What is a moment?

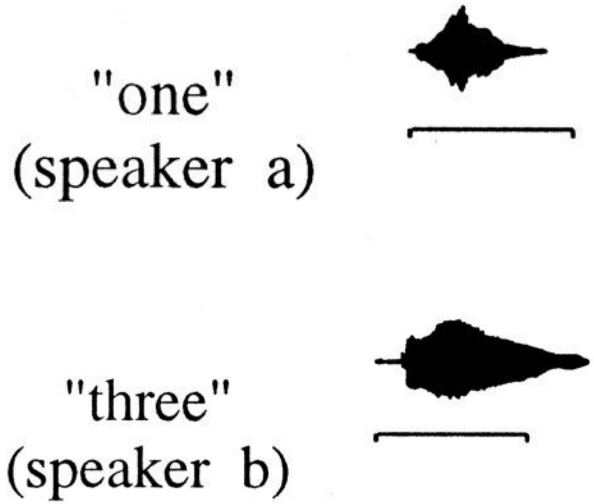
J. J. Hopfield and Carlos D. Brody

Ca. 2001

Contents

1. Brief discussion of problem + other solutions (context)
2. Behavior of current network
3. Context for this kind of behavior
4. Behavior of single-neurons in network
5. Conclusion

How do neural networks “integrate” information across time?

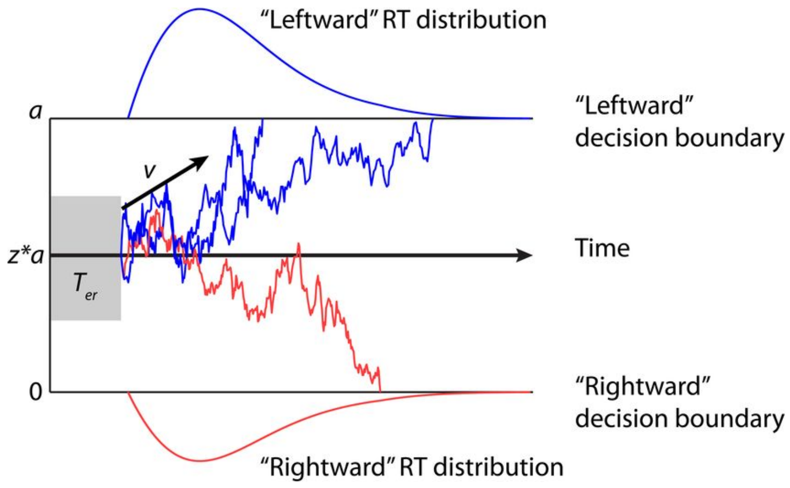


Transmission delays can only accounts for integrations on the order of 10s of milliseconds

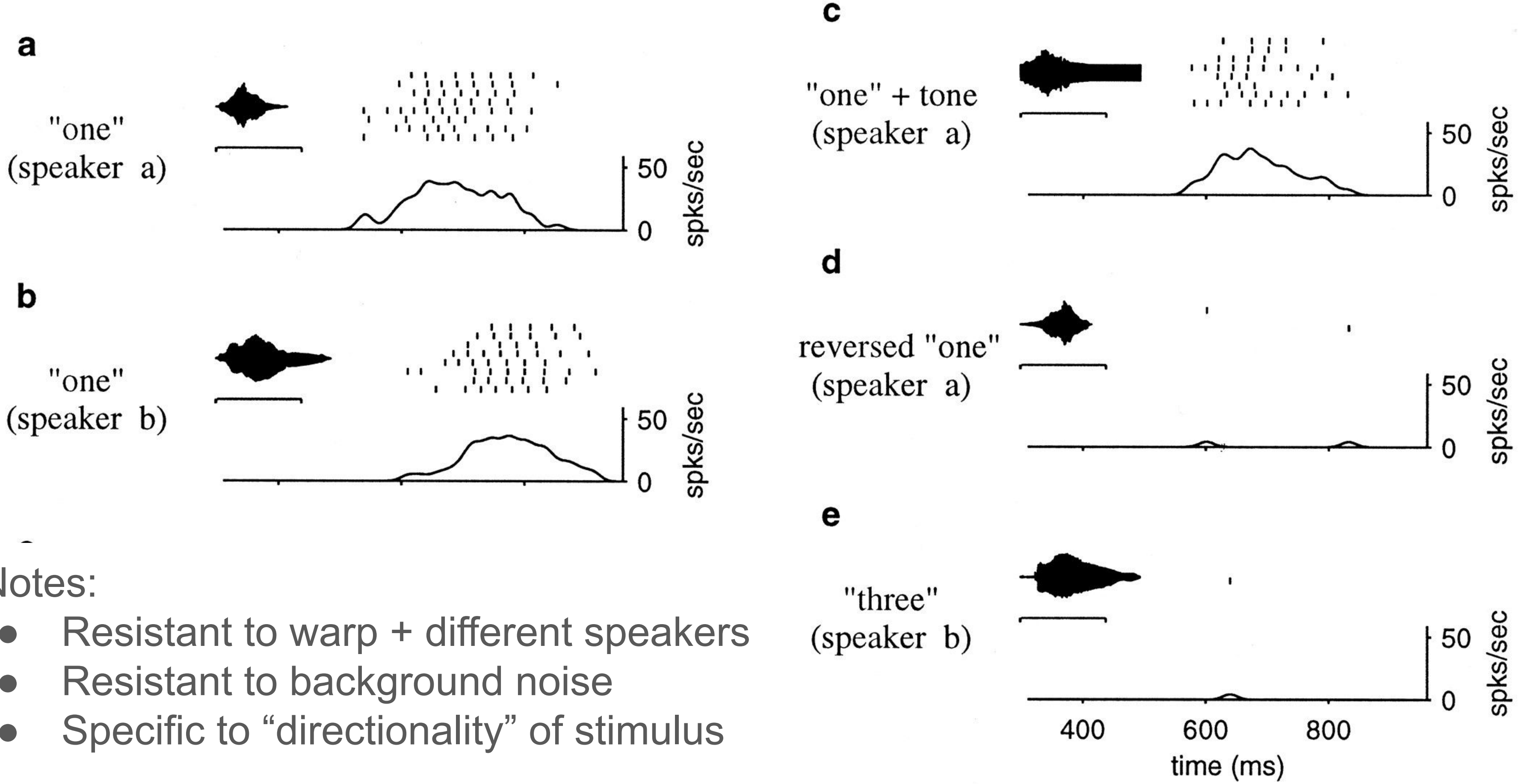
How do neural networks “integrate” information across time?

