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Jingyi Zhou
Binghamton University--SUNY

J. David Schaffer
Binghamton University--SUNY, dschaffe@binghamton.edu

Patricia Dilorenzo
Binghamton University--SUNY

Craig B. Laramee
Binghamton University--SUNY

Novel Dynamics Observed in a Spiking Neural Network Model of the NTS in the Rat Hind-brain

Jingyi Zhou[1], J. David Schaffer [1], Craig B. Laramee[1], Patricia M. Di Lorenzo[2]

[1] Department of Bioengineering and [2] Department of Psychology. Binghamton University Binghamton NY 13902

Abstract: The Nucleus of the Solitary Tract (NTS) is a hind-brain structure in the rat that is the first way-station in taste processing. Its structure and function are poorly understood. Recently our group produced a model, implemented as a spiking neural network (SNN), that successfully replicated experimental data. The model's topology was manually devised and the parameters were set by a genetic algorithm. In order to better understand its information processing capabilities, we probed the model with a variety of input spike patterns and observed a striking winner-take-all decision-making dynamic. We show how the topology and tuned parameters enable this decision to depend on precise spike timing events. It is curious that the experimental data upon which the model was originally evolved did not include winner-take-all examples; this was an emergent capability. It remains for additional experiments on rats to confirm or reject this model prediction.

Methods Our simulator [1] is based on the Spike Response Model (SRM) developed by Gerstner et al. [2]. Figure 1 depicts such a spiking neuron and Equations 1-3 show the underlying mathematical model. The simulator control parameters (refractory periods, time constants, etc.) were tuned by a genetic algorithm to replicate measurements from anesthetized rats to paired pulse and triad stimulation (Figures 2,3) [4]. Figure 4 shows the network topology for two taste inputs. Neither phase space methods using ISIs or membrane potential (MP), nor ISI-CI methods [5] revealed anything interesting. Spike sweeps drifting in and out of phase (Figure 5) revealed interesting behavior.

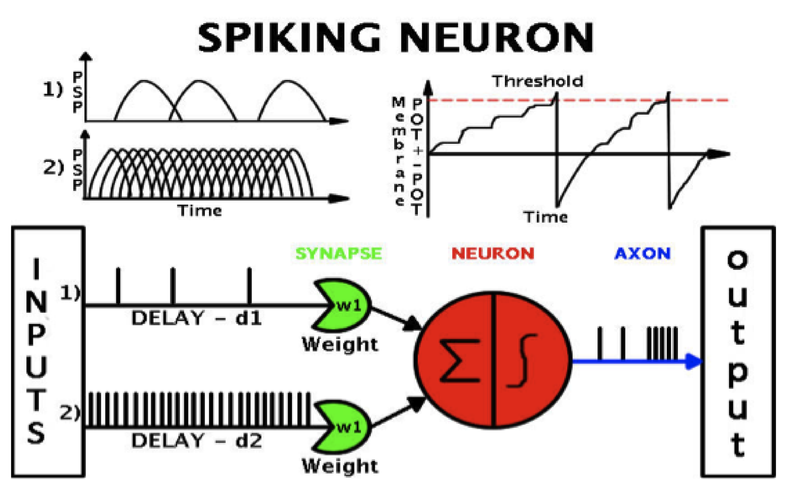

Figure 1: Spiking neuron

$$u_j(t) = \sum_{t_j} \eta(t - t_j) + \sum_{i} \sum_{t_i} w_{ji} \times \epsilon(t - t_i - d_{ji}) \quad (1)$$

$$\eta = (ETA_0 - U_R) \times \exp^{\frac{-(\Delta t)}{T_r}} \quad (2)$$

$$\epsilon = \frac{1}{1 - \frac{T_s}{T_m}} \times \exp^{\frac{-(\Delta t)}{T_m}} - \exp^{\frac{-(\Delta t)}{T_s}} \quad (3)$$

