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All-in-One Course

RNN/LSTM for Sequence and Time-Series Data

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Ph.D. in Computer Science

Year 2023

Outline

- RNN in PyTorch
- RNNs for Time-Series Data
- RNNs for IMDB dataset
- From RNN to LSTM
- LSTM Applications

Embedding Layer

Increase space dimentions

index	word
0	[UNK]
1	[pad]
2	ai
3	a
4	are
5	cs
6	is
7	learning

0
4
7
2
1

We are learning AI

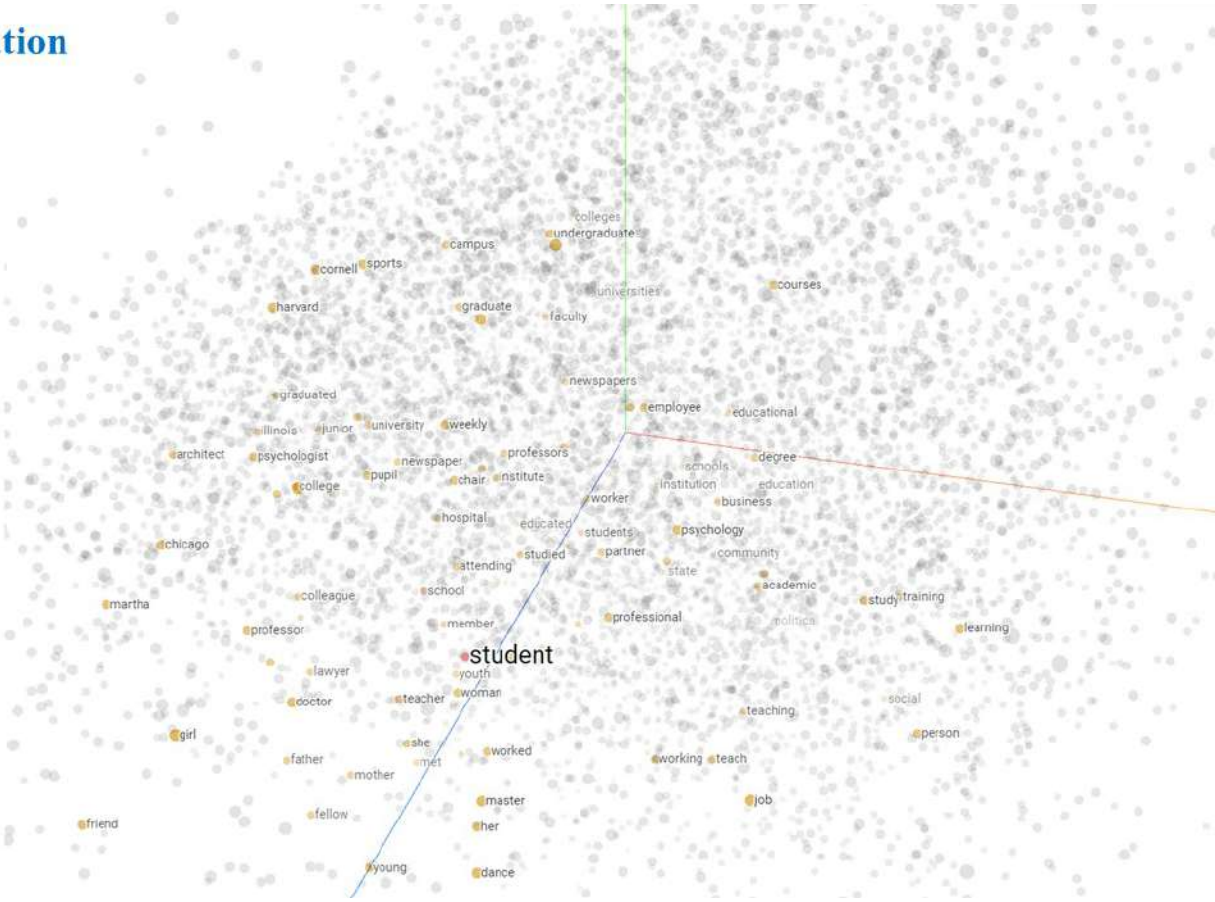
be updated

After one update

```
Parameter containing:
tensor([[-0.1882,  0.5530,  1.6267,  0.7013],
        [ 1.7840, -0.8278, -0.2701,  1.3586],
        [ 1.0281, -1.9094,  0.3182,  0.4211],
        [-1.3083, -0.0987,  0.7647, -0.3680],
        [ 0.2293,  1.3255,  0.1318,  2.0501],
        [ 0.4058, -0.6624, -0.8745,  0.7203],
        [ 0.5582,  0.0786, -0.6817,  0.6902],
        [ 0.4309, -1.3067, -0.8823,  1.5977]],
```

