

## **PREDICTIVE LEARNING IN TIME-CONTINUOUS SYSTEMS: A THEORETICAL APPROACH TOWARDS CLASSICAL CONDITIONING**

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Learning is an important feature of animal behavior, because it makes repeated de-novo analysis of the sensorial input unnecessary. Accordingly also in many artificial systems learning algorithms are utilized and artificial neural networks, that can learn, have become of far reaching influence in physics and engineering. Recently systems have also been investigated that can learn temporally extended input patterns (time-sequences, for a review see (Dayan and Abbott 2001). These systems consist of so-called "spiking-units" which produce an output-pulse (a "spike"), like a real neuron, as soon as all summed inputs exceed a certain threshold. Accordingly, the temporal patterns, which can be learned, consist of sequences of such pulses. Commonly the temporal correlation between input and output determines the weight change at the network units in such systems: A weight will be strengthened only if the input precedes the output by a short interval. If the order of input and output is reversed the weight will decrease (Song et al. 2000). The size of the temporal window within which the pulse-sequence is evaluated - the correlation window - is usually rather short, in order to assure a high temporal accuracy (Gerstner et al. 1996). Therefore, learning of longer-lasting pulse-sequences requires additional mechanisms (such as multiple delay lines (Dayan and Abbott 2001). In addition, these systems cannot very easily handle additional (second or more) independent inputs and they will also fail when subjected to complex input patterns. This, however, is the normal situation in almost all biological temporal learning situations. The most ubiquitous temporal learning known, "classical conditioning", takes place on rather long time scales and normally requires two input stimuli, the unconditioned and the conditioned stimulus, which often arise from different sensorial modalities. The unconditioned stimulus (food) is followed by an output event (salivation). After learning the conditioned stimulus (bell), which always precedes the conditioned stimulus will elicit the same event and, thus, the unconditioned stimulus can be interpreted as a predictor of the conditioned stimulus (the sound of a bell predicts the feeding). In this presentation we will present a theoretical framework for predictive (temporal) learning which does not require pulse-coding and, is, thus, able to handle time-continuous input signals of arbitrary shape. A new learning rule is developed which utilizes the temporal change (the derivative) of the output to modify the weights and we will show, that our approach allows to analytically calculate the initial development of the weights. In addition, we will demonstrate that very few components are required to cover large time intervals and that our framework allows to use multiple inputs, which are the two critical prerequisites for "classical conditioning".

### **References**

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- W. Gerstner, R. Kempter, J. L. van Hemmen, and H. Wagner (1996), A neuronal learning rule for sub-millisecond temporal coding *Nature* 383, 76-78.