SYDE 556/750

Simulating Neurobiological Systems
Lecture 12: Biological Detail

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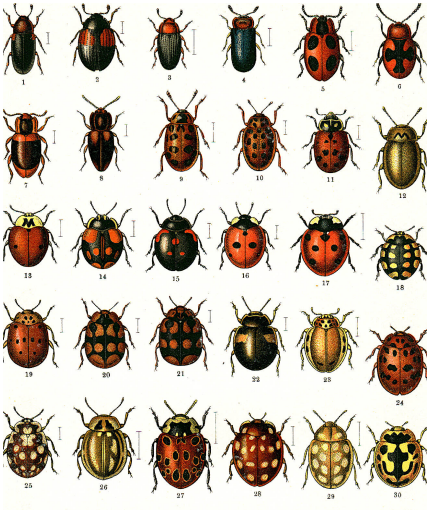
March 31, 2020



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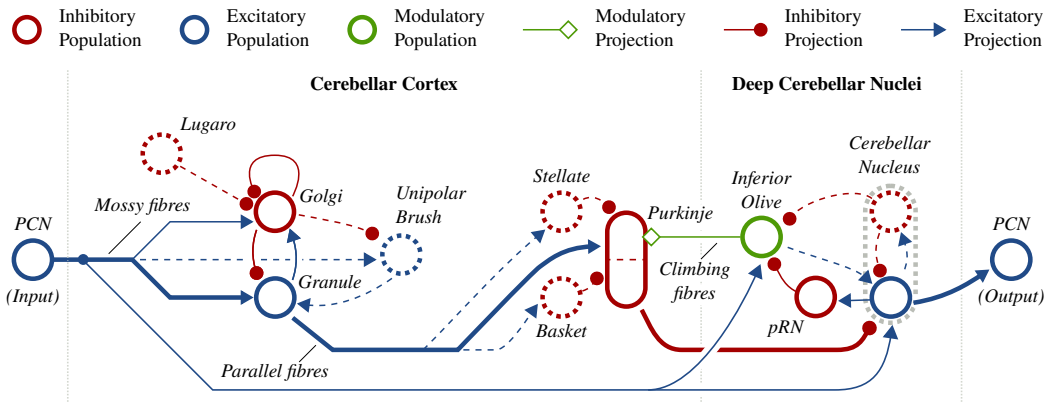
Cerebellum Model – Microcircuits



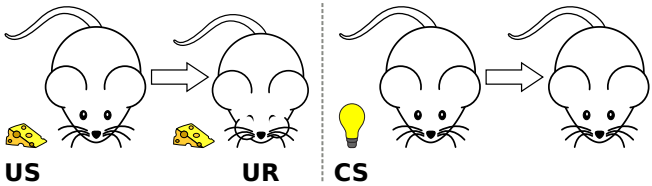
Cerebellum Model – Introduction

Cerebellum

- Important for motor control
- Mostly Feed-Forward architecture
- May support cognitive tasks
- Model task: eyeblink conditioning

Cerebellum Model – Review: Classical Conditioning

Before conditioning:



After conditioning:

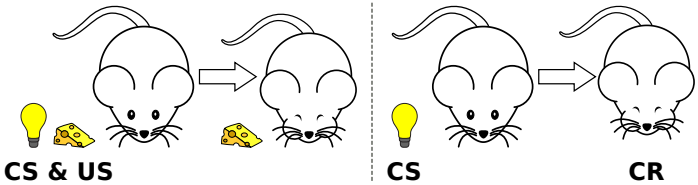
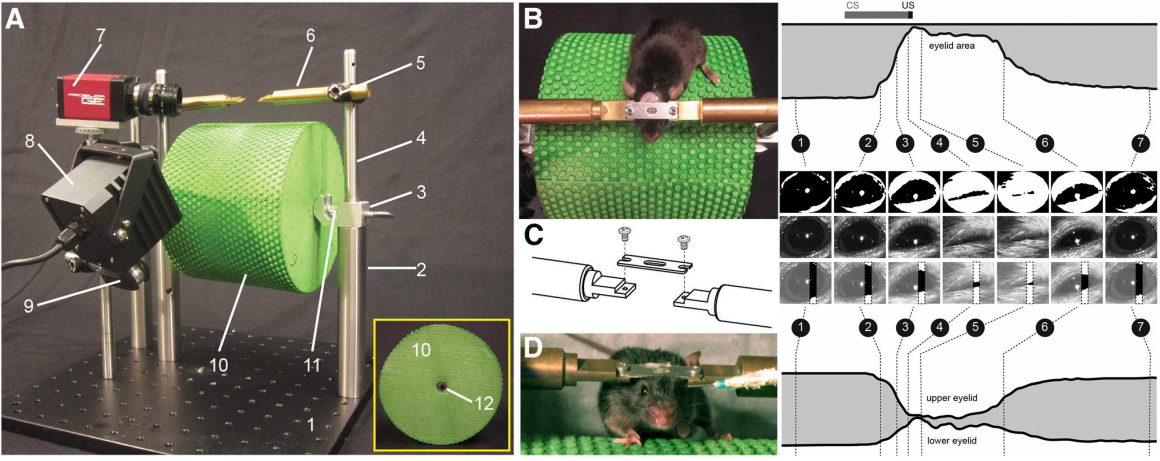
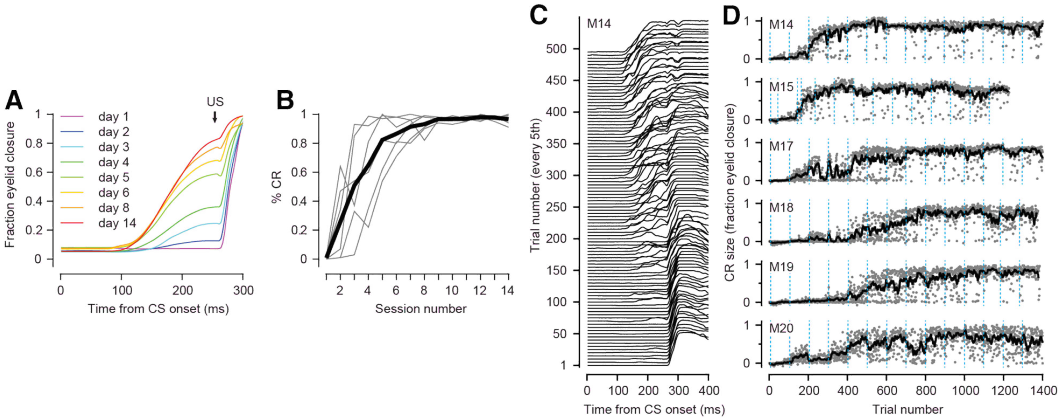


Image Sources. Images adapted from Wikimedia.

Cerebellum Model – Eyeblink Conditioning — Experimental Setup



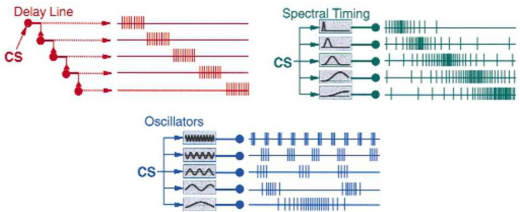
Cerebellum Model – Eyeblink Conditioning — Data



Cerebellum Model – Open Questions: How are Delays Learned?

Hypothesis 1

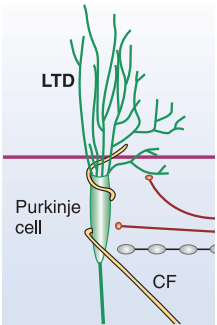
"Dynamics Representation"/
"Adaptive Filter Hypothesis"



Maybe dynamics are produced in the recurrent Granule-Golgi connection?

