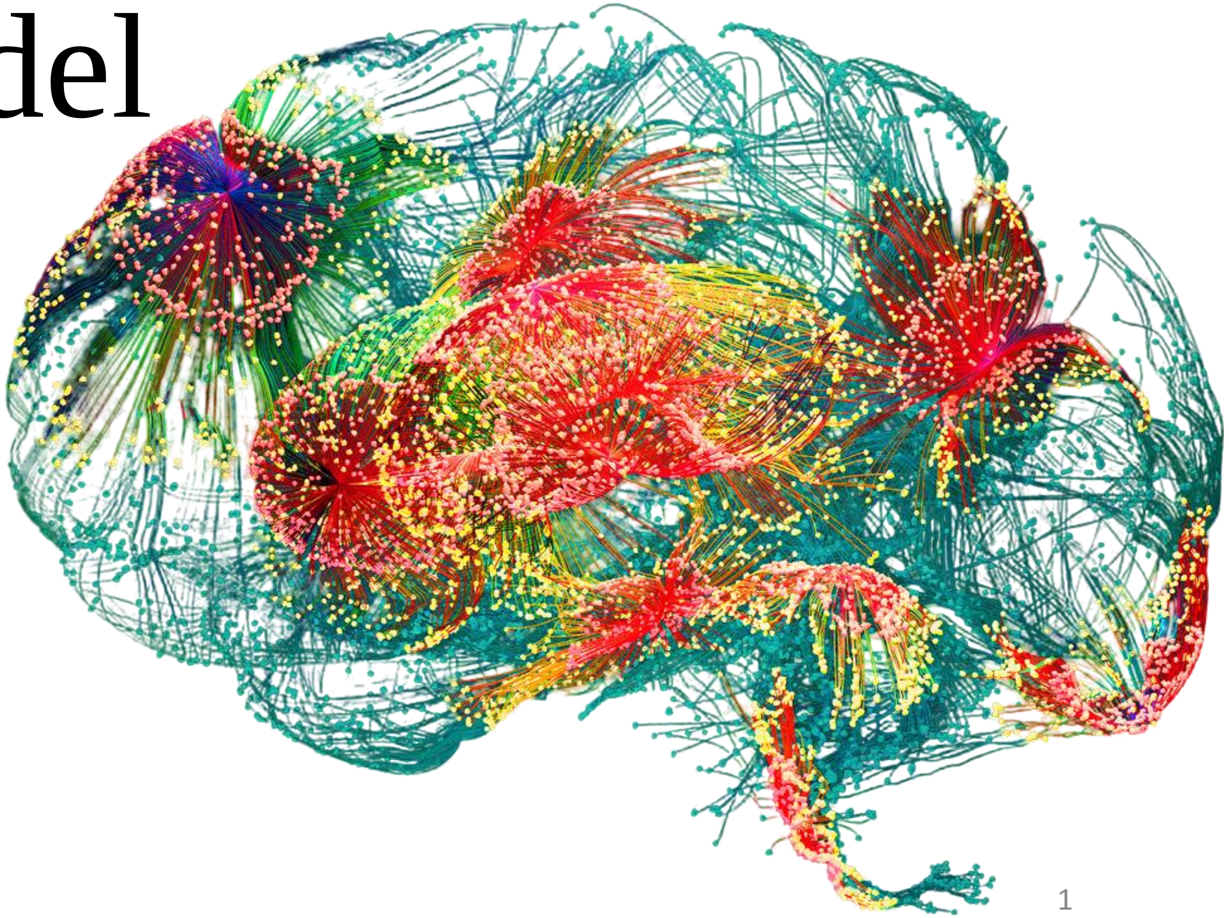
Simulating EEG Signals Using Wilson-Cowan based coupled Brain Network Model



Brains, Dynamics & Computation
Workshop on Network Neuroscience
June 04, 2025

Radhika Shrimankar , Amrita Mind Brain Centre, Kerala

Nimish Kumar, IIT Jodhpur

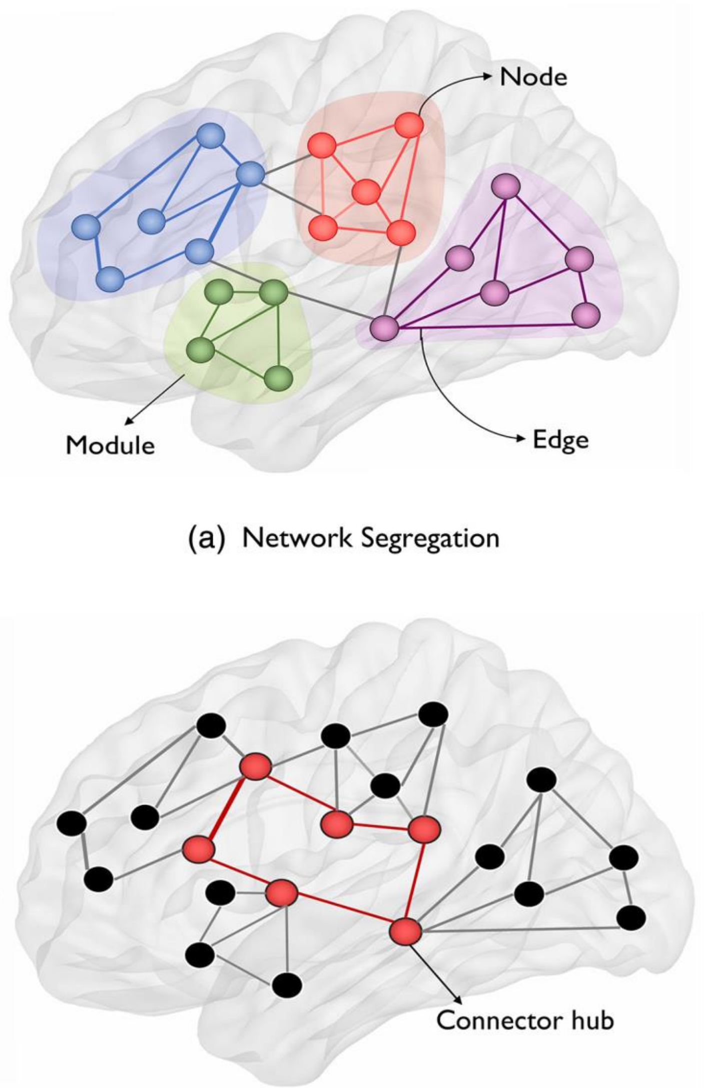
Sneha Biswas, NITK Surathkal

Brain as a Network

- Complex Connectivity

- Nodes

- Structural vs Functional Connectivity



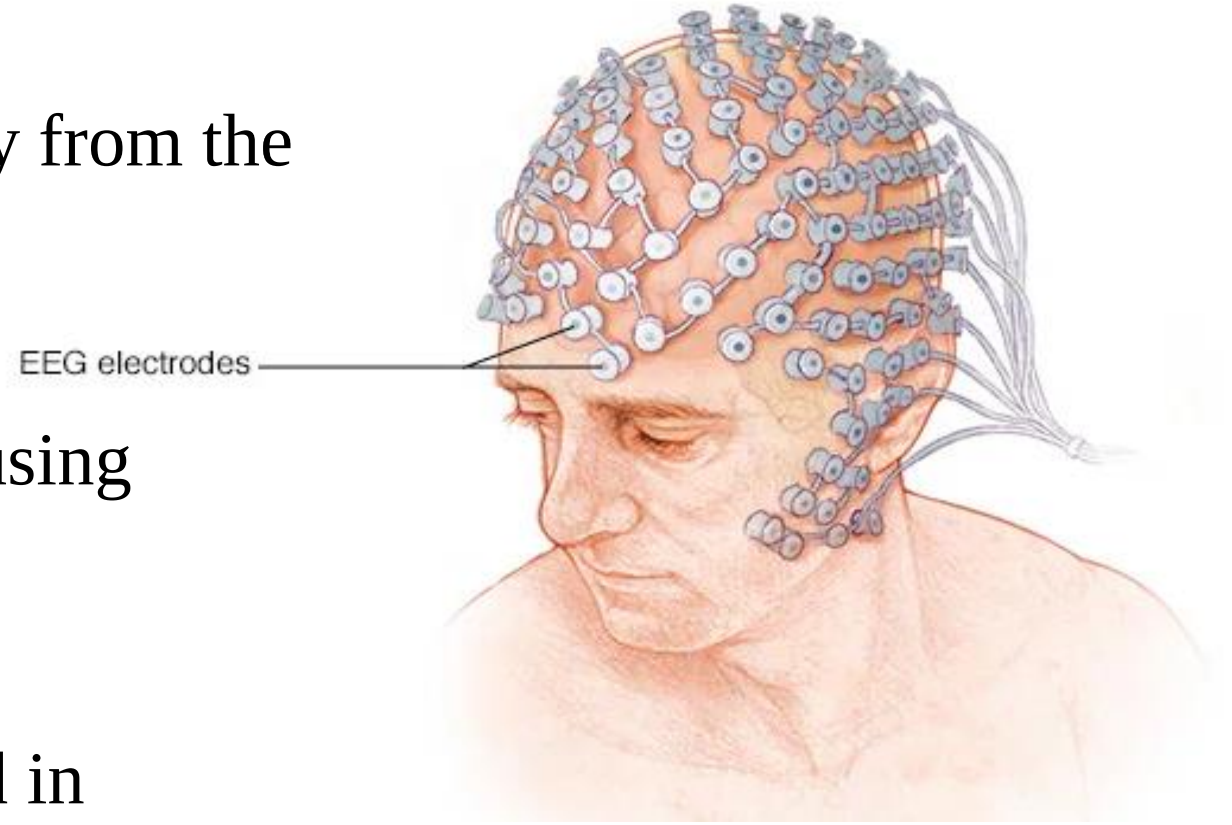
(a) Network Segregation

(b) Network Integration

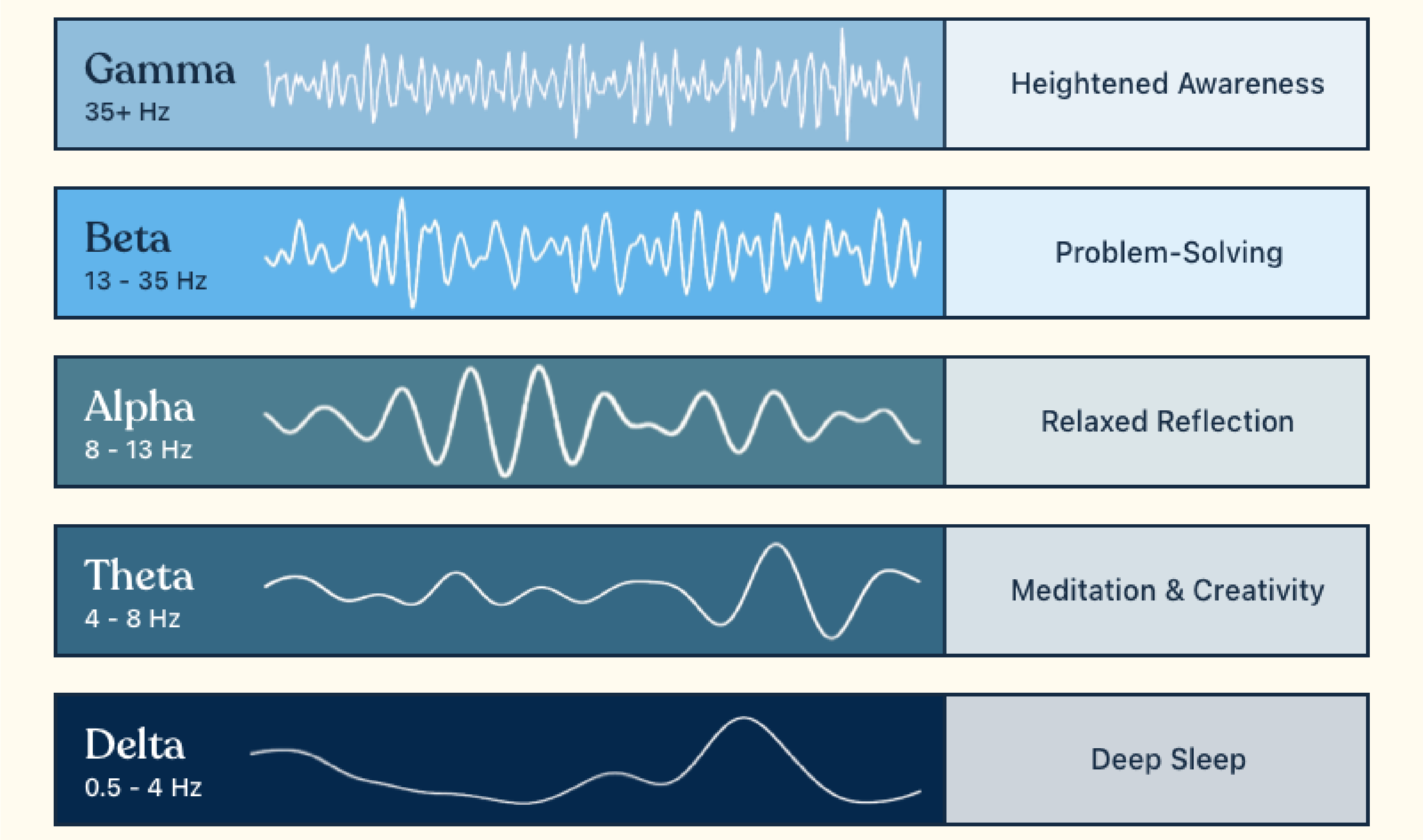
Image: Vikram Shenoy Handiru, Alaleh Alivar, Armand Hoxha, Soha Saleh, Easter S. Suviseshamuthu, Guang H. Yue, Didier Allexandre. Graph-theoretical analysis of EEG functional connectivity during balance perturbation in traumatic brain injury: A pilot study

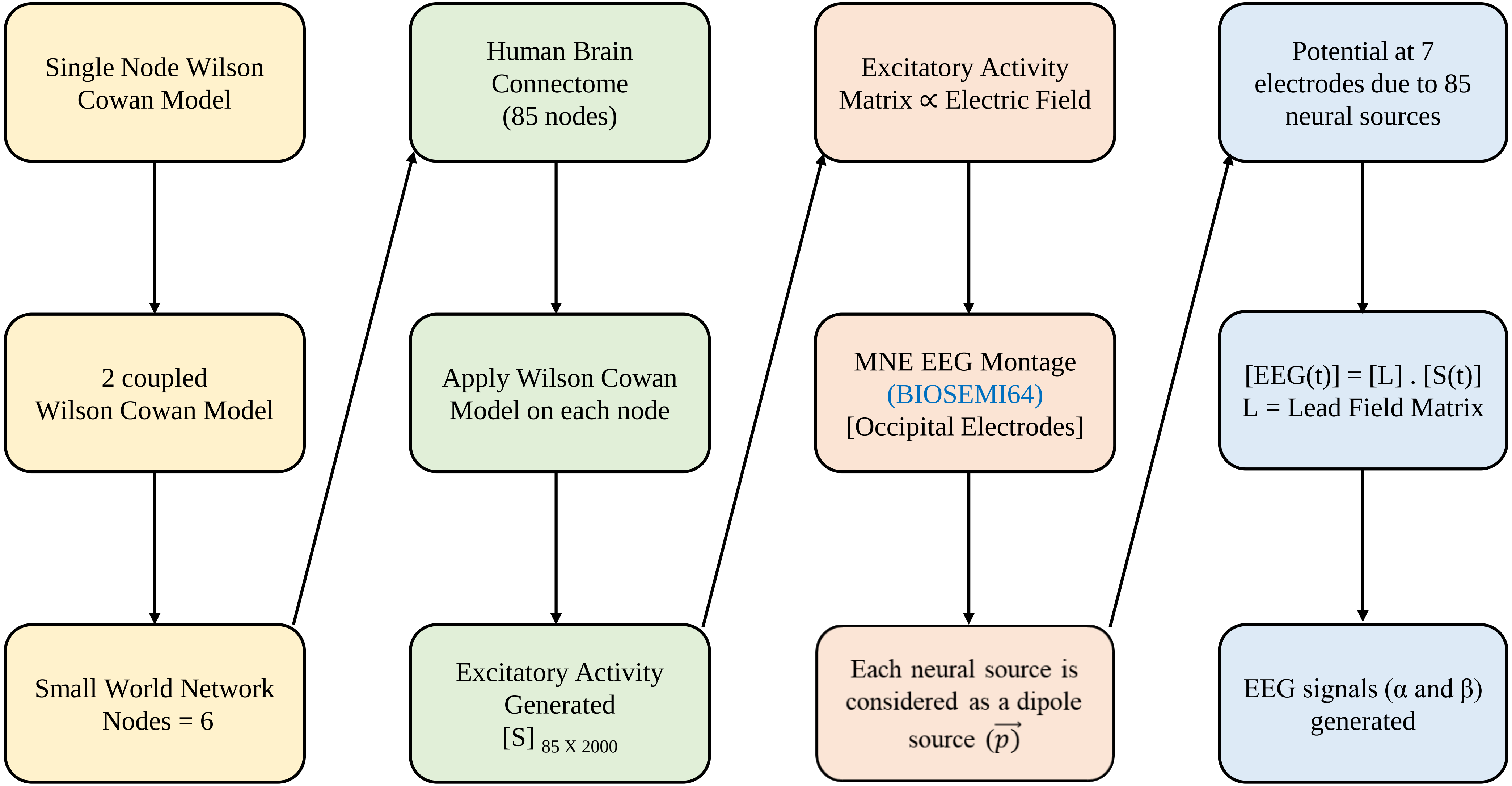
EEG: A Window into Brain Function

- EEG records electrical activity from the brain’s surface.
- Measures neural oscillations using scalp electrodes.
- Non-invasive and widely used in research and clinical settings.



