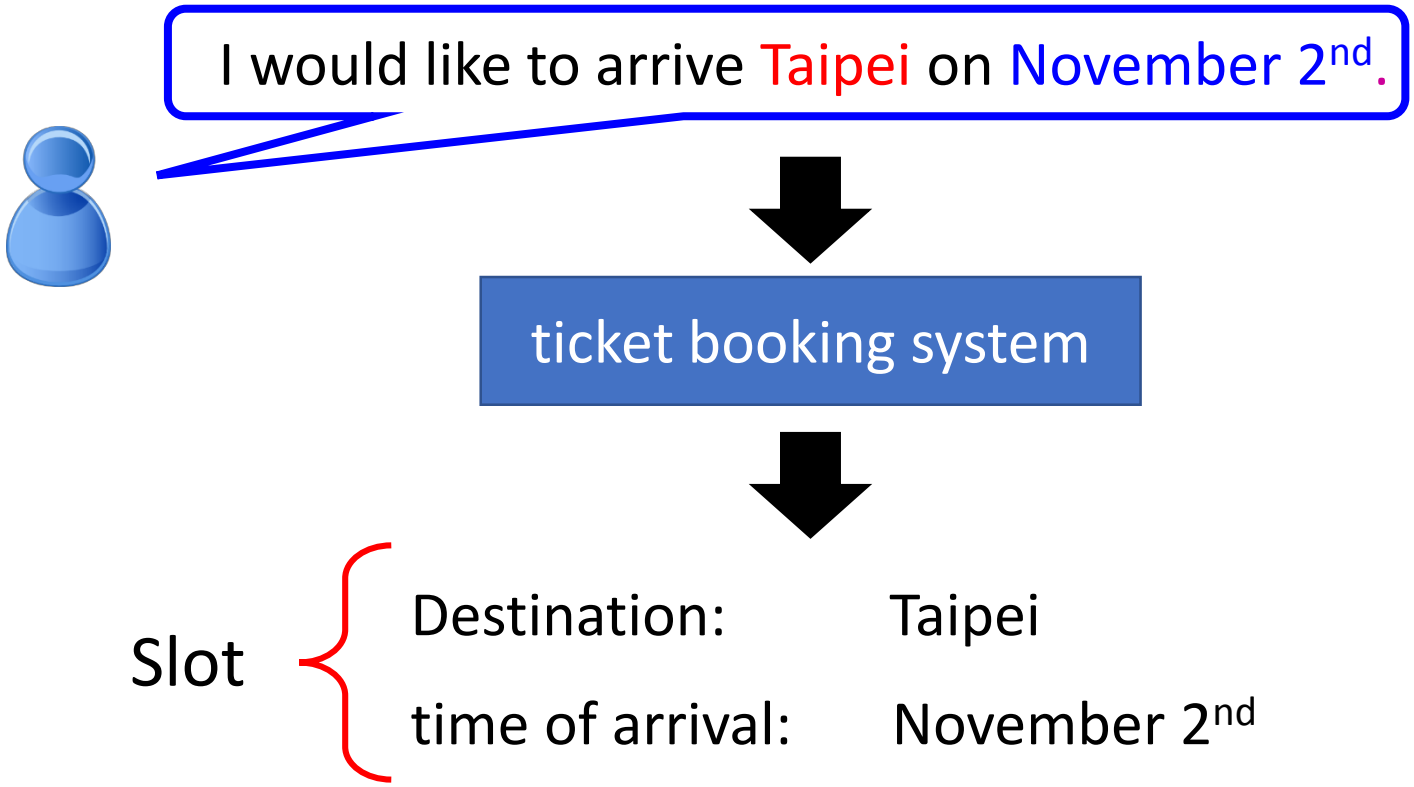
http://speech.ee.ntu.edu.tw/~tlkagk/courses_ML20.html

Recurrent Neural Network (RNN)

Example Application

- Slot Filling

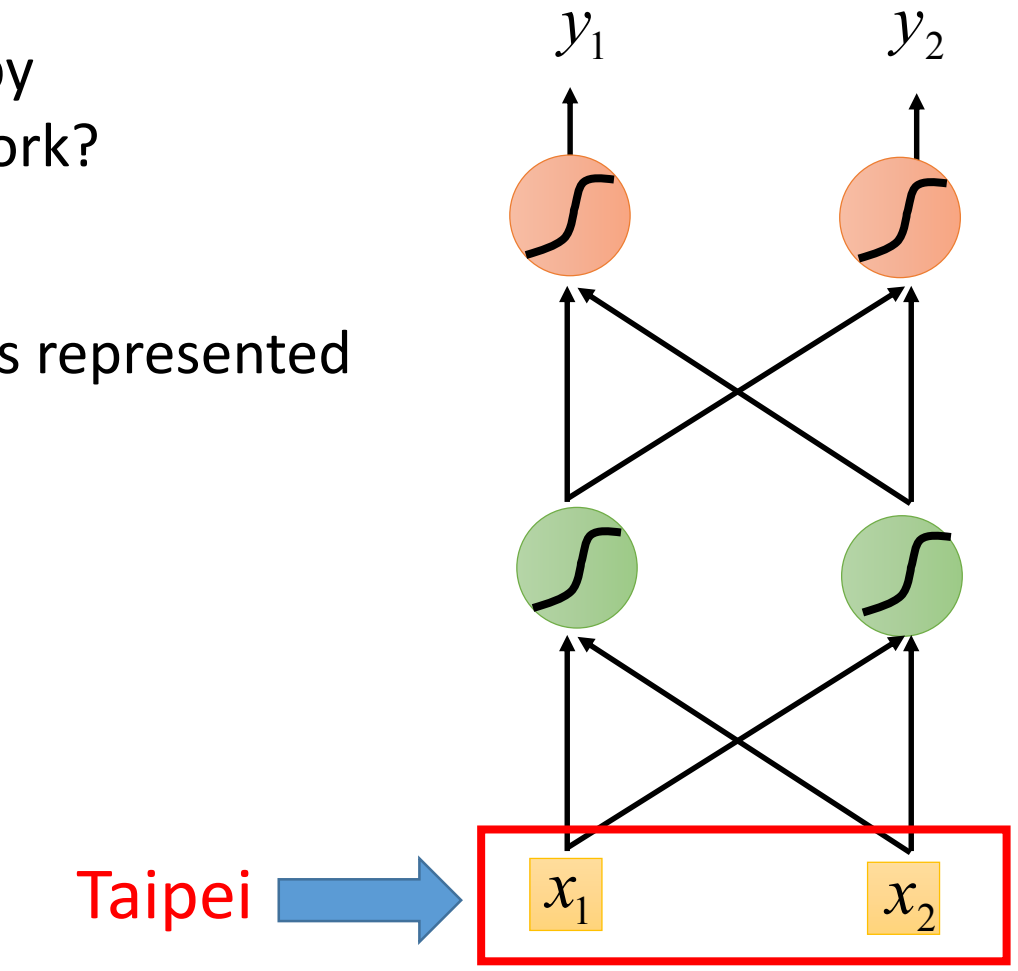


Example Application

Solving slot filling by Feedforward network?

Input: a word

(Each word is represented as a vector)



1-of-N encoding

How to represent each word as a vector?

1-of-N Encoding lexicon = {apple, bag, cat, dog, elephant}

The vector is lexicon size.

Each dimension corresponds to a word in the lexicon

The dimension for the word is 1, and others are 0

apple = [1 0 0 0 0]

bag = [0 1 0 0 0]

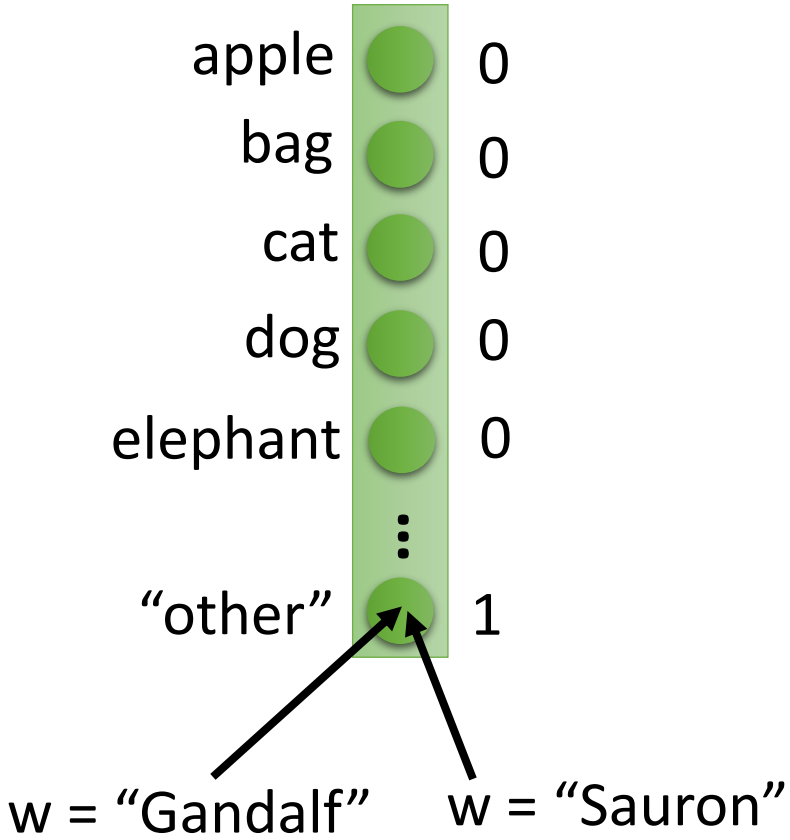
cat = [0 0 1 0 0]

dog = [0 0 0 1 0]

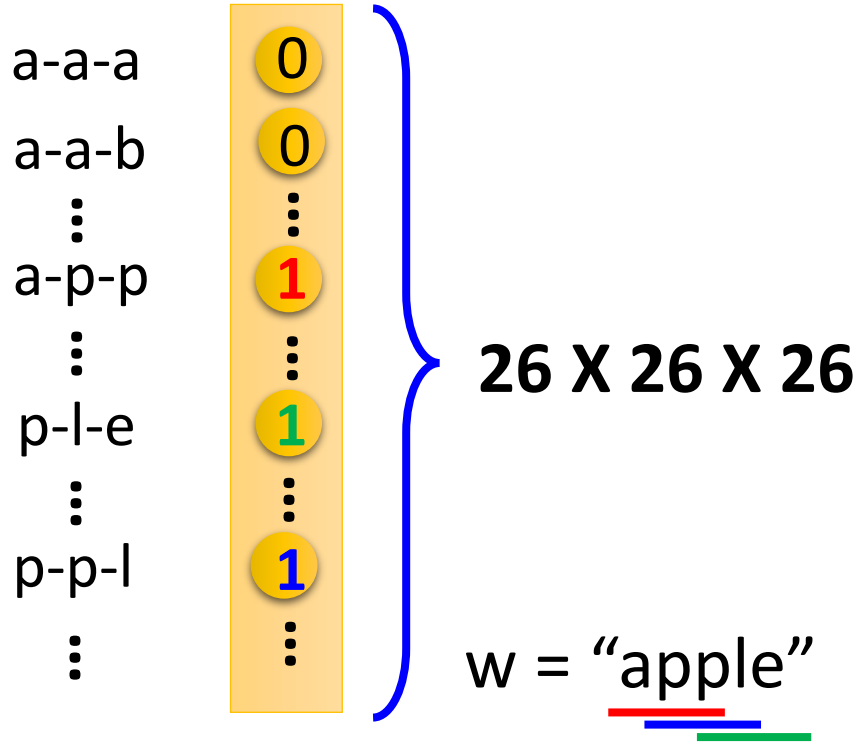
elephant = [0 0 0 0 1]

Beyond 1-of-N encoding

Dimension for "Other"



Word hashing



Example Application

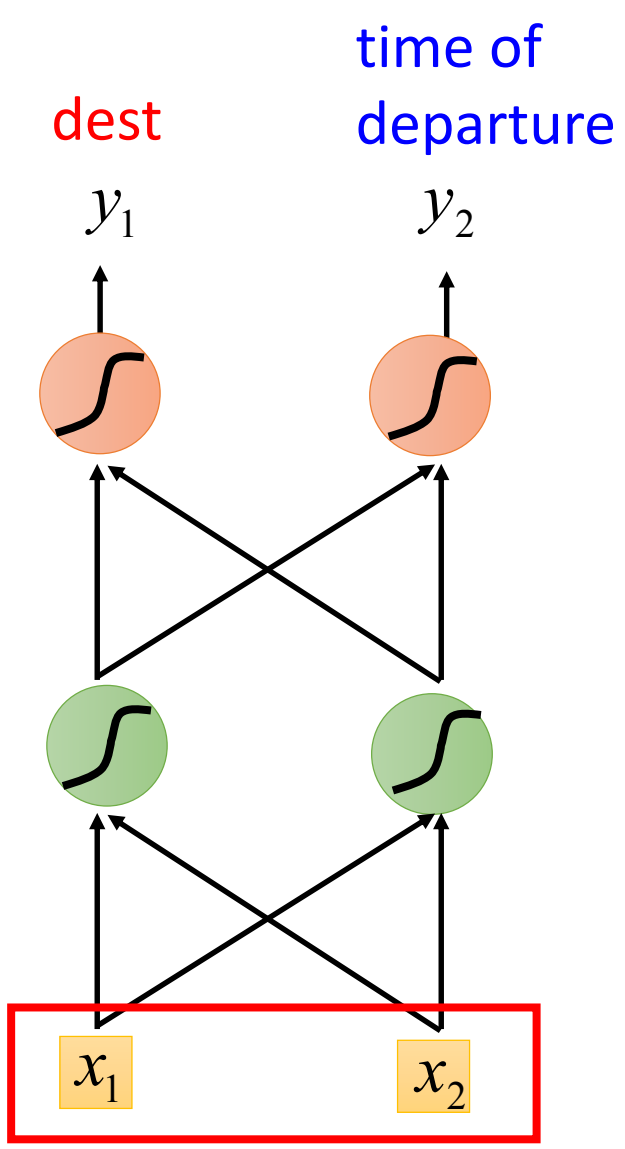
Solving slot filling by Feedforward network?

