

$$f\left(\begin{array}{|c|} \hline \text{Data} \\ \hline \end{array} \begin{array}{|c|} \hline \text{Labels} \\ \hline \end{array}\right) = \text{Rules}$$

1

2

3

5

8

13

21

34

55

89

1

2

3

5

8

13

21

34

55

89

n_0

n_1

n_2

n_3

n_4

n_5

n_6

n_7

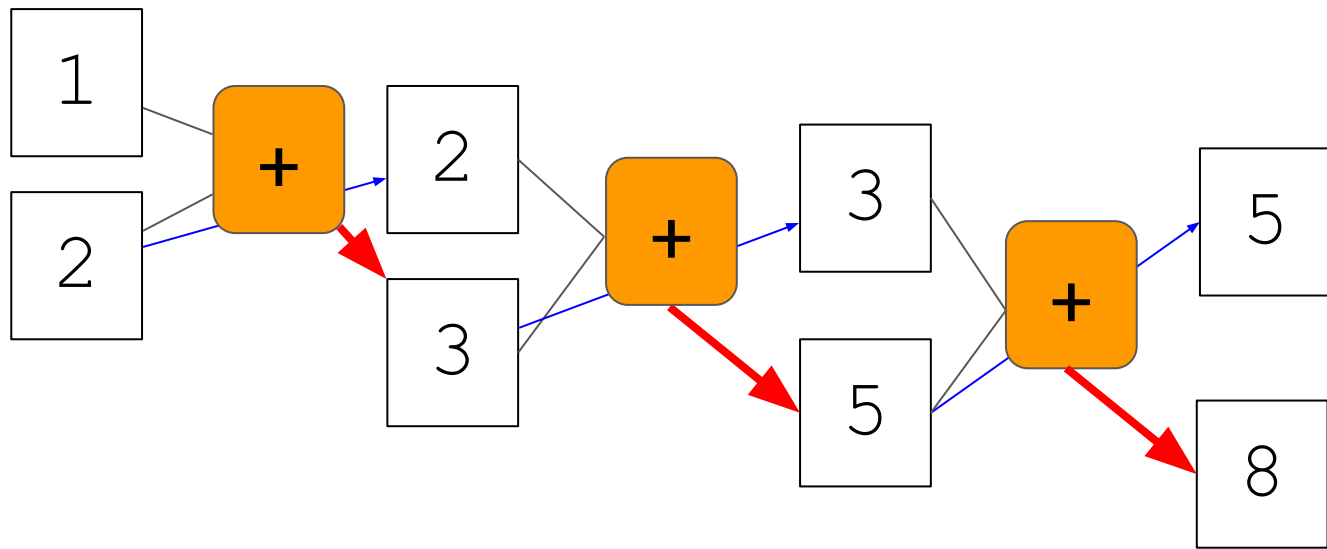
n_8

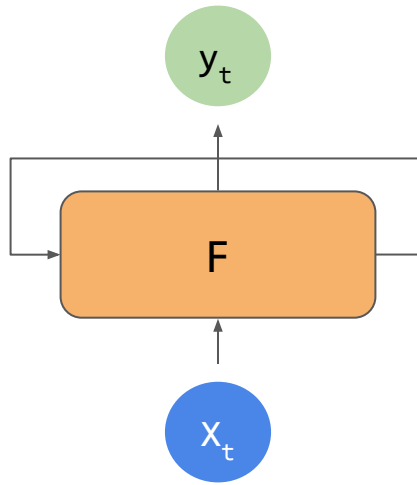
n_9

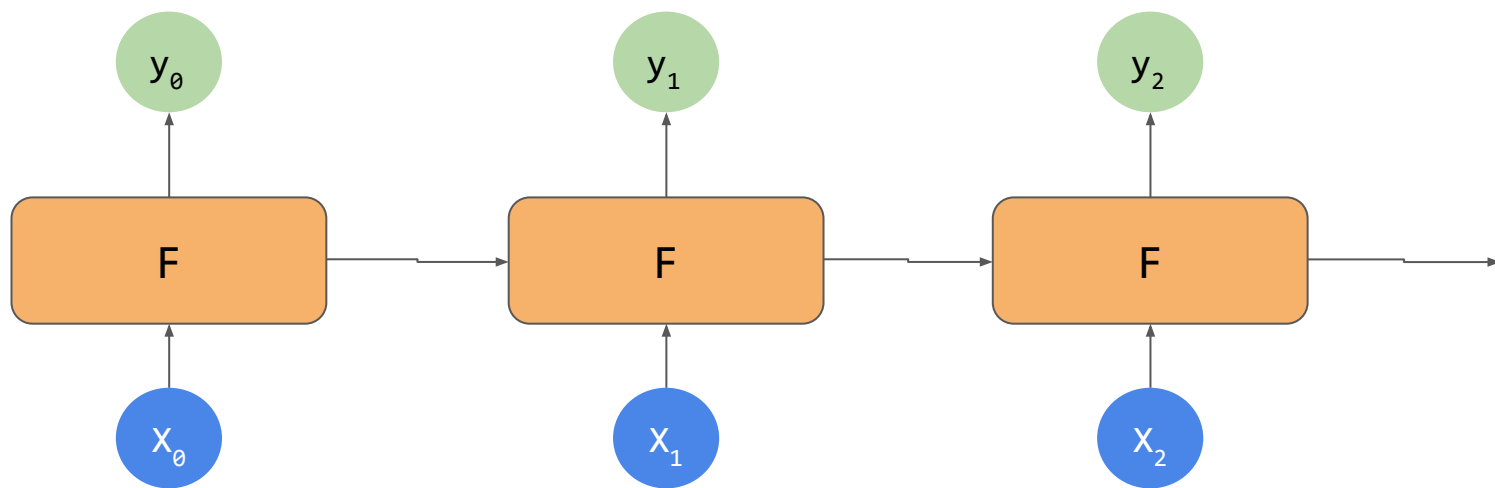
1	2	3	5	8	13	21	34	55	89
---	---	---	---	---	----	----	----	----	----

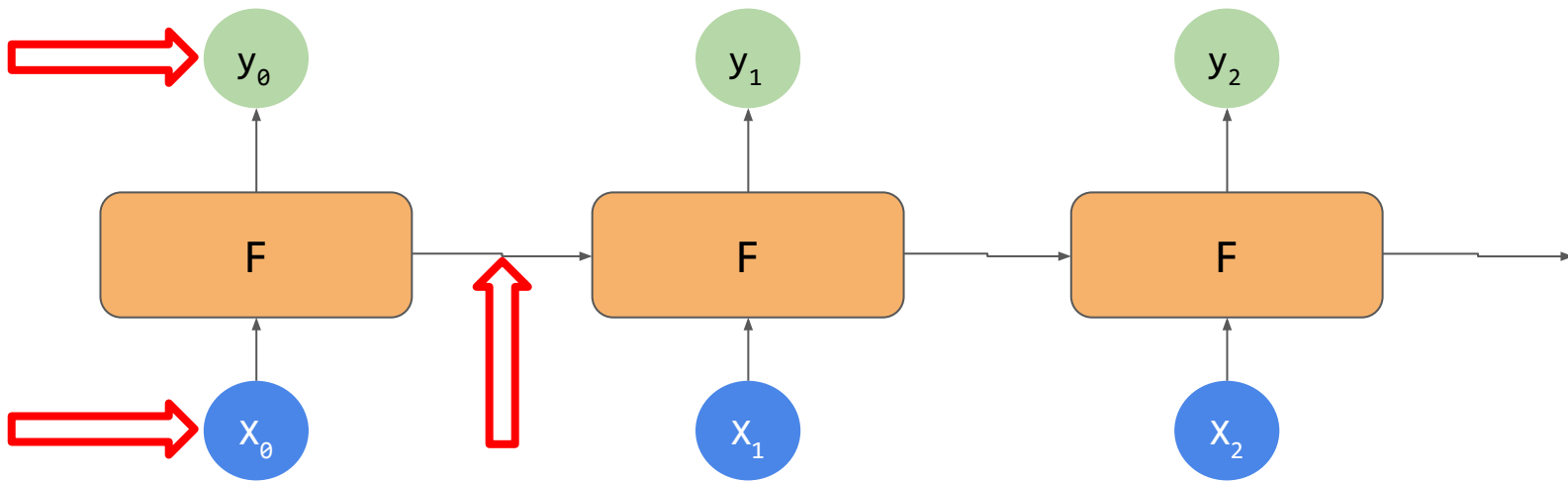
n_0	n_1	n_2	n_3	n_4	n_5	n_6	n_7	n_8	n_9
-------	-------	-------	-------	-------	-------	-------	-------	-------	-------

