Pattern Matching Using Coupled Oscillators

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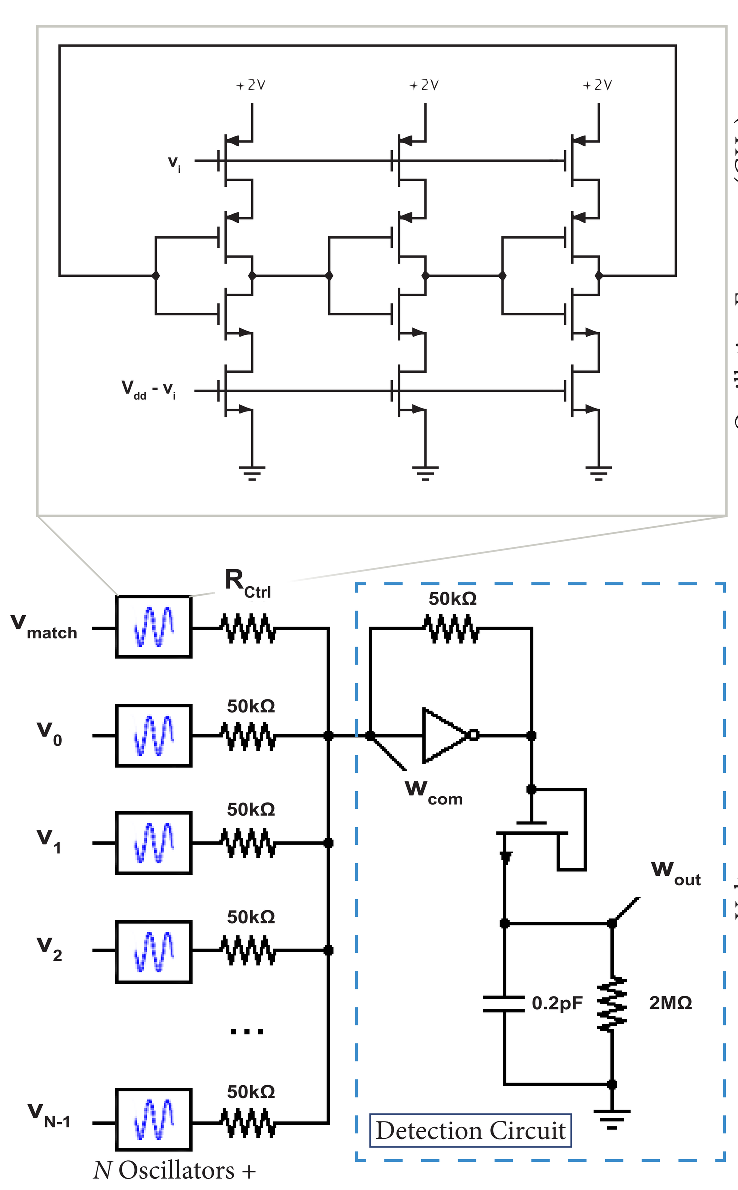
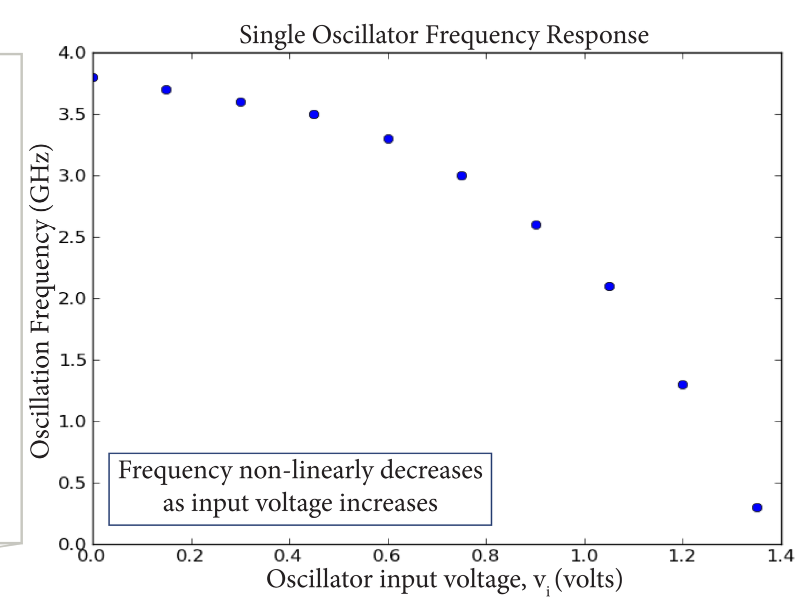
Background

