SCIENCE
PASSION
TECHNOLOGY

Late Breaking News: Bio Theory

Switching Dynamics of Working Memory

Ghanendra Singh (PhD Student)
Institute of Neural Engineering
ghanendra.singh@tugraz.at

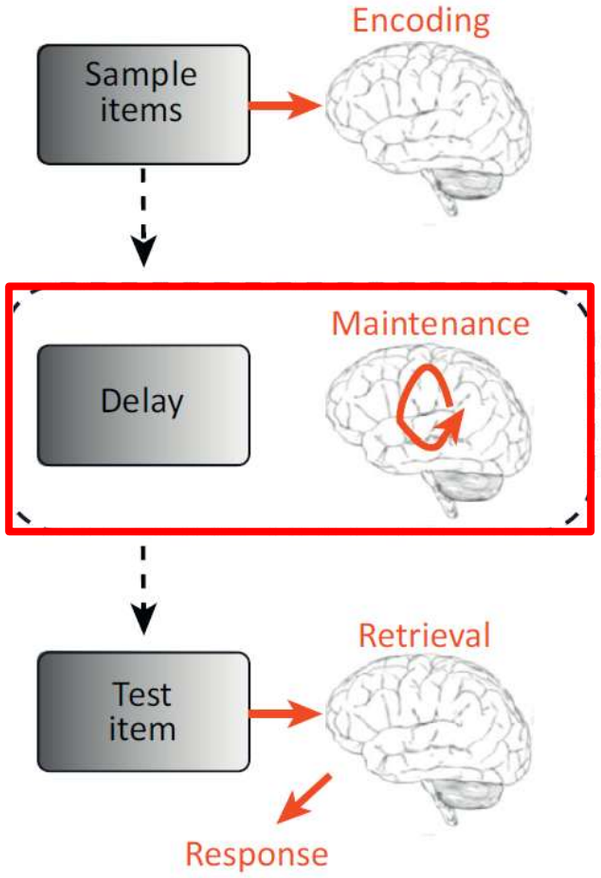
European Institute for Neuromorphic Computing (EINC)
Heidelberg, Germany

27.03.25

https://niceworkshop.org/

Highlights

Stages of WM



- **Working Memory (WM):** To temporary store and manipulate information.
- **Persistent activity:** Exists during the maintenance phase of WM.
- **Memory States:** Persistent and silent states exists during WM maintenance.
- **Existing Models:** Consider persistent & silent phase operate at same time scale.

Proposal: **Transition occurs between these two phases at different time scales which might be required for an (efficient) maintenance of WM.**

* Manuscript In Preparation (2025)

Memory Views

Classical View

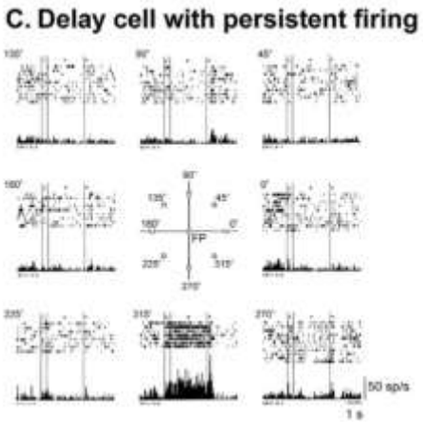
Persistent activity underlies WM maintenance.

- (Persistent spikes are metabolically expensive)

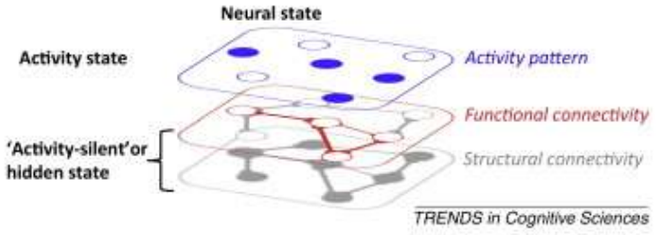
Does WM depend on neurons firing persistently or in brief, coordinated bursts?