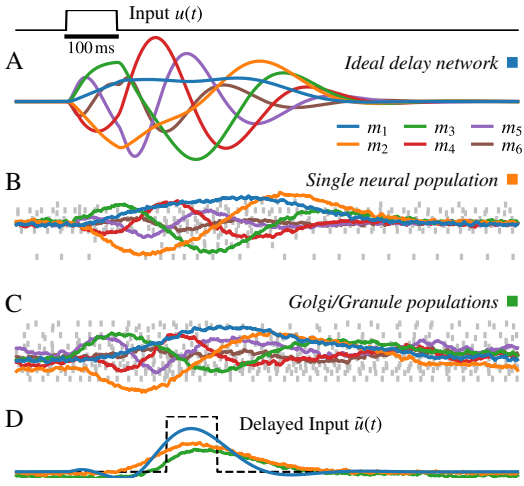
Hypothesis 2

"Intrinsic Neural Properties"

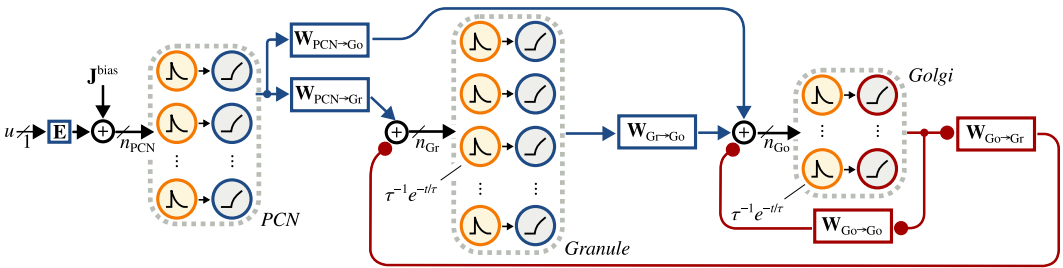


Maybe the Purkinje cells are able to learn timings?

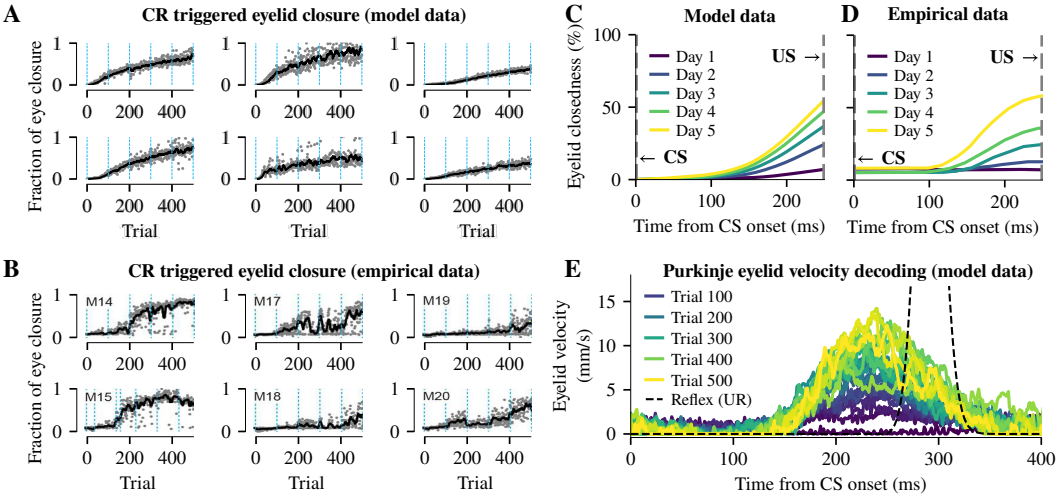
Cerebellum Model – The Delay Network



Cerebellum Model – Implementing The Delay Network



Cerebellum Model – Experiment & Results

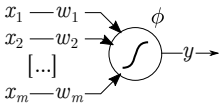


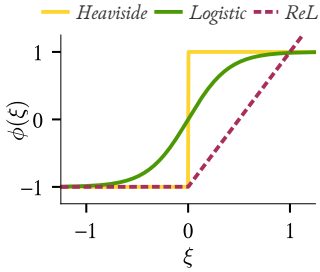
Review – Neuron Models

FUNCTIONAL — MECHANISTIC

Artificial Neurons

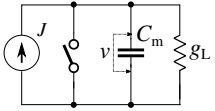
(McCulloch & Pitts – 1943)

