Input Image
3x3

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10	17	22
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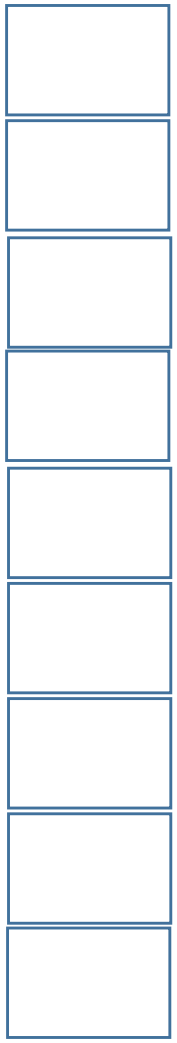
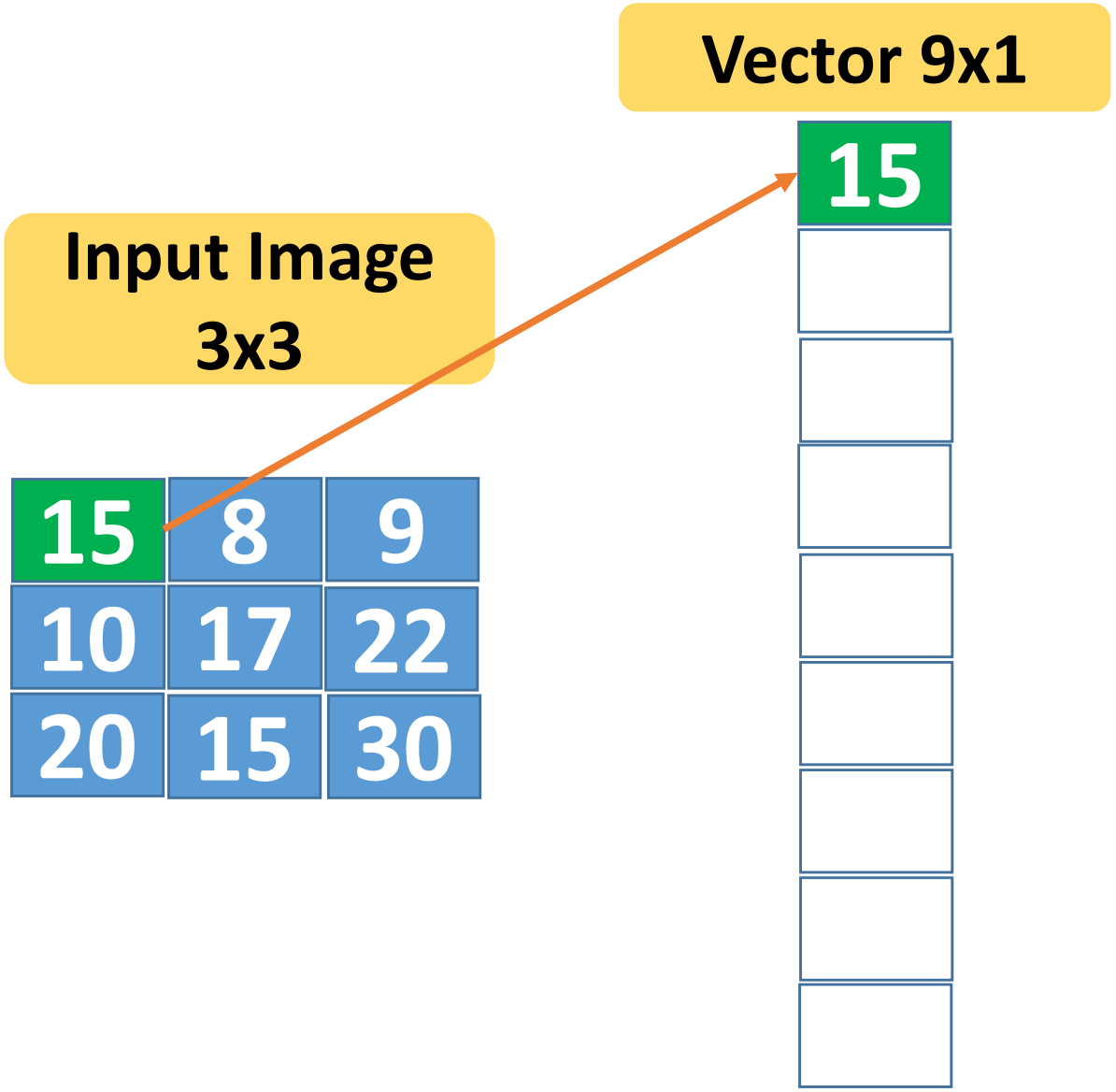
Input Image 3x3

15	8	9
10	17	22
20	15	30

Vector 9x1

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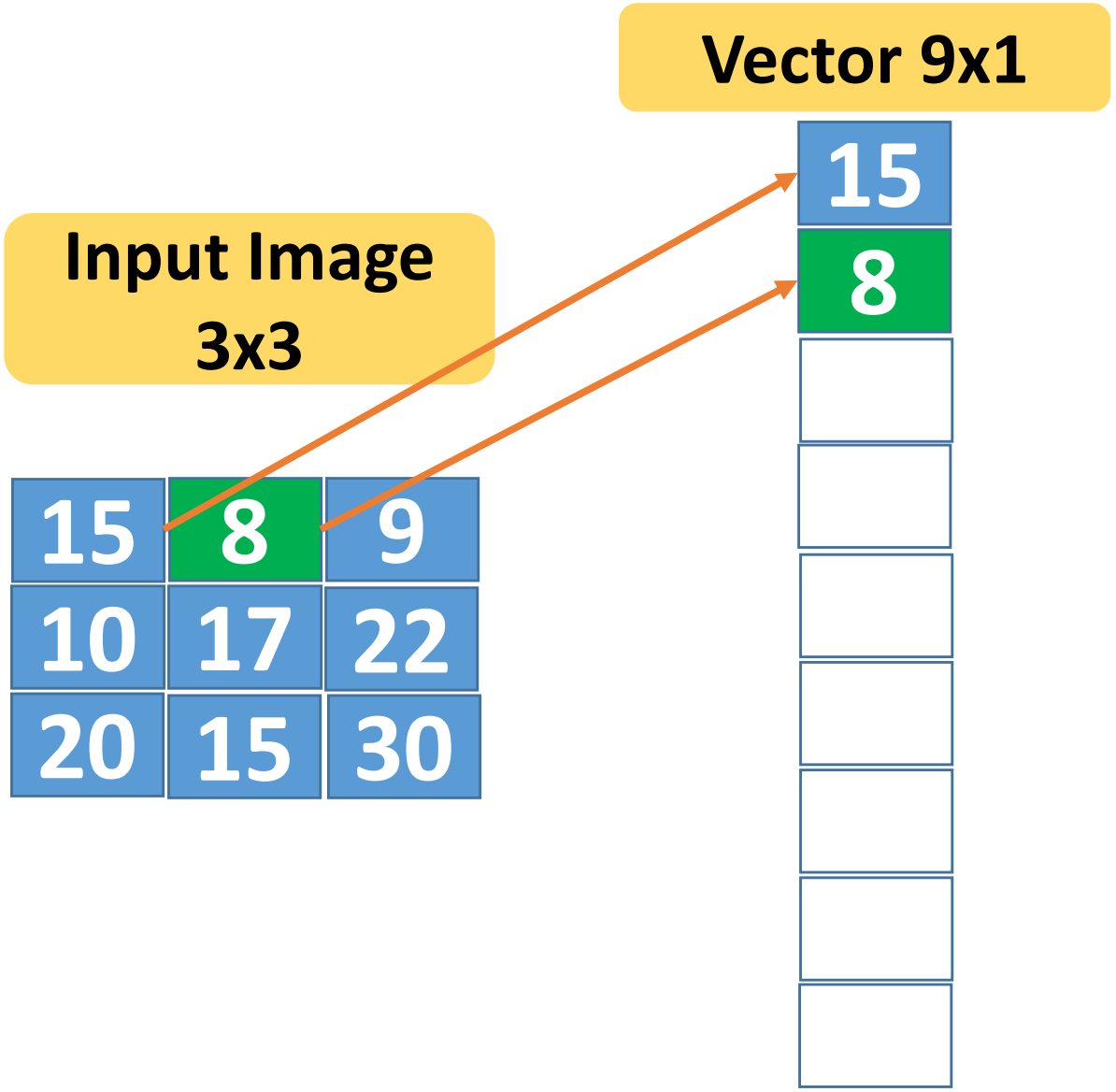
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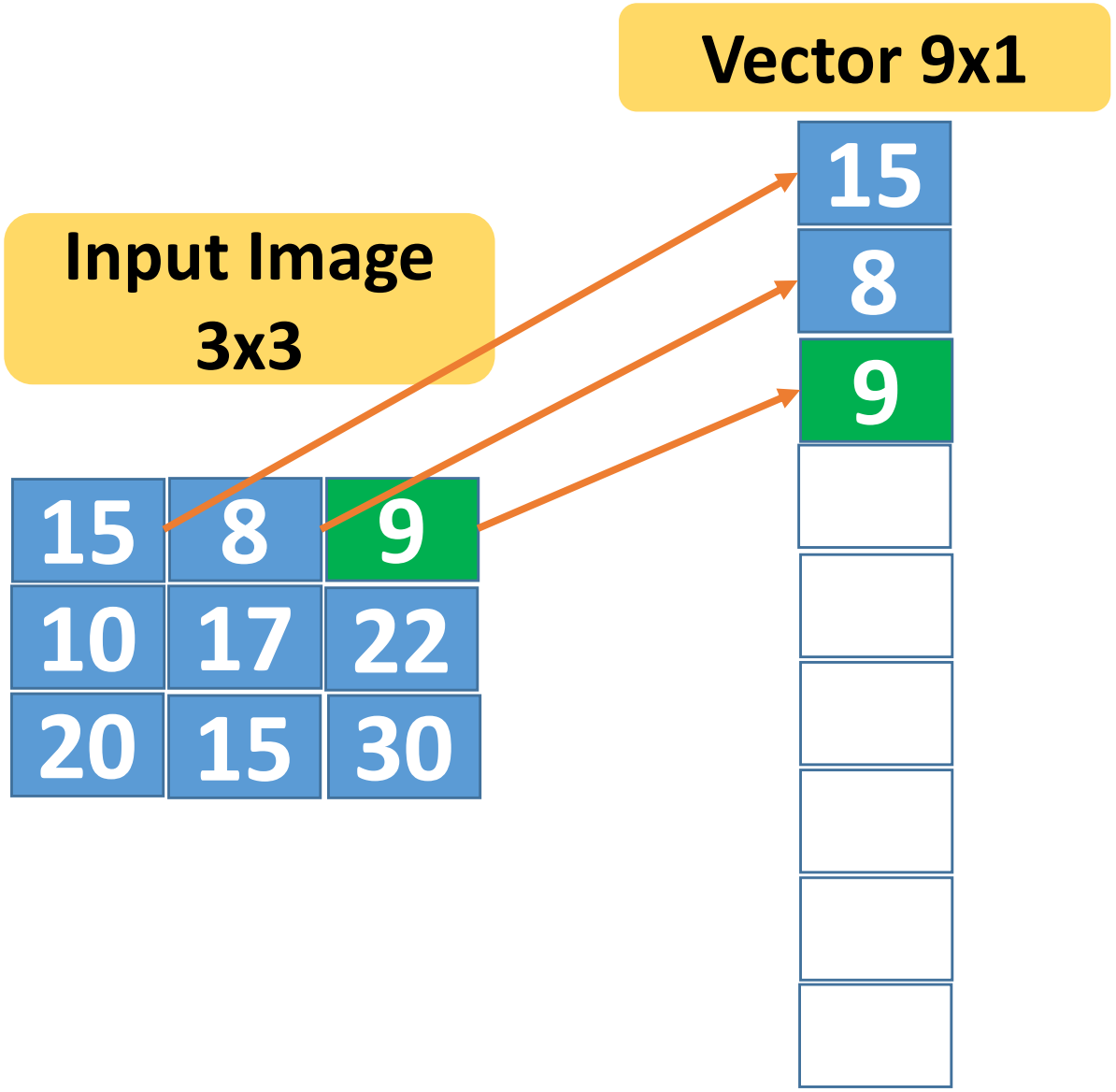
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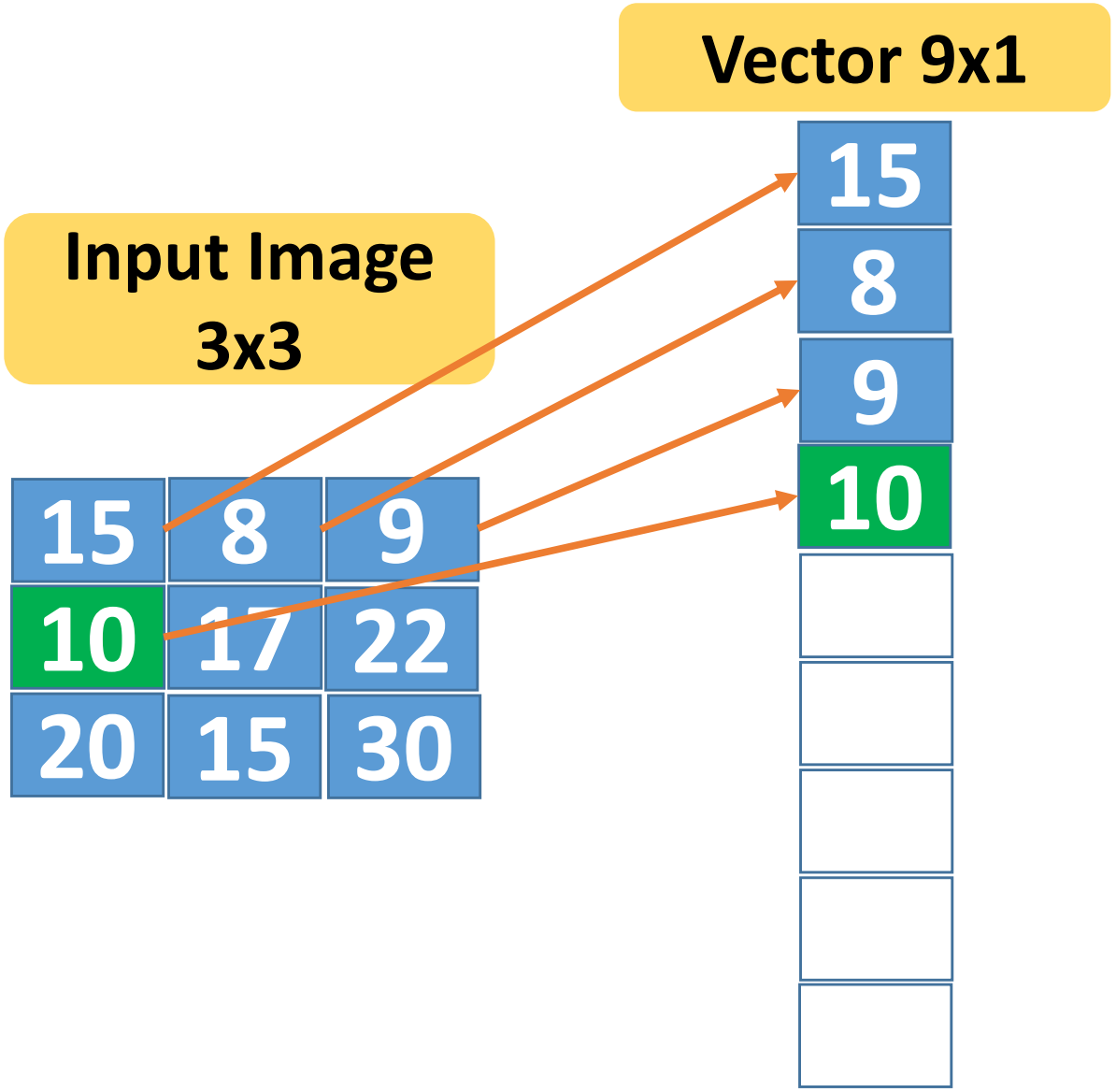
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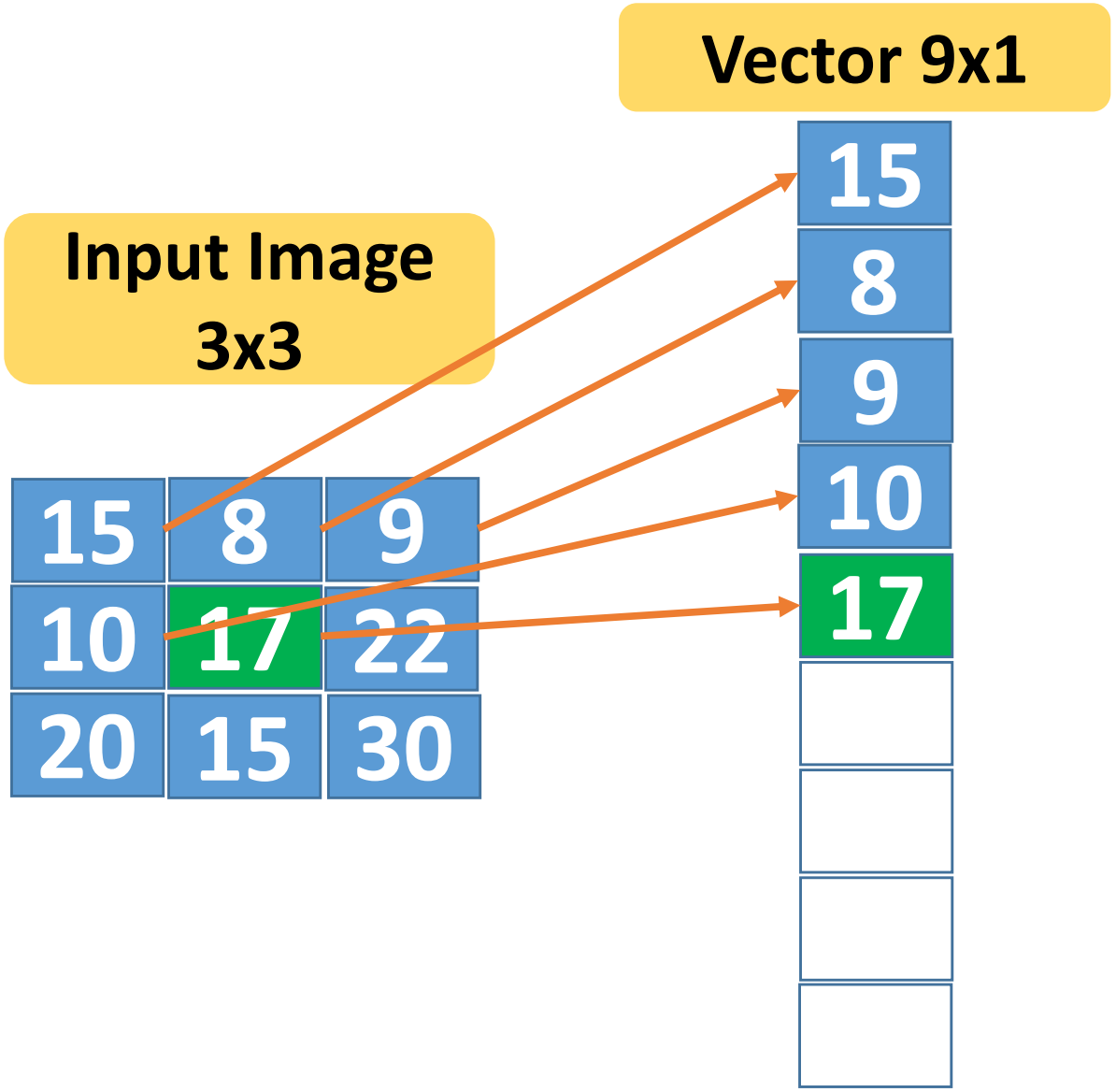
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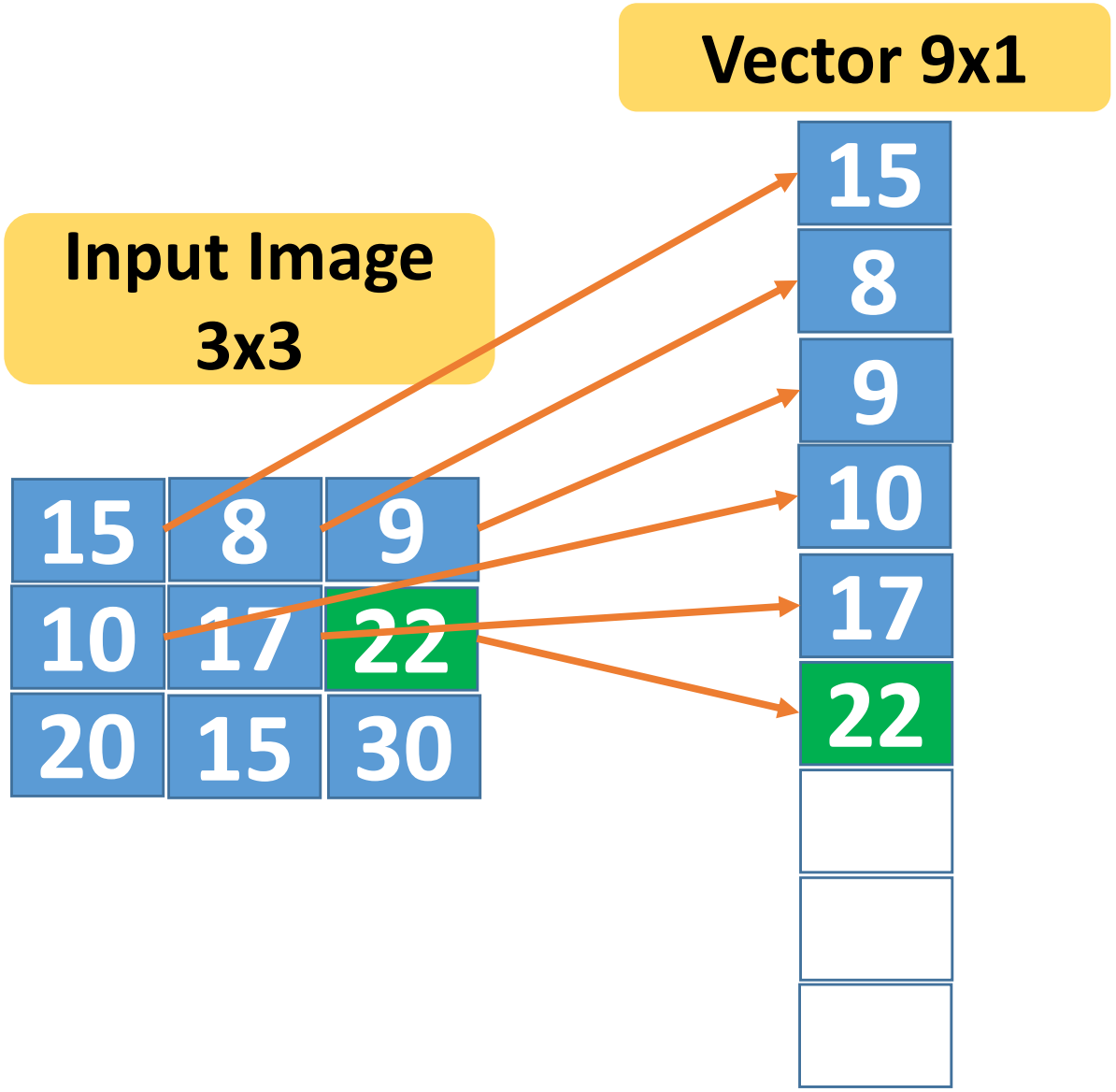
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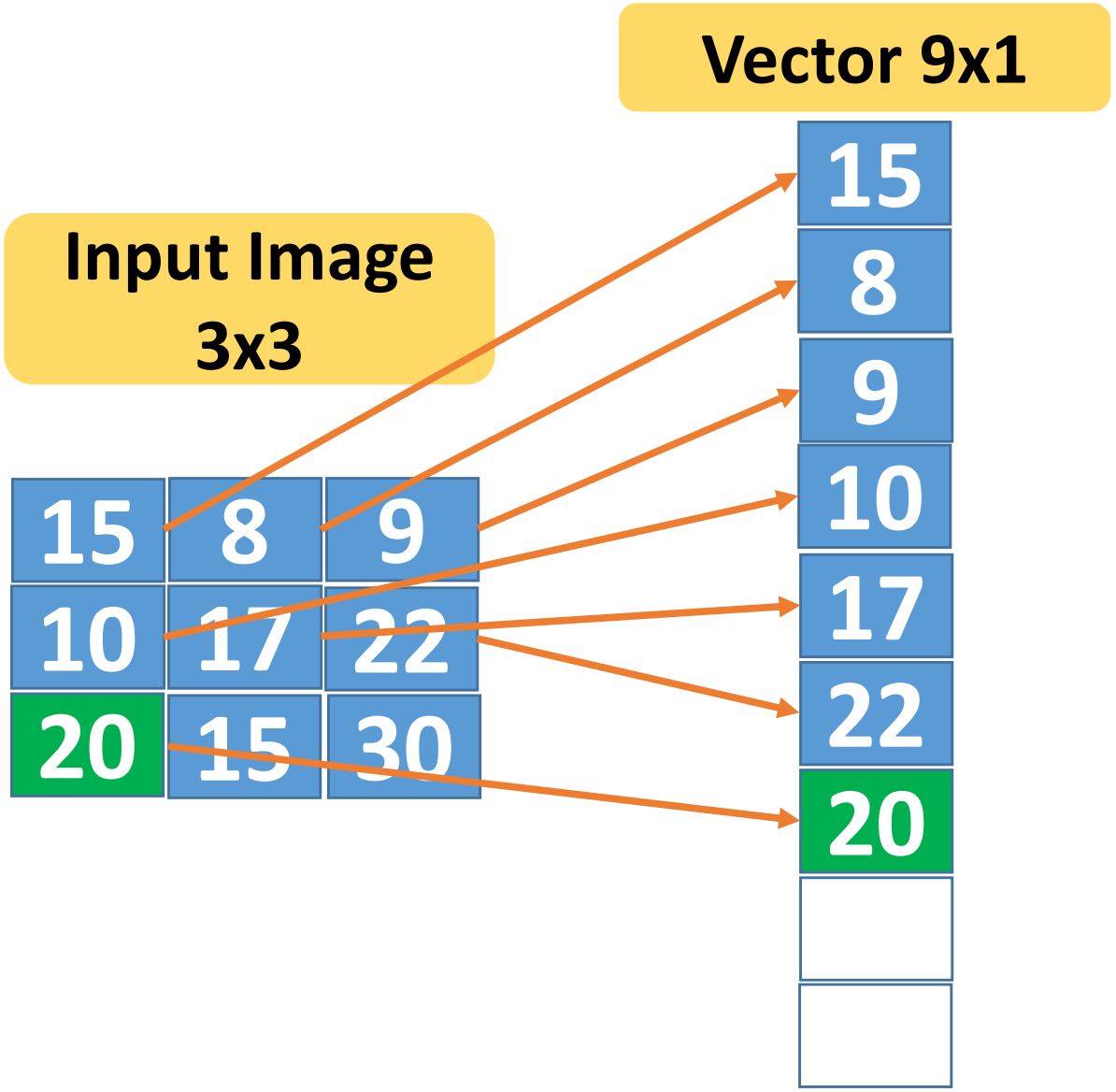
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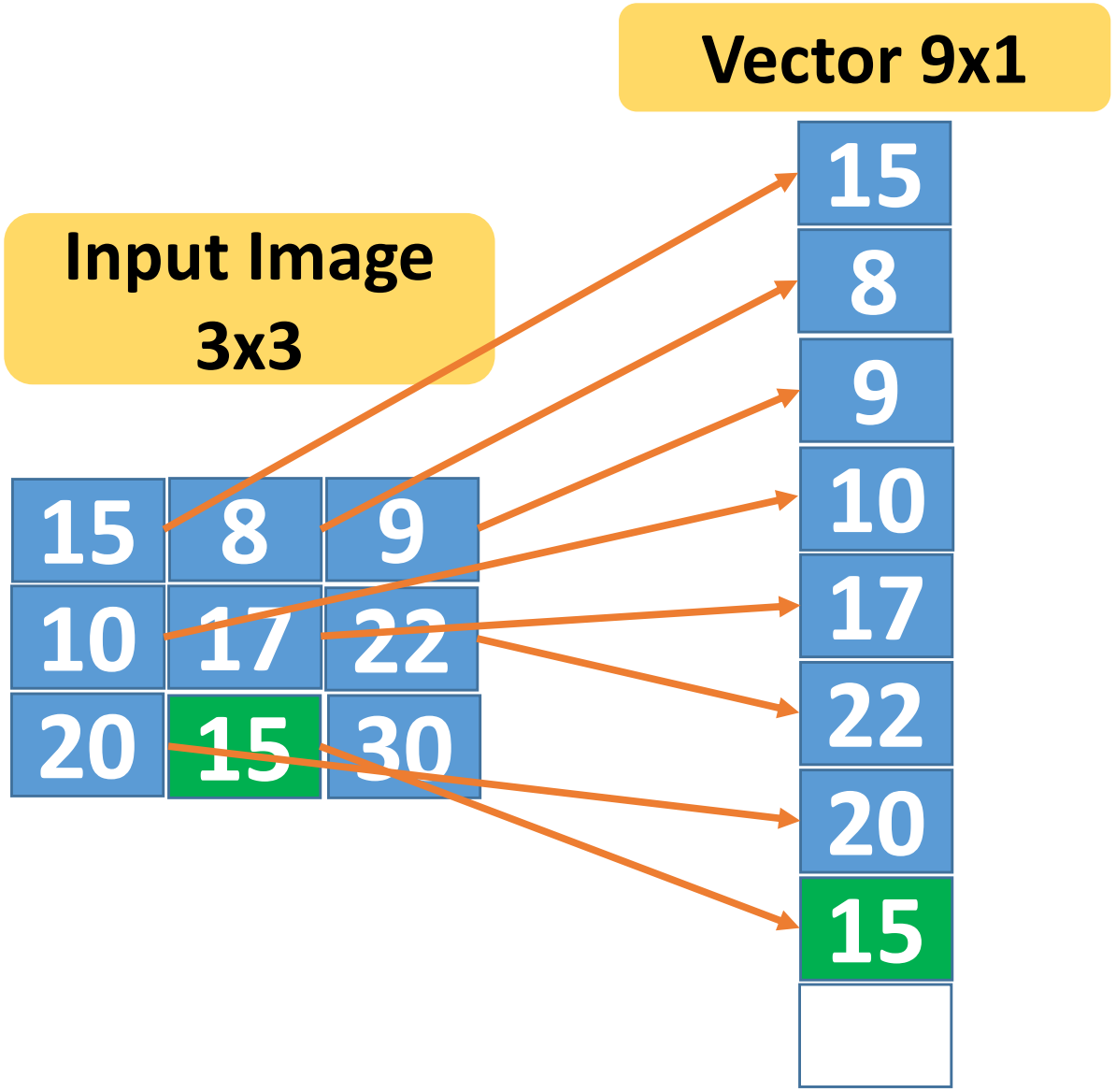
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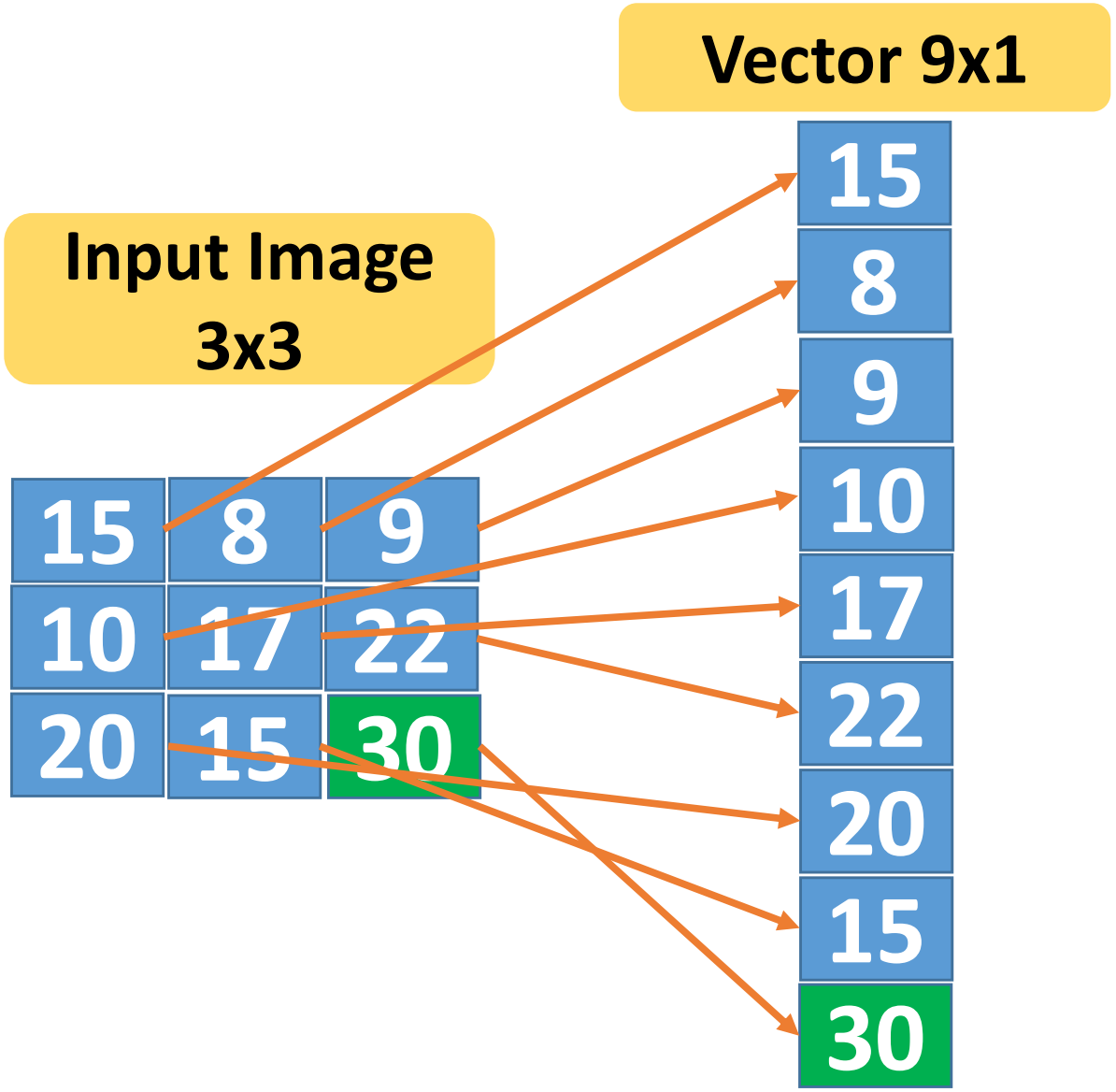
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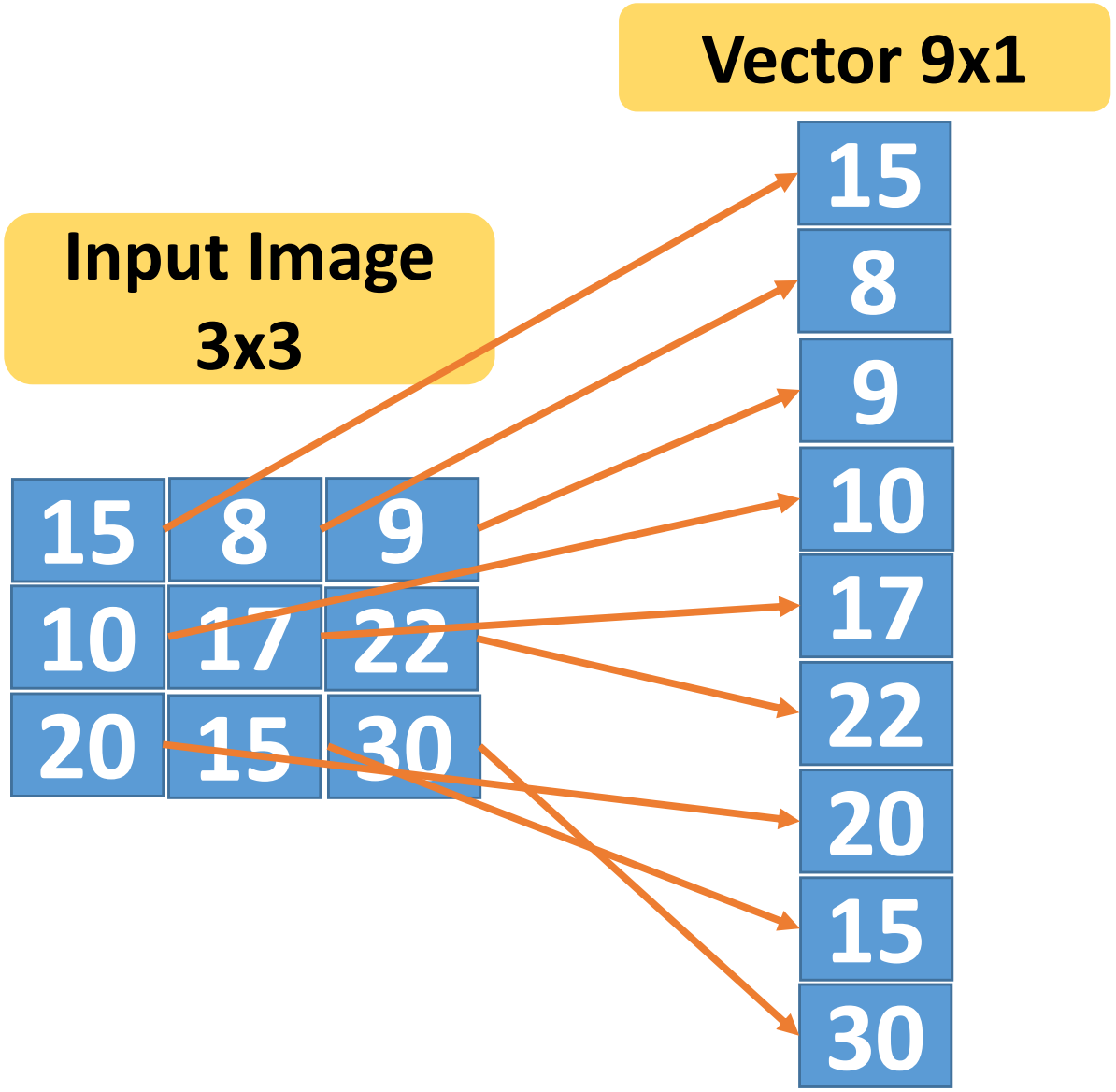
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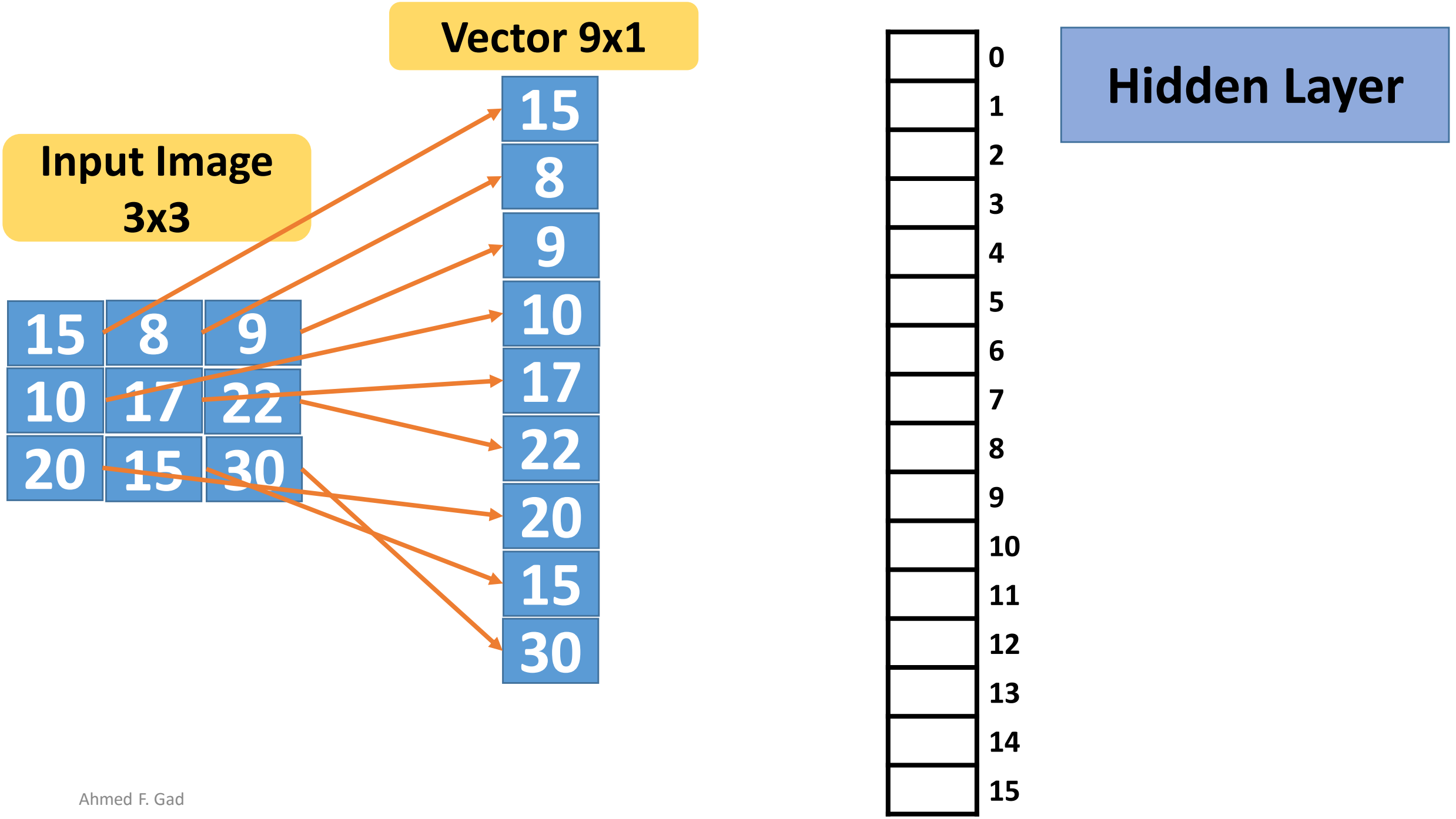
Vector 9x1
Input Image
3x3
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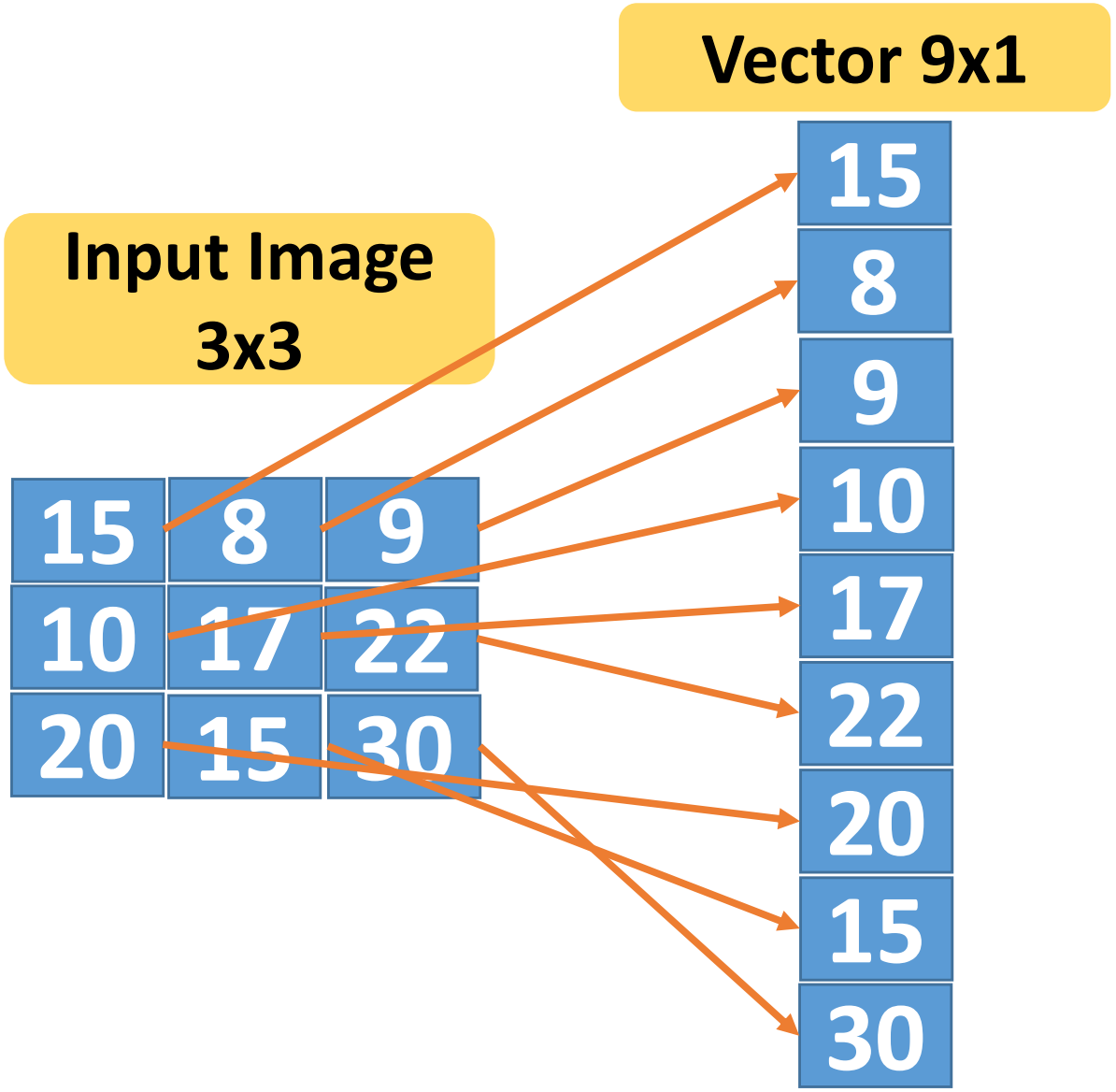
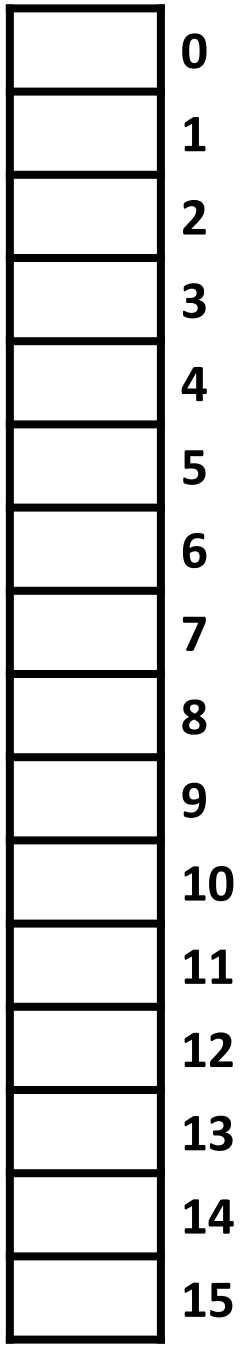
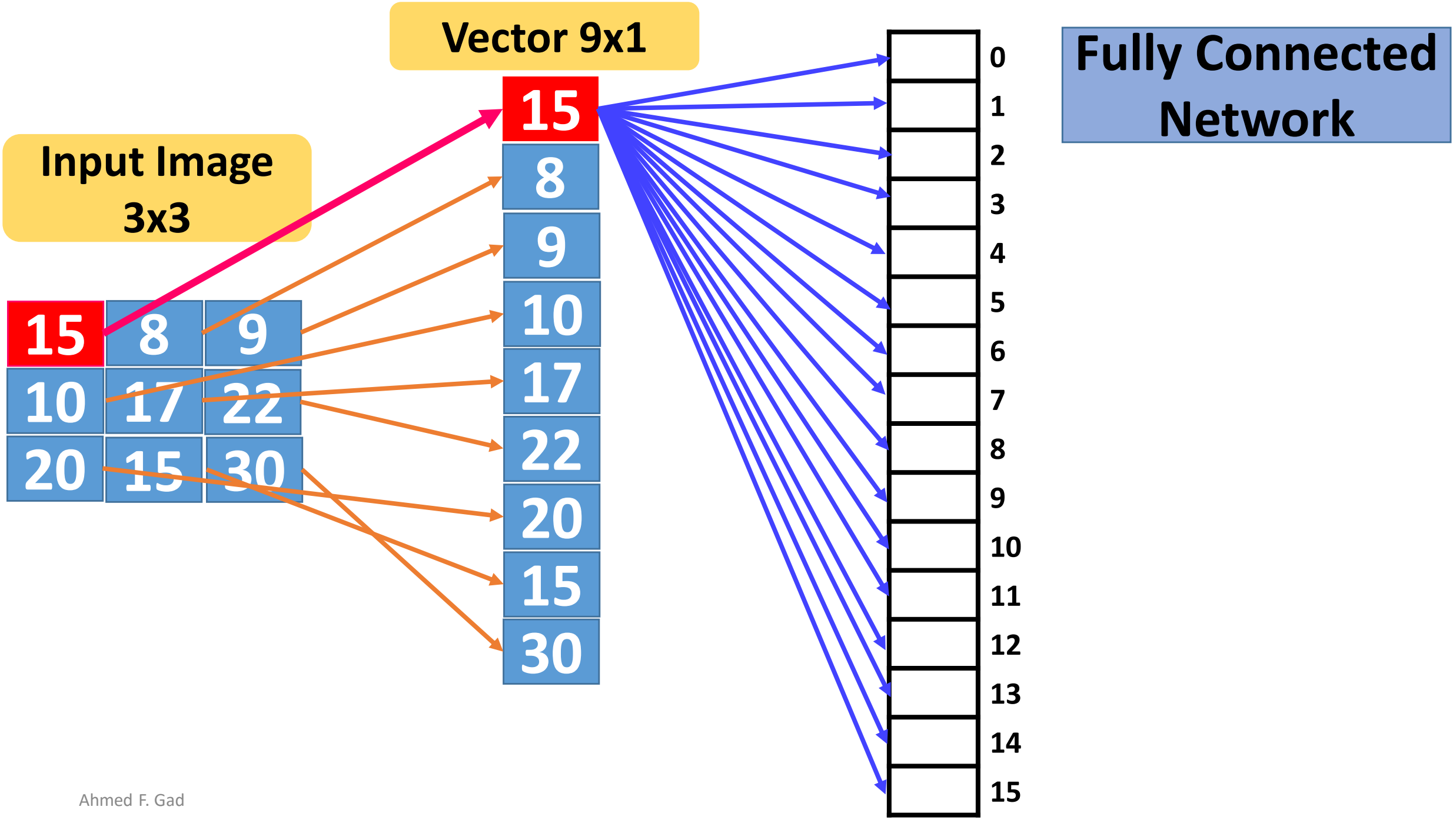
15
Hidden Layer





