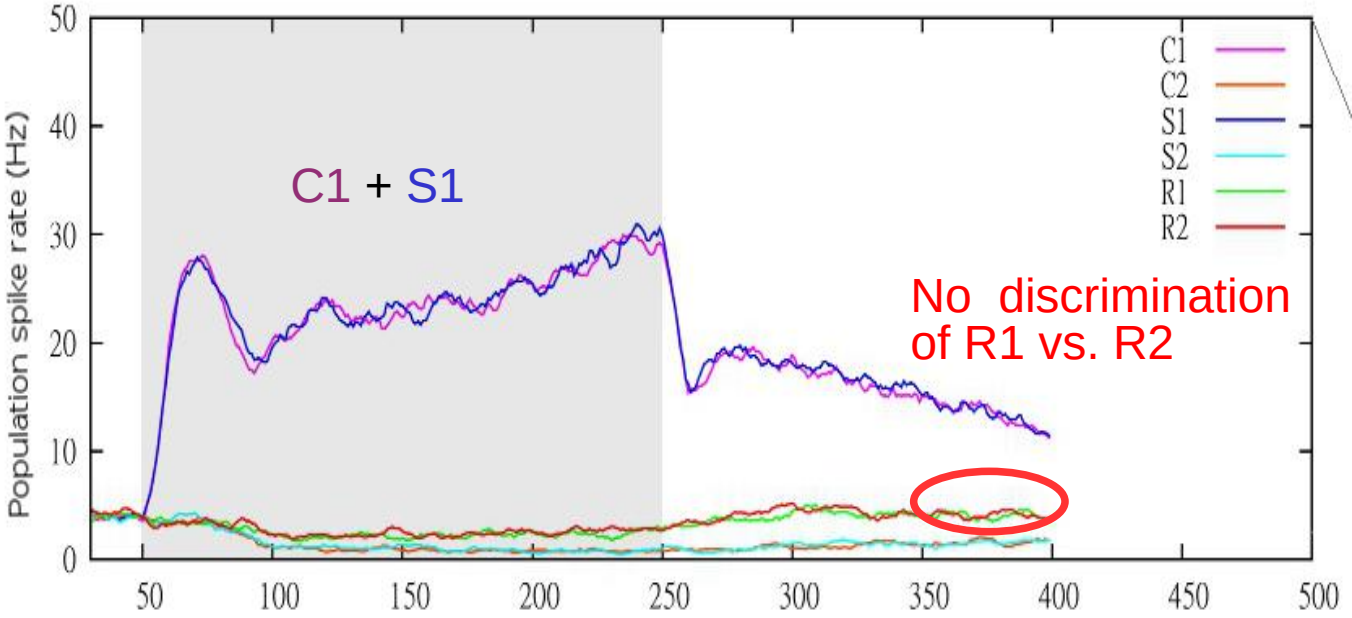
Local Hebbian learning



Pairwise synaptic efficacies

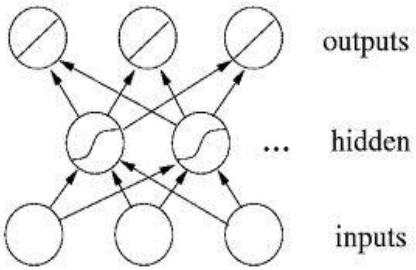
Computationnal model of a cortical network
Hebbian learning





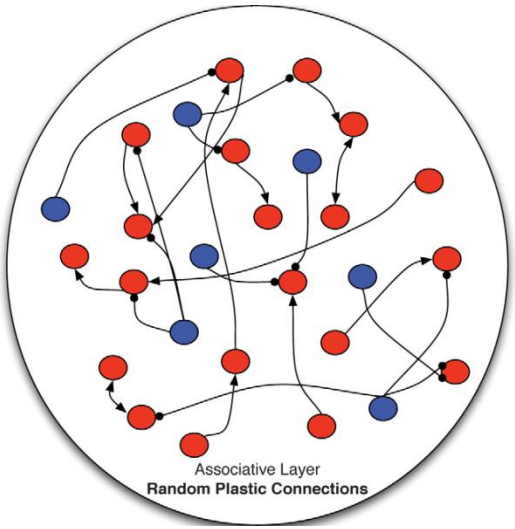
What are learning solutions found by the brain?

