Parallel Computation using MEMS Oscillator-based Computing System

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Background

- Brains consisting of neurons characterized by periodic activities are good at information processing. The rhythmic behaviors of networks of neurons inspire human to unveil the rationale behind the scene.
- Parallel computing systems such as artificial neural network, which emulate the behaviors of human brains, have been developed where execution of processes are carried out simultaneously.

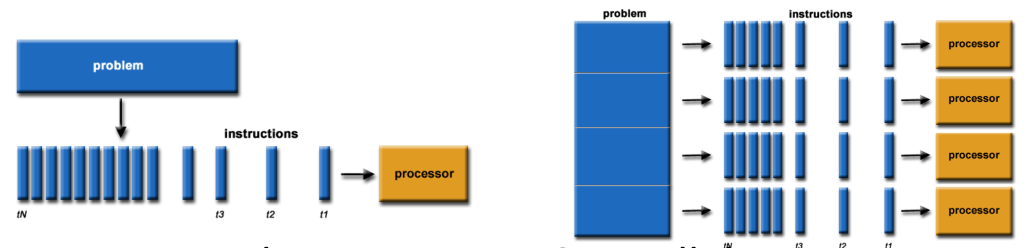

Figure 1 Serial Computation & Parallel Computation

- However, it is still a challenging engineering problem to design highly efficient hardware for parallel computing systems.

Why MEMS Oscillator?

Definition:

- Microelectromechanical system (MEMS) oscillators are timing devices that generate highly stable reference frequencies.

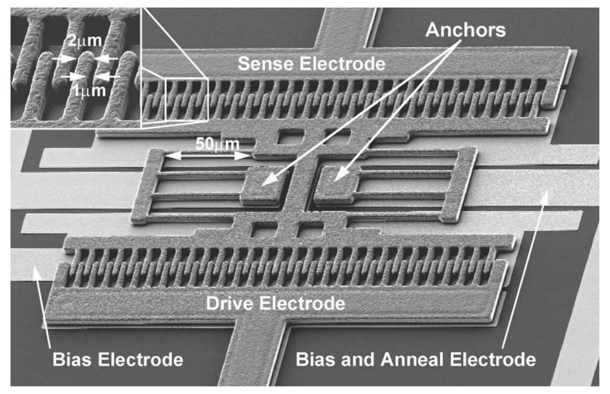

Figure 2 MEMS Oscillator Structure

- Feasibility:
  - Frequency locking
  - Phase locking
  - Synchronization
- Advantage:
  - Lower price and easiness for manufacturing
  - More power efficient than CMOS
  - Processing nonelectric analog information from physical world

Phase Locking

If the oscillator network has symmetrical coupling, the states of the network will always converge to an oscillatory phase locked pattern.

```
Coupling strength
[[ 0.   -3.07 -0.92]
 [-3.07  0.   -0.78]
 [-0.92 -0.78  0.  ]]
Initial Frequency of Oscillator 1:1.04rad/s
Initial Phase of Oscillator 1:0.70
Initial Frequency of Oscillator 2:0.21rad/s
Initial Phase of Oscillator 2:0.02
Initial Frequency of Oscillator 3:0.63rad/s
Initial Phase of Oscillator 3:0.92
```

Figure 3 Initial Setting of a 3-oscillator Network

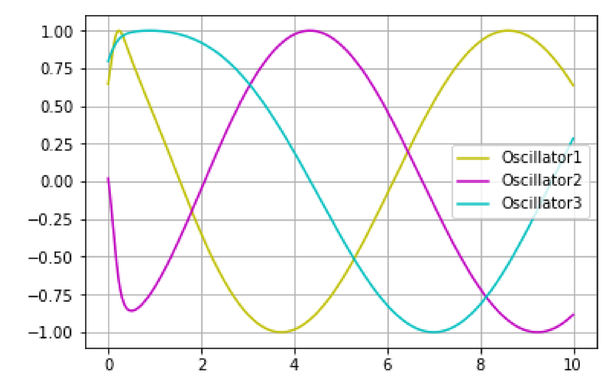

Figure 4 Simulation Result of Oscillator Network

Phase Locking Application:

Pattern Recognition

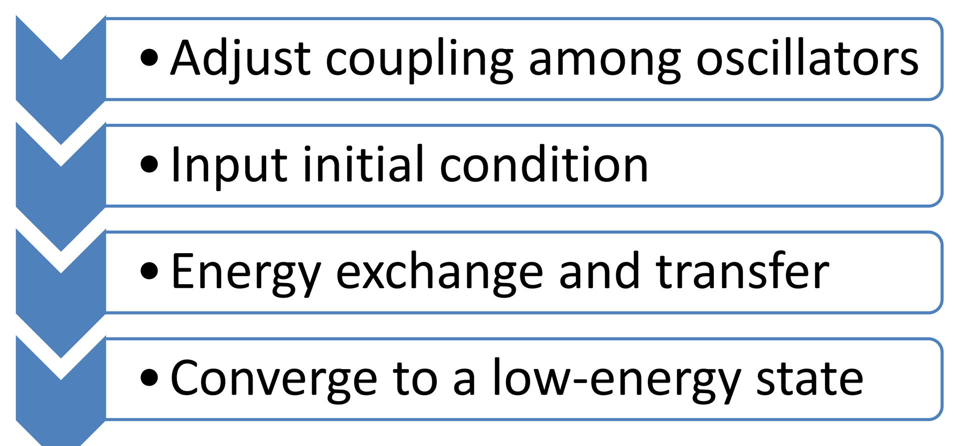

Figure 5 Pattern Recognition Process

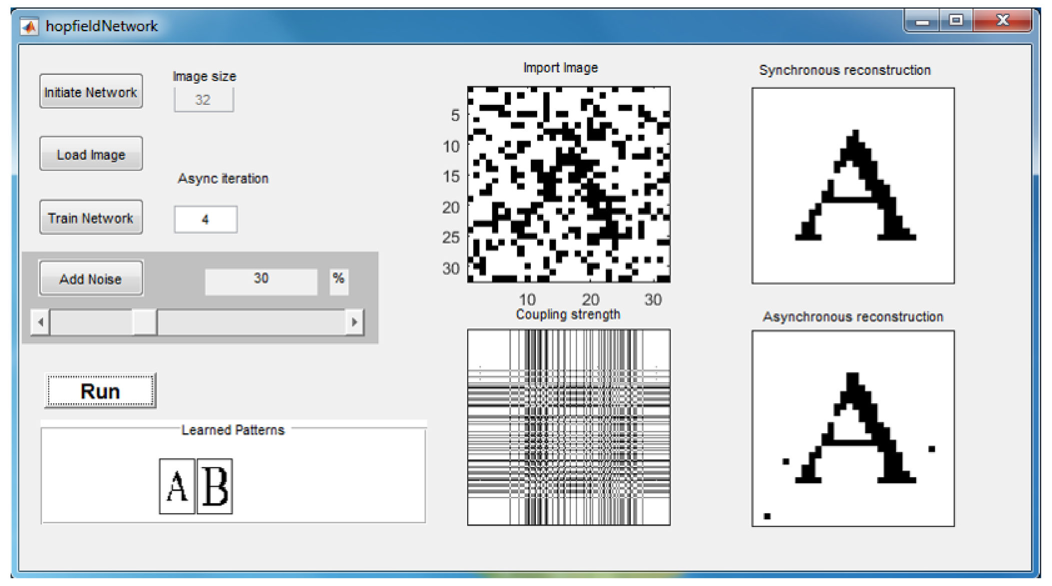

Figure 6 Pattern Recognition Simulation Result

Degree of Match

Degree of Match measures the extent the oscillator network synchronize.

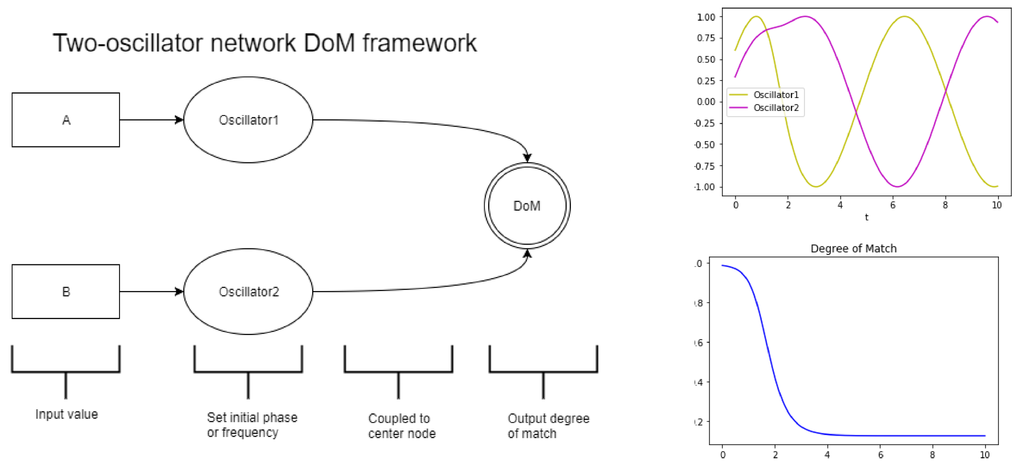

Figure 7 Degree of Match Simulation of 2-oscillator network

If input pattern A is similar to B, the oscillators' final frequencies or phases will be similar. If A is quite different from B, the final signal of oscillators will be chaotic and desynchronized.

