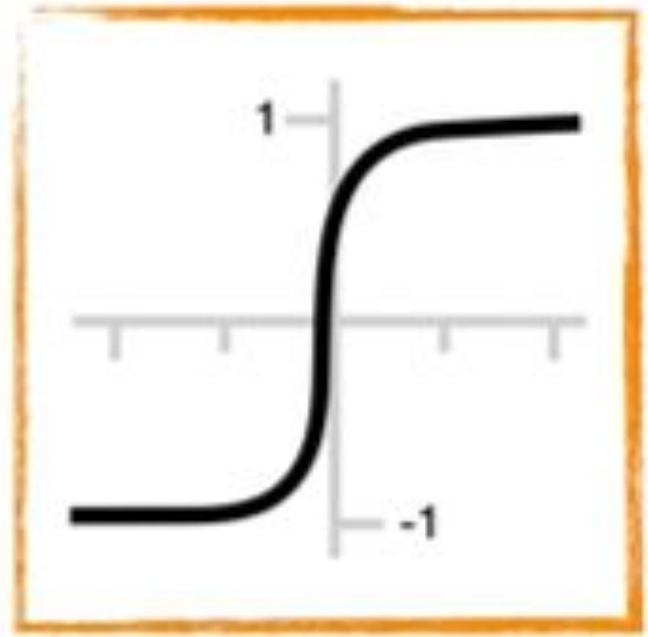
LSTM

So, now that we know that the **Sigmoid Activation Function** turns any input into a number between **0** and **1**...

...and the **Tanh Activation Function** turns any input into a number between **-1** and **1**...

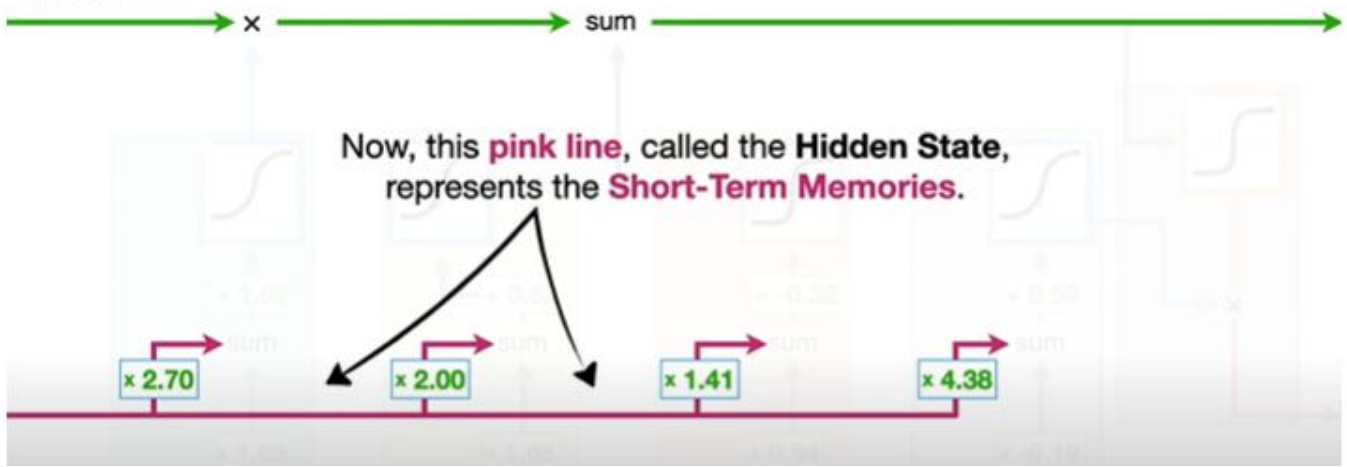


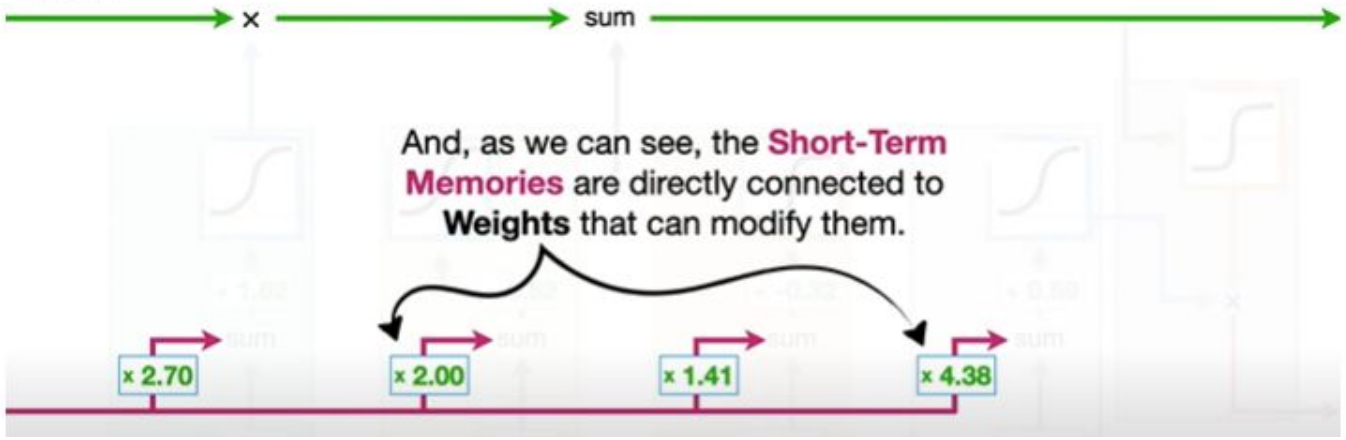
First, this **green line** that runs all the way across the top of the unit is called the **Cell State** and represents the **Long-Term Memory**.

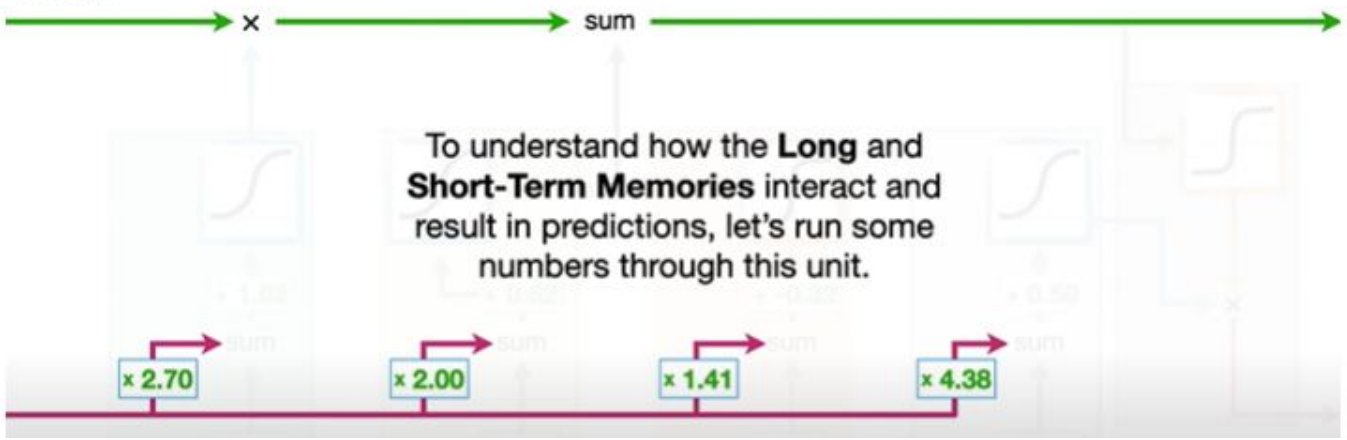
Although the **Long-Term Memory** can be modified by this multiplication…

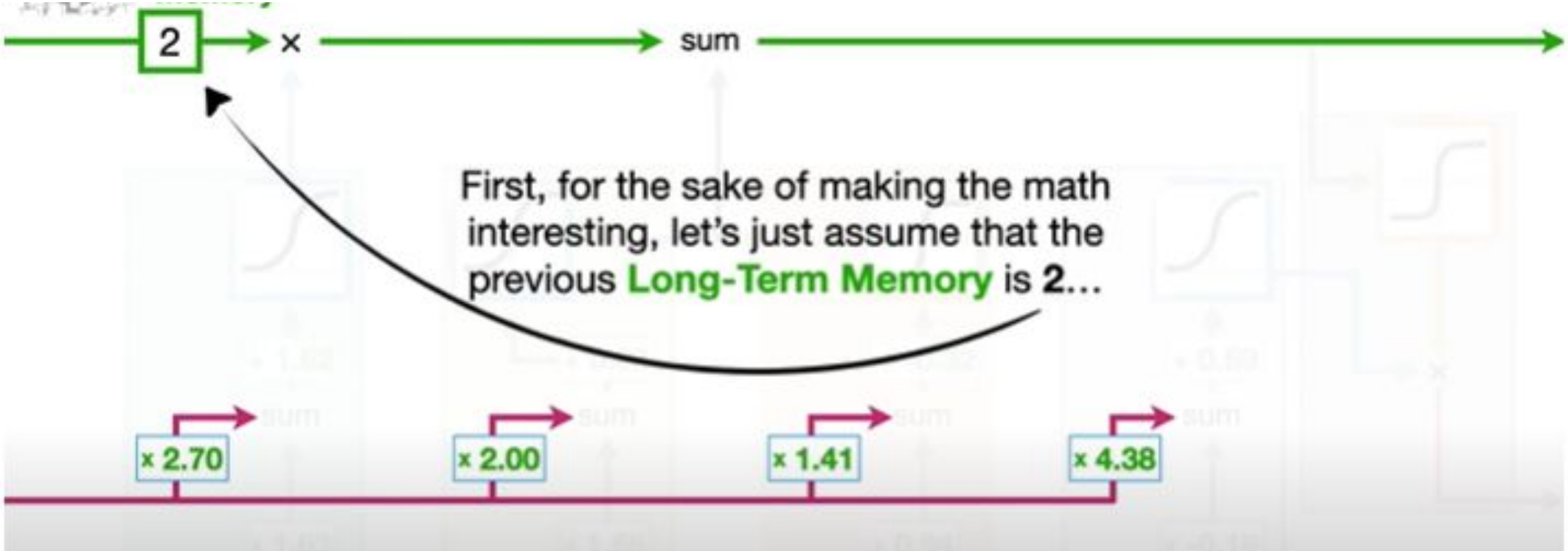
…you'll notice that there are no **Weights** and **Biases** that can modify it directly.

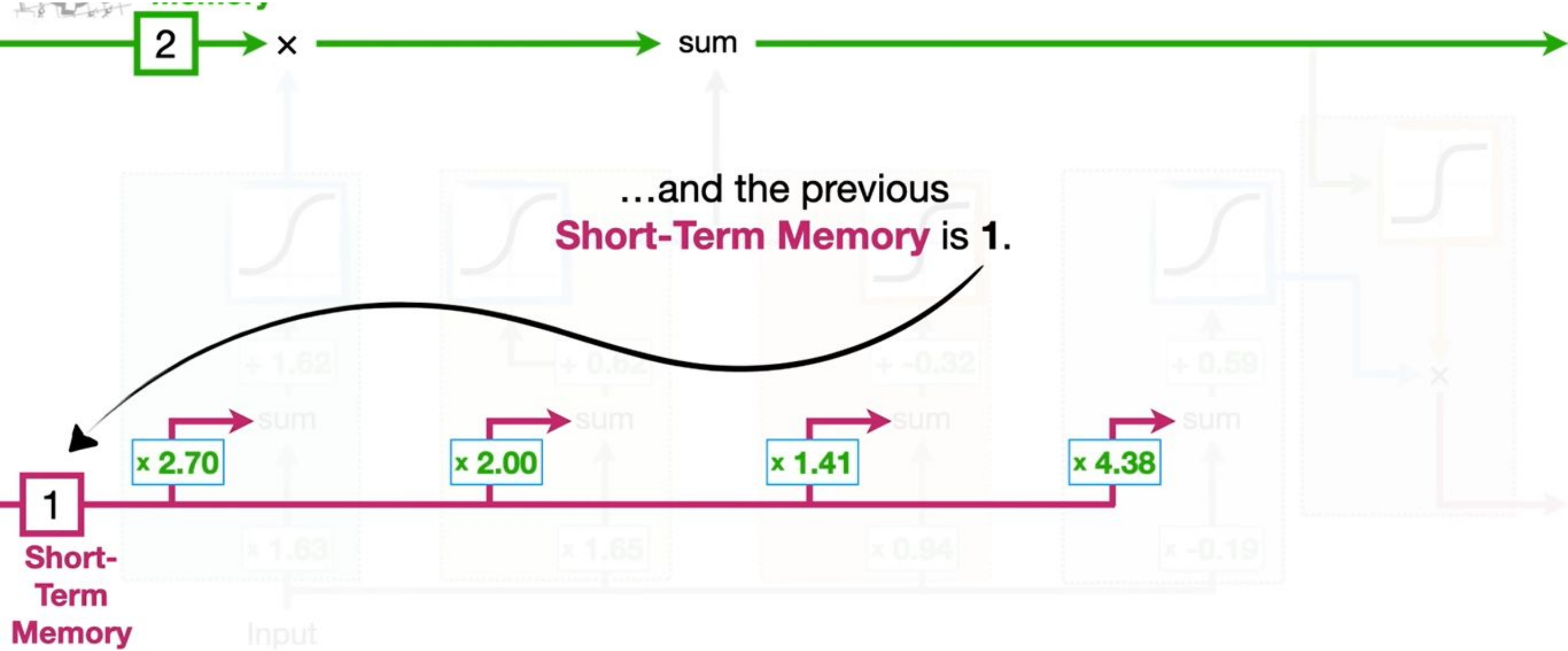
The lack of **Weights** allows the **Long-Term Memories** to flow through a series of unrolled units without causing the gradient to **explode** or **vanish**.

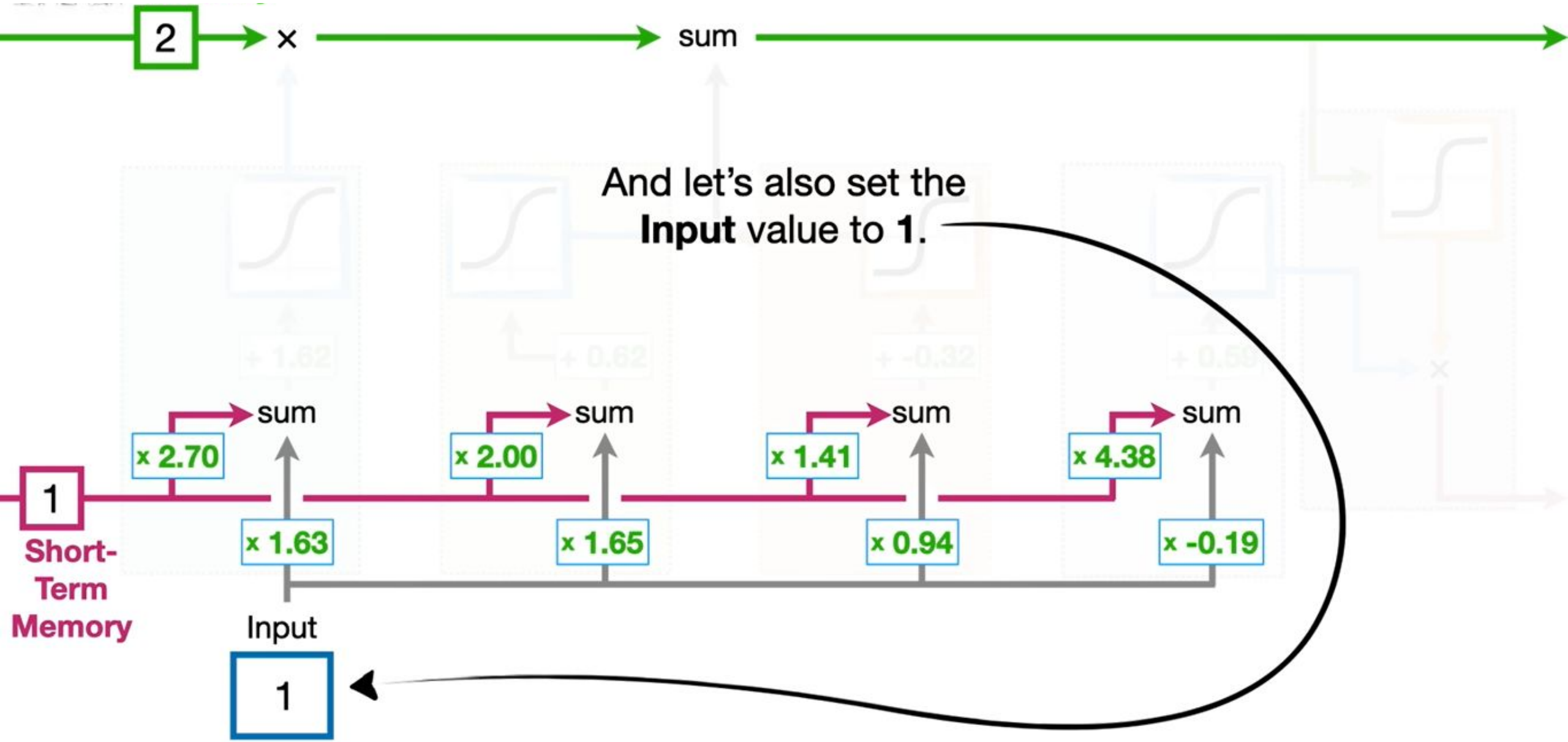

x
sum
Now, this pink line, called the Hidden State, represents the Short-Term Memories.
x 2.70
x 2.00
x 1.41
x 4.38

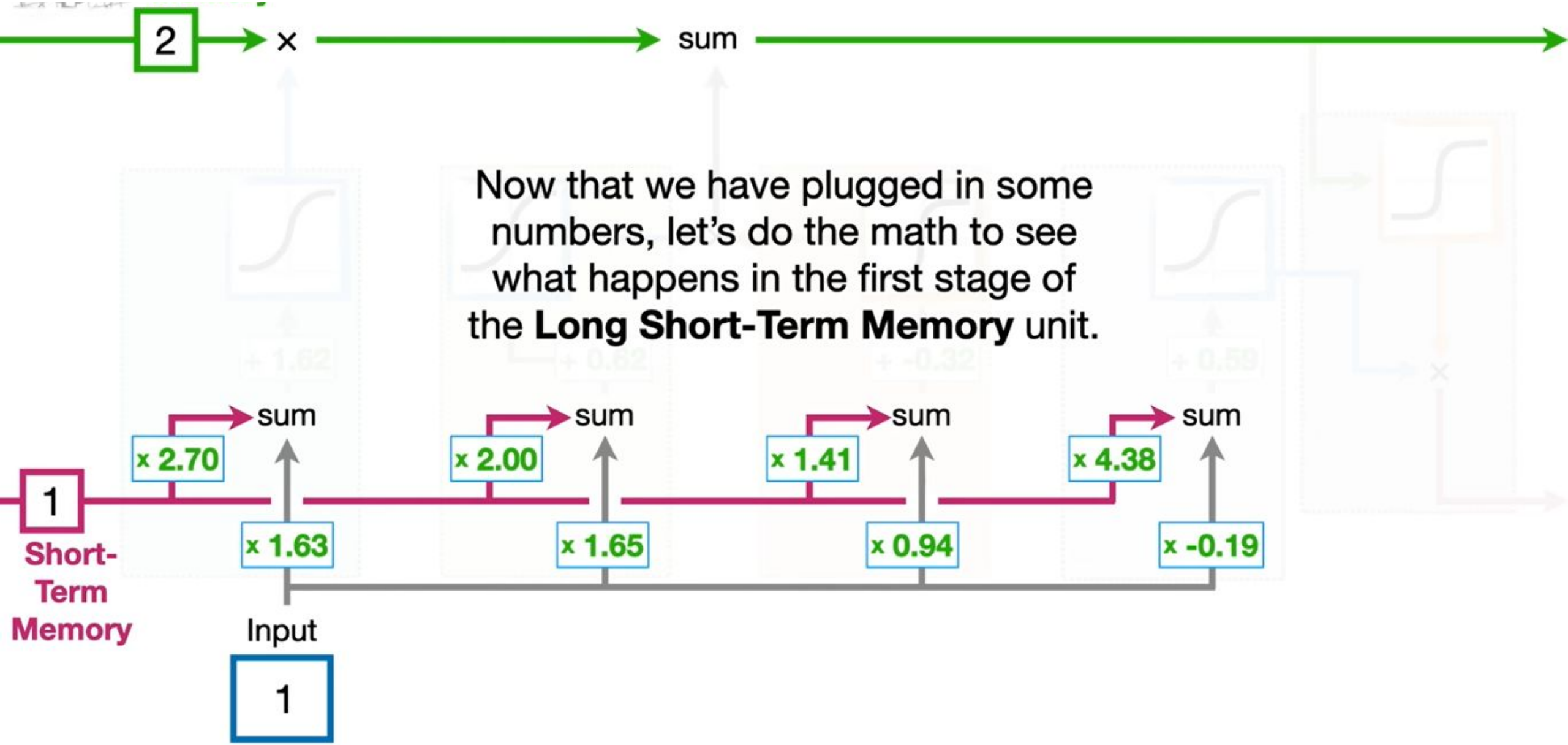

x
sum
And, as we can see, the Short-Term Memories are directly connected to Weights that can modify them.
x 2.70
x 2.00
x 1.41
x 4.38

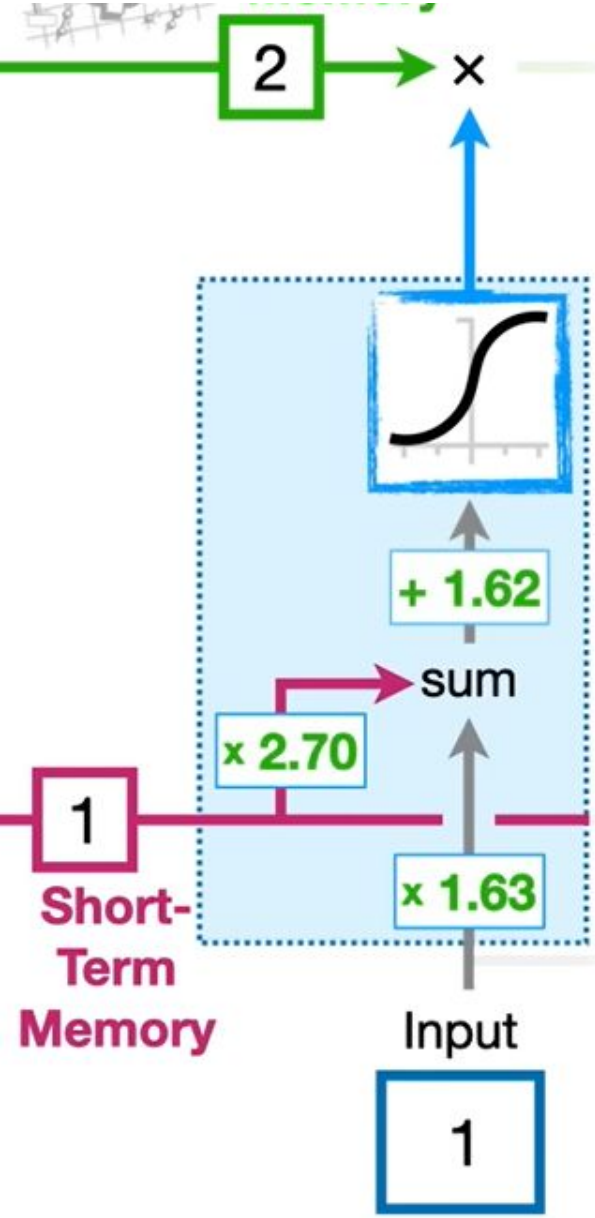

x
sum
To understand how the Long and Short-Term Memories interact and result in predictions, let's run some numbers through this unit.
x 2.70
x 2.00
x 1.41
x 4.38


2
x
sum
First, for the sake of making the math interesting, let's just assume that the previous Long-Term Memory is 2...
x 2.70
x 2.00
x 1.41
x 4.38

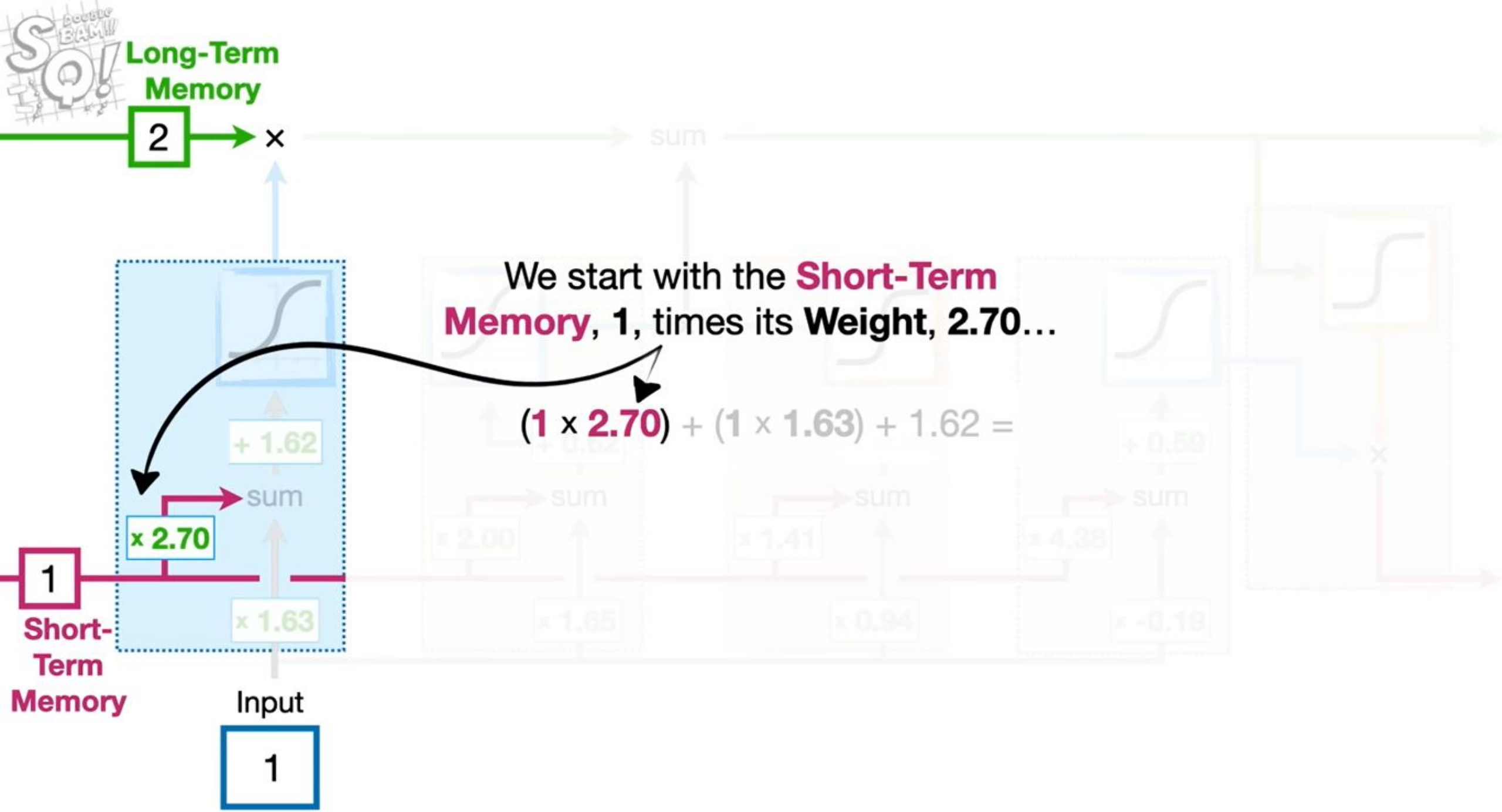

2
x
sum
…and the previous
Short-Term Memory is 1.
x 2.70
x 2.00
x 1.41
x 4.38
1
Short-
Term
Memory

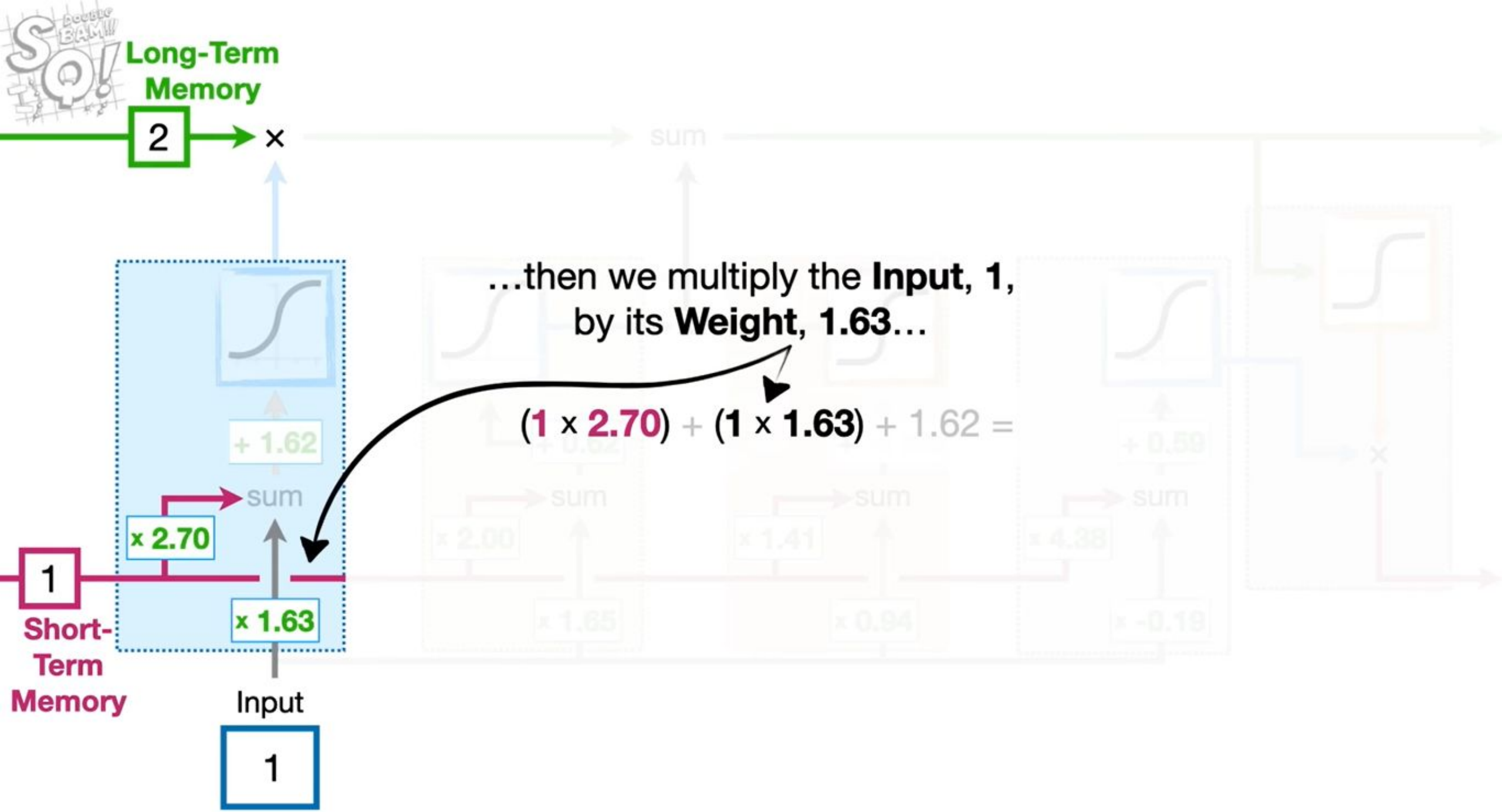

2
x
sum
And let's also set the
Input value to **1**.
sum
sum
sum
sum
x 2.70
x 2.00
x 1.41
x 4.38
1
x 1.63
x 1.65
x 0.94
x -0.19
Short-
Term
Memory
Input
1

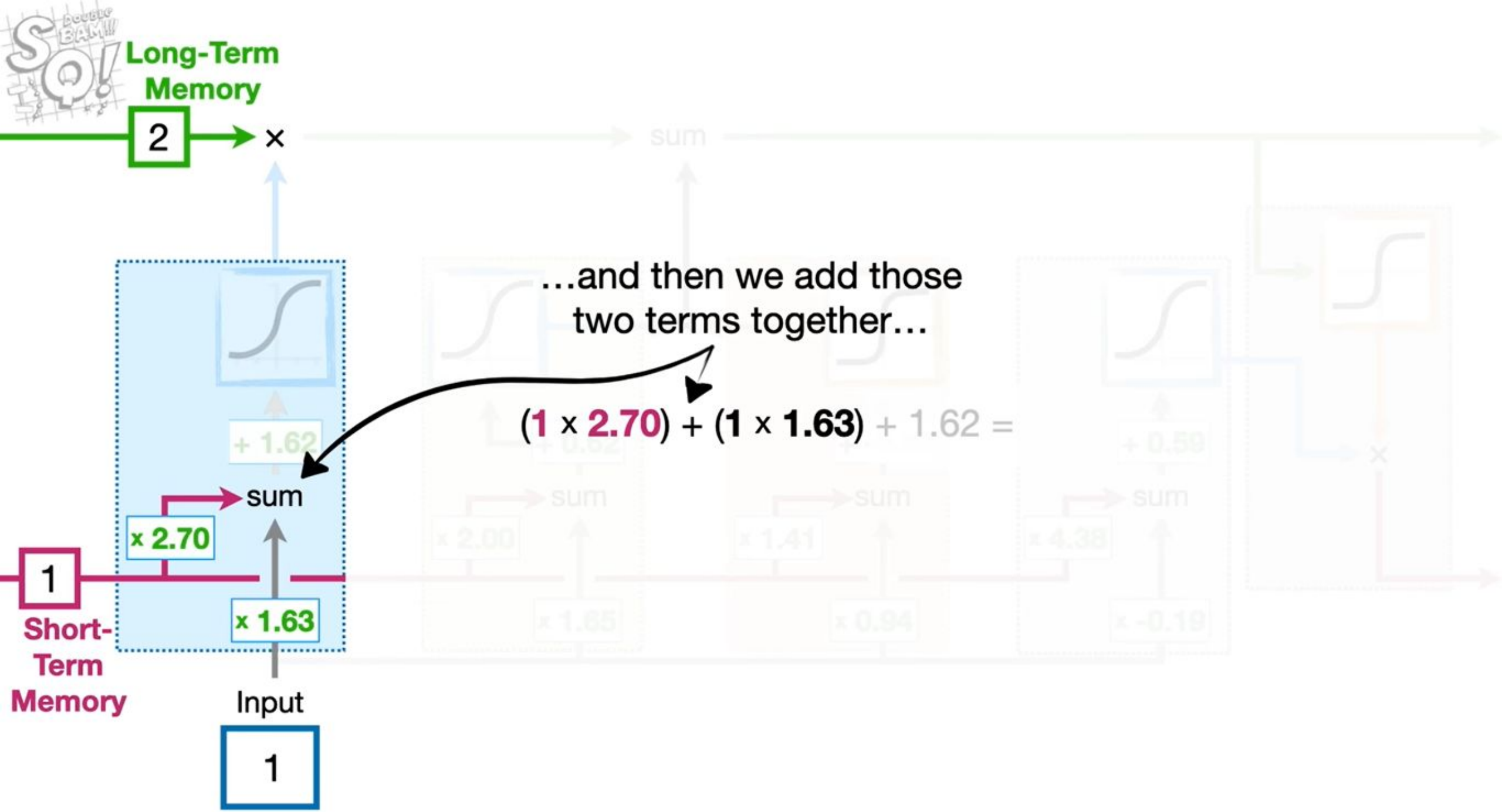

2
x
sum
Now that we have plugged in some numbers, let's do the math to see what happens in the first stage of the Long Short-Term Memory unit.
sum
sum
sum
sum
x 2.70
x 2.00
x 1.41
x 4.38
1
x 1.63
x 1.65
x 0.94
x -0.19
Short-Term Memory
Input
1

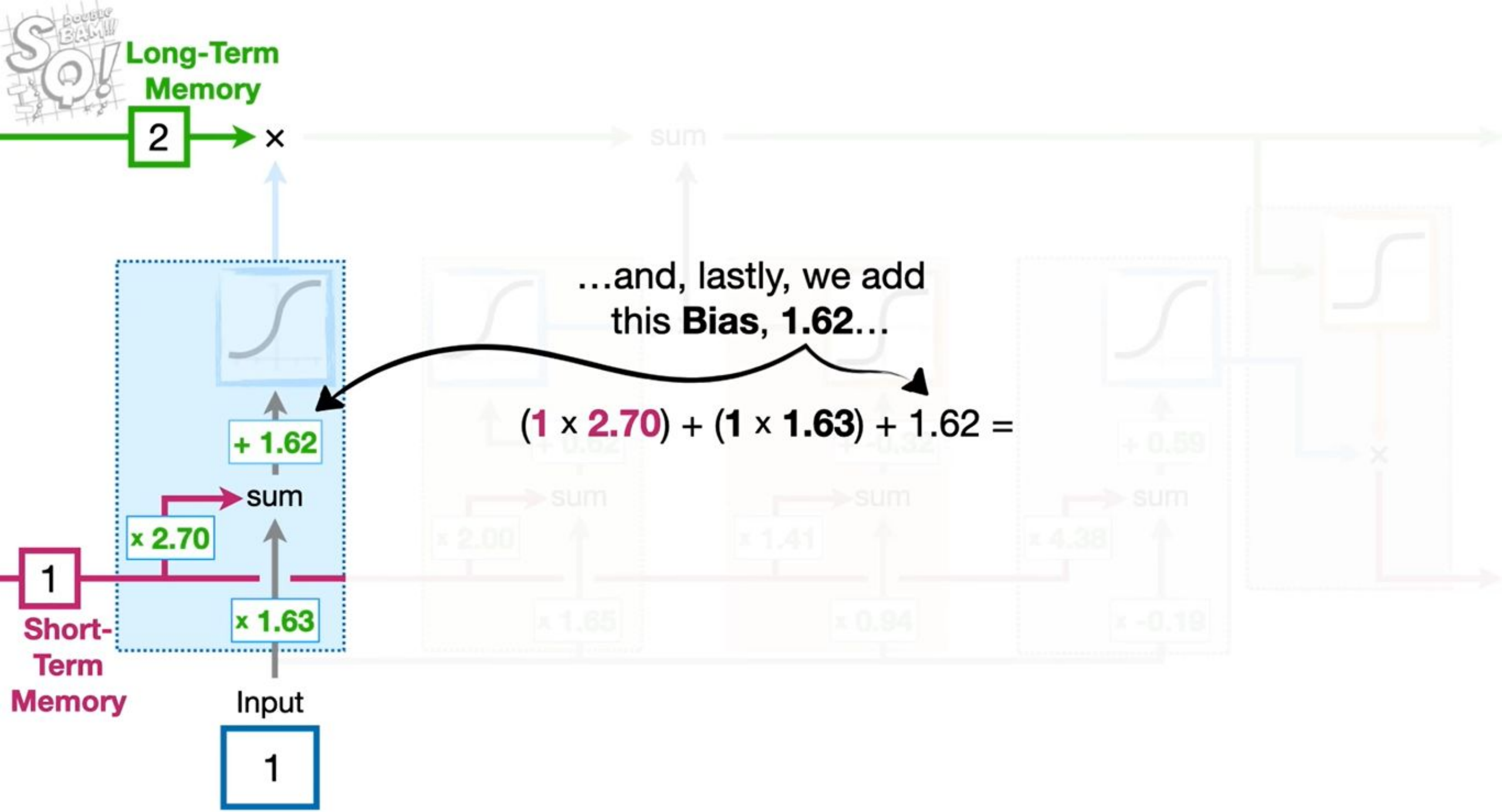


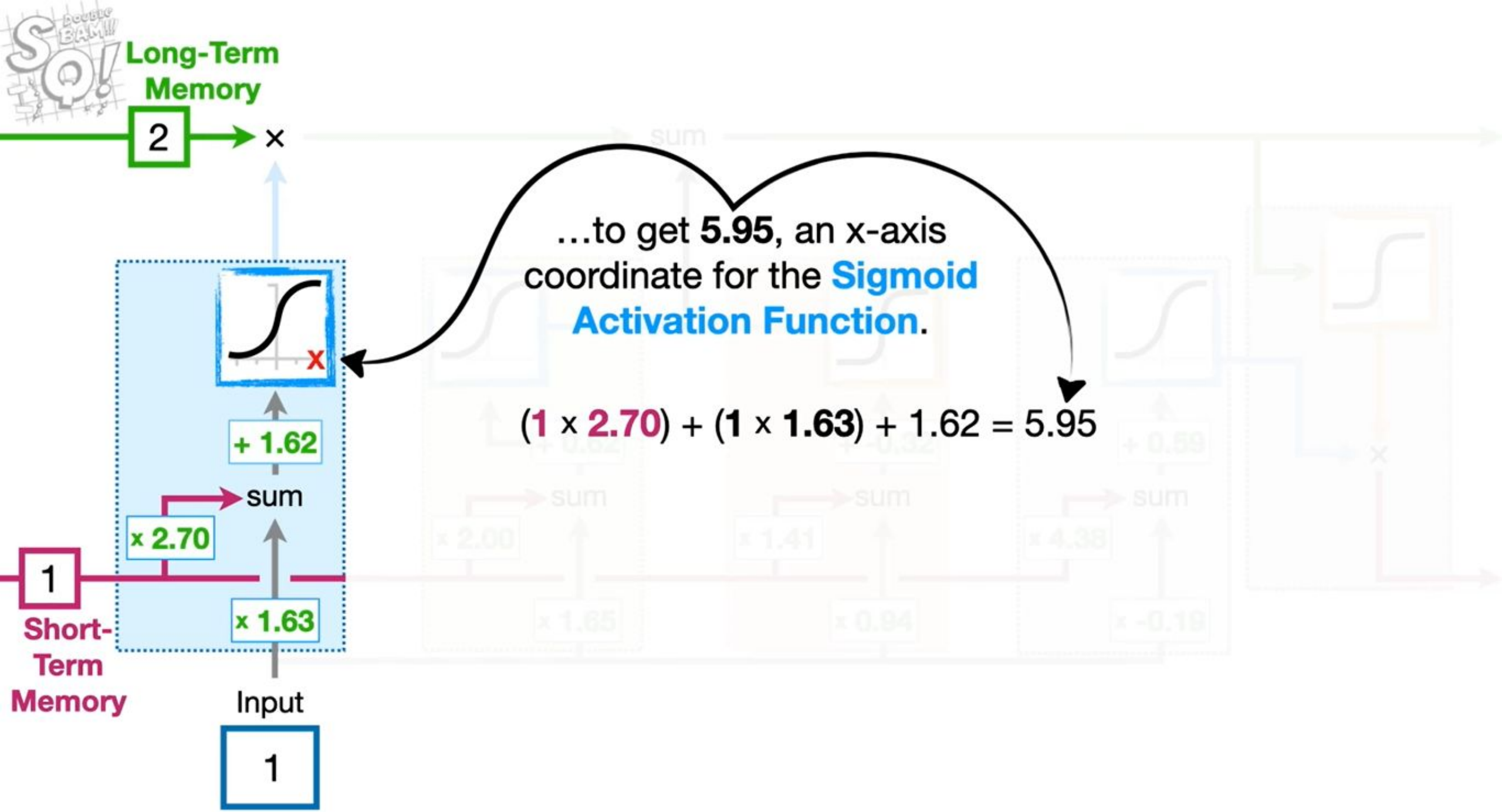
Now that we have plugged in some numbers, let's do the math to see what happens in the first stage of the **Long Short-Term Memory** unit.

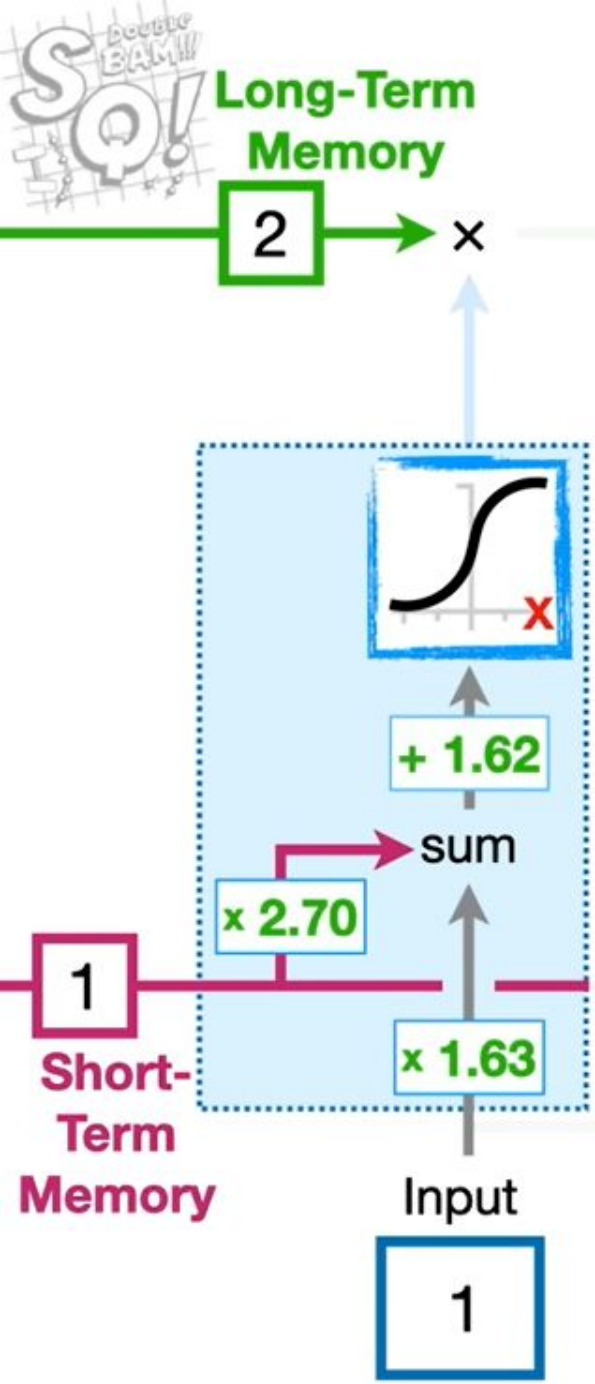

Long-Term Memory
2
×
+ 1.62
sum
x 2.70
1
Short-Term Memory
x 1.63
Input
1
We start with the Short-Term Memory, 1, times its Weight, 2.70…
(1 x 2.70) + (1 x 1.63) + 1.62 =


Long-Term Memory
2
×
+ 1.62
sum
x 2.70
1
Short-Term Memory
x 1.63
Input
1
…then we multiply the Input, 1, by its Weight, 1.63…
(1 x 2.70) + (1 x 1.63) + 1.62 =


Long-Term Memory
2
×
+ 1.62
sum
x 2.70
1
Short-Term Memory
x 1.63
Input
1
…and then we add those two terms together…
(1 x 2.70) + (1 x 1.63) + 1.62 =


Long-Term Memory
2
×
+ 1.62
sum
x 2.70
1
Short-Term Memory
x 1.63
Input
1
…and, lastly, we add this Bias, 1.62…
(1 x 2.70) + (1 x 1.63) + 1.62 =


Long-Term Memory
2
x
x
+ 1.62
sum
x 2.70
1
x 1.63
Short-Term Memory
Input
1
…to get 5.95, an x-axis coordinate for the Sigmoid Activation Function.
(1 x 2.70) + (1 x 1.63) + 1.62 = 5.95



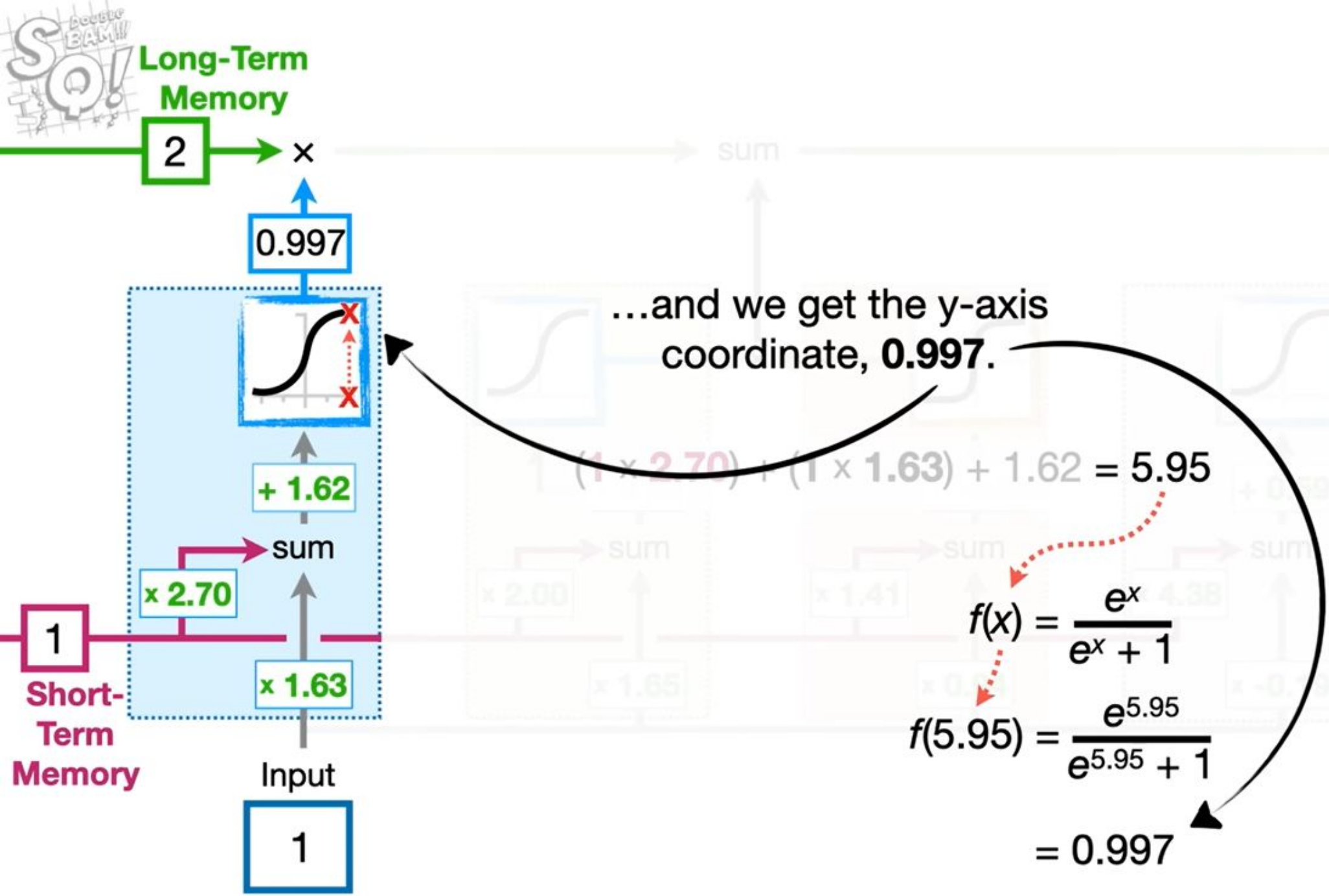
Now we plug the x-axis coordinate into the equation for the **Sigmoid Activation Function**…

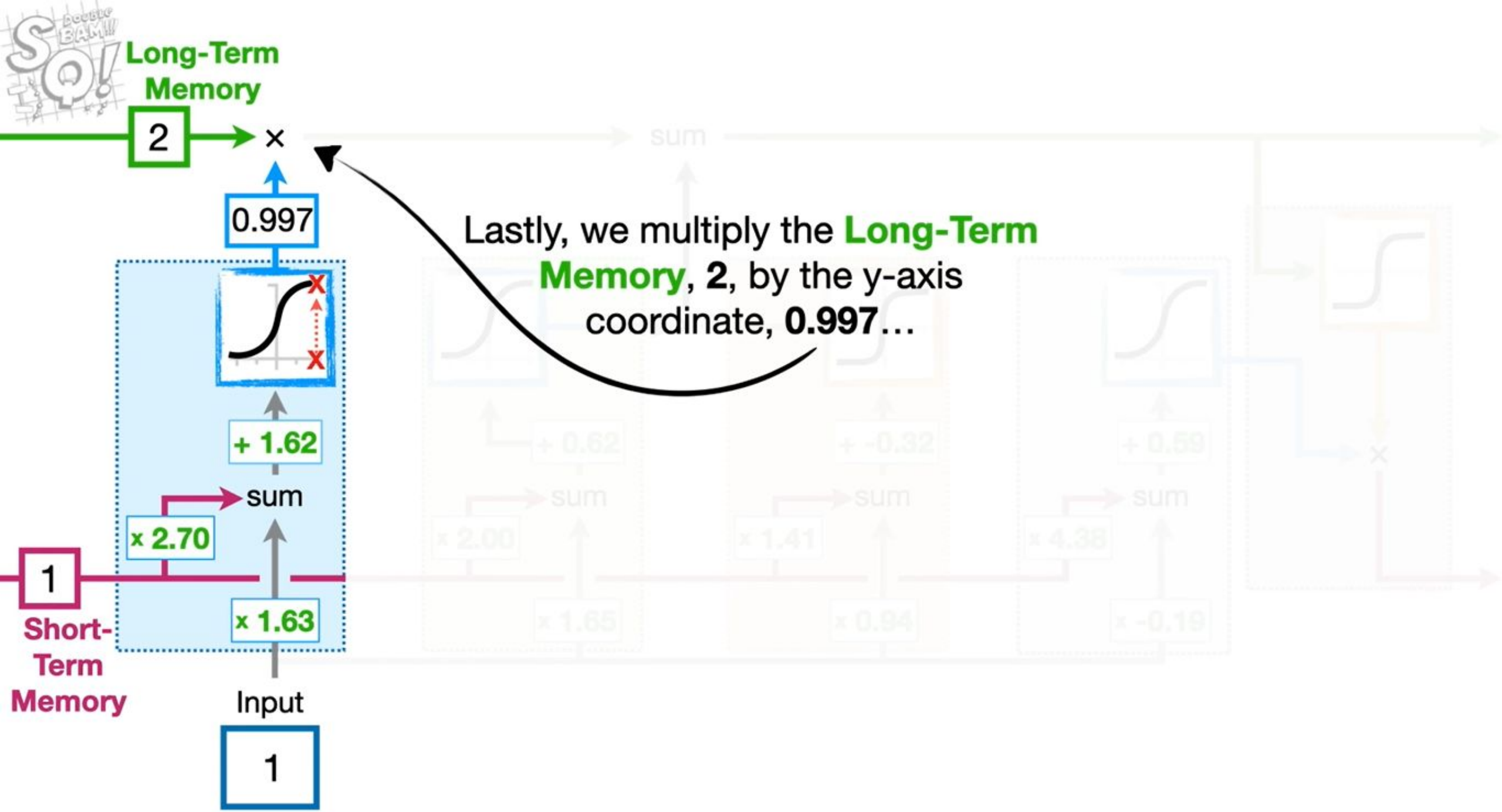
$$(1 \times 2.70) + (1 \times 1.63) + 1.62 = 5.95$$