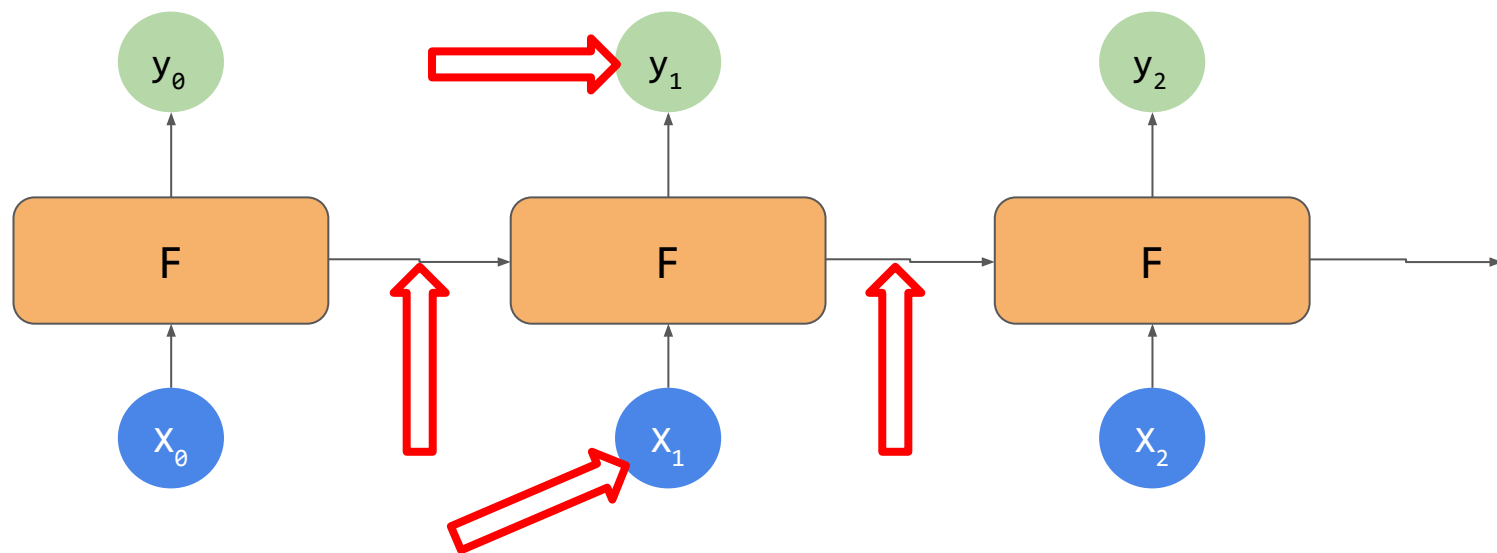
$$n_x = n_{x-1} + n_{x-2}$$

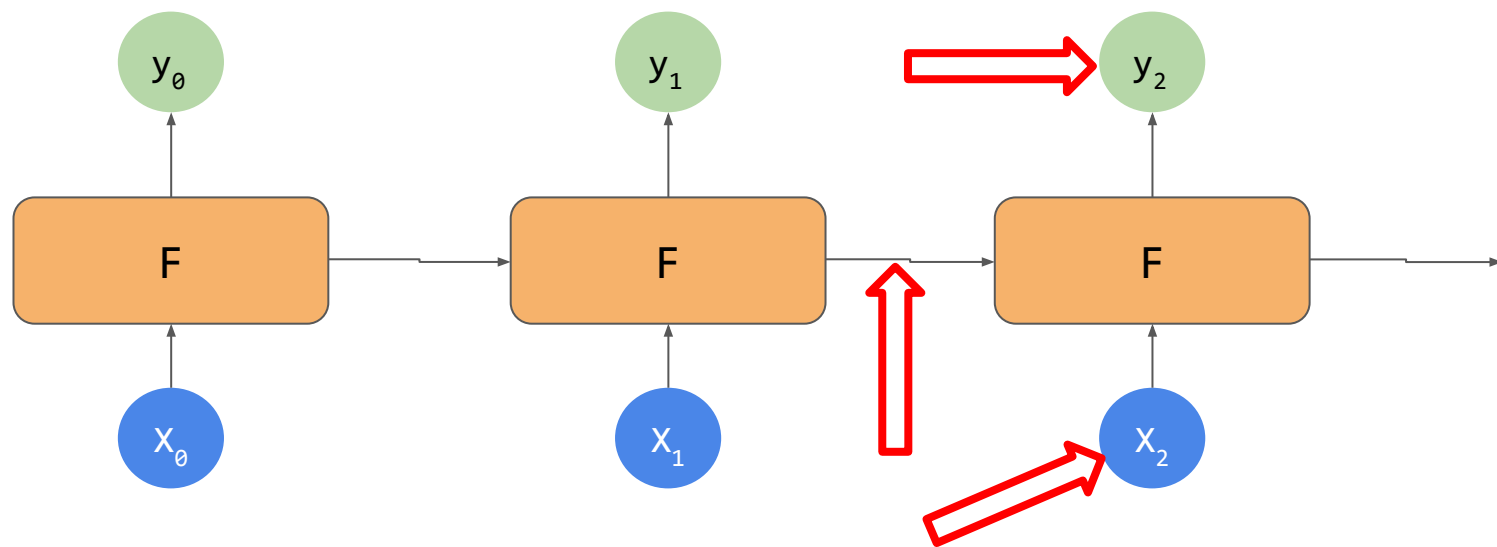


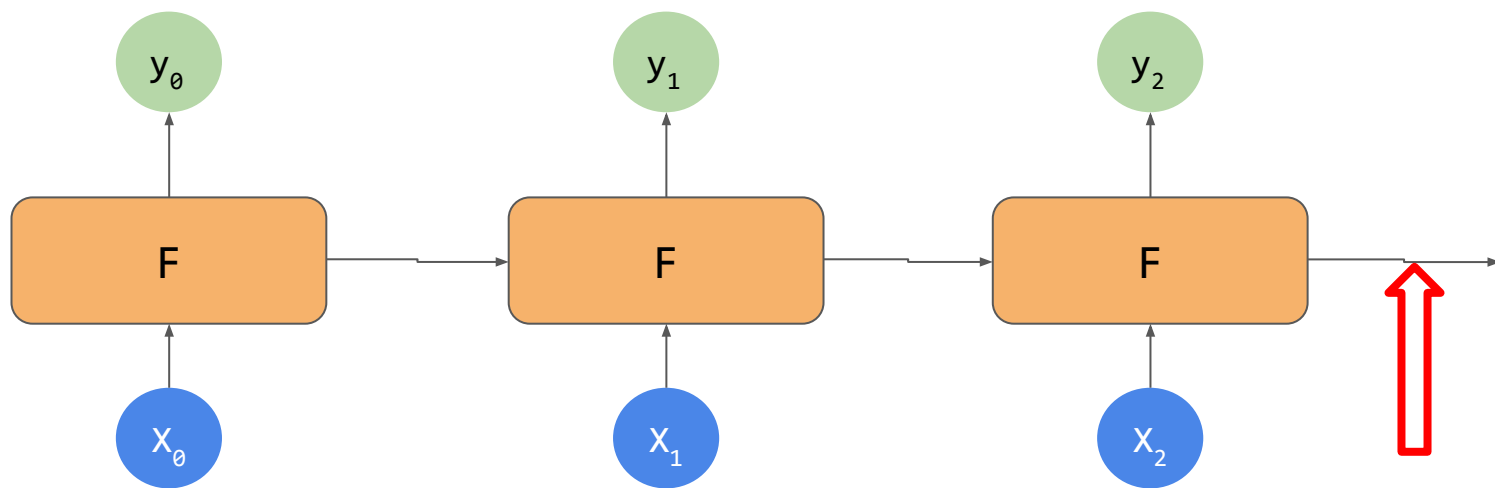












Deep RNNs

Deep RNN example

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Course 5 of 5 in the Specialization [Deep Learning](#)