- **Still ongoing topic of research**
- Evolving dynamics converge onto a solution.
  - Illustration: Drift-diffusion
- What kind of networks are required for these non-linear solutions?
  - Drift diffusion network → Neural implementation?
  - Attractor networks
    - Point vs. ongoing stimuli
- Multi-scale / Scale-invariant behavior

Drift-diffusion model of decision making



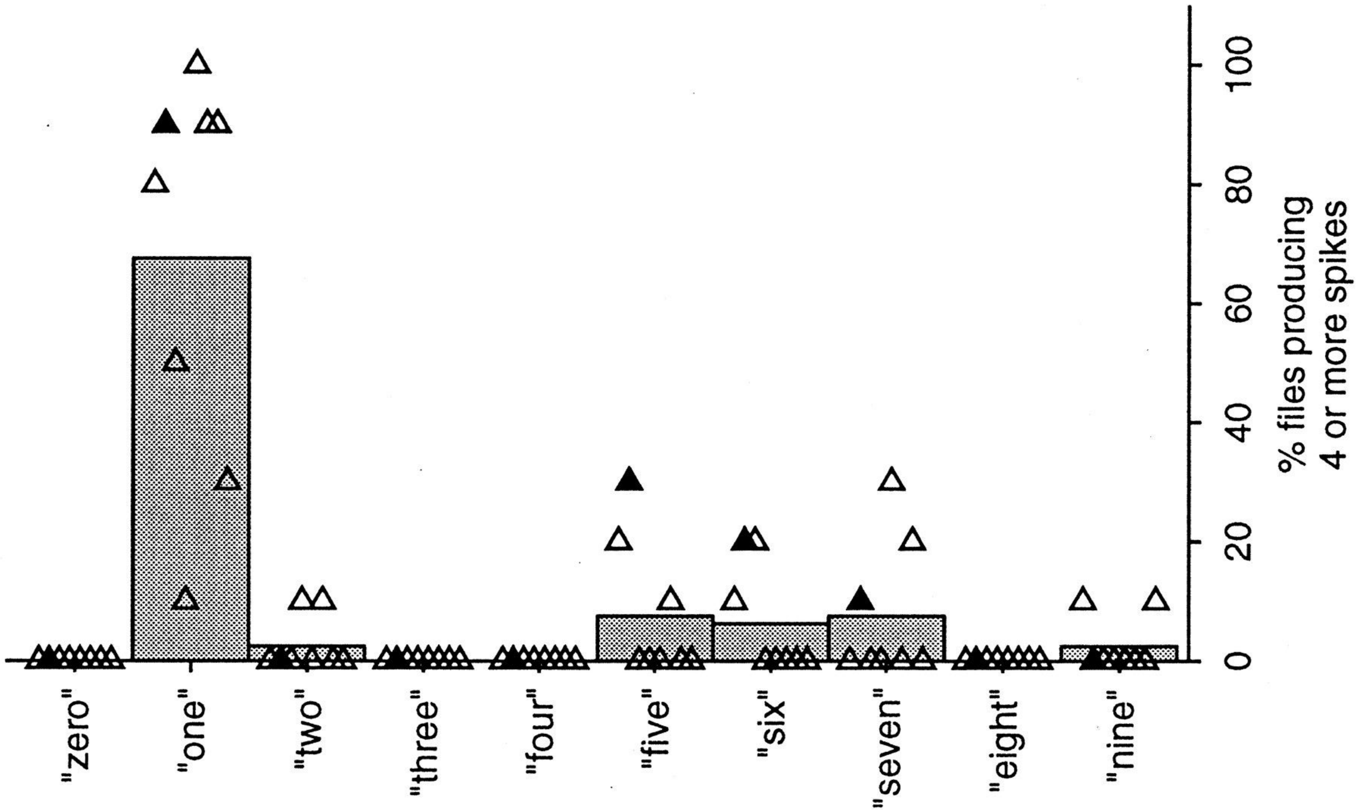
Response of 1 neuron to different stimuli



Notes:

- Resistant to warp + different speakers
- Resistant to background noise
- Specific to “directionality” of stimulus

