

SYDE 556/750

Simulating Neurobiological Systems
Lecture 12: Biological Detail

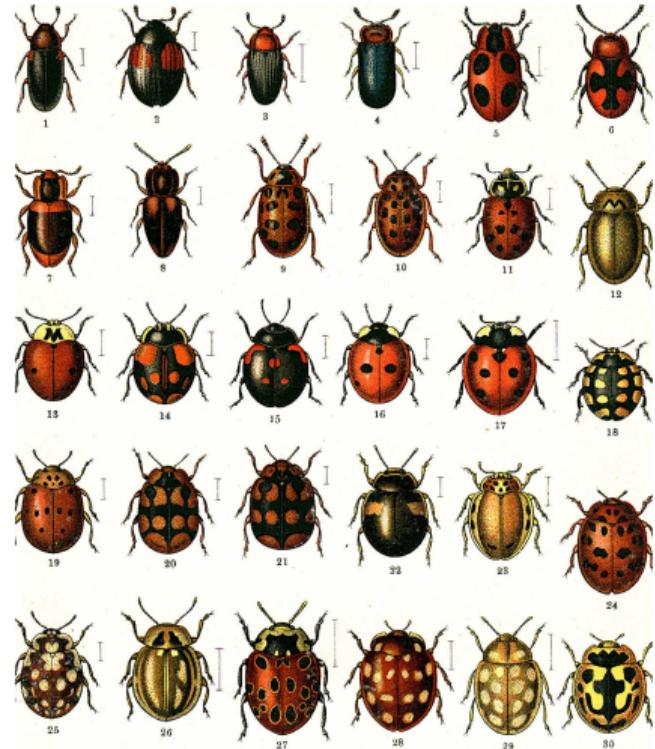
Andreas Stöckel

March 31, 2020

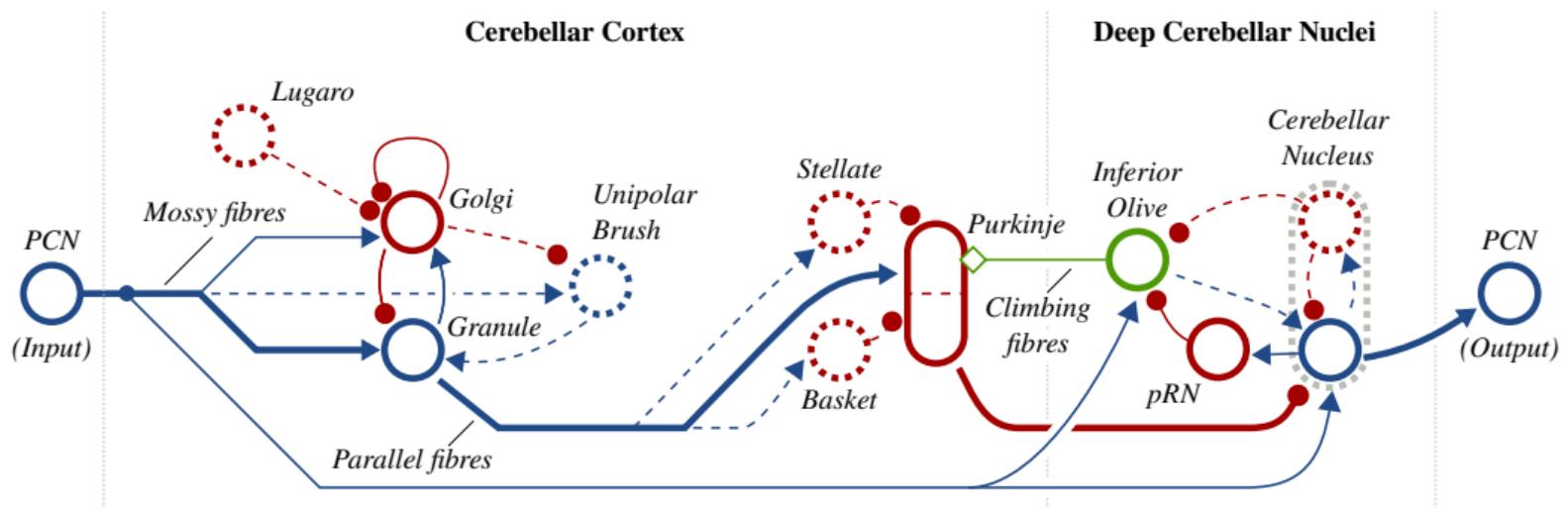


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Cerebellum Model – Microcircuits