This course will teach you how to build models for natural language, audio, and other sequence data. Thanks to deep learning, sequence algorithms are working far better than just two years ago, and this is enabling numerous exciting applications in speech recognition, music synthesis, chatbots, machine translation, natural language understanding, and many others. You will: - Understand how to build and train Recurrent Neural Networks (RNNs), and commonly-

More

Today has a beautiful blue <...>

Today has a beautiful blue <...>

Today has a beautiful blue sky

Today has a beautiful blue <...>

Today has a beautiful blue sky

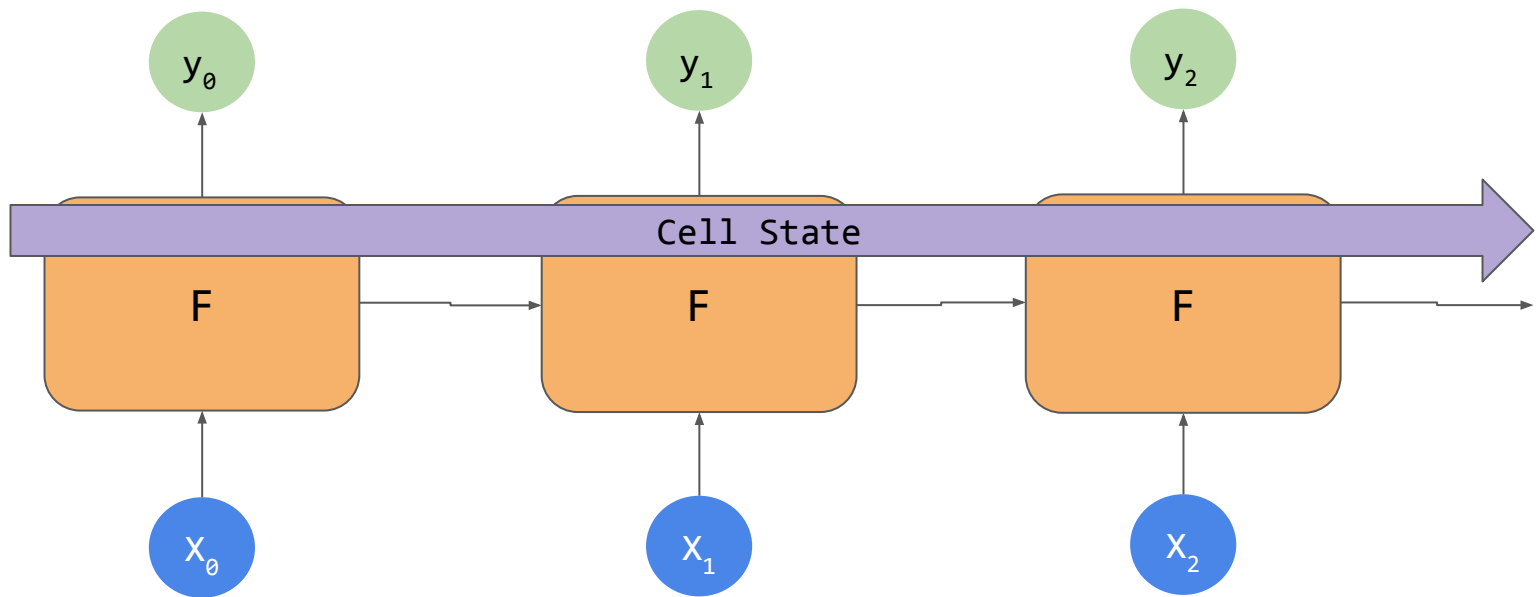
I lived in Ireland, so at school they made me learn how to speak <...>

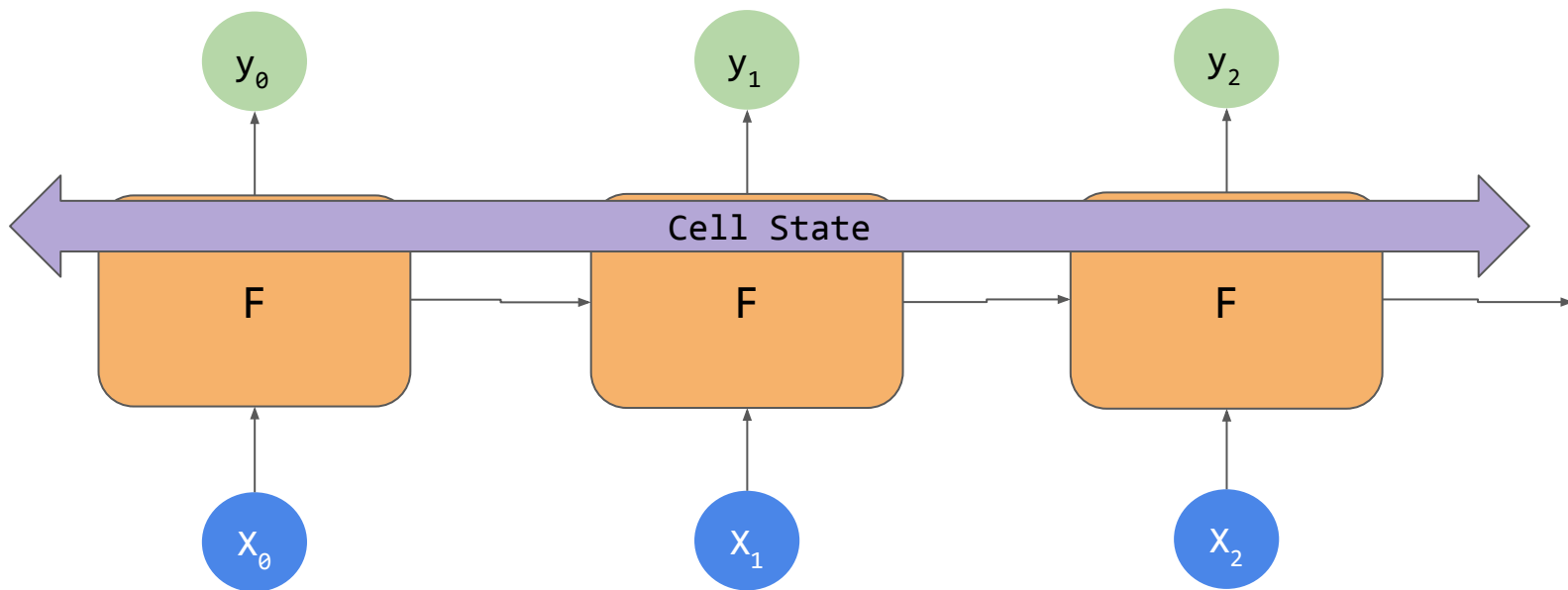
I lived in Ireland, so at school they made me learn how to speak <...>

I lived in Ireland, so at school they made me learn how to speak Gaelic

I lived in Ireland, so at school they made me learn how to speak <...>

I lived in Ireland so at school they made me learn how to speak Gaelic

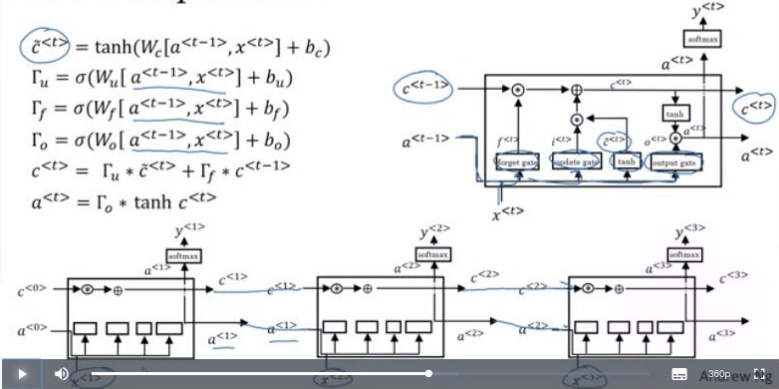




Long Short Term Memory (LSTM)

