Model: Ventral "Object" Pathway: Modeling Interregional Connectivity Changes

Authors		
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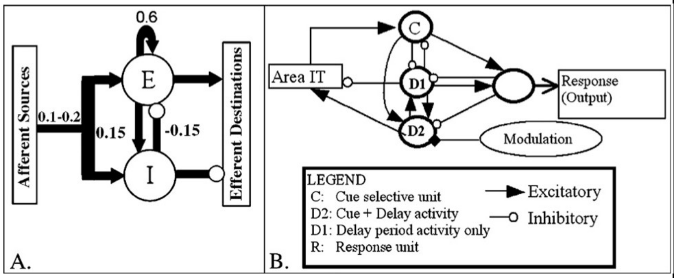
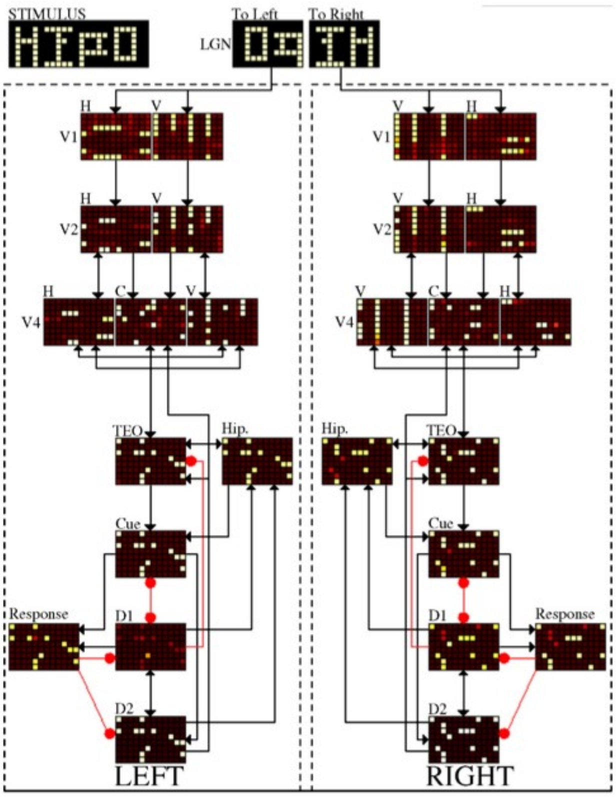
Brief Description *	Ventral "object" pathway network with a local memory circuit that models neuronal behaviors in the prefrontal cortex during different phases of a visual working memory cognitive task.	
Narrative *	This is a neural network model of the ventral visual pathway and associated functional connections. It features a a learning method for adjusting the magnitude of interregional connections. This enables simulations of functional magnetic resonance imaging (fMRI) data sets. We demonstrated that this method finds the appropriate connection strengths when trained on a model system with known, randomly chosen connection weights. We then used the method for examining fMRI results from a one-back matching task in human subjects, both healthy and those with schizophrenia. This model extends Tagamets and Horwitz (1998), who modeled a visual delayed match-to-sample circuit for detecting repeated stimuli that were encoded along a path of several regions modeling the functions of their counterparts in the human brain. Their model included only a single hemisphere. In the current two-hemisphere model, stimuli pass from an input region (lateral geniculate nucleus, LGN, not explicitly modeled) to the prefrontal cortex via modeled regions corresponding to V1, V2, V4, and inferior temporal cortex (TEO/IT), and the hippocampus. During the progression, stimuli break into pieces to distribute feature information throughout the areas. A prefrontal (PFC) region implements a form of working memory, which maintains stimuli online and makes decisions about matches. The modeled task is lateralized to the left. In the original model, stimuli were simple shapes. Now, stimuli are four-letter words that are made up from symbols resembling alphabetic letters. Real words and non-words are represented by strings that have and have not been trained, respectively, with a competitive Hebbian learning method. In a manner that is analogous to the human visual system, the right half of the stimulus goes to the modelâ€™s left hemisphere and the left half of the stimulus goes to the right. A decision circuit detects both matches and non-matches. Although progress has been made in relating neuronal events to changes in brain metabolism and blood flow, the interpretation of functional neuroimaging data in terms of the underlying brain circuits is still poorly understood. Computational modeling of connection patterns both among and within regions can be helpful in this interpretation. The results discovered by the learning method support previous findings of a disconnection between left temporal and frontal cortices in the group with schizophrenia and a concomitant increase of right-sided temporo-frontal connection strengths. We further demonstrated that the disconnection may be	