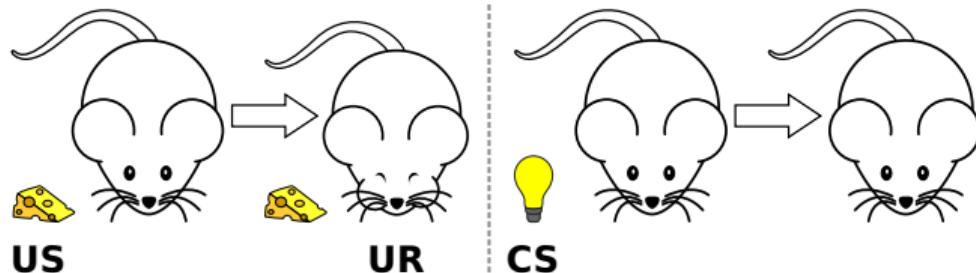
Cerebellum Model – Introduction

Cerebellum

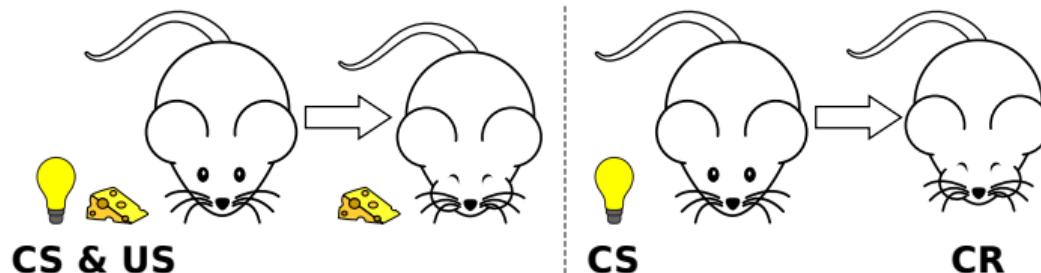
- ▶ Important for motor control
- ▶ Mostly Feed-Forward architecture
- ▶ May support cognitive tasks
- ▶ Model task: eyeblink conditioning

Cerebellum Model – Review: Classical Conditioning

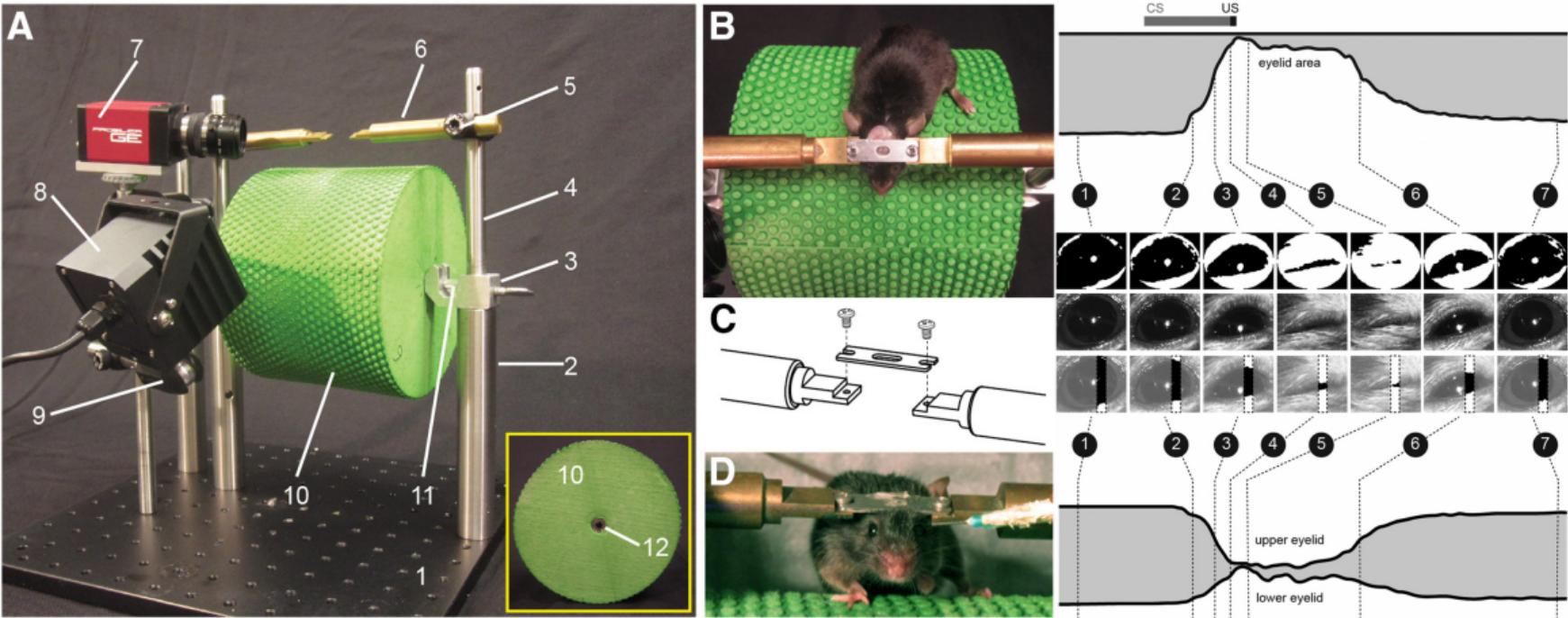
Before conditioning:



