Model: Corticostriatal model of oculomotor learning

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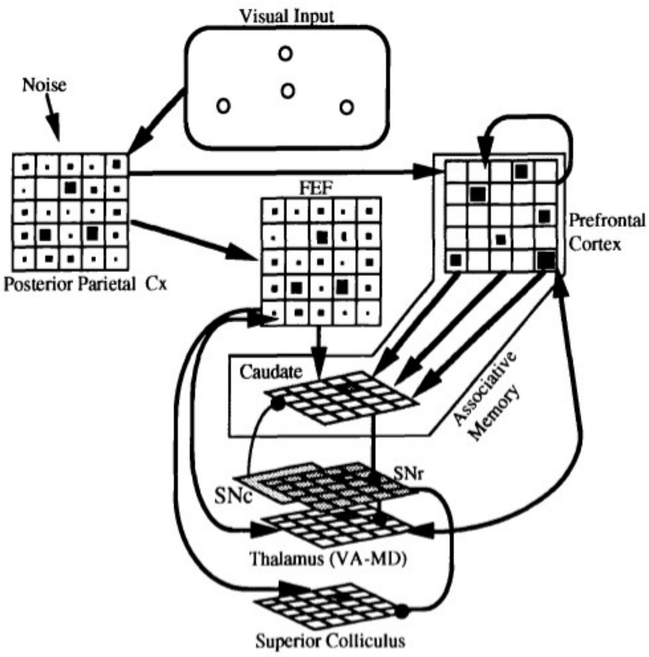
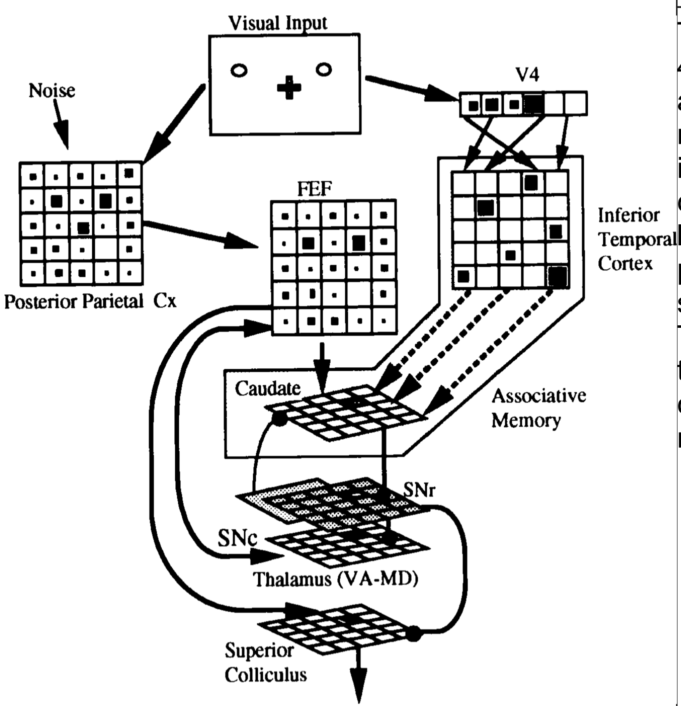
Brief Description *	This model of the corticostriatal system has been developed to explain two key functions of this brain structure in the context of an oculomotor task. First, the model shows how a reinforcement learning mechanism modifying corticostriatal synapses from one cortical area can facilitate integration of information from different cortical areas sending projections to the same striatal layer. Secondly, the model introduces a new type of recurrent neural network - the temporal recurrent network (TRN) - to process temporal information in order to model sequence processing within the prefrontal cortex.Experimental results successfully reproduce key properties of electrophysiological data from monkeys performing the oculomotor task.
Narrative *	The model is designed to simulate what happens when a sequence of visual stimuli is presented, and then the system executes a sequence of saccades to the remembered sequence of targets. The left side of the model illustrates the classic oculomotor circuit. Retinotopic input passes via parietal cortex to frontal eye fields (FEF). FEF activates the caudate (CD) which inhibits the substantia nigra (SNr), thus disinhibiting the superior colliculus. This allows the FEF activation of SC to drive a saccade to the visual target. This is inhibited when a central target is being fixated. During the sequence task, while the system fixates a central fixation point (FP), a sequence of targets is presented. The visual input arrives at the prefrontal cortex (PFC). There, a mixture of excitatory and inhibitory recurrent connections produces a dynamic system that is sensitive to the serial and temporal structure of the input sequence of activations. After the input sequence, the PFC dynamic state thus reflects the structure of the input sequence. When the FP is removed and the three targets are presented, the system generates a saccade. The spatial choice is driven in part by noise input that forces the model to choose between the three targets. At the same time, the PFC projects its context coding to the CD. During learning, when a correct saccade is made, the PFC-CD connections that contribute to that choice are strengthened. This corresponds to the action of reward-related dopamine release in the striatum from SNc. Follwing this learning, the dynamic states in PFC are associated with the successive saccade choices, and the model thus learns to reproduce the 6 sequences (LRU, LUR, RUL, RLU, URL, ULR).
Tags	associative learning, computational model, corticostriatal system, learning sequence, oculomotor, recurrent network, reinforcement learning, sequential behavior, simulation

