Visualization of RNN through Feed-Forward Neural Network

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Problem and Data

Let

- I/p sequence (X) : $X^0, X^1, \ldots, X^T$

- O/p sequence (O) : $O^0, O^1, \ldots, O^T$

Representation of data

Let

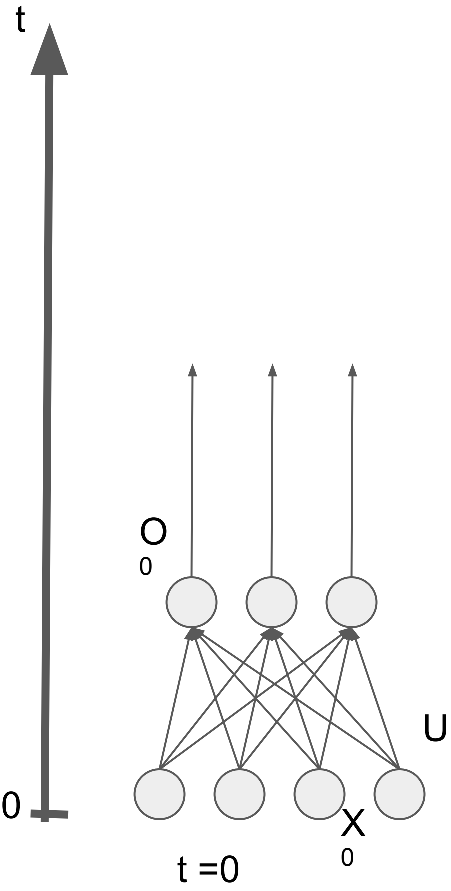
- I/p dimension : 4
  - $X^0 \rightarrow 0\ 1\ 1\ 0$

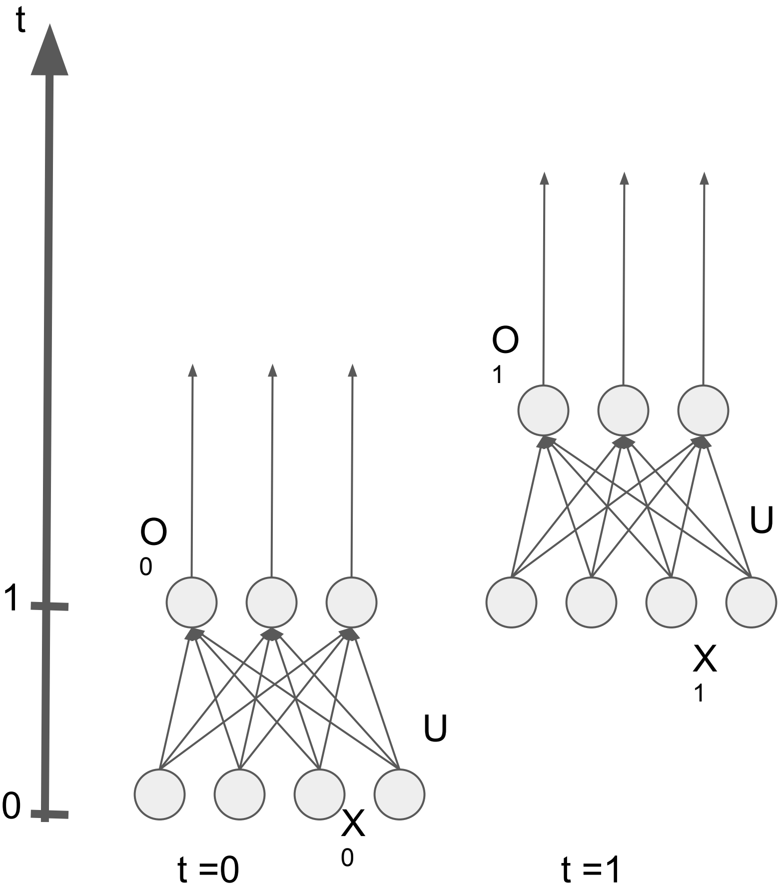
- O/p dimension : 3
  - $O^0 \rightarrow 0\ 0\ 1$

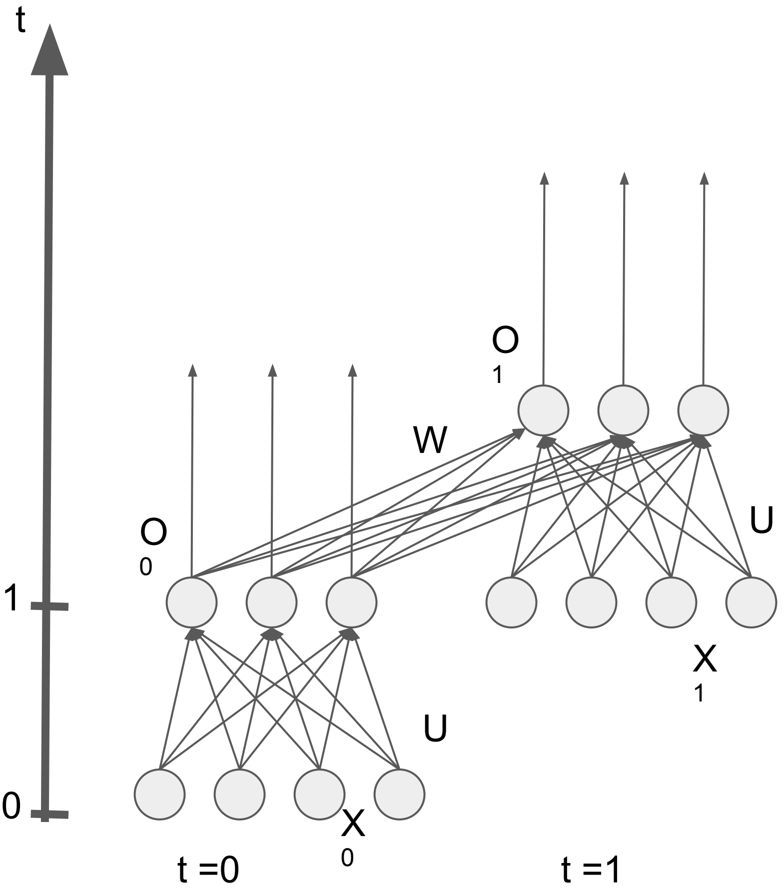
Network Architecture

- Number of neurons at I/p layer : 4
- Number of neurons at O/p layer : 3
- Do we need hidden layers?
  - If yes, number of neurons at each hidden layers