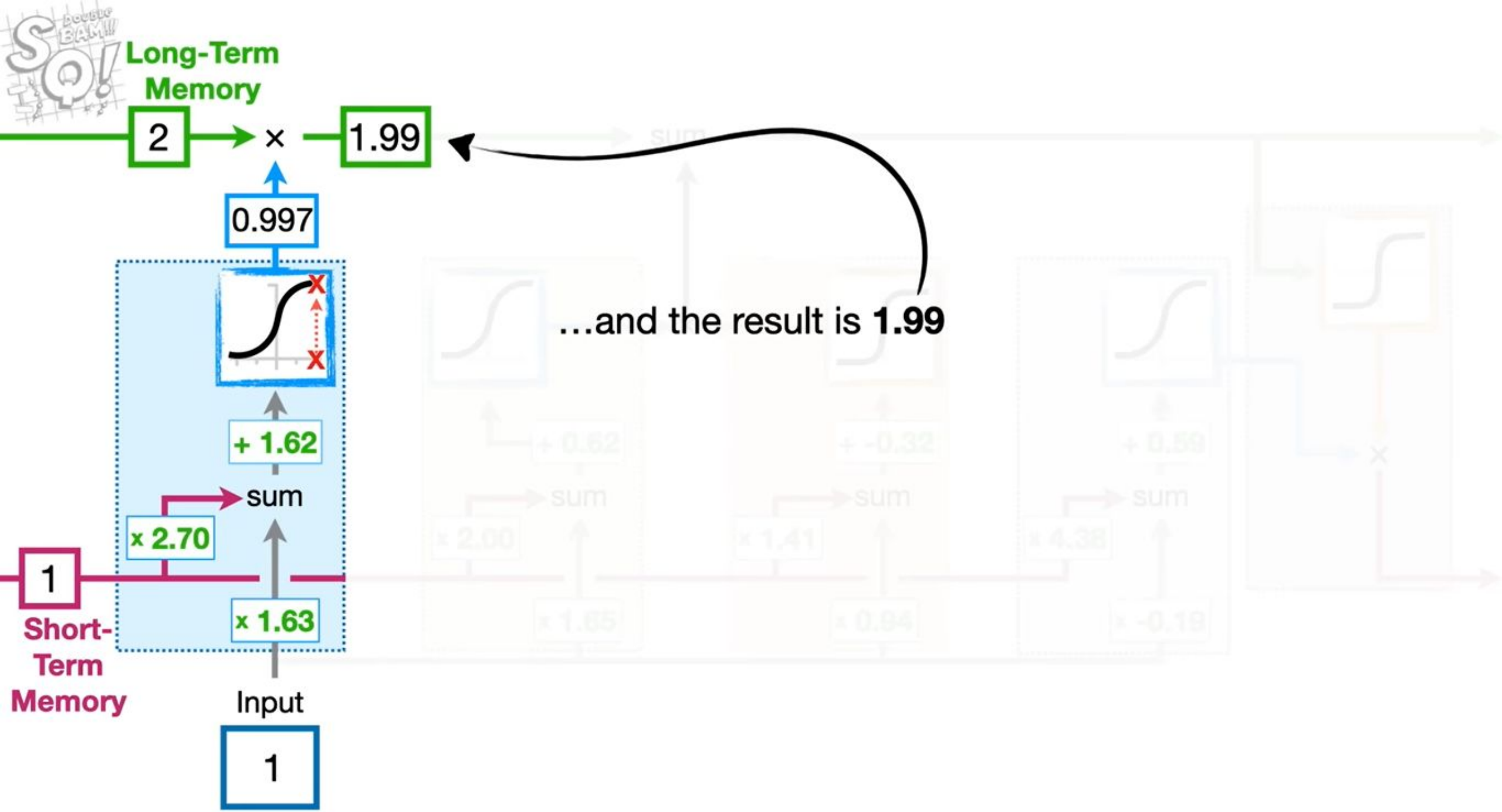
$$f(x) = \frac{e^x}{e^x + 1}$$

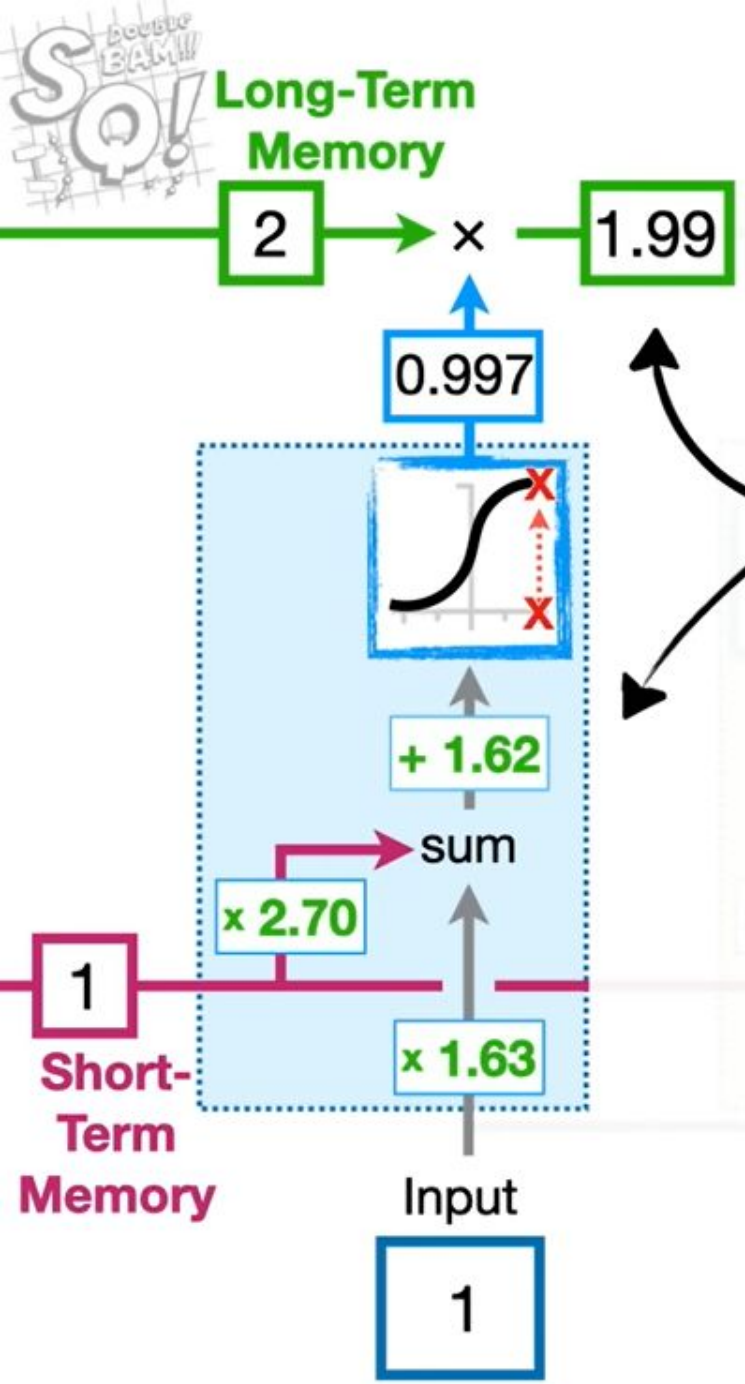
$$f(5.95) = \frac{e^{5.95}}{e^{5.95} + 1}$$

$$= 0.997$$

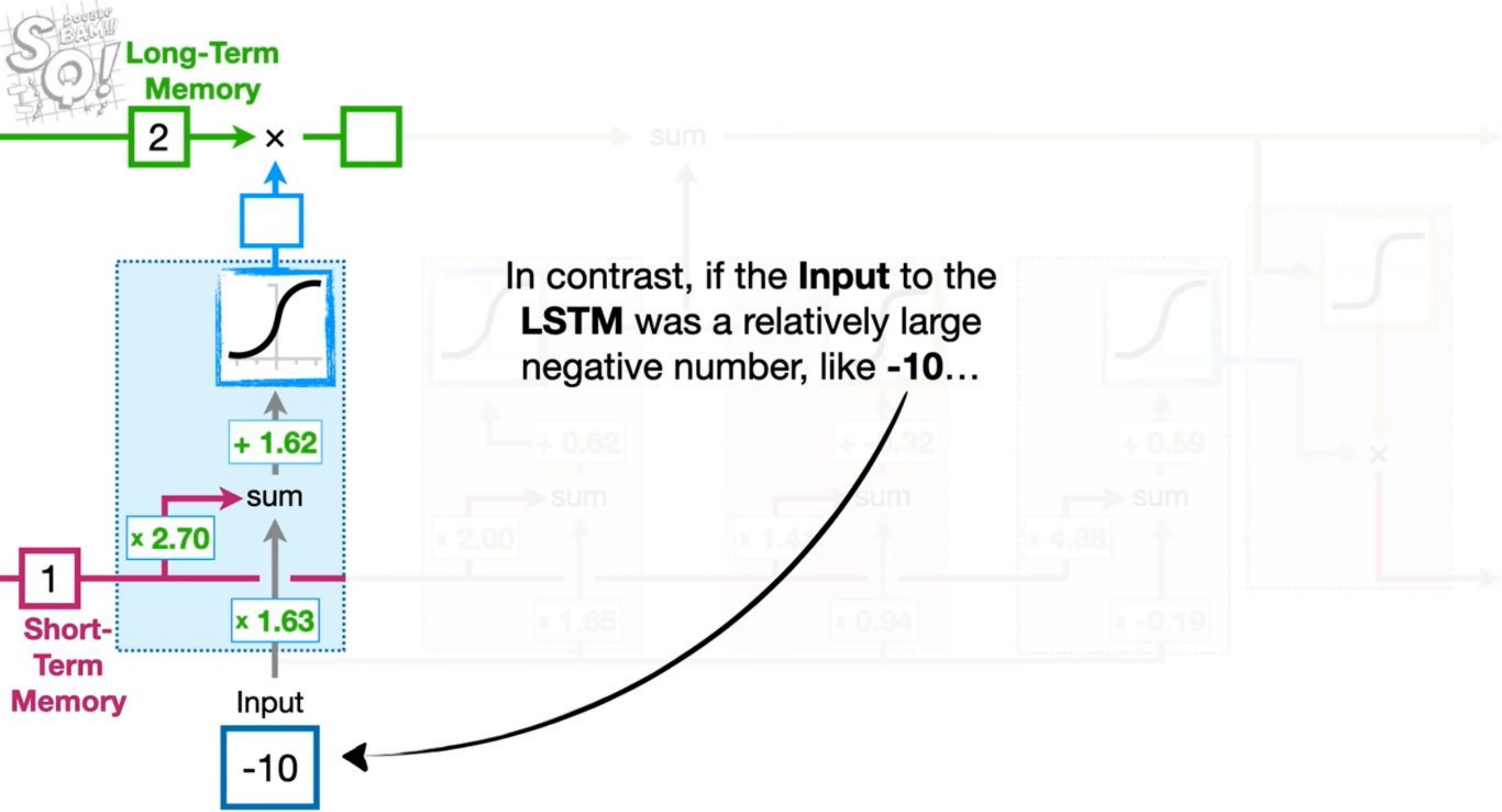

Long-Term Memory
2
×
0.997
…and we get the y-axis coordinate, 0.997.
+ 1.62
sum
x 2.70
1
x 1.63
Short-Term Memory
Input
1
(1 × 2.70) + (1 × 1.63) + 1.62 = 5.95
$f(x) = \frac{e^x}{e^x + 1}$
$f(5.95) = \frac{e^{5.95}}{e^{5.95} + 1}$
= 0.997

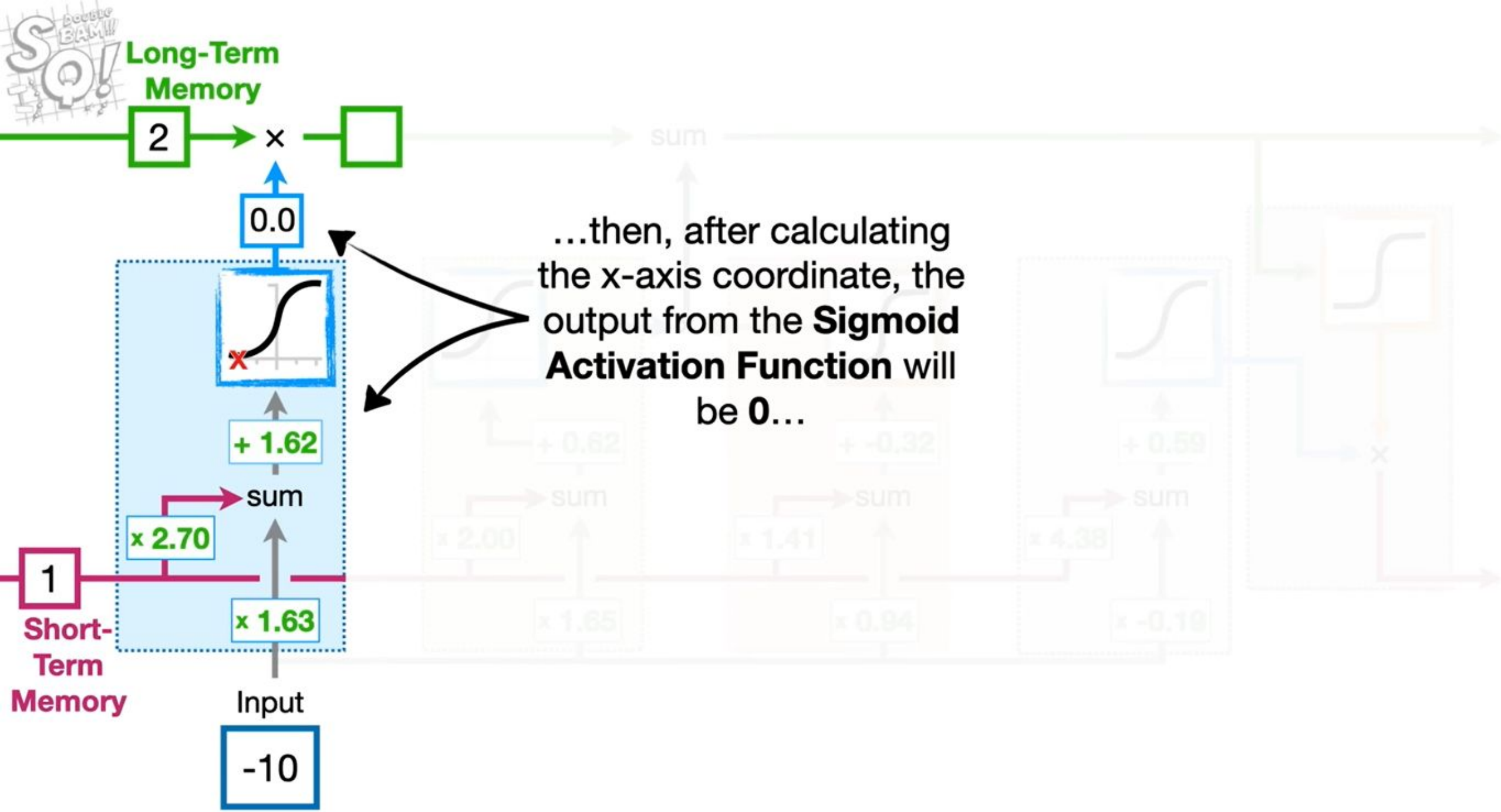

Long-Term Memory
2
×
0.997
Lastly, we multiply the Long-Term Memory, 2, by the y-axis coordinate, 0.997…
+ 1.62
sum
x 2.70
1
x 1.63
Short-Term Memory
Input
1

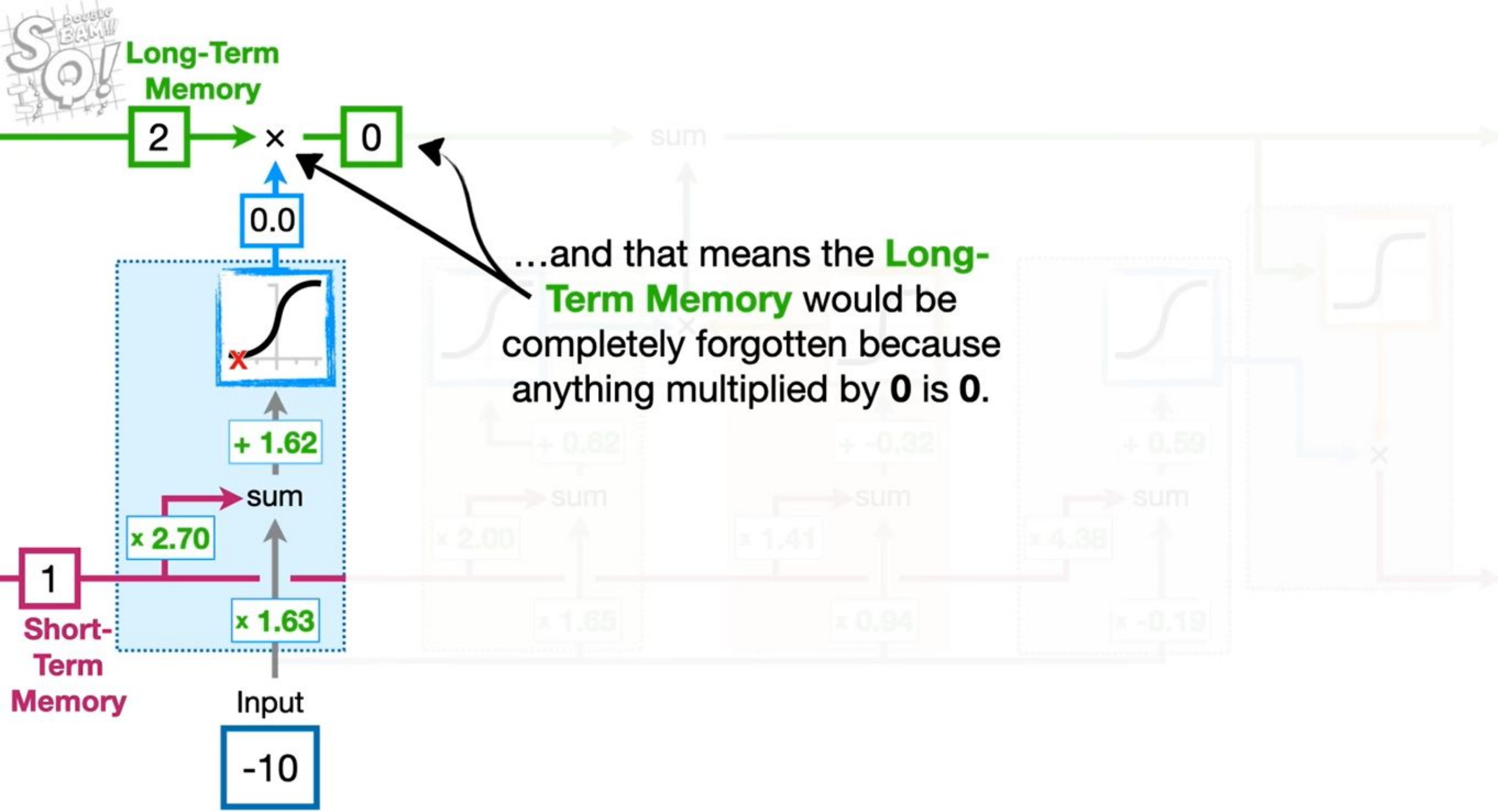

Long-Term Memory
2
×
1.99
0.997
…and the result is 1.99
+ 1.62
sum
x 2.70
1
x 1.63
Short-Term Memory
Input
1

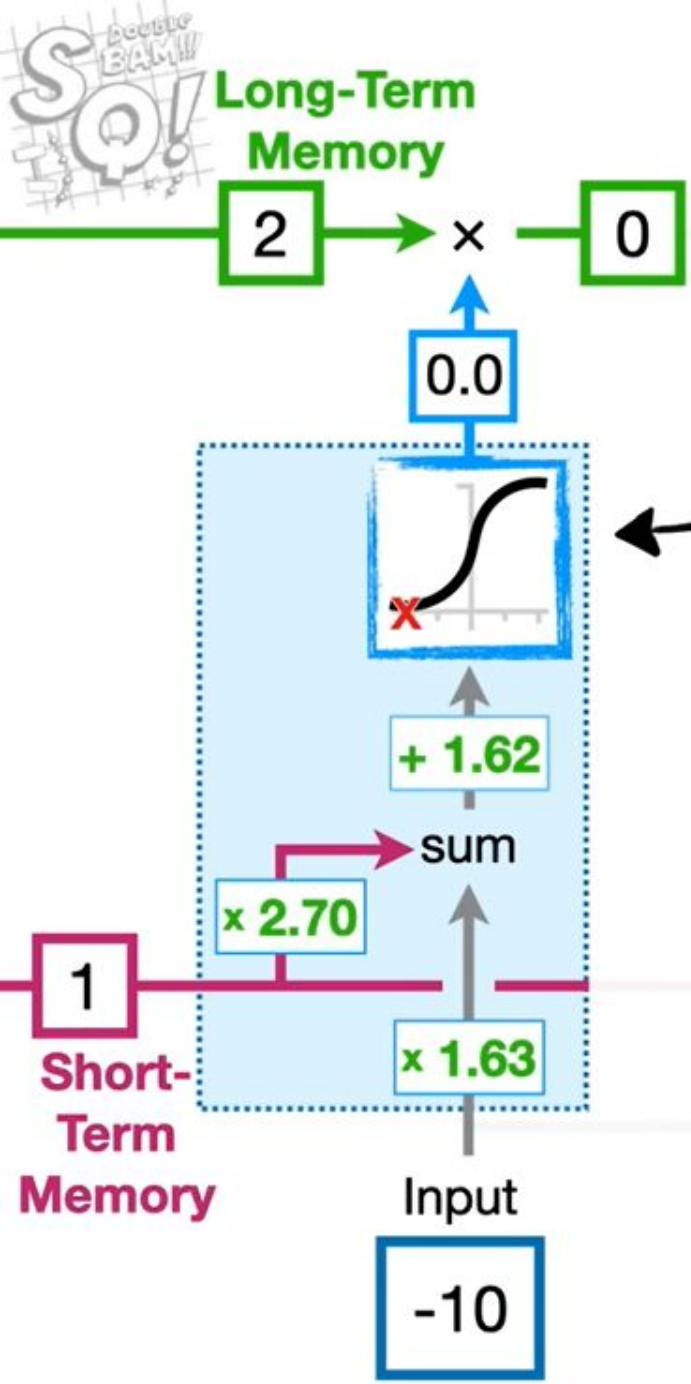


So this first stage of the **Long Short-Term Memory (LSTM)** unit reduced the **Long-Term Memory** by a little bit.

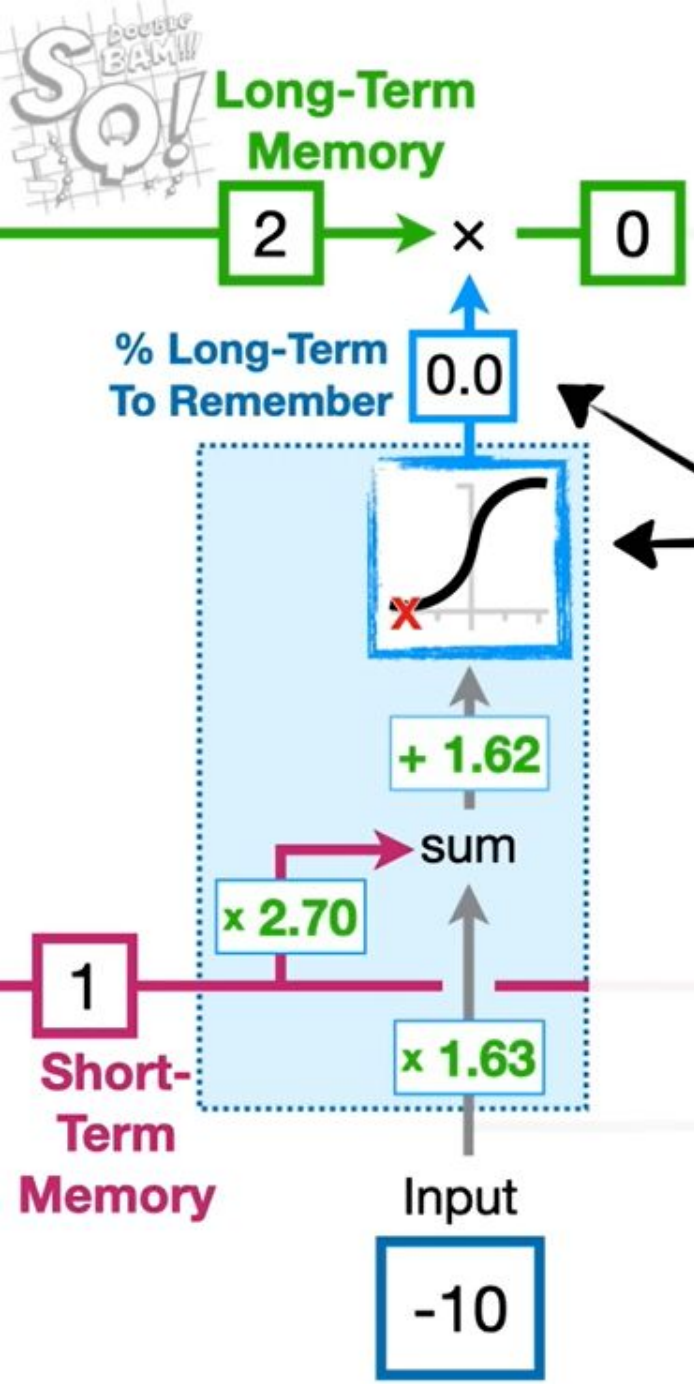

Long-Term Memory
2
×
+ 1.62
sum
x 2.70
1
x 1.63
Short-Term Memory
Input
-10
In contrast, if the **Input** to the **LSTM** was a relatively large negative number, like **-10**…


Long-Term Memory
2
×
0.0
x
+ 1.62
sum
x 2.70
1
x 1.63
Short-Term Memory
Input
-10
…then, after calculating the x-axis coordinate, the output from the **Sigmoid Activation Function** will be **0**…

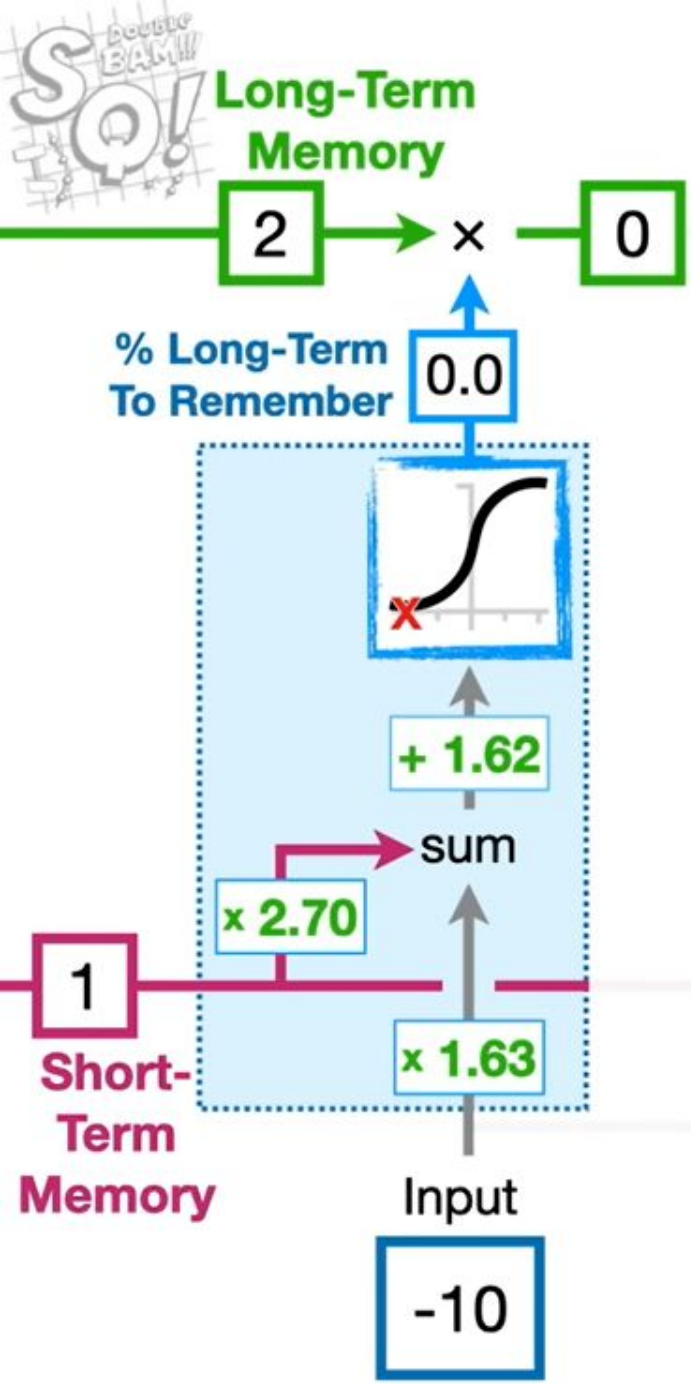

Long-Term Memory
2
×
0
0.0
+ 1.62
sum
x 2.70
1
x 1.63
Short-Term Memory
Input
-10
…and that means the Long-Term Memory would be completely forgotten because anything multiplied by 0 is 0.



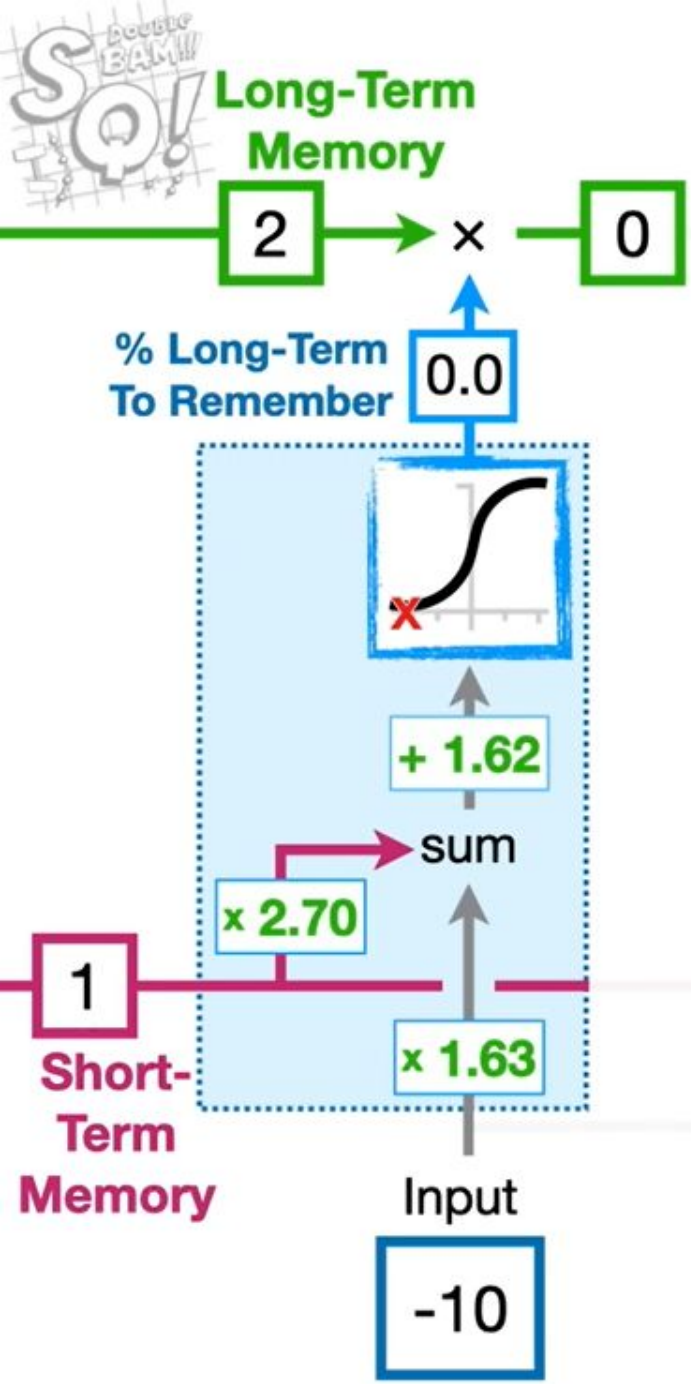
Thus, because the **Sigmoid Activation Function** turns any input into a number between **0** and **1**...



…the output determines what percentage of the **Long-Term Memory** is remembered.



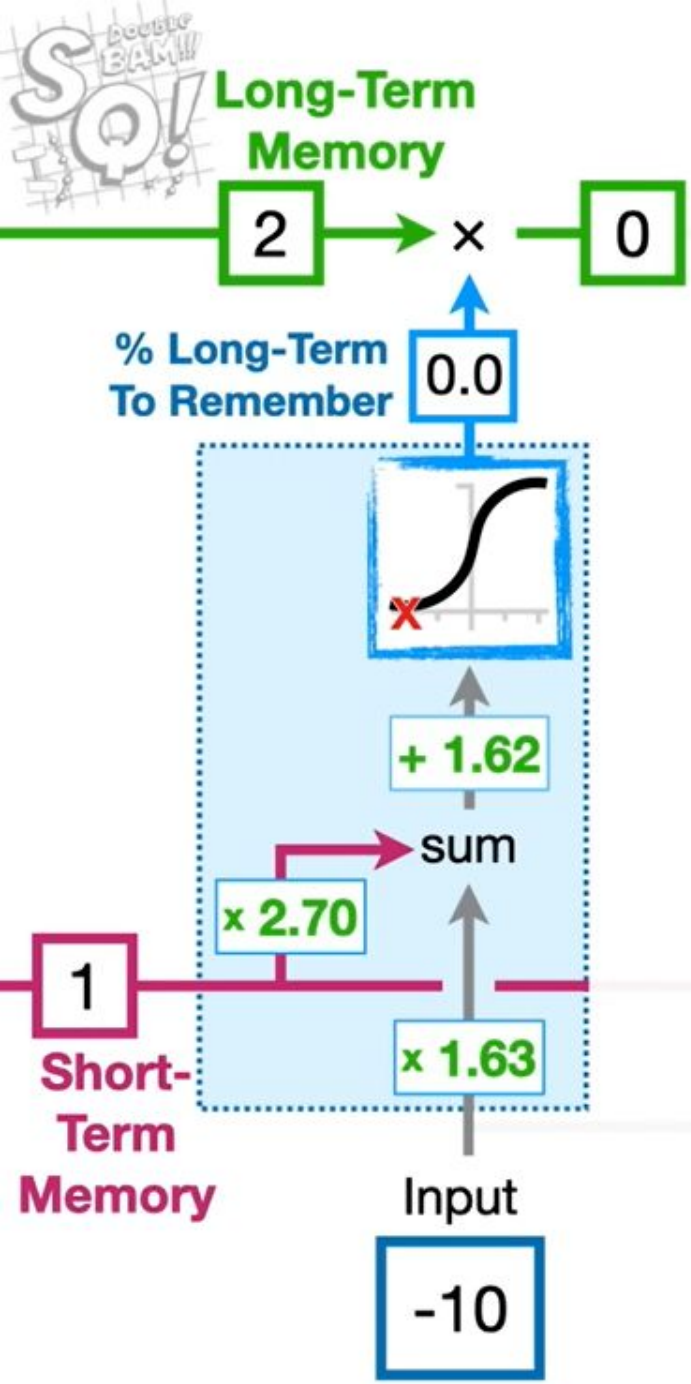
To summarize, the first stage in a **Long Short-Term Memory** unit determines what percentage of the **Long-Term Memory** is remembered.



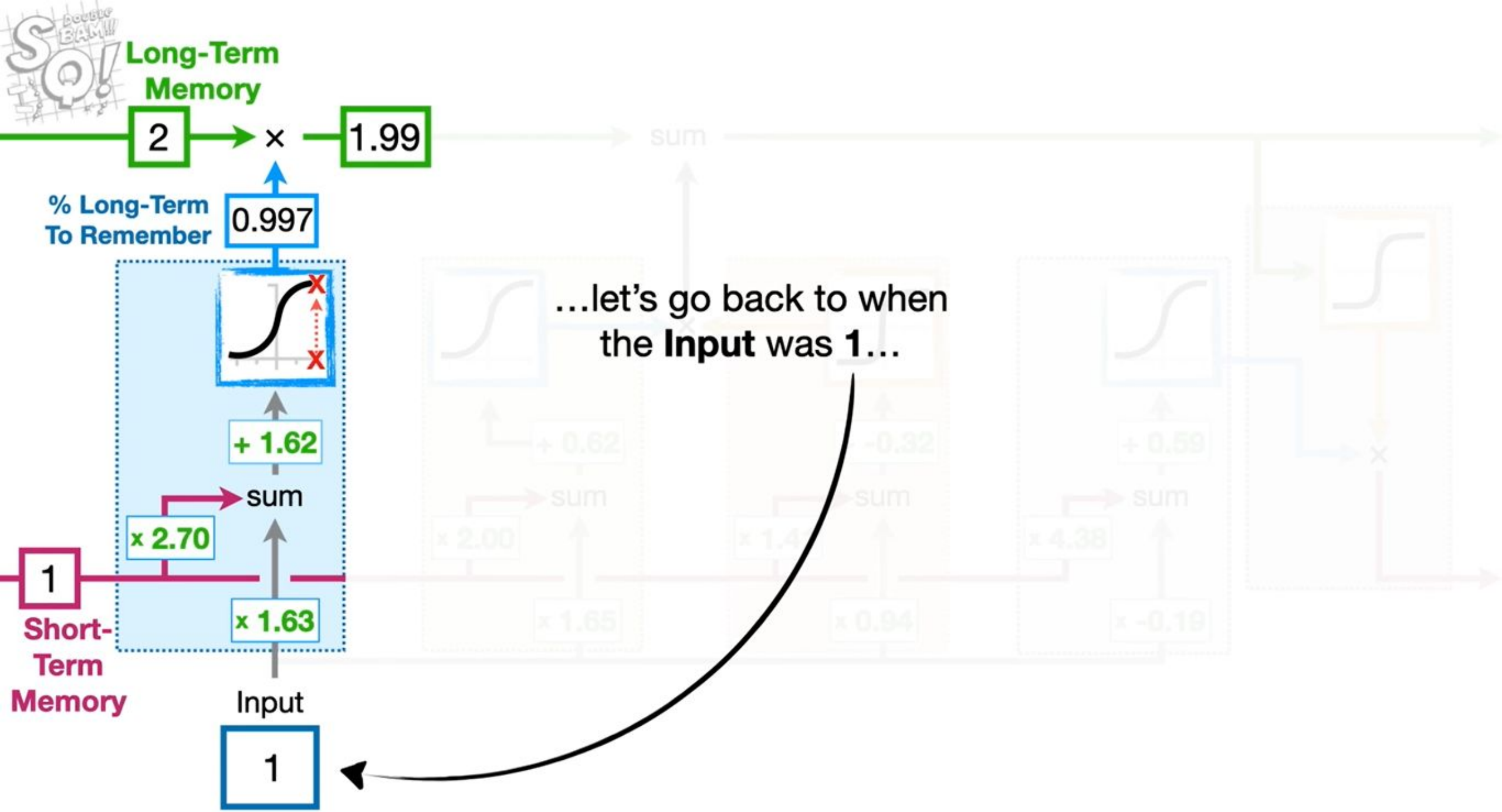
TERMINOLOGY ALERT!!!

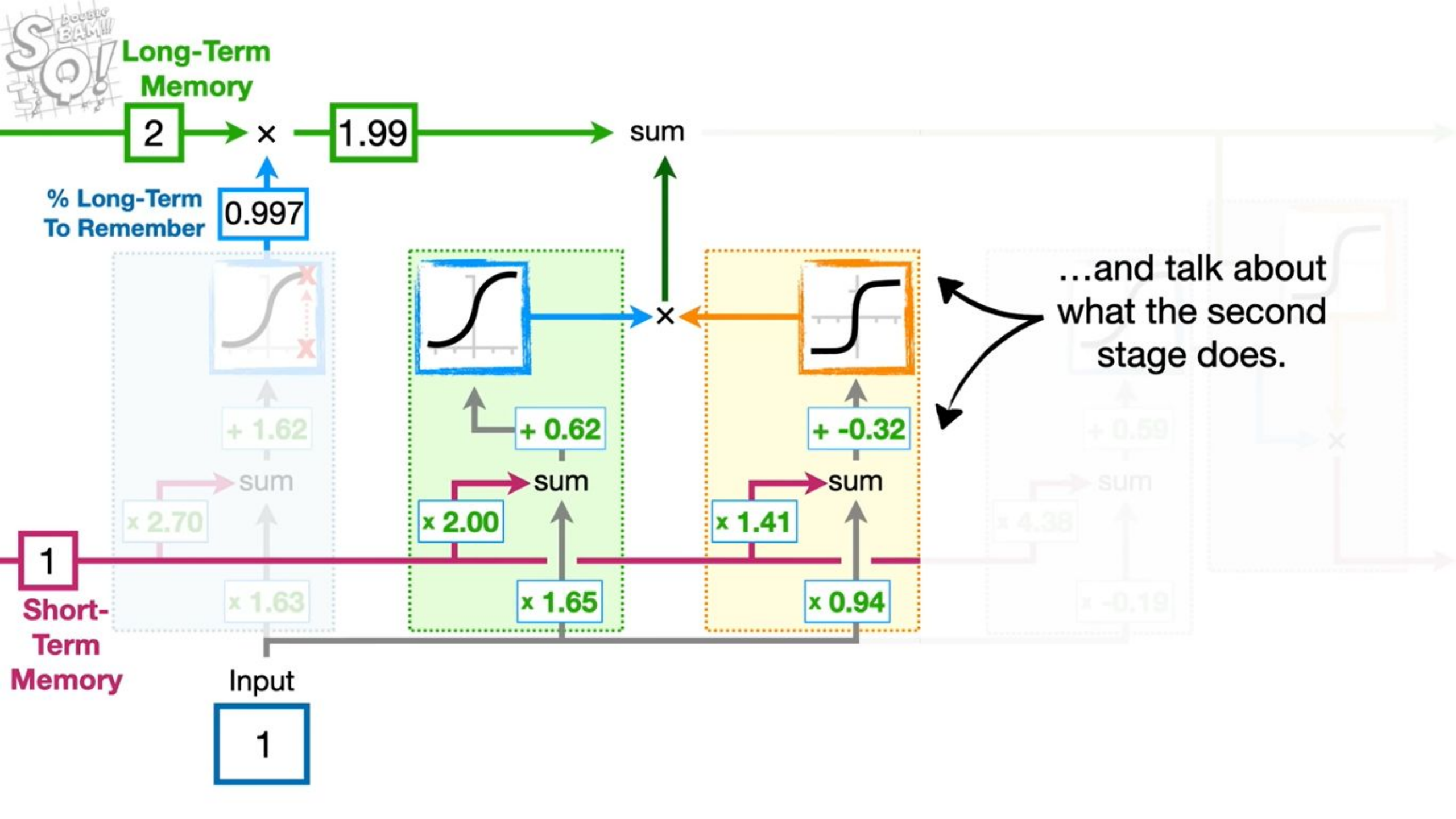
Even though this part of the **Long Short-Term Memory** unit determines what percentage of the **Long-Term Memory** will be remembered…

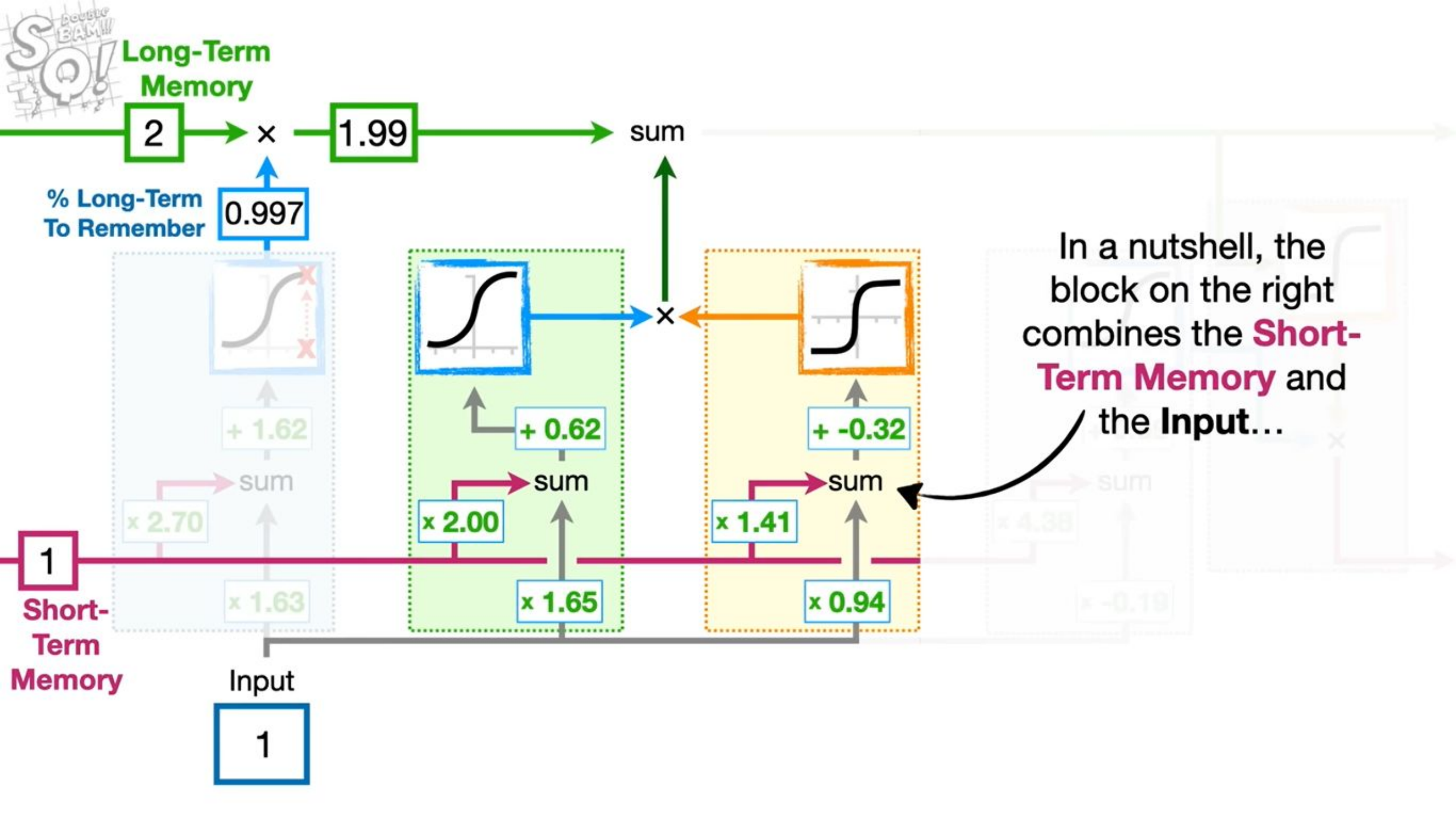
…it is usually called the **Forget Gate**.

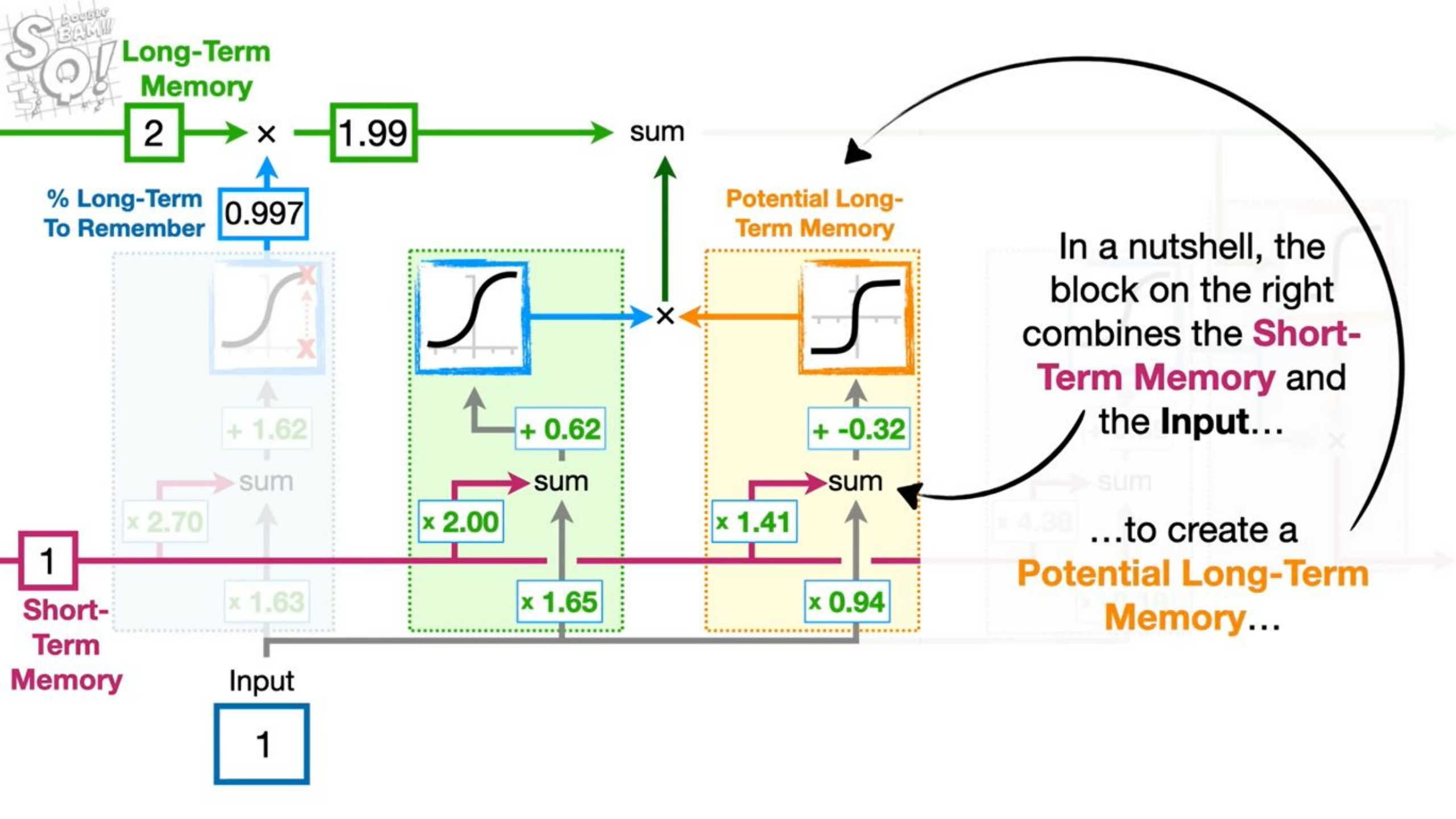


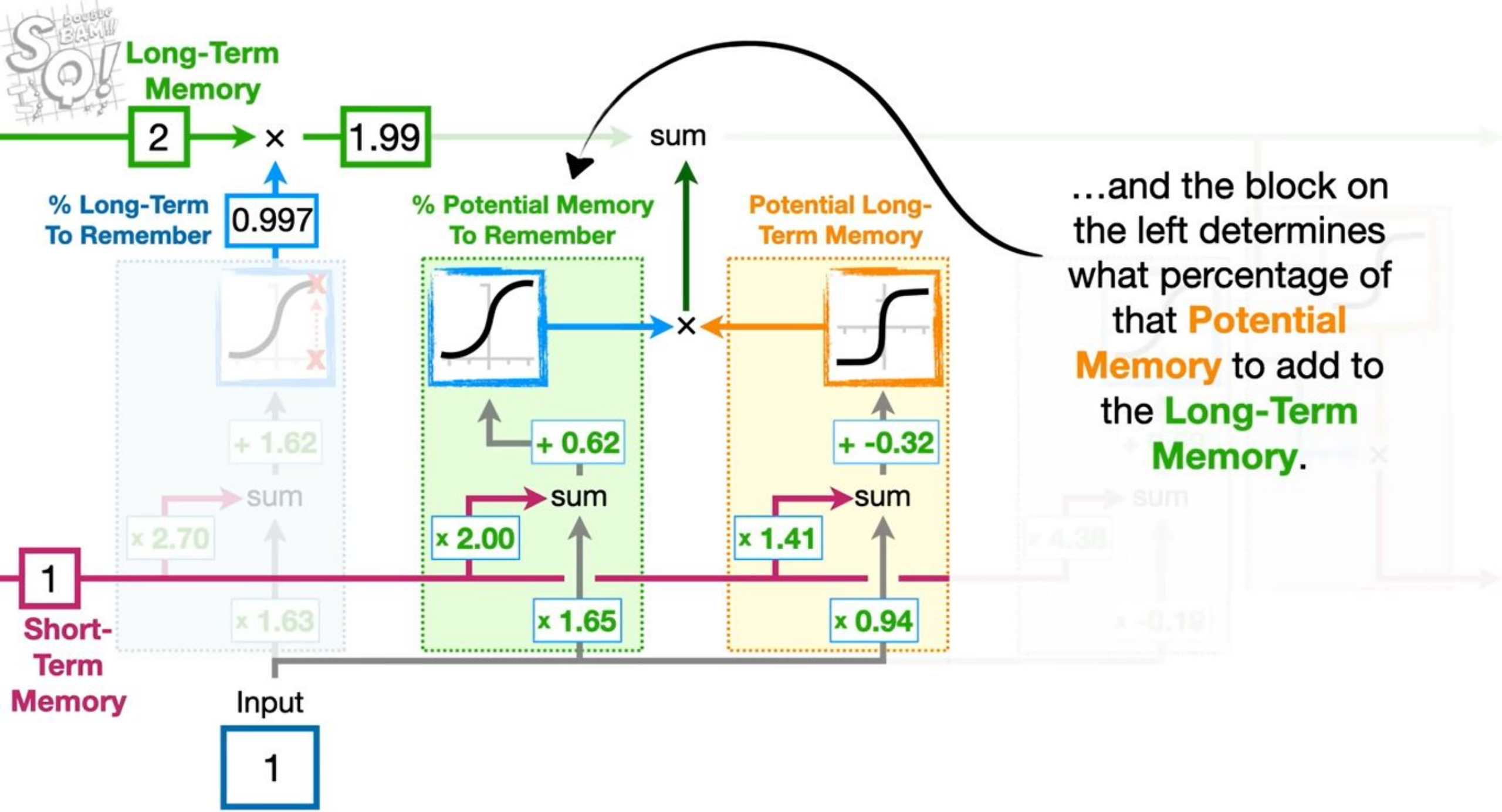
Now that we know what the first part of the **LSTM** unit does, it determines what percentage of the **Long-Term Memory** will be remembered…

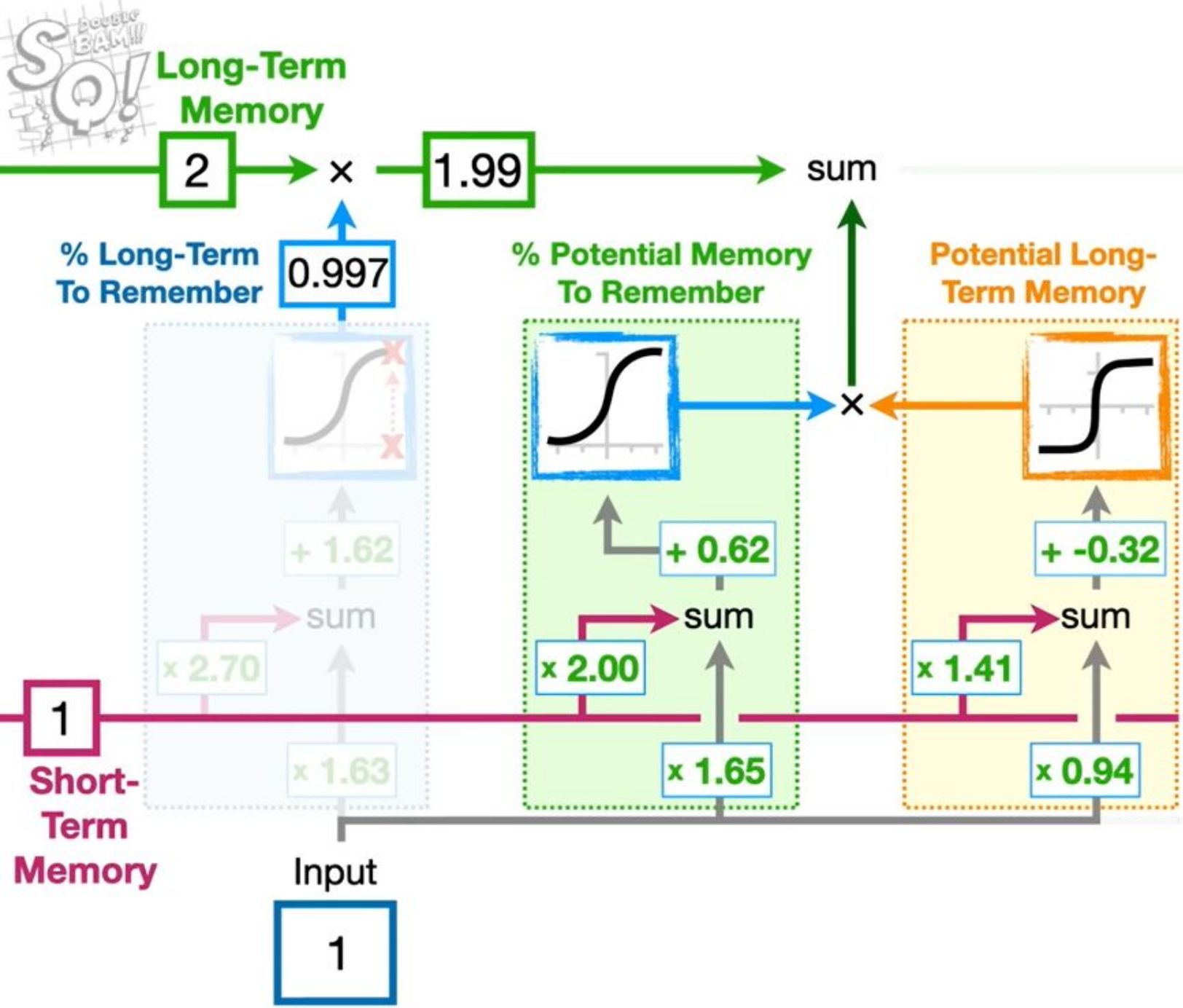

Long-Term Memory
2
×
1.99
% Long-Term To Remember
0.997
+ 1.62
sum
x 2.70
1
x 1.63
Short-Term Memory
Input
1
…let's go back to when the **Input** was **1**…


Long-Term Memory
2
×
1.99
sum
% Long-Term To Remember
0.997
+ 1.62
sum
x 2.70
x 1.63
+ 0.62
sum
x 2.00
x 1.65
×
+ -0.32
sum
x 1.41
x 0.94
…and talk about what the second stage does.
1
Short-Term Memory
Input
1

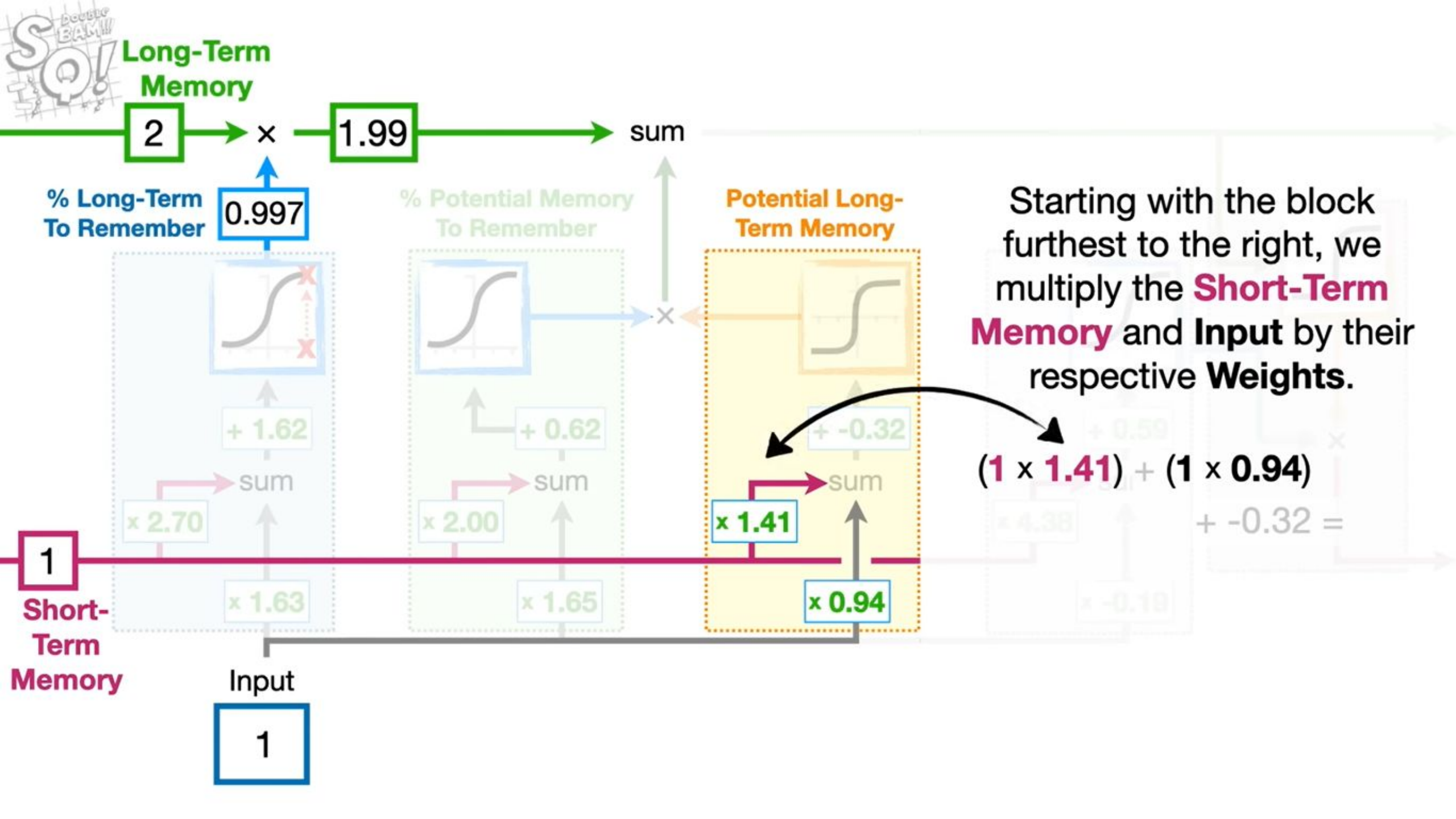

Long-Term Memory
2
×
1.99
sum
% Long-Term To Remember
0.997
+ 1.62
sum
x 2.70
x 1.63
+ 0.62
sum
x 2.00
x 1.65
×
+ -0.32
sum
x 1.41
x 0.94
In a nutshell, the block on the right combines the Short-Term Memory and the Input…
1
Short-Term Memory
Input
1

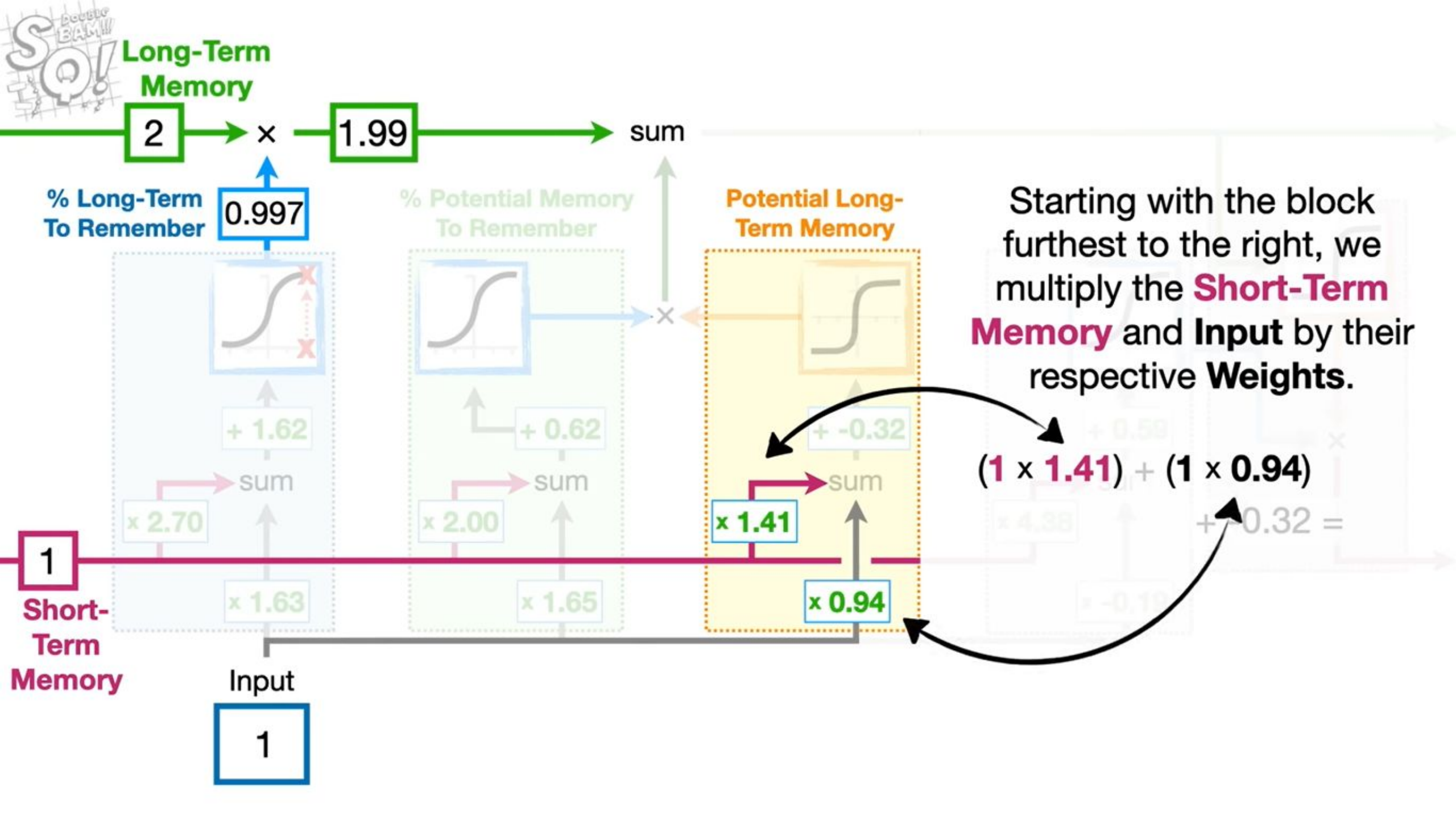

Long-Term Memory
2
×
1.99
sum
% Long-Term To Remember
0.997
Potential Long-Term Memory
In a nutshell, the block on the right combines the Short-Term Memory and the Input…
+ 1.62
sum
x 2.70
x 1.63
+ 0.62
sum
x 2.00
x 1.65
×
+ -0.32
sum
x 1.41
x 0.94
…to create a Potential Long-Term Memory…
1
Short-Term Memory
Input
1

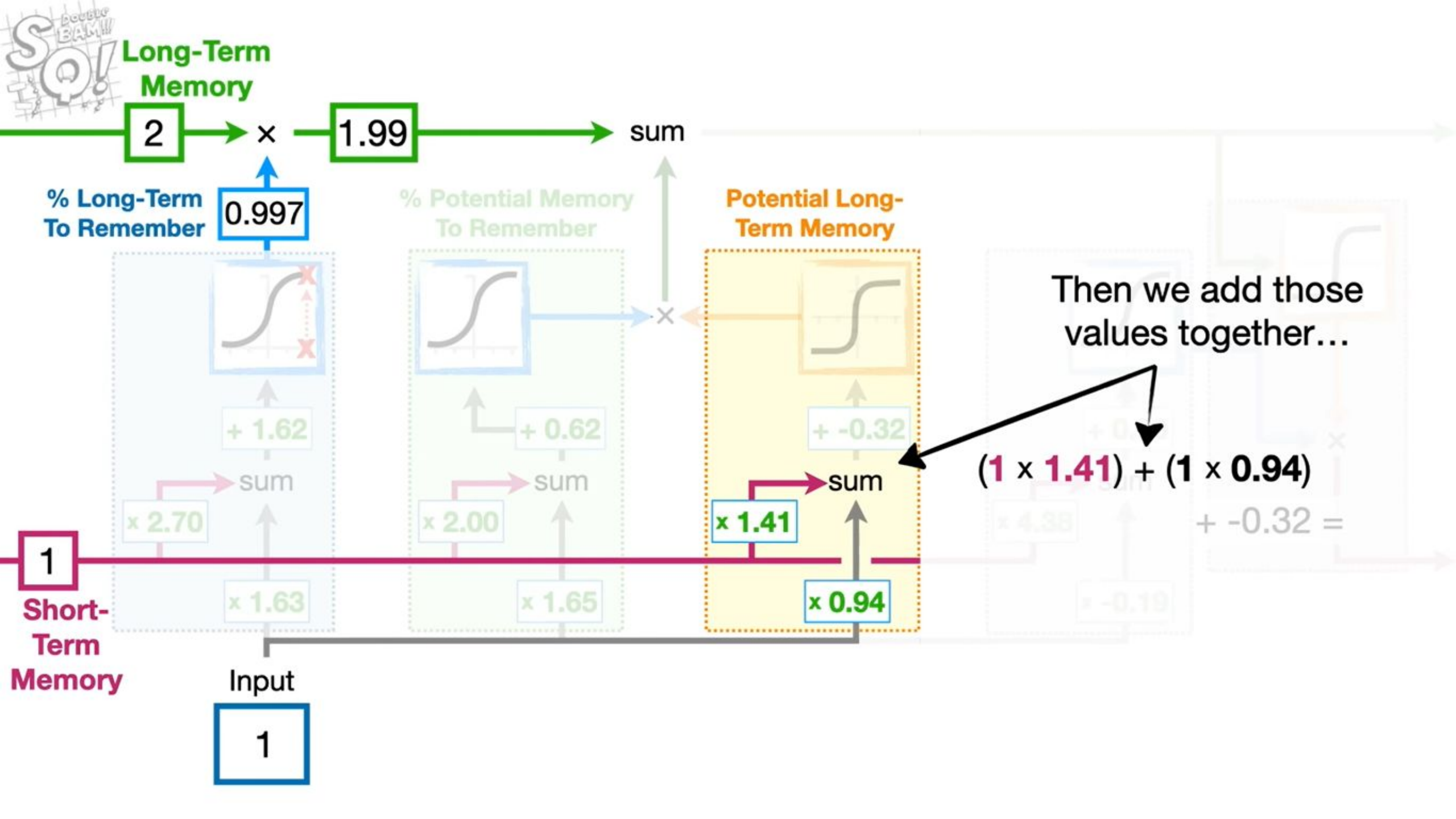

Long-Term Memory
2
×
1.99
sum
% Long-Term To Remember
0.997
% Potential Memory To Remember
Potential Long-Term Memory
×
+ 1.62
sum
x 2.70
x 1.63
+ 0.62
sum
x 2.00
x 1.65
+ -0.32
sum
x 1.41
x 0.94
1
Short-Term Memory
Input
1
…and the block on the left determines what percentage of that Potential Memory to add to the Long-Term Memory.