Learning of non-linearly separable combinations

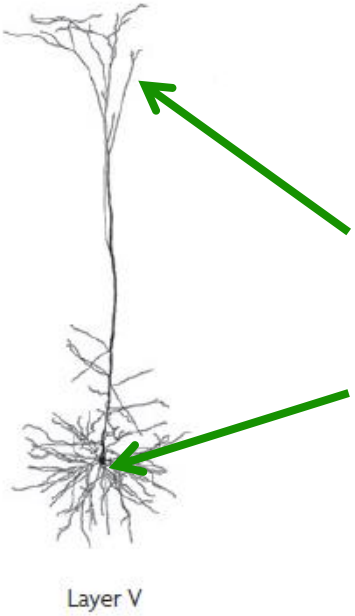


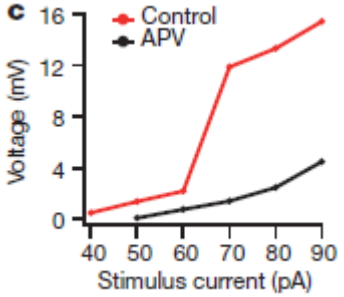
a priori wired hidden layer of neurons

increase of network size



The problem of random connectivity
in the cerebral cortex (Markram et al., 2005, 2006)





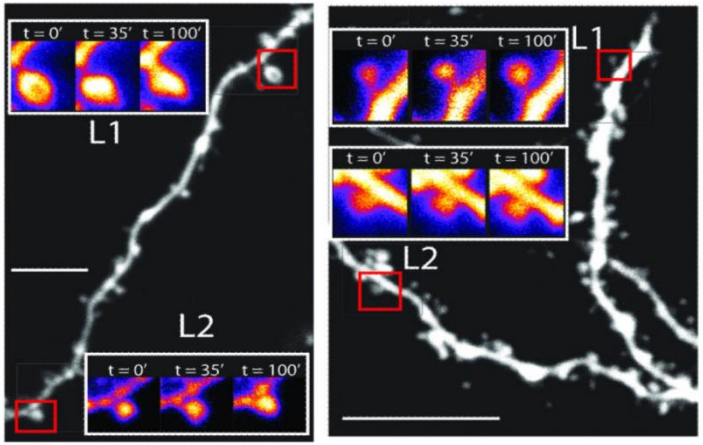
Non-linear dendritic integration
(from Lavzin et al., 2012 Nature;
Spruston, 2008, Nature)

Integration in the cell body

How synaptic efficacies are learned at the level of dendrites?

Intra-dendritic amplification of synaptic potentiation

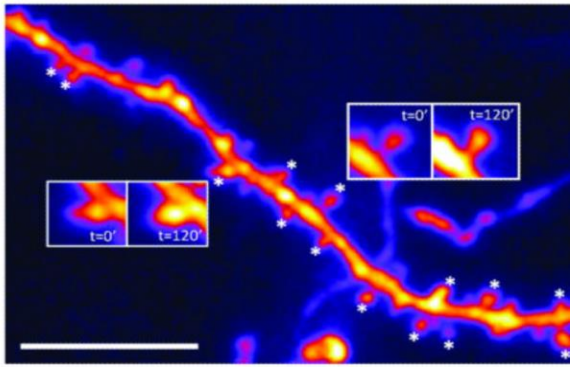
Within dendritic potentiation is stronger



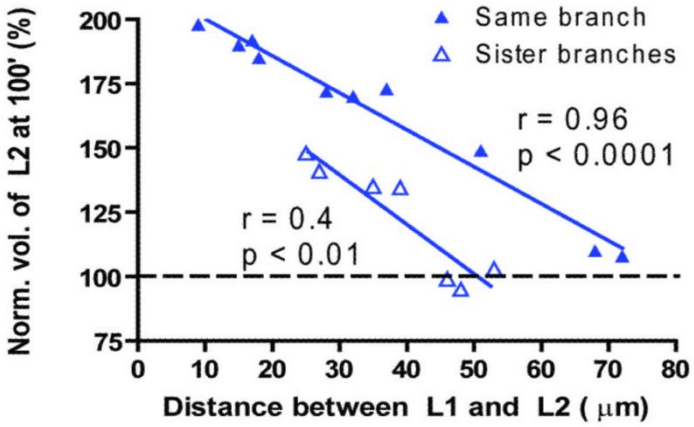
data from Govindarajan et al., 2012, Neuron