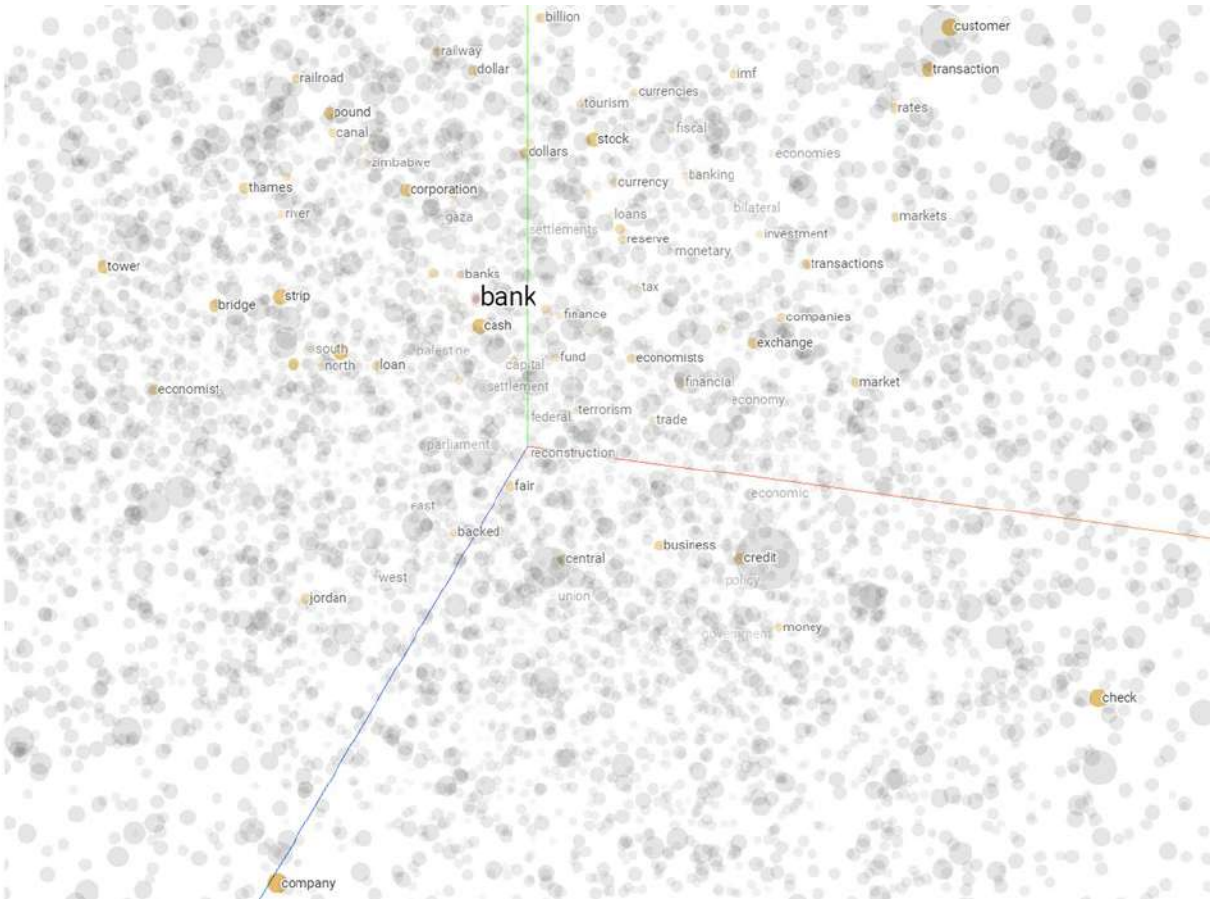
```
Parameter containing:
tensor([[-0.1872,  0.5540,  1.6277,  0.7023],
        [ 1.7830, -0.8268, -0.2711,  1.3576],
        [ 1.0291, -1.9084,  0.3192,  0.4201],
        [-1.3083, -0.0987,  0.7647, -0.3680],
        [ 0.2303,  1.3245,  0.1308,  2.0511],
        [ 0.4058, -0.6624, -0.8745,  0.7203],
        [ 0.5582,  0.0786, -0.6817,  0.6902],
        [ 0.4299, -1.3077, -0.8833,  1.5967]],
```