Equations: 1-3

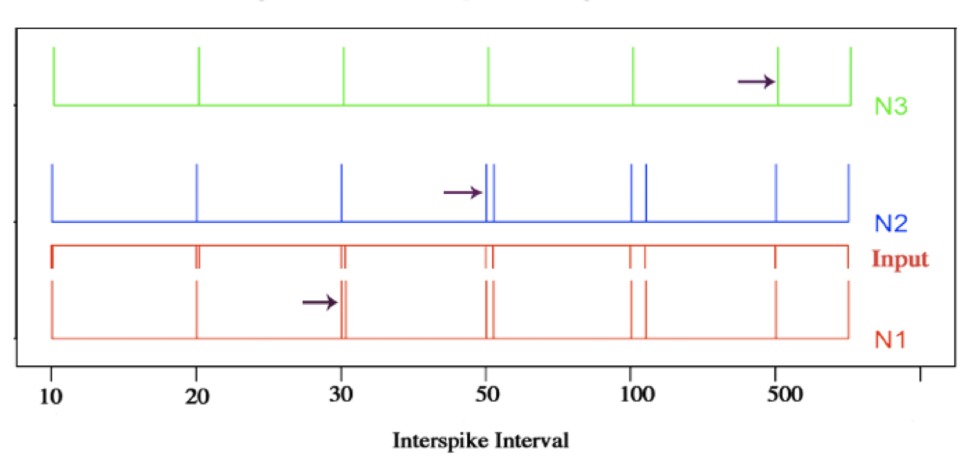

Figure 2: Paired pulse input/output

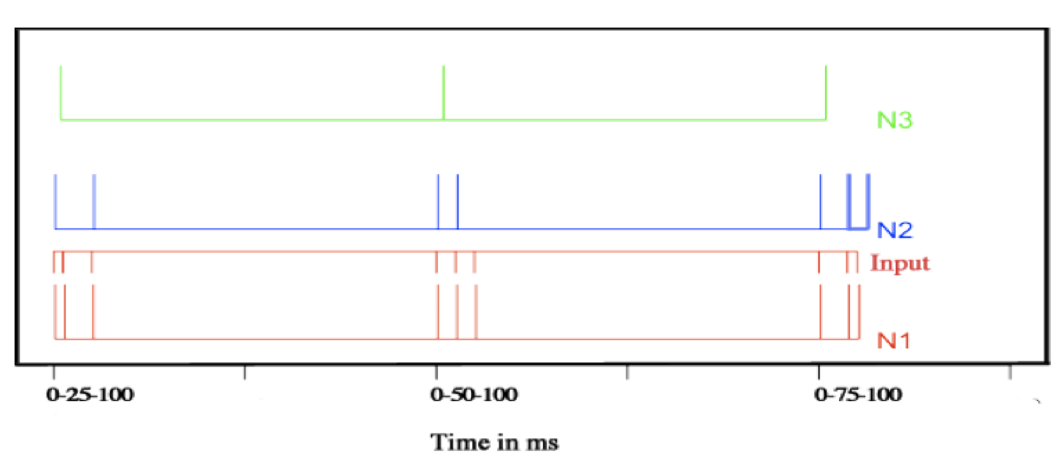

Figure 3: Triad input/output

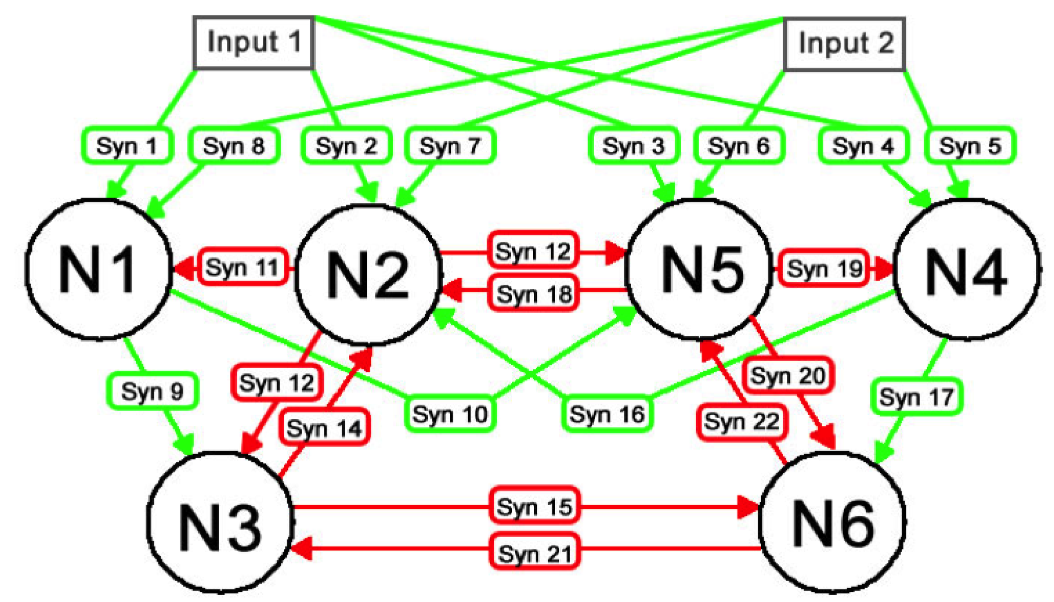

Figure 4: NTS network topology

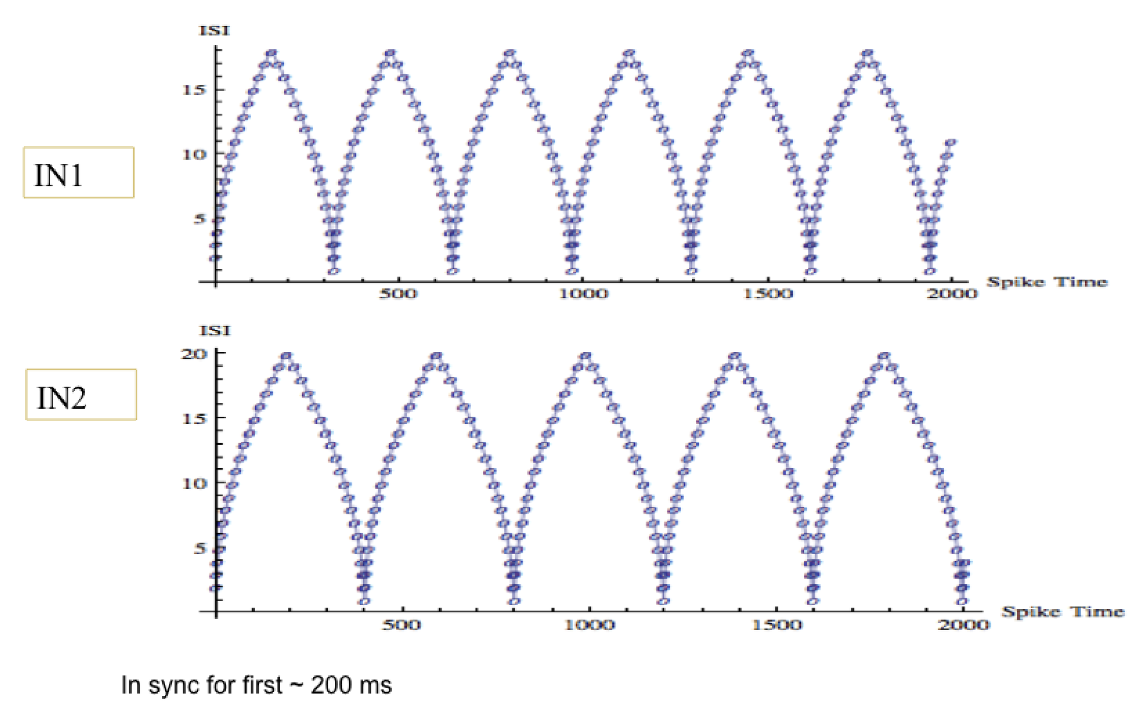

Figure 5: Spike sweeps

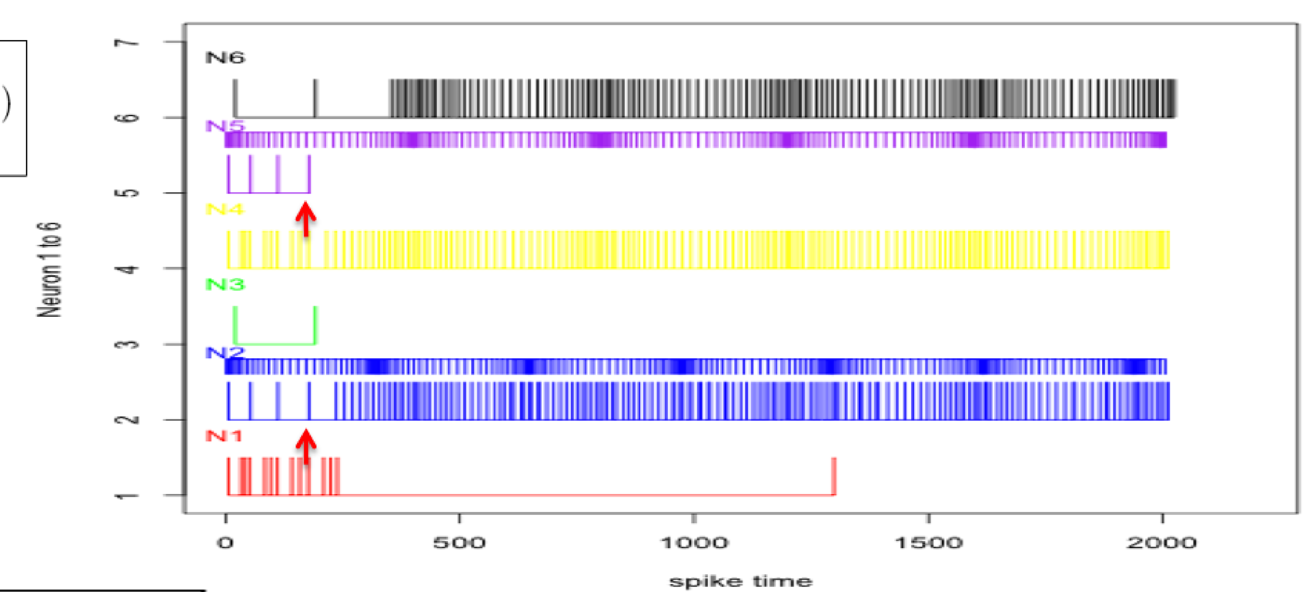

Figure 6: Winner-take-all dynamics

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[4] David C. Tam. (1998), "A cross-interval spike train analysis: the correlation between spike generation and temporal integration of doublets". Biol. Cybern. 78, 95–106