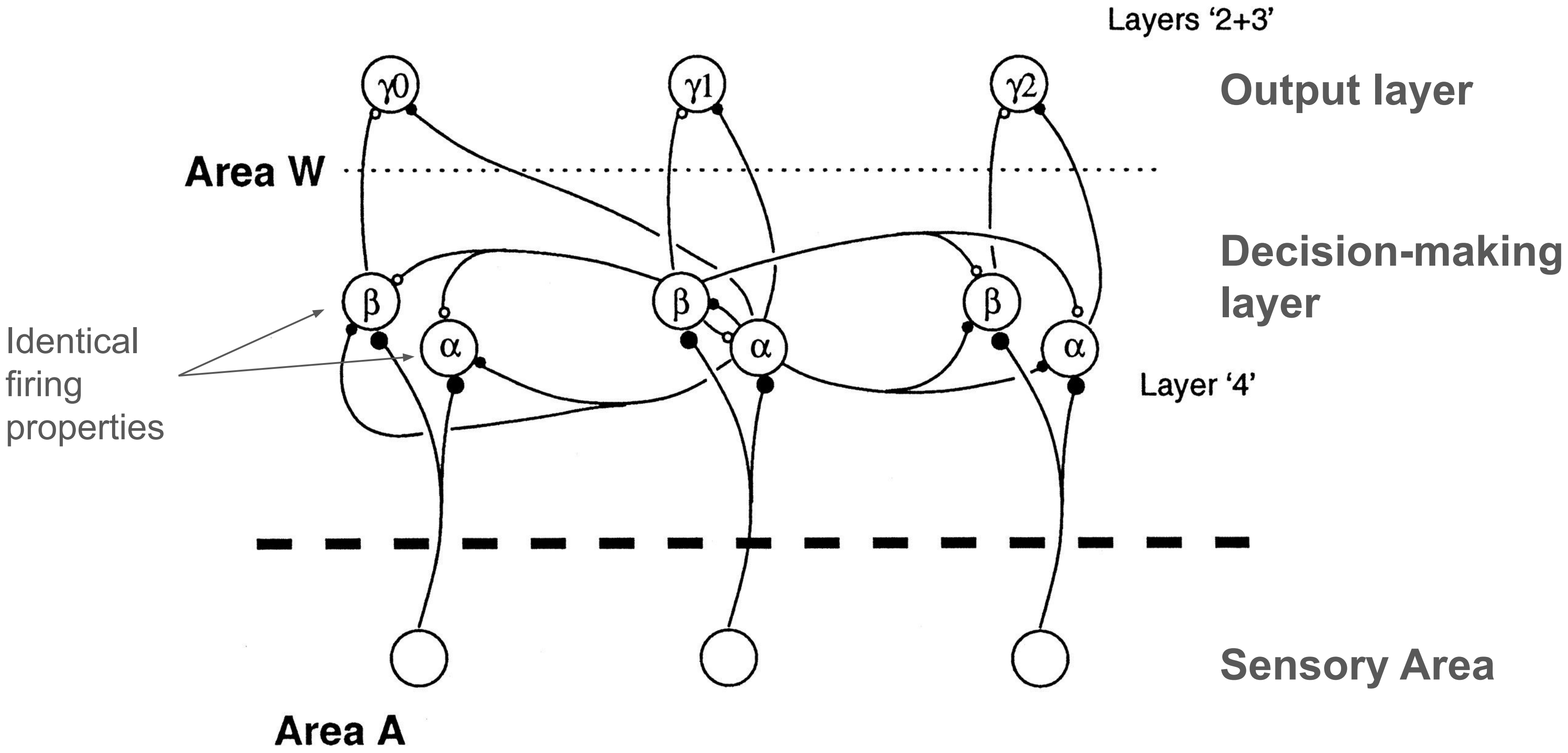
Accuracy of “one” neuron



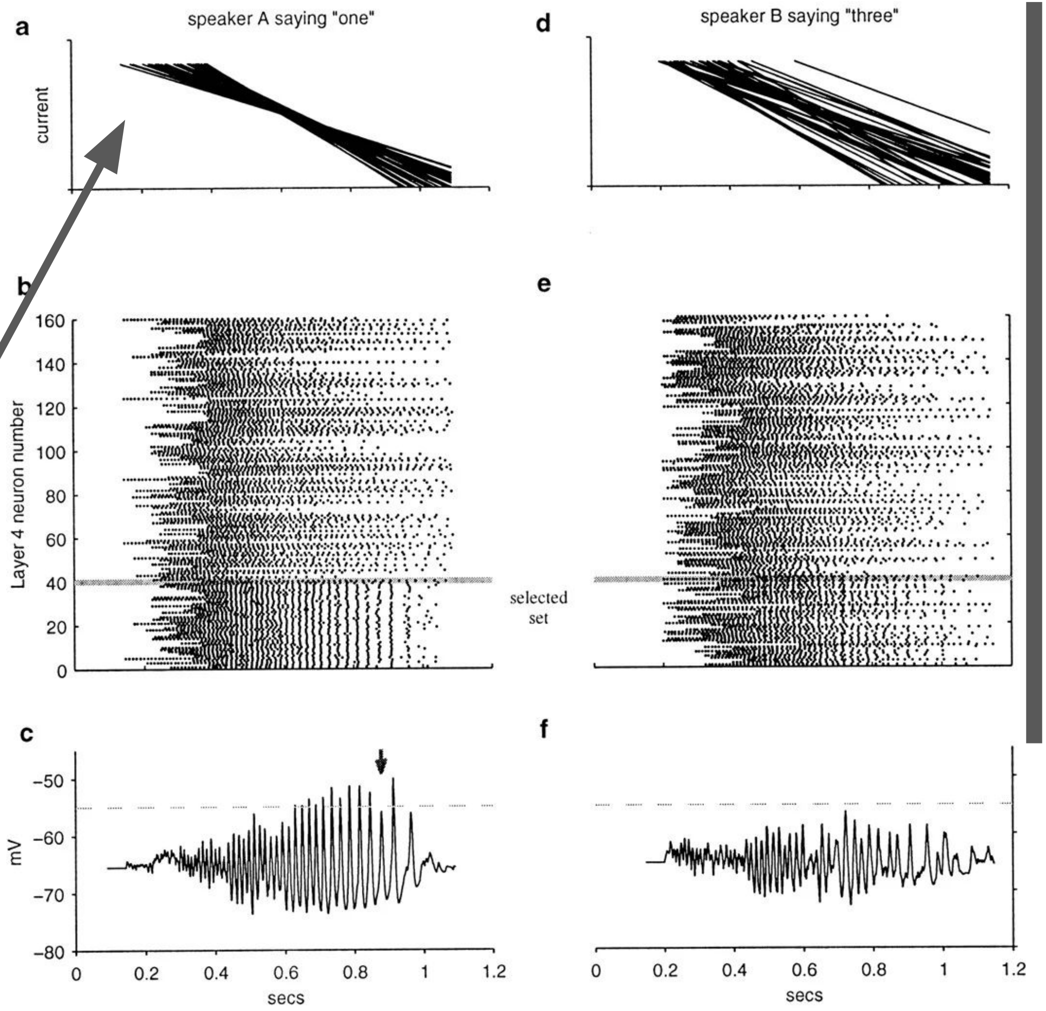
How does it work?

- Coincidence of variable timescales leading to neural synchronization
- Can be performed by simple leaky integrate-and-fire neurons
- No dependence on <u>specific</u> cell-types
- Varying synaptic strength randomly by “+/-50% has no appreciable effect on the response”.

