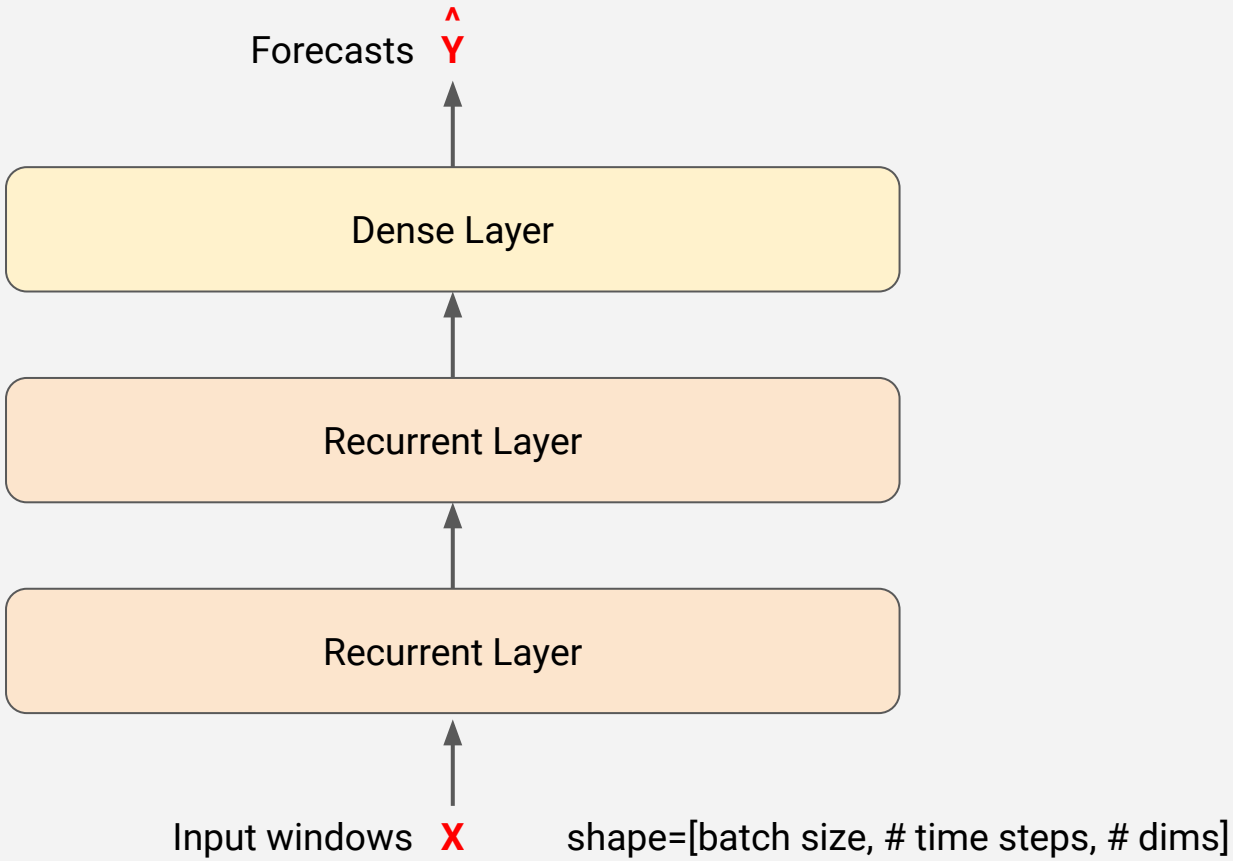
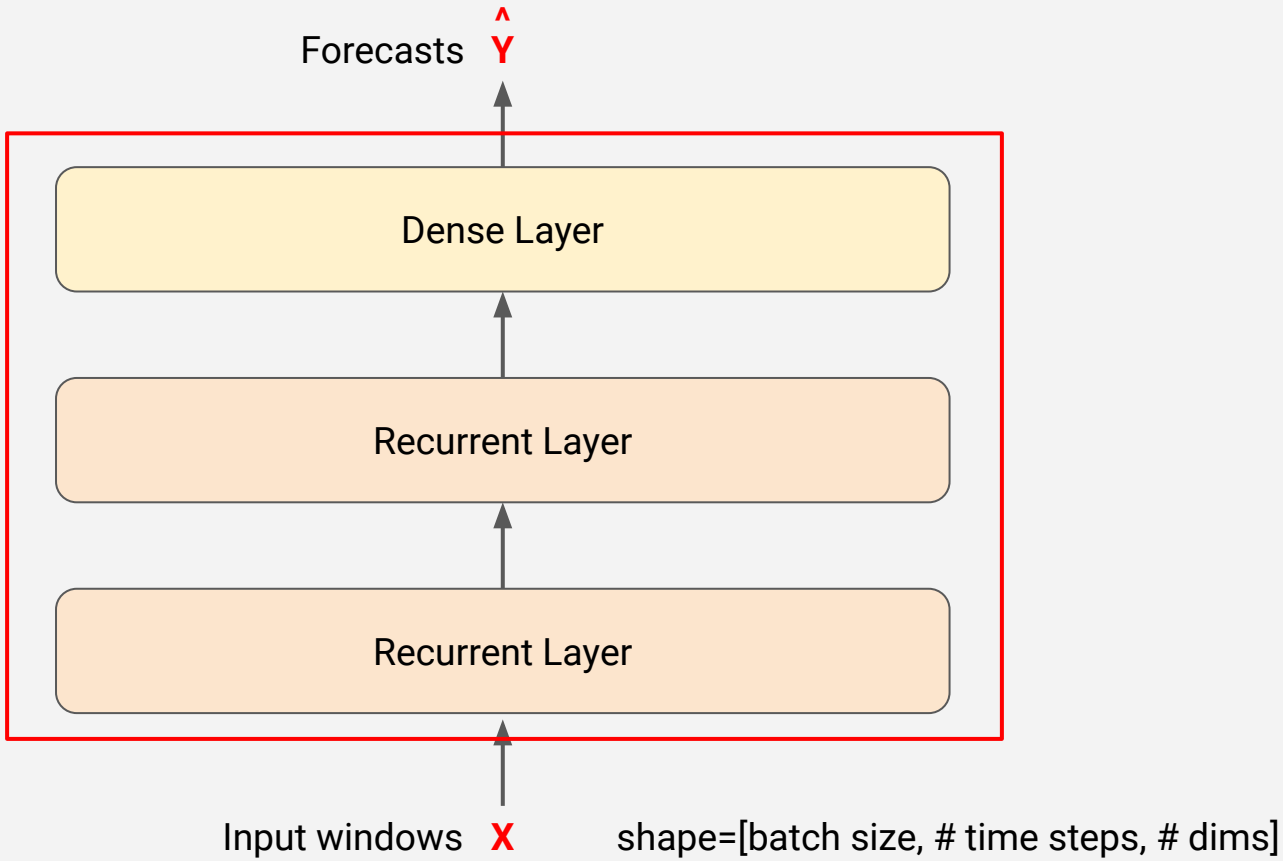
# Copyright Notice