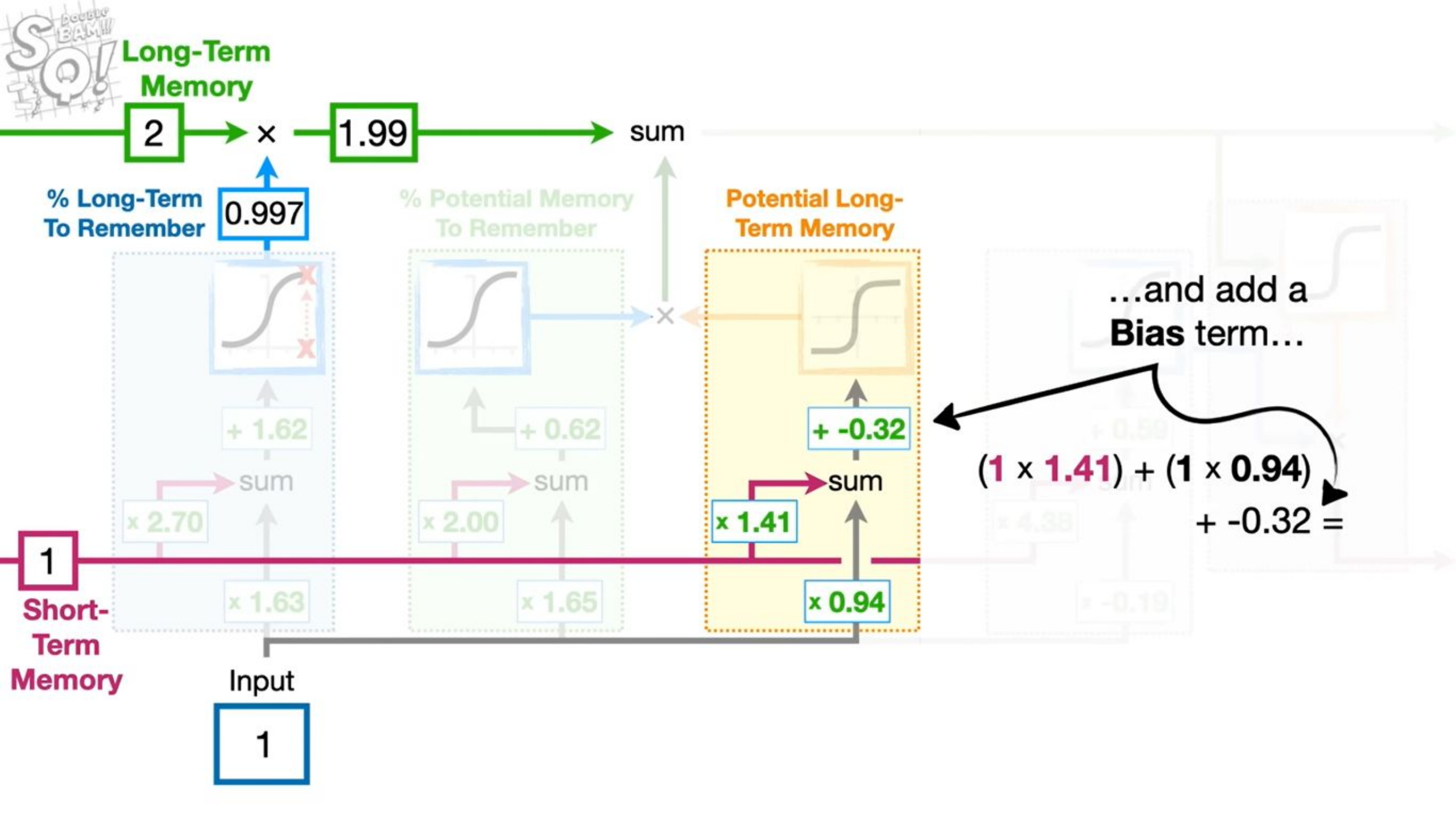


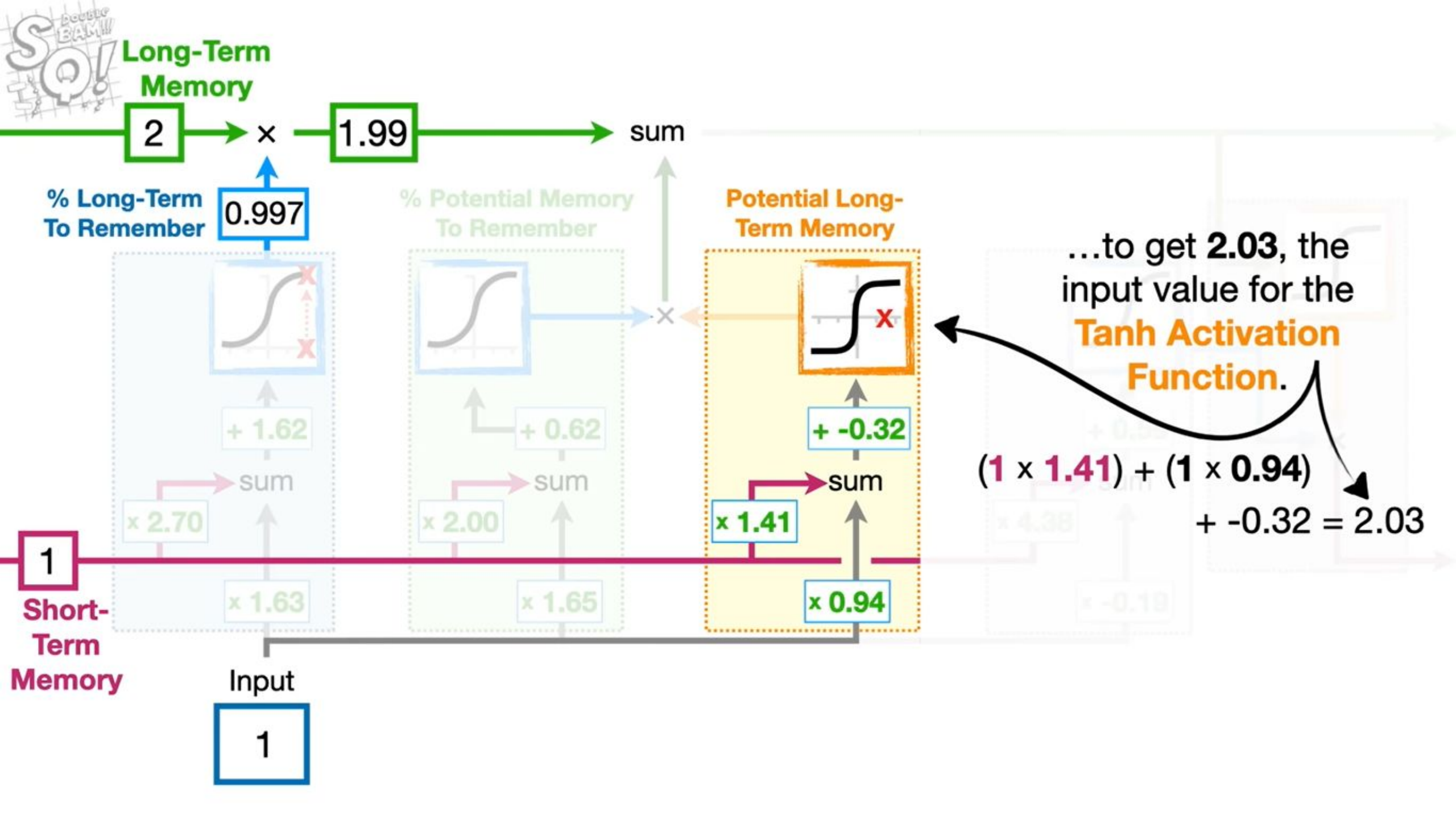
So let's plug the numbers in and do the math to see how a **Potential Memory** is created and how much of it is added to the **Long-Term Memory**.

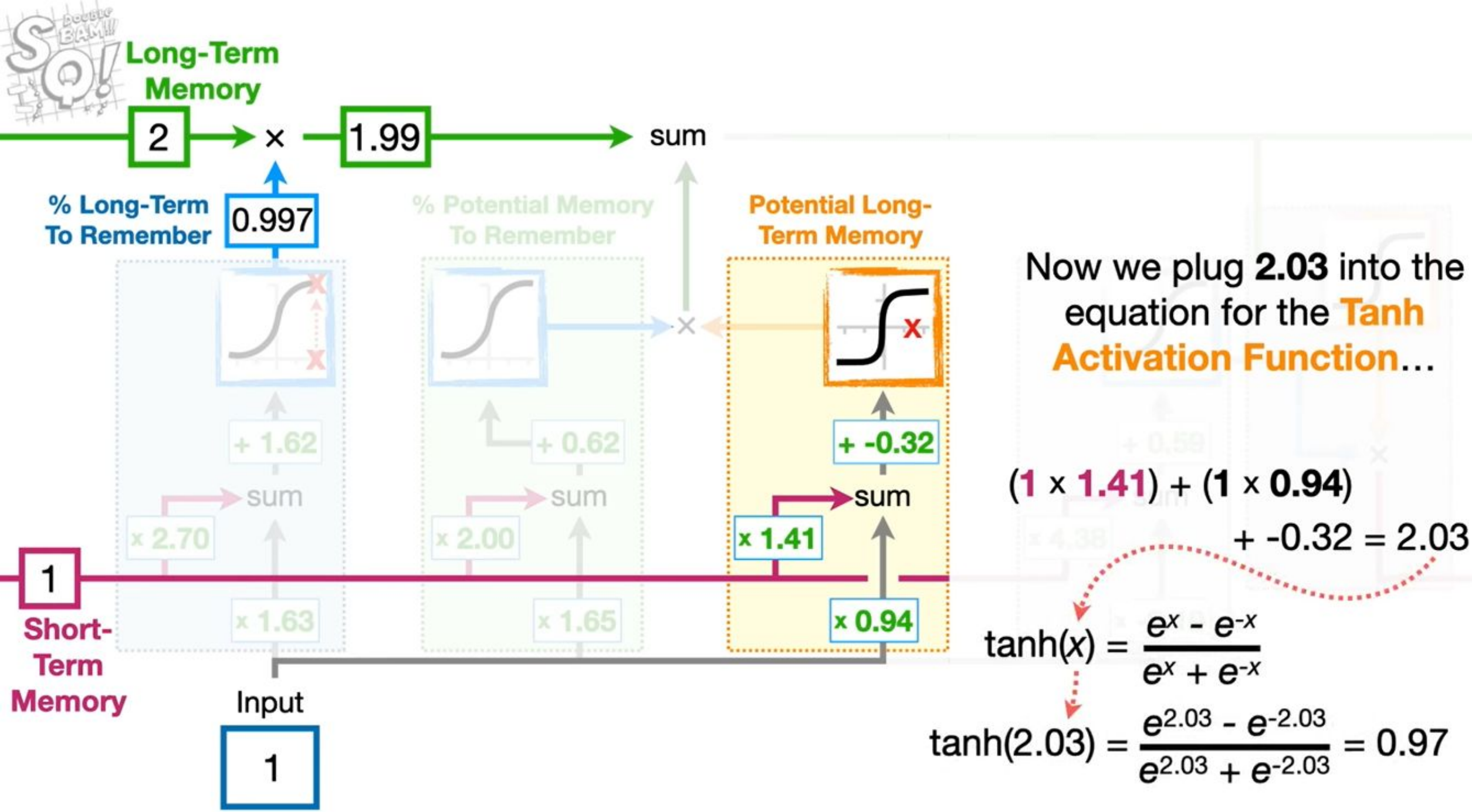

Long-Term Memory
2
×
1.99
sum
% Long-Term To Remember
0.997
% Potential Memory To Remember
Potential Long-Term Memory
+ 1.62
+ 0.62
+ -0.32
sum
sum
sum
x 2.70
x 2.00
x 1.41
1
x 1.63
x 1.65
x 0.94
Short-Term Memory
Input
1
Starting with the block furthest to the right, we multiply the Short-Term Memory and Input by their respective Weights.
(1 x 1.41) + (1 x 0.94)
+ -0.32 =


Long-Term Memory
2
×
1.99
sum
% Long-Term To Remember
0.997
% Potential Memory To Remember
Potential Long-Term Memory
Starting with the block furthest to the right, we multiply the Short-Term Memory and Input by their respective Weights.
+ 1.62
sum
x 2.70
x 1.63
+ 0.62
sum
x 2.00
x 1.65
+ -0.32
sum
x 1.41
x 0.94
(1 x 1.41) + (1 x 0.94)
1
Short-Term Memory
Input
1


Long-Term Memory
2
×
1.99
sum
% Long-Term To Remember
0.997
% Potential Memory To Remember
Potential Long-Term Memory
+ 1.62
+ 0.62
+ -0.32
sum
sum
sum
x 2.70
x 2.00
x 1.41
1
x 1.63
x 1.65
x 0.94
Short-Term Memory
Input
1
Then we add those values together…
(1 x 1.41) + (1 x 0.94)
+ -0.32 =


Long-Term Memory
2
×
1.99
sum
% Long-Term To Remember
0.997
% Potential Memory To Remember
Potential Long-Term Memory
+ 1.62
+ 0.62
+ -0.32
sum
sum
sum
x 2.70
x 2.00
x 1.41
x 1.63
x 1.65
x 0.94
1
Short-Term Memory
Input
1
…and add a Bias term…
(1 x 1.41) + (1 x 0.94) + -0.32 =


Long-Term Memory
2
×
1.99
sum
% Long-Term To Remember
0.997
% Potential Memory To Remember
Potential Long-Term Memory
+ 1.62
+ 0.62
+ -0.32
sum
sum
sum
x 2.70
x 2.00
x 1.41
1
x 1.63
x 1.65
x 0.94
Short-Term Memory
Input
1
…to get 2.03, the input value for the Tanh Activation Function.
(1 x 1.41) + (1 x 0.94)
+ -0.32 = 2.03

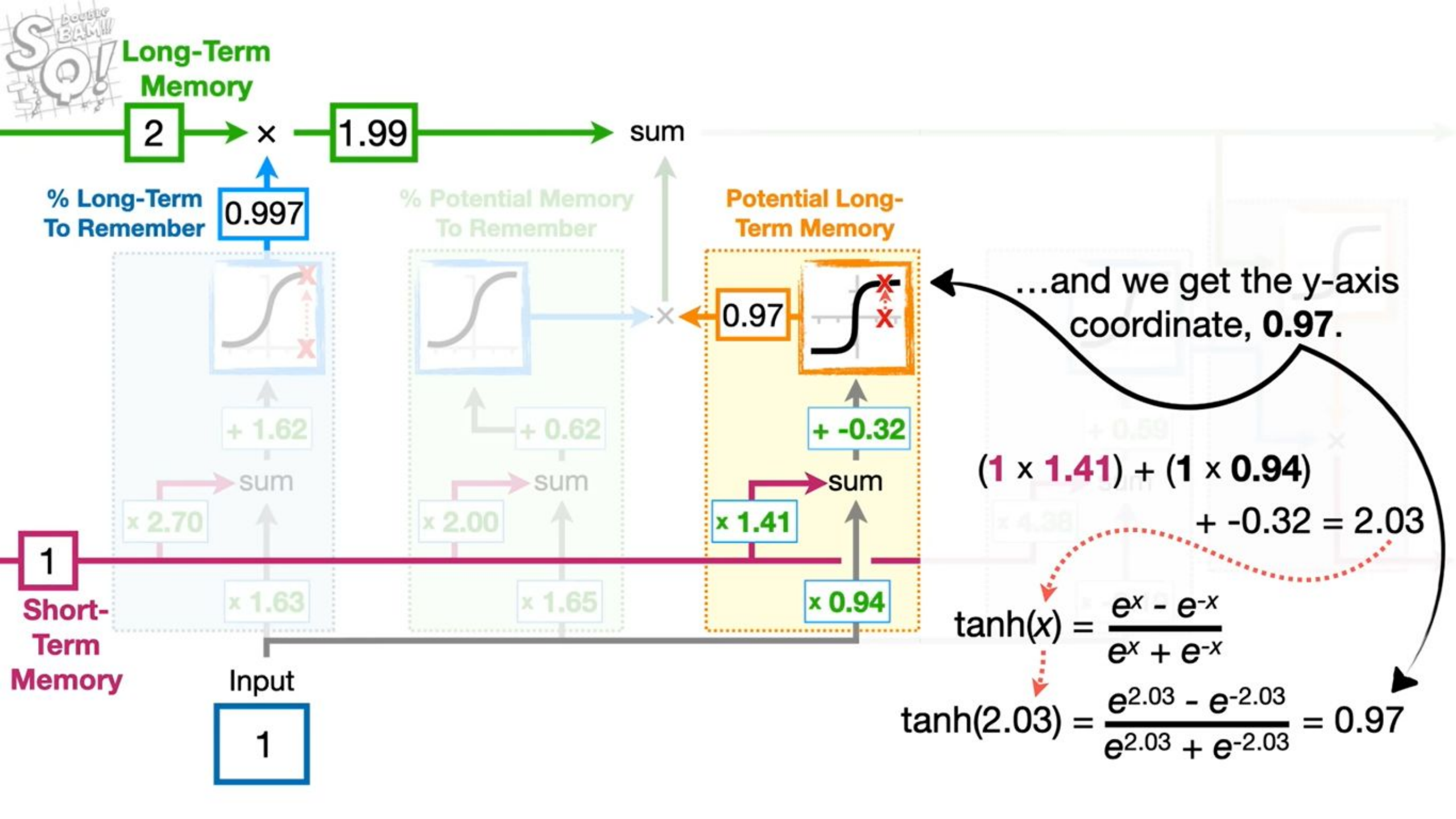


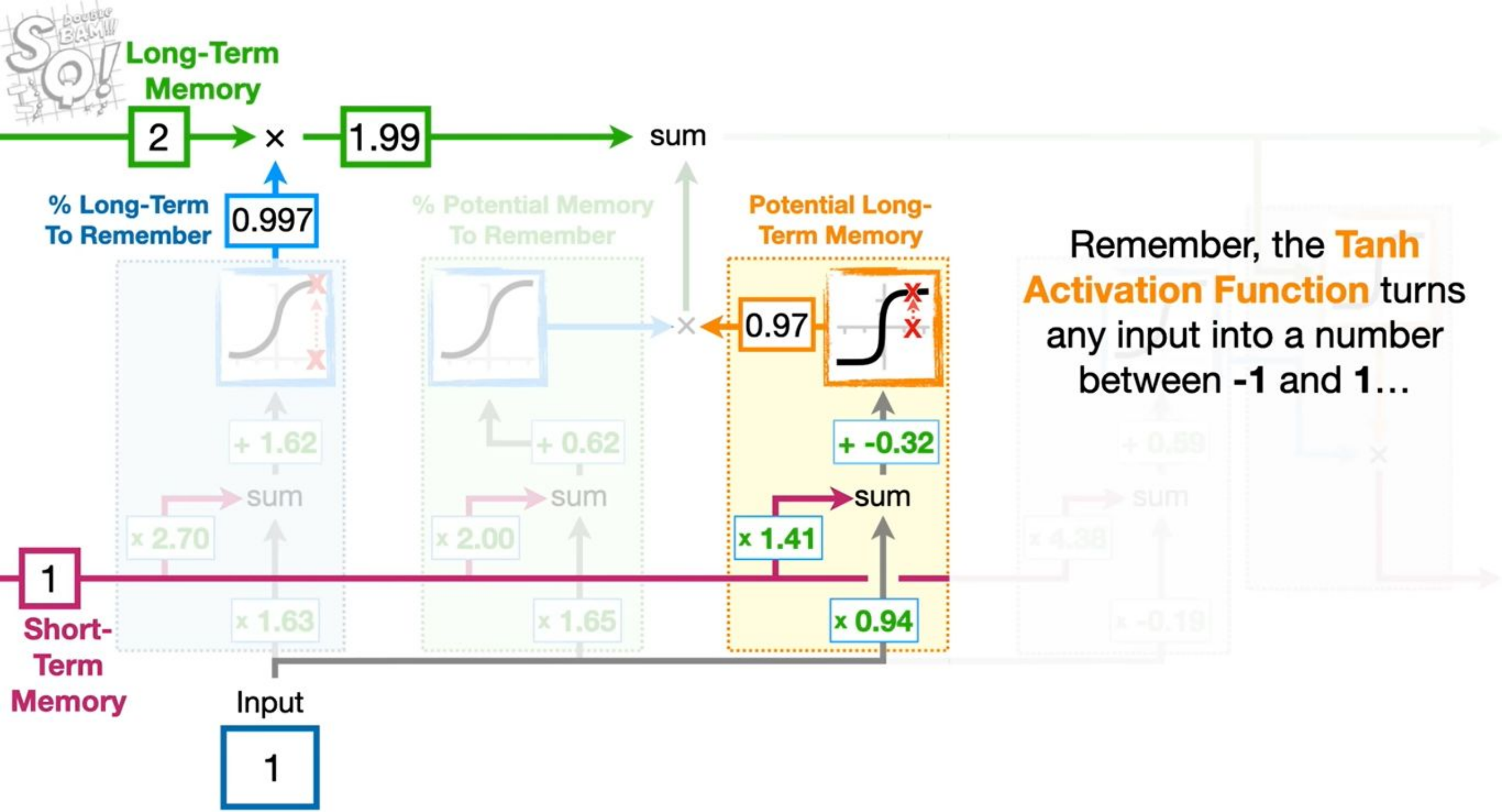
Now we plug **2.03** into the equation for the **Tanh Activation Function**…

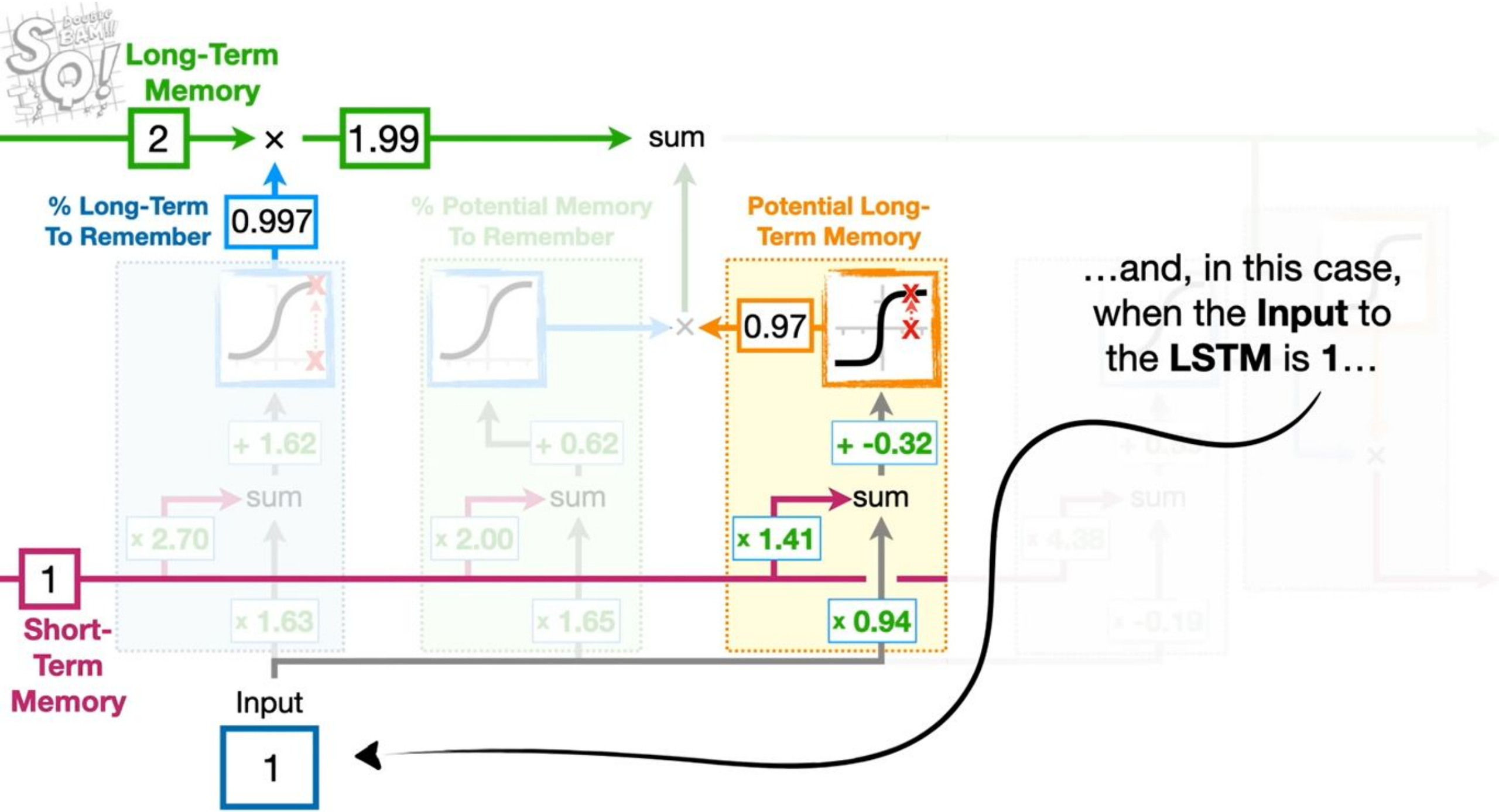
$$(1 \times 1.41) + (1 \times 0.94) + -0.32 = 2.03$$

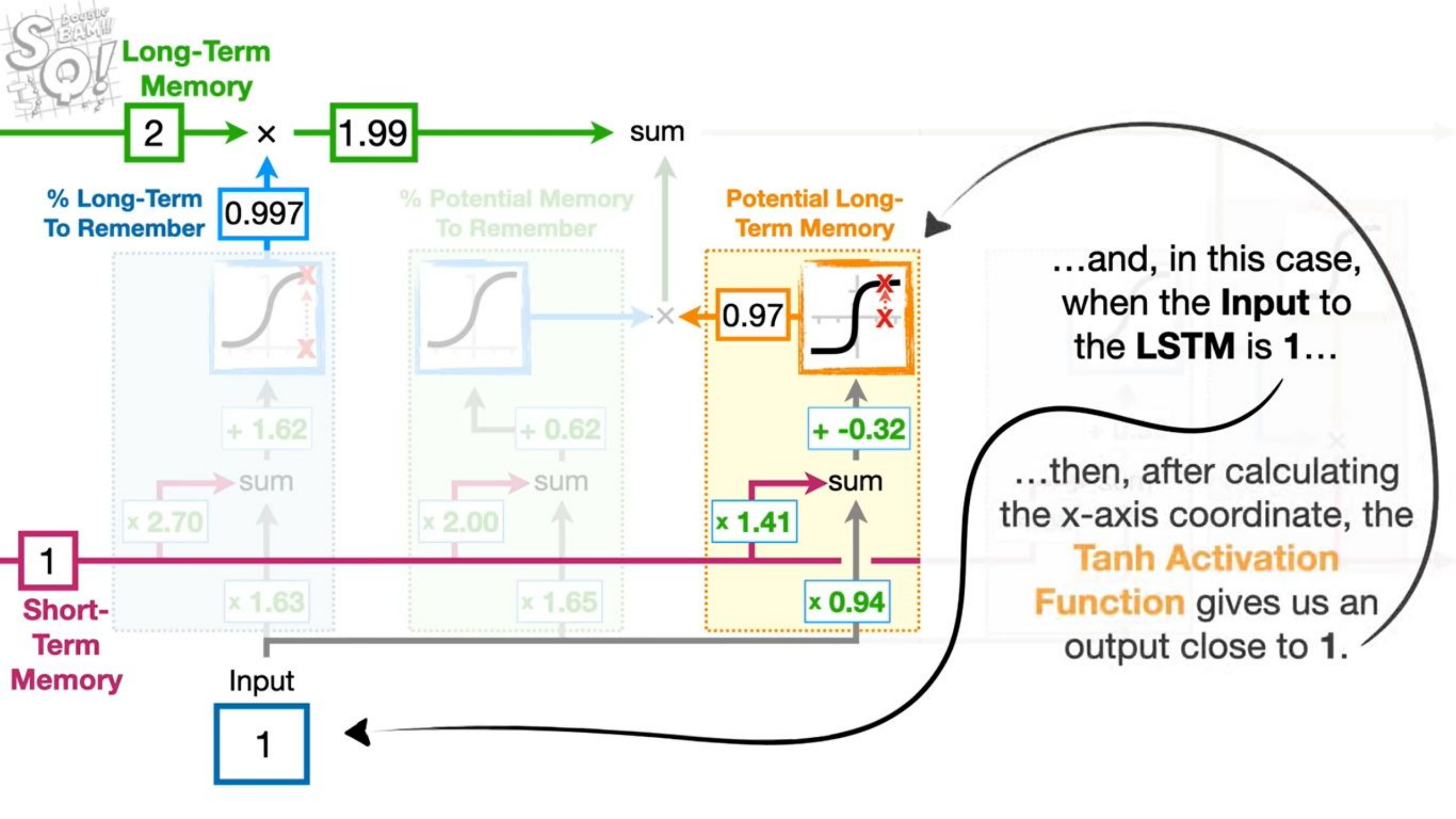
$$\tanh(x) = \frac{e^{x} - e^{-x}}{e^{x} + e^{-x}}$$

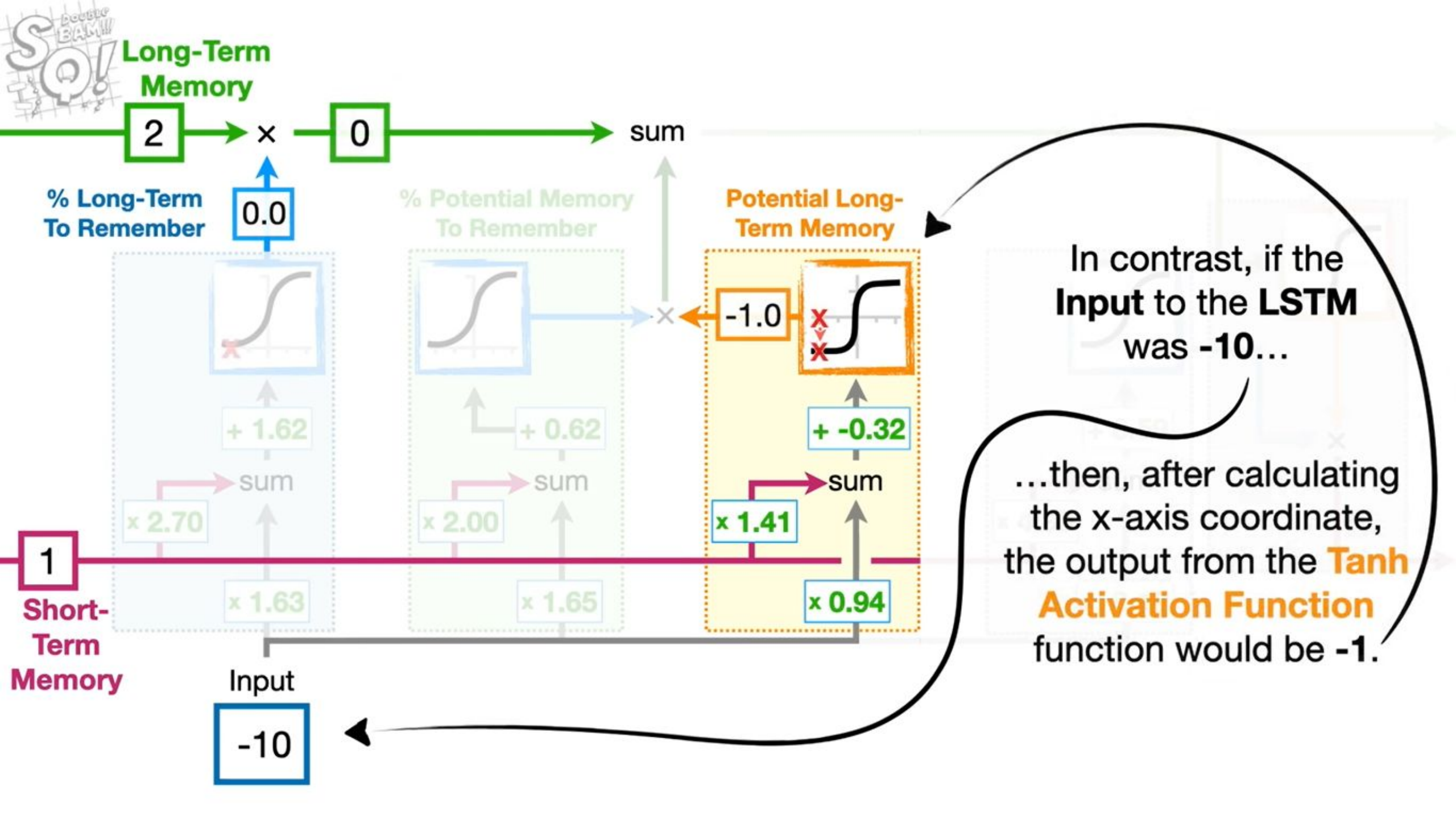
$$\tanh(2.03) = \frac{e^{2.03} - e^{-2.03}}{e^{2.03} + e^{-2.03}} = 0.97$$

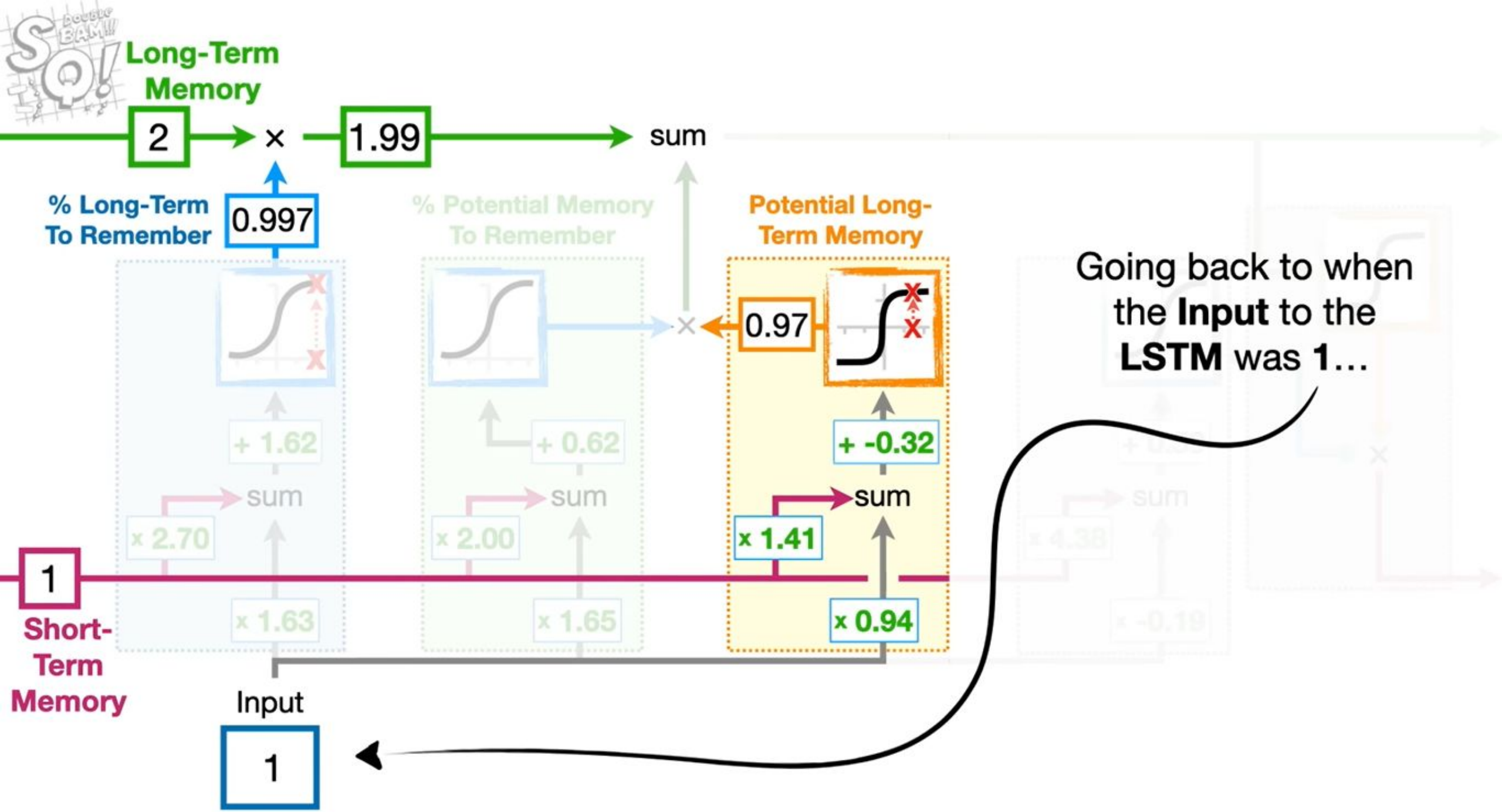

Long-Term Memory
2
×
1.99
sum
% Long-Term To Remember
0.997
% Potential Memory To Remember
Potential Long-Term Memory
0.97
+ 1.62
+ 0.62
+ -0.32
sum
sum
sum
x 2.70
x 2.00
x 1.41
1
x 1.63
x 1.65
x 0.94
Short-Term Memory
Input
1
…and we get the y-axis coordinate, 0.97.
(1 x 1.41) + (1 x 0.94)
+ -0.32 = 2.03
$\tanh(x) = \frac{e^{x} - e^{-x}}{e^{x} + e^{-x}}$
$\tanh(2.03) = \frac{e^{2.03} - e^{-2.03}}{e^{2.03} + e^{-2.03}} = 0.97$

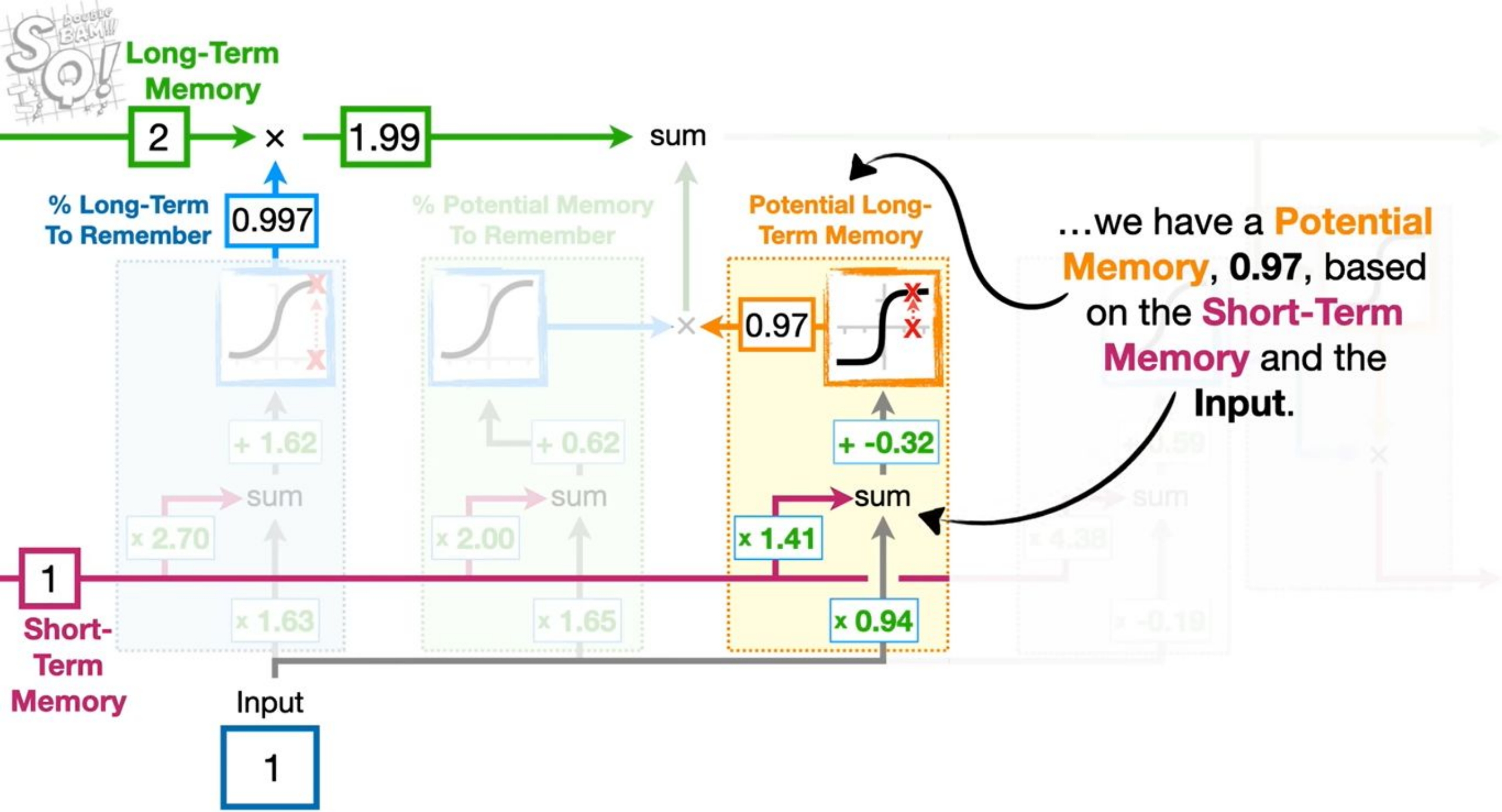

Long-Term Memory
2
×
1.99
sum
% Long-Term To Remember
0.997
% Potential Memory To Remember
Potential Long-Term Memory
0.97
+ 1.62
+ 0.62
+ -0.32
sum
sum
sum
x 2.70
x 2.00
x 1.41
1
x 1.63
x 1.65
x 0.94
Short-Term Memory
Input
1
Remember, the Tanh Activation Function turns any input into a number between -1 and 1…

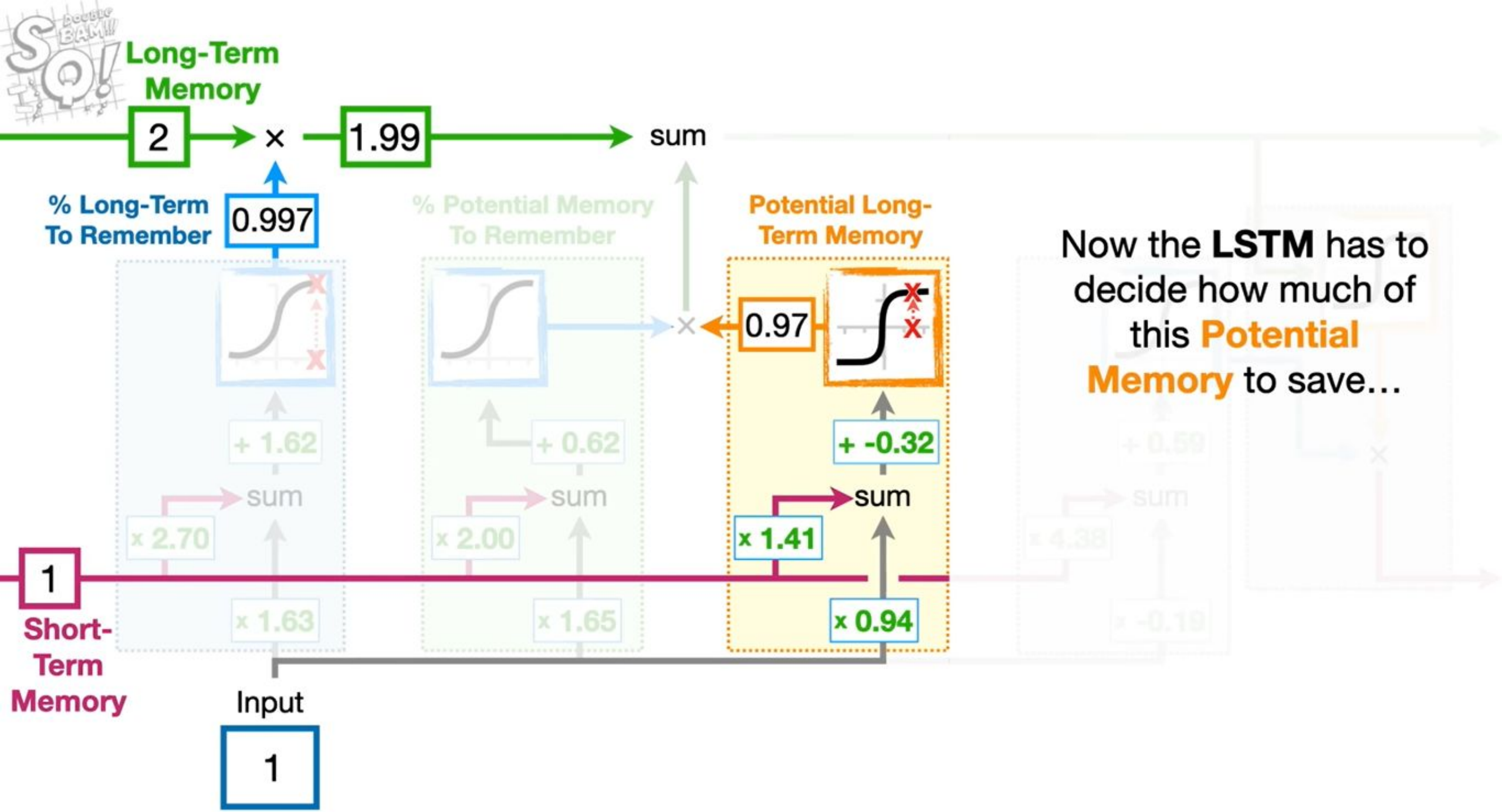

Long-Term Memory
2
×
1.99
sum
% Long-Term To Remember
0.997
% Potential Memory To Remember
Potential Long-Term Memory
0.97
+ 1.62
+ 0.62
+ -0.32
sum
sum
sum
x 2.70
x 2.00
x 1.41
1
x 1.63
x 1.65
x 0.94
Short-Term Memory
Input
1
…and, in this case, when the Input to the LSTM is 1…

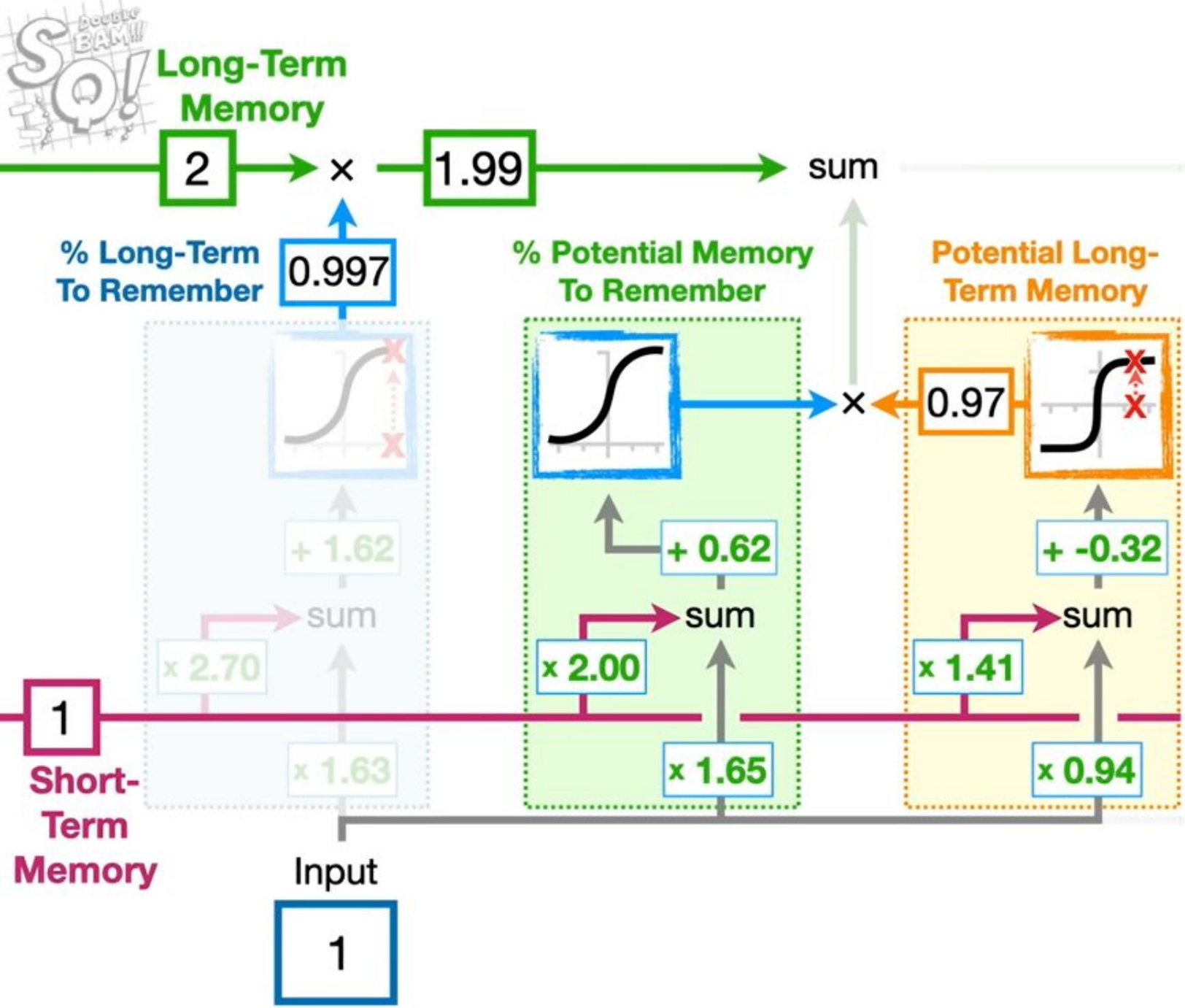

Long-Term Memory
2
×
1.99
sum
% Long-Term To Remember
0.997
% Potential Memory To Remember
Potential Long-Term Memory
0.97
+ 1.62
+ 0.62
+ -0.32
sum
sum
sum
x 2.70
x 2.00
x 1.41
1
x 1.63
x 1.65
x 0.94
Short-Term Memory
Input
1
…and, in this case, when the Input to the LSTM is 1…
…then, after calculating the x-axis coordinate, the Tanh Activation Function gives us an output close to 1.


Long-Term Memory
2
×
0
sum
% Long-Term To Remember
0.0
% Potential Memory To Remember
Potential Long-Term Memory
-1.0
+ 1.62
+ 0.62
+ -0.32
sum
sum
sum
x 2.70
x 2.00
x 1.41
1
x 1.63
x 1.65
x 0.94
Short-Term Memory
Input
-10
In contrast, if the Input to the LSTM was -10…
…then, after calculating the x-axis coordinate, the output from the Tanh Activation Function function would be -1.