Brain waves with EEG




Single Node Wilson Cowan Model
2 coupled Wilson Cowan Model
Small World Network Nodes = 6
Human Brain Connectome (85 nodes)
Apply Wilson Cowan Model on each node
Excitatory Activity Generated [S] 85 X 2000
Excitatory Activity Matrix ∝ Electric Field
MNE EEG Montage (BIOSEMI64) [Occipital Electrodes]
Each neural source is considered as a dipole source $(\vec{p})$
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Wilson-Cowan Dynamics

$$\tau_u \dot{u}_i = -\, u_i + (\kappa_u - r_u u_i)\, s_u(u_i^{in})$$

$$\tau_v \dot{v}_i = -\, v_i + (\kappa_v - r_v v_i)\, s_v\,(v_i^{in})$$

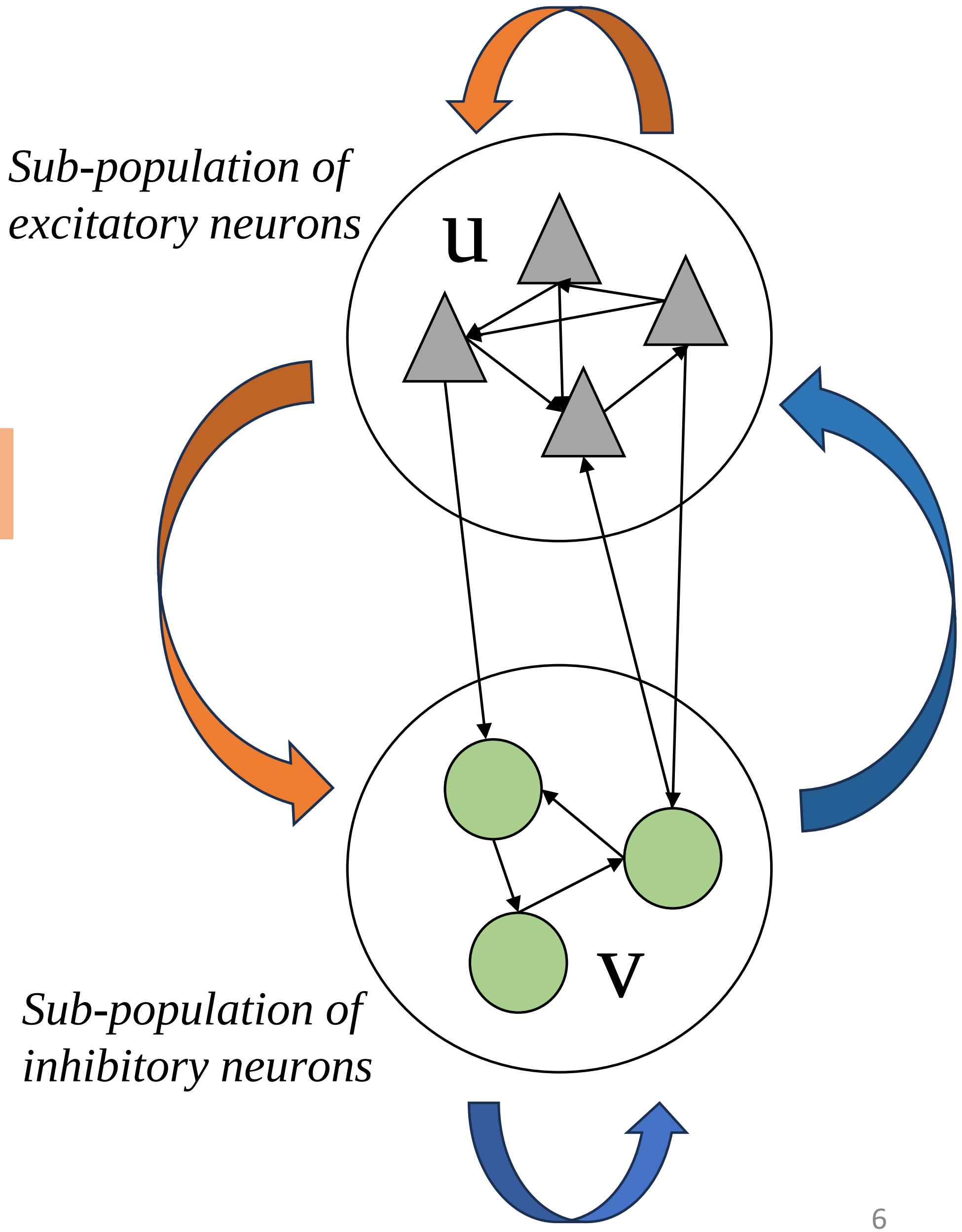
$$u_i^{in} = c_{uu} u_i - c_{uv} v_i + \Sigma' \left(w_{ij}^{uu}\, u_j - w_{ij}^{uv}\, v_j \right) + I_u^{ext}$$

$$v_i^{in} = c_{vu} u_i - c_{vv} v_i + \Sigma' \left(w_{ij}^{vu}\, u_j - w_{ij}^{vv}\, v_j \right) + I_u^{ext}$$

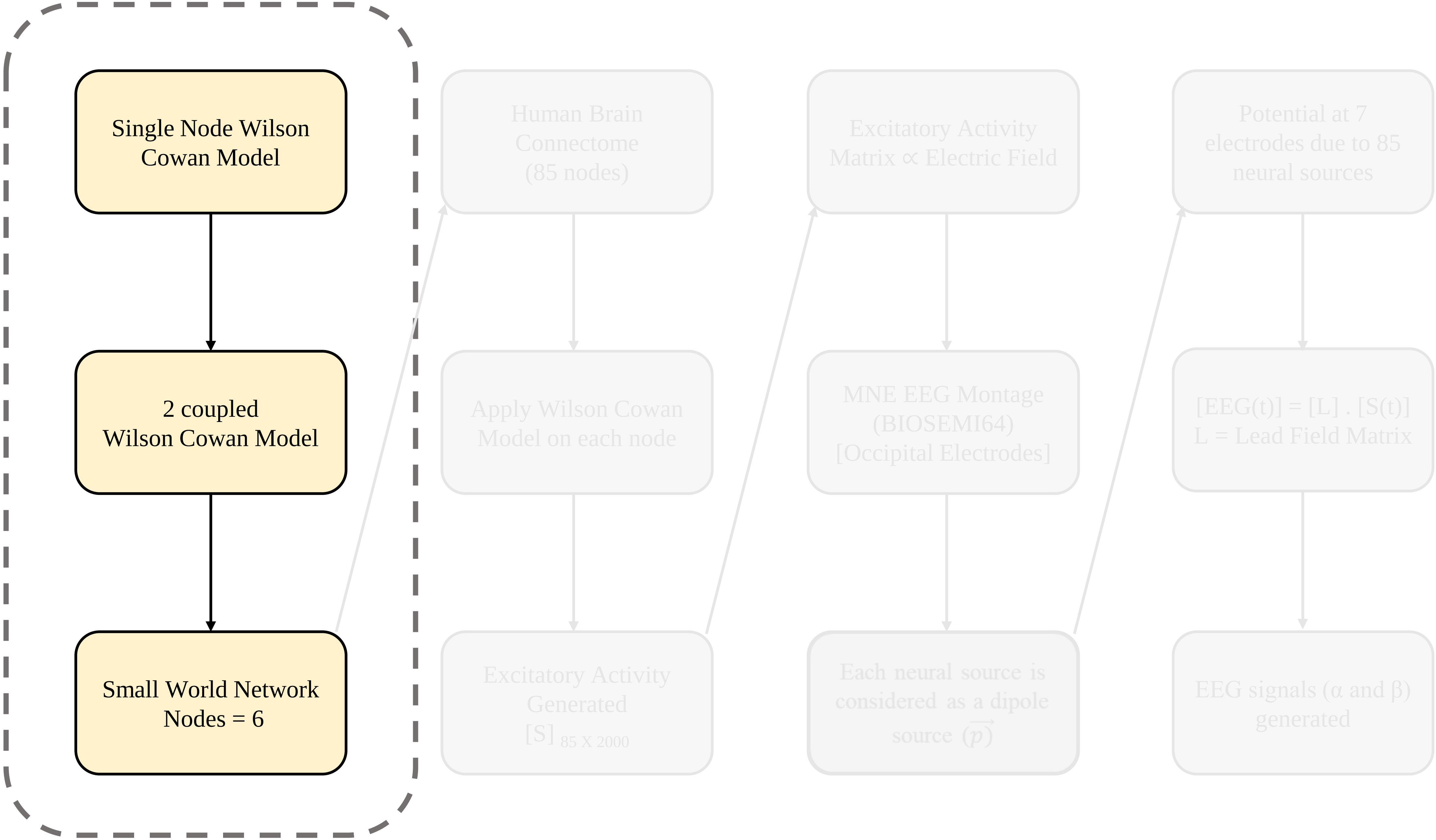
Sigmoid Function:

$$S_u\,(z) = [\,1 + \exp\{-\, a_\mu (z - \theta_\mu)\}]^{-1} + \kappa_\mu - 1$$

$$\kappa_\mu = 1 - [1 + \exp(a_\mu \theta_\mu)]^{-1}$$



Singh, R., Menon, S. & Sinha, S. Complex patterns arise through spontaneous symmetry breaking in dense homogeneous networks of neural oscillators. *Sci Rep* **6**, 22074 (2016). https://doi.org/10.1038/srep22074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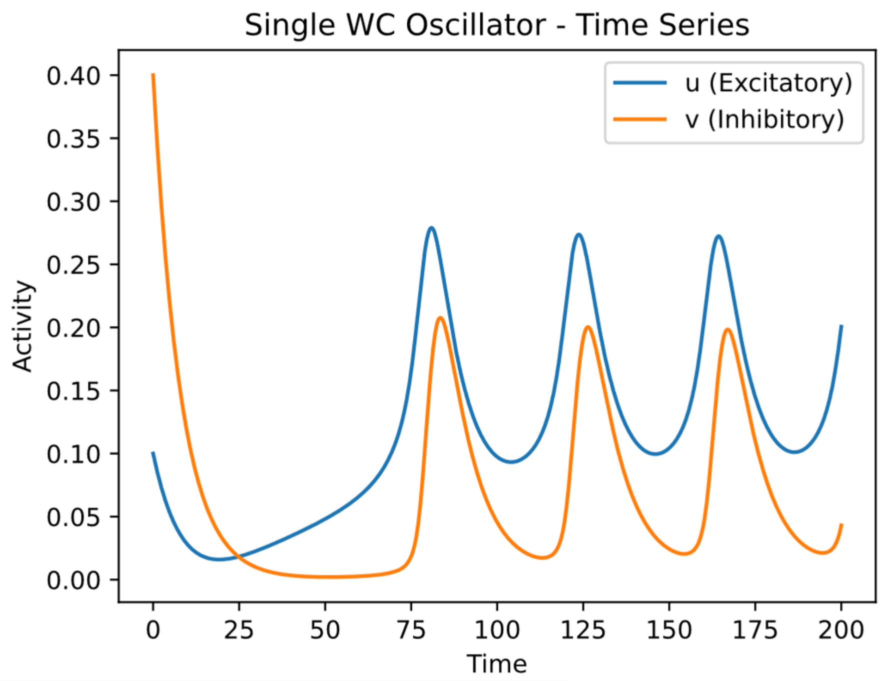