Embedding visualization



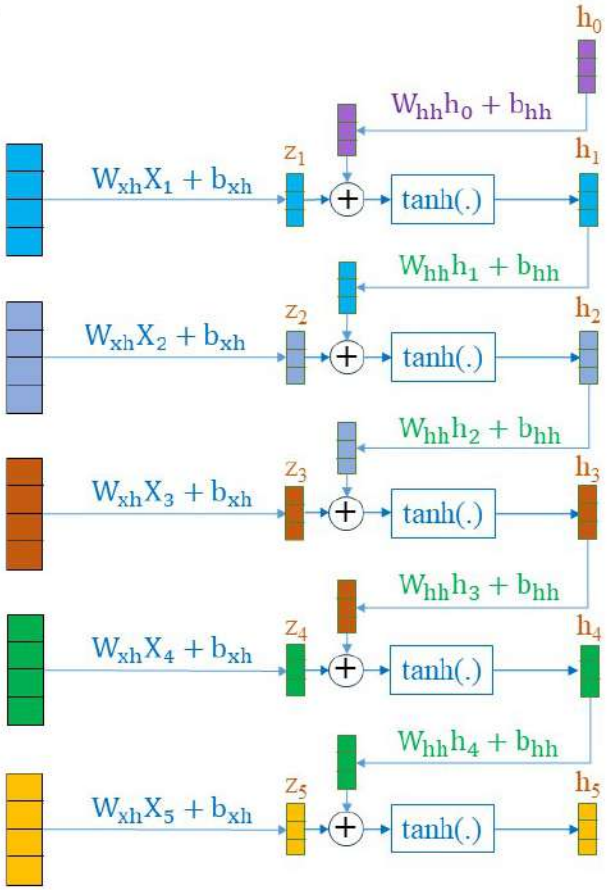
https://projector.tensorflow.org/

Embedding visualization



https://projector.tensorflow.org/

RNN



$h_0 = \mathbf{0}$ $b_{hh} = \mathbf{0}$

$$h_1 = \tanh(W_{xh}X_1 + b_{xh} + W_{hh}h_0 + b_{hh})$$

$$h_2 = \tanh(W_{xh}X_2 + b_{xh} + W_{hh}h_1 + b_{hh})$$

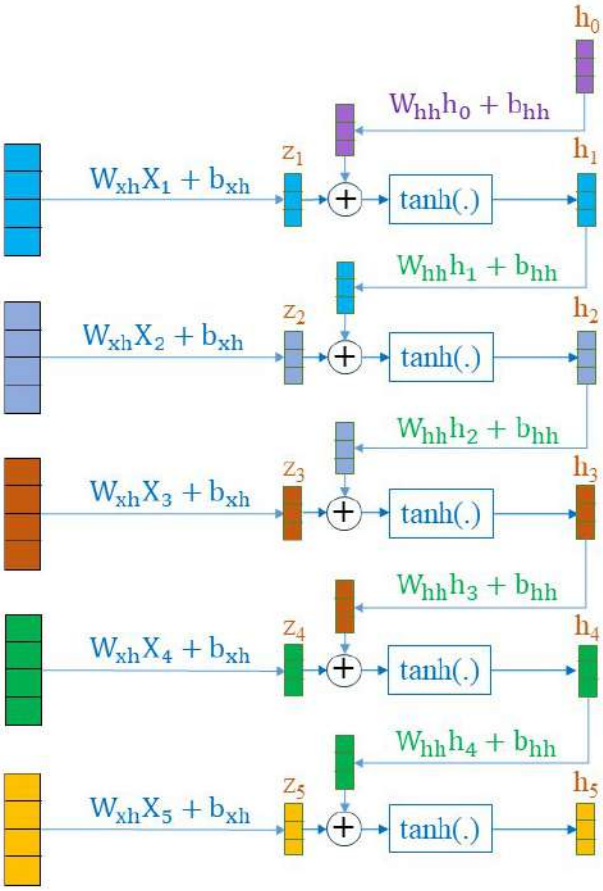
$$h_3 = \tanh(W_{xh}X_3 + b_{xh} + W_{hh}h_2 + b_{hh})$$

$$h_4 = \tanh(W_{xh}X_4 + b_{xh} + W_{hh}h_3 + b_{hh})$$

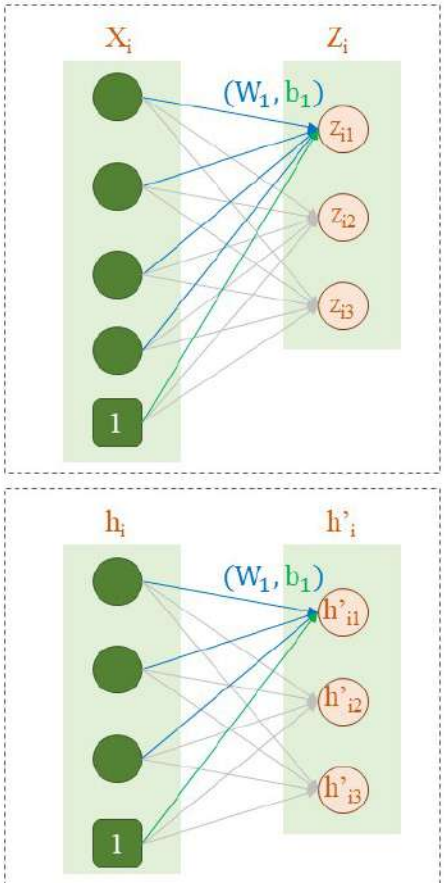
$$h_5 = \tanh(W_{xh}X_5 + b_{xh} + W_{hh}h_4 + b_{hh})$$