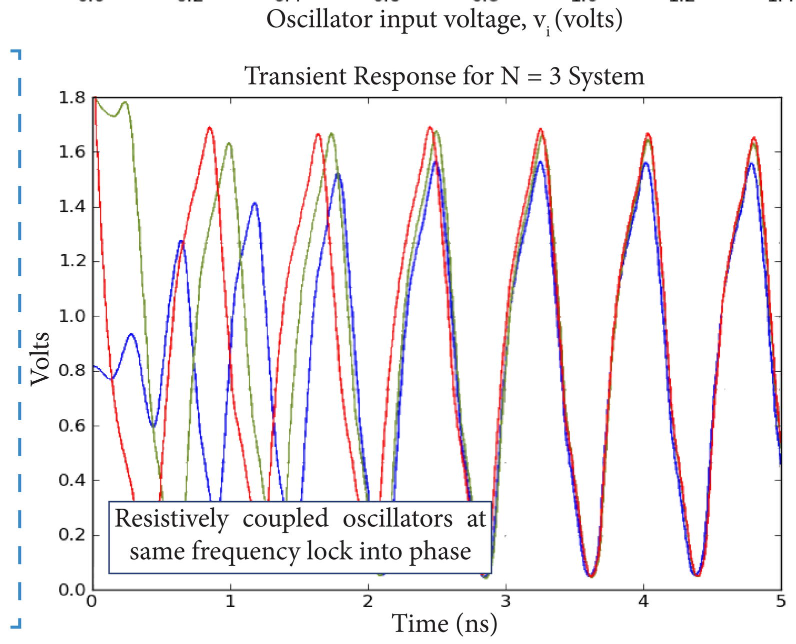
To overcome the power and performance limitations of CMOS technology, researchers are developing new technologies that are not based on a charge-based representation of state. In this work, we introduce a network of weakly coupled oscillators to perform the cognitive task of pattern recognition. We use a CMOS ring oscillator to study the behavior of the system, treating the ring oscillator as an analog for a class of emerging technologies that includes spin torque oscillators and resonant body transistors.

Pattern Matching

We compare two vectors, whose pairwise difference is represented by $\mathbf{V} = [v_0, v_1, v_2, ..., v_{N-1}]$ and offset by v_{match}. If all elements of $\mathbf{V}$ are equal to v_{match}, we have a perfect match.