Fully Connected Network


Vector 9x1
Input Image
3x3
15
8
9
10
17
22
20
15
30
Fully Connected
Network
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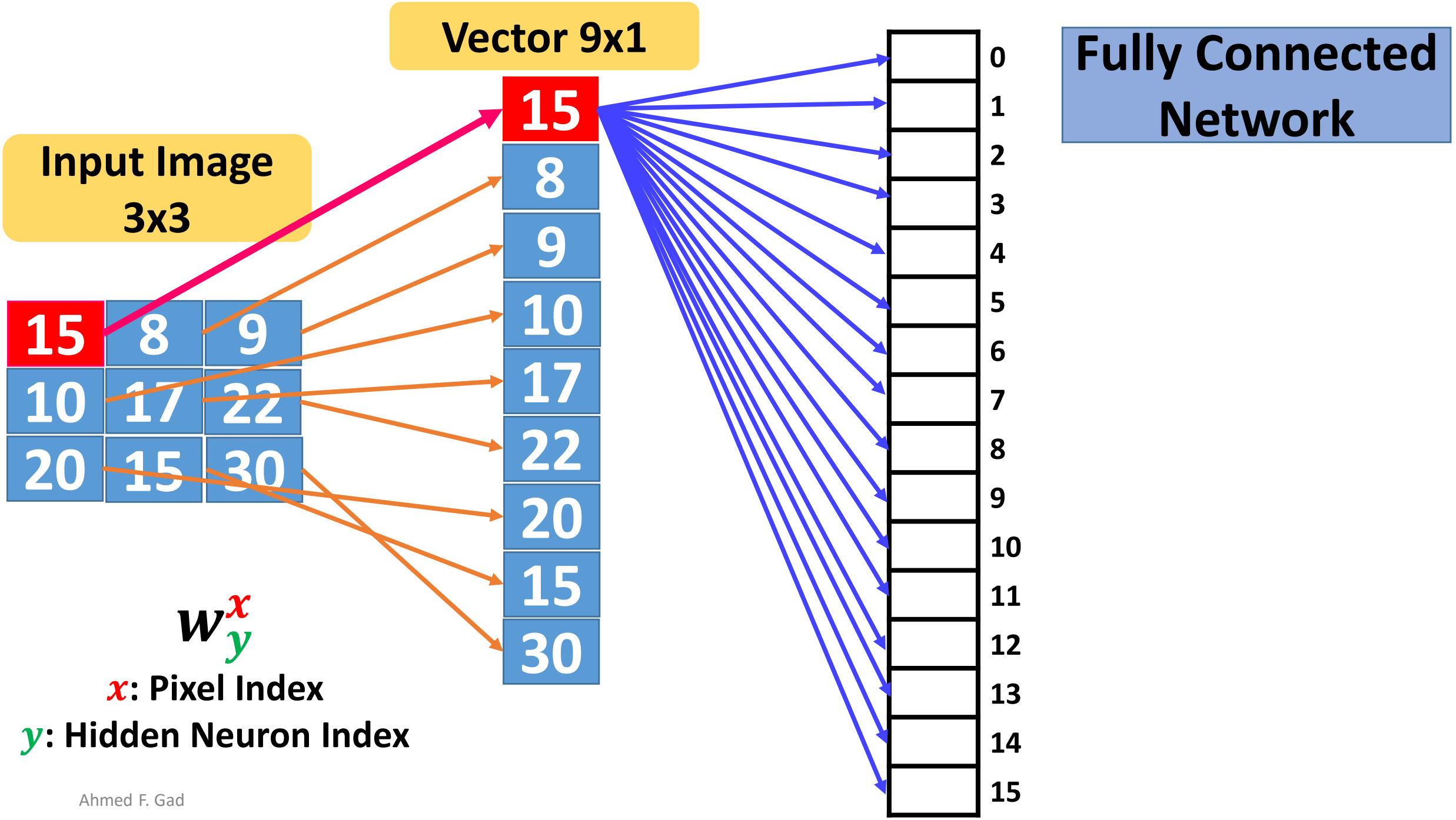
14
15


Vector 9x1
Input Image
3x3
15
8
9
10
17
22
20
15
30
Fully Connected
Network
0
1
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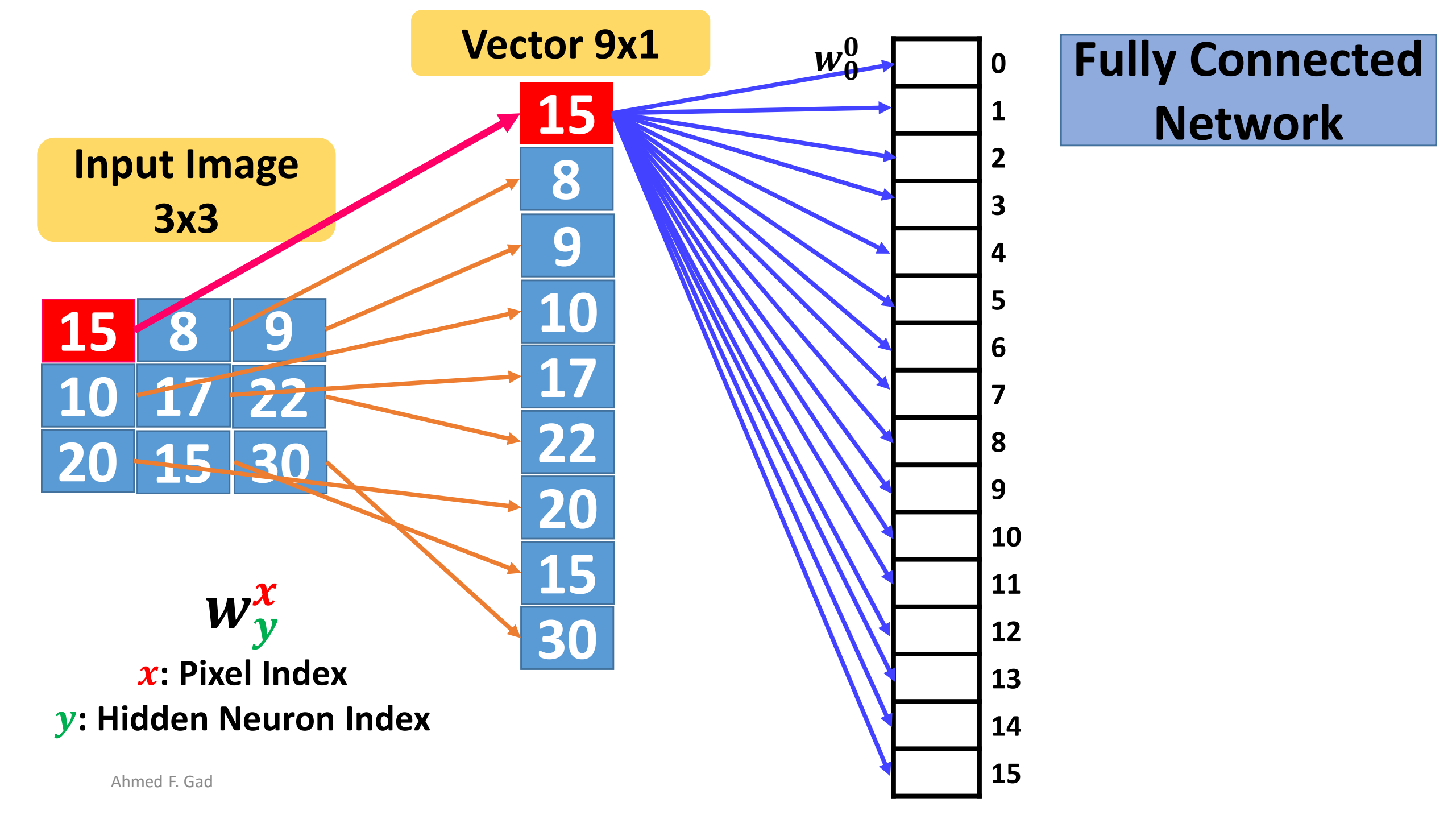
10
11
12
13
14
15
w_y^x
x: Pixel Index
y: Hidden Neuron Index


Vector 9x1
Input Image
3x3
15
8
9
10
17
22
20
15
30
w_0^0
0
1
2
3
4
5
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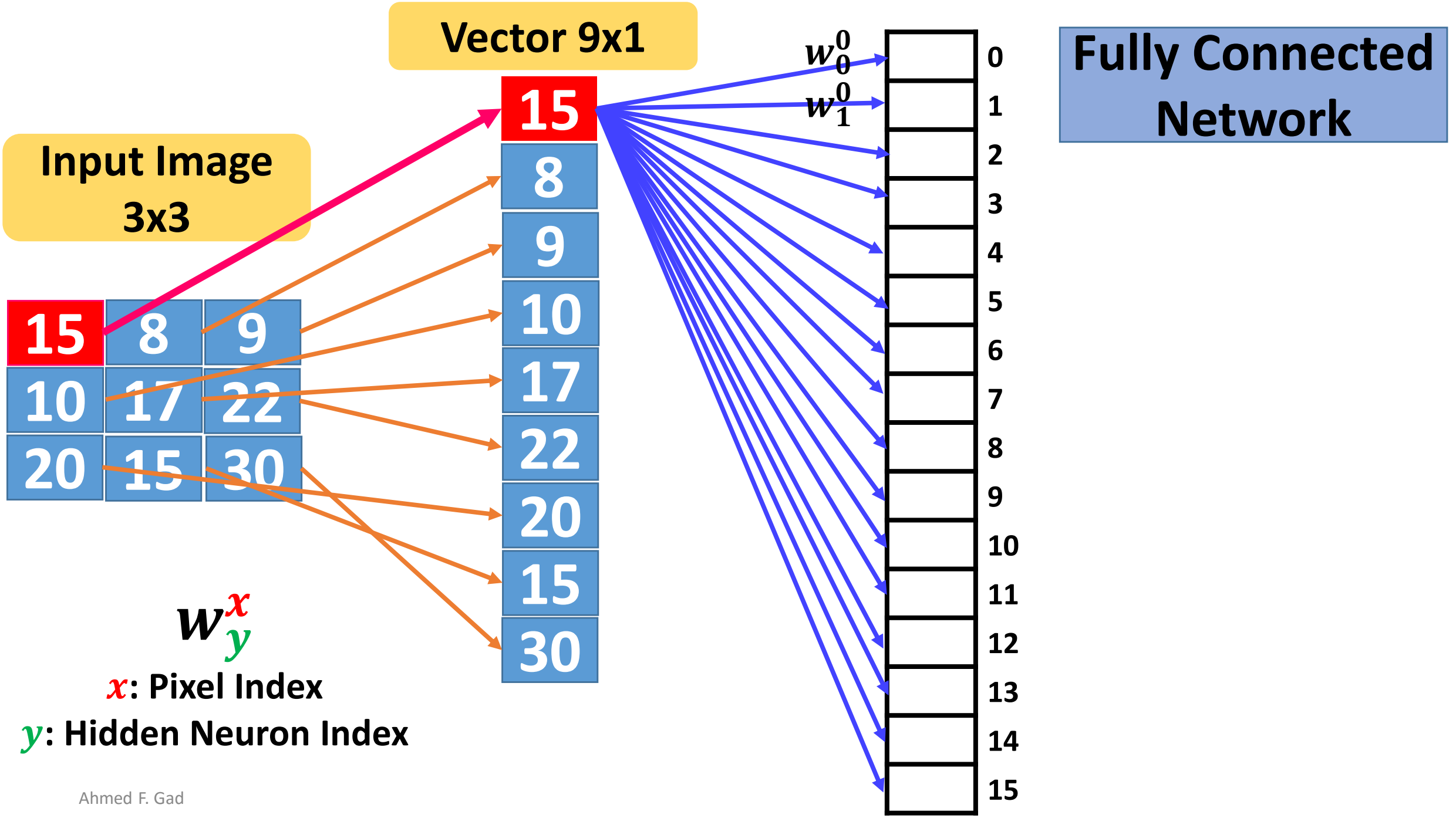
9
10
11
12
13
14
15
Fully Connected Network
w_y^x
x: Pixel Index
y: Hidden Neuron Index


Vector 9x1
Input Image
3x3
15
8
9
10
17
22
20
15
30
w_0^0
w_1^0
0
1
2
3
4
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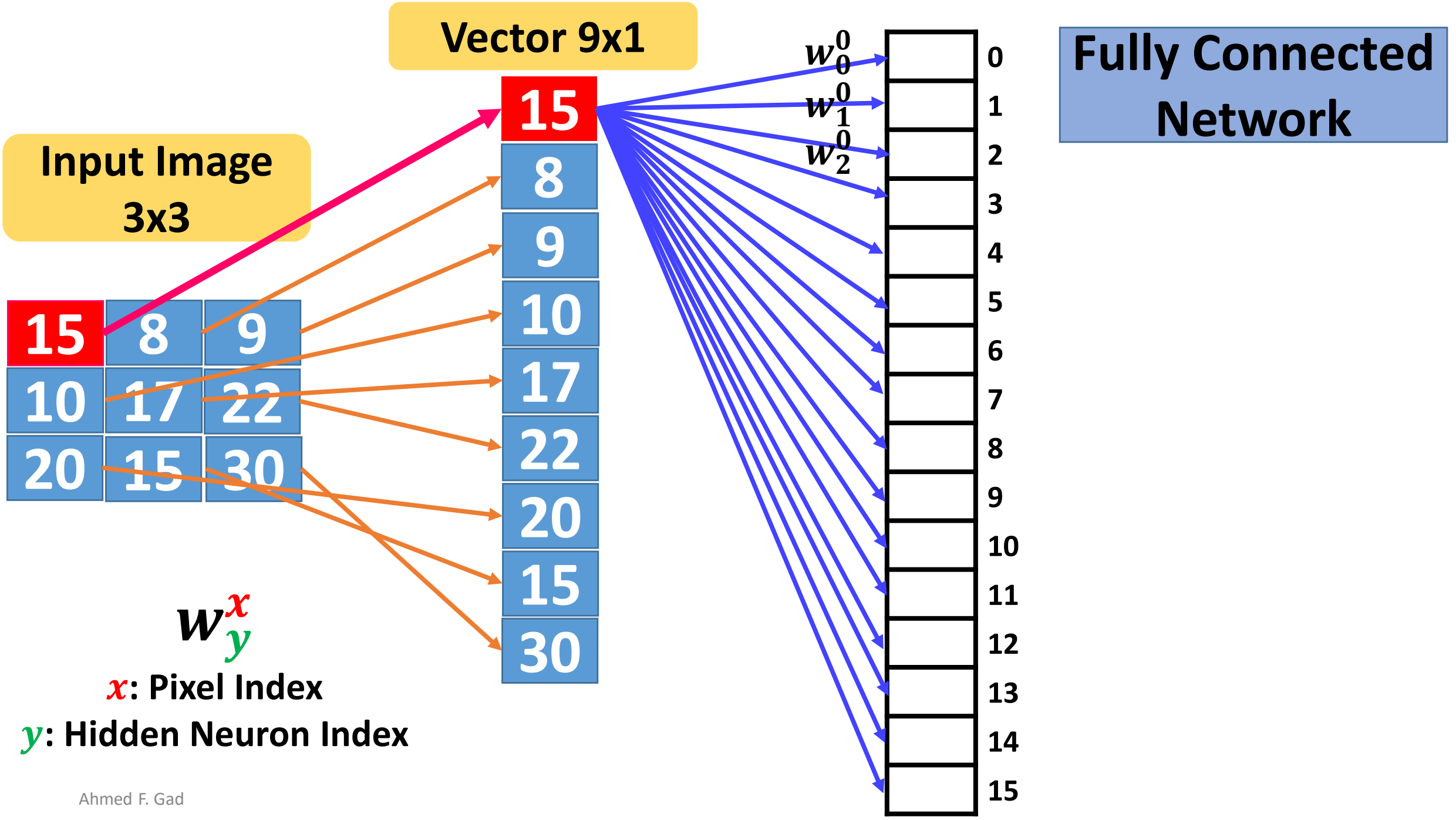
9
10
11
12
13
14
15
Fully Connected Network
w_y^x
x: Pixel Index
y: Hidden Neuron Index


Vector 9x1
Input Image
3x3
15
8
9
10
17
22
20
15
30
w_0^0
w_1^0
w_2^0
0
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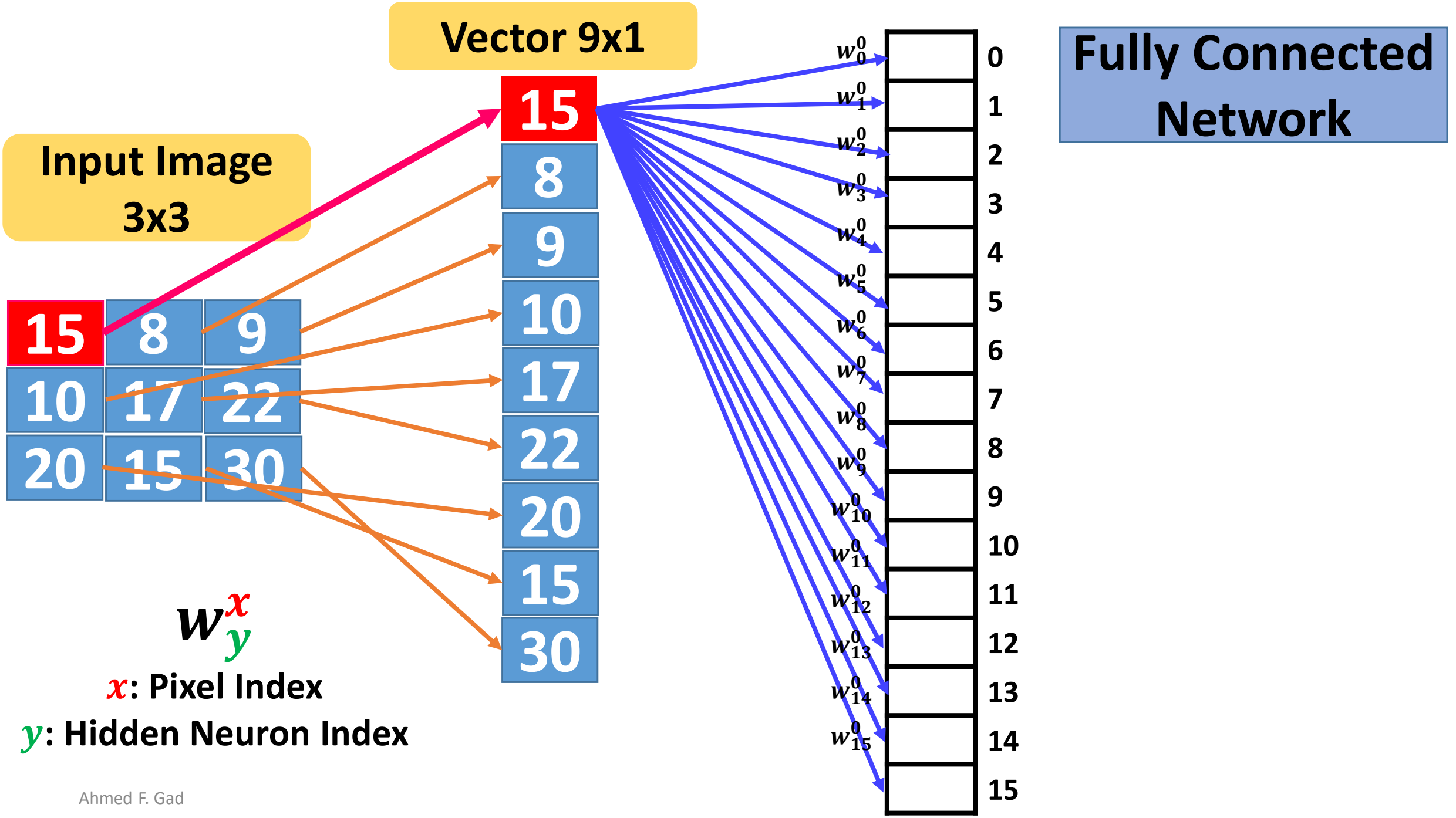
15
Fully Connected Network
w_y^x
x: Pixel Index
y: Hidden Neuron Index