LSTM in pictures

$$\tilde{c}^{<t>} = \tanh(W_c[a^{<t-1>}, x^{<t>}] + b_c)$$
$$\Gamma_u = \sigma(W_u[a^{<t-1>}, x^{<t>}] + b_u)$$
$$\Gamma_f = \sigma(W_f[a^{<t-1>}, x^{<t>}] + b_f)$$
$$\Gamma_o = \sigma(W_o[a^{<t-1>}, x^{<t>}] + b_o)$$
$$c^{<t>} = \Gamma_u * \tilde{c}^{<t>} + \Gamma_f * c^{<t-1>}$$
$$a^{<t>} = \Gamma_o * \tanh c^{<t>}$$



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More

```
model = tf.keras.Sequential([  
    tf.keras.Input(shape=(None,)),  
    tf.keras.layers.Embedding(vocab_size, 64),  
    tf.keras.layers.Bidirectional(tf.keras.layers.LSTM(64)),  
    tf.keras.layers.Dense(64, activation='relu'),  
    tf.keras.layers.Dense(1, activation='sigmoid')  
])
```

```
model = tf.keras.Sequential([
    tf.keras.Input(shape=(None,)),
    tf.keras.layers.Embedding(vocab_size, 64),
    tf.keras.layers.Bidirectional(tf.keras.layers.LSTM(64)),
    tf.keras.layers.Dense(64, activation='relu'),
    tf.keras.layers.Dense(1, activation='sigmoid')
])
```



```
model = tf.keras.Sequential([  
    tf.keras.Input(shape=(None,)),  
    tf.keras.layers.Embedding(vocab_size, 64),  
    tf.keras.layers.Bidirectional(tf.keras.layers.LSTM(64)),  
    tf.keras.layers.Dense(64, activation='relu'),  
    tf.keras.layers.Dense(1, activation='sigmoid')  
])
```



Layer (type)	Output Shape	Param #
embedding_2 (Embedding)	(None, None, 64)	523840
bidirectional_1 (Bidirectional)	(None, 128)	66048
dense_4 (Dense)	(None, 64)	8256
dense_5 (Dense)	(None, 1)	65
Total params: 598,209		
Trainable params: 598,209		
Non-trainable params: 0		

Layer (type)	Output Shape	Param #
embedding_2 (Embedding)	(None, None, 64)	523840
bidirectional_1 (Bidirectional)	(None, 128)	66048
dense_4 (Dense)	(None, 64)	8256
dense_5 (Dense)	(None, 1)	65
Total params: 598,209		
Trainable params: 598,209		
Non-trainable params: 0		

```
model = tf.keras.Sequential([  
    tf.keras.Input(shape=(None,)),  
    tf.keras.layers.Embedding(vocab_size, 64),  
    tf.keras.layers.Bidirectional(tf.keras.layers.LSTM(64, return_sequences=True)),  
    tf.keras.layers.Bidirectional(tf.keras.layers.LSTM(32)),  
    tf.keras.layers.Dense(64, activation='relu'),  
    tf.keras.layers.Dense(1, activation='sigmoid')  
])
```

```
model = tf.keras.Sequential([
    tf.keras.Input(shape=(None,)),
    tf.keras.layers.Embedding(vocab_size, 64),
    tf.keras.layers.Bidirectional(tf.keras.layers.LSTM(64, return_sequences=True)),
    tf.keras.layers.Bidirectional(tf.keras.layers.LSTM(32)),
    tf.keras.layers.Dense(64, activation='relu'),
    tf.keras.layers.Dense(1, activation='sigmoid')
])
```

Layer (type)	Output Shape	Param #
=====		
embedding_3 (Embedding)	(None, None, 64)	523840

bidirectional_2 (Bidirection	(None, None, 128)	66048

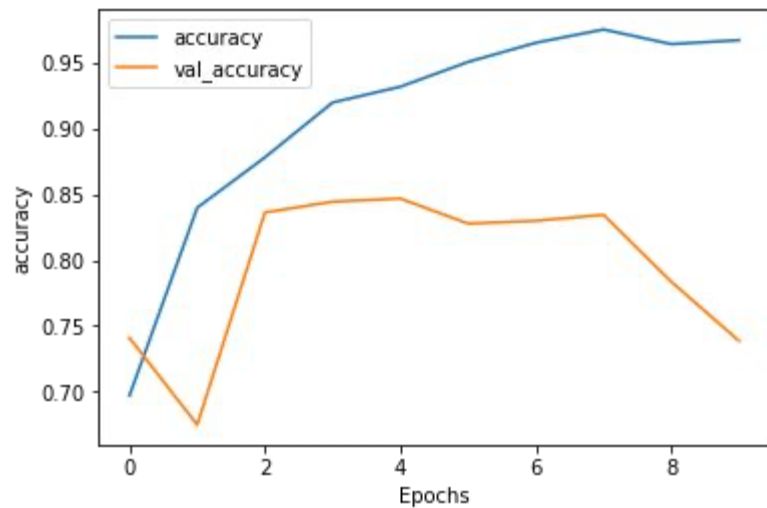
bidirectional_3 (Bidirection	(None, 64)	41216