Input: a word

(Each word is represented as a vector)

Output:

Probability distribution that the input word belonging to the slots



Example Application

arrive Taipei on November 2nd

other dest other time time

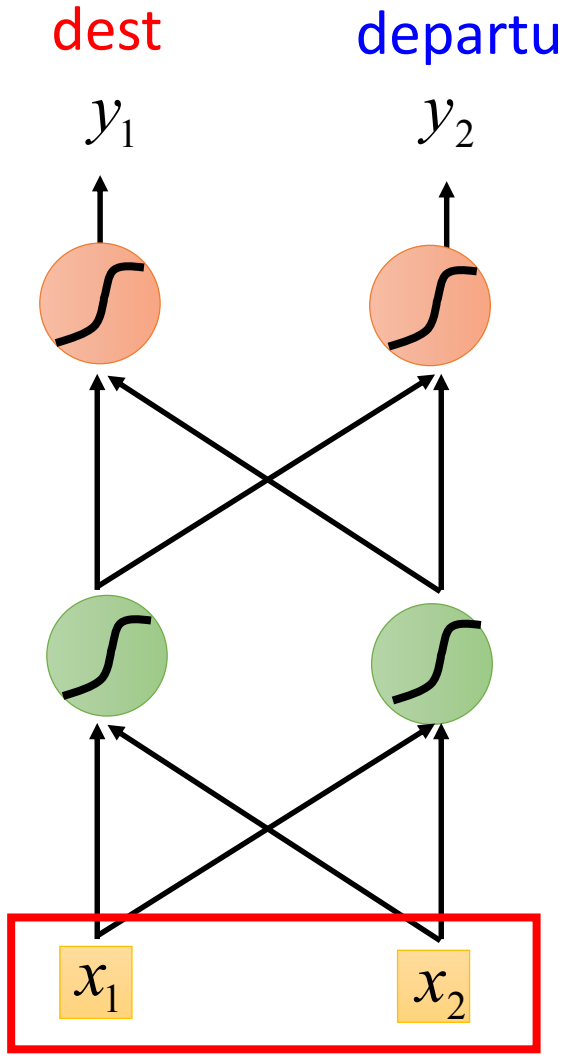
Problem?

leave Taipei on November 2nd

place of departure

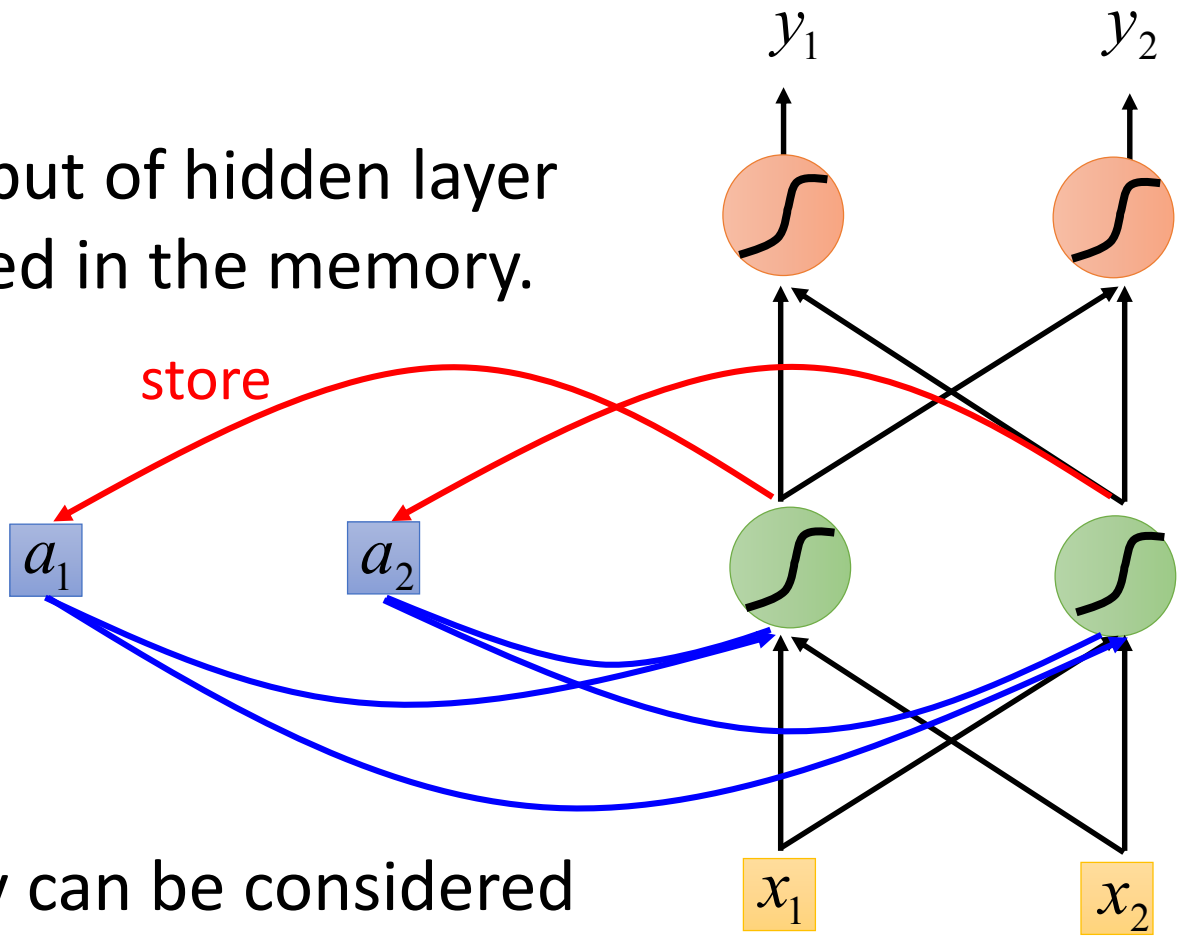
Neural network needs memory!

Taipei



Recurrent Neural Network (RNN)

The output of hidden layer are stored in the memory.

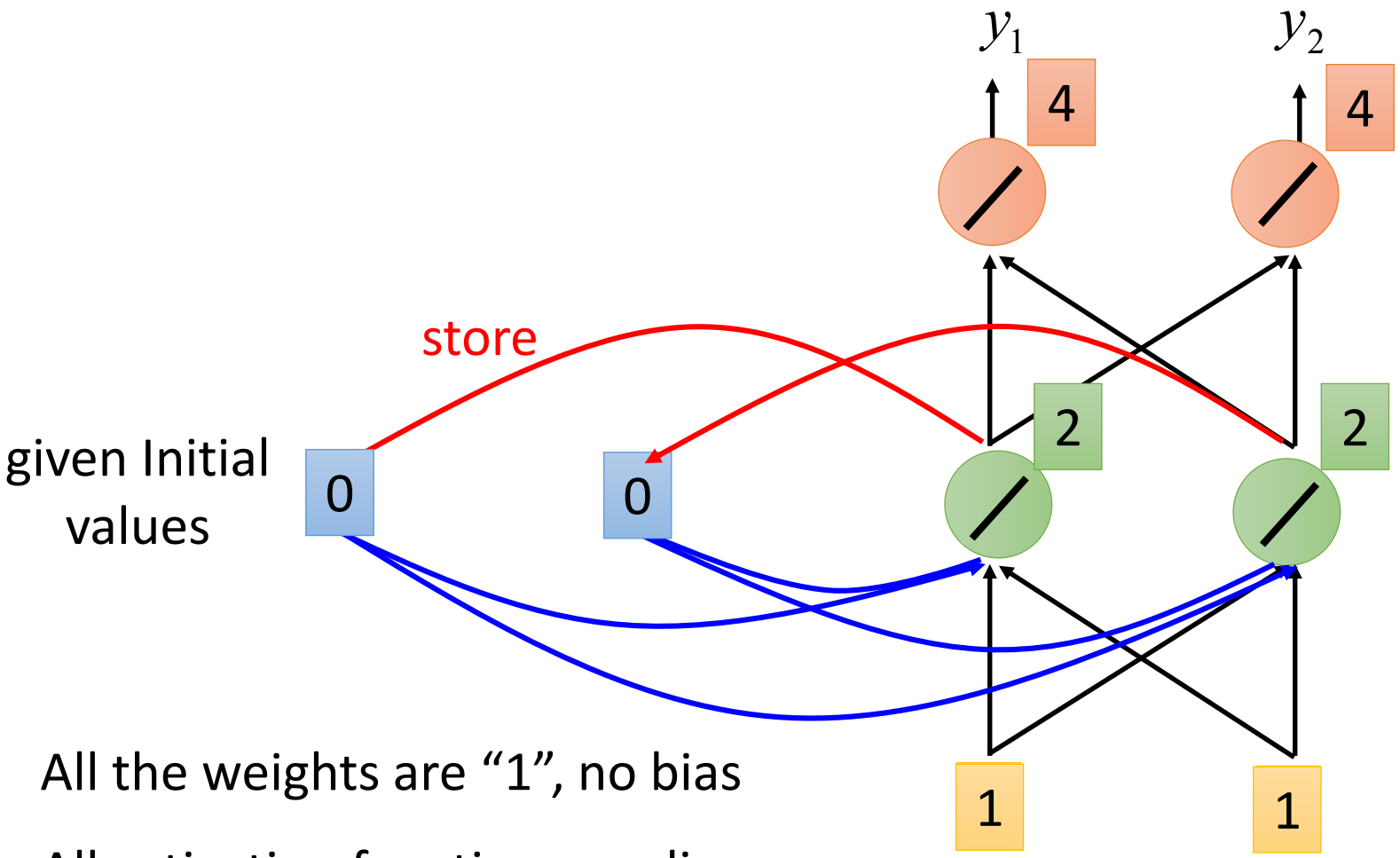


Memory can be considered as another input.

Example

Input sequence: $\begin{bmatrix}1\\1\end{bmatrix}$ $\begin{bmatrix}1\\1\end{bmatrix}$ $\begin{bmatrix}2\\2\end{bmatrix}$ ……

output sequence: $\begin{bmatrix}4\\4\end{bmatrix}$



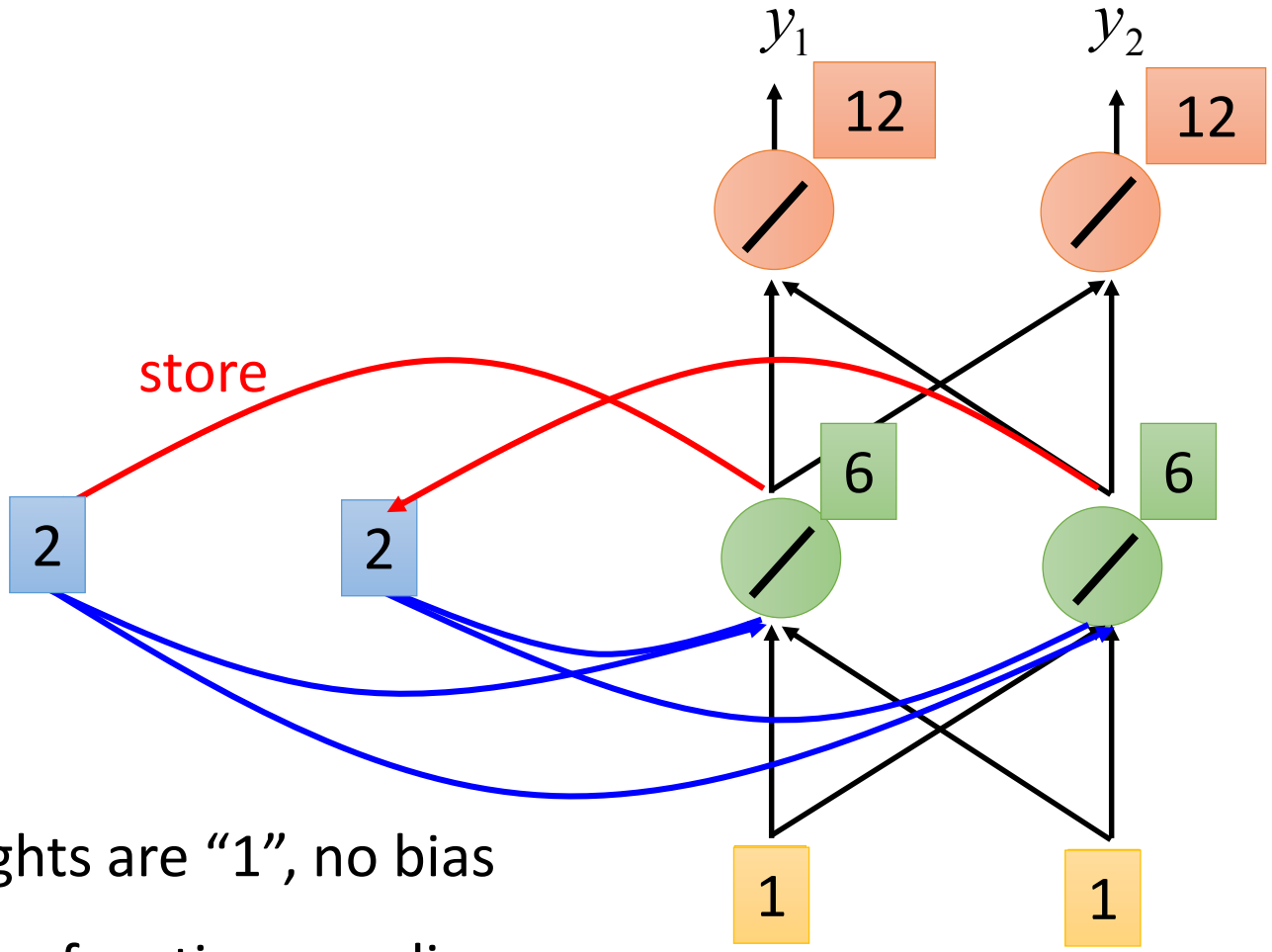
All the weights are “1”, no bias

All activation functions are linear

Example

Input sequence: $\begin{bmatrix}1\\1\end{bmatrix}\ \begin{bmatrix}1\\1\end{bmatrix}\ \begin{bmatrix}2\\2\end{bmatrix}\ \cdots\cdots$

output sequence: $\begin{bmatrix}4\\4\end{bmatrix}\begin{bmatrix}12\\12\end{bmatrix}$



All the weights are “1”, no bias

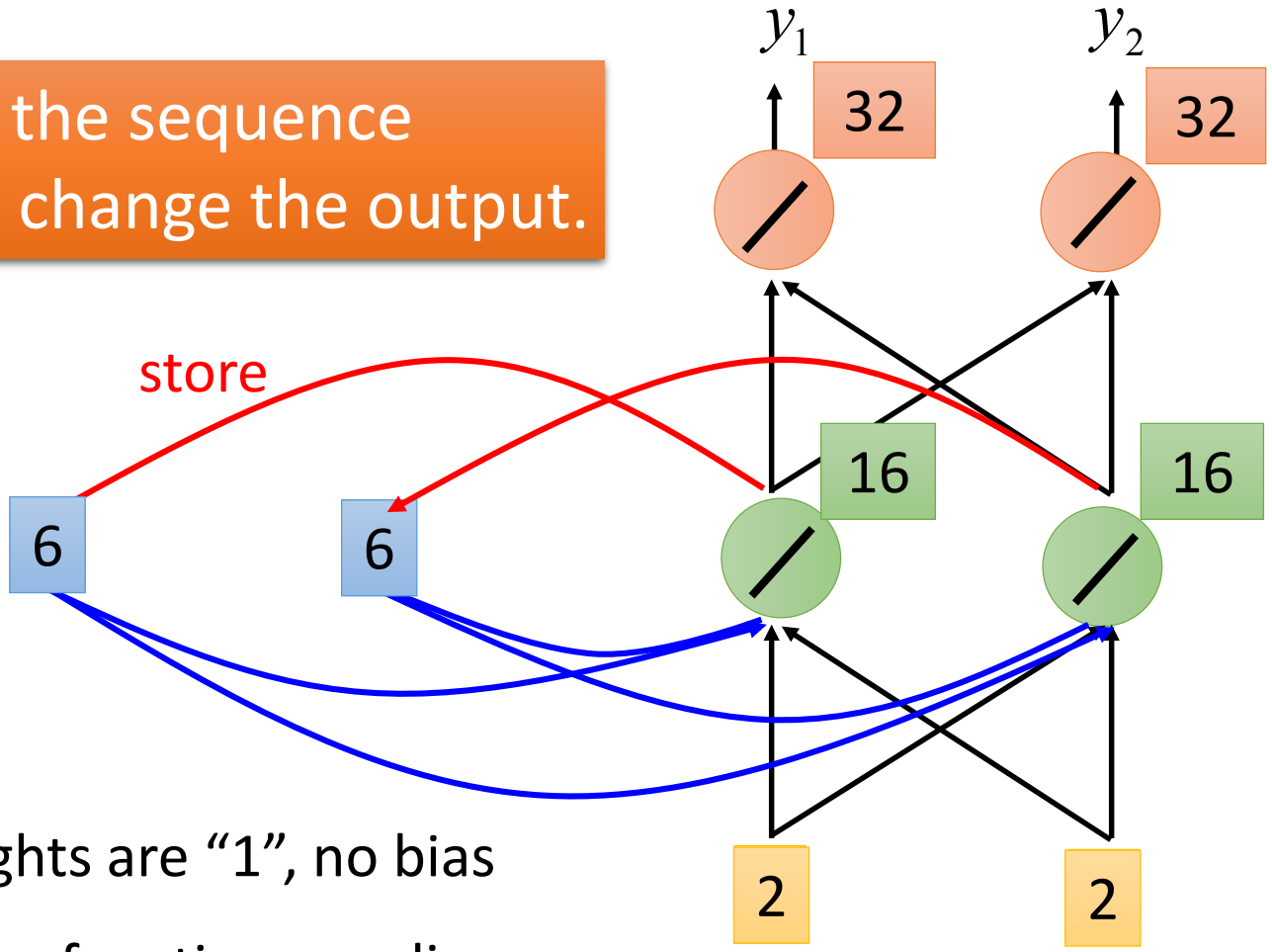
All activation functions are linear

Example

Input sequence: $\begin{bmatrix}1\\1\end{bmatrix}$ $\begin{bmatrix}1\\1\end{bmatrix}$ $\begin{bmatrix}2\\2\end{bmatrix}$ ……

output sequence: $\begin{bmatrix}4\\4\end{bmatrix}\begin{bmatrix}12\\12\end{bmatrix}\begin{bmatrix}32\\32\end{bmatrix}$

Changing the sequence order will change the output.