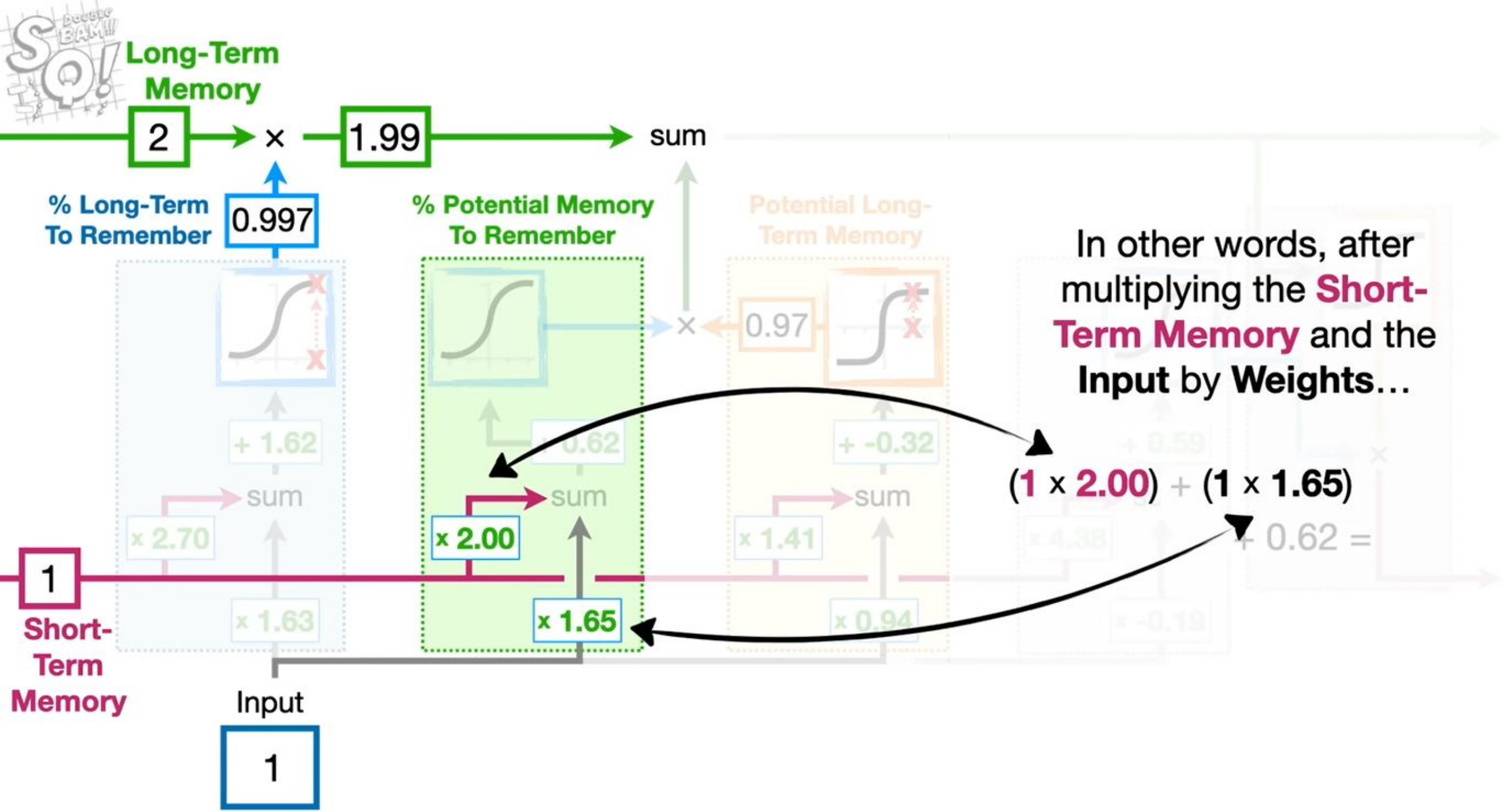

Long-Term Memory
2
×
1.99
sum
% Long-Term To Remember
0.997
% Potential Memory To Remember
Potential Long-Term Memory
0.97
+ 1.62
+ 0.62
+ -0.32
sum
sum
sum
x 2.70
x 2.00
x 1.41
1
x 1.63
x 1.65
x 0.94
Short-Term Memory
Input
1
Going back to when the Input to the LSTM was 1…

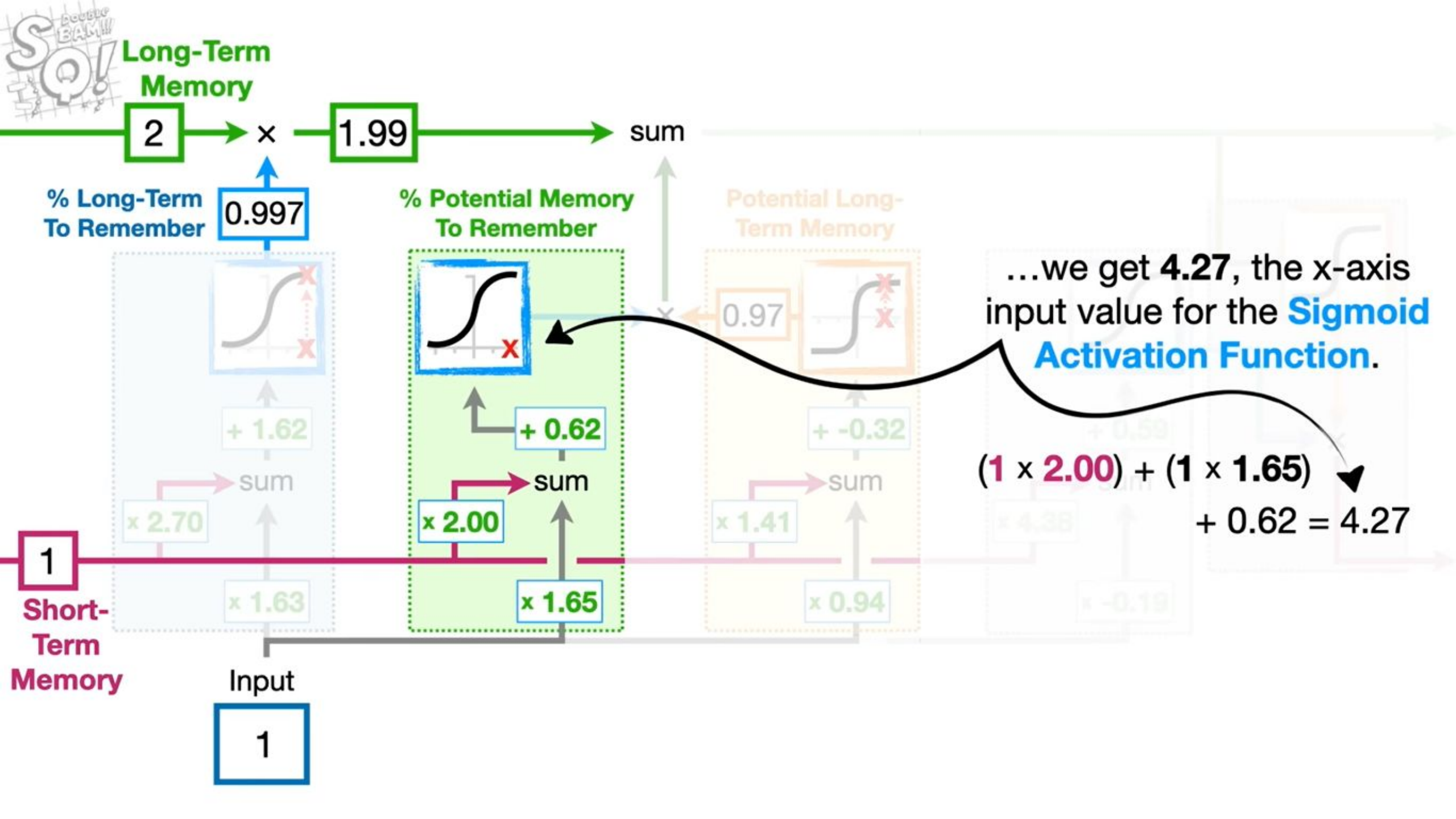

Long-Term Memory
2
×
1.99
sum
% Long-Term To Remember
0.997
% Potential Memory To Remember
Potential Long-Term Memory
…we have a Potential Memory, 0.97, based on the Short-Term Memory and the Input.
0.97
+ 1.62
+ 0.62
+ -0.32
sum
sum
sum
x 2.70
x 2.00
x 1.41
1
x 1.63
x 1.65
x 0.94
Short-Term Memory
Input
1

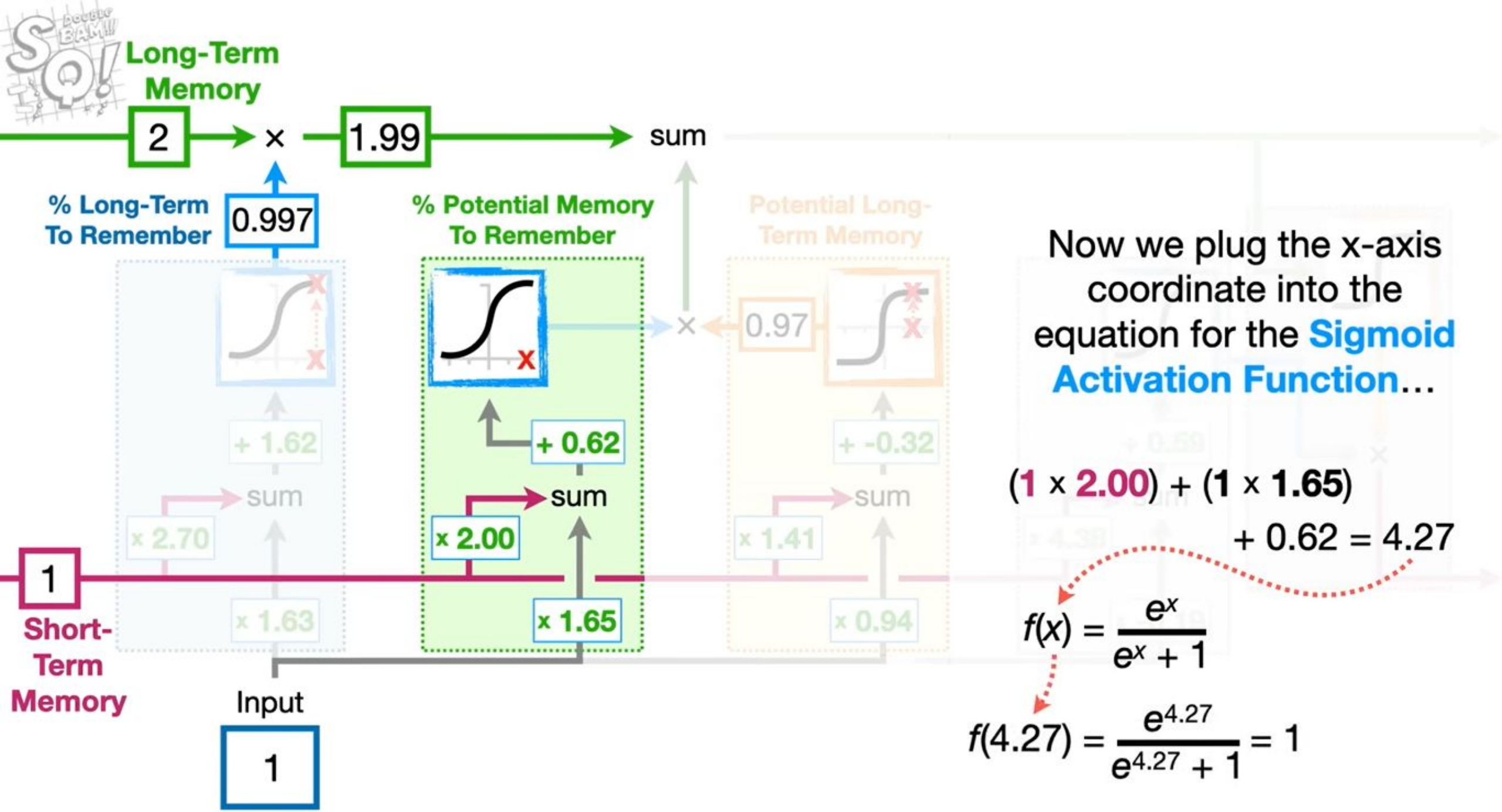

Long-Term Memory
2
×
1.99
sum
% Long-Term To Remember
0.997
% Potential Memory To Remember
Potential Long-Term Memory
0.97
+ 1.62
+ 0.62
+ -0.32
sum
sum
sum
x 2.70
x 2.00
x 1.41
1
x 1.63
x 1.65
x 0.94
Short-Term Memory
Input
1
Now the LSTM has to decide how much of this Potential Memory to save…



…and this is done using the exact same method we used earlier, when we determined what percentage of the **Long-Term Memory** to remember.


Long-Term Memory
2
×
1.99
sum
% Long-Term To Remember
0.997
% Potential Memory To Remember
Potential Long-Term Memory
0.97
+ 1.62
sum
x 2.70
x 1.63
+ 0.62
sum
x 2.00
x 1.65
+ -0.32
sum
x 1.41
x 0.94
1
Short-Term Memory
Input
1
In other words, after multiplying the Short-Term Memory and the Input by Weights…
(1 x 2.00) + (1 x 1.65)
+ 0.62 =


Long-Term Memory
2
×
1.99
sum
% Long-Term To Remember
0.997
% Potential Memory To Remember
Potential Long-Term Memory
0.97
+ 1.62
+ 0.62
+ -0.32
sum
sum
sum
x 2.70
x 2.00
x 1.41
1
x 1.63
x 1.65
x 0.94
Short-Term Memory
Input
1
…we get 4.27, the x-axis input value for the Sigmoid Activation Function.
(1 x 2.00) + (1 x 1.65)
+ 0.62 = 4.27

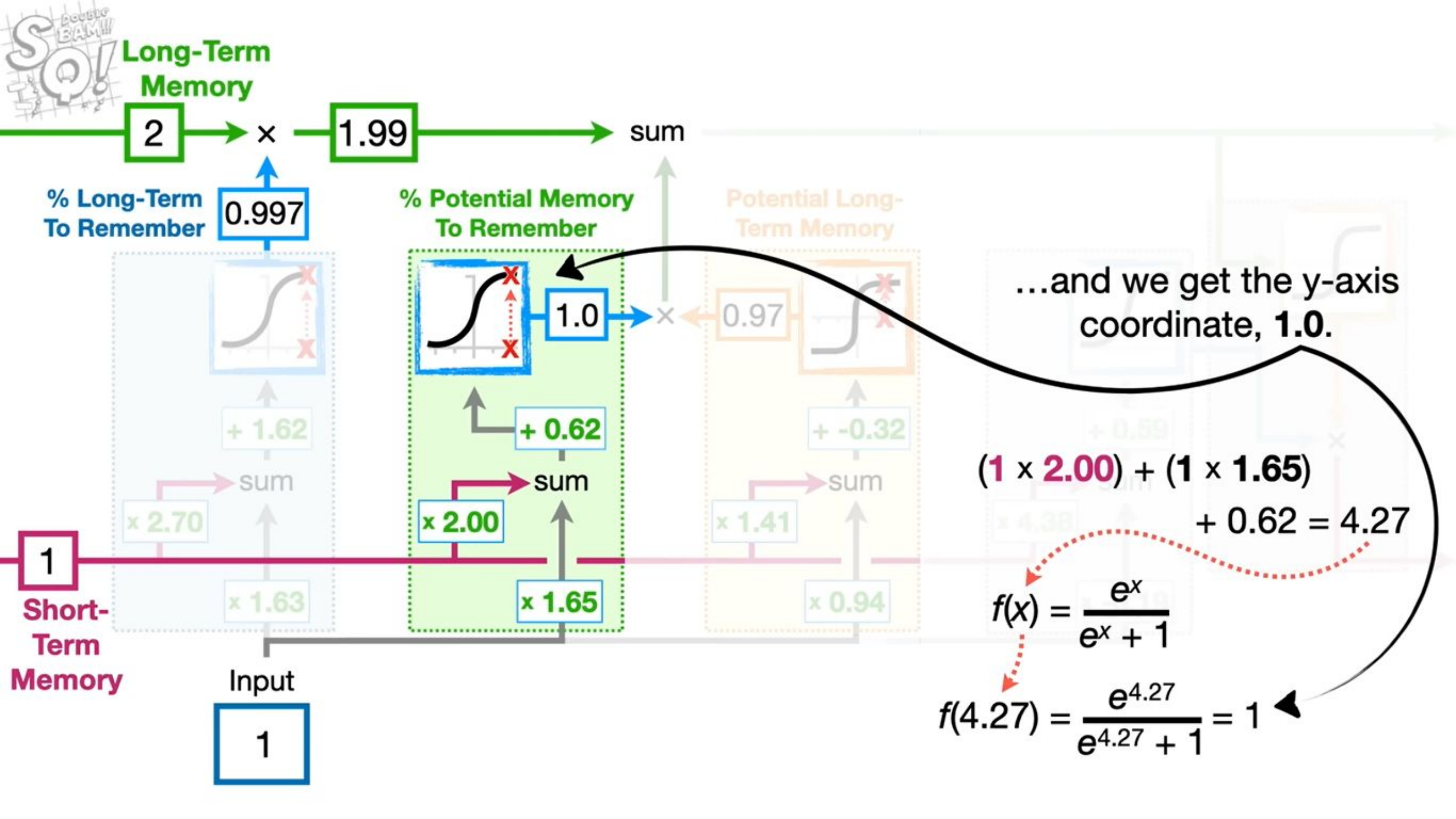


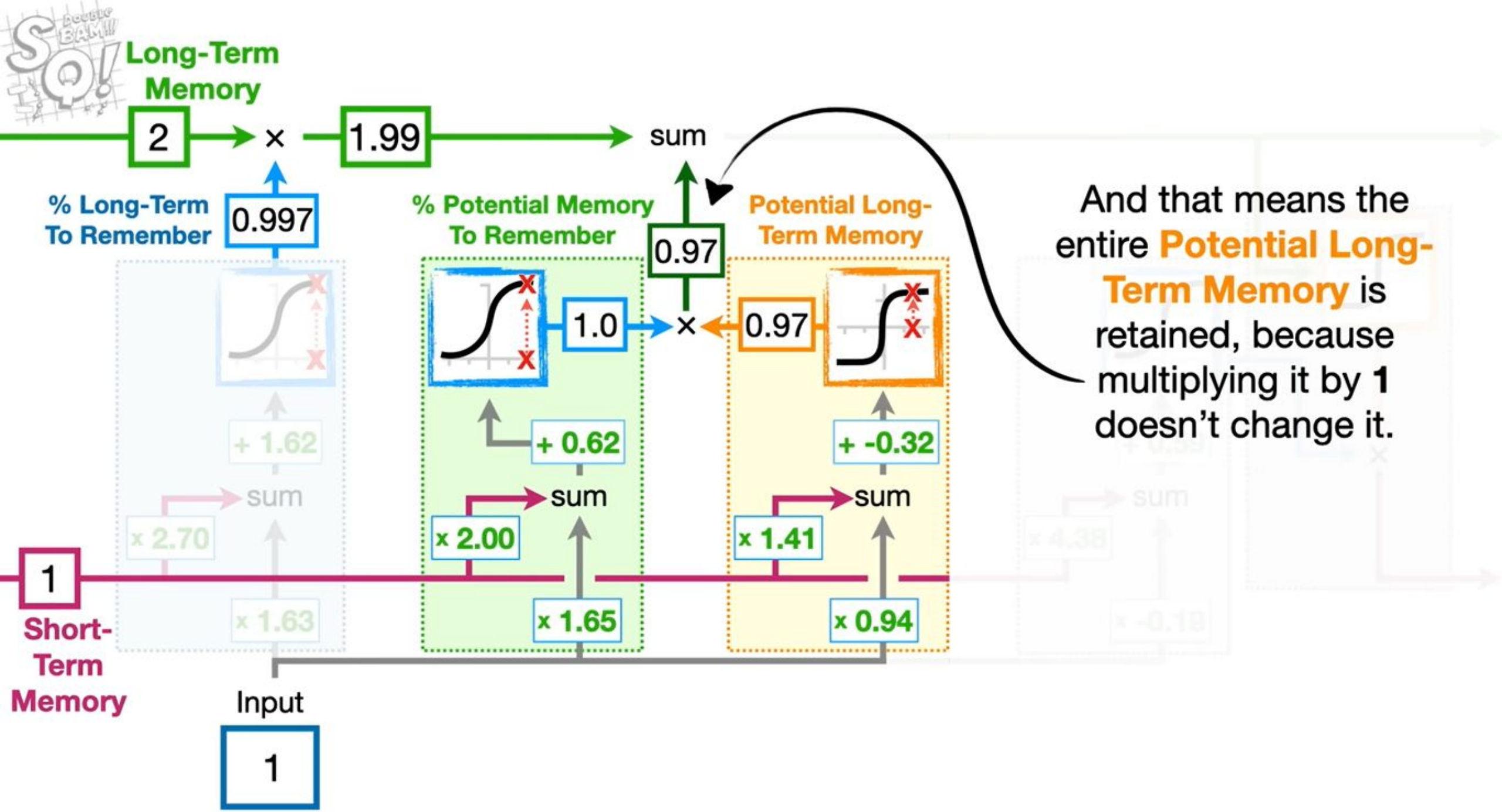
Now we plug the x-axis coordinate into the equation for the **Sigmoid Activation Function**…

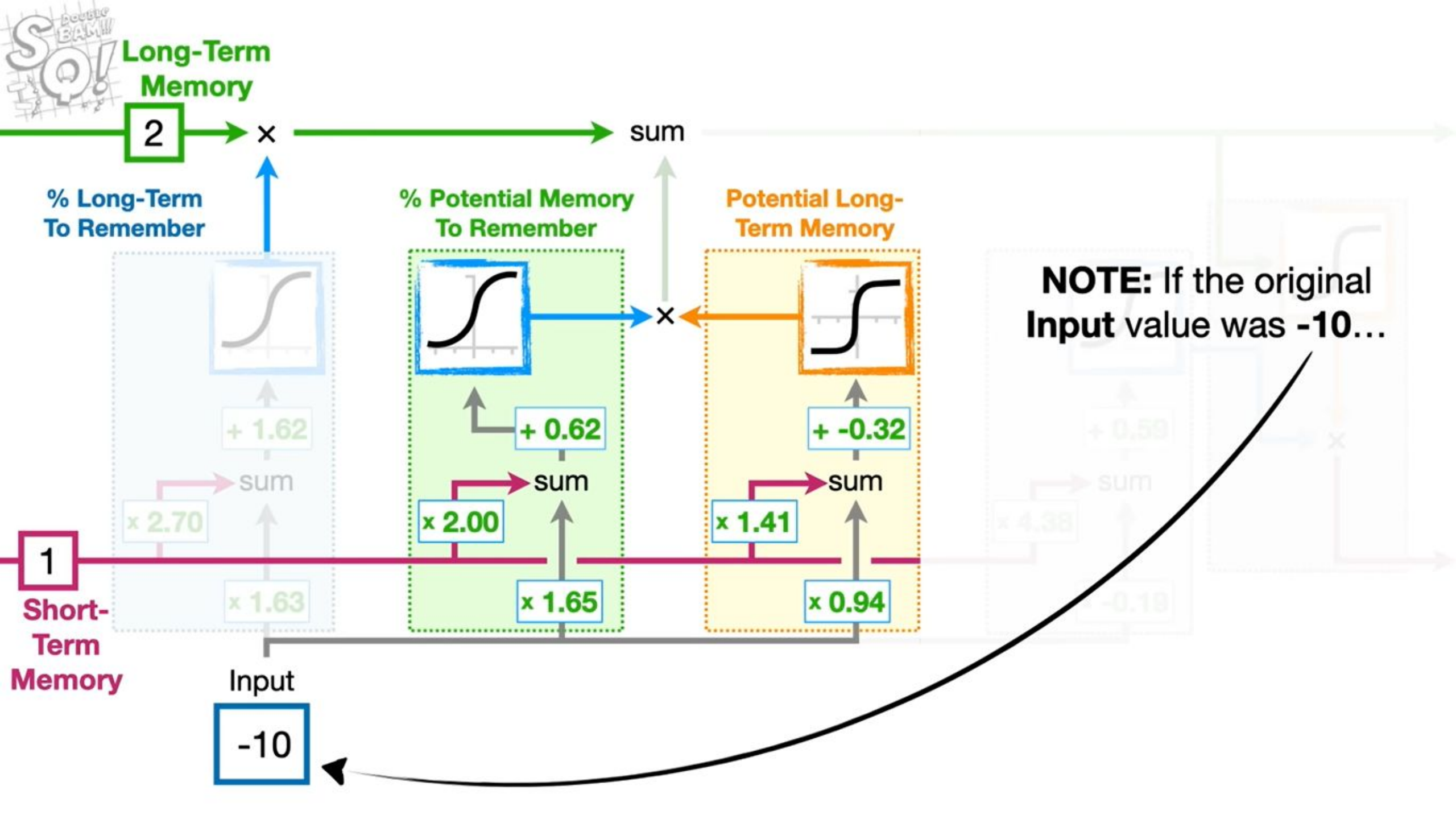
$$(1 \times 2.00) + (1 \times 1.65) + 0.62 = 4.27$$

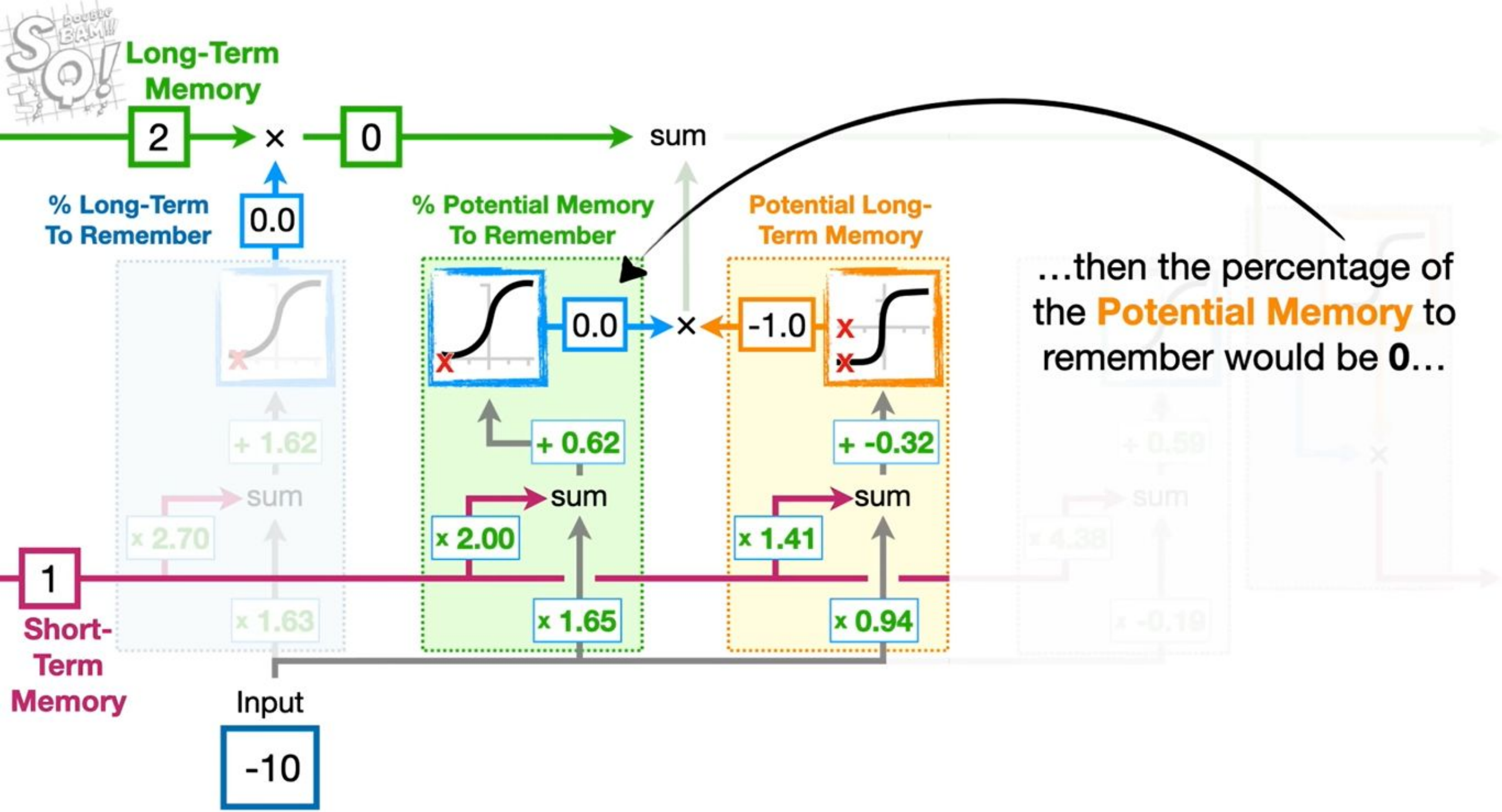
$$f(x) = \frac{e^x}{e^x + 1}$$

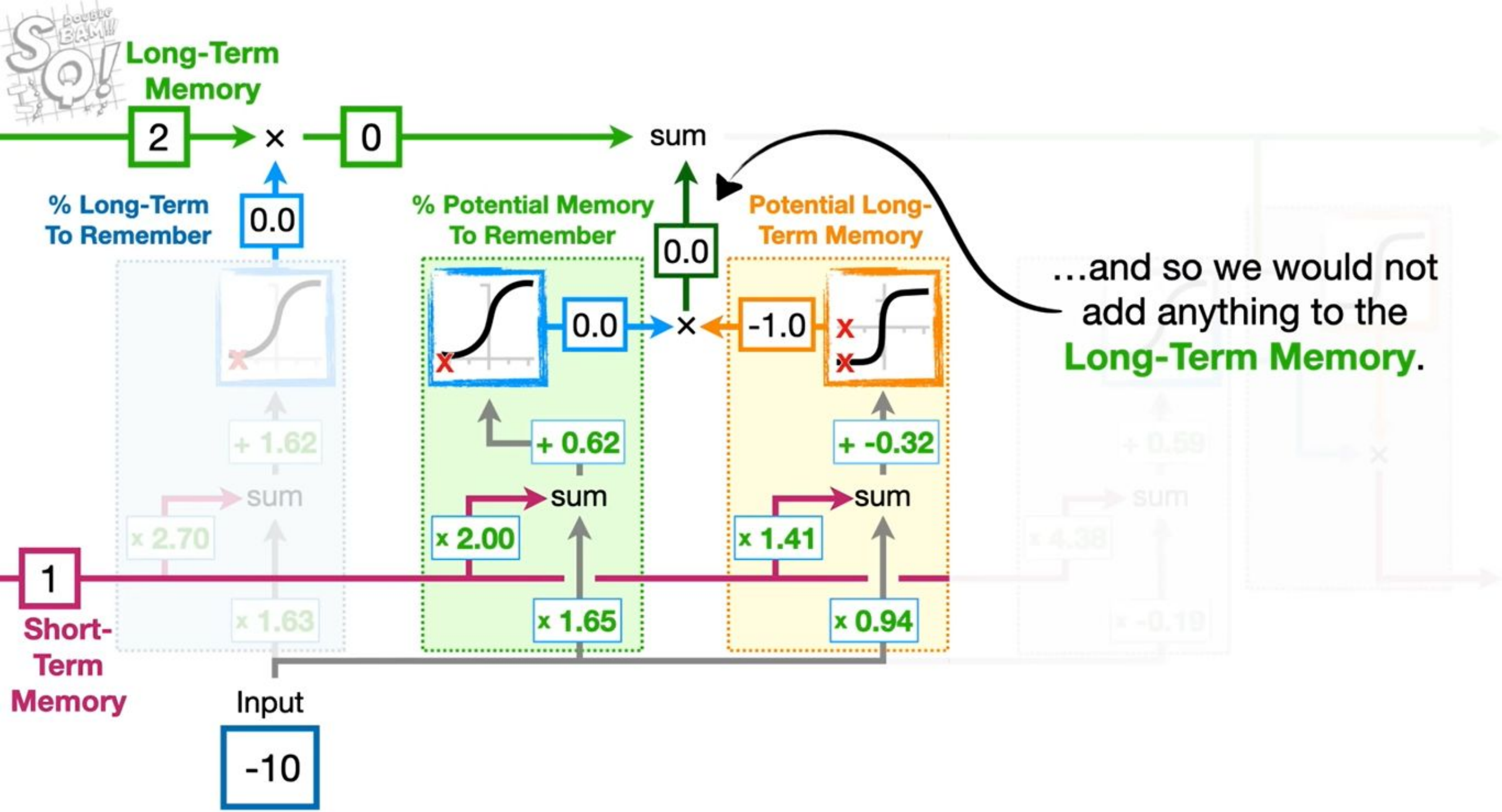
$$f(4.27) = \frac{e^{4.27}}{e^{4.27} + 1} = 1$$

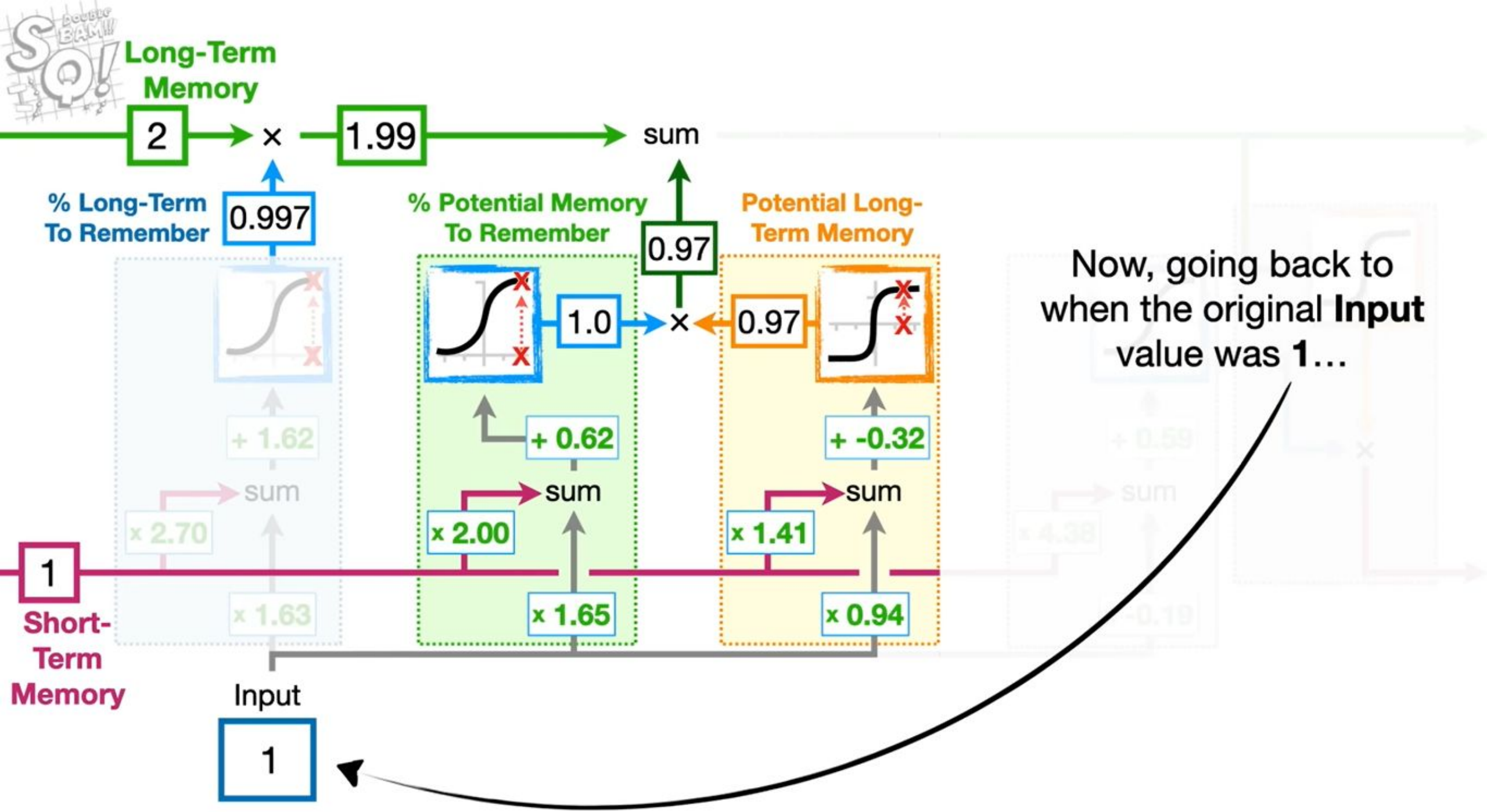

Long-Term Memory
2
×
1.99
sum
% Long-Term To Remember
0.997
% Potential Memory To Remember
Potential Long-Term Memory
1.0
0.97
+ 0.62
+ 1.62
+ -0.32
sum
sum
x 2.70
x 2.00
x 1.41
1
x 1.63
x 1.65
x 0.94
Short-Term Memory
Input
1
…and we get the y-axis coordinate, 1.0.
(1 x 2.00) + (1 x 1.65)
+ 0.62 = 4.27
$f(x) = \frac{e^x}{e^x + 1}$
$f(4.27) = \frac{e^{4.27}}{e^{4.27} + 1} = 1$

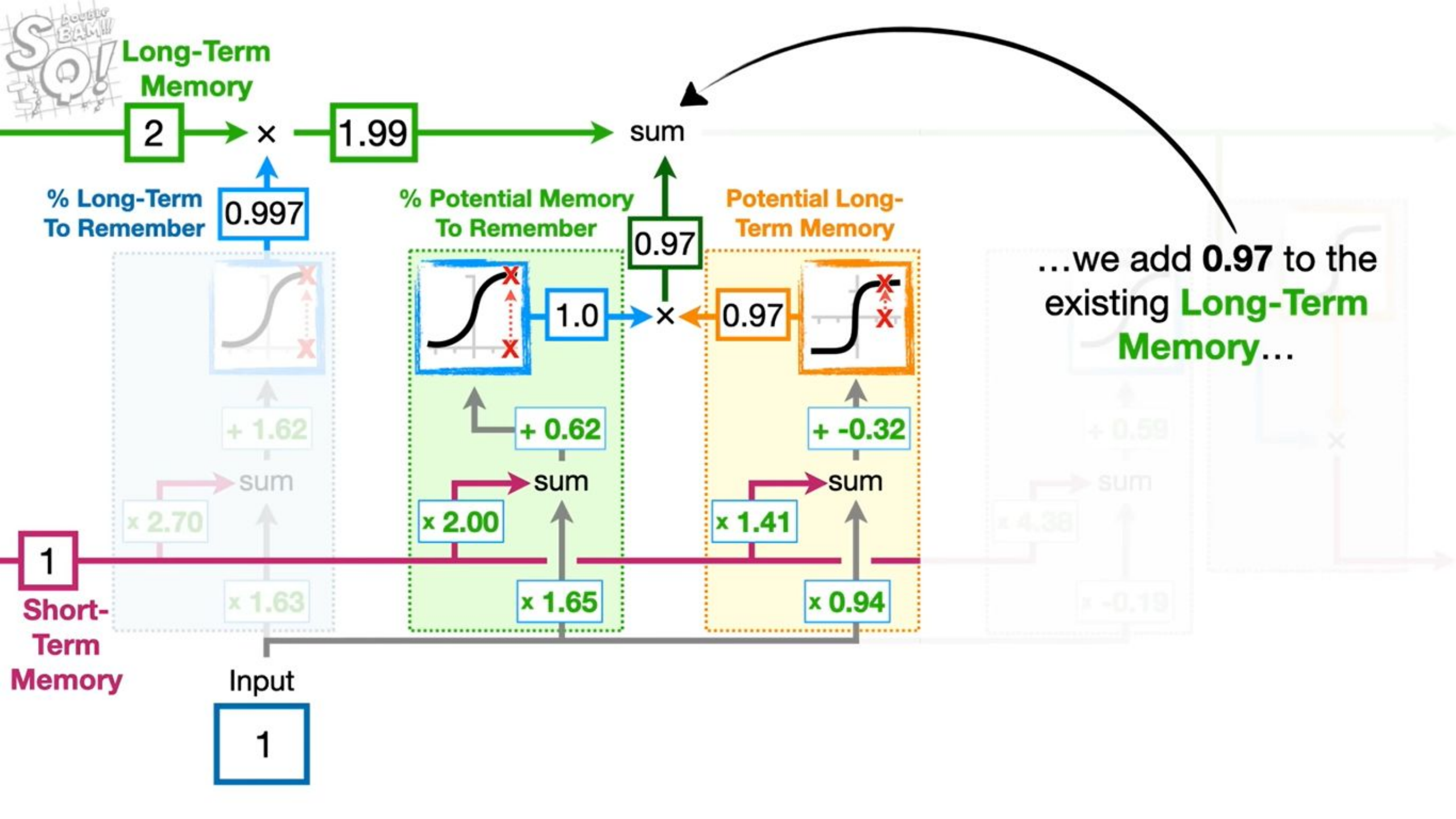

Long-Term Memory
2
×
1.99
sum
% Long-Term To Remember
0.997
% Potential Memory To Remember
0.97
Potential Long-Term Memory
1.0
×
0.97
+ 0.62
+ -0.32
sum
sum
x 2.00
x 1.41
1
Short-Term Memory
x 1.65
x 0.94
Input
1
And that means the entire Potential Long-Term Memory is retained, because multiplying it by 1 doesn't change it.

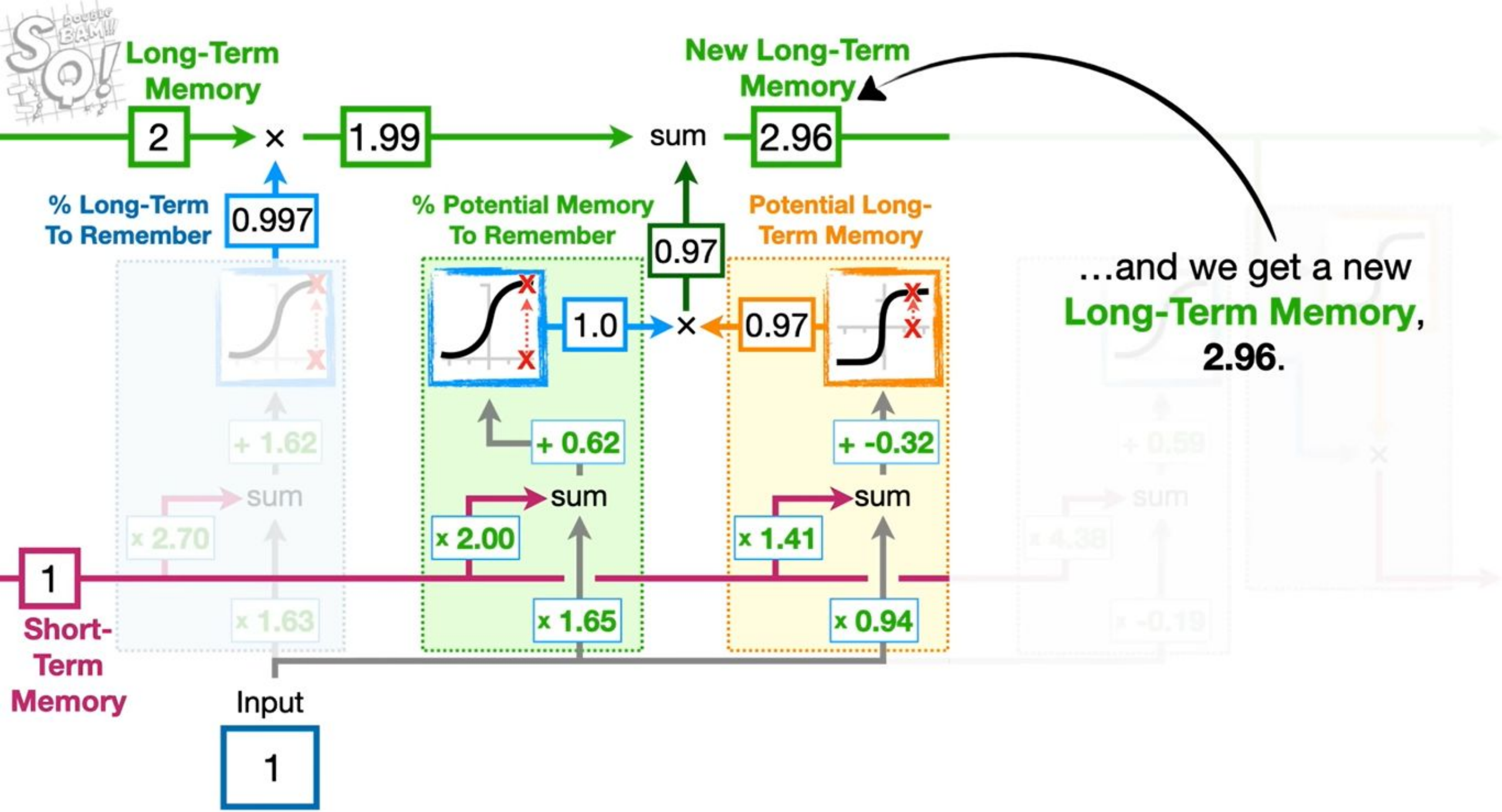

Long-Term Memory
2
x
sum
% Long-Term To Remember
% Potential Memory To Remember
Potential Long-Term Memory
x
+ 1.62
+ 0.62
+ -0.32
sum
sum
sum
x 2.70
x 2.00
x 1.41
1
x 1.63
x 1.65
x 0.94
Short-Term Memory
Input
-10
NOTE: If the original Input value was -10…

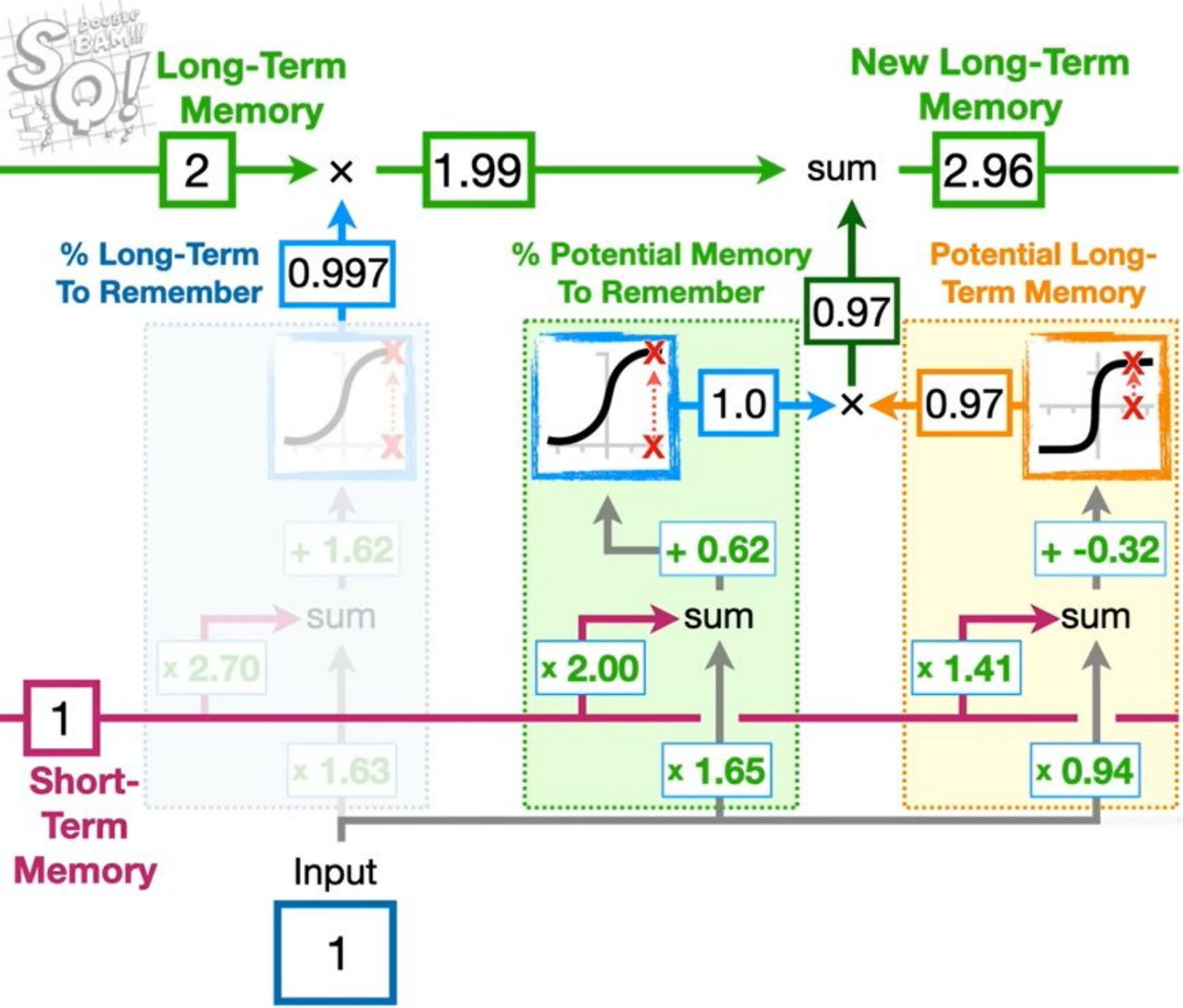

Long-Term Memory
2
×
0
sum
% Long-Term To Remember
0.0
% Potential Memory To Remember
Potential Long-Term Memory
0.0
×
-1.0
+ 0.62
+ -0.32
sum
sum
x 2.00
x 1.41
1
x 1.65
x 0.94
Short-Term Memory
Input
-10
…then the percentage of the Potential Memory to remember would be 0…


Long-Term Memory
2
×
0
sum
% Long-Term To Remember
0.0
% Potential Memory To Remember
0.0
Potential Long-Term Memory
0.0
×
-1.0
+ 0.62
+ -0.32
sum
sum
x 2.00
x 1.41
1
x 1.65
x 0.94
Short-Term Memory
Input
-10
…and so we would not add anything to the Long-Term Memory.


Long-Term Memory
2
×
1.99
sum
% Long-Term To Remember
0.997
% Potential Memory To Remember
0.97
Potential Long-Term Memory
1.0
×
0.97
+ 0.62
+ -0.32
sum
sum
x 2.00
x 1.41
1
x 1.65
x 0.94
Short-Term Memory
Input
1
Now, going back to when the original Input value was 1…


Long-Term Memory
2
×
1.99
sum
…we add 0.97 to the existing Long-Term Memory…
% Long-Term To Remember
0.997
% Potential Memory To Remember
0.97
Potential Long-Term Memory
1.0
×
0.97
+ 1.62
+ 0.62
+ -0.32
sum
sum
sum
x 2.70
x 2.00
x 1.41
1
x 1.63
x 1.65
x 0.94
Short-Term Memory
Input
1

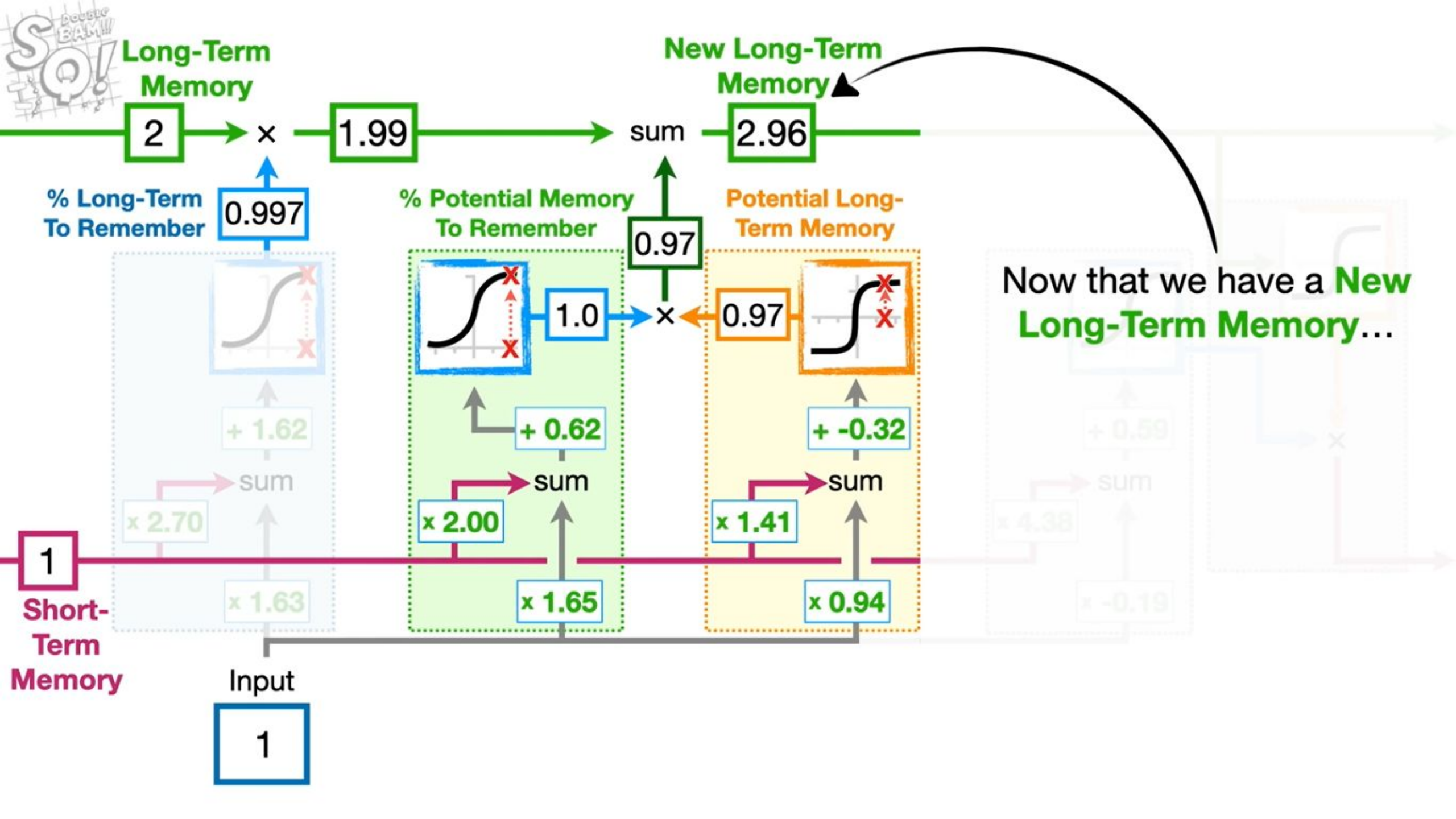

Long-Term Memory
2
×
1.99
sum
2.96
New Long-Term Memory
% Long-Term To Remember
0.997
% Potential Memory To Remember
0.97
Potential Long-Term Memory
1.0
×
0.97
+ 1.62
sum
x 2.70
x 1.63
+ 0.62
sum
x 2.00
x 1.65
+ -0.32
sum
x 1.41
x 0.94
1
Short-Term Memory
Input
1
…and we get a new Long-Term Memory, 2.96.

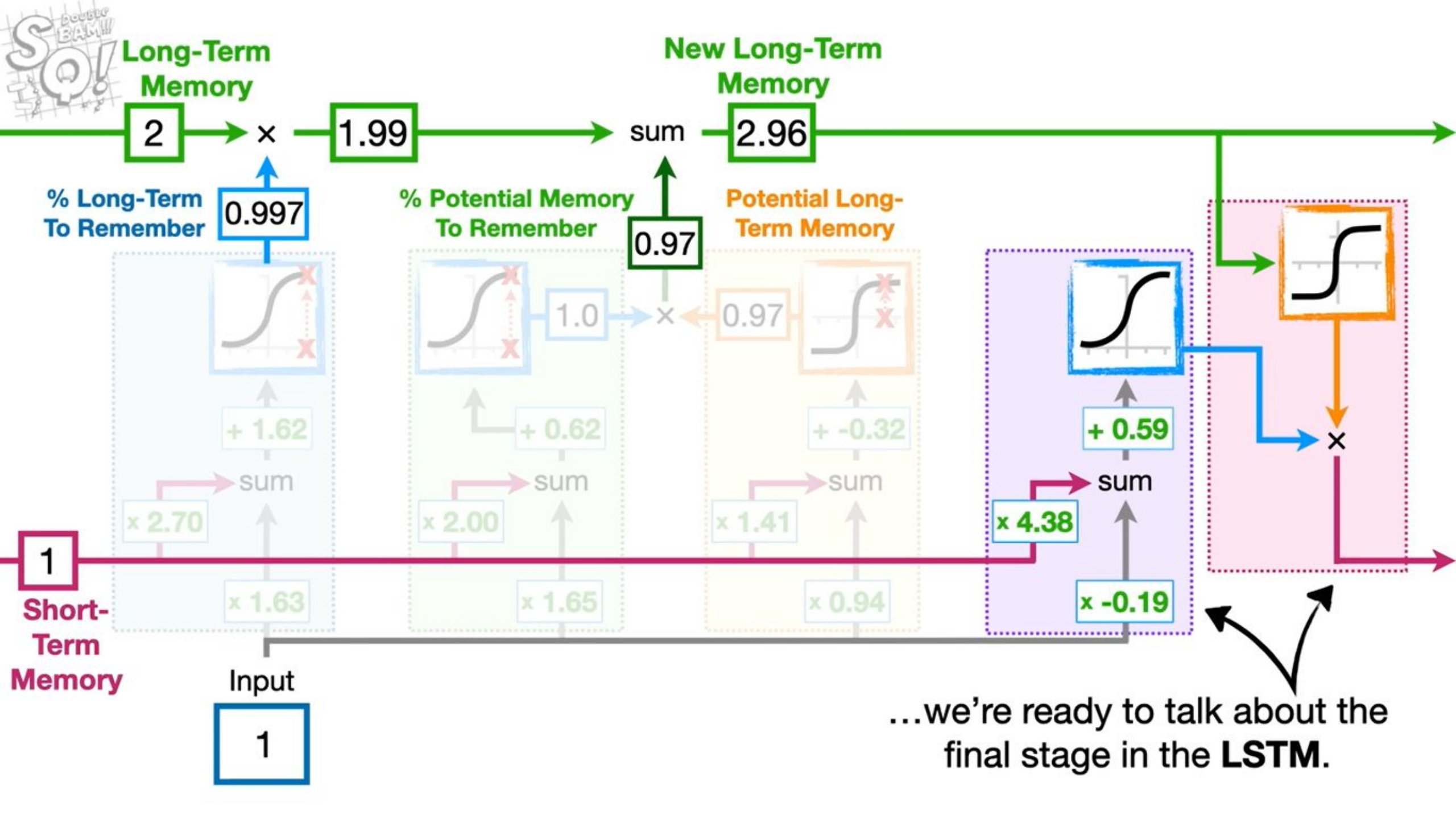


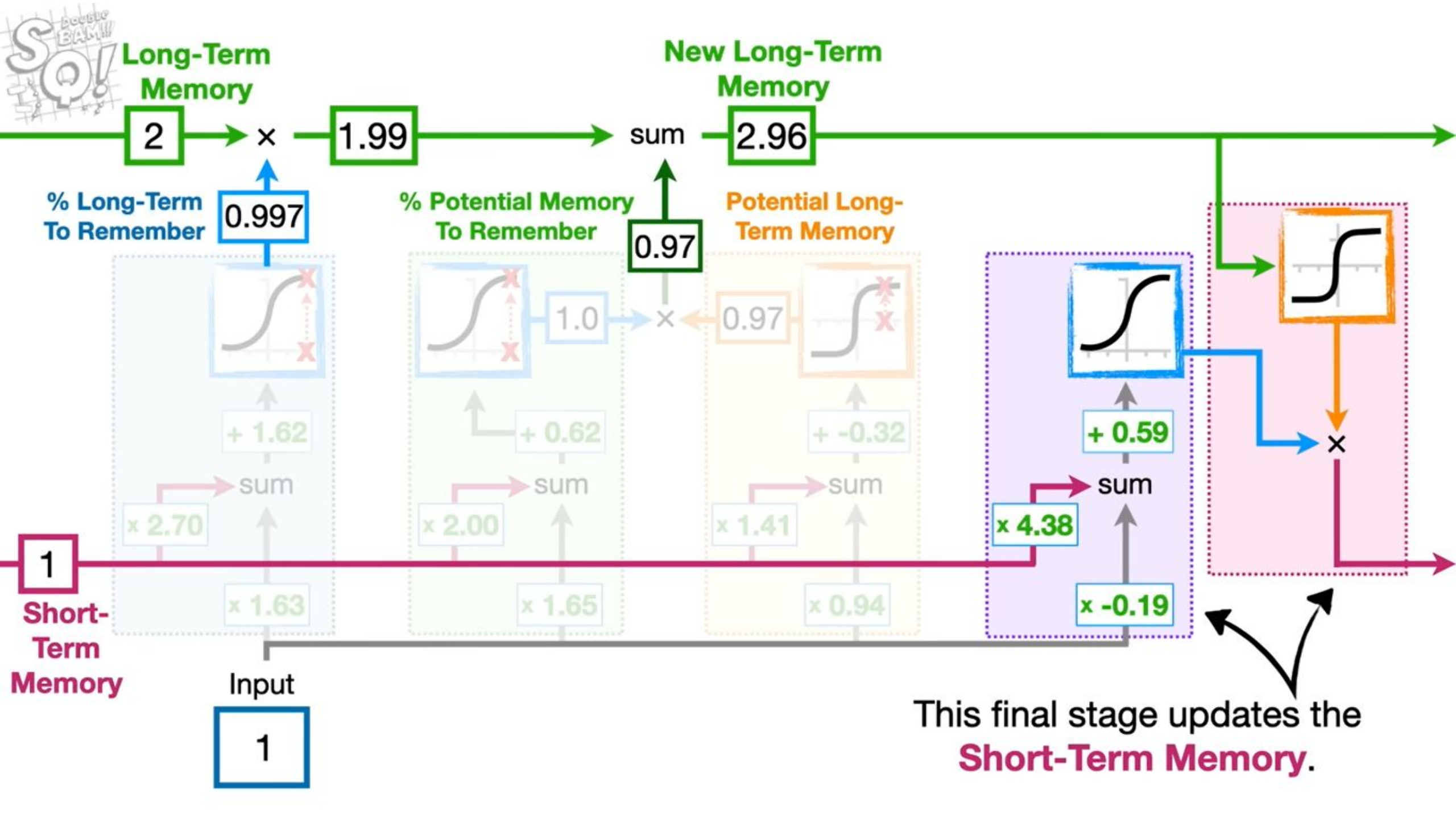
TERMINOLOGY ALERT!!!