	explained by reduced local recurrent circuitry in frontal cortex. This model extends methods for estimating functional connectivity from human imaging data by including both local circuits and features of interregional connections, such as topography and sparseness, in addition to total connection strengths. Furthermore, our results suggest how fronto-temporal functional disconnection in schizophrenia can result from reduced local synaptic connections within frontal cortex rather than compromised interregional connections.
Tags	

Architecture

Diagrams	
	(A) Representation of a single unit in the model. Total synaptic input adds up to about 1.0, and each connection strength represents an approximate percentage of the total synapses in the unit. Incoming connections from other regions typically account for anywhere from 10 to 20% of a unit's total synapses. (B) The working memory circuit in the PFC region of the model. Stimuli enter the circuit via the cue units. D1 and D2 units maintain delay period activity, and the response unit activates only when the current stimulus matches the one held in memory. The Cue units are active only when a stimulus is present. D1 and D2 units maintain delay period activity. Response units activate only if the current stimulus matches the one held in working memory.
	Snapshot of the running model at the resolution of the hypercolumns, and separated into distinct regions and subpopulations. This picture was taken at the end of the response period where the second stimulus, HIPO, matched the first stimulus. On both the left and right, the response units are activated sufficiently to indicate that the model recognizes a match. Excitatory connections end in arrows, while the inhibitory connections end in a circle. Not depicted are self excitatory and inhibitory connections or callosal connections.

Inputs		
Name	**Data Type**	**Description**
Words and Nonwords	2D Matrix	Real words and non- words are four-letter strings and are made up from symbols that resemble alphabetic letters. In a manner that is analogous to the human visual system, the right half of the stimulus goes to the modelâ€™s left hemisphere and the left half of the stimulus goes to the right. Stimuli are passed from an input region (lateral geniculate nucleus, LGN, not explicitly modeled).
Outputs		
Name	**Data Type**	**Description**
Connection Values	Matrix	In order to estimate the connection weights for each group, two identical instantiations of the model were initialized with identical random weights. Gains learning was applied to each instantiation of the model to fit the HV data and the SV data, respectively.
Match or Nonmatch decision	scaler	There are two decision units in the PFC circuit, "match" and "mismatch". Match and mismatch units are tracked during the response period, and whichever one is higher for the sum over both hemispheres is the decision the model makes about the task performed during that trial. The match and mismatch units inhibit one another. The response units are the sole source of excitation of the match unit, and they inhibit the mismatch units. The mismatch unit is excited by cue and D1 units. The activity of the mismatch unit will be larger for words that have a stronger neural representation and aids in preventing false positives for matches based only on the number of units excited rather than the response to matching patterns. D2 inhibits the mismatch unit so there is not too much excitation in the mismatch in the first two stages of the task.
Simulated BOLD time series	Matrix	For each value w of recurrent excitation, simulations are runwith sixteen trials of the delayed match-to-sample task. The summed synaptic activity is saved over each 200-iteration interval, which corresponds to about 1 s in time. Mean BOLD activation is computed as the total summed synaptic activity over all sixteen trials. In order to compute correlations between TEO/IT and PFC, it is necessary to account for the convolution of the BOLD response with the summed synaptic activity. The modeled synaptic activity is convolved

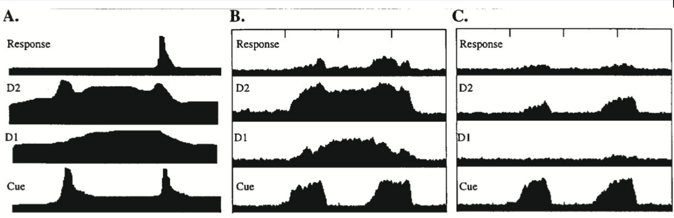
		with a Poisson function that has a peak at 5 s. Correlation coefficients between IT and PFC activations are then computed from their respective convolved time series.

