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A Cortical Network Model of Cognitive Attentional Streams, Rhythmic Expectation, and Auditory Stream Segregation

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We have developed a neural network cortical architecture that implements a theory of attention, learning, and communication between cortical areas by adaptive synchronization of 5-15 Hz and 30-80 Hz oscillations (pp 67-75 in "Advances In Neural Information Processing Systems 6", 1994). Here we present a specific model of rhythmic expectancy and the interaction of higher order and primary cortical levels of processing which accounts for the results of psychological experiments of Jones (pp 1059-1073 of the "Journal of Experimental Psychology: Human Perception and Performance", 7, 1981) showing that auditory stream segregation depends on the rhythmic structure of inputs. Further references not cited here may be found in these papers.

Using dynamical systems theory, the architecture is constructed from recurrently interconnected oscillatory associative memory modules that model hypercolumns of associational and higher-order sensory and motor cortical areas. The system learns connection weights between the modules that cause it to evolve under a 10 Hz clocked sensory/motor processing cycle through a sequence of transitions of synchronized 40 Hz oscillatory attractors within the modules. In the brain, we hypothesize these cycles to be adaptively controled by septal and thalamic pacemakers which alter excitability of hippocampal and neocortical tissue through nonspecific biasing currents that appear as the cognitive and sensory evoked potentials of the EEG. The cycles "quantize time" and form the basis of derived rhythms with periods up to 1.5 seconds that entrain to each other in motor coordination and to external rhythms in speech and music perception.

The architecture employs selective"attentional" control of the synchronization of the 30-80 Hz oscillations between modules to direct the flow of communication and computation to recognize and generate sequences. The 30-80 Hz attractor amplitude patterns code the information content of a cortical area, whereas phase and frequency are used to "softwire" the network, since only the synchronized areas communicate by exchanging amplitude information. The system works like a broadcast network where the unavoidable crosstalk to all areas from previous learned connections is overcome by frequency coding to allow attentional communication only between selected areas relevant to the task of the moment. The behavior of the time traces in different modules of the architecture models the temporary appearance and switching of the synchronization of 5-15 and 30-80 Hz oscillations between cortical areas that is observed during sensory/motor tasks in monkeys and humans.

The "binding" of sequences of attractor transitions between modules of the architecture by synchronization of their activity is similar to the phenomenon of "streaming" in audition. There *successive* perceptual events are bound together into a sequence object or "stream" such that one pays attention to only one source at a time (the "cocktail party" effect). The model illustrates the hypothesis that a thalamically coordinated "cognitive stream" of this synchronized activity loops from primary cortex to associational and higher order sensory and motor areas through hippocampus and back to bind them into an evolving attentional network of intercommunicating cortical areas that directs behavior. The feedback to primary from higher order cortical areas allows top down voluntary control to switch this attentional stream or "searchlight" from one source preattentively bound in primary cortex to another source separately bound at a nearby frequency or phase.

To implement Jones's theory and account for her data, subsets of the oscillatory modules are coupled to form a temporal coordinate frame or rhythmic time base of nested periodicites dividing down the thalamic 10 Hz base clock rate from 10 to .5 Hz. These areas feed their internal 30-80 Hz activity back to primary auditory cortex through fast adapting connections that continually attempt to match incomming patterns. Those patterns which meet these established rhythmic expectancy signals in time are boosted in amplitude and pulled into synchrony with the 30-80 Hz "searchlight signal" to become part of the primary attention stream sending input to higher areas. In accordance with Jones' theory, top down attention can selectively probe input at different hierarchical levels of periodicity by selectively driving a particular cortical patch in the time base set at the particular 30-80 Hz frequency of the attentional stream. This is the temporal analog of the body centered spatial coordinate frame and multiscale covert attention window system in vision. Here the body centered temporal coordinates of the internal time base orient by entrainment to the external rhythm, and the window of covert temporal attention can then select a level of the multiscale temporal coordinate frame.