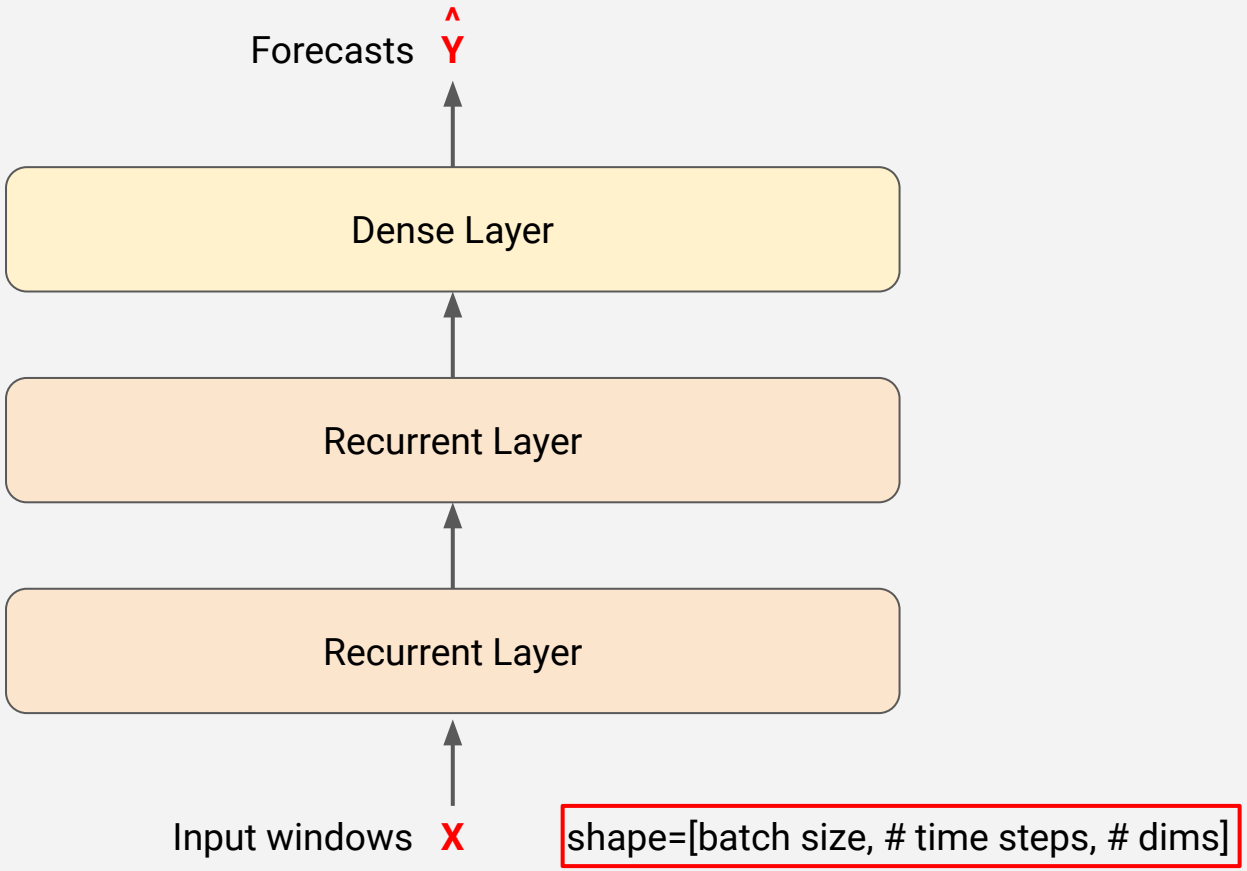
# Recurrent Neural Network



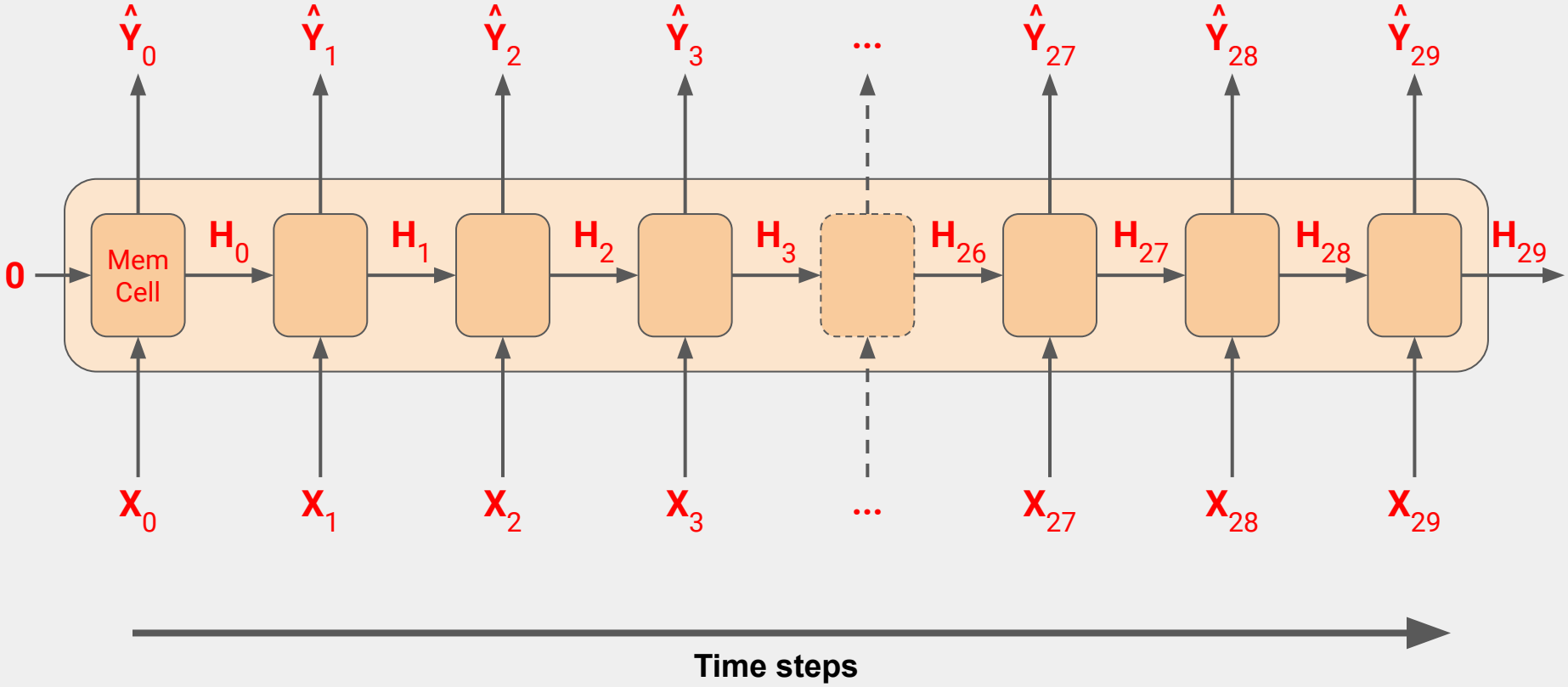
# Recurrent Neural Network



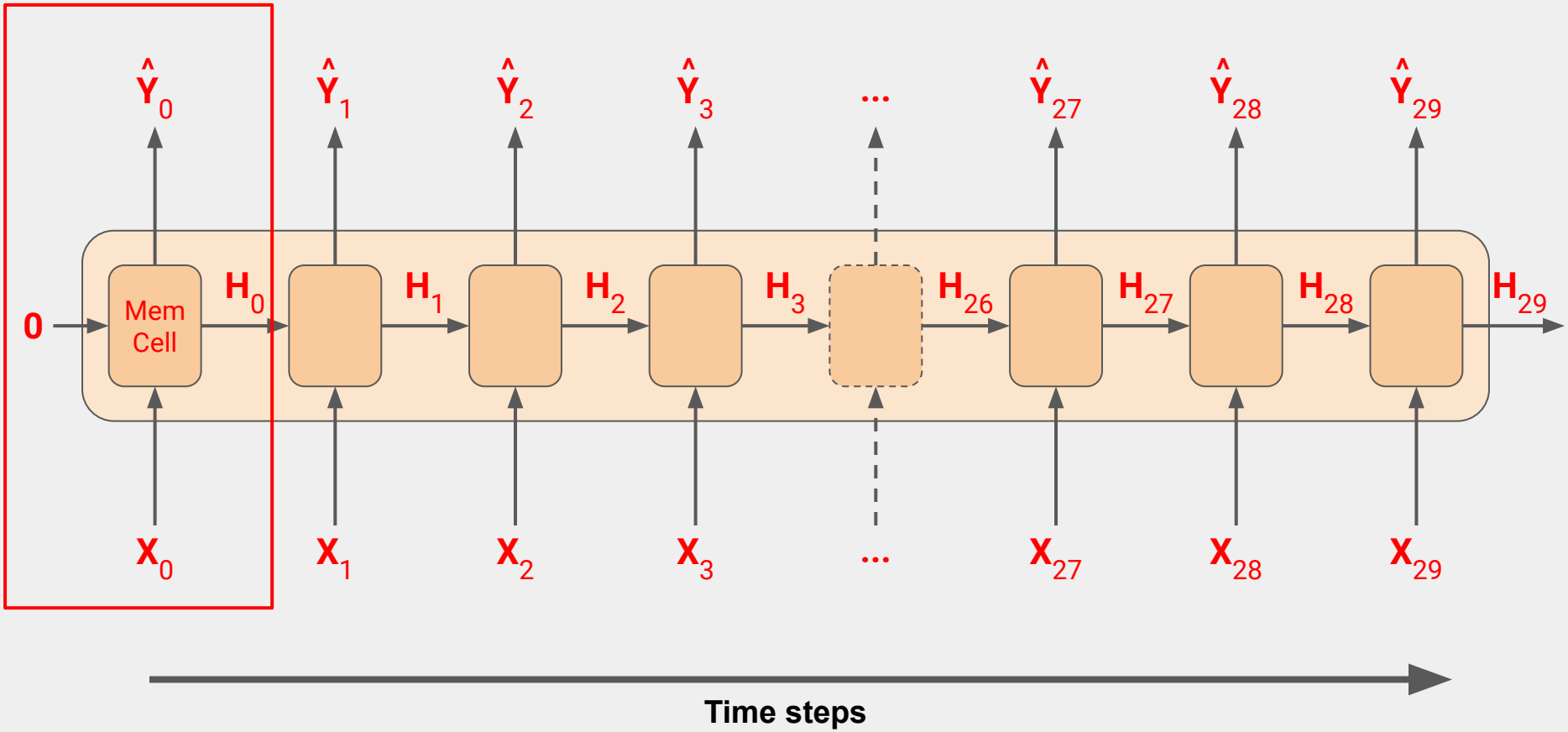
# Recurrent Neural Network



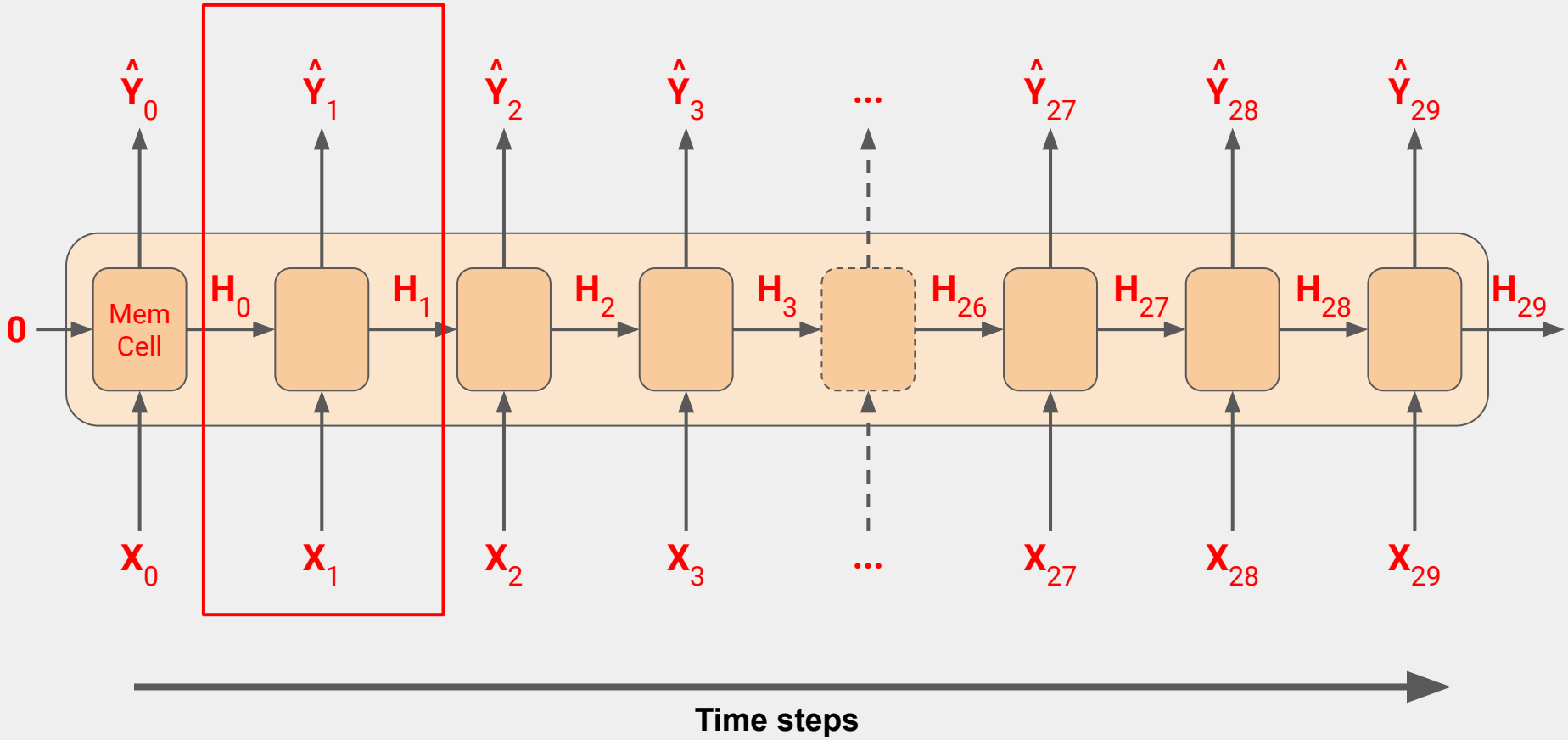
# Recurrent Layer



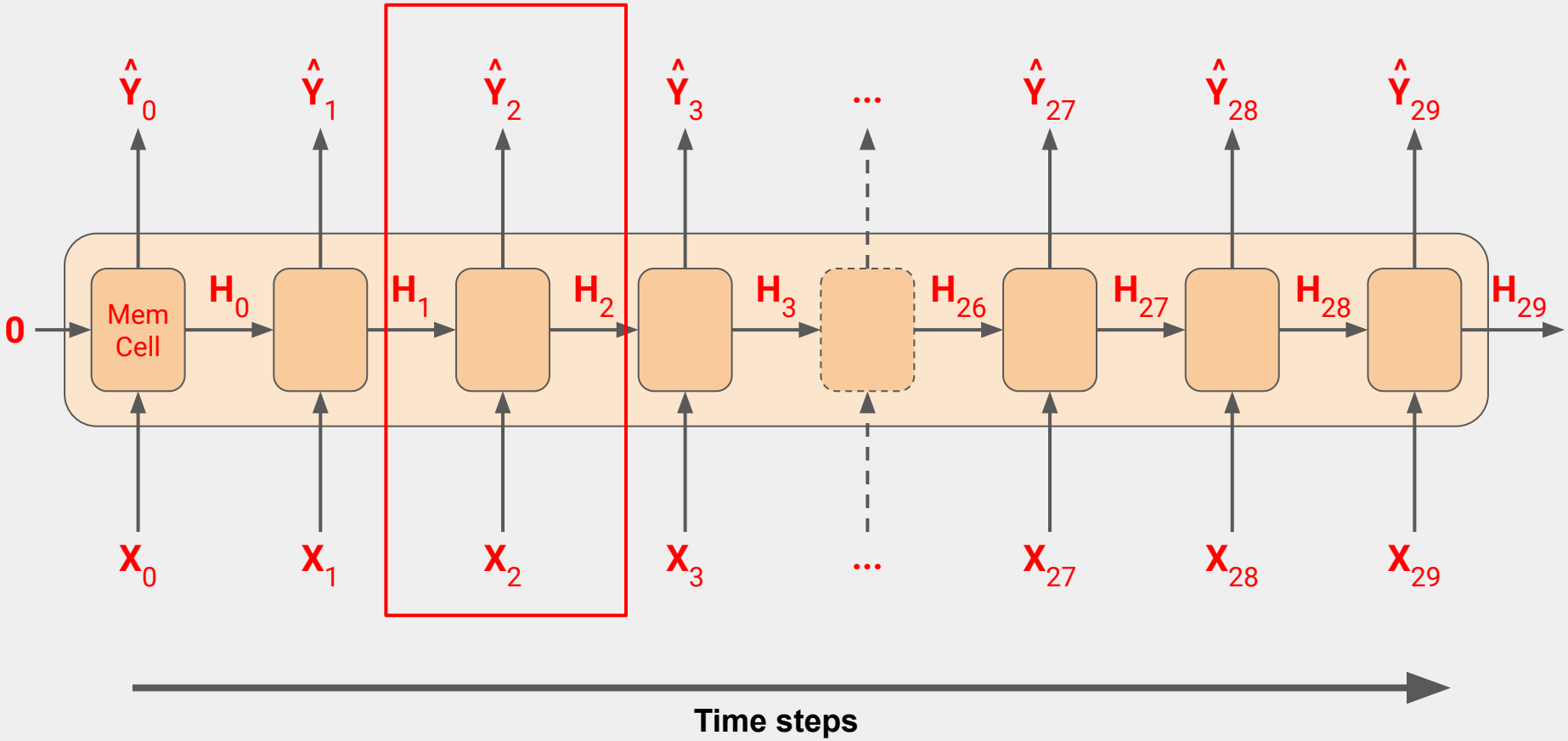
# Recurrent Layer



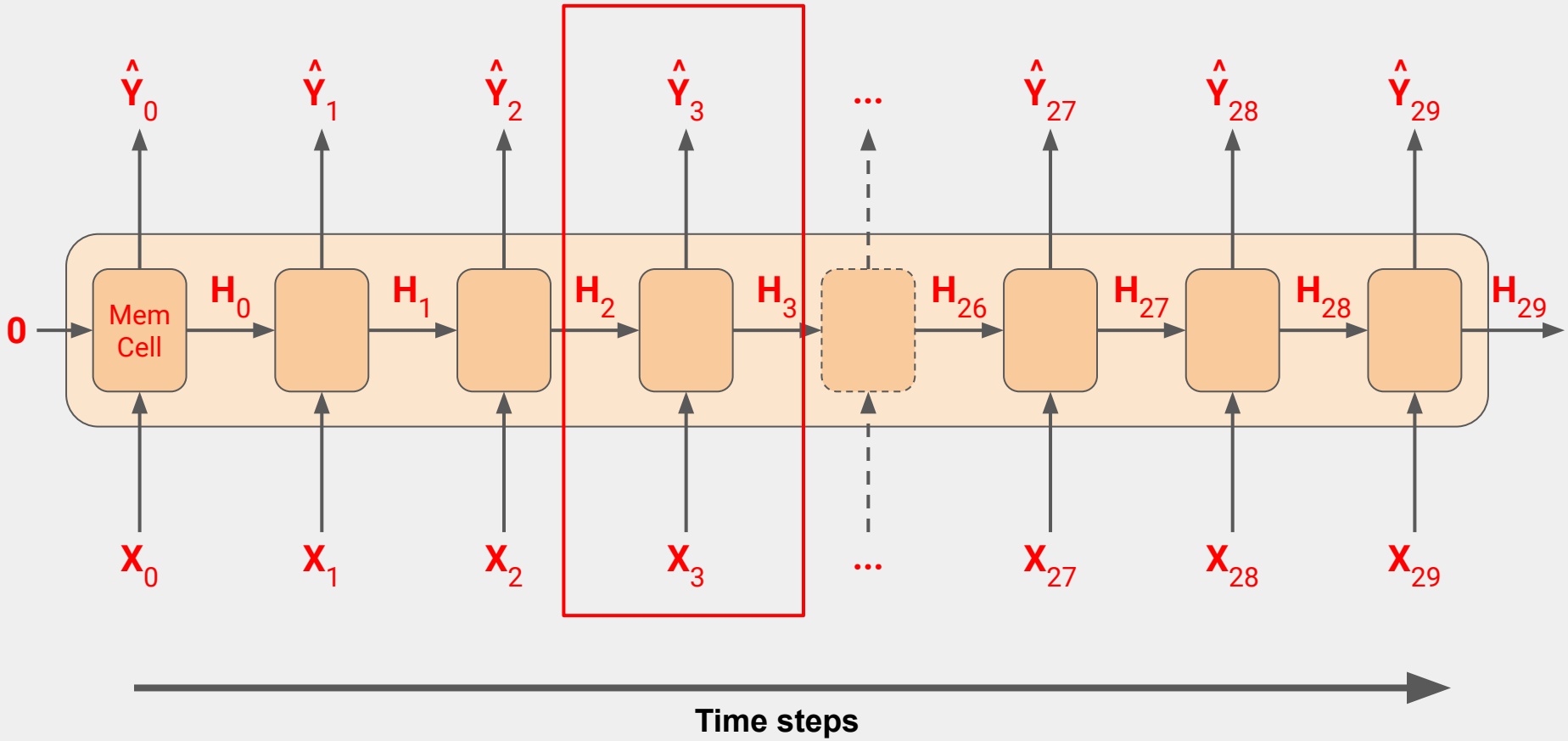
# Recurrent Layer



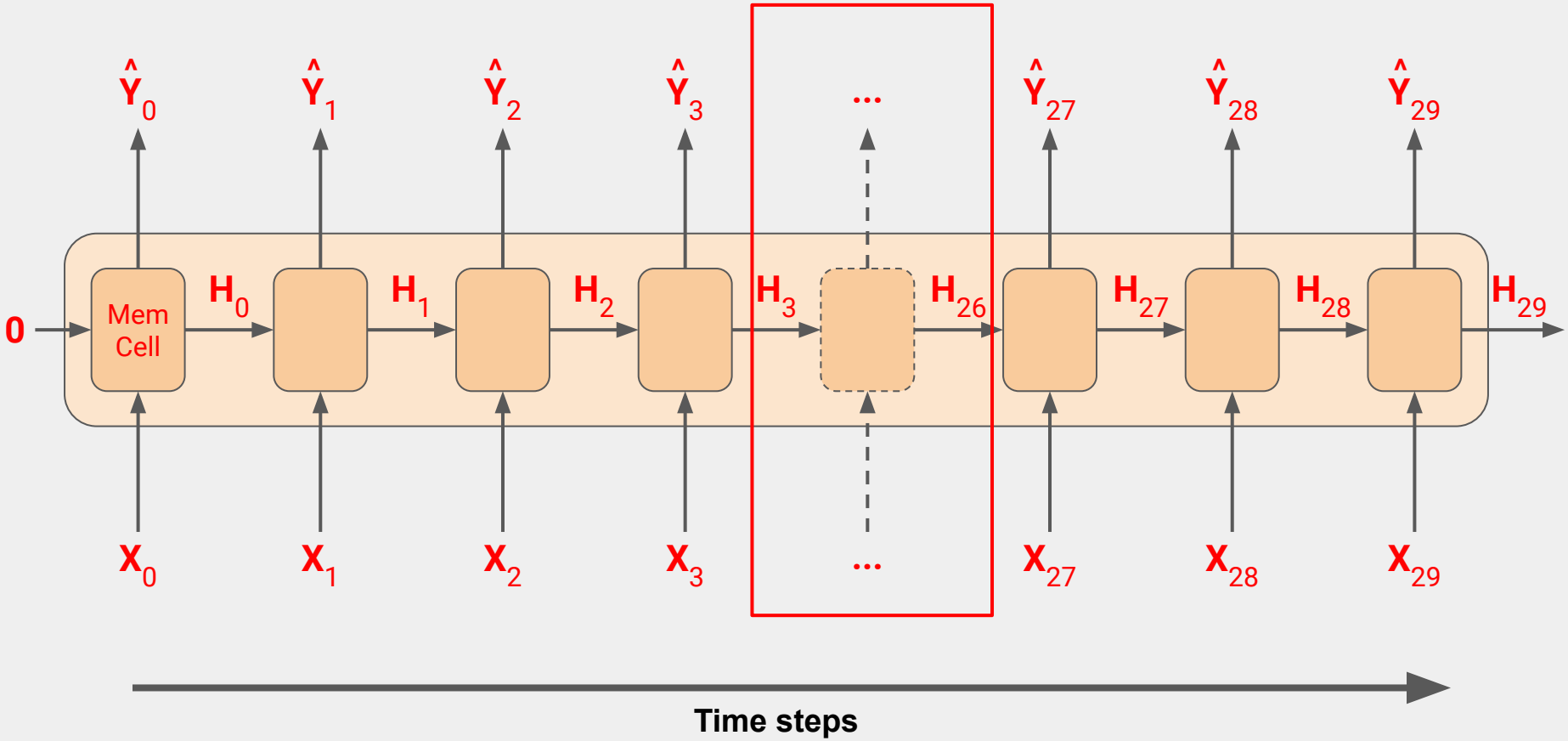
# Recurrent Layer



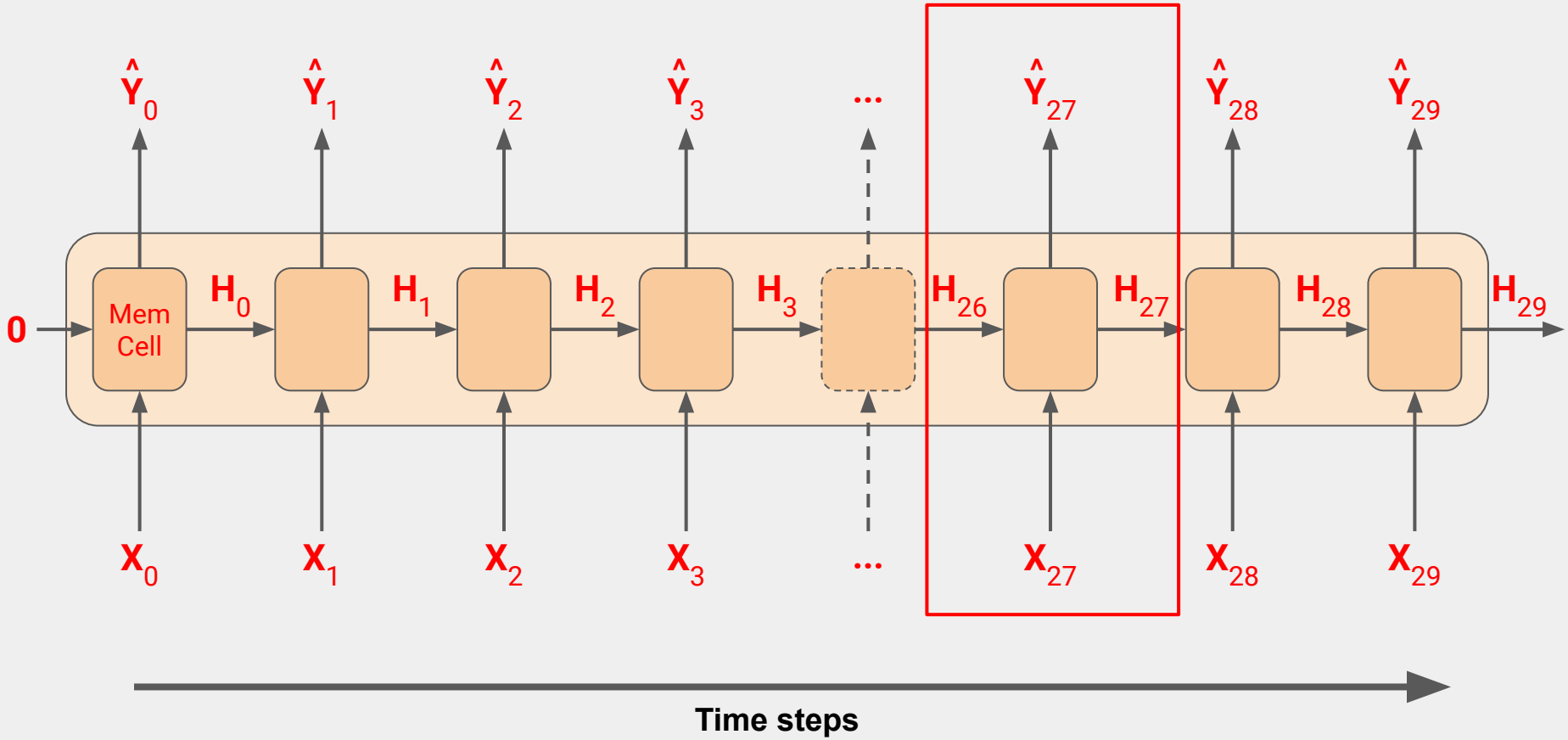
# Recurrent Layer



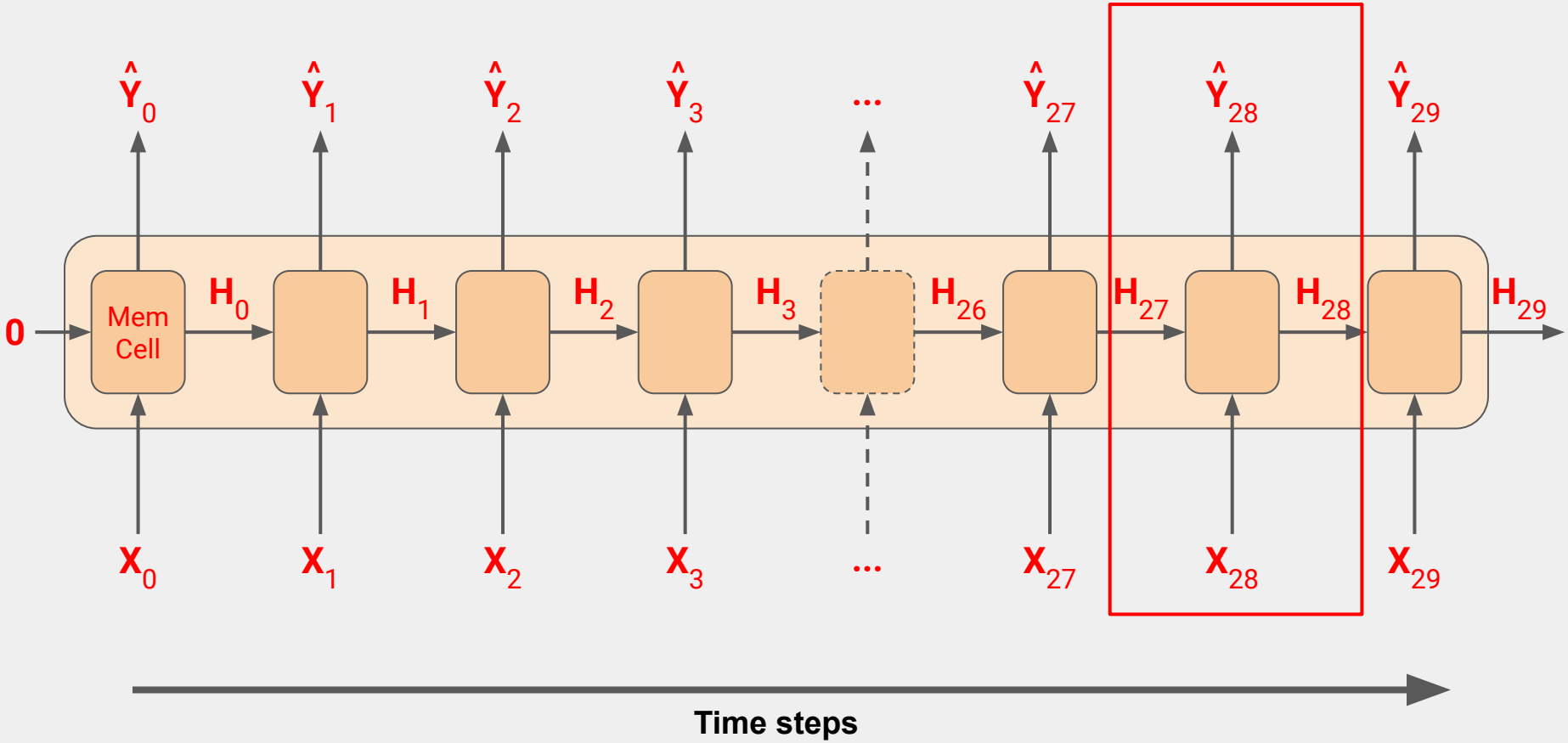
