Training an Asymmetric Signal Perceptron in an Artificial Chemistry

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Abstract

Autonomous learning implemented purely by means of a synthetic chemical system has not been previously realized. Learning promotes reusability, and minimizes the system design to simple input-output specification.

In this poster, I present a simulated chemical system, the first full-featured implementation of a perceptron in an artificial (simulated) chemistry, which can successfully learn all 14 linearly separable logic functions. A perceptron is the simplest system capable of learning inspired by the functioning of a biological neuron. My newest model called the asymmetric signal perceptron (ASP) is, as opposed to its predecessors such as the weight-race perceptron (WRP), substantially simpler by exploiting asymmetric chemical arithmetics and is fully described by mass-action kinetics. I suggest that DNA strand displacement could, in principle, provide an implementation substrate for my model, allowing the chemical perceptron to perform reusable, programmable and adaptable wet biochemical computing.

Problem and Approach

• Issues of biochemical computing: time-consuming and costly design, no reset, no reusability (hard-wired purpose), lacks programming paradigms.
• I address these issues by introducing an artificial chemical machine capable of learning = chemical perceptron. A perceptron inspired by the functioning of a biological neuron (Figure 1).
• Serves as a general template that can be trained to act as desired binary function. Strict online (autonomous) learning; no external help needed.

Model

• Two-input binary perceptron implemented in an unstructured artificial chemistry driven by mass-action or Michaelis-Menten kinetics.
• Two models:
  - Weight-race perceptron (WRP) = symmetric design, uses two species to represent 0 and 1, learned by desired output (Figure 2 (left)).
  - Asymmetric Signal Perceptron (ASP) = asymmetric design, uses a single species with a 0.5 threshold to represent 0 and 1, learned by reinforcements (Figure 2 (right)).
• Optimal rate constants found by genetic algorithms
• Operate in two modes:
  - Binary function mode – output species produced as a product of weight-species driven catalysis; input molecules injected
  - Learning mode (weight adaptation) – the concentration of weight species change as a result of discrepancy between actual and desired output; input and desired-output (or penalty signal) molecules injected (Figure 3).

Results

• ASP is simpler since it requires just 12 species and 16 reactions as opposed to 14 species and 30 reactions required by WRP.
• ASP employs the Runge-Kutta 4 numerical integration of the rate differential equations, which produces a higher-precision concentration series.
• ASP learns by a more biologically plausible reinforcement method (penalty signal).
• ASP determines the output value by thresholding as opposed to the comparison of positive and negative output species concentrations.
• ASP is transformable to the DNA-strand displacement primitives by Soloveichik’s method giving our symbolic species DNA-strand counterparts.

Conclusion

• The first full-featured implementation of online learning in (simulated) chemistry called the chemical perceptron.
• Learning as well as linear integration of weights are handled internally.
• A chemical perceptron
  - is reusable, since it recovers its internal ready state after each processing;
  - both WRP and ASP versions learn successfully all 14 linearly-separable logic functions with correct rate of 100%;
  - is robust to perturbations of rate constants that alleviates reaction-timing restrictions for real chemical implementation (using DNA-strand displacement technique);
  - is implemented in artificial chemistry, but real chemistry extension possible (DNA strand displacement) + applications: chemical hardware abstraction (prog. interface), ALIFE, spiders; and
  - can serve as basis of programmable and adaptable wet chemical computing.
• Next steps: random DNA circuits with complex dynamics, and Reservoir Computing.

References