Vector 9x1
Input Image
3x3
15
8
9
10
17
22
20
15
30
w_y^x
x: Pixel Index
y: Hidden Neuron Index
Fully Connected Network
w_0^0
w_1^0
w_2^0
w_3^0
w_4^0
w_5^0
w_6^0
w_7^0
w_8^0
w_9^0
w_{10}^0
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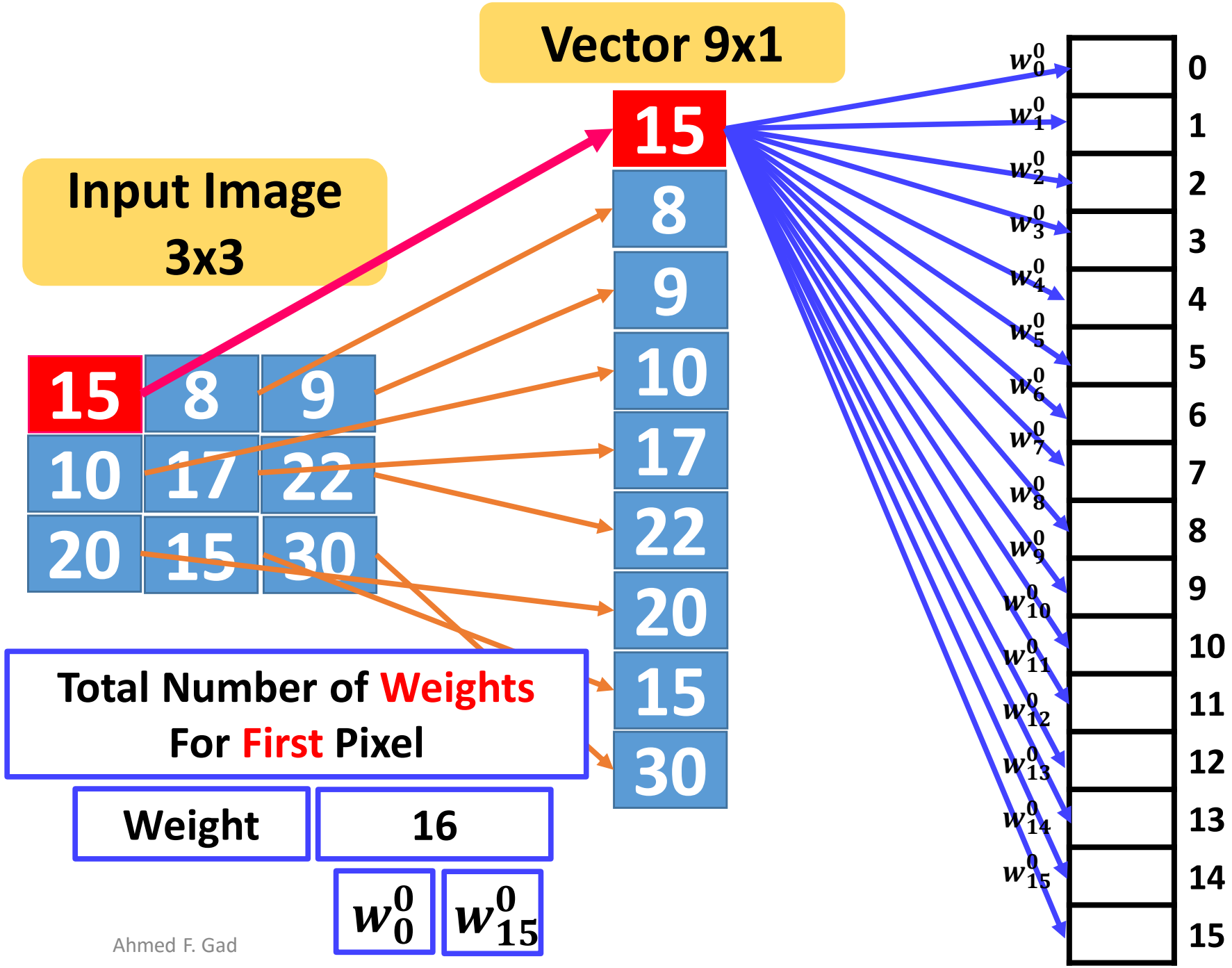
Vector 9x1
15
8
9
10
17
22
20
15
30
Input Image
3x3
15
8
9
10
17
22
20
15
30
Total Number of Weights
For First Pixel
Weight
16
w_0^0
w_{15}^0
w_0^0
w_1^0
w_2^0
w_3^0
w_4^0
w_5^0
w_6^0
w_7^0
w_8^0
w_9^0
w_{10}^0
w_{11}^0
w_{12}^0
w_{13}^0
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w_{15}^0
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12
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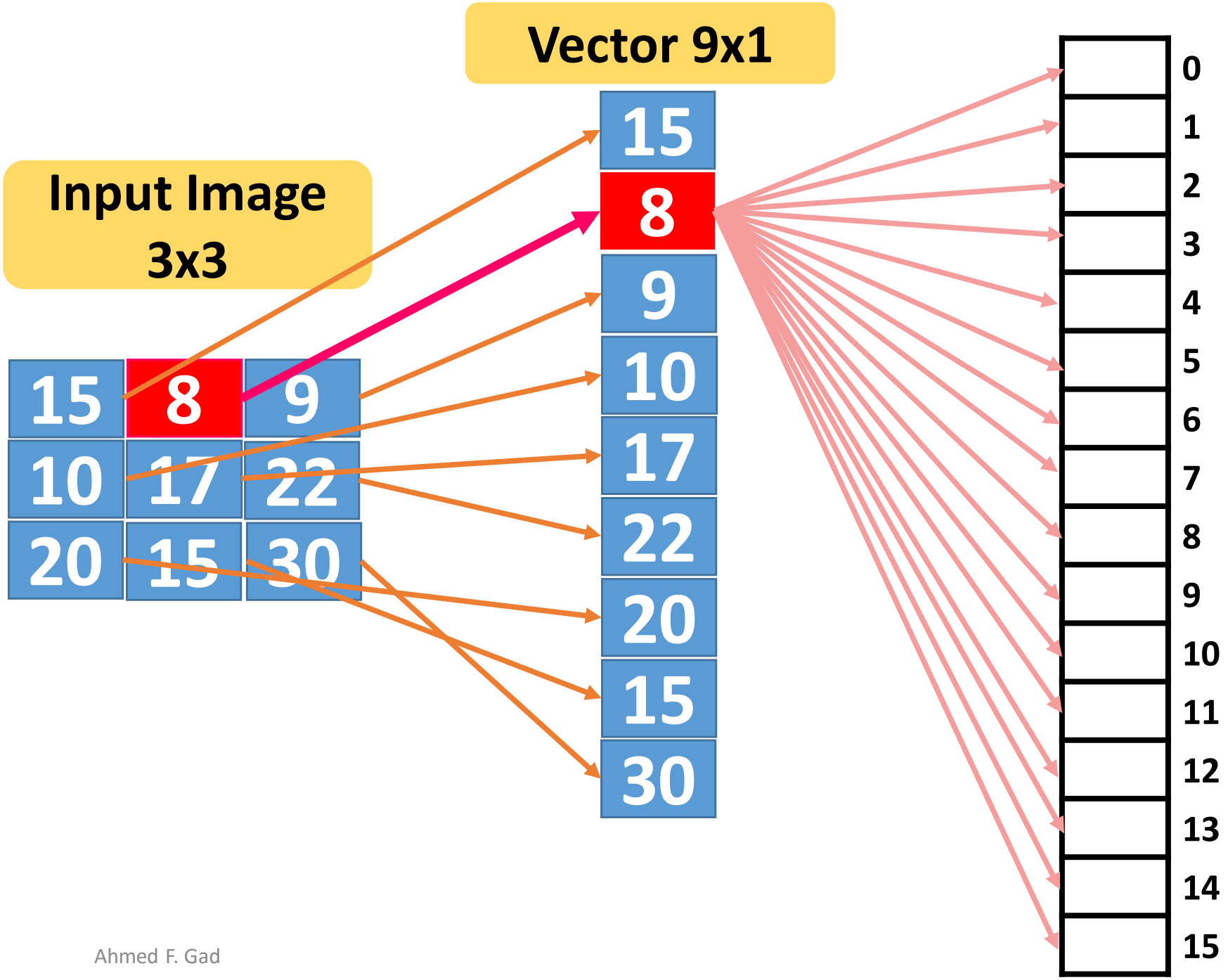
15


Vector 9x1
Input Image
3x3
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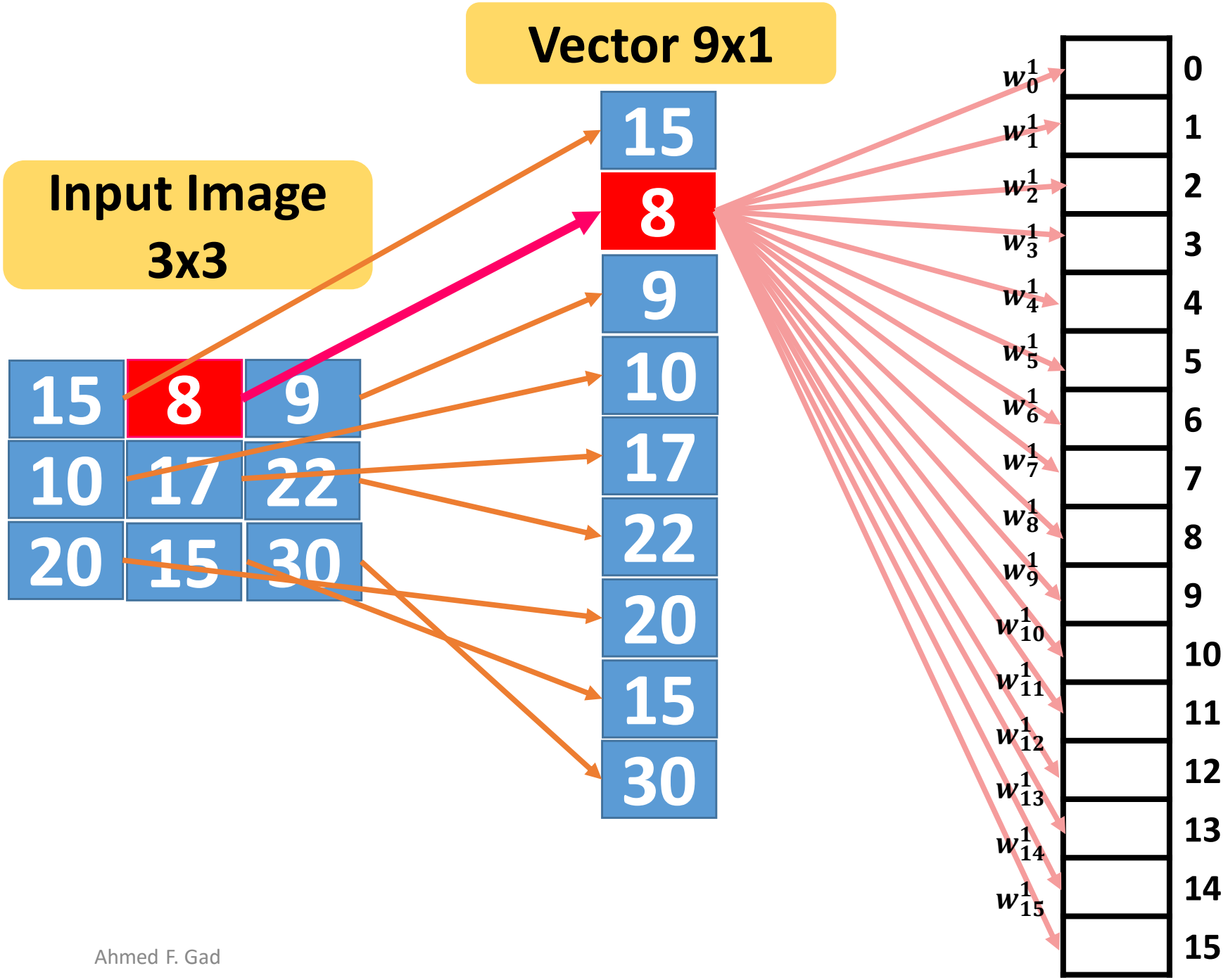
Vector 9x1
Input Image
3x3
15
8
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10
17
22
20
15
30
w_0^1
w_1^1
w_2^1
w_3^1
w_4^1
w_5^1
w_6^1
w_7^1
w_8^1
w_9^1
w_{10}^1
w_{11}^1
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w_{14}^1
w_{15}^1
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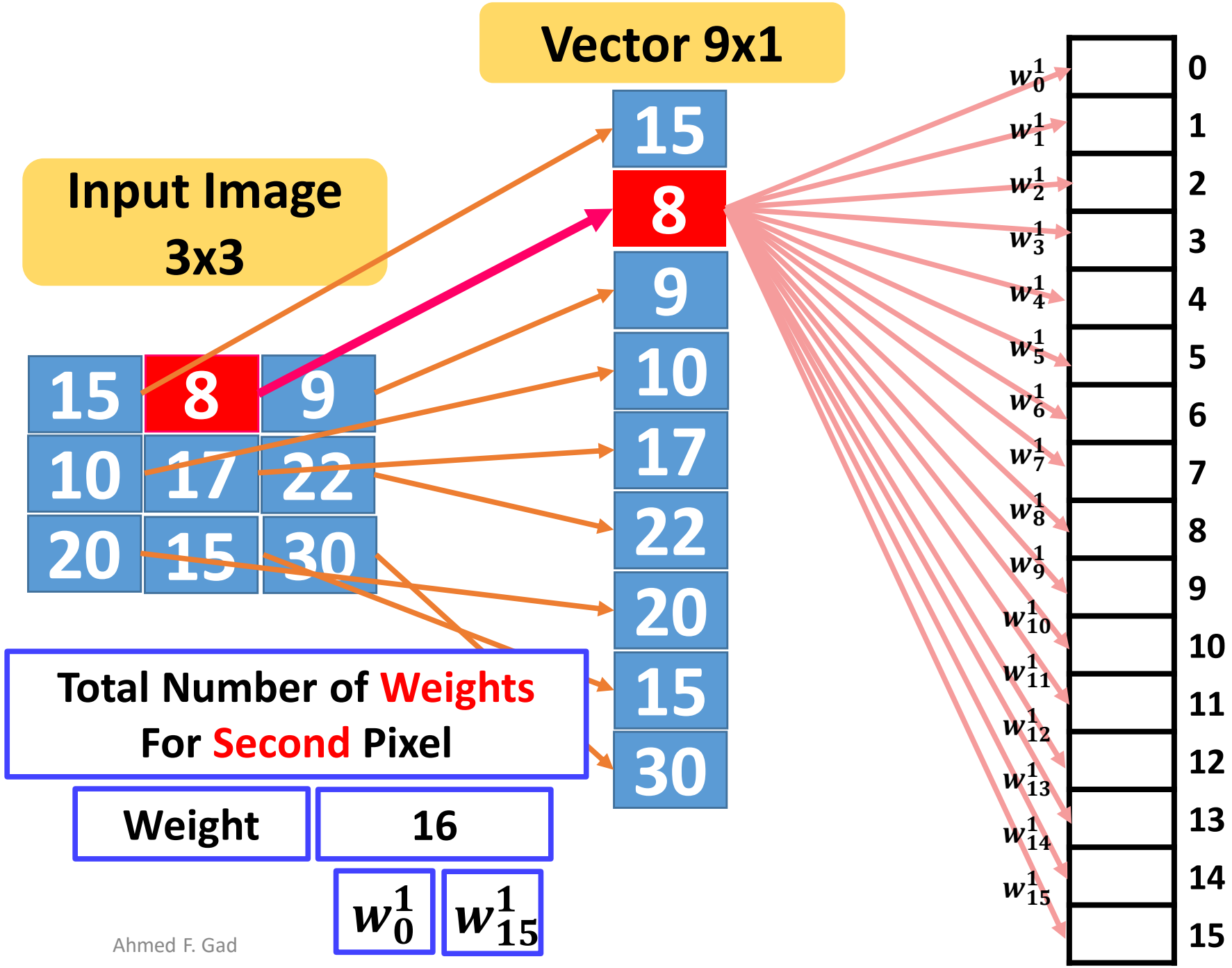
Vector 9x1
15
8
9
10
17
22
20
15
30
Input Image
3x3
15 8 9
10 17 22
20 15 30
Total Number of Weights
For Second Pixel
Weight
16
w_0^1
w_{15}^1
w_0^1
w_1^1
w_2^1
w_3^1
w_4^1
w_5^1
w_6^1
w_7^1
w_8^1
w_9^1
w_{10}^1
w_{11}^1
w_{12}^1
w_{13}^1
w_{14}^1
w_{15}^1
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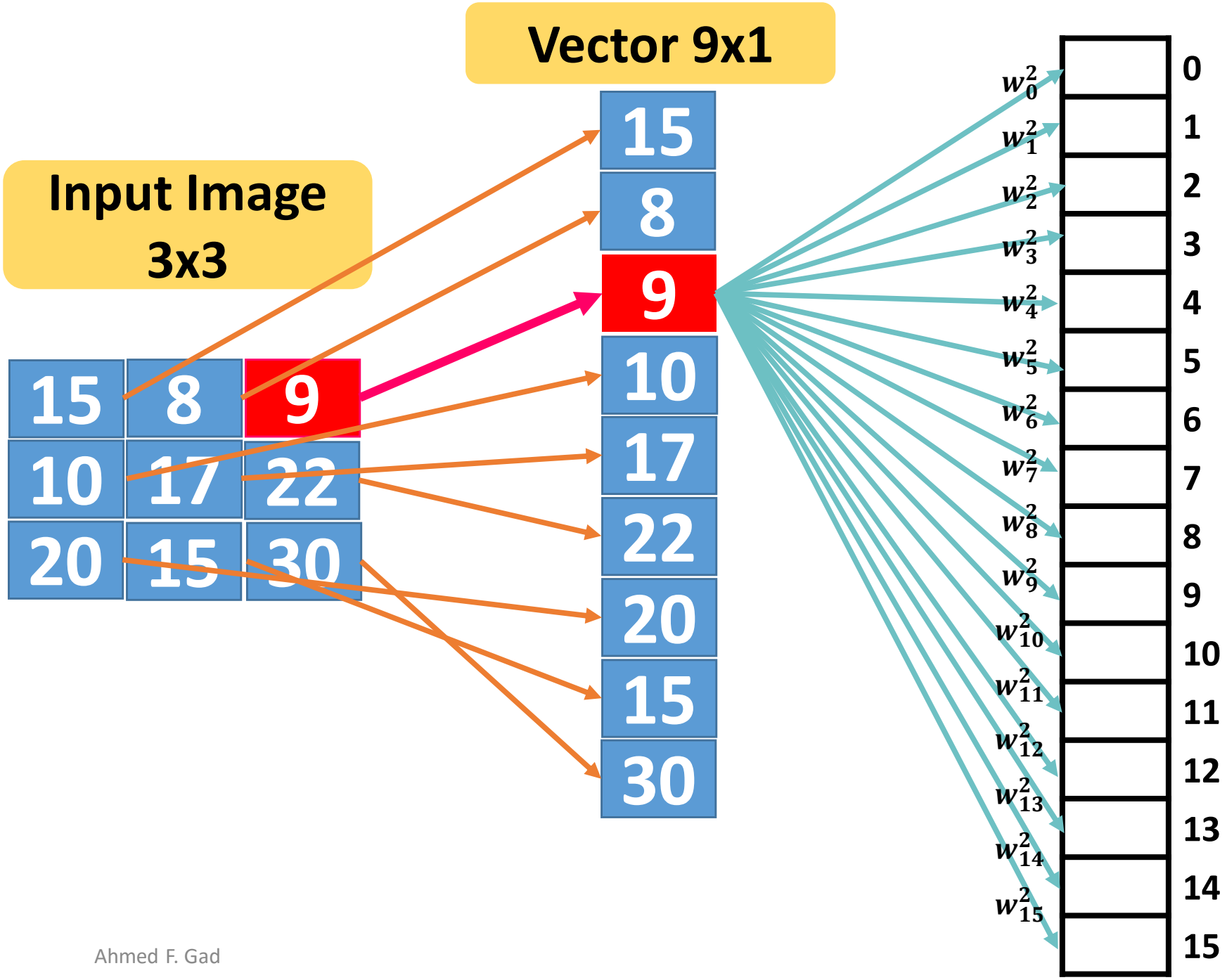
Vector 9x1
Input Image
3x3
15
8
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10
17
22
20
15
30
w_0^2
w_1^2
w_2^2
w_3^2
w_4^2
w_5^2
w_6^2
w_7^2
w_8^2
w_9^2
w_{10}^2
w_{11}^2
w_{12}^2
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w_{14}^2
w_{15}^2
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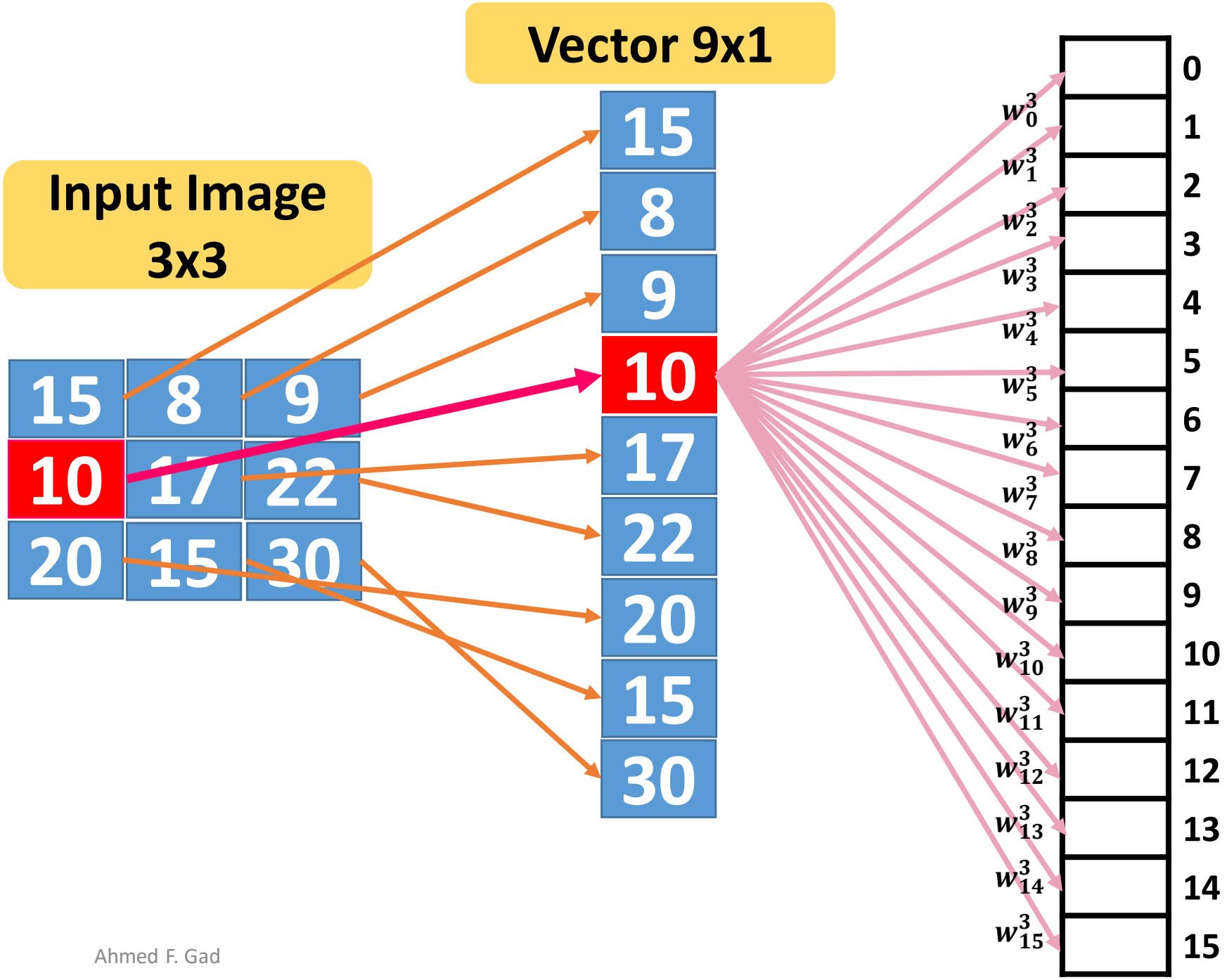
Vector 9x1
Input Image
3x3
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22
20
15
30
w_0^3
w_1^3
w_2^3
w_3^3
w_4^3
w_5^3
w_6^3
w_7^3
w_8^3
w_9^3
w_{10}^3
w_{11}^3
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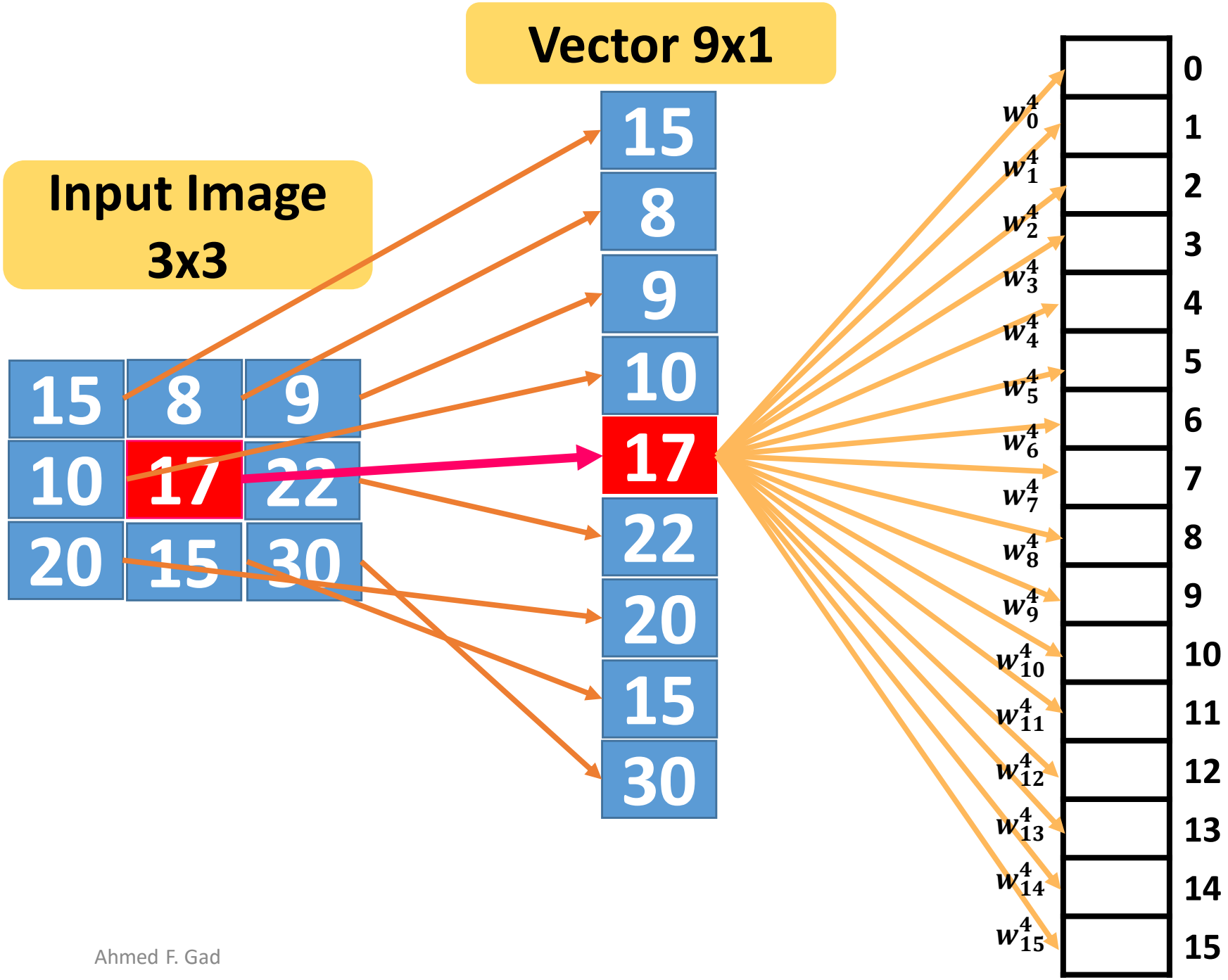
Vector 9x1
Input Image
3x3
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8
9
10
17
22
20
15
30
w_0^4
w_1^4
w_2^4
w_3^4
w_4^4
w_5^4
w_6^4
w_7^4
w_8^4
w_9^4
w_{10}^4
w_{11}^4
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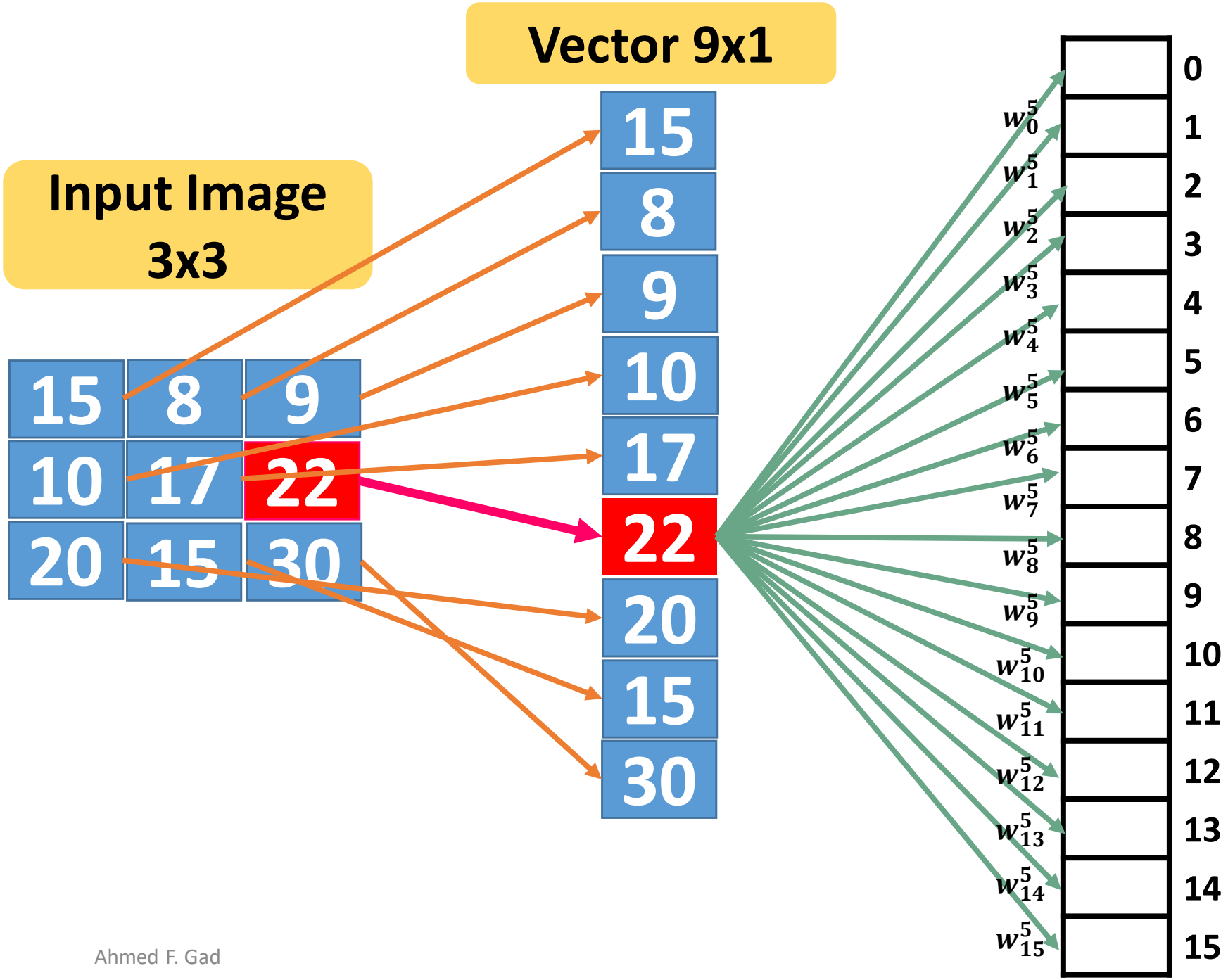
Vector 9x1
Input Image
3x3
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8
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22
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15
8
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10
17
22
20
15
30
w_0^5
w_1^5
w_2^5
w_3^5
w_4^5
w_5^5
w_6^5
w_7^5
w_8^5
w_9^5
w_{10}^5
w_{11}^5
w_{12}^5
w_{13}^5
w_{14}^5
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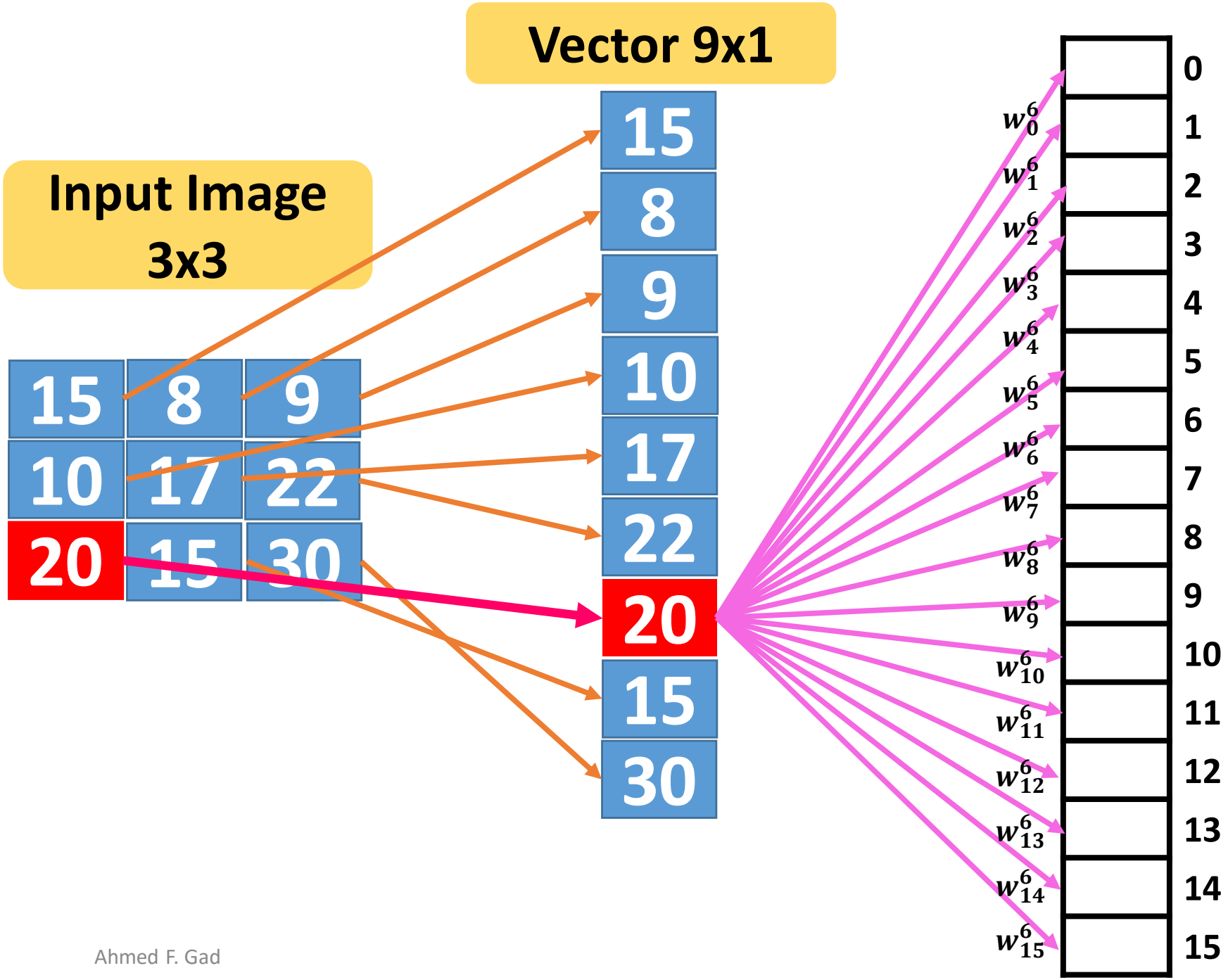
Vector 9x1
Input Image
3x3
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8
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22
20
15
30
w_0^6
w_1^6
w_2^6
w_3^6
w_4^6
w_5^6
w_6^6
w_7^6
w_8^6
w_9^6
w_{10}^6
w_{11}^6
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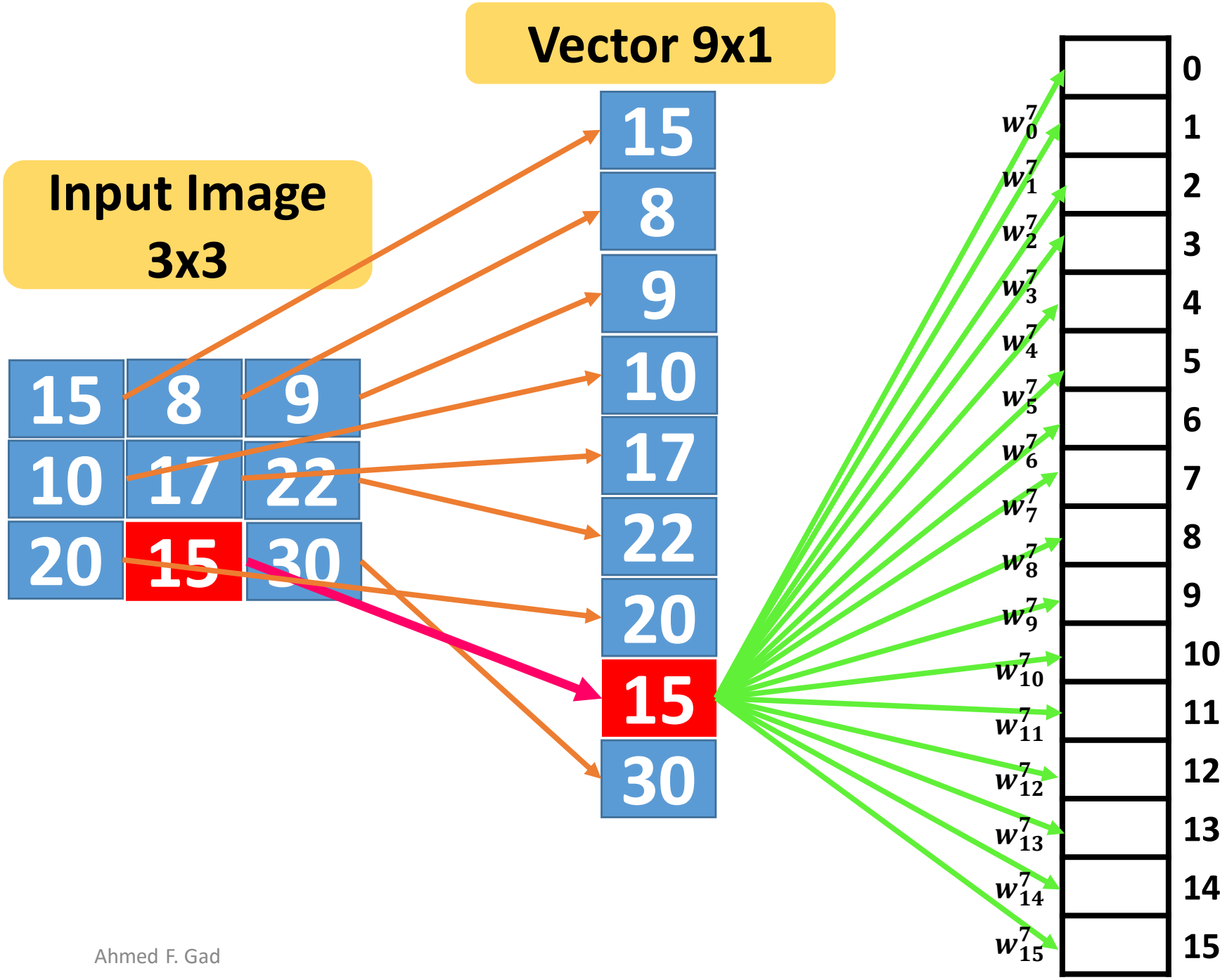
Vector 9x1
Input Image
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15
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w_0^7
w_1^7
w_2^7
w_3^7
w_4^7
w_5^7
w_6^7
w_7^7
w_8^7
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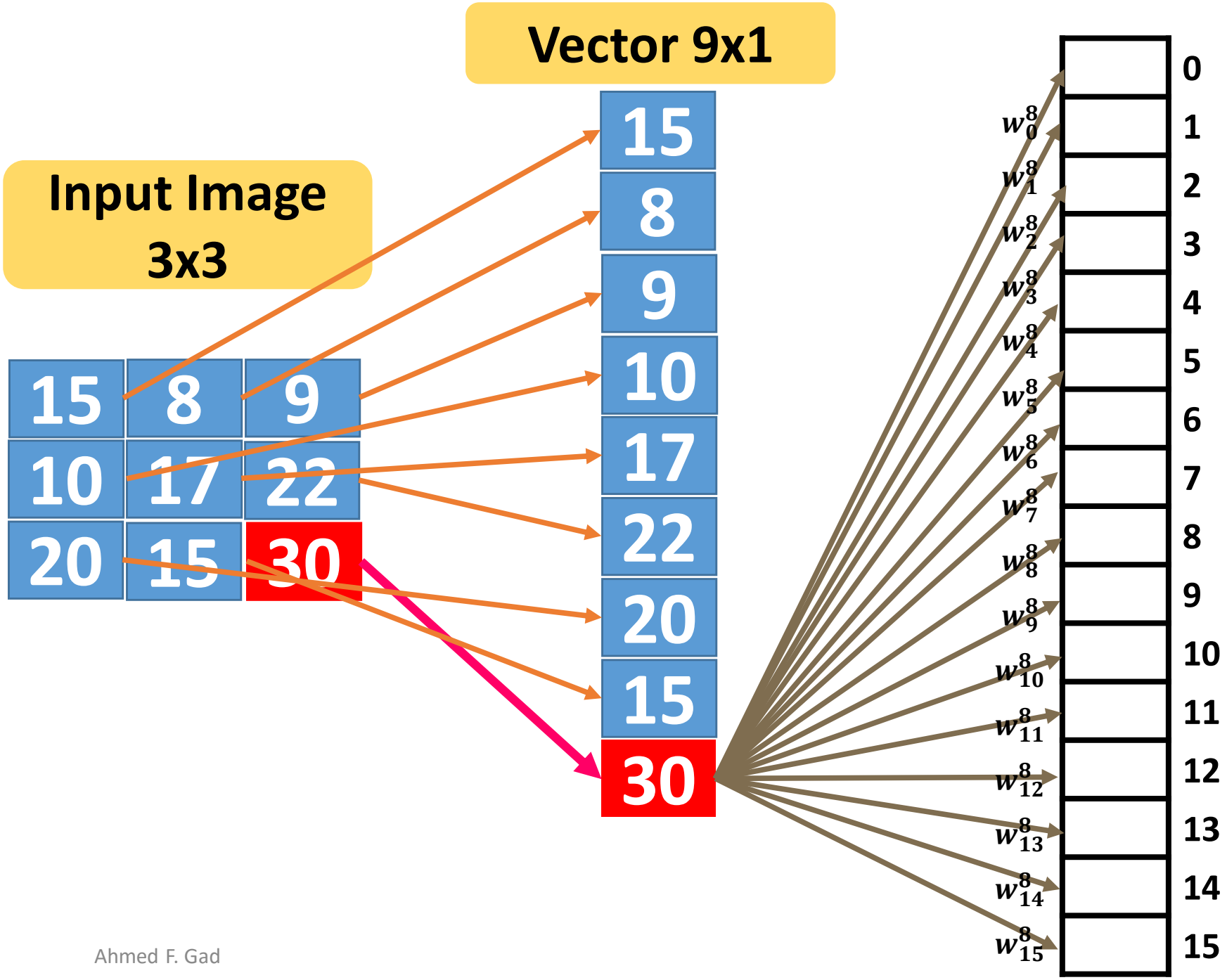
Vector 9x1
Input Image
3x3
15
8
9
10
17
22
20
15
30
15
8
9
10
17
22
20
15
30
w_0^8
w_1^8
w_2^8
w_3^8
w_4^8
w_5^8
w_6^8
w_7^8
w_8^8
w_9^8
w_{10}^8
w_{11}^8
w_{12}^8
w_{13}^8
w_{14}^8
w_{15}^8
0
1
2
3
4
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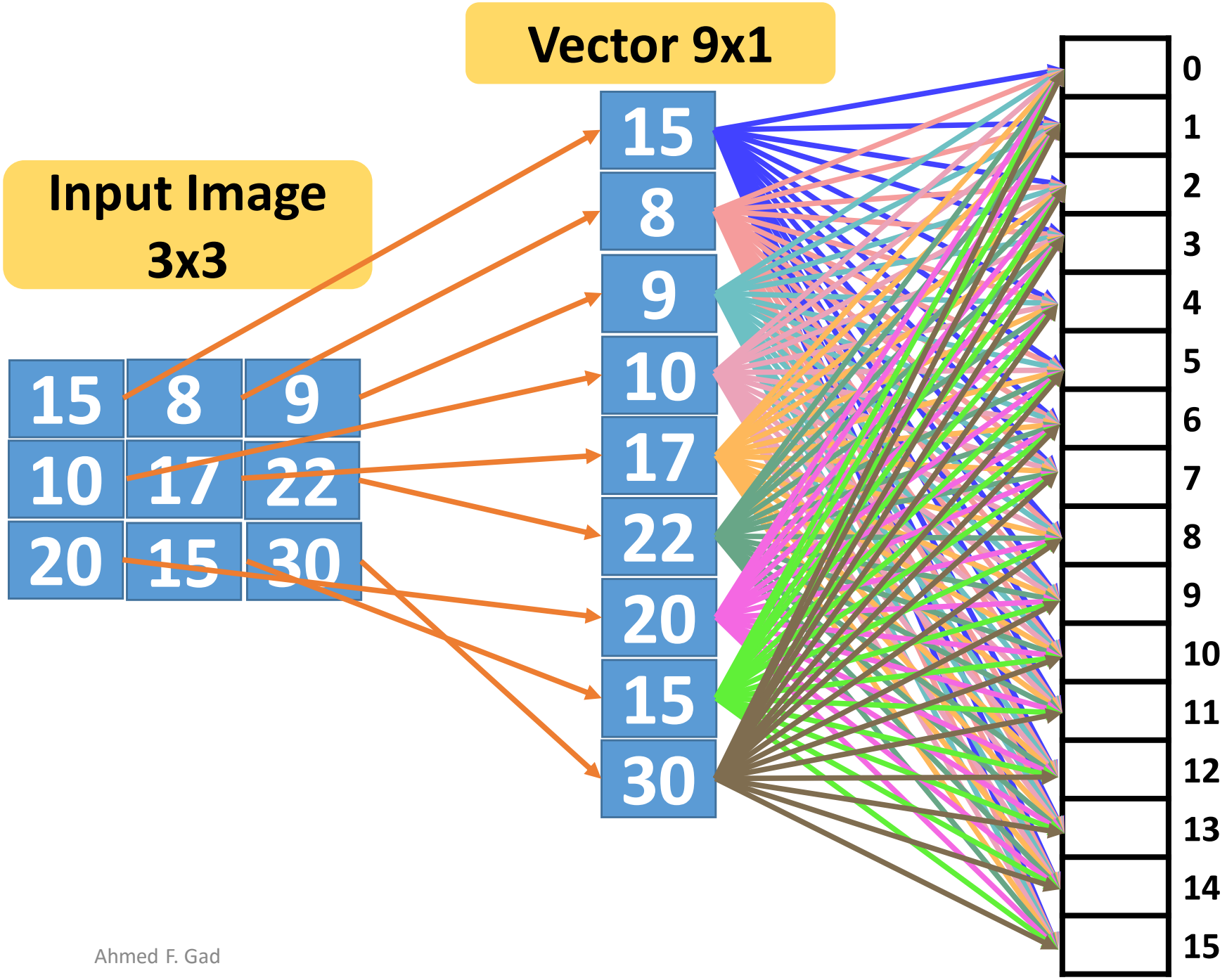
6
7
8
9
10
11
12
13
14
15