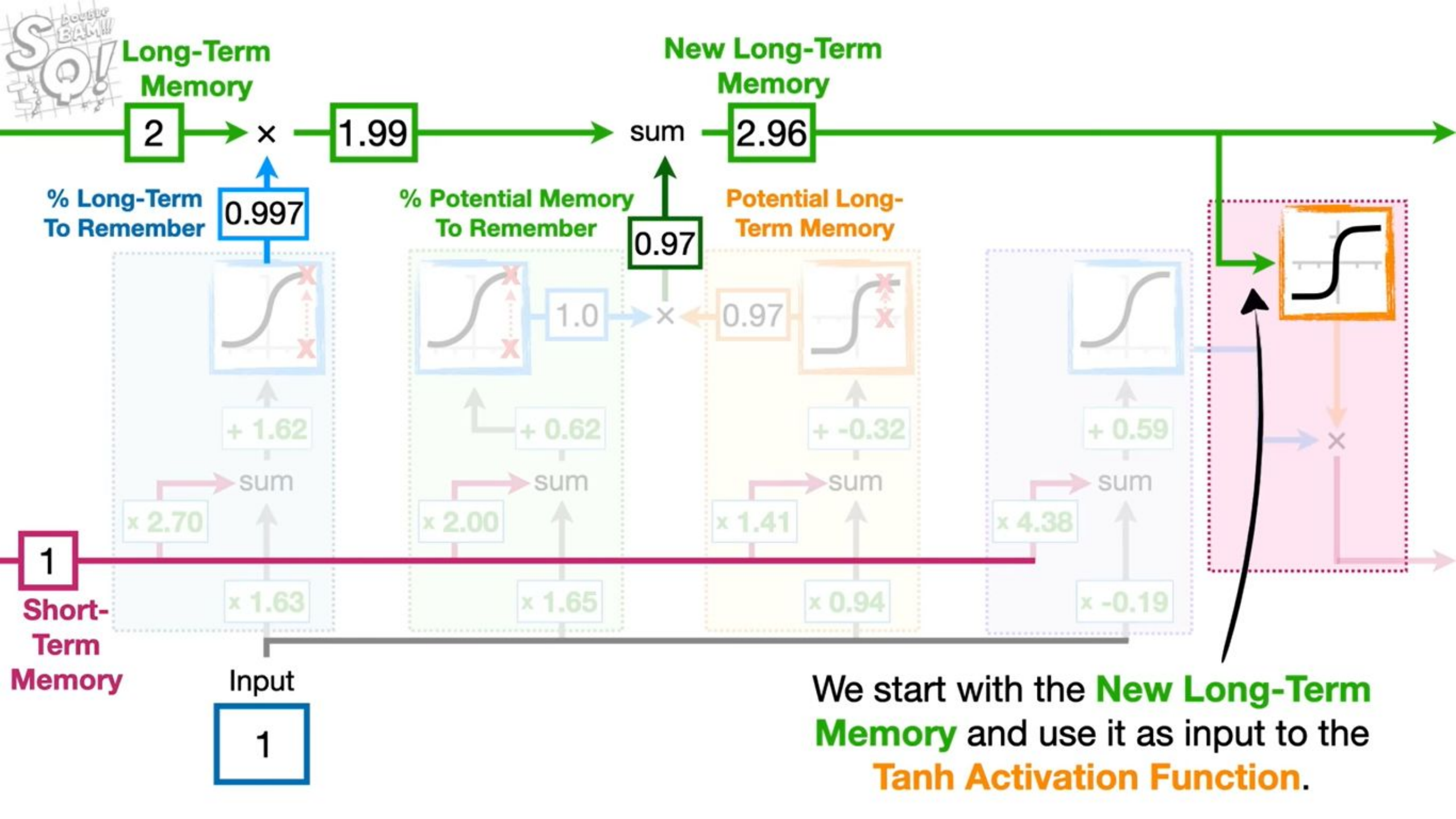
Even though this part of the **Long Short-Term Memory** unit determines how we should update the **Long-Term Memory**…

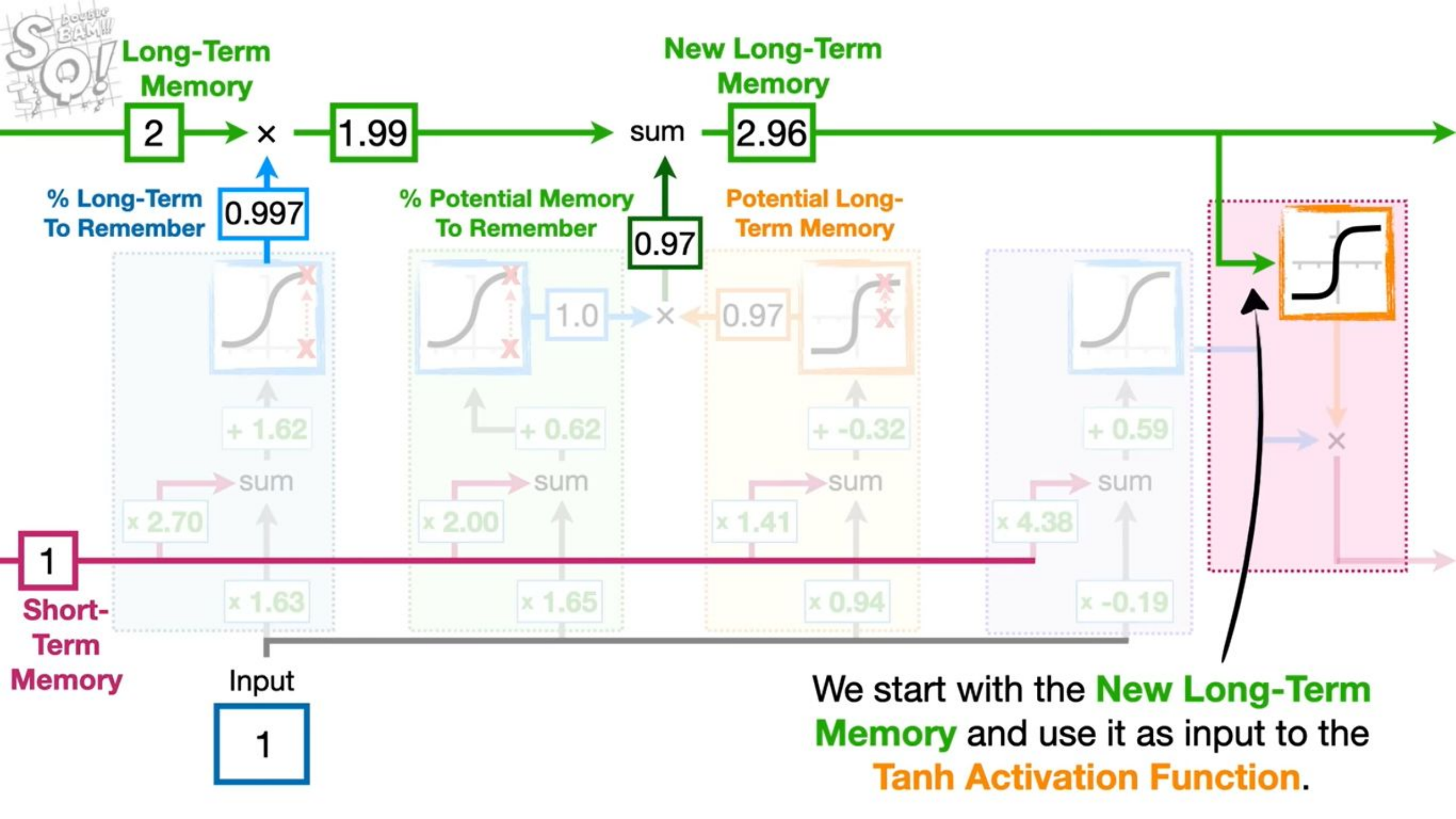
…it is usually called the **Input Gate**.

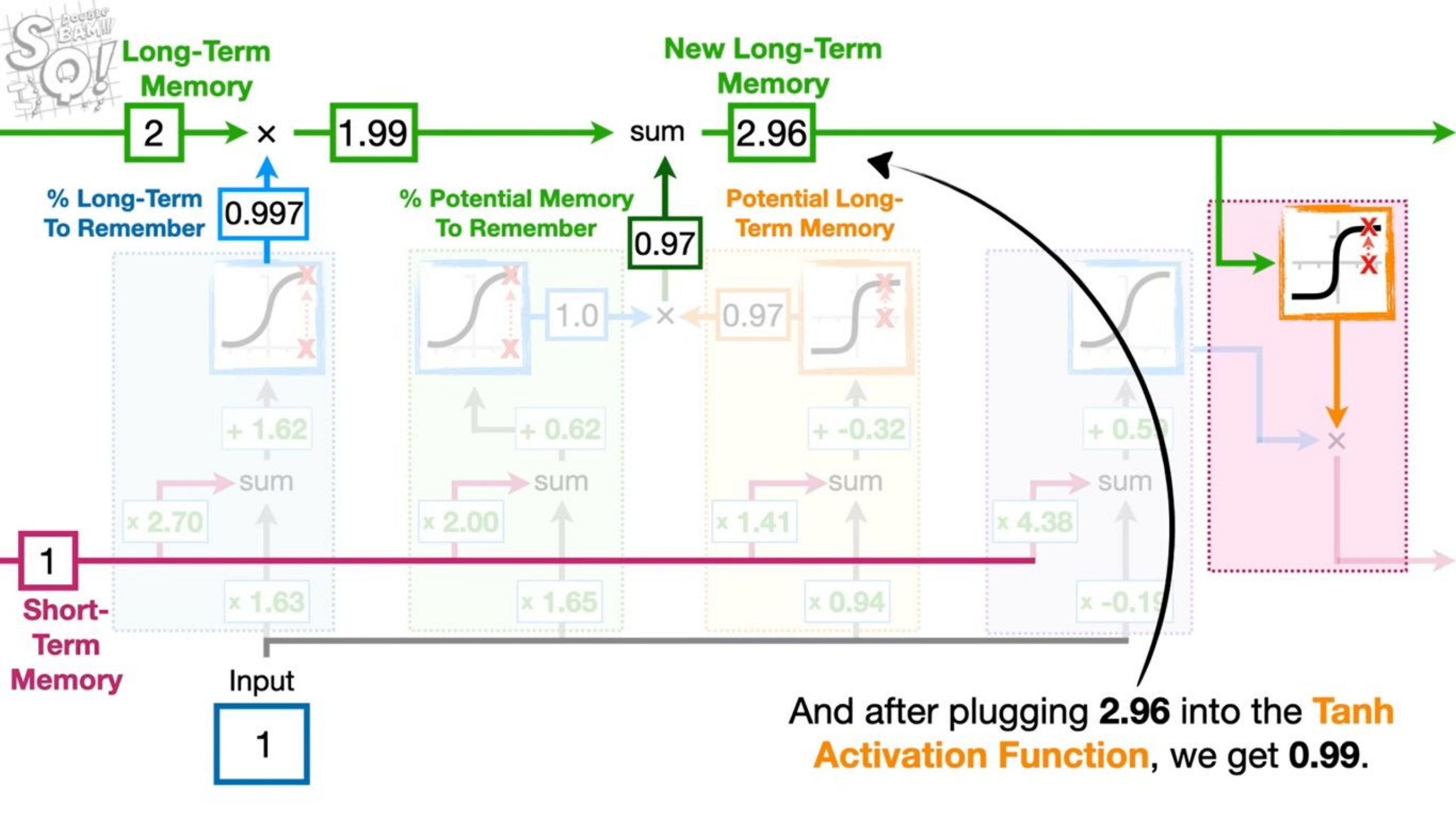

Long-Term Memory
2
×
1.99
sum
2.96
New Long-Term Memory
% Long-Term To Remember
0.997
% Potential Memory To Remember
0.97
Potential Long-Term Memory
1.0
×
0.97
+ 1.62
sum
x 2.70
x 1.63
+ 0.62
sum
x 2.00
x 1.65
+ -0.32
sum
x 1.41
x 0.94
1
Short-Term Memory
Input
1
Now that we have a New Long-Term Memory…

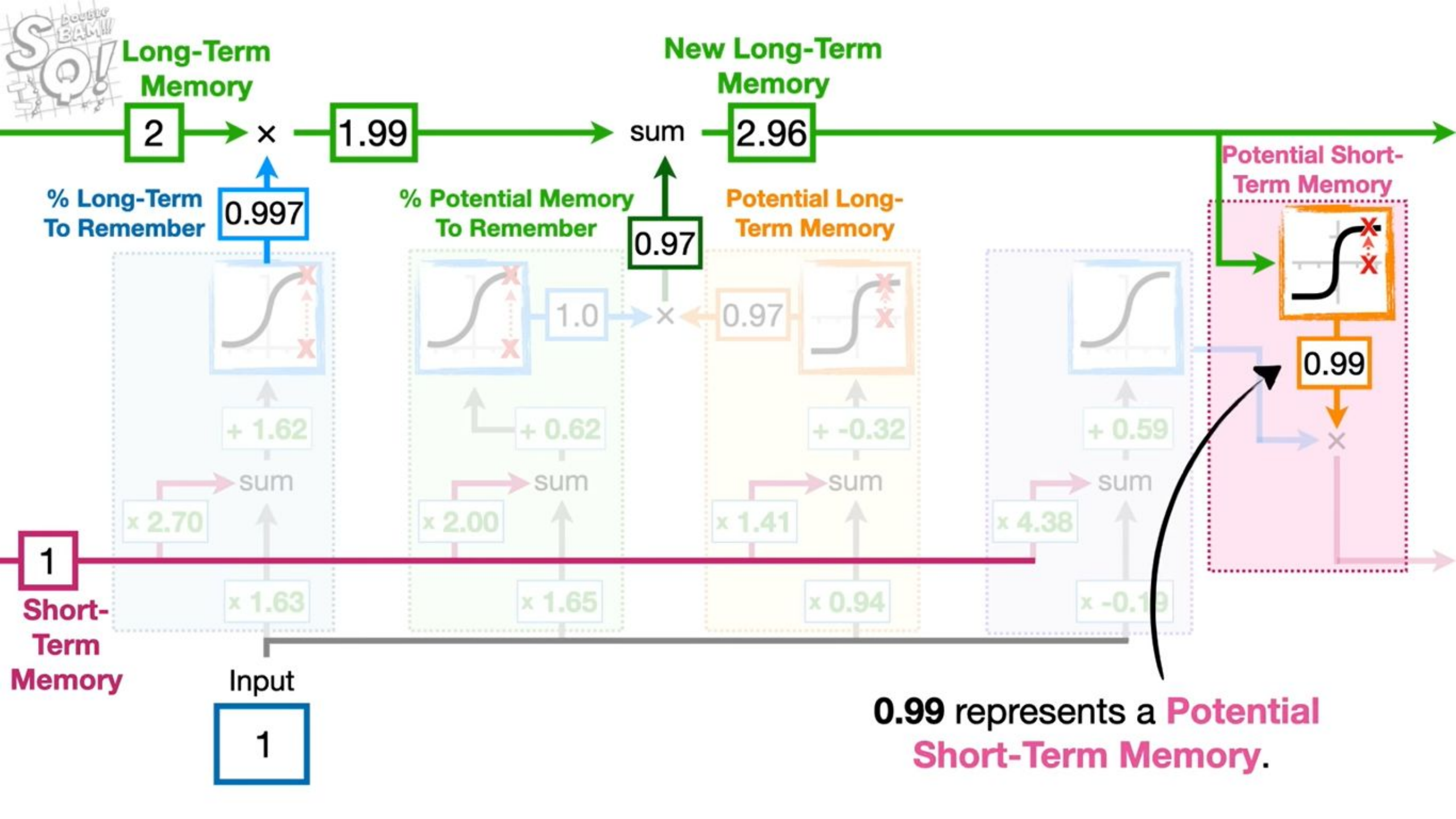

Long-Term Memory
2
×
1.99
sum
New Long-Term Memory
2.96
% Long-Term To Remember
0.997
% Potential Memory To Remember
0.97
Potential Long-Term Memory
1.0
×
0.97
+ 1.62
sum
x 2.70
x 1.63
+ 0.62
sum
x 2.00
x 1.65
+ -0.32
sum
x 1.41
x 0.94
+ 0.59
sum
x 4.38
x -0.19
×
1
Short-Term Memory
Input
1
…we're ready to talk about the final stage in the **LSTM**.

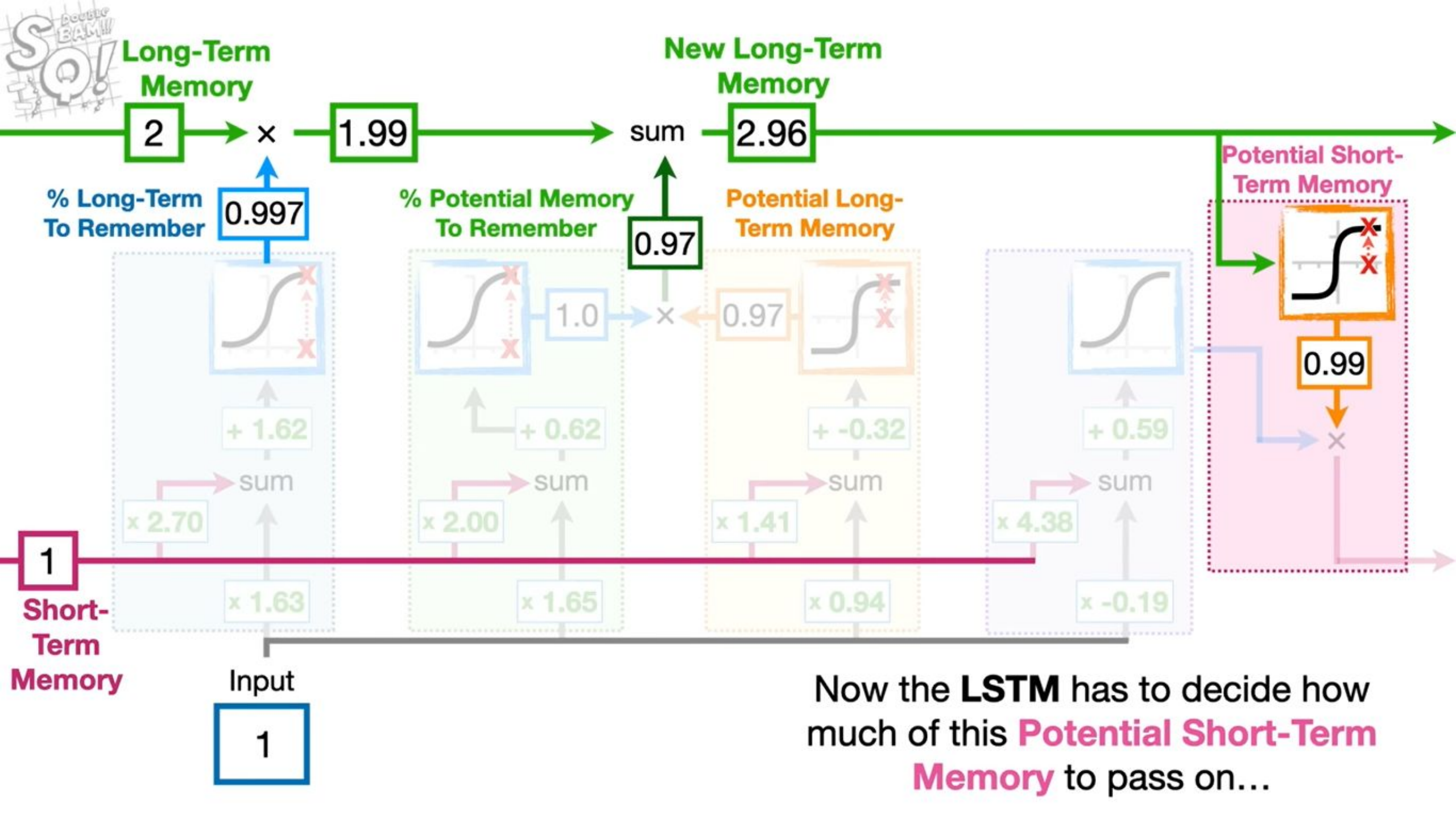

Long-Term Memory
2
×
1.99
sum
New Long-Term Memory
2.96
% Long-Term To Remember
0.997
% Potential Memory To Remember
0.97
Potential Long-Term Memory
1.0
×
0.97
+ 1.62
sum
x 2.70
x 1.63
+ 0.62
sum
x 2.00
x 1.65
+ -0.32
sum
x 1.41
x 0.94
+ 0.59
sum
x 4.38
x -0.19
×
1
Short-Term Memory
Input
1
This final stage updates the Short-Term Memory.

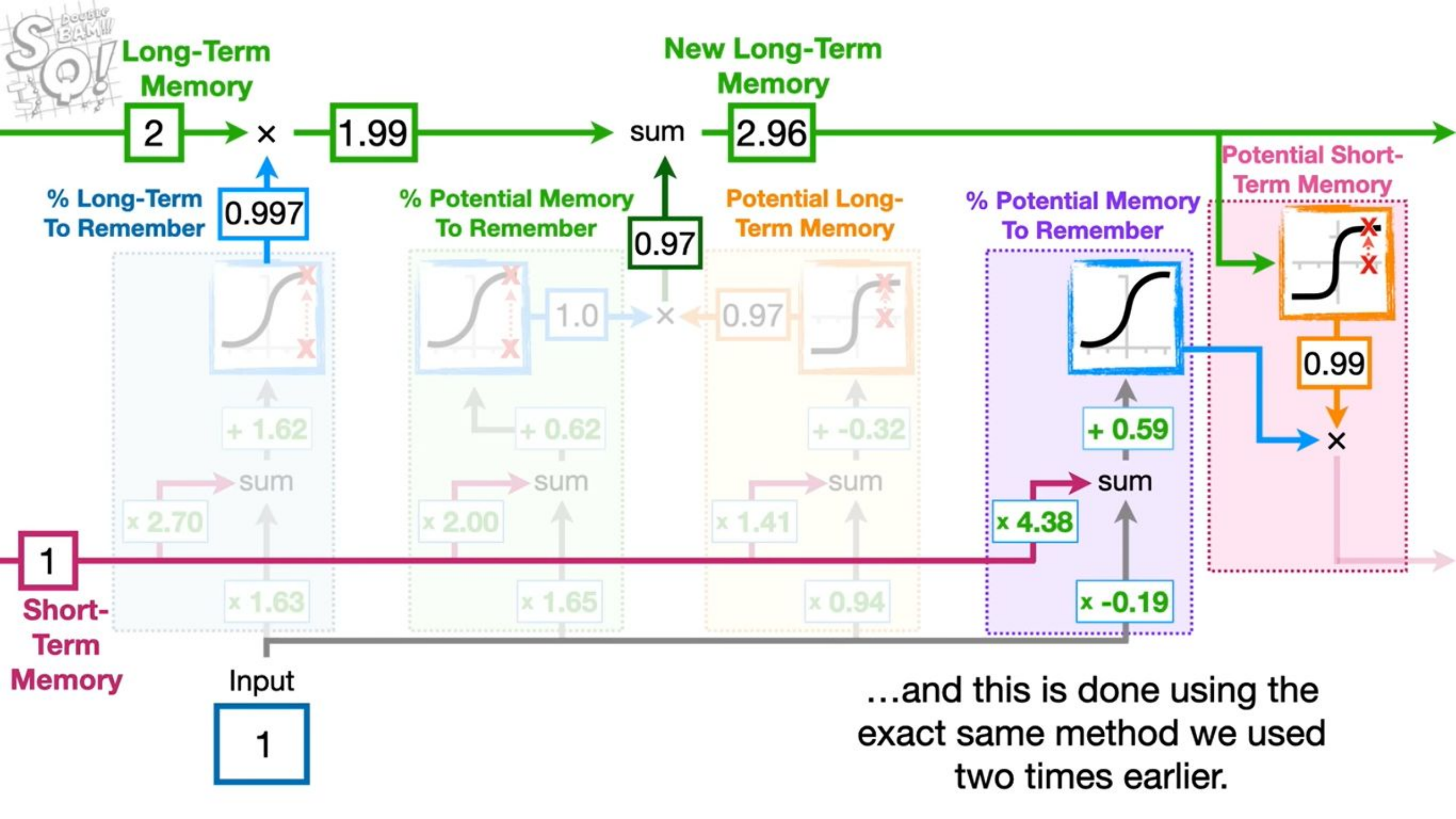

Long-Term Memory
2
×
1.99
sum
New Long-Term Memory
2.96
% Long-Term To Remember
0.997
% Potential Memory To Remember
0.97
Potential Long-Term Memory
1.0
×
0.97
+ 1.62
sum
x 2.70
x 1.63
+ 0.62
sum
x 2.00
x 1.65
+ -0.32
sum
x 1.41
x 0.94
+ 0.59
sum
x 4.38
x -0.19
1
Short-Term Memory
Input
1
We start with the New Long-Term Memory and use it as input to the Tanh Activation Function.

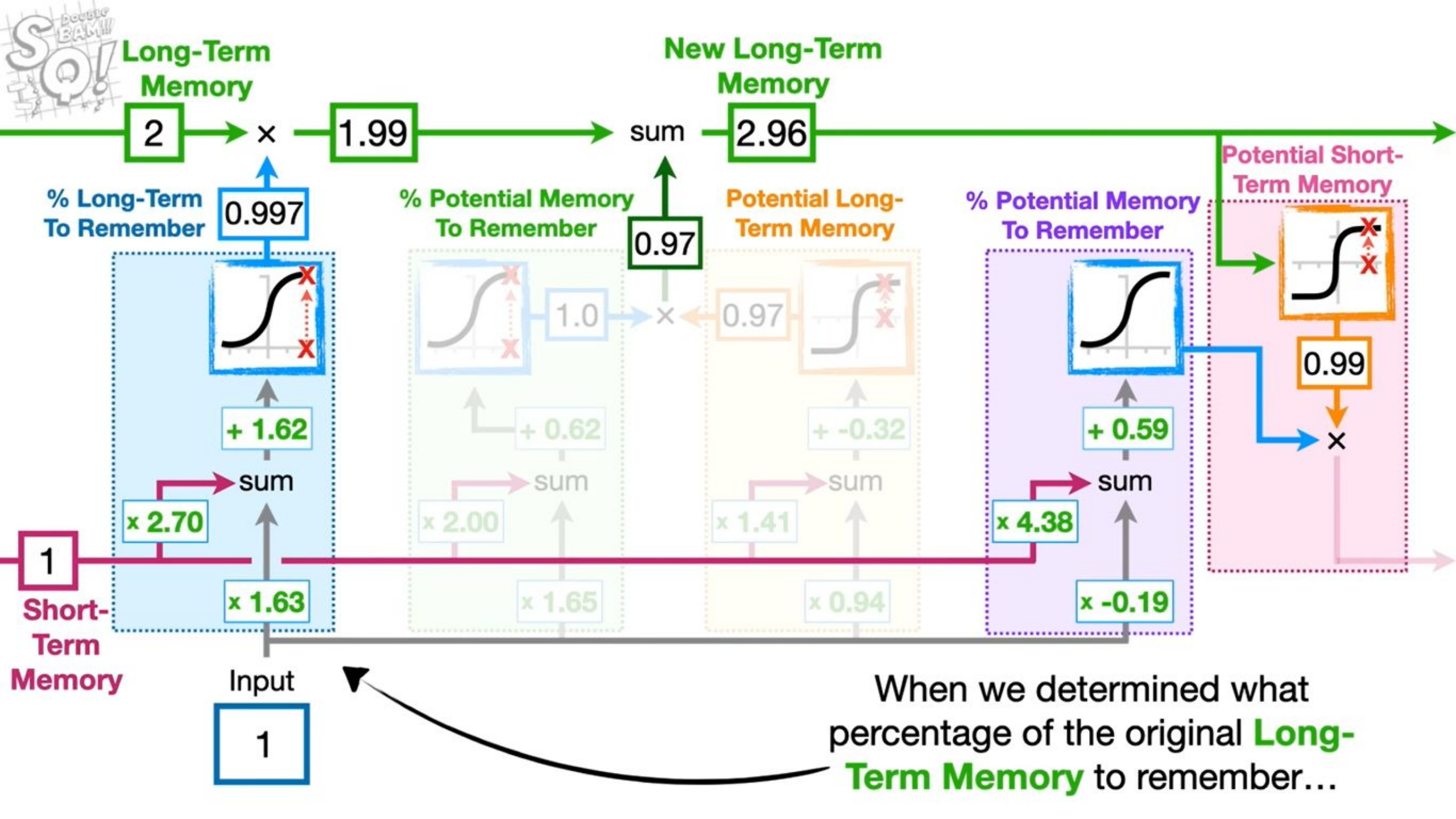

Long-Term Memory
2
×
1.99
sum
New Long-Term Memory
2.96
% Long-Term To Remember
0.997
% Potential Memory To Remember
0.97
Potential Long-Term Memory
1.0
×
0.97
+ 1.62
sum
x 2.70
x 1.63
+ 0.62
sum
x 2.00
x 1.65
+ -0.32
sum
x 1.41
x 0.94
+ 0.59
sum
x 4.38
x -0.19
1
Short-Term Memory
Input
1
We start with the New Long-Term Memory and use it as input to the Tanh Activation Function.

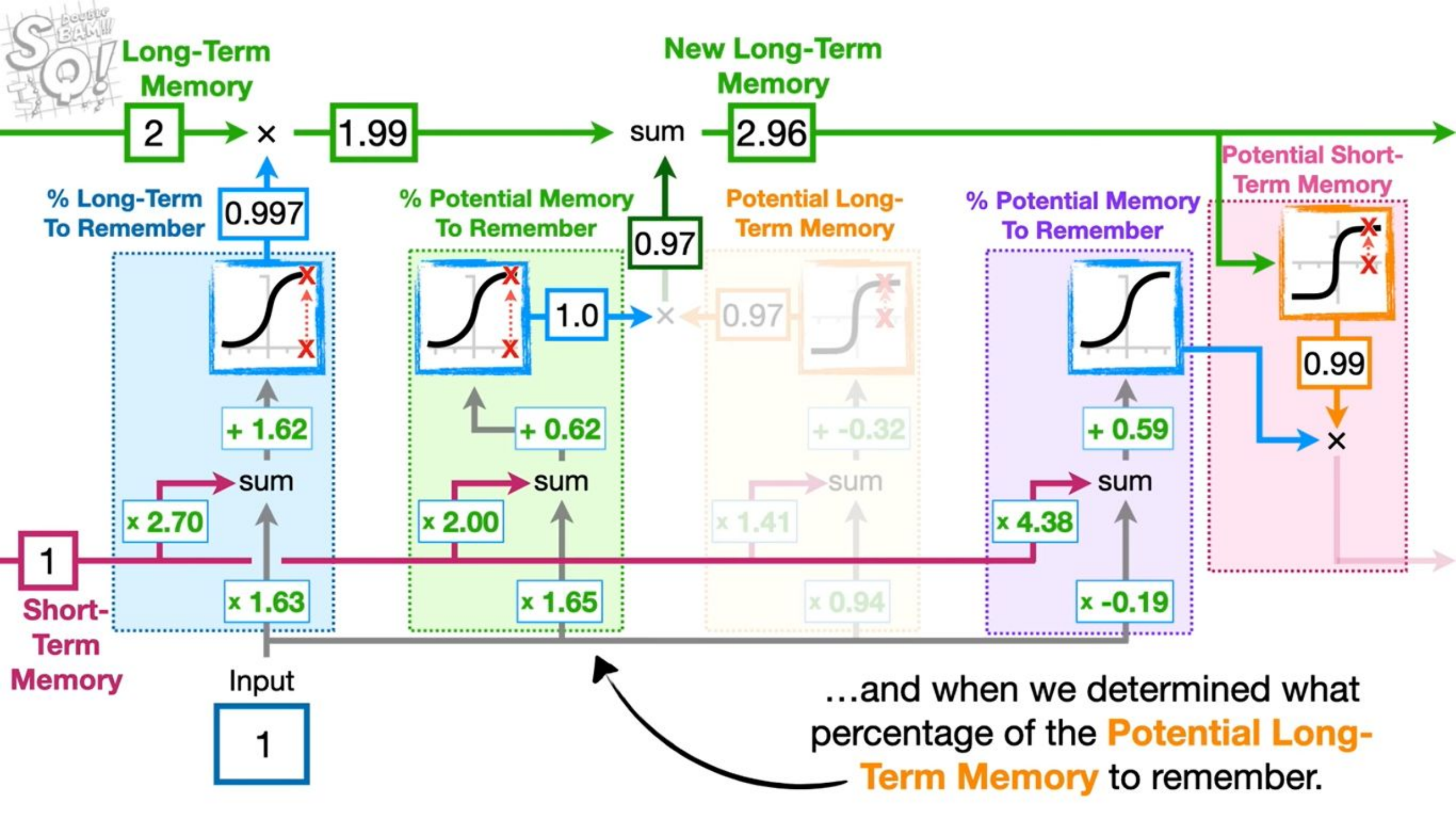

Long-Term Memory
2
×
1.99
sum
New Long-Term Memory
2.96
% Long-Term To Remember
0.997
% Potential Memory To Remember
0.97
Potential Long-Term Memory
1.0
×
0.97
+ 1.62
+ 0.62
+ -0.32
+ 0.5
sum
sum
sum
sum
x 2.70
x 2.00
x 1.41
x 4.38
1
x 1.63
x 1.65
x 0.94
x -0.1
Short-Term Memory
Input
1
And after plugging 2.96 into the Tanh Activation Function, we get 0.99.

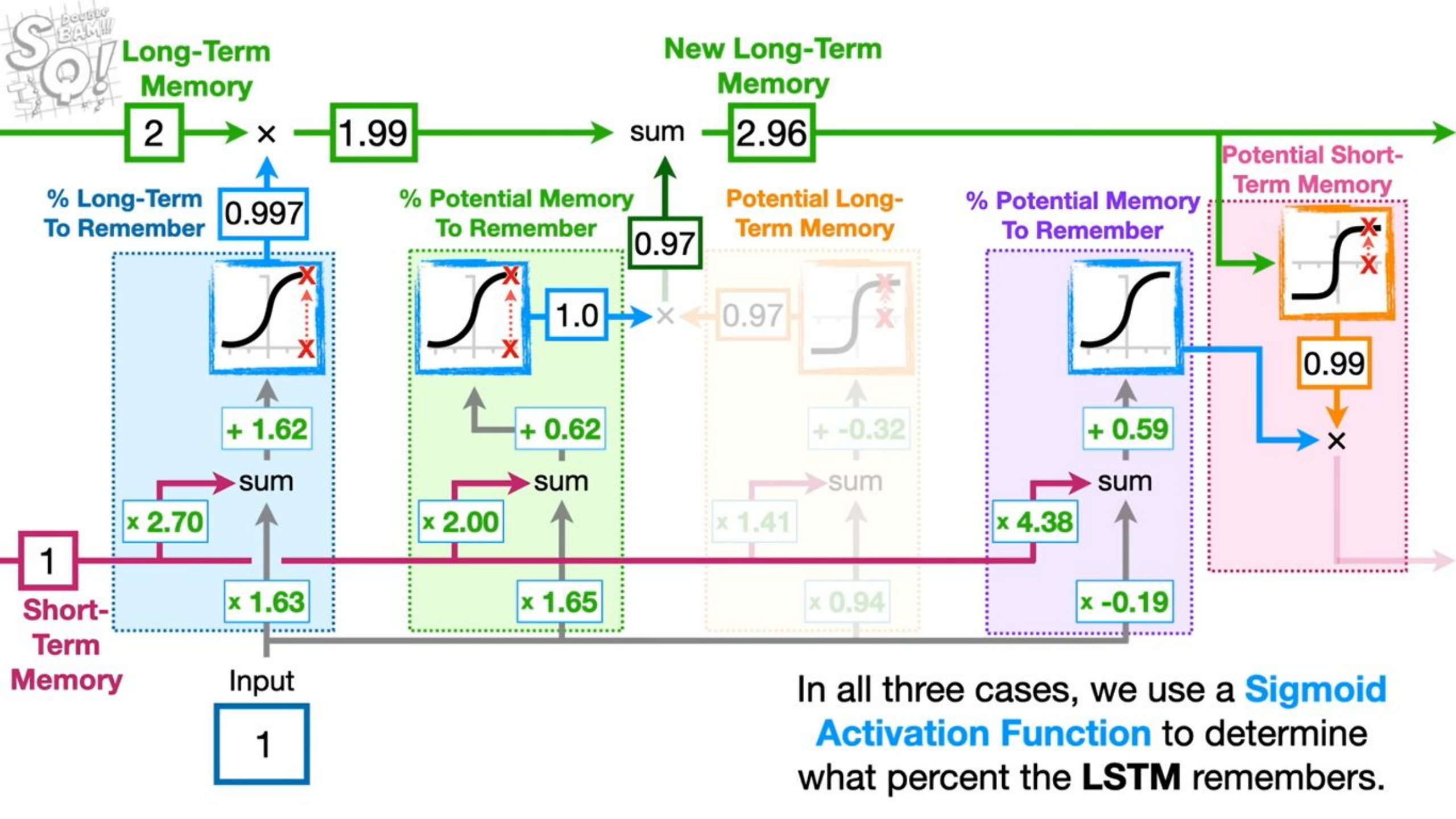

Long-Term Memory
2
×
1.99
sum
New Long-Term Memory
2.96
% Long-Term To Remember
0.997
% Potential Memory To Remember
0.97
Potential Long-Term Memory
Potential Short-Term Memory
1.0
0.97
0.99
+ 1.62
+ 0.62
+ -0.32
+ 0.59
sum
x 2.70
x 2.00
x 1.41
x 4.38
1
x 1.63
x 1.65
x 0.94
Short-Term Memory
Input
1
0.99 represents a Potential Short-Term Memory.

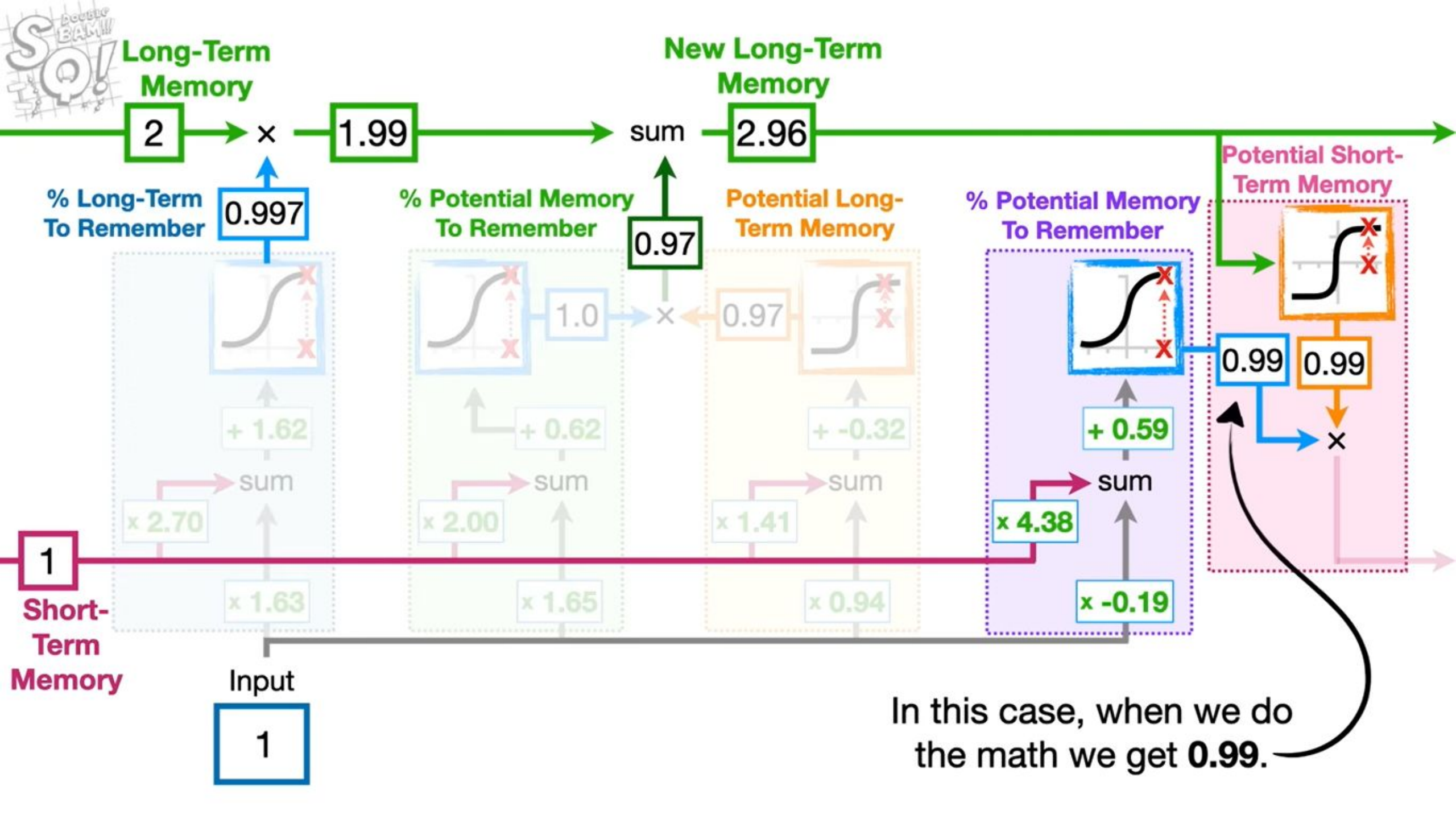

Long-Term Memory
2
×
1.99
sum
New Long-Term Memory
2.96
% Long-Term To Remember
0.997
% Potential Memory To Remember
0.97
Potential Long-Term Memory
Potential Short-Term Memory
0.99
1.0
0.97
+ 1.62
+ 0.62
+ -0.32
+ 0.59
sum
x 2.70
x 2.00
x 1.41
x 4.38
x 1.63
x 1.65
x 0.94
x -0.19
1
Short-Term Memory
Input
1
Now the LSTM has to decide how much of this Potential Short-Term Memory to pass on…

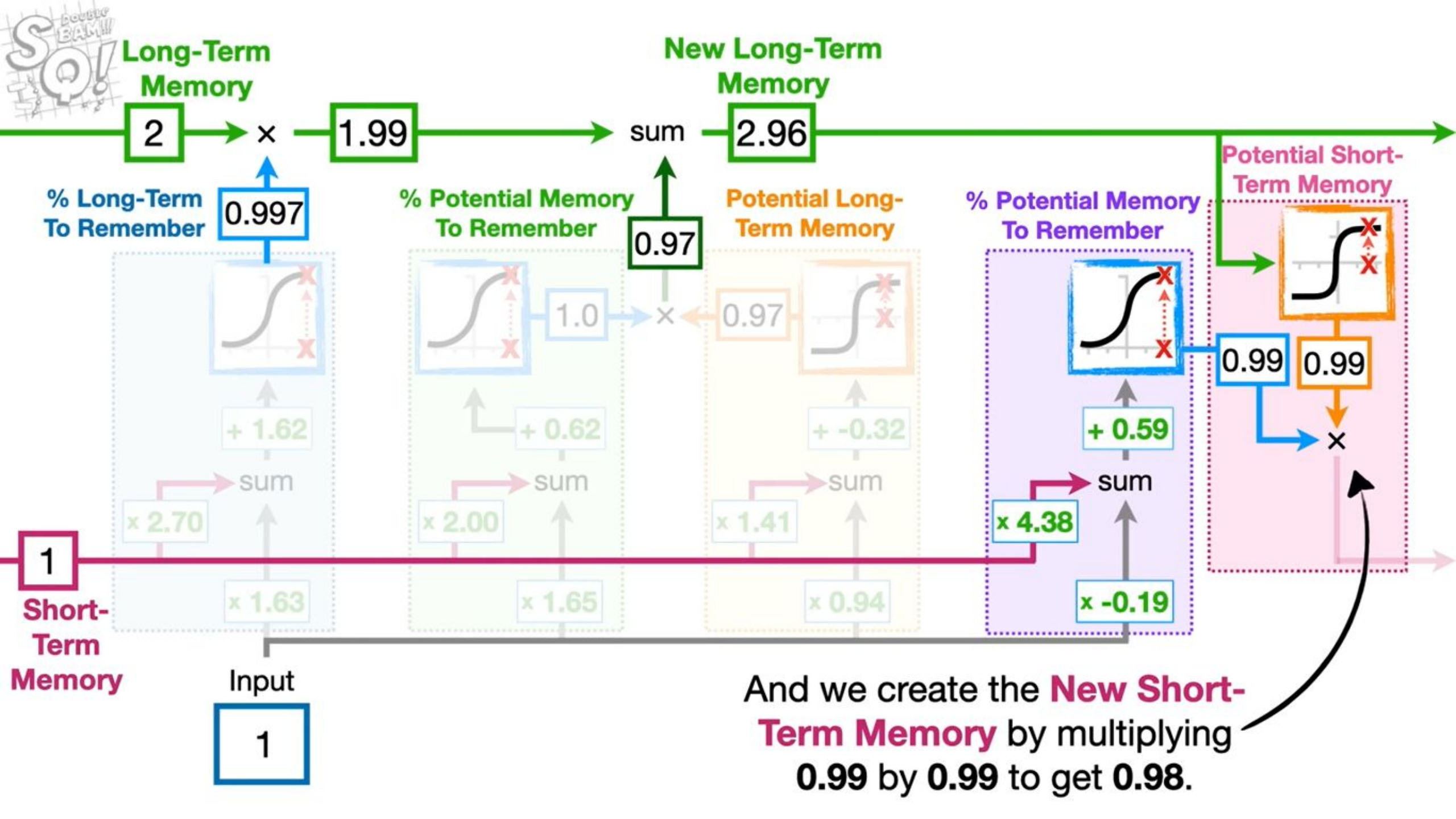

Long-Term Memory
2
×
1.99
sum
New Long-Term Memory
2.96
% Long-Term To Remember
0.997
% Potential Memory To Remember
0.97
Potential Long-Term Memory
% Potential Memory To Remember
Potential Short-Term Memory
1.0
×
0.97
+ 1.62
+ 0.62
+ -0.32
+ 0.59
sum
sum
sum
x 2.70
x 2.00
x 1.41
x 4.38
0.99
×
1
Short-Term Memory
x 1.63
x 1.65
x 0.94
x -0.19
Input
1
…and this is done using the exact same method we used two times earlier.

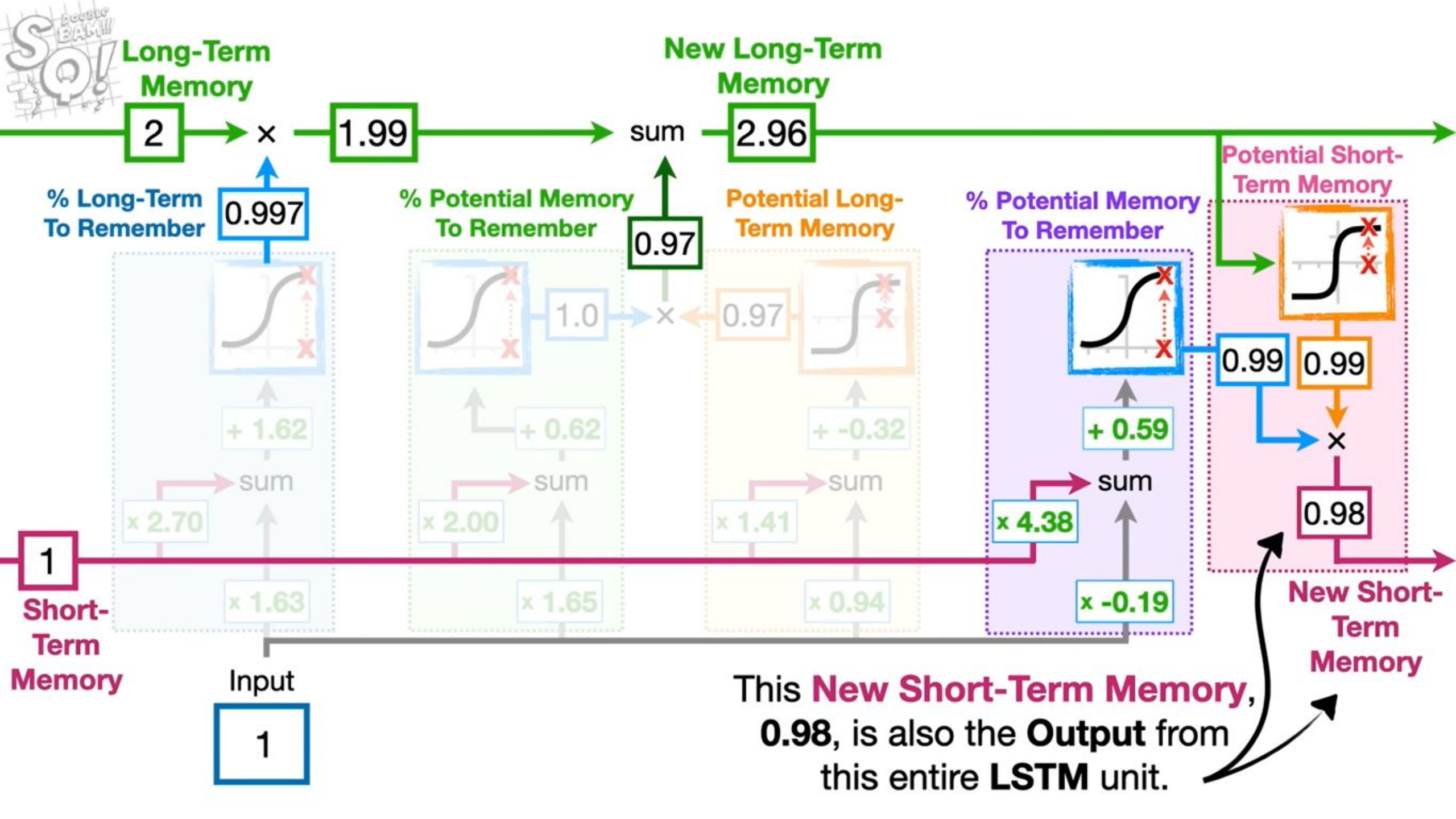

Long-Term Memory
2
×
1.99
sum
New Long-Term Memory
2.96
% Long-Term To Remember
0.997
+ 1.62
sum
x 2.70
1
Short-Term Memory
x 1.63
Input
1
% Potential Memory To Remember
0.97
1.0
×
+ 0.62
sum
x 2.00
x 1.65
Potential Long-Term Memory
0.97
+ -0.32
sum
x 1.41
x 0.94
% Potential Memory To Remember
+ 0.59
sum
x 4.38
x -0.19
Potential Short-Term Memory
0.99
×
When we determined what percentage of the original Long-Term Memory to remember…

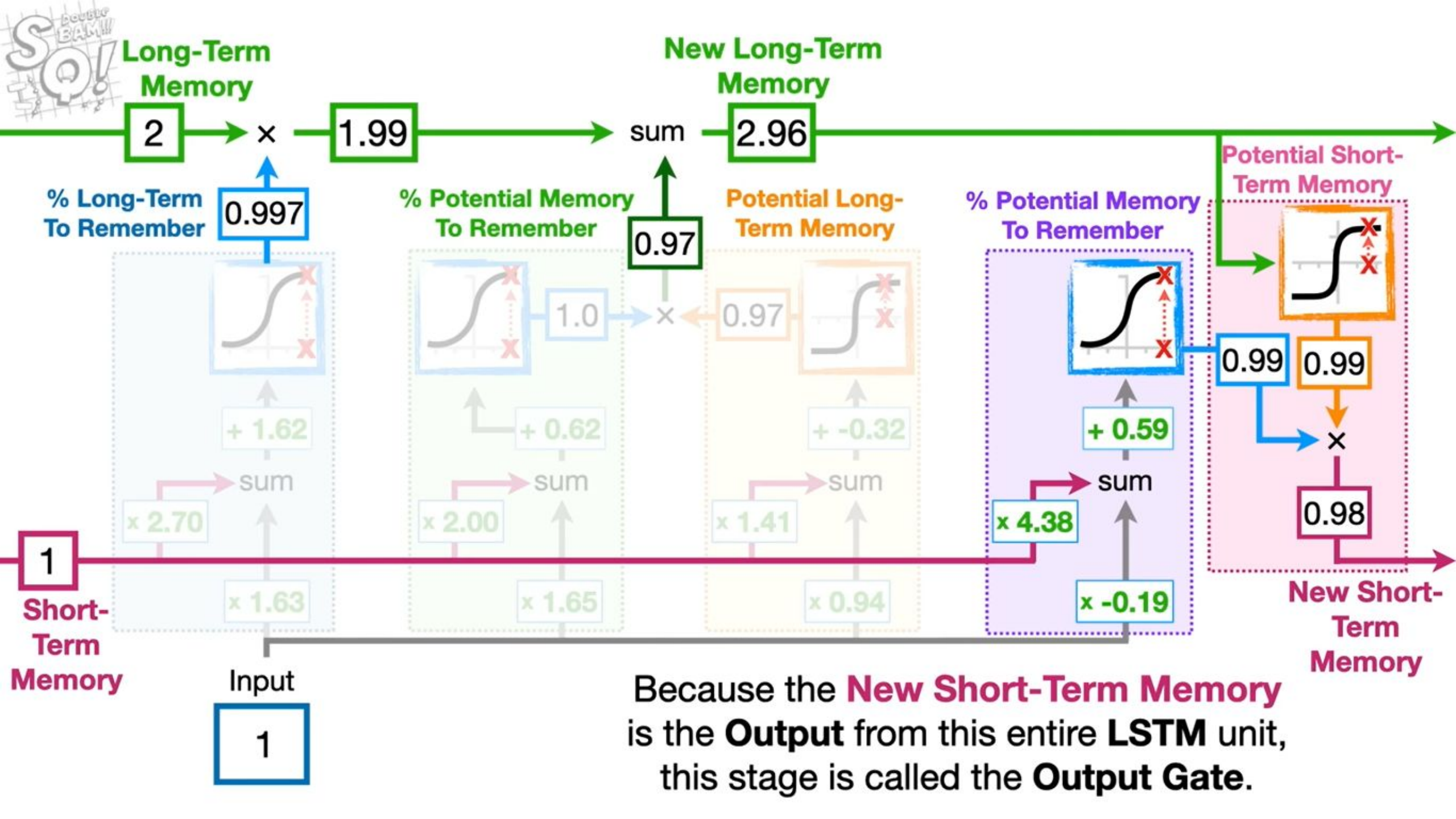

Long-Term Memory
2
×
1.99
sum
New Long-Term Memory
2.96
% Long-Term To Remember
0.997
+ 1.62
sum
x 2.70
x 1.63
% Potential Memory To Remember
1.0
0.97
+ 0.62
sum
x 2.00
x 1.65
Potential Long-Term Memory
0.97
+ -0.32
sum
x 1.41
x 0.94
% Potential Memory To Remember
+ 0.59
sum
x 4.38
x -0.19
Potential Short-Term Memory
0.99
×
1
Short-Term Memory
Input
1
…and when we determined what percentage of the Potential Long-Term Memory to remember.

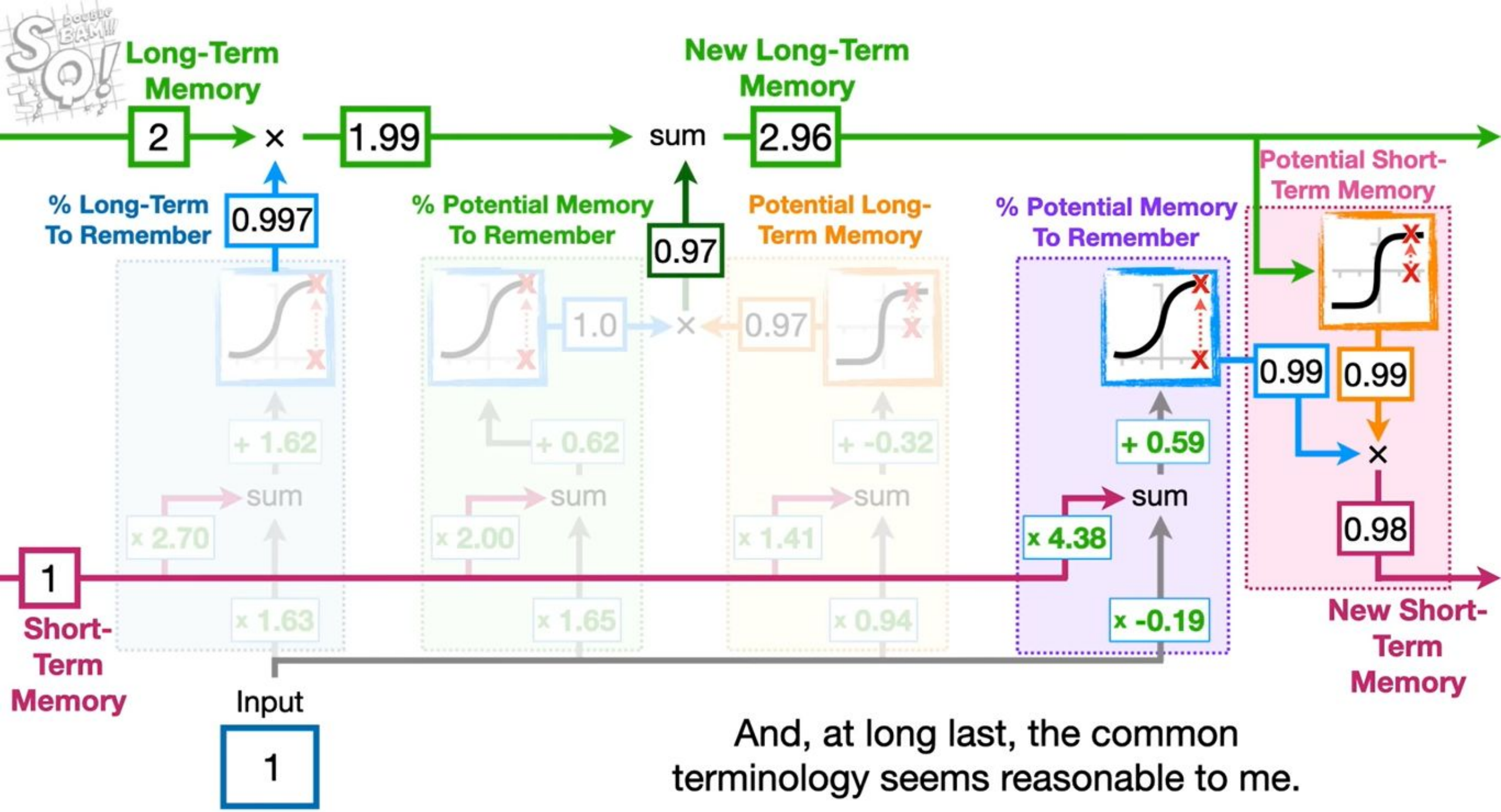

Long-Term Memory
2
×
1.99
sum
New Long-Term Memory
2.96
% Long-Term To Remember
0.997
+ 1.62
sum
x 2.70
x 1.63
% Potential Memory To Remember
0.97
1.0
+ 0.62
sum
x 2.00
x 1.65
Potential Long-Term Memory
0.97
+ -0.32
sum
x 1.41
x 0.94
% Potential Memory To Remember
+ 0.59
sum
x 4.38
x -0.19
Potential Short-Term Memory
0.99
×
1
Short-Term Memory
Input
1
In all three cases, we use a Sigmoid Activation Function to determine what percent the LSTM remembers.


Long-Term Memory
2
×
1.99
sum
New Long-Term Memory
2.96
% Long-Term To Remember
0.997
% Potential Memory To Remember
0.97
Potential Long-Term Memory
% Potential Memory To Remember
Potential Short-Term Memory
1.0
×
0.97
+ 1.62
+ 0.62
+ -0.32
+ 0.59
sum
sum
sum
sum
x 2.70
x 2.00
x 1.41
x 4.38
0.99
0.99
×
1
Short-Term Memory
x 1.63
x 1.65
x 0.94
x -0.19
Input
1
In this case, when we do the math we get 0.99.