Current View

- WM are held between spiking by spiking-induced changes in synaptic weights, **“impressions”** left in the network. Sparse bursting activity optimize information not persistent activity (Naud et al., 2018).
- Interplay between persistent and activity-silent dynamics exist in WM (Barbosa et al., 2020)

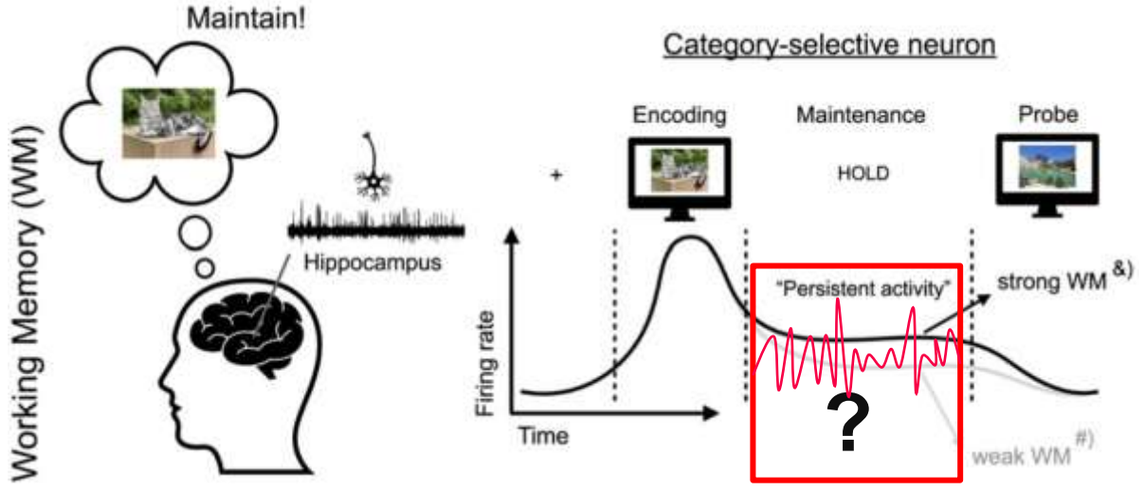


Constantinidis et al., 2018



Stokes, Cell 2015

The neural state comprises **‘activity state’:** measured in typical experiments, **‘silent state or hidden states’:** functional and structural connectivity. *Changes in these states play an important role in WM.*



Daume et al, Neuron 2024

* Manuscript In Preparation (2025)

Background

Roux et al., Cell 2014,
Kopell et al., PNAS, 2011,
Champion et al., 2023

The brain saves energy (spikes cost energy) by keeping memory ensembles in an active state with help of impressions instead of continual spiking.

Observation:

- Self sustained activity occurs during WM tasks despite stimulus removal indicating existence of attractor dynamics.

Question:

- How does persistent and silent activity together encodes information?
- What is the nature of such mechanisms during WM maintenance?

Motivation:

- For efficient hardware implementation of WM using SNN.

* Manuscript In Preparation (2025)

Mean Field Model

Based on Wilson-Cowan dynamics.

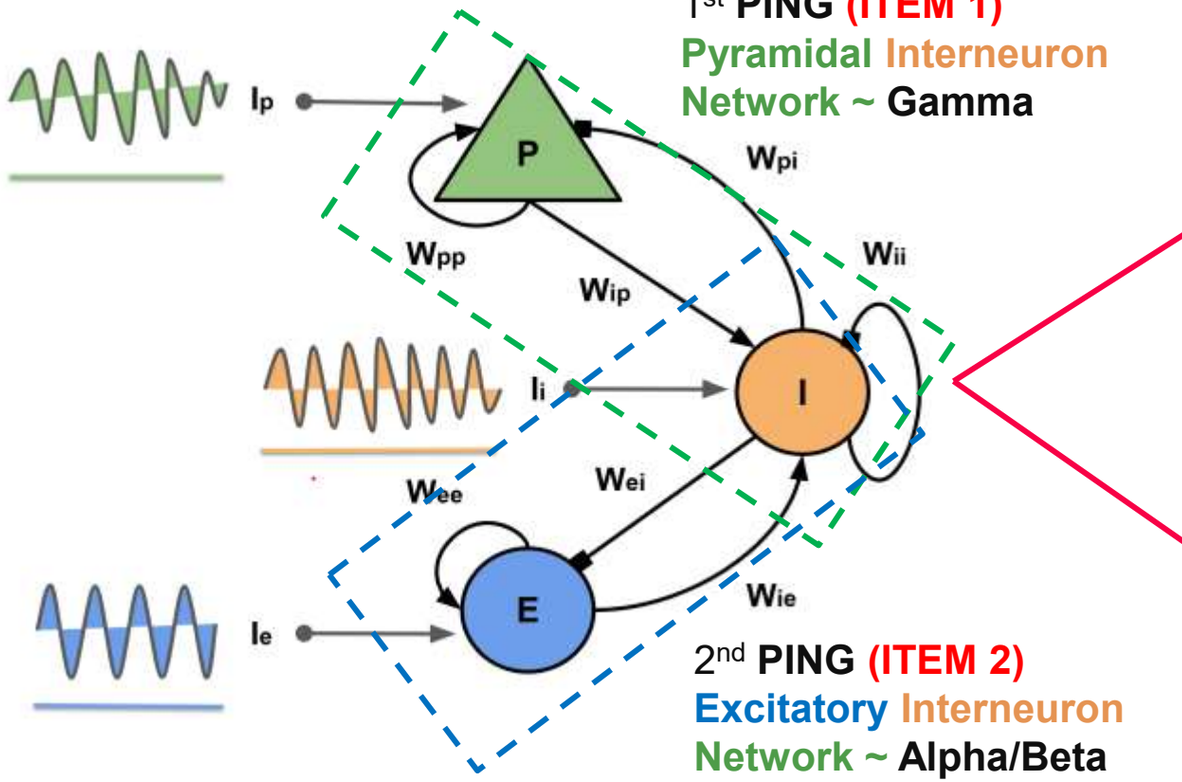
Consists of pyramidal neurons, interneurons and an excitatory neurons forming 2 PING networks coupled by Interneuron.