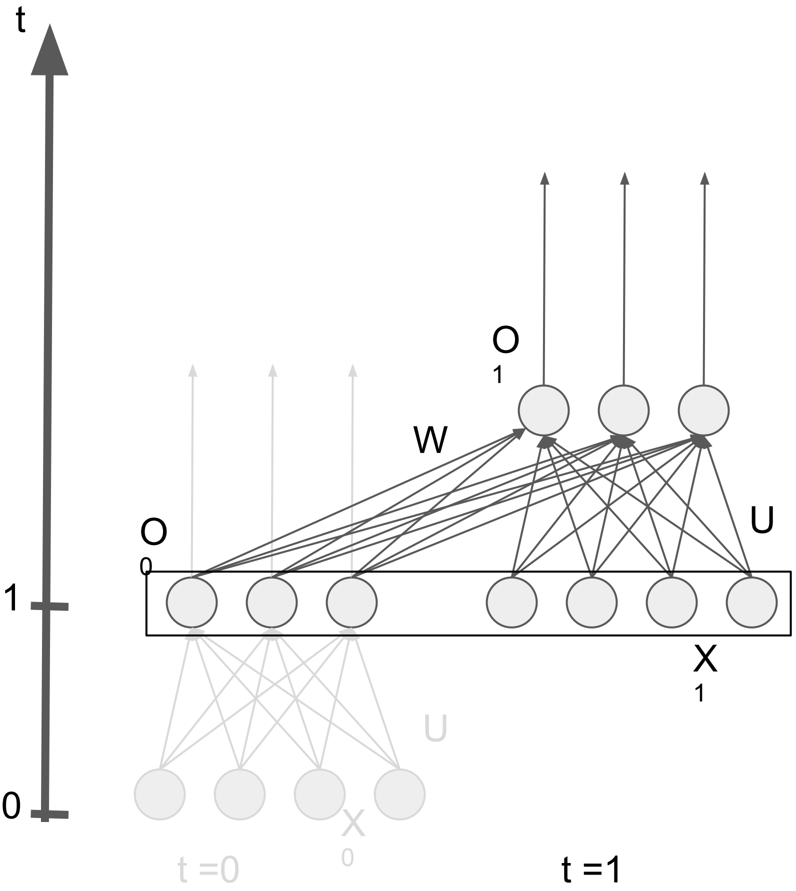
Visualization of RNN through Feed-Forward Neural Network