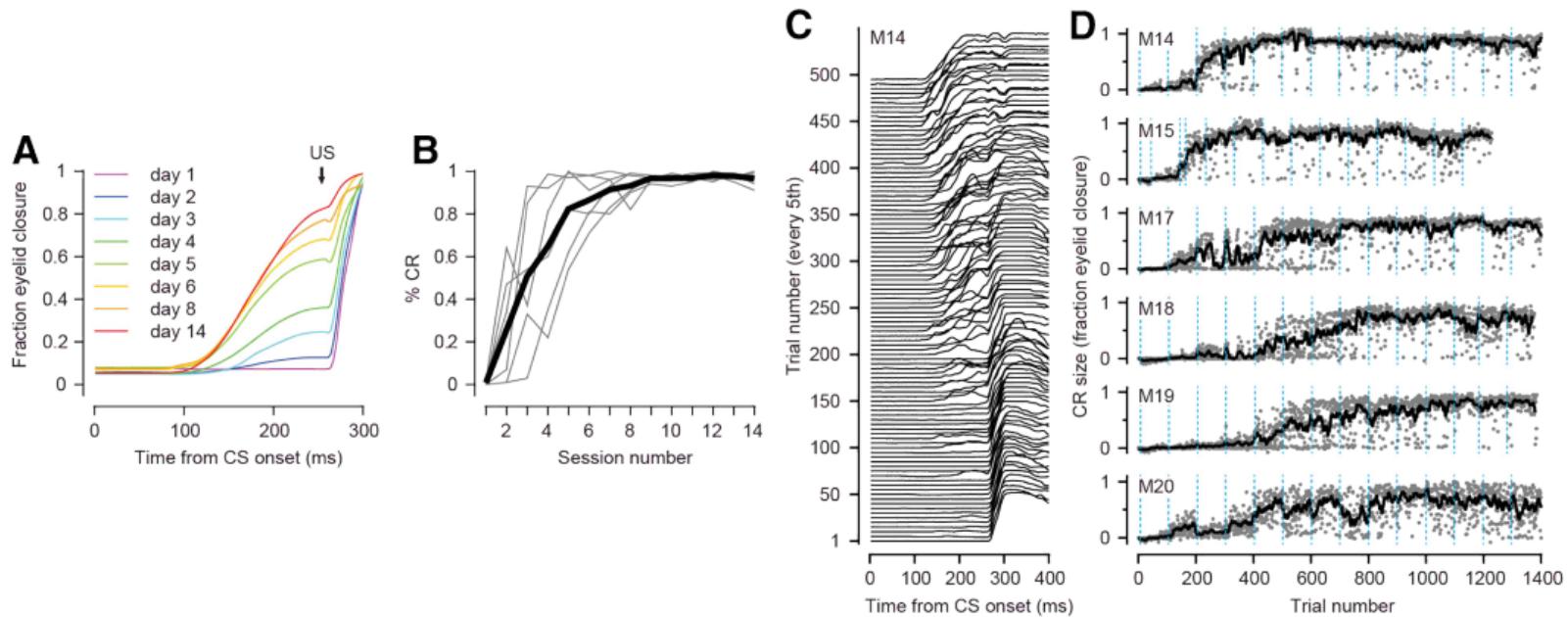
After conditioning:



Cerebellum Model – Eyeblink Conditioning — Experimental Setup



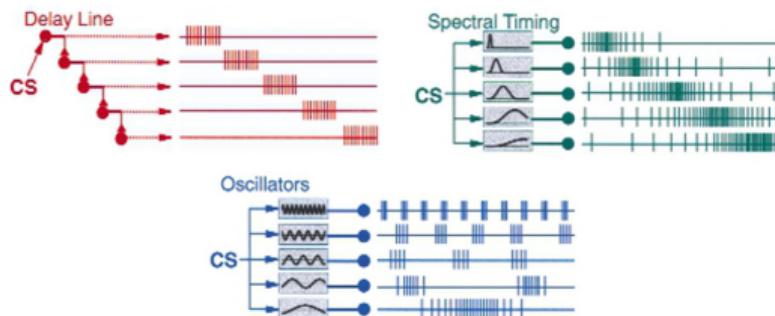
Cerebellum Model – Eyeblink Conditioning — Data



Cerebellum Model – Open Questions: How are Delays Learned?

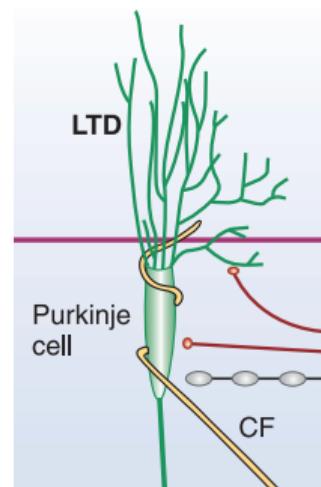
Hypothesis 1

“Dynamics Representation”/
“Adaptive Filter Hypothesis”



