A Biologically Plausible Spiking Neural Model of Eyeblink Conditioning in the Cerebellum

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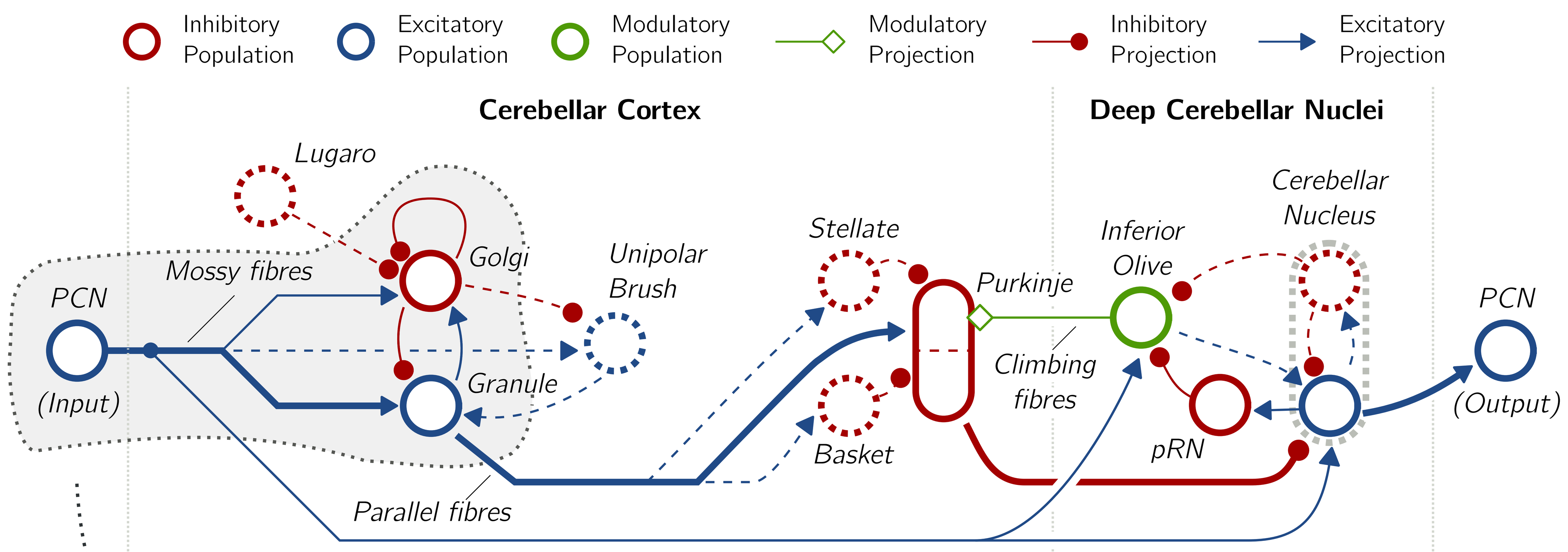
Introduction ①

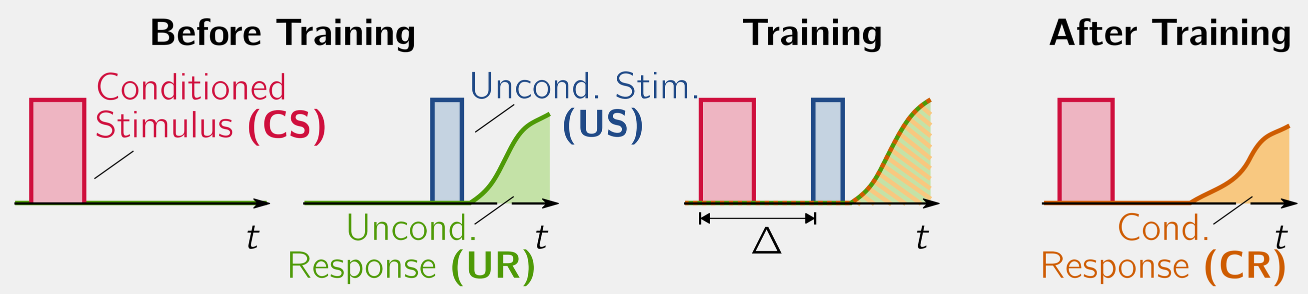
- ▶ The Cerebellum is essential for **fine-motor skills** and tasks such as **eyeblink conditioning**.
- ▶ The cerebellum likely supports cognition.
- ▶ Marr suggested functional cerebellar circuitry (Fig. 1; [1]).
- ▶ **This work:** Novel spiking neural **model of eyeblink conditioning** based on **temporal basis** generated in the **Granule-Golgi circuit**.