Vector 9x1
Input Image
3x3
15
8
9
10
17
22
20
15
30
15
8
9
10
17
22
20
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3
4
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8
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12
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14
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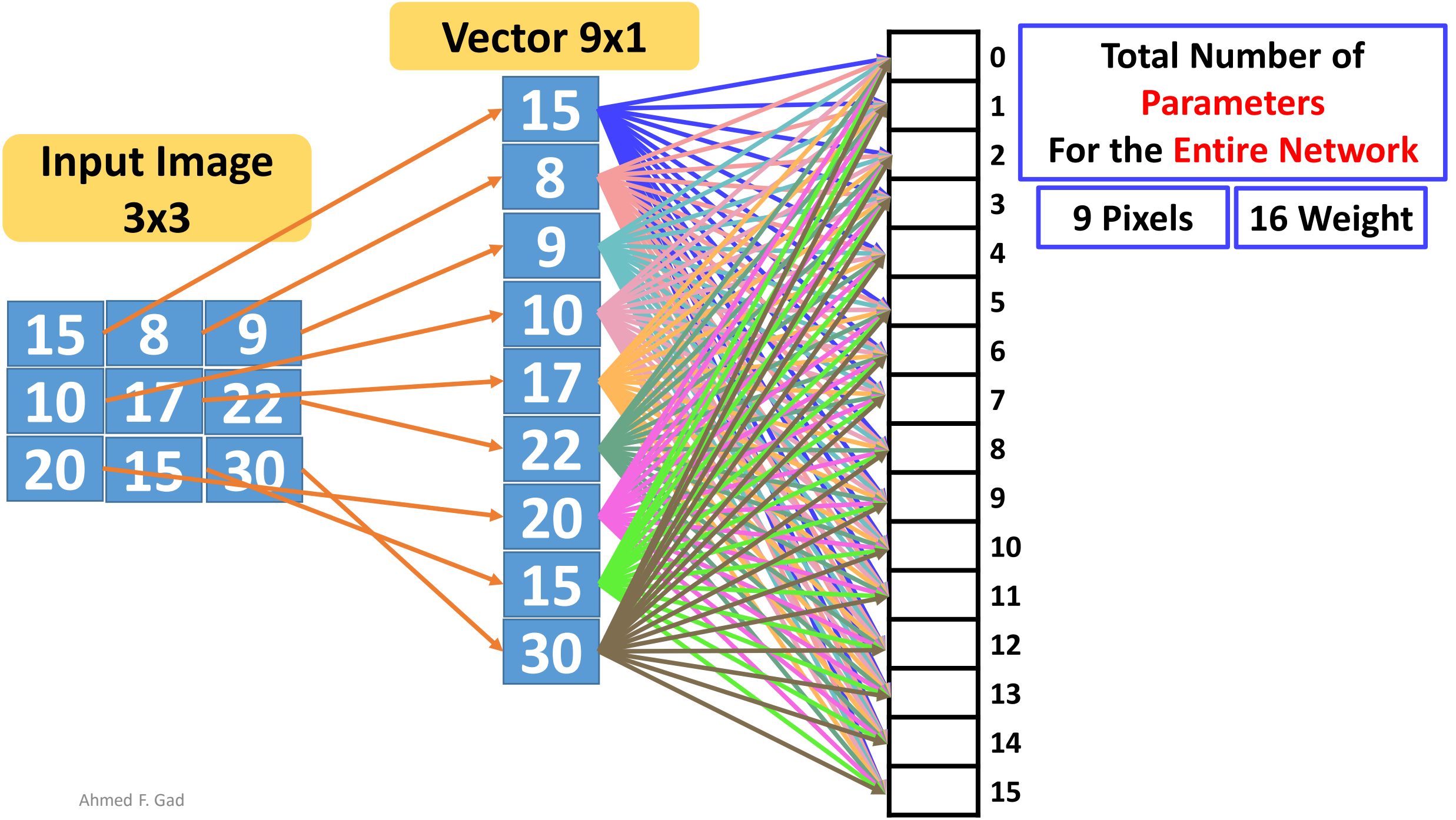
Vector 9x1
Input Image
3x3
15
8
9
10
17
22
20
15
30
0
1
2
3
4
5
6
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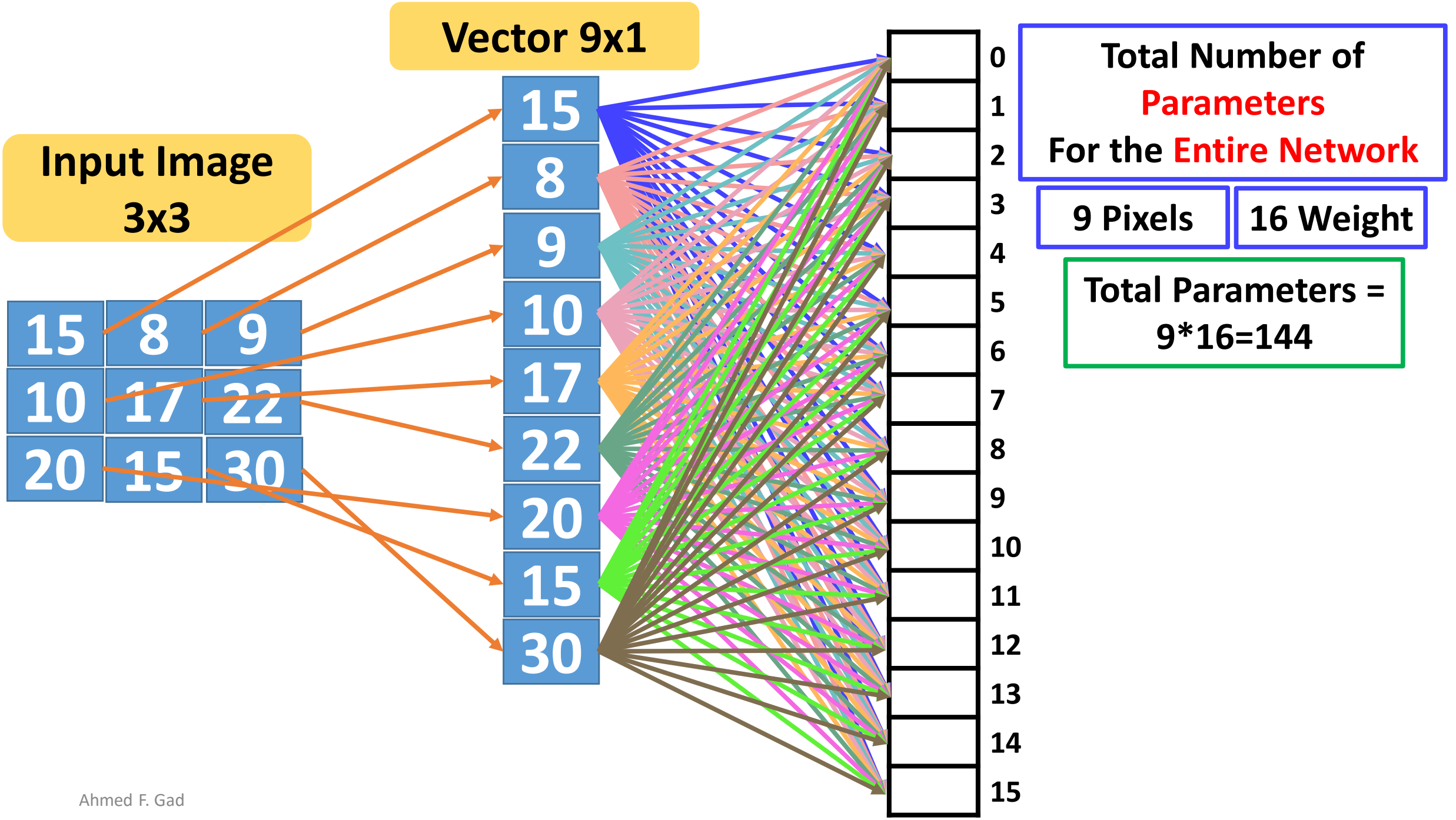
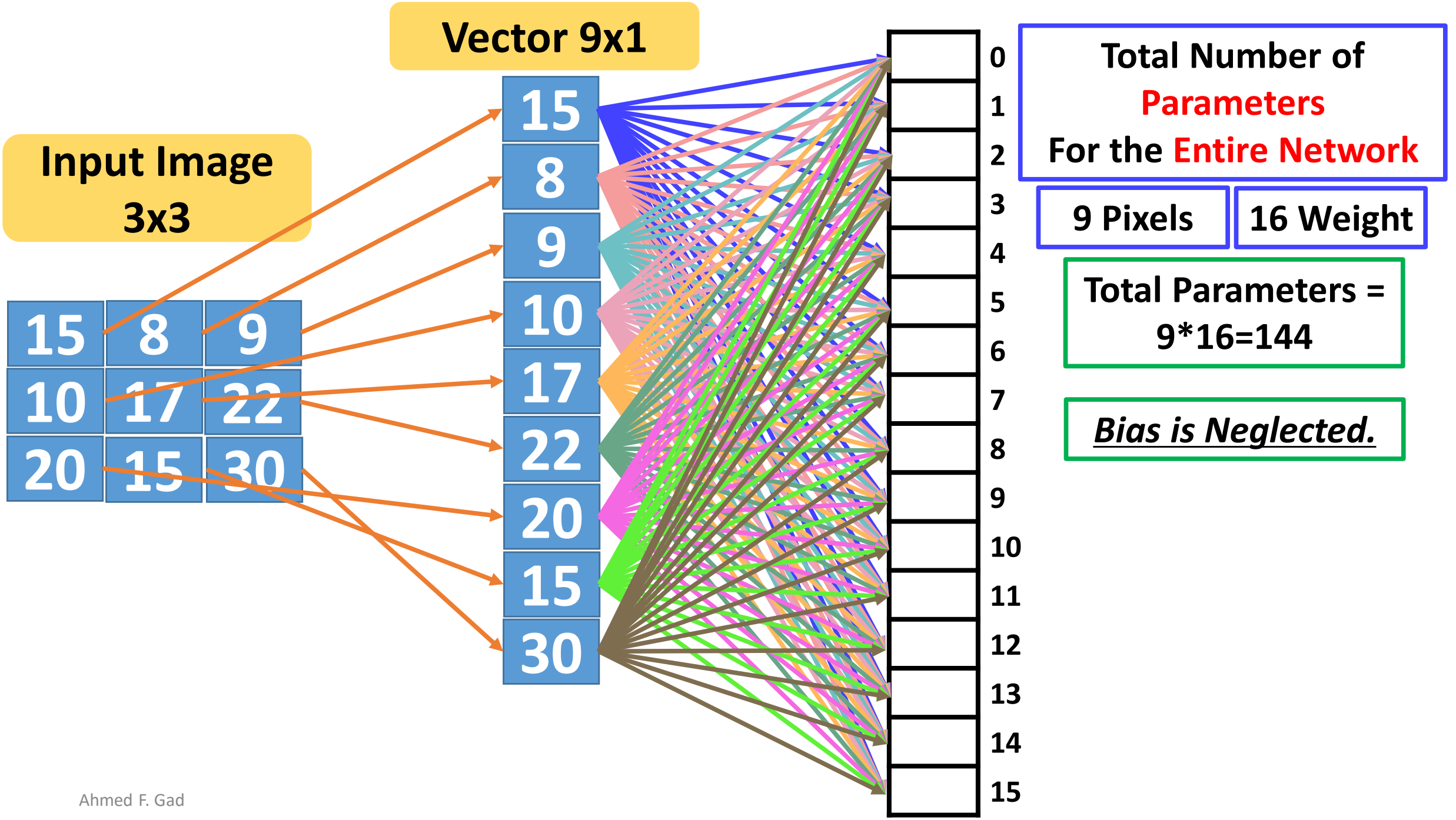
8
9
10
11
12
13
14
15
Total Number of
Parameters
For the Entire Network
9 Pixels
16 Weight

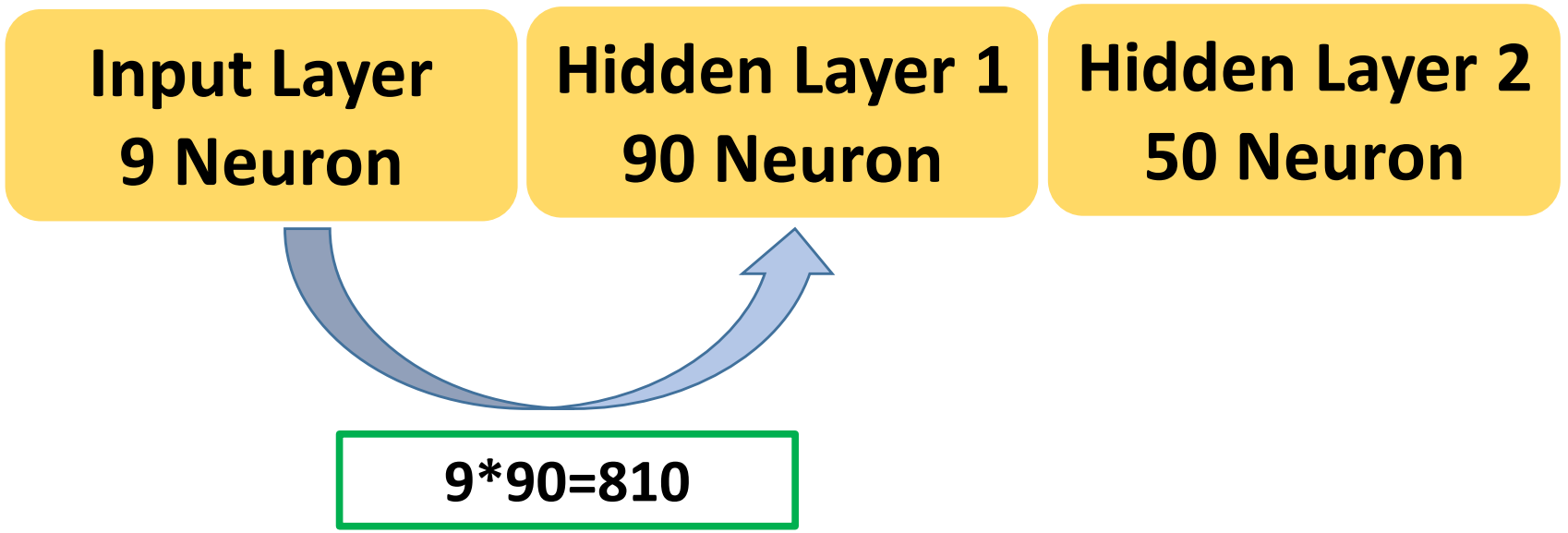

Vector 9x1
Input Image
3x3
15
8
9
10
17
22
20
15
30
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Total Number of
Parameters
For the Entire Network
9 Pixels
16 Weight
Total Parameters =
9*16=144


Vector 9x1
Input Image
3x3
15
8
9
10
17
22
20
15
30
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Total Number of
Parameters
For the Entire Network
9 Pixels
16 Weight
Total Parameters =
9*16=144
Bias is Neglected.