# Recurrent Layer



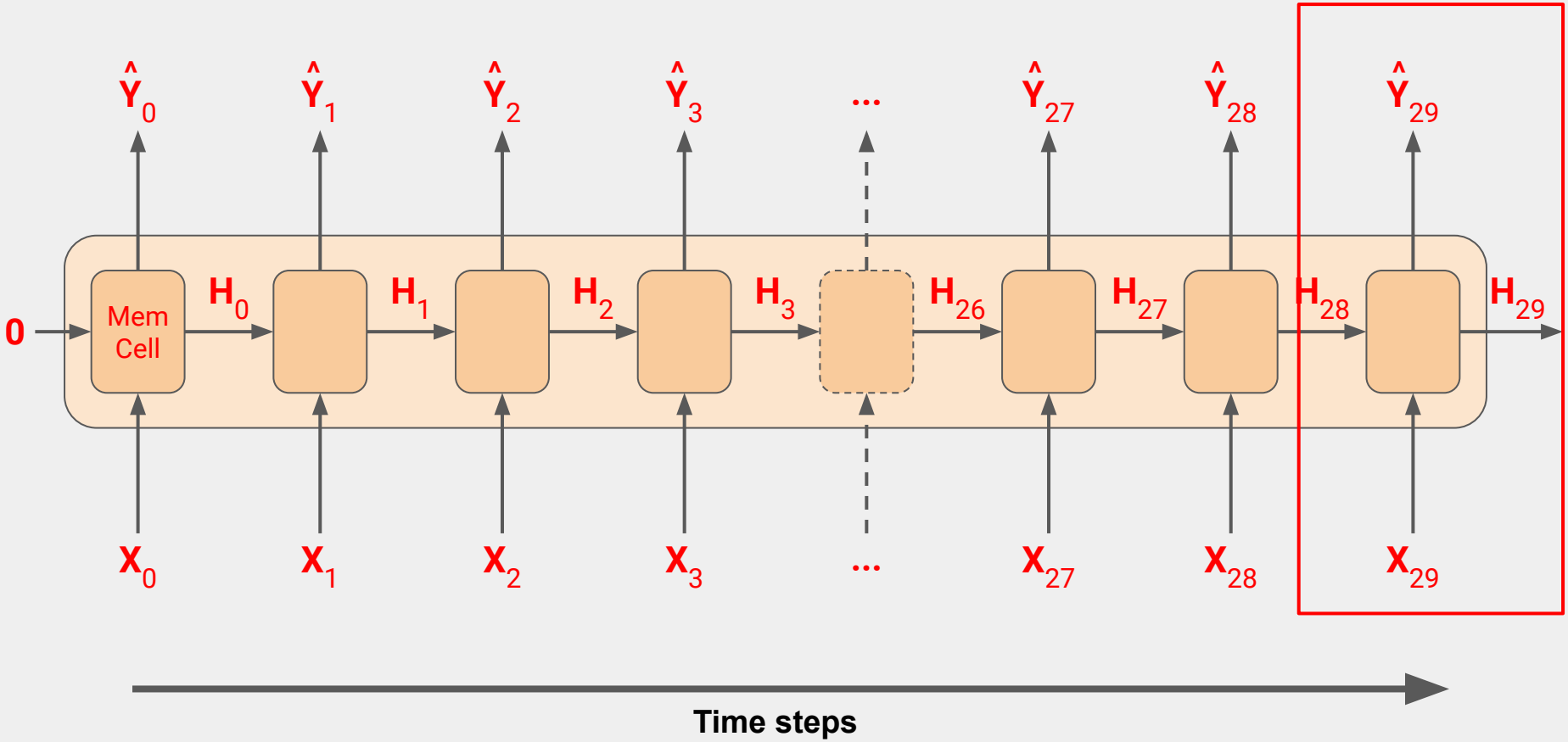
# Recurrent Layer



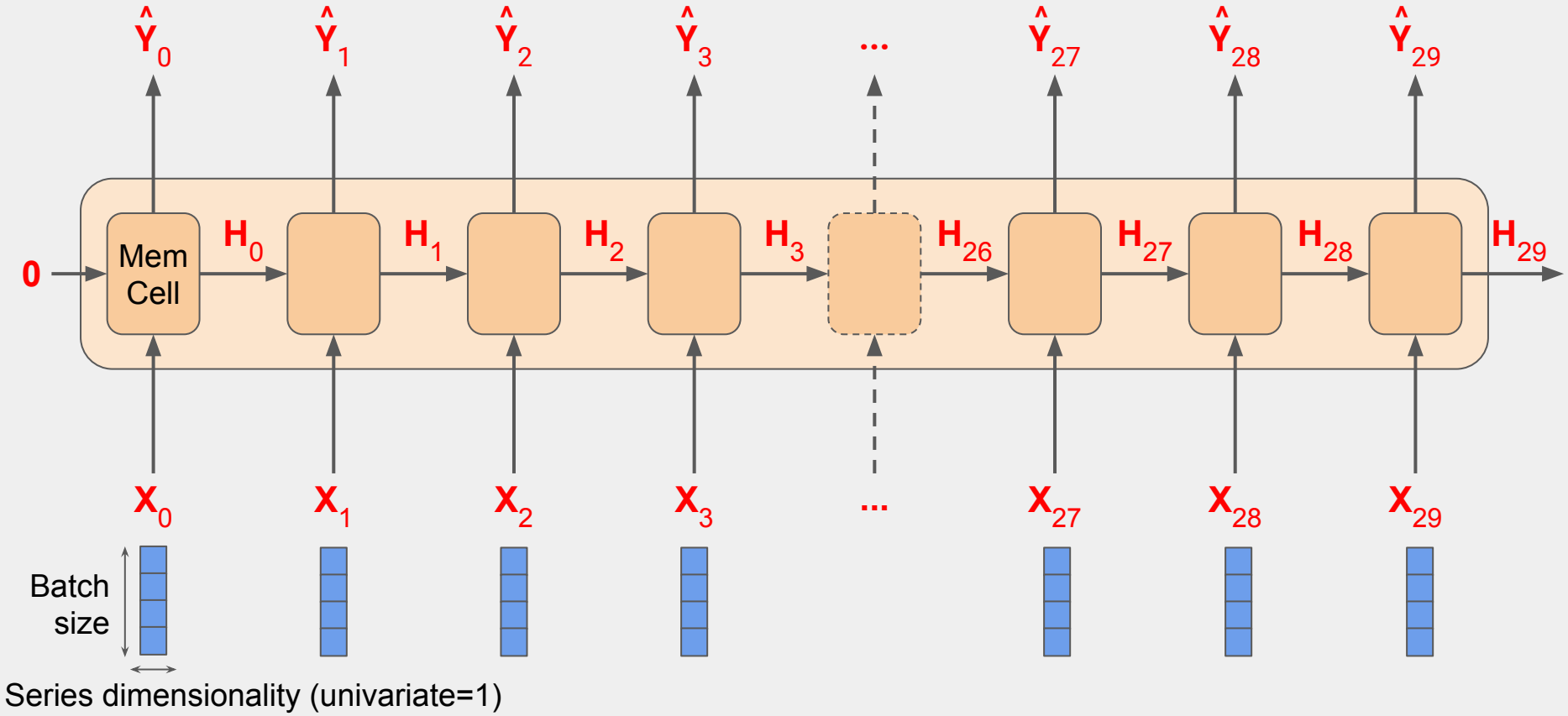
# Recurrent Layer



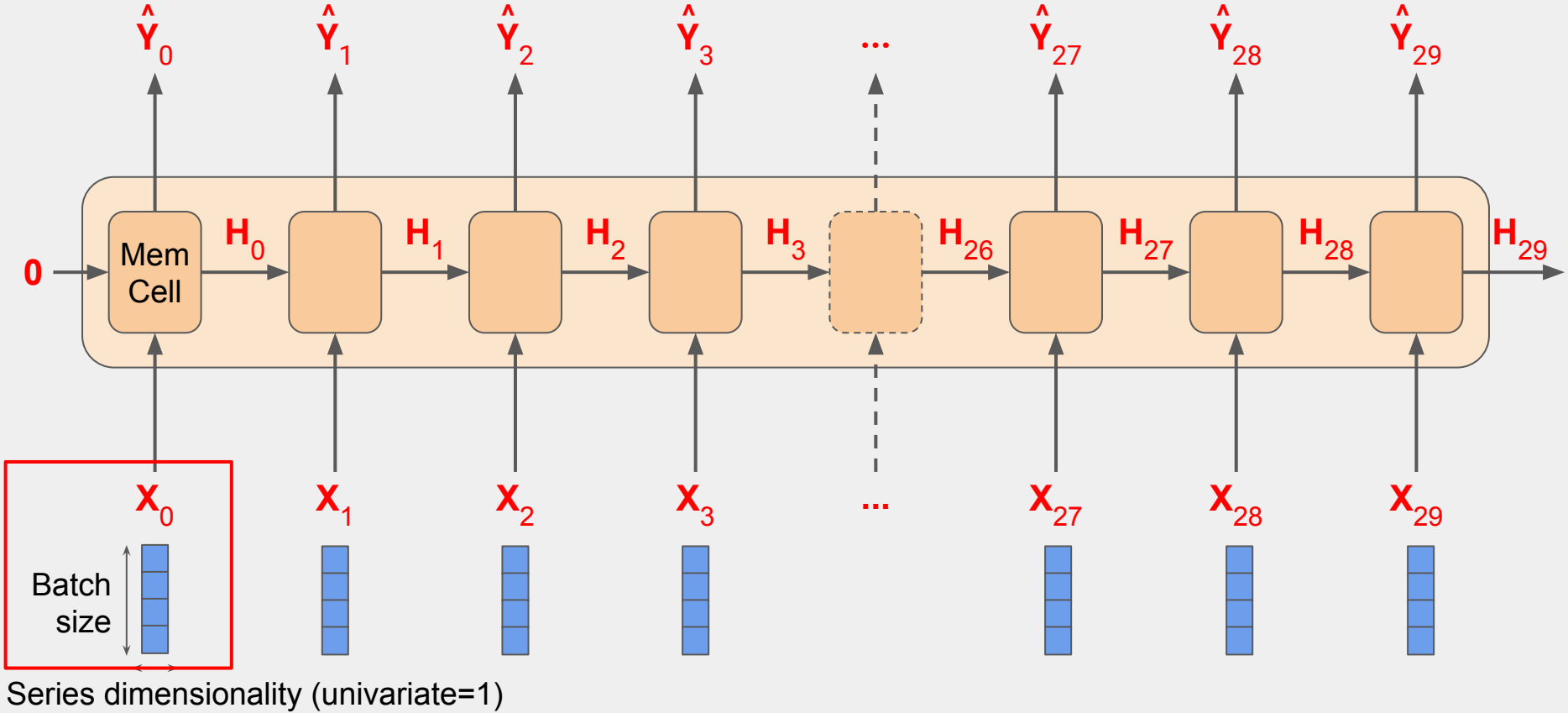
# Recurrent Layer

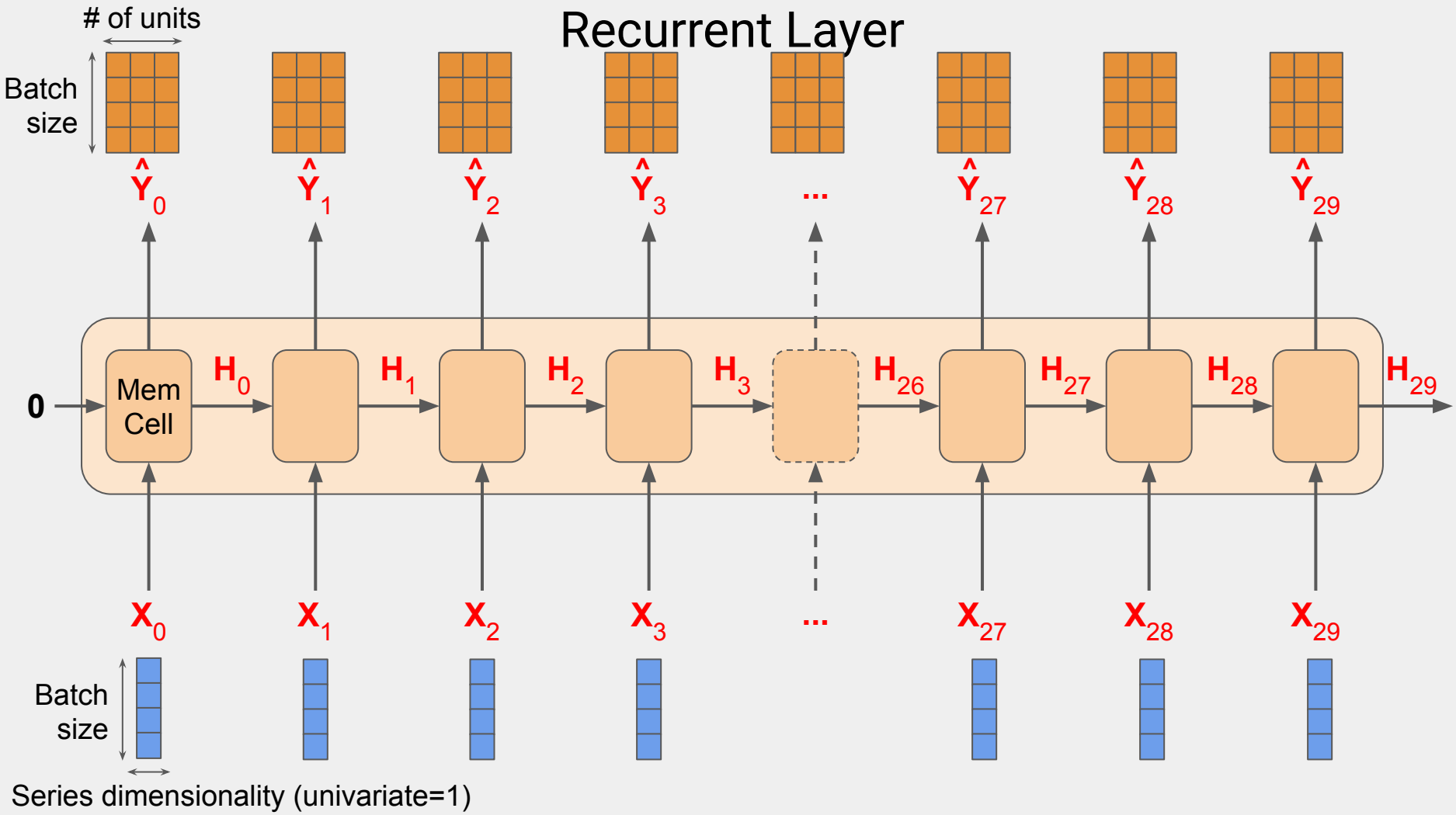


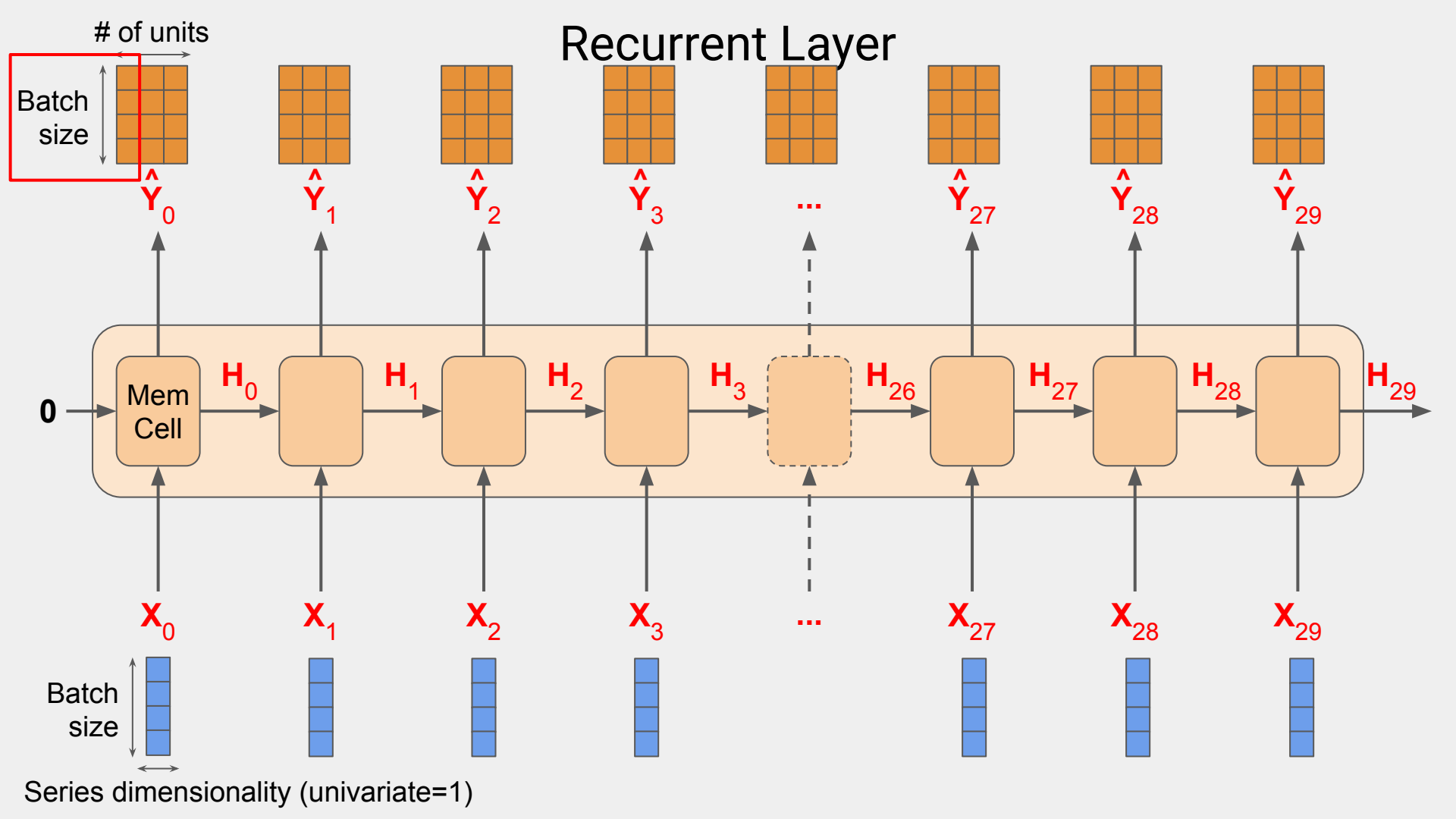
# Recurrent Layer

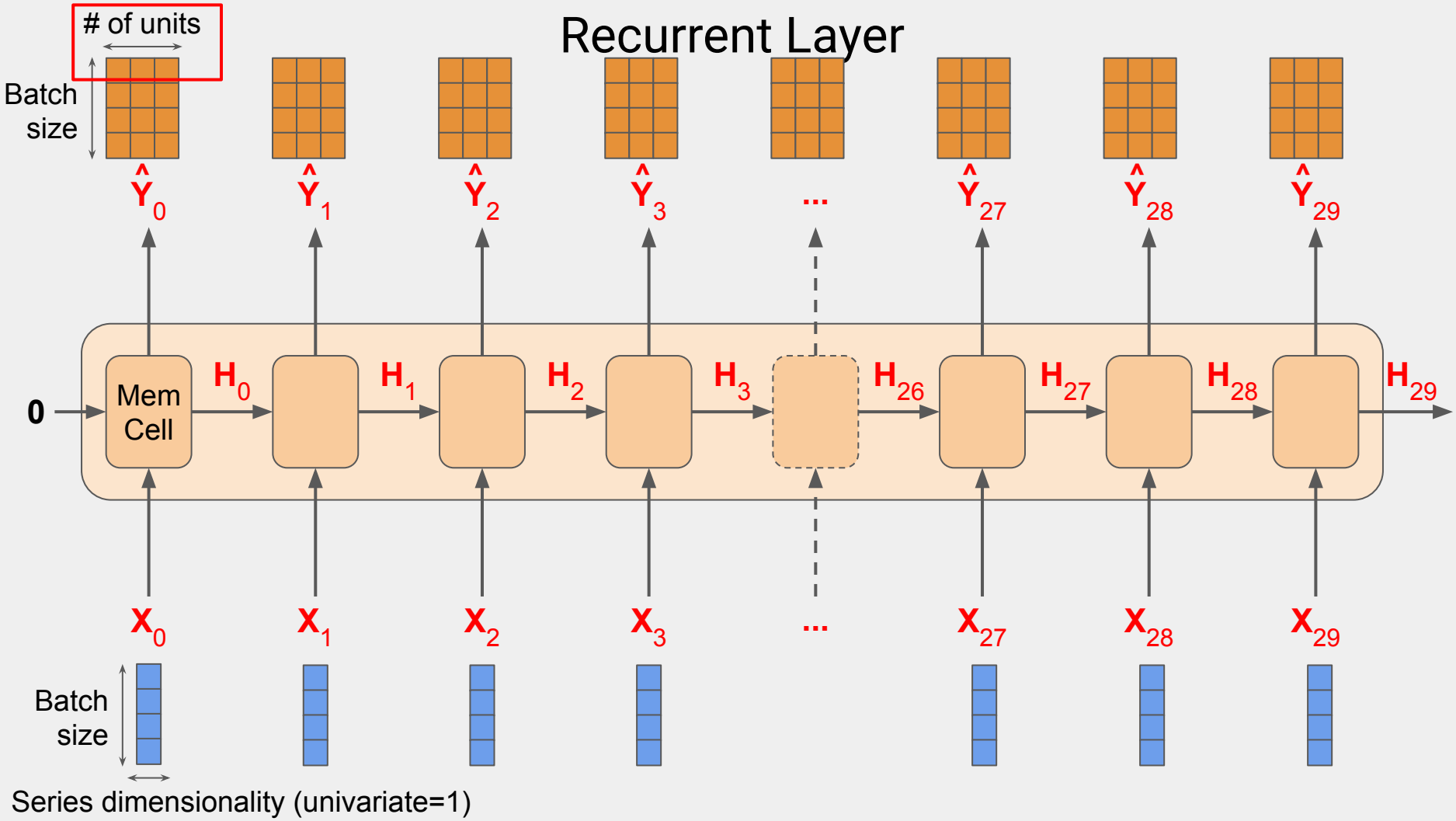


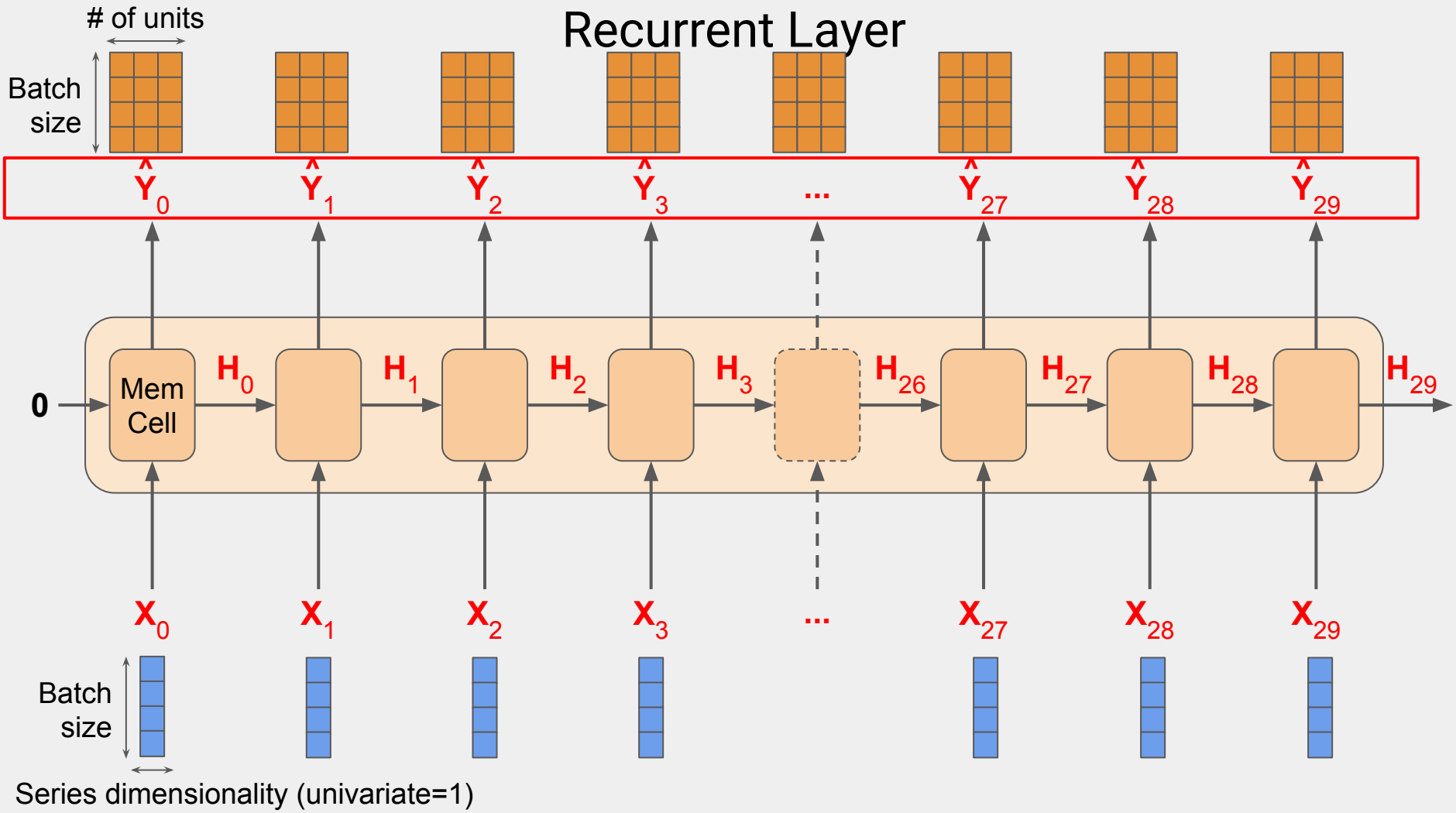
# Recurrent Layer

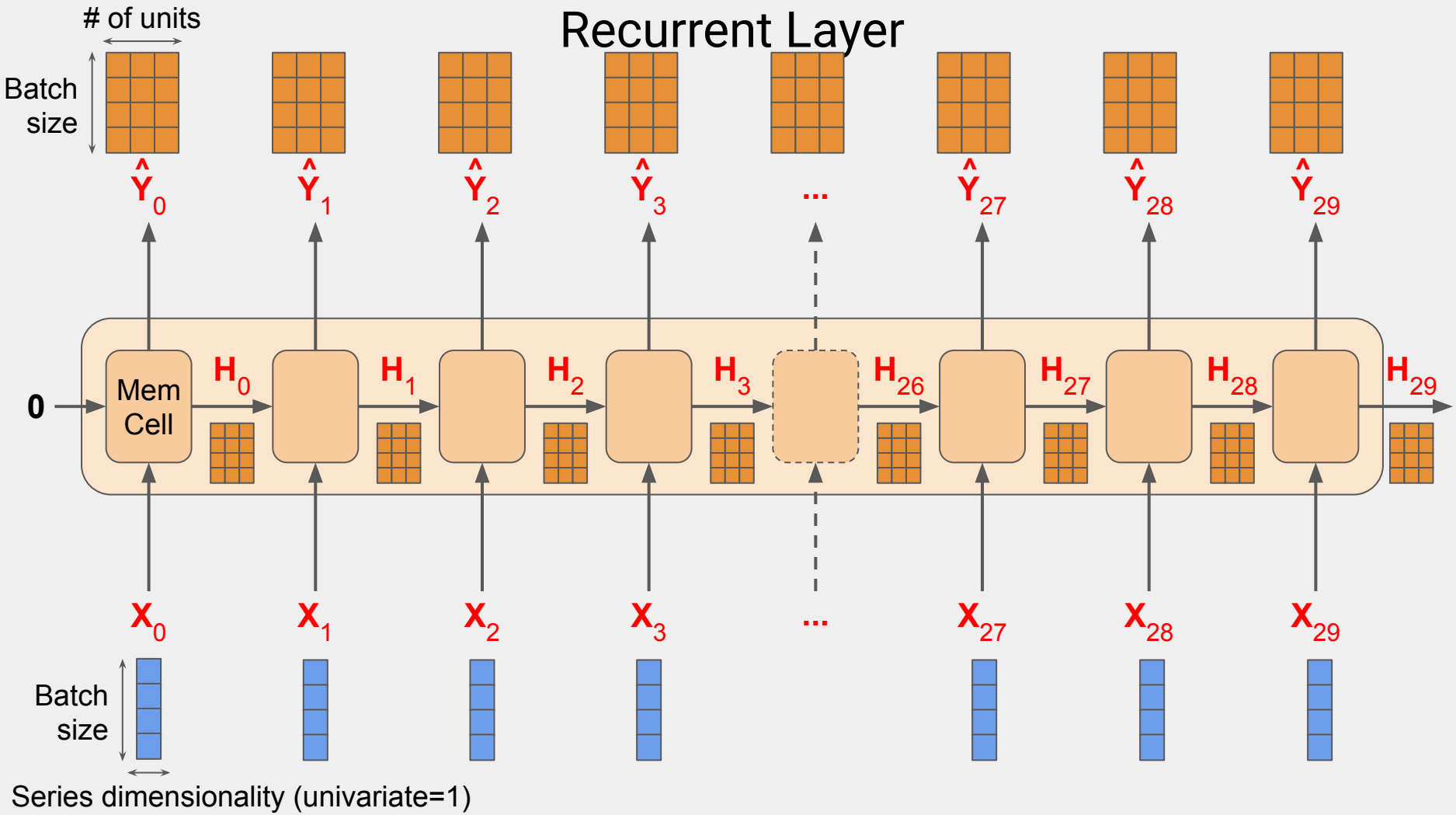


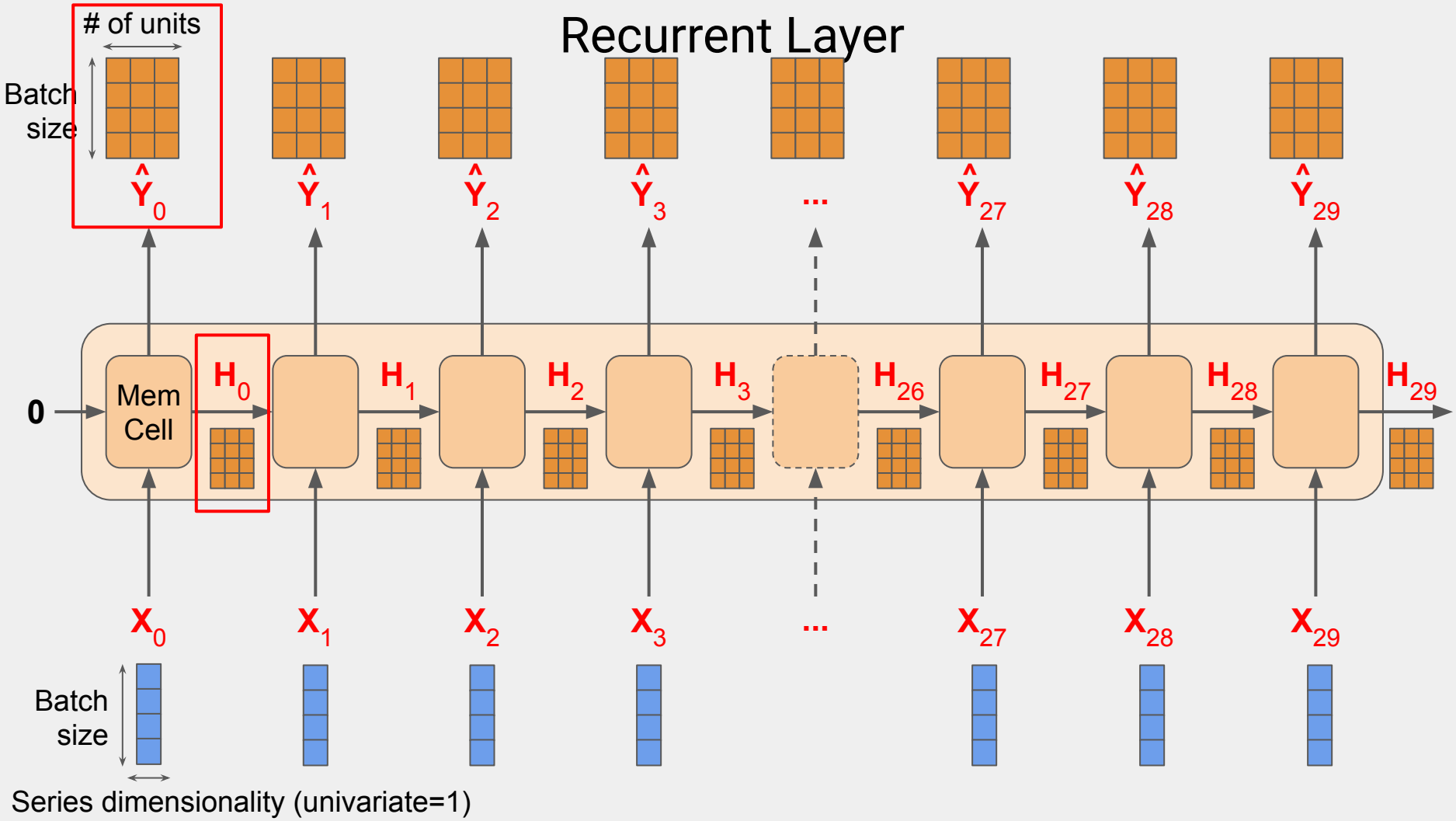

Recurrent Layer
# of units
Batch size
$\hat{Y}_0$
$\hat{Y}_1$
$\hat{Y}_2$
$\hat{Y}_3$
...