All the weights are “1”, no bias

All activation functions are linear

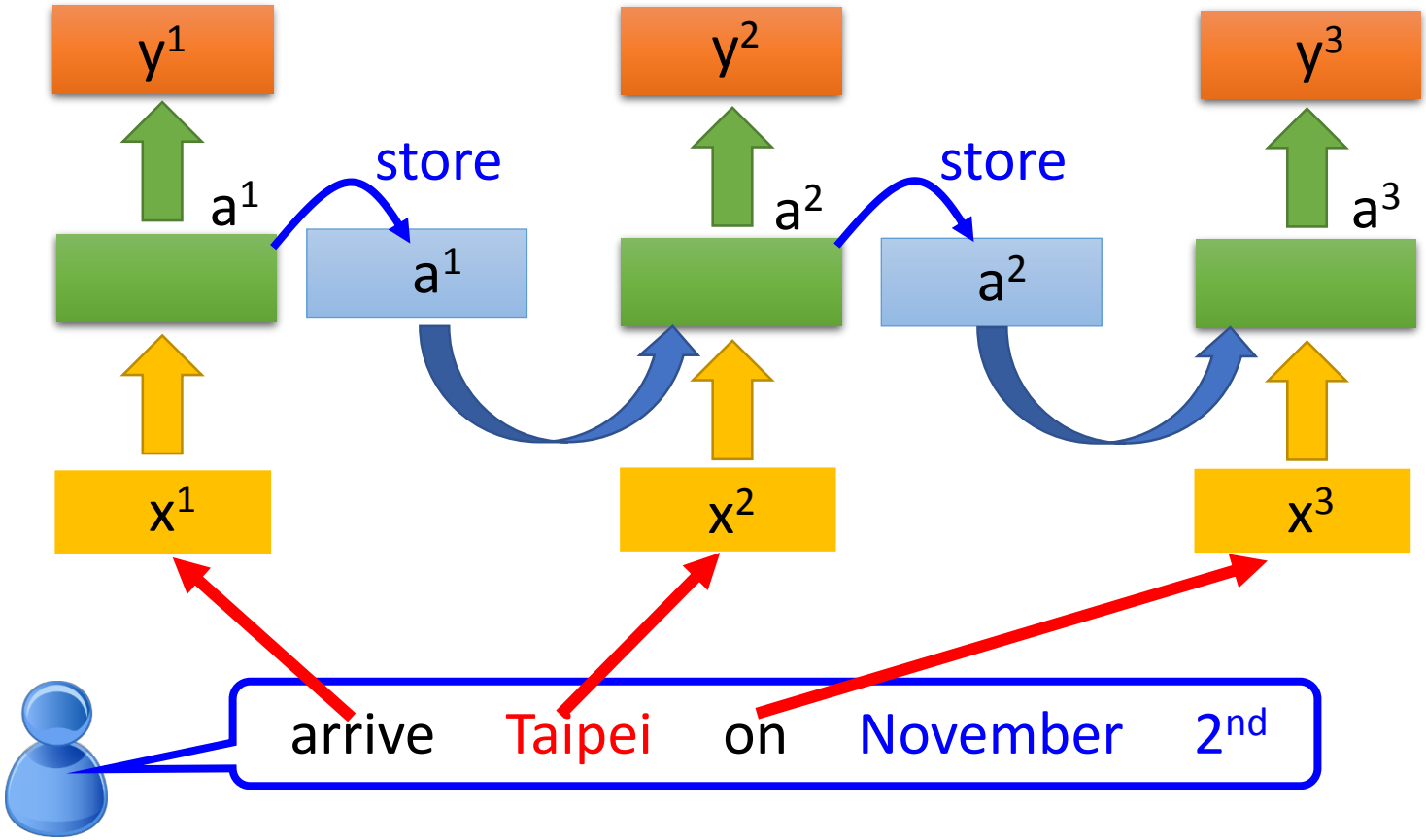
RNN

The same network is used again and again.

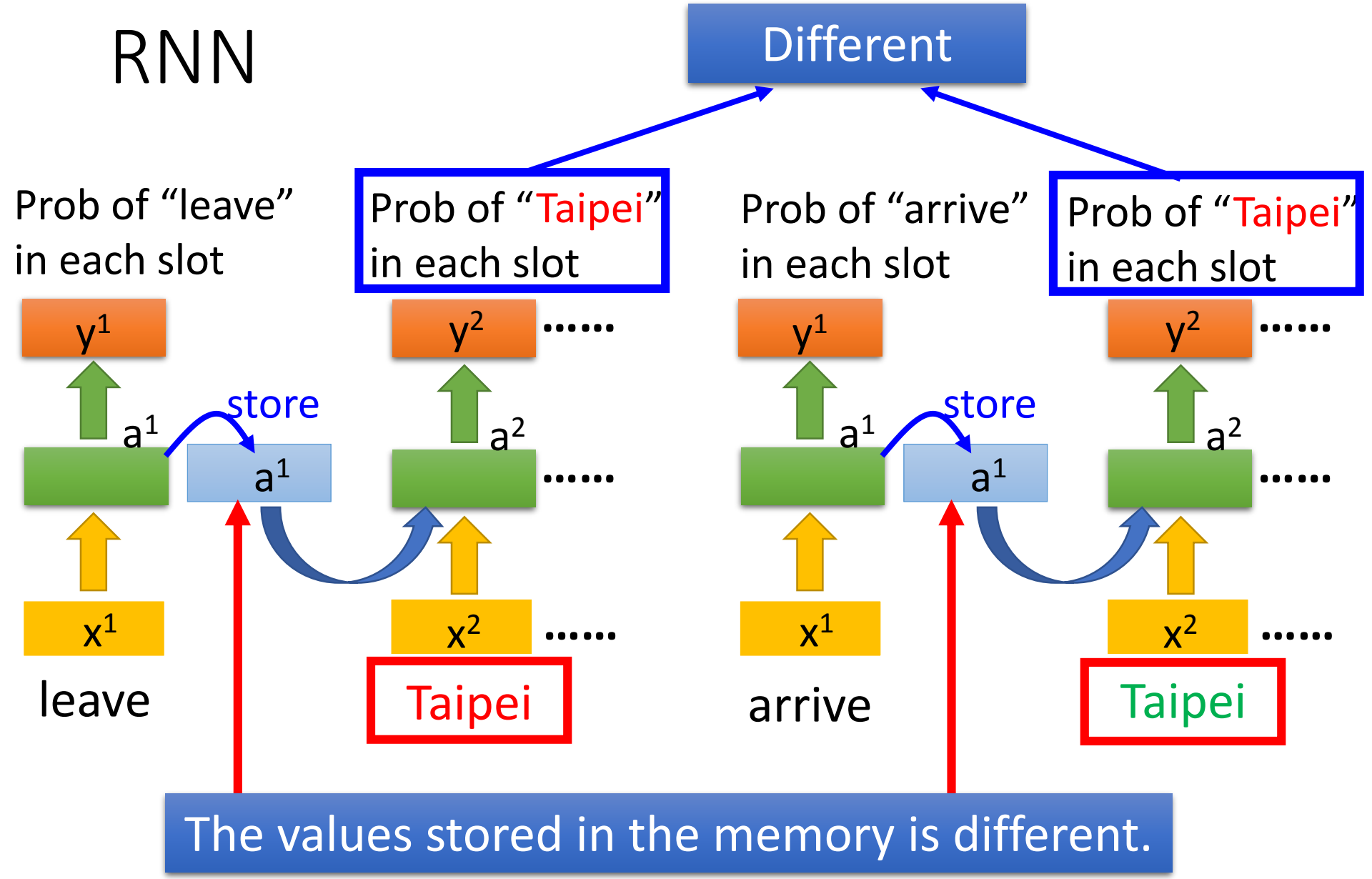
Probability of "arrive" in each slot

Probability of "Taipei" in each slot

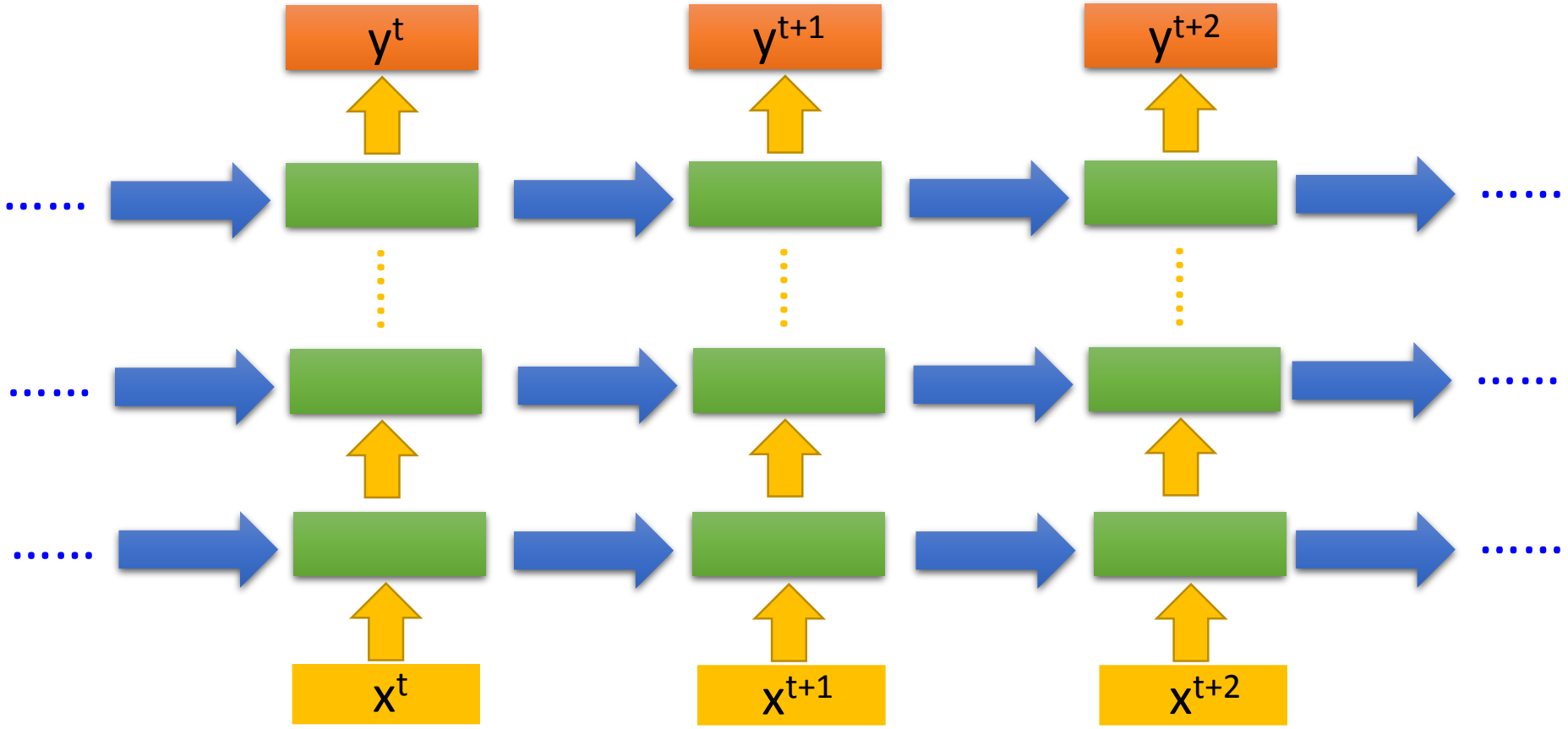
Probability of "on" in each slot



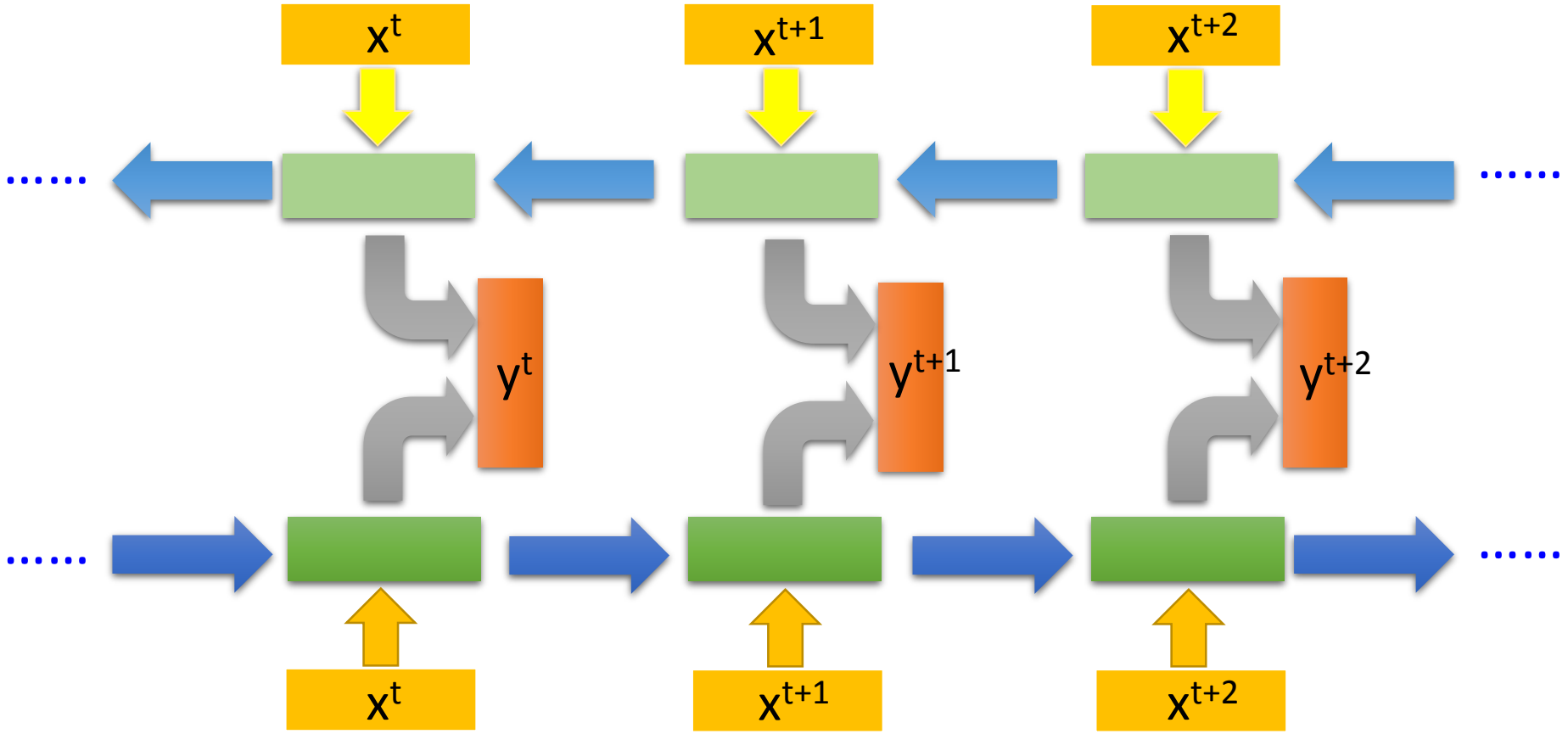
RNN


Different
Prob of "leave" in each slot
Prob of "Taipei" in each slot
Prob of "arrive" in each slot
Prob of "Taipei" in each slot
y1
y2
.....
store
a1
a2
x1
x2
leave
Taipei
arrive
Taipei
The values stored in the memory is different.

