Information Processing in Adaptive Cellular Automata

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An adaptive, biologically feasible, information processing cellular automaton is constructed with a fixed update rule, but weights of its influence neighborhood are adaptable. An algorithm adjusts the neighborhood connection weights as a function of accumulated activity state and environmental bias. Association, habituation and sensitization are demonstrated. Each automaton consists of a set of neighborhood connections with corresponding weights, a discrete-time update rule, and an activity state. Each automaton has three states – idle, active, and refractive.

The update rule consists of two phases – state and weight updates. The state update accumulates the weighted sum of neighborhood activity states, where active neighbors and other states are represented as one and zero, respectively. If this sum exceeds a threshold, the automaton proceeds to the active state, then to refractive, and finally idle in subsequent updates. When a cell enters the active state, a decaying accumulator is incremented, shown in equation 2. The bias α is added to the threshold when a cell is refractive, increasing the signal necessary to activate the cell, shown in equation 1.

$$f(x) = \begin{cases} 1 & \sum_{i=1}^{n} x_i w_i \geq \theta + \alpha \\ 0 & otherwise \end{cases} \quad (1) \qquad \beta(t) = \frac{\beta(t-1) + f(x)}{1-\lambda} \quad (2)$$

Weight update uses an environmental bias and the cell activity accumulator to determine the magnitude and direction of weight updates (eq. 3). This resembles BCM synaptic modification, which has many desirable stability properties [1]. Where ε is the learning rate, ρ is activity equilibrium, and δ is the environmental bias.

$$\Delta w_i = f(x)\varepsilon(\theta - w_i)(\rho - \beta(t) + \delta) \qquad (3)$$

A first experiment demonstrates the information processing capability of a single adaptive unit with controlled neighborhood. The ratio of information content, as measured by quadratic entropy (eq. 4), between the inputs and output of the cell is recorded to gauge information processing [2]. It is shown that as the cell adapts, the output to input information content ratio decreases, implying that the cell is attempting to maximize information processing.

$$\begin{cases} H(\{a_i\}) = R_2(Y|\{a_i\}) = -\log P(\{a_i\}) \\ P(\{a_i\}) = \frac{1}{N^2}\sum_{i=1}^{N}\sum_{j=1}^{N} G(a_i - a_j, 2\sigma^2 I) \end{cases} \qquad (4)$$

Future development will include evaluation and analysis of these automata in groups and embodied in simulated organisms.

[1] E. L. Beinenstock, L. Cooper, and P. Munro, "Theory for the development of neuron selectivity: orientation specifity and binocular interaction in the visual cortex," *Journal of Neuroscience,* vol. 2, pp. 32-48, 1982.

[2] X. Dongxin, J. C. Principe, J. Fisher, III, and Hsiao-Chun Wu, "A novel measure for independent component analysis (ICA)," in *Acoustics, Speech and Signal Processing, 1998. Proceedings of the 1998 IEEE International Conference on*, 1998, pp. 1161-1164 vol.2.