Modeling of the interaction between neuronal populations involved in memory consolidation during the sleep-wake switch

Auteur : Preud'Homme, Chloé
Promoteur(s) : Drion, Guillaume
Faculté : Faculté des Sciences appliquées
Diplôme : Master en ingénieur civil biomédical, à finalité spécialisée
Année académique : 2020-2021
URI/URL : http://hdl.handle.net/2268.2/11559

Faculty: Applied Sciences
Section: Biomedical Engineering
Academic year: 2020-2021

Author: Chloé PREUD'HOMME
Supervisor: Guillaume DRION

Modeling of the interaction between neuronal populations involved in memory consolidation during the sleep-wake switch

Abstract

It has been shown experimentally that memory consolidation occurs during sleep and that three brain regions are involved in this process: the thalamus, the neocortex and the hippocampus. The hippocampus has been shown as being the short-term store of the representation, the neocortex as the long-term store and the thalamus as the coordinator of the consolidation during sleep. As an illustration, when an individual experiences a camping event in which he observes his tent and the trees, he can recall a representation of this event after a night of sleep at the sight of his tent. The representation has been consolidated in the long-term store, the connections between the two items are reinforced in the neocortex thanks to neuronal ensemble reactivations occurring in the hippocampus during sleep. It appears that the synchronization of their electrical behaviour is essential for the consolidation of the experience in the neocortex.

In order to deepen our knowledge about how memories are consolidated thanks to those organs, computational modeling is a powerful approach for testing various stimuli. However, the cellular communication between these three regions is computationally under-investigated.

Therefore, this present work aims to reproduce a simplified and faithful computational representation of global and local interactions in the context of memory consolidation. The global anatomy and the role of these brain regions are first highlighted and the oscillations of the sleep-wake cycle are examined. The neurophysiology of each cell types composing the different regions is deeply studied by exploring the literature. Then, the way the cells communicate is inspected in order to build a simplified but still representative cellular network connecting the three regions and demonstrating their communication during wakefulness and sleep. To that aim, conductance-based models are suitable modeling tools used for reproducing the electrical behaviour of the distinct types of cells constituting the thalamus, neocortex and hippocampus.

The behaviour of each cell taken individually is favourably reproduced with the aim of replicating the communication between each cell in the built network, which is performed successfully. Moreover, the network developed is robust to variability

STATE-OF-ART					
Region	Mnemonic role	Cell type	Generic Currents	Synaptic receptors	Firing mode Wake/*sleep* *(burst = B)*
Thalamus	Wake: relay Switch wakefulness/sleep Sleep: generator of sleep rhythm	Reticular cell	Na, Kd, H, T, Kca, leak	AMPA NMDA	Tonic *Endogenous B*
		Thalamocortical cell	Na, Kd, H, T, Kca, leak	AMPA GABAa,b	Tonic *Endogenous B*
Neocortex	Information processing	Pyramidal cell	Na, Kd, KCa, leak	AMPA NMDA GABAa,b	Tonic *Exogenous B*
	Long-term memory storage	Parvalbmin positive interneuron	Na, Kd, KCa, leak	AMPA NMDA	Tonic *Tonic*
Entorhinal cortex layer II	Input stream to the hippocampus Associative function	Stellate cell	Na, Kd, H, leak	AMPA NMDA GABAa,b	Tonic *Exogenous B*
		Parvalbmin positive interneuron	Na, Kd, KCa, leak	AMPA NMDA	Tonic *Tonic*
Entorhinal cortex layer III	Input stream to the hippocampus Associative function	Pyramidal cell	Na, Kd, Kca, leak	AMPA NMDA GABAa,b	Tonic *Exogenous B*
		Parvalbmin positive interneuron	Na, Kd, Kca, leak	AMPA NMDA	Tonic *Tonic*
Entorhinal cortex layer V	Output stream from the hippocampus Associative function	Pyramidal cell	Na, Kd, Kca, leak	AMPA NMDA GABAa,b	Tonic *Exogenous B*
		Parvalbmin positive interneuron	Na, Kd, Kca, leak	AMPA NMDA	Tonic *Tonic*
Dentate gyrus	Pattern separation = distinguishing similar memories	Granule cell	Na, Kd, A, T, L, KCa, leak	AMPA GABAa	Tonic *Exogenous B*
		Basket cell	Na, Kd, A, L, Kca, leak	AMPA	Tonic *Tonic*
CA3	Encodes the representation Reactivation Spatial processing	Pyramidal cell	Na, Kd, A, L, Kca, leak	AMPA NMDA GABAa,b	Tonic *Exogenous B*
		Basket cell	Na, Kd, A, L, Kca, leak	AMPA	Tonic *Tonic*
CA1	Temporal and spatial processing	Pyramidal cell	Na, Kd, H, T, Kca leak	AMPA NMDA GABAa,b	Tonic *Exogenous B*
		Basket cell	Na, Kd, H, T, Kca, leak	AMPA	Tonic *Tonic*
Subiculum	Pivotal role Increase synaptic reinforcement	Pyramidal cell	Na, Kd, H, T, L Kca, leak	AMPA NMDA GABAa	Tonic *Endogenous B*
		Fast-spiking interneuron	Na, Kd, leak	AMPA	Tonic *Tonic*