see also
Branco et al., 2010, Science
Harvey & Svoboda, 2007, Nature

Multi-synaptic potentiation is stronger

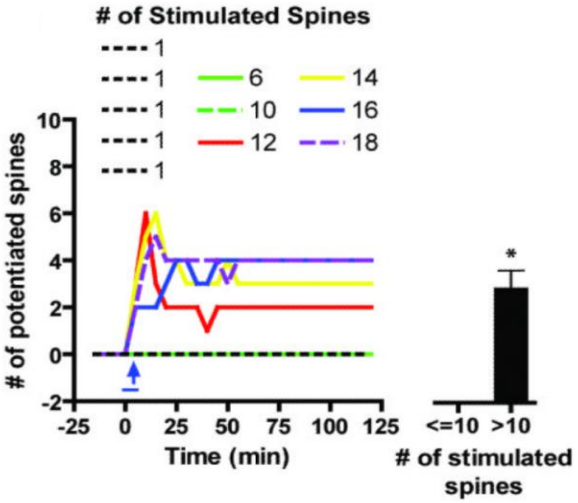


Potentiation if several synapses are active within a same dendrite

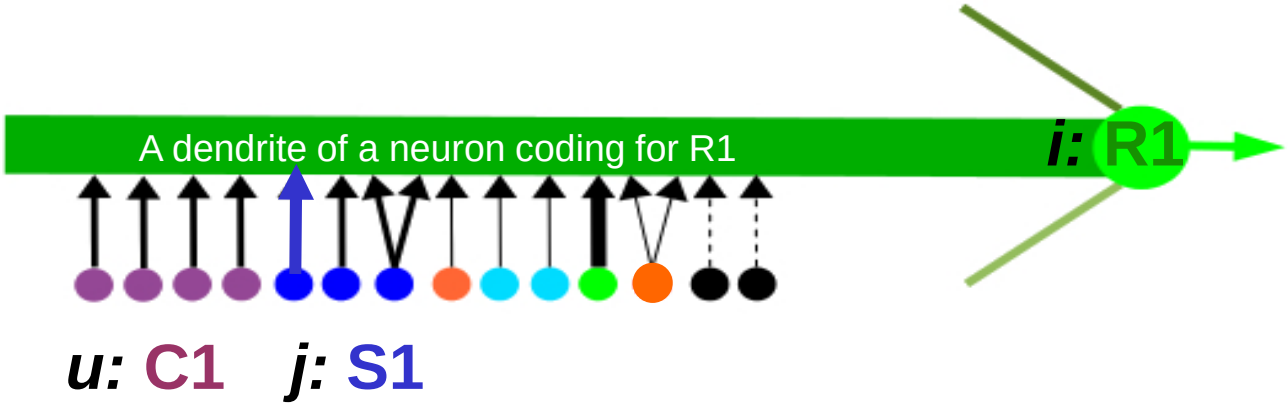


Before learning, connectivity is random and combinations are not known *a priori*.

How to link combinations of items to efficacies within dendrites?



A solution: Intra-dendritic Inter-synaptic learning



Hebbian learning with pre-synaptic neuron *j*

Amplification of potentiation inside population *J* (minus Hebbian learning of the pre-synaptic neuron)

Amplification of potentiation by other populations *U*

$$a_{ij}(D) = q^{+}\xi_i\xi_j + q^{+}\xi_i\xi_J(n_j - 1) + q^{+}\xi_i\xi_j\left(\sum_{u=1,\ u\neq j}^{g}\xi_{Pu}n_u\right)$$

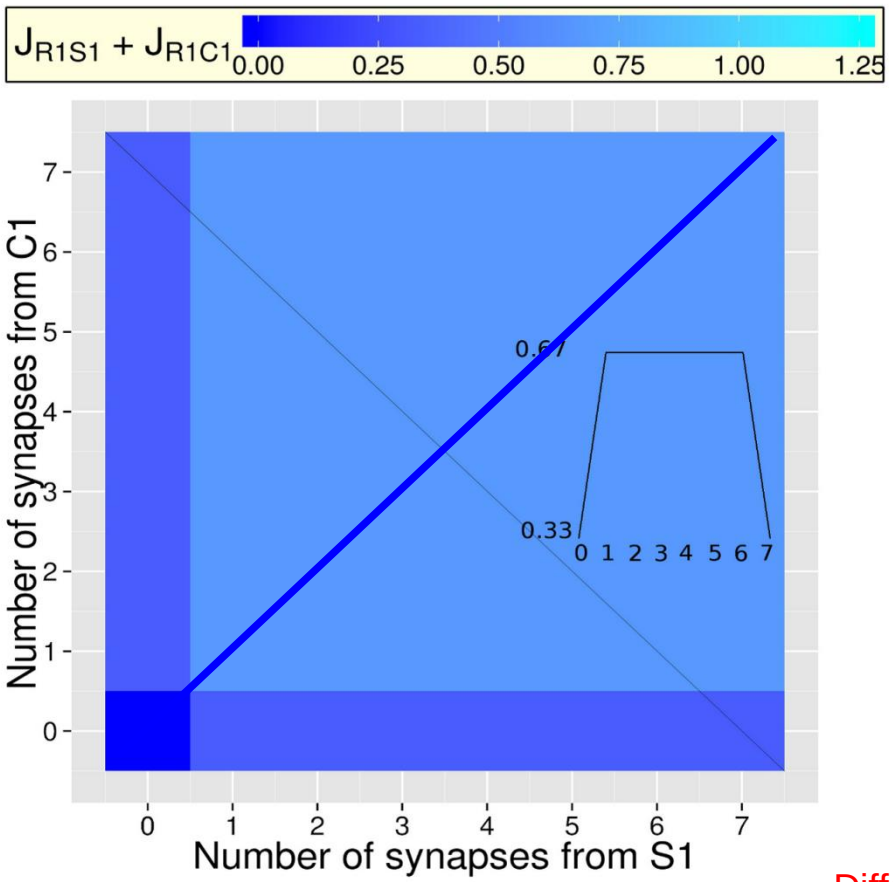
Inter-Synaptic learning links groups of items to clusters of synapses from neurons coding for several items

Lavigne, Avnaïm & Dumercy (2014). Frontiers in Cognitive Science.