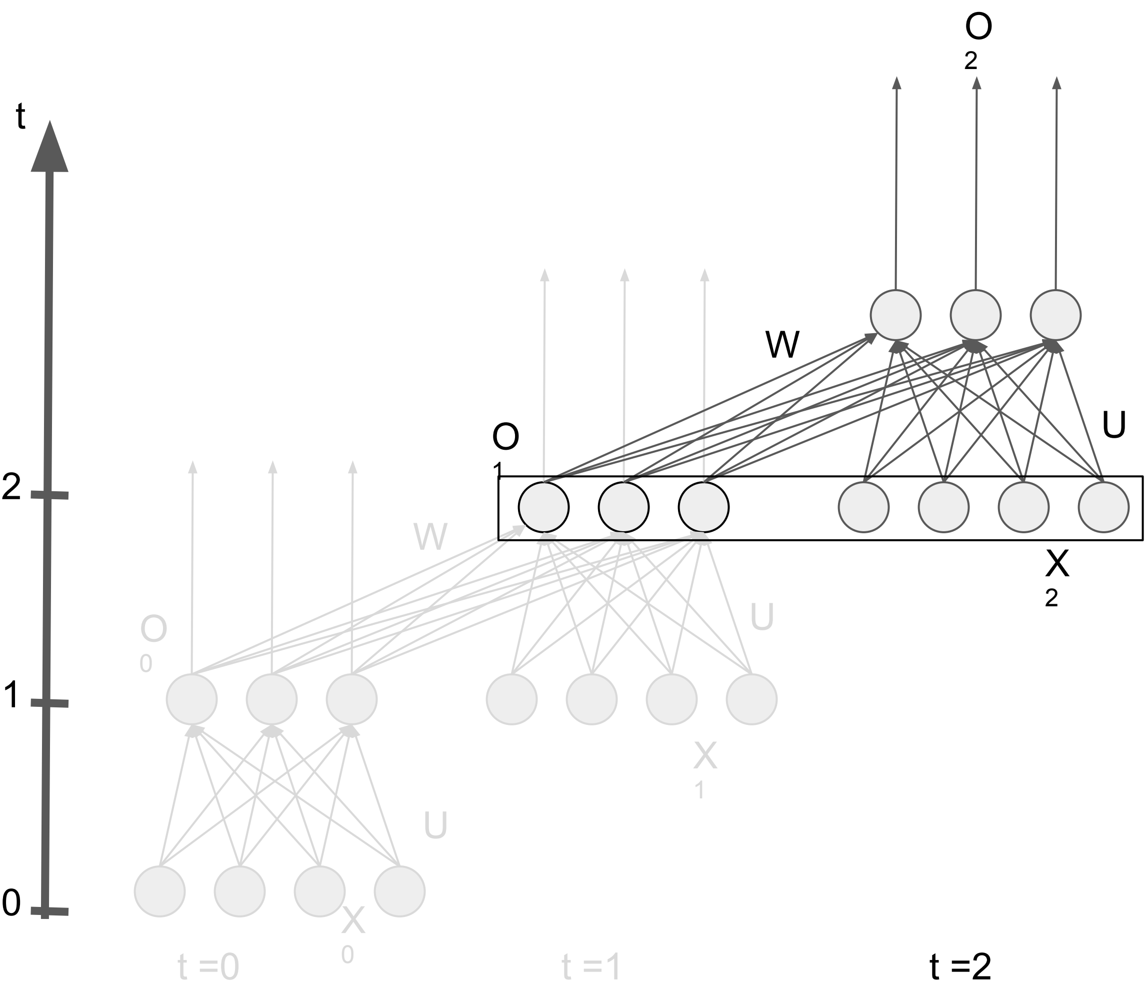



t
1
0
O
0
U
X
0
t =0
O
1
U
X
1
t =1

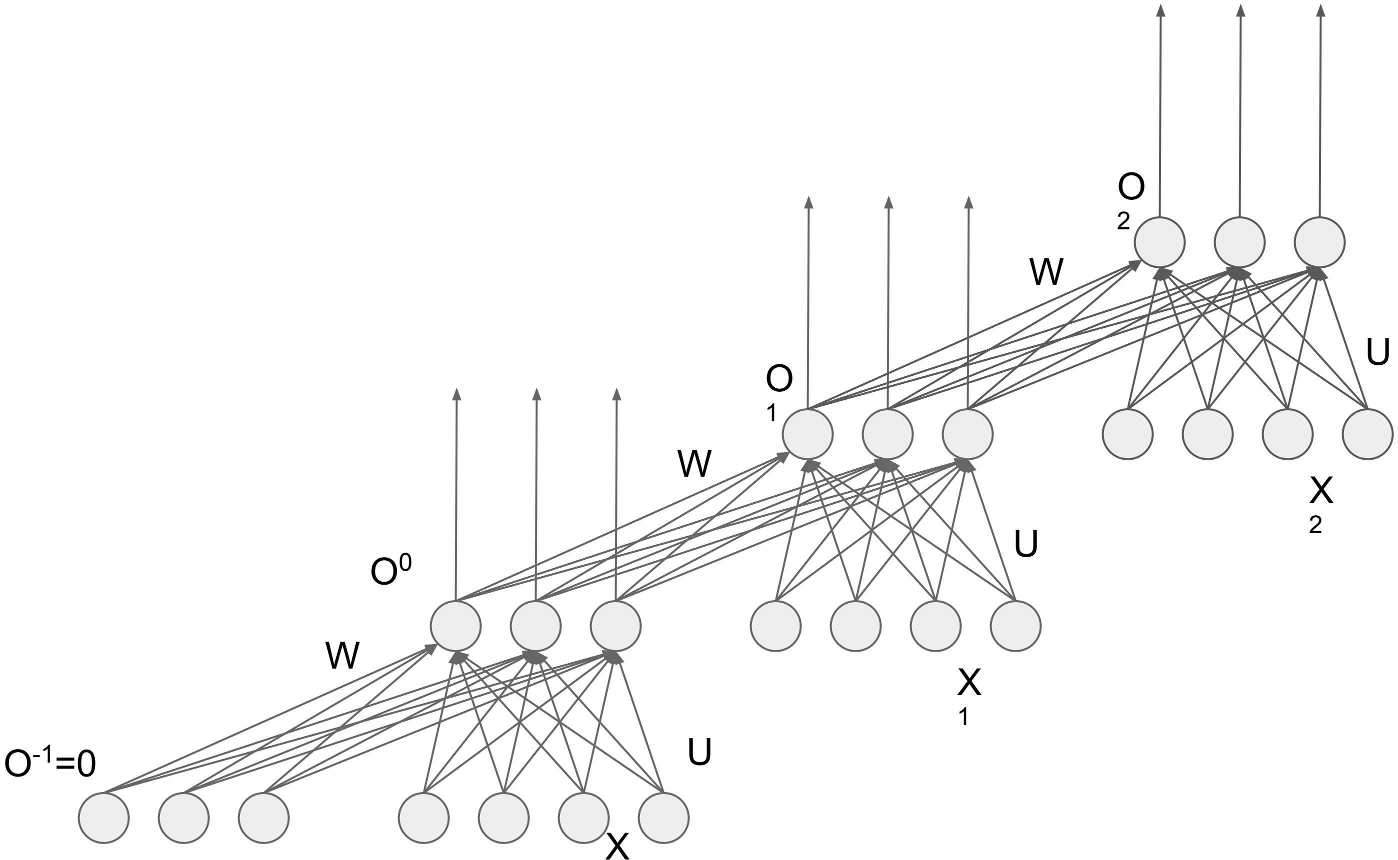

t
1
0
O
0
O
1
W
U
U
X
0
X
1
t =0
t =1

$$O^1 = f(W.O^0 + U.X^1)$$
$$= f([W, U] . [O^0, x^1])$$



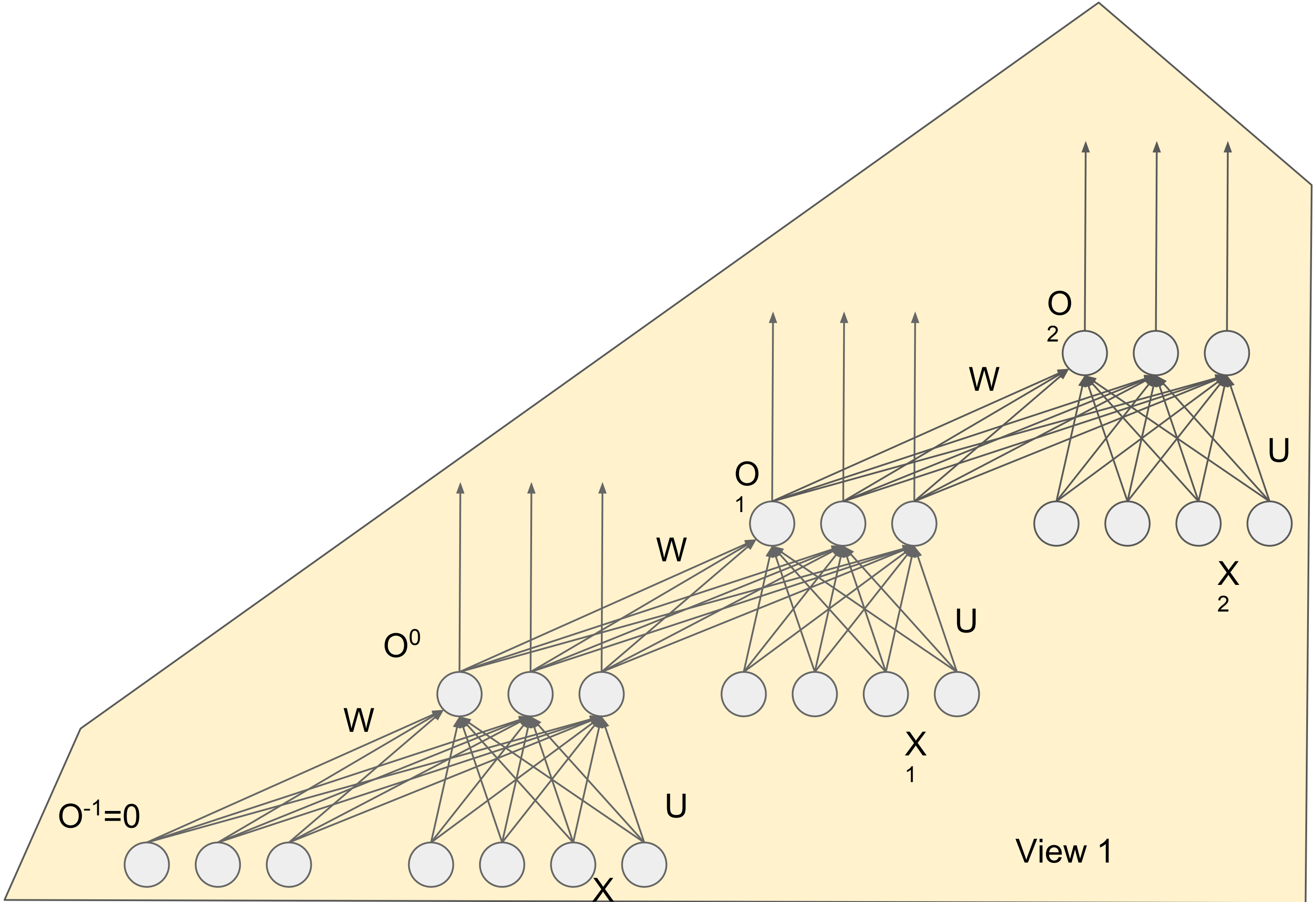


$$O^2 = f(W.O^1 + U.X^2)$$
$$= f([W, U] \;.\; [O^1, x^2])$$