$\hat{Y}_{27}$
$\hat{Y}_{28}$
$\hat{Y}_{29}$
0
Mem Cell
$H_0$
$H_1$
$H_2$
$H_3$
$H_{26}$
$H_{27}$
$H_{28}$
$H_{29}$
$X_0$
$X_1$
$X_2$
$X_3$
...
$X_{27}$
$X_{28}$
$X_{29}$
Batch size
Series dimensionality (univariate=1)

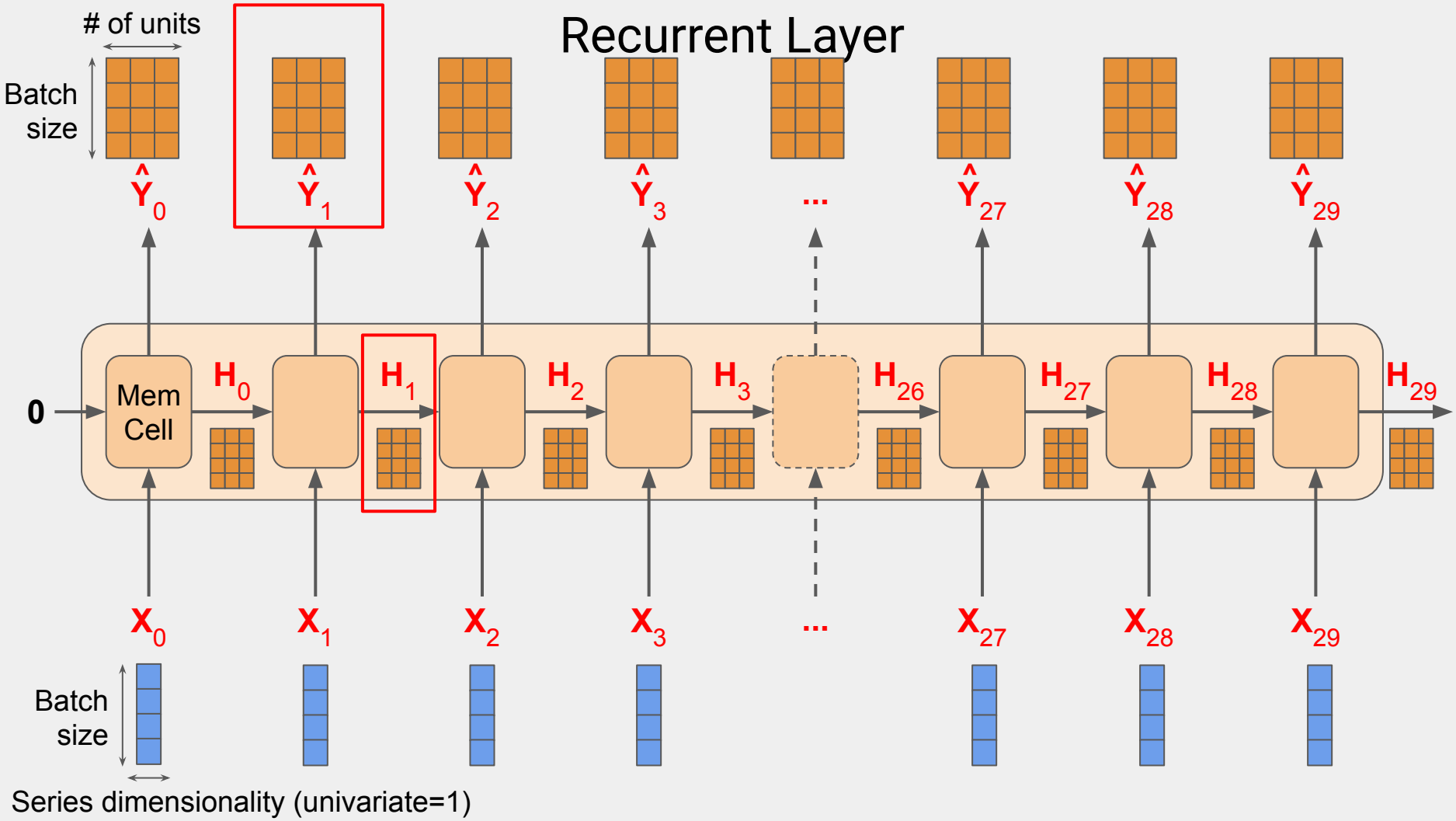

Recurrent Layer
# of units
Batch size
$\hat{Y}_0$
$\hat{Y}_1$
$\hat{Y}_2$
$\hat{Y}_3$
...
$\hat{Y}_{27}$
$\hat{Y}_{28}$
$\hat{Y}_{29}$
0
Mem Cell
$H_0$
$H_1$
$H_2$
$H_3$
$H_{26}$
$H_{27}$
$H_{28}$
$H_{29}$
$X_0$
$X_1$
$X_2$
$X_3$
...
$X_{27}$
$X_{28}$
$X_{29}$
Batch size
Series dimensionality (univariate=1)