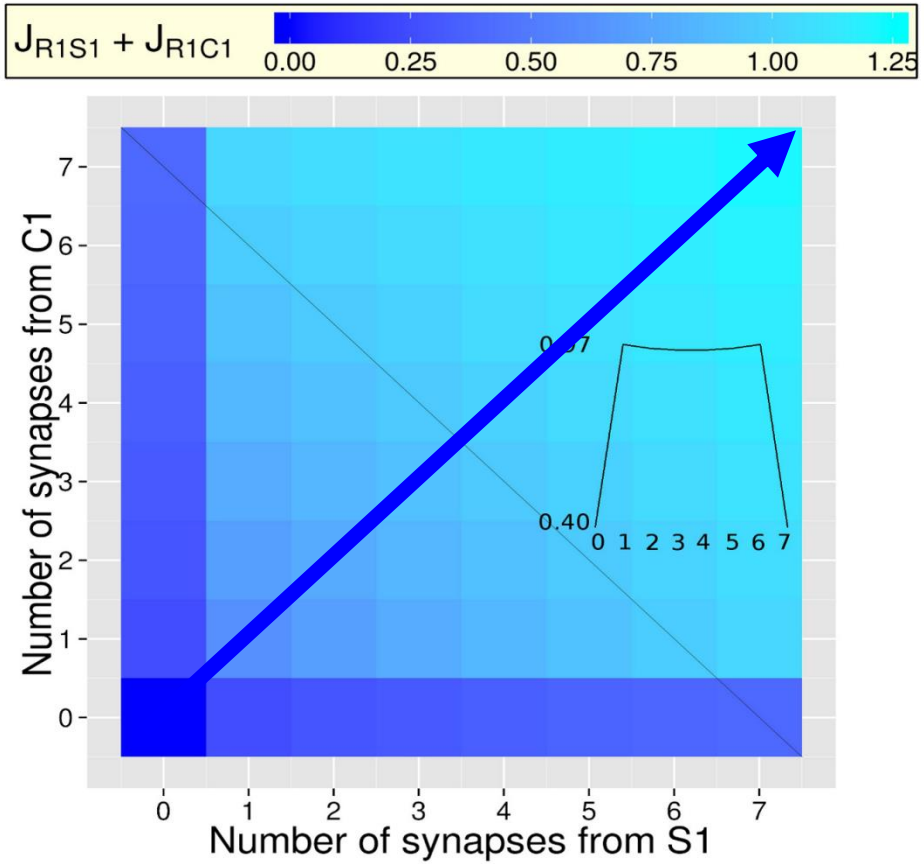
Amplification of potentiation with increasing number of synapses

Dendrites with different numbers of synapses from C1 and S1
on a neuron coding for R1 (learned combinaison C1S1R1)

Hebbian learning



Inter-synaptic leaning



Different dendrites learn some combinations better than others

Network processing of XOR combinations

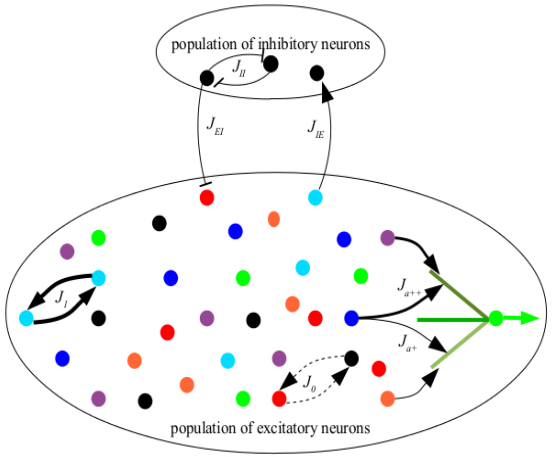
Inter-synaptic learning on random connectivity