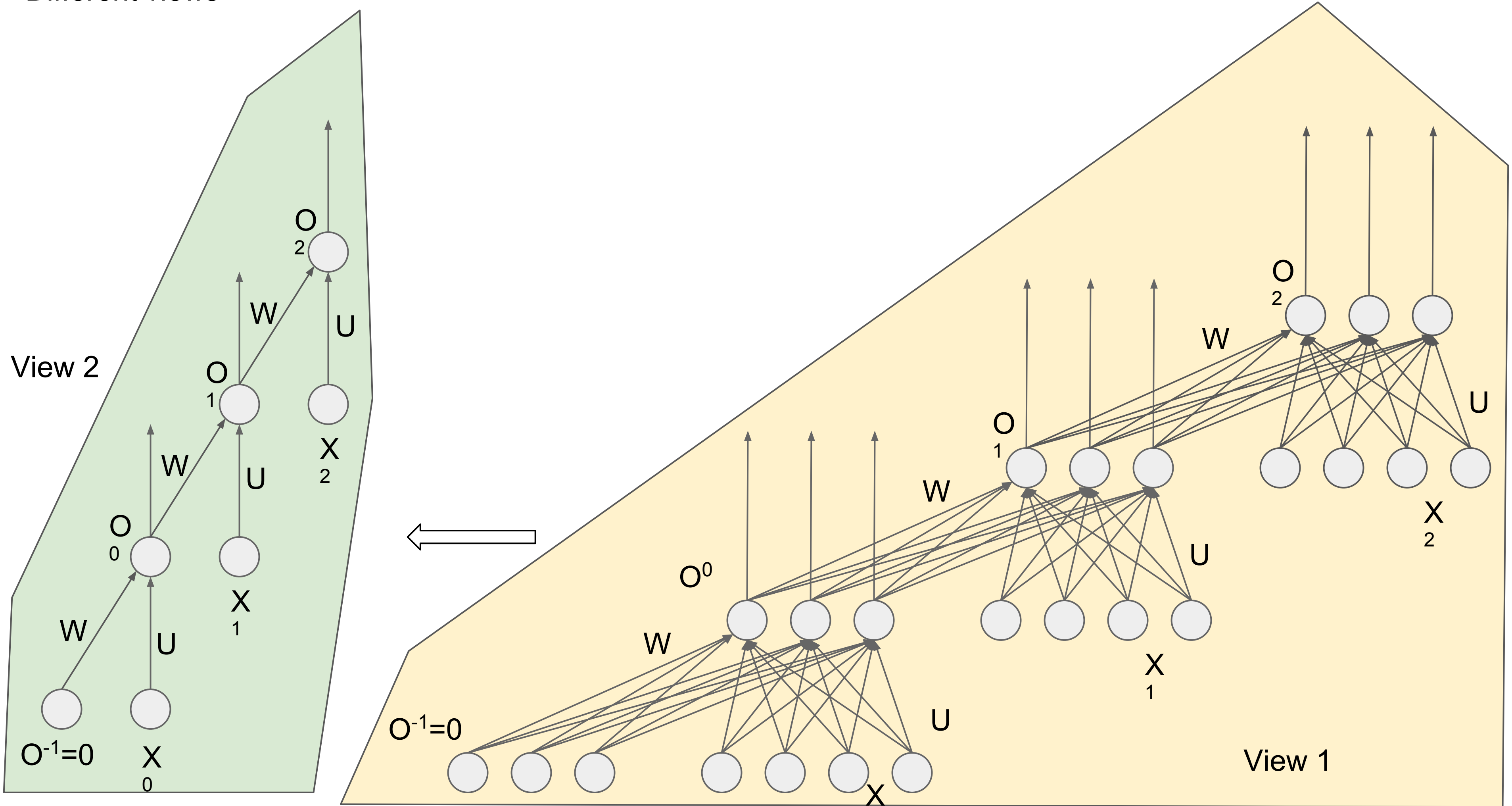


O
2
W
U
O
1
W
U
X
2
O0
W
X
1
O-1=0
U
X

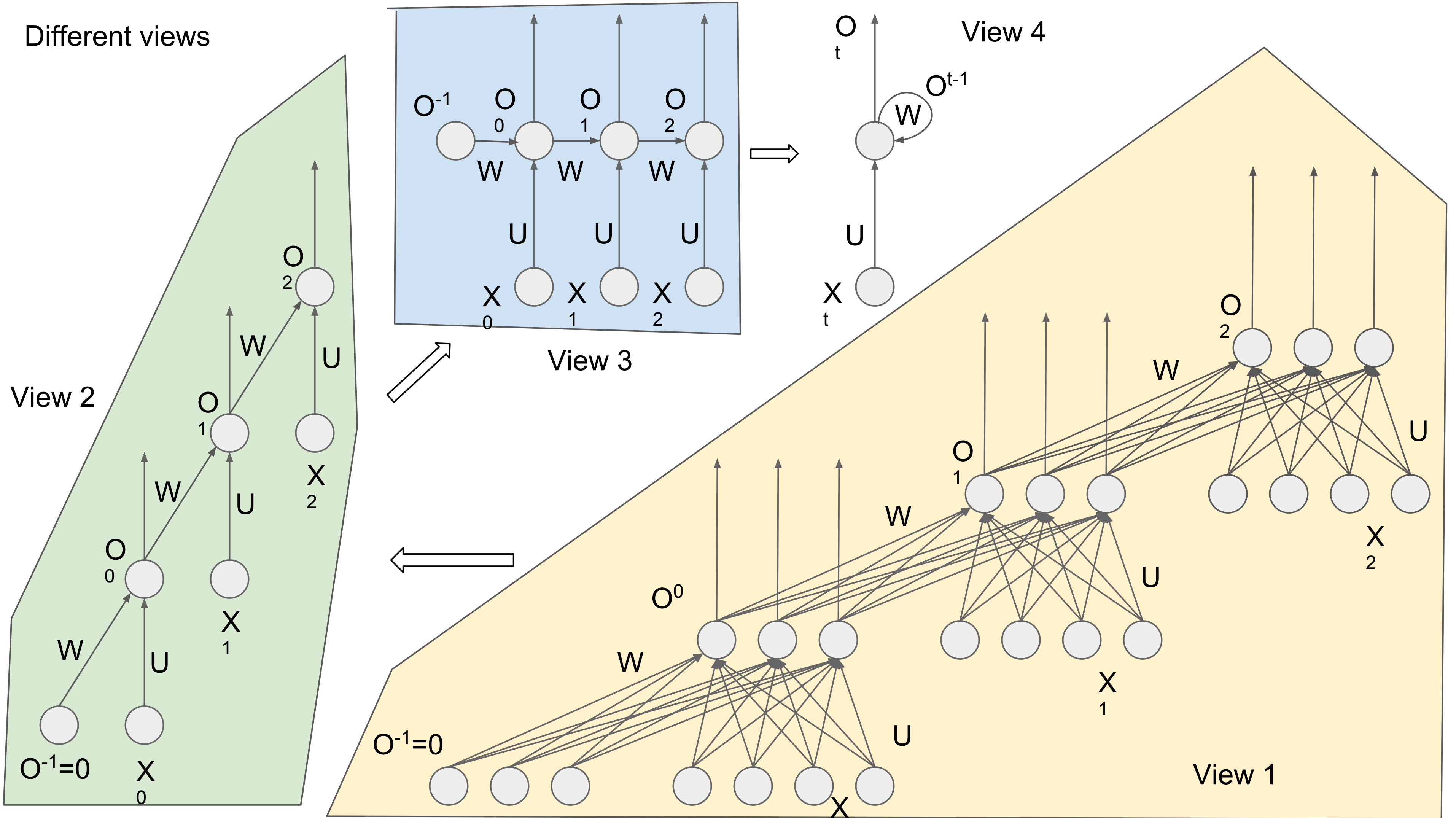
Different views



Different views



Different views



Problem 1: Bit Reverse

Bit Reverse

- Problem definition:
  - **Problem 1:** Reverse a binary digit.
    - 0 → 1   and   1 → 0
  - **Problem 2:** Reverse a sequence of binary digits.
    - 0 1 0 1 0 0 1   →   1 0 1 0 1 1 0
    - Sequence: Fixed or Variable length
  - **Problem 3:** Reverse a sequence of bits over time.
    - 0 1 0 1 0 0 1   →   1 0 1 0 1 1 0
  - **Problem 4:** Reverse a bit if the current i/p and previous o/p are same.