➡ $$h_t = \tanh(W_{xh}X_t + b_{xh} + W_{hh}h_{(t-1)} + b_{hh})$$

RNN



Discussion



Stack of RNNs

❖ **Recurrent Neural Networks (RNNs)**

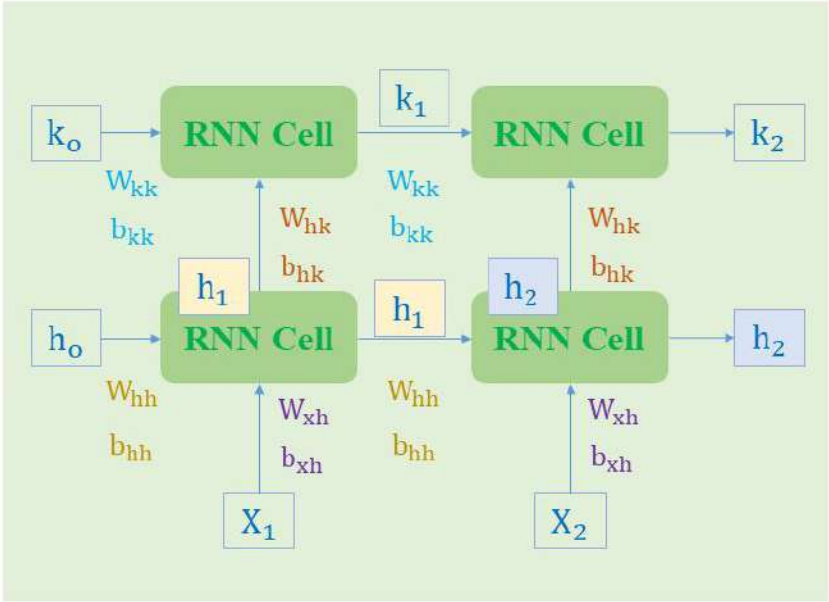
❖ **Two layers**

$$k_1 = \tanh(W_{hk}h_1 + b_{hk} + W_{kk}k_0 + b_{kk})$$

$$k_2 = \tanh(W_{hk}h_2 + b_{hk} + W_{kk}k_1 + b_{kk})$$

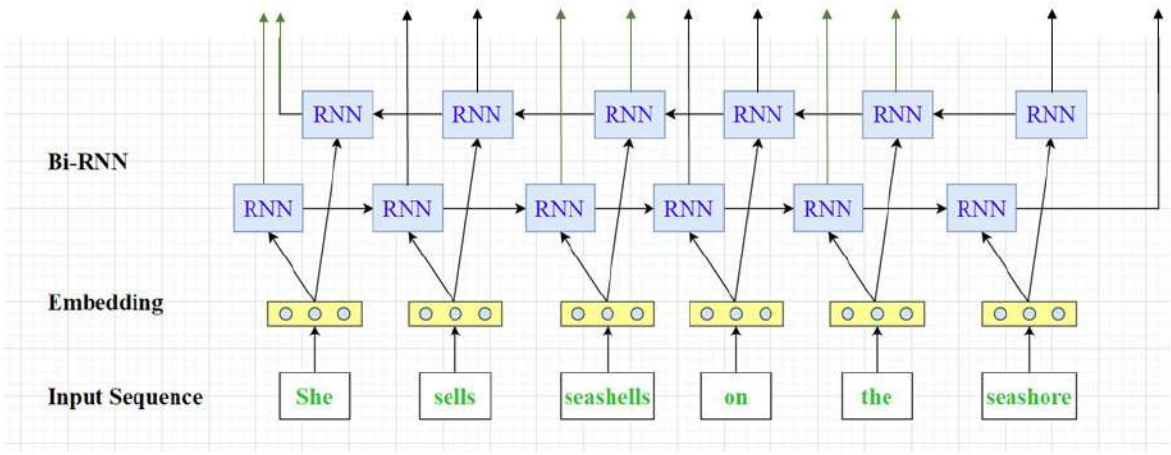
$$h_1 = \tanh(W_{xh}X_1 + b_{xh} + W_{hh}h_0 + b_{hh})$$

$$h_2 = \tanh(W_{xh}X_2 + b_{xh} + W_{hh}h_1 + b_{hh})$$



RNNs

❖ Bidirectional RNNs



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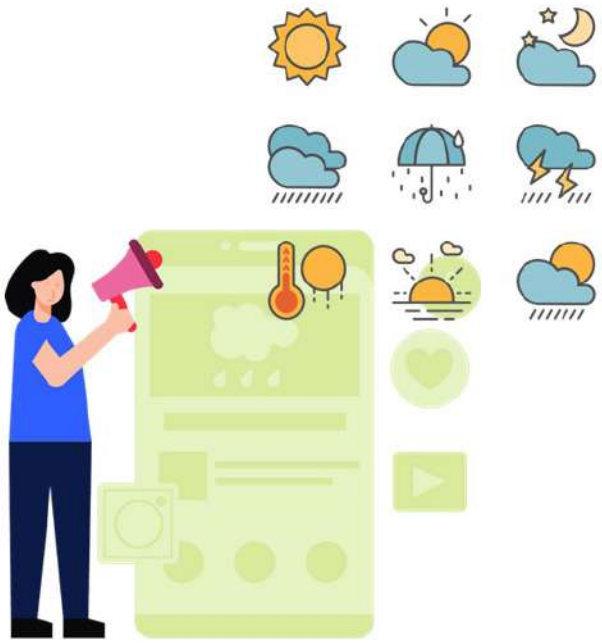
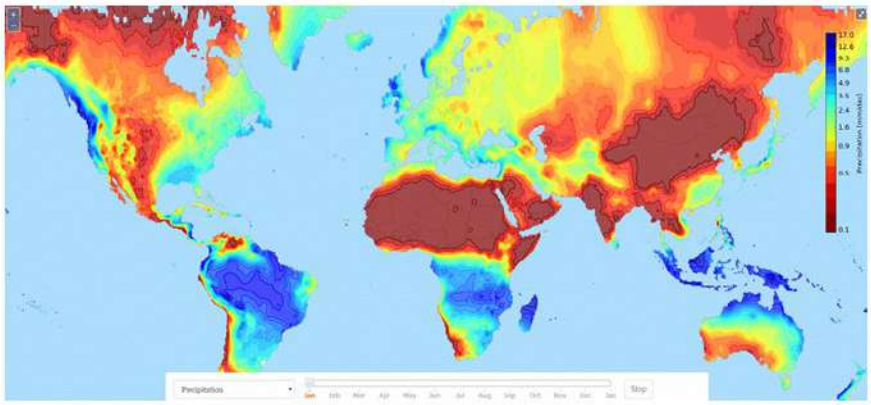
Weather Forecasting

