Sleep-like Homeostatic and Associative Plasticity Enhances Learning and Power in Multi-layer Spiking Network

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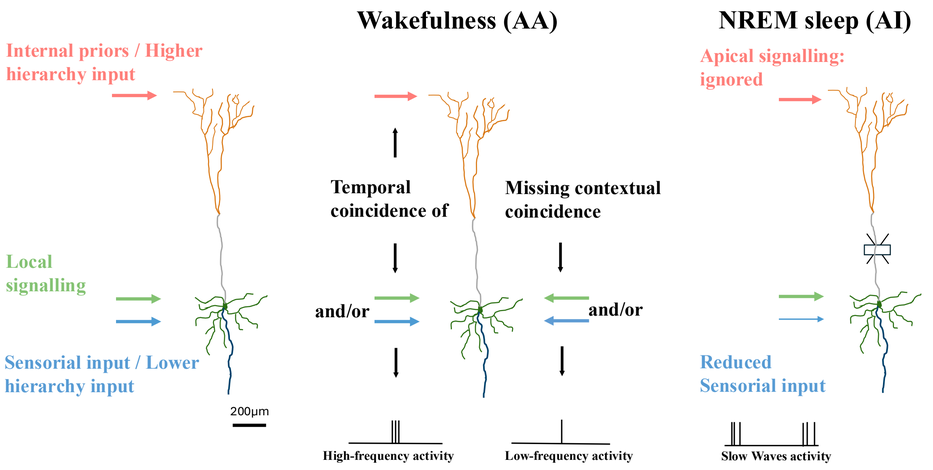
Motivation

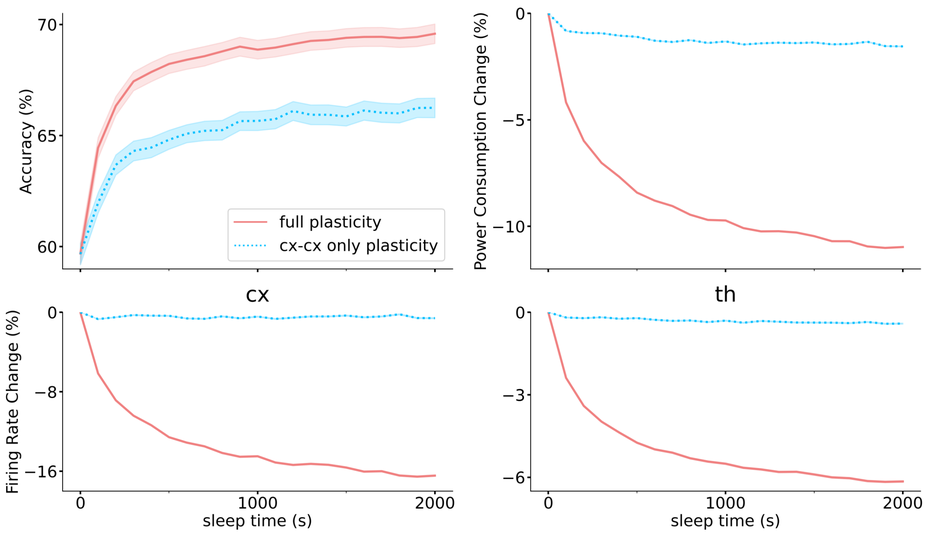


Apical Amplification [1-3] (AA) is believed to play a crucial role during **wakefulness** [4], inducing high-frequency bursting enabling the detection of temporal coincidences between internal priors and perceptual signals. During **learning**, AA supports the **formation** of novel experience specific **neuronal assemblies** while **avoiding catastrophic forgetting**.

Apical Isolation (AI) is thought to decouple somatic and apical compartments during **deep sleep** [5]. AI restricts processing to local interactions ignoring inter-areal contextual information conveyed by projections from non-specific thalamic nuclei targeting the apical tuft. During NREM sleep AI should facilitate **local synaptic optimization** within cortical areas, with **cognitive and energetic benefits** observed during post-sleep wakefulness.