▲ **Figure 1** Cerebellar microcircuit [2, 3]. Stimuli from pre-cerebellar nuclei pass through the Golgi-Granule circuit, creating a high-dimensional representation. Training ("modulation") of the parallel fibre synaptic weights allows the circuit to learn complex functions of the input **[1]**. "Dashed" populations not included in our model.

Methods ②

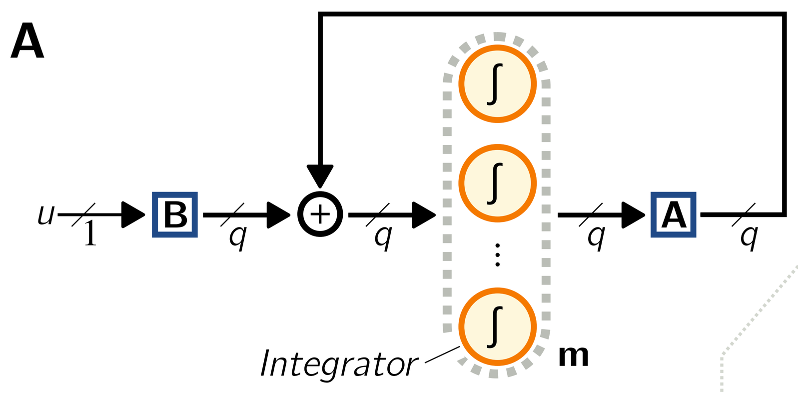
- ▶ **Goal:** Model that learns to produce CR



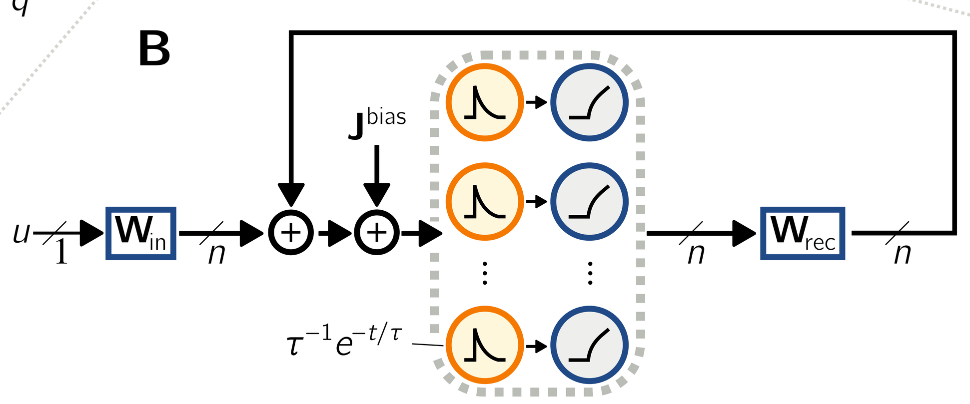
- ▶ CR ≈ delayed CS ⇒ **Delay Network** [5]

$$\theta\dot{\mathbf{m}} = \mathbf{A}\mathbf{m} + \mathbf{B}u, \quad \mathbf{A} \in \mathbb{R}^{q\times q}, \quad \mathbf{m}, \mathbf{B} \in \mathbb{R}^{q}$$

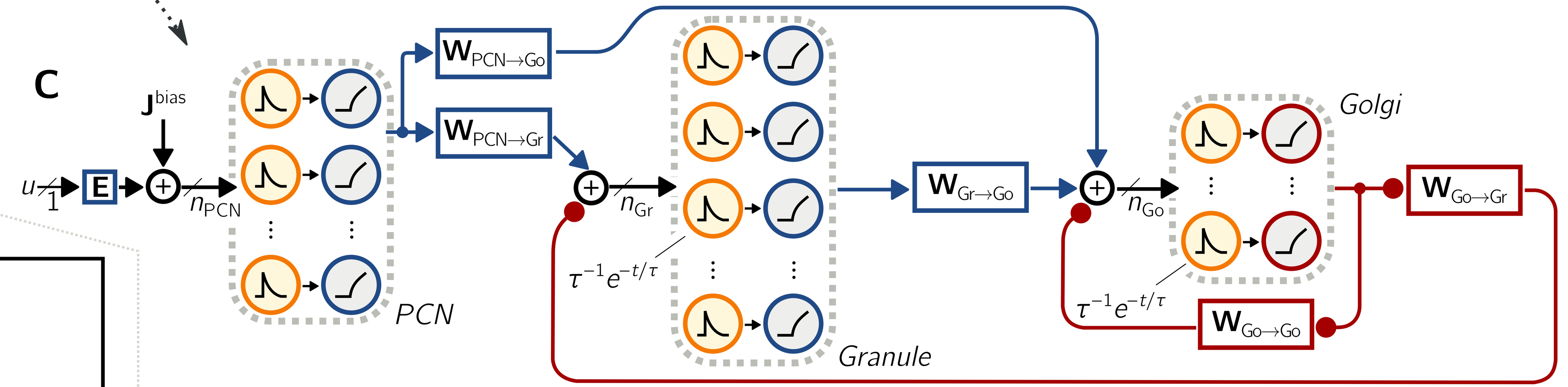
- ▶ Realize system in Granule-Golgi circuit (Fig. 2)
- ▶ Decode delay Δ by learning the Granule-Purkinje weights online.