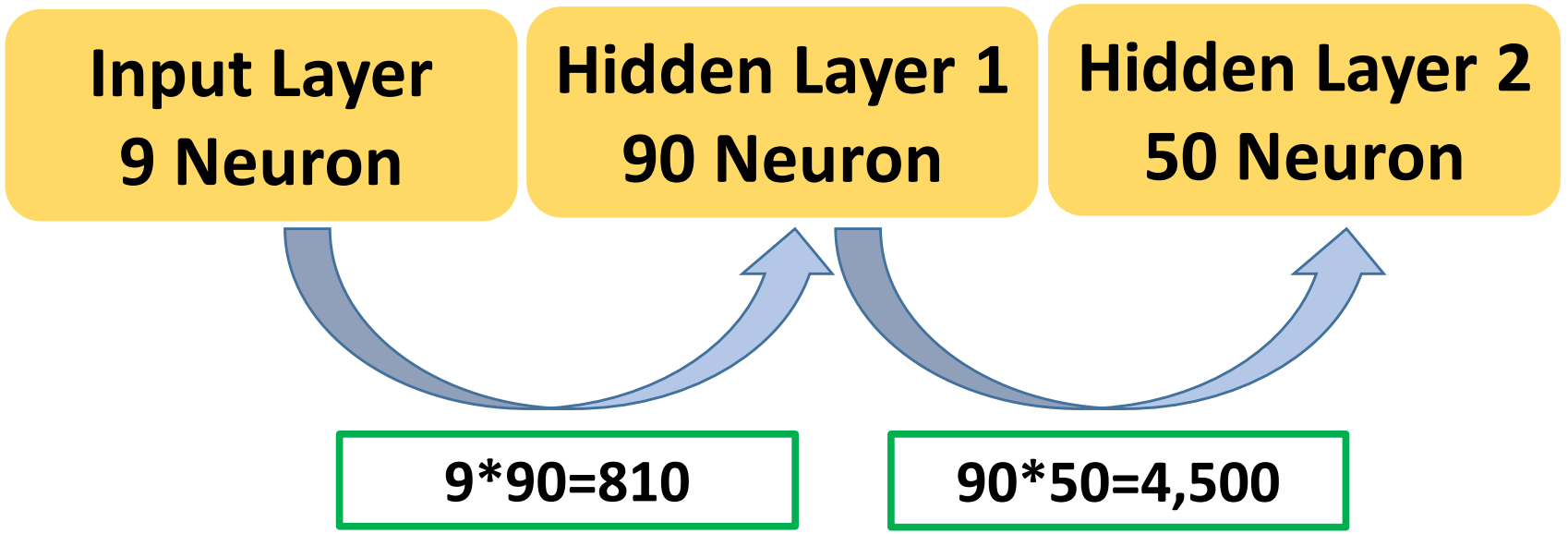
Too Many Parameters

Input Layer	Hidden Layer 1	Hidden Layer 2
9 Neuron	90 Neuron	50 Neuron

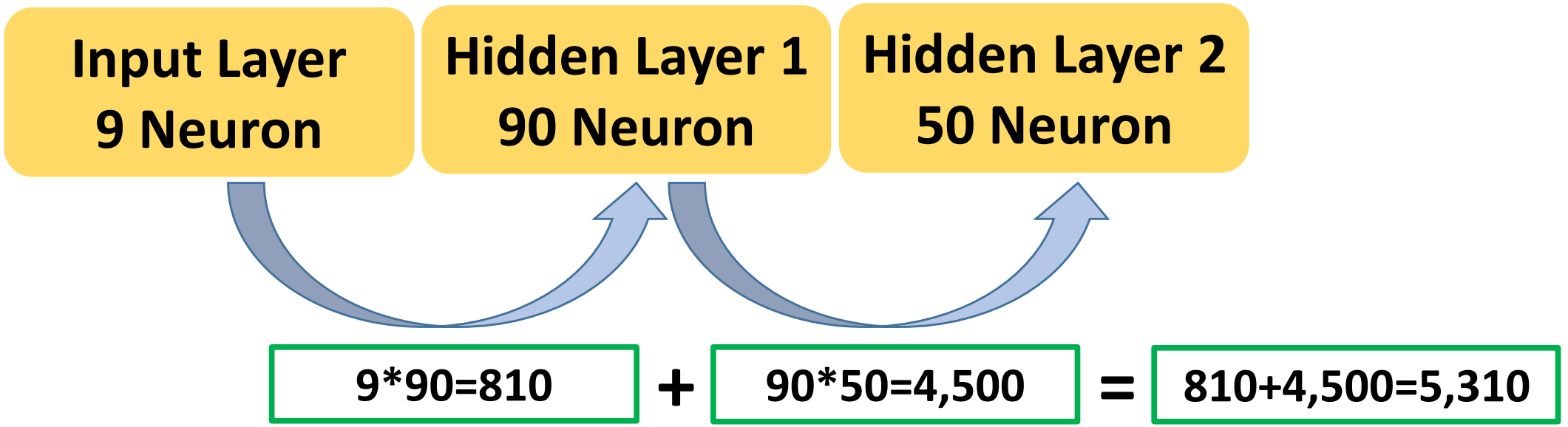
Too Many Parameters



Too Many Parameters



Too Many Parameters



Input Image
32x32

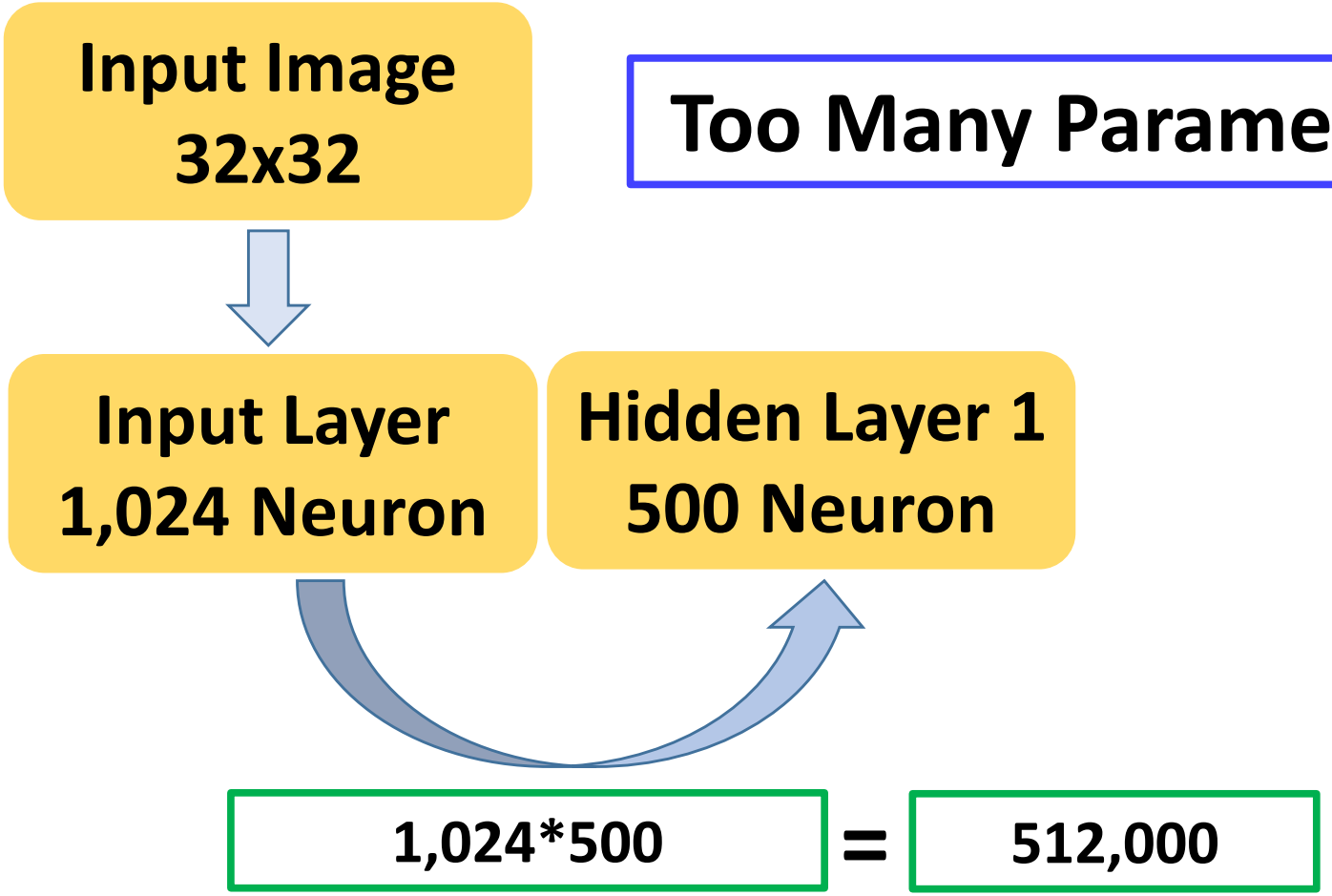
Too Many Parameters

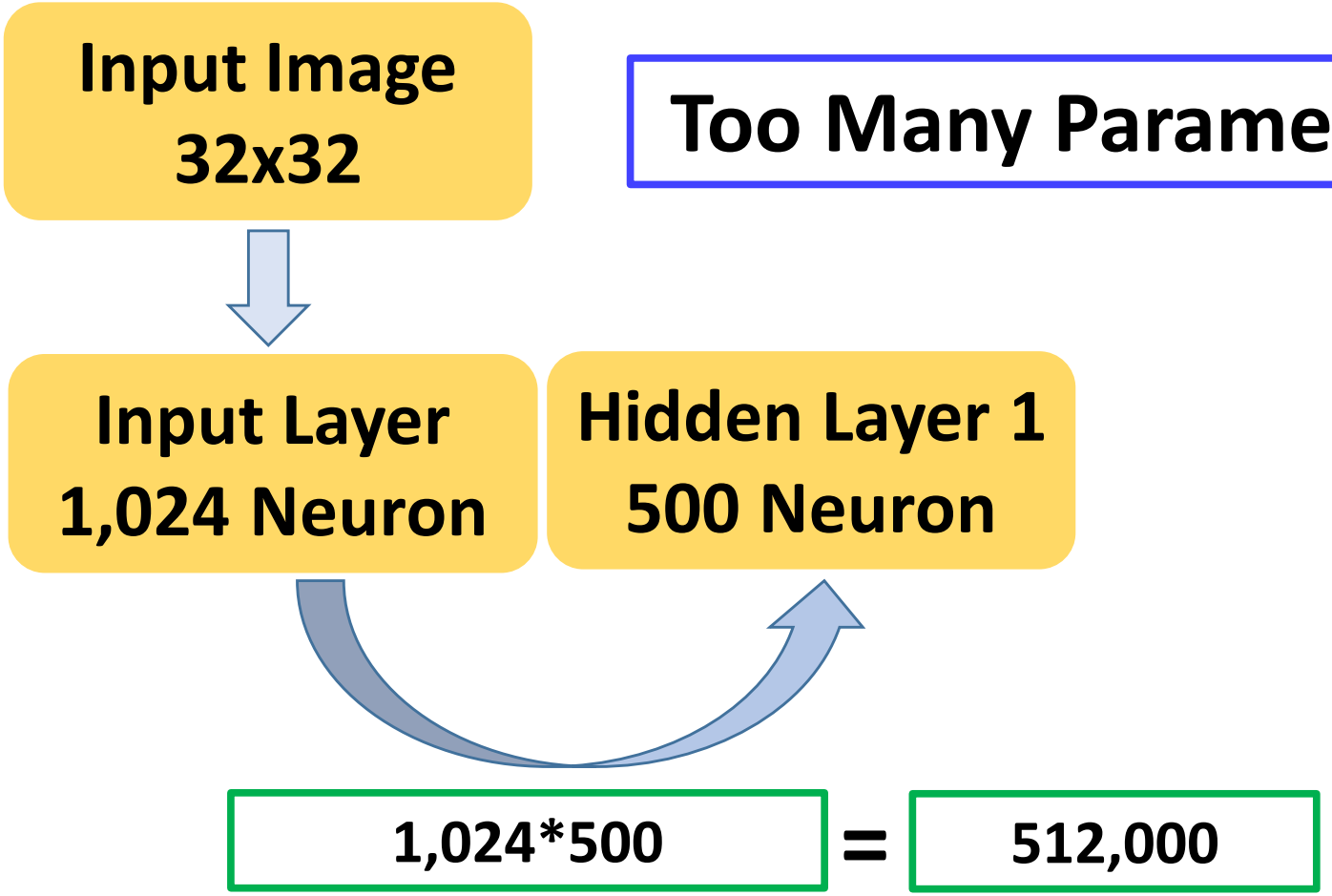
Input Image
32x32

Input Layer
1,024 Neuron

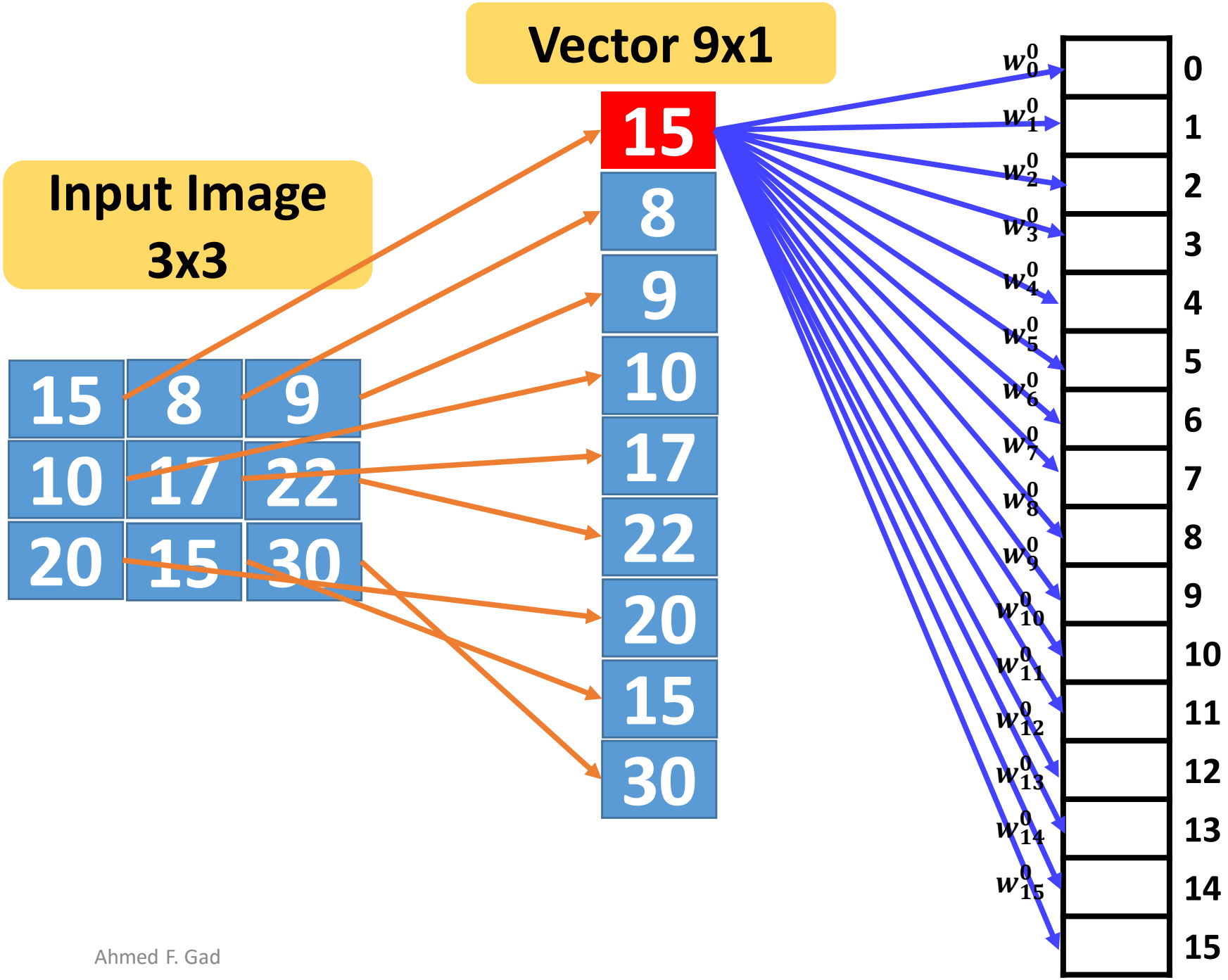
Hidden Layer 1
500 Neuron

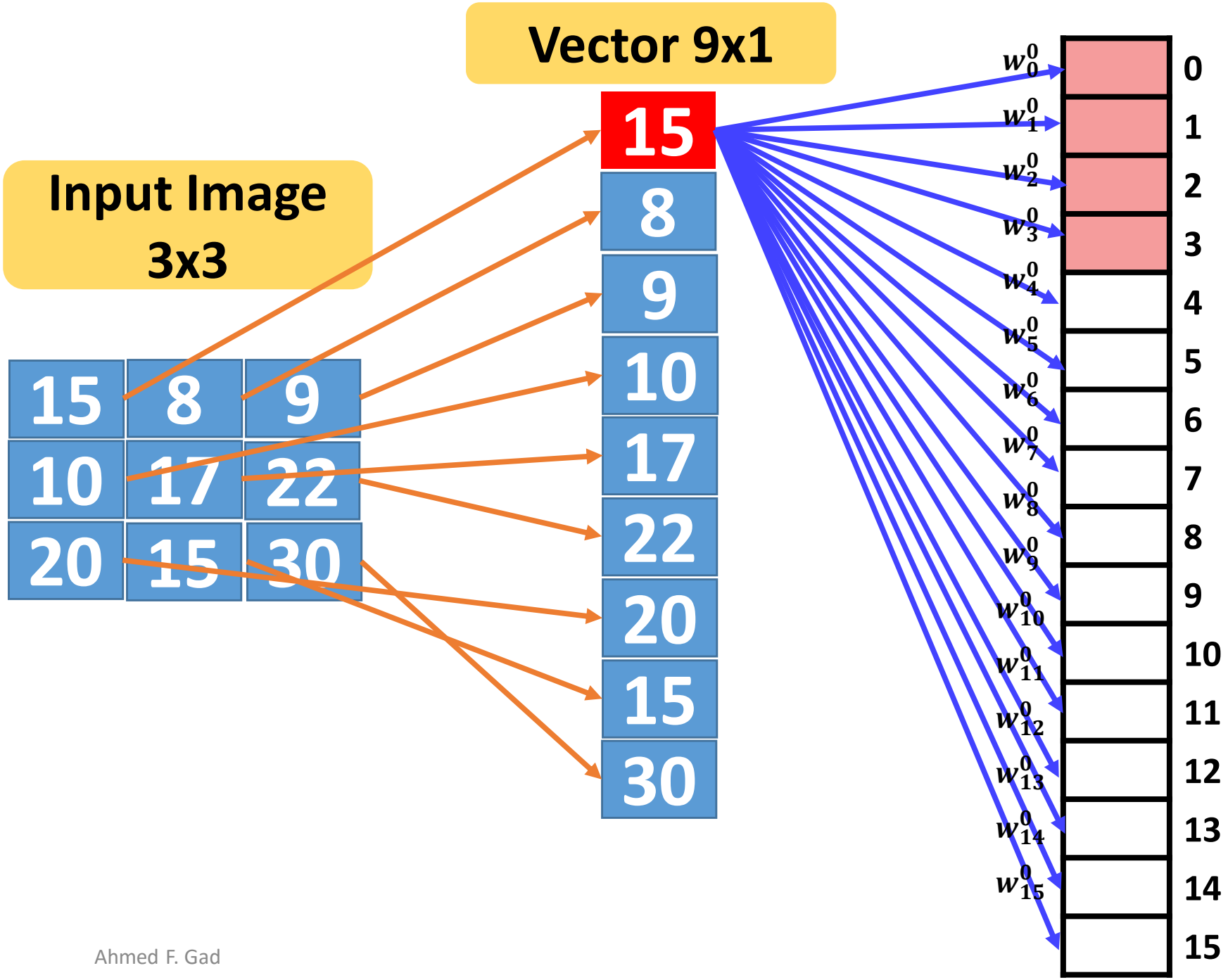
Too Many Parameters

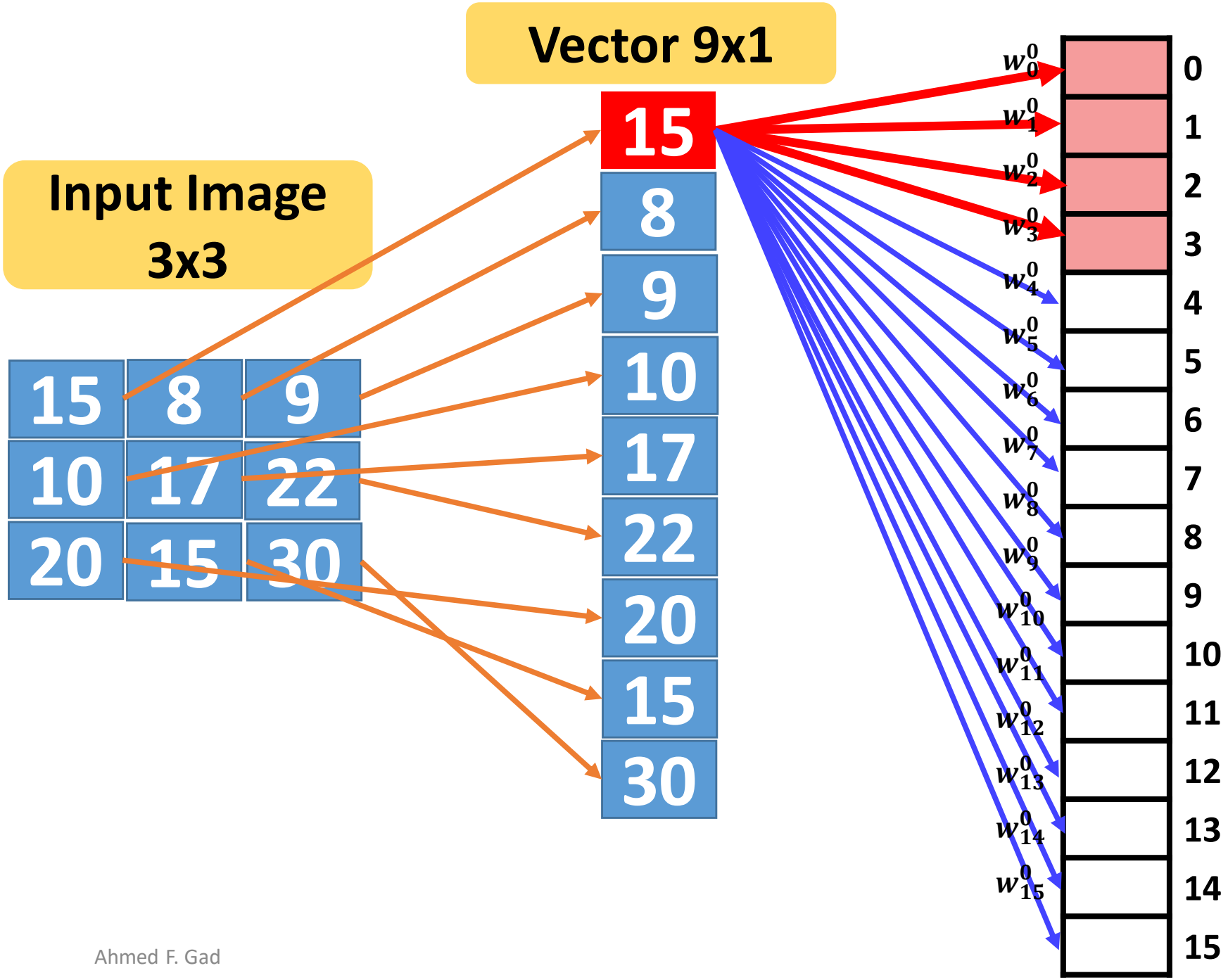

Input Image
32x32
Too Many Parameters
Input Layer
1,024 Neuron
Hidden Layer 1
500 Neuron
1,024*500
=
512,000



CNN can create a large network but with less number of parameters than FC networks


Vector 9x1
Input Image
3x3
15
8
9
10
17
22
20
15
30
15
8
9
10
17
22
20
15
30
w_0^0
w_1^0
w_2^0
w_3^0
w_4^0
w_5^0
w_6^0
w_7^0
w_8^0
w_9^0
w_{10}^0
w_{11}^0
w_{12}^0
w_{13}^0
w_{14}^0
w_{15}^0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15


Vector 9x1
Input Image
3x3
15
8
9
10
17
22
20
15
30
15
8
9
10
17
22
20
15
30
w_0^0
w_1^0
w_2^0
w_3^0
w_4^0
w_5^0
w_6^0
w_7^0
w_8^0
w_9^0
w_{10}^0
w_{11}^0
w_{12}^0
w_{13}^0
w_{14}^0
w_{15}^0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15


Vector 9x1
Input Image
3x3
15
8
9
10
17
22
20
15
30
15
8
9
10
17
22
20
15
30
w_0^0
w_1^0
w_2^0
w_3^0
w_4^0
w_5^0
w_6^0
w_7^0
w_8^0
w_9^0
w_{10}^0
w_{11}^0
w_{12}^0
w_{13}^0
w_{14}^0
w_{15}^0
0
1
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4
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6
7
8
9
10
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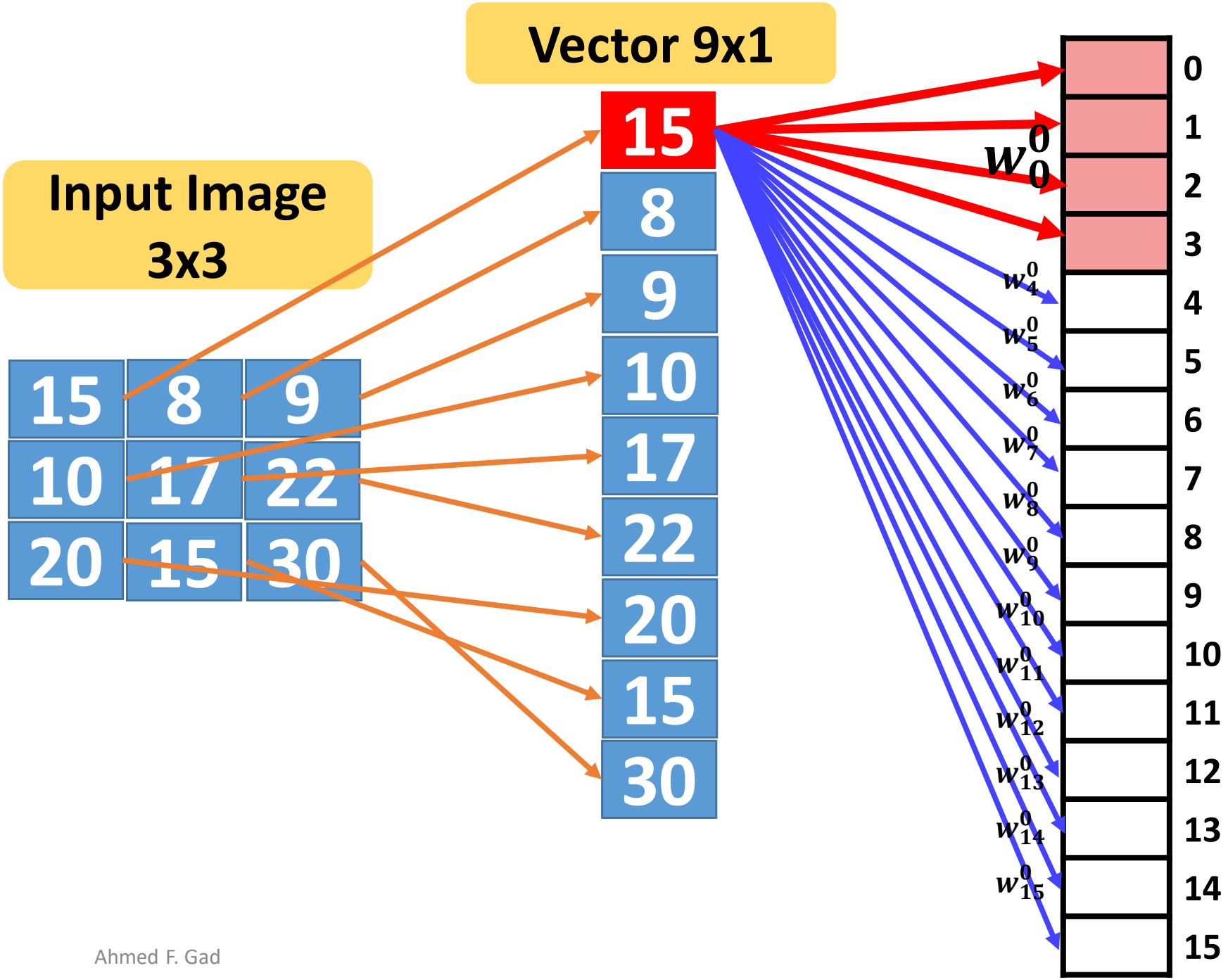
12
13
14
15


Vector 9x1
Input Image
3x3
15
8
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10
17
22
20
15
30
15
8
9
10
17
22
20
15
30
w_0^0
w_4^0
w_5^0
w_6^0
w_7^0
w_8^0
w_9^0
w_{10}^0
w_{11}^0
w_{12}^0
w_{13}^0
w_{14}^0
w_{15}^0
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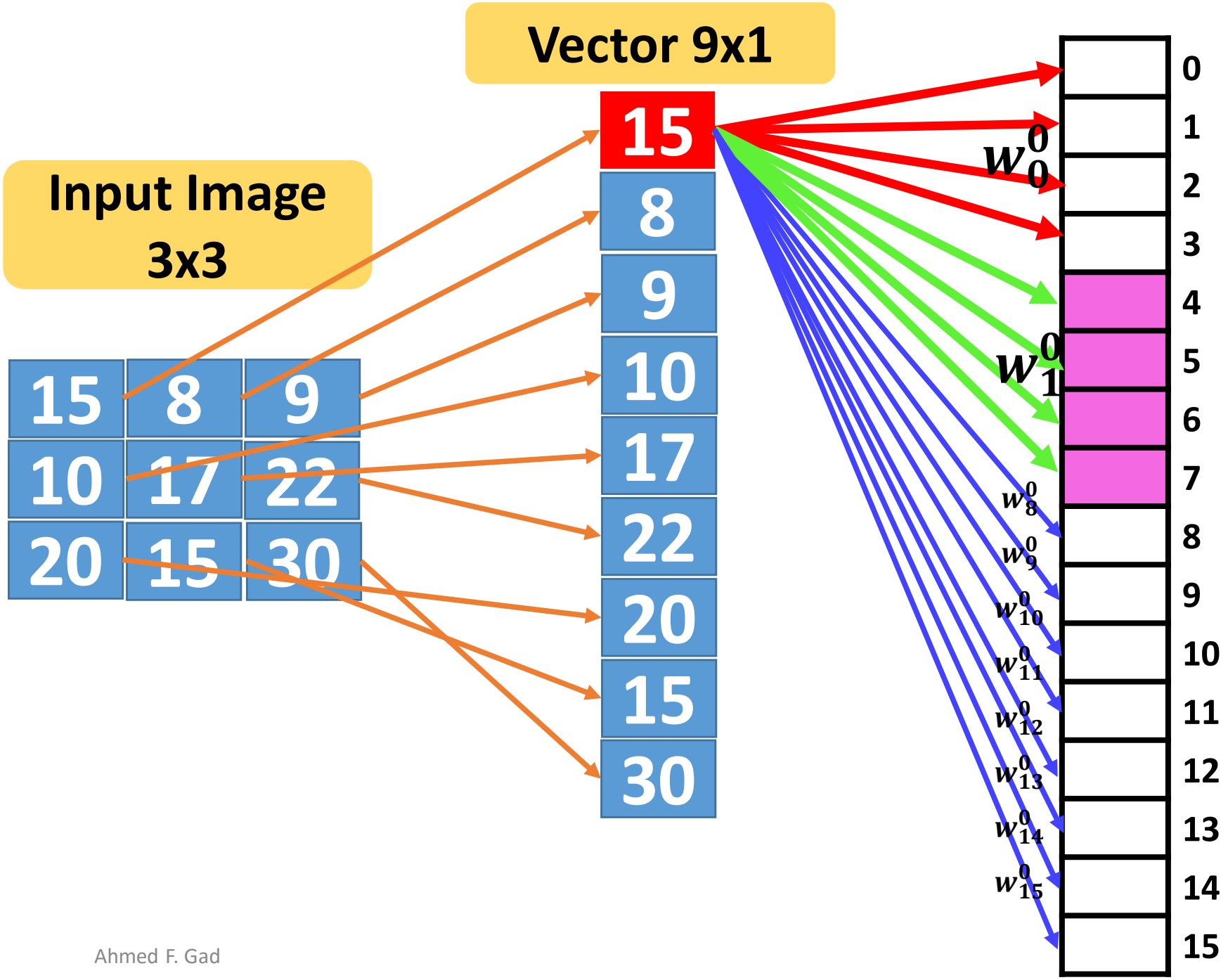
15


Vector 9x1
Input Image
3x3
15
8
9
10
17
22
20
15
30
15
8
9
10
17
22
20
15
30
w_0^0
w_1^0
w_8^0
w_9^0
w_{10}^0
w_{11}^0
w_{12}^0
w_{13}^0
w_{14}^0
w_{15}^0
0
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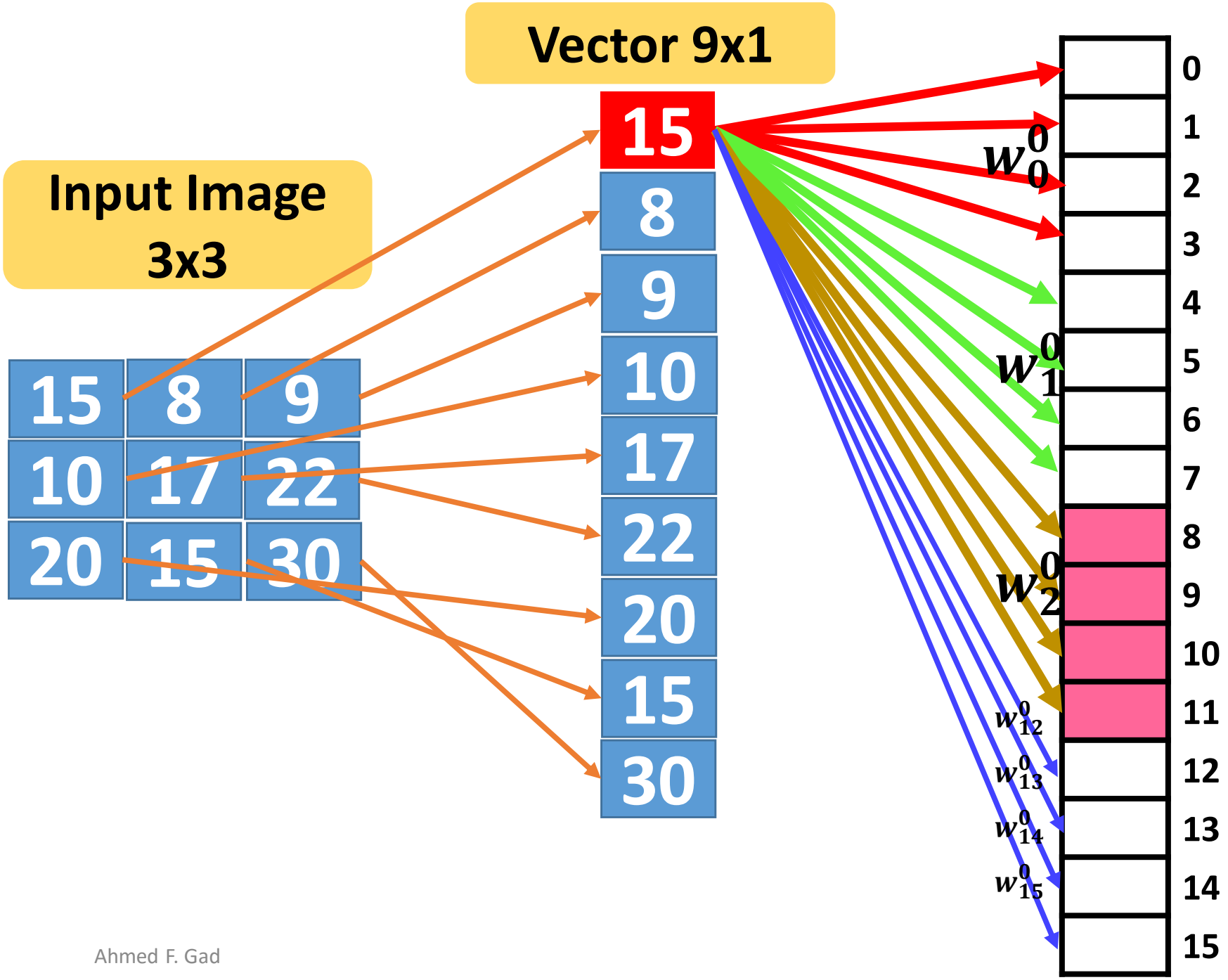
15


