A neuronal model of a global workspace in effortful cognitive tasks - Review

CS297

Presented To

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Abstract

- Two main computational spaces are involved:
  - **Global workspace**: Composed of distributed, heavily interconnected neurons with long-range axons
  - **Specialized processors**: These include perceptual, motor, memory, evaluative, and attentional processors
- These neurons are **engaged in effortful tasks** where specialized processors alone are insufficient
- Workspace neurons can **mobilize or suppress** the activity of specialized processors via descending connections
- A computer simulation of the Stroop task shows workspace activation to increase during acquisition of a novel task, effortful execution, and after errors

Theoretical Premises

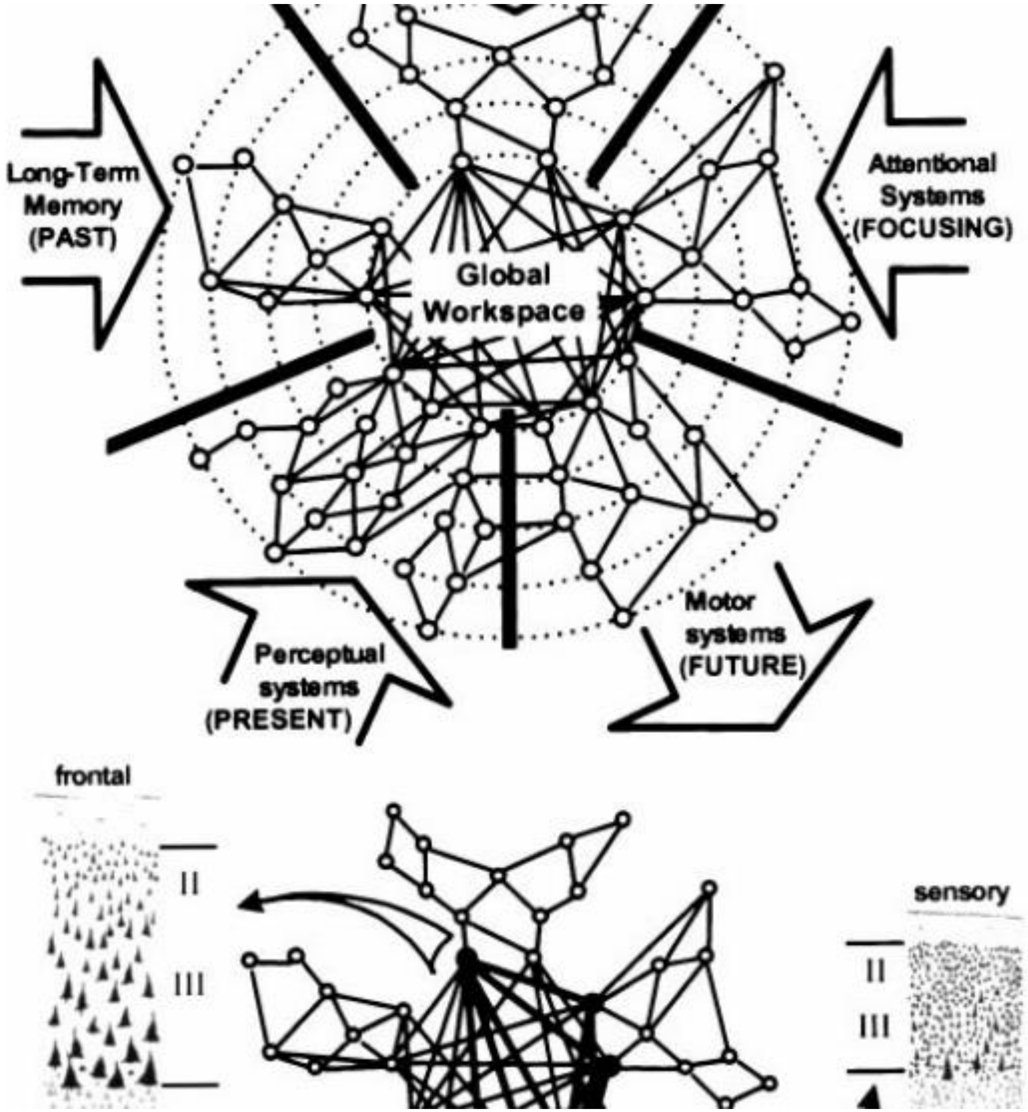
- Two Main Computational Spaces
  - The first is a processing network, composed of a set of parallel, distributed and functionally specialized processors or modular subsystems
  - The second computational space is a global workspace, consisting of a distributed set of cortical neurons characterized by their ability to receive from and send back to homologous neurons in other cortical areas horizontal projections through long-range excitatory axons
- Selective Gating of Workspace Inputs and Outputs - Although a variety of processor areas project to the interconnected set of neurons composing the global workspace, at any given time only a subset of inputs effectively accesses it.