dense_6 (Dense)	(None, 64)	4160

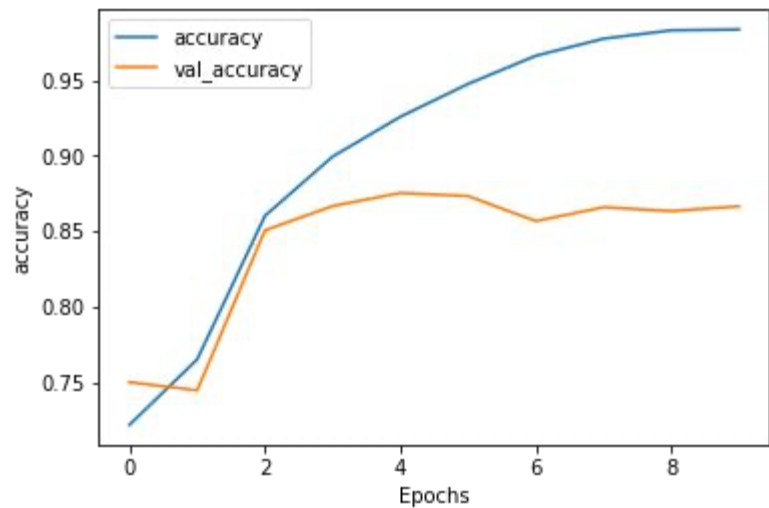
dense_7 (Dense)	(None, 1)	65
=====		

Total params: 635,329
Trainable params: 635,329
Non-trainable params: 0

10 Epochs : Accuracy Measurement

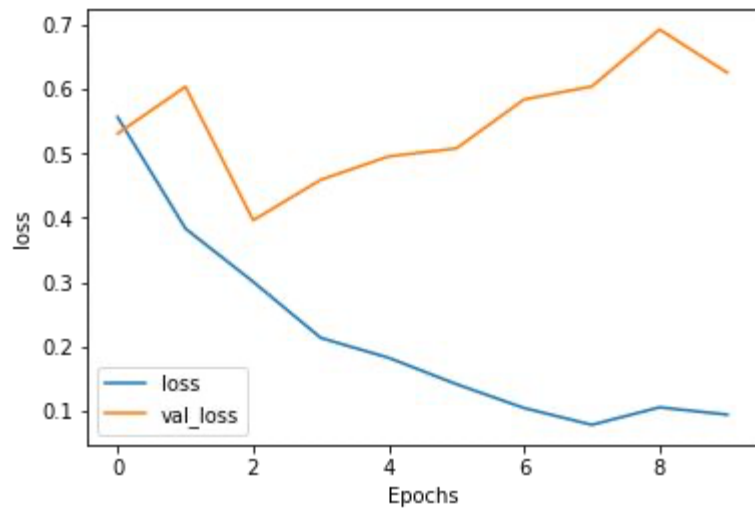


1 Layer LSTM

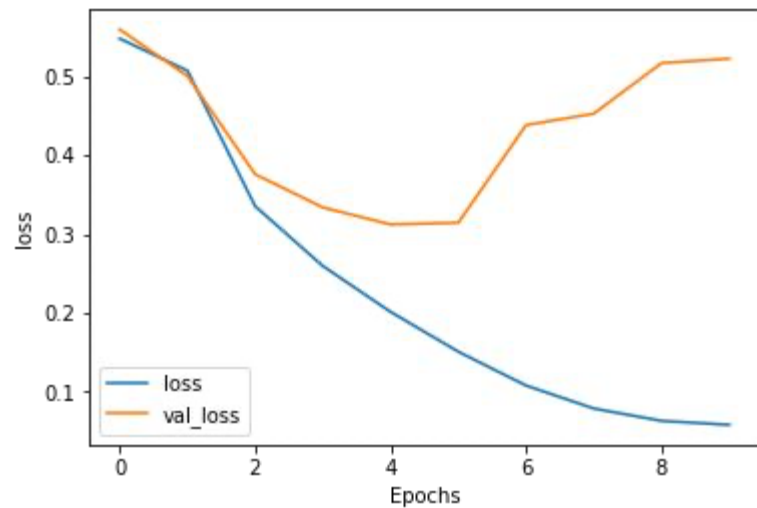


2 Layer LSTM

10 Epochs : Loss Measurement

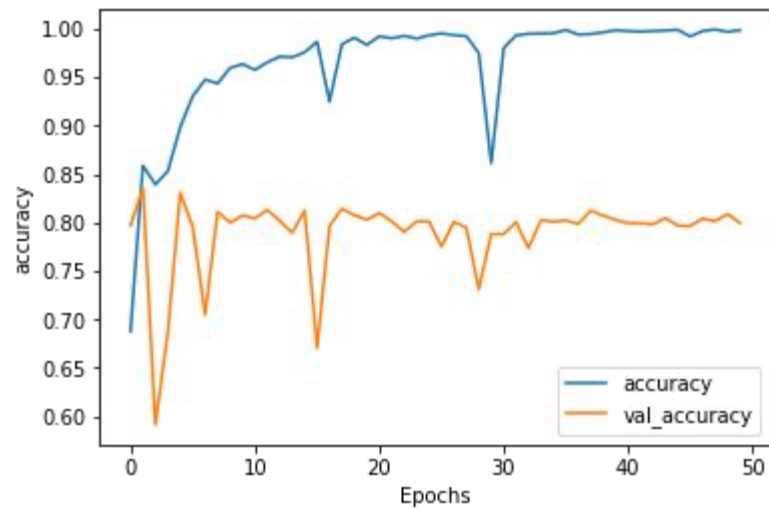


1 Layer LSTM

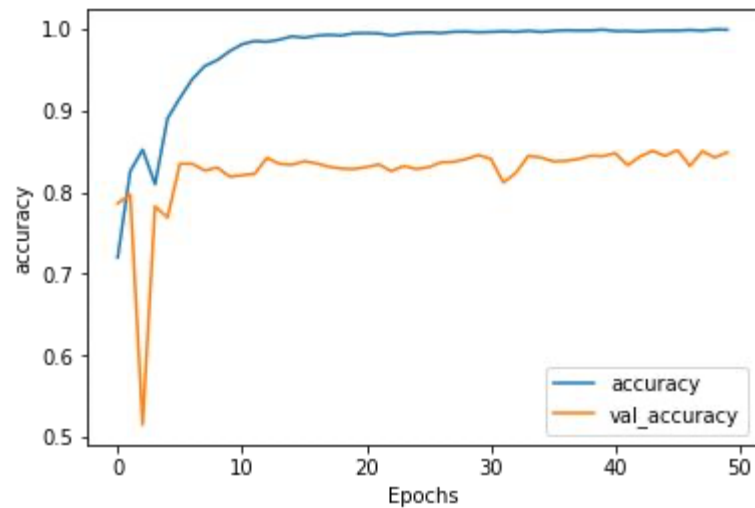


2 Layer LSTM

50 Epochs : Accuracy Measurement

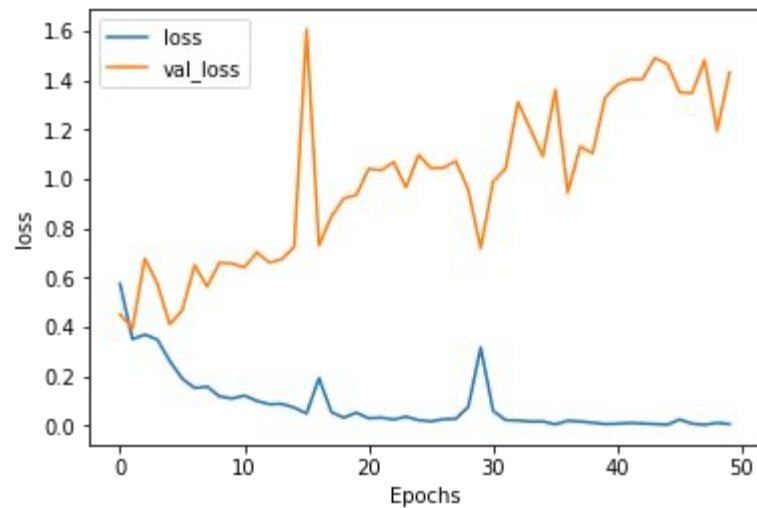


1 Layer LSTM

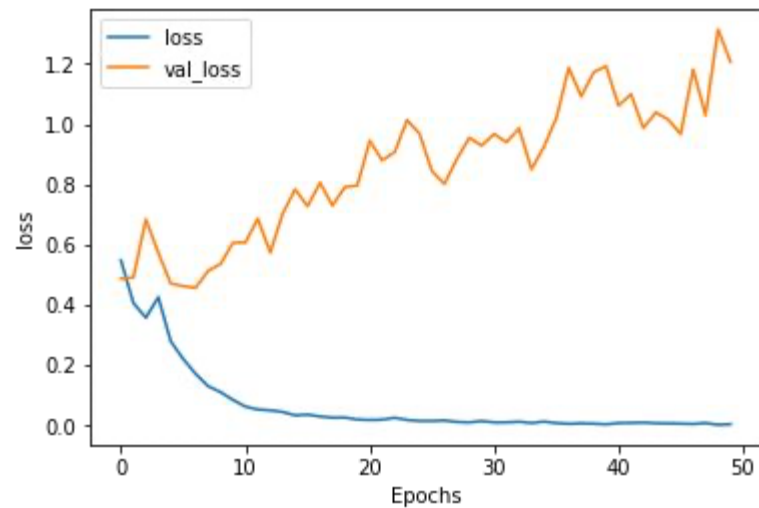


2 Layer LSTM

50 Epochs : Loss Measurement



1 Layer LSTM

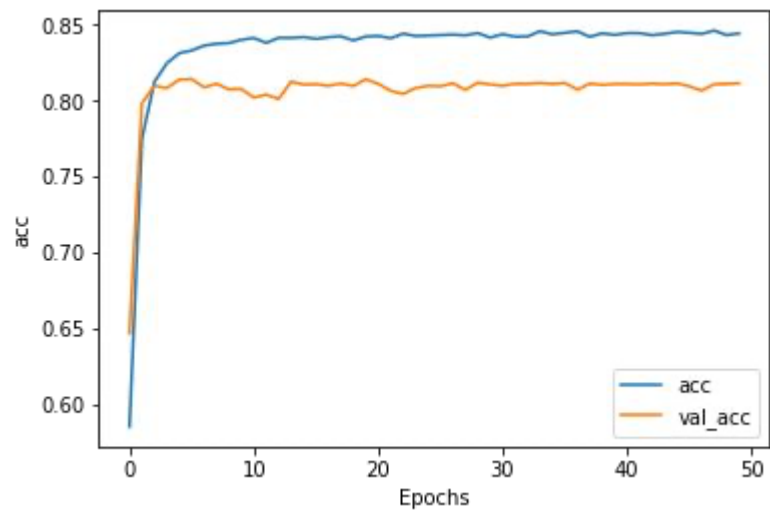


2 Layer LSTM

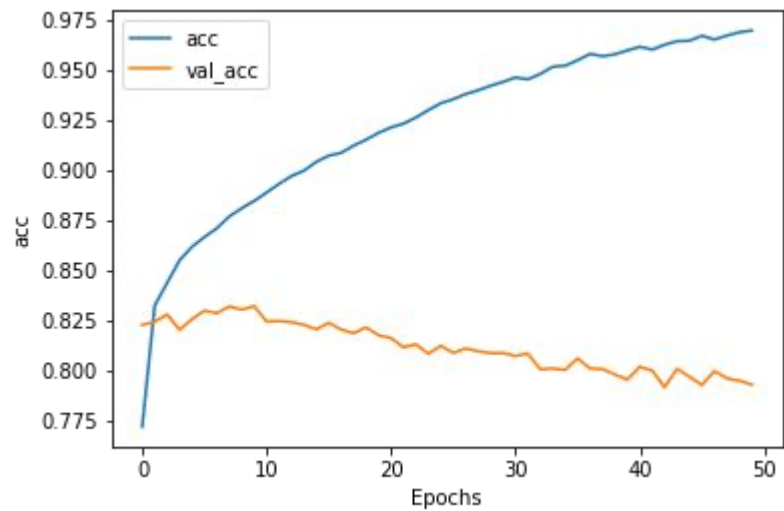
```
model = tf.keras.Sequential([  
    tf.keras.Input(shape=(None,)),  
    tf.keras.layers.Embedding(vocab_size, embedding_dim, input_length=max_length),  
    tf.keras.layers.GlobalAveragePooling1D(),  
    tf.keras.layers.Dense(24, activation='relu'),  
    tf.keras.layers.Dense(1, activation='sigmoid')  
])
```

```
model = tf.keras.Sequential([
    tf.keras.Input(shape=(None,)),
    tf.keras.layers.Embedding(vocab_size, embedding_dim, input_length=max_length),
    tf.keras.layers.GlobalAveragePooling1D(),
    tf.keras.layers.Dense(24, activation='relu'),
    tf.keras.layers.Dense(1, activation='sigmoid')
])
```

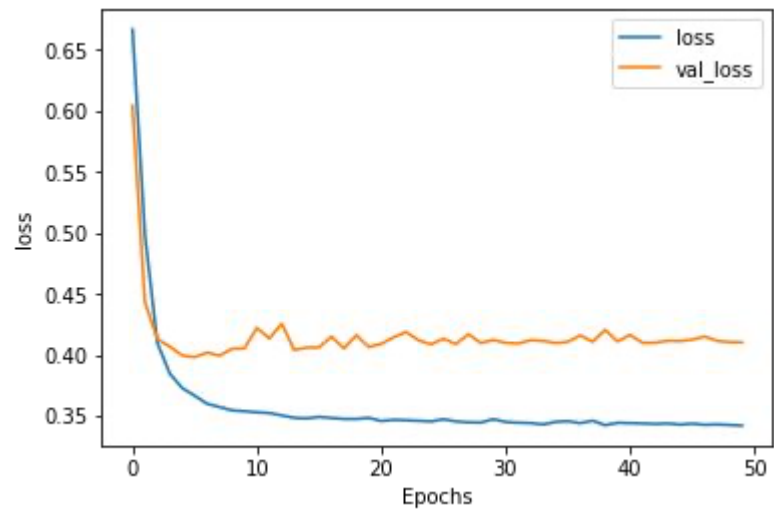
```
model = tf.keras.Sequential([  
    tf.keras.Input(shape=(None,)),  
    tf.keras.layers.Embedding(vocab_size, embedding_dim, input_length=max_length),  