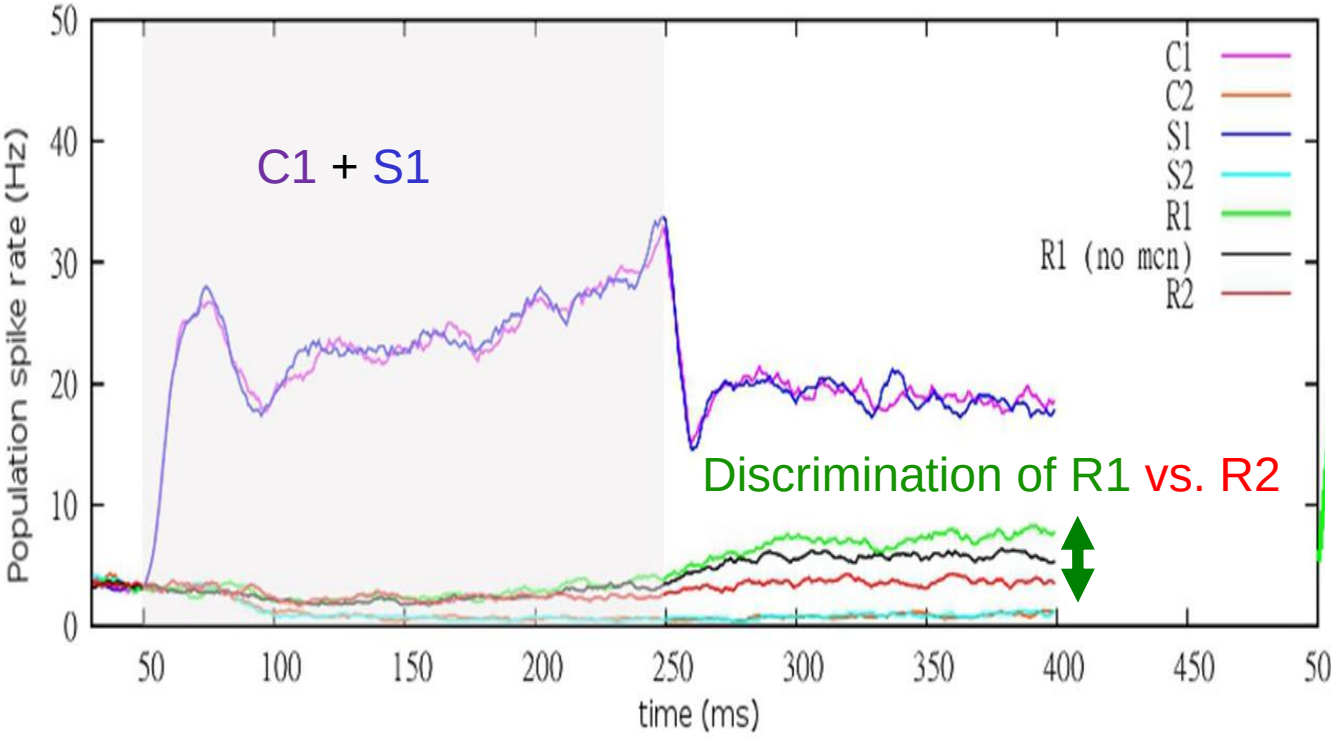
5000 neurons with 50 dendrites of 20 synapses

Prospective activity of neurons coding for Response 1 like in electrophysiological studies in monkeys

(Wallis & Miller, 2009, Science)

Cortical network model
With dendrites and
Inter-synaptic learning



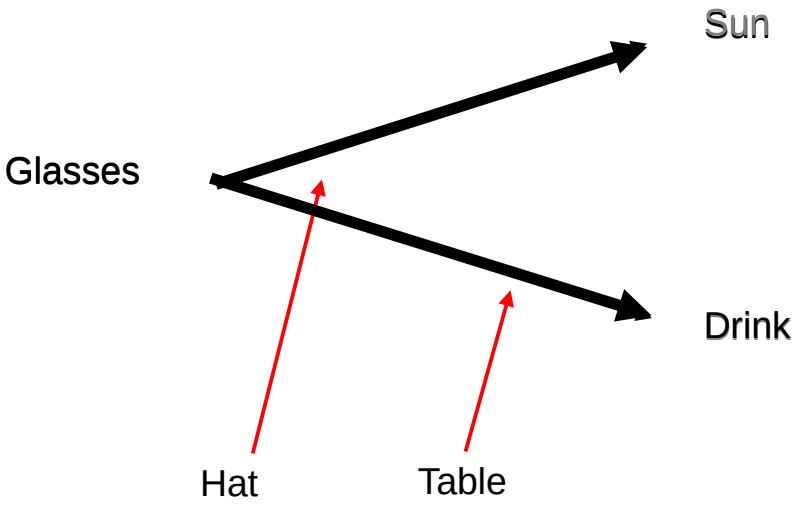


Conclusion: generalization to conditional activation

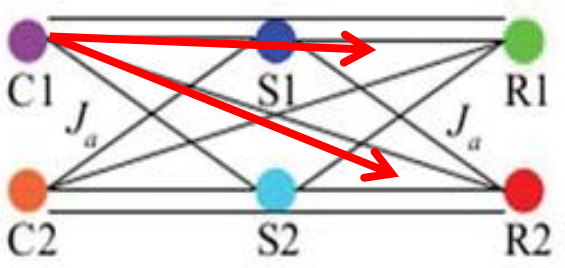
Inter Synaptic learning: biologically realistic, on random connectivity, without additional neurons

Non-local learning involving several pre-synaptic neurons increases network capacity (Alemi, Baldassi, Brunel & Zecchina, 2015)