Equation

$$\tau_i \frac{dr_i}{dt} = -r_i + \phi_i(a_i, \theta_i, \Sigma w_{ij} r_j + I_i)$$

τ: *time constant*,
r: *mean rate*
ϕ: *activation*,
a: *gain*,
θ: *threshold*
ω: *weights*,
I: *external current*

$$\phi_i = \frac{1}{1 + e^{-a_i(I_t - \theta_i)}}$$

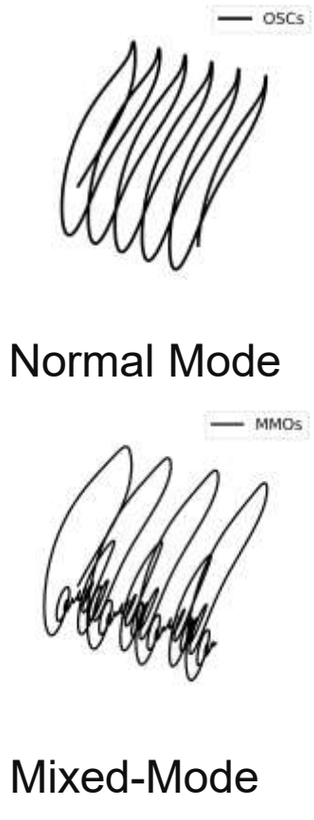


1st **PING (ITEM 1)**
Pyramidal Interneuron Network ~ Gamma

2nd **PING (ITEM 2)**
Excitatory Interneuron Network ~ Alpha/Beta

P: Pyramidal, **I:** Interneuron, **E:** Excitatory

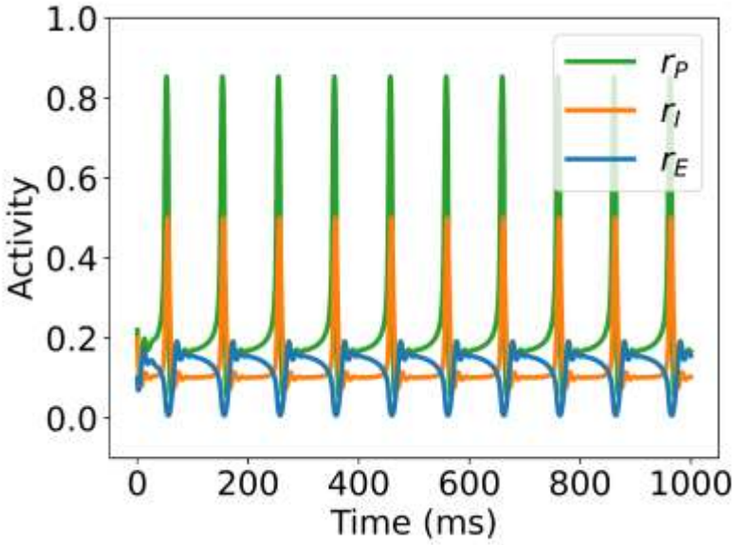
Output



* Manuscript In Preparation (2025)