Hypothesis 2

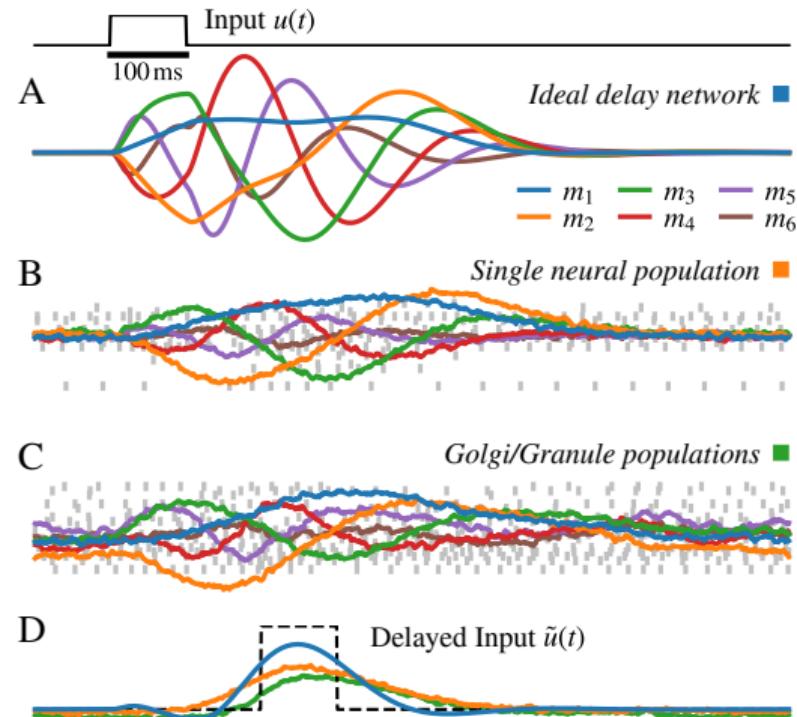
“Intrinsic Neural Properties”



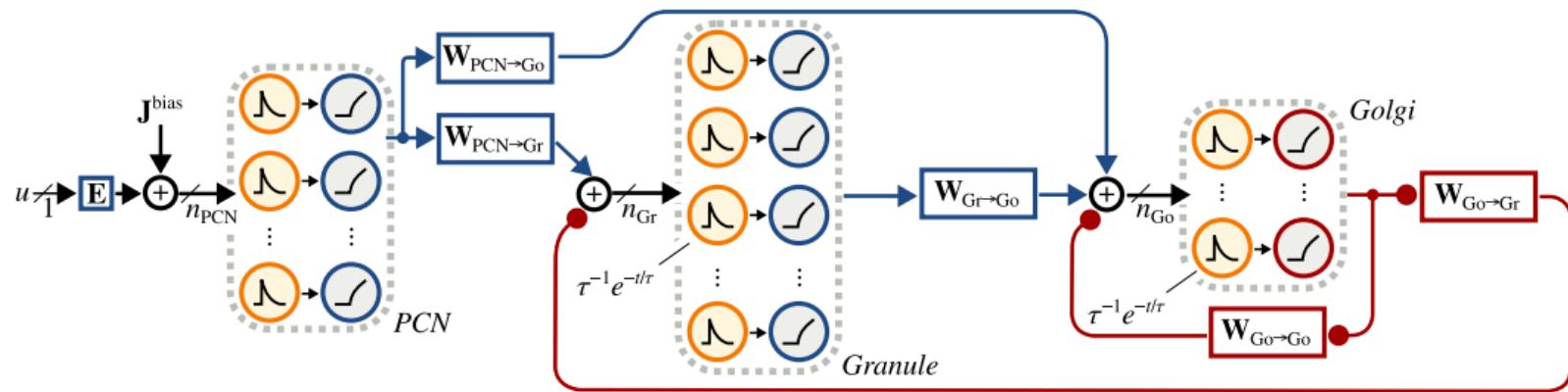
Maybe dynamics are produced in the recurrent Granule-Golgi connection?

Maybe the Purkinje cells are able to learn timings?