Input sequence	1	1	0	0	1	0	0	0	1	1
Output sequence	1	0	1	0	1	0	1	0	1	0

Prepare Data

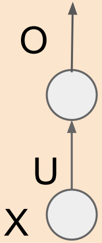
Let

- **Problem 1**
  - I/p dimension: **1 bit** O/p dimension: **1 bit**
- **Problem 2**
  - Fixed
    - I/p dimension: **10 bit** O/p dimension: **10 bit**
  - Variable: Pad each sequence upto max sequence length: **10**
    - Padding value: **-1**
    - I/p dimension: **10 bit** O/p dimension: **10 bit**
- **Problem 3 & 4**
  - Dimension of each element of I/p (X) : **1 bit**
  - Dimension of each element of O/p (O) : **1 bit**
  - Sequence length : **10**

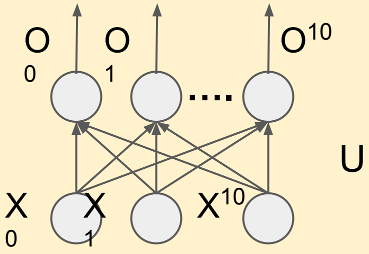
No. of I/p neurons = I/p dimension
No. of O/p neurons = O/p dimension

Network Architecture

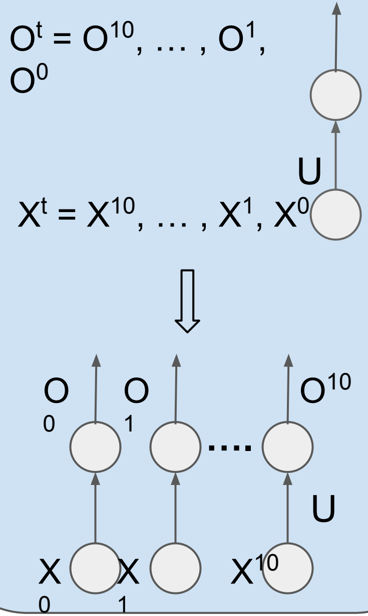
Problem 1:
- I/p neurons = 1
- O/p neurons = 1



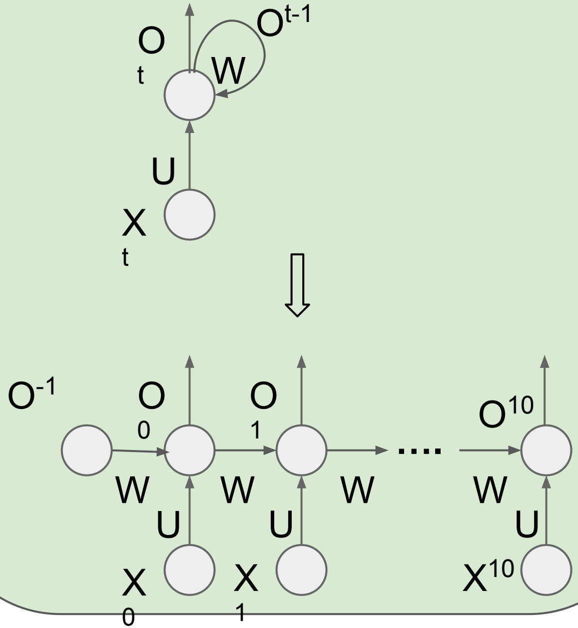
Problem 2: Fixed & Variable
- I/p neurons = 10
- O/p neurons = 10



Problem 3:
- I/p neurons = 1
- O/p neurons = 1
- Seq len = 10



Problem 4:
- I/p neurons = 1
- O/p neurons = 1
- Seq len = 10



Implementation using Keras: Basic steps

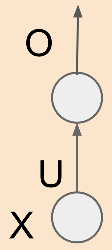
1. Import necessary libraries
2. Design Network
3. Compile Network
4. Print the the network summary
5. Prepare/Load training data
6. Reshape data *w.r.t.* the network
7. Train the network
8. Print final *weights*
9. Evaluate the network
    a. Prepare/Load testing data
    b. Predict o/p
    c. Print test and its prediction

Implementation using Keras: Import necessary libraries 1/9

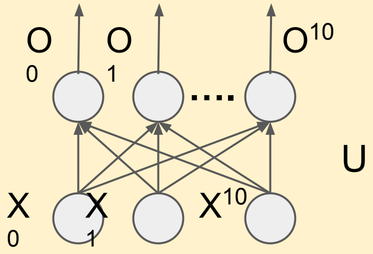
```
import numpy                                # Numpy for mathematical ops
import keras                                # Keras main library
from keras.models import Sequential     # Model type
from keras.layers import SimpleRNN      # Recurrent layer
```