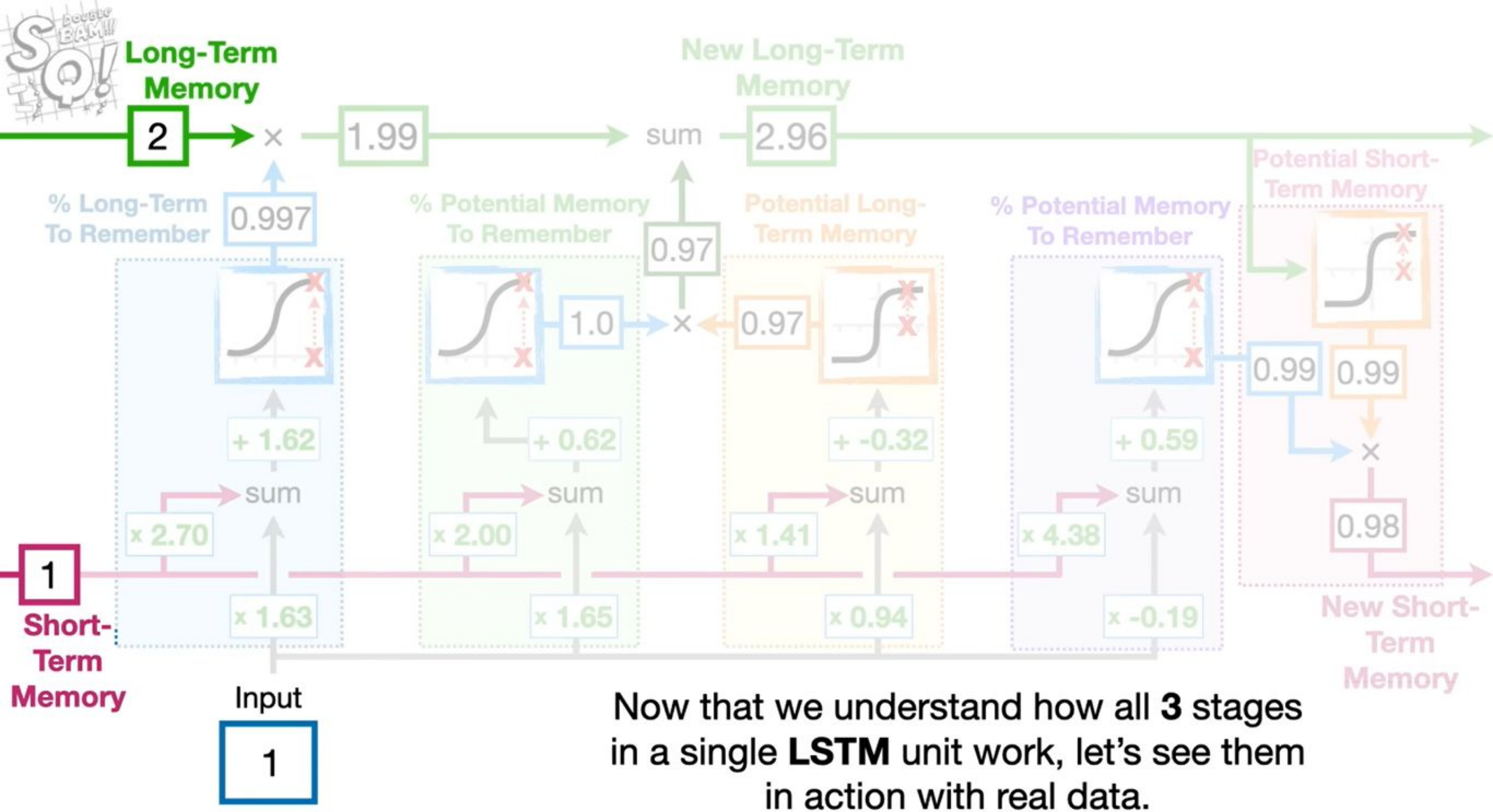

Long-Term Memory
2
×
1.99
sum
New Long-Term Memory
2.96
% Long-Term To Remember
0.997
% Potential Memory To Remember
0.97
Potential Long-Term Memory
% Potential Memory To Remember
Potential Short-Term Memory
1.0
×
0.97
+ 1.62
+ 0.62
+ -0.32
+ 0.59
sum
sum
sum
x 2.70
x 2.00
x 1.41
x 4.38
x 1.63
x 1.65
x 0.94
x -0.19
0.99
0.99
×
1
Short-Term Memory
Input
1
And we create the New Short-Term Memory by multiplying 0.99 by 0.99 to get 0.98.

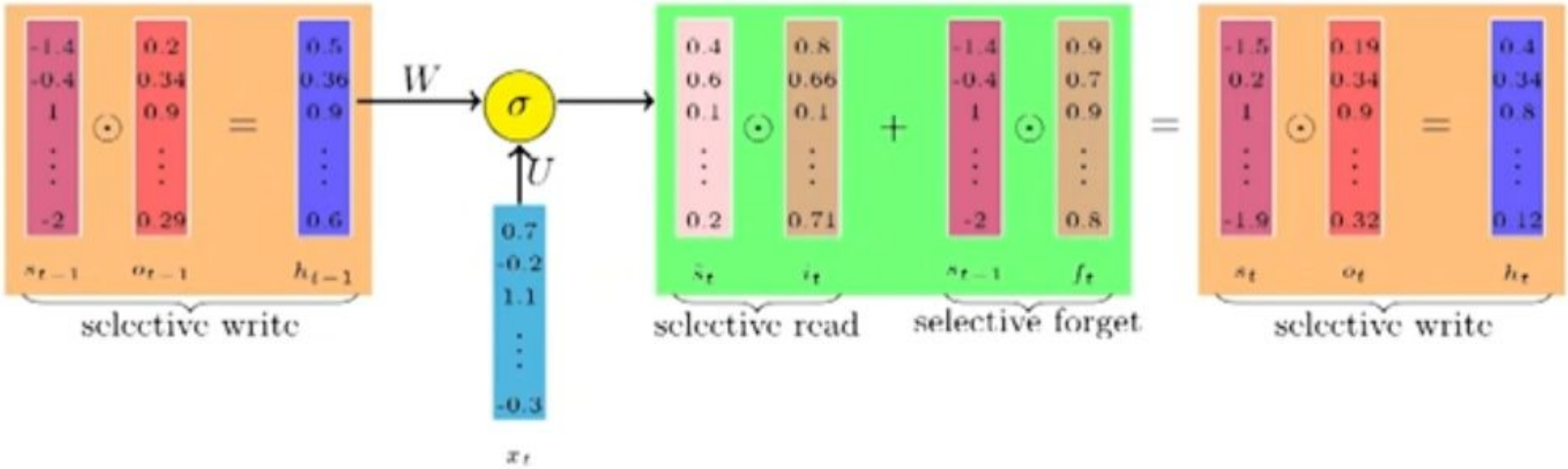

Long-Term Memory
2
×
1.99
sum
New Long-Term Memory
2.96
% Long-Term To Remember
0.997
% Potential Memory To Remember
0.97
Potential Long-Term Memory
% Potential Memory To Remember
Potential Short-Term Memory
+ 1.62
sum
× 2.70
× 1.63
1.0
× 0.97
+ 0.62
sum
× 2.00
× 1.65
+ -0.32
sum
× 1.41
× 0.94
+ 0.59
sum
× 4.38
× -0.19
0.99
0.99
×
0.98
1
Short-Term Memory
Input
1
New Short-Term Memory
This New Short-Term Memory, 0.98, is also the Output from this entire LSTM unit.


Long-Term Memory
2
×
1.99
sum
New Long-Term Memory
2.96
% Long-Term To Remember
0.997
% Potential Memory To Remember
0.97
Potential Long-Term Memory
Potential Short-Term Memory
% Potential Memory To Remember
1.0
×
0.97
+ 1.62
+ 0.62
+ -0.32
+ 0.59
sum
sum
sum
x 2.70
x 2.00
x 1.41
x 4.38
x 1.63
x 1.65
x 0.94
x -0.19
0.99
0.99
×
0.98
1
Short-Term Memory
Input
1
New Short-Term Memory
Because the New Short-Term Memory is the Output from this entire LSTM unit, this stage is called the Output Gate.



And, at long last, the common terminology seems reasonable to me.


Long-Term Memory
2
×
1.99
New Long-Term Memory
sum
2.96
% Long-Term To Remember
0.997
% Potential Memory To Remember
0.97
Potential Long-Term Memory
% Potential Memory To Remember
Potential Short-Term Memory
1.0
×
0.97
0.99
0.99
+ 1.62
+ 0.62
+ -0.32
+ 0.59
sum
sum
sum
sum
x 2.70
x 2.00
x 1.41
x 4.38
×
0.98
1
Short-Term Memory
x 1.63
x 1.65
x 0.94
x -0.19
New Short-Term Memory
Input
1
Now that we understand how all 3 stages in a single LSTM unit work, let's see them in action with real data.



- We now have the full set of equations for LSTMs
- The green box together with the selective write operations following it, show all the computations which happen at timestep t

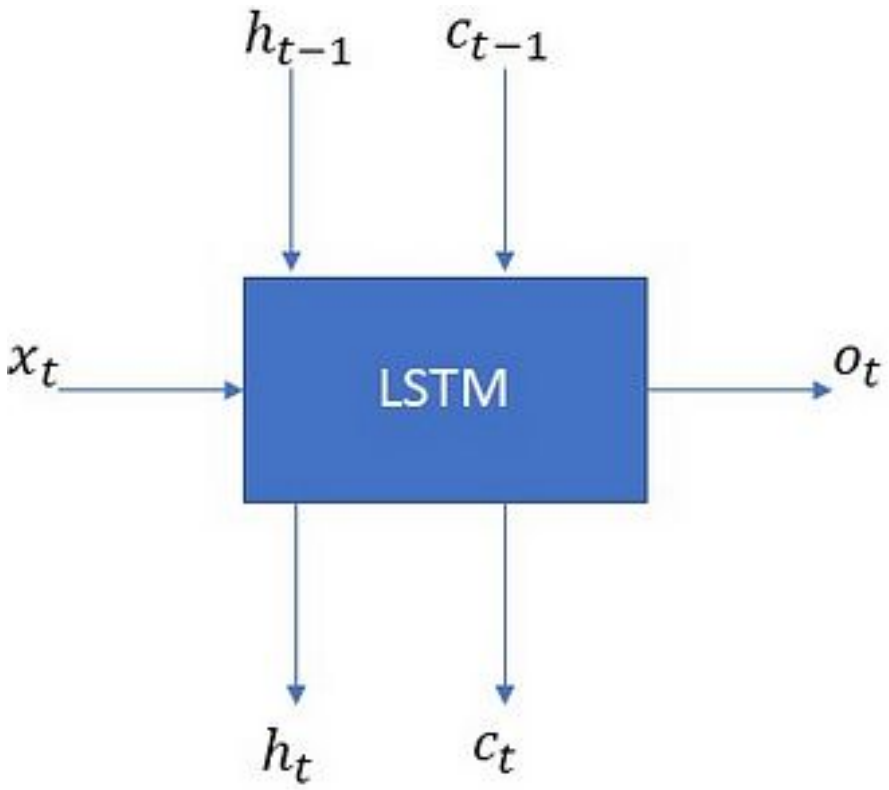
Gates:

$$o_t = \sigma(W_o h_{t-1} + U_o x_t + b_o)$$
$$i_t = \sigma(W_i h_{t-1} + U_i x_t + b_i)$$
$$f_t = \sigma(W_f h_{t-1} + U_f x_t + b_f)$$

States:

$$\tilde{s}_t = \sigma(W h_{t-1} + U x_t + b)$$
$$s_t = f_t \odot s_{t-1} + i_t \odot \tilde{s}_t$$
$$h_t = o_t \odot \sigma(s_t)$$

LSTM Equations



$$f_t = \sigma_g\,(W_f \times x_t + U_f \times h_{t-1} + b_f)$$

$$i_t = \sigma_g\,(W_i \times x_t + U_i \times h_{t-1} + b_i)$$

$$o_t = \sigma_g\,(W_o \times x_t + U_o \times h_{t-1} + b_o)$$

$$c'_t = \sigma_c\,(W_c \times x_t + U_c \times h_{t-1} + b_c)$$

$$c_t = f_t \cdot c_{t-1} + i_t \cdot c'_t$$

$$h_t = o_t \cdot \sigma_c(c_t)$$

σ_g : $sigmoid$

σ_c : tanh

. : element wise multiplication

f_t *is the forget gate*

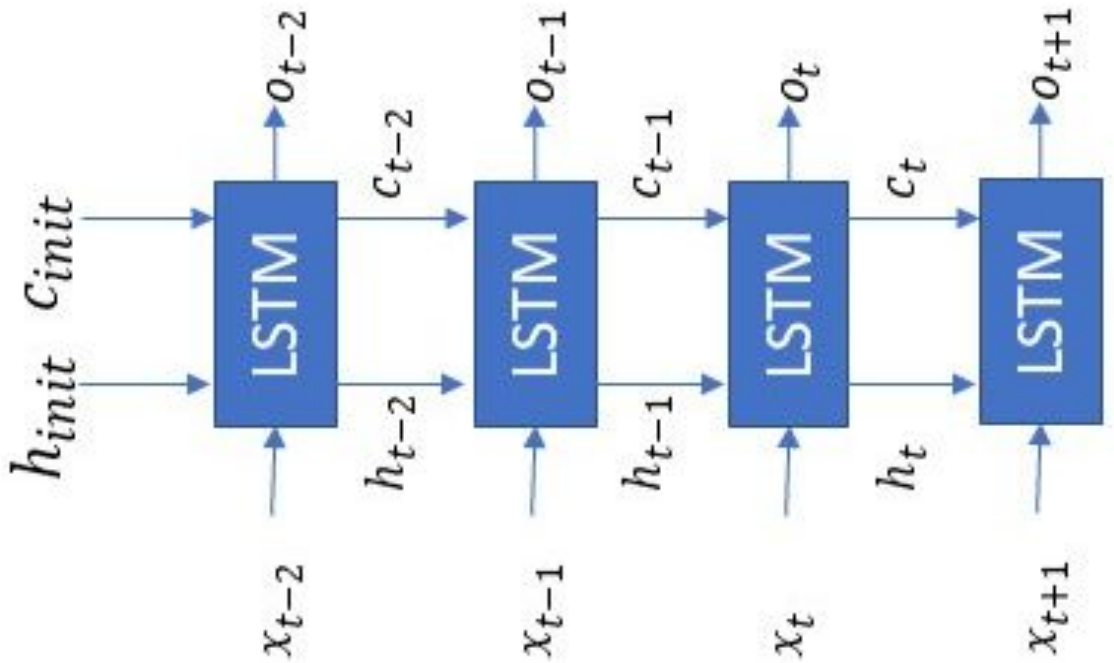
i_t *is the input gate*

o_t *is the output gate*

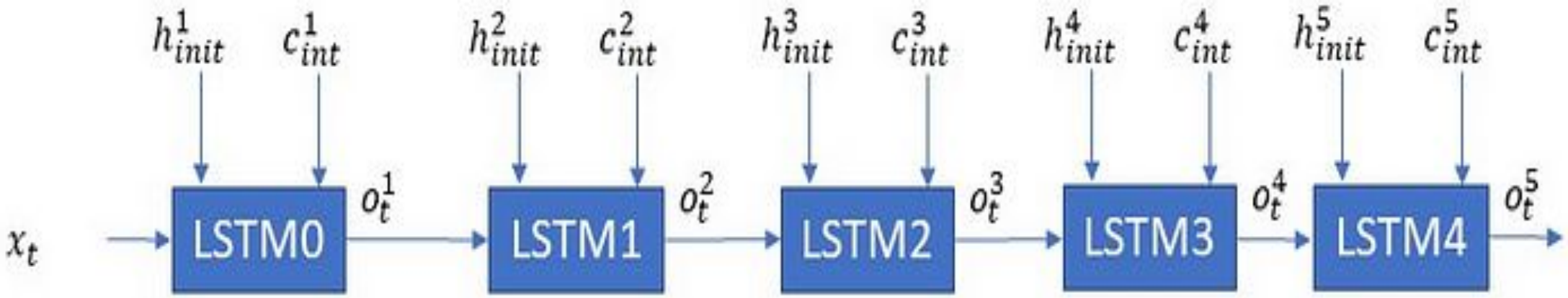
c_t *is the cell state*

h_t *is the hidden state*

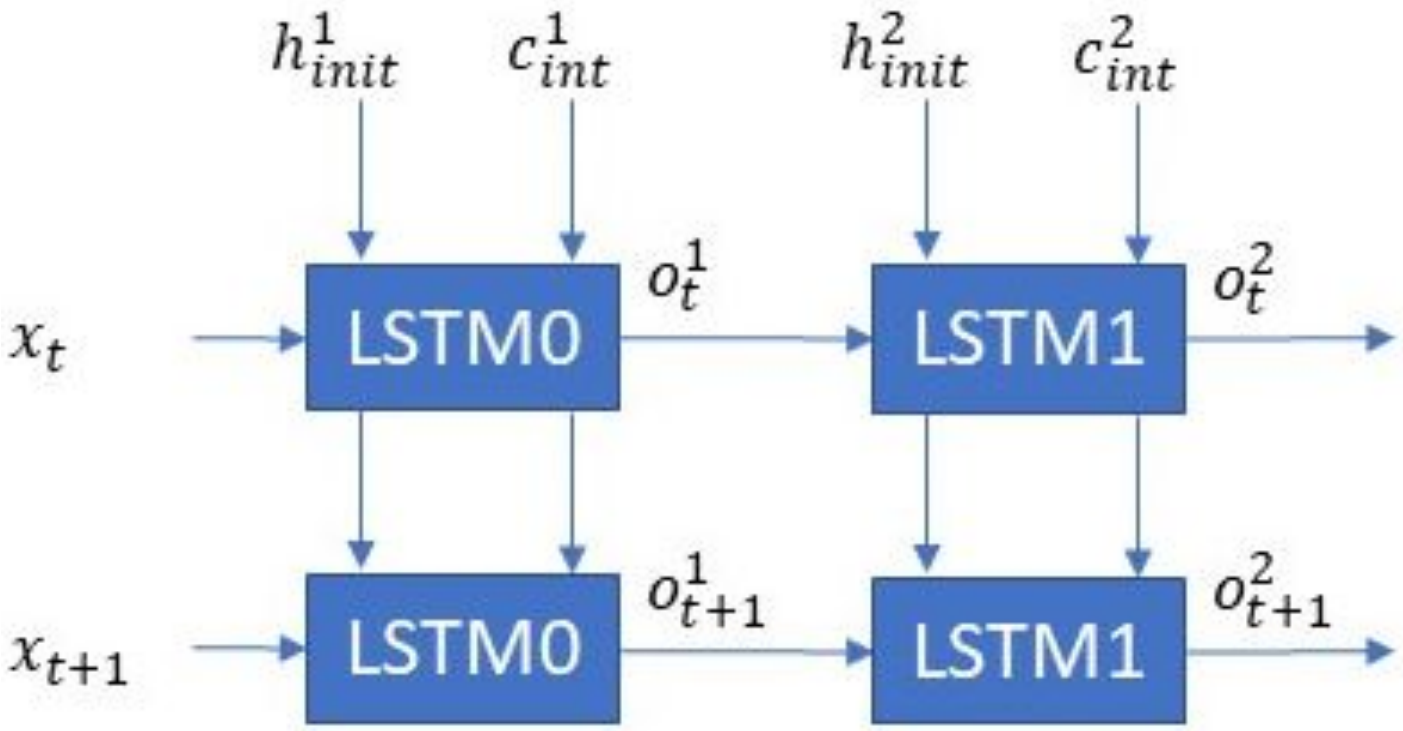
Network with 1 layer of LSTM with 4 timestamps



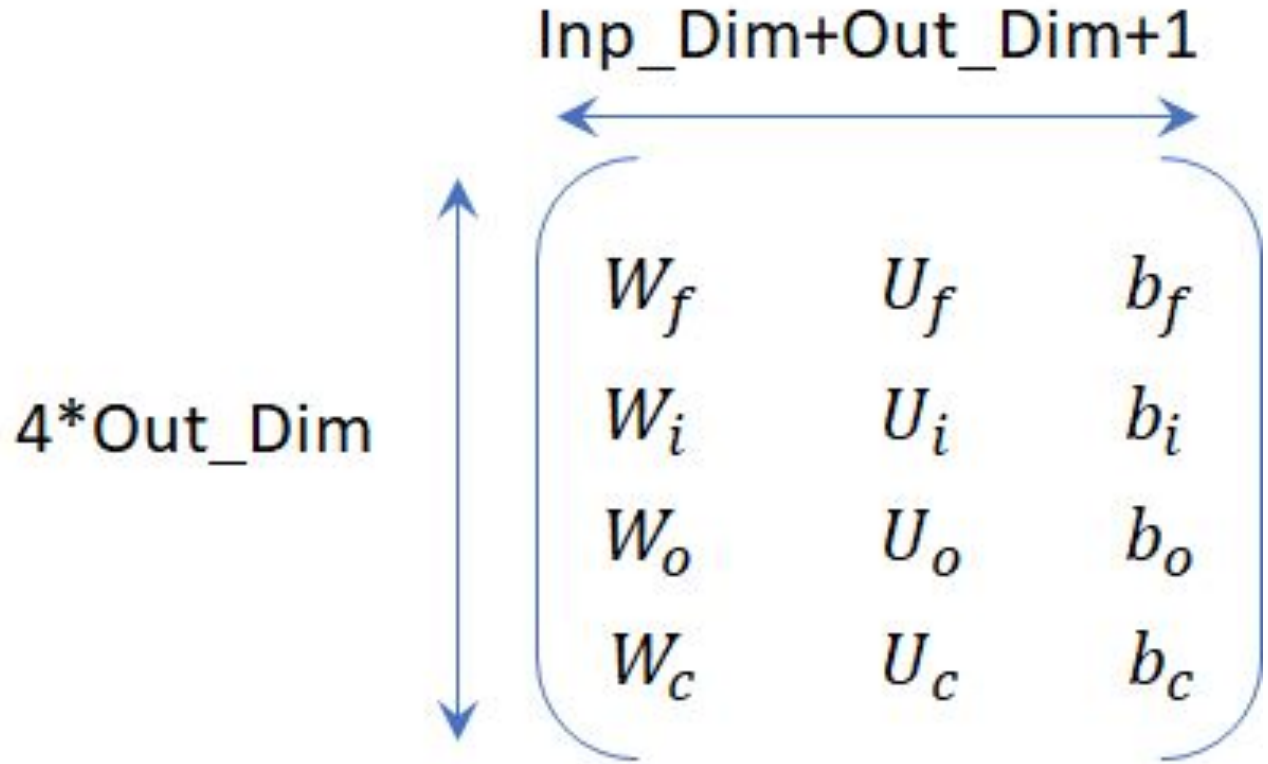
Network with 5 layers of LSTM with time stamp =1



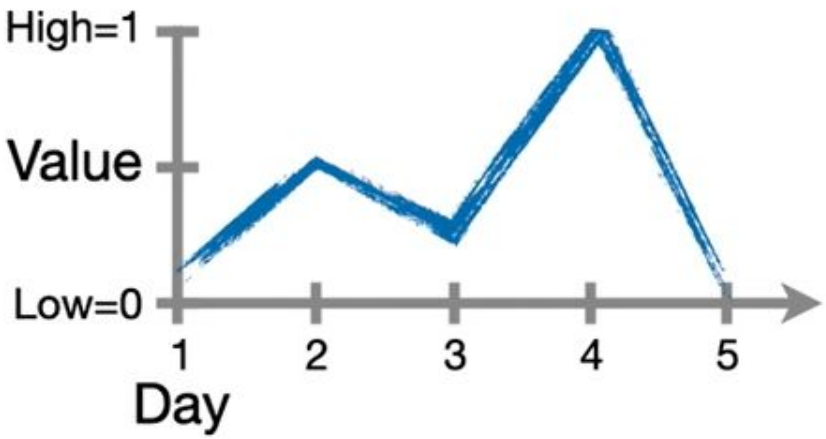
Network with 2 layers of LSTM with time stamp =2

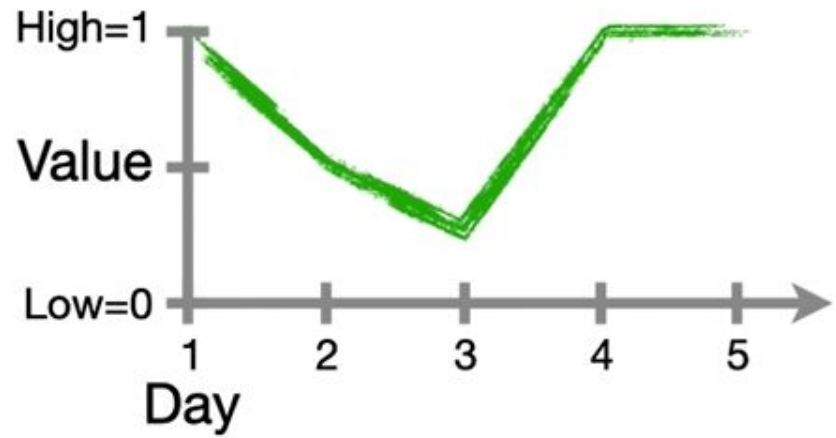


LSTM Weights



Here we have stock prices for two companies, **Company A** and **Company B**.

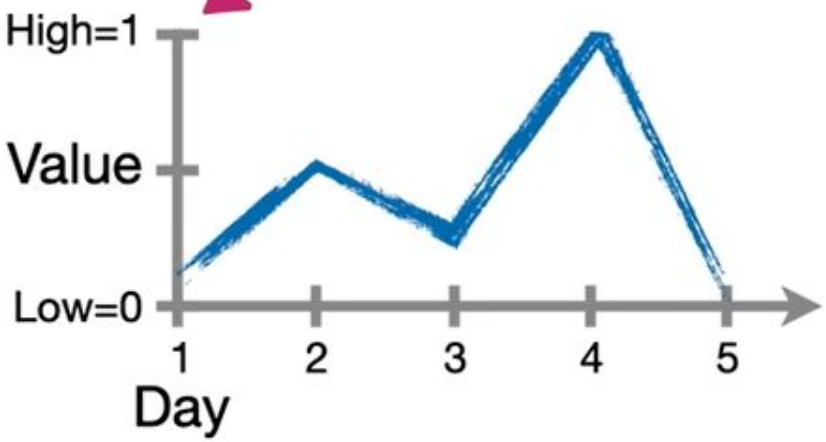


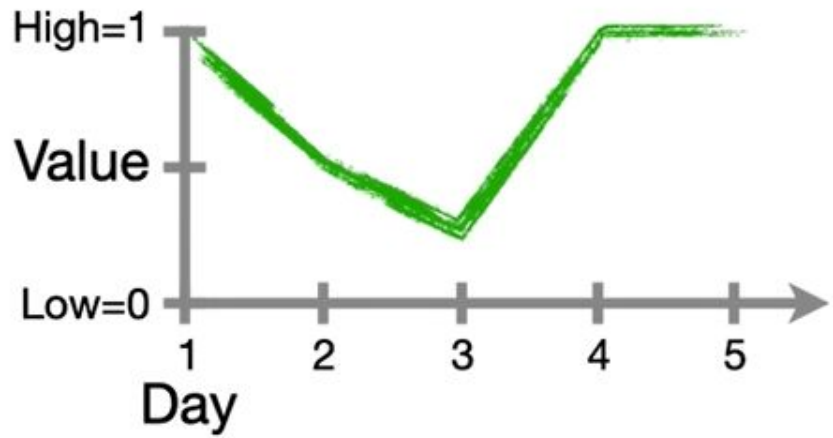


Company A =

Company B =

On the y-axis, we have the stock value…

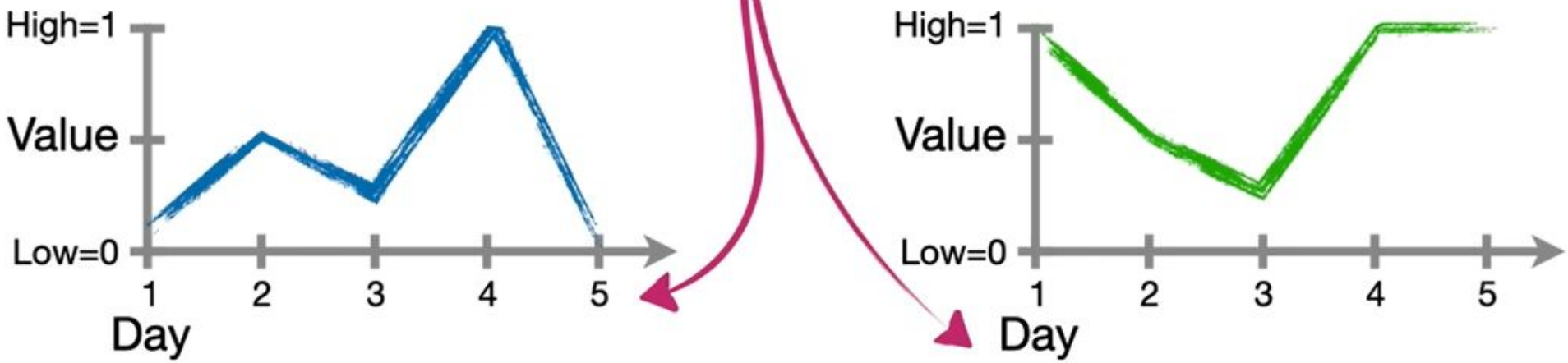




Company A =

Company B =

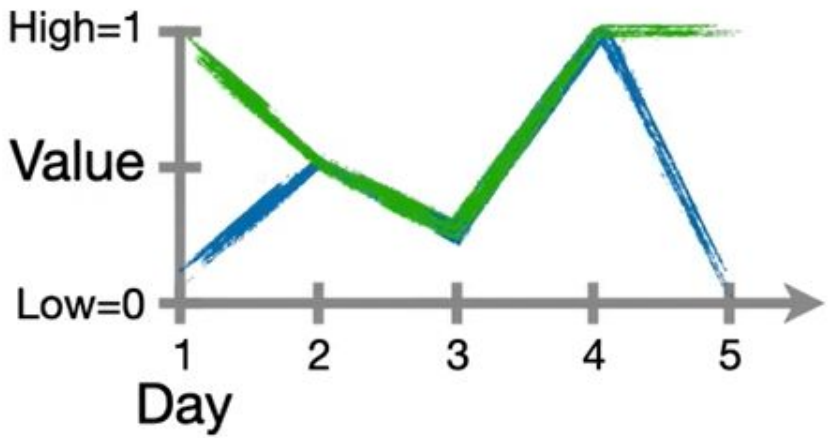
…and on the x-axis, we have
the day the value was recorded.



Company A =

Company B =

NOTE: If we overlap the data from the two companies…

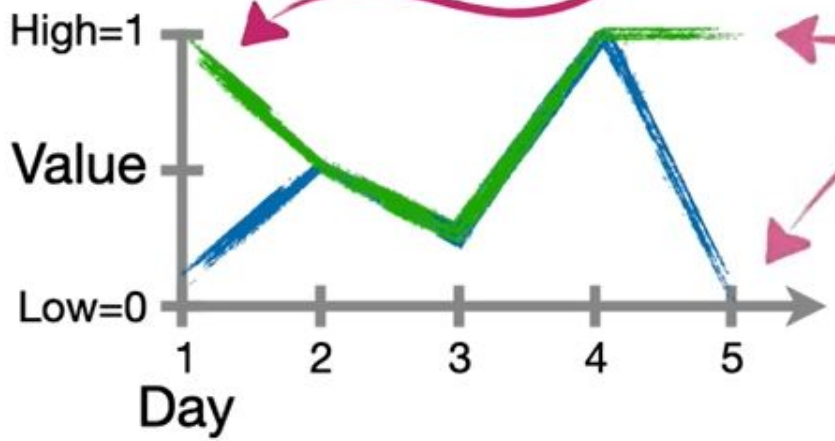


Company A =

Company B =

…we see that the only differences occur on **Day 1**…

…and on **Day 5**.

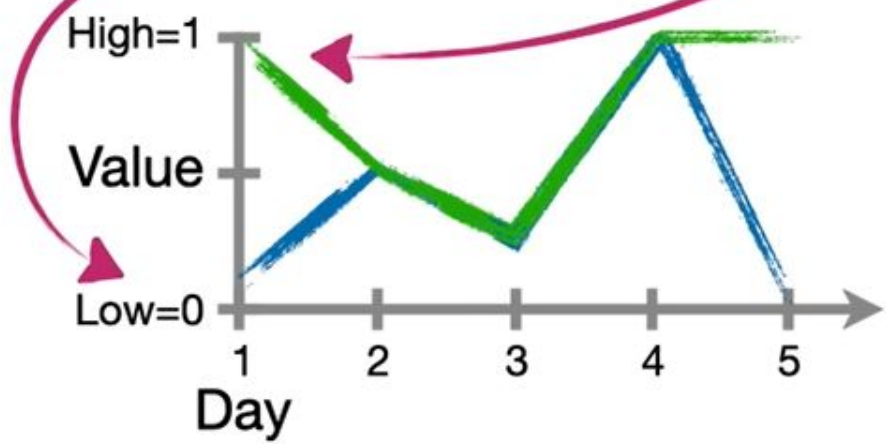


Company A =

Company B =

On **Day 1**, **Company A** is at **0**…

…and **Company B** is at **1**.

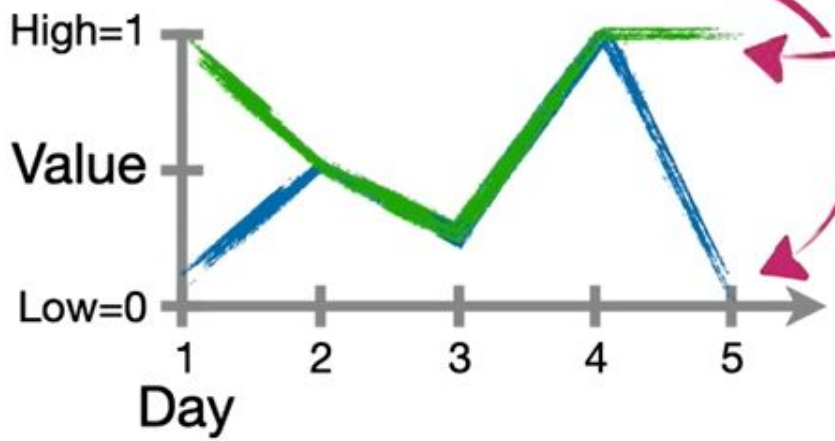


Company A =

Company B =

And on **Day 5**, **Company A** is returns to **0**…

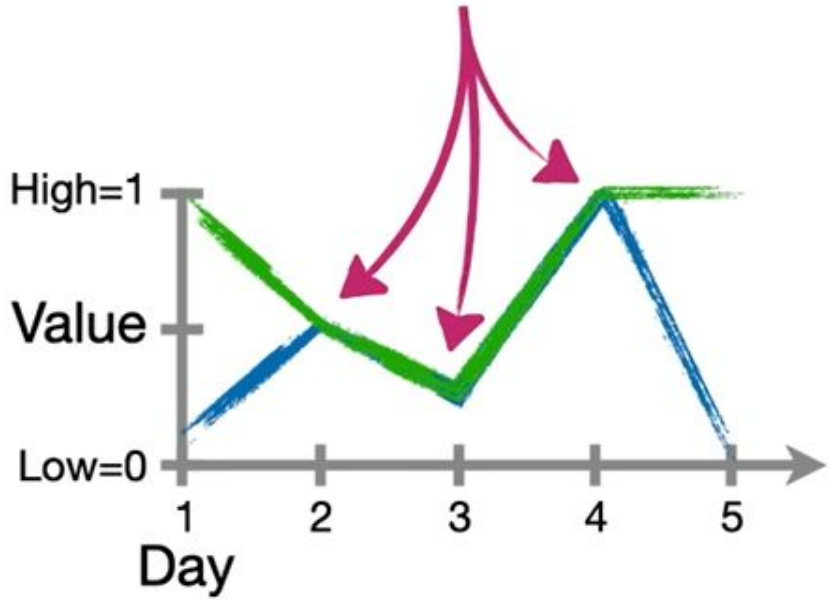
…and **Company B** returns to **1**.



Company A =

Company B =

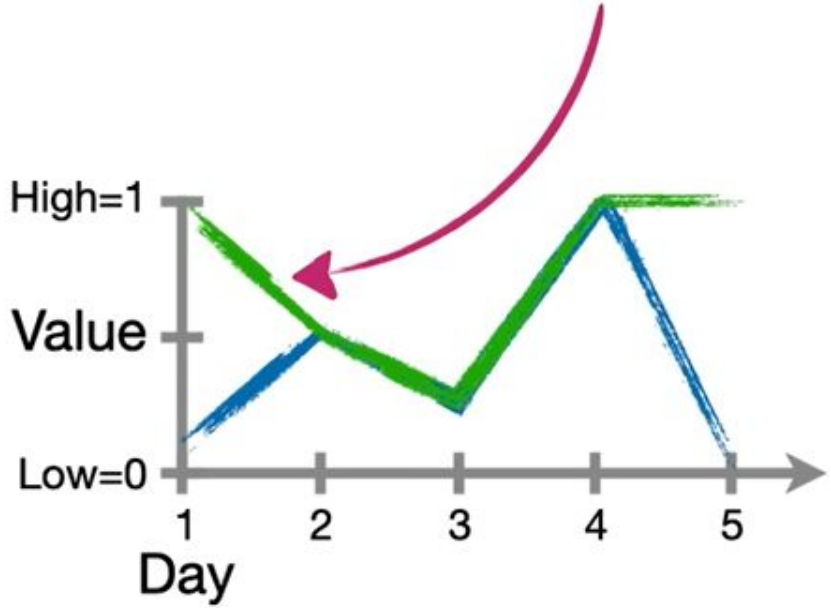
On all of the other days, **Days 2**, **3** and **4**, both companies have the exact same values.



Company A =

Company B =

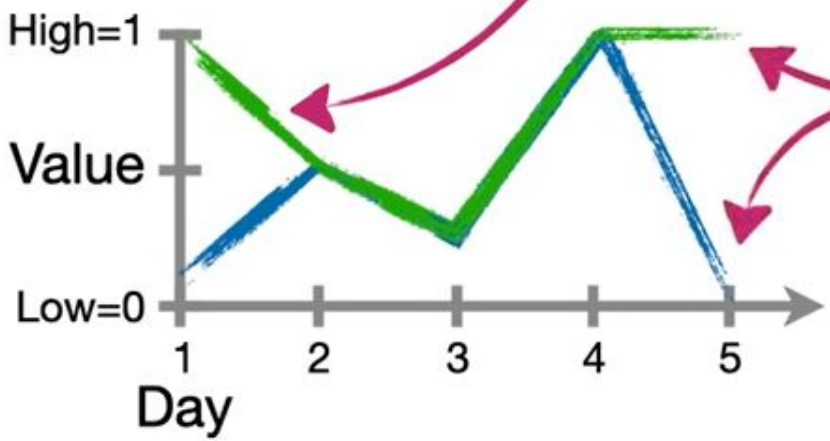
Given this sequential data, we want the **LSTM** to remember what happened on **Day 1**…



Company A =

Company B =

Given this sequential data, we want the **LSTM** to remember what happened on **Day 1**…

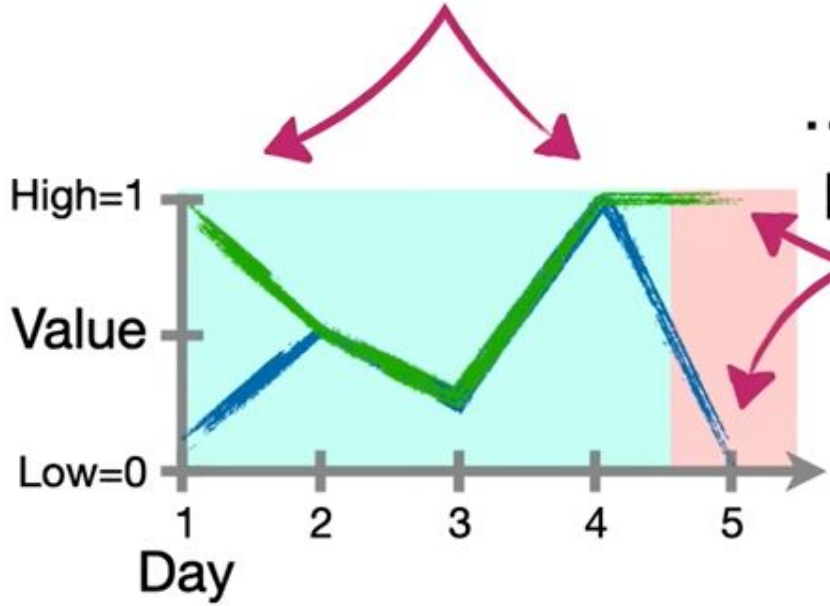


…so it can correctly predict what will happen on **Day 5**.

Company A =

Company B =

In other words, we're going to sequentially run the data from **Days 1** through **4** through an unrolled **LSTM**…

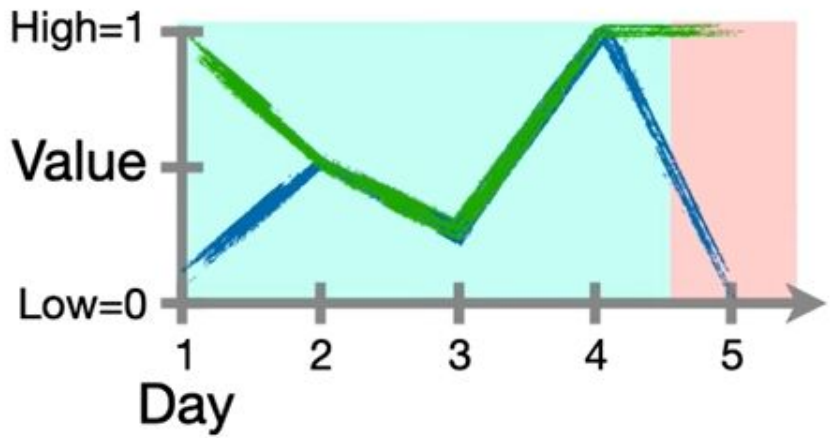


…and see if it can correctly predict the values for **Day 5** for both companies.

Company A =

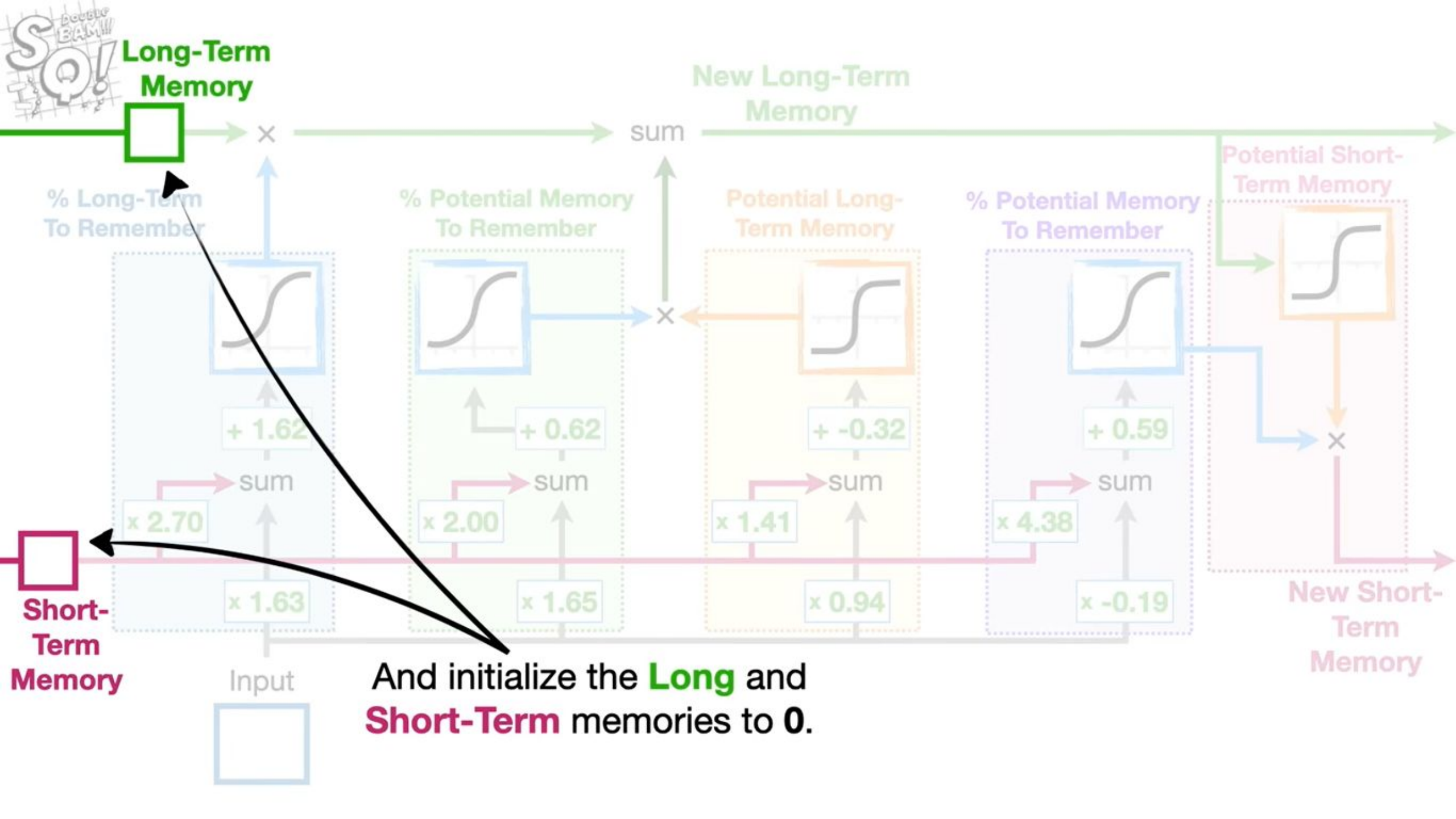
Company B =

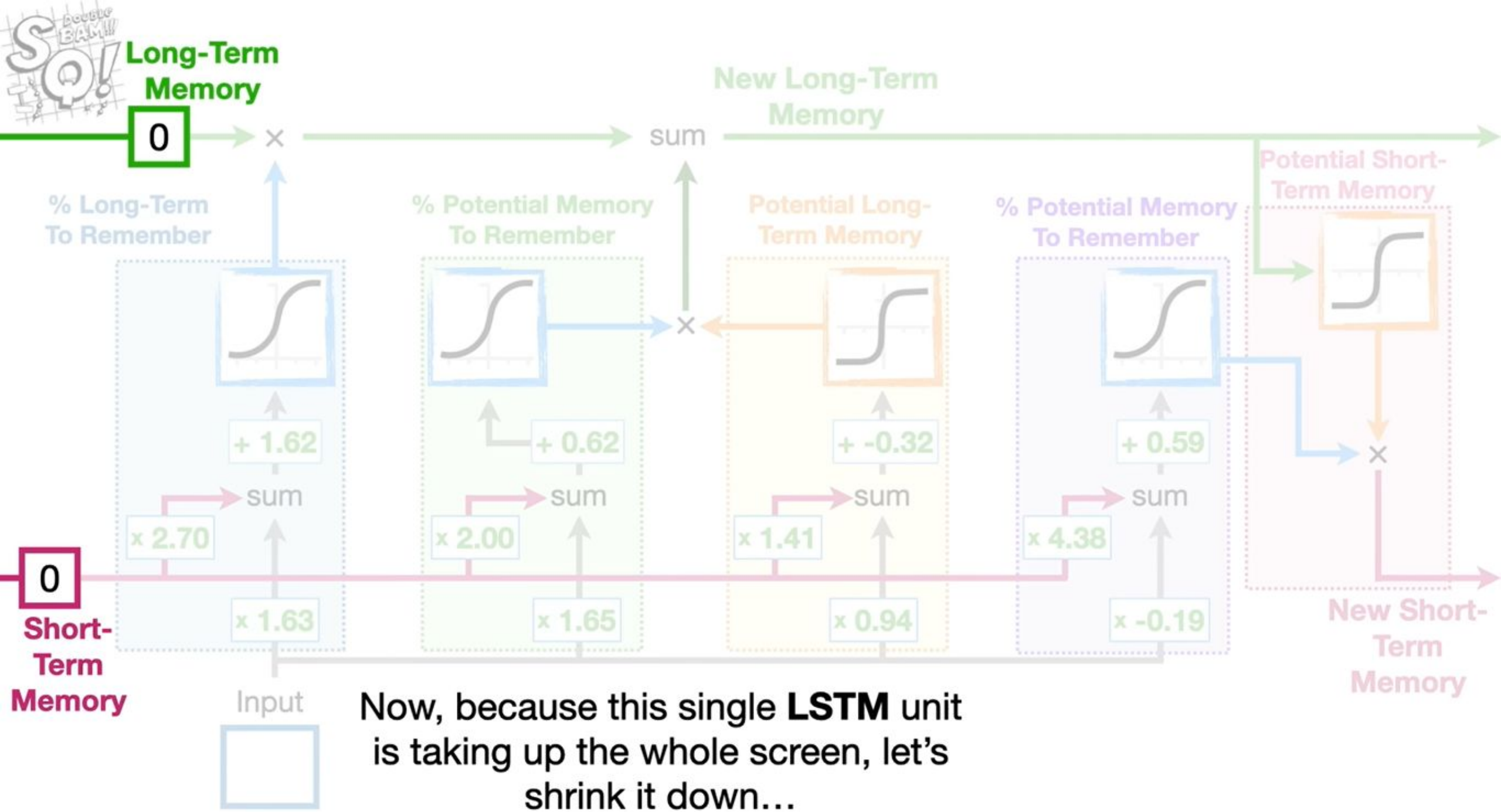
So let's go back to the **LSTM**…



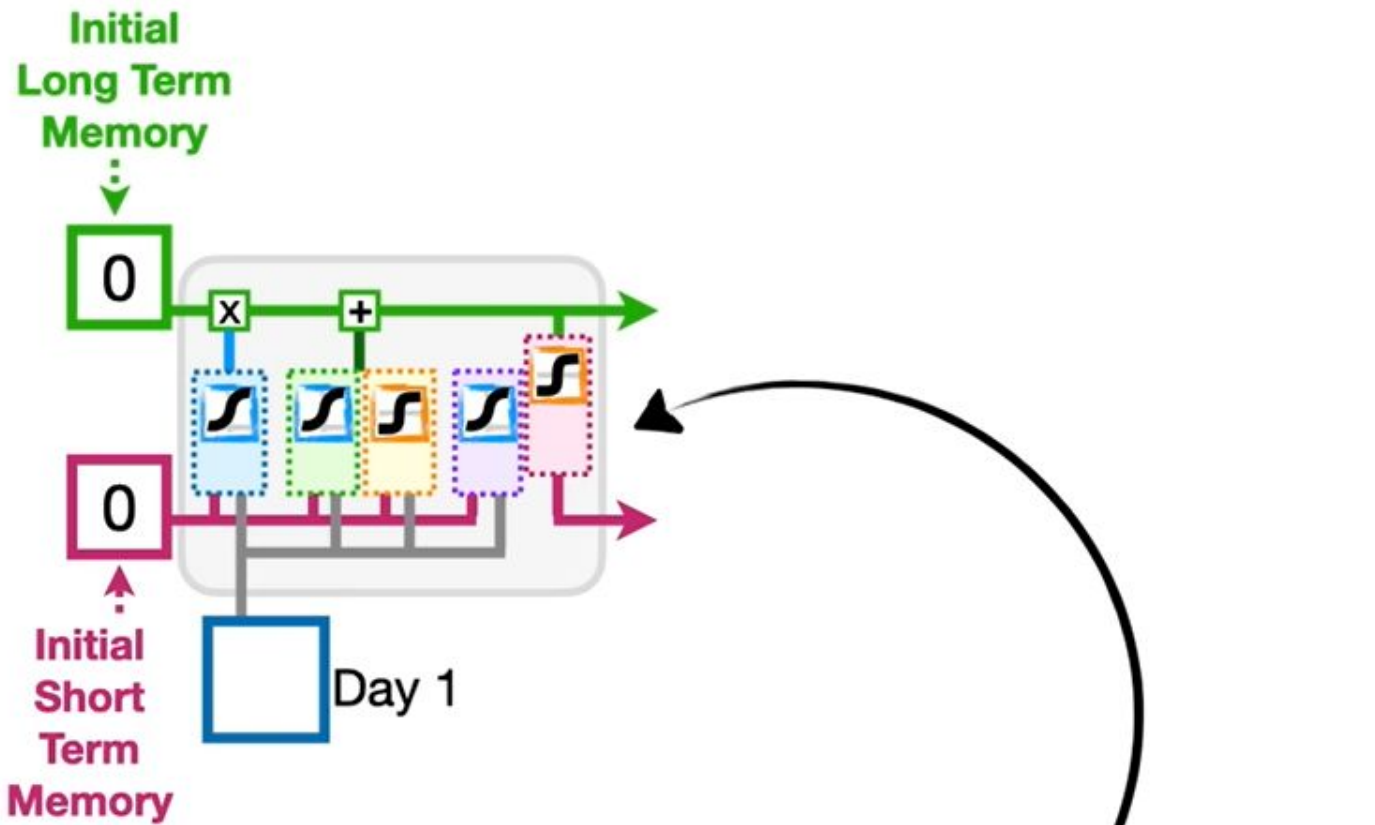
Company A =

Company B =

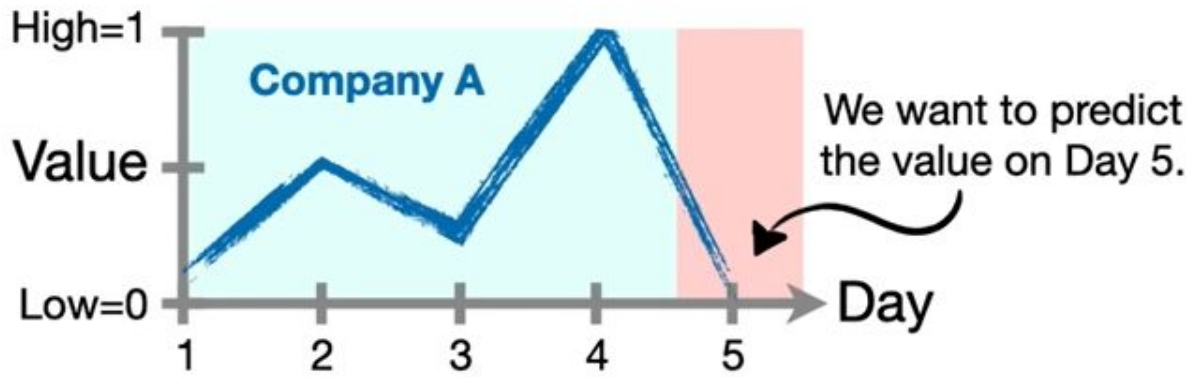

Long-Term Memory
New Long-Term Memory
sum
Potential Short-Term Memory
% Long-Term To Remember
% Potential Memory To Remember
Potential Long-Term Memory
% Potential Memory To Remember
+ 1.62
+ 0.62
+ -0.32
+ 0.59
sum
sum
sum
sum
x 2.70
x 2.00
x 1.41
x 4.38
x 1.63
x 1.65
x 0.94
x -0.19
Short-Term Memory
Input
New Short-Term Memory
And initialize the Long and Short-Term memories to 0.

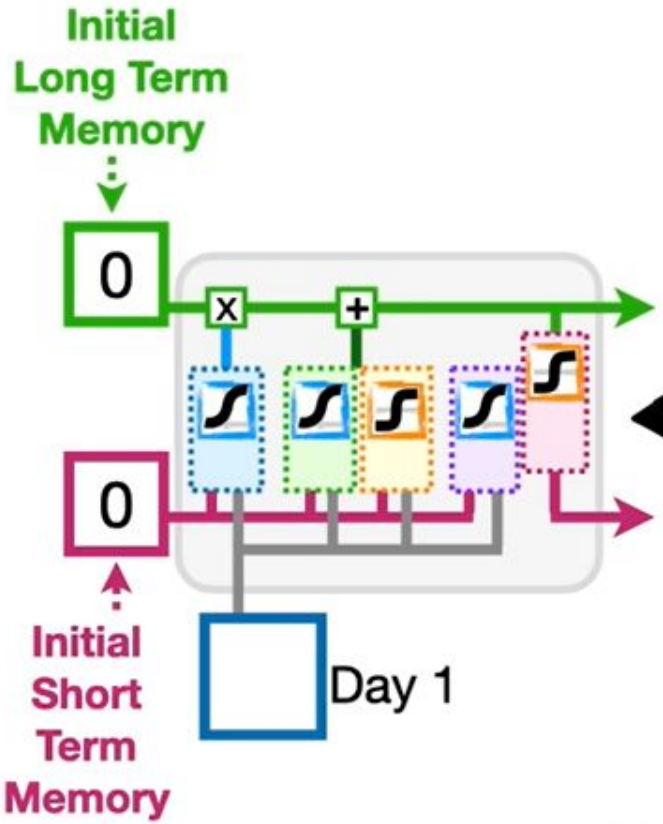


Now, because this single **LSTM** unit is taking up the whole screen, let's shrink it down…

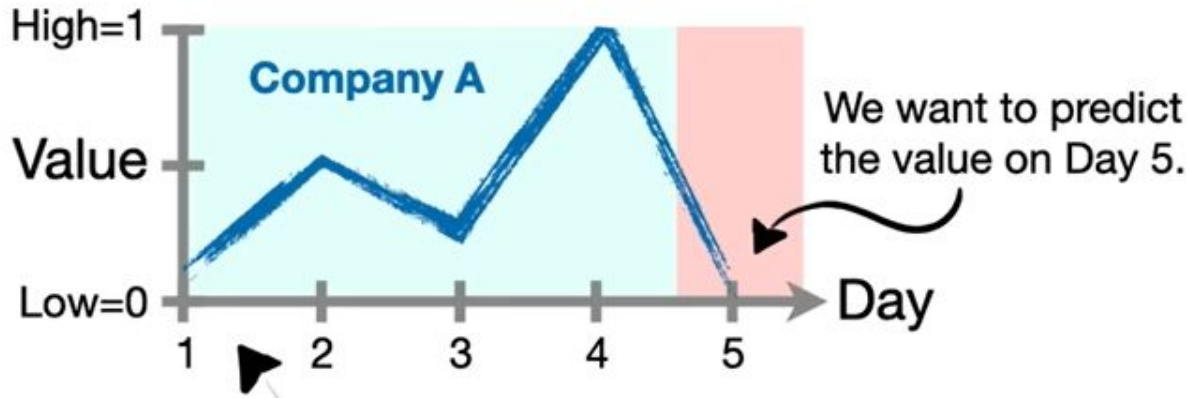


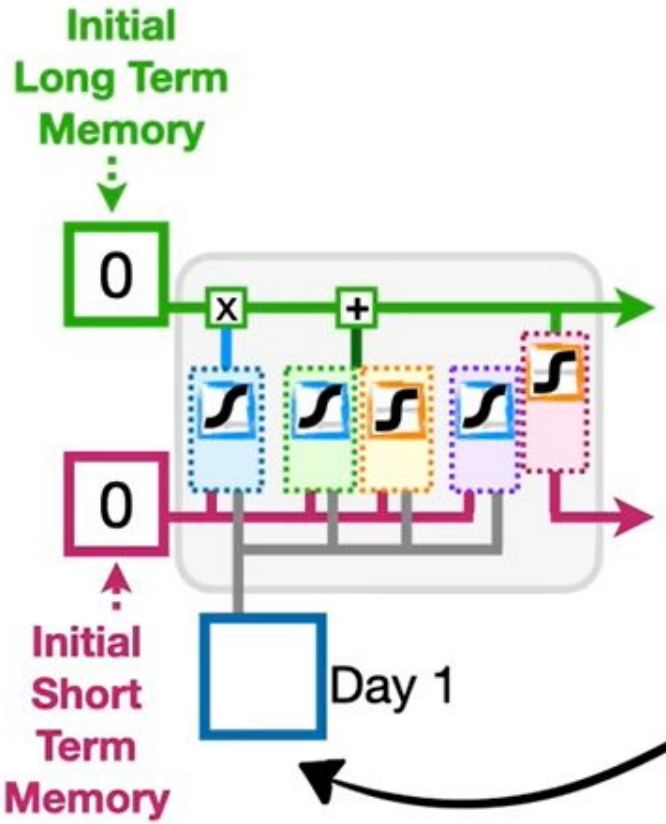
…to this, smaller,
simplified diagram.