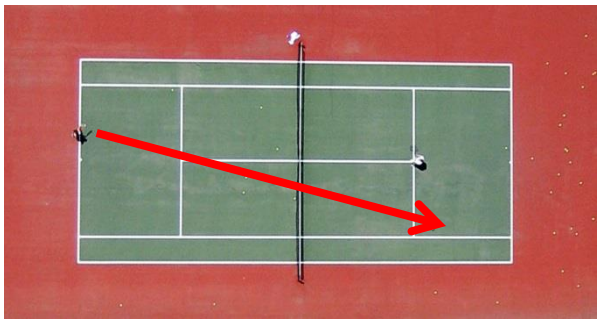
General problems of context-dependent conditional activation in cognitive processing (semantic priming, mental arithmetics)



Arrows on arrows…

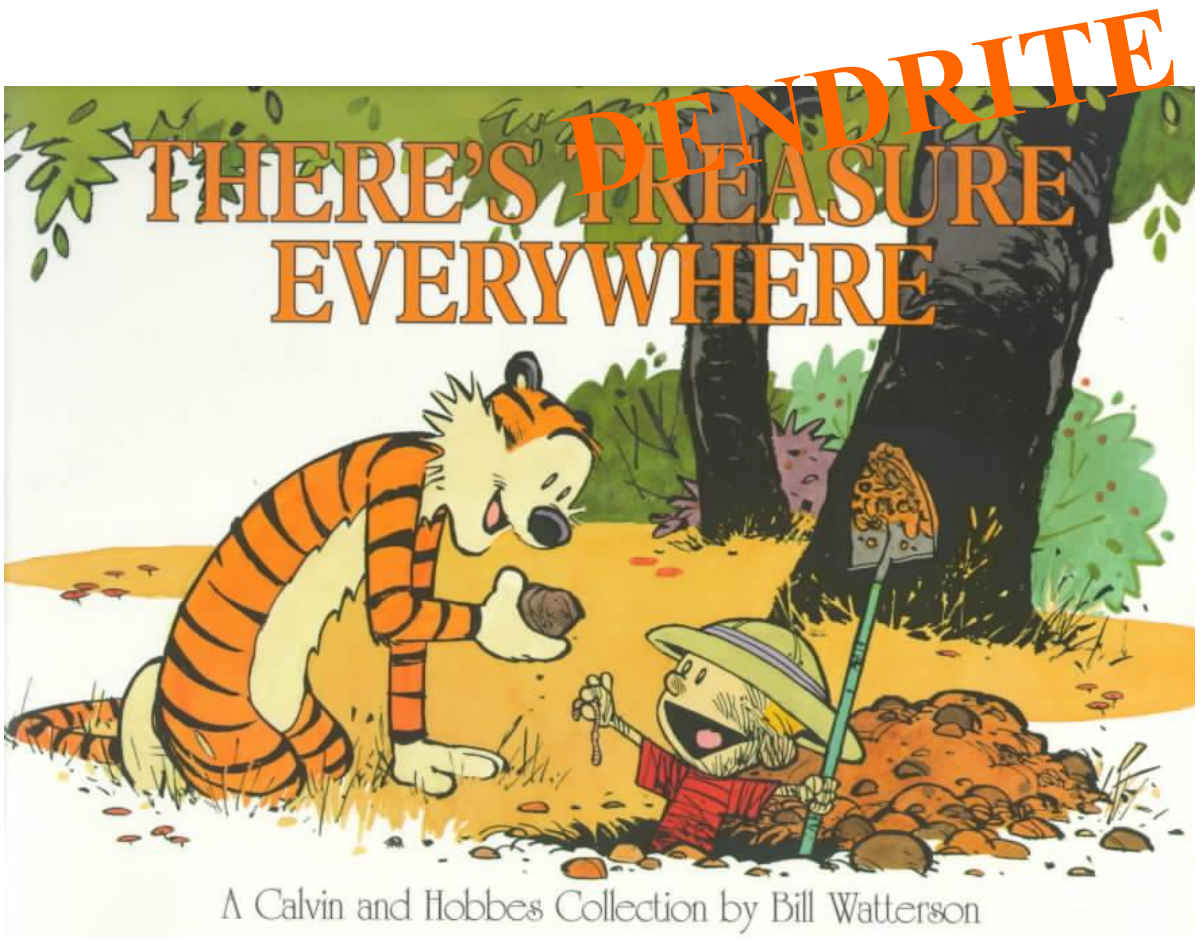


to better play tennis!



