Yan Fang, Donald M. Chiarulli, Steven P. Levitan

Associative Processing Using Coupled Oscillators

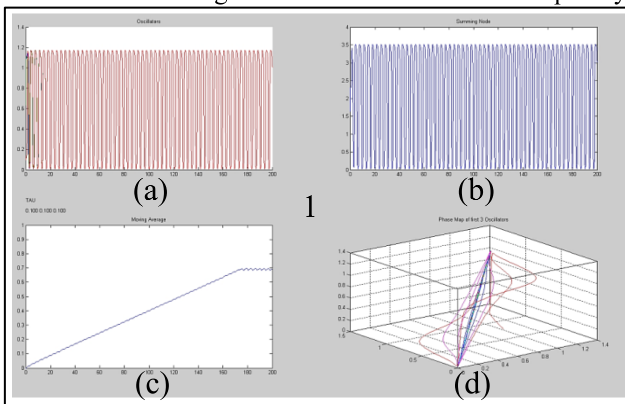
Our goal is to exploit the capabilities of coupled nano-scale oscillators to compute vector comparison operations and thus perform nearest neighbor (or K-nearest neighbor) search. Examples of such oscillators in emerging technologies include magnetic spin-torque oscillators and resonant body transistor based oscillators [Rip05][Wein10]. Using coupled oscillators to perform pattern matching was introduced by Hoppensteadt and Izhikevich and shown to be able to form attractor basins at the minima of a Lyapunov energy function [Hop99]. In this work, we show how we can use weakly coupled, non-linear oscillators as functional units to perform approximate pattern matching (i.e., hetero-associative processing) in high dimensional vector spaces.

To illustrate the behavior of weakly coupled oscillators to perform matching, in figures 1 and 2 we show the behavior of three coupled oscillators following the Oregonator model after [Asa05] where the model is a non-linear relaxation oscillator. In each example the oscillators' control input is a vector of analog values representing points in a vector space. In this example the "template vector" is (0.1, 0.1, 0.1) and the input is (0.1, 0.1, 0.1) for a match, or (0.19, 0.009, 0.16) which leads to a "mis-match". In Figure 1(a) we can see, soon after the start of simulation, the three oscillators converge; 1(b) shows a resistive summation of the three outputs; 1(c) shows that the integration of the summed value quickly rises to a stable value; and 1(d) shows the three oscillators output plotted parametrically to be in phase. Figure 2(a-d) shows the same data for the case that the input 3-vector is not a good match to the stored values.

Figures 3 and 4 show the relationship of the "degree of match" (DOM) to the L1 (Manhattan) distance norm for 3-dimension and 16-dimension tests respectively. Each data point represents the comparison between an input vector and a template, with varying degrees of match. DOM is measured as the amount of energy in the lowest frequency component of the summation waveform. The straight line fit shows reasonable agreement between this norm and the ability of the oscillator cluster to give an equivalent distance metric directly, without performing any Boolean or arithmetic operations.

We are investigating other measures that can be easily implemented in hardware. Our plan is to design hybrid CMOS/nano-oscillator architectures for accelerating pattern recognition applications.

[Rip05] W. Rippard, et al, Physical Review Letters, 95, 10-13.
[Wein10] Dana Weinstein and Sunil A. Bhave, Nano Letters 10(4) 1234-37 (2010).
[Hop99] F. C. Hoppensteadt and E.M. Izhikevich, 1999 Phys. Rev. Lett. 82 2983.
[Asa05] Tetsuya Asai, et.al., Int. J. Unconventional Computing, 1 123-147.



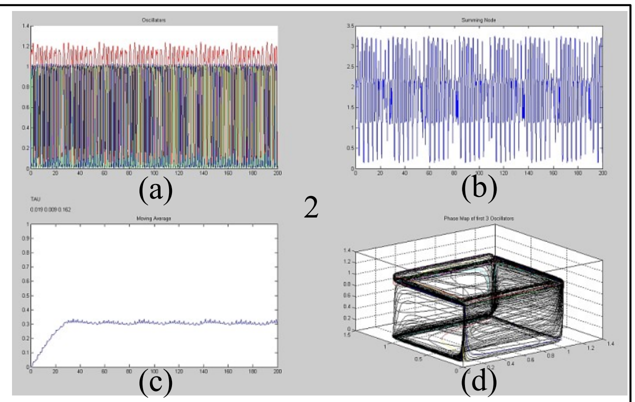


Figure 1 (Matching) and Figure 2 (Mis-Matching) behavior of three coupled oscillators. (a) Oscillator outputs; (b) summing node; (c) voltage at clipped and integrated "degree of match" node; (d) phase map of the three oscillators

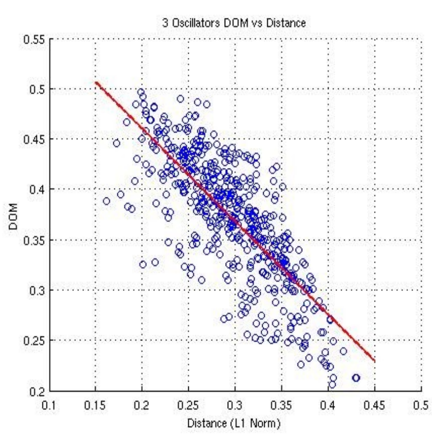


Figure 3 (3 oscillators) degree of match vs. L1 (Manhattan) distance, 500 runs. Max residual: 0.1334, square sum of residuals: 0.7616

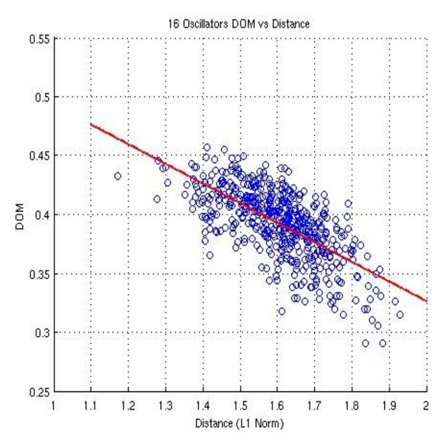


Figure 4 (16 oscillators) degree of match vs. L1 (Manhattan) distance, 500 runs. Max residual: 0.0727, square sum of residuals: 0. 2433