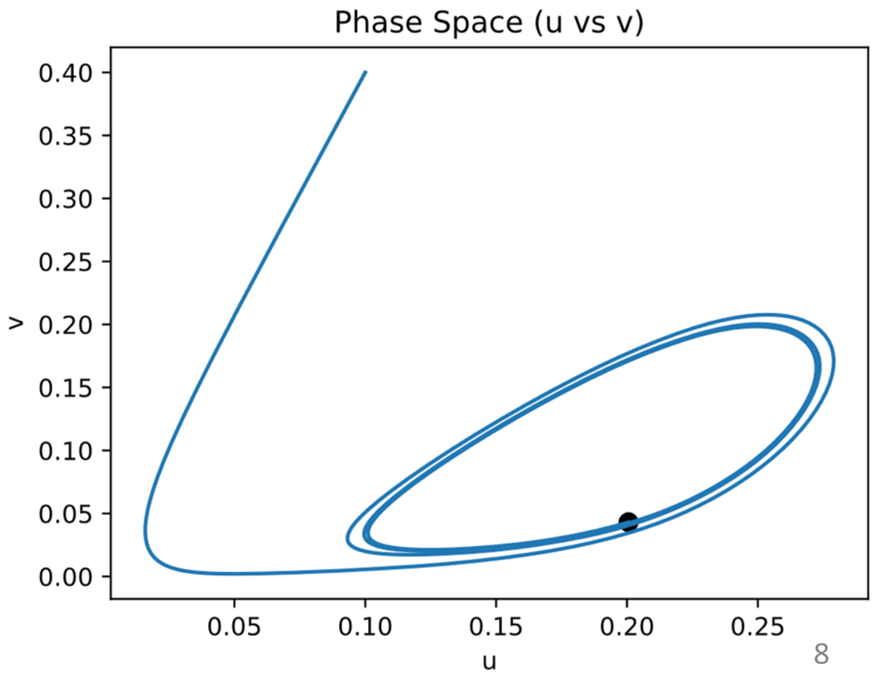

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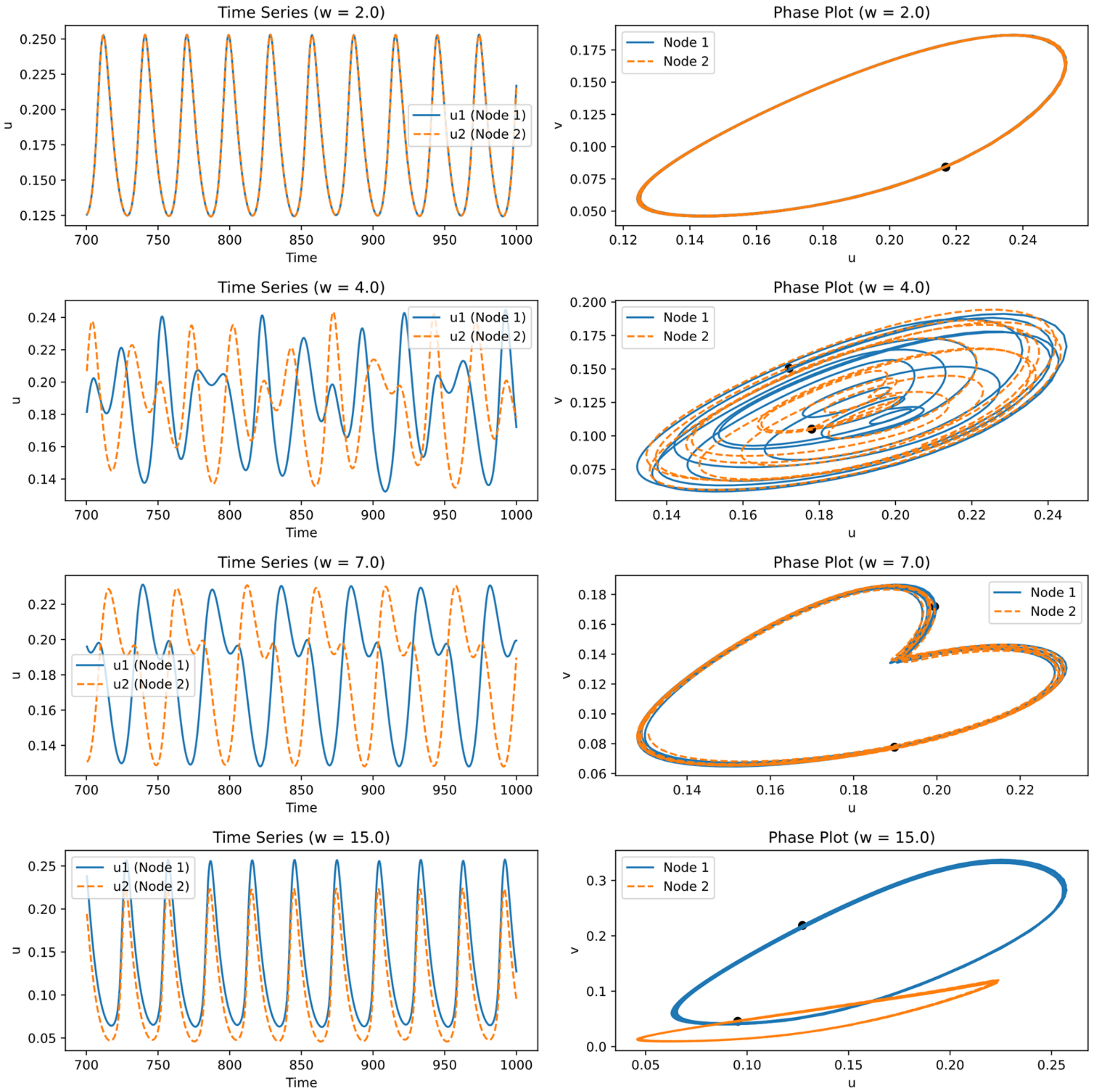
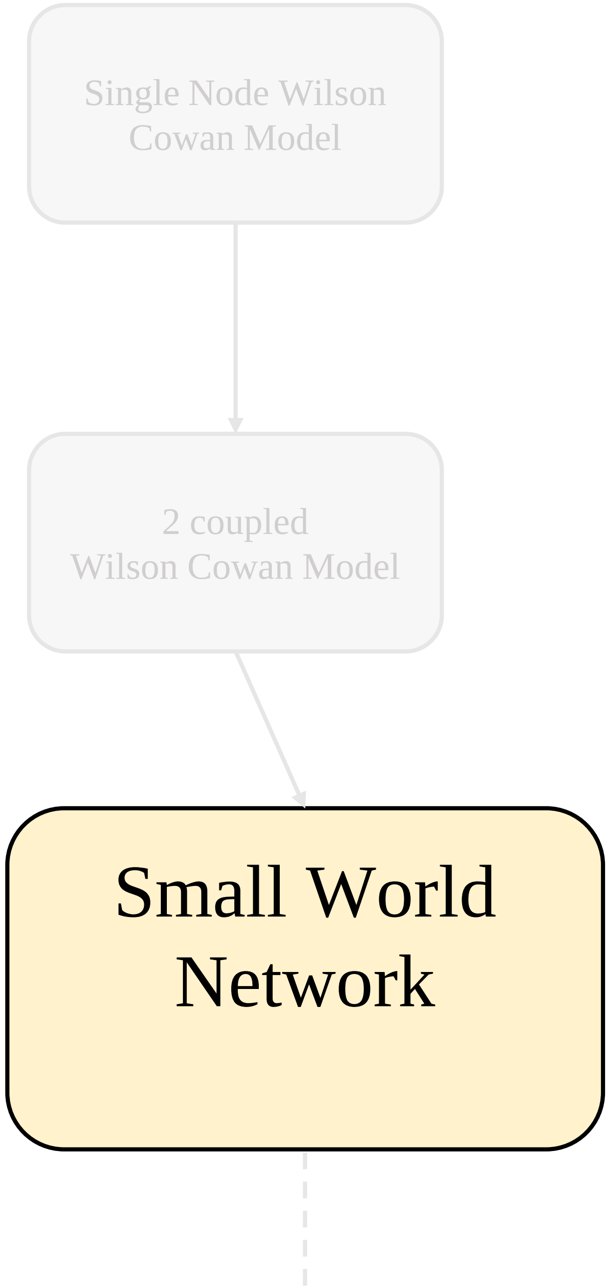
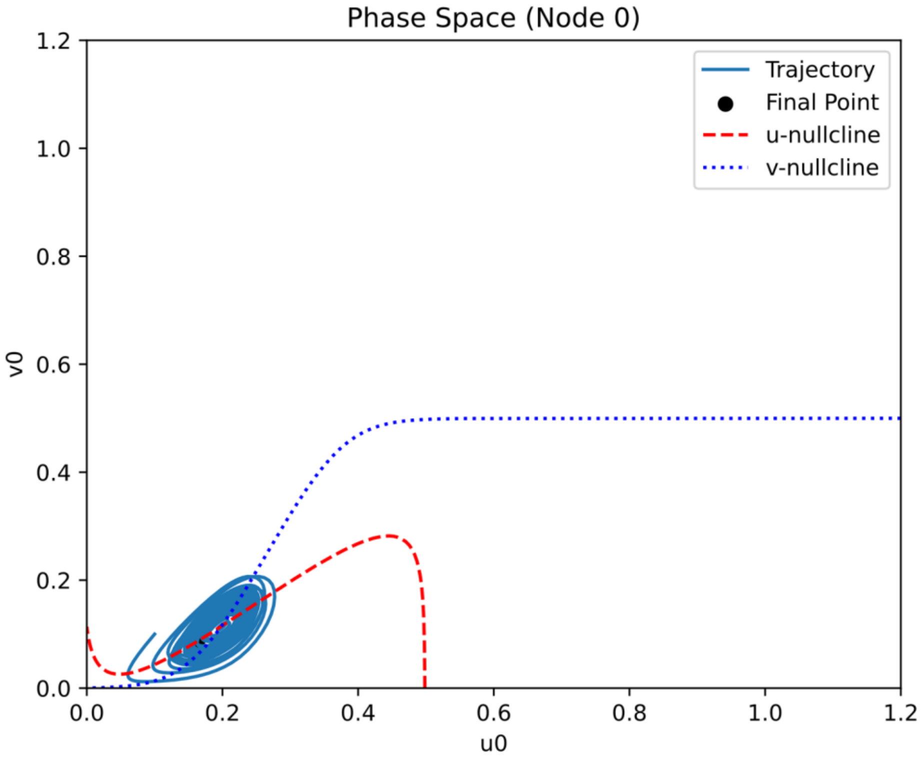
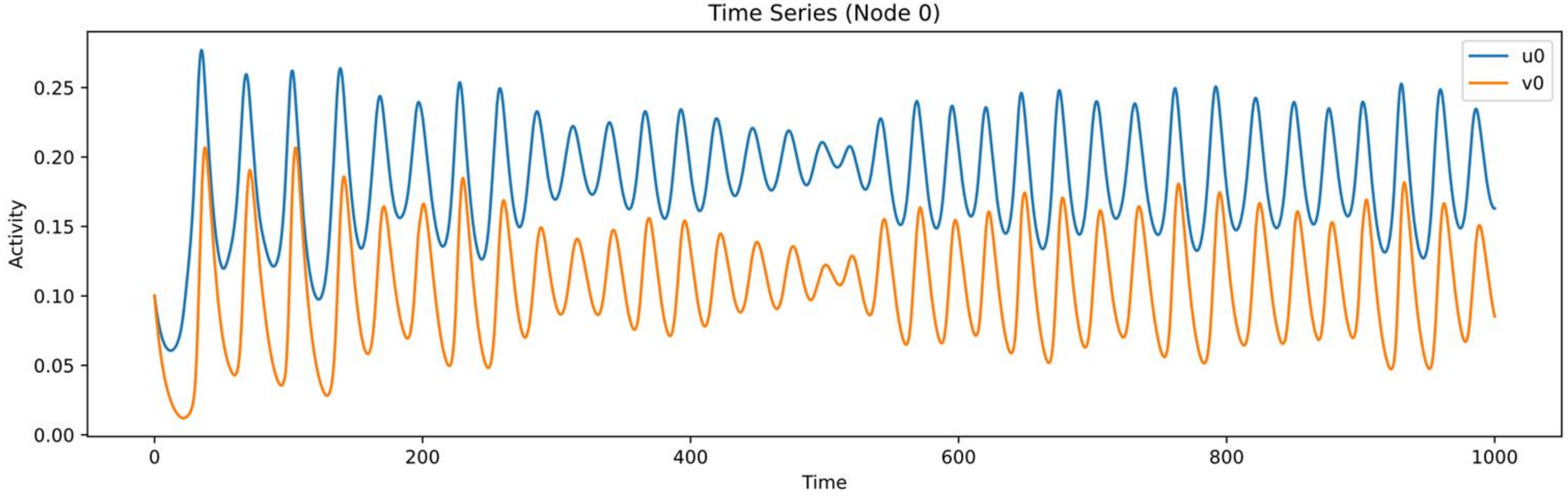
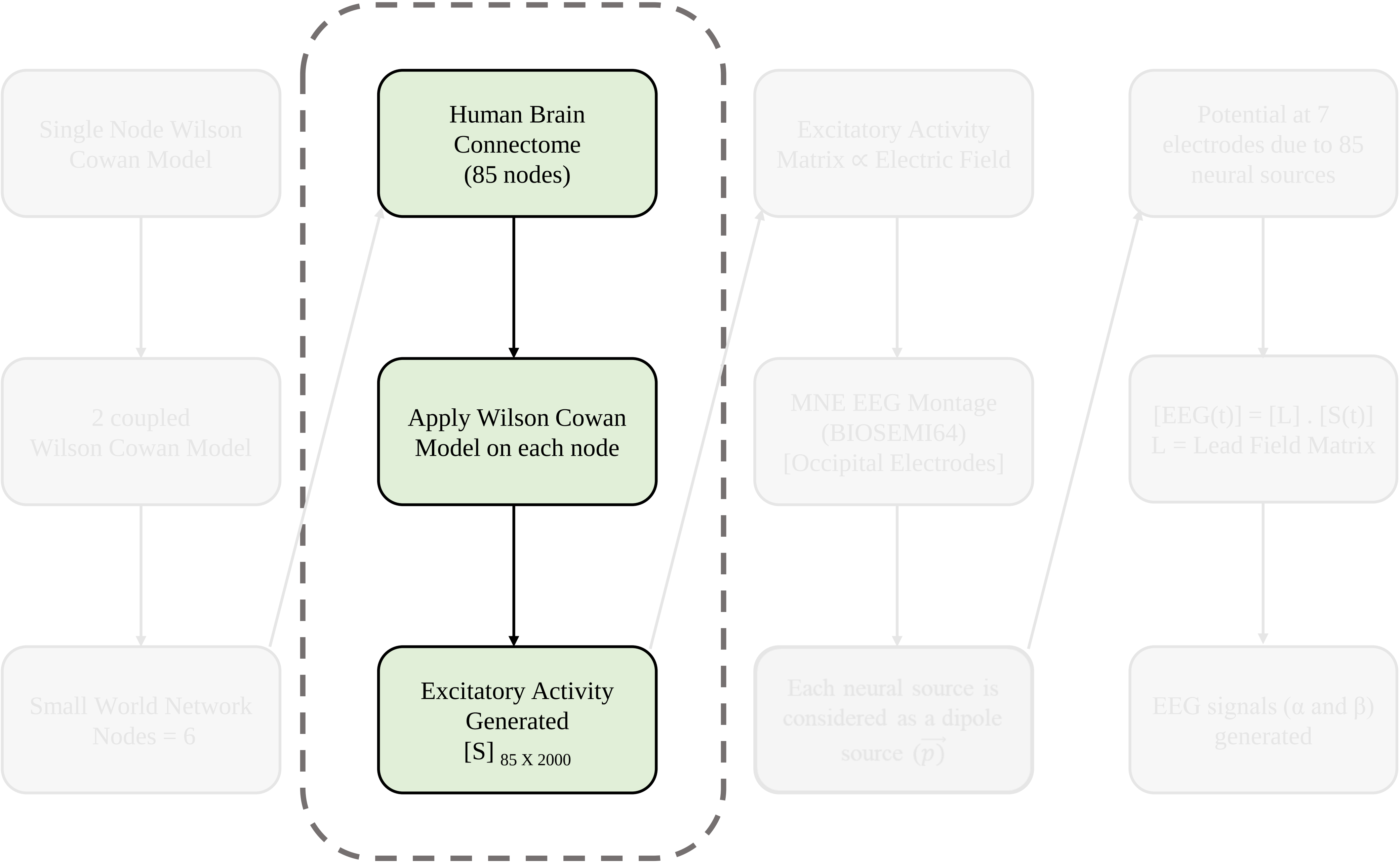