❖ Introduction





Predict future temperature in weather forecasting

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Weather Forecasting

❖ Introduction

Problem Statement: Given temperature from the previous 5 hours (including the current one), predict temperature of the next 1 hour.

Hour	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00
Condition								
Temperature	32	31	31	30	29	26	25	

Time-series Data

Temperature forecasting

Date	Summary	Precip Type	Temperature (C)	Apparent Temperature (C)	Humidity	Wind Speed (km/h)	Wind Bearing (degrees)	Visibility (km)
2006-04-01 00	Partly Cloudy	rain	9.472222222	7.388888889	0.89	14.1197	251	15.8263
2006-04-01 01	Partly Cloudy	rain	9.355555556	7.227777778	0.86	14.2646	259	15.8263
2006-04-01 02	Mostly Cloudy	rain	9.377777778	9.377777778	0.89	3.9284	204	14.9569
2006-04-01 03	Partly Cloudy	rain	8.288888889	5.944444444	0.83	14.1036	269	15.8263
2006-04-01 04	Mostly Cloudy	rain	8.755555556	6.977777778	0.83	11.0446	259	15.8263
2006-04-01 05	Partly Cloudy	rain	9.222222222	7.111111111	0.85	13.9587	258	14.9569
2006-04-01 06	Partly Cloudy	rain	7.733333333	5.522222222	0.95	12.3648	259	9.982
2006-04-01 07	Partly Cloudy	rain	8.772222222	6.527777778	0.89	14.1519	260	9.982
2006-04-01 08	Partly Cloudy	rain	10.82222222	10.82222222	0.82	11.3183	259	9.982
2006-04-01 09	Partly Cloudy	rain	13.77222222	13.77222222	0.72	12.5258	279	9.982
2006-04-01 10	Partly Cloudy	rain	16.01666667	16.01666667	0.67	17.5651	290	11.2056
2006-04-01 11	Partly Cloudy	rain	17.14444444	17.14444444	0.54	19.7869	316	11.4471
2006-04-01 12	Partly Cloudy	rain	17.8	17.8	0.55	21.9443	281	11.27
2006-04-01 13	Partly Cloudy	rain	17.33333333	17.33333333	0.51	20.6885	289	11.27
2006-04-01 14	Partly Cloudy	rain	18.87777778	18.87777778	0.47	15.3755	262	11.4471
2006-04-01 15	Partly Cloudy	rain	18.91111111	18.91111111	0.46	10.4006	288	11.27
2006-04-01 16	Partly Cloudy	rain	15.38888889	15.38888889	0.6	14.4095	251	11.27
2006-04-01 17	Mostly Cloudy	rain	15.55	15.55	0.63	11.1573	230	11.4471
2006-04-01 18	Mostly Cloudy	rain	14.25555556	14.25555556	0.69	8.5169	163	11.2056
2006-04-01 19	Mostly Cloudy	rain	13.14444444	13.14444444	0.7	7.6314	139	11.2056
2006-04-01 20	Mostly Cloudy	rain	11.55	11.55	0.77	7.3899	147	11.0285
2006-04-01 21	Mostly Cloudy	rain	11.18333333	11.18333333	0.76	4.9266	160	9.982
2006-04-01 22	Partly Cloudy	rain	10.11666667	10.11666667	0.79	6.6493	163	15.8263
2006-04-01 23	Mostly Cloudy	rain	10.2	10.2	0.77	3.9284	152	14.9569
2006-04-10 00	Partly Cloudy	rain	10.42222222	10.42222222	0.62	16.9855	150	15.8263
2006-04-10 01	Partly Cloudy	rain	9.911111111	7.566666667	0.66	17.2109	149	15.8263
2006-04-10 02	Mostly Cloudy	rain	11.18333333	11.18333333	0.8	10.8192	163	14.9569
2006-04-10 03	Partly Cloudy	rain	7.155555556	5.044444444	0.79	11.0768	180	15.8263
2006-04-10 04	Partly Cloudy	rain	6.111111111	4.816666667	0.82	6.6493	161	15.8263