Implementation using Keras: Design Network

Problem 1:
- I/p neurons = 1
- O/p neurons = 1



Problem 2: Fixed & Variable
- I/p neurons = 10
- O/p neurons = 10

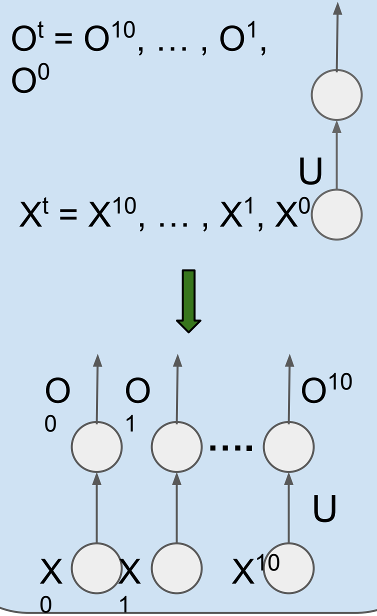



```
numInNeurons = 1          #numInNeurons = 10 for Problem2
numOutNeurons = 1         #numOutNeurons = 10 for Problem2

model = Sequential()      # Instantiate sequential network

# Add a Dense layer.
# input_dim is required only in the first layer of the network.
model.add(Dense(numOutNeurons, input_dim=numInNeurons),
activation='sigmoid'))

# If we need to add more layers we have to call model.add()
again. Next time input_dim is not required.
```

Implementation using Keras: Design Network

Problem 3:

- I/p neurons = 1
- O/p neurons = 1
- Seq len = 10

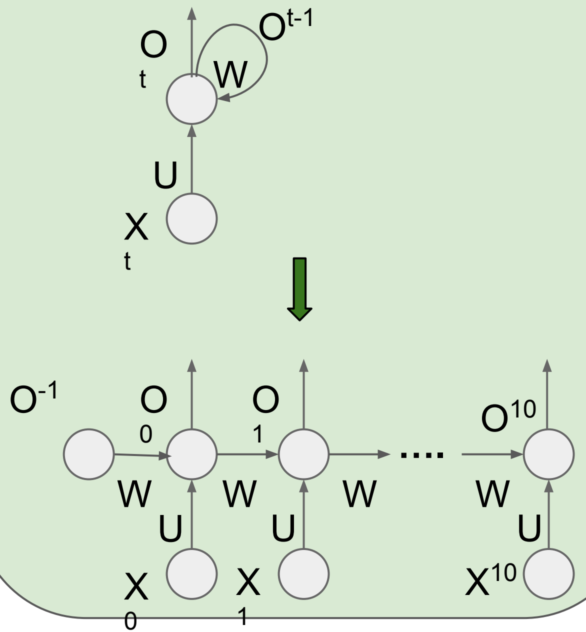



```
numInNeurons = 1
numOutNeurons = 1
seqLength = 10

model = Sequential()     # Instantiate sequential network

# Add a TimeDistributed Dense layer.

model.add(TimeDistributed(Dense(numOutNeurons,
activation='sigmoid'), input_shape=(seqLength,
numInNeurons)))
```

Implementation using Keras: Design Network

Problem 4:

- I/p neurons = 1
- O/p neurons = 1
- Seq len = 10




```
numInNeurons = 1
numOutNeurons = 1
seqLength = 10

model = Sequential()     # Instantiate sequential network

# Add a SimpleRNN Layer.
model.add(SimpleRNN(numOutNeurons, input_shape=(seqLength, numInNeurons), return_sequences=True, activation='sigmoid'))
```

Implementation using Keras: Compile the network 3/9

```
model.compile(optimizer='sgd', loss='mse')

# Validate the network. If any issues (dimension mismatch etc.) are found, they will be reported.
# Optimization algorithm is stochastic gradient descent
# Loss is mean squared error


# At this point network is ready for training
```

Implementation using Keras: Print the network summary

```
model.summary()        # Print summary of the network
```

Problem	Layer (Type)	Output Shape	Param #	Params Description
1	`dense_1 (Dense)`	`(None,1)`	2	I/p → layer[0] weight : 1 I/p bias weight : 1
2	`dense_1 (Dense)`	`(None,1)`	110	I/p → layer[0] weight : 100 I/p bias weight : 10
3	`time_distributed_1 (TimeDistributed)`	`(None,10,1)`	2	I/p → layer[0] weight : 1 I/p bias weight : 1
4	`simple_rnn_1 (SimpleRNN)`	`(None,10,1)`	3	I/p → layer[0] weight : 1 layer[0] (t-1) → layer[0] (t) weight : 1 I/p bias weight : 1

Implementation using Keras: Prepare/Load training data


```
X = np.loadtxt(open('x.txt','r'))     # load sequence i/p file
O = np.loadtxt(open('o.txt','r'))     # load sequence o/p file

numInstances = 1000                    # Number of instances in training data
```

Implementation using Keras: Reshape data *w.r.t.* network 6/9

- **Problem 1 & 2**

```
X = X.reshape(numInstances, numInNeurons)
# Input file has 'numInstances', each instance has dimension 'numInNeurons'.

O = O.reshape(numInstances, numOutNeurons)
# Output file has 'numInstances', each instance has dimension 'numInNeurons'.
```

- **Problem 3 & 4**

```
X = X.reshape(numInstances, numUnits, numInNeurons)
# Input file has 'numInstances', each instance has 'numUnits' and each unit has
dimension 'numInNeurons'.

O = O.reshape(numInstances, numUnits, numOutNeurons)
# Output file has 'numInstances', each instance has 'numUnits' and each unit
has dimension 'numInNeurons'.
```

Implementation using Keras: Train the network

```
model.fit(X, O, epochs=5, validation_split=0.2)  # Train network for 5 epochs
```

```
Epoch 1/5
800/800 [==============================] - 0s - loss: 0.4118 - val_loss: 0.4520
Epoch 2/5
800/800 [==============================] - 0s - loss: 0.4116 - val_loss: 0.4517
Epoch 3/5
800/800 [==============================] - 0s - loss: 0.4114 - val_loss: 0.4514
Epoch 4/5
800/800 [==============================] - 0s - loss: 0.4112 - val_loss: 0.4512
Epoch 5/5
800/800 [==============================] - 0s - loss: 0.4110 - val_loss: 0.4509
```