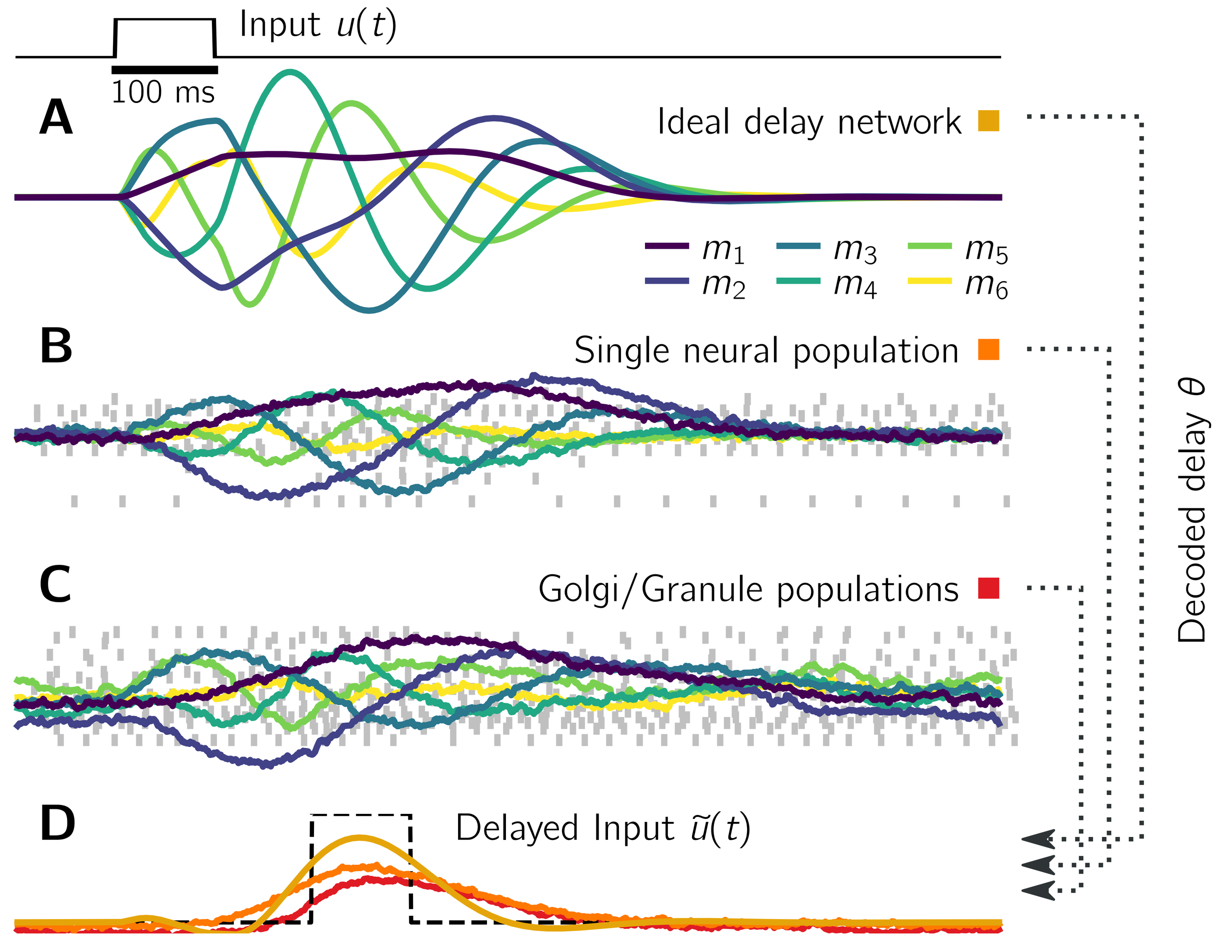
▲ **Figure 2A** Ideal implementation of the delay network. The LTI system defined by the feedback and input matrices **A** and **B** is implemented using ideal integrators.



▼ **Figure 2B** Spiking neural network implementation. Spiking neurons with synaptic filters are used instead of integrators. **A** and **B** are replaced by weights **W** optimized using least squares.