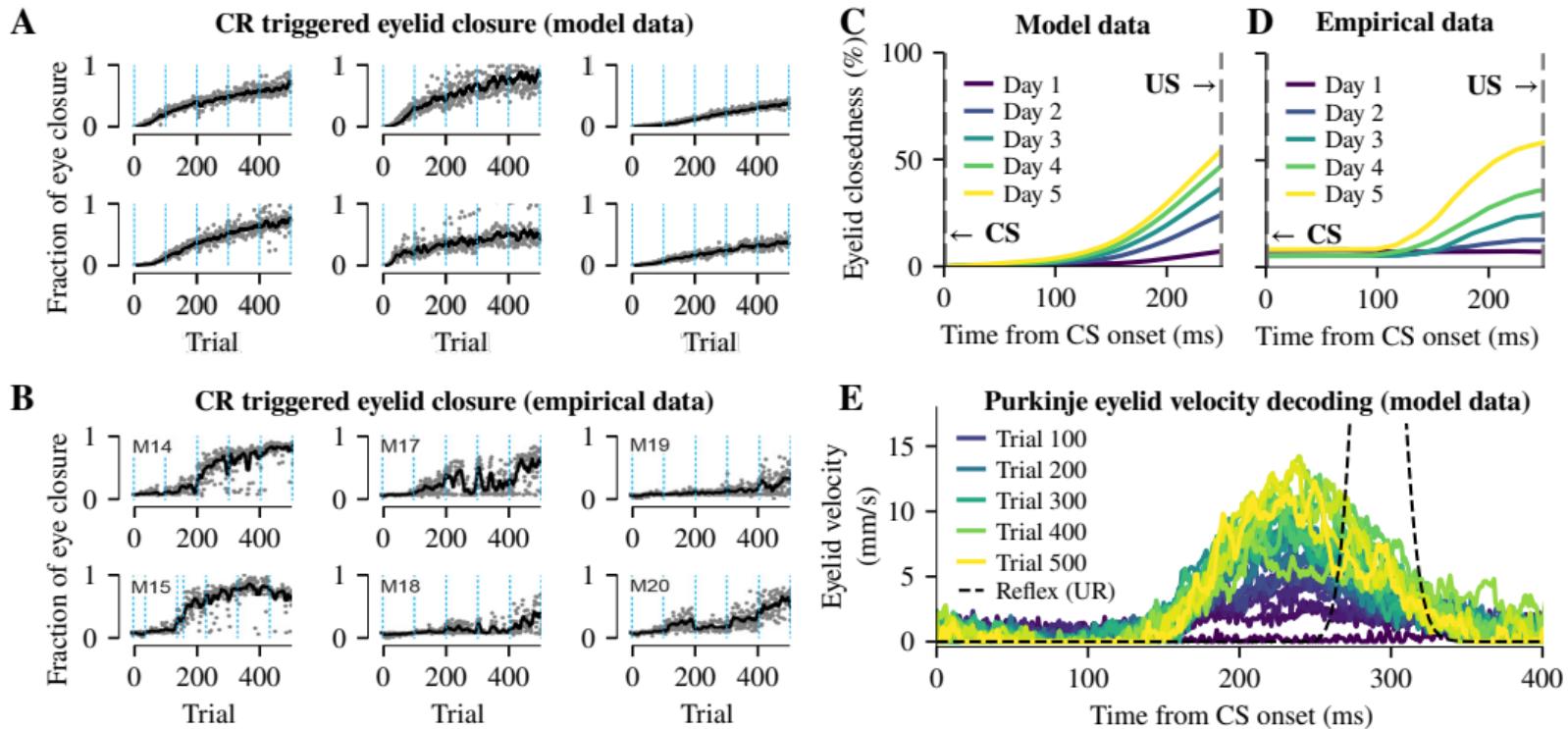
Cerebellum Model – The Delay Network



Cerebellum Model – Implementing The Delay Network



Cerebellum Model – Experiment & Results



Review – Neuron Models

FUNCTIONAL

MECHANISTIC

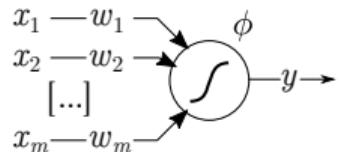
Review – Neuron Models

FUNCTIONAL

MECHANISTIC

Artificial Neurons

(McCulloch & Pitts – 1943)



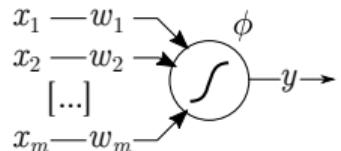
Review – Neuron Models

FUNCTIONAL

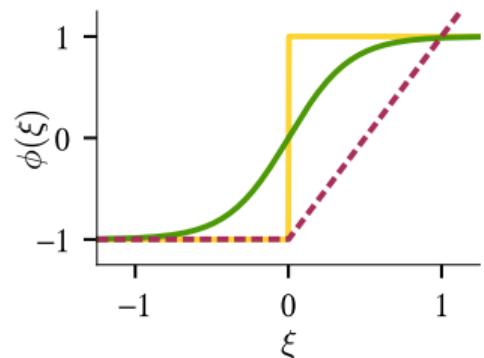
MECHANISTIC

Artificial Neurons

(McCulloch & Pitts – 1943)



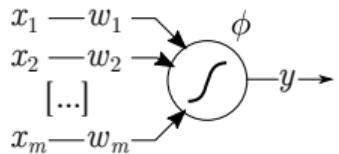
— Heaviside — Logistic - - - ReLU



Review – Neuron Models

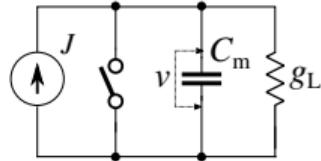
FUNCTIONAL

Artificial Neurons
(McCulloch & Pitts – 1943)

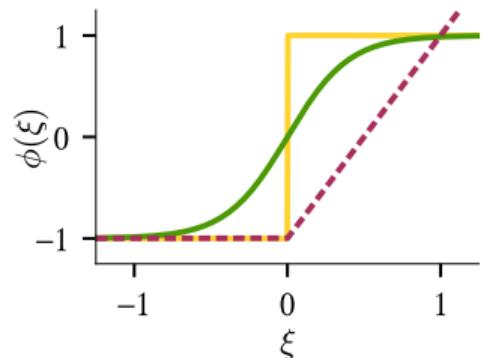


MECHANISTIC

Leaky Integrate-and-Fire
(Lapicque – 1907)



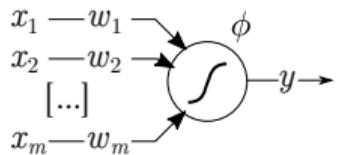
— Heaviside — Logistic - - - ReLU



Review – Neuron Models

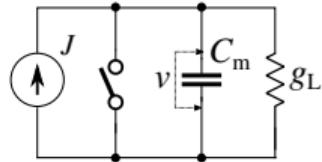
FUNCTIONAL

Artificial Neurons
(McCulloch & Pitts – 1943)