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Weather Forecasting

❖ Introduction

Time	Temperature (C)
2006-04-01 00:00:00.000 +0200	9.472222
2006-04-01 01:00:00.000 +0200	9.355556
2006-04-01 02:00:00.000 +0200	9.377778
2006-04-01 03:00:00.000 +0200	8.288889
2006-04-01 04:00:00.000 +0200	8.755556
2006-04-01 05:00:00.000 +0200	9.222222

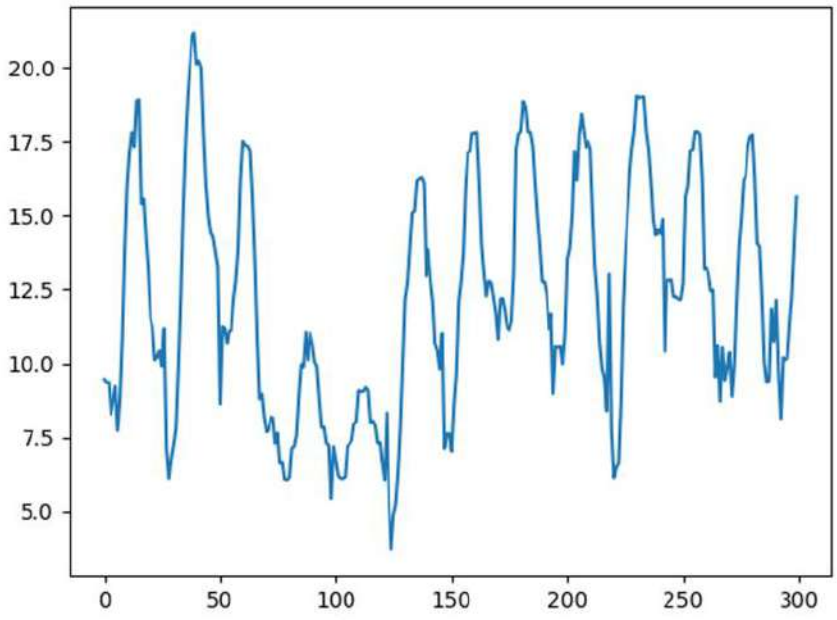
X

y

Temperature forecasting datatable

Time-series Data

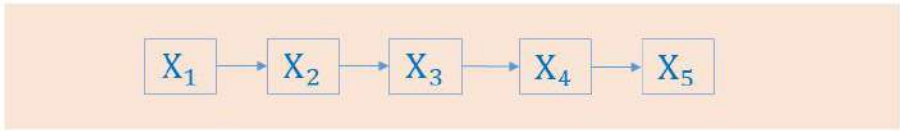
Temperature forecasting

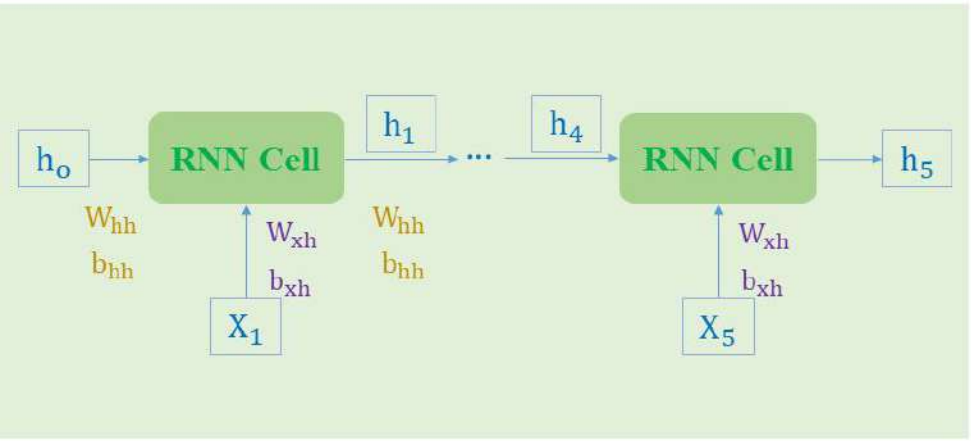


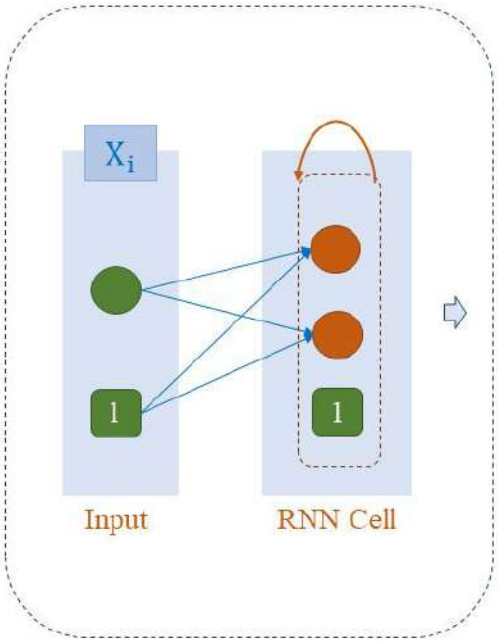
Date	Temperature (C)
2006-04-01 00	9.472222222
2006-04-01 01	9.355555556
2006-04-01 02	9.377777778
2006-04-01 03	8.288888889
2006-04-01 04	8.755555556
2006-04-01 05	9.222222222