    tf.keras.layers.Bidirectional(tf.keras.layers.LSTM(32)),  
    tf.keras.layers.Dense(24, activation='relu'),  
    tf.keras.layers.Dense(1, activation='sigmoid')  
])
```



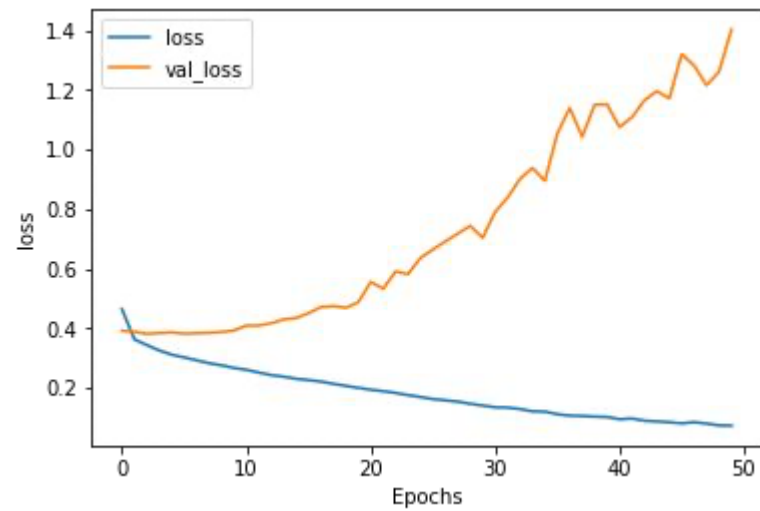
Without LSTM



With LSTM



Without LSTM

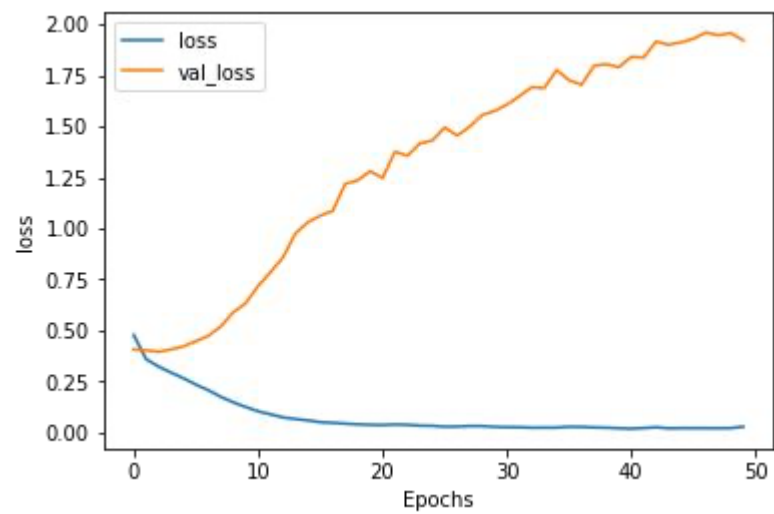
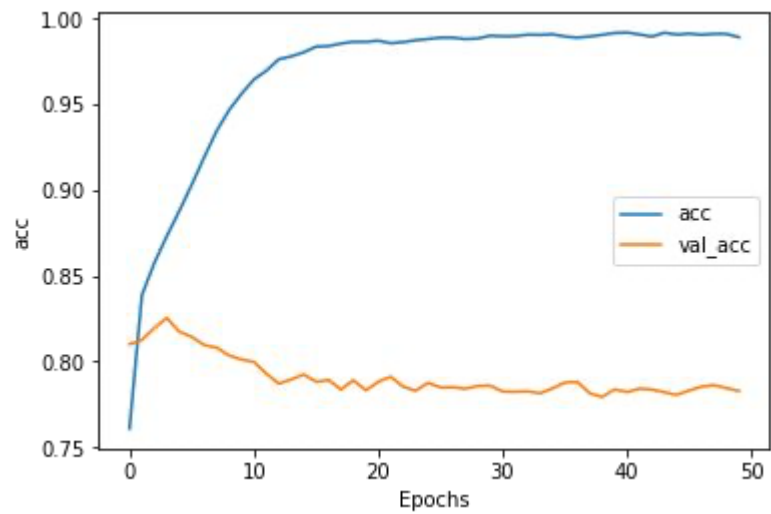


With LSTM

```
model = tf.keras.Sequential([
    tf.keras.Input(shape=(None,)),
    tf.keras.layers.Embedding(vocab_size, embedding_dim, input_length=max_length),
    tf.keras.layers.Conv1D(128, 5, activation='relu'),
    tf.keras.layers.GlobalMaxPooling1D(),
    tf.keras.layers.Dense(6, activation='relu'),
    tf.keras.layers.Dense(1, activation='sigmoid')
])
```



```
model = tf.keras.Sequential([  
    tf.keras.Input(shape=(None,)),  
    tf.keras.layers.Embedding(vocab_size, embedding_dim, input_length=max_length),  
    tf.keras.layers.Conv1D(128, 5, activation='relu'),  
    tf.keras.layers.GlobalMaxPooling1D(),  
    tf.keras.layers.Dense(6, activation='relu'),  
    tf.keras.layers.Dense(1, activation='sigmoid')  
])
```



```
model = tf.keras.Sequential([
    tf.keras.Input(shape=(None,)),
    tf.keras.layers.Embedding(vocab_size, embedding_dim, input_length=max_length),
    tf.keras.layers.Conv1D(128, 5, activation='relu'),
    tf.keras.layers.GlobalMaxPooling1D(),
    tf.keras.layers.Dense(6, activation='relu'),
    tf.keras.layers.Dense(1, activation='sigmoid')
])
```

```
max_length=120)
layer1=Conv1D(128, 5, activation='relu'),
```