Submodules	
Name	**Description**
Frontal Working Memory	Prefrontal working memory functions of stimulus encoding, maintenance, updating and decision making in WM processing.
Hippocampus	Hippocampal encoding and retrieval activity covary with specific Inferior Temporal and Prefrontal Cortex activity during certain phases of delayed match-to-sample tasks.
TEO/IT	Inferior Temporal region in the ventral object pathway model.
Visual	V1, V2, and V4 regions in the ventral object pathway model.

Submodule: Frontal Working Memory

Brief Description *	Prefrontal working memory functions of stimulus encoding, maintenance, updating and decision making in WM processing.
Tags	

Diagrams



The leftmost panel shows patterns of behavior of the different types of neurons that have been identified in prefrontal cortex of the macaque in spatial delayed-response experiments [Funahashi et al., 1990; Goldman-Rakic, 1995]. Two types of delay units are part of the memory circuit. D1 units become active only when the stimulus has disappeared from view, while the D2 units are active both during the stimulus and during the delay period. In addition there are Cue units that respond only when a stimulus is in view, and response units that show a brief activation after presentation of the test stimulus if it matches the item currently in memory. (B), (C) Behavior of averaged activity over 5 trials of the analogous units in the prefrontal area of the model, with attention (B), and without (C). In the model, the response units indicate whether a match has occurred. (From Tagamets and Horwitz 1998).

Inputs		
Name	**Data Type**	**Description**
Hippocampus	Matrix	Stimulus representation activation dependent on task relevance.
TEO/IT	Matrix	Stimulus representation.
Outputs		
Name	**Data Type**	**Description**
Hippocampus	Matrix	Delay specific stimulus signals.

Match and Mismatch Units	matrix	Enhancement and suppression, as relevant to current comparison.
PFC Response Units	scalar	Match or Mismatch response for current comparison.
TEO/IT	Matrix	Top down feedback, both excitatory and inhibitory regarding delay activation.
V4	matrix	Top down feedback.

Submodule: Hippocampus

Brief Description *	Hippocampal encoding and retrieval activity covary with specific Inferior Temporal and Prefrontal Cortex activity during certain phases of delayed match-to-sample tasks.	
Tags		
Inputs		
Name	**Data Type**	**Description**
PFC, D1 & D2 units	matrix	PFC signals regarding tasks states and representations.
TEO/IT	matrix	Object representations (abstraction) of 4 character words.
Outputs		
Name	**Data Type**	**Description**
PFC Cue	matrix	Contextual enhancement of cue activation.
TEO/IT	matrix	Feedback regarding word representation comparisons for task relevant state.

Submodule: TEO/IT

Brief Description *	Inferior Temporal region in the ventral object pathway model.	
Tags		
Inputs		
Name	**Data Type**	**Description**
Hippocampus	matrix	Interaction between stimulus representation and stimulus state in task context.
PFC D1 & D2 units	matrix	Interaction between stimulus representation and stimulus state in task context.
V4	matrix	Abstracted features of 4 character word.
Outputs		
Name	**Data Type**	**Description**
Hippocampus	matrix	Interaction between stimulus representation and stimulus state in task context.
PFC cue unit	matrix	Feedforward stimulus representation.
V4	matrix	Feedback to visual area for stimulus processing

Submodule: Visual

Brief Description *	V1, V2, and V4 regions in the ventral object pathway model.

Tags	vision, object recognition, feature selection	
Inputs		
Name	**Data Type**	**Description**
Input Layer (LGN)	matrix	Inputs are 4 character words. The lateral geniculate nucleus is the input for the primary visual cortex.
Outputs		
Name	**Data Type**	**Description**
Inferior Temporal corte	matrix	Outputs are horizontal, vertical and corner features of the words.