2006-04-01 06	7.733333333
2006-04-01 07	8.772222222
2006-04-01 08	10.82222222
2006-04-01 09	13.77222222
2006-04-01 10	16.01666667
2006-04-01 11	17.14444444
2006-04-01 12	17.8
2006-04-01 13	17.33333333
2006-04-01 14	18.87777778
2006-04-01 15	18.91111111
2006-04-01 16	15.38888889
2006-04-01 17	15.55
2006-04-01 18	14.25555556
2006-04-01 19	13.14444444
2006-04-01 20	11.55
2006-04-01 21	11.18333333
2006-04-01 22	10.11666667
2006-04-01 23	10.2

Time-series Data

Temperature forecasting







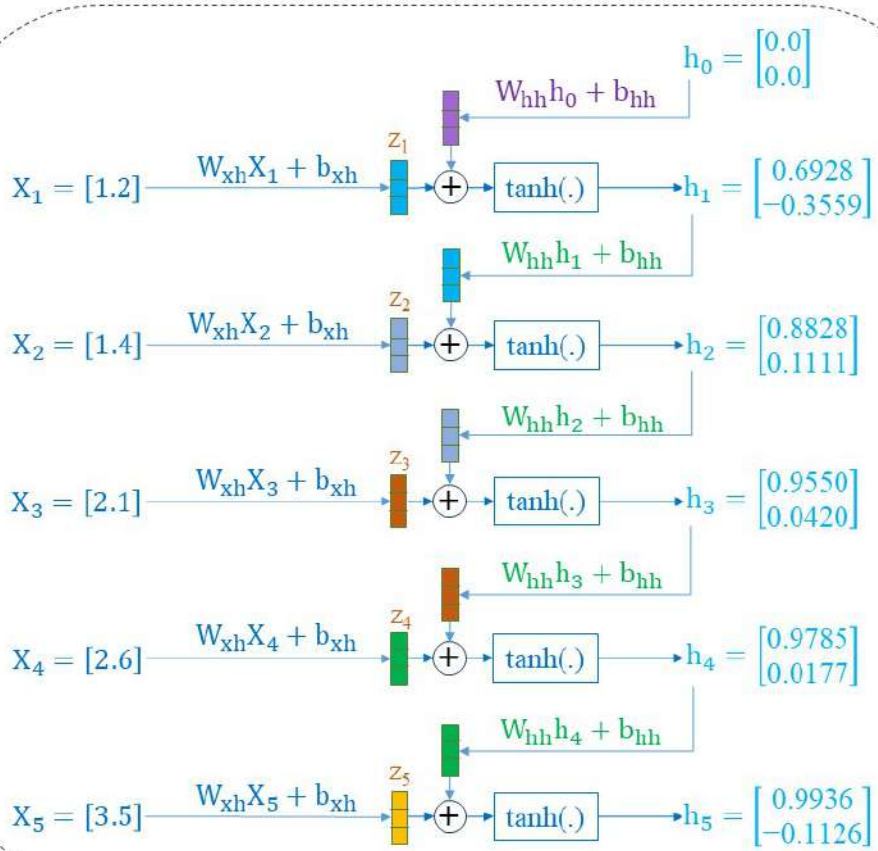
Example

$$W_{xh} = \begin{bmatrix} 0.6584 \\ -0.1671 \end{bmatrix}$$

$$b_{xh} = \begin{bmatrix} -0.5966 \\ 0.0945 \end{bmatrix}$$

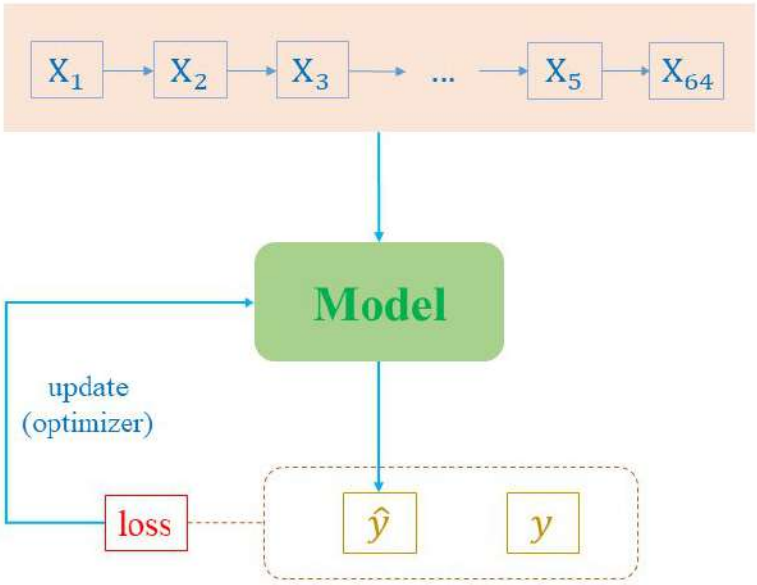
$$W_{hh} = \begin{bmatrix} 0.5147 & -0.1310 \\ 0.6606 & -0.1671 \end{bmatrix}$$