Schematic of Network Structure



Synchronous input activates downstream decision neurons



Different onset times + different decay slopes

Decision-making layer

Output neuron

Other literature on utility of synchronization

- Is this commonly seen?
  - Expected from Hebbian plasticity

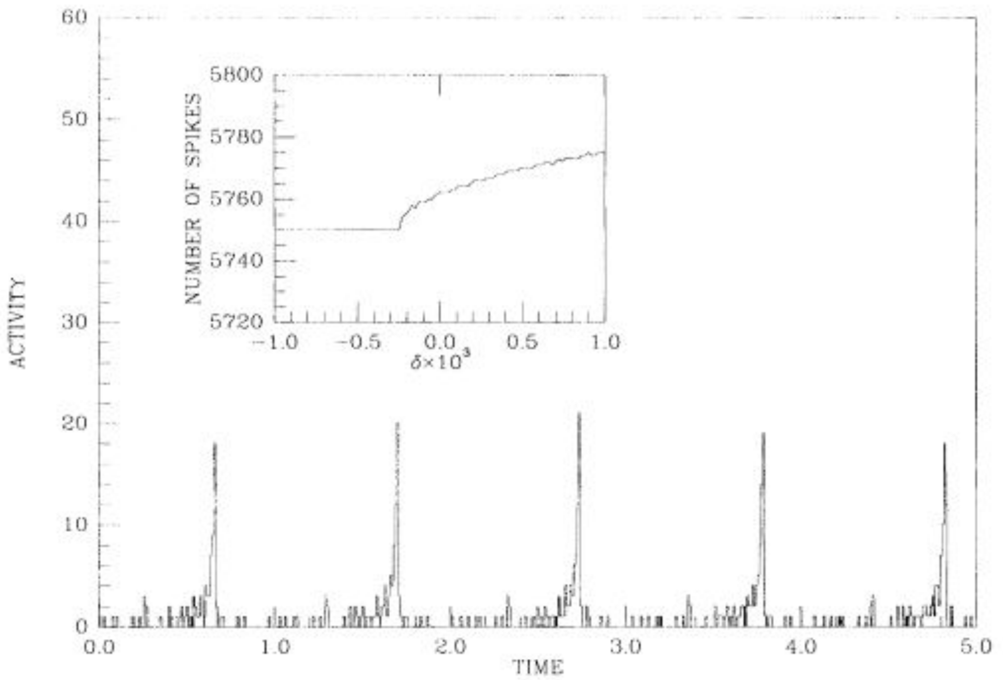


FIG. 2. Simulated activity of an inhomogeneous network of 100 neurons, with $\Delta = 10^{-3}$. Other parameters are the same as in Fig. 1. The number of spikes emitted by the network in the time interval $dt = 0.01$ is plotted vs time. The transient up to $t = 5000$ was discarded. Inset: the number of spikes emitted by a neuron in a time window of length 6000, against the deviation of its local external current I^0 from the mean

Tsodyks, M., et al. “Pattern of Synchrony in Inhomogeneous Networks of Oscillators with Pulse Interactions.” *Physical Review Letters*, vol. 71, no. 8, Aug. 1993, pp. 1280–83. *DOI.org (Crossref)*, https://doi.org/10.1103/PhysRevLett.71.1280.

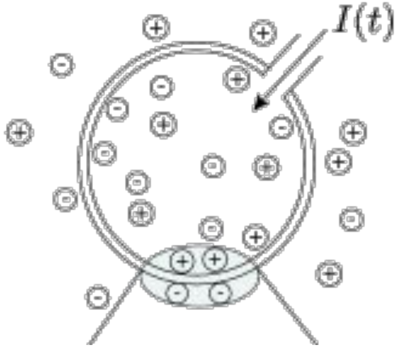
Other literature on utility of synchronization

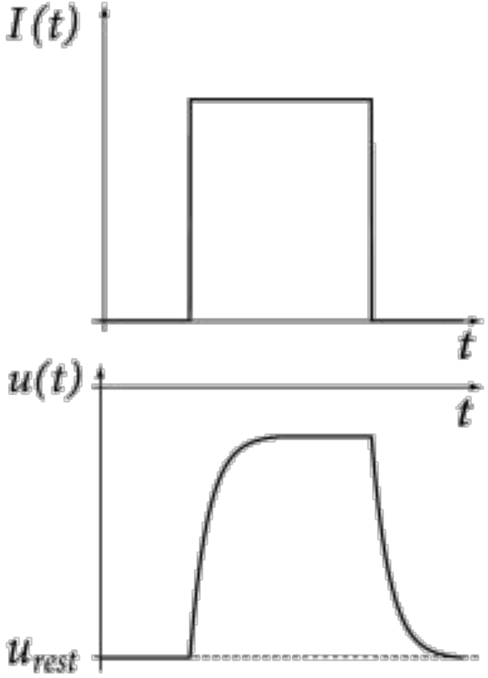
- Plenty of interest in measuring synchrony:
  - Kreuz, Thomas, Daniel Chicharro, et al. "Monitoring Spike Train Synchrony." Journal of Neurophysiology, vol. 109, no. 5, Mar. 2013, pp. 1457–72. DOI.org (Crossref), https://doi.org/10.1152/jn.00873.2012.
  - Kreuz, Thomas, Mario Mulansky, et al. "SPIKY: A Graphical User Interface for Monitoring Spike Train Synchrony." Journal of Neurophysiology, vol. 113, no. 9, May 2015, pp. 3432–45. PubMed Central, https://doi.org/10.1152/jn.00848.2014.
  - Lama, Nikesh, et al. "Spike Train Synchrony Analysis of Neuronal Cultures." 2018 International Joint Conference on Neural Networks (IJCNN), 2018, pp. 1–8. IEEE Xplore, https://doi.org/10.1109/IJCNN.2018.8489728.
  - Mulansky, Mario, and Thomas Kreuz. "PySpike—A Python Library for Analyzing Spike Train Synchrony." SoftwareX, vol. 5, Jan. 2016, pp. 183–89. ScienceDirect, https://doi.org/10.1016/j.softx.2016.07.006.
  - Satuvuori, Eero, et al. "Measures of Spike Train Synchrony for Data with Multiple Time Scales." Journal of Neuroscience Methods, vol. 287, Aug. 2017, pp. 25–38. PubMed Central, https://doi.org/10.1016/j.jneumeth.2017.05.028.

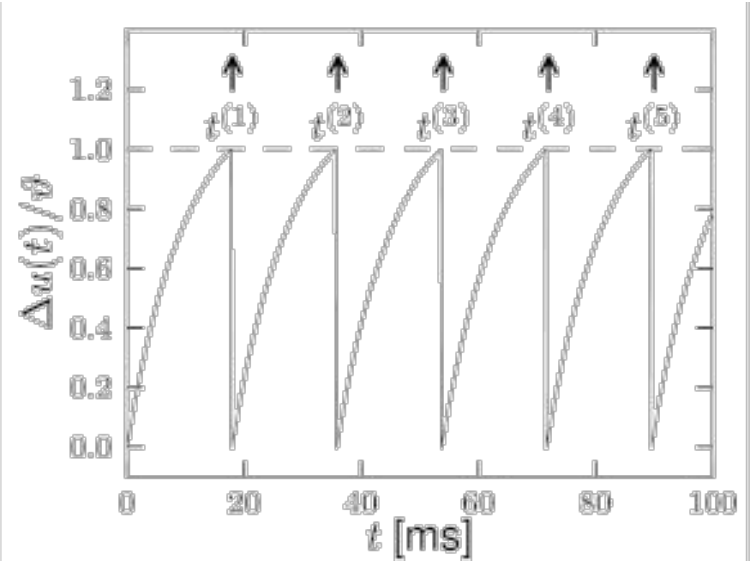
Other literature on utility of synchronization

- Relation to actual brain function?
  - Signal propagation…improve signal-to-noise ratio
  - Seen in coordination of brain regions (putting cart before horse?)