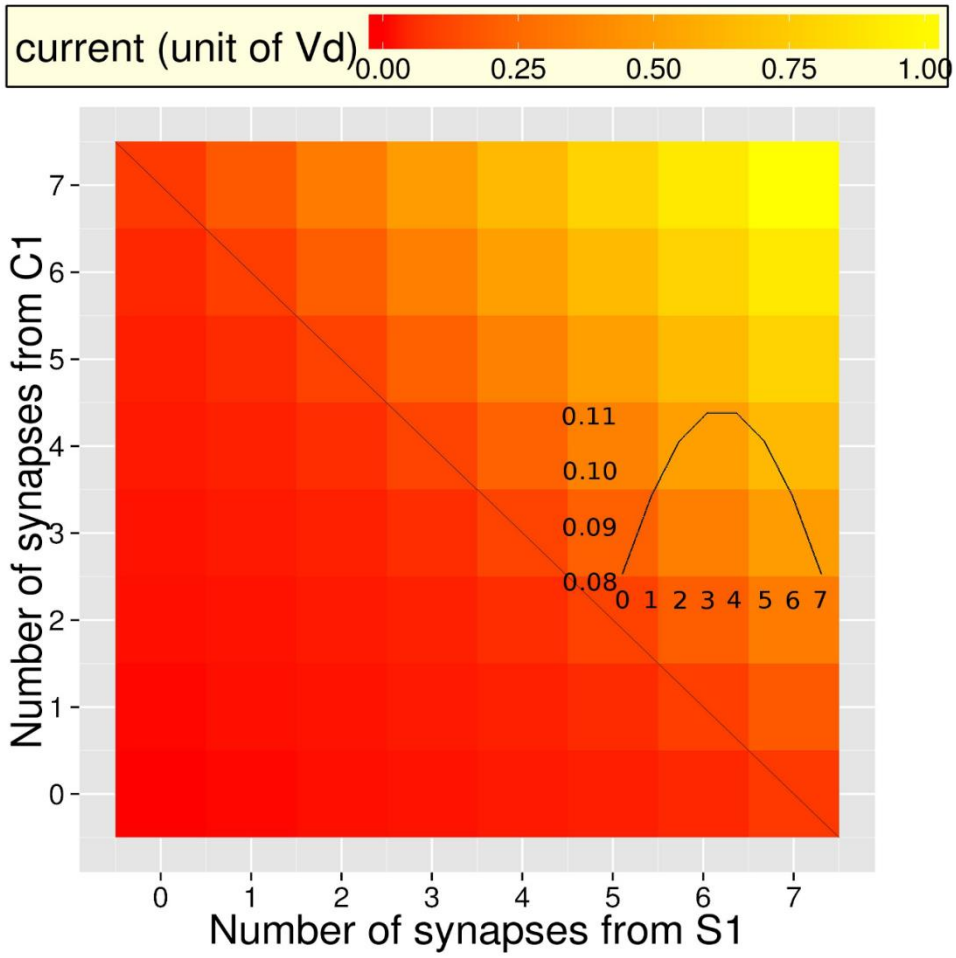
Thank you for your attention

Many thanks to Francis Avnaïm, Nicolas Brunel and Laurent Dumercy

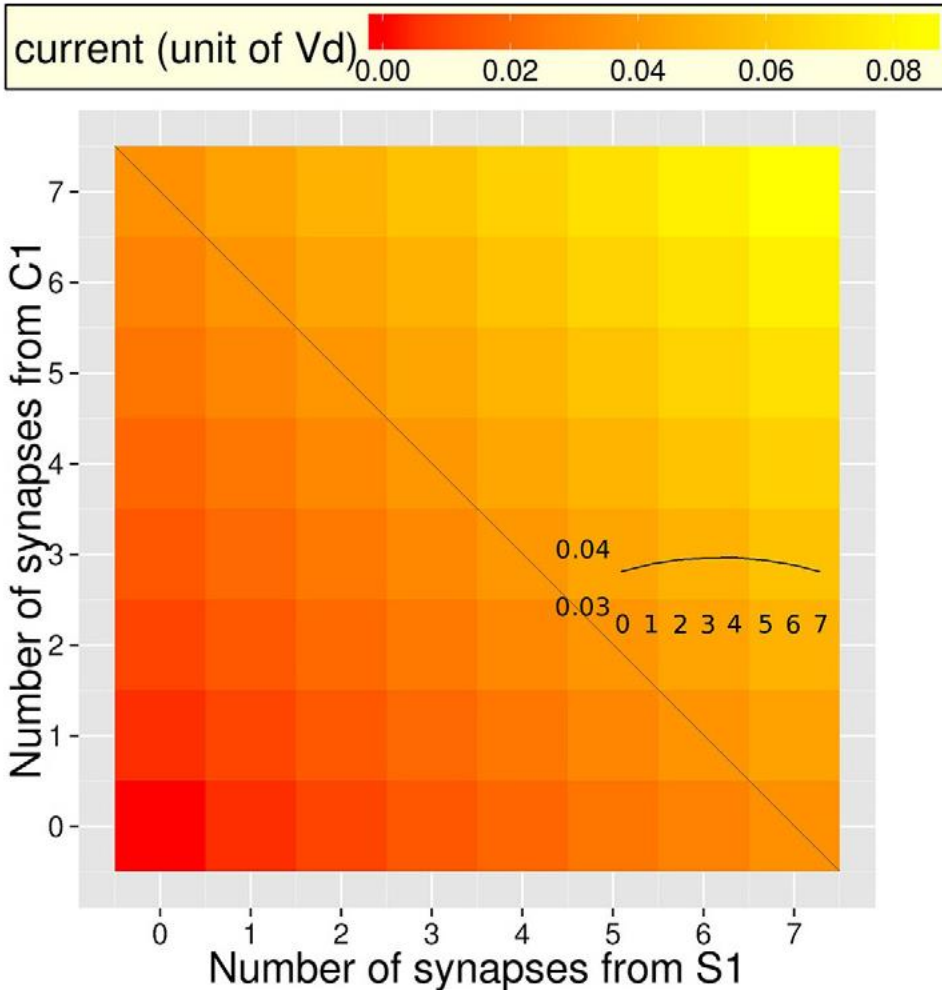


Amplification of dendritic currents with increasing number of synapses (learned combinaison **C1S1R1**)