Phase Space and Time Series plot for Small World Network

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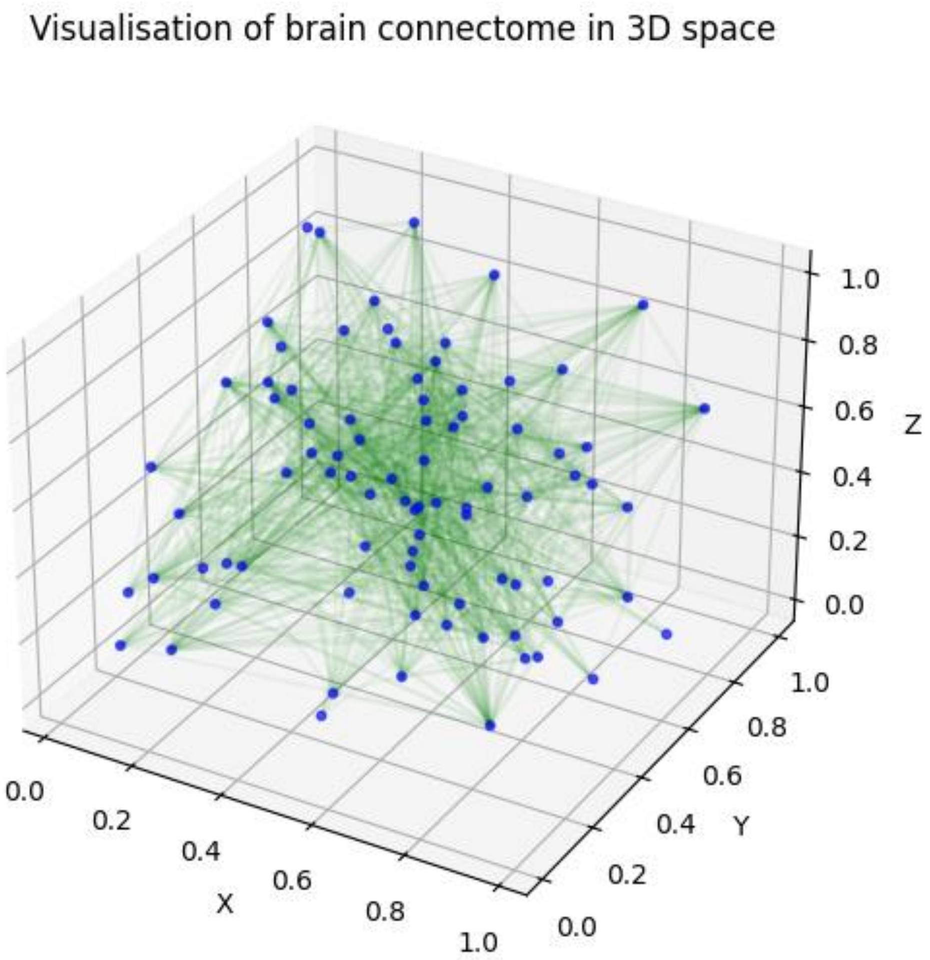
Spatial Layout of Nodes

Human Brain Connectome (85 nodes)

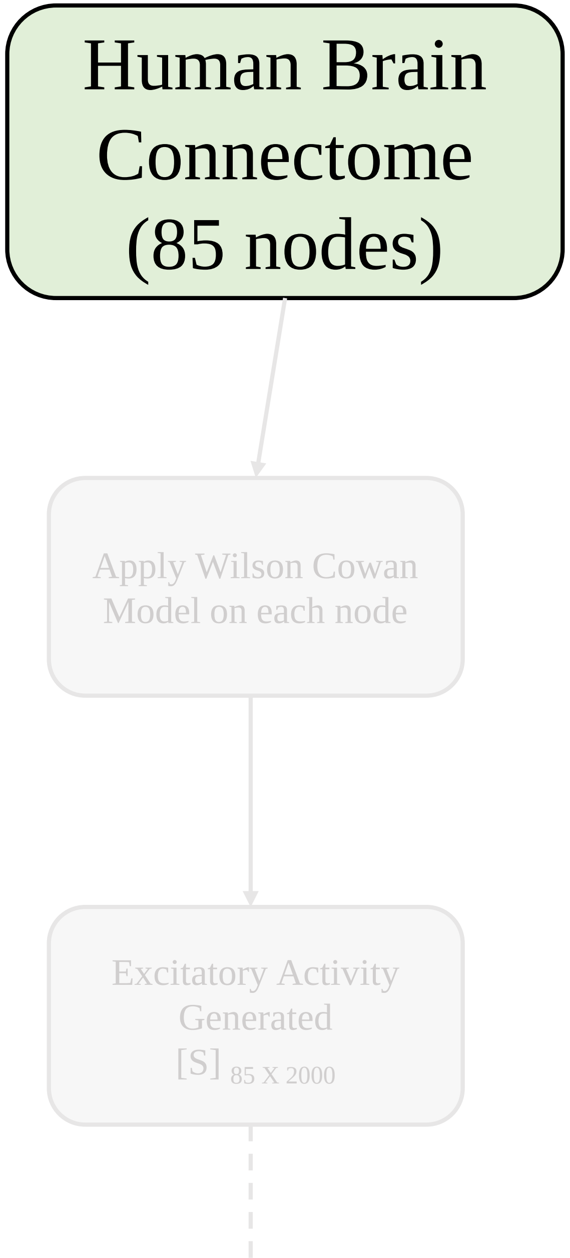
Apply Wilson Cowan Model on each node

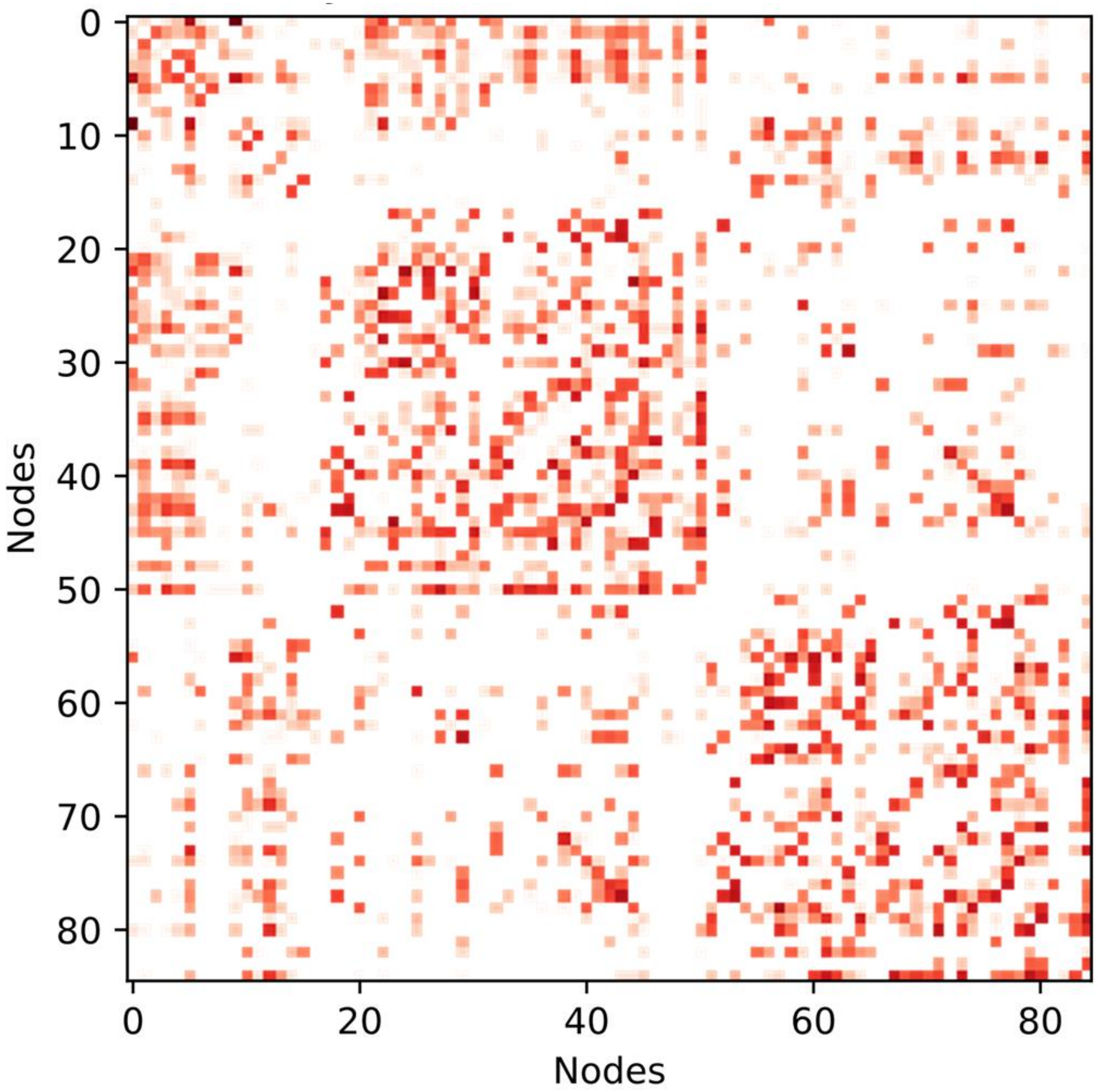
Excitatory Activity Generated
$[S]_{85 \times 2000}$



Data: http://umcd.humanconnectomeproject.org/

Connectivity Matrix of Human Brain Connectome





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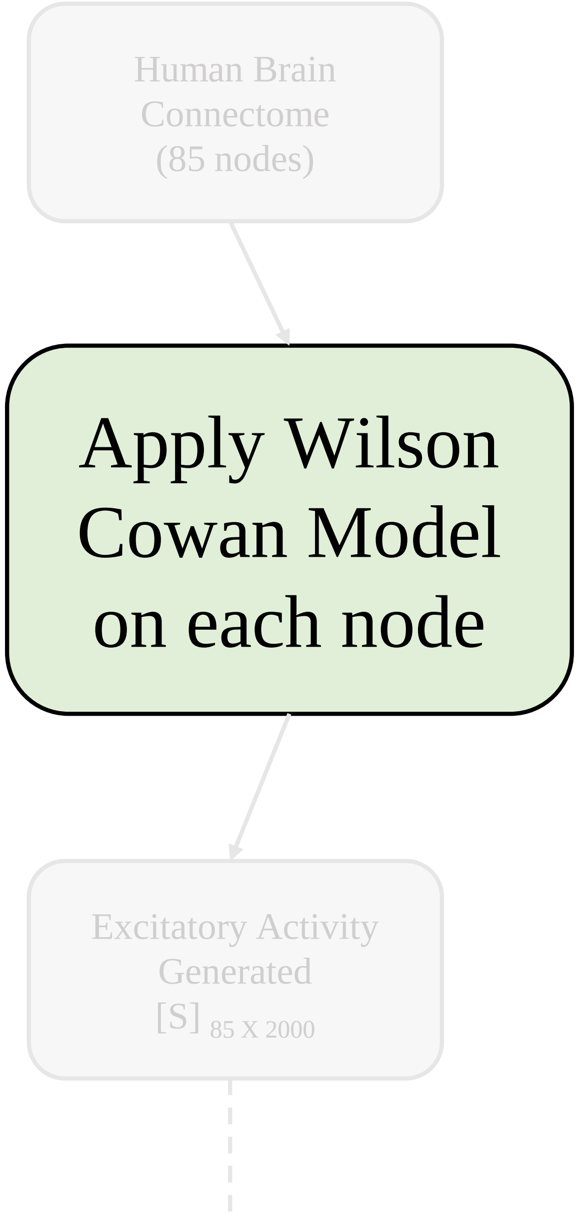

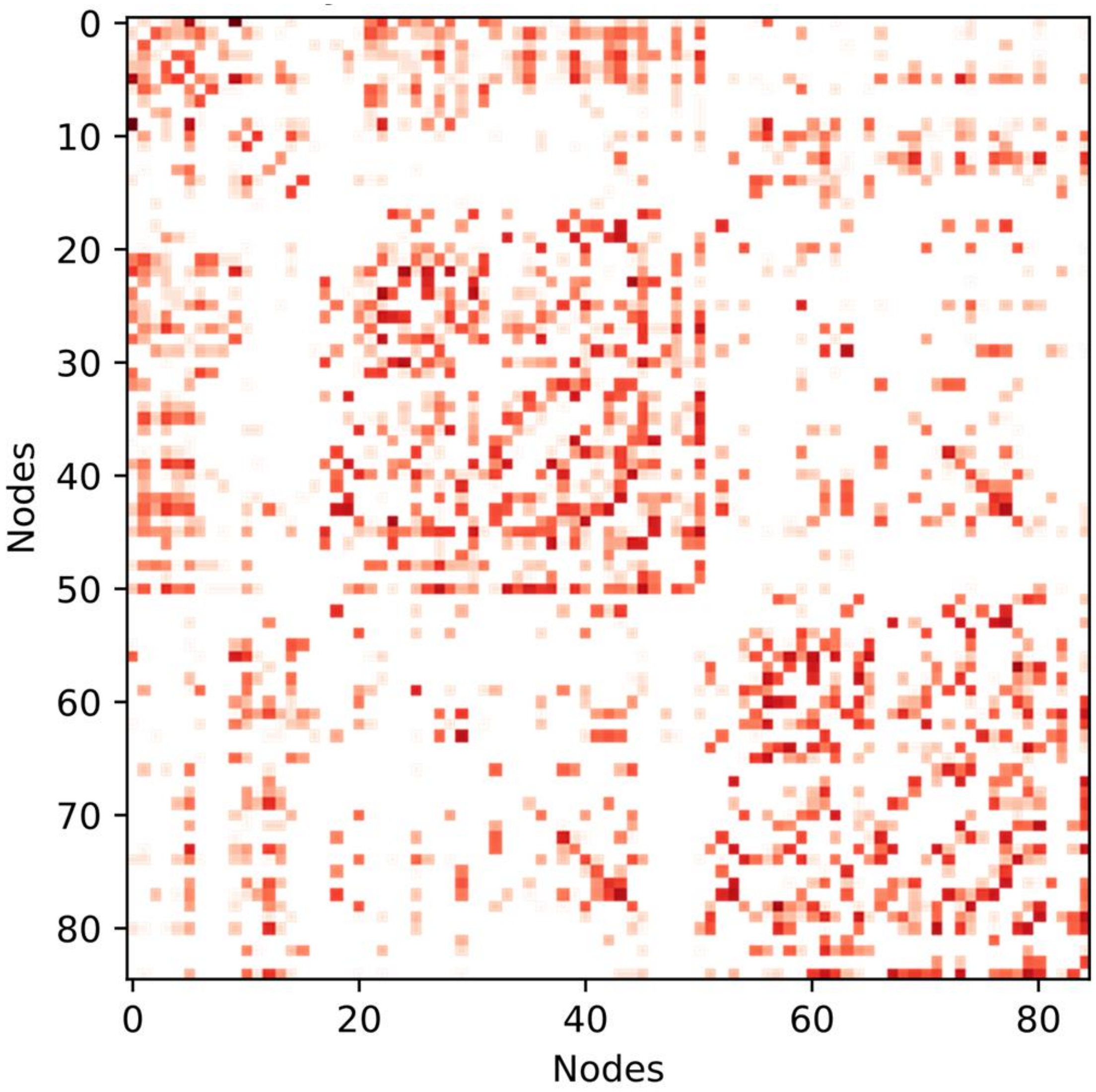

Connectivity Matrix of Human Brain Connectome

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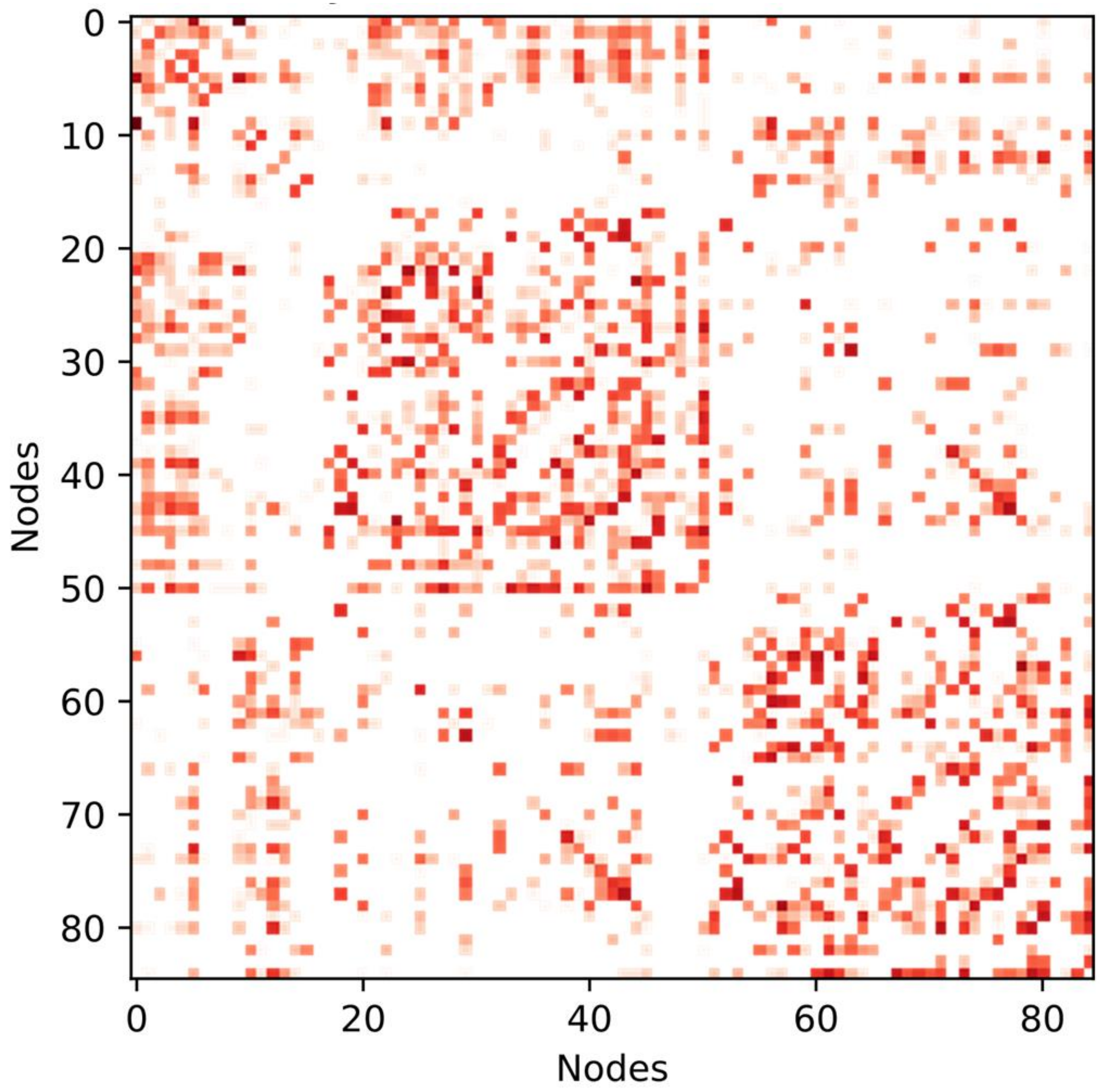