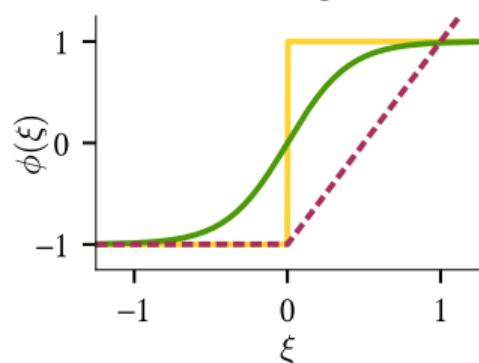


MECHANISTIC

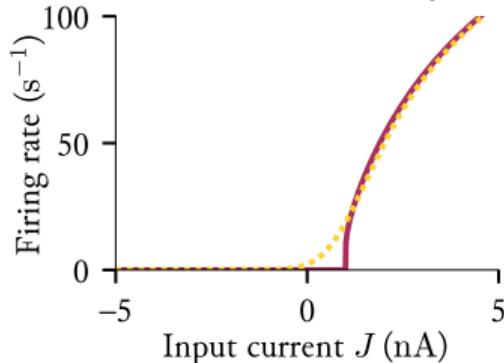
Leaky Integrate-and-Fire
(Lapicque – 1907)



— Heaviside — Logistic -·- ReLU



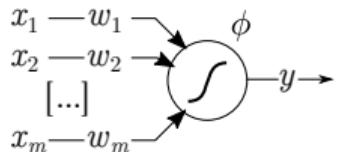
— No noise ··· Noisy



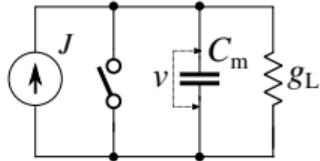
Review – Neuron Models

FUNCTIONAL

Artificial Neurons (McCulloch & Pitts – 1943)

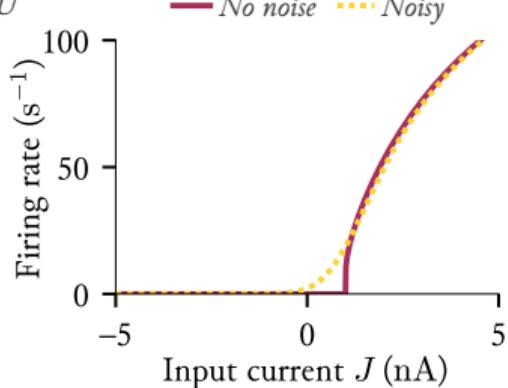
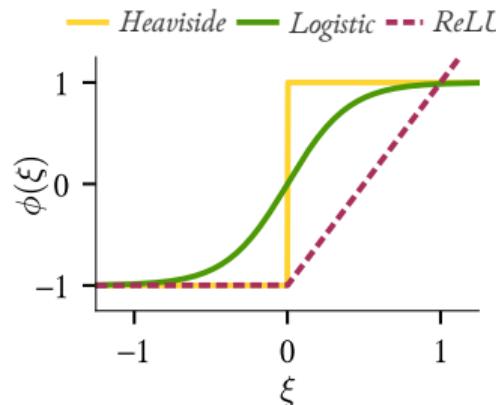


Leaky Integrate-and-Fire (Lapicque – 1907)



MECHANISTIC

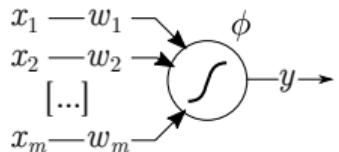
Biologically Detailed (Hodgkin & Huxley – 1953)



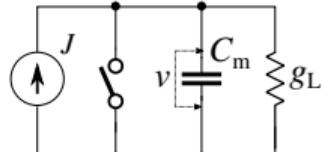
Review – Neuron Models

FUNCTIONAL

Artificial Neurons
(McCulloch & Pitts – 1943)

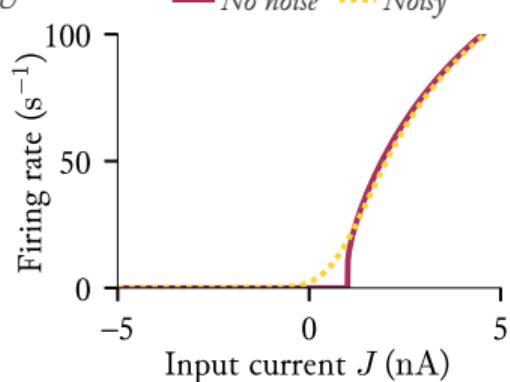
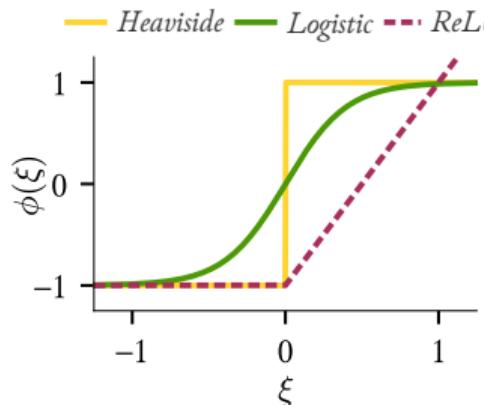