Results

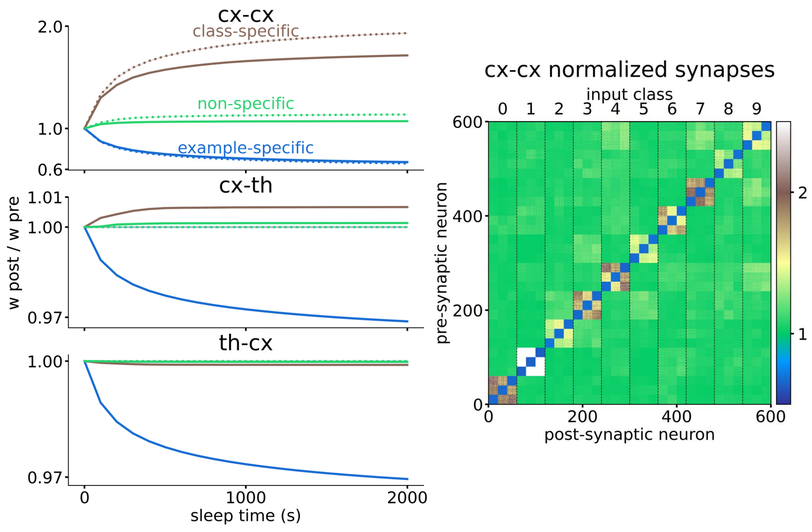
Sleep Benefits on Cognitive and Energetic Performance



- Most-active neuron classification accuracy (10 classes, 25 example per class, averaged over 100 configurations)
- $P_{post}/P_{pre} = 0.25 + 0.45 \cdot \left\langle \frac{r_{i\,post}}{r_{i\,pre}} \right\rangle + 0.35 \cdot \left\langle \frac{r_{i\,post} \sum_j W_{ij\,post}}{r_{i\,pre} \sum_j W_{ij\,pre}} \right\rangle$

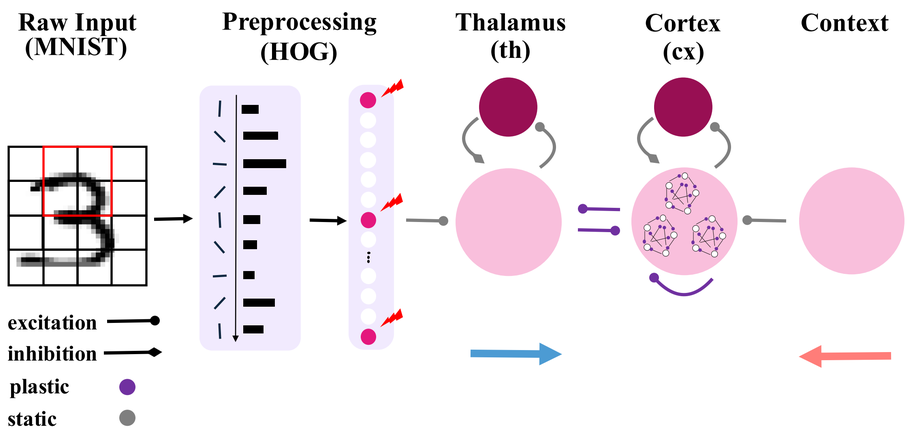
- **Classification accuracy enhanced**
- **Power consumption reduced**
- **General firing rates reduction**
- **General homeostatic depression** of cx-cx, cx-th and th-cx synapses
- **Class specific associations** of cx-cx and cx-th synapses

Sleep Effects on Synapses



- Cortico-cortical (cx-cx), cortico-thalamic (cx-th) and thalamo-cortical (th-cx) connections.
- Post- to pre-sleep normalized synapses: same input image (blue), same inputs class (brown), non-specific (green)