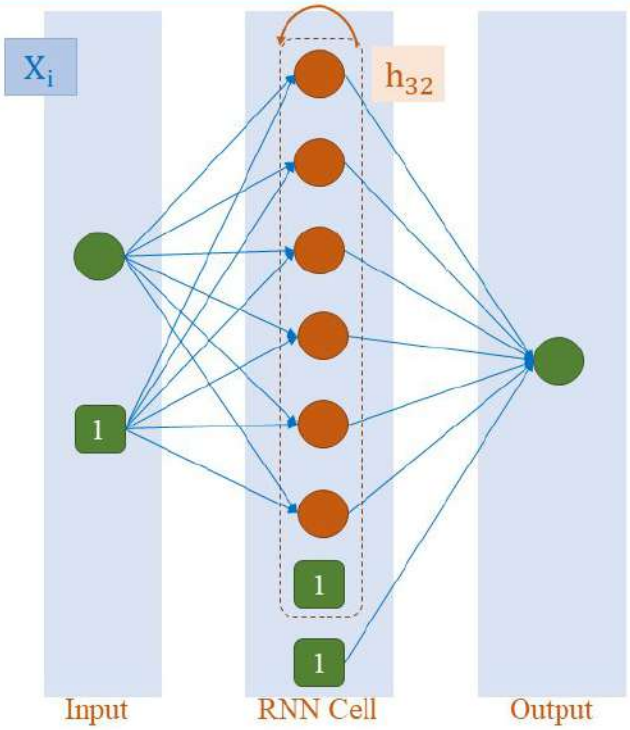
$$b_{hh} = \begin{bmatrix} 0.6599 \\ -0.2662 \end{bmatrix}$$



Implementation

Temperature forecasting





Implementation

Back to Temperature forecasting

sequence_length = 64 embed_dim = 1

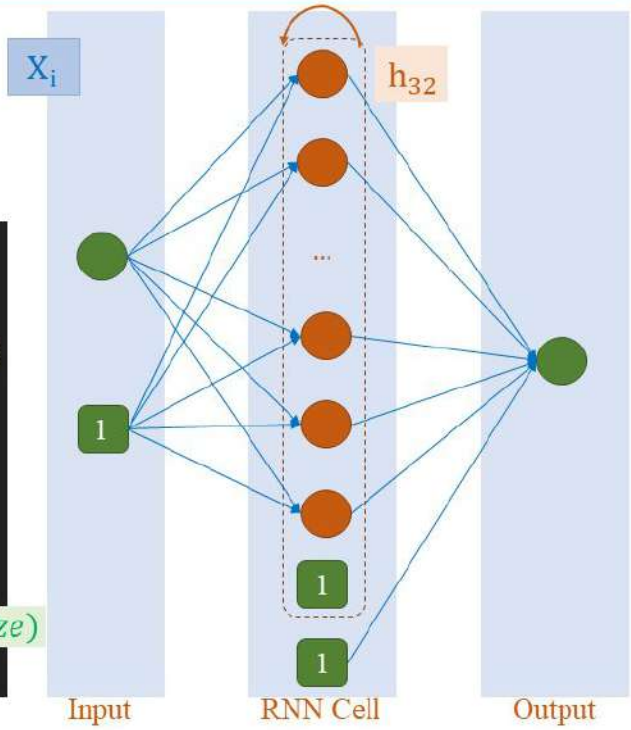
output_dim = 1 hidden_dim = 32

```
class RNNModel(nn.Module):
    def __init__(self, hidden_dim, output_dim):
        super(RNNModel, self).__init__()
        self.rnn = nn.RNN(1, hidden_dim, batch_first=True)
        self.fc = nn.Linear(hidden_dim, output_dim)

    def forward(self, x):
        output_rnn, hidden_rnn = self.rnn(x)
        last_hidden = hidden_rnn[-1,:,:]
        output = self.fc(last_hidden)
        return output

model = RNNModel(hidden_dim=32, output_dim=1)
```

$(num\_rnn\_layers, N, hidden\_size)$



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Implementation

Stack of three RNNs

sequence_length = 64 embed_dim = 1

output_dim = 1 hidden_dim = 32

```
class RNNModel(nn.Module):
    def __init__(self, hidden_dim, output_dim):
        super(RNNModel, self).__init__()
        self.rnn = nn.RNN(1, hidden_dim,
                          num_layers=3,
                          batch_first=True)
        self.fc = nn.Linear(hidden_dim, output_dim)

    def forward(self, x):
        output_rnn, hidden_rnn = self.rnn(x)
        last_hidden = hidden_rnn[-1,:,:]
        output = self.fc(last_hidden)
        return output

model = RNNModel(hidden_dim=32, output_dim=1)
```