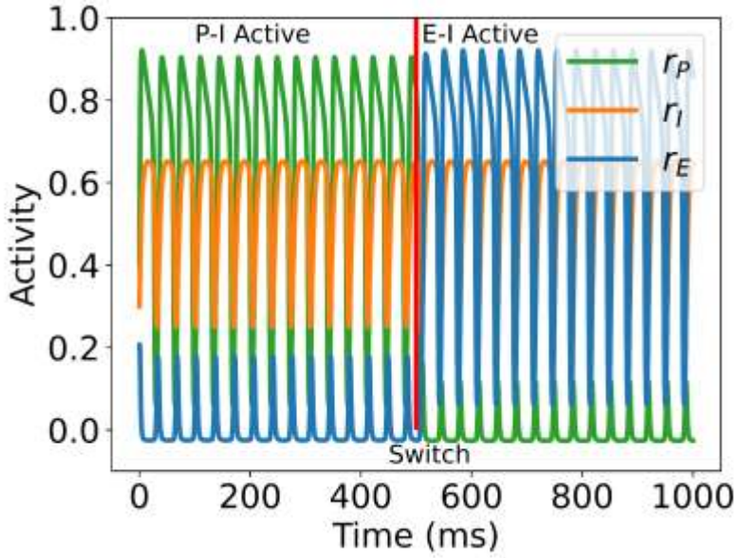
Persistent Activity

(Normal mode)



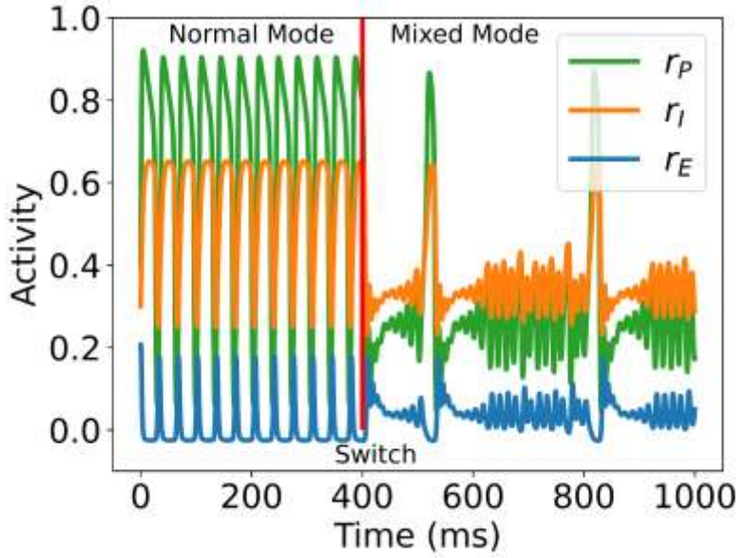
- 1st PING (P-I) network activity is high and 2nd PING (E-I) network activity is low.

Mean firing rate: ~ 10 (Alpha range)



- Switching from 1st PING network (P-I) to 2nd (E-I) for current change at t=500.

Mean firing rate: ~ 30 (Gamma)



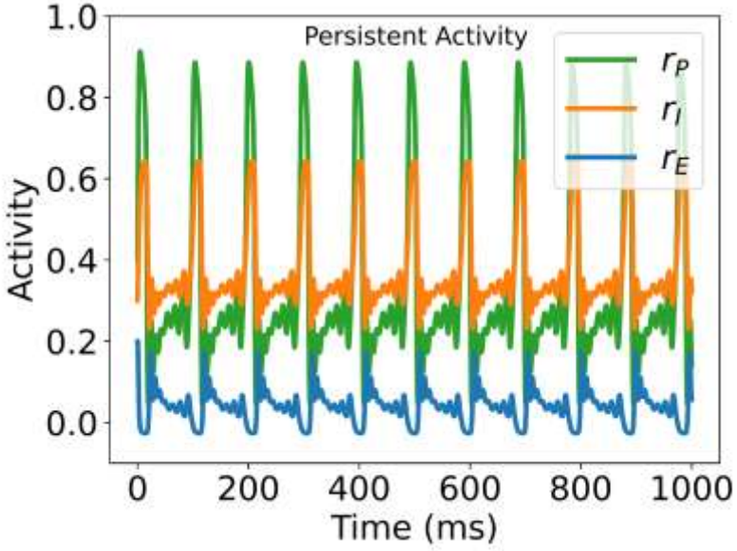
- Transition from normal mode oscillations to mixed-mode oscillations at t=400.