Leaky Integrate-and-Fire
(Lapicque – 1907)

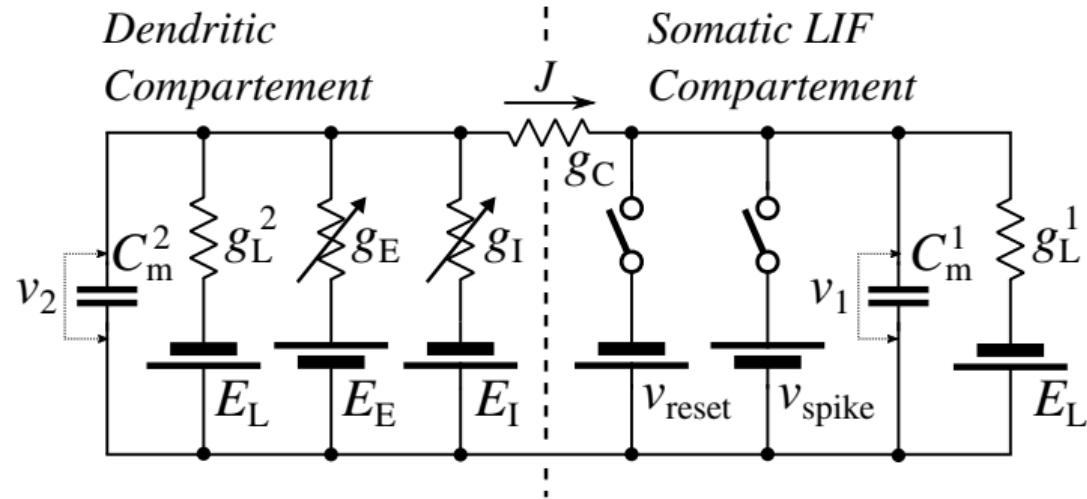


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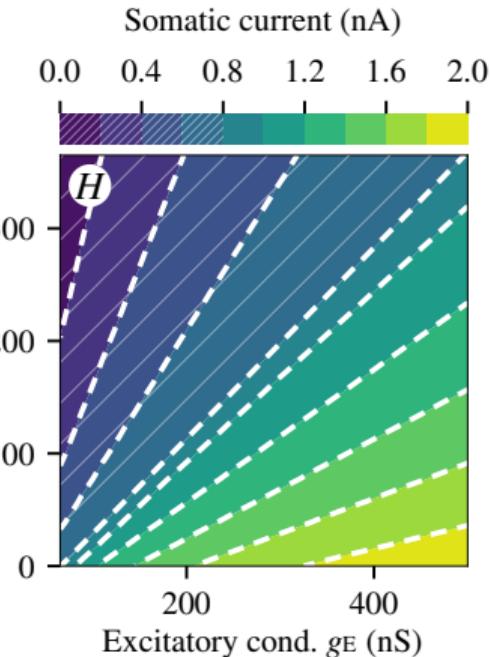
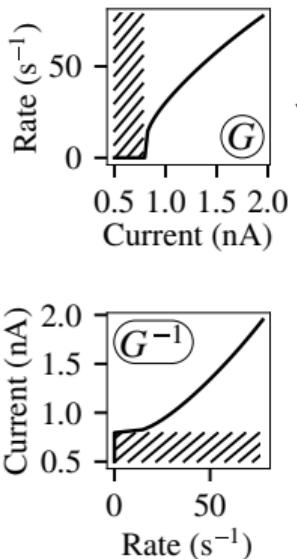
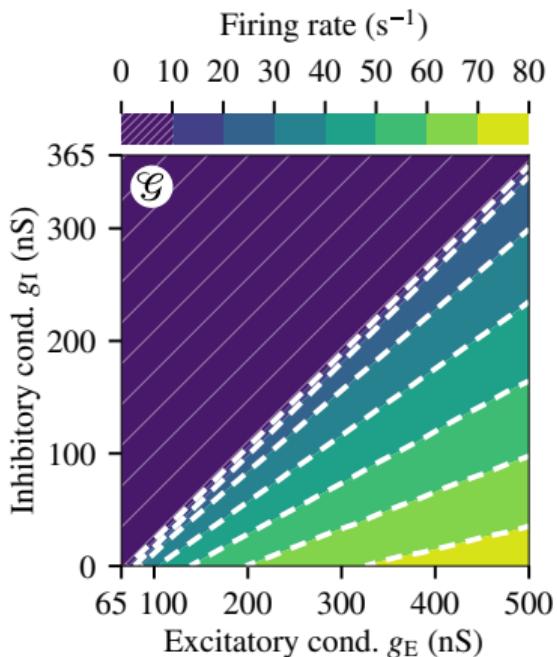
Biologically Detailed
(Hodgkin & Huxley – 1953)



Conductance-Based Synapses – Neuron Model



Synaptic Nonlinearity Function



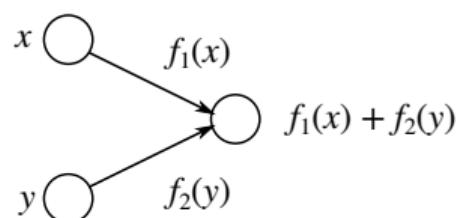
Conductance-Based Synapses – Dendritic Computation Experiment (I)

