Solving Constraint Satisfaction Problem with Spiking Neural Network based on 1.4M 6T2R PCM Synaptic Array with 1.6K Stochastic LIF Neurons Neuromorphic Hardware

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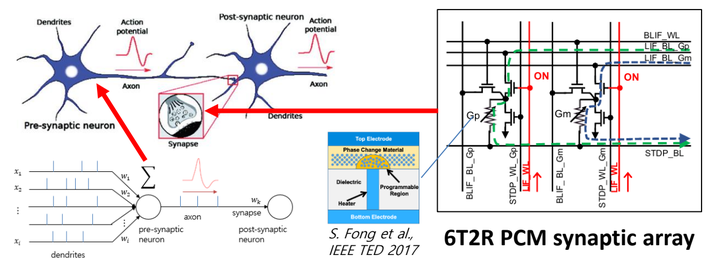
Introduction

Spiking Neural Network in 6T2R neuromorphic hardware

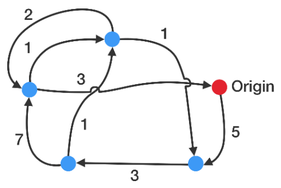


S. Fong et al., IEEE TED 2017

6T2R PCM synaptic array

Leaky-Integrate and Fire neuron
Phase Change Memory (PCM) synapse

Efficiently solve Non-deterministic Polynomial-time **(NP) hard problems**

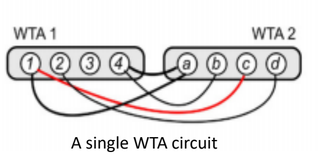


ex) Traveling Salesman Problem

Mathematically Formalized Algorithm

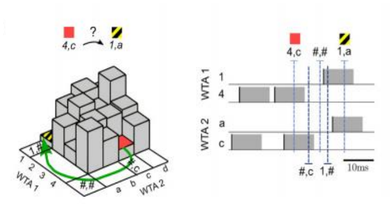
SNN with noise (such as random walk) stochastically searches to find the global minimum energy solution.

Variables are represented by Winner-Take-All (WTA) circuits



A single WTA circuit

Constraints are encoded into the interconnectivity (weight) between WTAs



Stochastic search via SNN enables faster convergence than pure gradient dynamics

Simulation

Ideal case

Mimic the activity of **ideal neuron** in the paper (Jonke et al.)
: Using **timestep** in simulation to **calculate firing probability** and decide which neuron to fire.

Real case

Parameters
Inhibition of neuron
Resting potential
Setting weights between neurons …

Whenever the potential of neuron (hidden) side exceed the threshold, the spike profile is synchronized to axon (visible) side to form **Boltzmann Machine(BM) structure**

Hardware Implementation

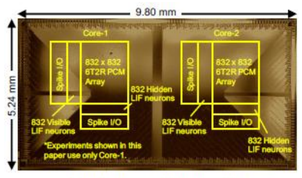
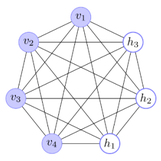


Fig. 10 Fabricated prototype chip

1.4M 6T2R PCM synaptic array with 1.6K stochastic LIF neurons neuromorphic hardware

Background Theory

Boltzmann Machine (BM)

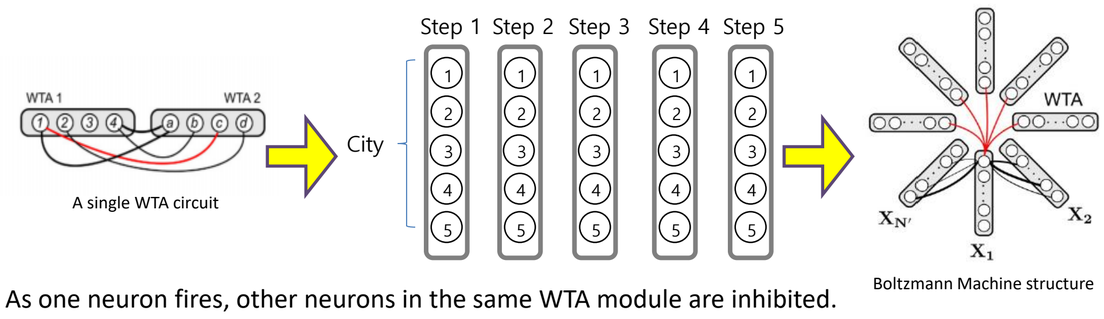


Network of symmetrically connected, neuron units that make stochastic decisions about whether to be on or off.

Traveling Salesman Problem (TSP)

Find a tour that visits all nodes in the graph exactly once with minimal total distance

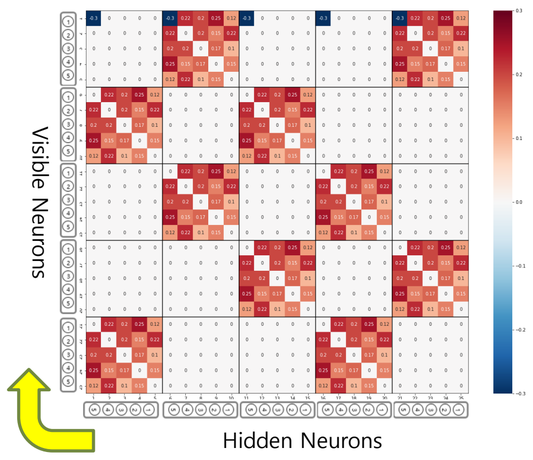
Winner-take-all (WTA) module



Boltzmann Machine structure

As one neuron fires, other neurons in the same WTA module are inhibited.
A single step form one WTA circuit. The number of neurons inside the step are the number of cities

Simulation Scheme



- The conductance of PCM synapse that reflects the constraints (for TSP, the distance between cities) are set before neuron activation.

