Emergence of binding capabilities in generic spiking neural networks

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Summary

- Spiking networks with random connectivity support binding through STDP
- Values are encoded by emerging assemblies
- Variable activity is shaped by the content, consistent with fMRI data [1]
- This binding mechanism allows performing elementary cognitive operations
- Preprint available: `https://arxiv.org/abs/1611.03698`

Model architecture

- Linked populations of spiking neurons controlled by disinhibition
- Sparse random connectivity with STDP
- Content space: stable assemblies for concepts (like concept cells, [2])
- Variable spaces: encode variables
- Disinhibition of variable space while content assembly is active: emergence of assembly linked with content representation

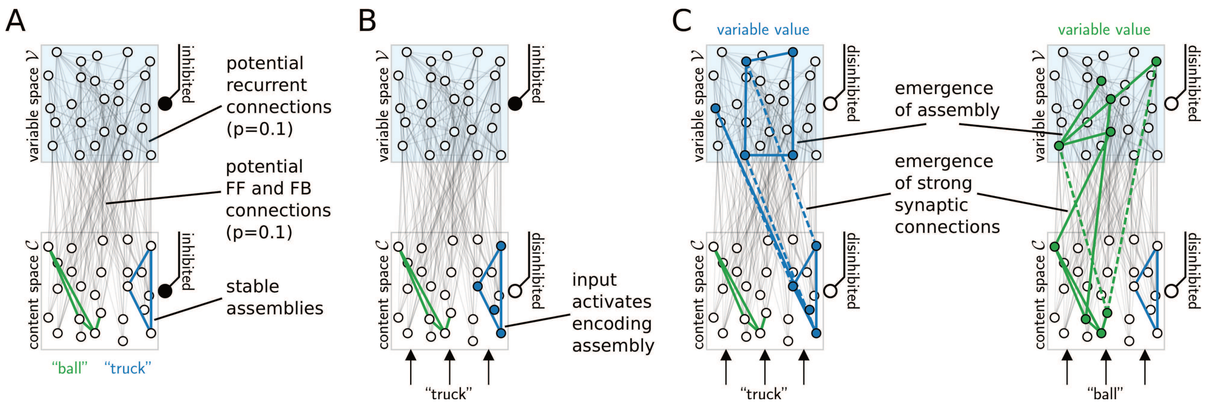

Figure 1: **A** Network structure with content space $\mathcal{C}$, one variable space $\mathcal{V}$, and potential connections (with STDP). **B** Inputs are represented by stable assemblies in $\mathcal{C}$. **C** Disinhibition of $\mathcal{V}$ leads to the emergence of an encoding assembly. Content identity shapes this assembly.

Recalling variables

- Disinhibition of variable space after delay: previously active assembly activates content representation
- Neurons driven to fire by transiently increased excitability
- Simulation results: robust recall for different network wirings and content assemblies (success rate 100%, success criterion: $> 80\%$ assembly overlap)

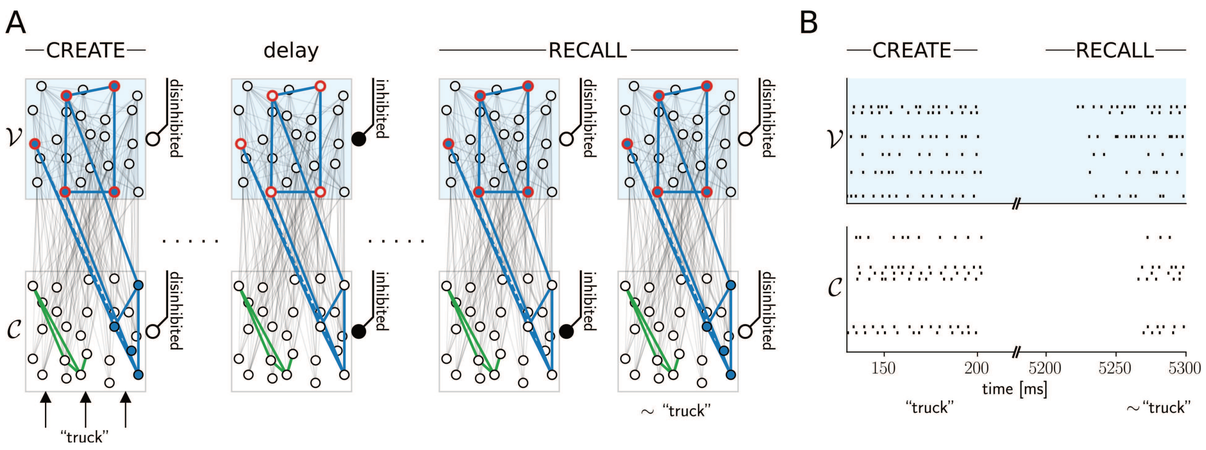

Figure 2: **A** Storing and recalling some value, controlled by disinhibition. Red circles denote increased excitability of neurons. **B** Spike trains from model simulation.

References

[1] Frankland SM, Greene JD. An architecture for encoding sentence meaning in left mid-superior temporal cortex. Proceedings of the National Academy of Sciences. 2015;112(37):11732–11737.

[2] Quian Quiroga R. Neuronal codes for visual perception and memory. Neuropsychologia. 2016;83:227–241.