Architecture

Diagrams



In this version of the model, the (unseen here) retina layer receives spatial information of visual cues from the visual input and sends it to the parietal cortex that in its turn sends it to the frontal eye field (FEF) and the prefrontal cortex (PFC) module. FEF is the cortical part of the corticostriatal loop that comprises the caudate, the substantia nigra pars reticulata (SNr) and the thalamus. The latter projects back the FEF to close the loop. FEF and SNr are the output layers of the loop and project to the superior colliculus layer which is the output layer of the model. It sends its activity to the the brain saccade generator that transform the collicular activity into a motor command for the retina. In the model, the contextual module encoding information relevant to perform the right saccade. In this case the contextual module is the PFC made of two layers connected in a recurrent fashion enabling it to process temporal information. Spatial information from FEF and contextual information from PFC are integrated in the caudate layer. Connections from the PFC to the caudate are modified through reinforcement to enable correct saccade responses to be reinforced and incorrect responses to be inhibited. See diagram entry below for the model verion with the inferior temporal cortex as contextual cortical module.



This version of the model has a visual area 4 (V4) and inferior temporal cortex (IT) layer as contextual module. Layer V4 that receives visual information from the visual input layer encodes the visual identity of the cues and send this information to the IT layer. In its turn the IT layer sends projections to the caudate nucleus where spatial and cue information are integrated. The IT to caudate projections are modified through reinforcement to influence the choice of saccade. See diagram above for more details on the global architecture.

Inputs		
Name	**Data Type**	**Description**
Visual area 4	6-length vector of	In the conditional visual discrimination task

	leaky integrator neurons	the visual identity of the cues are directly encoded in the visual area 4 layer. Different predefined patterns of activity are selectively activated in the layer to simulate the presence of a particular visual cue.
Visual input	7 by 7 array	This layer sends the visual spatial information to the posterior parietal cortex layer. The spatial information is encoded in a 7 by 7 matrix where each active unit represents the presence of a visual object at the spatial position of the active unit.
Outputs		
Name	**Data Type**	**Description**
Brain saccade generator	Tuple of integers	This module receives projections from the superior colliculus to generate a saccade if the activity in the superior colliculus exceeds a threshold. This module sends a command to the retina in the form of a tuple of integers representing the horizontal and vertical shift made by the retina on the visual input.
Submodules		
Name	**Description**	
Temporal recurrent network (TRN)	This module is a recurrent network made of two interconnected layers of leaky integrator neurons, the PFC and PFC damped layers, modelling the recurrent property of the prefrontal cortex. It projects towards an output layer that represents the striatum. The PFC damped layer neurons have higher and inhomogeneous time constants providing slower dynamics that allow the layer to merge current activity of previous inputs to activity induced by new inputs. This property allows this module to process temporal information, and typically to process sequence of inputs. Connections between the two layers are not modifiable. Learning takes place between the PFC module and the striatum through reinforcement on a trial and error basis.	

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