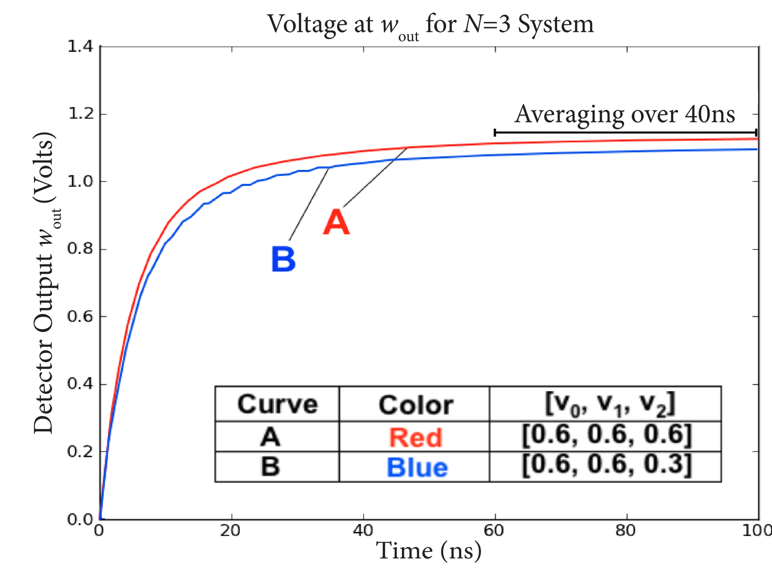


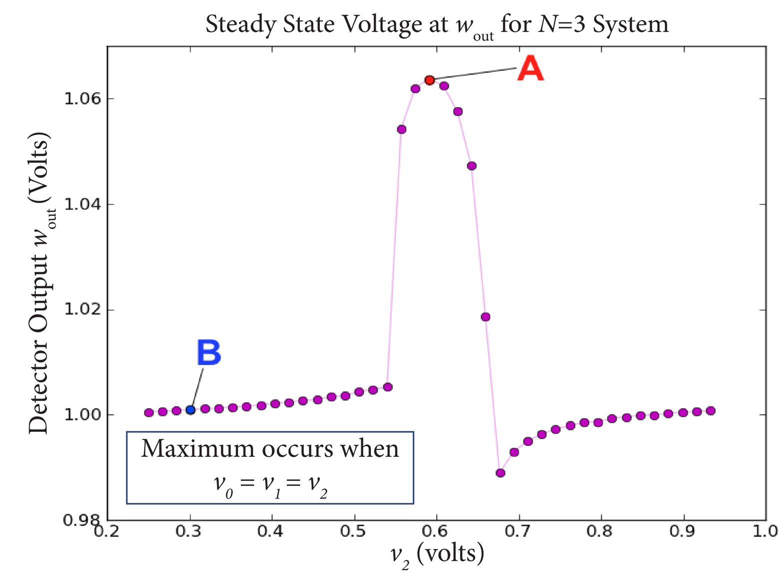


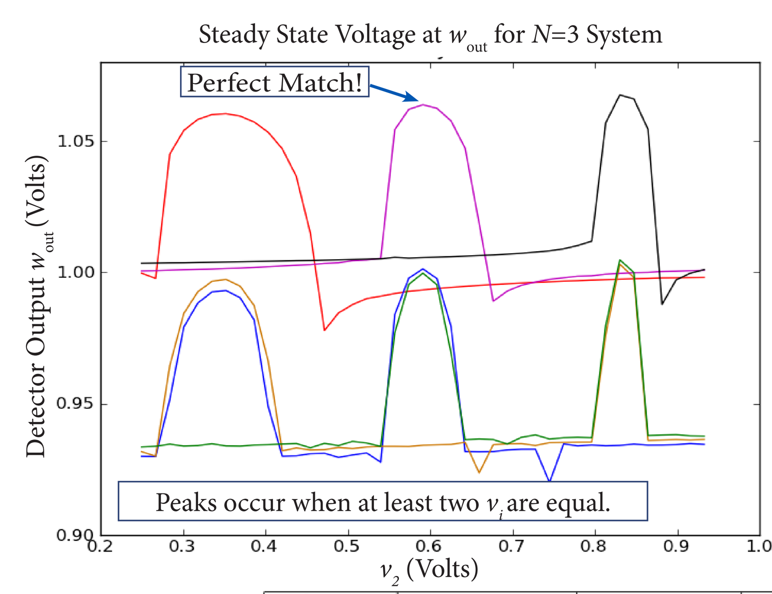


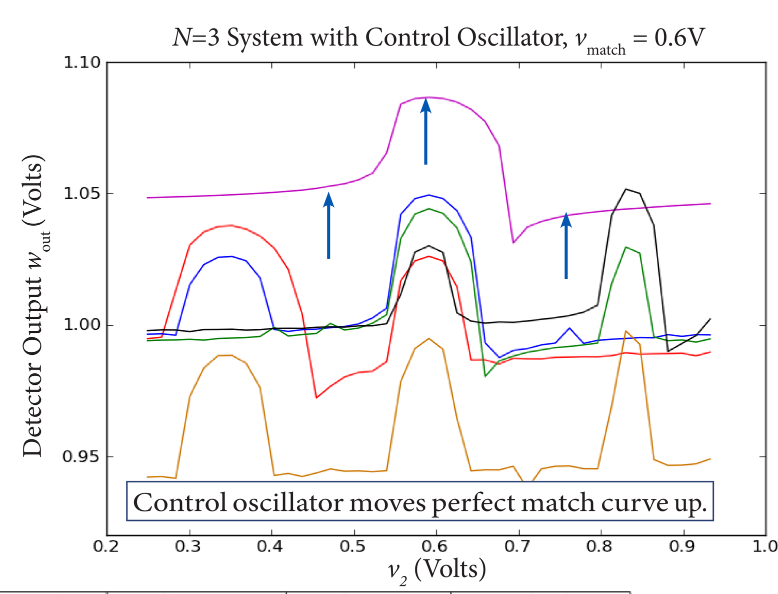
Oscillator System Design

- Each inverter ring produces a frequency non-linearly dependent on its input voltage, v_i
- N oscillators coupled resistively through common node, w_{com}
- Oscillators at same frequency and lock in phase
- Common node is buffered using a CMOS inverter
- Buffered signal is rectified and integrated









Color	Red	Blue	Purple	Orange	Green	Black
$[v_0, v_1]$	[0.35, 0.35]	[0.35, 0.6]	[0.6, 0.6]	[0.35, 0.85]	[0.6, 0.85]	[0.85, 0.85]

Steady State Response

- Resonance causes increased values of w_{out}
- Detector shows maximum when elements of input vector are all equal
- Different input vectors produce family of curves shown above
- Curves produced by cases where $v_0 = v_1$ have overall higher voltages and only have a single peak corresponding to $v_0 = v_1 = v_2$
- For cases where $v_0 \neq v_1$, we see two peaks where $v_0 = v_2$ and where $v_1 = v_2$
- This system reports a perfect match when all v_i are equal, but not necessarily equal to to v_{match}.