Compute various two-dimensional functions

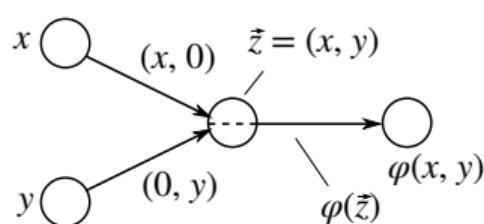
► Domain $(x, y) \in [0, 1]^2$

► 100 neurons per population

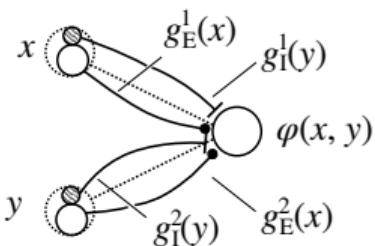
► Three topologies



(a) Additive network

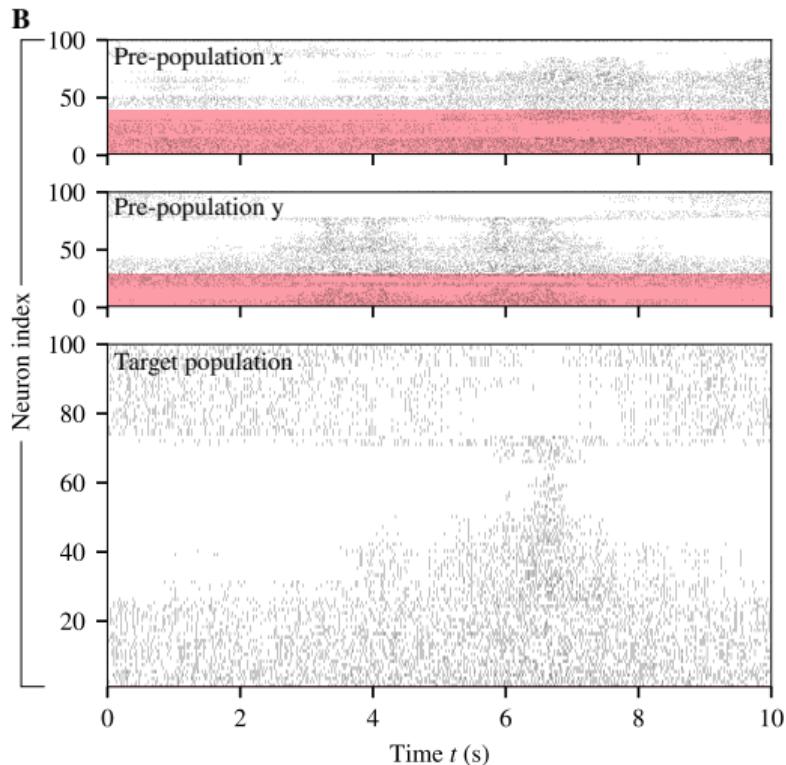
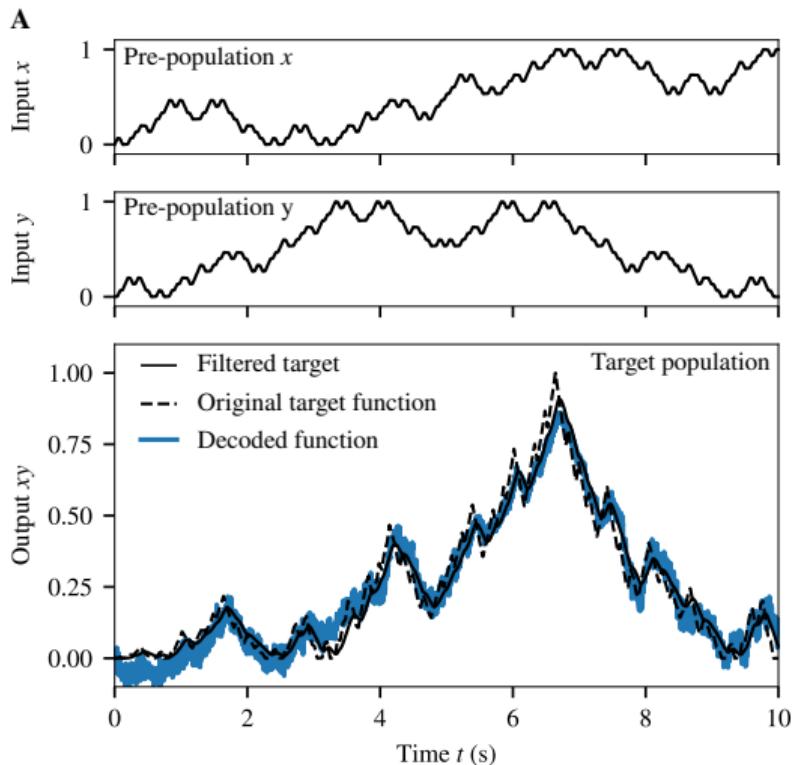


(b) Intermediate layer



(c) Synaptic computation

Conductance-Based Synapses – Dendritic Computation Experiment (II)



Conductance-Based Synapses – Dendritic Computation Experiment (III)

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

Image sources

Title slide

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