- The start city (city 1) fires at certain frequency.

- As one neuron in the visible side fires, the spike will be delivered to the post-synaptic neurons (hidden side).

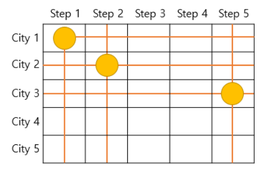
- Whenever the membrane potential of hidden neuron reaches the threshold voltage, the spike information will be synchronized to the visible neurons.

- This will form the complete setup of the Boltzmann Machine structure.

Results and Discussion

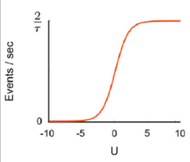
Simulation Setup for solving Traveling Salesman Problem

Neuron inhibition for WTA mechanism



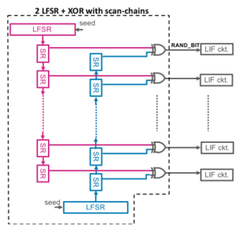
For WTA mechanism, neurons in the same step and same cities are inhibited after a single neuron fires.
This will remain for a **refractory period**

Resting potential



Resting potential after refractory period are set to **0.2** for every step to have at least one neuron to fire

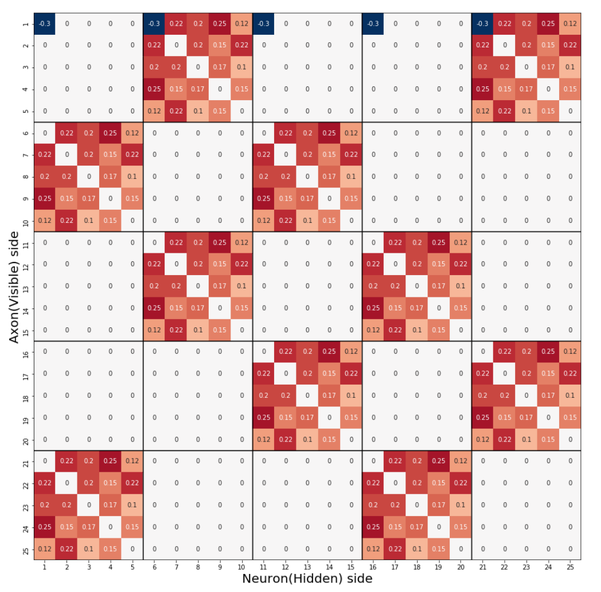
Stochastic behavior due to random walk



In order for network state to escape from the local minima, the stochastic computational annealing is adopted, using random walk by linear feedback shift register (LFSR).

Two LFSRs are prepared in one core as a random number generator.
In this work, the membrane potential of each neurons are changed by +0.06V or -0.06V in every random walk timestep.

PCM synaptic array weight setup



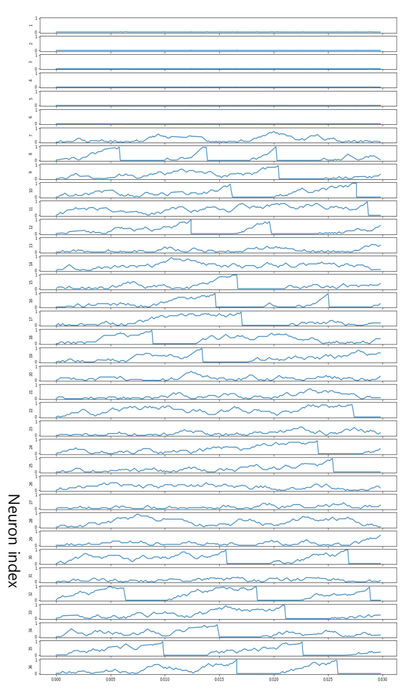
1. No self connection and no connection between non-adjacent steps (=0)
2. Inhibition of start city 1 neurons inside each steps = **- 0.3**
3. Inhibition of same city neurons between WTA modules are controlled by **freezing** the neurons
4. Weights between adjacent steps

$$weight = 0.1 + \left(1 - \widetilde{c_{ij}}\right) * 0.2$$

$\widetilde{c_{ij}}$ denotes the distance normalized by the maximum distance

Positive weight is controlled by *Gp* while negative weight is controlled by *Gm* from 6T2R PCM synapse structure

Simulation Results for solving Traveling Salesman Problem



Potential-time plot TSP simulation solver of 5 cities

Potential-time plot TSP simulation solver of 5 cities

- By recording for each WTA module which neuron has fired most recently, we can decode at any time *t* the firing activity of the whole network as a proposed TSP solution

- The simulation of SNN based on the characteristics of 6T2R neuromorphic hardware shows desired behavior; refractory period with inhibition of other neurons.

- For the TSP of 5 cities, the simulation quickly search the optimal solution of 1-3-2-5-4 tour with 0.02547 seconds in simulation time and frequently shows the optimal tour.

Stochastic search by random walk enables fast search of optimal solution for TSP of 5 cities

Summary

- The spiking neuron simulation based on 6T2R neuromorphic hardware works in a desirable fashion; spike generated from the hidden side are synchronized to visible side for Boltzmann Machine structure.

- For the TSP of 5 cities, the simulation quickly search the optimal solution at 0.02547 seconds in simulation time and frequently shows the optimal tour. The result is also reproducible.

- In order to solve large scale TSP, weights (the conductance of PCM) should be carefully optimized.