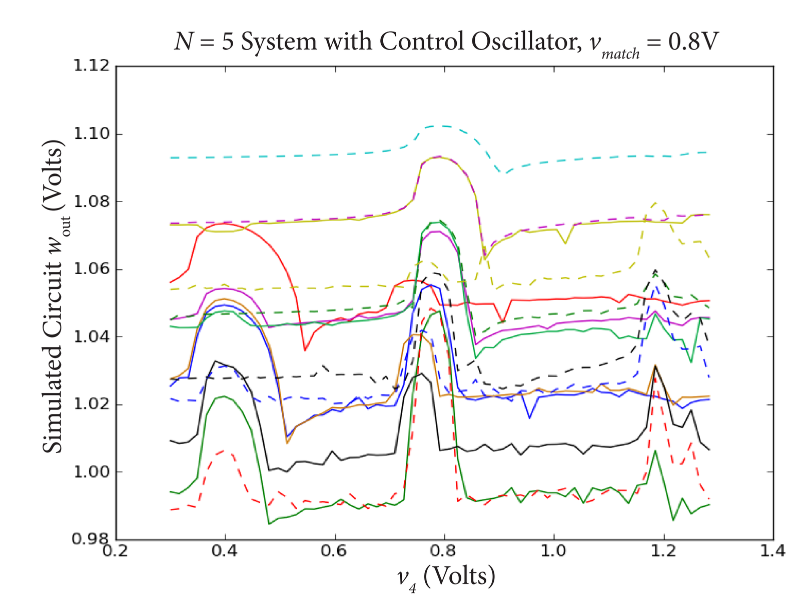
Control Oscillator

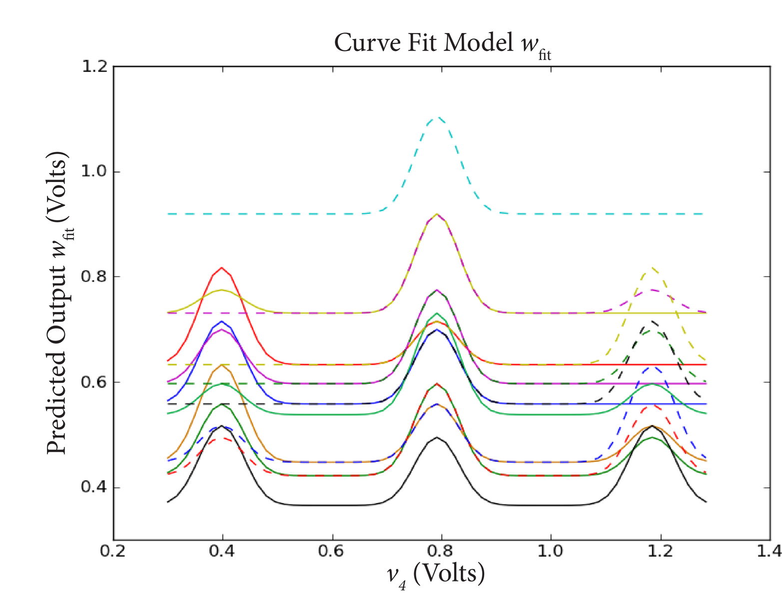
- To increase the output of a perfect match, ensuring that it is a global maxima, we couple an additional 'control' oscillator with a constant input voltage
- Control oscillator coupled through R_{ctrl}, whose value can be lowered to increase the weighting of the control oscillator
- By lowering R_{ctrl}, we raise the curve corresponding to a perfect match
- For N = 3, we use 50kΩ for R_{ctrl}, but as we increase N to 5, the value of R_{ctrl} is decreased to 30kΩ

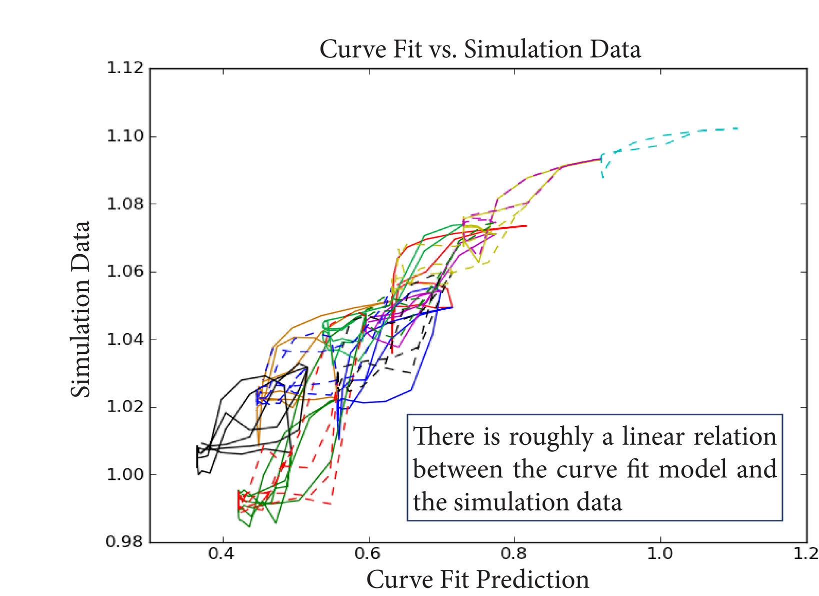
Mathematical Model

- To integrate the oscillator behavior into a higher level architecture, we model the behavior of the detector circuit using the curve fit equation, w_{fit}
- Pairwise differences between v_i and v_j are more important than the actual values of v_i and v_j
- Peaks occur when pairwise differences between different elements of $\boldsymbol{V}$ are zero and are represented by Gaussian curves
- Parameter γ describes the width of the peaks
- α equals $50k\Omega/R_{ctrl}$ to account for the weighting of control oscillator
- Equation is normalized to the number of pairwise differences between each pair of inputs and also v_{match}, $N(N+1)/2$
- Exponent 1/2 is a curve fit parameter to reduce the height of upper peaks

$$w_{fit}(\vec{V}) = \left[\frac{2}{N(N+1)}\left(\sum_{i}^{N-1}\sum_{j}^{i-1} exp\left(-\frac{|v_i - v_j|^2}{\gamma}\right) + \alpha\sum_{i}^{N-1} exp\left(-\frac{|v_{match} - v_i|^2}{\gamma}\right)\right)\right]^{\frac{1}{2}}$$







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