Layer (type)	Output Shape	Param #
embedding (Embedding)	(None, 120, 16)	16000
conv1d (Conv1D)	(None, 116, 128)	10368
global_max_pooling1d (Global	(None, 128)	0
dense (Dense)	(None, 24)	3096
dense_1 (Dense)	(None, 1)	25

```
Total params: 29,489
Trainable params: 29,489
Non-trainable params: 0
```

```
max_length=120, Conv1D(128, 5, activation='relu'),
```



Layer (type)	Output Shape	Param #
embedding (Embedding)	(None, 120, 16)	16000
conv1d (Conv1D)	(None, 116, 128)	10368
global_max_pooling1d (Global	(None, 128)	0
dense (Dense)	(None, 24)	3096
dense_1 (Dense)	(None, 1)	25
Total params: 29,489		
Trainable params: 29,489		
Non-trainable params: 0		

```
max_length=120)Conv1D(128, 5, activation='relu'),
```



Layer (type)	Output Shape	Param #
embedding (Embedding)	(None, 120, 16)	16000
conv1d (Conv1D)	(None, 116, 128)	10368
global_max_pooling1d (Global	(None, 128)	0
dense (Dense)	(None, 24)	3096
dense_1 (Dense)	(None, 1)	25

Total params: 29,489
Trainable params: 29,489
Non-trainable params: 0

```
imdb, info = tfds.load("imdb_reviews", with_info=True, as_supervised=True)

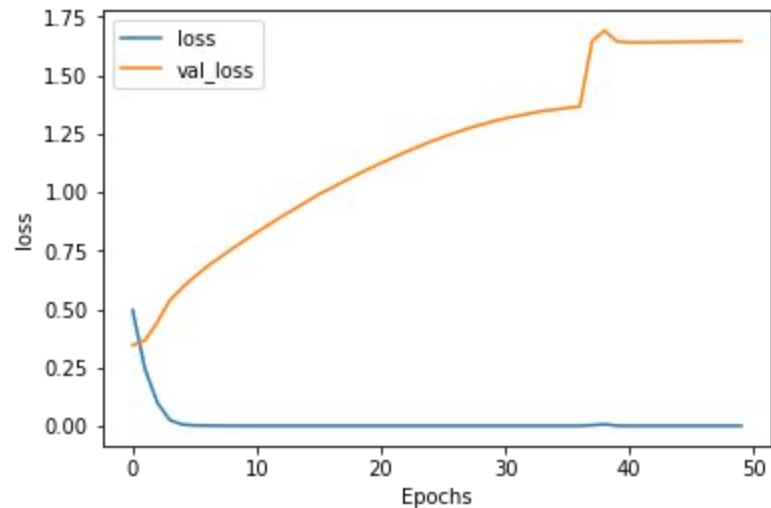
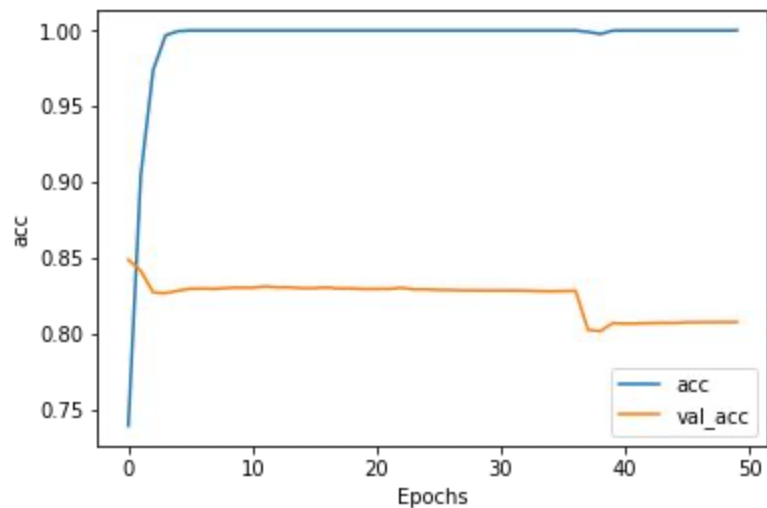
model = tf.keras.Sequential([
    tf.keras.Input(shape=(None,)),
    tf.keras.layers.Embedding(vocab_size, embedding_dim, input_length=max_length),
    tf.keras.layers.Flatten(),
    tf.keras.layers.Dense(6, activation='relu'),
    tf.keras.layers.Dense(1, activation='sigmoid')
])

model.compile(loss='binary_crossentropy', optimizer='adam', metrics=['accuracy'])
model.summary()
```



Layer (type)	Output Shape	Param #
embedding (Embedding)	(None, 120, 16)	160000
flatten (Flatten)	(None, 1920)	0
dense (Dense)	(None, 6)	11526
dense_1 (Dense)	(None, 1)	7

Total params: 171,533
Trainable params: 171,533
Non-trainable params: 0



IMDB with Embedding-only : ~ 5s per epoch

```
imdb, info = tfds.load("imdb_reviews", with_info=True, as_supervised=True)

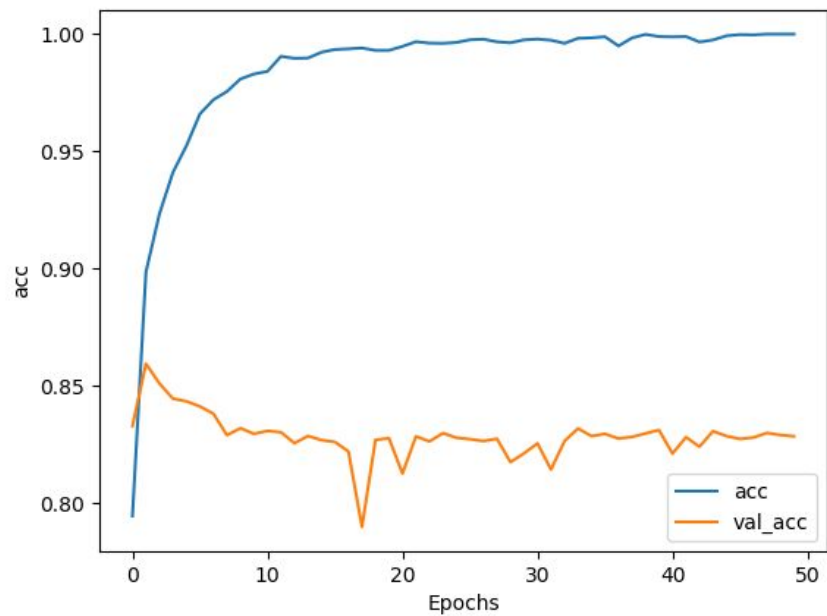
model = tf.keras.Sequential([
    tf.keras.Input(shape=(None,)),
    tf.keras.layers.Embedding(vocab_size, embedding_dim, input_length=max_length),
    tf.keras.layers.Bidirectional(tf.keras.layers.LSTM(32)),
    tf.keras.layers.Dense(6, activation='relu'),
    tf.keras.layers.Dense(1, activation='sigmoid')
])

model.compile(loss='binary_crossentropy', optimizer='adam', metrics=['accuracy'])
model.summary()
```