Content-shaped activity

- fMRI data from Frankland and Greene [1]: areas in lmSTC encode specific semantic variables
- Example: can read out agent ("truck") and patient ("ball") in a sentence ("The truck hit the ball.")
- Simulation results: robust readout ($> 97\%$ accuracy) from subsampled activity under severe noise conditions

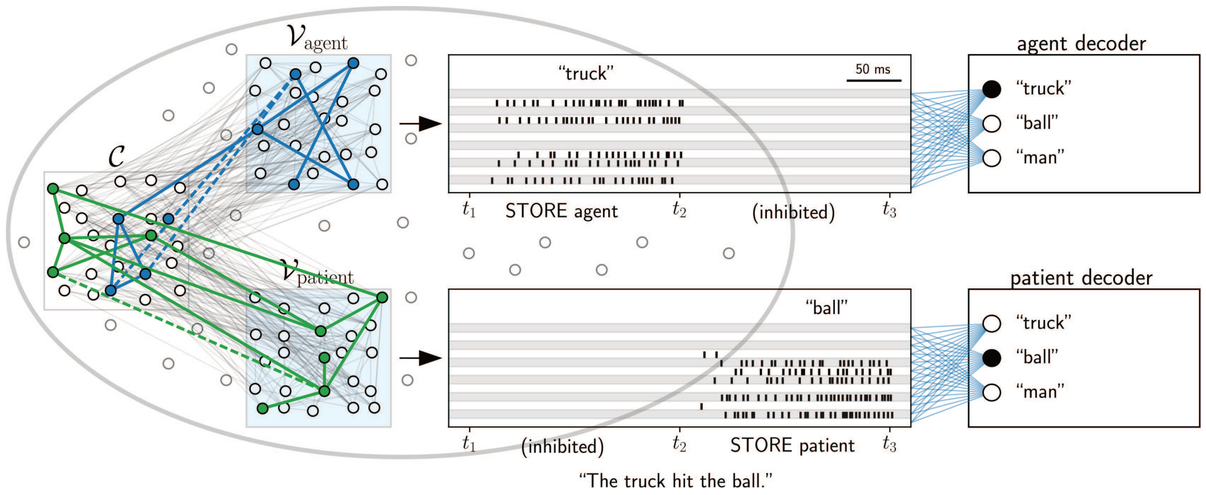

Figure 3: Model with two variable spaces storing semantic values. As the encoding assemblies are shaped by the contents, the variable values can be read out from the neurons' activity (similar to fMRI data).

Symbolic operations

Elementary cognitive computations supported by this model:

- Copying contents between variables:

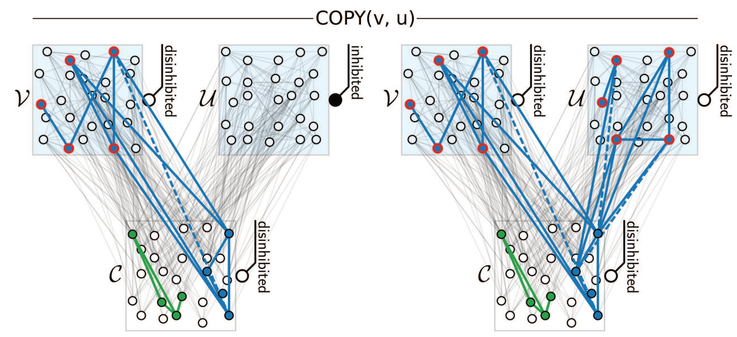

Figure 4: To copy variable contents, a value is recalled from the source variable space while the target variable space is simultaneously disinhibited.

- Comparing variable contents:

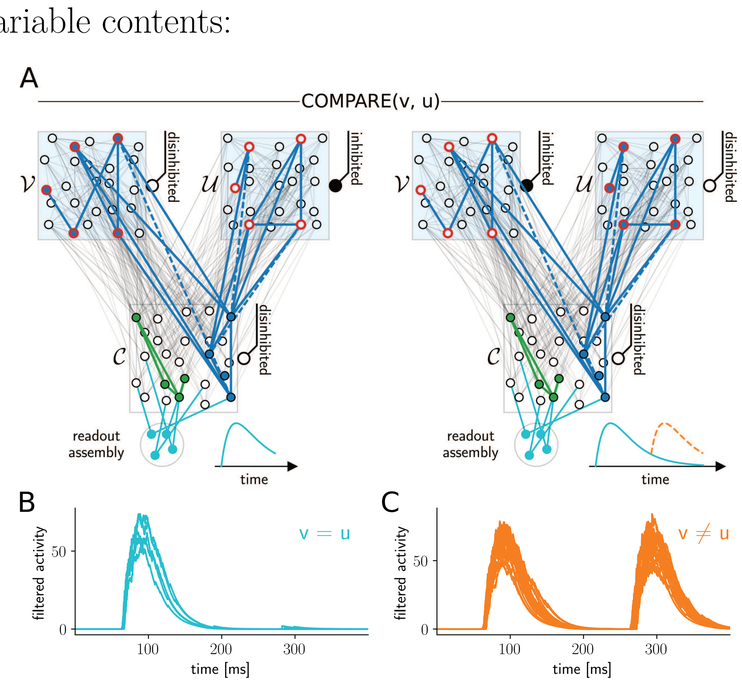

Figure 5: **A** To compare variable contents, variable spaces are sequentially recalled. A readout assembly connected to content space via depressing synapses tests for equality. **B** Low readout activity during second recall indicates equal values. **C** High readout activity indicates inequality.