Theoretical Premises

- Spatio-Temporal Dynamics of Workspace Activity
  - The entire workspace is globally interconnected in such a way that only one such “workspace representation’’ can be active at any given time. This is different from the parallel processors
  - If it is negatively evaluated, or if attention fails, it may however be spontaneously and randomly replaced by another discrete combination of workspace neurons.

Content of the Global Workspace

- Perceptual circuits give the workspace access to the present state of the external world
- Motor programming circuits allow the content of the workspace to be used to guide future intentional behavior
- Long-term memory circuits provide the workspace with an access to past percepts and events
- Evaluation circuits allow representations in the workspace to be associated with a positive or negative value
- Attention circuits allow the workspace to mobilize its own circuits independently from the external world



COMPUTER SIMULATION

- Neuronal architecture, composed of excitatory and inhibitory units grouped into different assemblies: input systems, specialized processors, workspace neurons, vigilance, and reward systems
- Each assembly is composed of multiple replicas of a basic element comprising an excitatory unit, a gating inhibitory unit, and a processing inhibitory unit
- Gating and processing inhibitory units are classical McCulloch–Pitts units – $S^i{}_{sigmoid}(\Sigma\, w^{i,j}\, S^j\,)$ where neuron ‘I’ is contacted

COMPUTER SIMULATION

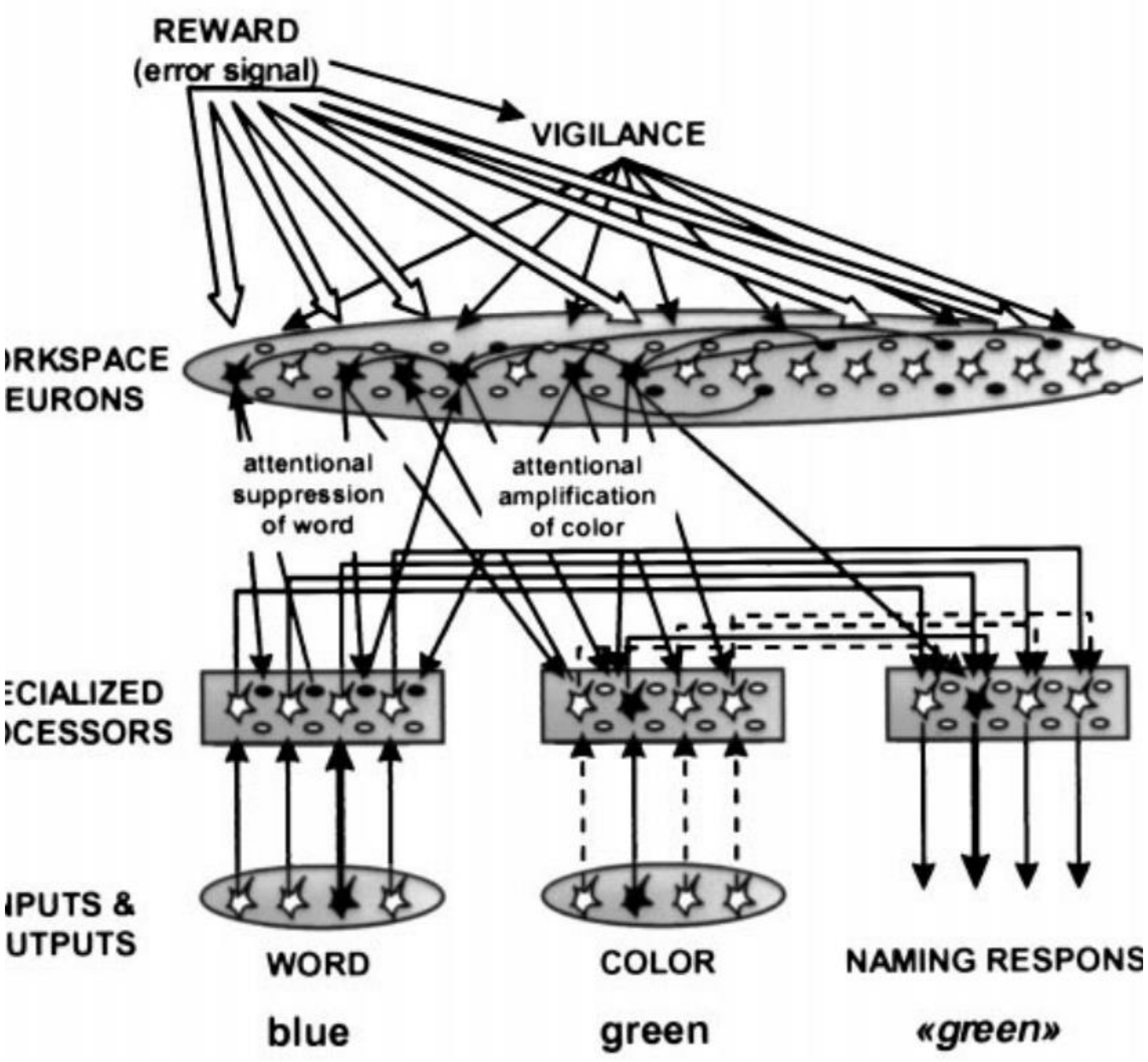
- Only excitatory units are assumed to make synaptic contact onto inhibitory units
- Inputs to excitatory units may come from excitatory as well as inhibitory units – $S^i_{EXC} = \text{sigmoid}(\Sigma^i_{asc}\,\Phi(\Sigma^i_{desc}))$
- Phi function is a sigmoid multiplied by 2
- Only the synaptic weights between two excitatory units are assumed to be modifiable according to Hebbian rule,

$$\Delta w^{post,pre} = \varepsilon\, R\, S^{pre}\,(2\, S^{post} - 1)$$

- Weights are bounded to remain between 0 and 7

COMPUTER SIMULATION

- The vigilance signal V is treated as having a descending modulatory influence on all workspace neurons according to the above-described gating mechanism. It is updated after each response: if R > 0, then ΔV=-0.1 V, otherwise ΔV = 0.5 (1 - V)



Implementation of the Stroop Tasks

- Routine task 1 (color naming) - Turning a single color unit on and rewarding the network for turning the corresponding naming unit
- Routine task 2 (word naming with color interference) - Turning a word unit on together with another incompatible ink color unit and rewarding the network for turning on the naming unit appropriate to the word, not the ink color
- Effortful task (color naming with word interference) - Providing conflicting word and color inputs, as in task 2, but rewarding the network for turning on the naming unit appropriate to the ink color, not the word

