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A 3D Liquid Hippocampus Model for Memory Replay and Learning

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We introduce a fully spiking, three-dimensional model of the hippocampus–neocortex loop that captures the complementary learning systems (CLS) functions [1] of rapid pattern separation, sequence completion and slow cortical consolidation. Dentate gyrus (DG), CA3 and CA1 are represented as spatially distinct 3-D liquid-state networks [2] whose connectivity mirrors hippocampal anatomy: extremely sparse feed-forward DG ⟶ CA3 projections support pattern separation, dense recurrent links within CA3 enable auto-completion, and plastic CA1 ⟶ cortex pathways transfer reactivated traces to long-term memory. Intrinsic θ–γ oscillations emerge from local inhibition and periodically trigger sharp-wave replay events. The model is embedded in a minimal T-maze task in which an agent's position is encoded by place-cell activity and decoded by a basal-ganglia read-out that selects actions through deep learning. Preliminary simulations indicate that sparse DG input markedly enhances CA3 pattern separation, while replay-driven potentiation at CA1 ⟶ cortex synapses clearly improves post-sleep maze performance. Conversely, reducing DG sparsity, which is an analogue of early Alzheimer pathology, induces pronounced place-field overlap, increases recall errors and degrades spatial navigation. These results demonstrate that large-scale, 3-D spiking substrates can reproduce key hippocampal dynamics and their behavioural consequences, positioning NEST as a practical platform for studying memory consolidation, replay and disease-related degeneration in silico.

Acknowledgements

References

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