Model

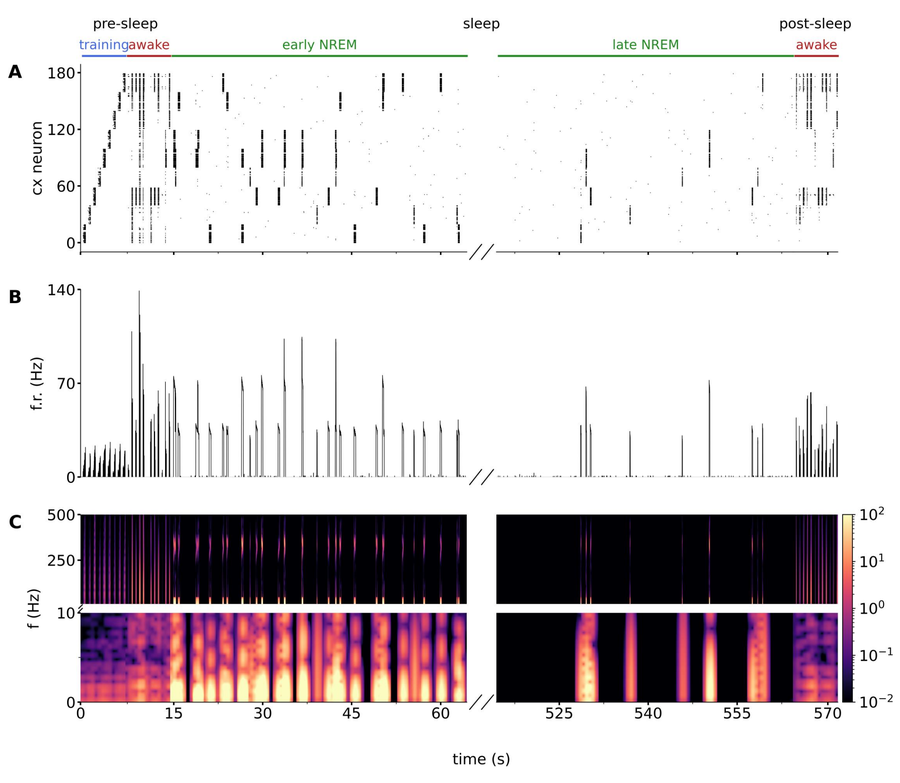


Two-layers plastic spiking network representing a small cortical patch (**cx**) and its specific thalamic nucleus (**th**) capable to **learn**, **sleep** and **classify**:

- Incremental learning from few examples (3 per class, 10 classes)
- HOG filtered MNIST images translated to binary sequences as network's input

- Poisson noise as internal (**context** ↓) and external stimuli (**perception** ↑)
- Conductance-based integrate-and-fire neurons with spike-frequency adaptation
- Spike-timing-dependent plasticity (STDP)
- Winner-Take-All dynamics

Wake – Sleep Cycle Activity

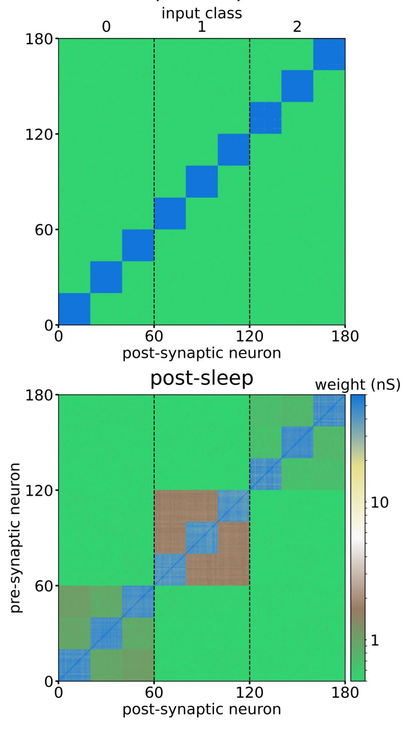


Training
Temporal coincidence of **context** and **perception** creates **th-cx cell assemblies** for each percept

Awake
Perceptual stimuli alone activates assemblies encoding for the same class of inputs enabling **classification**

NREM
Aspecific contextual stimuli to cx induce endogenous **slow oscilations** leading to **th-cx replay** and spontaneous **homeostatic** and **associative** synaptic changes

Sleep Effects on CX-CX Synaptic Matrix



Apical Amplification ↓↑
After **training**, **strong synapses** within independent groups encode percepts (grey boxes) while the majority remains weak (blue background)

Apical Isolation ↓✖
After **sleep,** strong synapses are **depressed** while **associations** emerge among neurons encoding for the same class of inputs (green/light blue boxes)

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