Cyclone Track Prediction with Matrix Neural Network

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Introduction

Background Briefing

What is cyclone?

Why we need to predict cyclone path?

Literature Reviews

Cyclone track prediction techniques can be roughly divided into several categories:

- Statistical Methods [9], [3], [10], [6]
- Deterministic Models [4], [8] [5]
- Machine Learning Methods [2], [1], [7], [11]

Research Setting

Methodology: Matrix Neural Network

Dataset: Cyclones in North Indian Ocean across 1986-2015

Baseline Model: Elman RNN, LSTM, GRU

Data Pre-processing

Data Pre-processing

Period: 1986-2013

Amount: 286 Cyclones

$(\mathrm{x}^j, \mathrm{y}^j) \in \mathbb{R}^{T_j \times 2}$ for longitude and latitude pairs as a sequence of the j-th cyclone (j$\in [1, 271]$).

We need to reshape each cyclone for training and prediction.

Data Reshape

$\mathbf{m}_t^j \in \mathbb{R}^{\alpha \times 2}$ as the input sliding window with the step size α covering observation from t to $(t+\alpha)$-th observations,

while $\mathbf{n}_t^j \in \mathbb{R}^2$ as the output for that specific sliding window, which is the subsequent 1 observation (the $(t+\alpha+1)$-th observations).

$$\mathbf{m}_t^j = \begin{bmatrix} x_{t+1}^j & y_{t+1}^j \\ x_{t+2}^j & y_{t+2}^j \\ \vdots & \vdots \\ x_{t+\alpha}^j & y_{t+\alpha}^j \end{bmatrix} \quad \text{and} \quad \mathbf{n}_t^j = \begin{bmatrix} x_{t+(\alpha+1)}^j \\ y_{t+(\alpha+1)}^j \end{bmatrix}. \tag{1}$$

The corresponding tensor input for the j-th cyclone is $\mathbf{m}^j \in \mathbb{R}^{(T_j-\alpha)\times\alpha\times 2}$,

while the tensor output is $\mathbf{n}^j \in \mathbb{R}^{(T_j-\alpha)\times 2}$

Methodologies

Tucker Decomposition

$$\mathcal{U} = \mathcal{V} \times_1 \mathsf{A}_1 \times_2 \mathsf{A}_2 \times_3 \cdots \times_n \mathsf{A}_n \tag{2}$$

Explantion

$\mathcal{V} \in \mathbb{R}^{a_1 \times a_2 \times \cdots \times a_n}$ as the core tensor,

and $\mathsf{A}_i \in \mathbb{R}^{a_i \times b_i}$ is matrix that update the certain mode a_i of the original $\mathcal{V}$.

These calculations above generate a new tensor $\mathcal{U} \in \mathbb{R}^{b_1 \times b_2 \times \cdots \times b_n}$.

Therefore we can say that an n-dimensional tensor $\mathcal{U}$ can be decomposed by an n-dimensional core tensor $\mathcal{V}$ and n matrices A_i $\forall i \in [1, n]$

Matrix Neural Network

Matrix Neural Network borrows the idea from Tucker Decomposition :

$$\mathsf{X}^{l+1} = \sigma(\mathsf{W}^l \mathsf{X}^l \mathsf{V}^{lT} + \mathsf{B}^l) \tag{3}$$

Explantion

where, $\mathsf{X}^l \in \mathbb{R}^{a \times b}$ is the input at layer l,

$\mathsf{X}^{l+1} \in \mathsf{R}^{p \times q}$ is the output from layer l,

W^l and V^l are the fully connected weights, and B^l is the bias term,

$\sigma(\cdot)$ serves as an activation function, whose mapping can be intuitively explained by the following figure:

Mapping of MNN

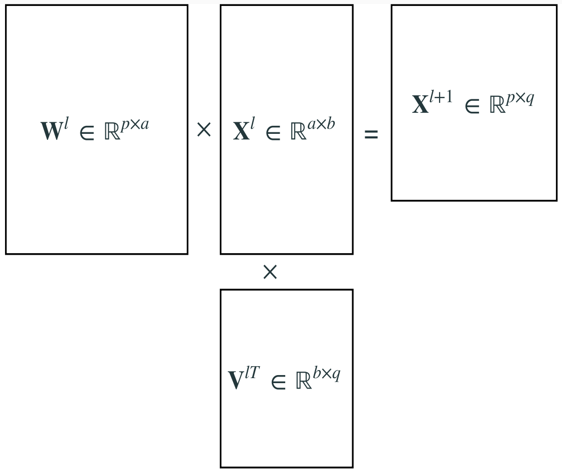


Figure 1: Matrix Neural Network Mapping

Other Details

Loss Function: $\min \sum_{j=1}^{N} L(\hat{\mathsf{n}}^j, \mathsf{n}^j) = \sum_{j=1}^{N} \frac{1}{T_j - \alpha} \|\mathsf{n}^j - \hat{\mathsf{n}}^j\|_2^2$

Optimisation Algorithms: RMSprop

Experiments

Origin: Joint Tropical Warning Center (JTWC)

Amount: 286 cyclones

Covering Period: 1986-2013

Individual Cyclone Length: between 20-40 locations point (6 hours for each location collection)

Training Set: 211 Cyclones

Testing Set: 75 Cyclones

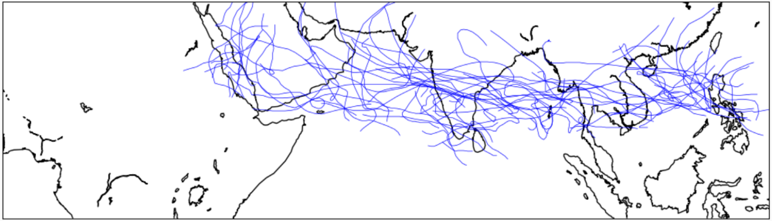


Figure 2: Cyclone tracks in the North Indian ocean

Training Process

Training process mimics SGD. While the network is trained with multiple cyclones, each training would only use one cyclone, and all the cyclones would be utilised in the whole training. Weights passes between different training.

