A neuron can make reliable binary, threshold gate like, decisions if and only if its afferents are synchronized.

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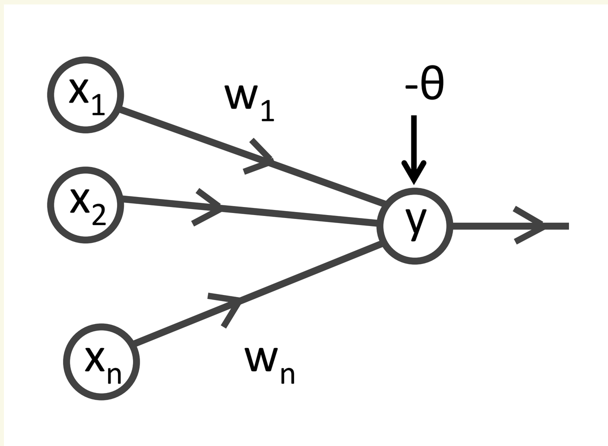
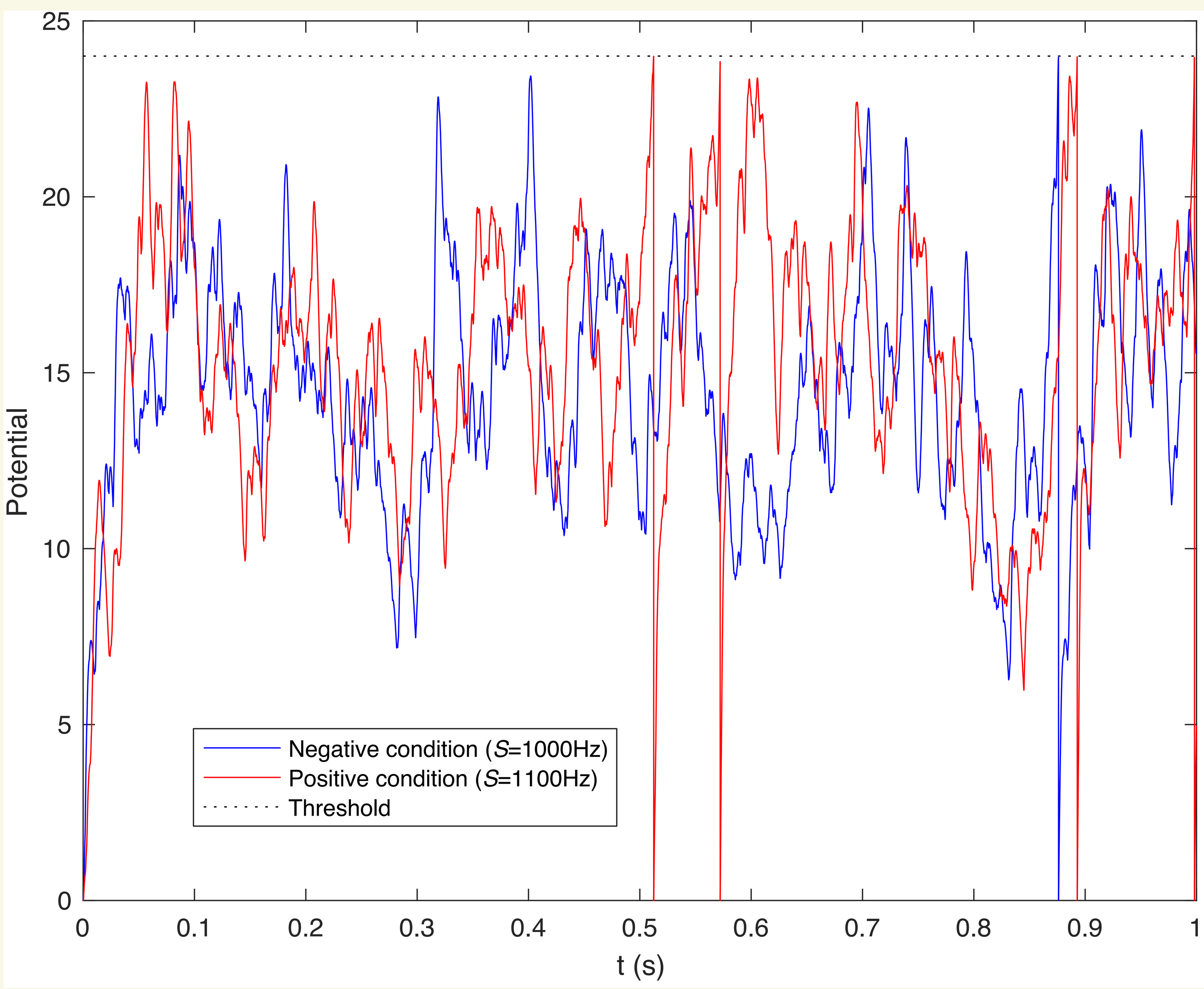
1. Introduction