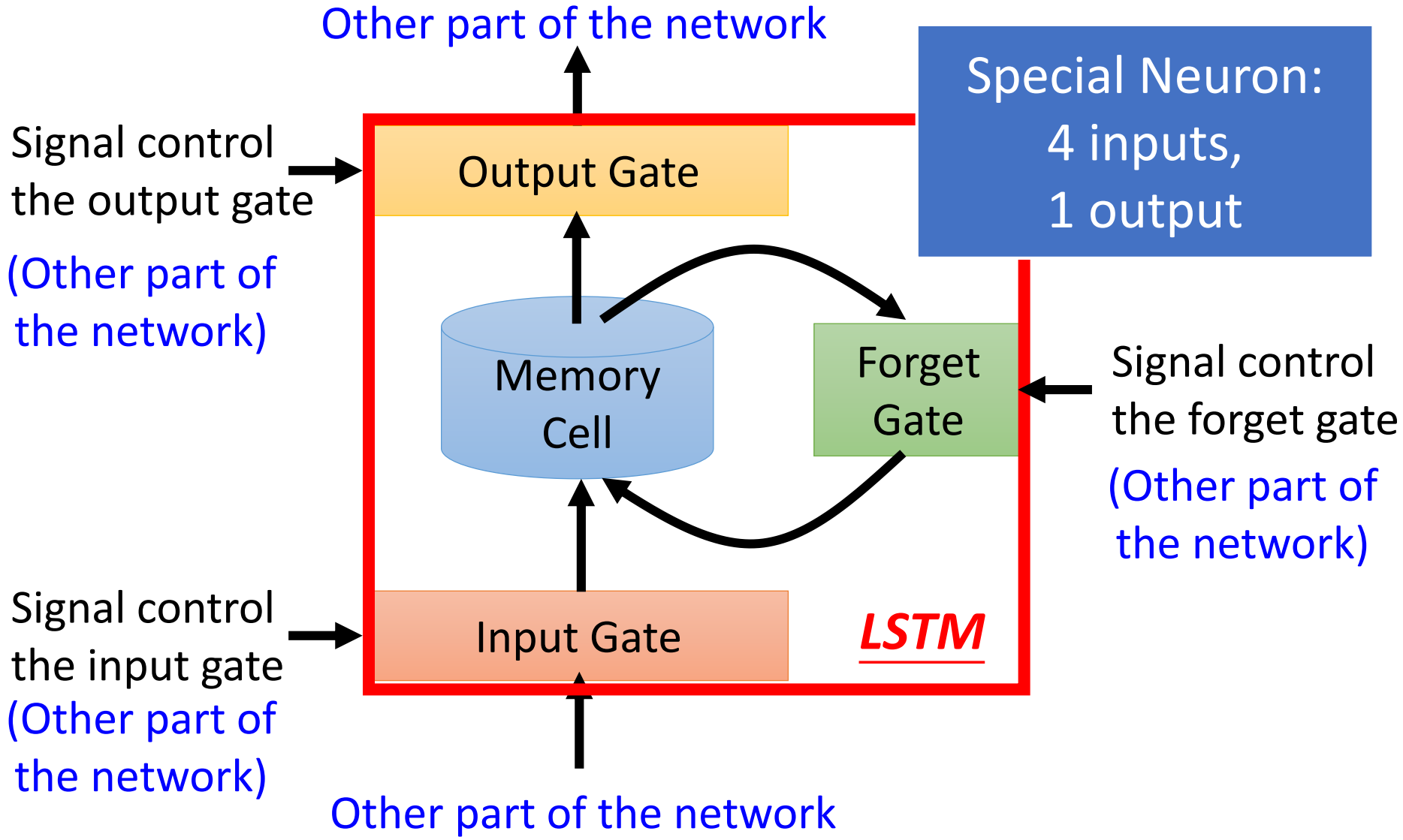
Of course it can be deep …

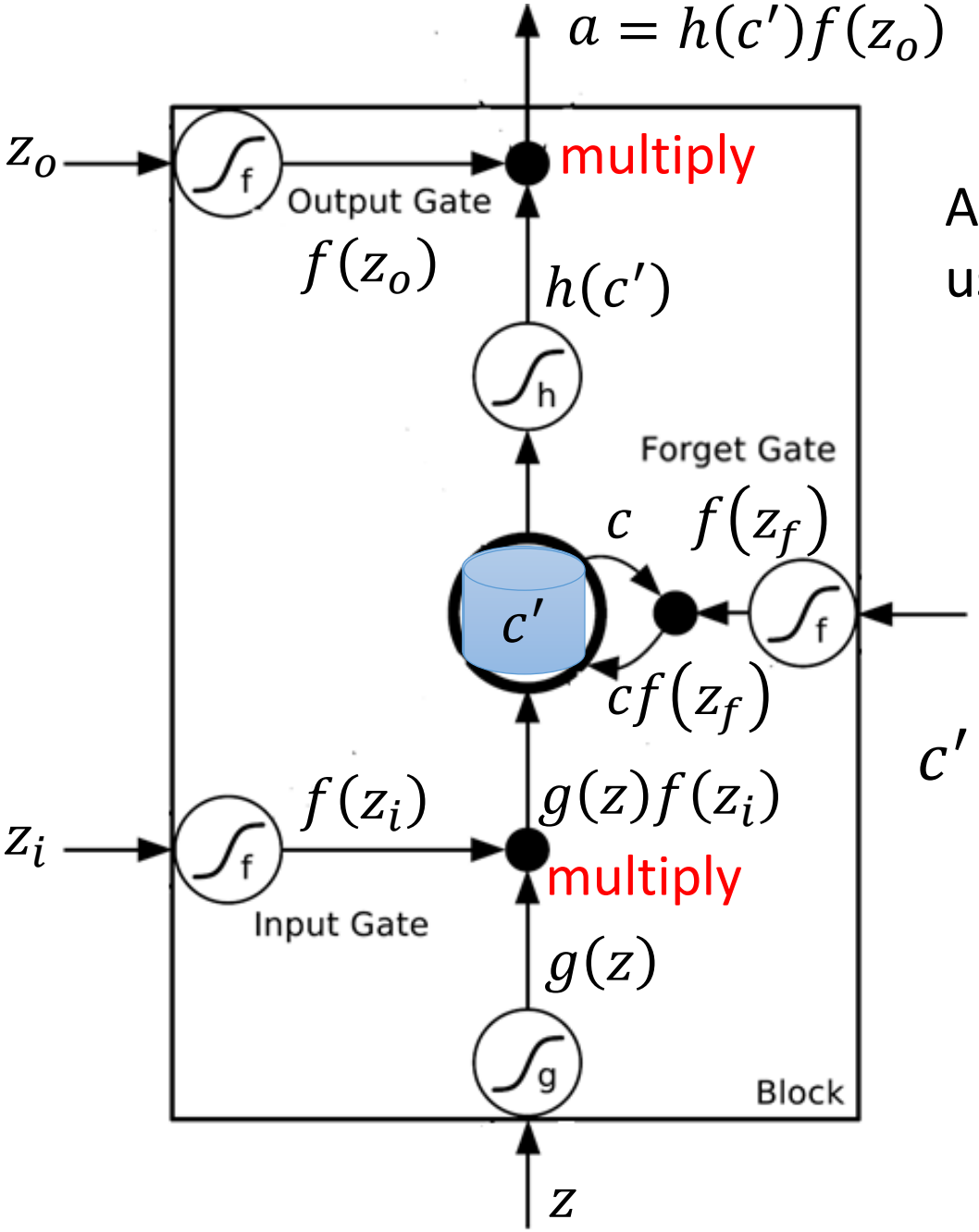


Bidirectional RNN



Long Short-term Memory (LSTM)





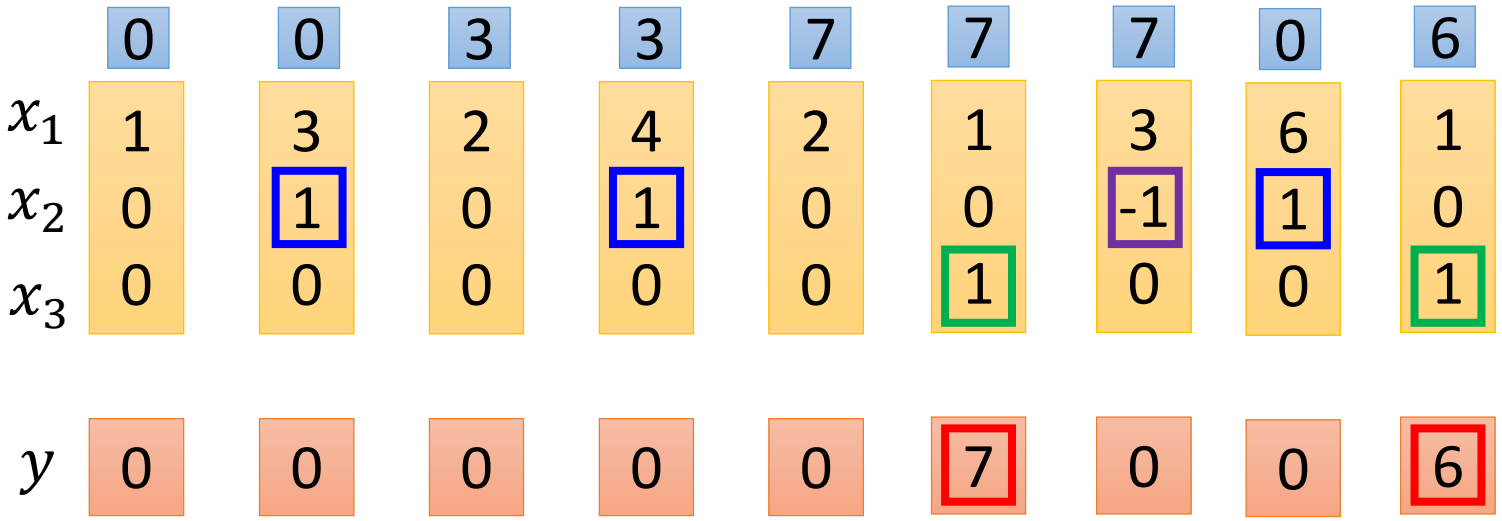
Activation function f is usually a sigmoid function