Recurrent Layer
# of units
Batch size
$\hat{Y}_0$
$\hat{Y}_1$
$\hat{Y}_2$
$\hat{Y}_3$
...
$\hat{Y}_{27}$
$\hat{Y}_{28}$
$\hat{Y}_{29}$
0
Mem Cell
$H_0$
$H_1$
$H_2$
$H_3$
$H_{26}$
$H_{27}$
$H_{28}$
$H_{29}$
$X_0$
$X_1$
$X_2$
$X_3$
...
$X_{27}$
$X_{28}$
$X_{29}$
Batch size
Series dimensionality (univariate=1)

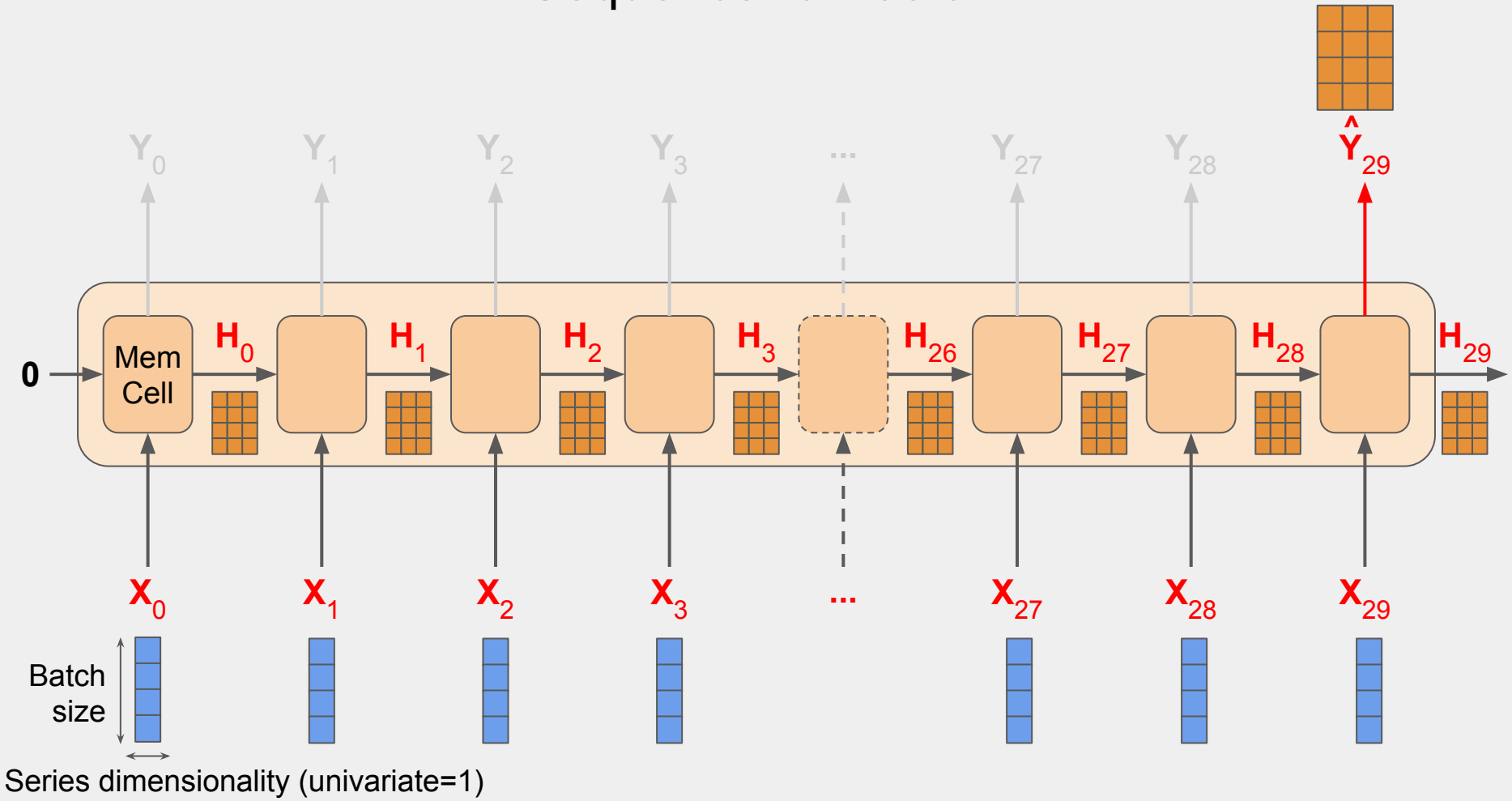

Recurrent Layer
# of units
Batch size
$\hat{Y}_0$
$\hat{Y}_1$
$\hat{Y}_2$
$\hat{Y}_3$
...
$\hat{Y}_{27}$
$\hat{Y}_{28}$
$\hat{Y}_{29}$
0
Mem Cell
$H_0$
$H_1$
$H_2$
$H_3$
$H_{26}$
$H_{27}$
$H_{28}$
$H_{29}$
$X_0$
$X_1$
$X_2$
$X_3$
...
$X_{27}$
$X_{28}$
$X_{29}$
Batch size
Series dimensionality (univariate=1)


Recurrent Layer
# of units
Batch size
$\hat{Y}_0$
$\hat{Y}_1$
$\hat{Y}_2$
$\hat{Y}_3$
...
$\hat{Y}_{27}$
$\hat{Y}_{28}$
$\hat{Y}_{29}$
0
Mem Cell
$H_0$
$H_1$
$H_2$
$H_3$
$H_{26}$
$H_{27}$
$H_{28}$
$H_{29}$
$X_0$
$X_1$
$X_2$
$X_3$
...
$X_{27}$
$X_{28}$
$X_{29}$
Batch size
Series dimensionality (univariate=1)

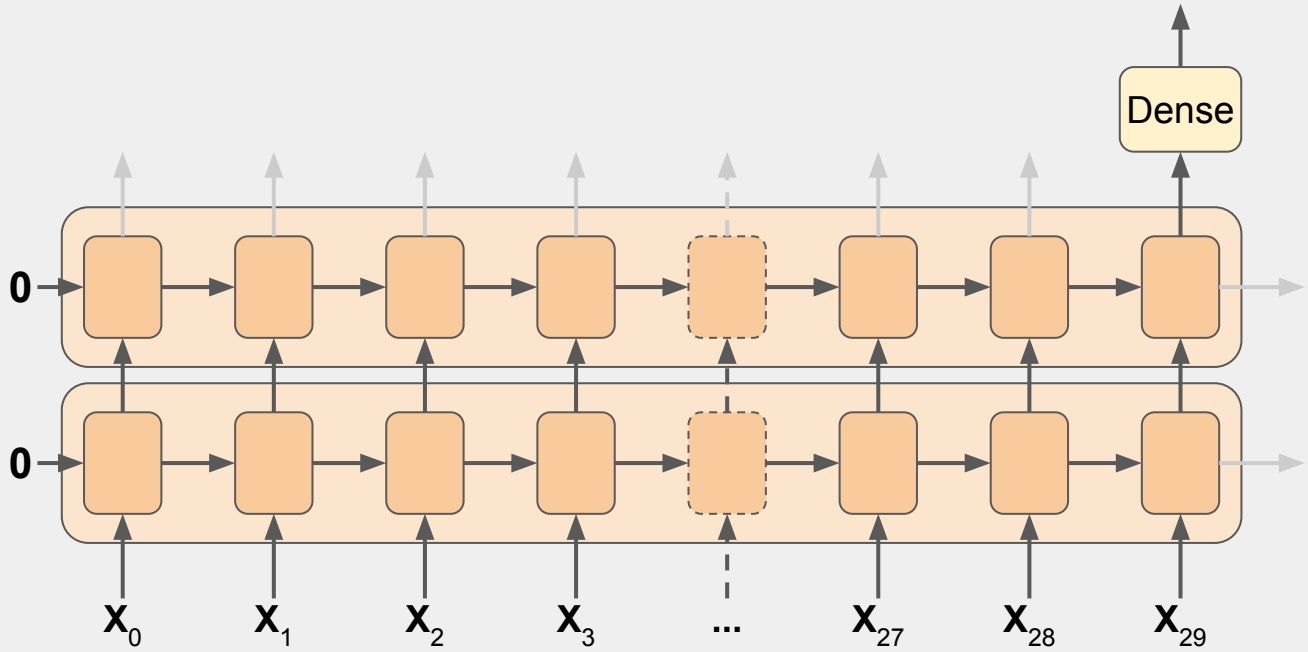

Recurrent Layer
# of units
Batch size
$\hat{Y}_0$
$\hat{Y}_1$
$\hat{Y}_2$
$\hat{Y}_3$
...
$\hat{Y}_{27}$
$\hat{Y}_{28}$
$\hat{Y}_{29}$
0
Mem Cell
$H_0$
$H_1$
$H_2$
$H_3$
$H_{26}$
$H_{27}$
$H_{28}$
$H_{29}$
$X_0$
$X_1$
$X_2$
$X_3$
...
$X_{27}$
$X_{28}$
$X_{29}$
Batch size
Series dimensionality (univariate=1)


Recurrent Layer
# of units
Batch size
Mem Cell
0
$\hat{Y}_0$
$\hat{Y}_1$
$\hat{Y}_2$
$\hat{Y}_3$
...
$\hat{Y}_{27}$
$\hat{Y}_{28}$
$\hat{Y}_{29}$
$H_0$
$H_1$
$H_2$
$H_3$
$H_{26}$
$H_{27}$
$H_{28}$
$H_{29}$
$X_0$
$X_1$
$X_2$
$X_3$
...
$X_{27}$
$X_{28}$
$X_{29}$
Batch size
Series dimensionality (univariate=1)

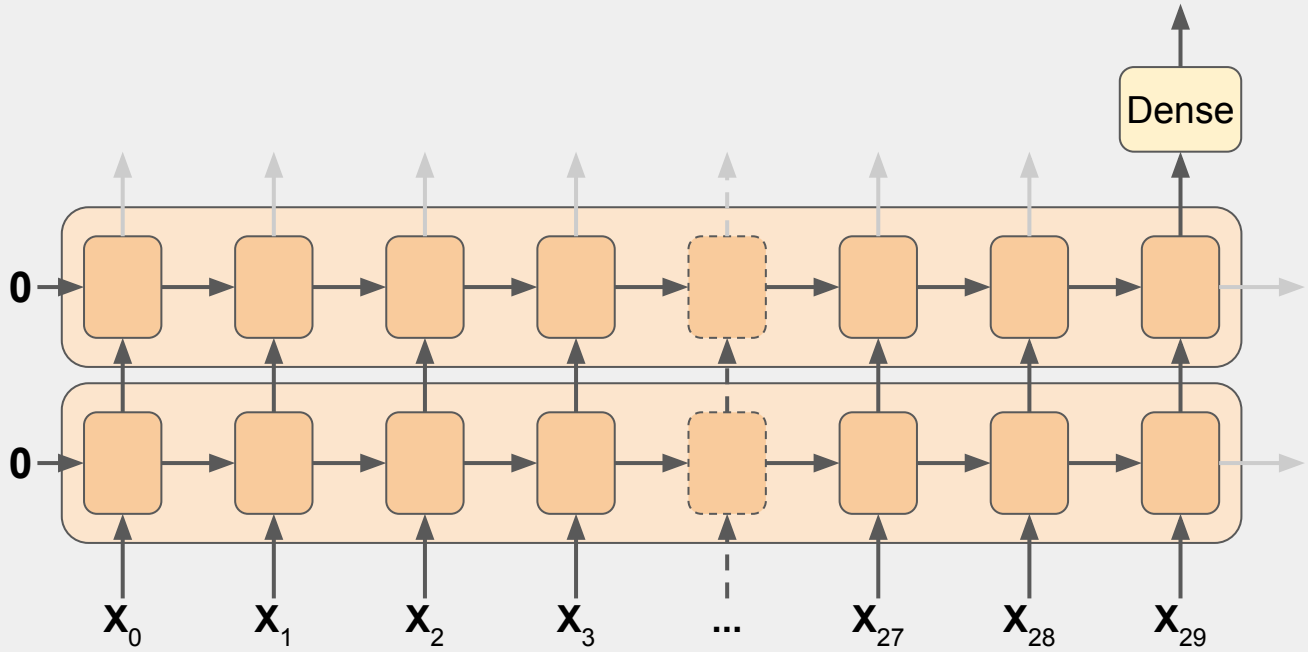
# Sequence-to-Vector



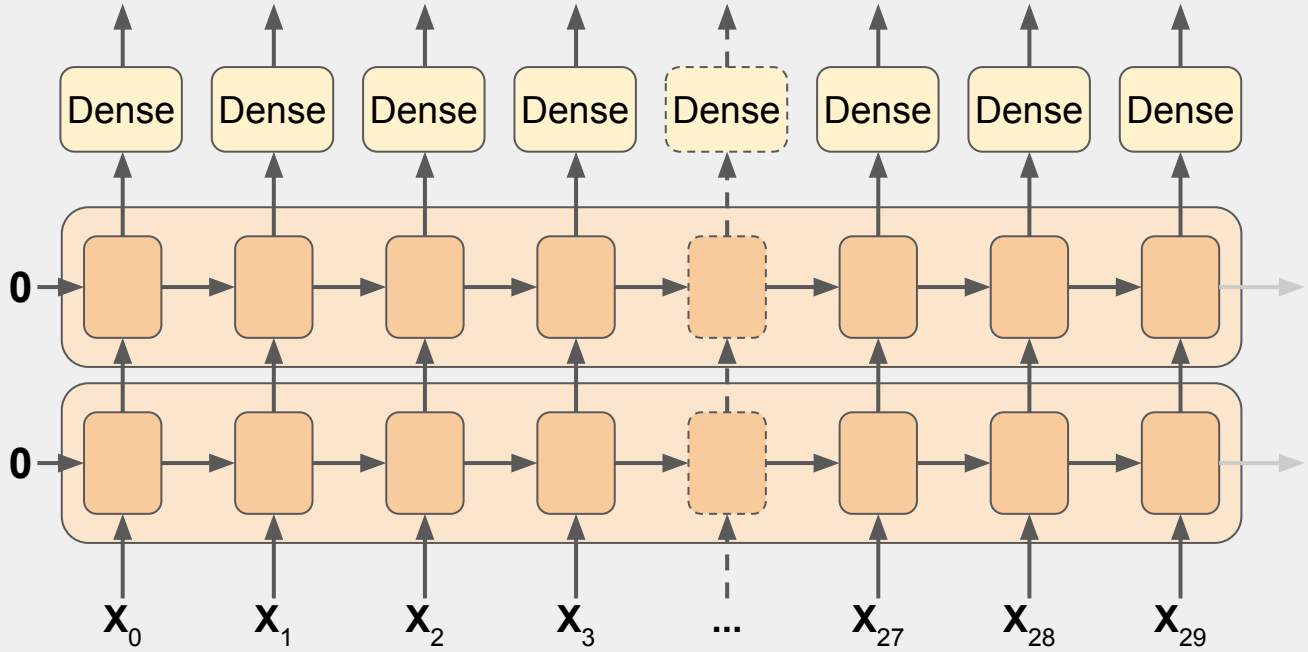
```
model = keras.models.Sequential([
  keras.layers.SimpleRNN(20, return_sequences=True,
                         input_shape=[None, 1]),
  keras.layers.SimpleRNN(20),
  keras.layers.Dense(1)
])
```



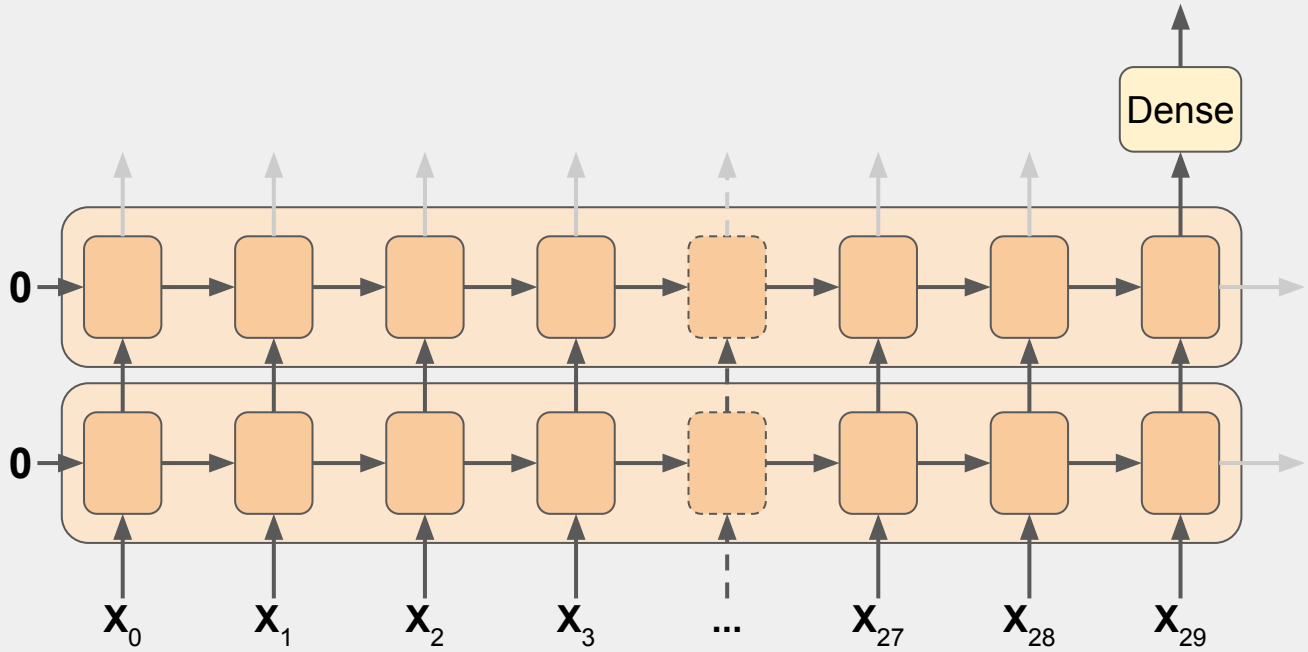
```
model = keras.models.Sequential([
  keras.layers.SimpleRNN(20, return_sequences=True,
                         input_shape=[None, 1]),
  keras.layers.SimpleRNN(20),
  keras.layers.Dense(1)
])
```



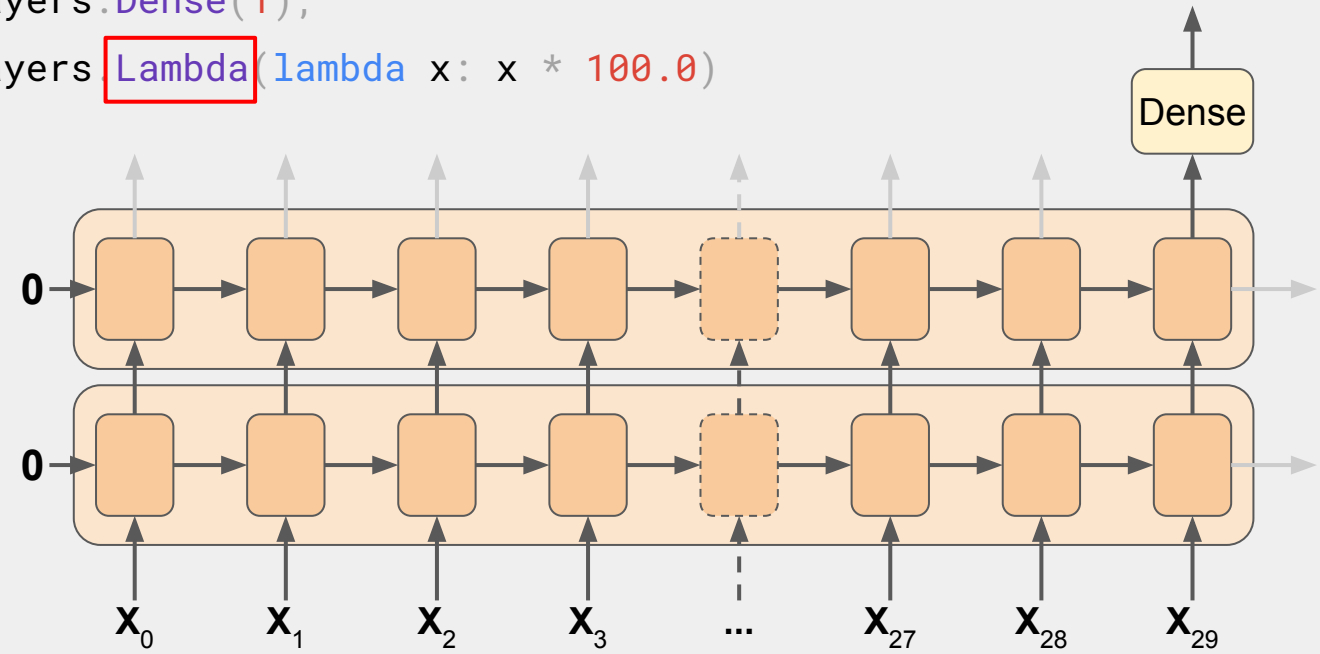
```
model = keras.models.Sequential([
  keras.layers.SimpleRNN(20, return_sequences=True,
                         input_shape=[None, 1]),
  keras.layers.SimpleRNN(20, return_sequences=True),
  keras.layers.Dense(1)
])
```