- Some binary decisions $y \in \{0, 1\}$ are presumably made by comparing a weighted sum of different factors $S = \sum_i w_i x_i$ to a threshold θ: $y = H(S - \theta)$, where H is the Heaviside step function: $H(x) = \begin{cases} 1 \text{ if } x \geq 1 \\ 0 \text{ if } x < 0 \end{cases}$



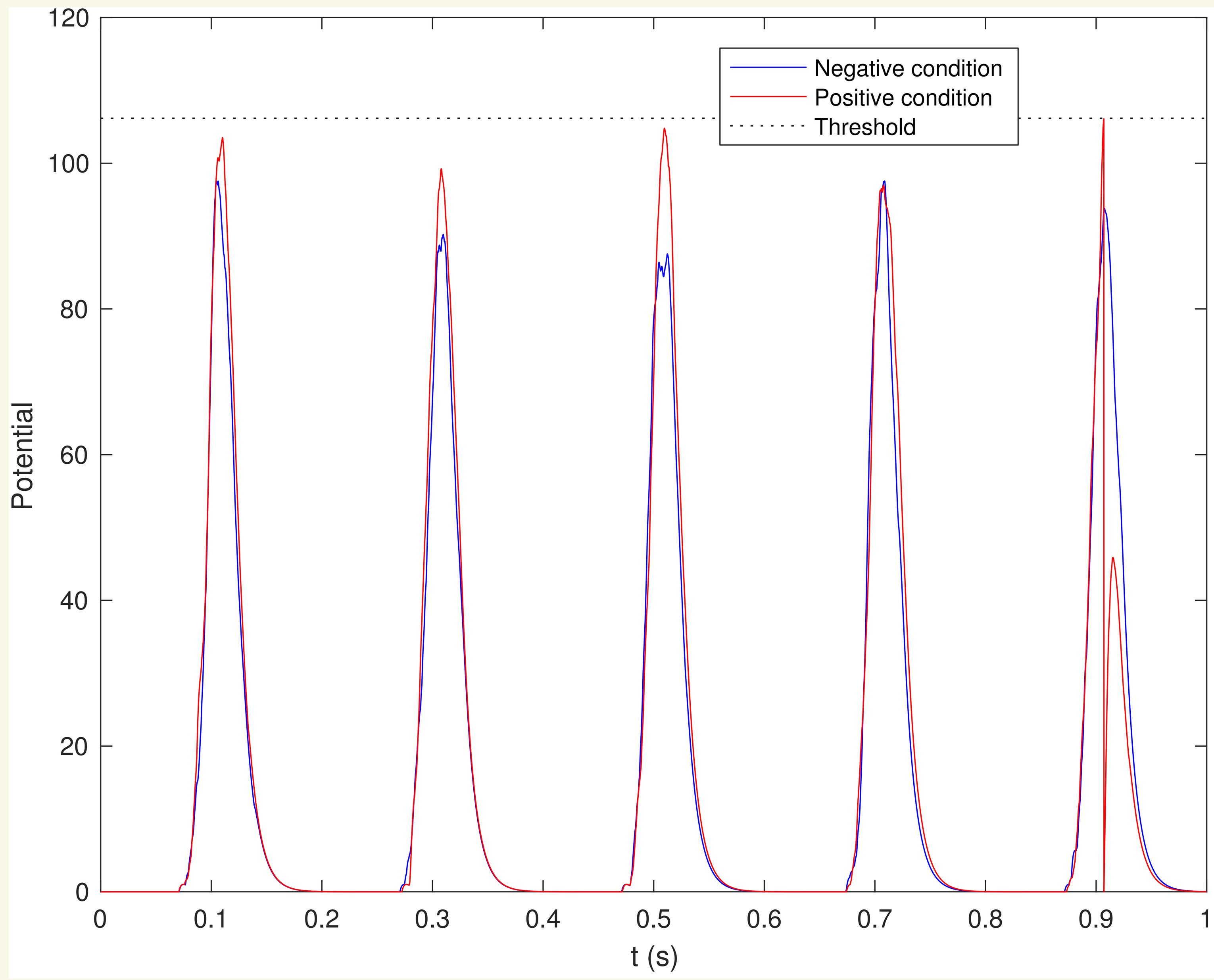
- This corresponds to the first neuron model proposed my McCulloch & Pitts in 1943, a.k.a threshold gate.
- Used in the perceptron, and more recently in binary deep neural networks.
- Can a single spiking neuron implement such a function, assuming that x_i are the afferent firing rates?
- We tackled this question using a leaky integrate-and-fire (LIF) neuron with $\tau = 10$ms.
- Goal: adjust the LIF's threshold so that it fires at least one spike over a period T if $S > \theta$ ("positive condition"), and none otherwise ("negative condition").
- We first assume binary weights.

2. The asynchronous regime



Input spike times are uniformly distributed over $[0; T = 1\text{s}]$. Any threshold will lead to false alarms and/or misses. Yet a threshold gate with $\theta = 1050$Hz would do the job perfectly!