Detour: Leaky Integrate-and-fire neurons







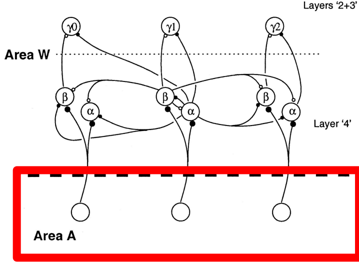
Gerstner, Wulfram, et al. *Neuronal Dynamics: From Single Neurons to Networks and Models of Cognition*. Cambridge University Press, 2014.
Online ebook: https://neuronaldynamics.epfl.ch/

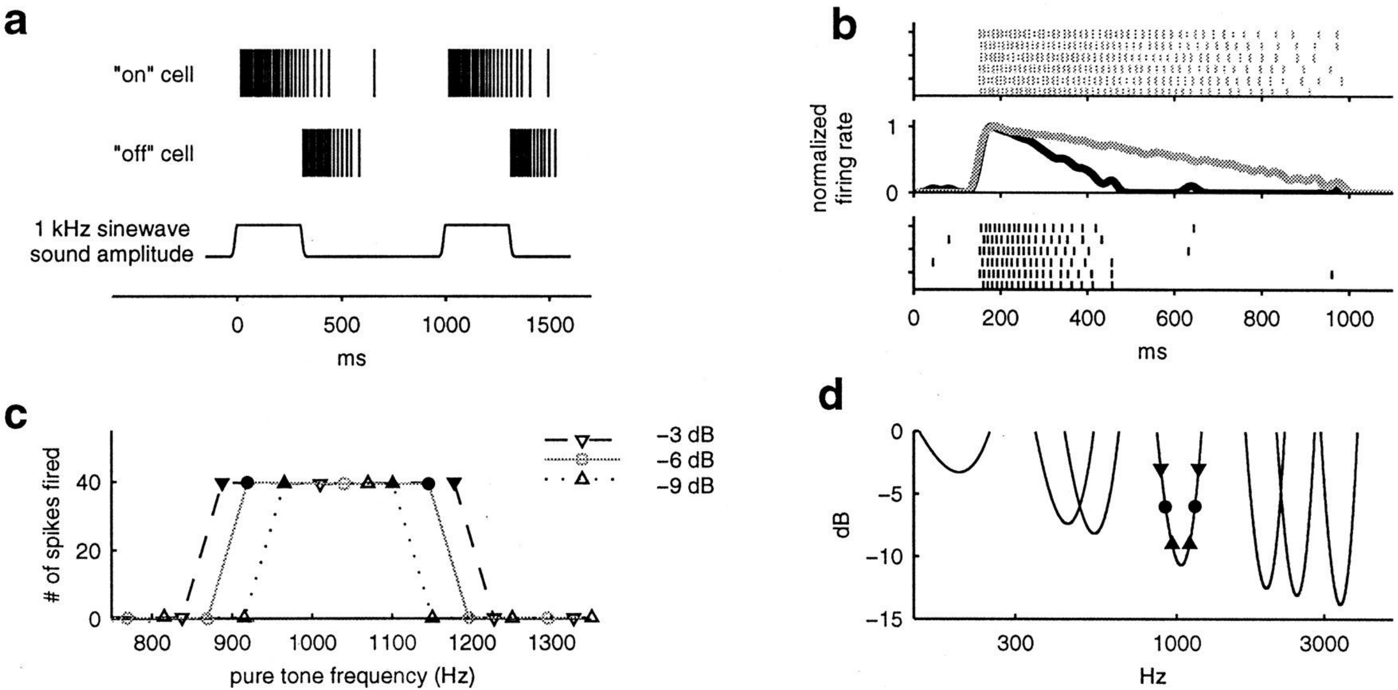
Properties of the network

- “Good” specificity to input
- Invariance to temporal warp of input

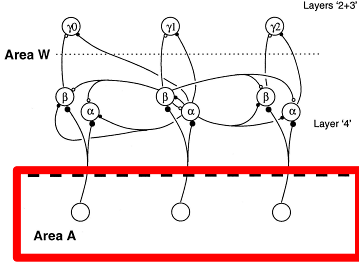
Note: Goal of paper was not to improve on the state-of-the-art of neural networks, but to demonstrate a mechanism of network function.

Response of “sensory” neurons (Area A)