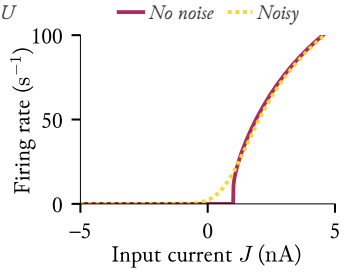




Leaky Integrate-and-Fire

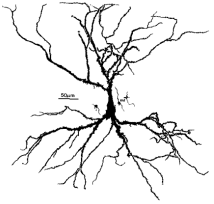
(Lapicque – 1907)





Biologically Detailed

(Hodgkin & Huxley – 1953)



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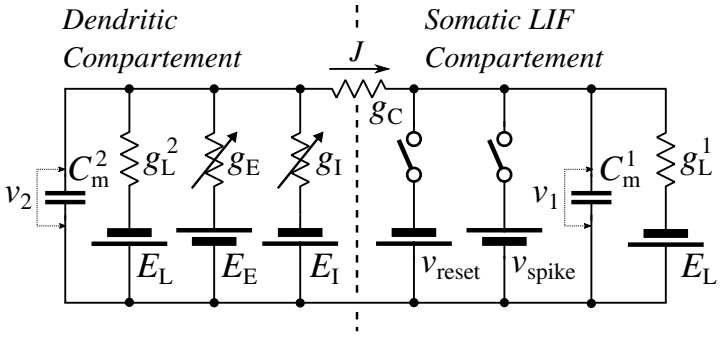
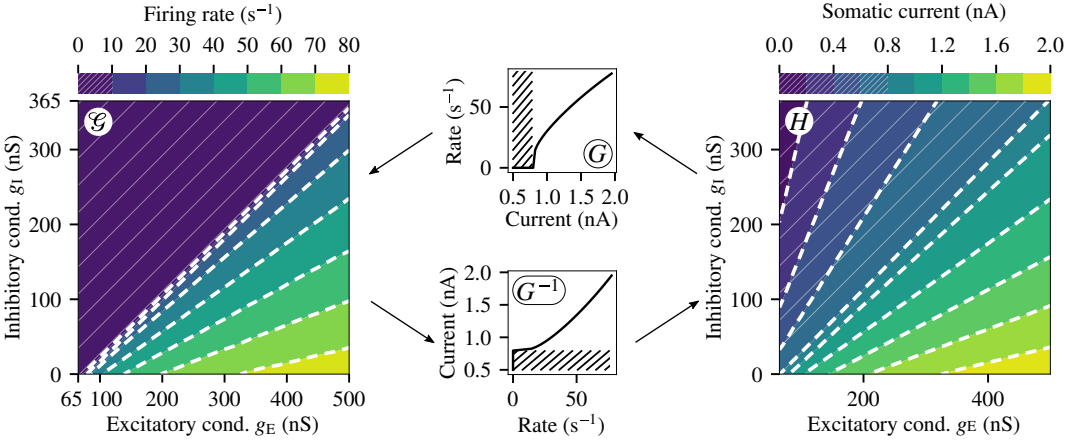
Conductance-Based Synapses – Neuron Model



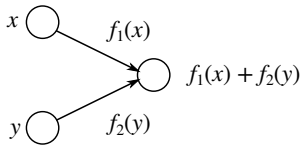
Synaptic Nonlinearity Function



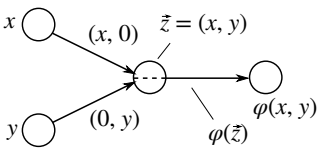
Conductance-Based Synapses – Dendritic Computation Experiment (I)

Compute various two-dimensional functions

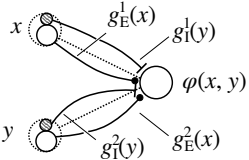
- Domain $(x, y) \in [0, 1]^2$
- 100 neurons per population
- Three topologies