Between 0 and 1

Mimic open and close gate

$$c' = g(z)f(z_i) + cf(z_f)$$

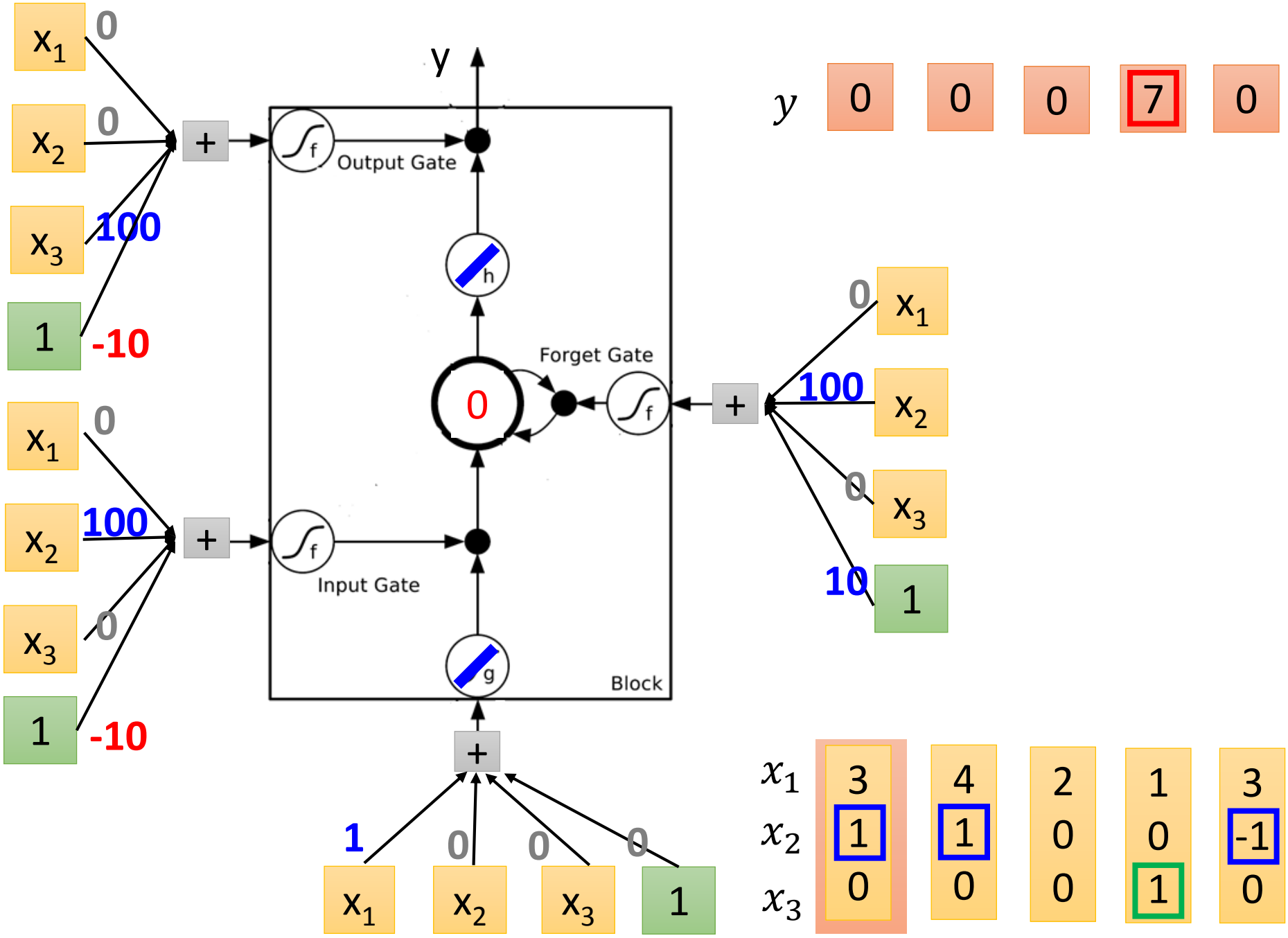
LSTM - Example

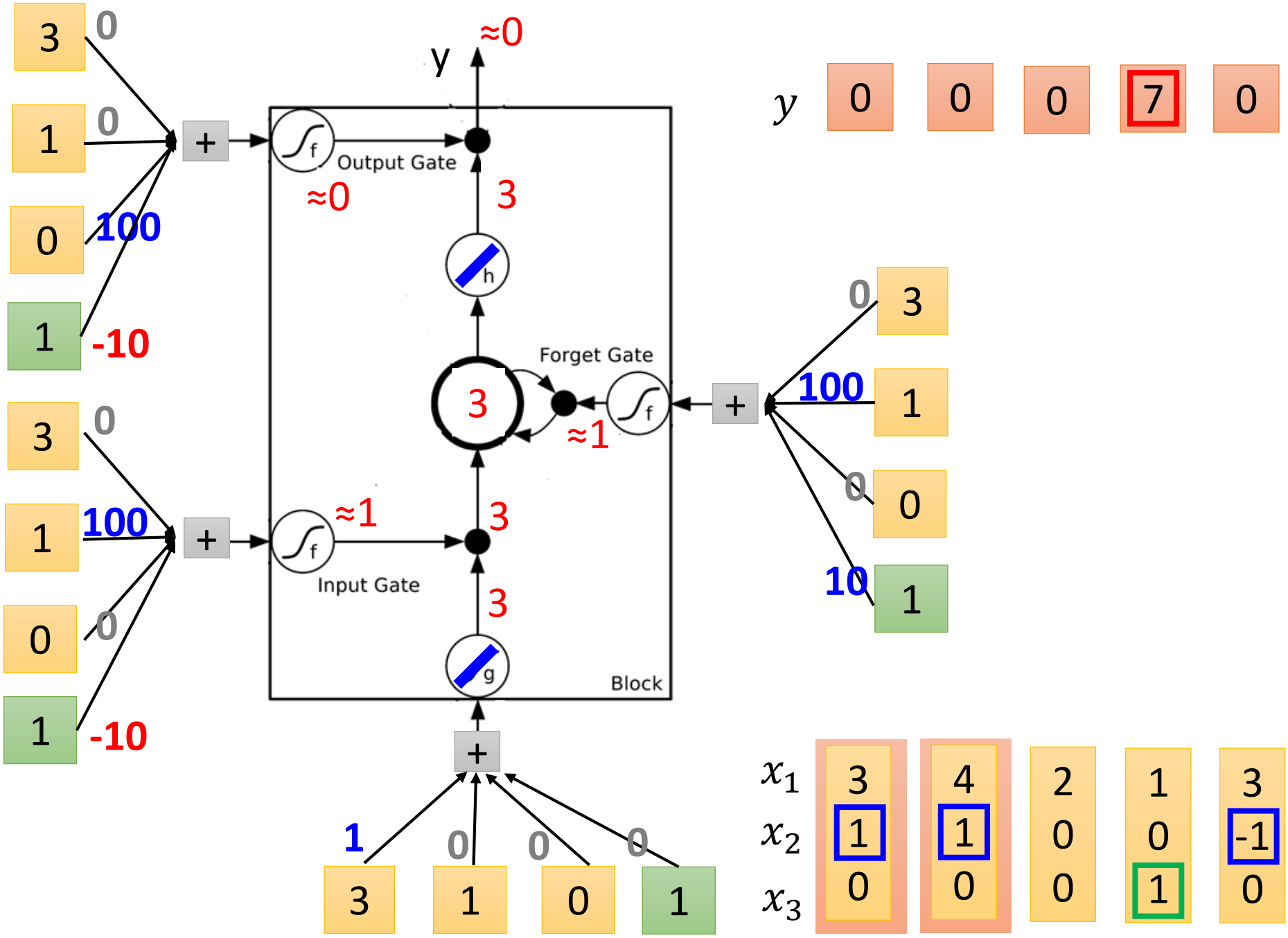


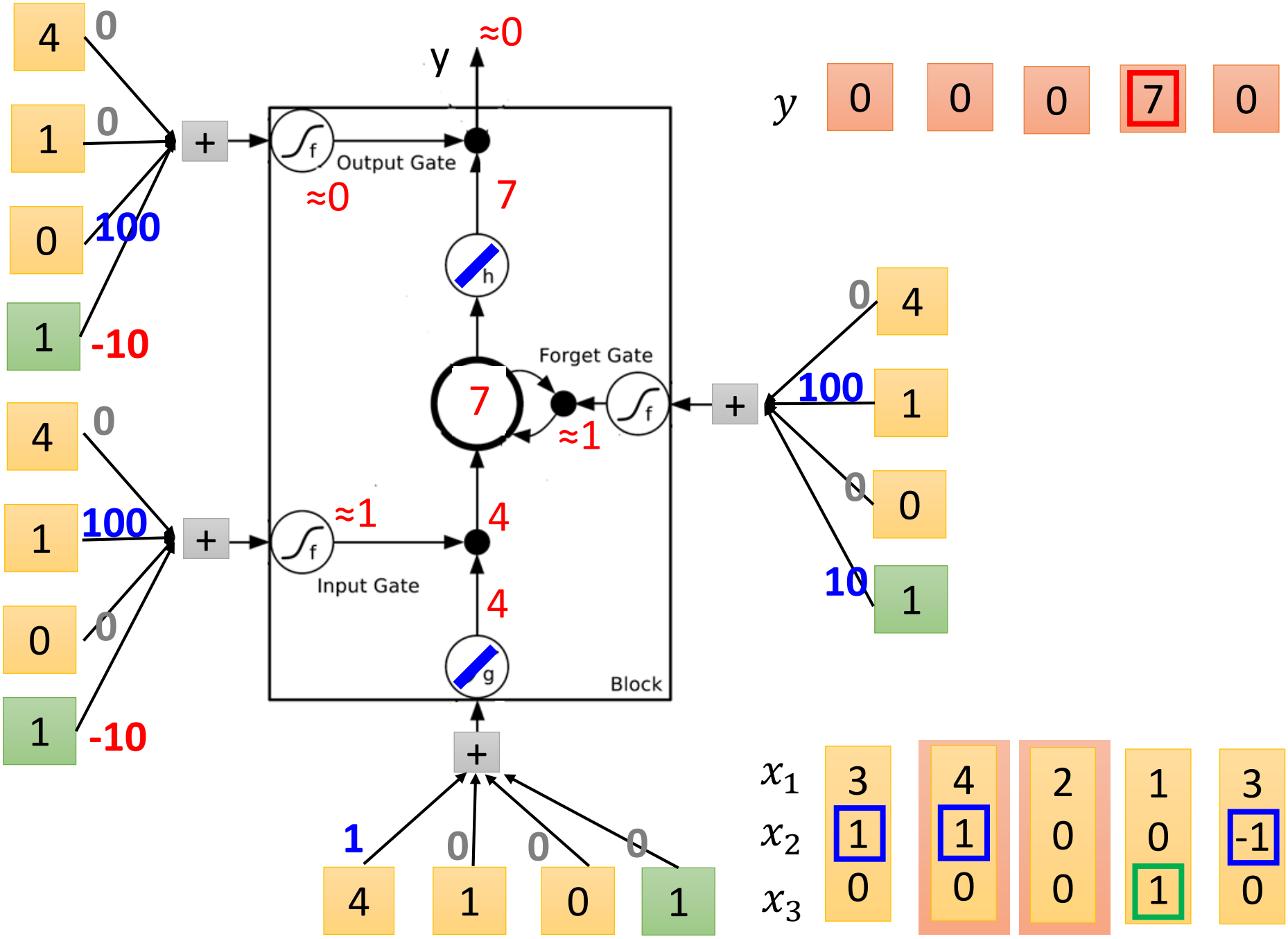
When x_2 = 1, add the numbers of x_1 into the memory

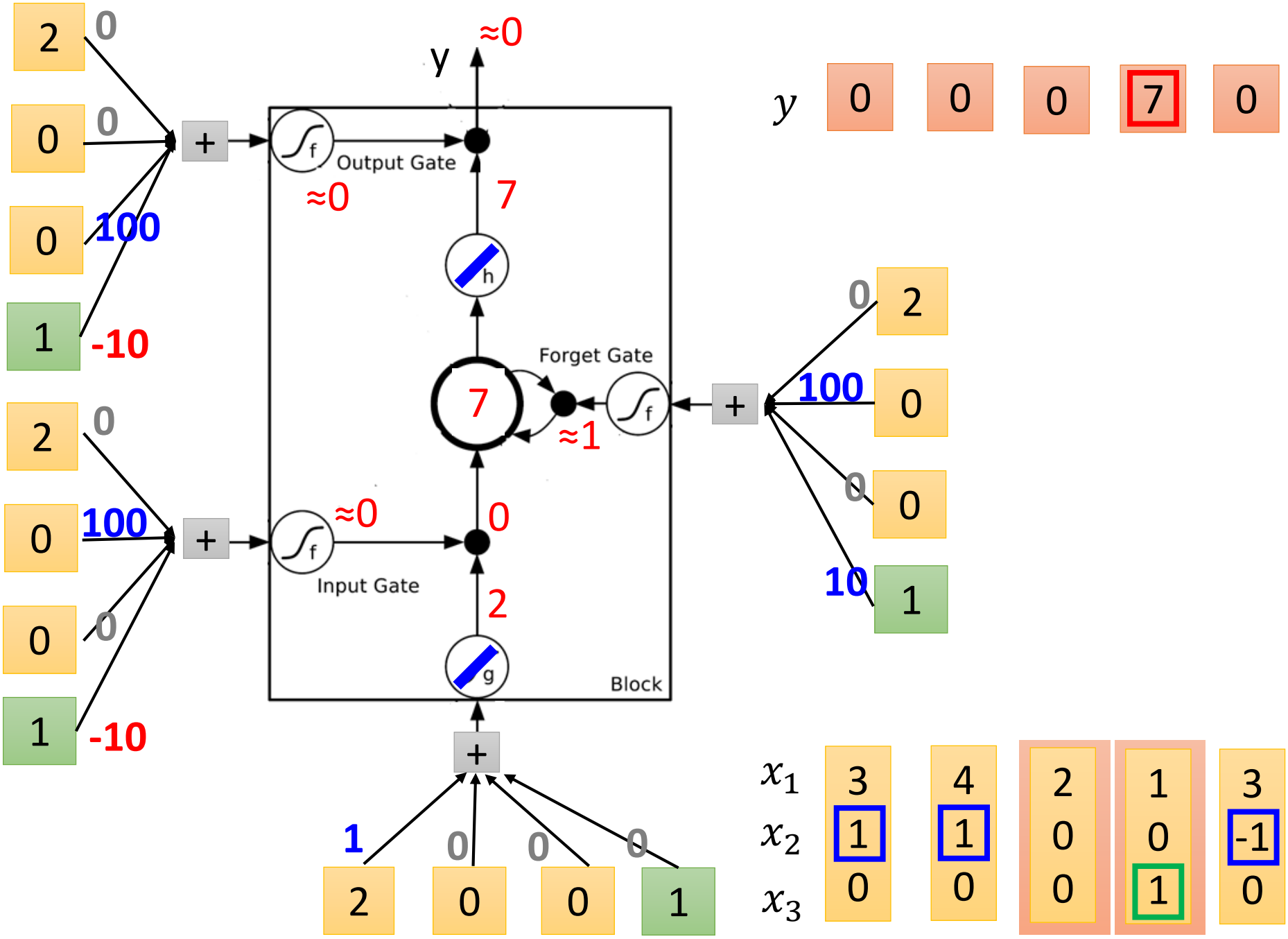
When x_2 = -1, reset the memory

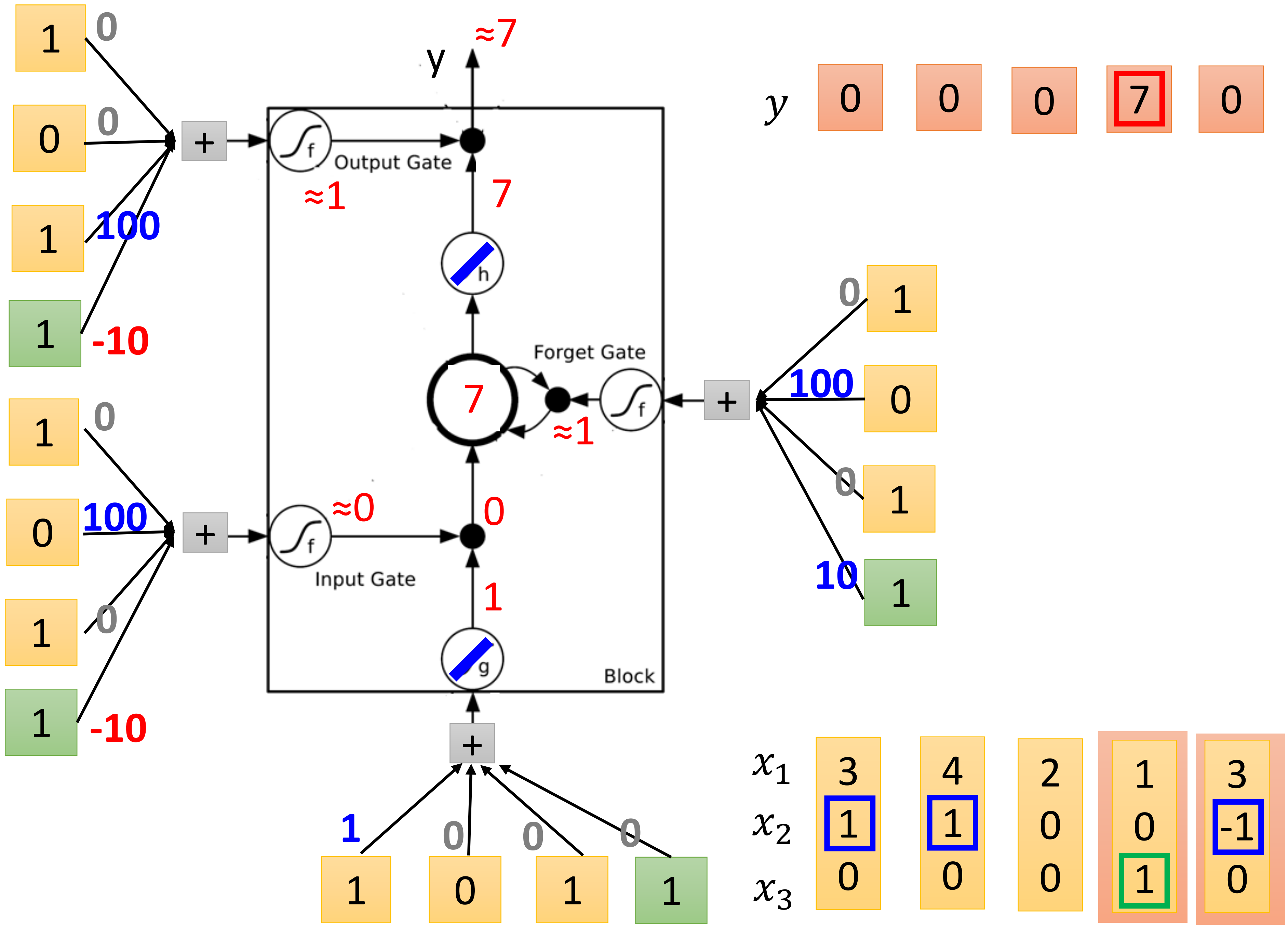
When x_3 = 1, output the number in the memory.


y
Output Gate
Forget Gate
Input Gate
Block
0
100
-10
1
x1
x2
x3
+
f
h
g
y 0 0 0 7 0
x1 3 4 2 1 3
x2 1 1 0 0 -1
x3 0 0 0 1 0

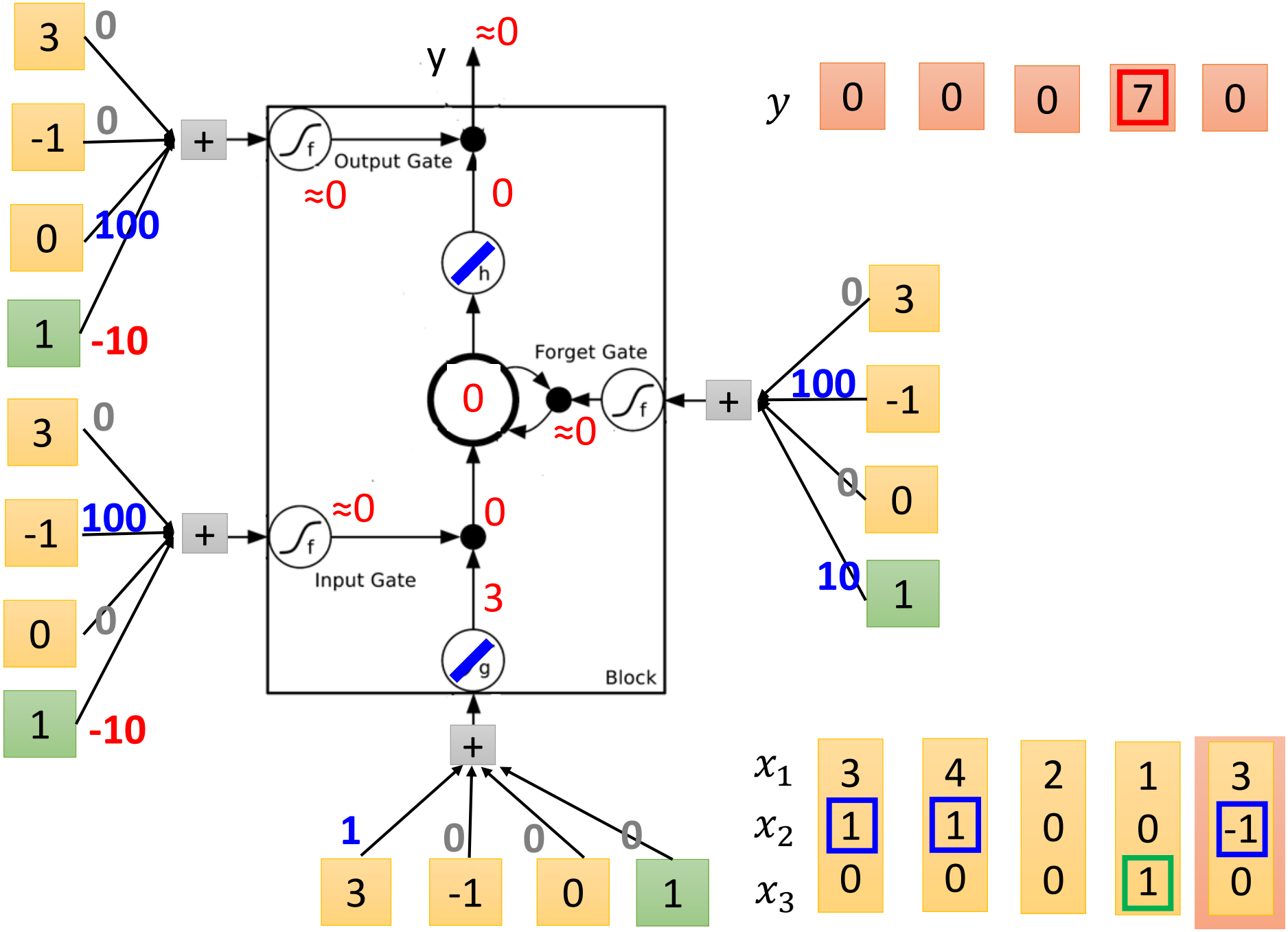

y
≈0
Output Gate
≈0
3
Forget Gate
3
≈1
Input Gate
≈1
3
3
Block
+
+
+
+
3
0
1
0
100
1
-10
3
0
1
100
0
0
1
-10
0
3
100
1
0
0
10
1
1
0
0
0
3
1
0
1
y
0
0
0
7
0
x_1
x_2
x_3
3
1
0
4
1
0
2
0
0
1
0
1
3
-1
0


y
≈0
Output Gate
≈0
7
Forget Gate
7
≈1
Input Gate
≈1
4
4
Block
Block
4
0
1
100
0
0
1
-10
4
0
1
100
0
0
1
-10
0
4
1
100
0
0
10
1
1
0
0
0
4
1
0
1
y
0
0
0
7
0
x_1
x_2
x_3
3
1
0
4
1
0
2
0
0
1
0
1
3
-1
0


y
≈0
Output Gate
≈0
7
Forget Gate
7
≈1
Input Gate
≈0
0
2
Block
+
f
h
g
2
0
0
1
0
0
0
100
-10
0
2
0
100
0
0
1
-10
0
2
0
0
100
0
0
10
1
1
0
0
0
2
0
0
1
y 0 0 0 7 0
x_1 3 4 2 1 3
x_2 1 1 0 0 -1
x_3 0 0 0 1 0