- All-or-nothing responses



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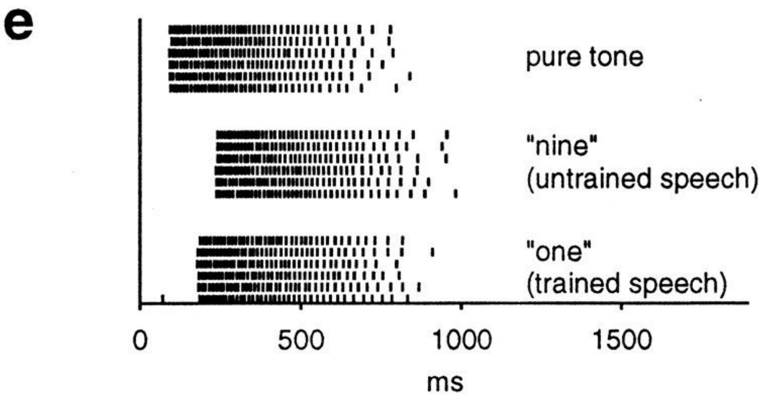
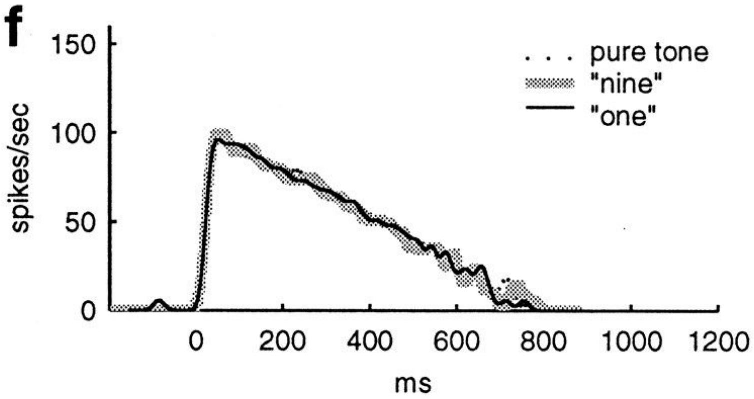
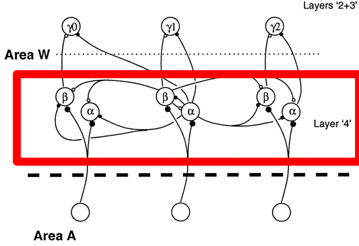
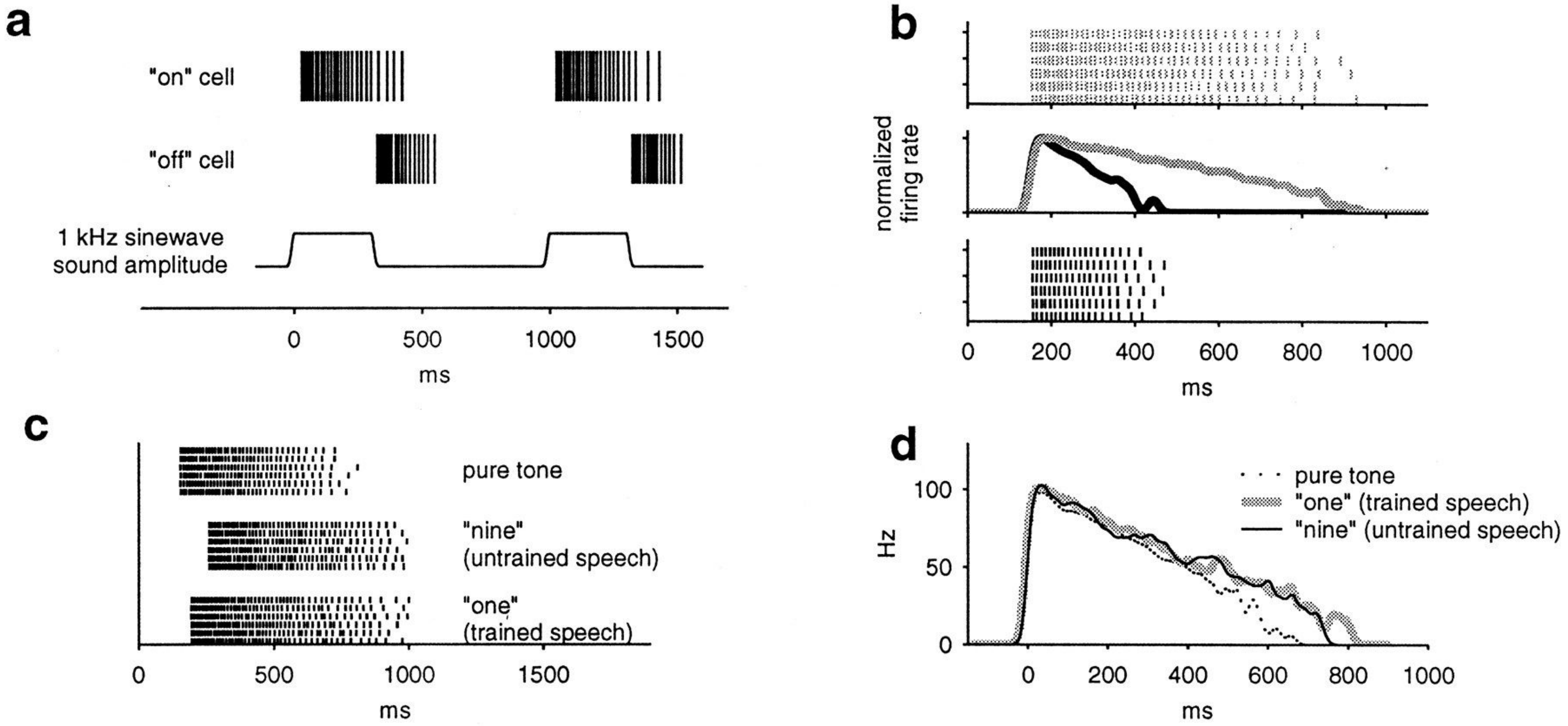


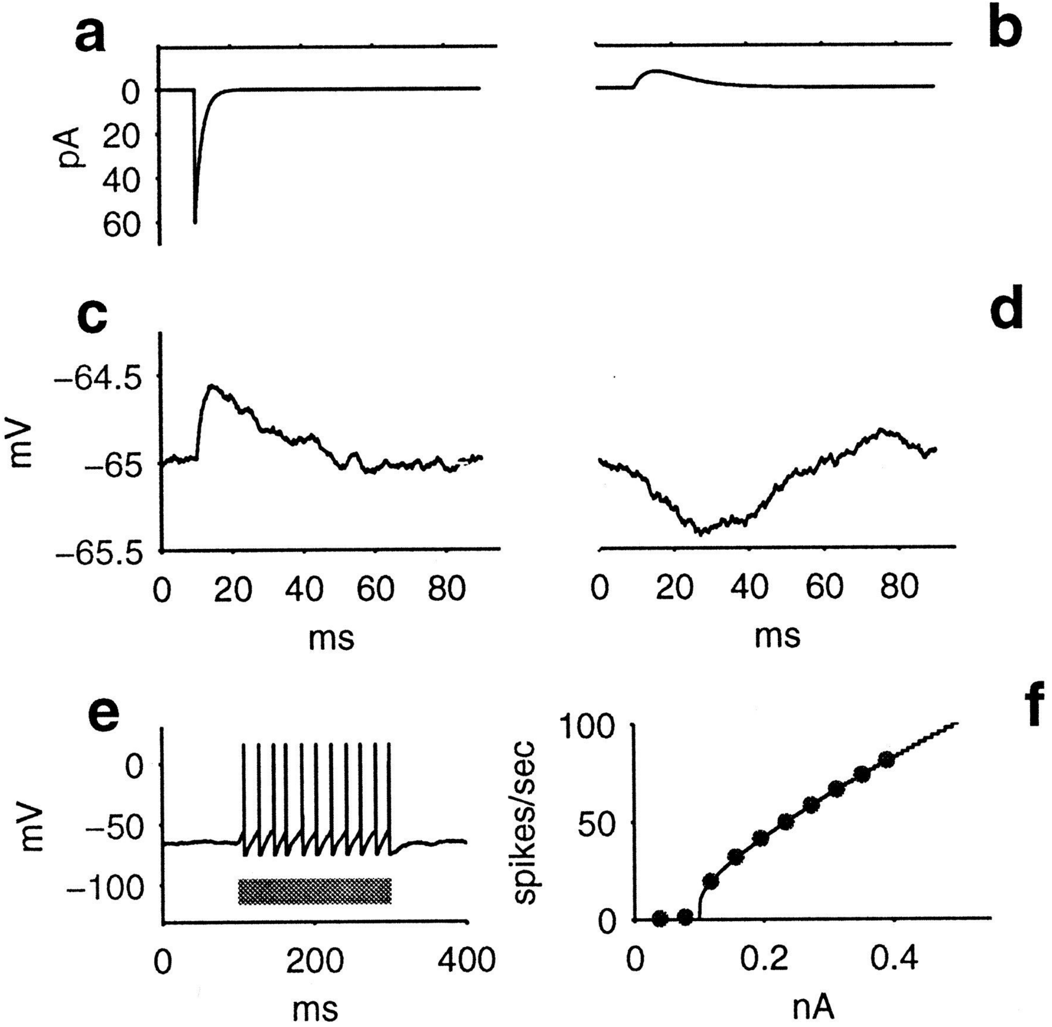


Response of Decision Neurons (Area W, Layer 4)