Implementation using Keras: Print final *weights* 8/9

```
print (model.layers[0].get_weights())    # Print weights of first layer
```

```
[
    array([[-0.4387919]], dtype=float32),     # Input to layer[0]
    array([[ 0.99820316]], dtype=float32),    # layer[0](t-1) to layer[0](t)
    array([-0.00290805], dtype=float32)       # Input bias
]
```

Implementation using Keras: Evaluate the network

a. Prepare the test data

- Problem 1

```
test = np.array([[0],[1]])          # Problem 1
```

- Problem 2, 3 & 4

```
test = np.random.randint(2, size=10)     # Sequence of 1 & 0 of len 10
```

b. Compute prediction

- Predict probabilities

```
probability = model.predict(test)        # predict o/p probabilities
```

- Predict o/p

```
prediction = model.predict_classes(test)       # predict o/p sequence
```

Implementation using Keras: Evaluate the network..(contd) 9/9

c. Print test, probability and its prediction

```
print ('Input seq:', test)
print ('Output seq:', prediction)
print ('Probabilities:', probability)
```

Problem	Input sequence	Output sequence	Probabilities
1	[0] [1]	[1] [0]	[0.84571224] [0.11714222]
2	[1 1 1 1 0 1 1 1 1 0]	[1 0 0 1 0 0 1 1 0 1]	[0.81408471 0.41276643 0.49722081 0.80422366 0.38091436 0.49808523 0.84009314 0.52011669 0.43402666 0.51361883]
3	[[1] [0] [1] [0] [1] [1] [0] [0] [1] [0]]	[[0] [1] [0] [1] [0] [0] [1] [1] [0] [1]]	[[0.40637609] [0.50014824] [0.40637609] [0.50014824] [0.40637609] [0.40637609] [0.50014824] [0.50014824] [0.40637609] [0.50014824]]]
4	[[1] [1] [0] [0] [1] [0] [0] [0] [1] [1]]	[[1] [0] [0] [0] [1] [1] [1] [1] [1] [0]]	[[[0.65988613] [0.3504880] [0.46813461] [0.47871199] [0.76111038] [0.550727370] [0.56818104] [0.57156205] [0.57221621] [0.42234275]]]

Putting everything together

Implementation using Keras: Problem 1&2

```
# Import libraries
import numpy
import keras
from keras.models import Sequential
from keras.layers import SimpleRNN

numInNeurons = 1            #numInNeurons = 10 for Problem2
numOutNeurons = 1           #numOutNeurons = 10 for Problem2
numInstances = 1000

# Design network
model = Sequential()
model.add(Dense(numOutNeurons, input_dim=numInNeurons), activation='sigmoid'))
model.compile(optimizer='sgd', loss='mse')
model.summary()

# Prepare data
X = np.loadtxt(open('x.txt','r'))
O = np.loadtxt(open('o.txt','r'))
X = X.reshape(numInstances, numInNeurons)
Y = Y.reshape(numInstances, numOutNeurons)

# Training
model.fit(X, O, epochs=5, validation_split=0.2)
print (model.layers[0].get_weights())

# Evaluation
test = np.array([[0],[1]])       #test = np.random.randint(2, size=10)   for  Problem 2
prediction = model.predict_classes(test)
probability = model.predict(test)
print ('Input seq:', test)
print ('Output seq:', prediction)
print ('Probability:', probability)
```

Implementation using Keras: Problem 3

```
# Import libraries
import numpy
import keras
from keras.models import Sequential
from keras.layers import SimpleRNN

numInNeurons = 1
numOutNeurons = 1
seqLength = 10
numInstances = 1000

# Design network
model = Sequential()
model.add(TimeDistributed(Dense(numOutNeurons, activation='sigmoid'), input_shape=(seqLength, numInNeurons)))
model.compile(optimizer='sgd', loss='mse')
model.summary()

# Prepare data
X = np.loadtxt(open('x.txt','r'))
O = np.loadtxt(open('o.txt','r'))
X = X.reshape(numInstances, seqLength, numInNeurons)
Y = Y.reshape(numInstances, seqLength, numOutNeurons)

# Training
model.fit(X, O, epochs=5, validation_split=0.2)
print (model.layers[0].get_weights())

# Evaluation
test = np.random.randint(2, size=10)
prediction = model.predict_classes(test)
probability = model.predict(test)
print ('Input seq:', test)
print ('Output seq:', prediction)
print ('Probability:', probability)
```

Implementation using Keras: Problem 4

```
# Import libraries
import numpy
import keras
from keras.models import Sequential
from keras.layers import SimpleRNN

numInNeurons = 1
numOutNeurons = 1
seqLength = 10
numInstances = 1000

# Design network
model = Sequential()
model.add(SimpleRNN(numOutNeurons, input_shape=(seqLength, numInNeurons), return_sequences=True, activation='sigmoid'))
model.compile(optimizer='sgd', loss='mse')
model.summary()

# Prepare data
X = np.loadtxt(open('x.txt','r'))
O = np.loadtxt(open('o.txt','r'))
X = X.reshape(numInstances, seqLength, numInNeurons)
Y = Y.reshape(numInstances, seqLength, numOutNeurons)

# Training
model.fit(X, O, epochs=5, validation_split=0.2)
print (model.layers[0].get_weights())

# Evaluation
test = np.random.randint(2, size=10)
prediction = model.predict_classes(test)
probability = model.predict(test)
print ('Input seq:', test)
print ('Output seq:', prediction)
print ('Probability:', probability)
```