Vector 9x1
Input Image
3x3
15
8
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10
17
22
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15
30
15
8
9
10
17
22
20
15
30
w_0^0
w_1^0
w_2^0
w_{12}^0
w_{13}^0
w_{14}^0
w_{15}^0
0
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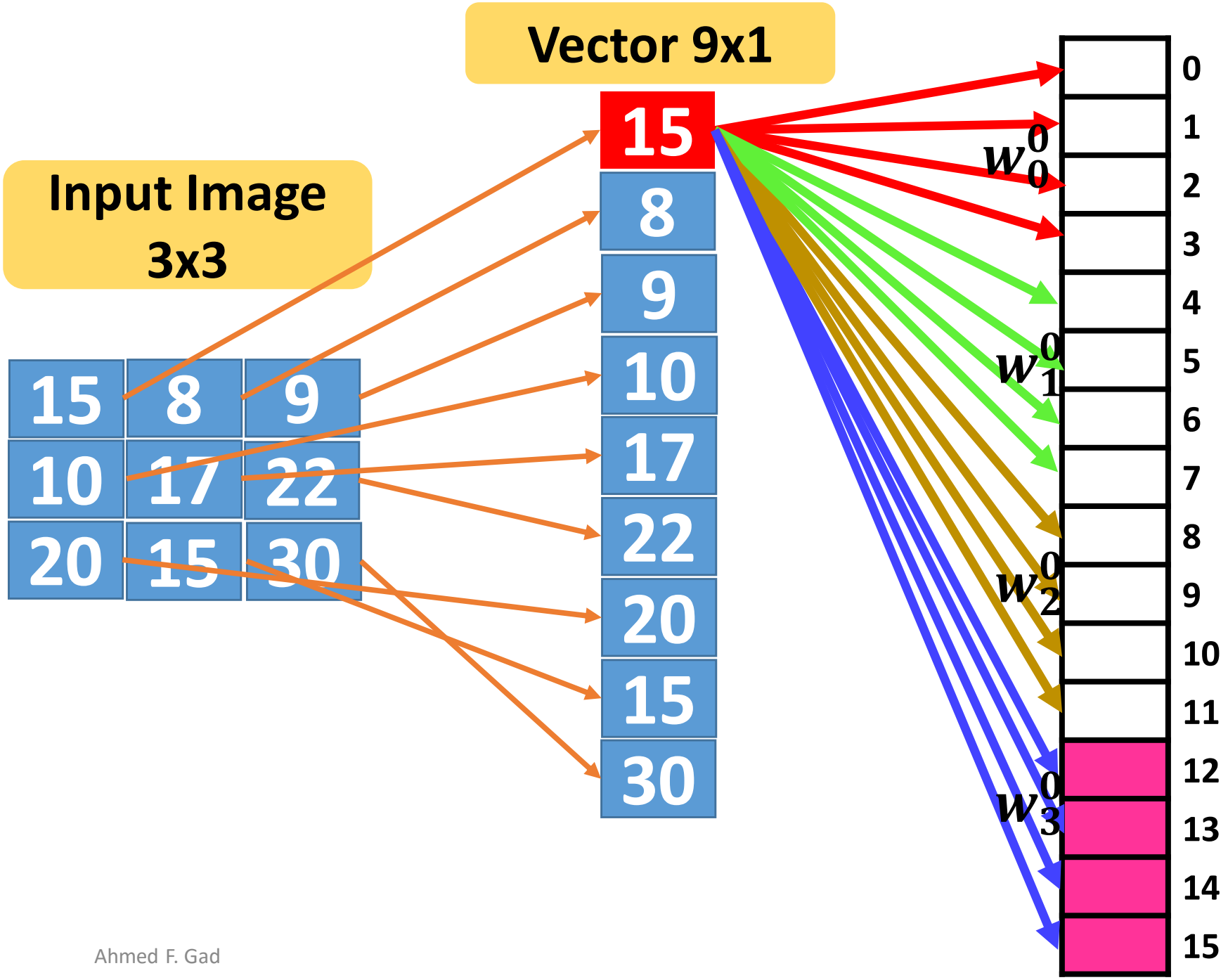
14
15


Vector 9x1
Input Image
3x3
15
8
9
10
17
22
20
15
30
15
8
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10
17
22
20
15
30
w_0^0
w_1^0
w_2^0
w_3^0
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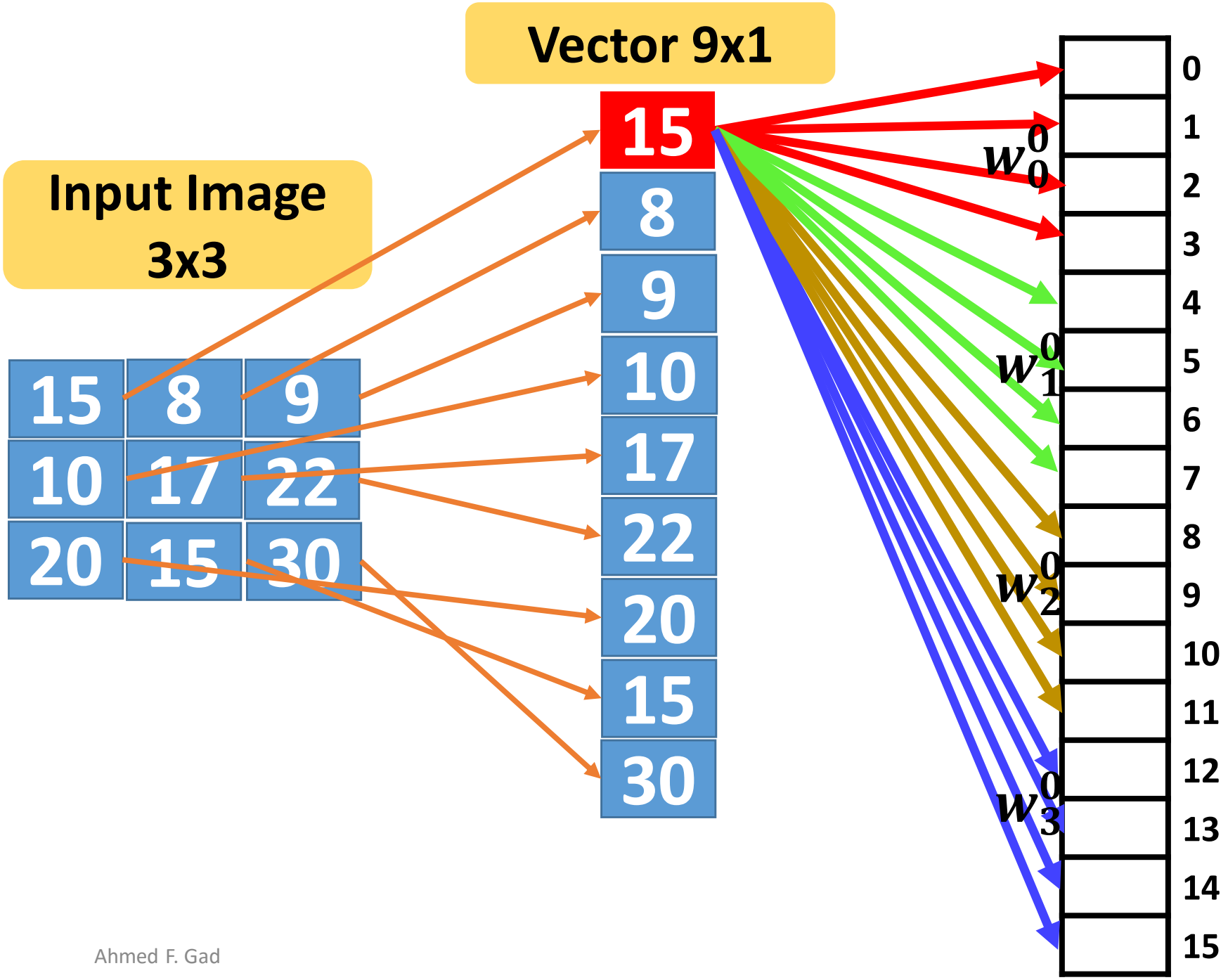
Vector 9x1
Input Image
3x3
15
8
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10
17
22
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15
8
9
10
17
22
20
15
30
w_0^0
w_1^0
w_2^0
w_3^0
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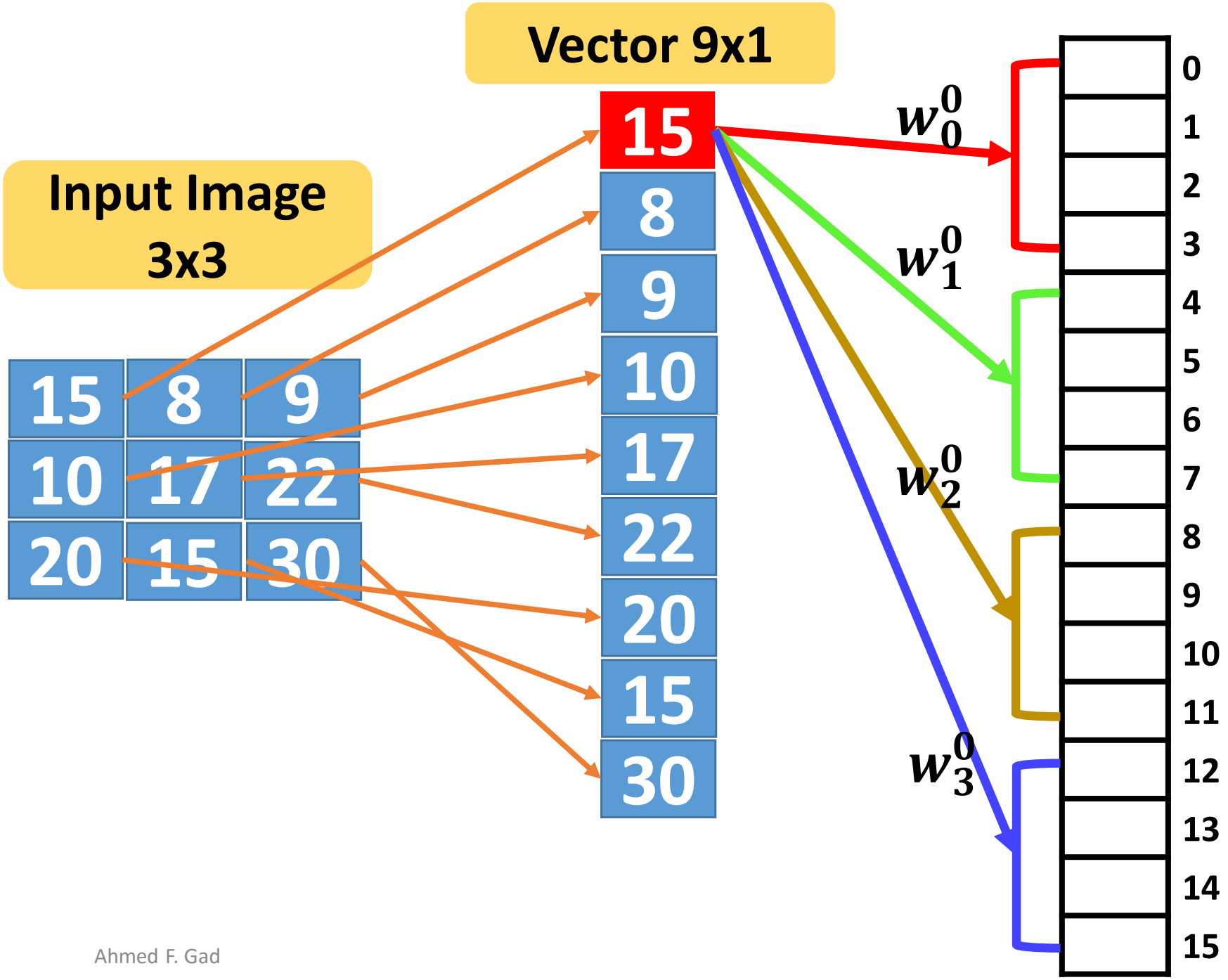
Vector 9x1
Input Image
3x3
15
8
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10
17
22
20
15
30
15
8
9
10
17
22
20
15
30
w_0^0
w_1^0
w_2^0
w_3^0
0
1
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14
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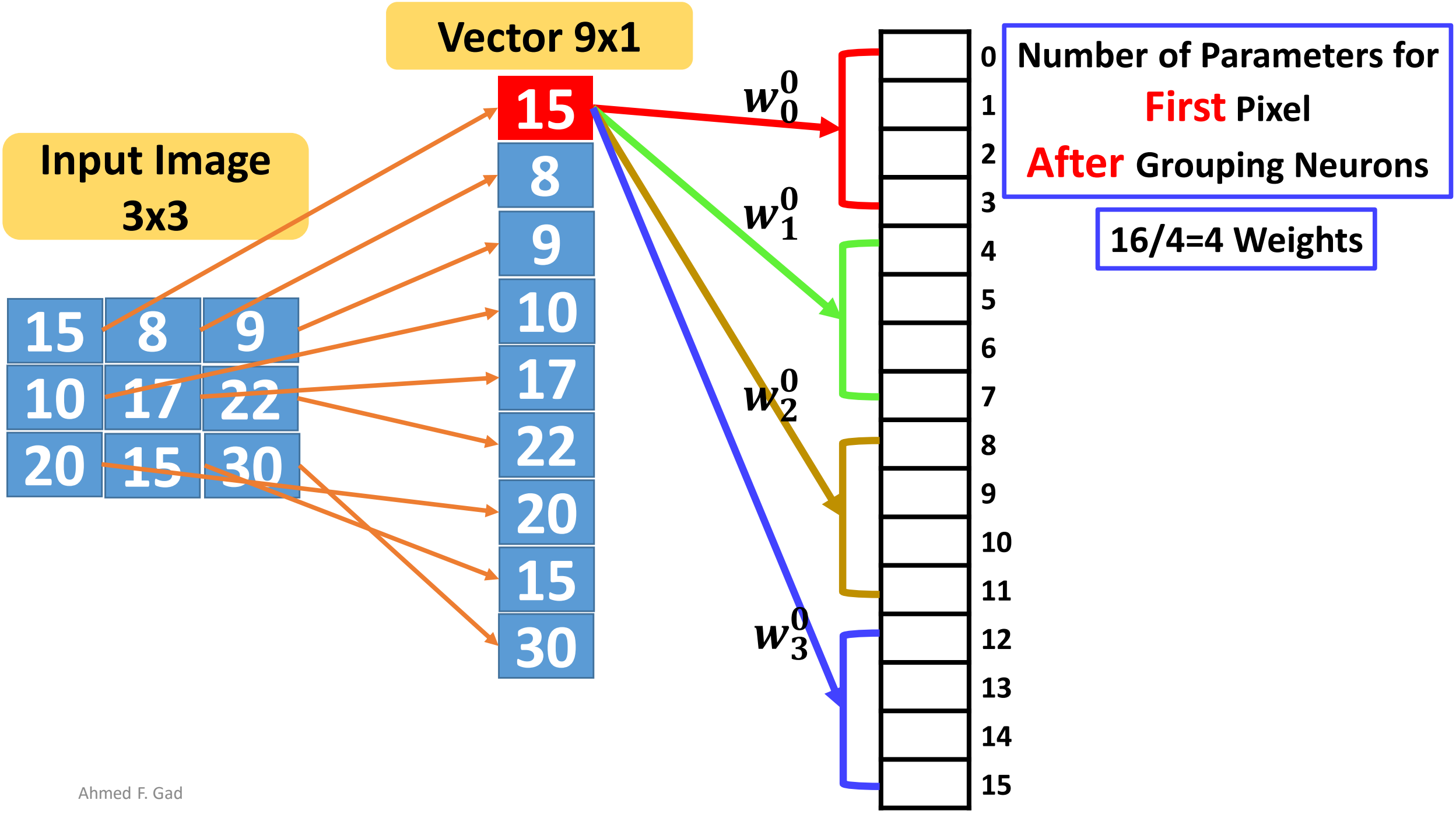
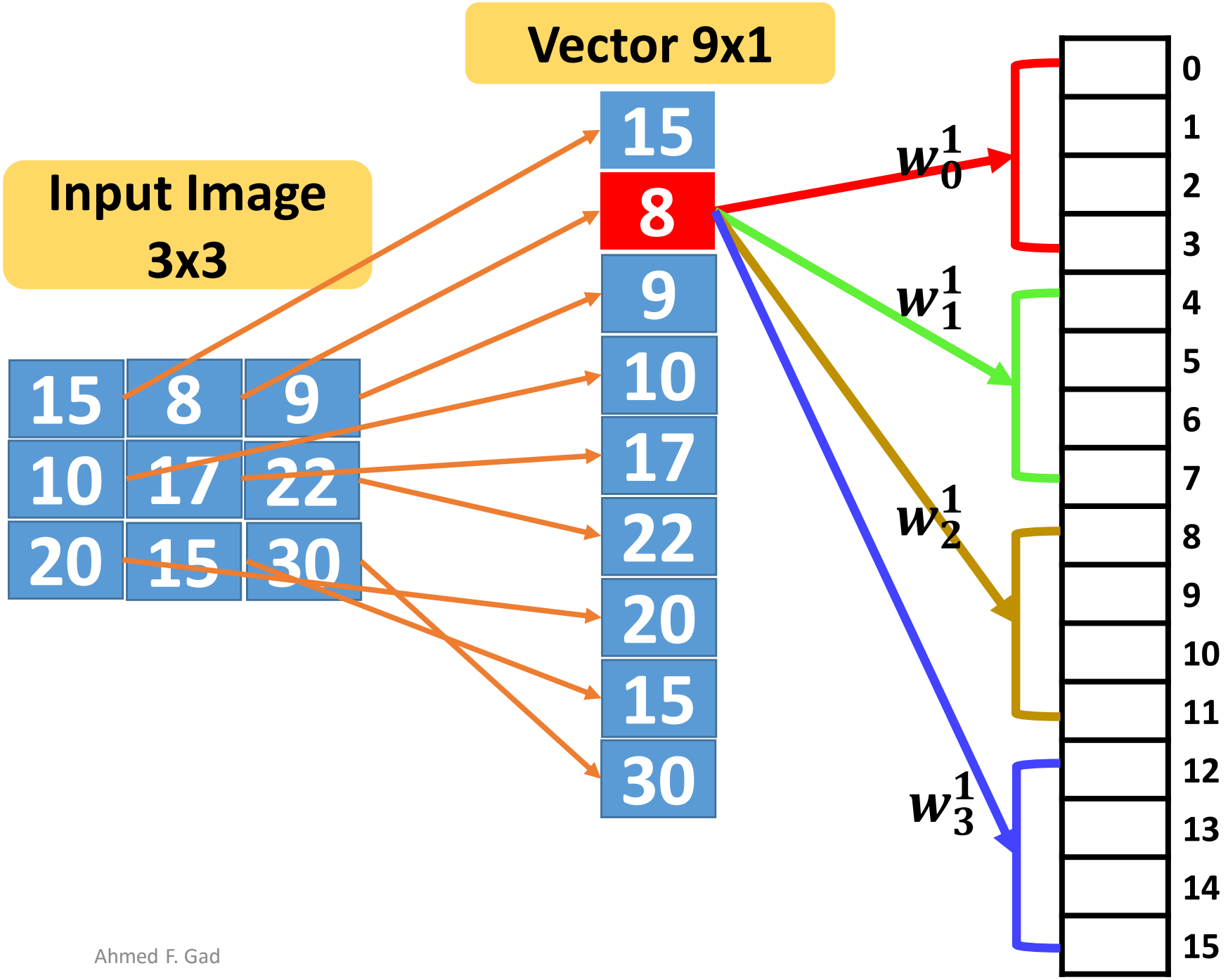
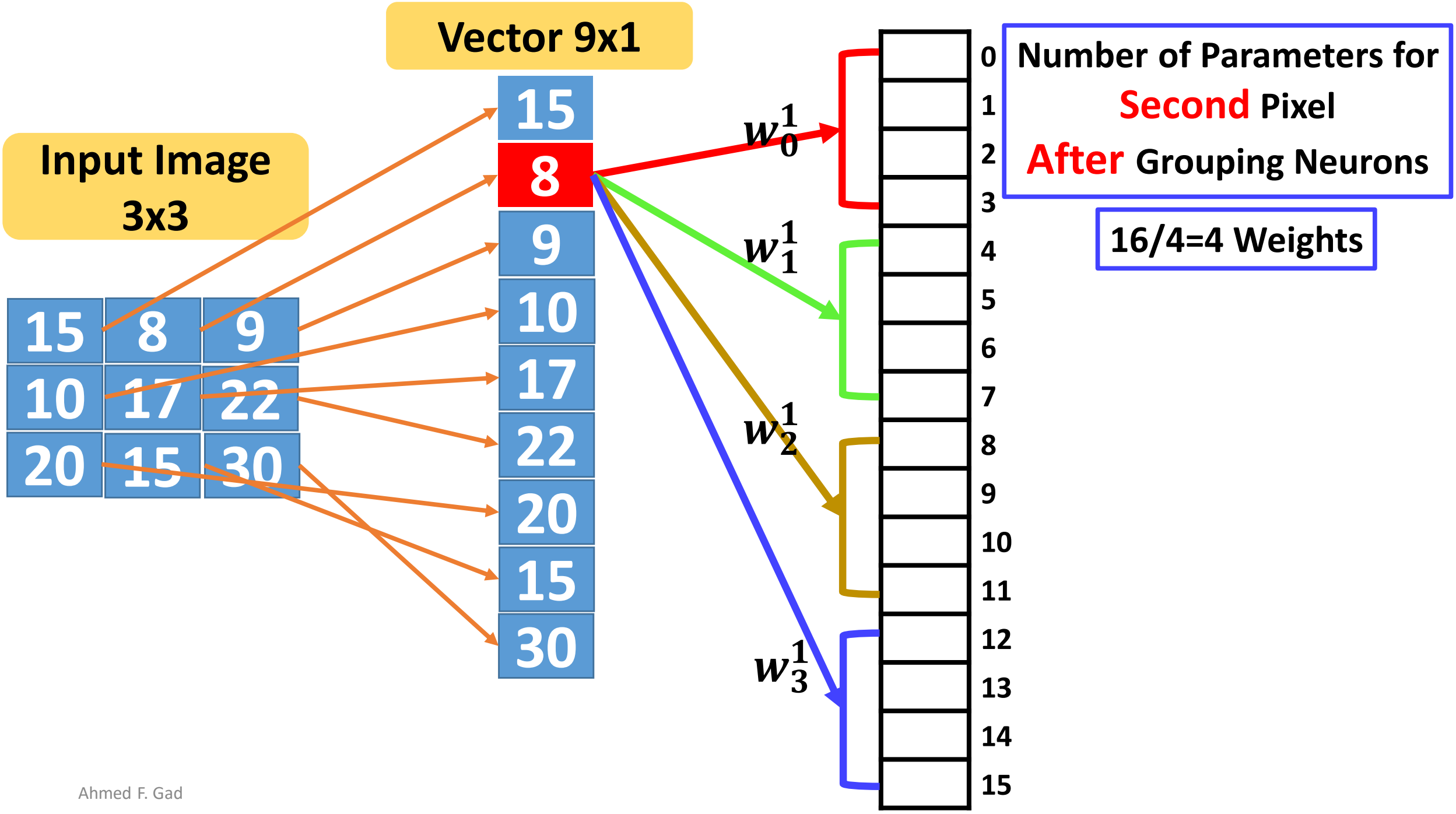
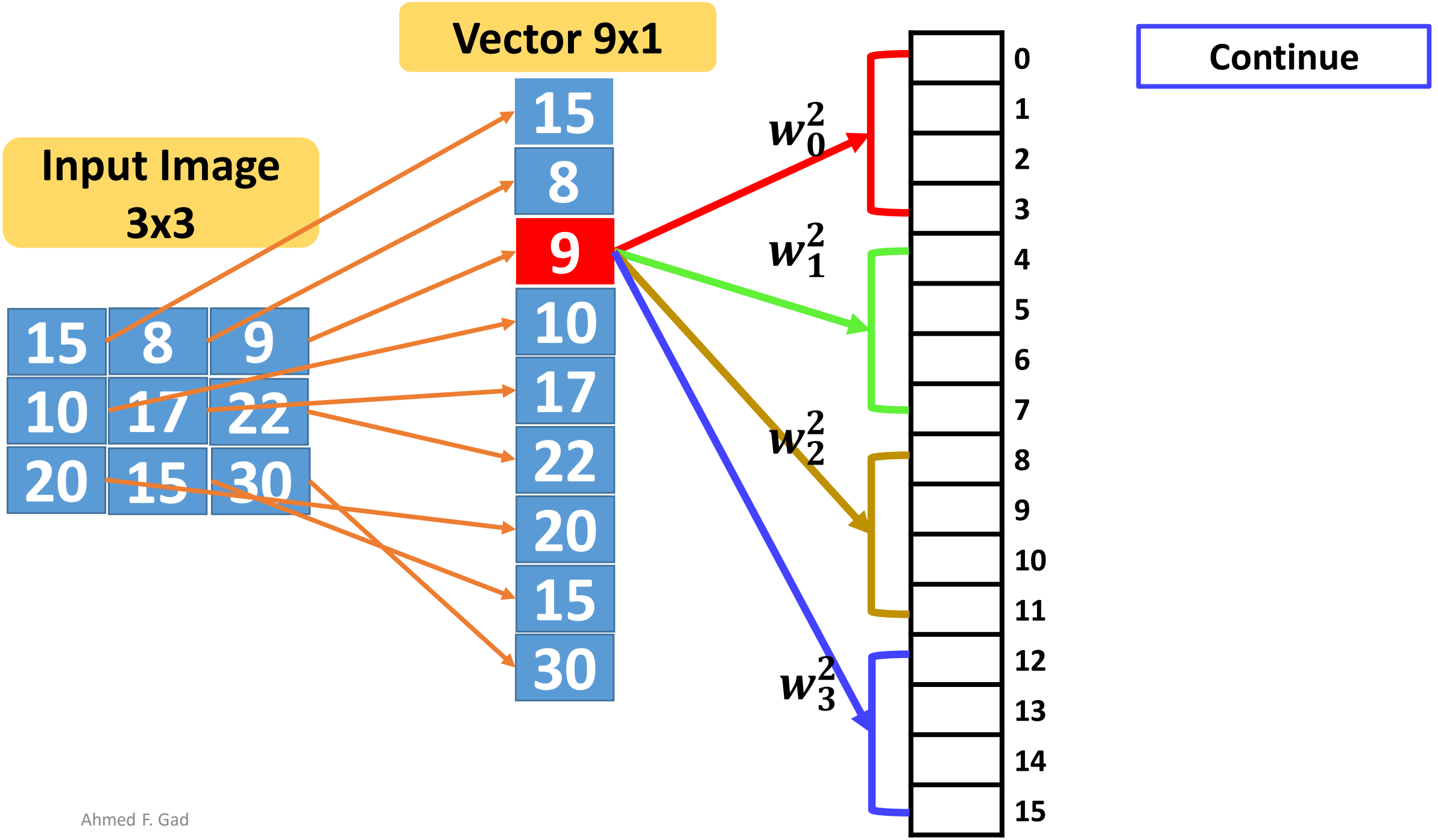

Vector 9x1
Input Image
3x3
15
8
9
10
17
22
20
15
30
w_0^0
w_1^0
w_2^0
w_3^0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Number of Parameters for
First Pixel
After Grouping Neurons
16/4=4 Weights


Vector 9x1
Input Image
3x3
15
8
9
10
17
22
20
15
30
w_0^1
w_1^1
w_2^1
w_3^1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15


Vector 9x1
Input Image
3x3
15
8
9
10
17
22
20
15
30
w_0^1
w_1^1
w_2^1
w_3^1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Number of Parameters for
Second Pixel
After Grouping Neurons
16/4=4 Weights


Vector 9x1
Input Image
3x3
15
8
9
10
17
22
20
15
30
w_0^2
w_1^2
w_2^2
w_3^2
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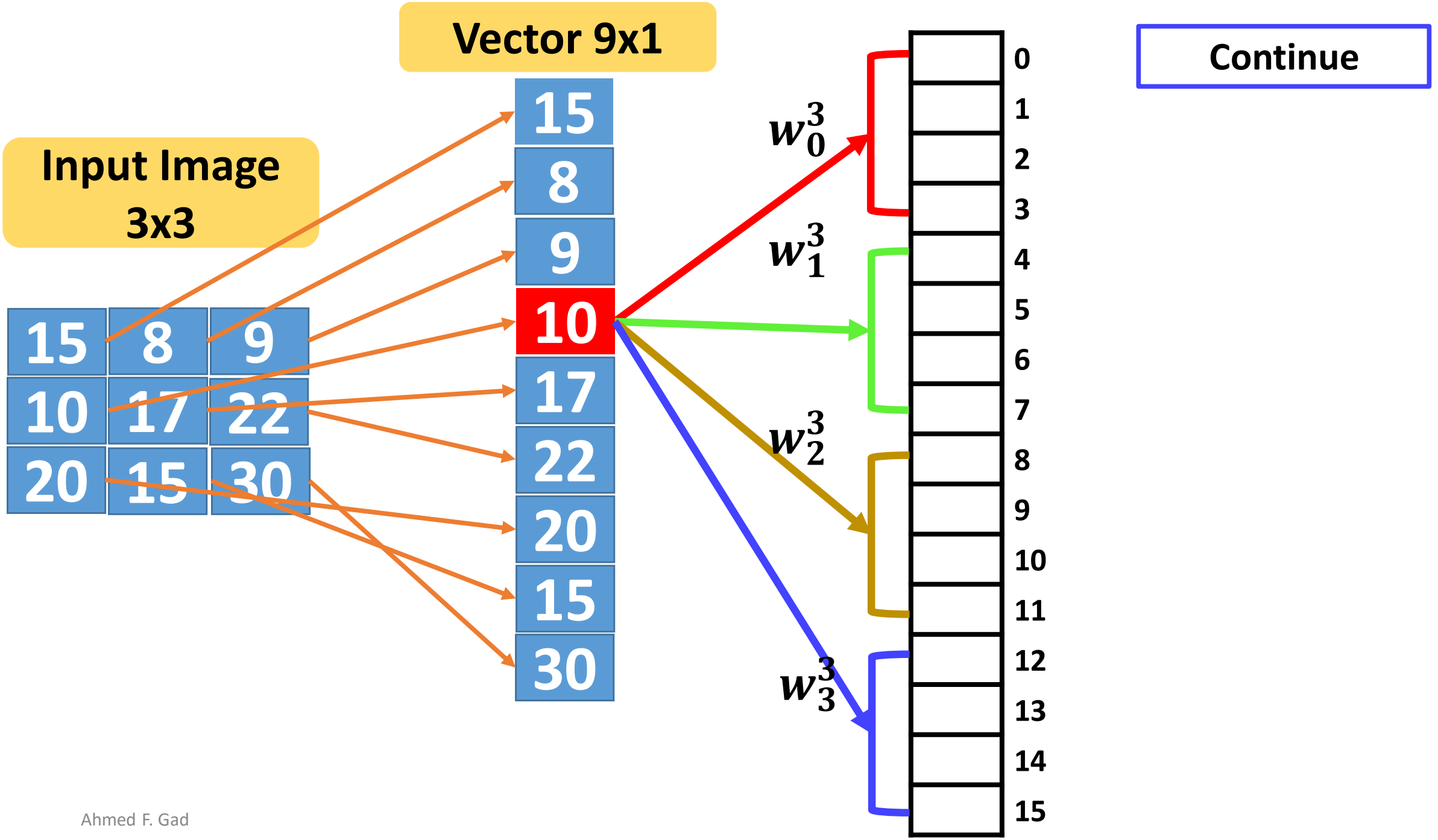
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Continue


Vector 9x1
Input Image
3x3
15
8
9
10
17
22
20
15
30
w_0^3
w_1^3
w_2^3
w_3^3
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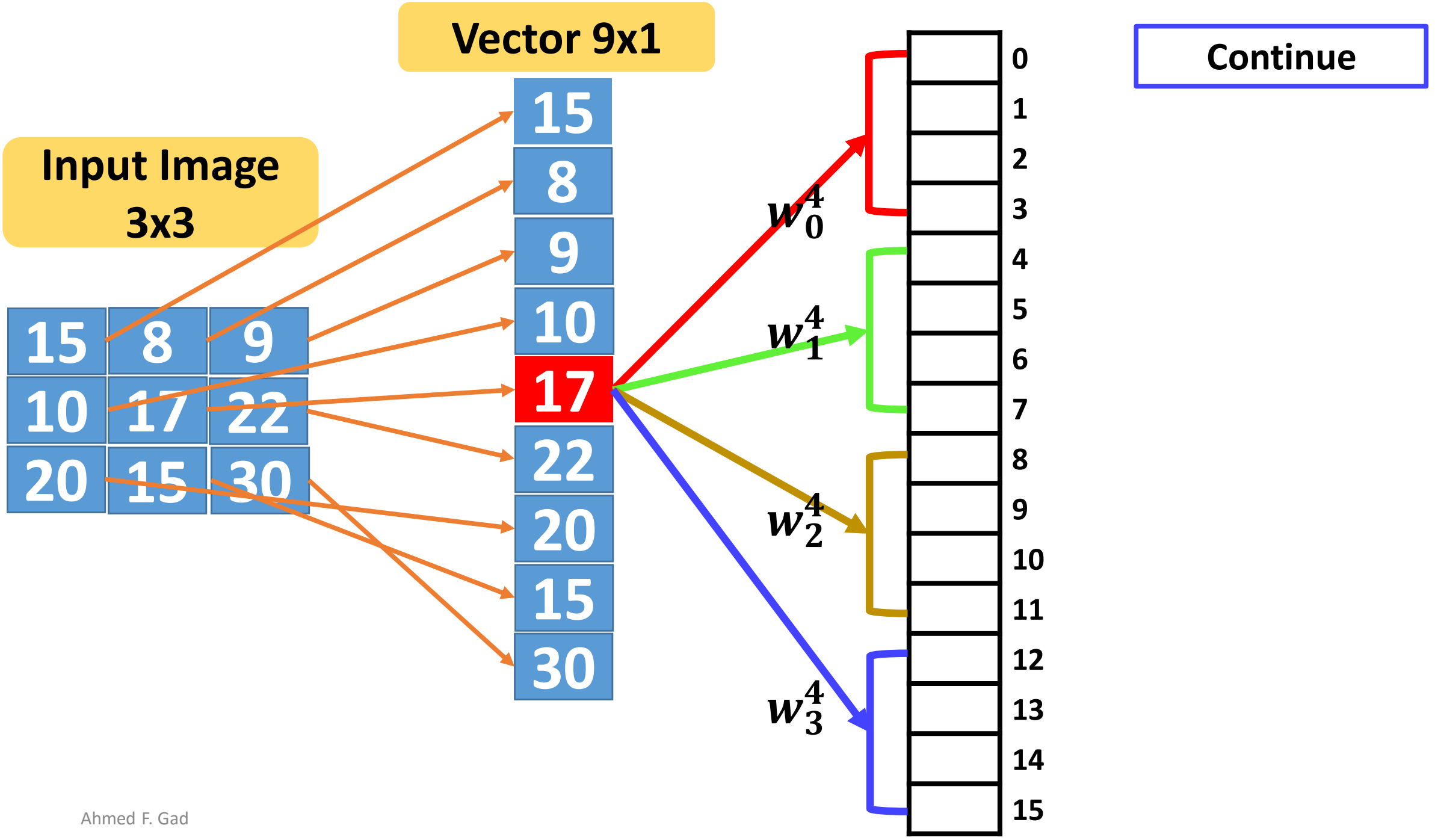
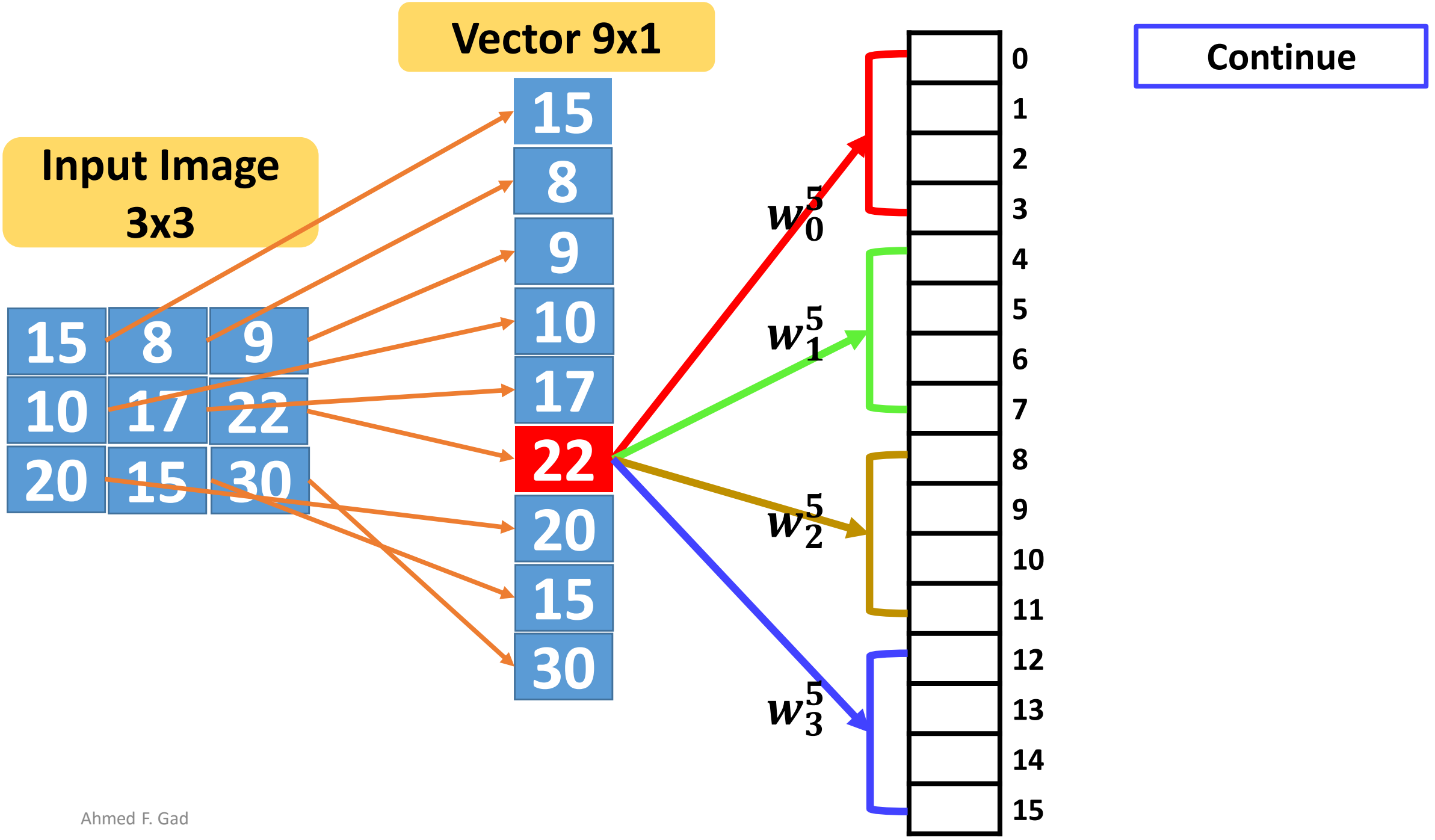
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Continue


