Artificial Kuramoto Oscillatory Neurons (AKOrN)

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Introduction

This paper presents **Artificial Kuramoto Oscillatory Neurons**, a dynamic alternative to traditional units in neural networks. The core advantage of AKOrN lies in:

- **Synchronization dynamics**, which enhance neuron binding and promote more abstract representations.
- **Versatile integration** with various network designs such as CNN and attention mechanisms.

The results show improved performance in tasks such as unsupervised object discovery, adversarial robustness, and uncertainty quantification.

Dataset and pre-processing

We focus on evaluating Sudoku-related tasks.

Dataset Overview

- Sudoku Dataset(ID): Contains 9,000 training samples and 1,000 testing samples.
- Hardsudoku Dataset(OOD): Contains 18,000 testing samples.

Pre-processing

Both data and label are transformed in one-hot encoded tensors of shape $(B,9,9,9)$.

Methods and tricks

To enhance synchronization and feature binding, we employ **Kuramoto oscillatory dynamics** in the K-Layer, where each neuron is a unit vector on a hypersphere, updated as:

$$\dot{x}_i = \Omega_i x_i + Proj_{x_i}(c_i + \sum_j J_{ij} x_j)$$

where: x_i is the neuron state,
Ω_i controls oscillatory frequency,
J_{ij} defines neuron coupling.

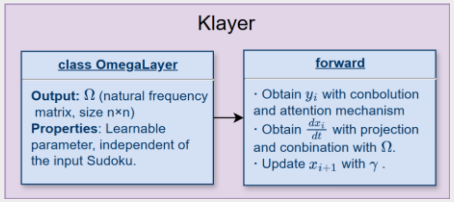
The network use convolution or attention block to capture the interaction between different network, simulating the syntony.

Training is stabilized with **adaptive learning rates** and **gradient clipping** to handle oscillation effects efficiently.

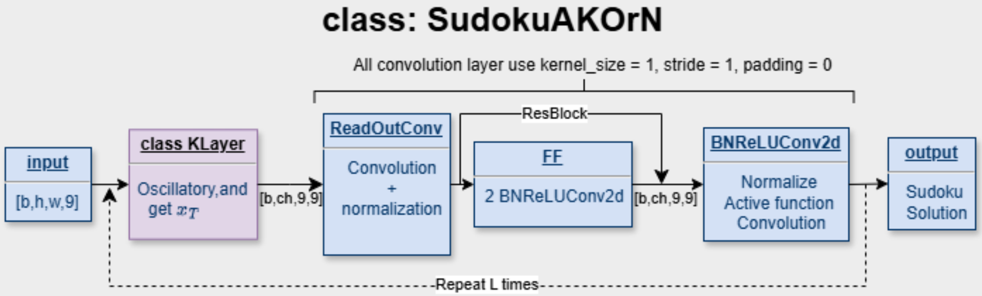
K-Layer

The KLayer is the key structure for implementing the Kuramoto Oscillatory. It demonstrates the logic of equation on the left.

It gives inherent frequency and capture the interactions between neurons, thus, donates the acceleration in the direction of the tangent to the sphere. After a predetermined time of synchronous oscillation, the results are obtained.



Flow chart of SudokuAkorN



Results

Model	ID	OOD
ItrSA($T_{eval}=32$)	100	37.7
Transformer($T_{eval}=1$, L=8)	99.6	9.3
AKOrN($T_{eval}=128$)	100	47.3
AKOrN($T_{eval}=128$, K=100)	100	76.6

Table: Board accuracy(%) on sudoku

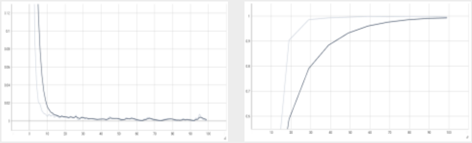


Figure: training loss(left) and board accuracy of AKOrN

Conclusion

Advantages

High accuracy with appropriately chosen hyperparameters, better than other models

Disadvantages

- Cost of increased computational time for bigger K
- Poor performance at complex problems
- Difficulty in constraint enforcement, like repetition problem

References

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