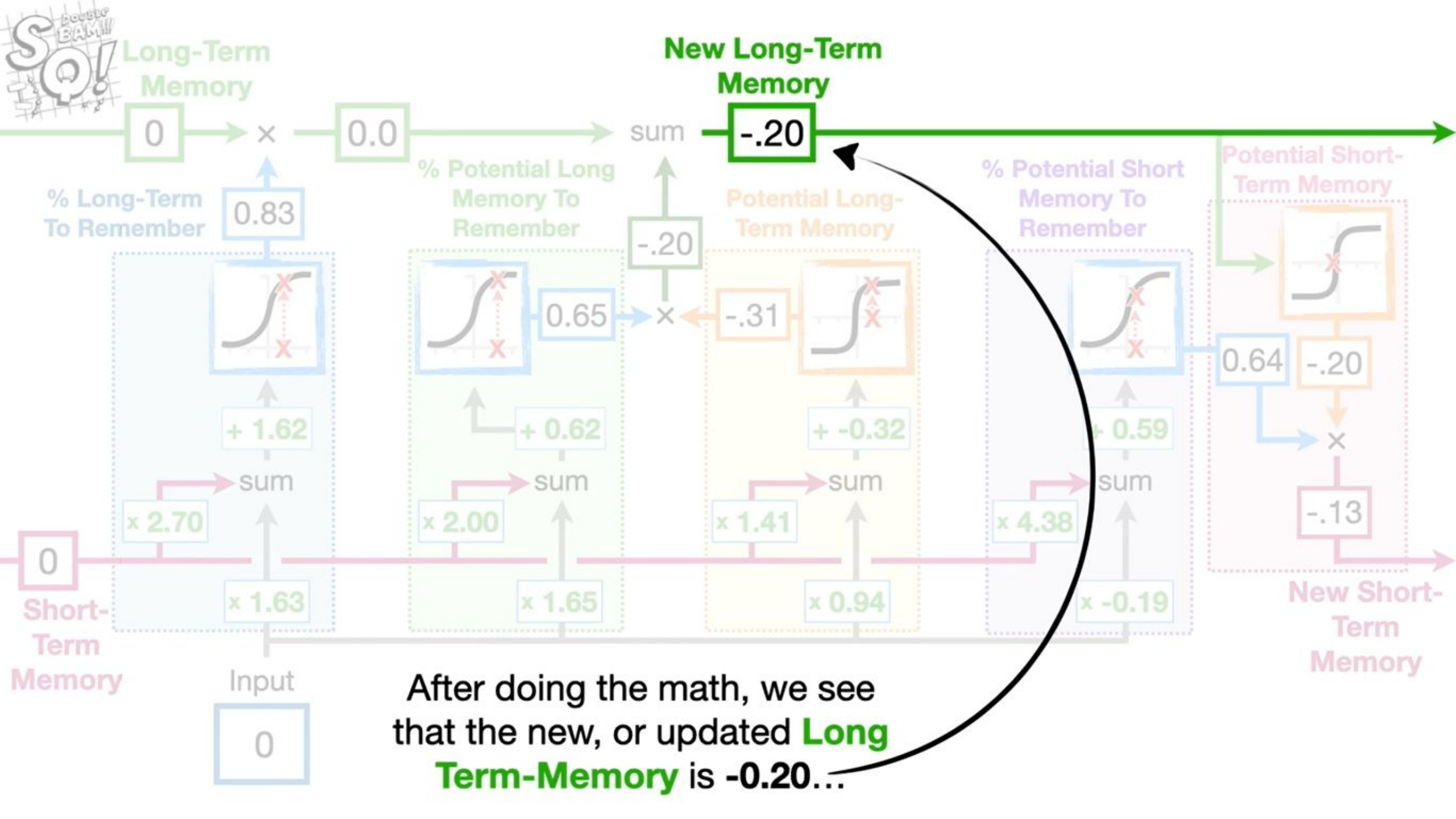


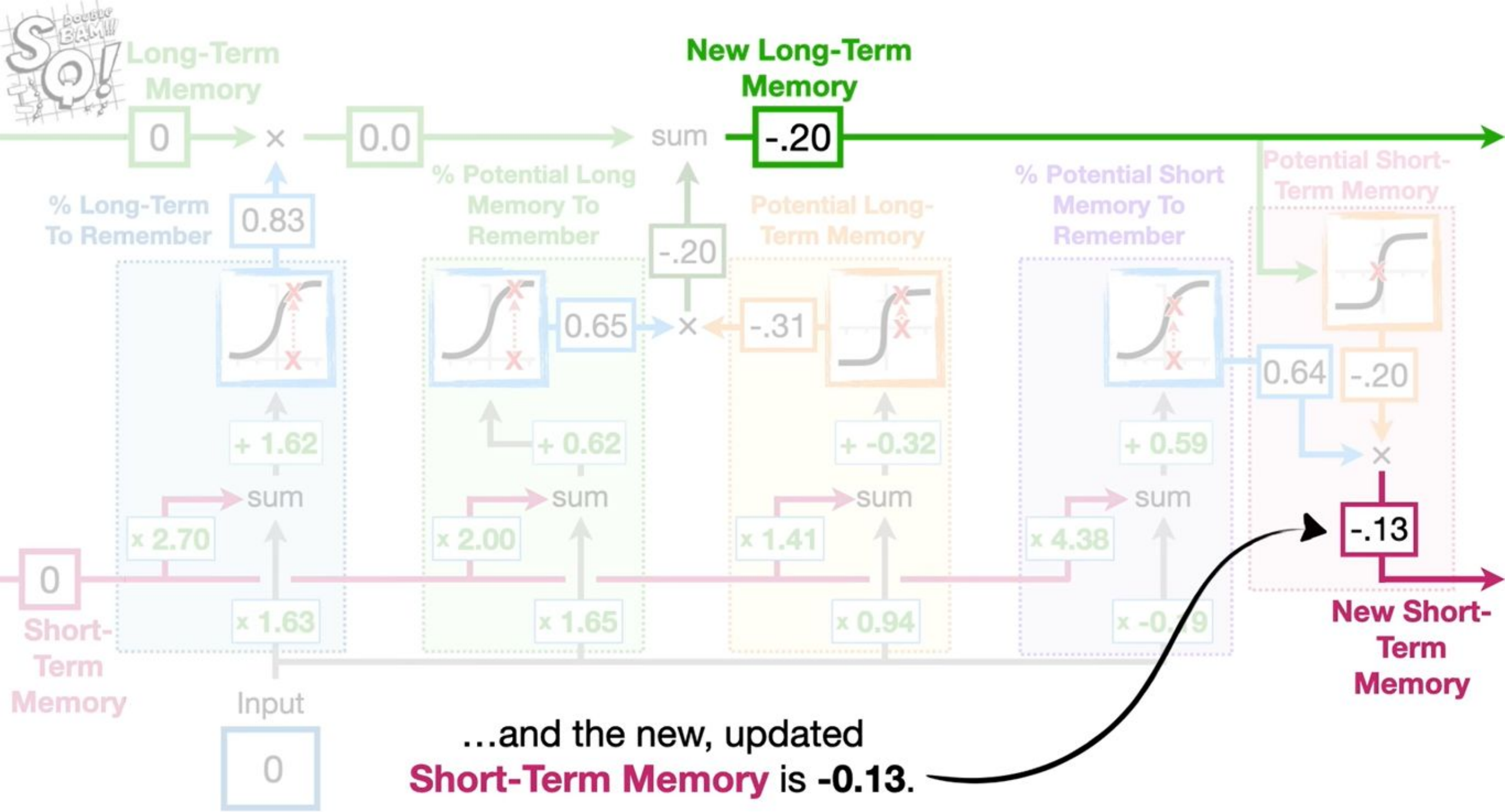
Now, if we want to sequentially run
Company A's values from **Days 1**
through **4** through this **LSTM**…

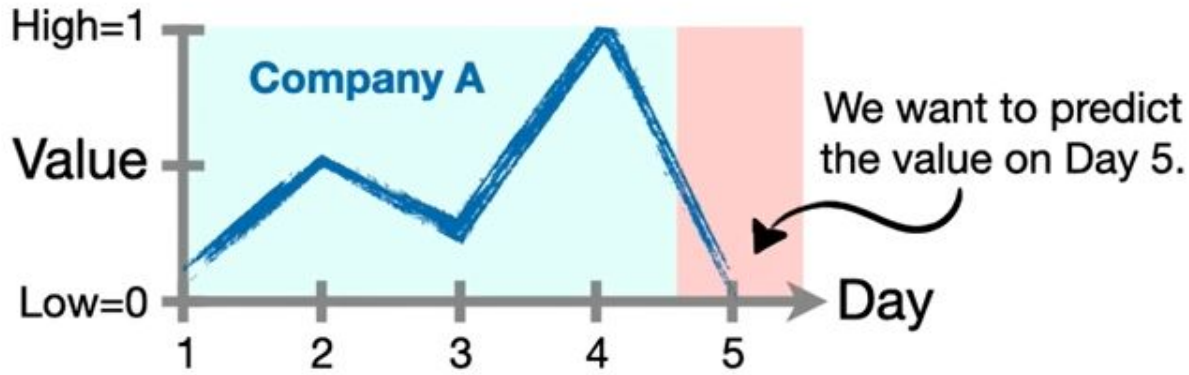


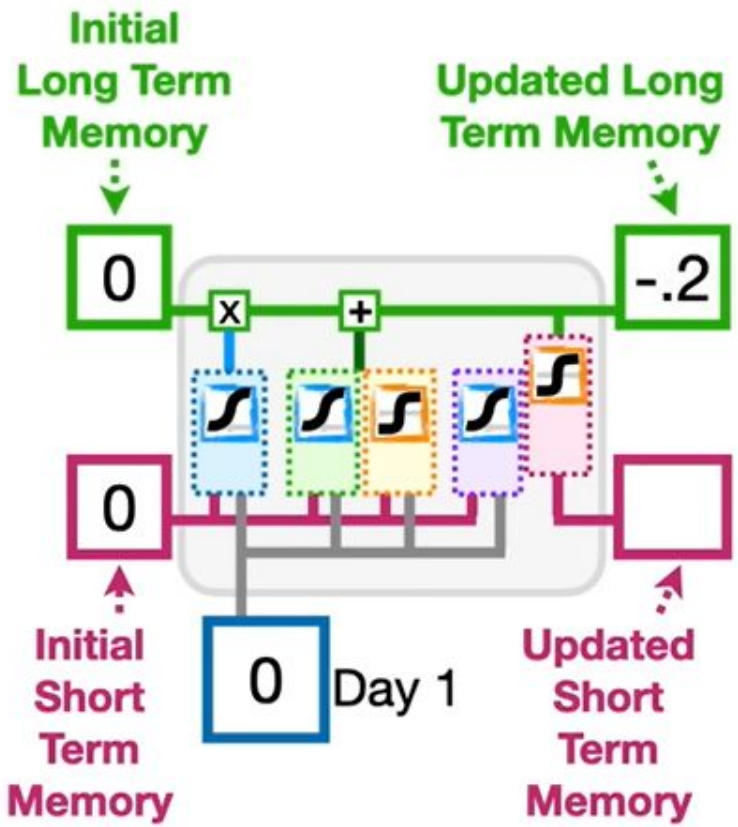


…then we'll start by plugging the value for **Day 1**, which is **0**, into the **Input**.

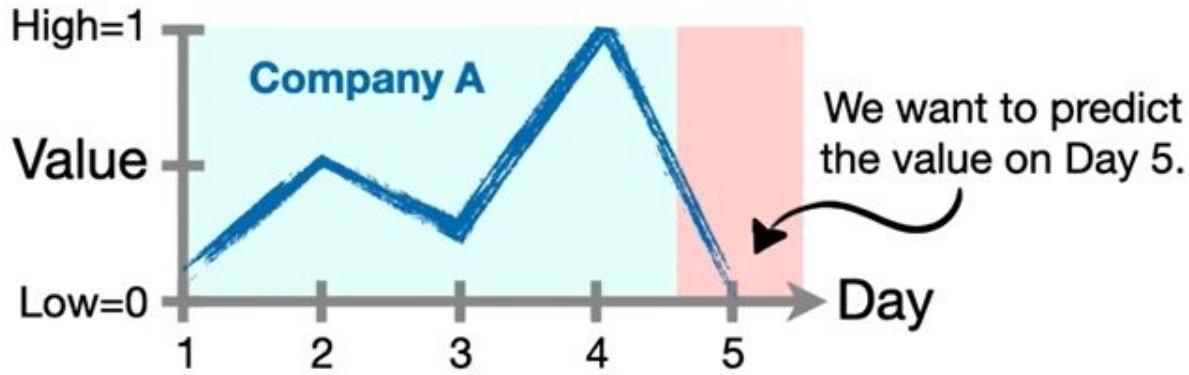

Long-Term Memory
0
×
0.0
sum
New Long-Term Memory
-.20
% Long-Term To Remember
0.83
% Potential Long Memory To Remember
-.20
Potential Long-Term Memory
% Potential Short Memory To Remember
Potential Short-Term Memory
0.65
×
-.31
0.64
-.20
+ 1.62
+ 0.62
+ -0.32
+ 0.59
sum
sum
sum
sum
×
x 2.70
x 2.00
x 1.41
x 4.38
-.13
0
x 1.63
x 1.65
x 0.94
x -0.19
Short-Term Memory
New Short-Term Memory
Input
0
After doing the math, we see that the new, or updated Long Term-Memory is -0.20…

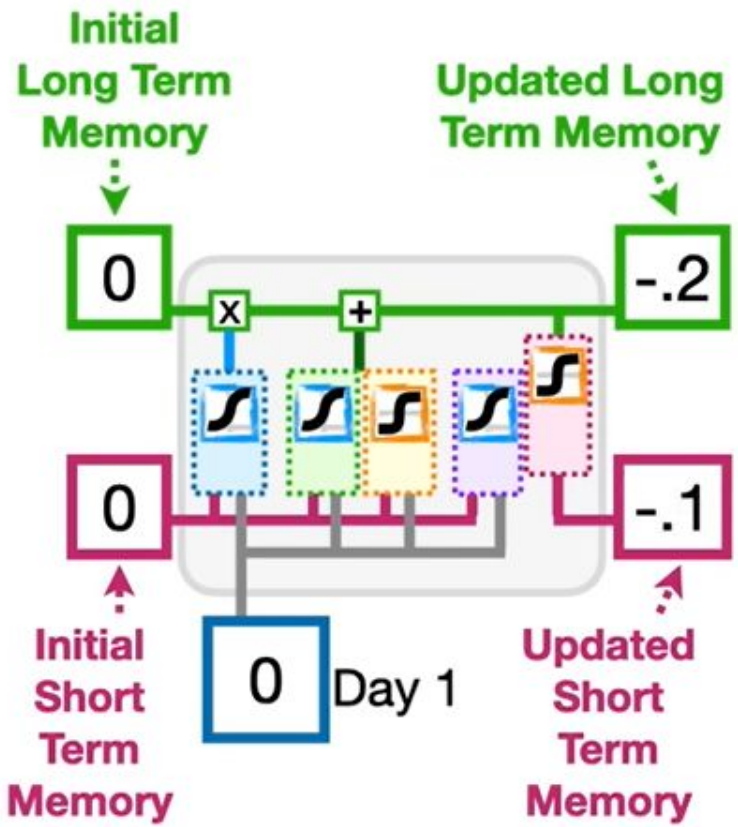

Long-Term Memory
0
×
0.0
sum
New Long-Term Memory
-.20
% Long-Term To Remember
0.83
% Potential Long Memory To Remember
-.20
Potential Long-Term Memory
% Potential Short Memory To Remember
Potential Short-Term Memory
0.65
×
-.31
0.64
-.20
+ 1.62
+ 0.62
+ -0.32
+ 0.59
sum
sum
sum
sum
x 2.70
x 2.00
x 1.41
x 4.38
×
-.13
0
Short-Term Memory
x 1.63
x 1.65
x 0.94
x -0.29
New Short-Term Memory
Input
0
…and the new, updated
Short-Term Memory is -0.13.



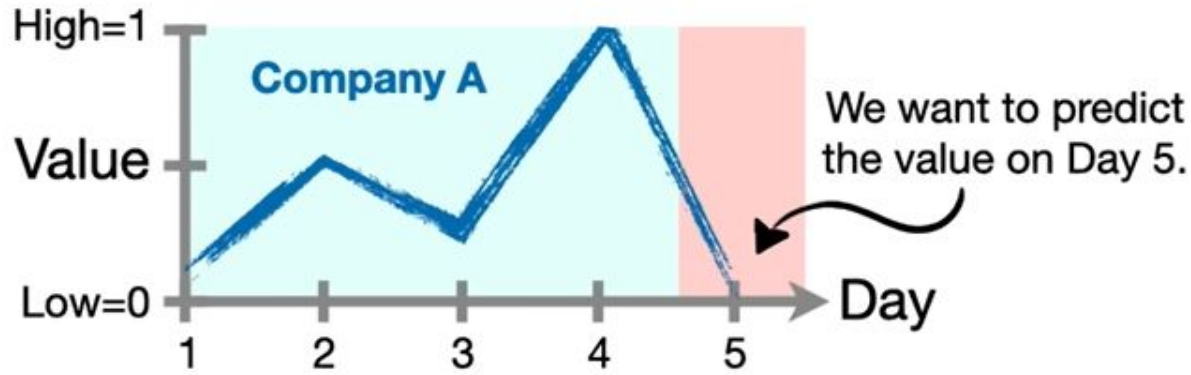


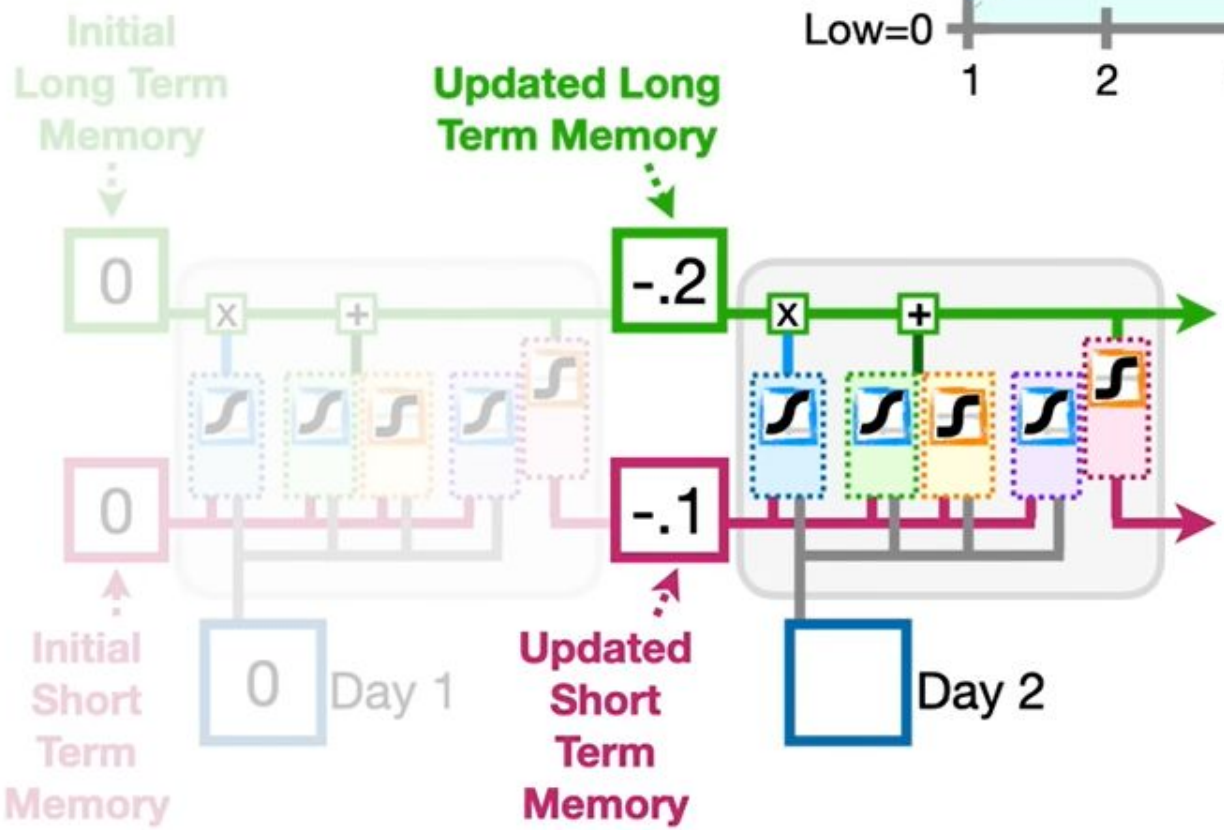
…so we plug in **-0.2** for the updated **Long-Term Memory**…



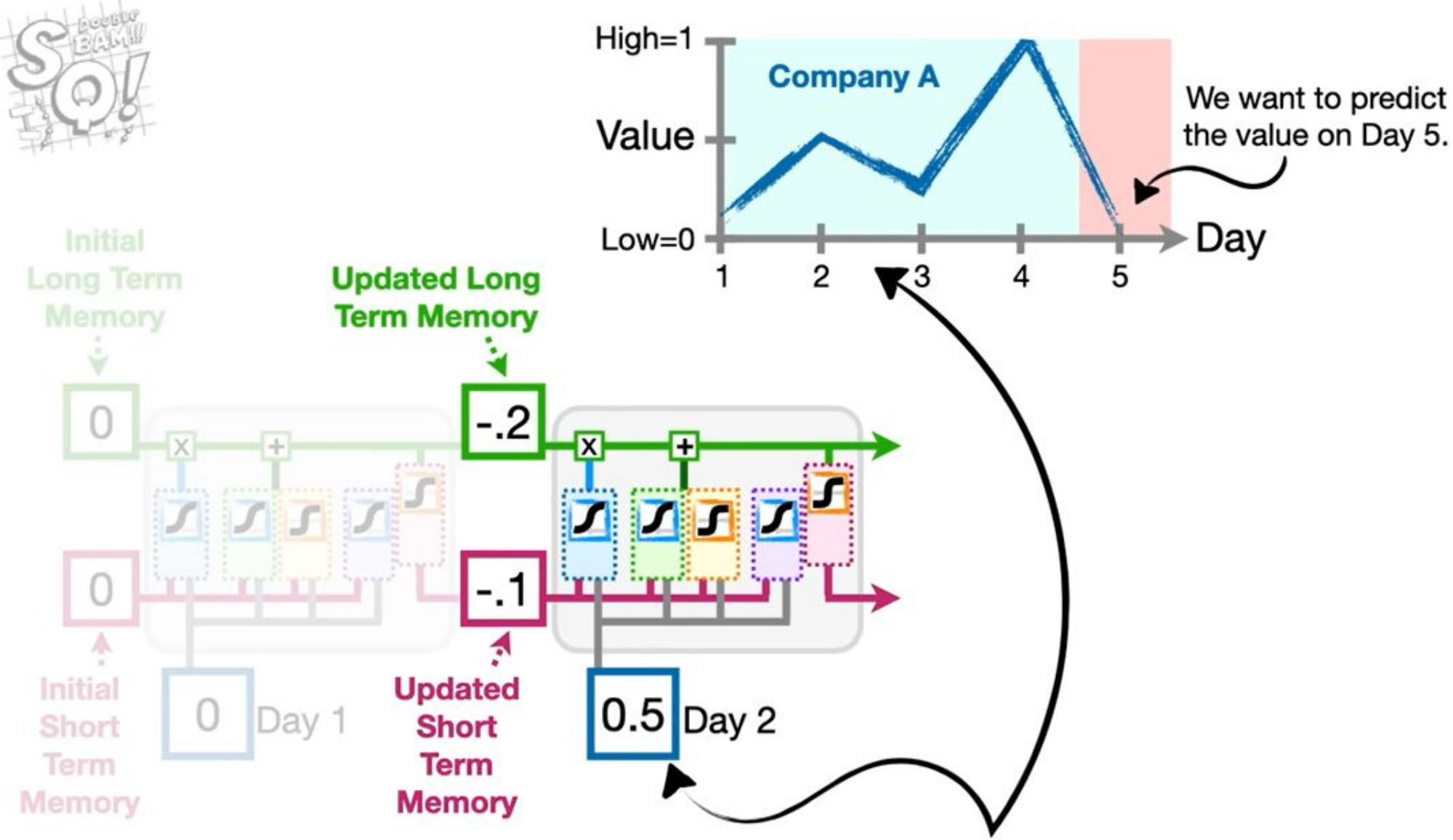


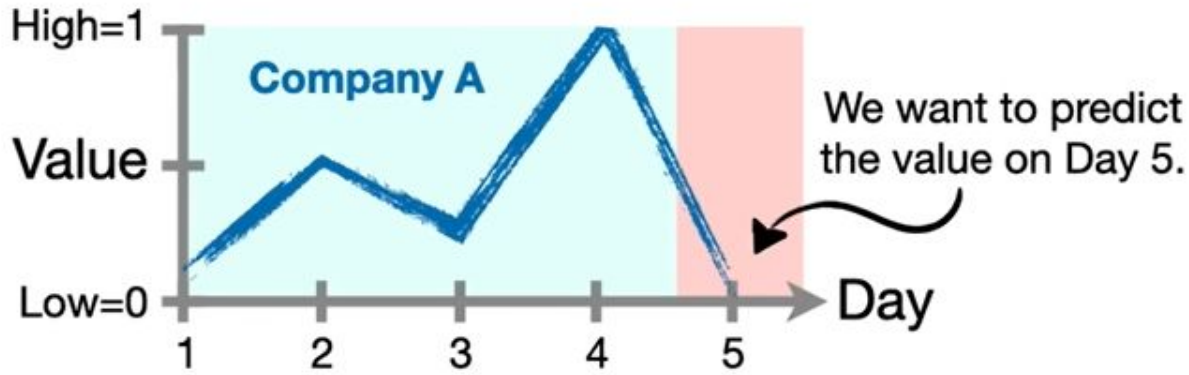
…and **-0.1** (rounded) for the updated **Short-Term Memory**.

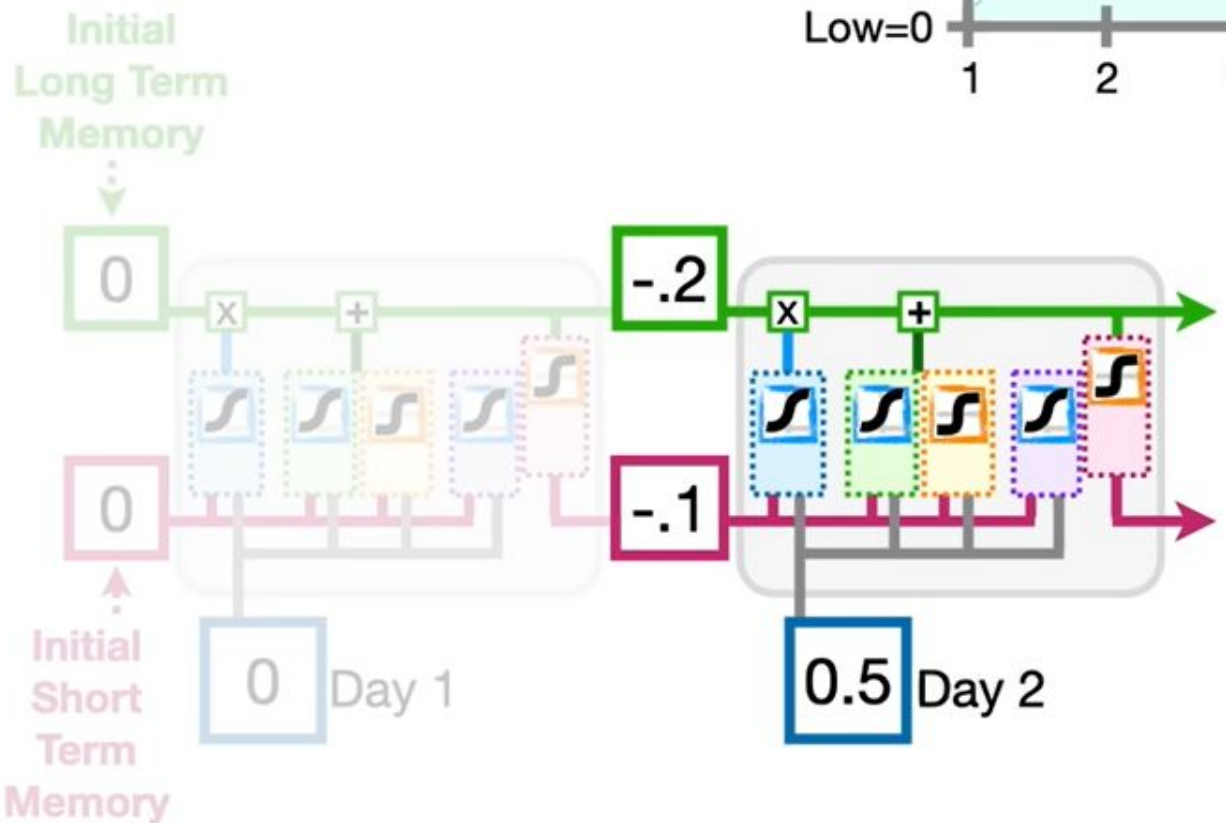




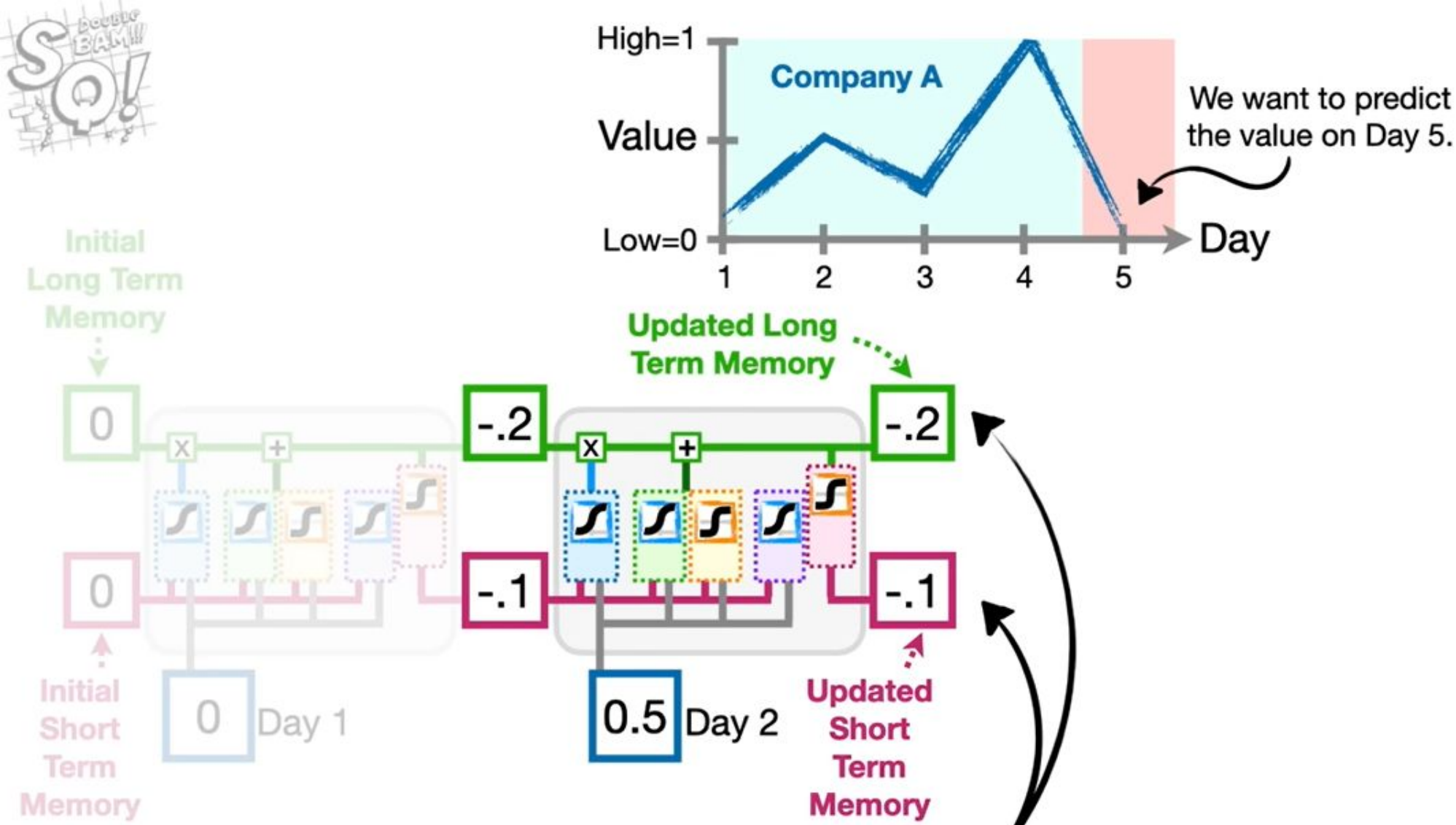
Now we unroll the **LSTM**, using the updated memories…

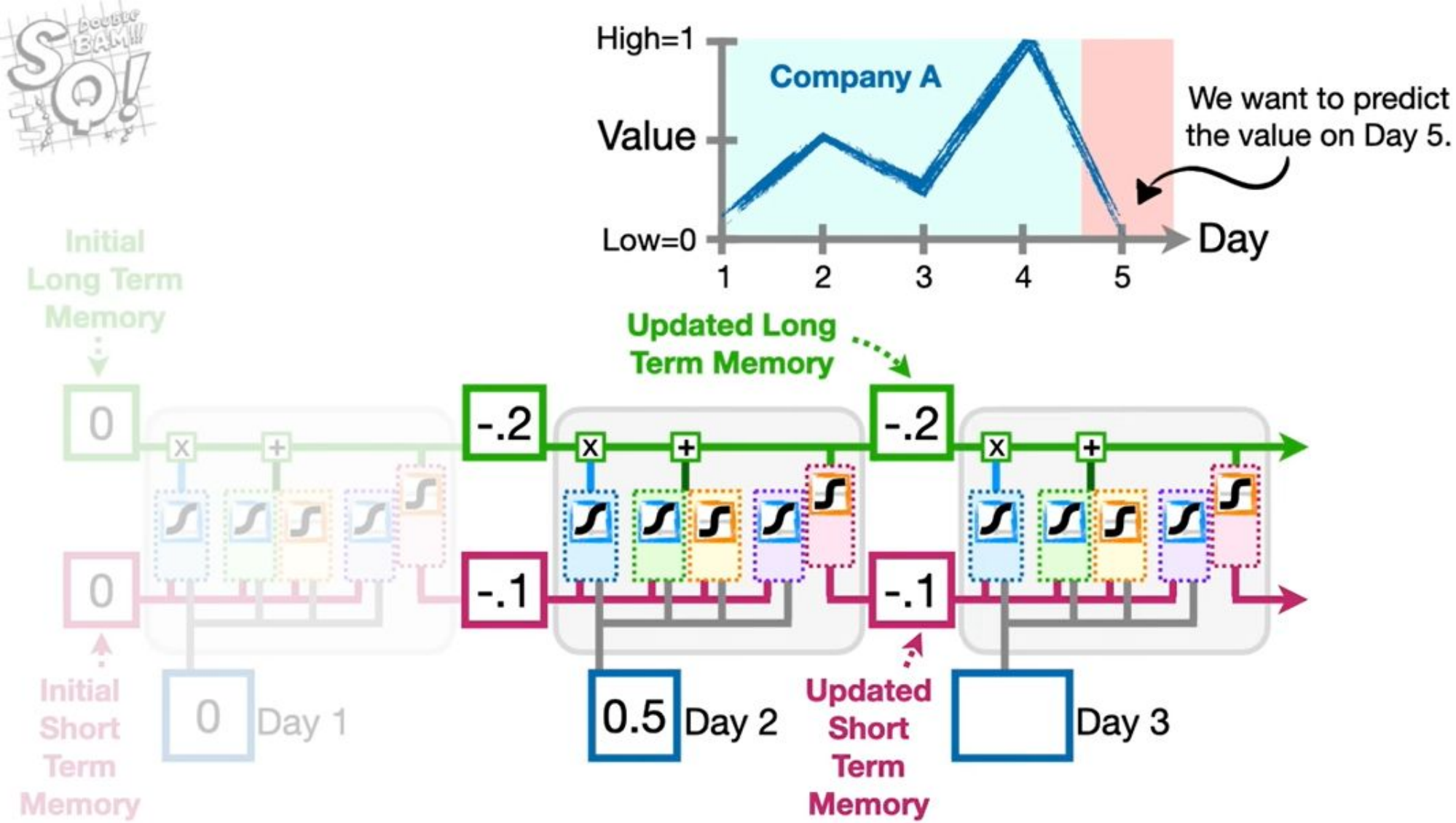

High=1
Value
Low=0
Company A
We want to predict the value on Day 5.
Day
1
2
3
4
5
Initial Long Term Memory
Updated Long Term Memory
0
-.2
0
-.1
Initial Short Term Memory
0
Day 1
Updated Short Term Memory
0.5
Day 2
…and plug the value from **Day 2**, **0.5**, into the **Input**.



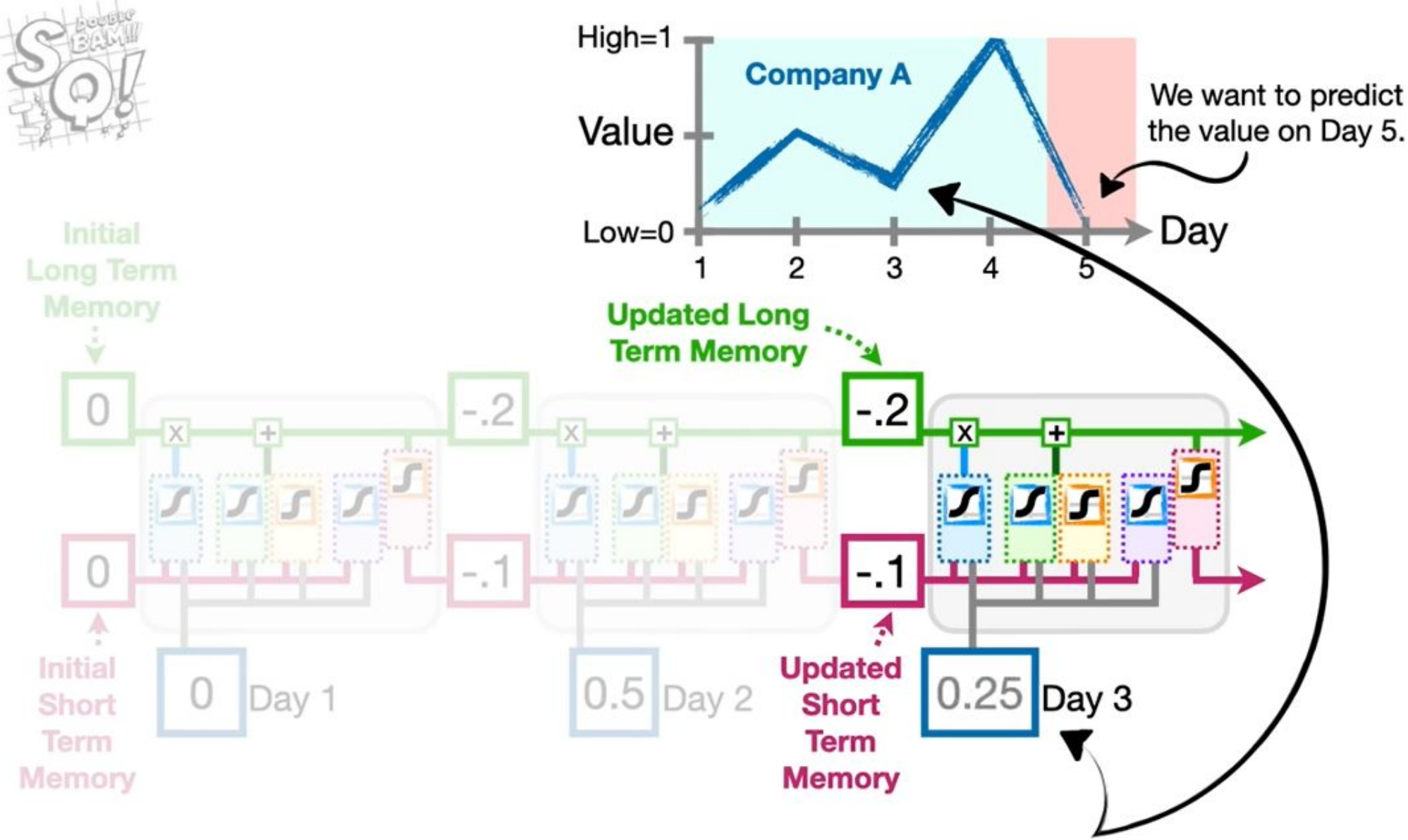


Then the **LSTM** does it's math,
using the exact same **Weights**
and **Biases** as before…

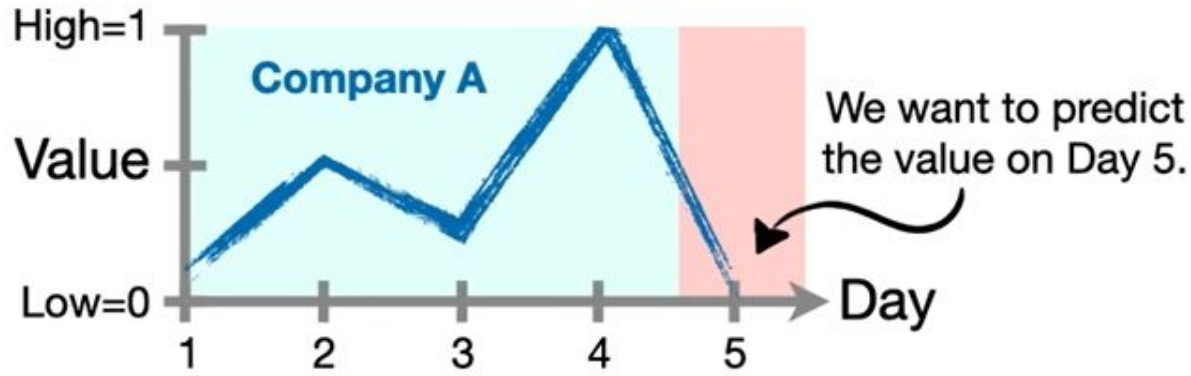

High=1
Value
Low=0
Company A
We want to predict the value on Day 5.
1
2
3
4
5
Day
Updated Long Term Memory
Initial Long Term Memory
0
-.2
-.2
0
-.1
-.1
Initial Short Term Memory
0
Day 1
0.5
Day 2
Updated Short Term Memory
…and we end up with these updated
Long and Short-Term Memories.

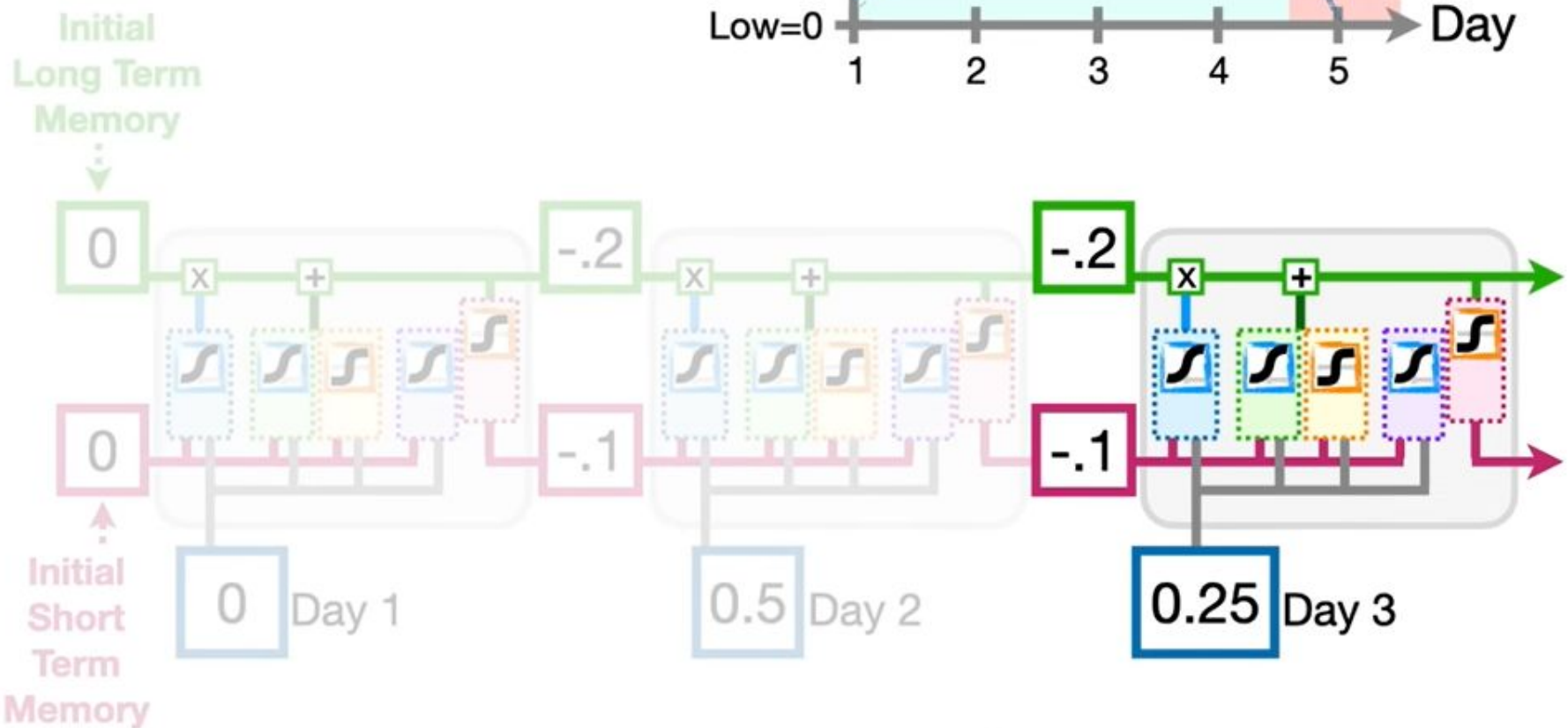


Anyway, we unroll the **LSTM** again…

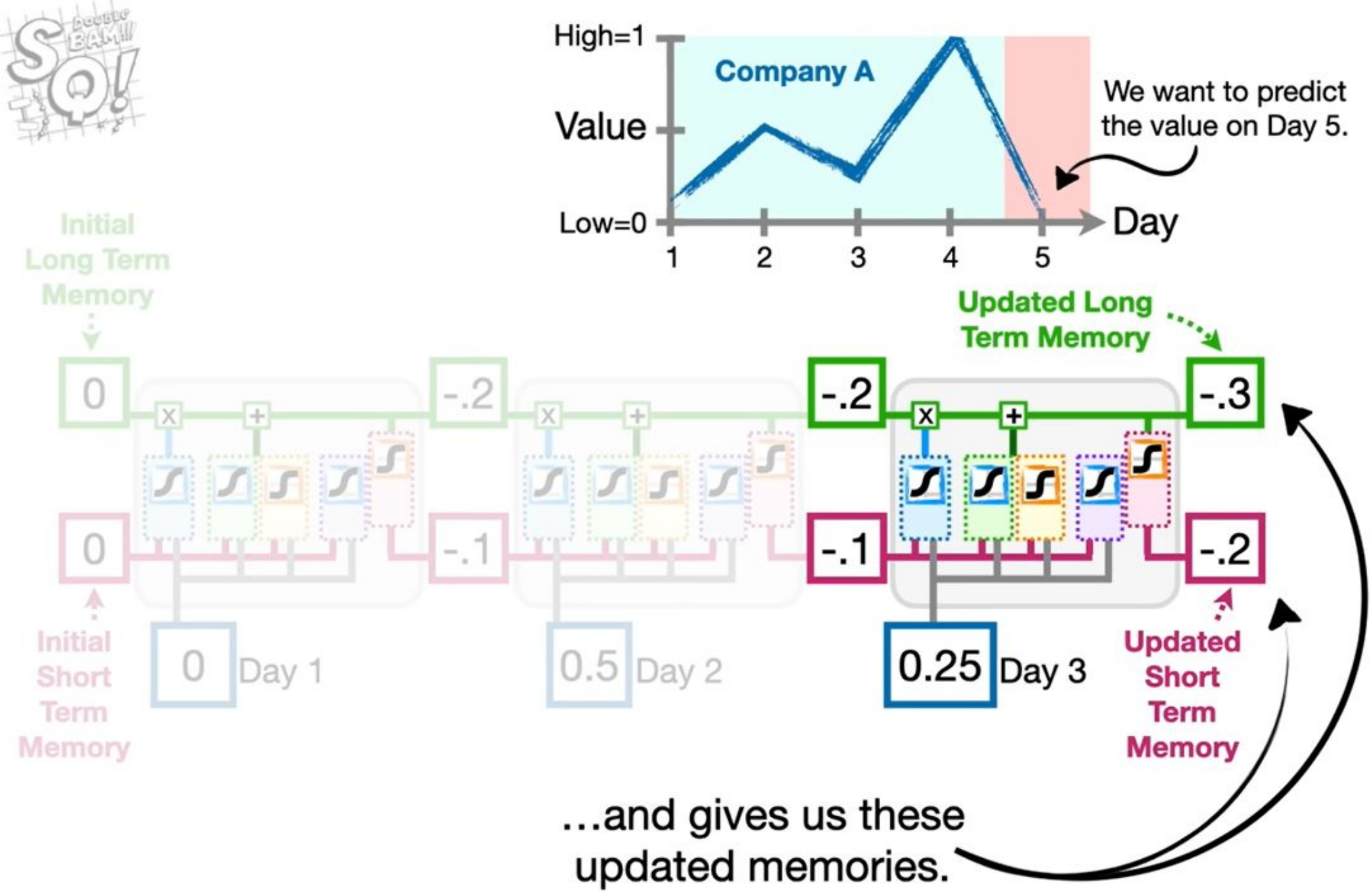


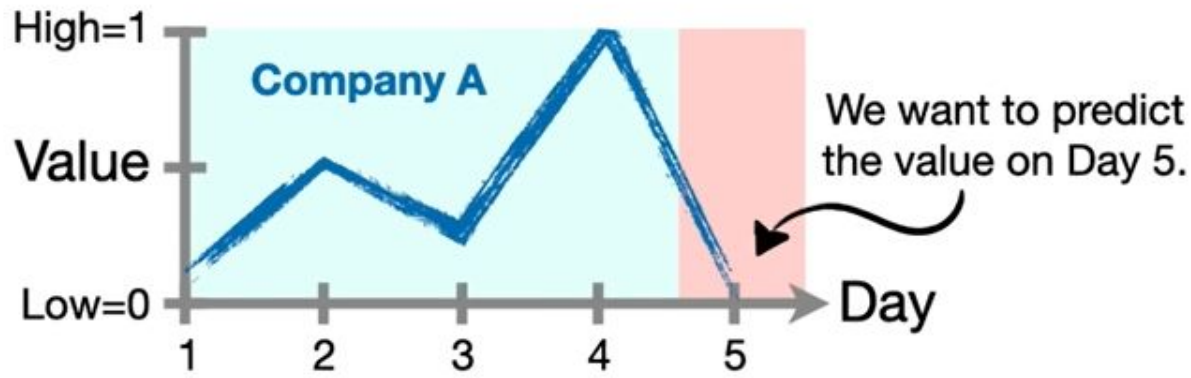
…and plug in the value for **Day 3**.

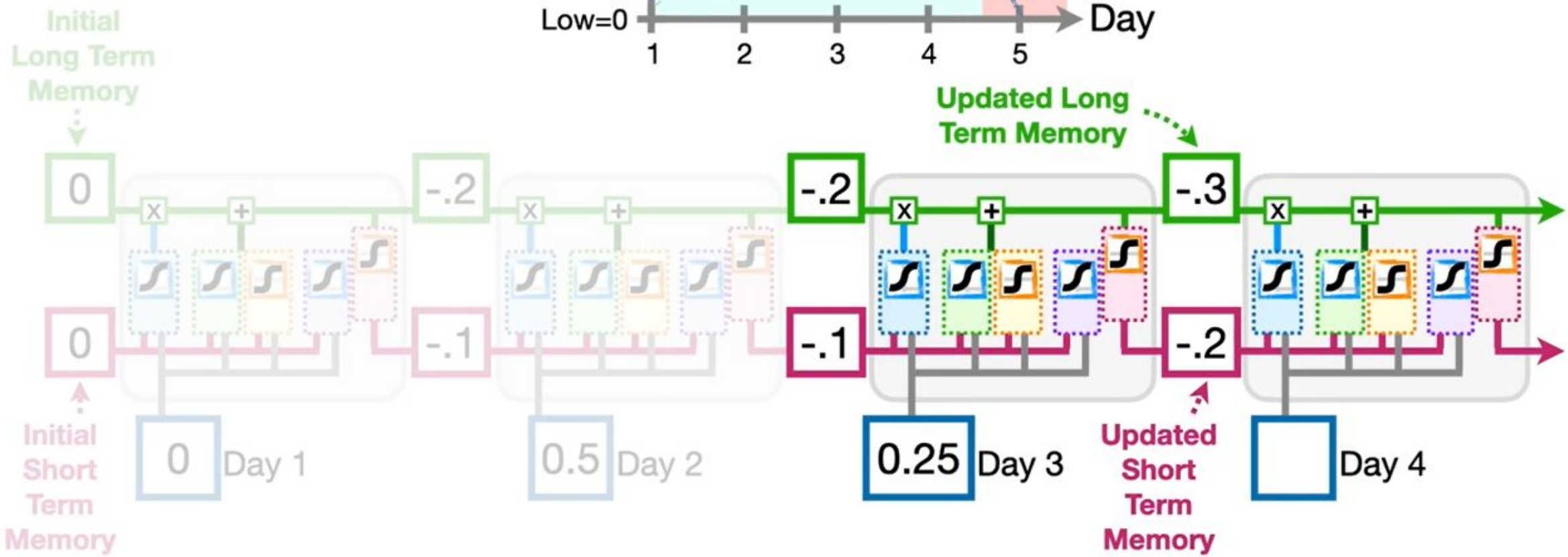




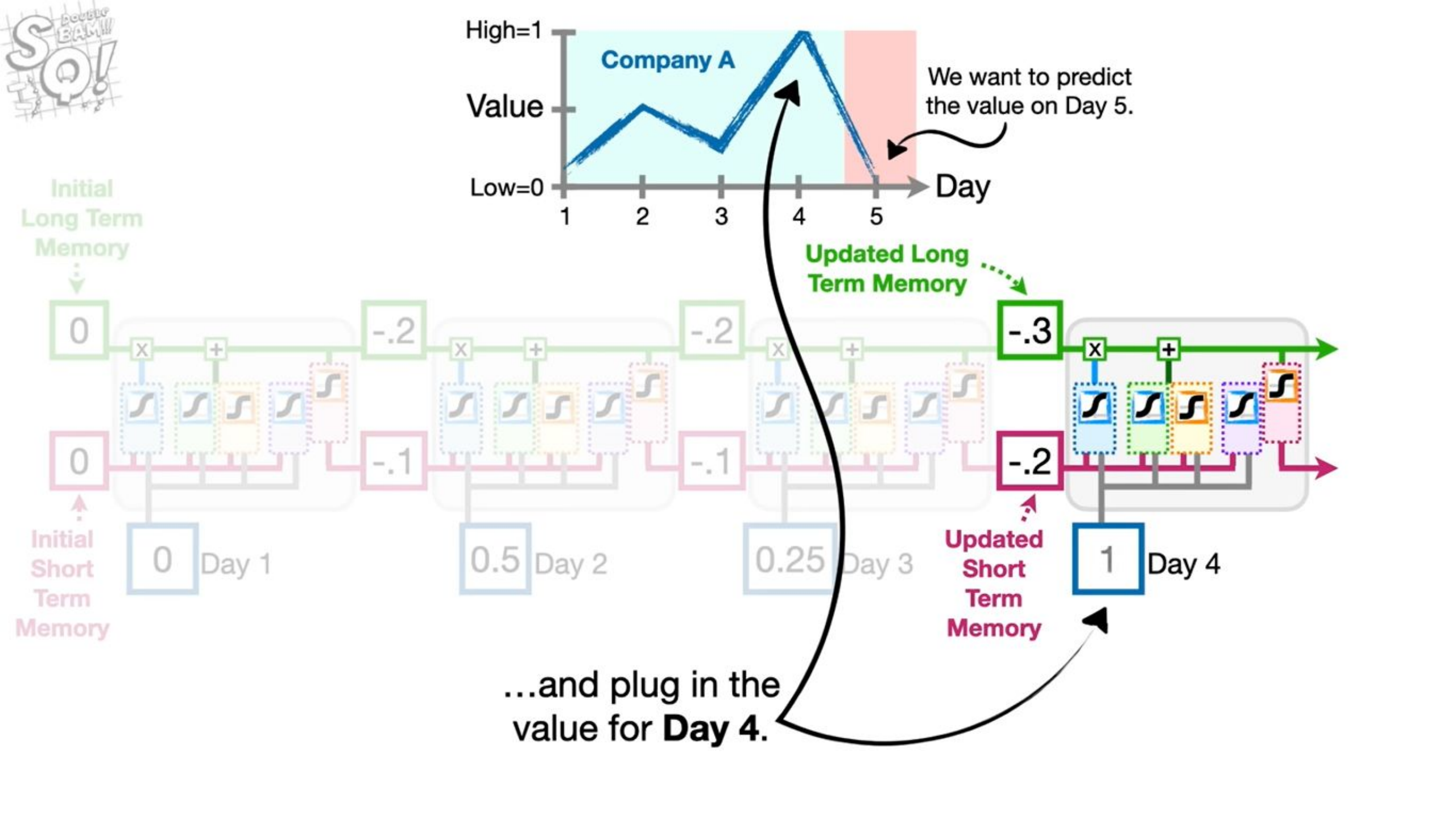
And then the **LSTM** does the math, again, using the exact same **Weights** and **Biases**…

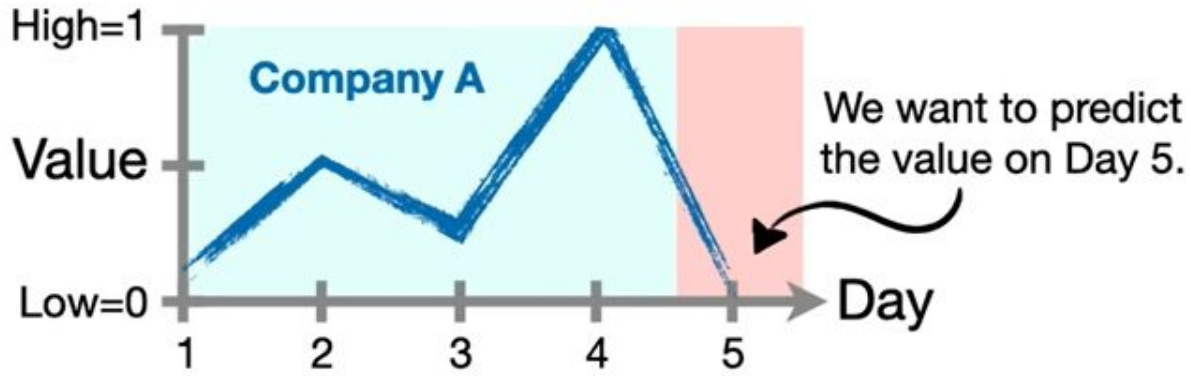

High=1
Value
Low=0
Company A
We want to predict the value on Day 5.
Day
1
2
3
4
5
Initial Long Term Memory
0
0
Initial Short Term Memory
-.2
-.1
0
Day 1
0.5
Day 2
Updated Long Term Memory
-.2
-.1
0.25
Day 3
-.3
-.2
Updated Short Term Memory
…and gives us these updated memories.