Vector 9x1
Input Image
3x3
15
8
9
10
17
22
20
15
30
w_0^4
w_1^4
w_2^4
w_3^4
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Continue


Vector 9x1
Input Image
3x3
15
8
9
10
17
22
20
15
30
w_0^5
w_1^5
w_2^5
w_3^5
0
1
2
3
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5
6
7
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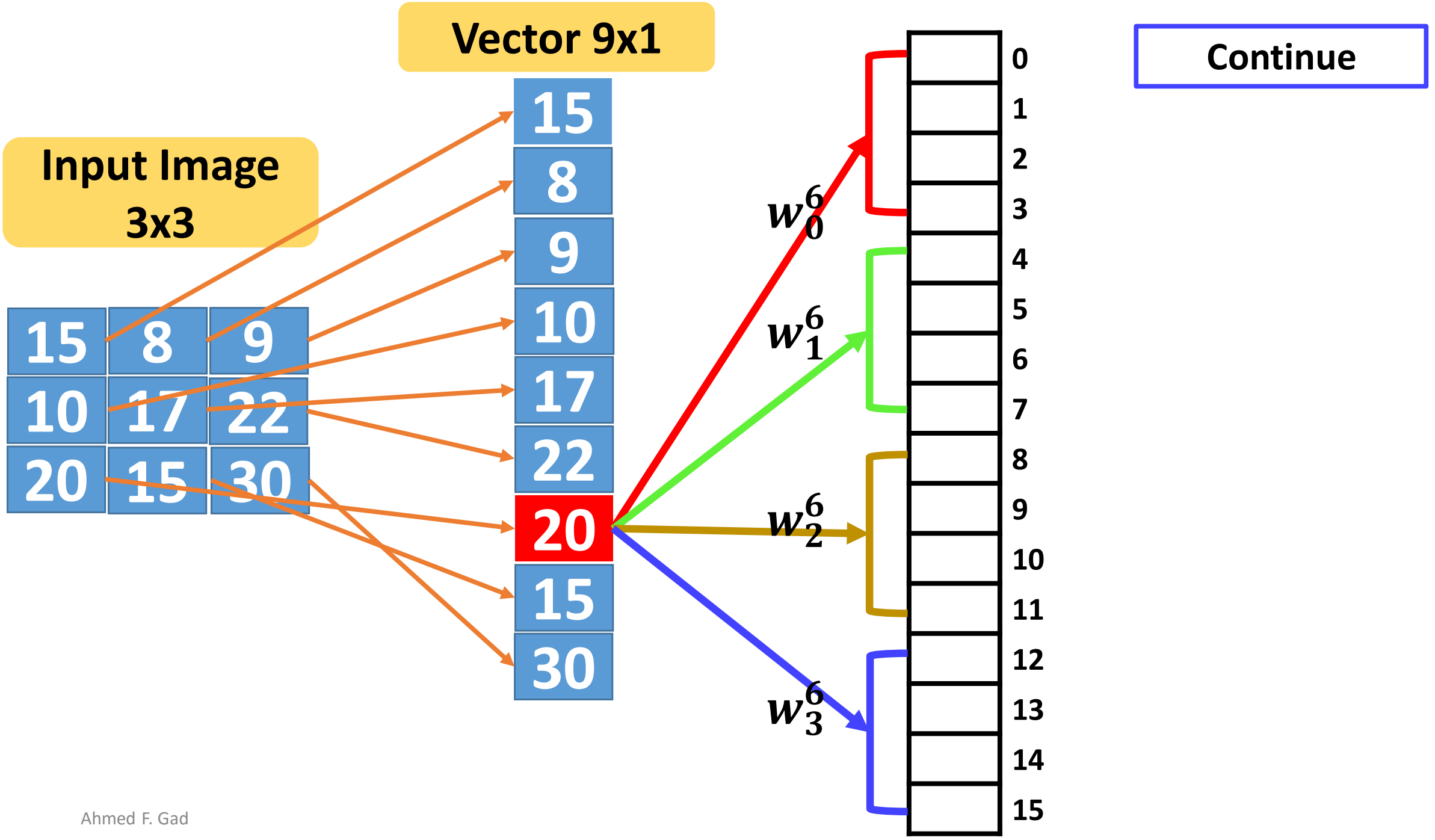
9
10
11
12
13
14
15
Continue


Vector 9x1
Input Image
3x3
15
8
9
10
17
22
20
15
30
w_0^6
w_1^6
w_2^6
w_3^6
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1
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5
6
7
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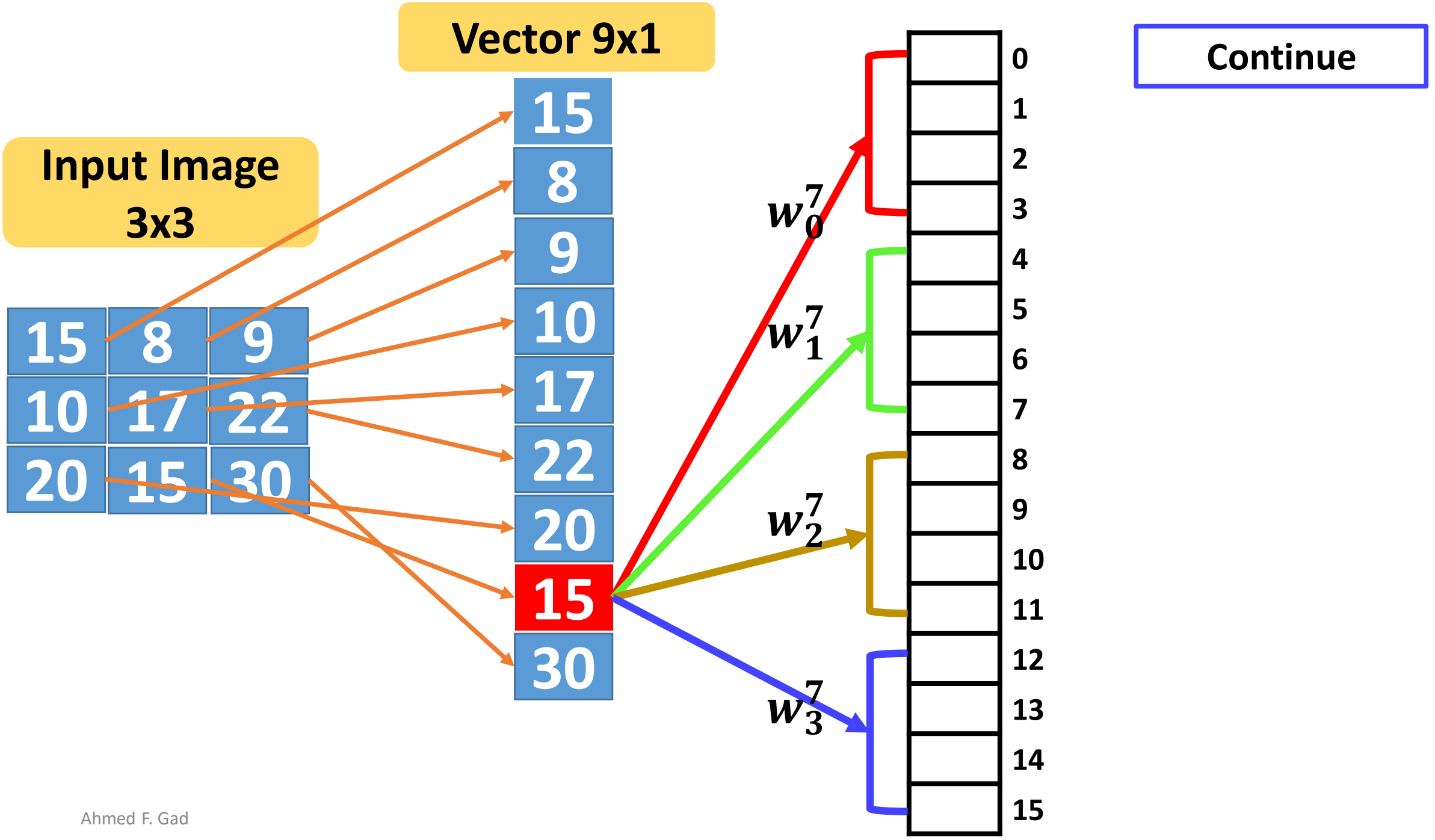
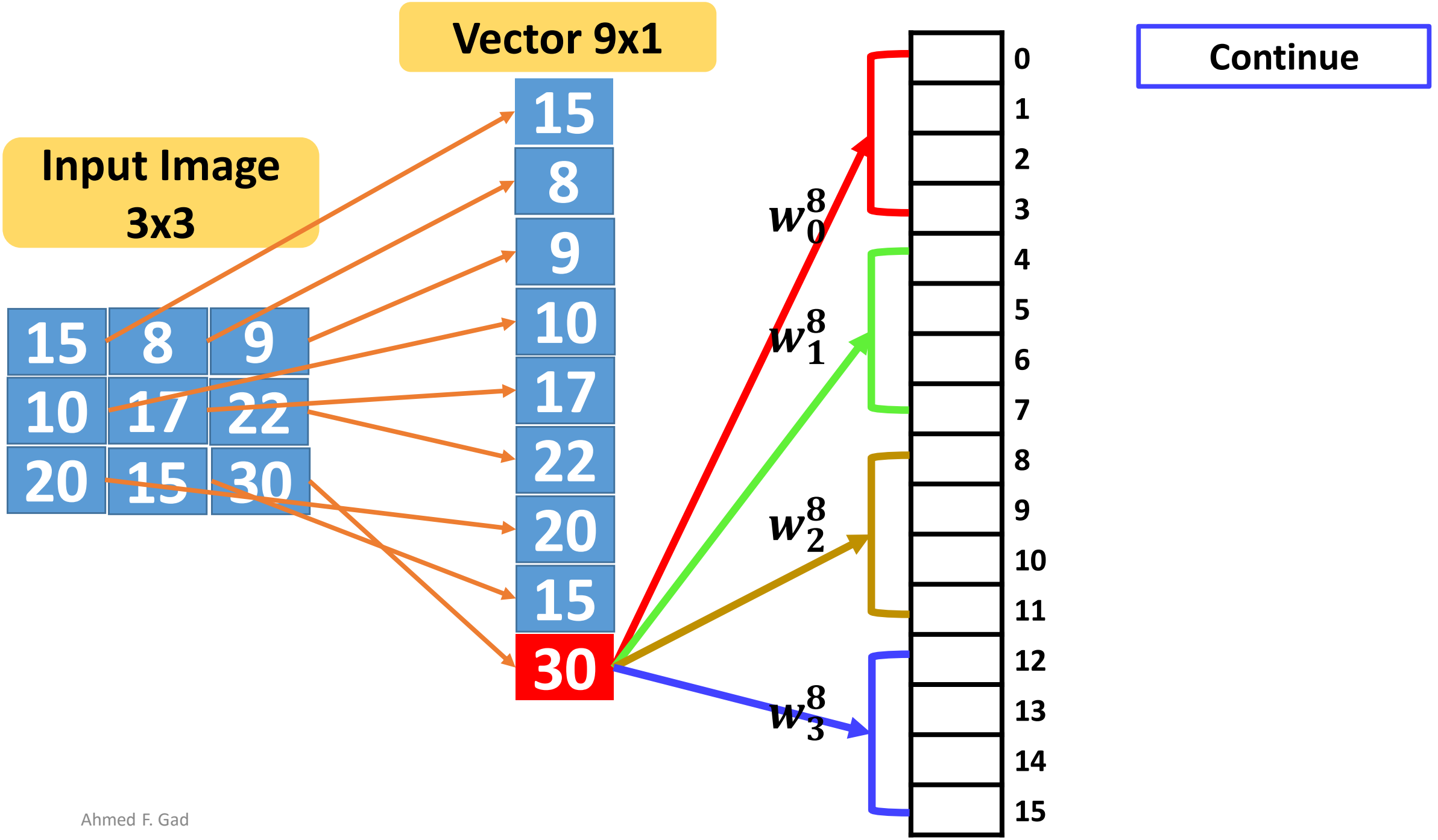
9
10
11
12
13
14
15
Continue


Vector 9x1
Input Image
3x3
15
8
9
10
17
22
20
15
30
w_0^7
w_1^7
w_2^7
w_3^7
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Continue


Vector 9x1
Input Image
3x3
15
8
9
10
17
22
20
15
30
w_0^8
w_1^8
w_2^8
w_3^8
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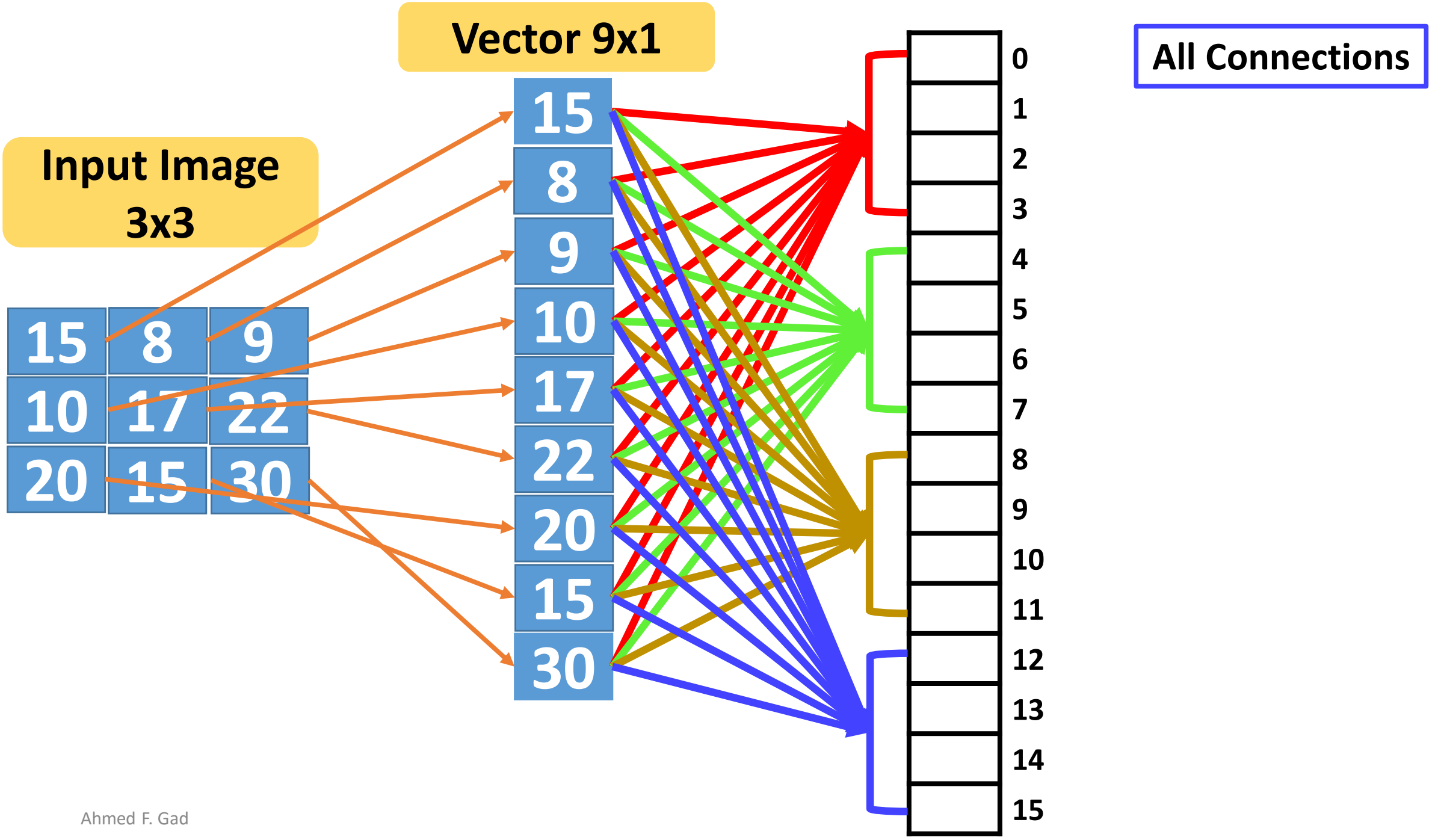
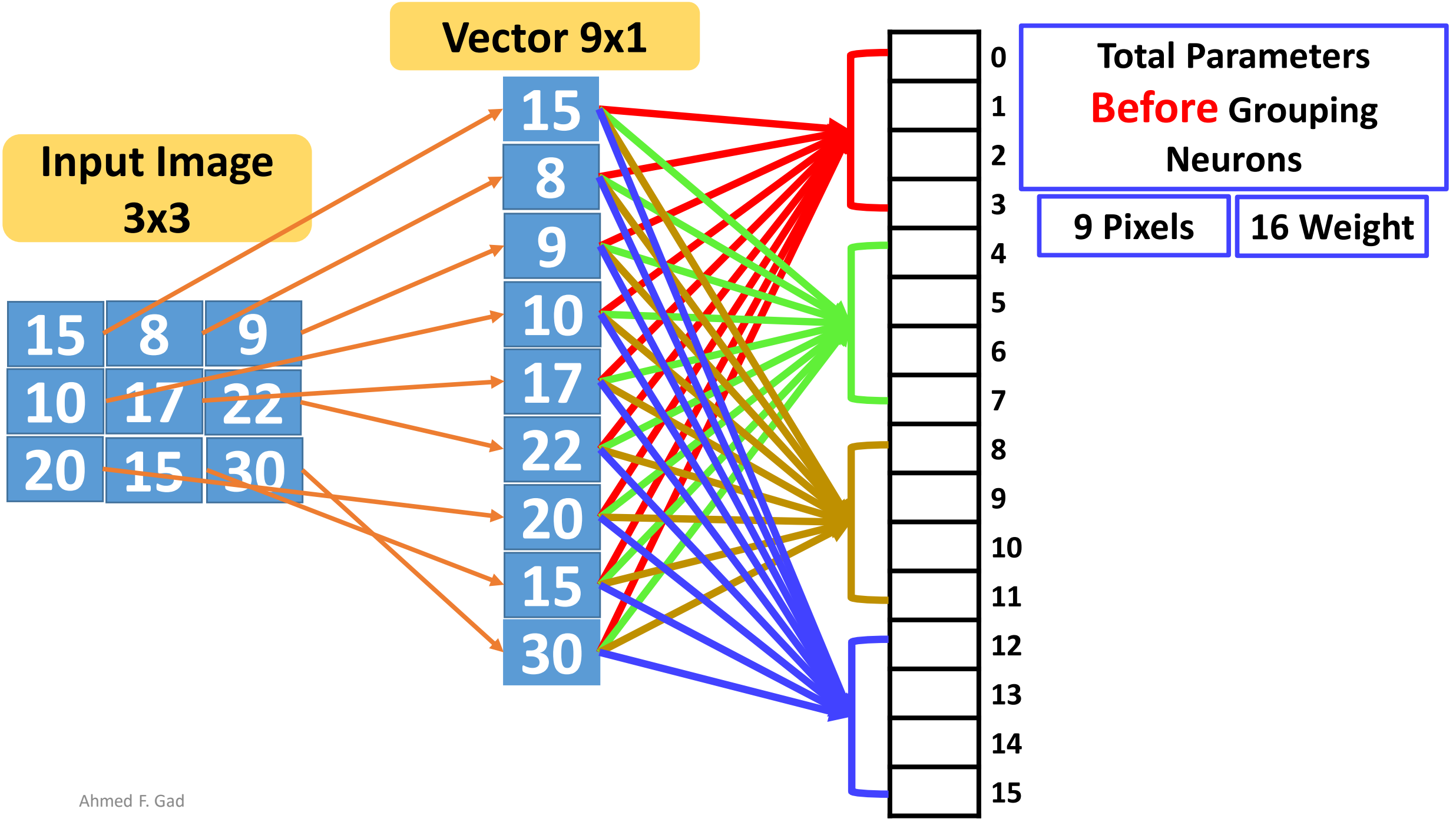
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Continue


Vector 9x1
Input Image
3x3
15
8
9
10
17
22
20
15
30
All Connections
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15


Vector 9x1
Input Image
3x3
15
8
9
10
17
22
20
15
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15
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17
22
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15
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0
1
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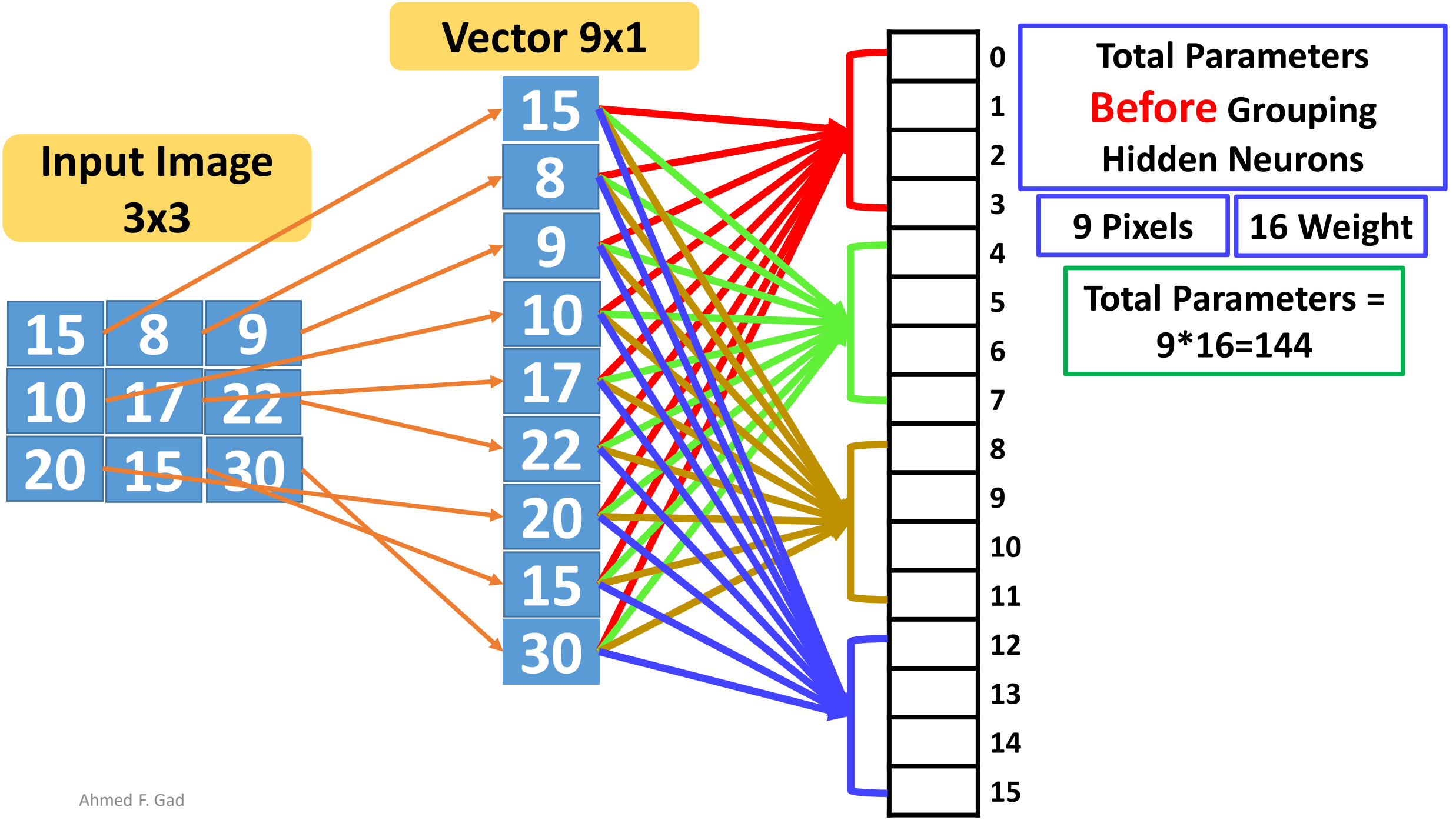
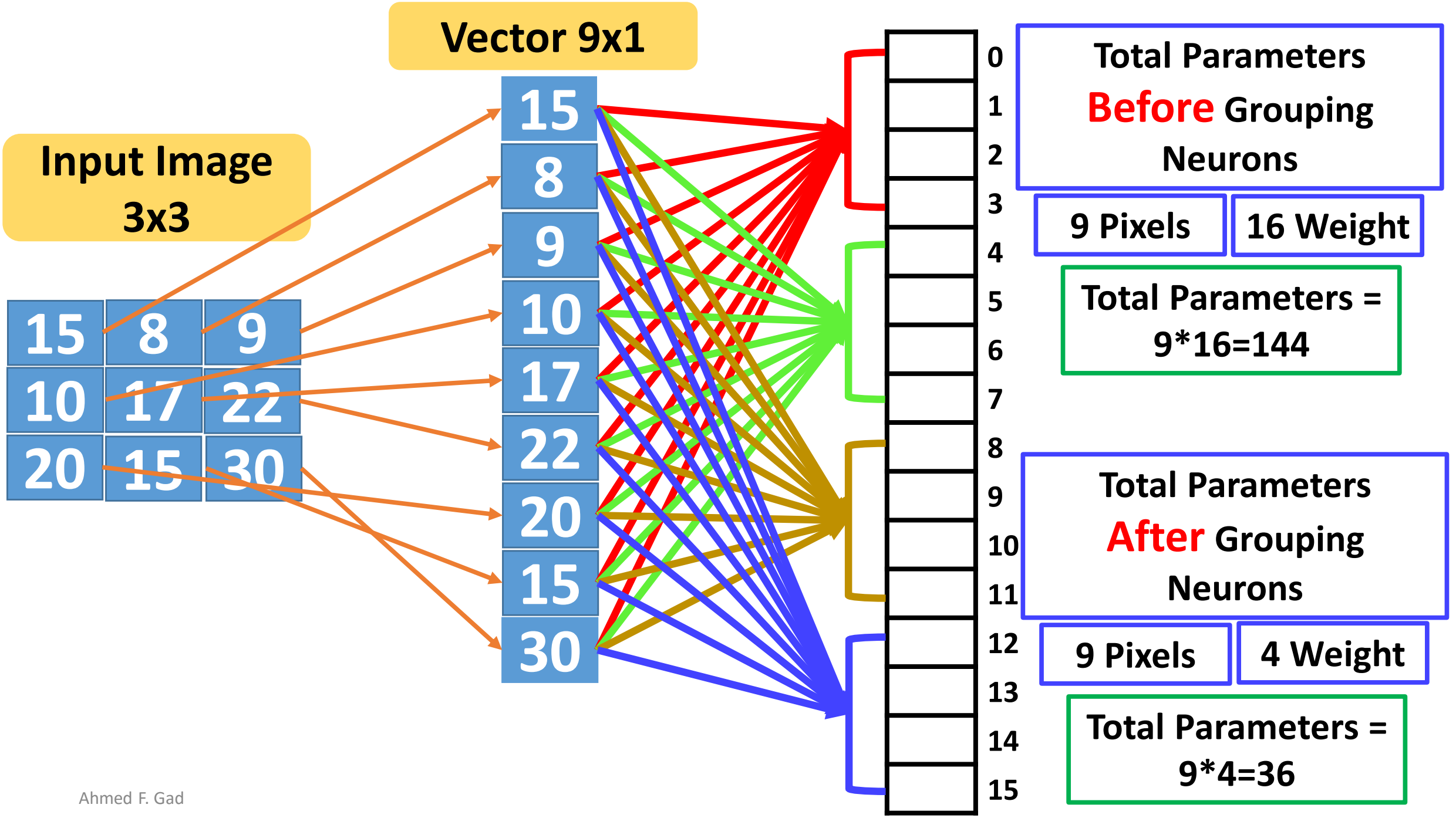
11
12
13
14
15
Total Parameters
Before Grouping
Neurons
9 Pixels
16 Weight


Vector 9x1
Input Image
3x3
15
8
9
10
17
22
20
15
30
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Total Parameters
Before Grouping
Hidden Neurons
9 Pixels
16 Weight
Total Parameters =
9*16=144


Vector 9x1
Input Image
3x3
15
8
9
10
17
22
20
15
30
0
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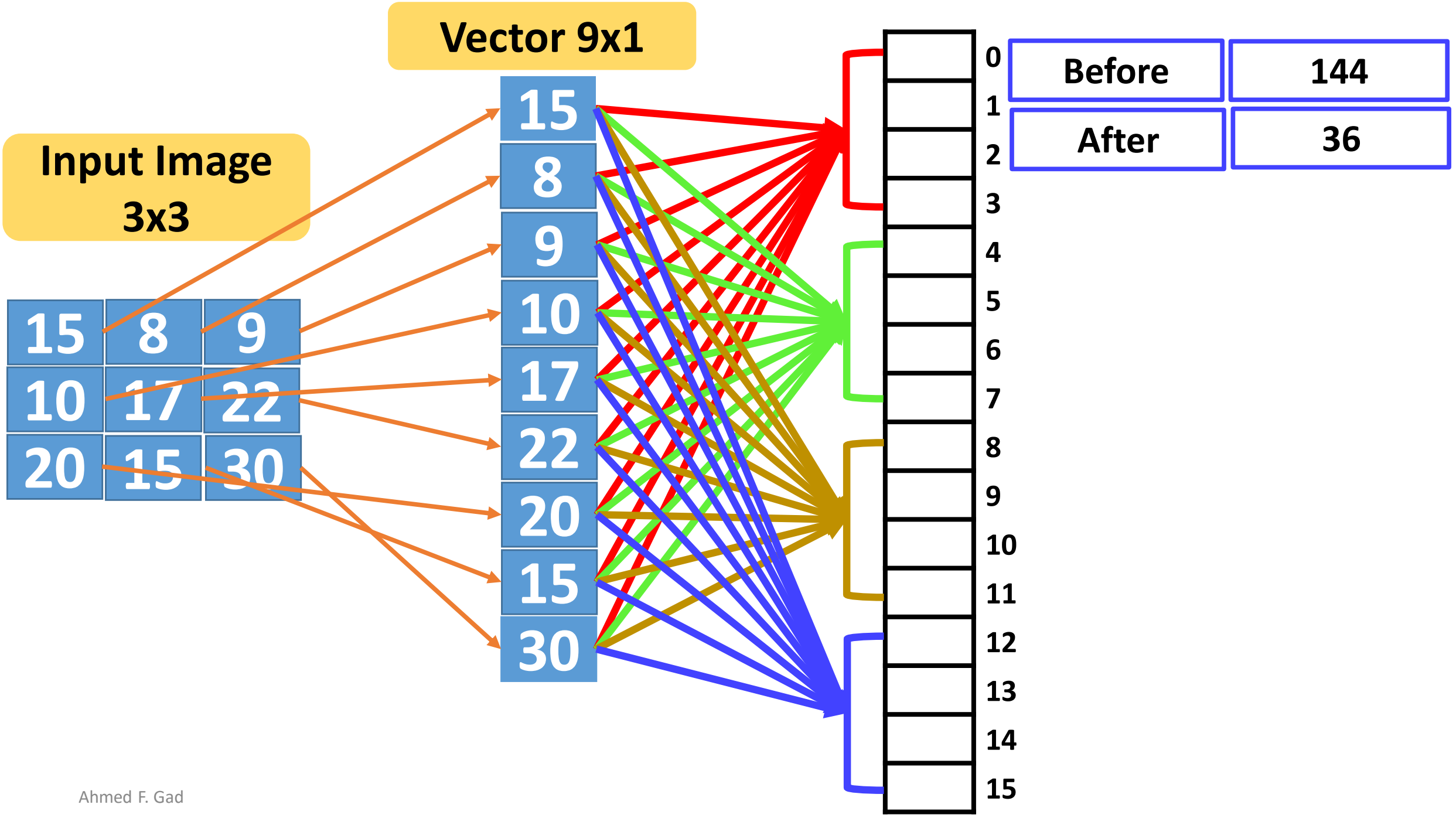
4
5
6
7
8
9
10
11
12
13
14
15
Total Parameters
Before Grouping
Neurons
9 Pixels
16 Weight
Total Parameters =
9*16=144
Total Parameters
After Grouping
Neurons
9 Pixels
4 Weight
Total Parameters =
9*4=36