firing rate transition: ~ (30 to 4)

* Manuscript In Preparation (2025)

Persistent Activity

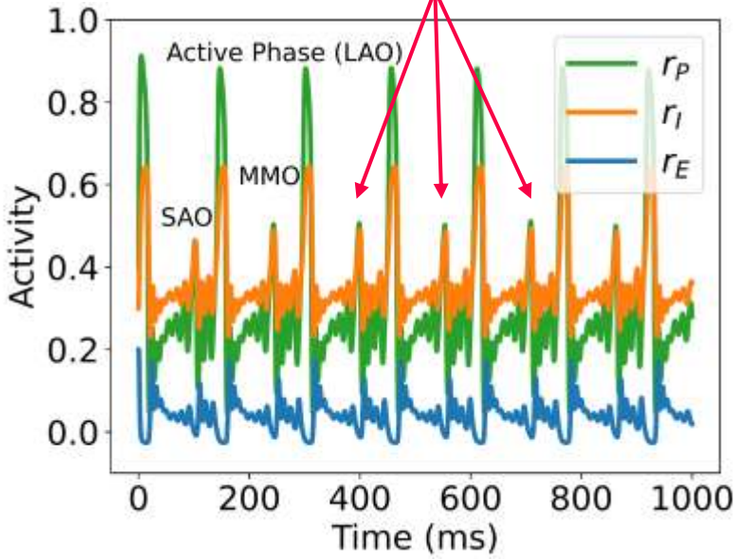
(Mixed mode)



- Persistent activity with regular mixed mode oscillations.

Mean firing rate: ~ 10

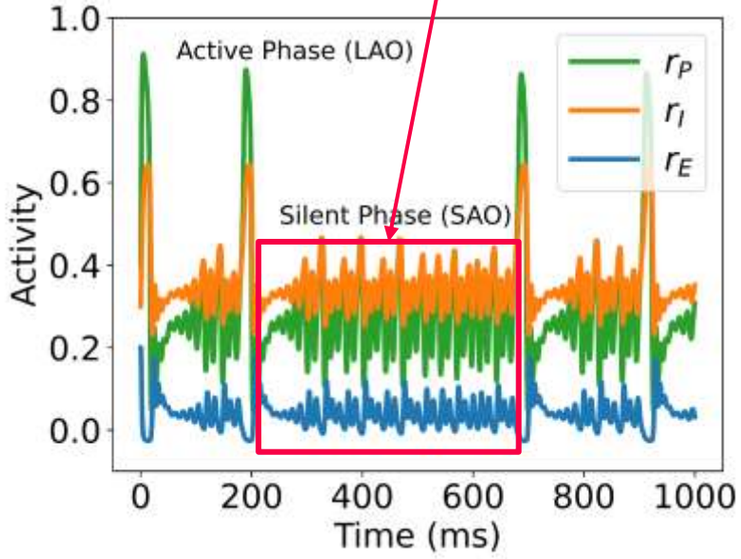
Periodic **refreshing** ?
Via intrinsic oscillations



- Active phase with large amplitude oscillation (LAO) and silent phase with small amplitude oscillations (SAO).

Mean firing rate: ~ 6-7 (Theta)

Maintenance ?
''silent' or hidden states



- Persistent activity with short duration active phase (LAO) and with long duration silent phase (SAO) periods.

Mean firing rate: ~ 4

* Manuscript In Preparation (2025)

Summary

Relevance:

- *A simple rate-based model to explain the WM dynamics using MMOs.*

Limitations:

- *Dynamics is ensitive to small parameter variations for MMOs.*
- *Improve robustness of the underlying mechanisms.*
- Synaptic plasticity mechanisms are not considered.

Key Takeaways

- *Both persistent and quiescent firing dynamics are required for efficient storage and retrieval of memories.*
- *WM may utilize such mixed mode oscillations (MMO) regime for robust and efficient encoding of information at different time scales.*

* Manuscript In Preparation (2025)

Thank You.

Visit **Poster 1st floor** for more details**.**

Questions?

* Manuscript In Preparation (2025)