[5] Patricia M. Di Lorenzo, NIDCD grant DC006914 to PMD.

Results Spike sweeps going in/out of phase revealed the winner-take-all behavior shown in Figure 6. When in-synch, both taste-specific subnets behave symmetrically, but shortly after going out of synch, one subnet takes over shutting down the other. The winning subnet is NOT always the one whose inputs first arrive faster, Table 1. Detailed analysis shows precise spike timing determines the winner, Figure 7. Decision is made by N2 and N5; first to get an input spike, when MP is near enough to fire, inhibits the other. The timing limits are shown in Figure 8. Winner remains the winner even when its input goes silent and other input continues. Winner can switch, but only after both inputs go silent for a time.

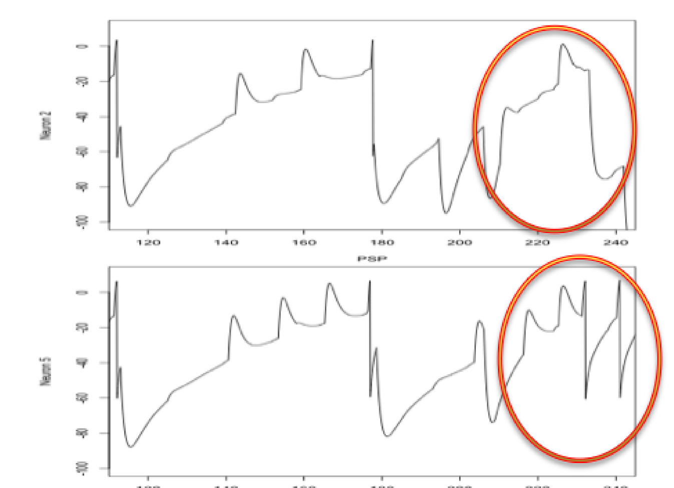

Figure 7: MP for N2, N5 at decision

		Peak ISI Input 2									
		15	16	17	18	19	20	21	22	23	24
Peak ISI Input 1	15		N4	N4	N1	N4	N1	N1	N1	N1	N1
	16	N1		N1	N1	N1	N1	N1	N1	N1	N1
	17	N1	N4		N1	N1	N1	N1	N1	N1	N1
	18	N4	N4	N4		N4	N4	N4	N4	N4	N4
	19	N1	N4	N4	N1		N4	N4	N4	N4	N4
	20	N4	N4	N4	N1	N1		N1	N1	N1	N1
	21	N4	N4	N4	N1	N1	N4		N1	N1	N1
	22	N4	N4	N4	N1	N1	N4	N4		N1	N1
	23	N4	N4	N4	N1	N1	N4	N4	N4		N1
	24	N4	N4	N4	N1	N1	N4	N4	N4	N4	