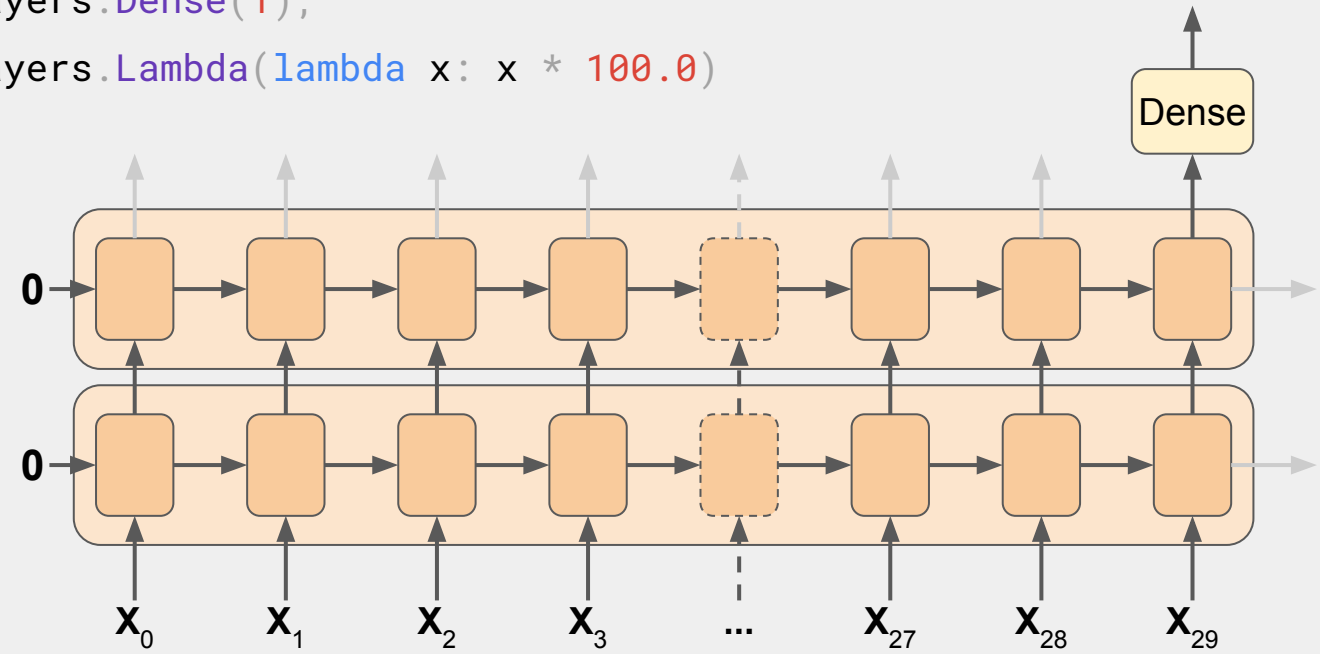
```
model = keras.models.Sequential([
  keras.layers.SimpleRNN(20, return_sequences=True,
                         input_shape=[None, 1]),
  keras.layers.SimpleRNN(20),
  keras.layers.Dense(1)
])
```



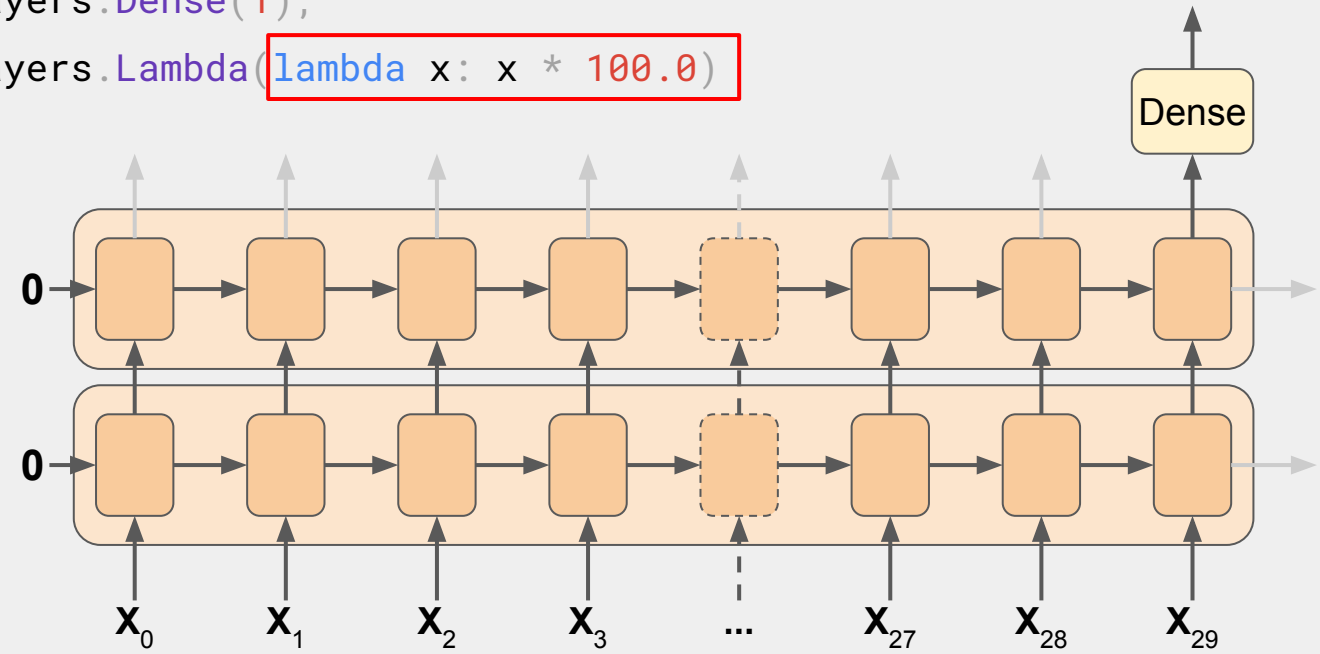
```
model = keras.models.Sequential([
  keras.layers.Lambda(lambda x: tf.expand_dims(x, axis=-1),
                      input_shape=[None]),
  keras.layers.SimpleRNN(20, return_sequences=True),
  keras.layers.SimpleRNN(20),
  keras.layers.Dense(1),
  keras.layers.Lambda(lambda x: x * 100.0)
])
```



```
model = keras.models.Sequential([
  keras.layers.Lambda(lambda x: tf.expand_dims(x, axis=-1),
                      input_shape=[None]),
  keras.layers.SimpleRNN(20, return_sequences=True),
  keras.layers.SimpleRNN(20),
  keras.layers.Dense(1),
  keras.layers.Lambda(lambda x: x * 100.0)
])
```



```
model = keras.models.Sequential([
  keras.layers.Lambda(lambda x: tf.expand_dims(x, axis=-1),
                      input_shape=[None]),
  keras.layers.SimpleRNN(20, return_sequences=True),
  keras.layers.SimpleRNN(20),
  keras.layers.Dense(1),
  keras.layers.Lambda(lambda x: x * 100.0)
])
```



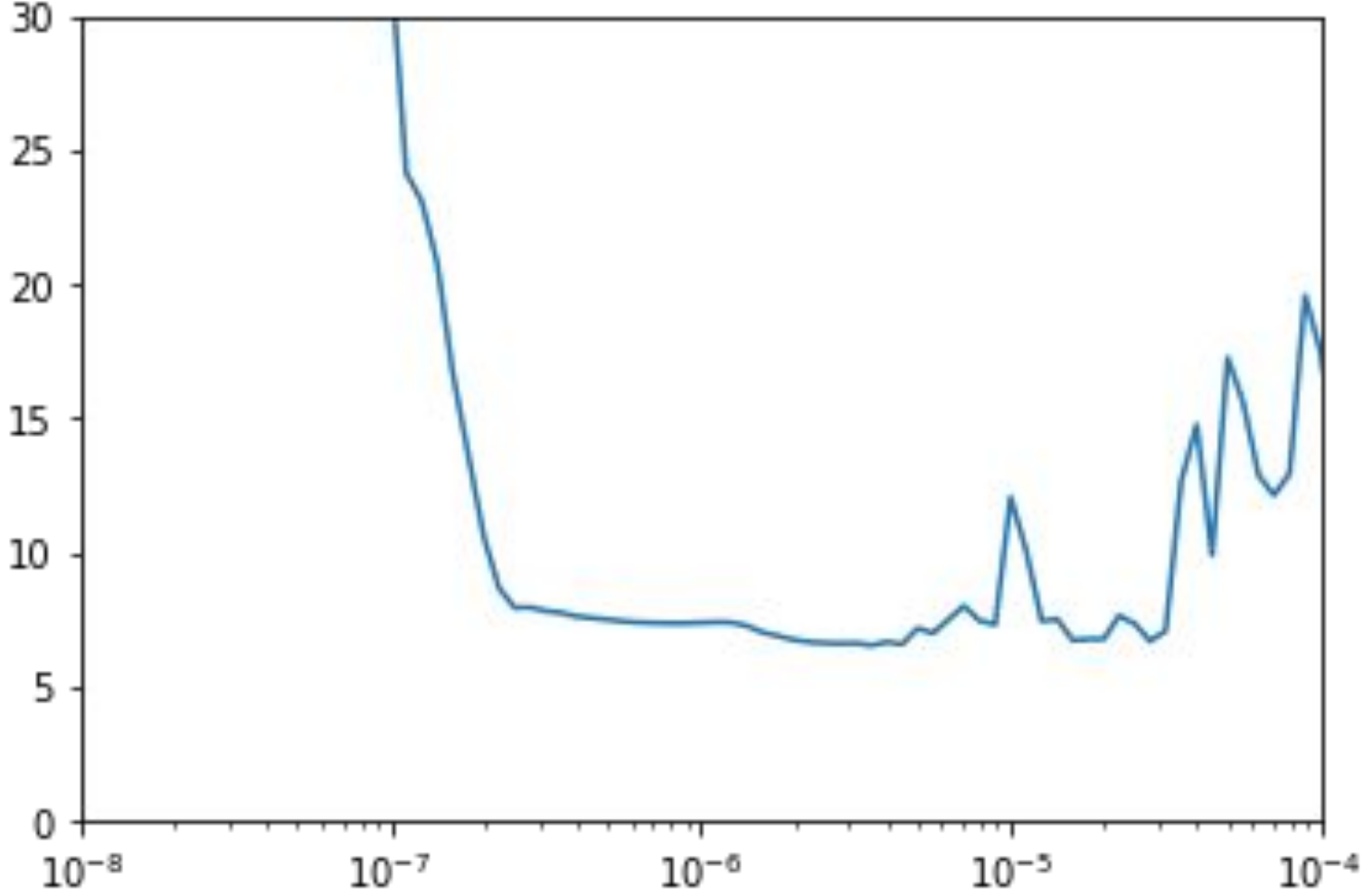
```
train_set = windowed_dataset(x_train, window_size, batch_size=128,
shuffle_buffer=shuffle_buffer_size)

model = tf.keras.models.Sequential([
  tf.keras.layers.Lambda(lambda x: tf.expand_dims(x, axis=-1), input_shape=[None]),
  tf.keras.layers.SimpleRNN(40, return_sequences=True),
  tf.keras.layers.SimpleRNN(40),
  tf.keras.layers.Dense(1),
  tf.keras.layers.Lambda(lambda x: x * 100.0)
])


lr_schedule = tf.keras.callbacks.LearningRateScheduler(lambda epoch: 1e-8 * 10**(epoch / 20))

optimizer = tf.keras.optimizers.SGD(learning_rate=1e-8, momentum=0.9)

model.compile(loss=tf.keras.losses.Huber(),
              optimizer=optimizer,
              metrics=["mae"])

history = model.fit(train_set, epochs=100, callbacks=[lr_schedule])
```

```
train_set = windowed_dataset(x_train, window_size, batch_size=128,
shuffle_buffer=shuffle_buffer_size)

model = tf.keras.models.Sequential([
  tf.keras.layers.Lambda(lambda x: tf.expand_dims(x, axis=-1), input_shape=[None]),
  tf.keras.layers.SimpleRNN(40, return_sequences=True),
  tf.keras.layers.SimpleRNN(40),
  tf.keras.layers.Dense(1),
  tf.keras.layers.Lambda(lambda x: x * 100.0)
])


lr_schedule = tf.keras.callbacks.LearningRateScheduler(lambda epoch: 1e-8 * 10**(epoch / 20))

optimizer = tf.keras.optimizers.SGD(learning_rate=1e-8, momentum=0.9)

model.compile(loss=tf.keras.losses.Huber(),
              optimizer=optimizer,
              metrics=["mae"])

history = model.fit(train_set, epochs=100, callbacks=[lr_schedule])
```

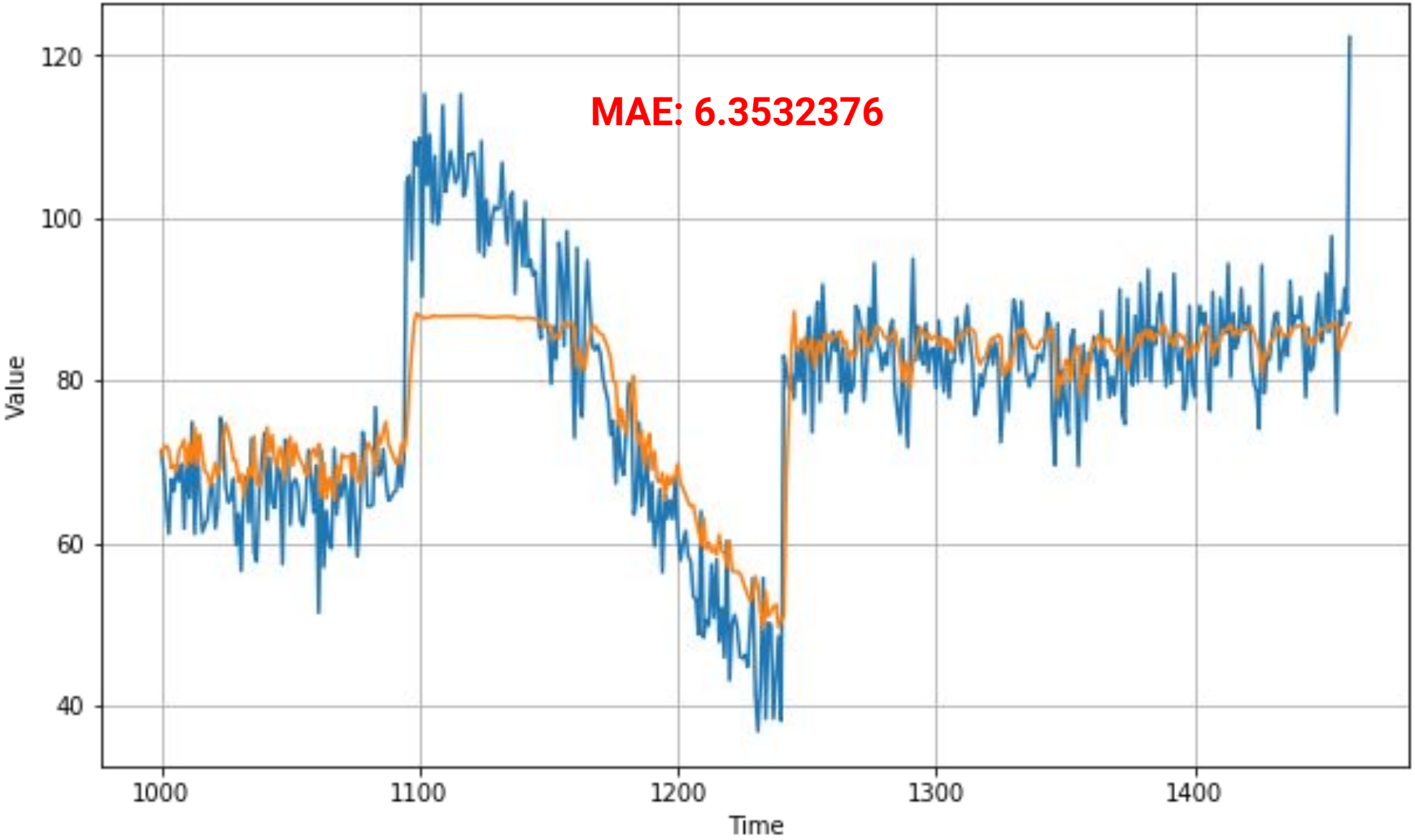
```
train_set = windowed_dataset(x_train, window_size, batch_size=128,
shuffle_buffer=shuffle_buffer_size)

model = tf.keras.models.Sequential([
  tf.keras.layers.Lambda(lambda x: tf.expand_dims(x, axis=-1), input_shape=[None]),
  tf.keras.layers.SimpleRNN(40, return_sequences=True),
  tf.keras.layers.SimpleRNN(40),
  tf.keras.layers.Dense(1),
  tf.keras.layers.Lambda(lambda x: x * 100.0)
])


lr_schedule = tf.keras.callbacks.LearningRateScheduler(lambda epoch: 1e-8 * 10**(epoch / 20))

optimizer = tf.keras.optimizers.SGD(learning_rate=1e-8, momentum=0.9)

model.compile(loss=tf.keras.losses.Huber(),
              optimizer=optimizer,
              metrics=["mae"])

history = model.fit(train_set, epochs=100, callbacks=[lr_schedule])
```

