Systems on Nanoscale Information fabriCs

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2015 SONIC John Bardeen Student Research Award
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Oscillatory Neural Networks Based on Emerging Technologies

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Themes: 2385.003, 2385.004; **Task**: D.4.2.3 [#4-02]

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Motivation

- Human brains significantly out-perform modern computers in energy efficiency

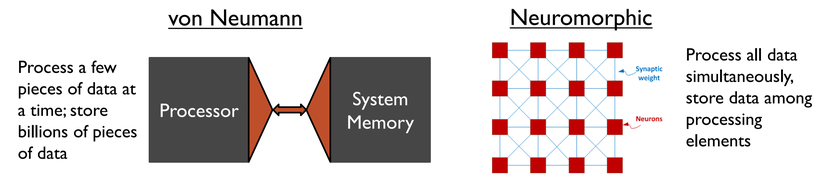
vs.

  - Human: 11 W, 1.2 Liters
  - IBM Watson: over 100 kW, 7500 Liters

- Inspired by the brain, we work to build integrated systems with brain-like architectures, called Neural Networks (NNs)
- The focus is to utilize emerging technologies to create novel neural circuits for information processing applications

Benefits and Opportunities

- NN circuits are proposed to surpass computational efficiency of von Neumann based systems for certain applications



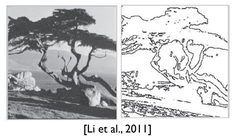
- However, implementations based on CMOS alone and conventional techniques are impractical due to complexity and power
- Mixed signal techniques can be more efficient through time-based processing
- Combining with emerging technologies has the potential to provide the efficiency that surpasses traditional solutions

Neural Network Applications

- All applications are based on same primitives with different arrangements of synaptic weights

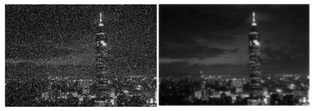
Image Processing

Edge Detection



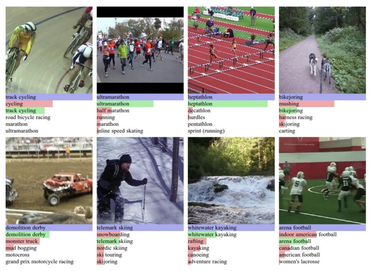
[Li et al., 2011]

Noise Removal



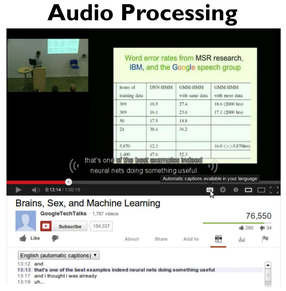
[Su et al., 2011]

Video Classification



[A. Karpathy et al., 2014]

Audio Processing



[H. Liao, E. McDermott, and A. Senior 2013]

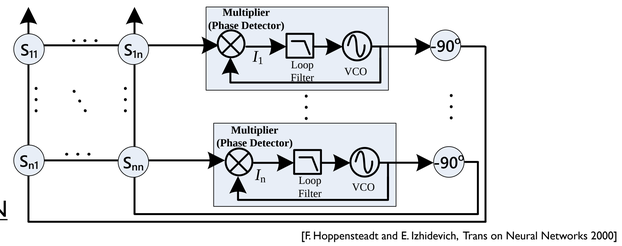
Objectives

- Build neuromorphic nano-primitives using emerging technologies and mixed signal design techniques for lower power
- Demonstrate the utility of combining CMOS with post-CMOS technologies in statistical information processing problems
- Further neuromorphic network theory in order to fabricate working systems

Oscillatory Neural Networks

- Oscillatory neural networks (ONNs) were inspired by the observation of synchronous oscillatory behavior in the human brain
- For IC integration, ONNs can be formulated as a set of neurons that are low-precision PLLs which are interconnected through synapses

Original PLL ONN

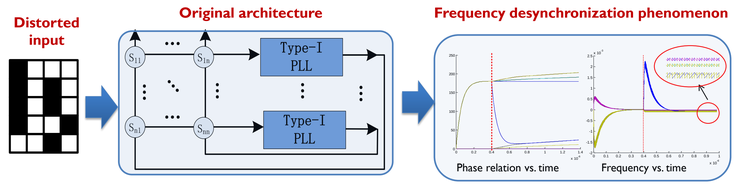


[F. Hoppensteadt and E. Izhidevich, Trans on Neural Networks 2000]

- Forms an associative memory where PLLs (neurons) synchronize and their phase relations settle to a stored pattern
- System works as-originally proposed in an infinite-bandwidth configuration