(a) Additive network

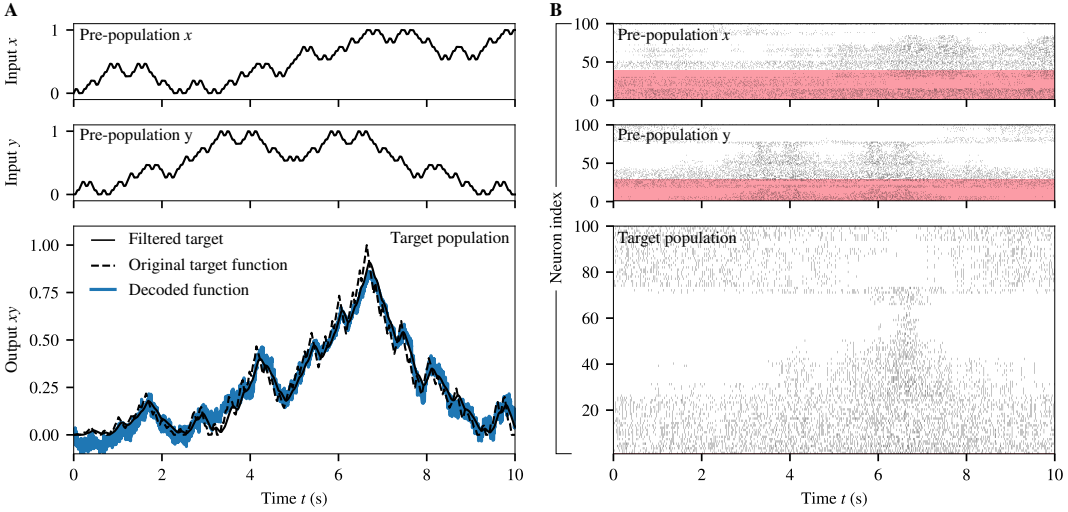


(b) Intermediate layer



(c) Synaptic computation

Conductance-Based Synapses – Dendritic Computation Experiment (II)



Conductance-Based Synapses – Dendritic Computation Experiment (III)

	Experiment setup						
	Standard LIF			Two comp. LIF $g_C = 50\,\text{nS}$		Two comp. LIF $g_C = 100\,\text{nS}$	
Target	no relaxation	Ⓐ standard	Ⓑ two-layer	Ⓒ standard	noise model	standard	noise model
$x + y$	5.1 ± 0.6%	5.5 ± 1.1%	11.0 ± 1.3%	**3.2 ± 1.1%**	9.1 ± 1.2%	5.1 ± 1.2%	11.5 ± 1.3%
$x \times y$	26.2 ± 0.4%	21.5 ± 6.6%	15.4 ± 4.0%	13.9 ± 2.9%	**11.9 ± 1.8%**	18.2 ± 4.0%	14.3 ± 2.1%
$\sqrt{x \times y}$	14.1 ± 0.4%	19.7 ± 6.1%	16.3 ± 3.0%	9.7 ± 2.6%	**7.1 ± 1.0%**	13.3 ± 4.2%	8.9 ± 1.7%
$(x \times y)^2$	44.5 ± 0.6%	33.0 ± 6.6%	**18.7 ± 6.7%**	27.7 ± 4.1%	27.4 ± 4.1%	34.3 ± 5.3%	30.3 ± 4.3%
$x/(1 + y)$	6.0 ± 0.4%	5.2 ± 0.7%	9.5 ± 0.8%	**3.4 ± 1.0%**	10.0 ± 1.6%	5.3 ± 1.3%	14.0 ± 1.9%
$\|\|(x, y)\|\|$	8.0 ± 0.4%	5.7 ± 1.1%	10.5 ± 1.0%	**3.1 ± 1.3%**	8.9 ± 1.2%	4.3 ± 1.8%	12.3 ± 1.8%
$\text{atan}(x, y)$	10.3 ± 0.3%	8.6 ± 1.0%	13.4 ± 1.1%	**5.8 ± 1.3%**	8.4 ± 1.0%	7.0 ± 1.2%	12.7 ± 1.6%
$\max(x, y)$	14.9 ± 0.3%	10.0 ± 0.9%	11.3 ± 1.4%	**5.5 ± 0.9%**	7.7 ± 0.9%	7.3 ± 0.9%	9.7 ± 1.0%

Image sources

Title slide
Illustration of monographs Georgiy Jacobson "Beetles Russia and Western Europe"
Around 1905
Wikimedia.