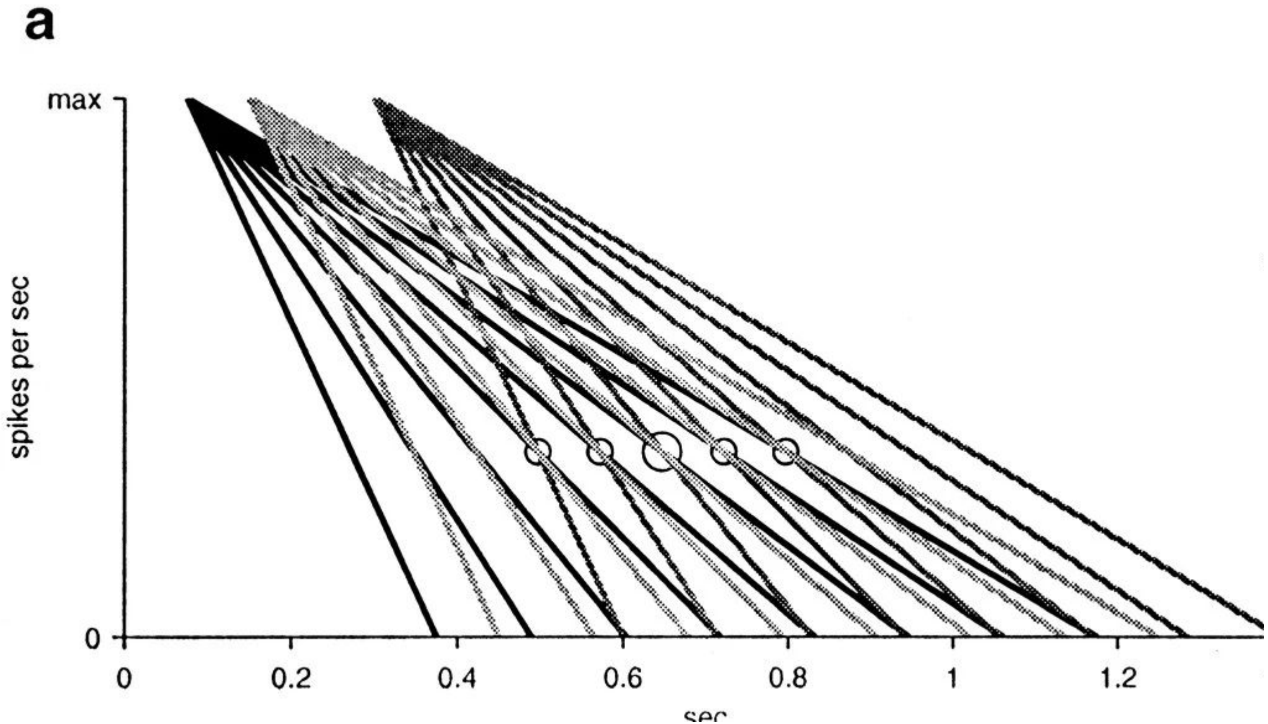




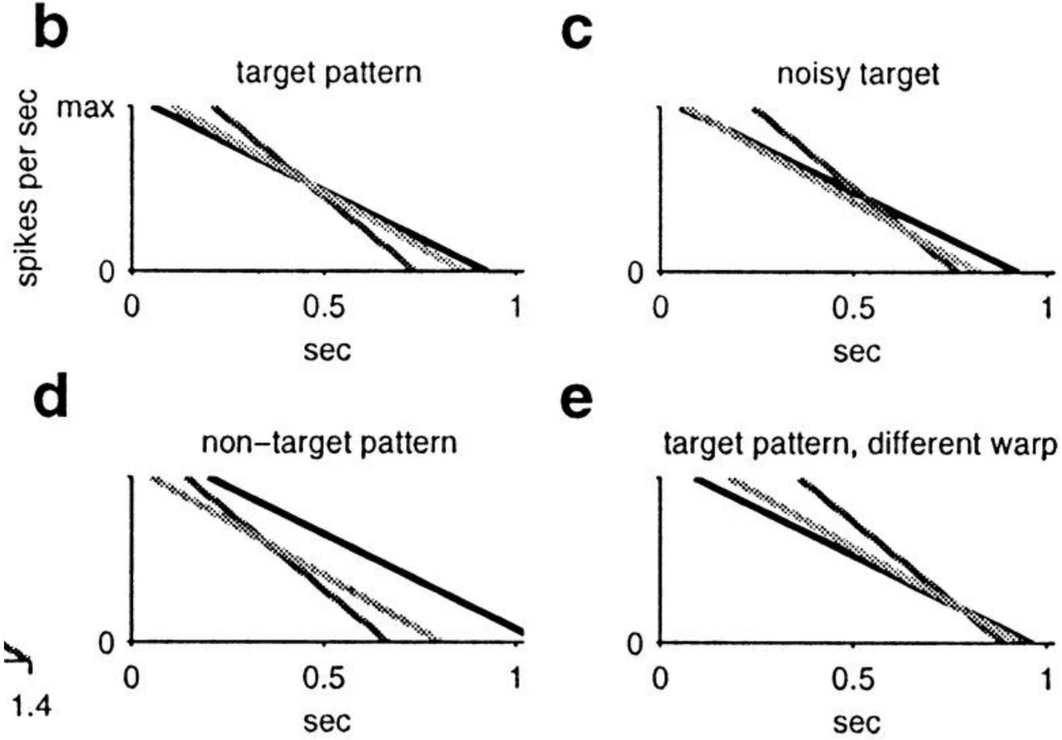
Synaptic Properties of Circuit



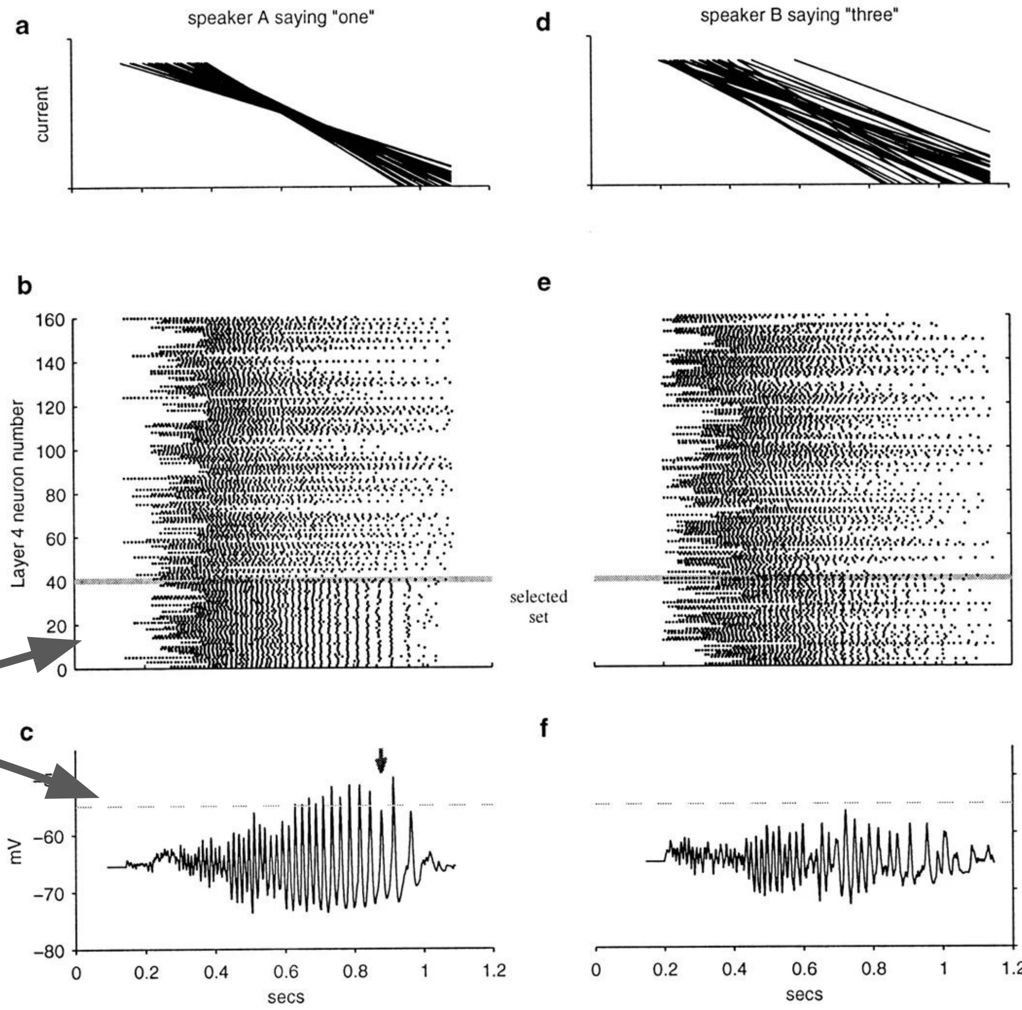
Propagation of activity based on coincidence of multiple timescales



Propagation of activity based on coincidence of multiple timescales



Synchronous input activates downstream decision neurons



Decision-making layer

Output neuron

Given biological parameters (not discussed), synchronization results in gamma-frequency activity