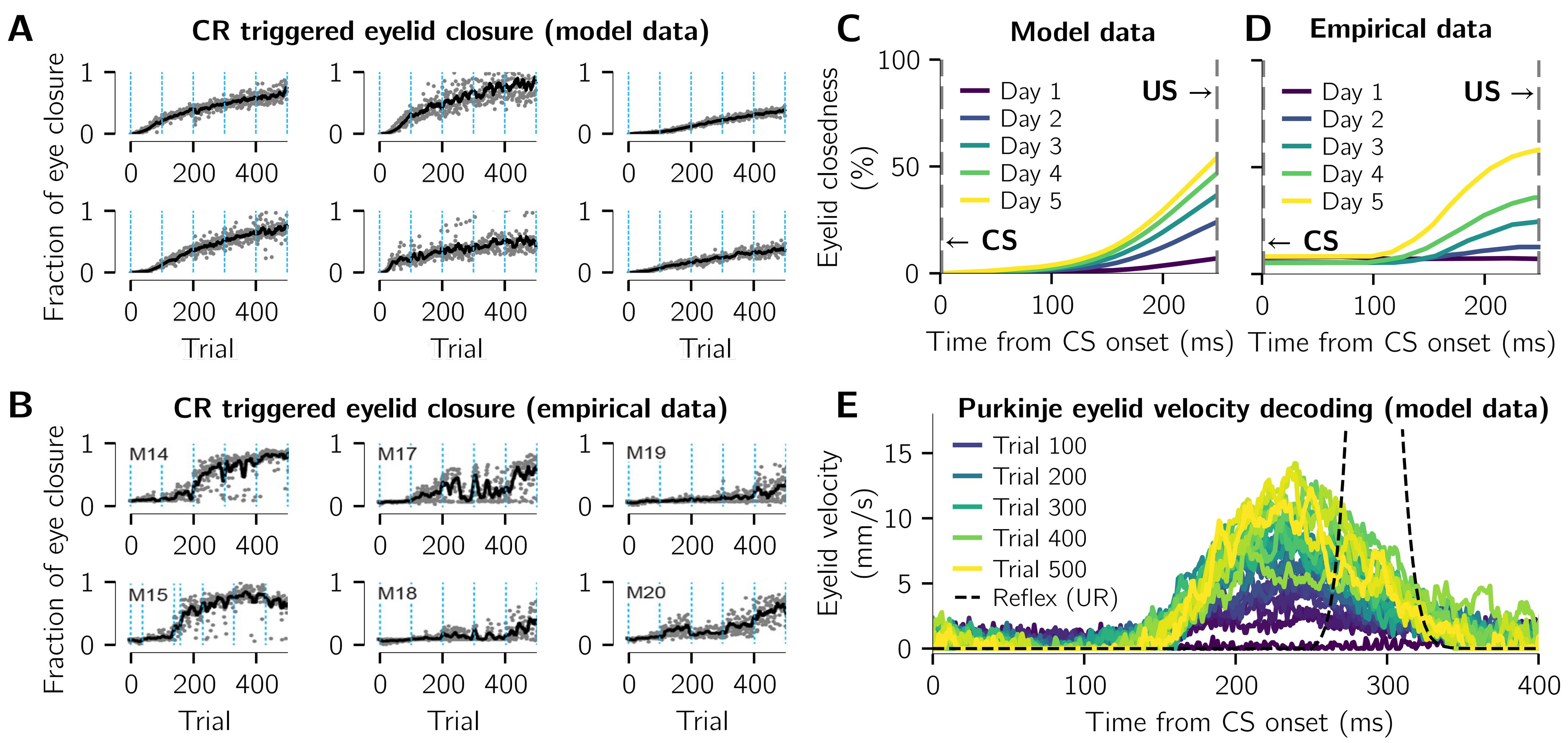
▲ **Figure 2C** Granule-Golgi implementation of the delay network. The recurrent pathway is split into two neuron populations. The **excitatory** Granule cells, and the **inhibitory** Golgi cells (200:20 ratio).



▲ **Figure 3** Delay network representation over time. (A-C) Response to a rectangle input of the three delay network implementations discussed above. Gray lines correspond to individual spikes. (D) Decoding of a delay of θ from the above representations.

Results ③

- ▶ The Granule-Golgi circuit can implement flexible delays under biological constraints (Dale's principle; time-constants; granule to Golgi ratio; Fig. 3).
- ▶ The learned eyeblink trajectories of our model **qualitatively match empirical data** (Fig. 4; [4]).
- ▶ Our techniques can be used to construct biologically plausible NEF/SPA models.
- ▶ Model may be used to explore timing-related cognitive phenomena in the cerebellum.



◄ **Figure 4** Simulation results compared to empirical data.
(A) CR learned over time as learned by the model.
(B) Empirical data for comparison. **[4]**
(C) Shape of the CR relative to the CS onset as learned by the model.
(D) Empirical data for comparison. **[4]**
(E) Learned eyelid velocity trajectory decoded from the Purkinje cell activities.

References

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