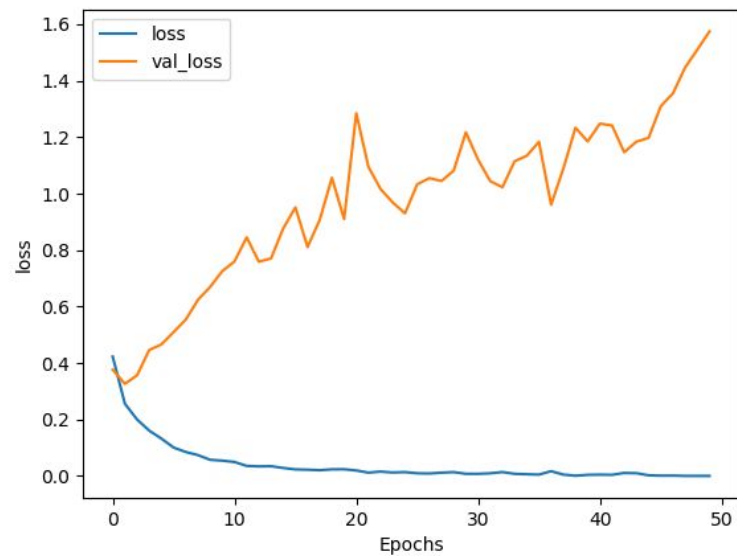


Layer (type)	Output Shape	Param #
embedding_7 (Embedding)	(None, 120, 16)	160000
bidirectional_7 (Bidirection	(None, 64)	12544
dense_14 (Dense)	(None, 6)	390
dense_15 (Dense)	(None, 1)	7

Total params: 173,941
Trainable params: 172,941
Non-trainable params: 0



IMDB with LSTM ~43s per epoch



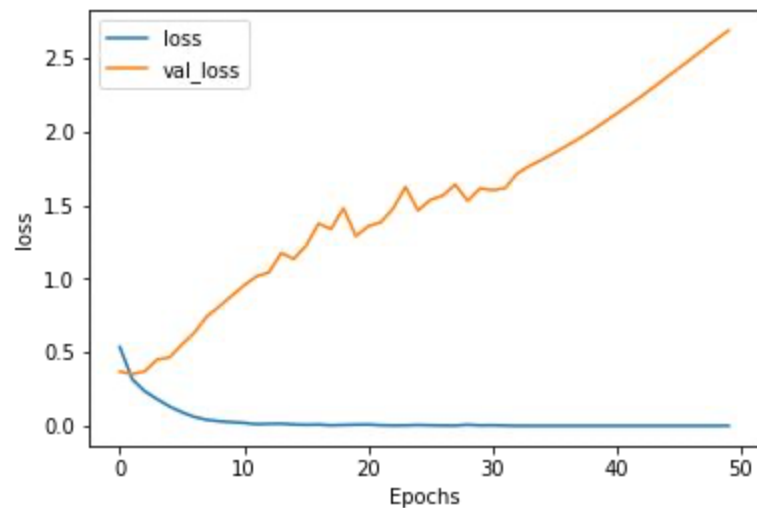
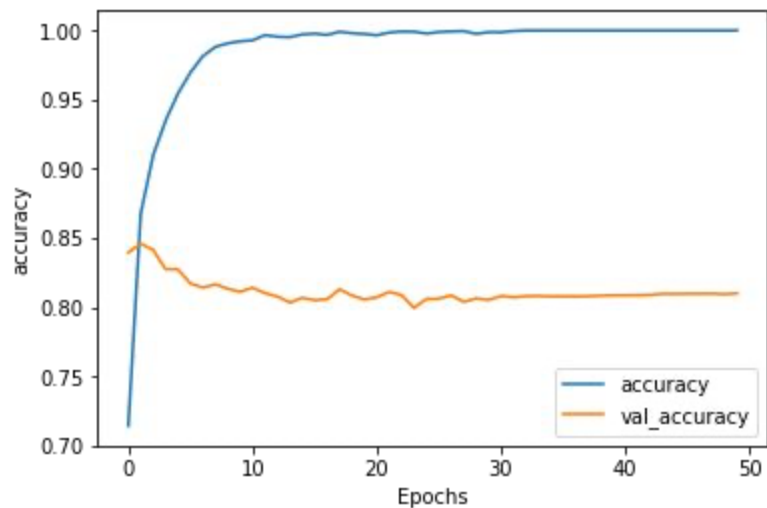
```
model = tf.keras.Sequential([
    tf.keras.Input(shape=(None,)),
    tf.keras.layers.Embedding(vocab_size, embedding_dim, input_length=max_length),
    tf.keras.layers.Bidirectional(tf.keras.layers.GRU(32)),
    tf.keras.layers.Dense(6, activation='relu'),
    tf.keras.layers.Dense(1, activation='sigmoid')
])

model.compile(loss='binary_crossentropy', optimizer='adam', metrics=['accuracy'])
model.summary()
```



Layer (type)	Output Shape	Param #
embedding_1 (Embedding)	(None, 120, 16)	160000
bidirectional_1 (Bidirection	(None, 64)	9600
dense_2 (Dense)	(None, 6)	390
dense_3 (Dense)	(None, 1)	7

Total params: 169,997
Trainable params: 169,997
Non-trainable params: 0



IMDB with GRU : ~ 20s per epoch

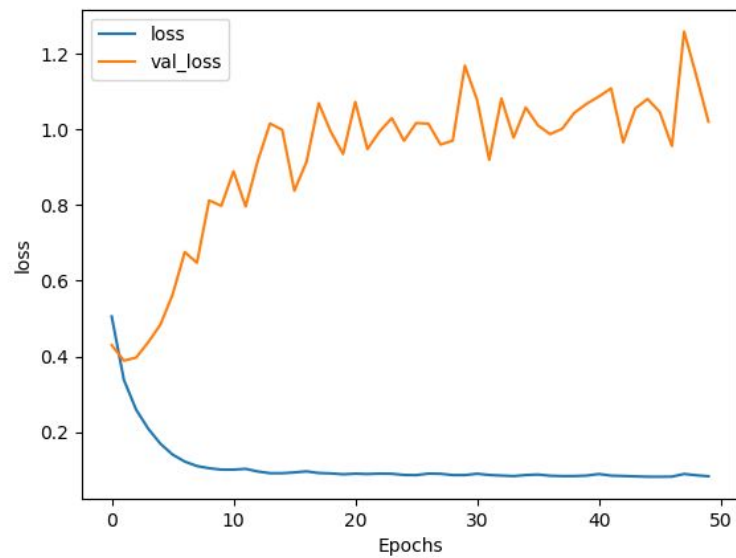
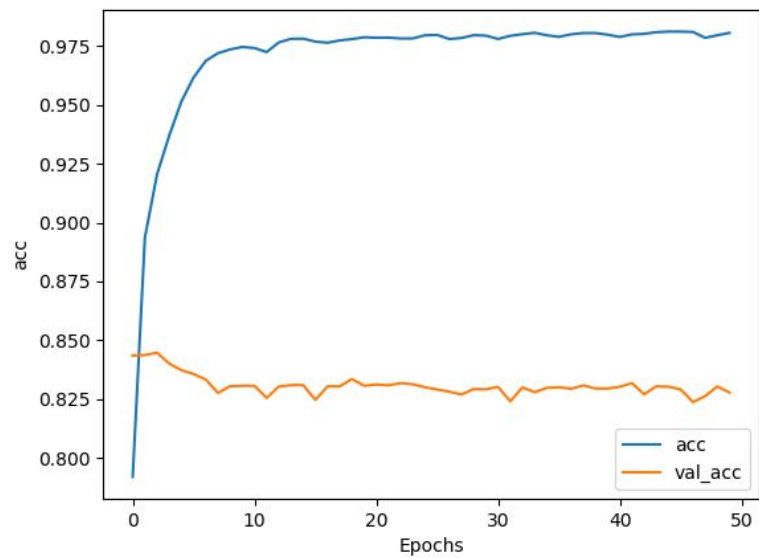
```
model = tf.keras.Sequential([
    tf.keras.Input(shape=(None,)),
    tf.keras.layers.Embedding(vocab_size, embedding_dim, input_length=max_length),
    tf.keras.layers.Conv1D(128, 5, activation='relu'),
    tf.keras.layers.GlobalAveragePooling1D(),
    tf.keras.layers.Dense(6, activation='relu'),
    tf.keras.layers.Dense(1, activation='sigmoid')
])

model.compile(loss='binary_crossentropy', optimizer='adam', metrics=['accuracy'])
model.summary()
```



Layer (type)	Output Shape	Param #
embedding (Embedding)	(None, 120, 16)	160000
conv1d (Conv1D)	(None, 116, 128)	10368
global_average_pooling1d (GlobalAveragePooling1D)	(None, 128)	0
dense (Dense)	(None, 6)	774
dense_1 (Dense)	(None, 1)	7

Total params: 171,149
 Trainable params: 171,149
 Non-trainable params: 0



IMDB with CNN : ~ 6s per epoch