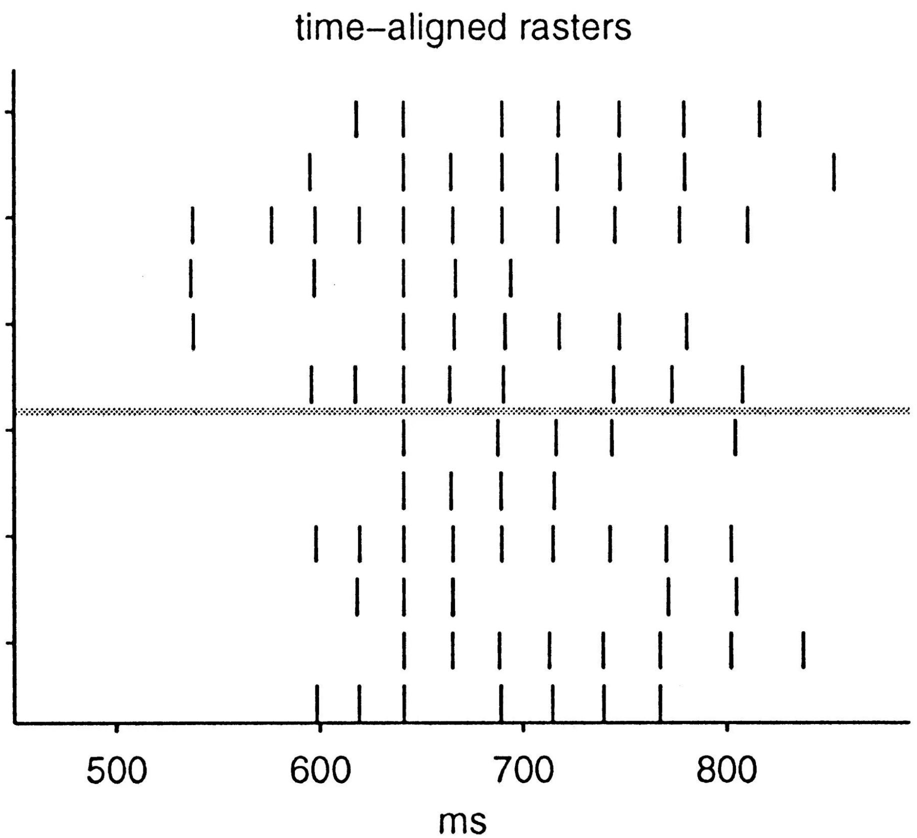
“Training” the network

1. Find neurons with converging firing rates in response to a stimulus
2. Creating mutual all-to-all connections within this set

Kinda-sorta like a reservoir network.

How does this happen?

- Proper synchronization (spike-by-spike) can ONLY happen at similar firing rates
- Anything special about 60Hz?


time–aligned rasters
500
600
700
800
ms

Questions?

- Does synchronization happen in GC?
    - Maybe as an output signal?
    - Or to trigger a state transition?