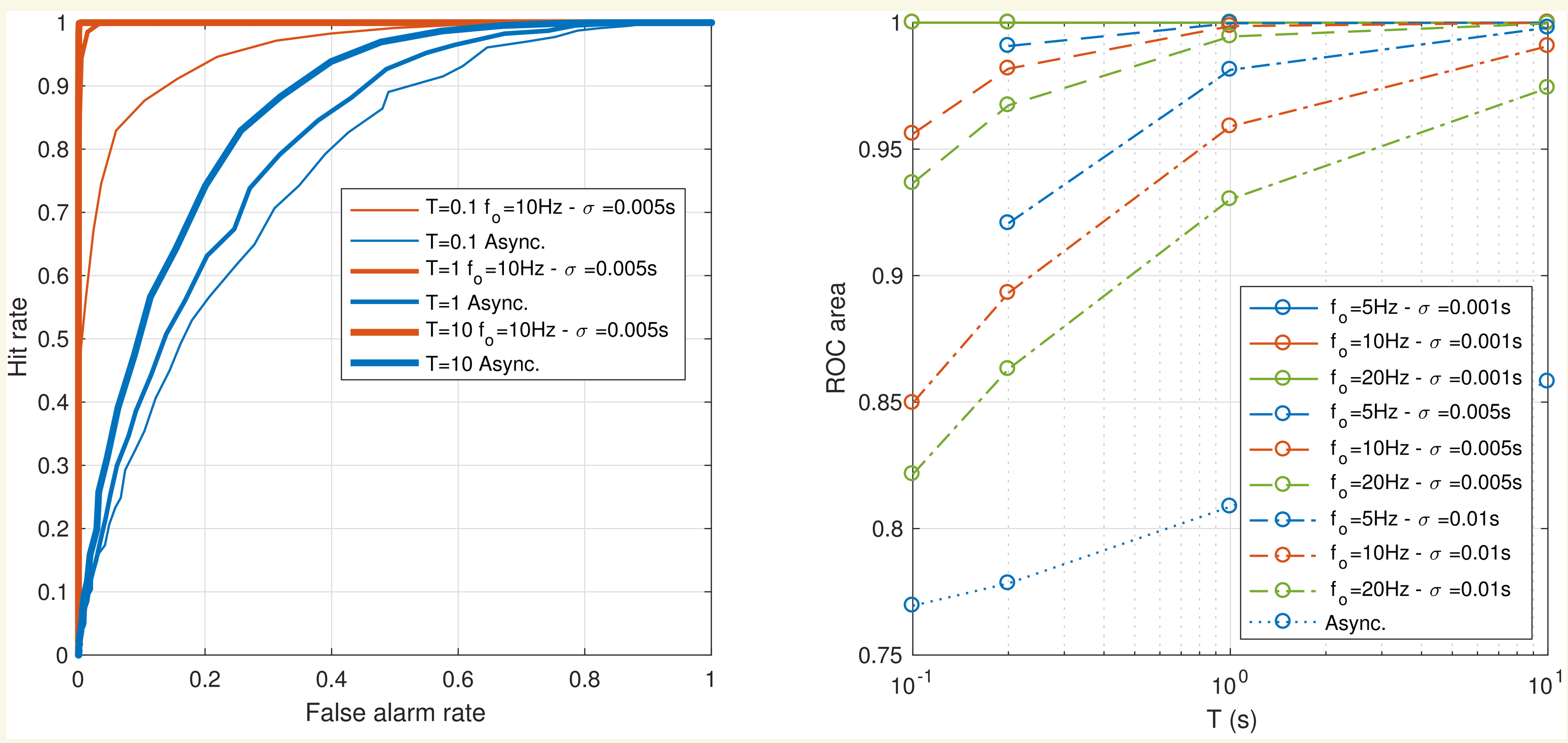
3. The synchronous regime



- The spikes arrive in discrete periodic volleys (with frequency $f_o = 5$Hz), and with a certain dispersion inside each volley ($\sigma = 10$ms).
- Threshold=105 causes a hit for the positive condition, and no false alarm for the negative one.

4. Receiver operating characteristics

We quantified the classification accuracy using the receiver operating characteristics (ROC):



- The asynchronous regime leads to poor accuracy, which increases with T, but very slowly.
- The synchronous regime leads to much better accuracy, which increases with T, but decreases with σ and f_o.

5. Discussion

- If the decision needs to be taken in a reasonable amount of time, only the synchronous regime is viable, and the precision of the synchronization should be in the millisecond range.
- The synchronous regime also does a better job at handling graded and negative weights (not shown).
- We are now exploring more biologically realistic regimes in which only a subset of the afferents are synchronized.
- In the brain, the required synchronization could come from abrupt changes in the environment (e.g., stimulus onset), active sampling (e.g., saccades and microsaccades, sniffs, licking, touching), or endogenous brain oscillations.