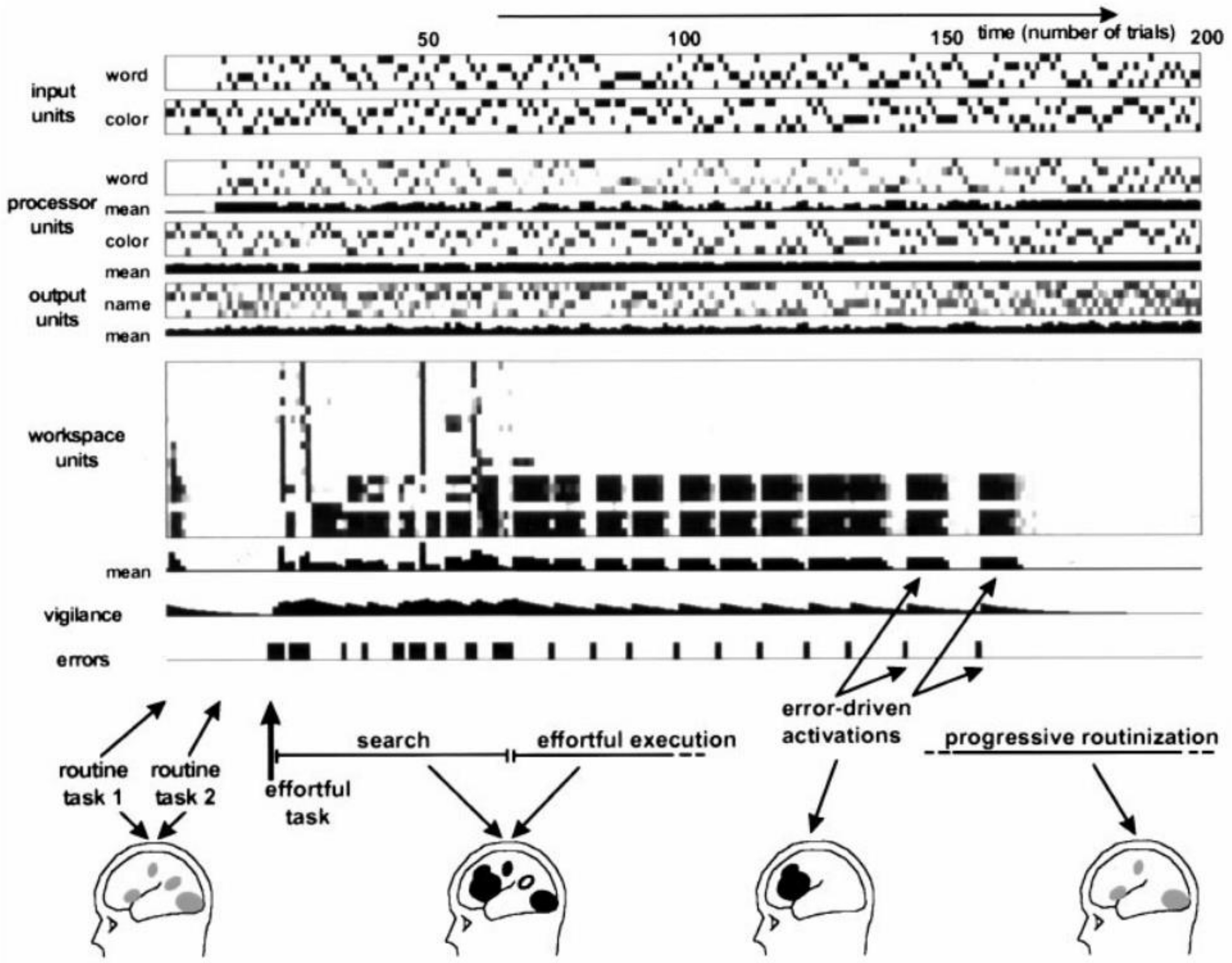
Results

- When placed in routine task 1 (color naming, no interfering word) the network performs correctly with only processor unit activation, using the direct one-to-one connections from color units to name units
- Similar results are obtained when the network is submitted to routine task 2 (word naming with color interference). Even though there are now two conflicting inputs, word-to-name connections are stronger than color-to-name connections

Results

- An initial series of errors takes place as the network perseverates in applying the routine task 2.
- The delivery of negative reward leads to an increase in vigilance and to the sudden activation of variable patterns amongst workspace units.
- The next 30 trials can be described as a search phase. Where workspace activation varies in a partly random manner as various response rules are explored
- Eventually, the network settles into a stable activation pattern, with a fringe of variability that slowly disappears in subsequent trials

Results



time (number of trials)
50
100
150
200
input units
word
color
processor units
word
mean
color
mean
output units
name
mean
workspace units
mean
vigilance
errors
routine task 1
routine task 2
effortful task
search
effortful execution
error-driven activations
progressive routinization