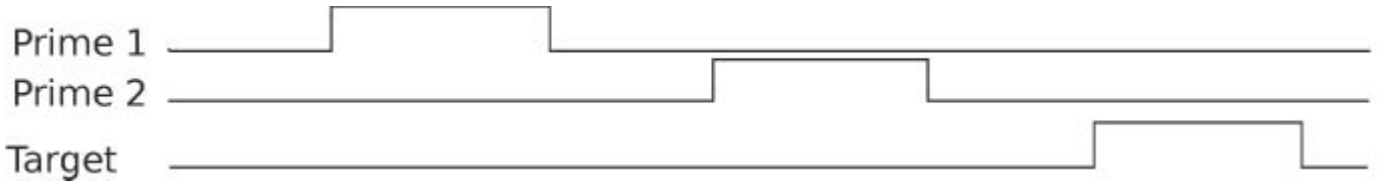
Linear dendritic integration

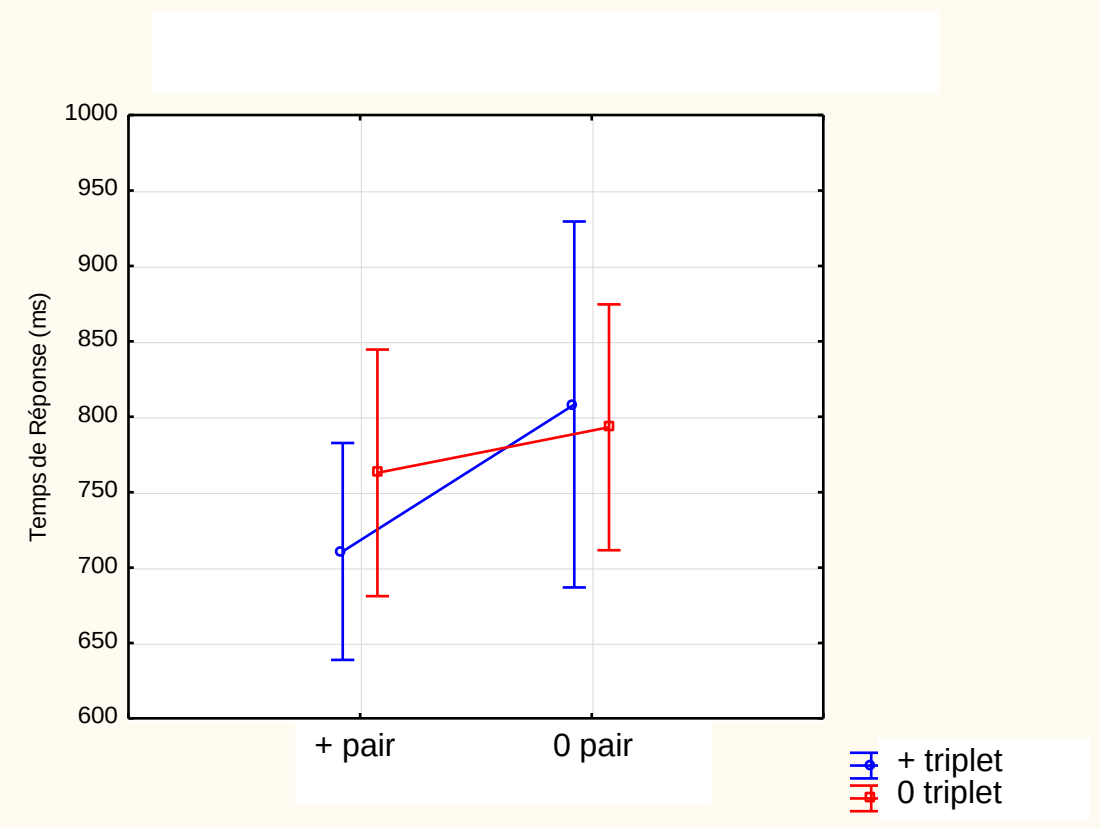


Non-linear dendritic integration



Au delà des paires: Priming par les triplets





Pour des paires équivalentes:

l'activation d'une cible 2 amorces est plus forte lorsque le triplet est fréquent

Processing of XOR combinations

Context (descend/climb)	Stimulus (normal/upside down))	Response (push/pull)
0	0	0
0	1	1
1	0	1
1	1	0