ENCODING SYMBOLIC SEQUENCES WITH SPIKING NEURAL RESERVOIRS

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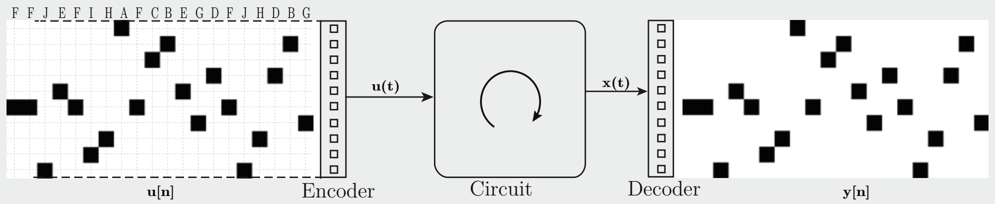
Introduction

- Spiking neural networks (SNN) are the computational substrate of neurobiological systems
- Study the nature of cognitive computation and the processes that subserve it
- Should consider known anatomical and physiological evidence; avoid introducing artificial biases

Survey the impact of:

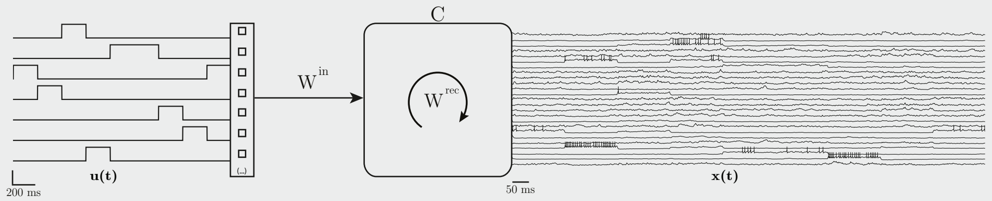
- Signal transduction and input delivery - the *encoding* problem
- Choice of state variables and readout algorithms - the *decoding* problem

Encoding symbolic sequences

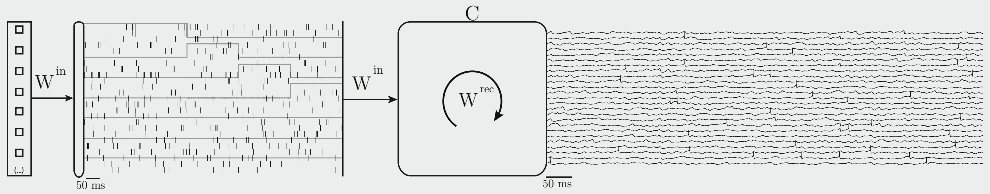


Explore two different encoding schemes:

1. **Direct** - somatic input current of amplitude ρ_u. Each input channel mapped onto a random subset of neurons (determined by the structure of the input weights $W^{in} \in \mathbb{R}_+^{N_u \times N}$).



2. **Indirect** - Each stimulus converted to a fixed spatio-temporal spike pattern across $N_{in} = N_E$ input neurons (*frozen noise*). ρ_u determines the average firing rate across the input population. Each input neuron mapped onto a random subset of neurons in the main circuit.



State decoding and readout

Circuit state, $x(t)$, consists of any adequate dynamical variable. We consider:

- Low-pass filtered spike trains (S): may introduce biases through the parameters of the filter kernel
- Membrane potentials (V): more natural, direct and unbiased alternative