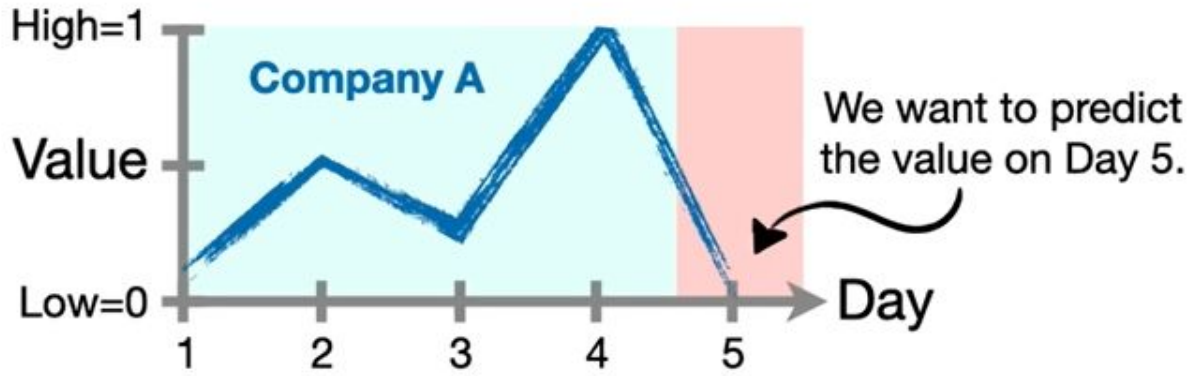


Then we unroll the **LSTM** one last time…


High=1
Value
Low=0
Company A
1
2
3
4
5
Day
We want to predict the value on Day 5.
Initial Long Term Memory
Updated Long Term Memory
0
-.2
-.2
-.3
0
-.1
-.1
-.2
Initial Short Term Memory
Updated Short Term Memory
0 Day 1
0.5 Day 2
0.25 Day 3
1 Day 4
…and plug in the value for Day 4.

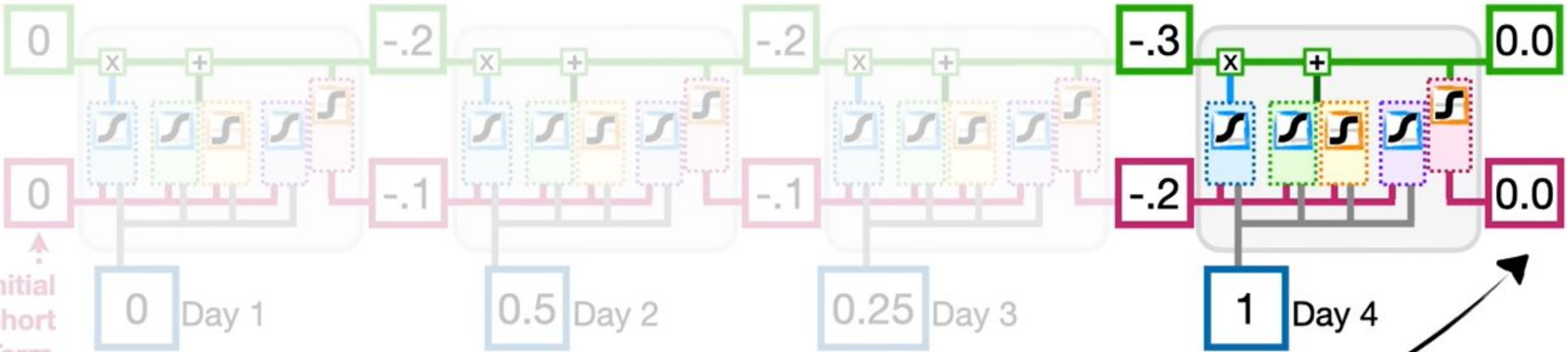


And the **LSTM** does the math,
again, using the exact same
Weights and **Biases**…

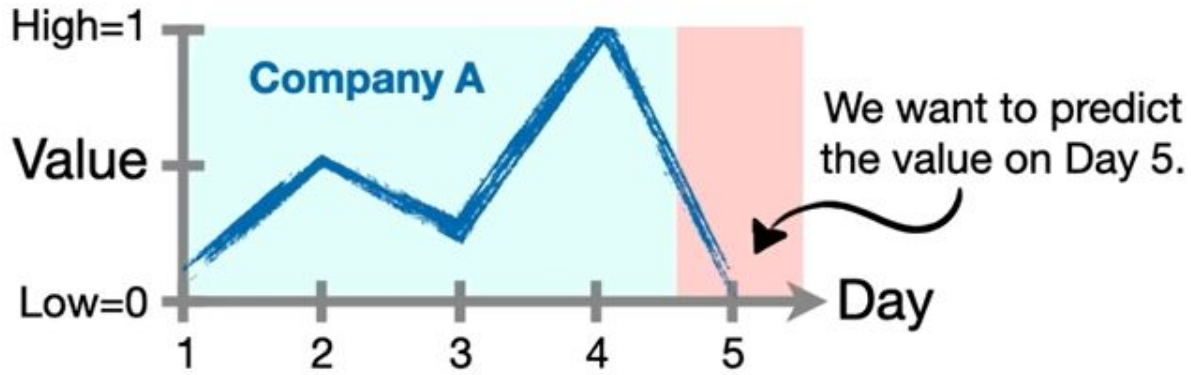


Initial Long Term Memory

Initial Short Term Memory

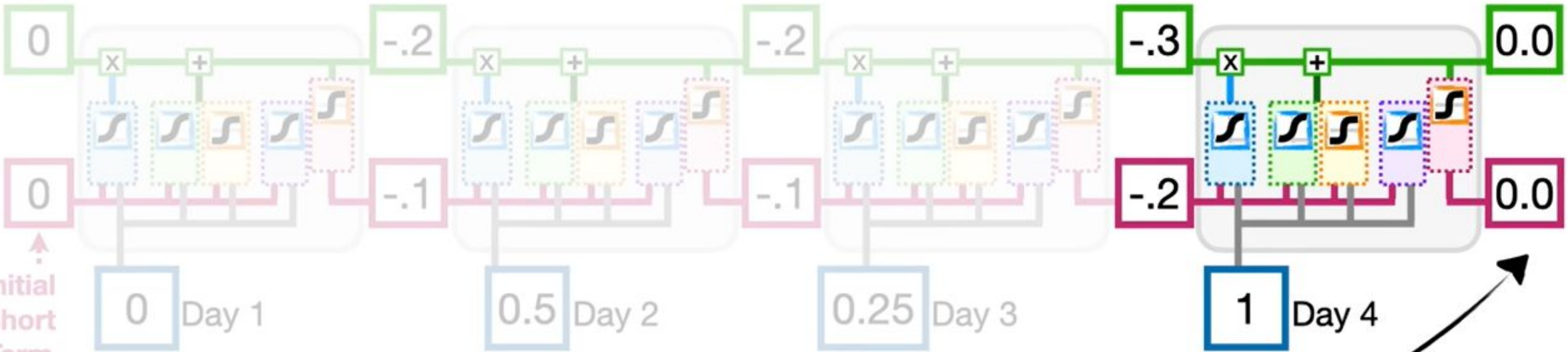


…and gives us the final memories.

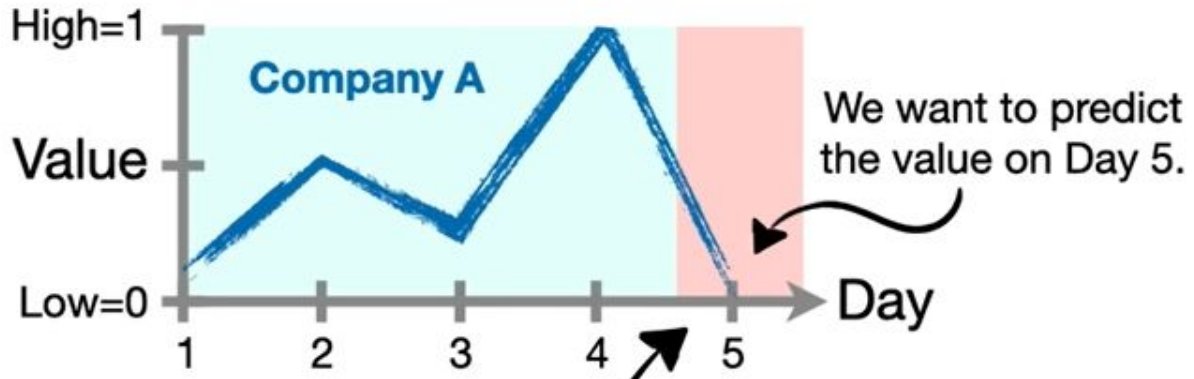


Initial Long Term Memory

Initial Short Term Memory



And the final **Short-Term Memory**, **0.0**, is the **Output** from the unrolled **LSTM**.

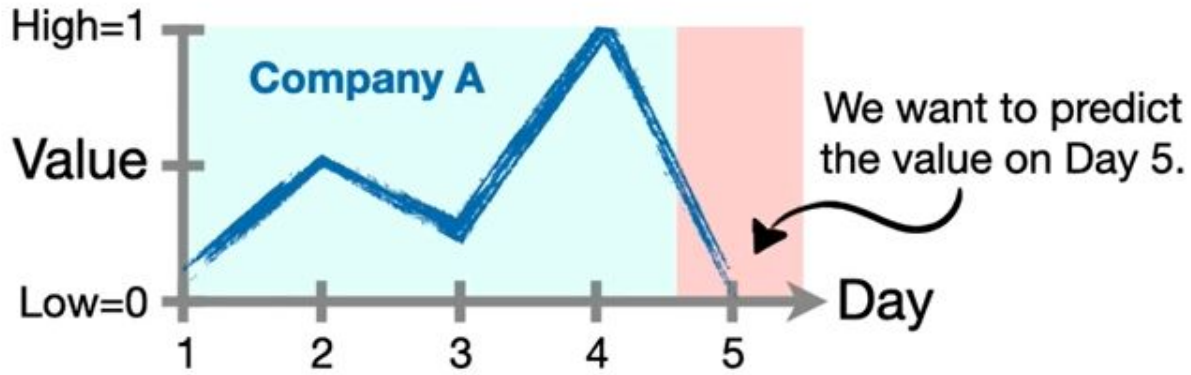


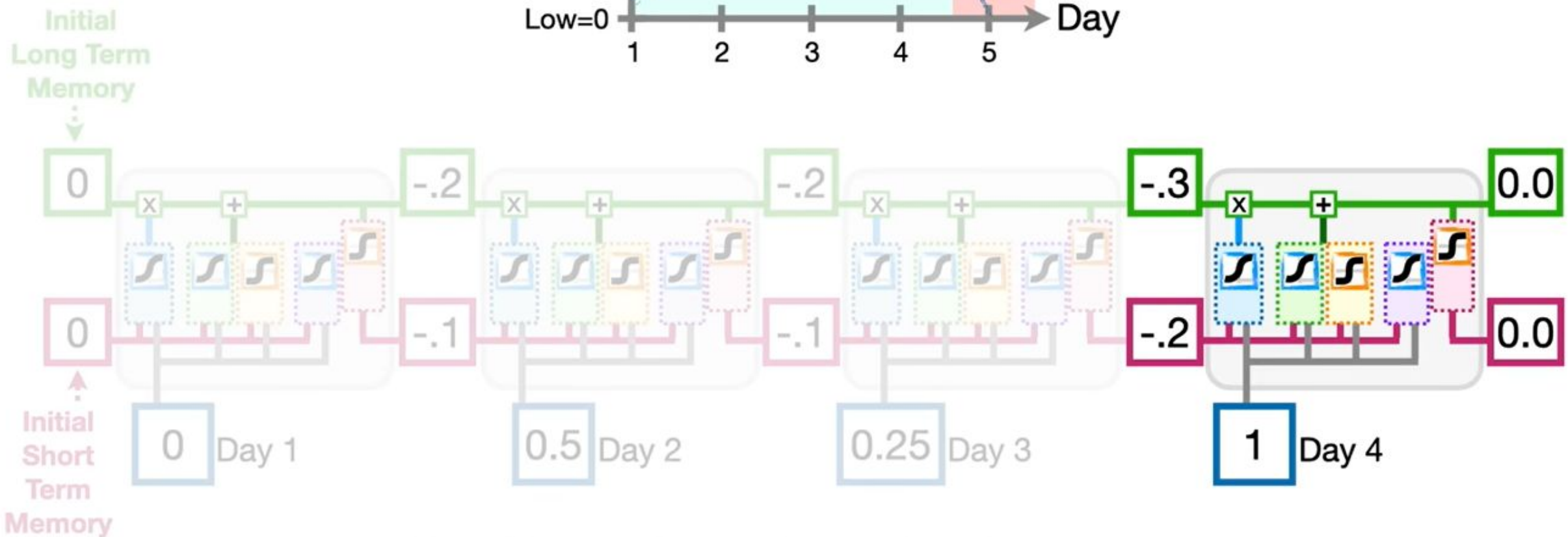
We want to predict the value on Day 5.

Initial Long Term Memory

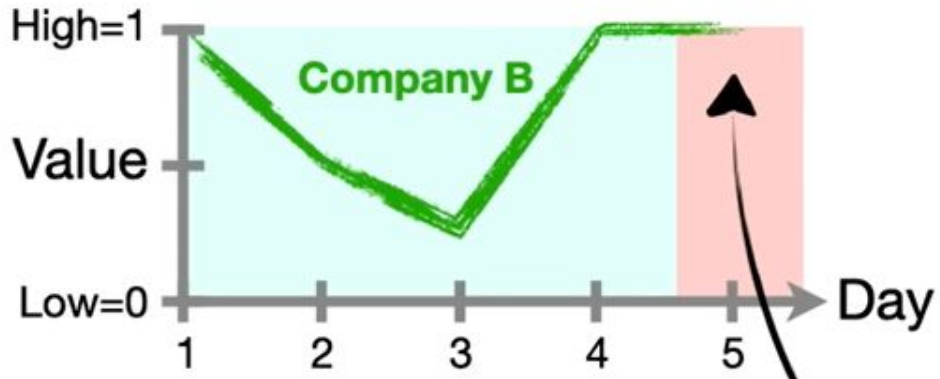
Initial Short Term Memory

And that means that the **Output** from the **LSTM** correctly predicts **Company A**'s value for **Day 5**.

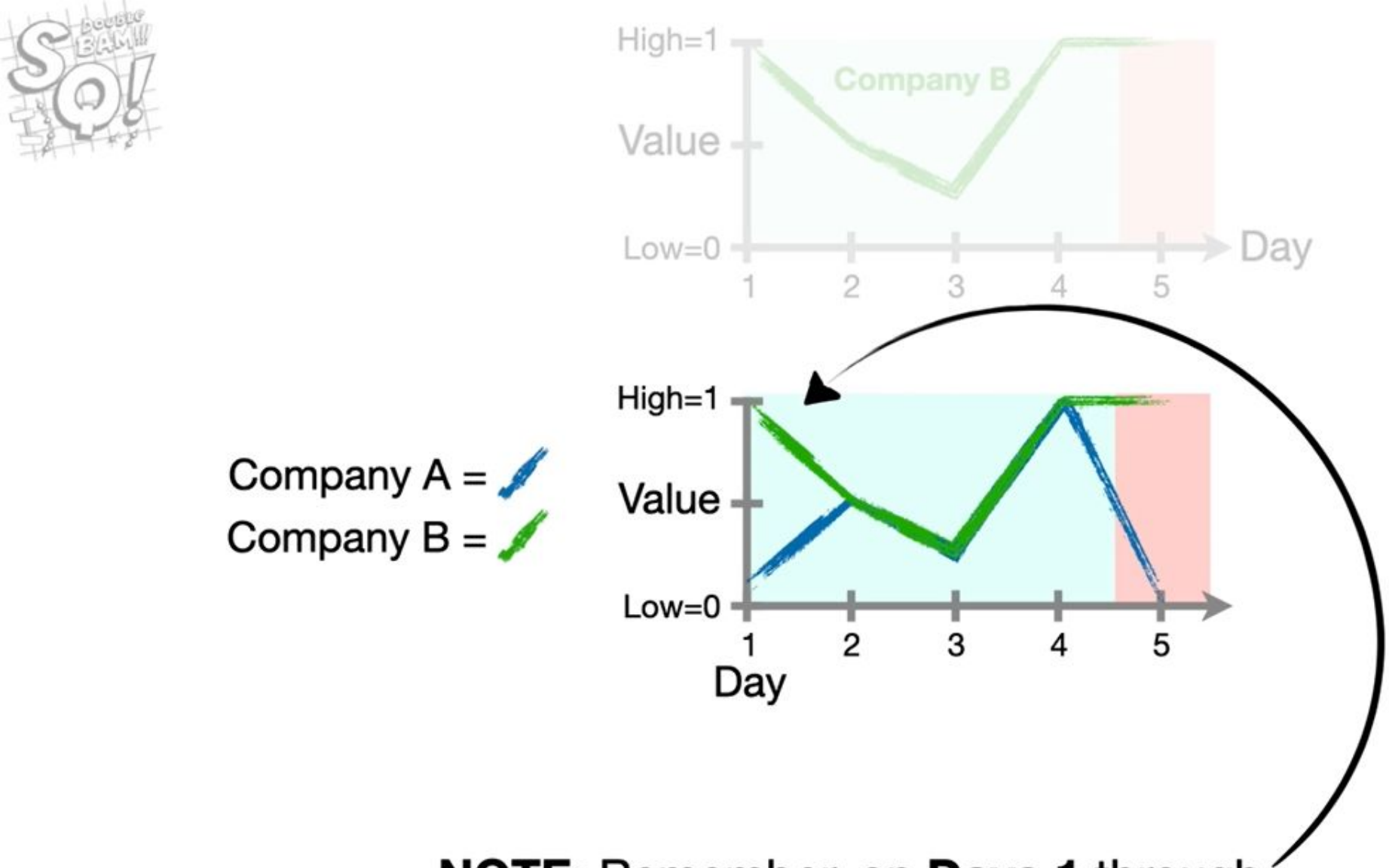




Now that we have shown that the **LSTM** can correctly predict the value on **Day 5** for **Company A**…



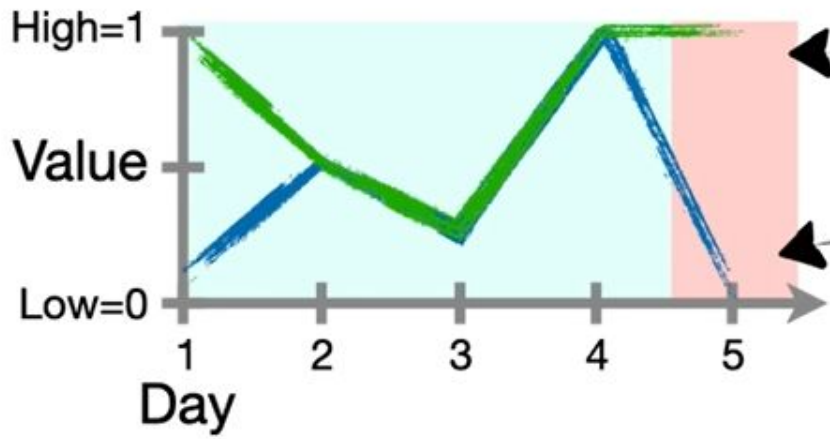
…let's show how the same **LSTM**, with the same **Weights** and **Biases**, can correctly predict the value on **Day 5** for **Company B**.



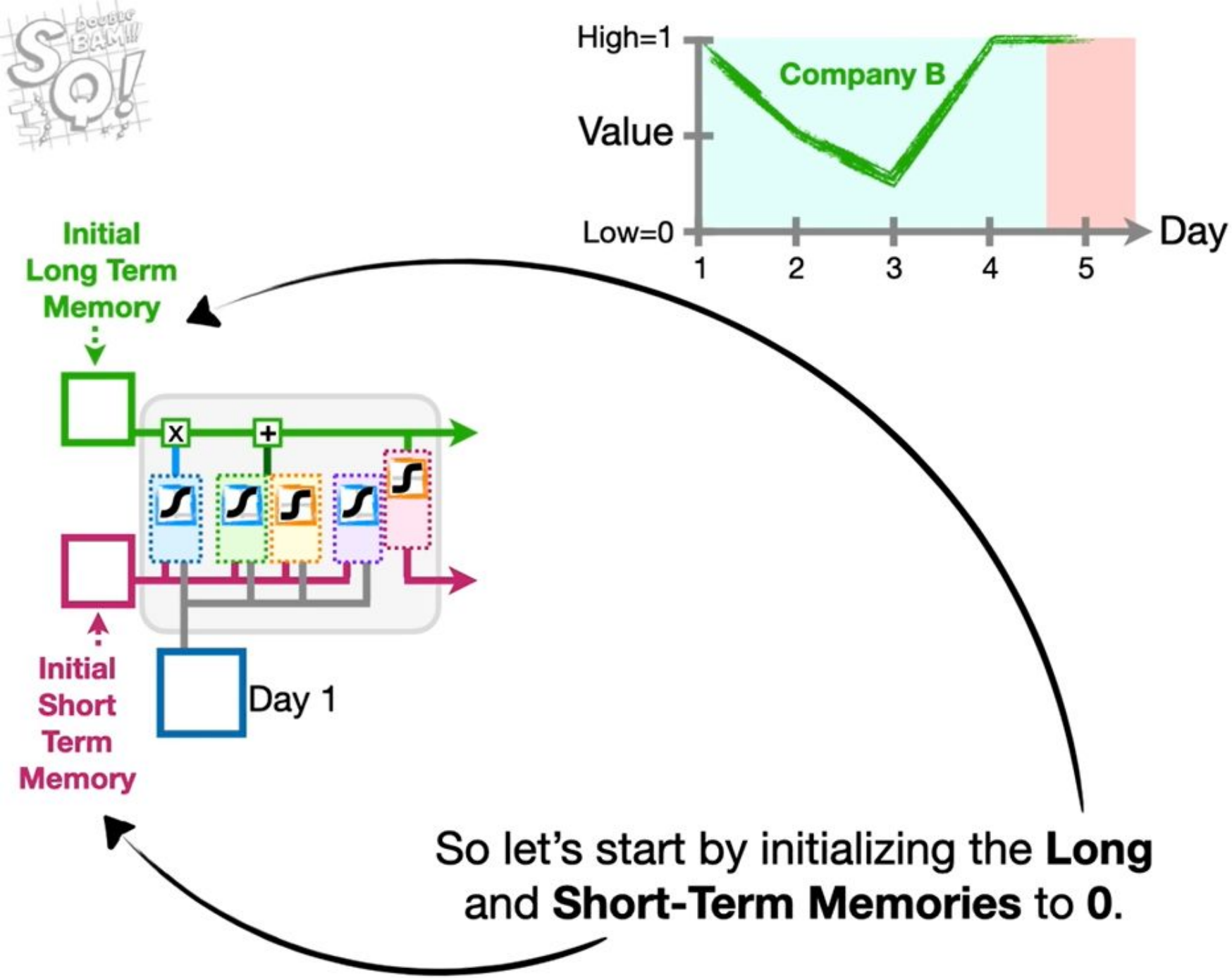
NOTE: Remember, on **Days 1** through **4**, the only difference between the companies occurs on **Day 1**…

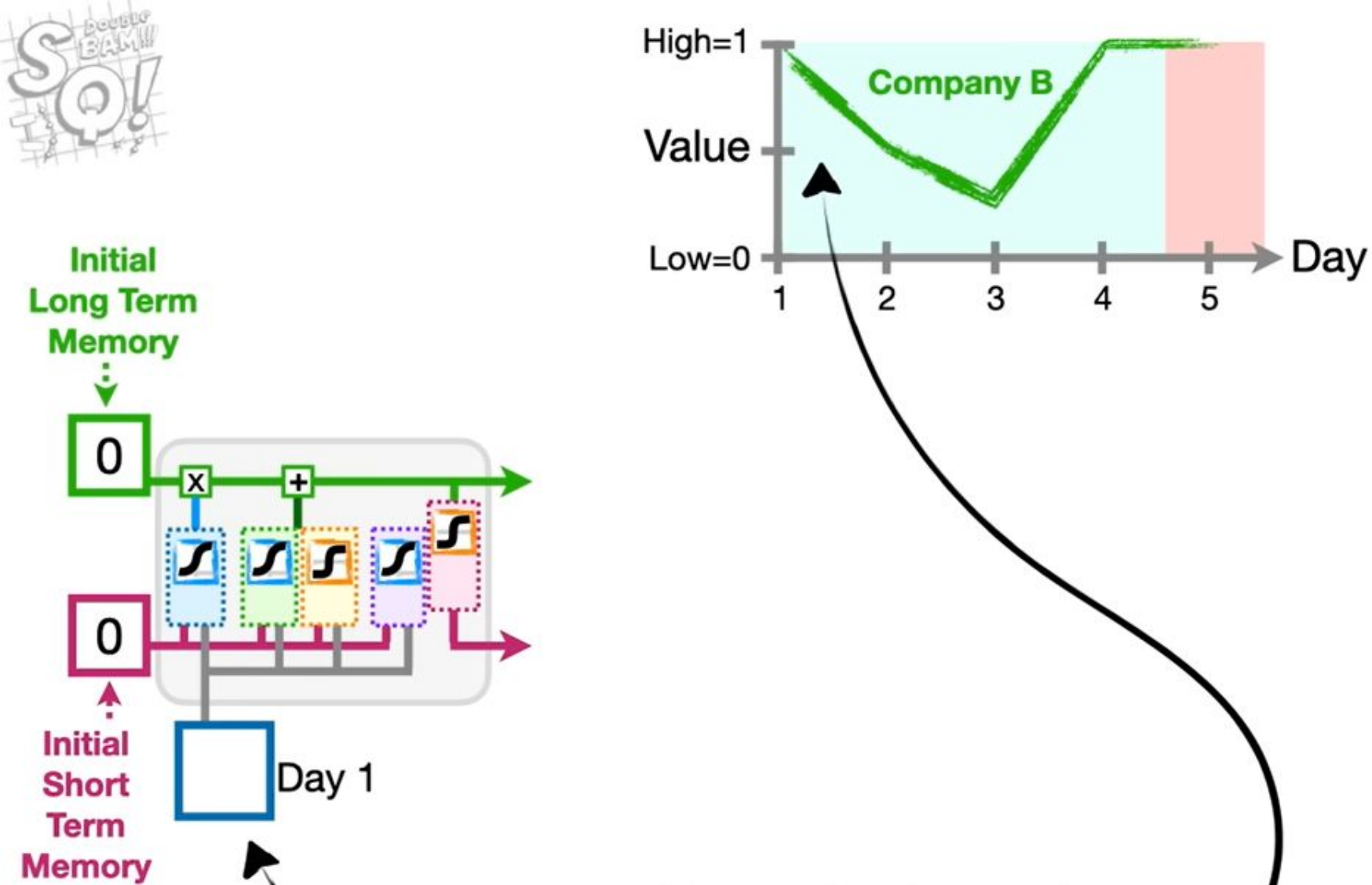
Company A =

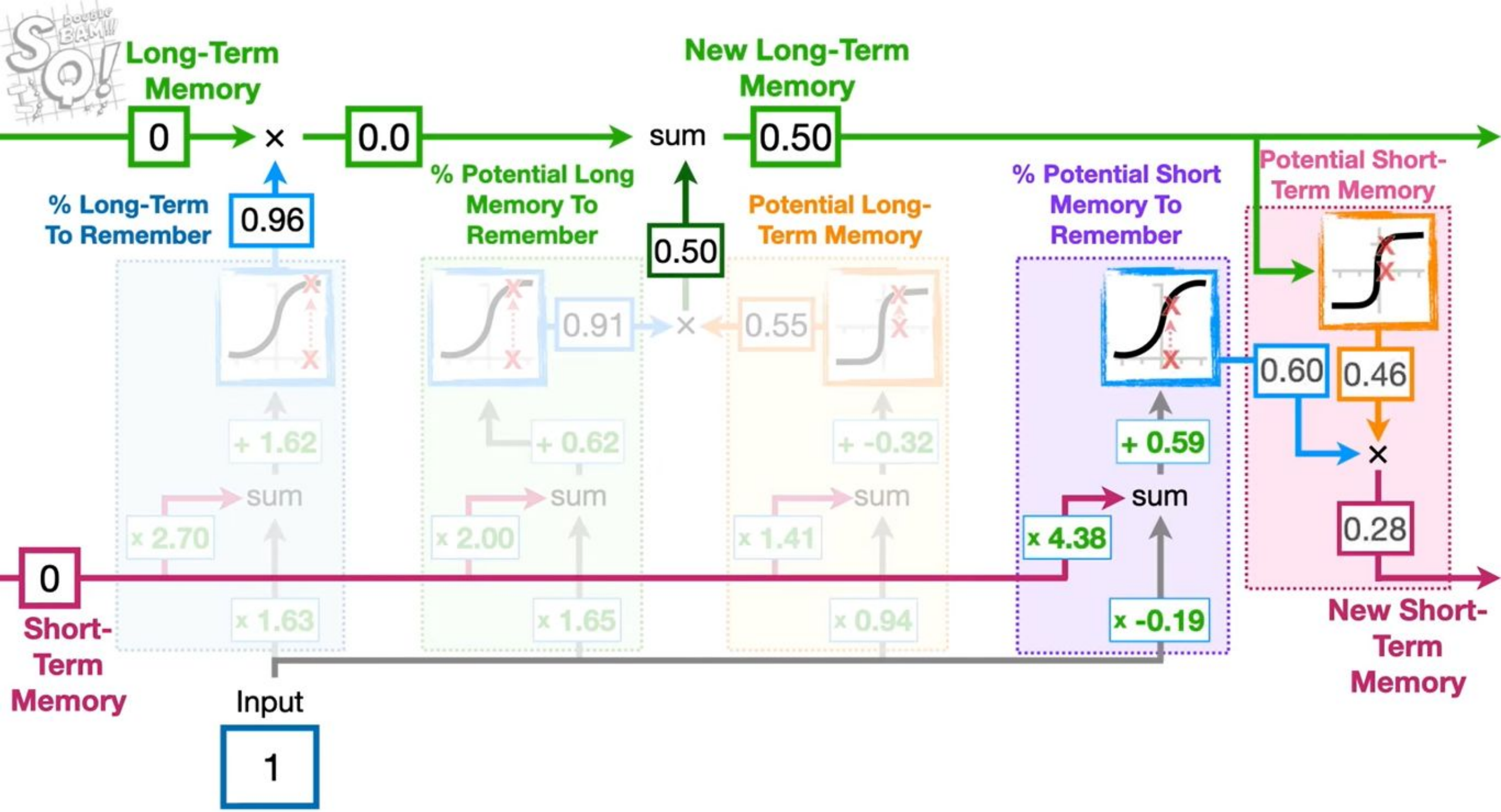
Company B =

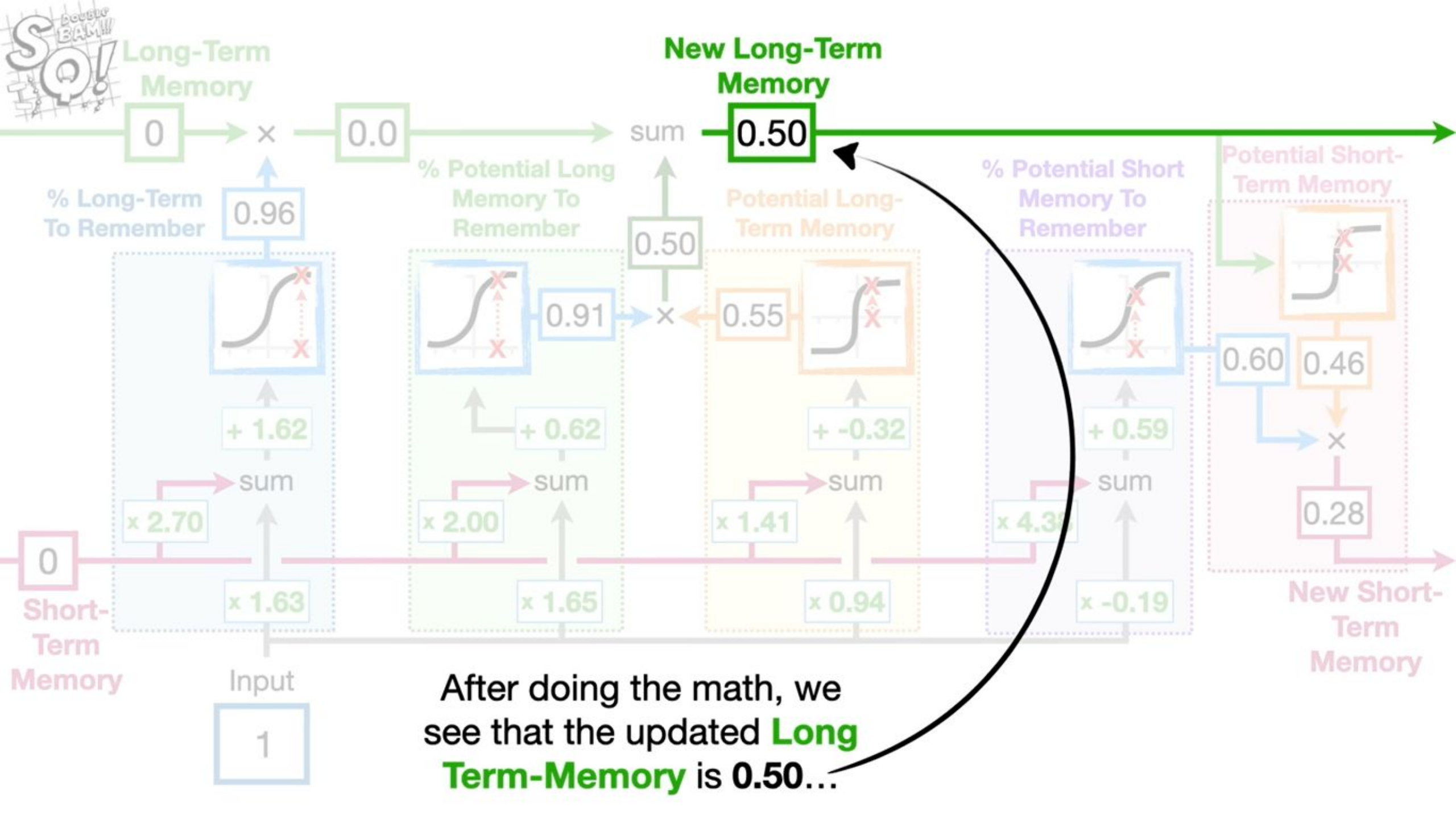


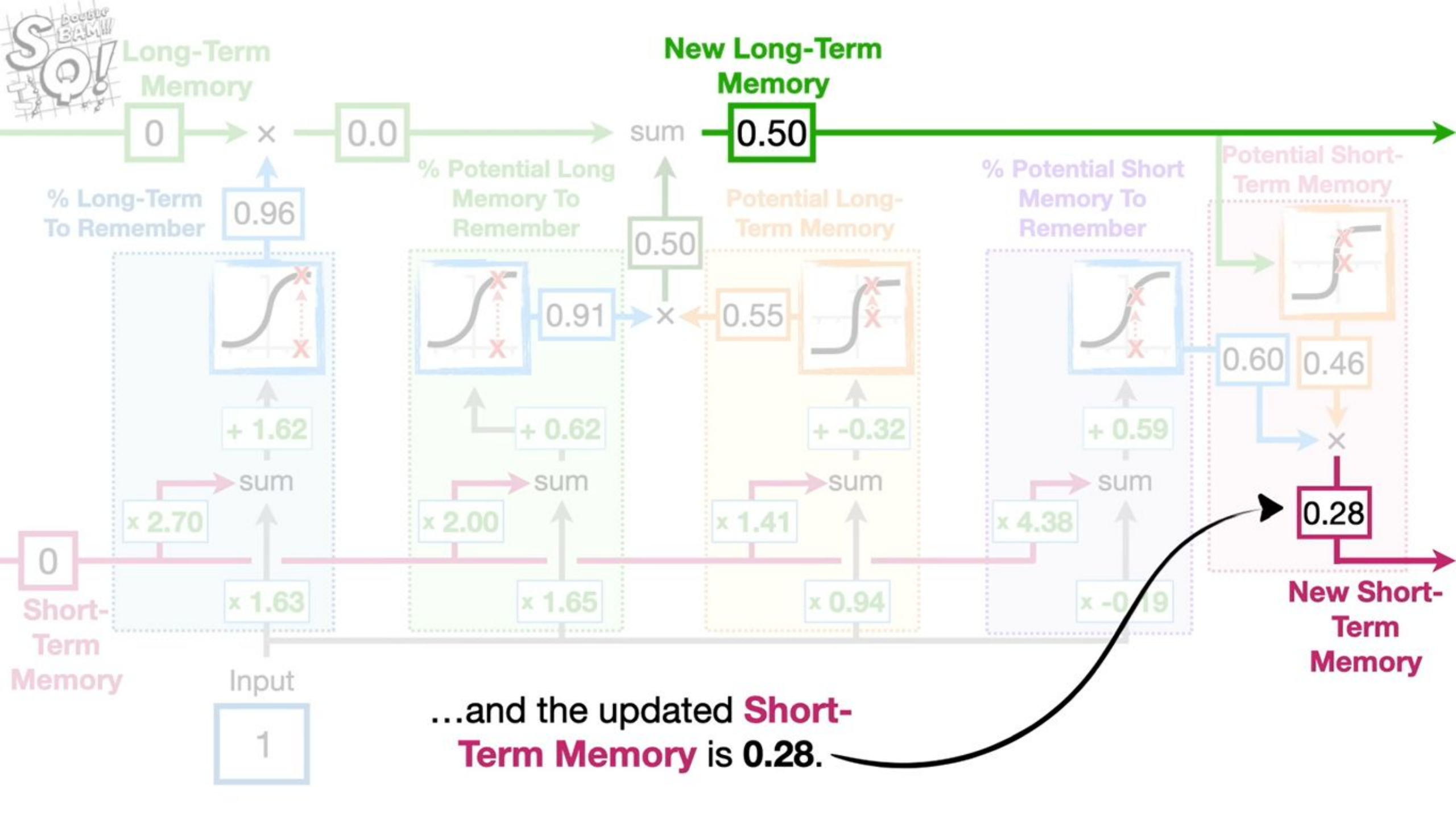
…and that means the **LSTM** has to remember what happened on **Day 1** in order to correctly predict the different output values on **Day 5**.

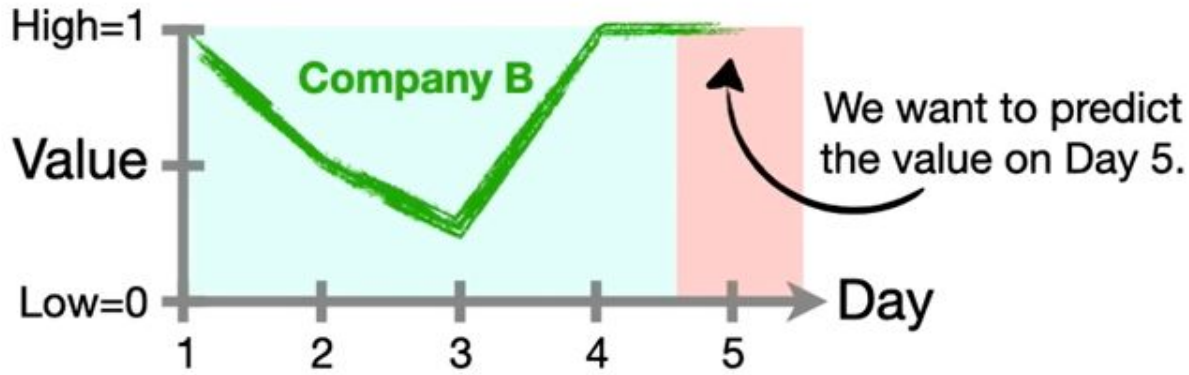

High=1
Value
Low=0
Company B
Day
1
2
3
4
5
Initial
Long Term
Memory
X
+
Initial
Short
Term
Memory
Day 1
So let's start by initializing the **Long** and **Short-Term Memories** to **0**.

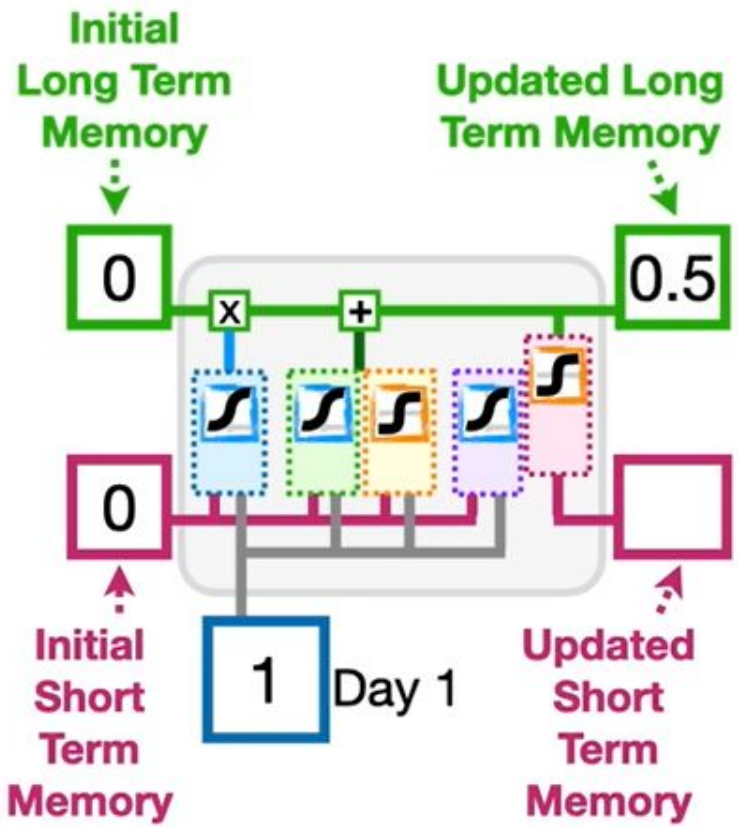

High=1
Value
Low=0
Company B
Day
1
2
3
4
5
Initial
Long Term
Memory
0
0
Initial
Short
Term
Memory
Day 1
Now let's plug in the
value for **Day 1** from
Company B, **1**…


Long-Term Memory
0
×
0.0
New Long-Term Memory
sum
0.50
% Long-Term To Remember
0.96
% Potential Long Memory To Remember
0.50
Potential Long-Term Memory
% Potential Short Memory To Remember
Potential Short-Term Memory
0.91
×
0.55
+ 1.62
+ 0.62
+ -0.32
+ 0.59
sum
sum
sum
sum
x 2.70
x 2.00
x 1.41
x 4.38
0.60
0.46
×
0
0.28
x 1.63
x 1.65
x 0.94
x -0.19
Short-Term Memory
New Short-Term Memory
Input
1

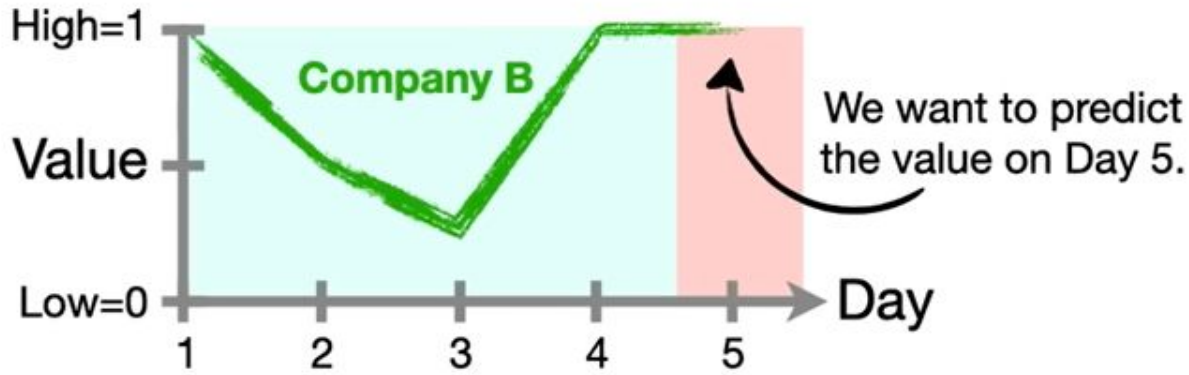

Long-Term Memory
0
×
0.0
sum
New Long-Term Memory
0.50
% Long-Term To Remember
0.96
% Potential Long Memory To Remember
0.50
Potential Long-Term Memory
% Potential Short Memory To Remember
Potential Short-Term Memory
0.91
×
0.55
0.60
0.46
+ 1.62
+ 0.62
+ -0.32
+ 0.59
sum
sum
sum
sum
× 2.70
× 2.00
× 1.41
× 4.38
×
0.28
0
Short-Term Memory
× 1.63
× 1.65
× 0.94
× -0.19
New Short-Term Memory
Input
1
After doing the math, we see that the updated Long Term-Memory is 0.50…

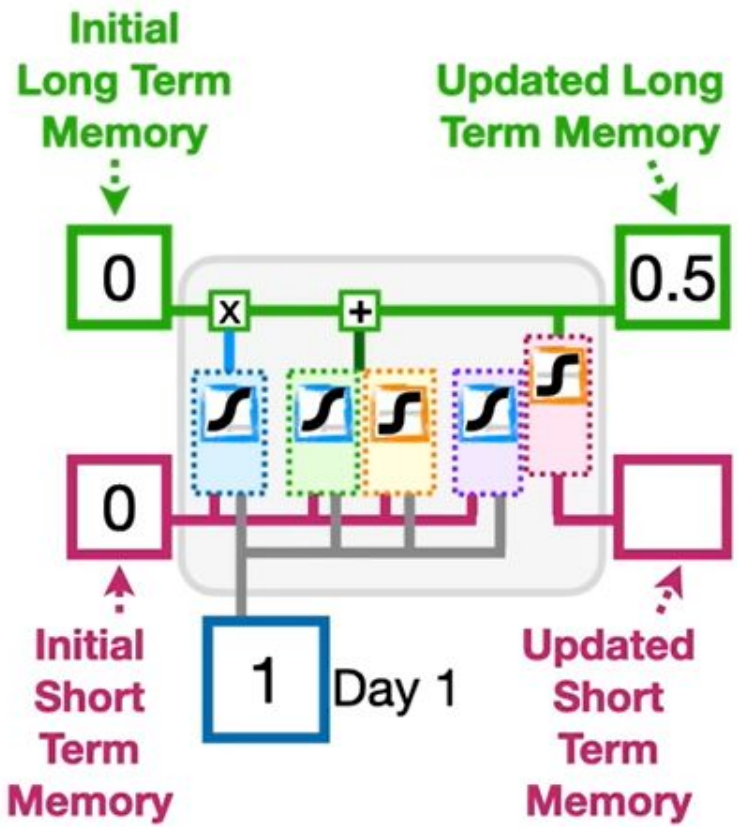

Long-Term Memory
0
×
0.0
sum
New Long-Term Memory
0.50
% Long-Term To Remember
0.96
% Potential Long Memory To Remember
0.50
Potential Long-Term Memory
% Potential Short Memory To Remember
Potential Short-Term Memory
0.91
×
0.55
0.60
0.46
+ 1.62
+ 0.62
+ -0.32
+ 0.59
sum
sum
sum
sum
× 2.70
× 2.00
× 1.41
× 4.38
0
Short-Term Memory
× 1.63
× 1.65
× 0.94
× -0.19
×
0.28
New Short-Term Memory
Input
1
…and the updated Short-Term Memory is 0.28.



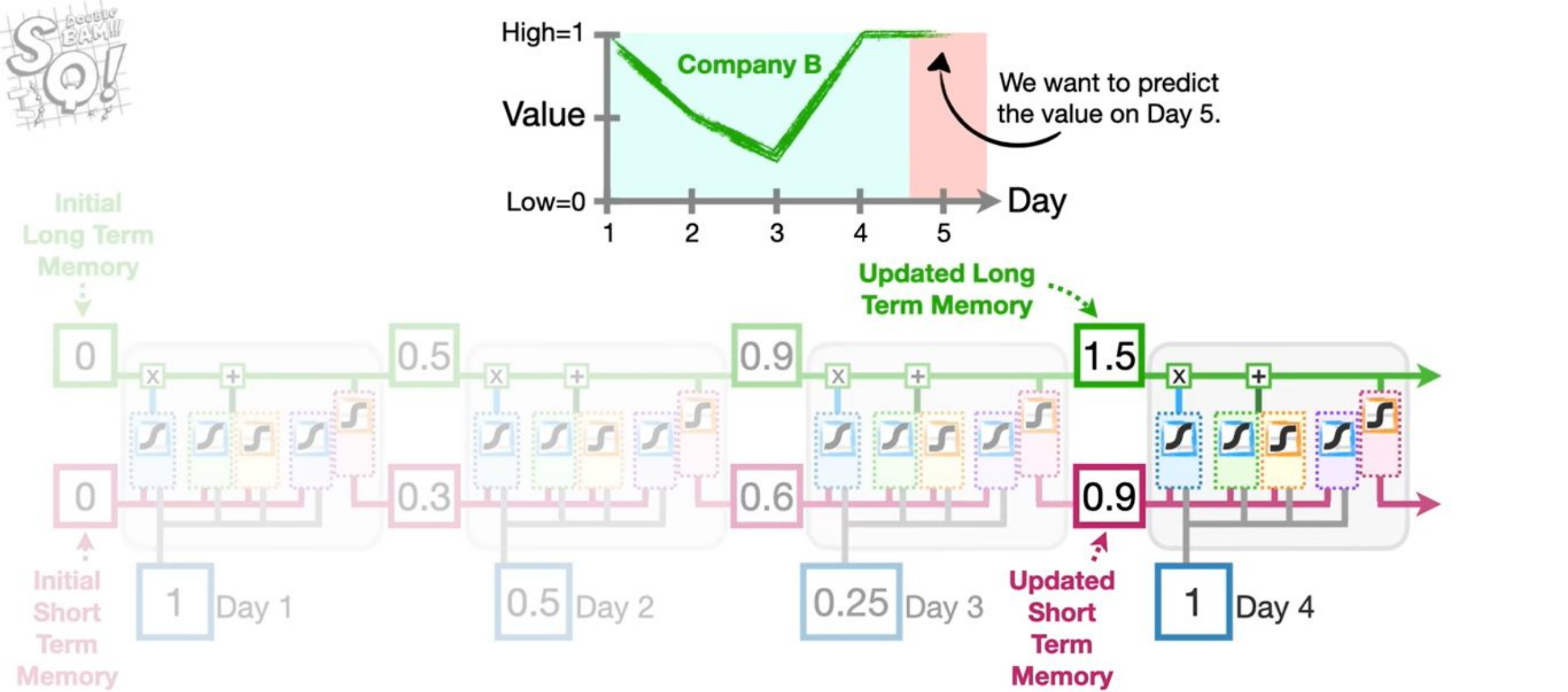


…so we plug in **0.5** for the updated **Long-Term Memory**…

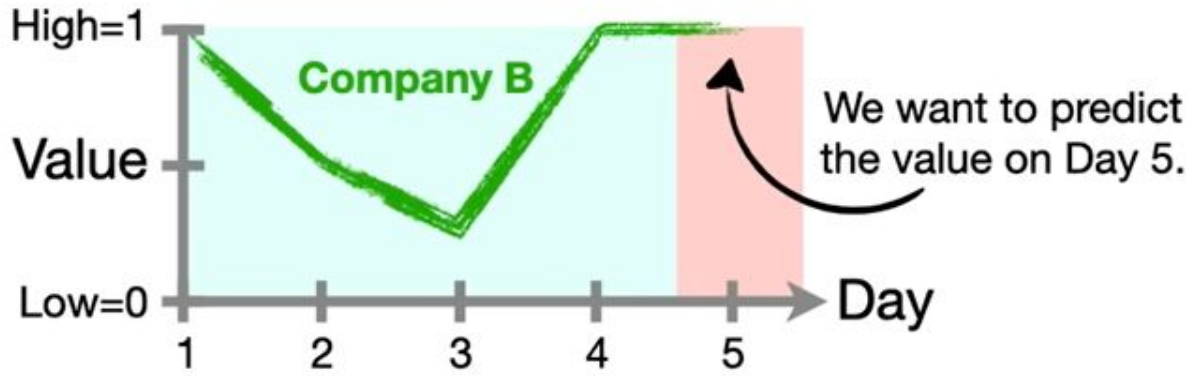


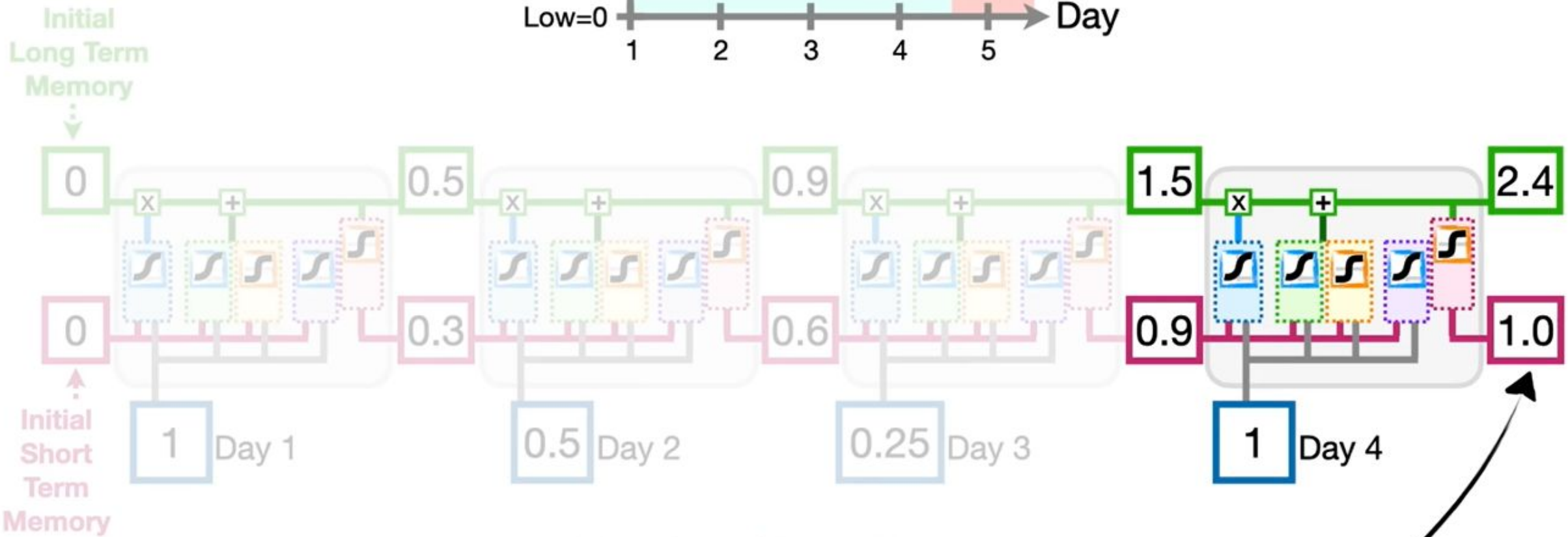


…and **0.3** (rounded) for the updated **Short-Term Memory**.



Now we unroll the **LSTM** and do the math with the remaining input values…

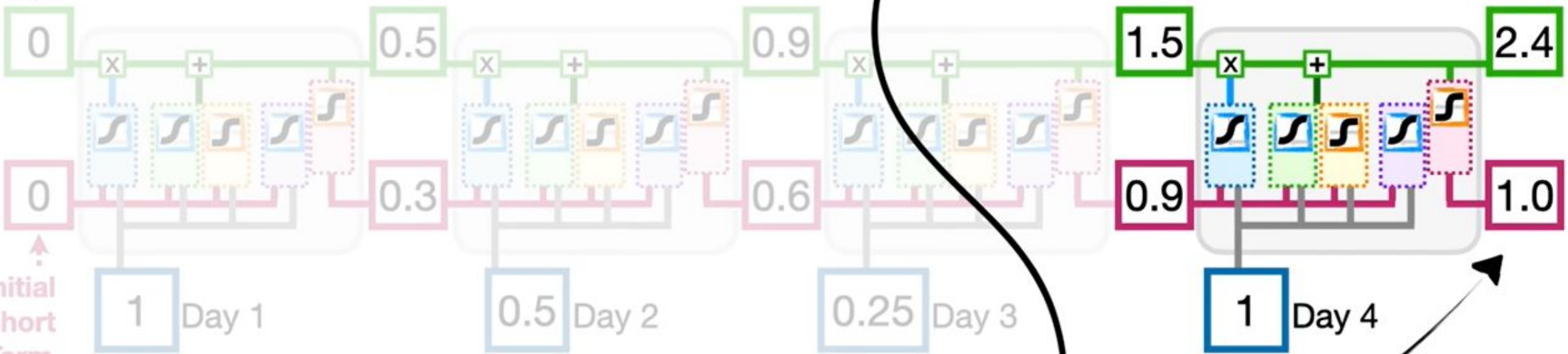




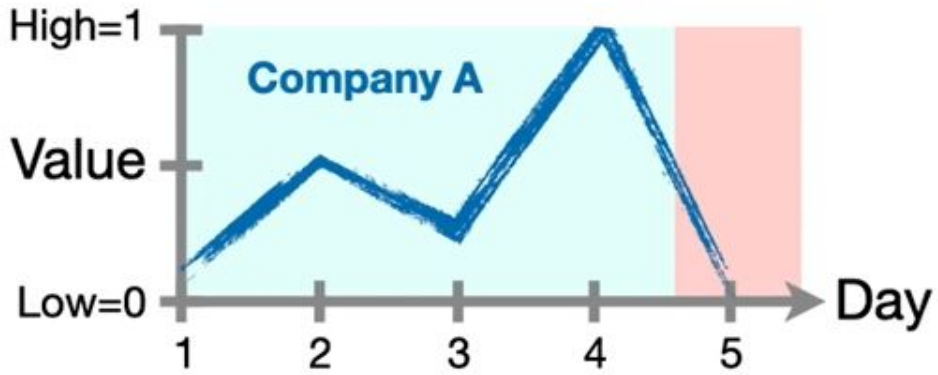
…and the final **Short-Term Memory**, **1.0**, is the **Output** from the **unrolled LSTM**.

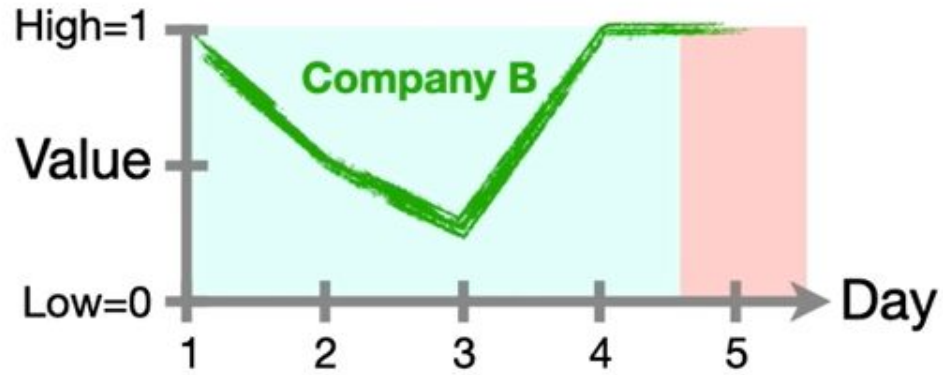
Initial Long Term Memory

Initial Short Term Memory



And that means that the **Output** from the **LSTM** correctly predicts **Company B**'s value for **Day 5**.





Initial Long Term Memory

Initial Short Term Memory

Day 1

Day 2

Day 3

Day 4

In summary, using separate paths for **Long-Term Memories**…

…**Long Short-Term Memory Networks** avoid the **exploding/ vanishing** gradient problem…

…and that means we can unroll them more times to accommodate longer sequences of input data than a vanilla **Recurrent Neural Network**.

https://towardsdatascience.com/tutorial-on-lstm-a-computational-perspective-f3417442c2cd

https://www.youtube.com/watch?v=YCzL96nL7j0&t=659s