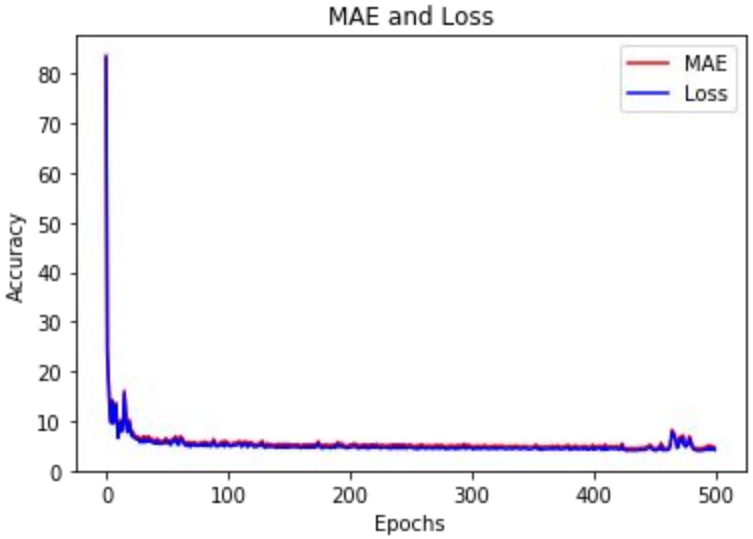
```
train_set = windowed_dataset(x_train, window_size, batch_size=128,
shuffle_buffer=shuffle_buffer_size)

model = tf.keras.models.Sequential([
  tf.keras.layers.Lambda(lambda x: tf.expand_dims(x, axis=-1), input_shape=[None]),
  tf.keras.layers.SimpleRNN(40, return_sequences=True),
  tf.keras.layers.SimpleRNN(40),
  tf.keras.layers.Dense(1),
  tf.keras.layers.Lambda(lambda x: x * 100.0)
])


lr_schedule = tf.keras.callbacks.LearningRateScheduler(lambda epoch: 1e-8 * 10**(epoch / 20))

optimizer = tf.keras.optimizers.SGD(learning_rate=1e-8, momentum=0.9)

model.compile(loss=tf.keras.losses.Huber(),
              optimizer=optimizer,
              metrics=["mae"])

history = model.fit(train_set, epochs=100, callbacks=[lr_schedule])
```

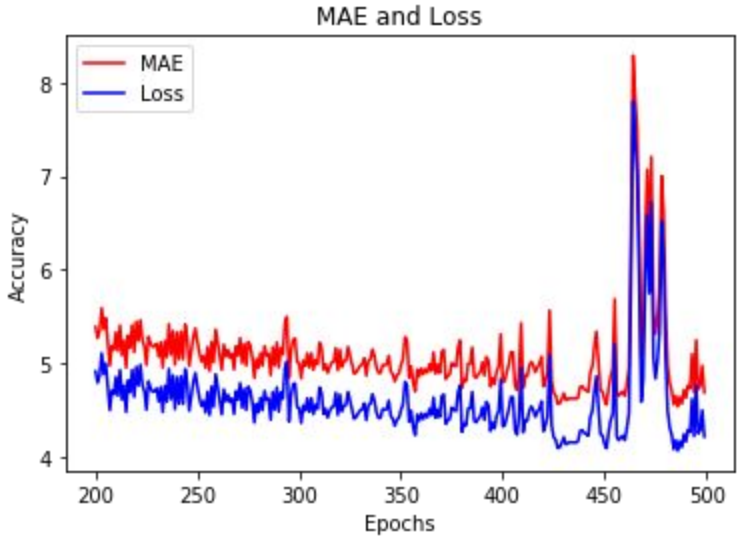
https://en.wikipedia.org/wiki/Huber_loss

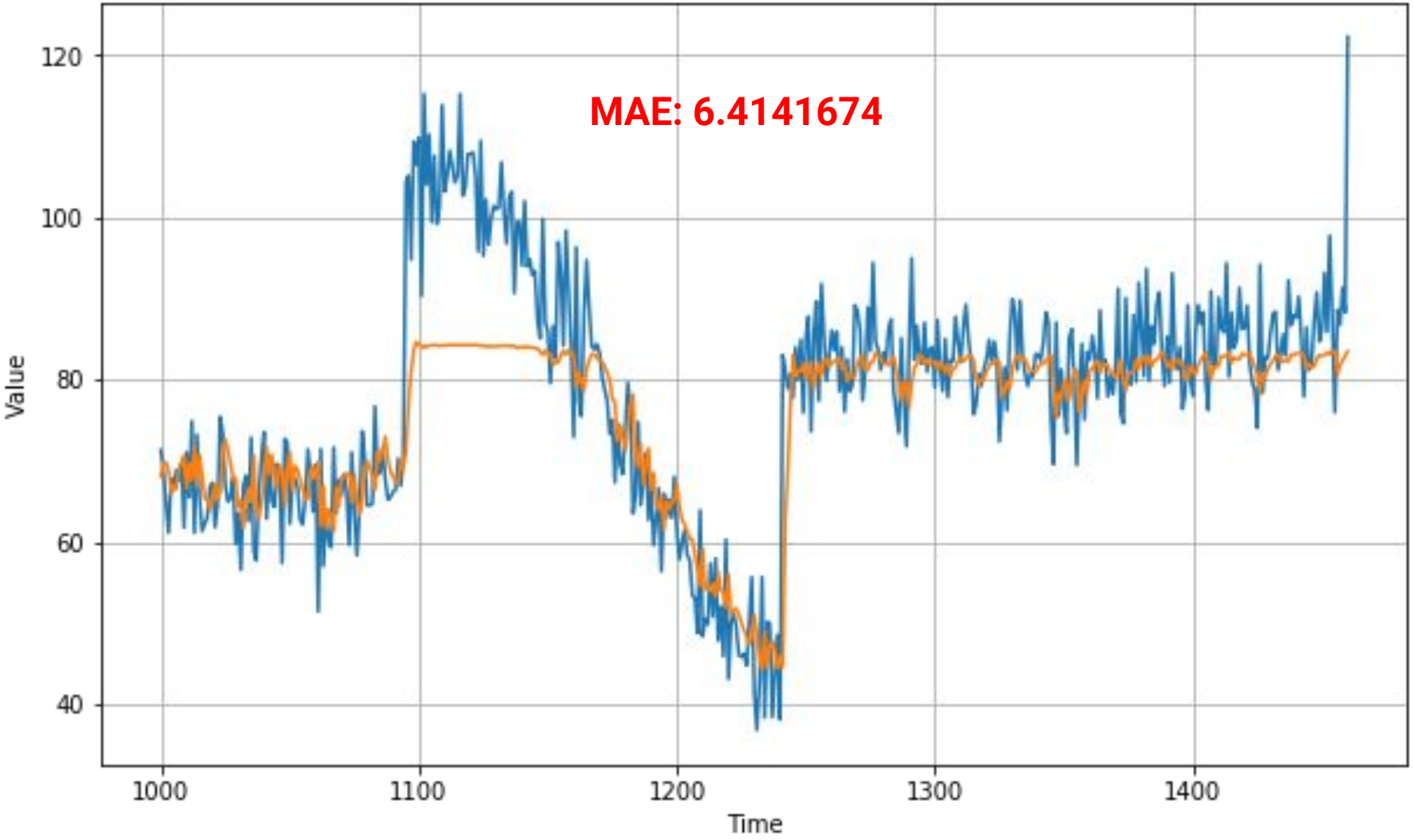

30
25
20
15
10
5
0
$10^{-8}$
$10^{-7}$
$10^{-6}$
$10^{-5}$
$10^{-4}$

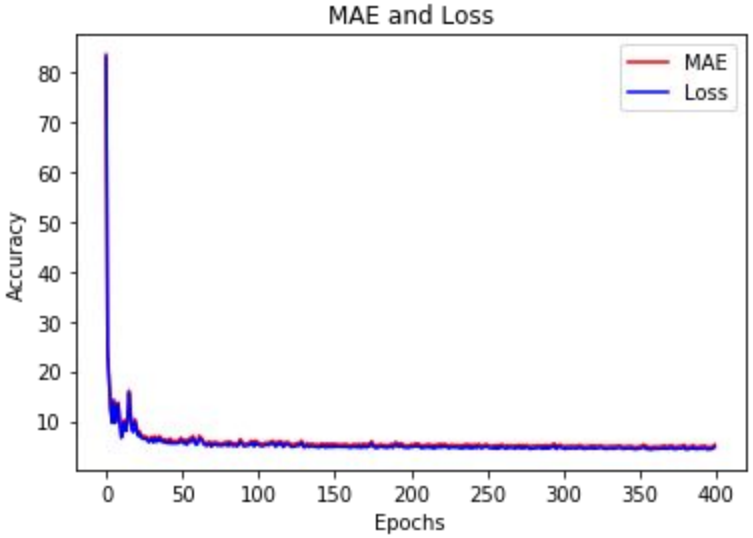
```
tf.keras.backend.clear_session()
tf.random.set_seed(51)
np.random.seed(51)

dataset = windowed_dataset(x_train, window_size, batch_size=128,
shuffle_buffer=shuffle_buffer_size)

model = tf.keras.models.Sequential([
  tf.keras.layers.Lambda(lambda x: tf.expand_dims(x, axis=-1), input_shape=[None]),
  tf.keras.layers.SimpleRNN(40, return_sequences=True),
  tf.keras.layers.SimpleRNN(40),
  tf.keras.layers.Dense(1),
  tf.keras.layers.Lambda(lambda x: x * 100.0)
])

optimizer = tf.keras.optimizers.SGD(learning_rate=5e-6, momentum=0.9)
model.compile(loss=tf.keras.losses.Huber(), optimizer=optimizer, metrics=["mae"])
history = model.fit(dataset,epochs=500)
```

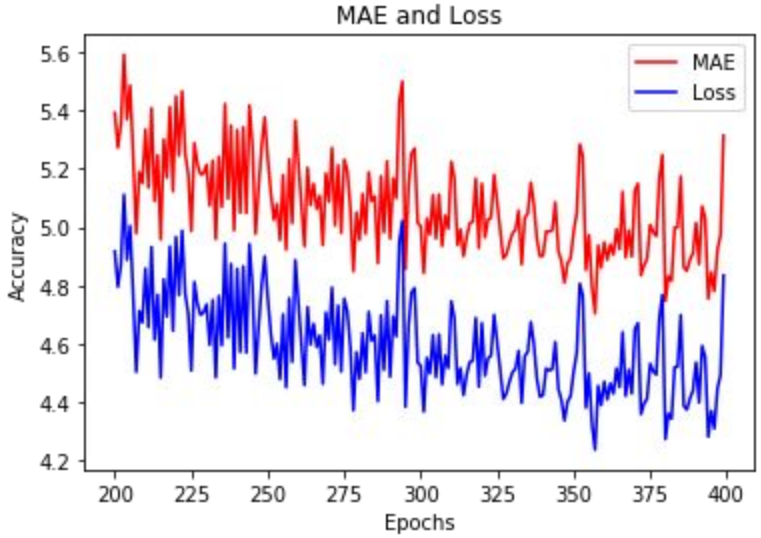

MAE: 6.3532376
120
100
80
60
40
Value
1000
1100
1200
1300
1400
Time

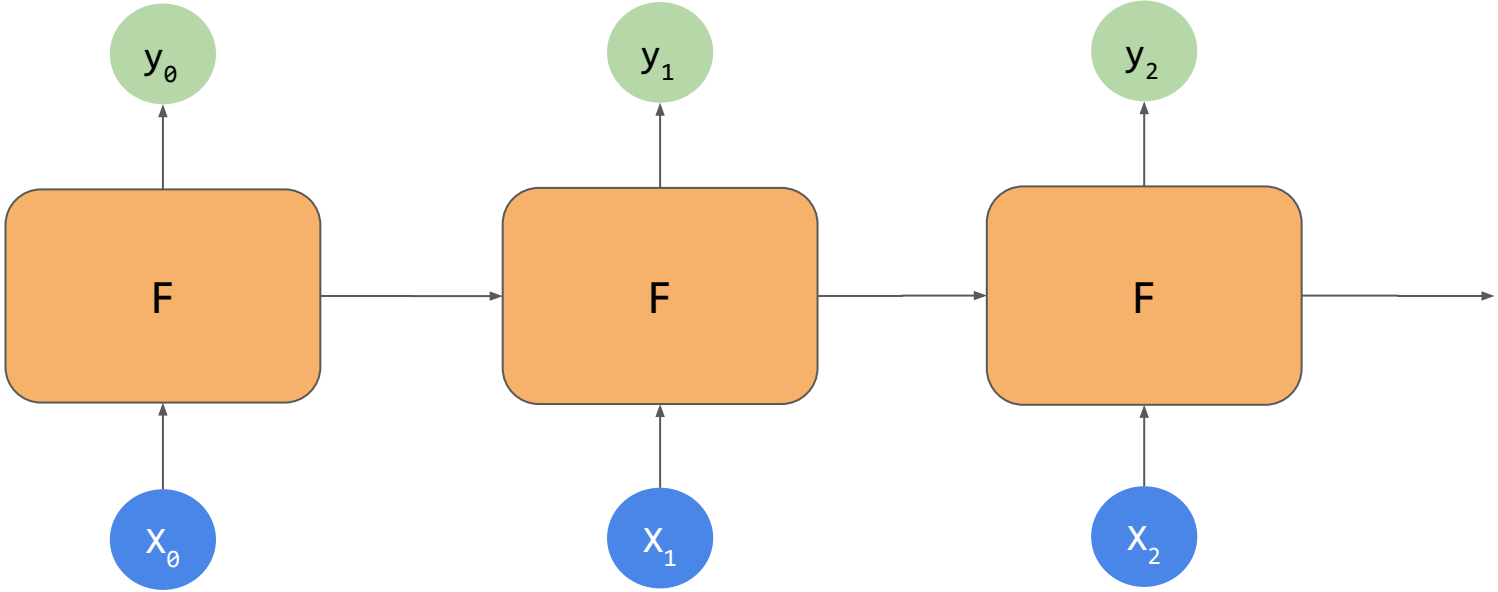

MAE and Loss
MAE
Loss
Accuracy
Epochs
0
10
20
30
40
50
60
70
80
0
100
200
300
400
500

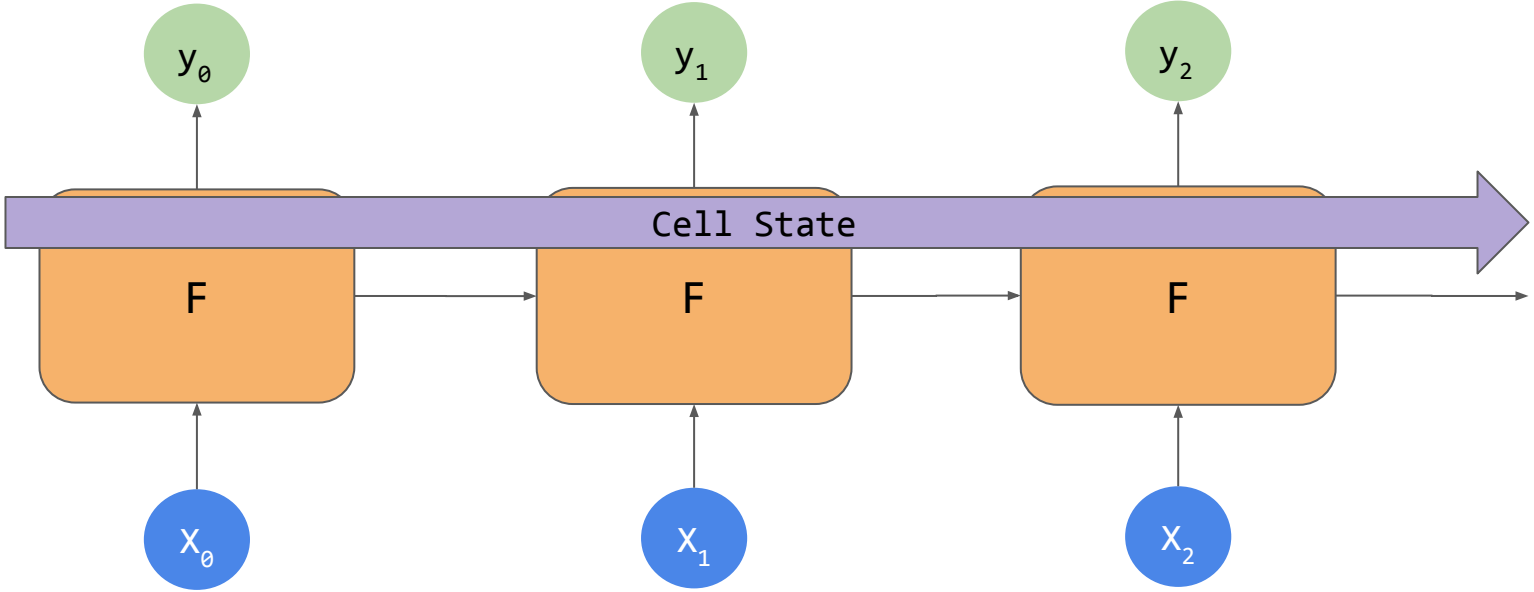

MAE and Loss
MAE
Loss
Accuracy
Epochs
4
5
6
7
8
200
250
300
350
400
450
500

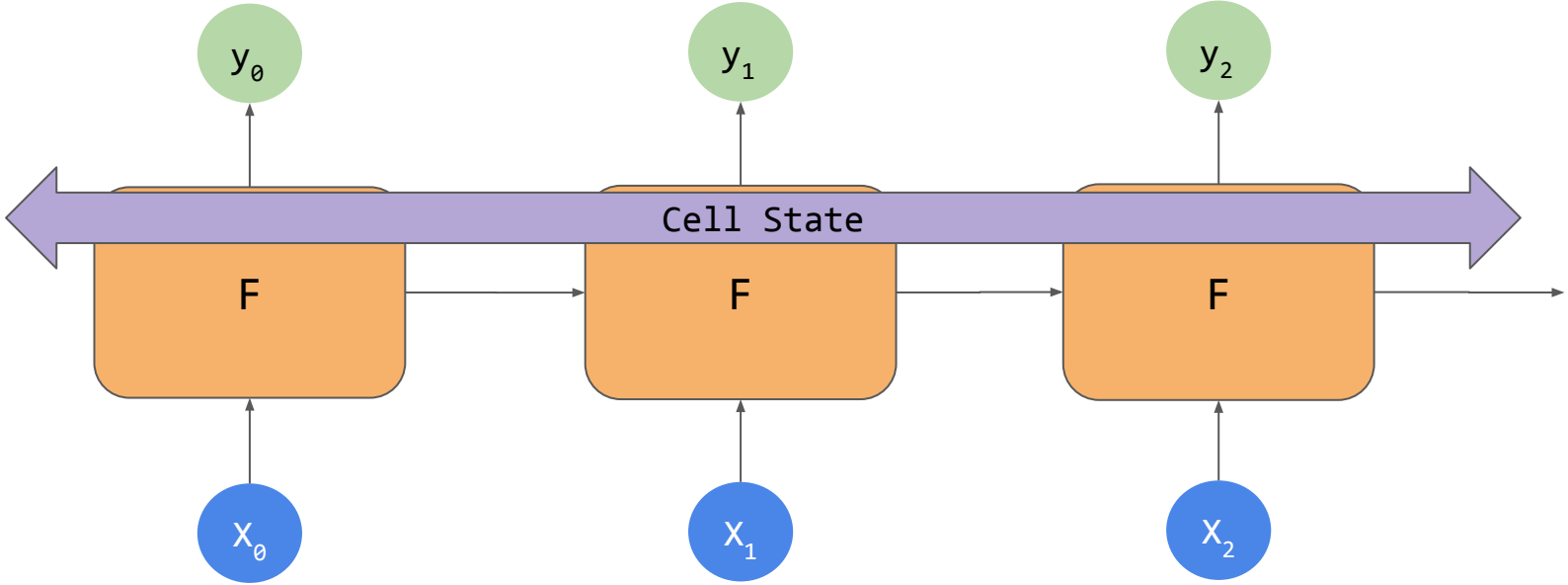

MAE: 6.4141674
120
100
80
60
40
Value
1000
1100
1200
1300
1400
Time


MAE and Loss
MAE
Loss
Accuracy
Epochs
80
70
60
50
40
30
20
10
0
50
100
150
200
250
300
350
400


MAE and Loss
MAE
Loss
Accuracy
Epochs
5.6
5.4
5.2
5.0
4.8
4.6
4.4
4.2
200
225
250
275
300
325
350
375
400