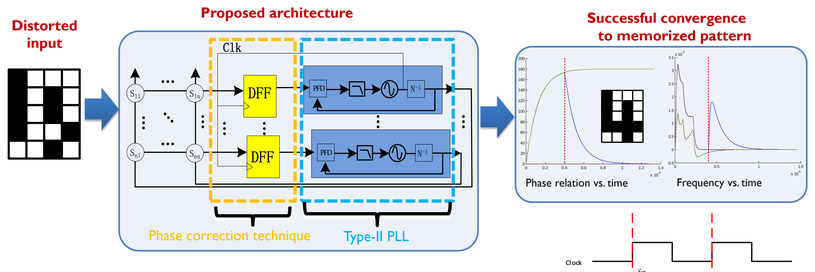
Theory to Hardware: Unexpected Challenges

- In a real system, physical components cause transmission delays
- These delays cause the failure in frequency synchronization

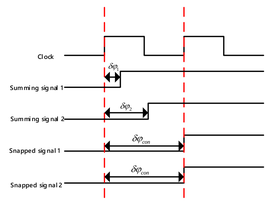


Solution through Improved Architecture

- Low-precision Type-II PLL ONNs combined with phase correction technique are robust against transmission delays in real system

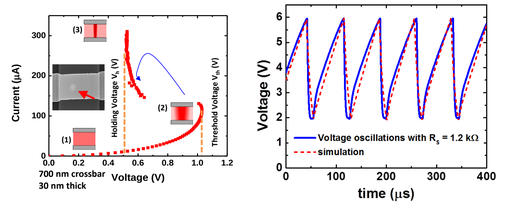


- See demo for a visualization of the frequency desynchronization phenomenon, and the behavior of the system once corrected

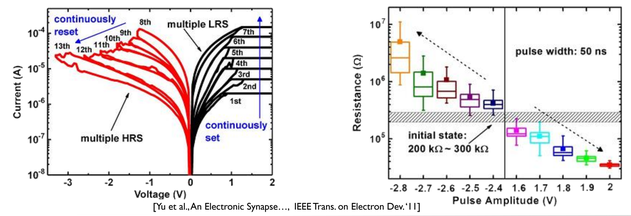


Transition Metal Oxide Nano-Oscillators and RRAM

- TMO nano-oscillators provide very dense low-power oscillators
- Neurons are formed from these nano-oscillators for power efficiency

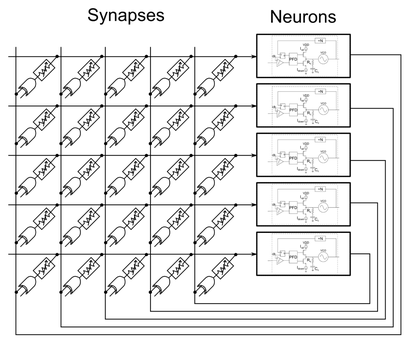


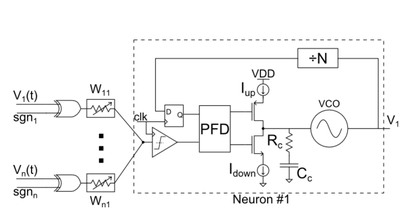
- Same CMOS-compatible material can be used for synaptic weights

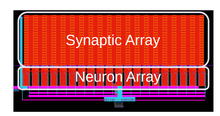


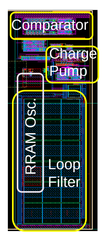
[Yu et al., An Electronic Synapse…, IEEE Trans. on Electron Dev.'11]

CMOS + TMO Nano-Oscillator Neural Networks





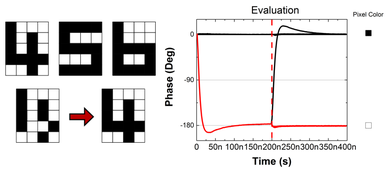




- CMOS taped out for fabrication in 28nm Samsung process
- TMO Nano-oscillators will be integrated at CMU
- Mostly-digital architecture allows for future scaling

Simulation Results and Estimated Performance

- Performs associative memory operation correctly in under 10ns
- Significant performance boosts over potential system previously reported



Design:	Oscillatory Network	Cellular Network
Technology	28 nm	65 nm
Neuron Area	1000 μm²	6400 μm²
Power	125 μW/Neuron	1.91 mW/Neuron
Time Constant	~ 10 ns	~ 50 ns

References

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