Circuit specifications

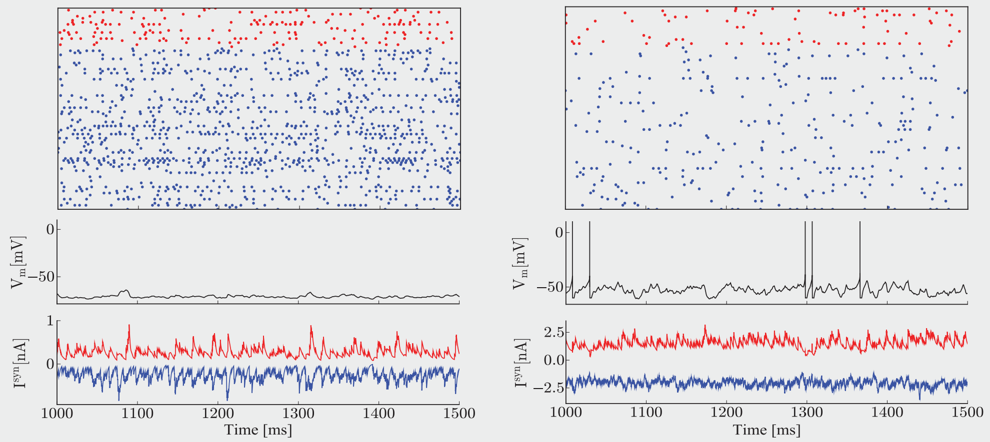
Random, sparse and recurrently coupled network of $N = 10000$ homogeneous, adaptive exponential (AdEx) IaF neurons

- $N_E = 0.8\,N$ excitatory and $N_I = 0.2\,N$ inhibitory neurons
- Sparse and random input and recurrent connections, with synaptic weights and delays drawn independently from truncated normal distributions
- Exponential, conductance-based synapses with fixed and static parameters

Population dynamics

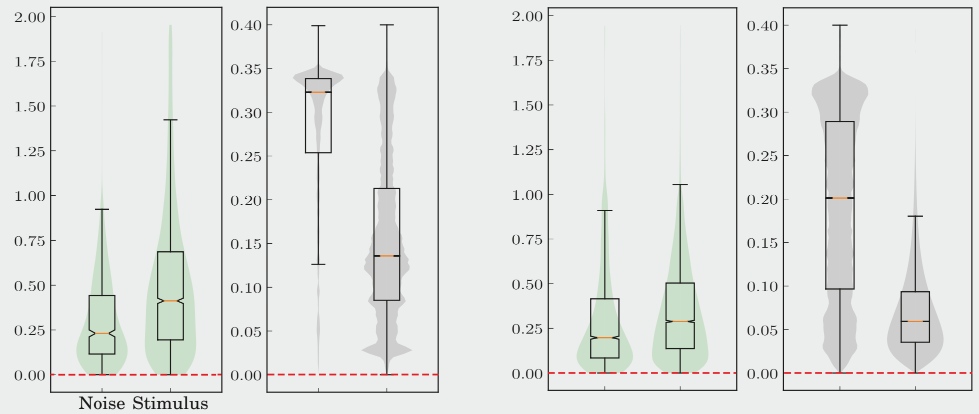
Quality of the input-state mappings and the underlying dynamics depends on the circuit's characteristics and how the input is delivered and interacts with it. Circuits should operate in physiologically plausible regimes.

- Tune input amplitude (ρ_u) and inhibition-to-excitation ratio (γ) in circuits driven by stationary, unspecific and stochastic input
- Goal: low-rate asynchronous irregular state, with balanced E/I (similar to active cortical states)



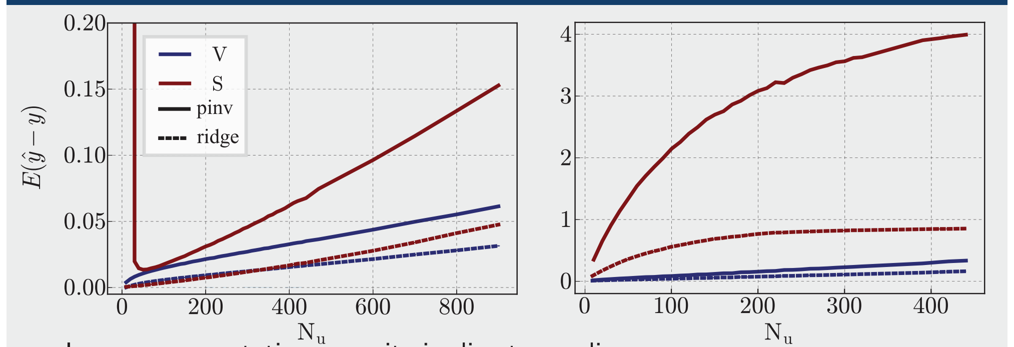
Spiking input leads to physiologically realistic responses:

- Sparser and more distributed activity patterns across the population; increased irregularity and reduced synchrony
- Provides the necessary synaptic drive to increase the circuit's overall responsiveness; Neurons operating close to threshold (high-conductance state)



Stimulus onset modulates the population state: desynchronization and increased regularity (more significant in indirect encoding)

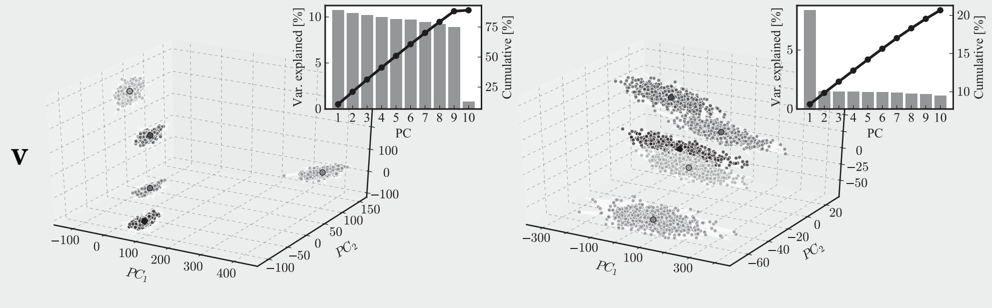
Encoding capacity



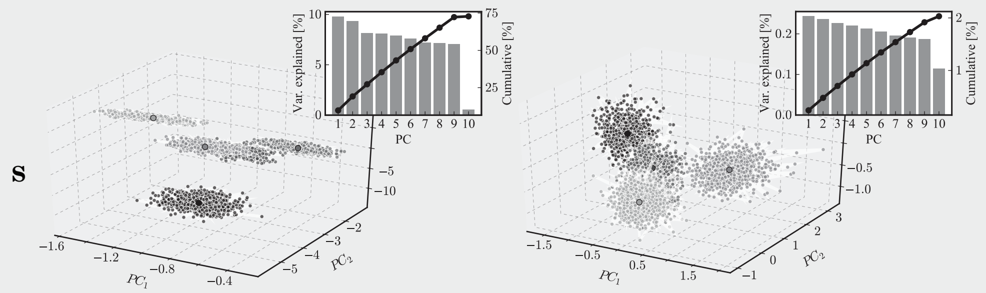
- Larger representation capacity in direct encoding
- Reading out V and regularization are beneficial - smaller classification errors

Internal representations

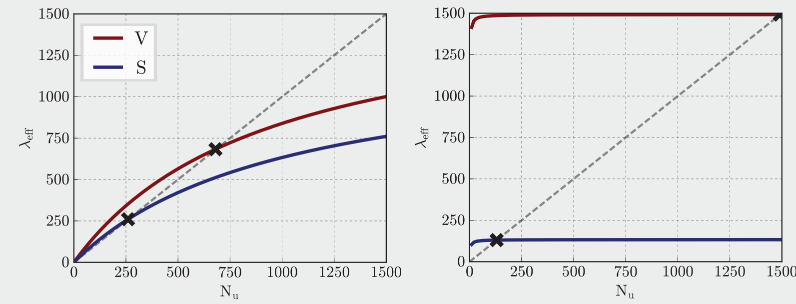
Circuit's macroscopic state determines how it exploits its high-dimensional state-space to project distinct input stimuli onto separable activity clusters.



- Direct encoding leads to clearer state separation: activity vectors in distinct and well segregated clusters
- Indirect encoding also leads to unique stimulus-specific representations, but with larger variance.



- Reading out from S 'distorts' the internal representations and reduces their uniqueness



- Indirect encoding leads to larger effective dimensionality (particularly for V); independent of the number of stimuli

Conclusions and Outlook

- Indirect encoding leads to more *realistic responses*: neurons operate close to threshold and population activity is sparser and more distributed
- Direct encoding is *computationally beneficial*: accurate classification and higher capacity; system's responses are enslaved by the input
- Larger variability and higher-dimensional responses in indirect encoding may be important for more complex computations
- The system's dynamics should be assessed with a direct, unbiased internal variable: information loss; under-represent the richness of the dynamics
- The (often arbitrary) choices of input encoding and decoding can significantly bias the results and lead to incorrect conclusions

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