Associative Processing with Coupled Oscillators

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***Abstract*—We discuss the opportunities of performing associative processing based on the phase locking of coupled oscillators. The use of coupled oscillators, rather than Boolean logic, provides for implementations using emerging nano-technology such as magnetic spin torque oscillators and resonant body transistor oscillators, which each have the potential of lower energy operations and higher density scaling than traditional CMOS solutions.**

Keywords—non-Boolean; coupled oscillator; associative processing; pattern matching

I. Introduction

The predicted power and performance limitations of end-of-life CMOS are encouraging researchers to investigate new technologies for computation [1]. However, to date, investigators have had little success in identifying technologies that can compete with CMOS when using charge based Boolean logic. This leads us to rethink the use of both charge-based state and Boolean logic for the application of emerging nano-technologies. Some of these devices have special non-linear responses in either the time or frequency domain that are quite different from the bi-stable step function of traditional CMOS devices. For example, some devices have more than two stable states, periodic response functions, or sigmoid response functions. Interestingly these new state variables and operations can be mapped to similar natural dynamic systems such as human neural circuitry. Therefore, these devices can provide opportunities for building novel architectures for cognitive tasks like pattern recognition or computer vision, where we bypass the low level Boolean operators and directly perform higher level operations.

In our work, we are focused on using nano-scale devices that can be used to create weakly coupled oscillators. Recently, oscillators have been fabricated with novel devices including spin torque oscillators (STO) [2], resonant body transistor oscillators (RBO) [3], and NeuroMOS [4].

Weakly coupled non-linear oscillators, in general, have a dynamic oscillatory behavior which is similar to the weakly coupled neural network model that has been used to perform pattern matching [5]. Based on these ideas, for a cluster of loosely coupled non-linear oscillators, we can use their relative phase relationship as a representation of state and perform associative processing by matching input vectors to a database of stored patterns. Thus, our primitive comparison operations are not based on Boolean XOR and Hamming (Manhattan or Euclidian) distances, but rather our primitive operation is the synchronization of the oscillators based on the degree of similarity between stored analog and input vectors, encoded as frequency control voltages. The degree of synchronization is used as a direct distance measure (or norm) for the pattern matching operations. This not only replaces the Boolean-logic for element wise comparison, but also simple analog circuits can detect the degree of synchronization rather than needing arithmetic logic to perform the bit-counting (for Hamming), summation (for Manhattan), or square-root of sum-of-squared differences (for Euclidian) distances.

Figure 1 illustrates the behavior of a three oscillator system. In (a) we see the oscillators locking in frequency due to coupling when their input values are "close." (b) Shows the time evolution of the three oscillators locking in phase. (c) Shows the range of locking, where the standard deviation of the frequencies (red crosses) goes to zero, as the standard deviation of the inputs (blue circles) is swept over a range of values.

Based on the abilities of these novel devices to perform complex computations, we are developing information processing systems to perform image recognition tasks by performing fast pattern recognition in high-dimension feature spaces [6].

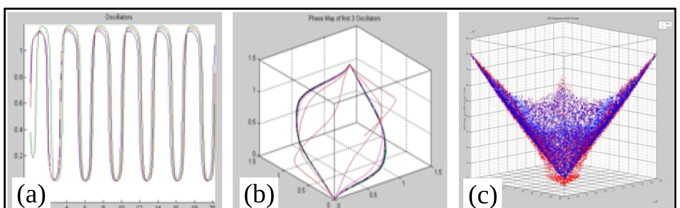

Figure 1: (a) 3 oscillators locking in phase and frequency; (b) time evolution phase map of 3 oscillators; (c) σ of input values (blue), and σ of final frequencies (red) for 3 coupled STO oscillators.

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