

Bridging Long Time Gaps in Trace Conditioning with a CA3 Model

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1 Abstract

In trace conditioning a conditioned stimulus (CS), e.g. a tone, is followed by a stimulus-free time gap (trace interval), which is then followed by an unconditioned stimulus (US), e.g. a shock or puff of air to the eye. The hippocampus is necessary for learning the timing for a conditioned response (CR) during the stimulus-free time gap. In anticipation of the unconditioned stimulus, for humans, monkeys, rats, and rabbits (for a review, see Disterhoft, et al 2002).

We recently showed that a model of the CA3 region of the hippocampus can reproduce behavioral and neurophysiological data in a rabbit for a 500 ms trace interval (Rodriguez & Levy, 2001). Based on simulations, we made two predictions. First, the CS initiates a stable sequence of neural firing patterns in the CA3 region that function as place cells in time. Second, analogous to place cells, the US code shifts backward in time, thereby serving as predictive information for producing a CR.

Humans, however, are capable of learning well-timed CRs for longer trace interval durations, up to 1700 ms (Finkbiner & Woodruff-Pak, 1990) In other words, hippocampal activity in humans is able to bridge longer time gaps. This could arise from a number of factors, such as a larger network of neurons or longer time windows for synaptic plasticity. Here we extend the previous result to account for human behavior in trace conditioning.

We demonstrate that the time gap is bridged by a sequence of firing patterns that change quickly at the beginning of the trace interval, change slowly toward the end of the trace interval, and finally transition into a stable attractor which represents a backward shift of the US. In other words, there is a sequence of neural assemblies that starts in a synfire-chain, transitions into a quasi-attractor, and ends in a stable attractor.

Through simulations and formal analysis we identify competition between the neural assemblies that depend on trade offs in parameter values. For example, we show that a lower percent connectivity between

Results: Fast and Slow Changing Firing Patterns

(TID = 55 time steps => 1100 ms)

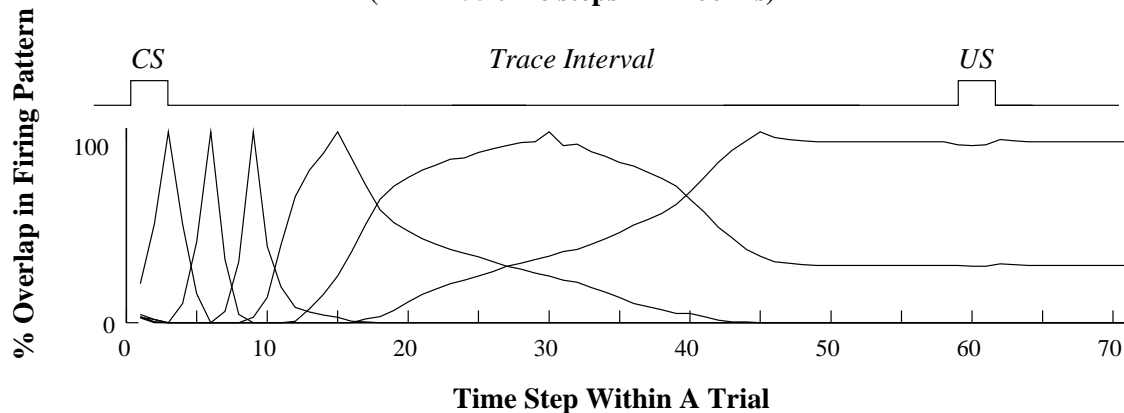


Figure 1: Simulations develop quickly changing firing patterns early in a trial (analogous to synfire chains), slowly changing patterns in the trace-interval (quasi-attractor), that are larger for longer trace intervals, and fixed point attractors at the end of the trial. The graphs show the percentage overlap between firing patterns within a trail at various reference time points. For example, the first line in the graph that reaches 100% uses state vector $Z(t = 3)$ as a reference point.

CA3 neurons improves performance, whereas longer NMDA time constants interacts with other parameters and may or may not improve performance. This leads to the prediction that the human ability for bridging longer time gaps in the trace conditioning arises in part from lower percentages of connectivity in the CA3 region. We also show that longer time gaps result in longer quasi-attractors, but these are more unstable and performance often decreases. This leads to the prediction that cellular recordings should show more evidence of quasi-attractors for longer trace intervals, which may be analogous the changes observed in place cell firing for scaled environments (Muller & Kubie, 1987).

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References

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