Modeling the prefrontal cortex as a lifelong learning system

Presented by Clara Yi on the 25th of April 2024 for NICE ‘24
Contextual Processing in the Prefrontal Cortex

Miller and Cohen, Annual Review of Neuroscience (2001)  
Tsuda et al, PNAS (2020)

Dynamic Mixture of Experts (DynaMoE)
Mixture of Experts with dynamic recruitment of new experts with gated transfer learning

Stage 1  
Stage 2
Neuromodulated Mixture of Experts

Supervisor Network

Expert Networks

Receptor Network

Inhibitory Action Selection

Input

Supervisor Signals

Neuromodulator

Signals

Long short-term memory network (LSTM)

Sensory Information

Filters

Sparsely Connected Feedforward Network (SCN)

Experts

Decisions

Final Decision

Batra, Bakhti-Suroosh et al., (Unpublished data from the Tye Lab)

\[ d = W_{E_1}d_1 + W_{E_2}d_2 + W_{E_3}d_3 \]
NeMoE Model Components

Supervisor Network

Computational

Neuromodulatory Signal

Batra, Bakhti-Suroosh et al., (Unpublished data from the Tye Lab)

Biological

\[ d = W_{E_1}d_1 + W_{E_2}d_2 + W_{E_3}d_3 \]
NeMoE Model Components

Expert Networks

Cortical Columns

Input

Supervisor

Neuromodulator Signals

\[ NM1 : n_1 \]
\[ NM2 : n_2 \]

Filters

Sensory Information

Experts (LSTMs)

Decisions

Final Decision

\[ d = W_{E_1}d_1 + W_{E_2}d_2 + W_{E_3}d_3 \]

Computational

Batra, Bakhti-Suroosh et al., (Unpublished data from the Tye Lab)
NeMoE Model Components

Receptor Network

G-Protein Coupled Receptor Distributions

Computational

Biological

Allen Institute for Brain Science 2004

Batra, Bakhti-Suroosh et al., (Unpublished data from the Tye Lab)
NeMoE Model Components

**Computational**

**Inhibitory Action Selection**

\[ P = \sum_{i,j} W_{N_i,j} P_j \]

- \( P \): Policy of jth expert
- \( N_i \): ith Neuromodulator
- \( W \): Weight Matrix

**Mutual Inhibition Circuit**

- Principal neuron
- Interneuron

**Biological**

- \(-\) Sign indicates inhibition
- \(+)\) Sign indicates excitation

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**Supervisor**

- Long short-term memory network (LSTM)

**Neuromodulator Signals**

- \( NM1 : n_1 \)
- \( NM2 : n_2 \)

**Filters**

- Sparsely Connected Feedforward Network (SCN)

**Experts (LSTMs)**

- \( E_1 \)
- \( E_2 \)
- \( E_3 \)

**Decisions**

- \( d_1 \)
- \( d_2 \)
- \( d_3 \)

**Final Decision**

\[ d = W_E_1 d_1 + W_E_2 d_2 + W_E_3 d_3 \]

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Batra, Bakhti-Suroosh et al., (Unpublished data from the Tye Lab)
NeMoE Model Components

**Computational**
- Micro-circuit dynamics: Rapid

**Biological**
- Ligand-gated Ionic Channel
- Metabotropic Channel

_Batra, Bakhti-Suroosh et al., (Unpublished data from the Tye Lab)_
Multi-context foraging reveals adaptive behavioral strategies

Batra, Bakhti-Suroosh et al., (Unpublished data from the Tye Lab)
Multi-context foraging reveals adaptive behavioral strategies

Batra, Bakhti-Suroosh et al., (Unpublished data from the Tye Lab)
Using behavioral features to predict context

Batra, Bakhti-Suroosh et al., (Unpublished data from the Tye Lab)
Prefrontal dopamine encodes contextual information
Prefrontal calcium distinguishes neural ensembles

Batra, Bakhti-Suroosh et al., (Unpublished data from the Tye Lab)
Prefrontal calcium distinguishes neural ensembles

**Dopamine Biosensor**
Decoding Performance

**Calcium Imaging**
Decoding Performance

Batra, Bakhti-Suroosh et al., (Unpublished data from the Tye Lab)
NeMoE modeled by deep reinforcement learning simulation

Batra, Bakhti-Suroosh et al., (Unpublished data from the Tye Lab)
Deep RL Simulation

Batra, Bakhti-Suroosh et al., (Unpublished data from the Tye Lab)
Deep RL Simulation probability mimics real behavior

Batra, Bakhti-Suroosh et al., (Unpublished data from the Tye Lab)
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