Figure 1: Summary table of the literature in terms of neuron types and their corresponding neurophysiology. The role of the different brain regions in memory is indicated.

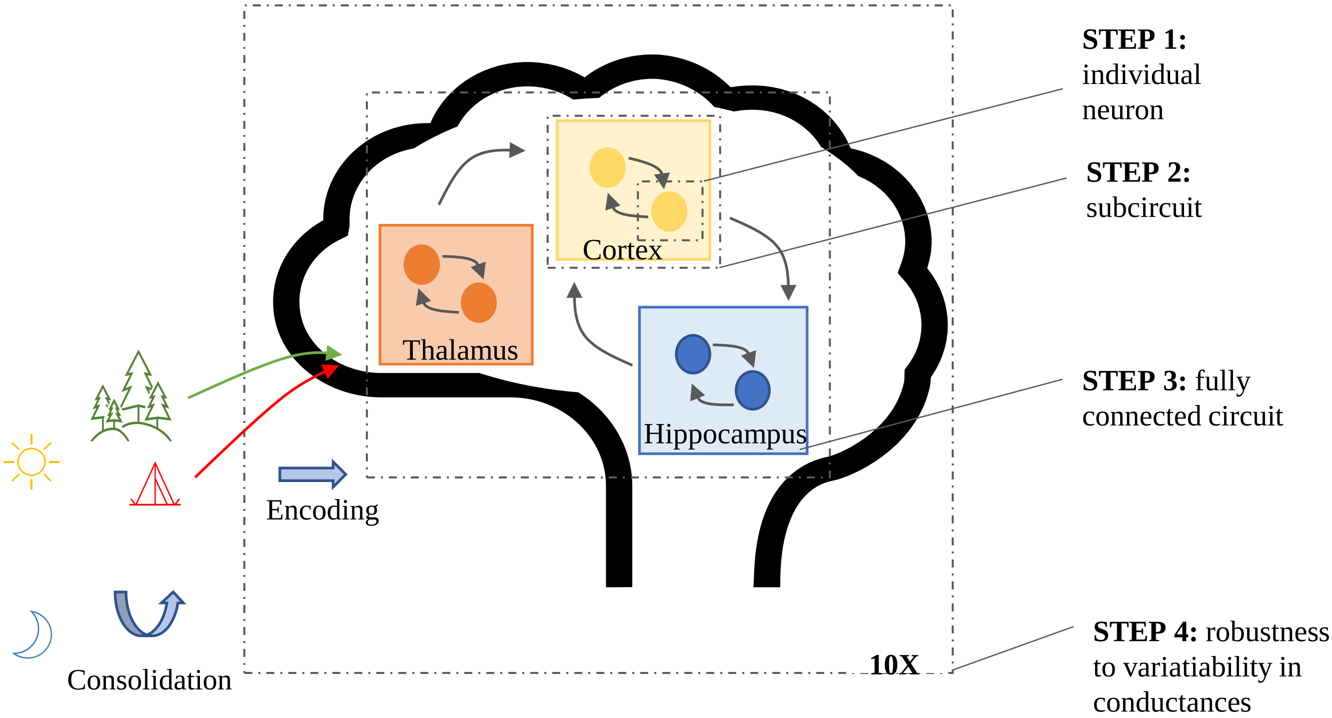

Figure 2: Summary of the modeling procedure

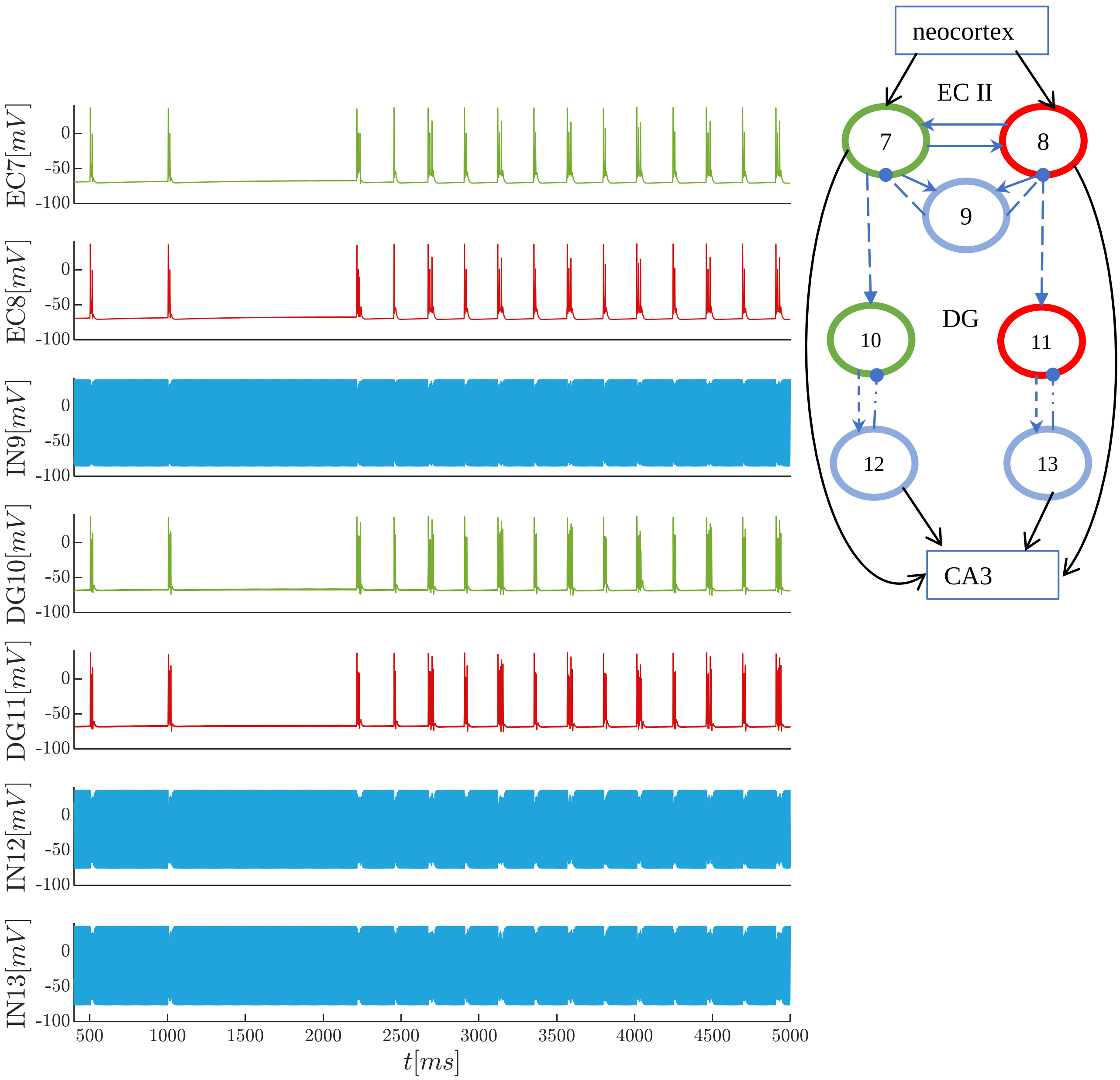

Figure 3: Voltage traces of a part of the full circuit modeling.