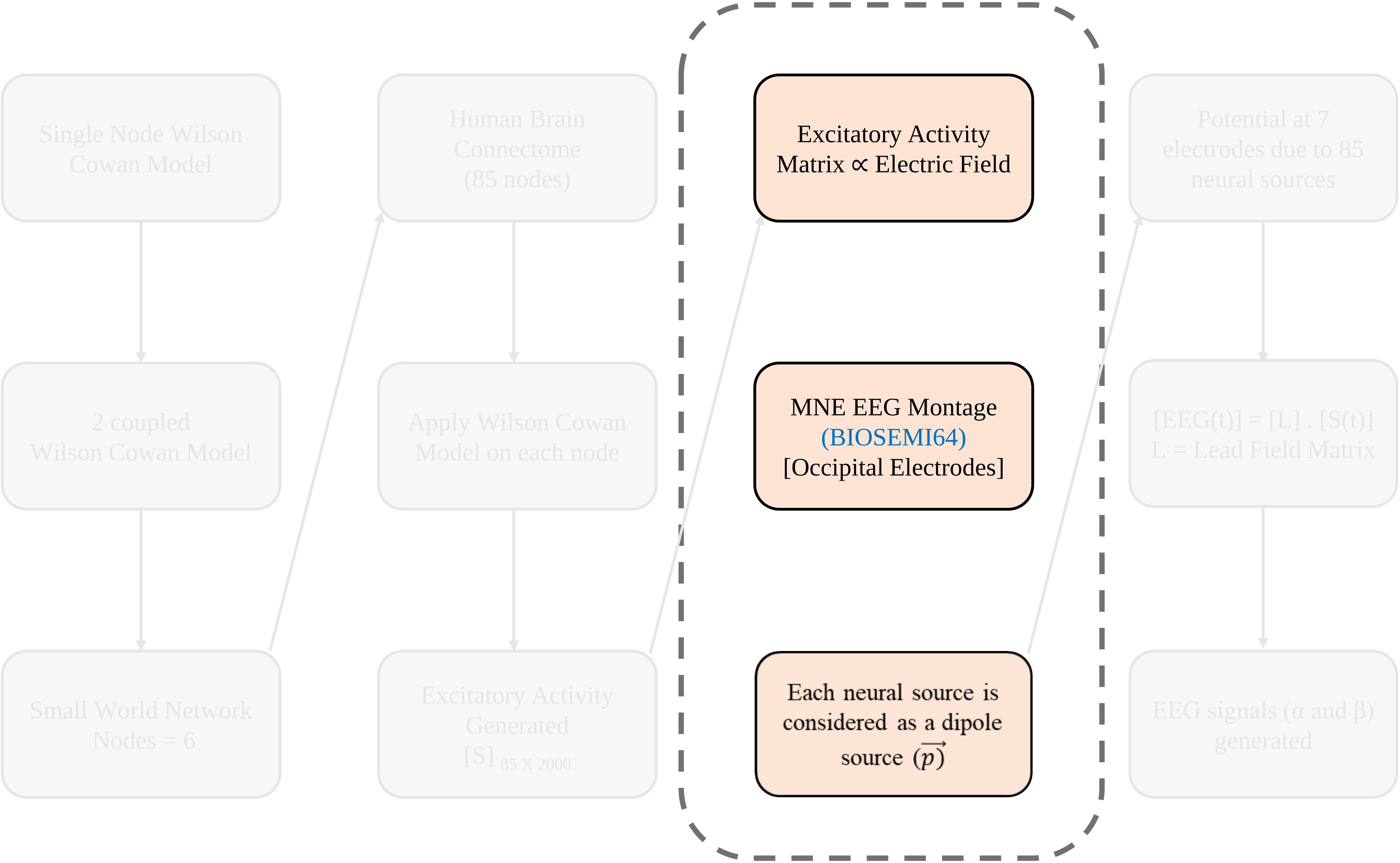
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Excitatory Activity Matrix $\propto$ Electric Field

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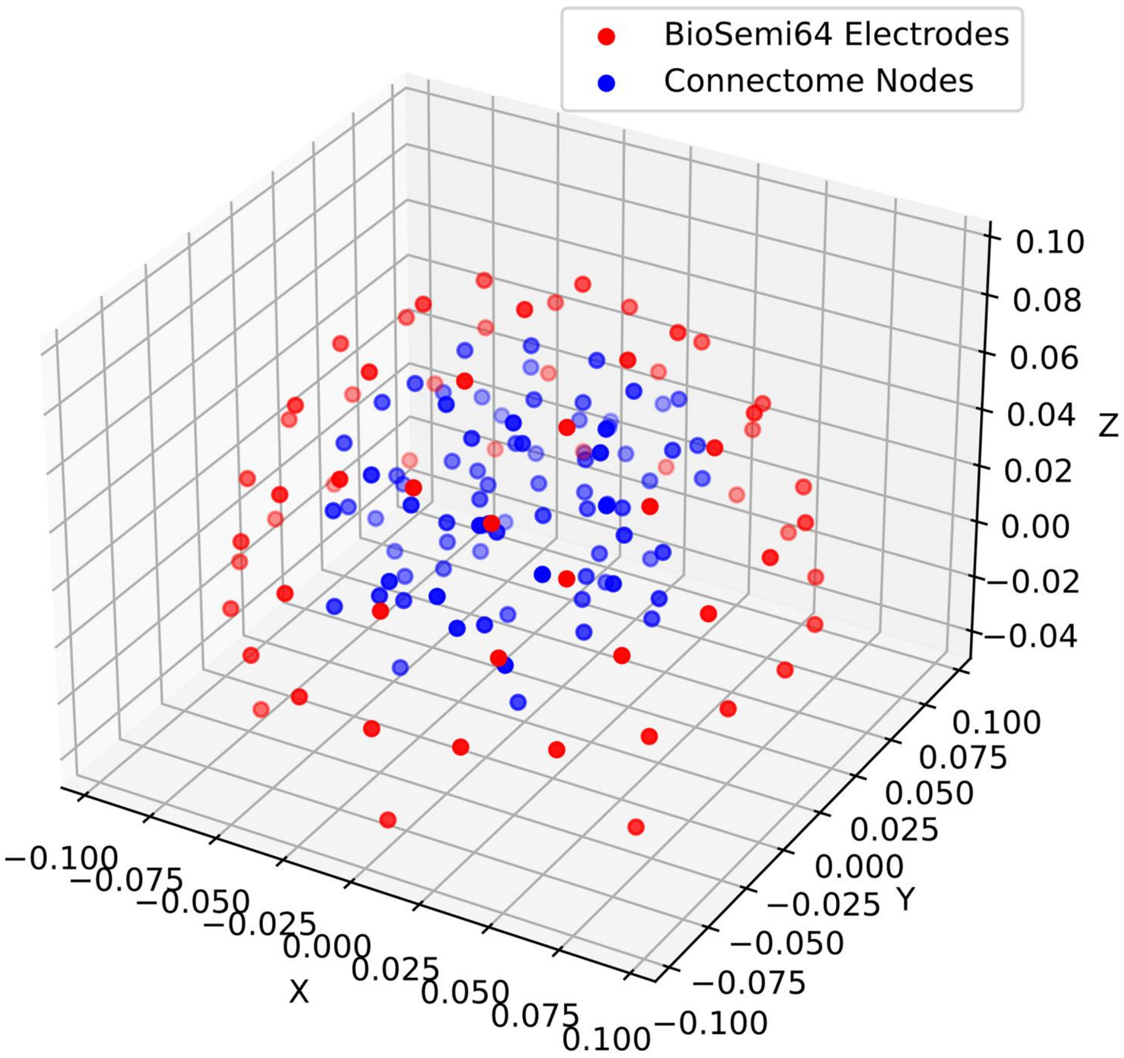
MNE EEG Montage: BioSemi64



MNE EEG Montage: BioSemi64

Excitatory Activity Matrix ∝ Electric Field

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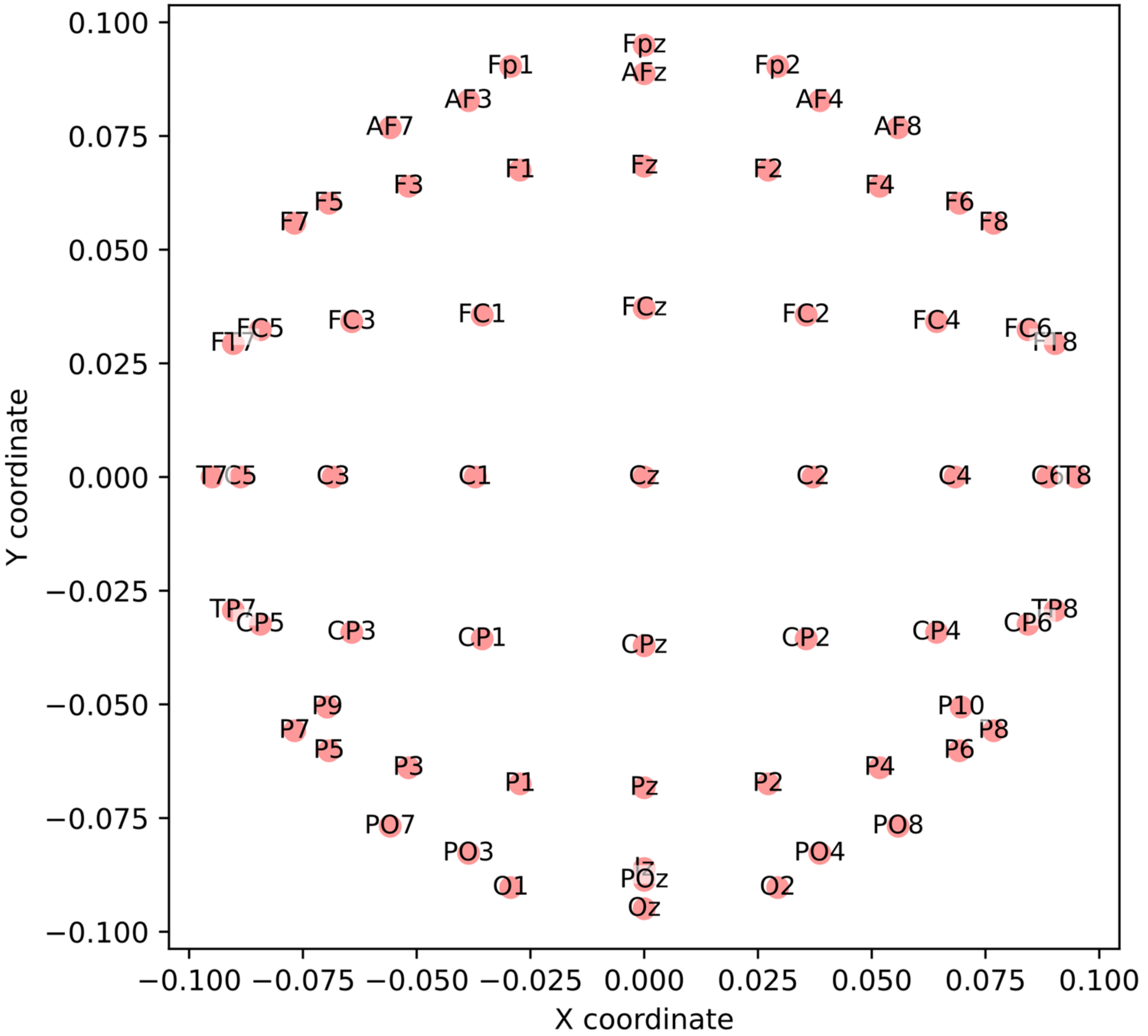

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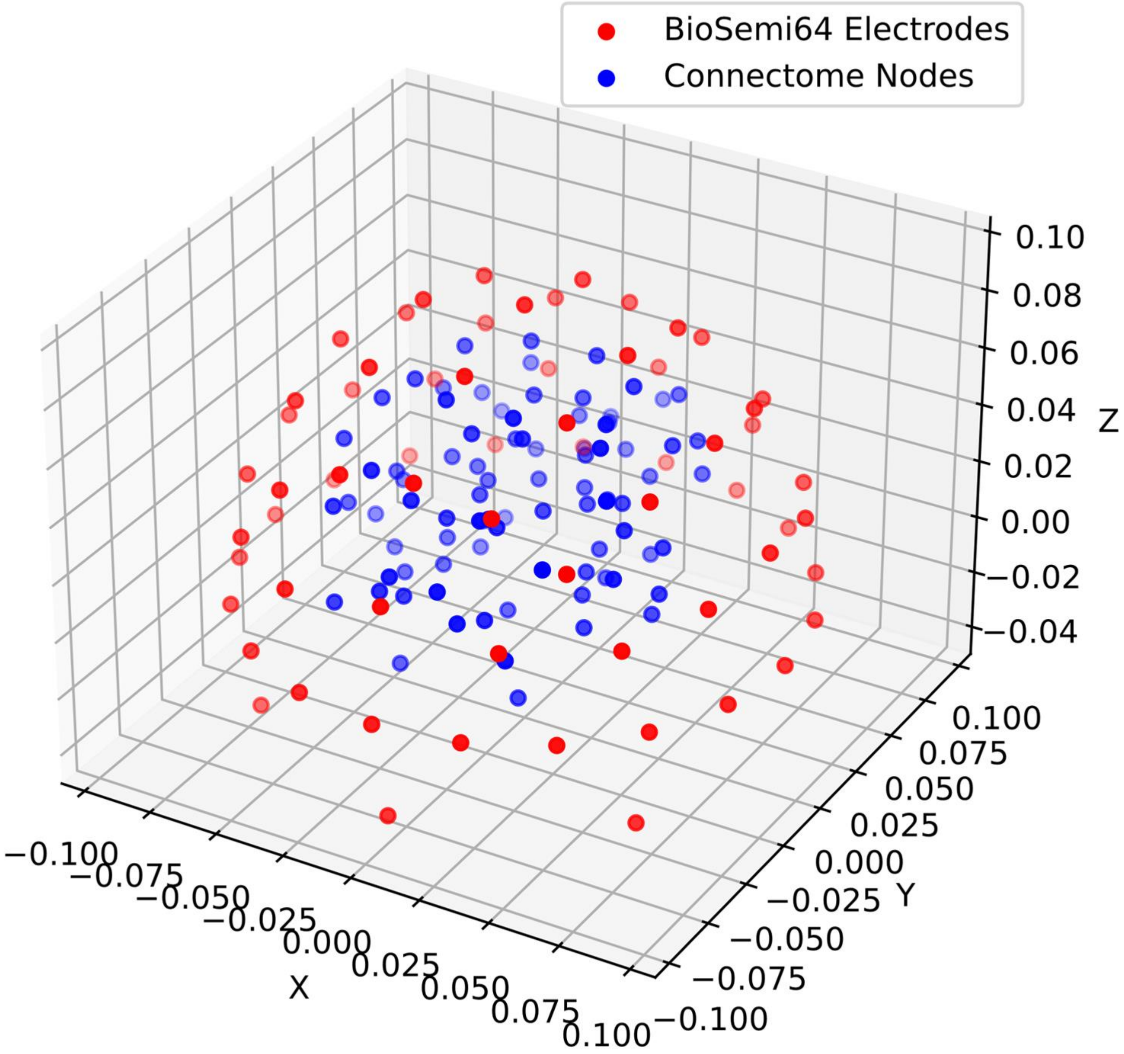