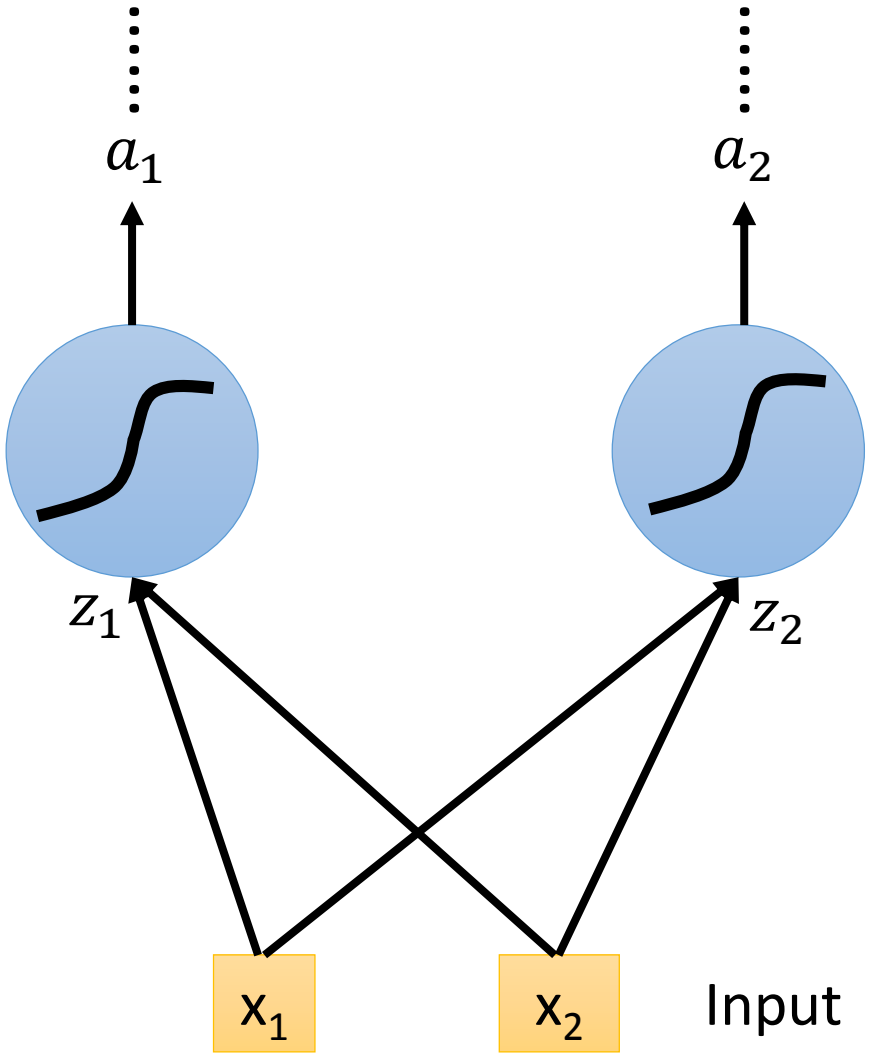


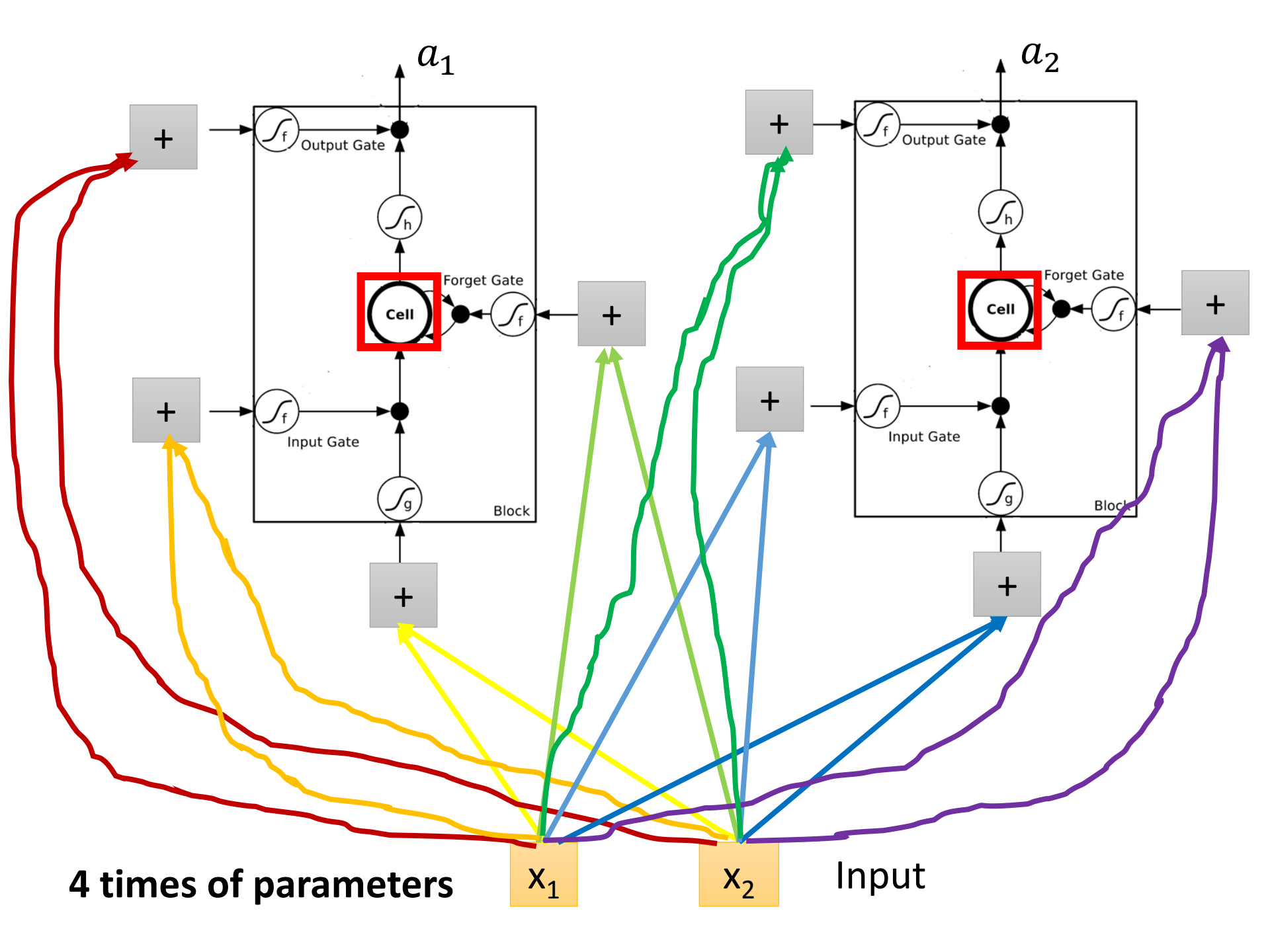
y
≈7
Output Gate
≈1
7
h
Forget Gate
≈1
Input Gate
≈0
0
1
g
Block
100
-10
10
y
0 0 0 7 0
x1 3 4 2 1 3
x2 1 1 0 0 -1
x3 0 0 0 1 0


y
≈0
Output Gate
≈0
0
h
Forget Gate
0
≈0
Input Gate
≈0
0
3
Block
+
3
-1
0
1
0
0
0
100
-10
0
3
-1
0
1
100
-10
0
3
-1
0
1
100
10
1
0
0
0
y 0 0 0 7 0
x_1 3 4 2 1 3
x_2 1 1 0 0 -1
x_3 0 0 0 1 0

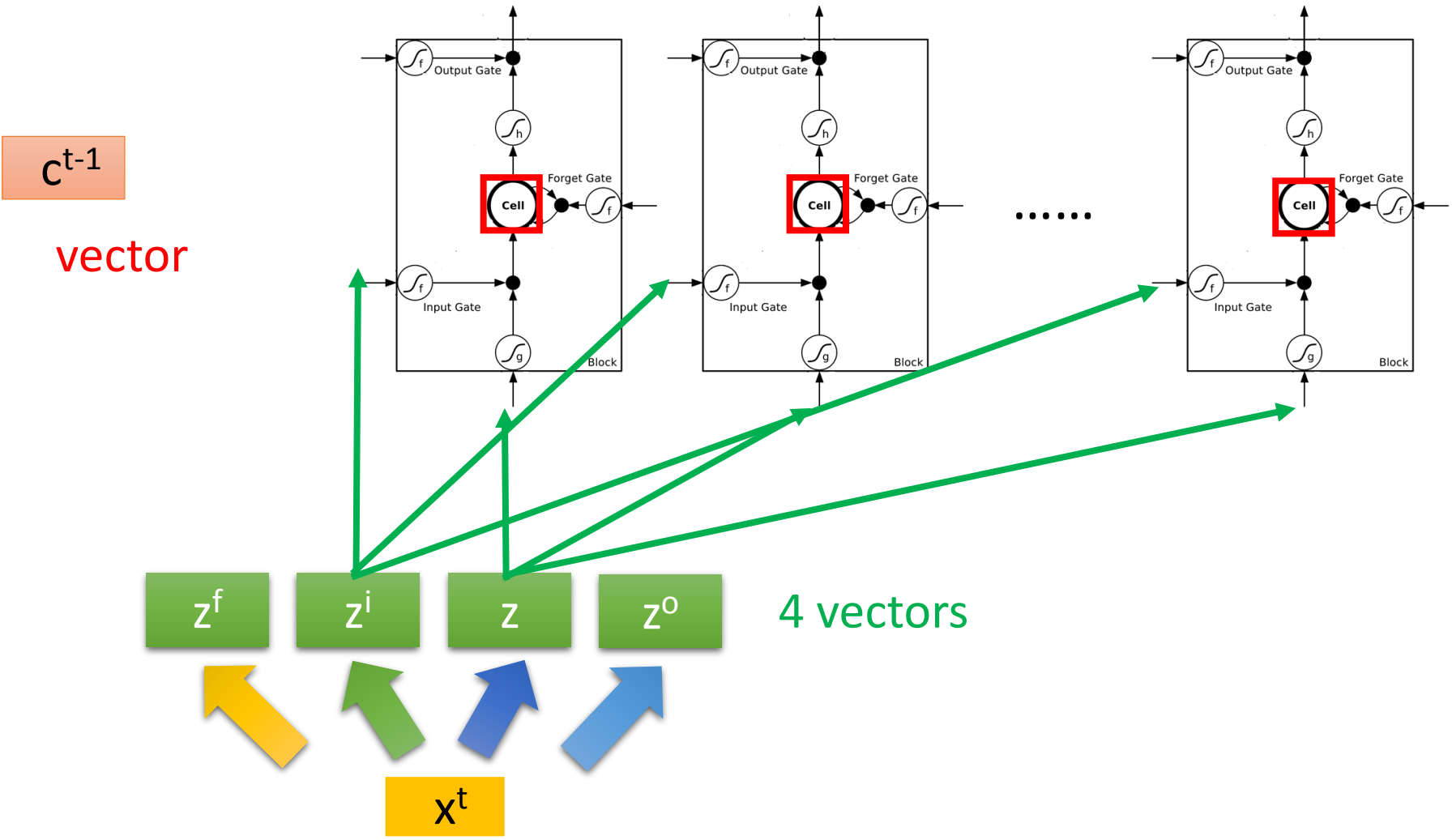
Original Network:

- Simply replace the neurons with LSTM

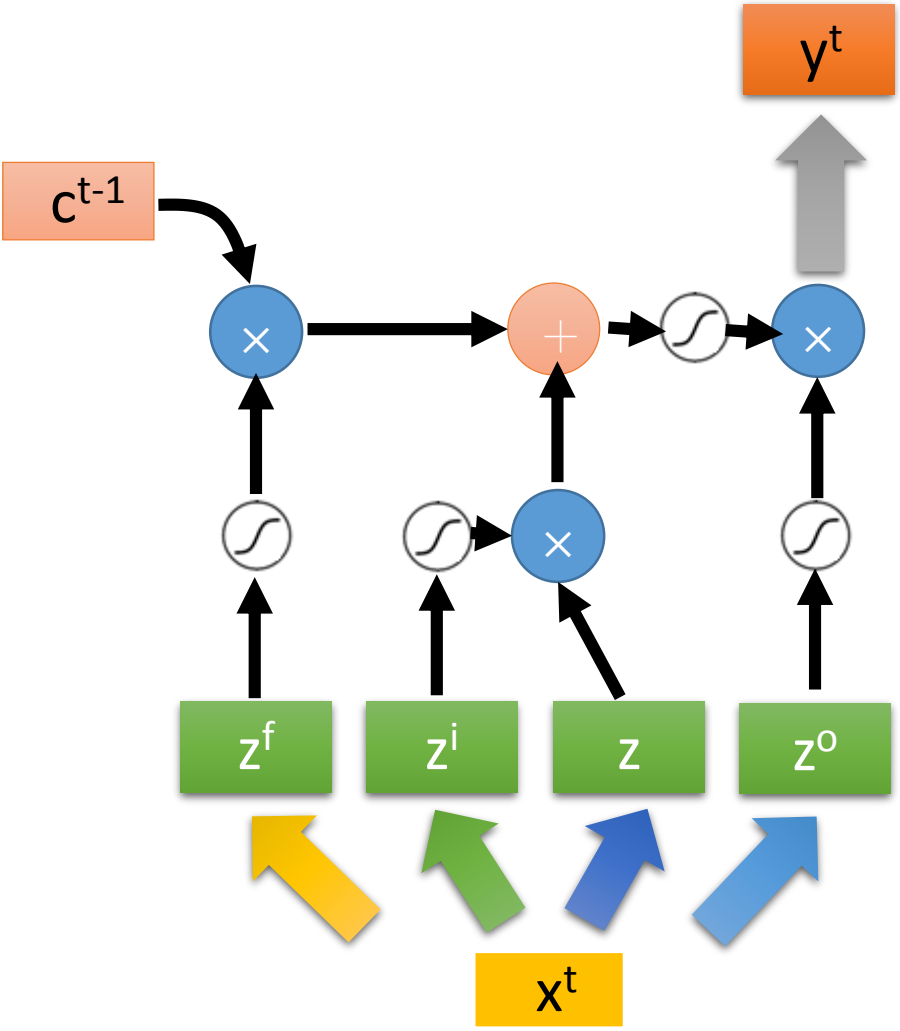


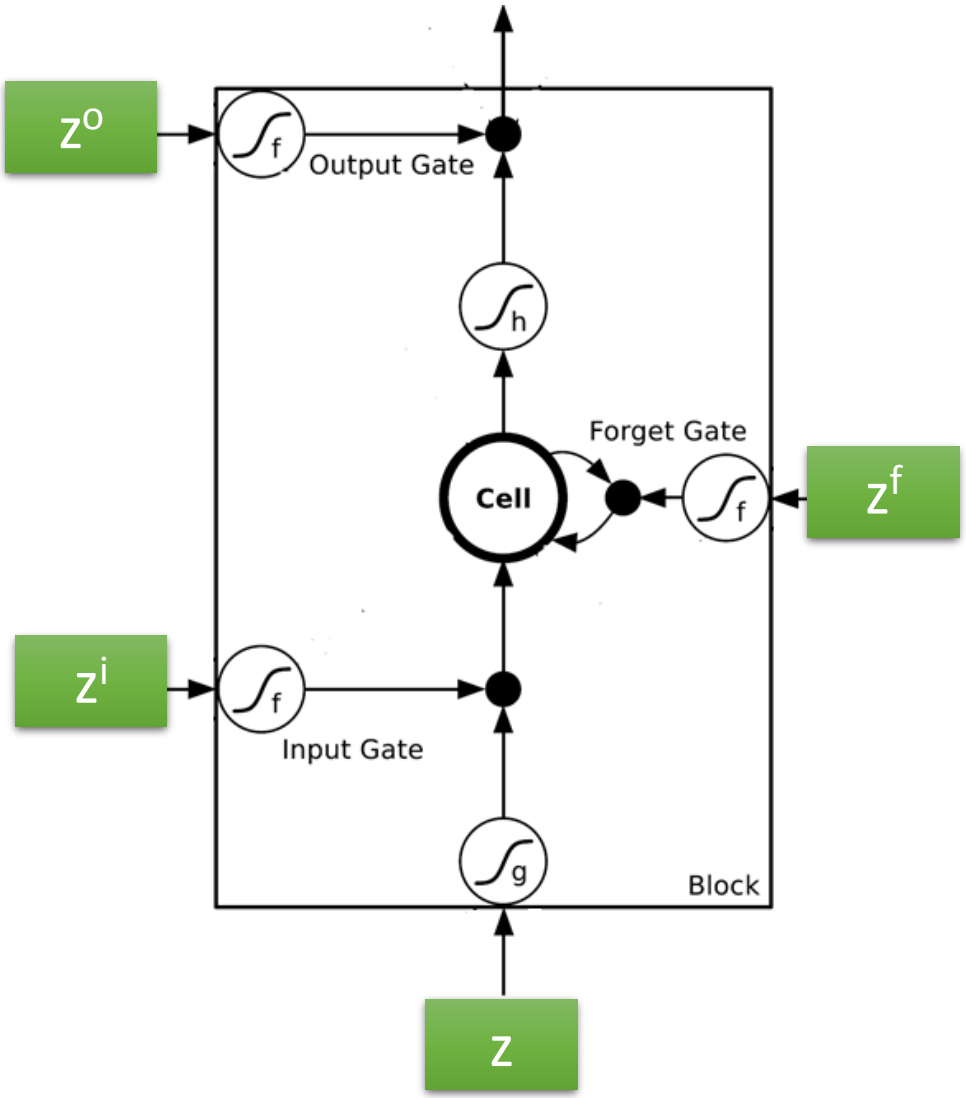

a_1
a_2
Output Gate
Forget Gate
Input Gate
Cell
Block
x_1
x_2
Input
4 times of parameters