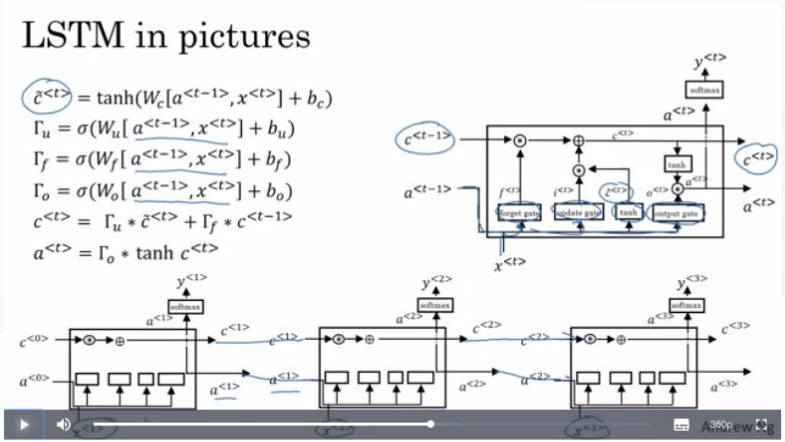

$y_0$
$y_1$
$y_2$
F
F
F
$x_0$
$x_1$
$x_2$


y0
y1
y2
Cell State
F
F
F
x0
x1
x2


$y_0$
$y_1$
$y_2$
Cell State
F
F
F
$x_0$
$x_1$
$x_2$

https://www.coursera.org/lecture/nlp-sequence-models/long-short-term-memory-lstm-KXoay

Long Short Term Memory (LSTM)




From the course by deeplearning.ai

Sequence Models

13393 ratings

Try the Course for Free

This Course | Video Transcript

deeplearning.ai

## Sequence Models

13393 ratings

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

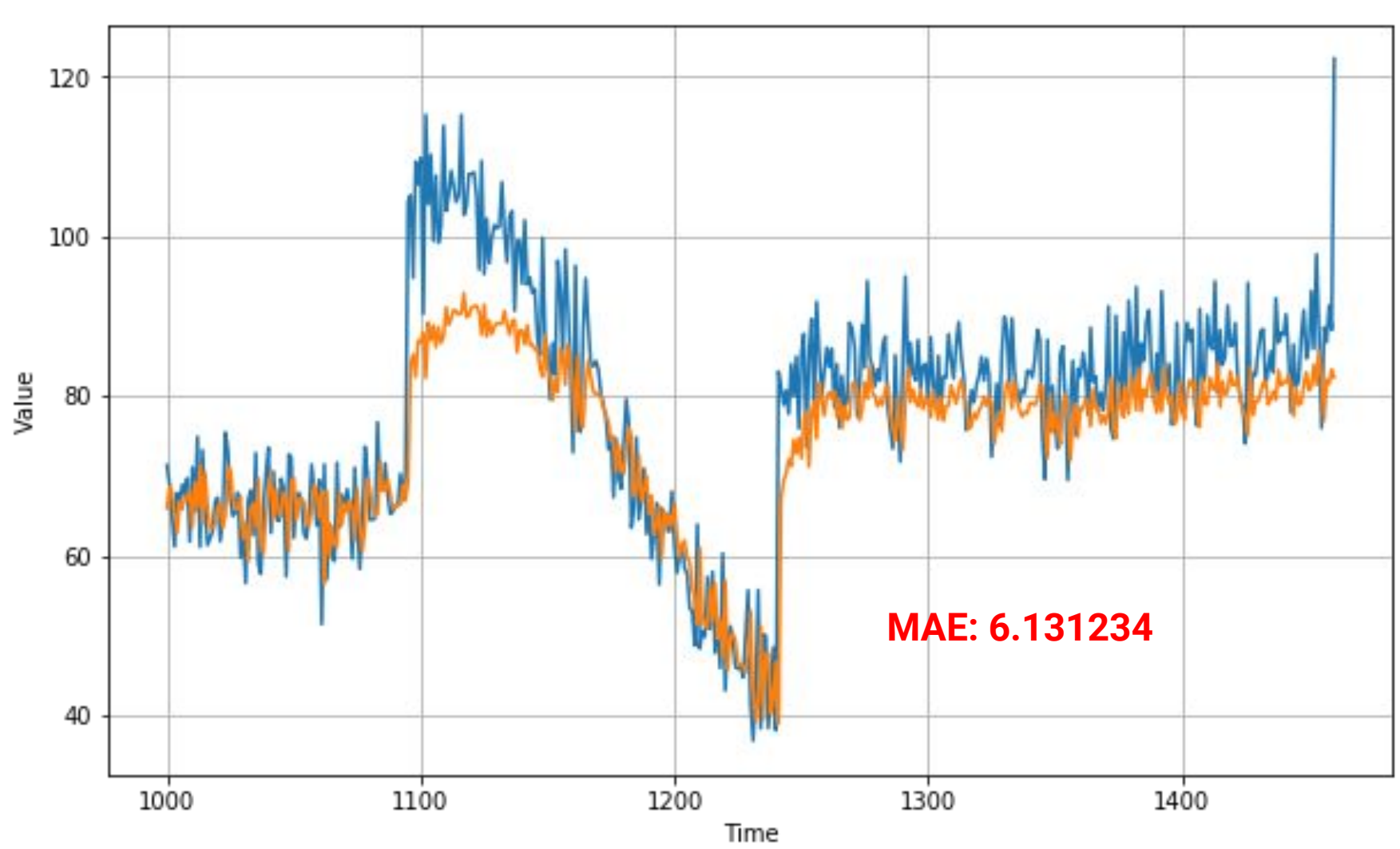
```
tf.keras.backend.clear_session()
dataset = windowed_dataset(x_train, window_size, batch_size, shuffle_buffer_size)

model = tf.keras.models.Sequential([
  tf.keras.layers.Lambda(lambda x: tf.expand_dims(x, axis=-1),
                      input_shape=[None]),
  tf.keras.layers.Bidirectional(tf.keras.layers.LSTM(32)),
  tf.keras.layers.Dense(1),
  tf.keras.layers.Lambda(lambda x: x * 100.0)
])


model.compile(loss="mse", optimizer=tf.keras.optimizers.SGD(learning_rate=1e-6,
momentum=0.9))
model.fit(dataset,epochs=100,verbose=0)
```

```
tf.keras.backend.clear_session()
dataset = windowed_dataset(x_train, window_size, batch_size, shuffle_buffer_size)

model = tf.keras.models.Sequential([
  tf.keras.layers.Lambda(lambda x: tf.expand_dims(x, axis=-1),
                      input_shape=[None]),
  tf.keras.layers.Bidirectional(tf.keras.layers.LSTM(32)),
  tf.keras.layers.Dense(1),
  tf.keras.layers.Lambda(lambda x: x * 100.0)
])


model.compile(loss="mse", optimizer=tf.keras.optimizers.SGD(learning_rate=1e-6,
momentum=0.9))
model.fit(dataset,epochs=100,verbose=0)
```

```
tf.keras.backend.clear_session()
dataset = windowed_dataset(x_train, window_size, batch_size, shuffle_buffer_size)

model = tf.keras.models.Sequential([
  tf.keras.layers.Lambda(lambda x: tf.expand_dims(x, axis=-1),
                      input_shape=[None]),
  tf.keras.layers.Bidirectional(tf.keras.layers.LSTM(32)),
  tf.keras.layers.Dense(1),
  tf.keras.layers.Lambda(lambda x: x * 100.0)
])


model.compile(loss="mse", optimizer=tf.keras.optimizers.SGD(learning_rate=1e-6,
momentum=0.9))
model.fit(dataset,epochs=100,verbose=0)
```

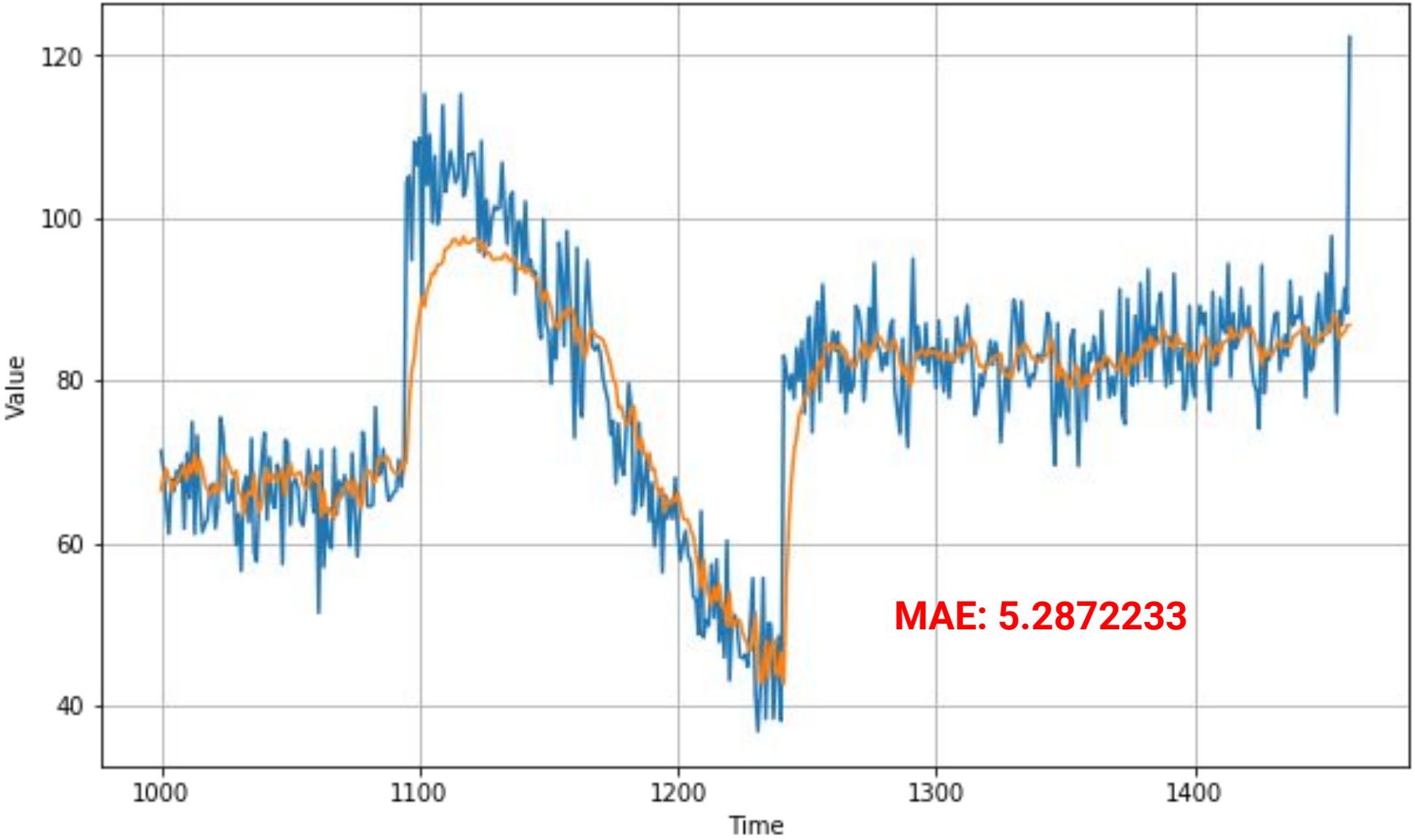
```
tf.keras.backend.clear_session()
dataset = windowed_dataset(x_train, window_size, batch_size, shuffle_buffer_size)

model = tf.keras.models.Sequential([
  tf.keras.layers.Lambda(lambda x: tf.expand_dims(x, axis=-1),
                      input_shape=[None]),
  tf.keras.layers.Bidirectional(tf.keras.layers.LSTM(32)),
  tf.keras.layers.Dense(1),
  tf.keras.layers.Lambda(lambda x: x * 100.0)
])


model.compile(loss="mse", optimizer=tf.keras.optimizers.SGD(learning_rate=1e-6,
momentum=0.9))
model.fit(dataset,epochs=100,verbose=0)
```

```
tf.keras.backend.clear_session()
dataset = windowed_dataset(x_train, window_size, batch_size, shuffle_buffer_size)

model = tf.keras.models.Sequential([
  tf.keras.layers.Lambda(lambda x: tf.expand_dims(x, axis=-1),
                      input_shape=[None]),
  tf.keras.layers.Bidirectional(tf.keras.layers.LSTM(32)),
  tf.keras.layers.Dense(1),
  tf.keras.layers.Lambda(lambda x: x * 100.0)
])


model.compile(loss="mse", optimizer=tf.keras.optimizers.SGD(learning_rate=1e-6,
momentum=0.9))
model.fit(dataset,epochs=100,verbose=0)
```


120
100
80
60
40
Value
1000
1100
1200
1300
1400
Time
MAE: 6.131234

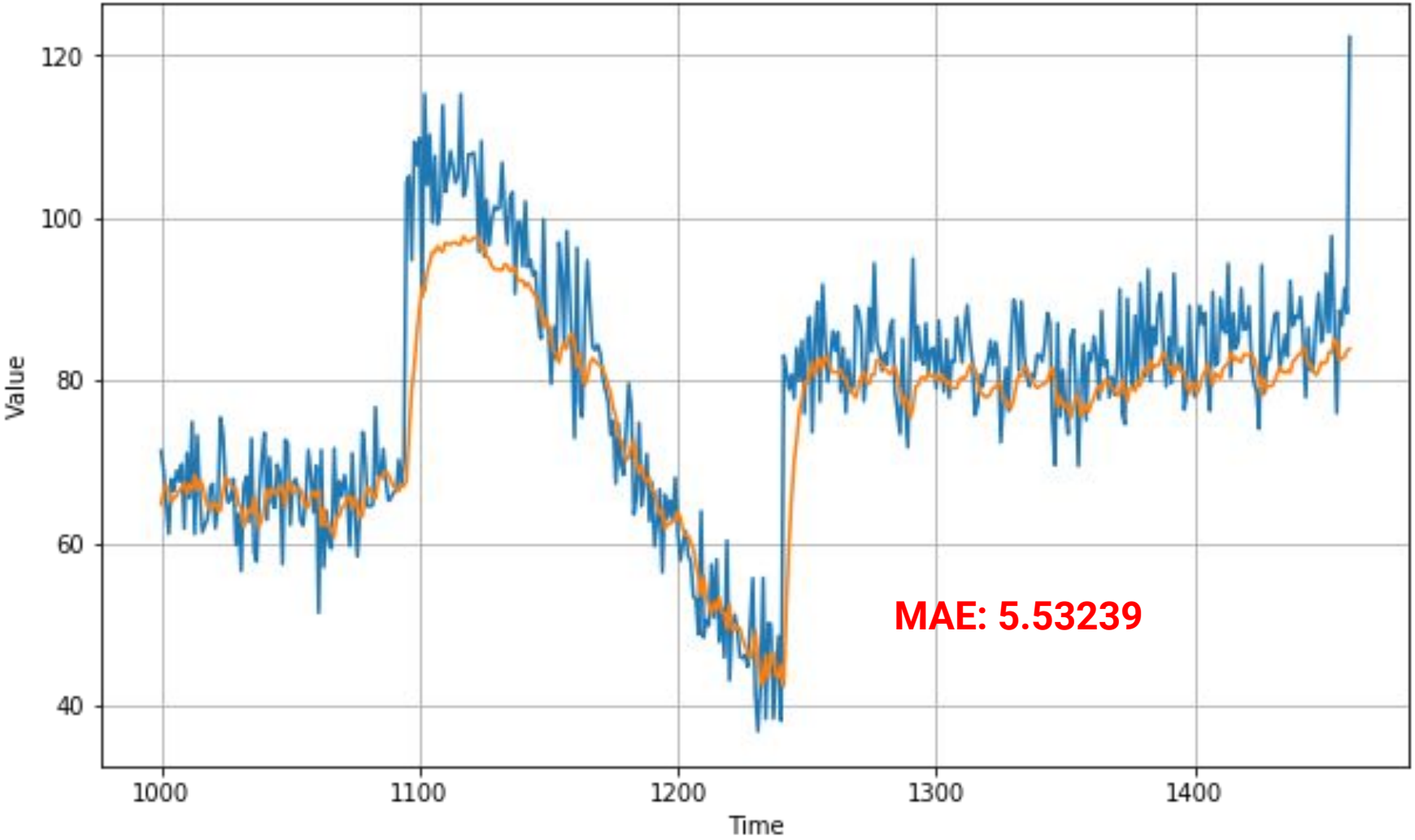
```
tf.keras.backend.clear_session()
dataset = windowed_dataset(x_train, window_size, batch_size, shuffle_buffer_size)

model = tf.keras.models.Sequential([
  tf.keras.layers.Lambda(lambda x: tf.expand_dims(x, axis=-1),
                      input_shape=[None]),
  tf.keras.layers.Bidirectional(tf.keras.layers.LSTM(32, return_sequences=True)),
  tf.keras.layers.Bidirectional(tf.keras.layers.LSTM(32)),
  tf.keras.layers.Dense(1),
  tf.keras.layers.Lambda(lambda x: x * 100.0)
])


model.compile(loss="mse", optimizer=tf.keras.optimizers.SGD(learning_rate=1e-6,
momentum=0.9))
model.fit(dataset,epochs=100, verbose=0)
```

```
tf.keras.backend.clear_session()
dataset = windowed_dataset(x_train, window_size, batch_size, shuffle_buffer_size)

model = tf.keras.models.Sequential([
  tf.keras.layers.Lambda(lambda x: tf.expand_dims(x, axis=-1),
                      input_shape=[None]),
  tf.keras.layers.Bidirectional(tf.keras.layers.LSTM(32, return_sequences=True)),
  tf.keras.layers.Bidirectional(tf.keras.layers.LSTM(32)),
  tf.keras.layers.Dense(1),
  tf.keras.layers.Lambda(lambda x: x * 100.0)
])


model.compile(loss="mse", optimizer=tf.keras.optimizers.SGD(learning_rate=1e-6,
momentum=0.9))
model.fit(dataset,epochs=100, verbose=0)
```


120
100
80
60
40
Value
1000
1100
1200
1300
1400
Time
MAE: 5.2872233

```
tf.keras.backend.clear_session()
dataset = windowed_dataset(x_train, window_size, batch_size, shuffle_buffer_size)

model = tf.keras.models.Sequential([
  tf.keras.layers.Lambda(lambda x: tf.expand_dims(x, axis=-1),
                      input_shape=[None]),
  tf.keras.layers.Bidirectional(tf.keras.layers.LSTM(32, return_sequences=True)),
  tf.keras.layers.Bidirectional(tf.keras.layers.LSTM(32, return_sequences=True)),
  tf.keras.layers.Bidirectional(tf.keras.layers.LSTM(32)),
  tf.keras.layers.Dense(1),
  tf.keras.layers.Lambda(lambda x: x * 100.0)
])


model.compile(loss="mse", optimizer=tf.keras.optimizers.SGD(learning_rate=1e-6,
momentum=0.9))
model.fit(dataset,epochs=100)
```

```
tf.keras.backend.clear_session()
dataset = windowed_dataset(x_train, window_size, batch_size, shuffle_buffer_size)

model = tf.keras.models.Sequential([
  tf.keras.layers.Lambda(lambda x: tf.expand_dims(x, axis=-1),
                      input_shape=[None]),
  tf.keras.layers.Bidirectional(tf.keras.layers.LSTM(32, return_sequences=True)),
  tf.keras.layers.Bidirectional(tf.keras.layers.LSTM(32, return_sequences=True)),
  tf.keras.layers.Bidirectional(tf.keras.layers.LSTM(32)),
  tf.keras.layers.Dense(1),
  tf.keras.layers.Lambda(lambda x: x * 100.0)
])


model.compile(loss="mse", optimizer=tf.keras.optimizers.SGD(learning_rate=1e-6,
momentum=0.9))
model.fit(dataset,epochs=100)
```


120
100
80
60
40
Value
1000
1100
1200
1300
1400
Time
MAE: 5.53239