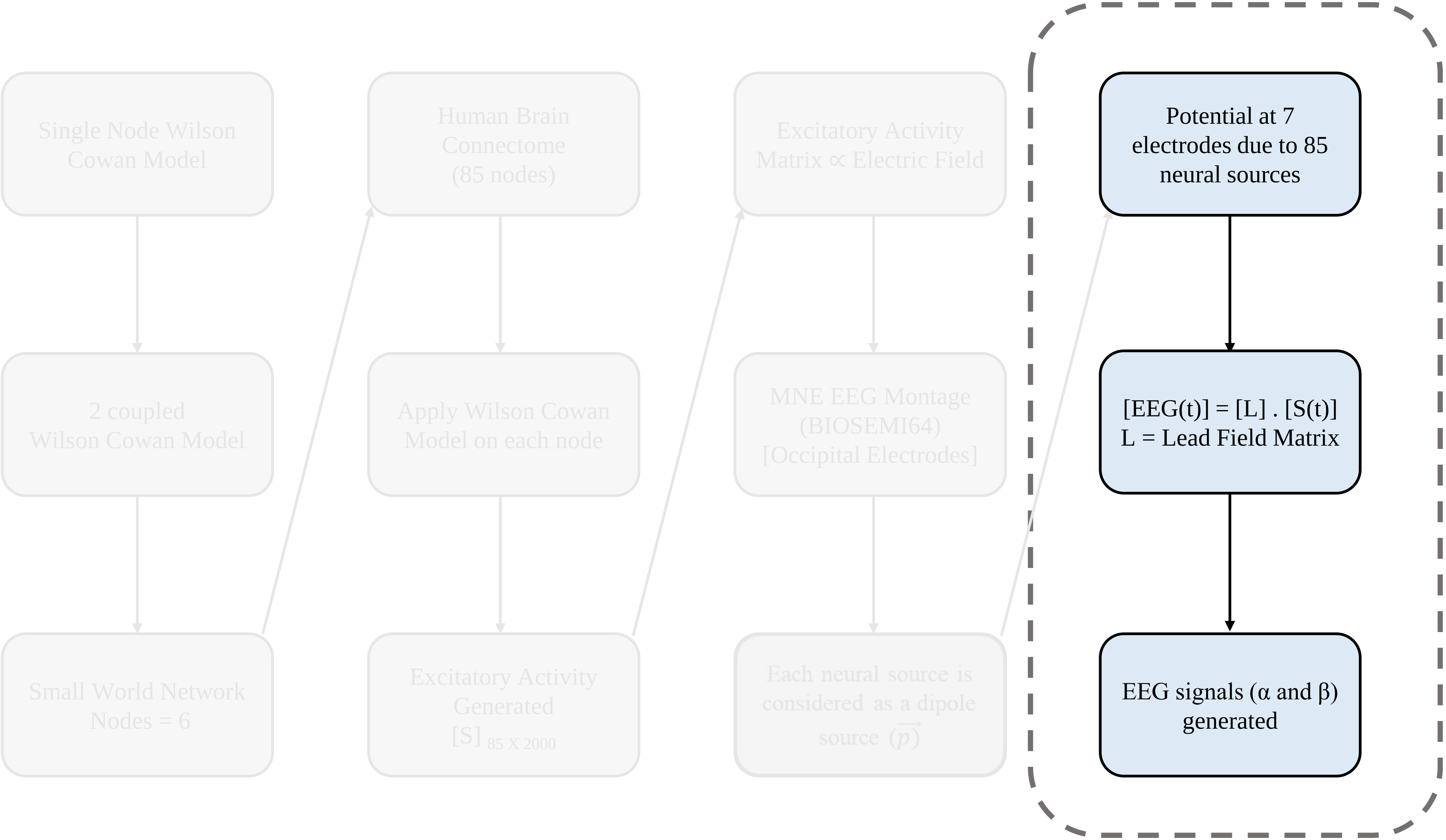
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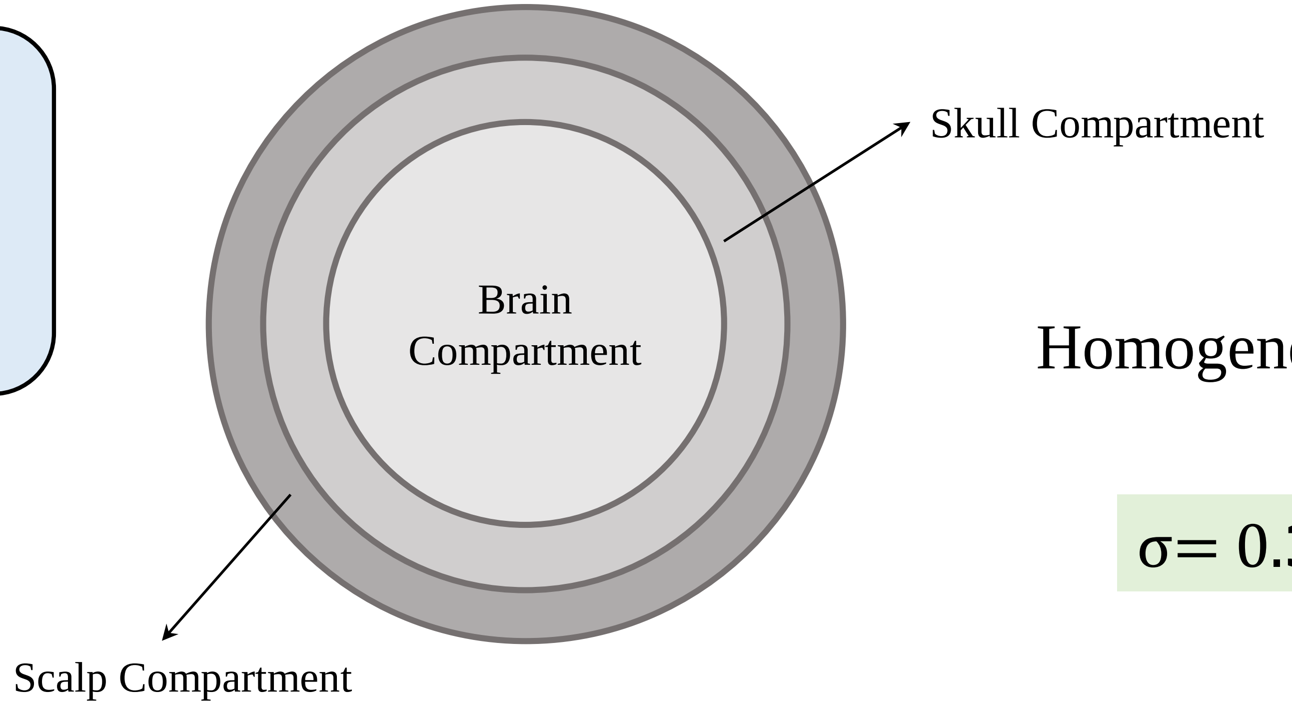

Homogeneous Model

$\sigma = 0.33\ S/m$

$$V(\vec{r}_e) = \frac{1}{4\pi\sigma} \frac{\vec{p}.(\vec{r}_e - \vec{r}_d)}{|\overrightarrow{r_e} - \vec{r}_d|^3}$$

$\vec{p}$: Dipole moment (in A.m)
$\vec{r}_e$: Position of the electrode (in mm)
$\vec{r}_d$: Position of the dipole (neural source) (in mm)

Potential at 7 electrodes due to 85 neural sources

L = Lead Field Matrix

EEG signals (α and β) generated

Lead Field Matrix linearly maps the neural source activity to the measured potentials at the electrodes.

Each column of L_{ij} gives us the potential pattern at electrode *i* due to unit dipole in direction *j*.

$\vec{p}$ = [0, 0, 1] (in z-direction)

$$[EEG(t)]_{7 \times 2000} = [L]_{7 \times 85} \cdot [S(t)]_{85 \times 2000}$$

Power Spectral Density and Excitatory Activity

Potential at 7 electrodes due to 85 neural sources

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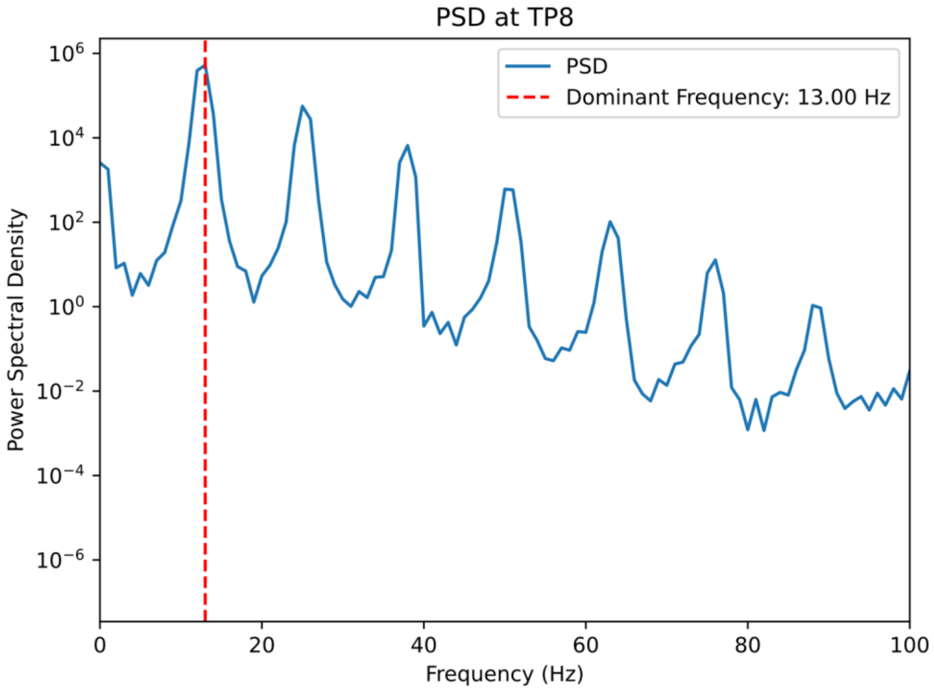
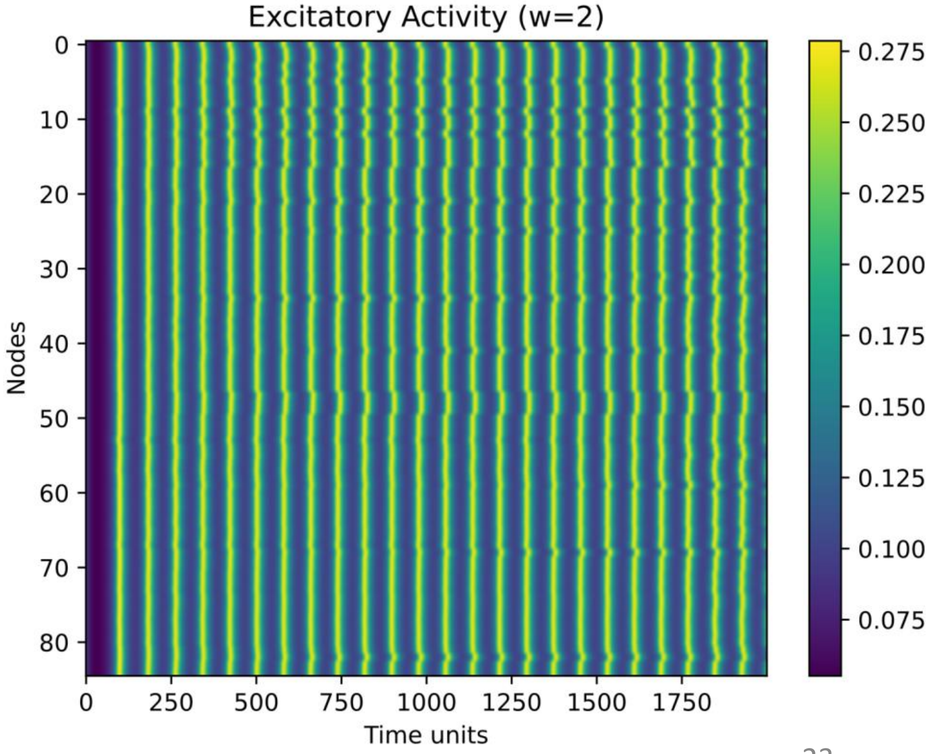
L = Lead Field Matrix