LSTM

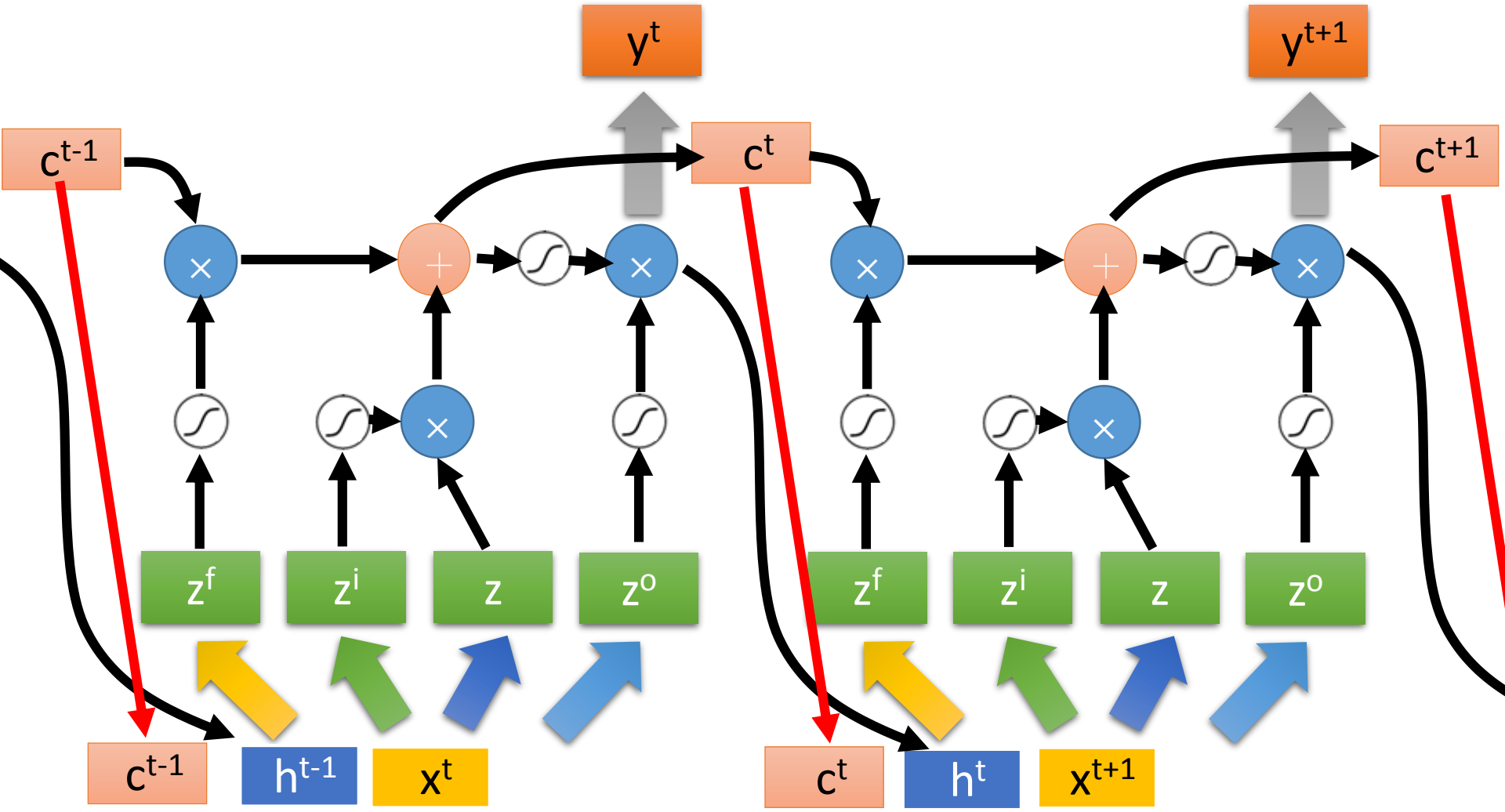

c^{t-1}
vector
Output Gate
Forget Gate
Cell
Input Gate
Block
.....
z^f
z^i
z
z^o
4 vectors
x^t

LSTM

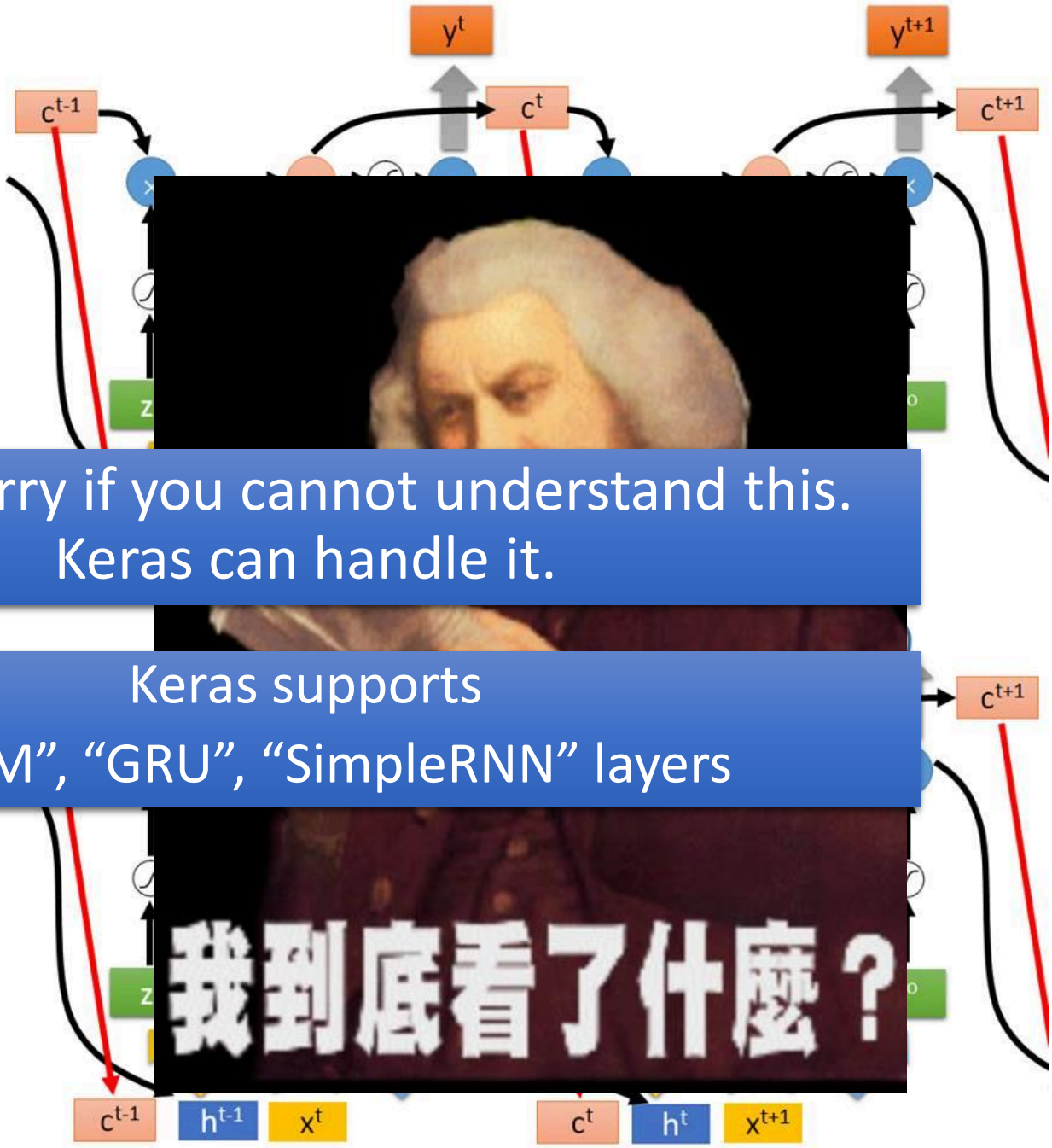

y^t
c^{t-1}
z^f
z^i
z
z^o
x^t


z^o
Output Gate
h
Forget Gate
Cell
z^f
z^i
Input Gate
g
Block
z

LSTM


Extension: “peephole”
y^t
y^{t+1}
c^{t-1}
c^t
c^{t+1}
z^f
z^i
z
z^o
c^{t-1}
h^{t-1}
x^t
c^t
h^t
x^{t+1}

Multiple-layer LSTM



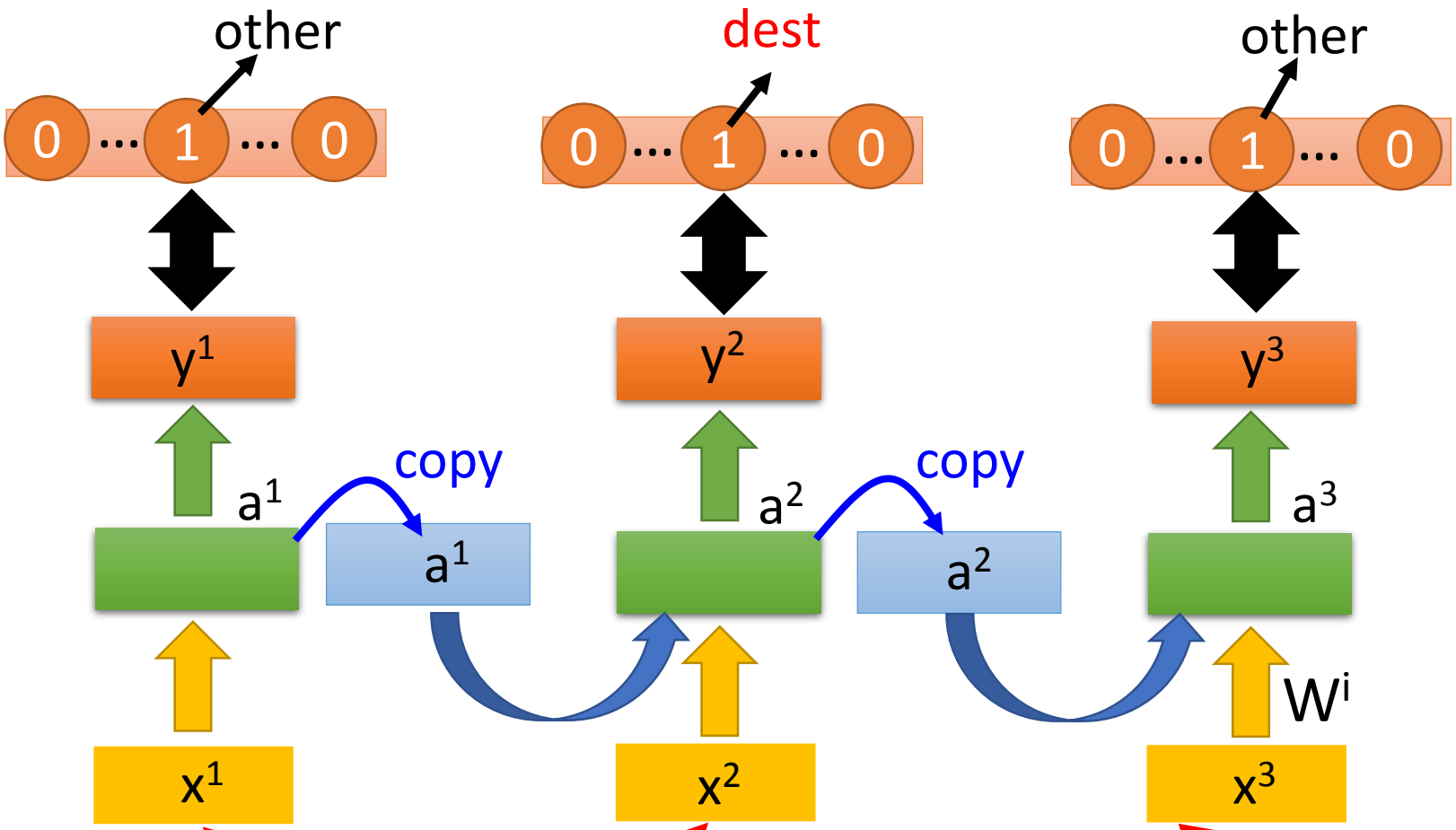
Don’t worry if you cannot understand this.
Keras can handle it.