Degree of Match Application:

Image Convolution

Motivation of Performing Convolution

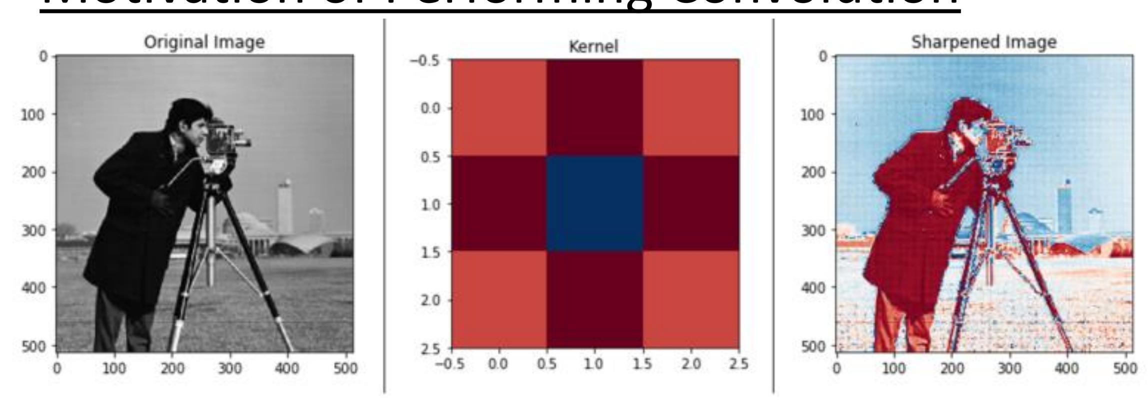

Figure 8 Sharpen via Convolution

- Convolution is the process of adding each element of the image to its local neighbors, weighted by the kernel.
- It is widely used in image processing and feature extraction.

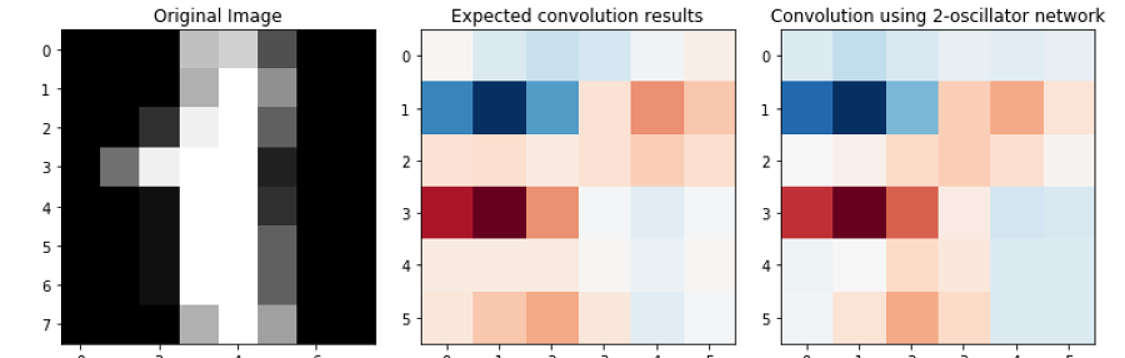

Figure 9 Simulation of Convolution using 2-oscillator Network

Conclusion

- MEMS oscillator network could be combined with algorithms to perform sensor-level information processing.
- MEMS oscillator network could become the future embedded computational system.
- MEMS oscillator network could be implemented in smart sensors.

Future Work

How can we find a learning rule that allows the arrays of MEMs oscillators to be adapted to new environment?

- To identify the ideal rule, we propose to explore an evolutionary approach. We think of a particular MEMS system as a living organism that compute for resources with each other. Organisms that are successful in learning tasks get to survive and produce offspring. Our application will be automatic memory formation and retention.

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Acknowledgement

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Reference

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