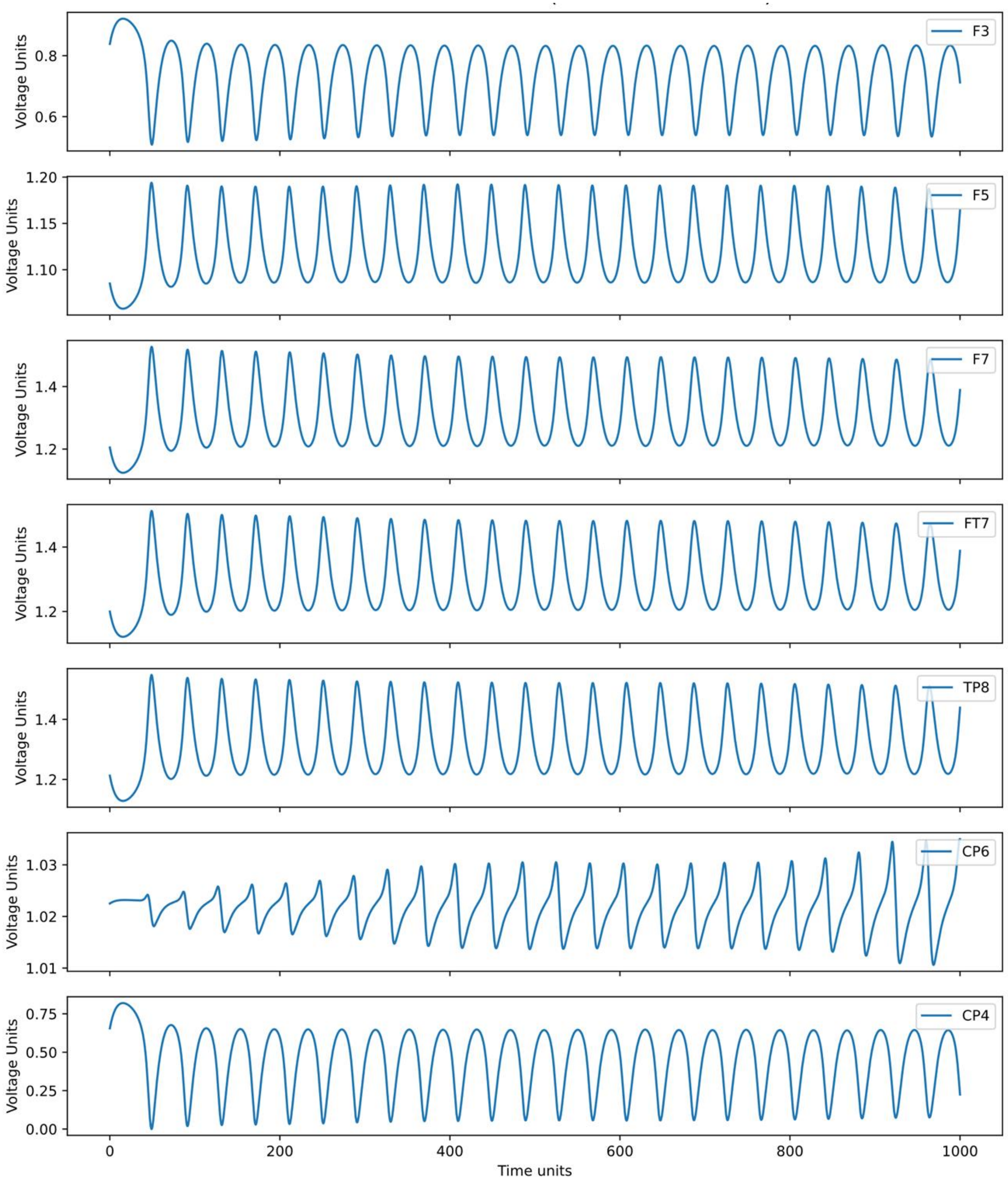
EEG signals (α and β) generated



Coupling Strength (w) = 2

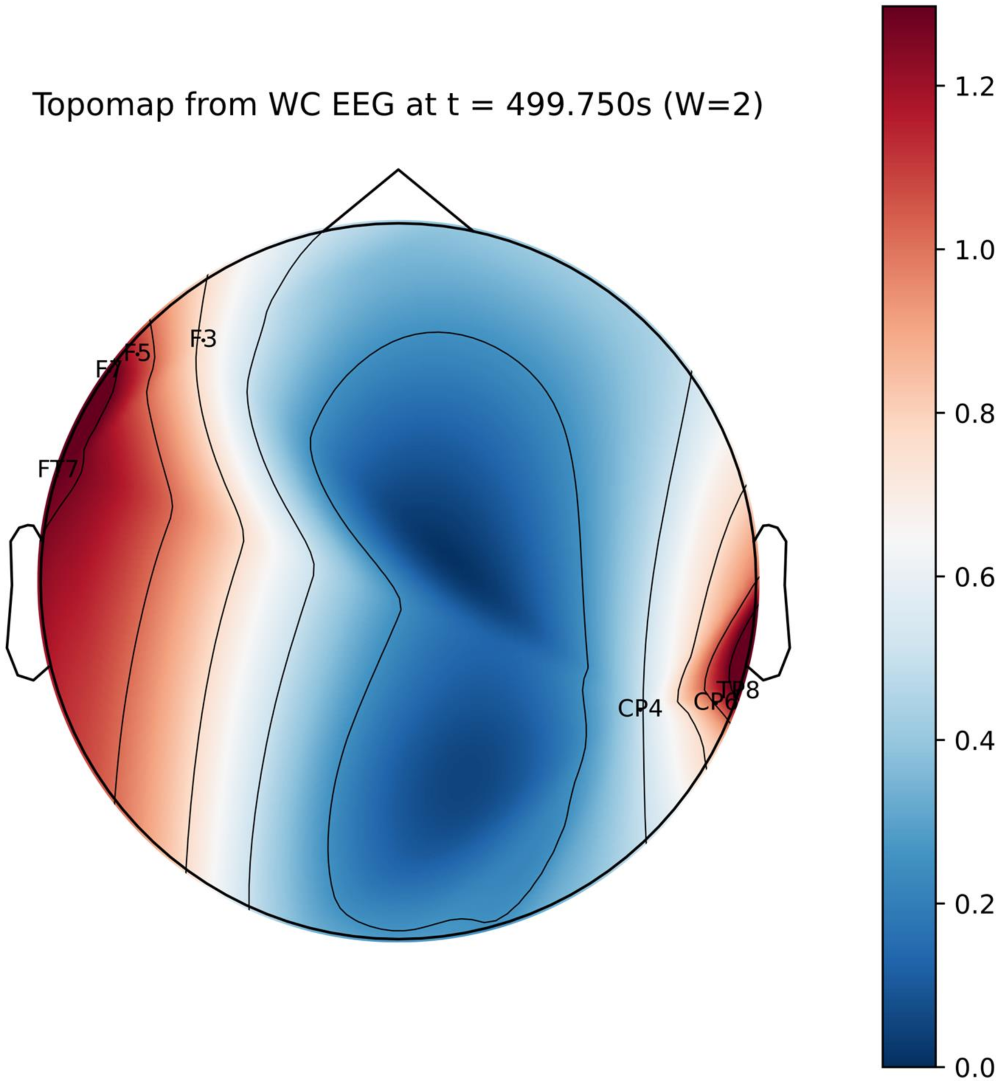


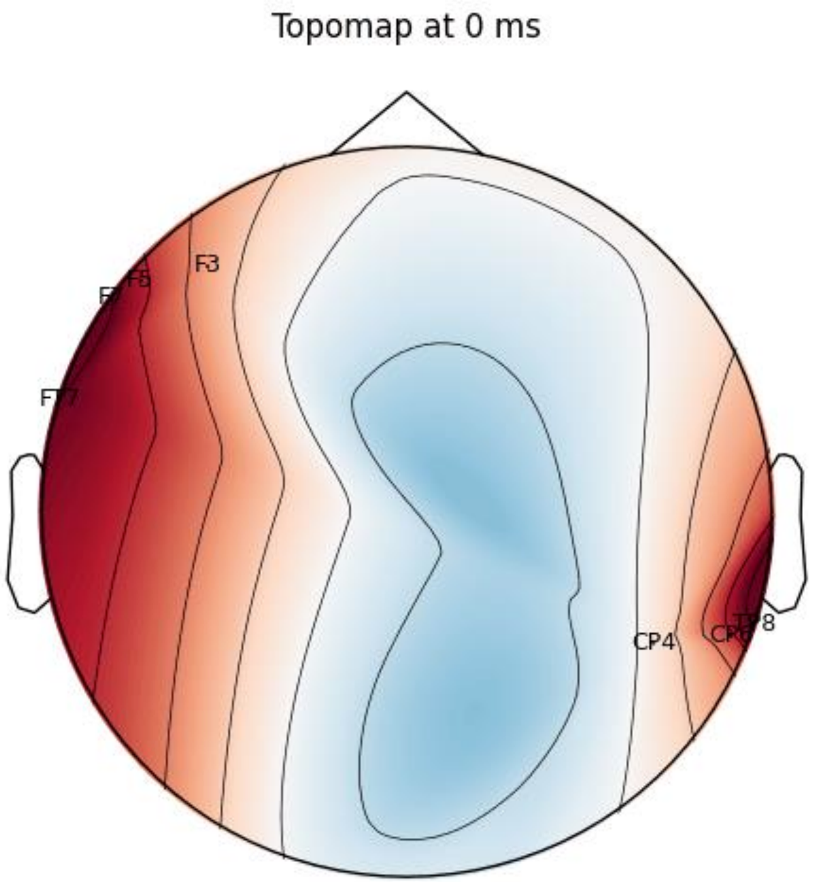
Simulated EEG from WC model (7 random electrodes)



Coupling Strength (w) = 2

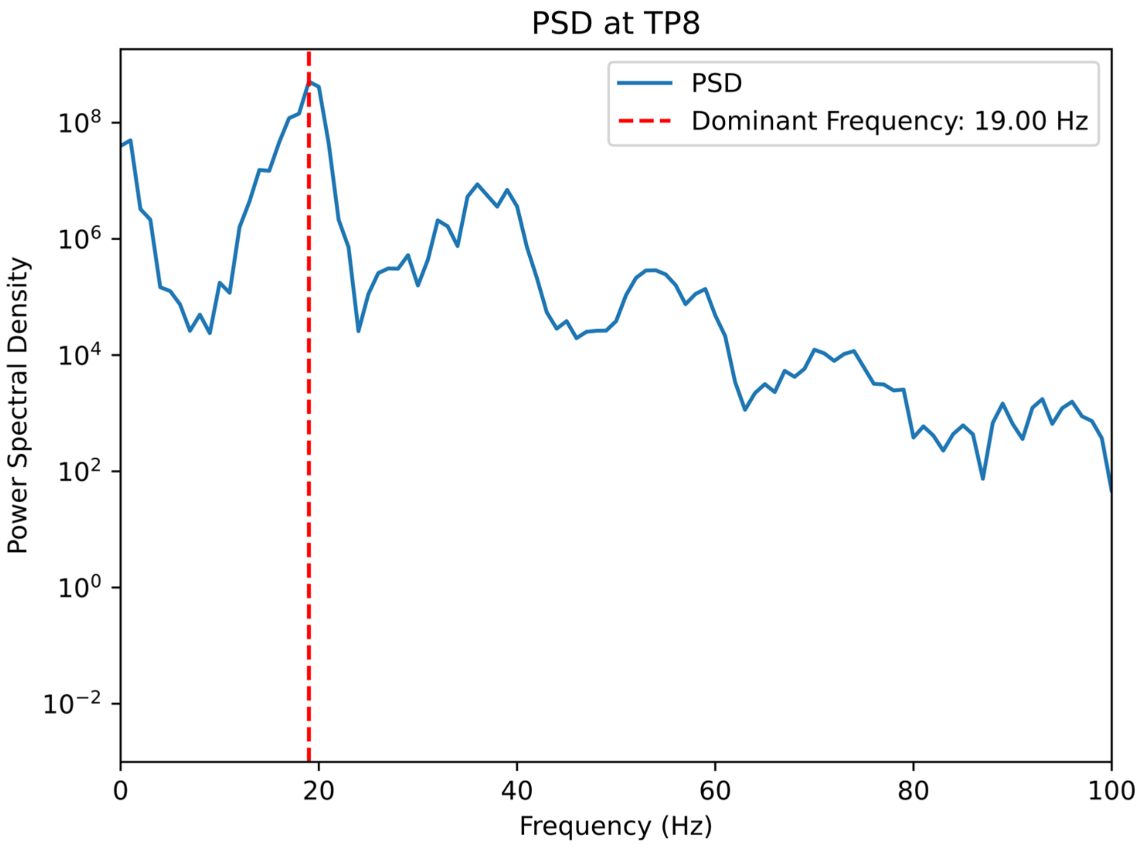
EEG Topomap from Wilson-Cowan Model

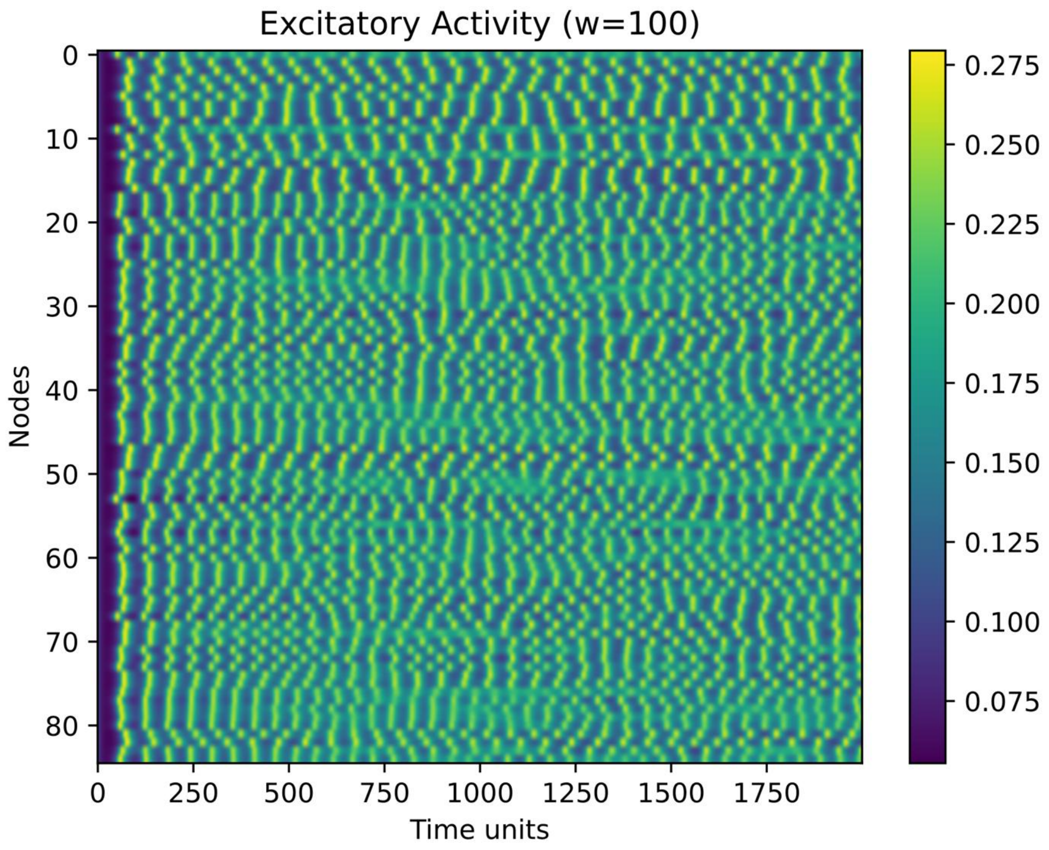




Power Spectral Density and Excitatory Activity

Coupling Strength (w) = 100





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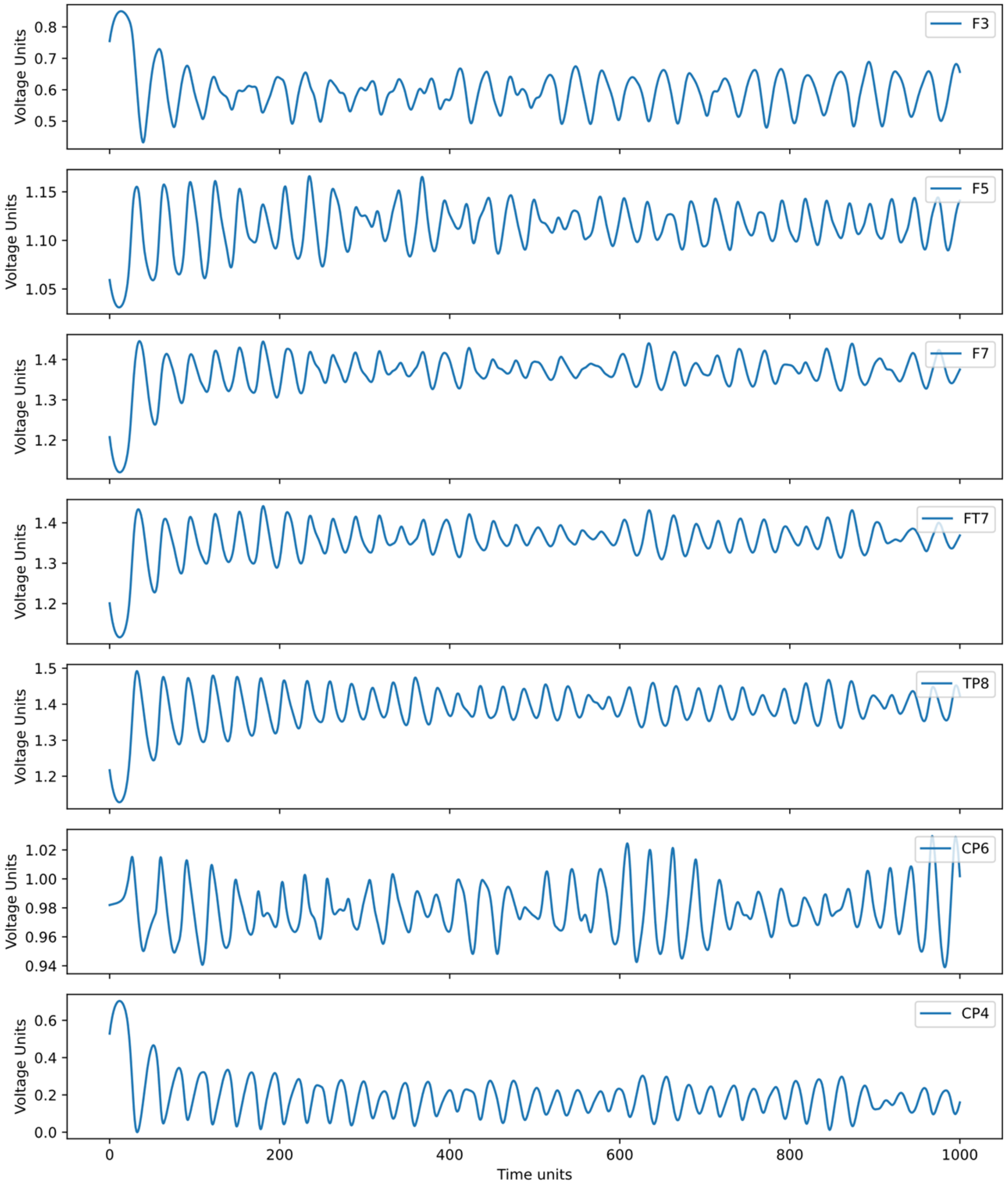