Keras supports
“LSTM”, “GRU”, “SimpleRNN” layers

This is quite standard now.

https://img.komicolle.org/2015-09-20/src/14426967627131.gif

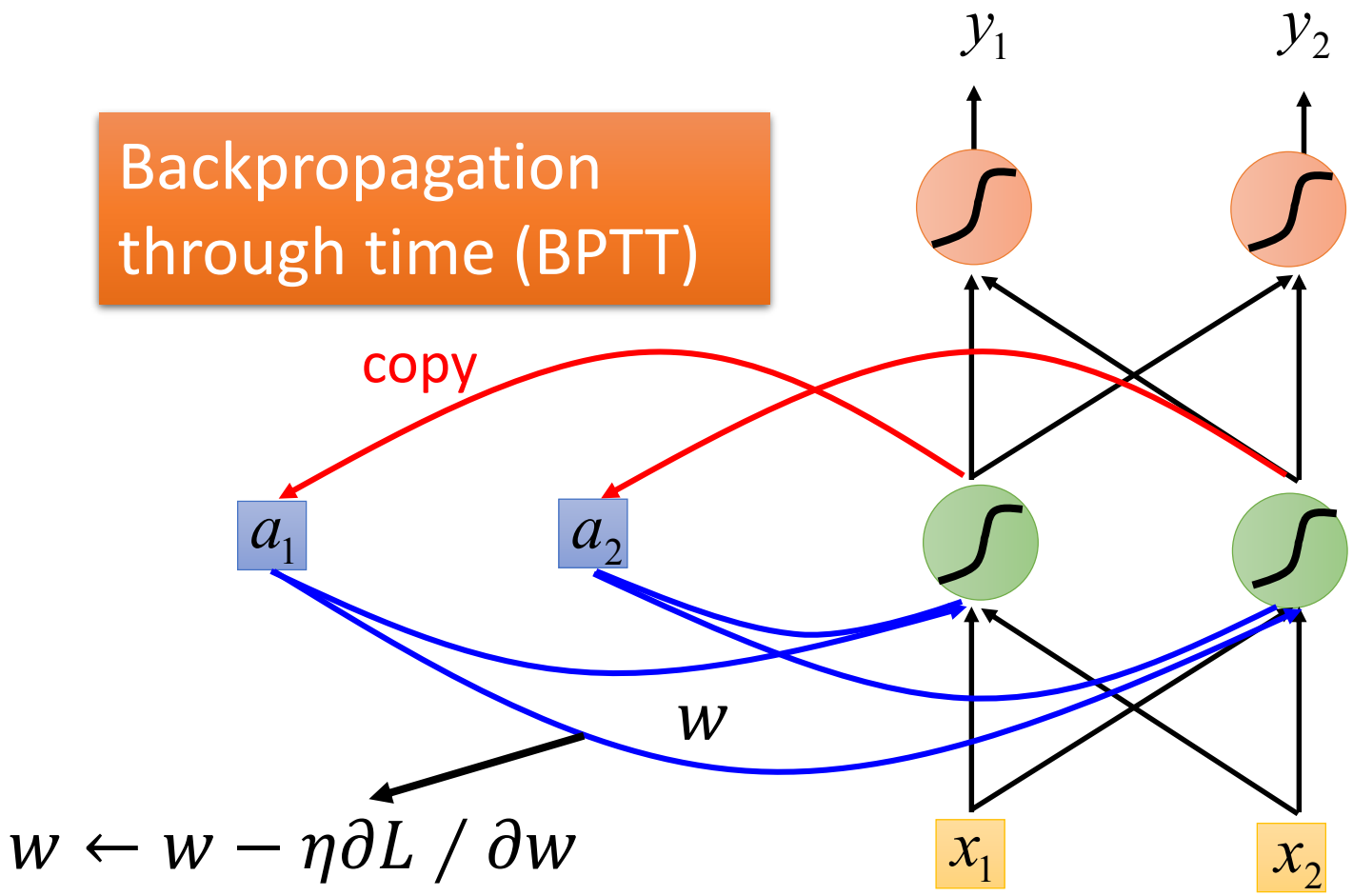
Learning Target



Training Sentences:

arrive	Taipei	on	November	2nd
other	dest	other	time	time

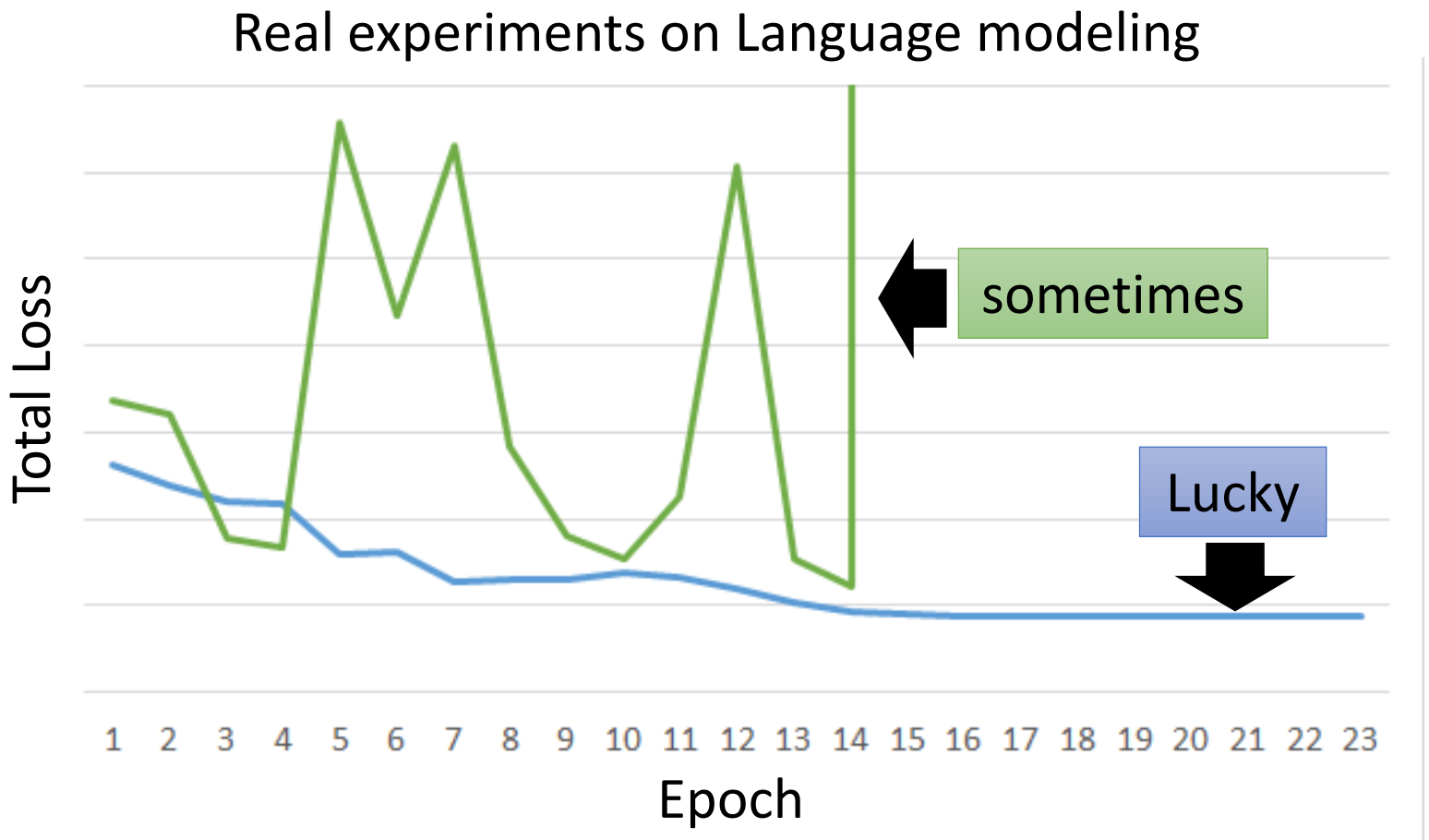
Learning


Backpropagation through time (BPTT)
copy
y_1
y_2
a_1
a_2
w
$w \leftarrow w - \eta \partial L / \partial w$
x_1
x_2

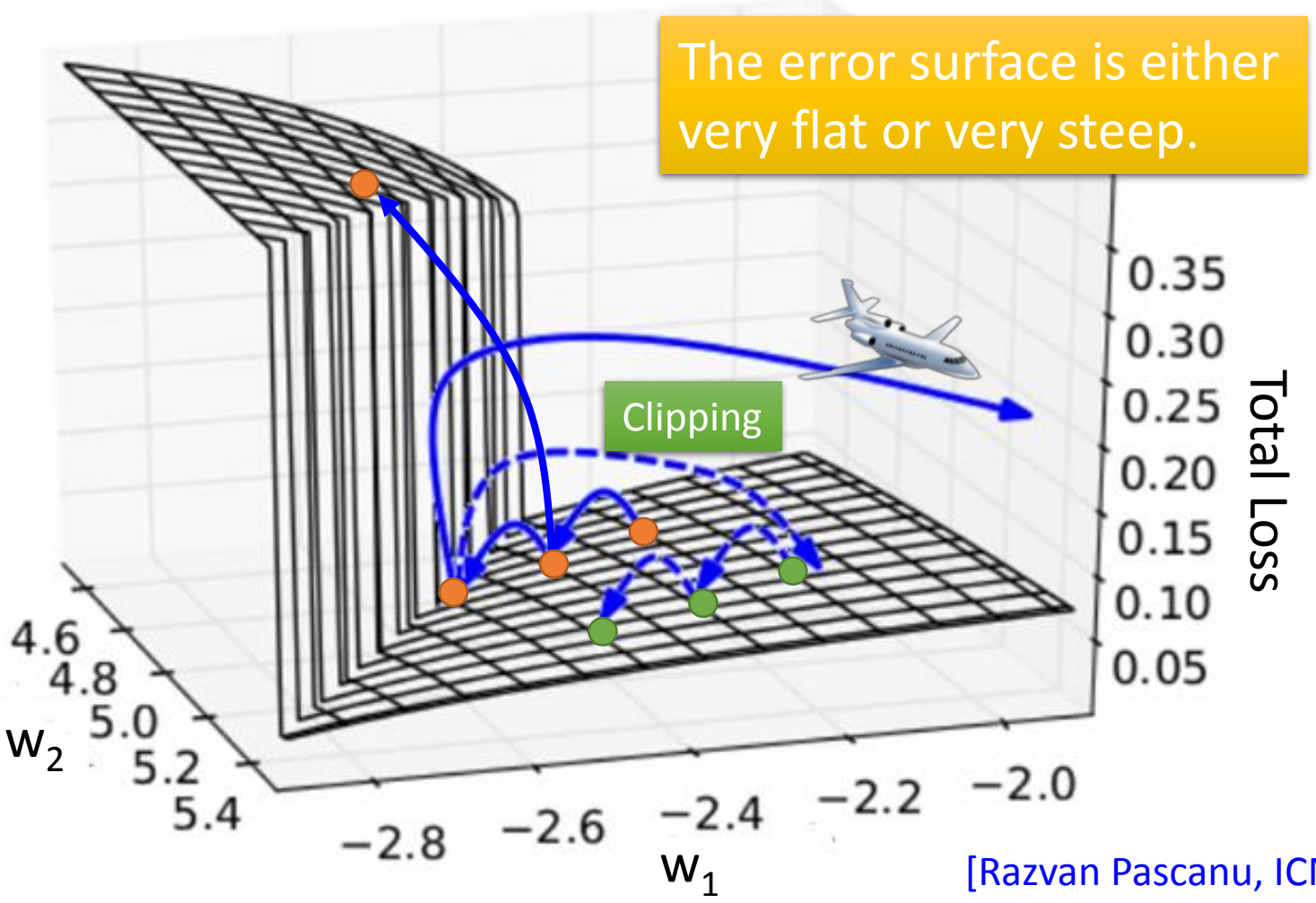
感謝 曾柏翔 同學
提供實驗結果

Unfortunately ……

- RNN-based network is not always easy to learn



The error surface is rough.



[Razvan Pascanu, ICML'13]

Why?

$w = 1 \Rightarrow y^{1000} = 1$

$w = 1.01 \Rightarrow y^{1000} \approx 20000$

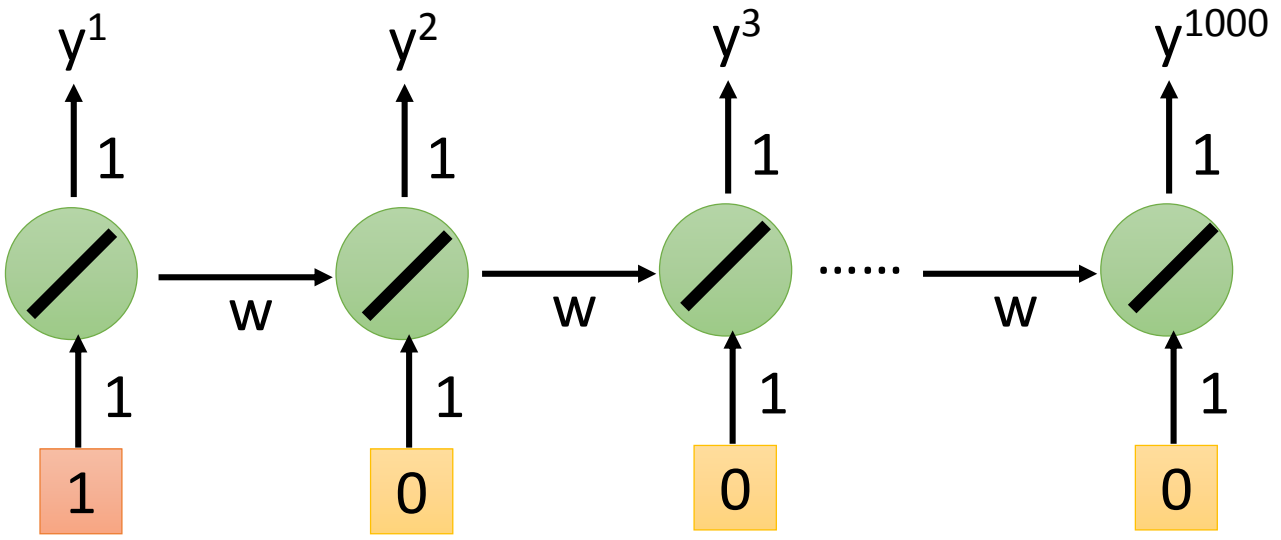
Large $\partial L/\partial w$ → Small Learning rate?

$w = 0.99 \Rightarrow y^{1000} \approx 0$

$w = 0.01 \Rightarrow y^{1000} \approx 0$

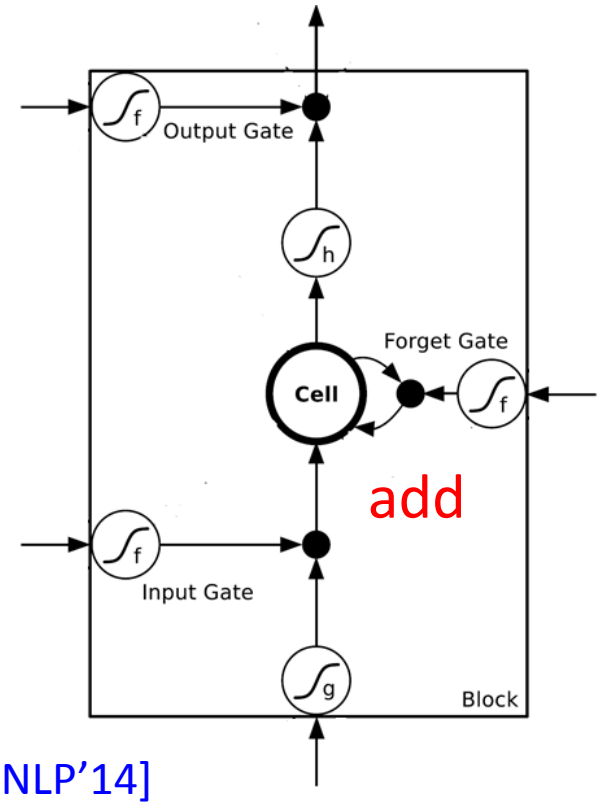
small $\partial L/\partial w$ → Large Learning rate?

Toy Example



Helpful Techniques

- Long Short-term Memory (LSTM)
  - Can deal with gradient vanishing (not gradient explode)
    - Memory and input are ***added***
    - The influence never disappears unless forget gate is closed



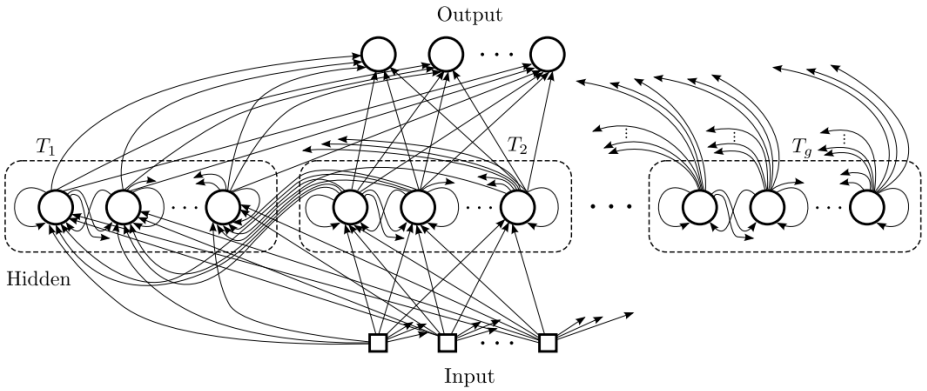
No Gradient vanishing
(If forget gate is opened.)

Gated Recurrent Unit (GRU): simpler than LSTM

[Cho, EMNLP'14]

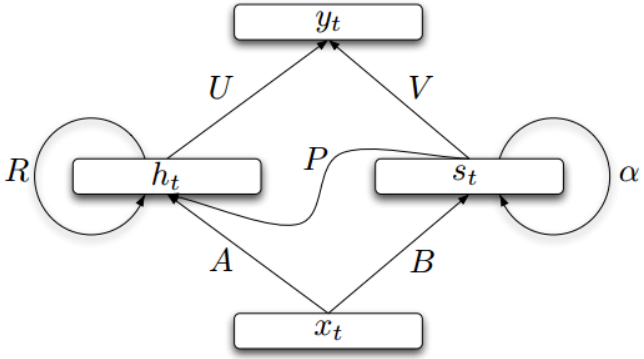
Helpful Techniques

Clockwise RNN



[Jan Koutnik, JMLR'14]

Structurally Constrained Recurrent Network (SCRN)



[Tomas Mikolov, ICLR'15]

Vanilla RNN Initialized with Identity matrix + ReLU activation function [Quoc V. Le, arXiv'15]

- Outperform or be comparable with LSTM in 4 different tasks