Creative memory semantization through adversarial dreaming

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Classical theories of memory consolidation emphasize the importance of episodic replay during non rapid-eye-movement (NREM) sleep as a key mechanism to extract semantic information from encoded memories (Lewis and Durrant, 2011). However, the characteristic creative nature of dreams (Fosse et al., 2003) suggests that memory semantization may go beyond merely replaying previous experiences.

Here, we propose that rapid-eye-movement (REM) dreaming is essential for efficient memory semantization by randomly combining episodic memories to create new, virtual visual experiences. We support this hypothesis by implementing a cortical architecture with hierarchically organized feedforward and feedback pathways, loosely inspired by generative adversarial networks (GANs; Goodfellow et al., 2014). Learning in our model is organized across three different global brain states mimicking wakefulness, NREM and REM sleep. In each of these phases synaptic plasticity optimizes different, but complementary objective functions via stochastic gradient descent. During wakefulness, our model learns to recognize externally-driven low-level activity patterns, stores high-level representations in a hippocampal module, and tries to predict low-level from high-level activity (Fig. 1A). During NREM sleep, our model learns to reconstruct replayed high-level activity patterns from generated low-level activity, perturbed by virtual occlusions (Fig. 1B). During REM sleep, our model learns to generate realistic low-level activity patterns from random combinations of high-level activities while simultaneously learning to distinguish these virtual experiences from waking experiences (Fig. 1C).

We illustrate our model by training it on standard datasets of natural images and show that it develops structured latent representations in an unsupervised fashion which can be efficiently used by downstreams areas, for example for object recognition tasks. Our results suggest that creative dreaming during REM is essential for efficient memory semantization and memory replay during NREM improves robustness of latent representation to sensory perturbations. Our biologically-inspired algorithmic framework provides a new computational perspective on the functional relevance of sleep, memory replay and dreams. It thereby helps to interpret existing data, makes predictions for future experiments, and serves as a basis for detailed microcircuit models of the described mechanisms.

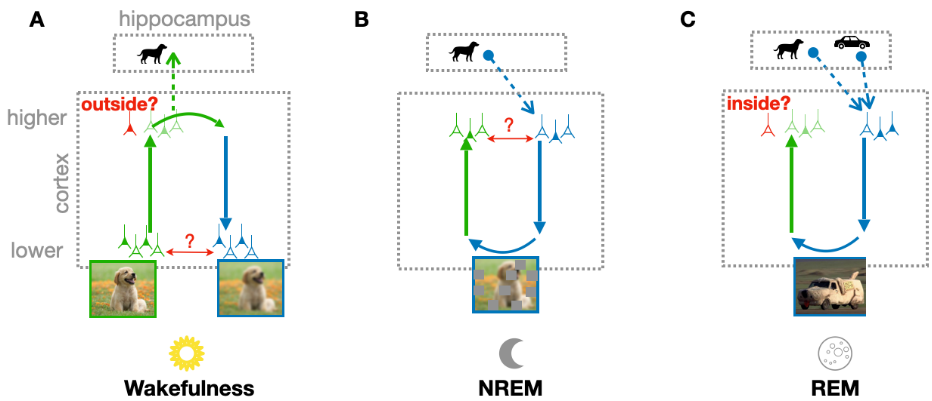

Figure 1: Memory semantization by complementary objective functions during wakefulness, NREM, and REM sleep.

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