Use of Common Information Models to Map from Cognition to Physiology

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***Abstract*—The behaviour of a very complex system cannot be understood by simultaneously imagining the operations of all its detailed components. A hierarchy of descriptions must be created on many levels of detail. At each level, descriptions can predict what will happen in different circumstances. At higher levels predictions are approximate to some degree but the information content is small enough that complete phenomena can be understood. At deeper levels descriptions are more precise, but require more information and only small segments of phenomena can be imagined at one time. The accuracy of any given level is understood, and descriptions at one level can be mapped into another as required. Understanding the brain requires such a hierarchy of descriptions. Natural selection pressures result in brains being constrained into forms which support such a hierarchy of description. The condition definition and detection and behavioural recommendation information models can be used to construct consistent descriptions on different levels of detail. [1]These information models are analogous with but qualitatively different from the data and instruction information models in computer systems. Consistent models on the levels of cognition, general and detailed anatomical structures, neurons, neuron substructures, and neurochemistry can be constructed.**

The detection of a cortical column receptive field can be interpreted as a recommendation in favour of many different behaviours, each with an individual weight. Selection of a currently appropriate behaviour is performed by the basal ganglia. Recommendation weights are implemented as synaptic strengths into striatal projection neurons, where the spines allow independent adjustment of individual weights. Each striatal neuron corresponds with one behaviour, and determines the total recommendation weight in favour of its behaviour. The total recommendation weights are compared in the GPi/SNr, resulting in selection of the most strongly recommended behaviour. The selection is limited to one behaviour by regulation of background dopamine levels in the striatum. The selected behaviour is implemented by release of appropriate cortical receptive fields, for example from the motor cortex to drive movement. Consequence feedback can adjust weights. Such weight changes are critical behaviours which must also be recommended by cortical receptive field detections, selected by the ventral basal ganglia, and in this case implemented by triggering burst dopamine firing.

Cortical receptive field changes are essential for learning, but can have undesirable side effects on the integrity of the recommendation weights that already exist. Fields must be carefully managed to ensure that changes are only made if too few are being detected [2]. Changes must be as small as possible. The hippocampal system receives input from across the cortex, determines which columns are most appropriate for changes, and drives those changes. These changes are the basis for declarative memory. At a more detailed level, internal activity (layers II/III) but no output (layers V/VI) in a cortical column indicates that just a slight receptive field expansion would result in detection. The hippocampus therefore receives inputs from layers II/III and performs a competition in CA3/dentate gyrus to determine the columns with the strongest internal activity. Once the competition is resolved, outputs from CA3 drive CA1 activity, which drives receptive field expansions in the cortex. At a yet more detailed level, expansion of a column receptive field is implemented by expansions of pyramidal neuron receptive fields in the column. Neuron receptive field expansions are achieved, for example, using dendritic tree sub-branches on which synaptic strengths from source cortical pyramidal neurons are low or zero. Sub-branches also have inputs from CA1 (via the EC, PRC and/or the PHC cortical areas). Such a sub-branch could only contribute to neuron firing if the hippocampal system input is active. If it is active and the neuron fires, the LTP mechanism increases the weights of the weak synapses, provided they were active. These increases mean that the sub-branch can contribute to neuron firing in the future in the absence of hippocampal input, in other words a new condition has been added, expanding the neuron receptive field.

If an event is novel, there will be simultaneous expansions in a range of cortical columns. Because the hippocampal system manages these expansions, it preserves information on the group of receptive fields that expanded at the same time. Later, if a seed group is activated, indirect activation of other columns on the basis of past simultaneous change can reconstruct an approximation to the activation during the event using this hippocampal information - an episodic memory. Semantic memory access depends on reactivation on the basis of frequent simultaneous past column activity. This information is not available from the hippocampal system, although the system drives the changes required for creation of semantic memories.

REFERENCES

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