A biologically based model of the two-phase theory of classical conditioning: The amygdala, auditory cortex and cerebellum.

Ivan Herreros-Alonso[1], Lukas Zimmerli[2], and Paul Verschure[1,3]

[1]Laboratory of Synthetic Perceptive, Emotive and Cognitive Systems, Institut of Audiovisual Studies, Universitat Pompeu Fabra, [2] Hocoma, Volketswil, Switzerland, [3] Catalan Institute of Advanced Studies (ICREA), Barcelona, Spain

The Polish psychologist Konorski has proposed in the early 1960ies that the associative processes underlying classical conditioning can be separated in a fast non-specific learning systems (NLS) and a slow specific one (SLS). In earlier work we have successfully individually modeled the roles of the amygdala, basal forebrain and auditory cortex (AC) as an example of NLS and the cerebellum (CE) as a model of SLS [1,2]. Here we provide a complete account of Konorski's proposal by integrating these two systems and thus provide the first complete biologically-grounded computational model of the two-phase theory of conditioning.

AC learning has been simulated using a biophysically realistic learning rule, where neuron's plasticity is controlled locally by a spike-time dependent learning rule (STDP). The occurrence of a unconditioned stimulus (US), signaled by a burst of activity in the model amygdala/nucleus basalis, switches a bigger fraction of synapses in the A1 into a plastic mode. As a result CS representations are enlarged, thus resulting in a higher global response to a CS stimulus At the level of the cerebellum, CS and US once more converge. Coincidence of these signals induce LTD at the level of the parallel fiber - Purkinje cell (PU) synapse. Due to this LTD the PU will cease to fire dis-inhibiting the neurons of the model deep cerebellar nucleus (DN), triggering a conditioned response (CR) that is matched to the experimental interstimulus interval (ISI).

Putting together both models requires solving the process of information transmission between the NLS and the SLS. The output of the AC comprises a continuous flow of information, whereas for our CE model to learn, a CS must be signaled by a discrete burst of activity. We investigate the hypothesis that the suitable transformation can be performed by the granule cells: 1) the mossyfibre-granule synapse acts as a filter allowing to pass only high amplitude signals[3]. 2) the tonic and spillover inhibition observed in the CE[4] are used to interrupt the information flow as soon as some action potentials are generated in direction to the PU.

The whole computational model is tested with simulated conditioning experiments and its real-time performance and ecological validity is tested using robot object avoidance tasks where the US is signaled with a particular tone and the CR is expressed as an obstacle dependent modification in the robot's trajectory.

References

[1] Learning sensory maps with real-world stimuli in real time using a biophysically realistic learning rule. M.A. Sanchez-Montanes, P. Koenig and P.F.M.J. Verschure, *IEEE Trans. on Neural Networks* 13:619-632, May 2002.
[2] The cerebellum in action: a simulation and a robotics study. C. Hofstoffer, M. Mintz and P.F.M.J. Verschure. *European Journal of Neuroscience* 16:1361-1376, July 2002.
[3] Integration of quanta in cerebellar granule cells during sensory processing. P. Chadderton, T.W. Margrie and M. Hausser, *Nature* 428:856-860, April 2004.
[4] Tonic and spillover inhibition of granule cells control information flow through cerebellar cortex. M. Hamann, D.J. Rossi and D. Attwell, *Neuron* 33:625-633, February 2002.