Table 1. Winning Subnet for Different Sweeps
Upper half matrix, N1 subnet gets faster spikes first.
Yellow highlights unexpected slower subnet winning.

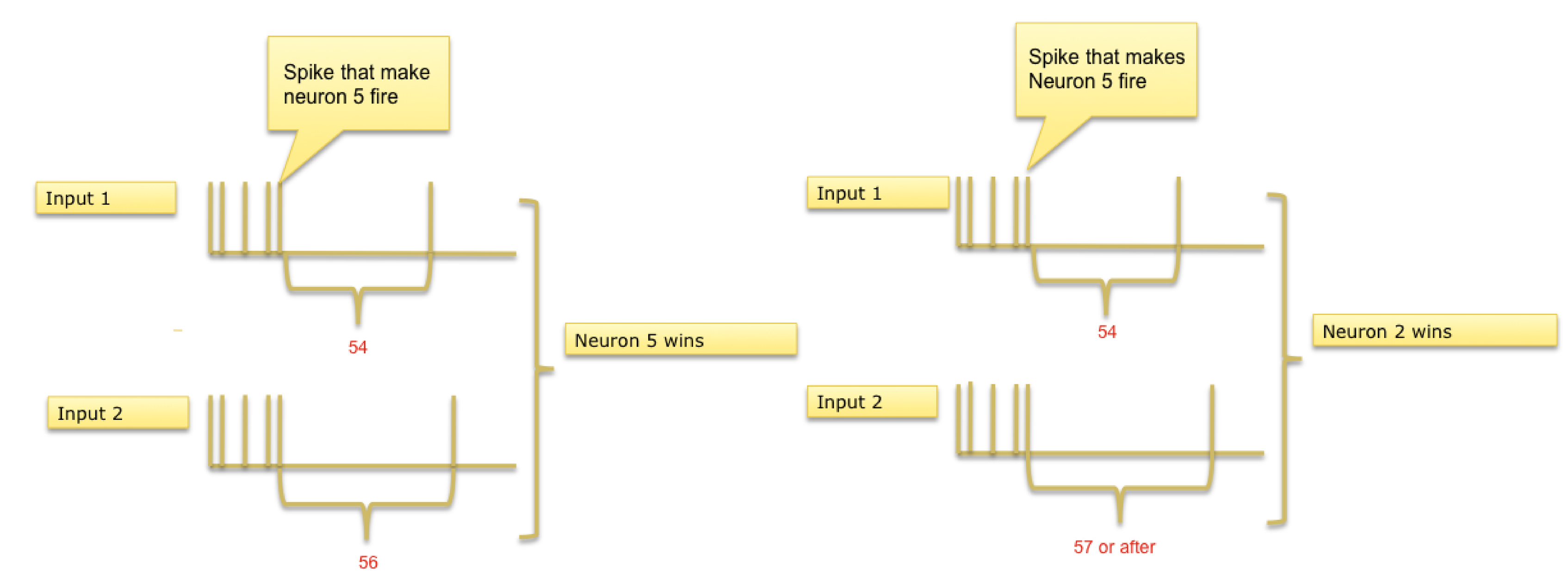

Figure 8: General decision rule

Conclusion A striking winner-take-all dynamic was revealed in a SNN model of the NTS. The model was evolved to replicate measurement data that DID NOT include spike sweeps drifting in/out of phase. This is an emergent phenomenon. Analysis revealed how precise spike timing accounts for the decision. It remains for additional experiments on rats to confirm or reject this model prediction. We are optimistic that this paradigm: (1) build-evolve a SNN model that is consistent with measurement data, (2) probe the network dynamics using engineering methods, (3) generate new hypotheses to test in the lab, may prove of value.