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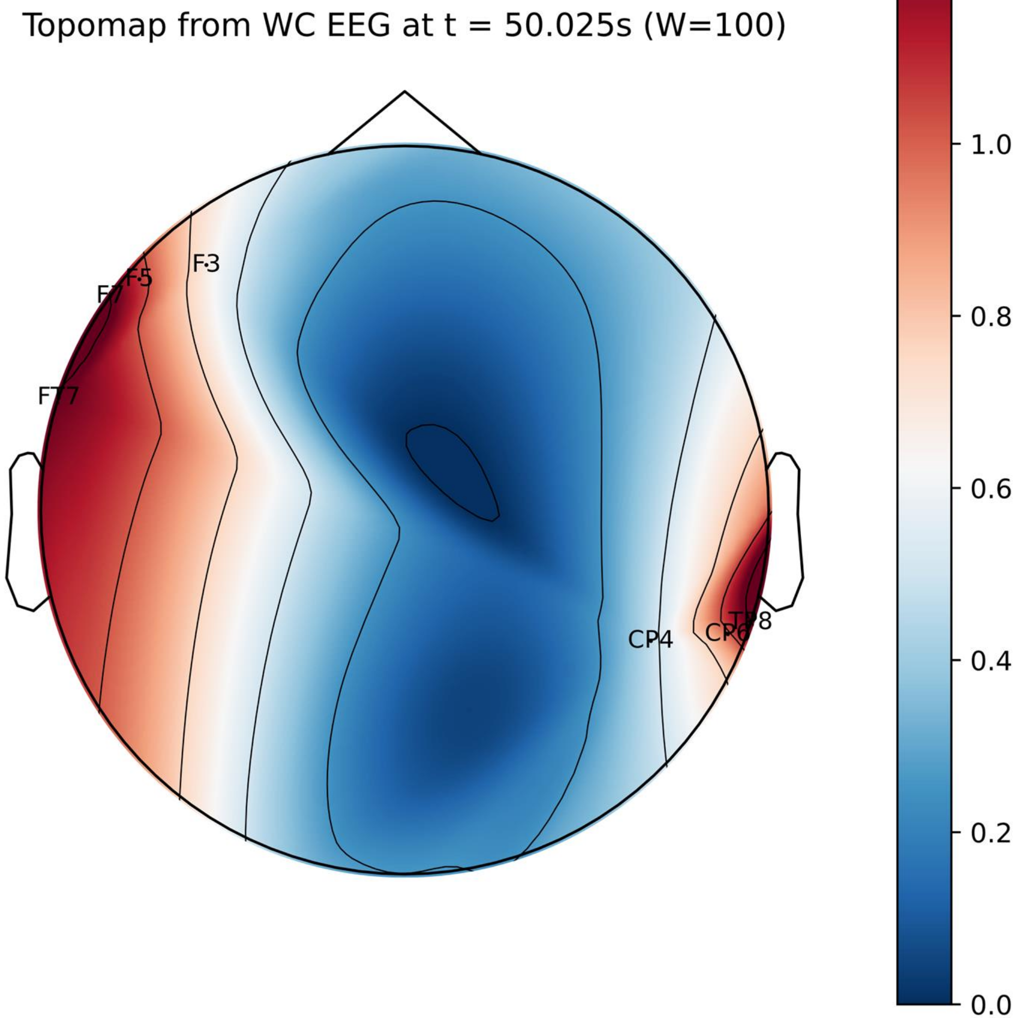
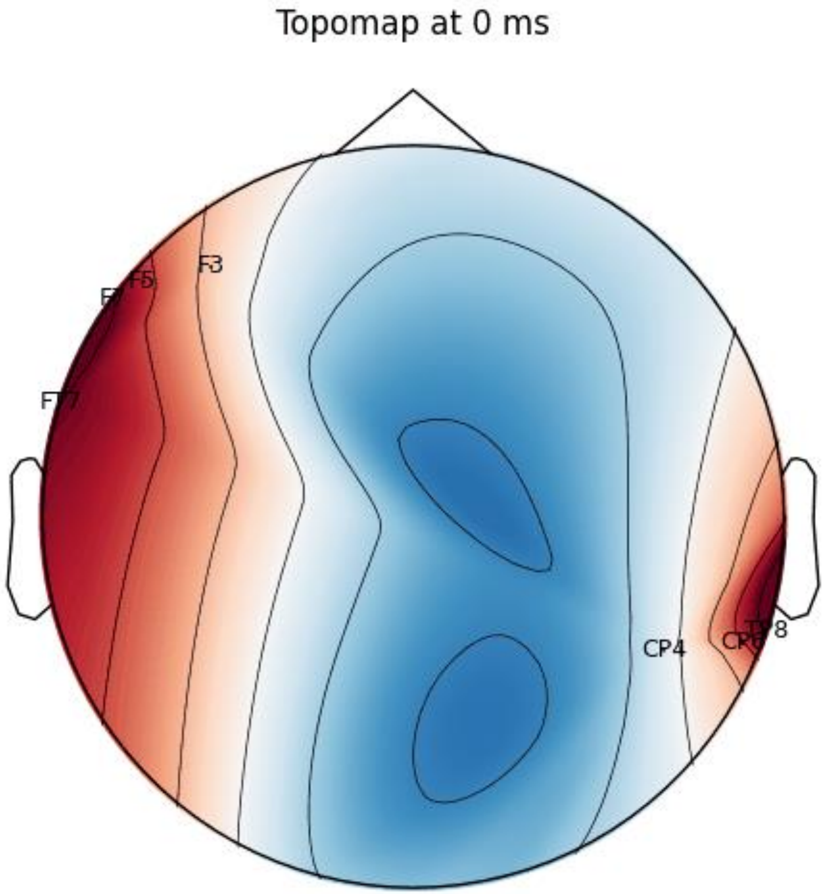
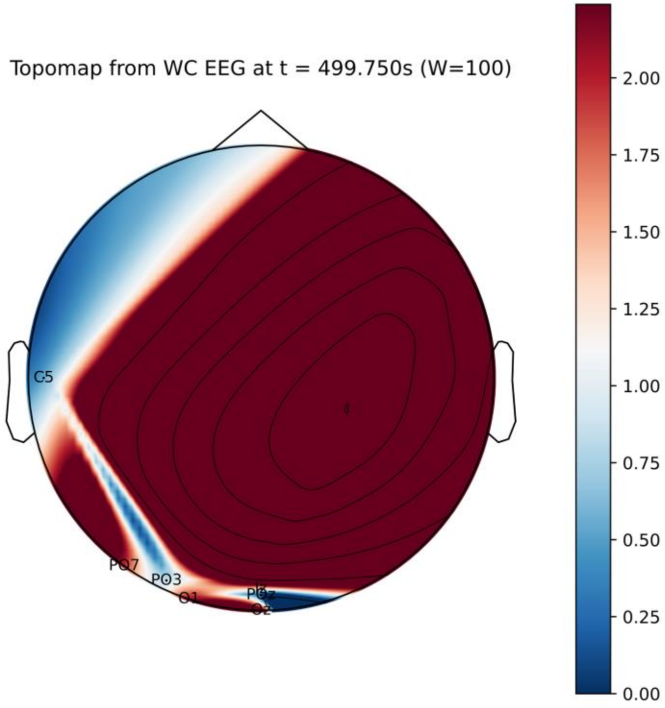
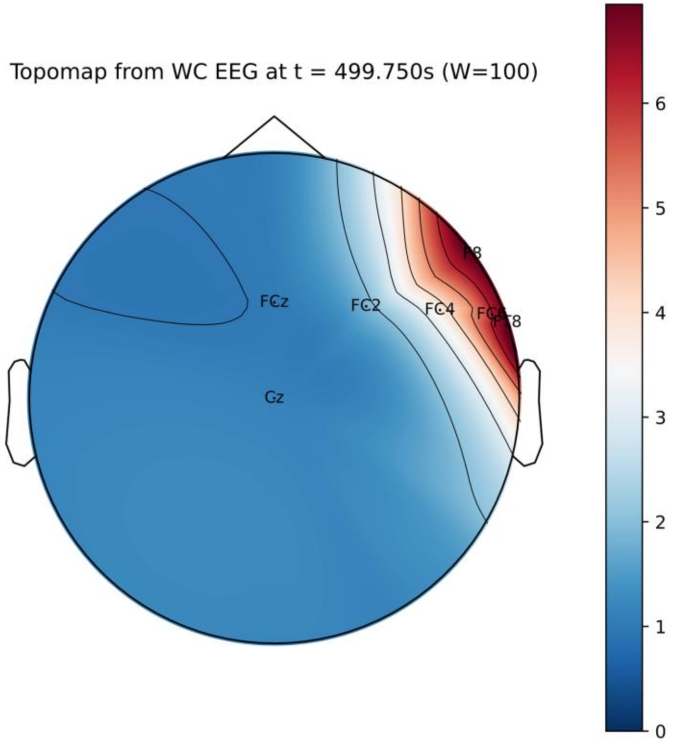
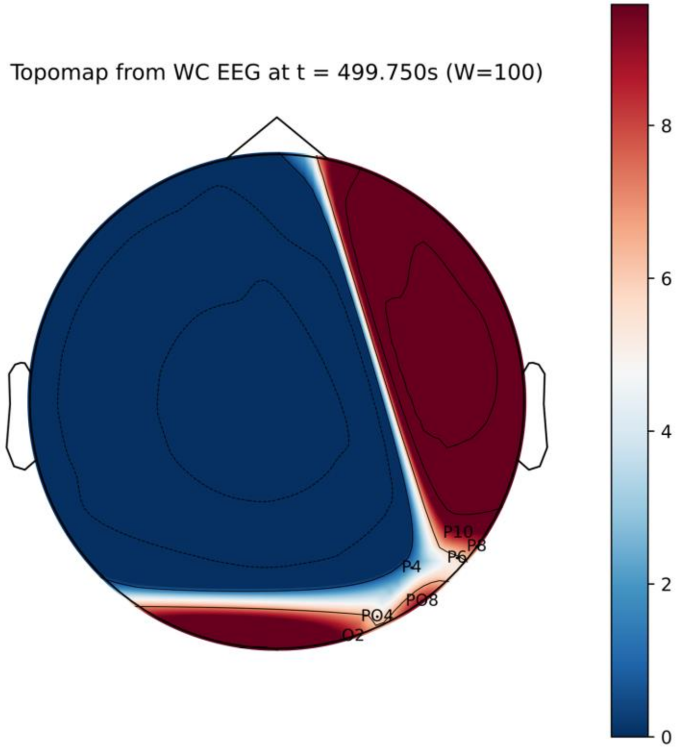




EEG Topomaps for different set of electrodes

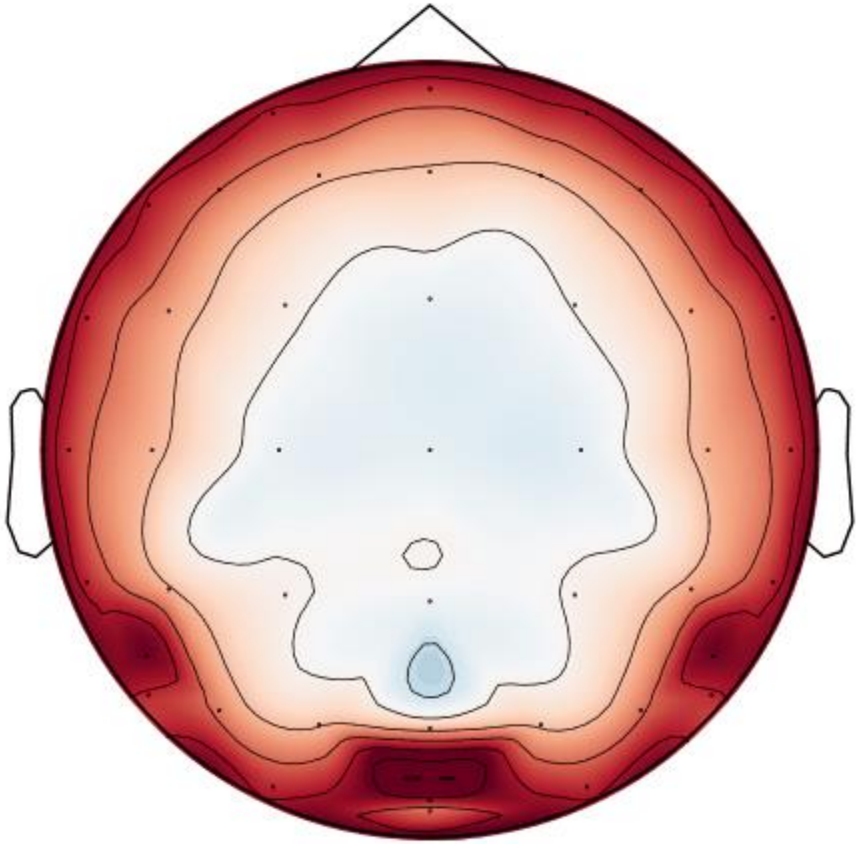






EEG Topomaps for 64 electrodes

Topomap at t = 0 ms



Conclusion

- Integrated Wilson–Cowan dynamics with connectome-defined node coordinates.
- Computed a forward lead field using a spherical head model and Biosemi64/occipital montage.
- Simulated realistic EEG waveforms from projected excitatory activity.
- Developed animated scalp maps to visualize spatiotemporal EEG patterns.
- Validation showed physiologically plausible features (eg: 1/f spectrum).
- Future work includes refining head models and expanding sensor configurations.

Thank you!