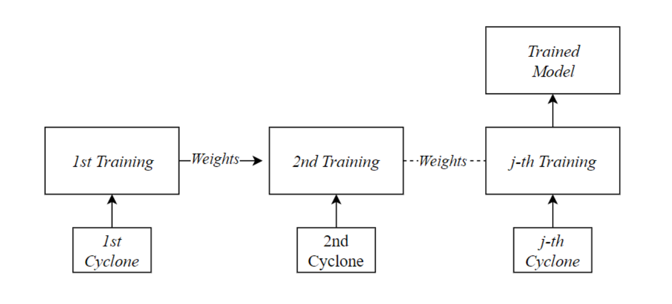


Figure 3: Training Process

Individual Training

The individual training process is explained as follows:

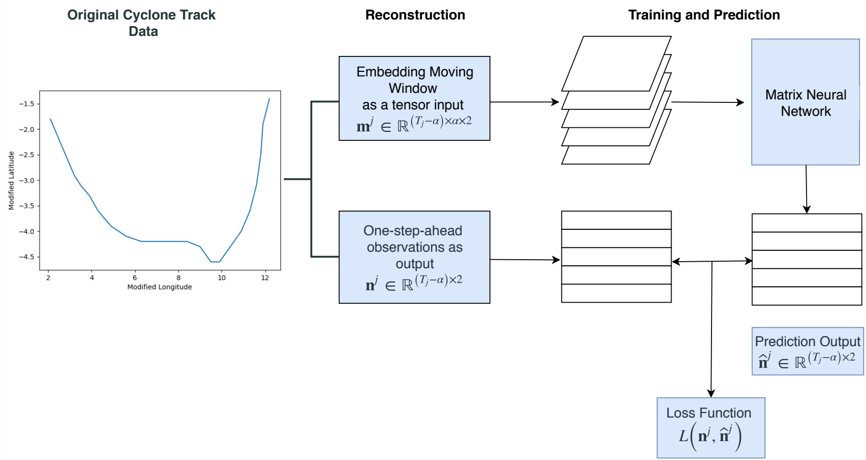
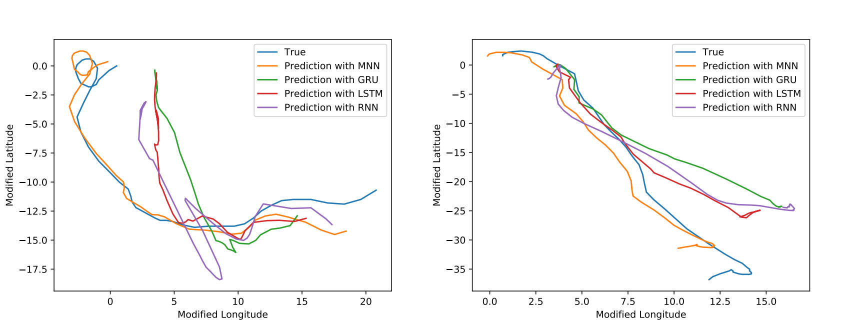


Figure 4: Individual Training Process

Examples of Prediction



(a) 8-th Cyclone **(b)** 38-th Cyclone

Testing RMSE

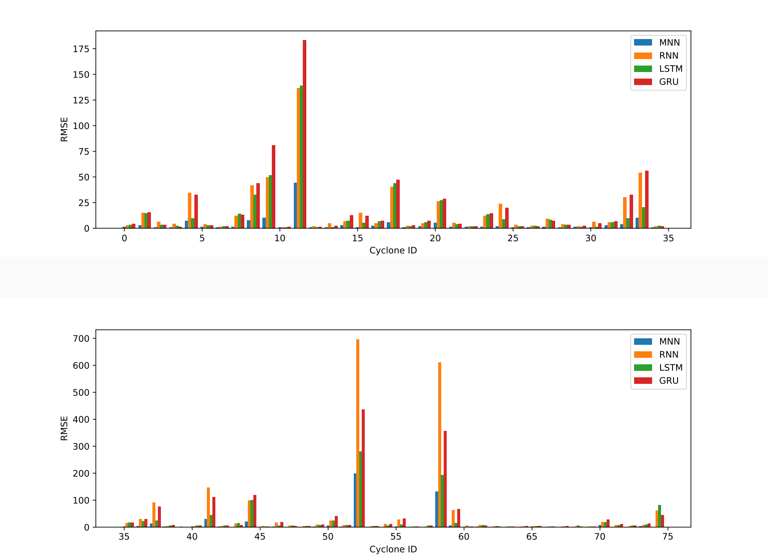


Figure 6: RMSE for Cyclones in Testing Set

Conclusion

Summary

The contribution of this article are listed as follows:

- Explored the performance of matrix neural network in time-series data
- Introduced a new method in cyclone track prediction

The drawback of this article is listed as follows:

- Why matrix neural network outperformed RNN, LSTM, and GRU hasn't yet been explained clearly

Questions?

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