Non-Boolean Associative Architectures Based on Nano-Oscillators

Yan Fang,
Advisor: Steven P. Levitan,
Department of Electrical & Computer Engineering, University of Pittsburgh
Collaborators: Denver H. Dash , Tadashi Shibata, Dmitri E. Nikonov, George I. Bourianoff

Overview

Motivation

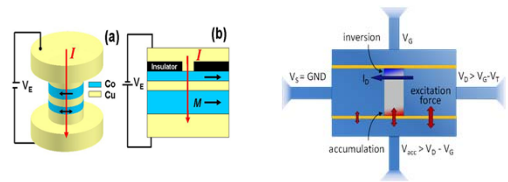
- Compete and complement "end of life" CMOS for low power high density applications
- Exploit non-charge based state variables and non-Boolean operations
- Explore systems based on new devices for compute intensive tasks such as pattern recognition and computer vision

Goals

- Implement non-Boolean associative memory using coupled oscillator network
- Represent states by frequency/phase relationship between oscillators.
- Develop a hierarchical architecture capable of storing large amounts of data and processing queries at high speed

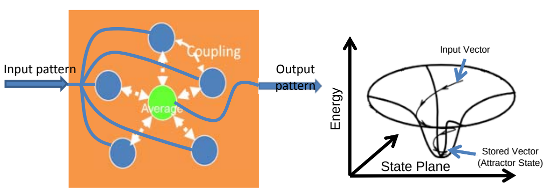
Approach & Method

Nano-Oscillator Associative Memory



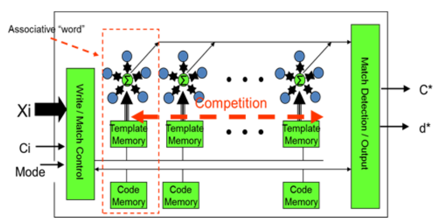
Spin Torque Oscillator　　Resonant Body Transistor

Two types of Nano-Oscillator: STO, RBO.



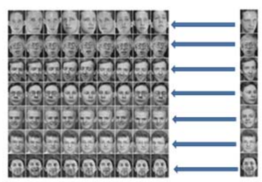
Coupled Oscillators　　Attractor Basin

Use synchronization of nano-scale non-linear oscillators to perform pattern matching operation.



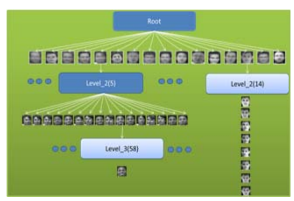
Associative Memory Module

N-Tree Structure

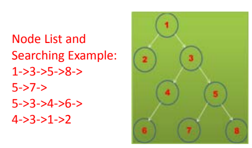


Training/Clustering Data　　Test Data

Face recognition problem: Retrieve the nearest neighbor of an input photo



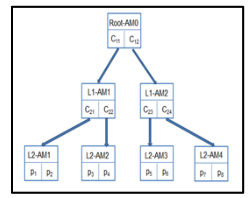
Use hierarchical k-means clustering to organize data into a tree structure

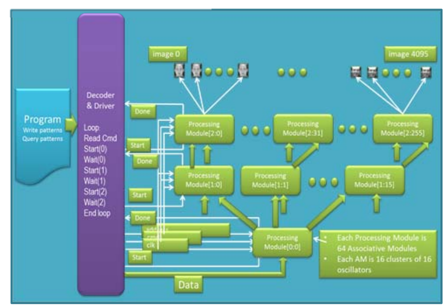


Branch and bound search algorithm provides lists of possible nodes that might contain nearest neighbor

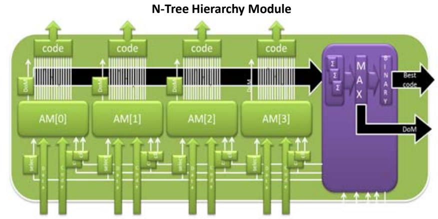
System Architecture

- Structure organizes the AM units as a decision tree
- The recognition process starts from the root node (Highest Level) and goes down the children nodes
- In each step, we recognize the cluster that the input pattern belongs to, instead of the pattern itself
- Only retrieve the stored pattern in the lowest level



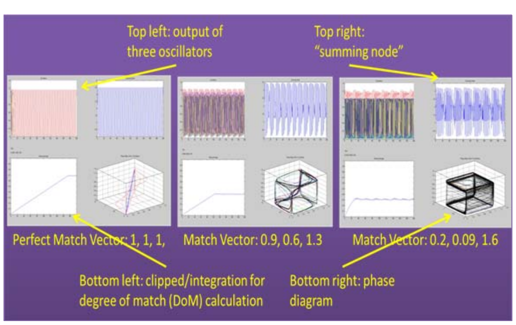


N-Tree Hierarchy Module

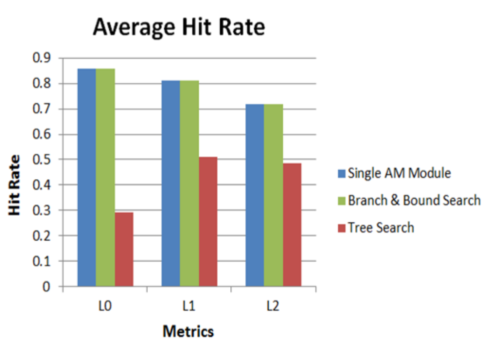


Processing Module (Word extension for AM)

Simulation & Performance



Simulation of a 3-oscillator cluster, three input vector generated different degrees of match



Recognition performance with different distance metrics, using FERET data set (2015 photos, 724 subjects)

The number of nodes visited during Branch and Bound search and the size of N-Tree structure

B&B Search	Total Nodes	Visited Nodes	Visited Leaf Nodes
Max	1199	454	293
Min	795	9	1
Mean	956.7	159.9	59.6
Standard Deviation	34.3	86.28	47.4
Average N-Tree Size	Total Nodes	Depth	Leaf Nodes
	956.7	9.3	846.7

A single AM module has to compare every stored pattern. N-tree hierarchy can achieve the same performance with much higher efficiency

Acknowledgements: Youssry Botros, Wolfgang Porod, Mircea Stan, Dan Hammerstrom, Dana Weinstein, Mathew Puffal, Tamas Roska, Valeriu Beiu
This work was partially supported by the Intel Labs University Research Office