Vector 9x1
Input Image
3x3
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22
20
15
30
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6
7
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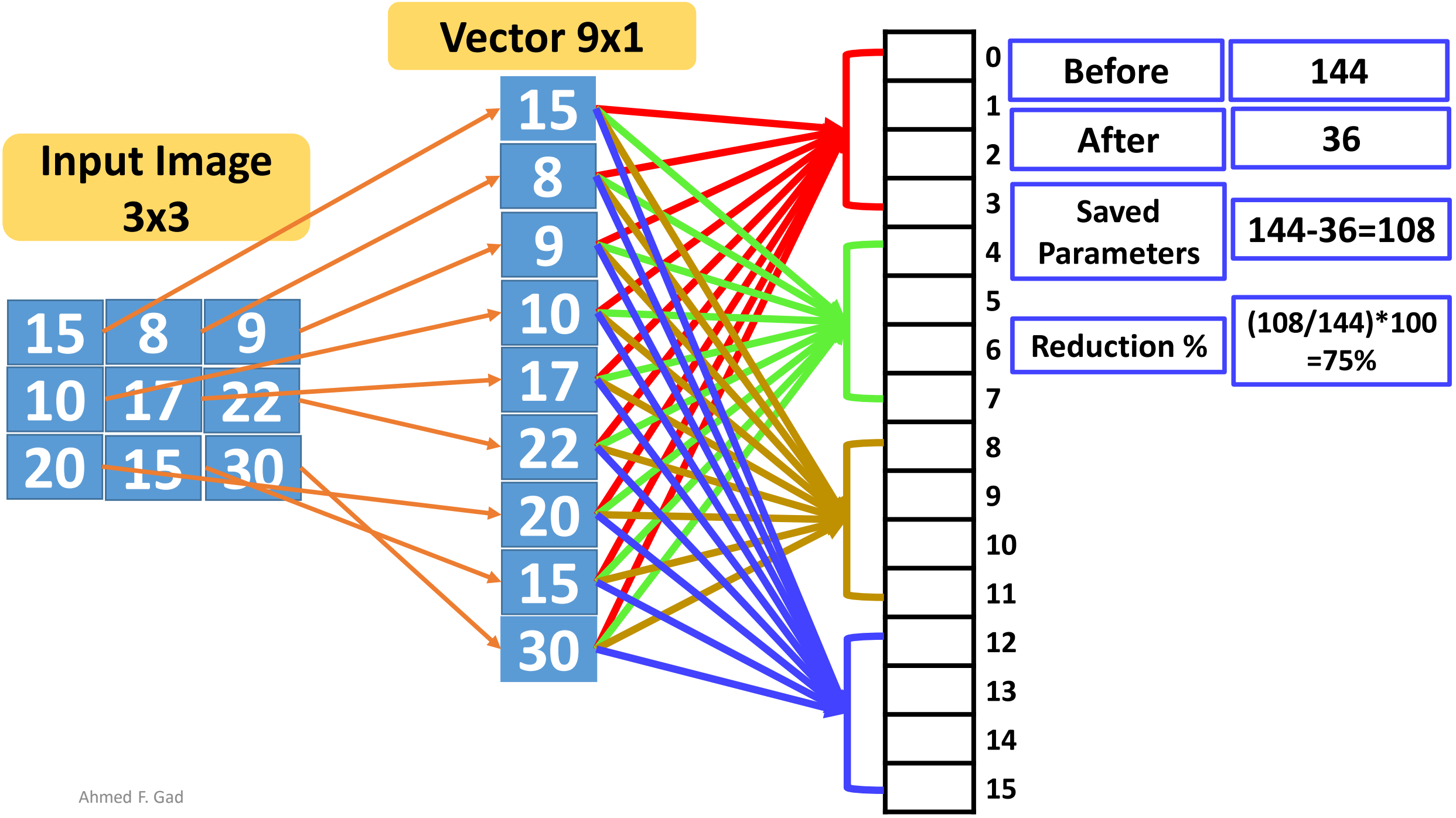
9
10
11
12
13
14
15
Before
144
After
36


Vector 9x1
Input Image
3x3
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22
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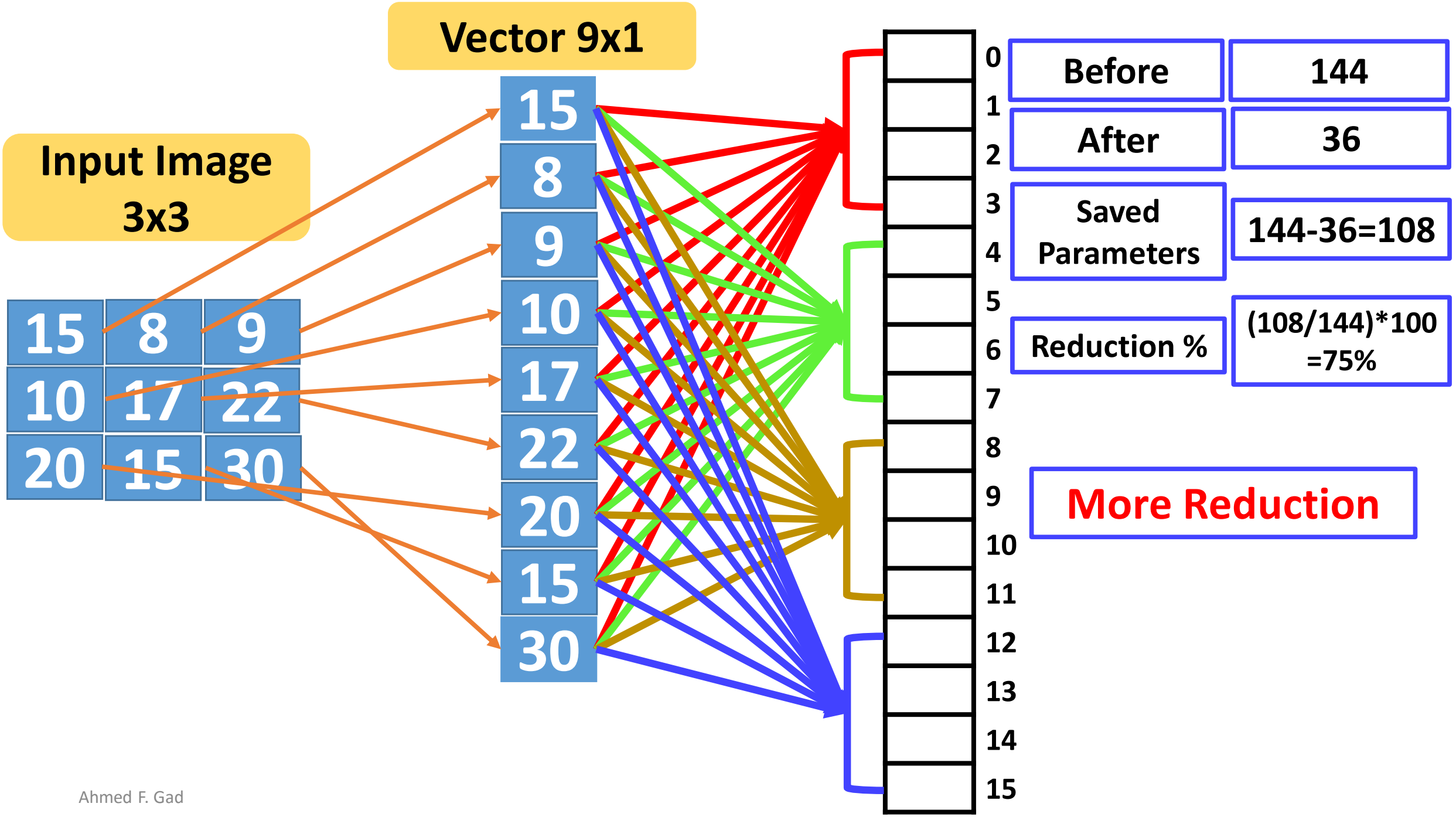
5
6
7
8
9
10
11
12
13
14
15
Before
144
After
36
Saved
Parameters
144-36=108
Reduction %
(108/144)*100
=75%


Vector 9x1
Input Image
3x3
15
8
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22
20
15
30
0
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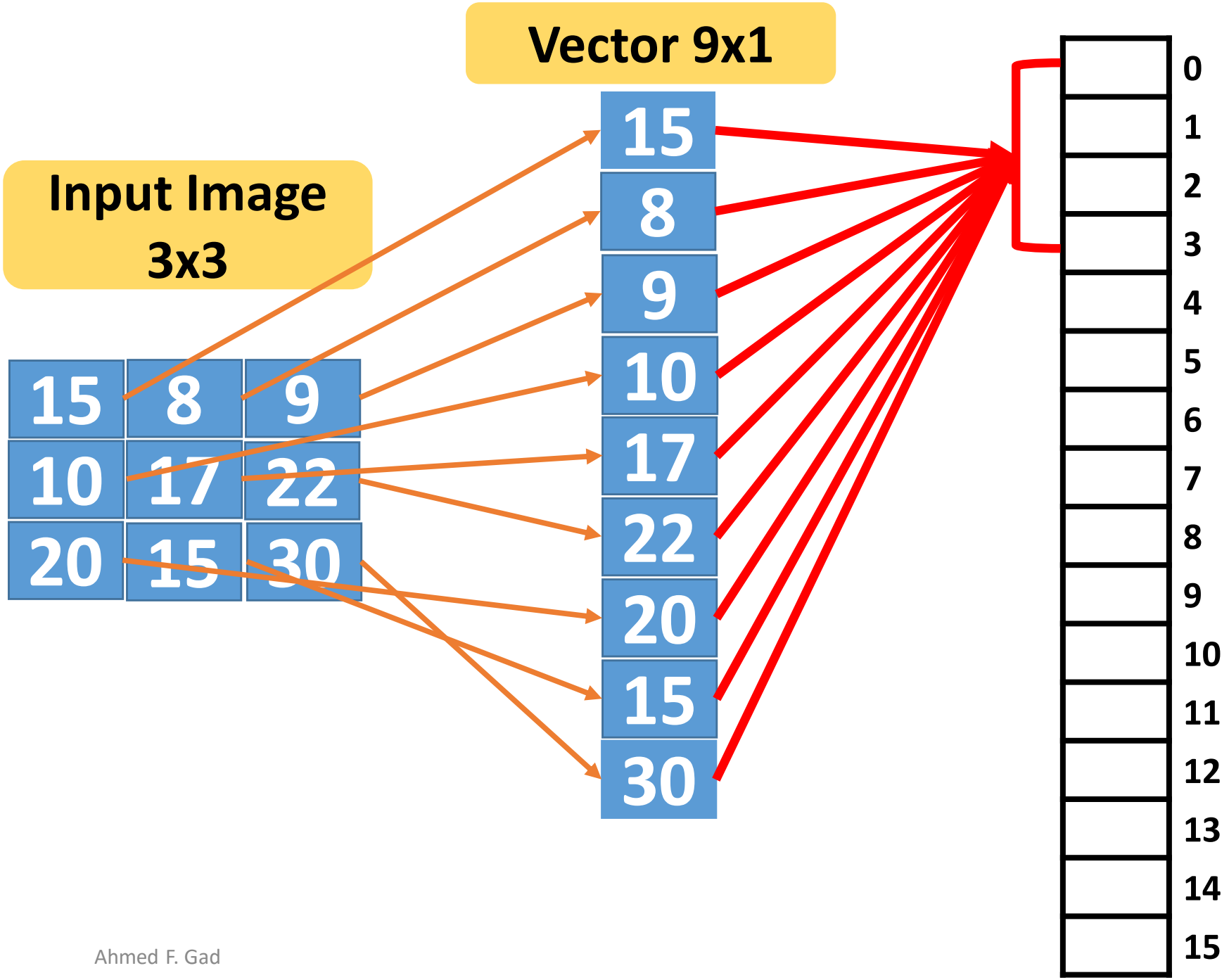
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Before
144
After
36
Saved
Parameters
144-36=108
Reduction %
(108/144)*100
=75%
More Reduction


Vector 9x1
Input Image
3x3
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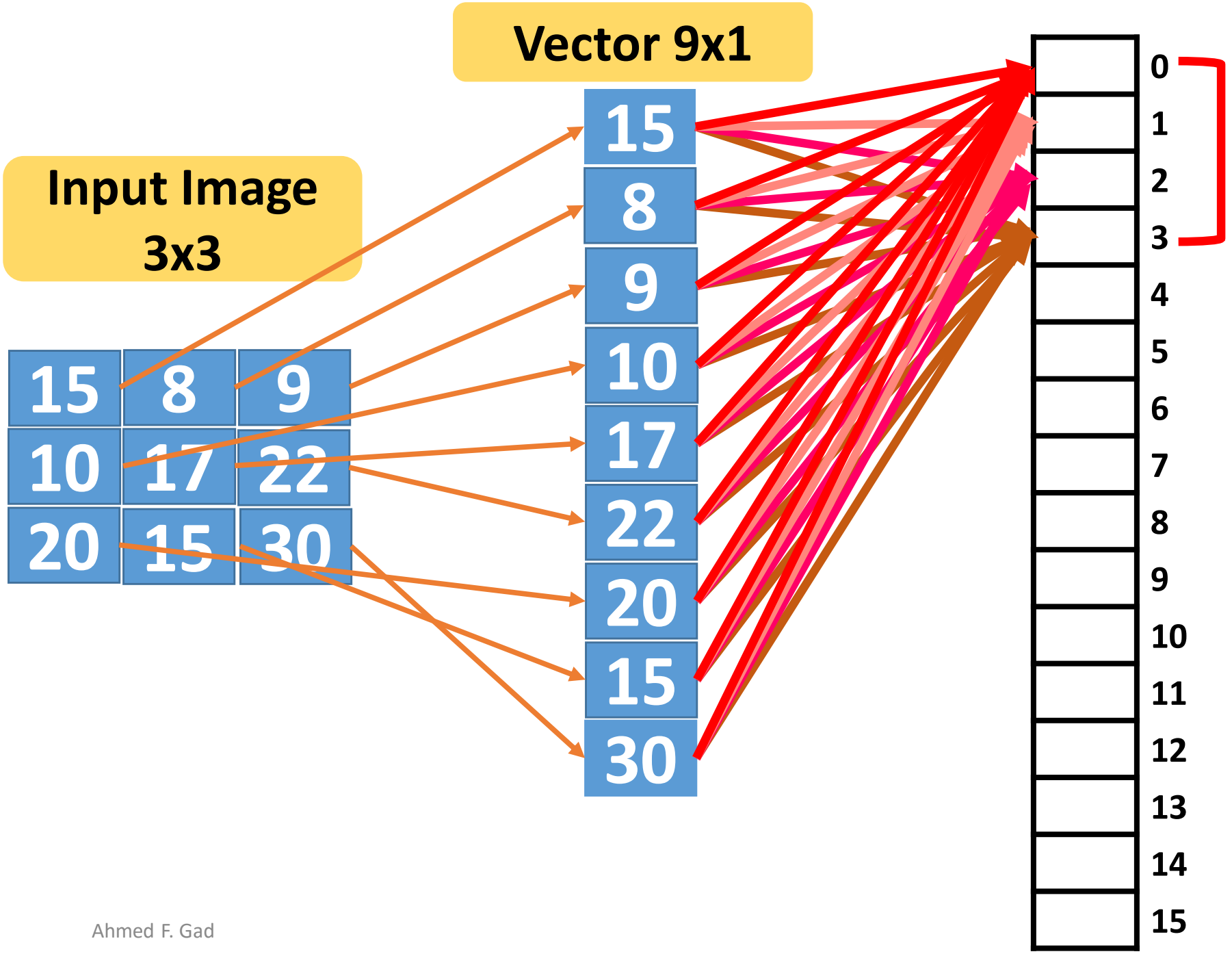
Vector 9x1
Input Image
3x3
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22
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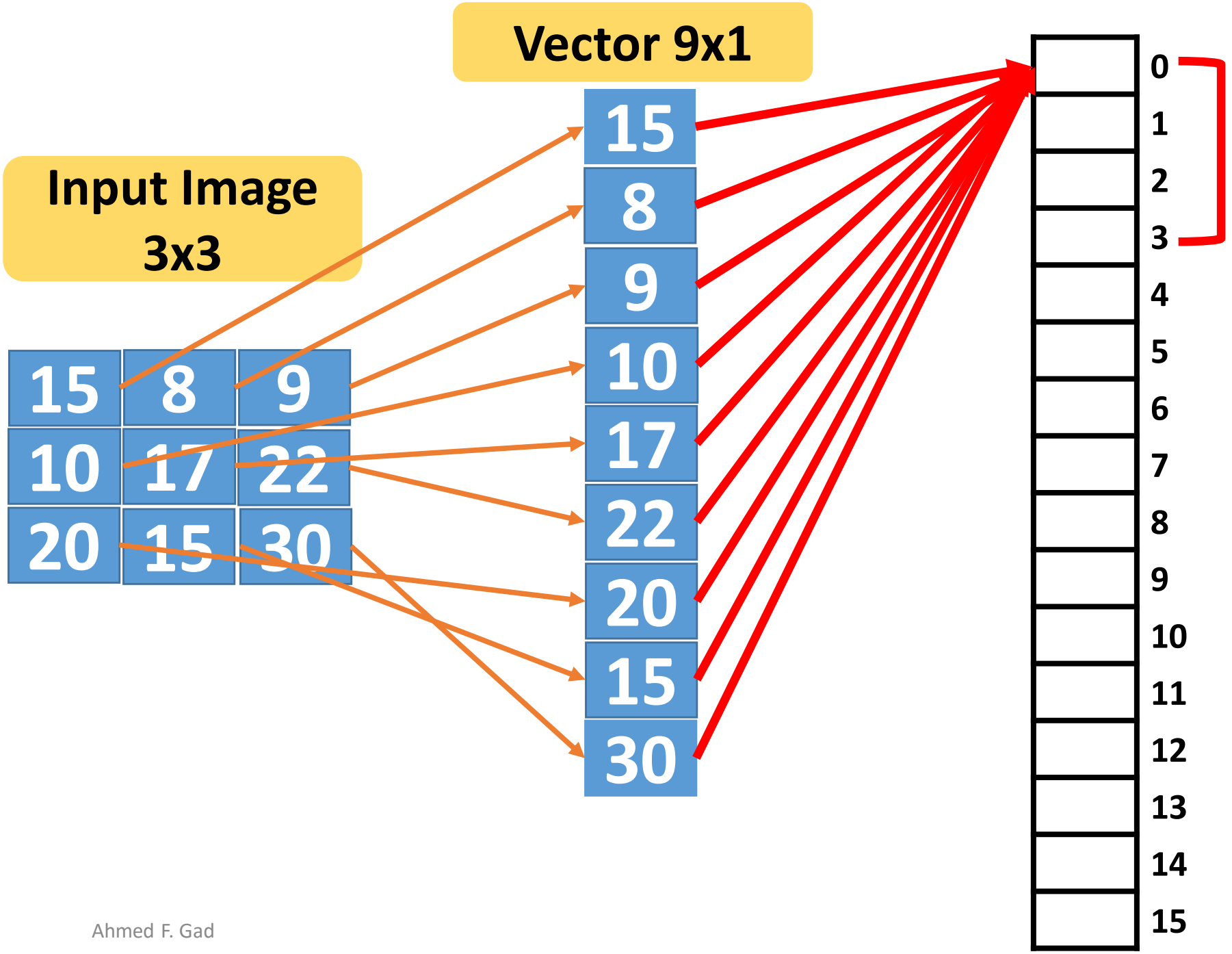
Vector 9x1
Input Image
3x3
15
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22
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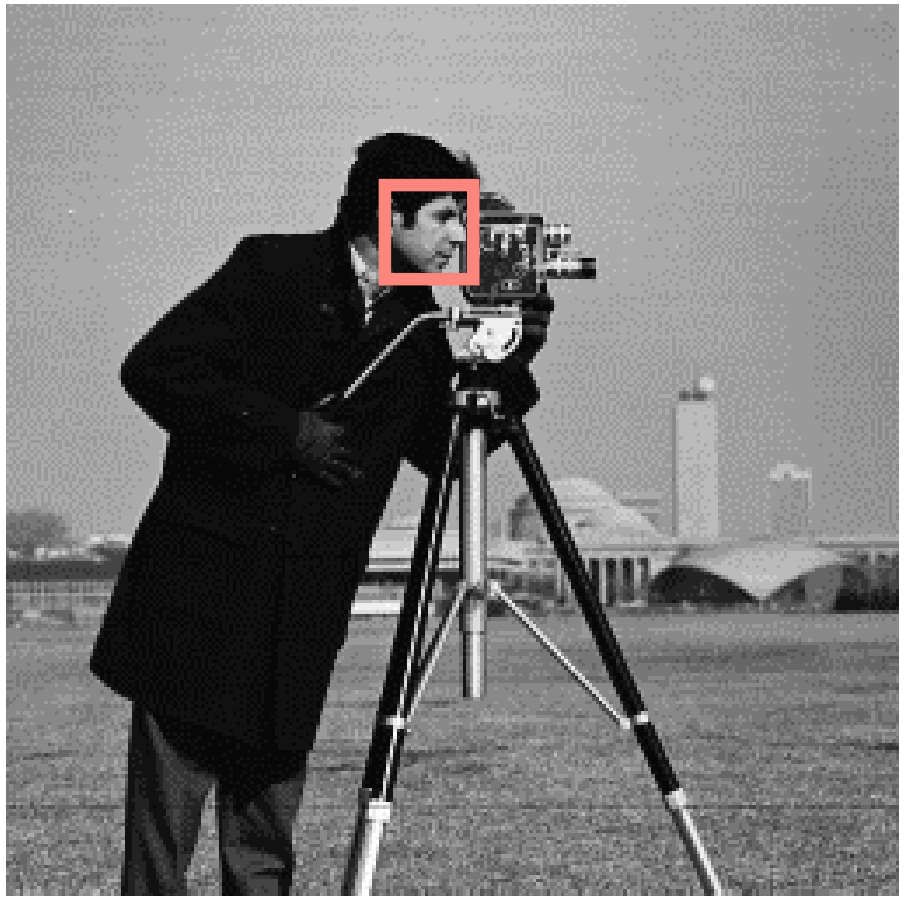
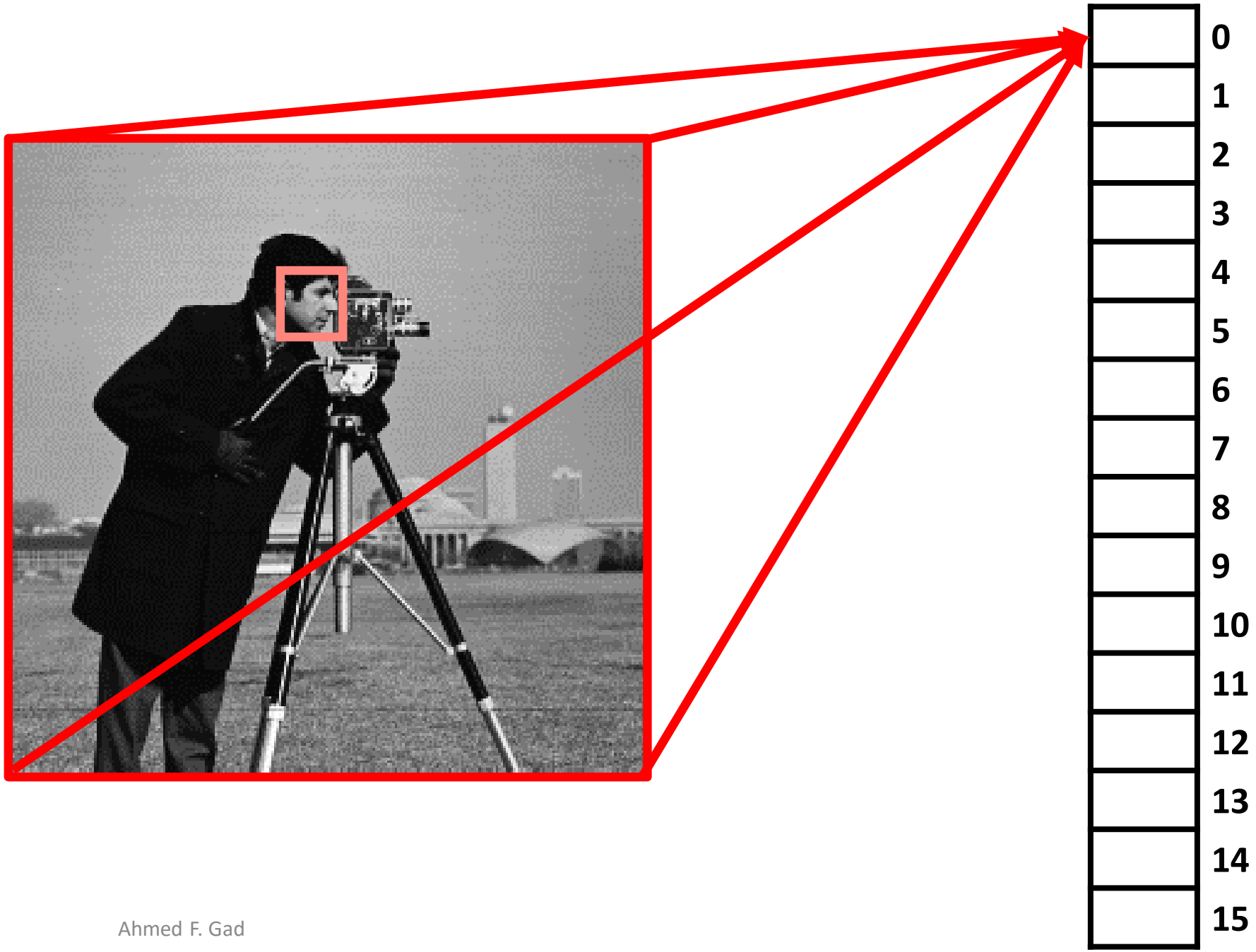
15

In image analysis, each pixel is highly correlated to pixels surrounding it (i.e. neighbors)

In image analysis, each pixel is highly correlated to pixels surrounding it (i.e. neighbors)




0
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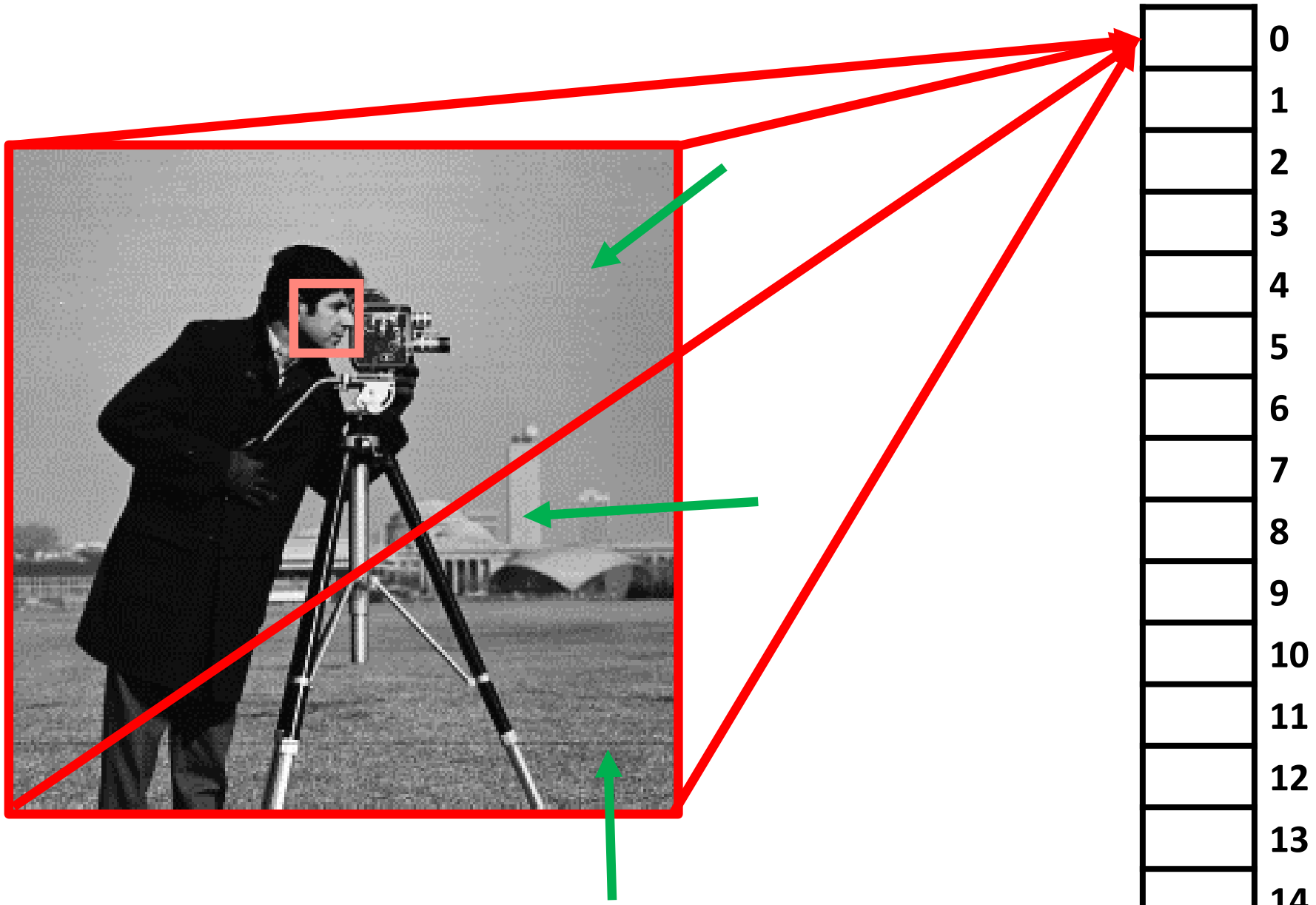
15



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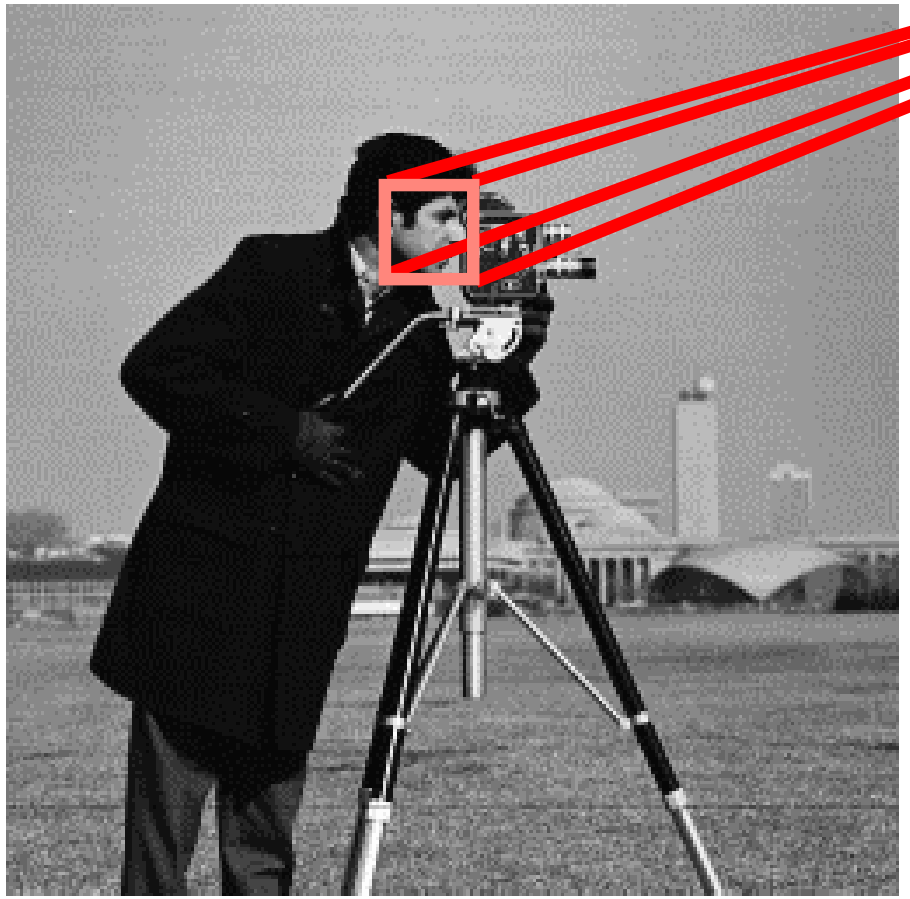
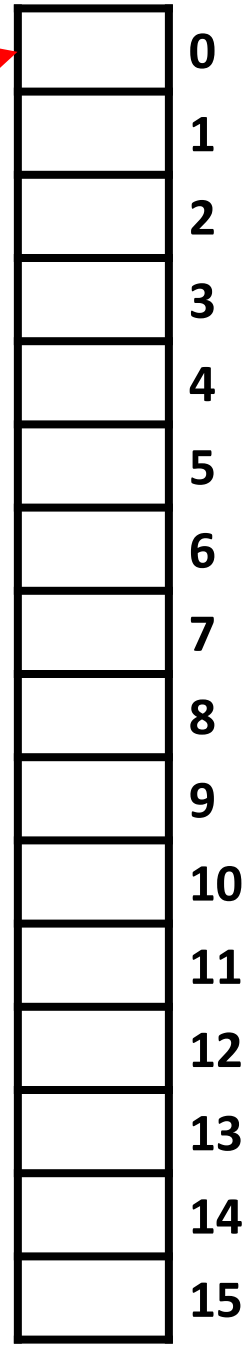
15

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11
12
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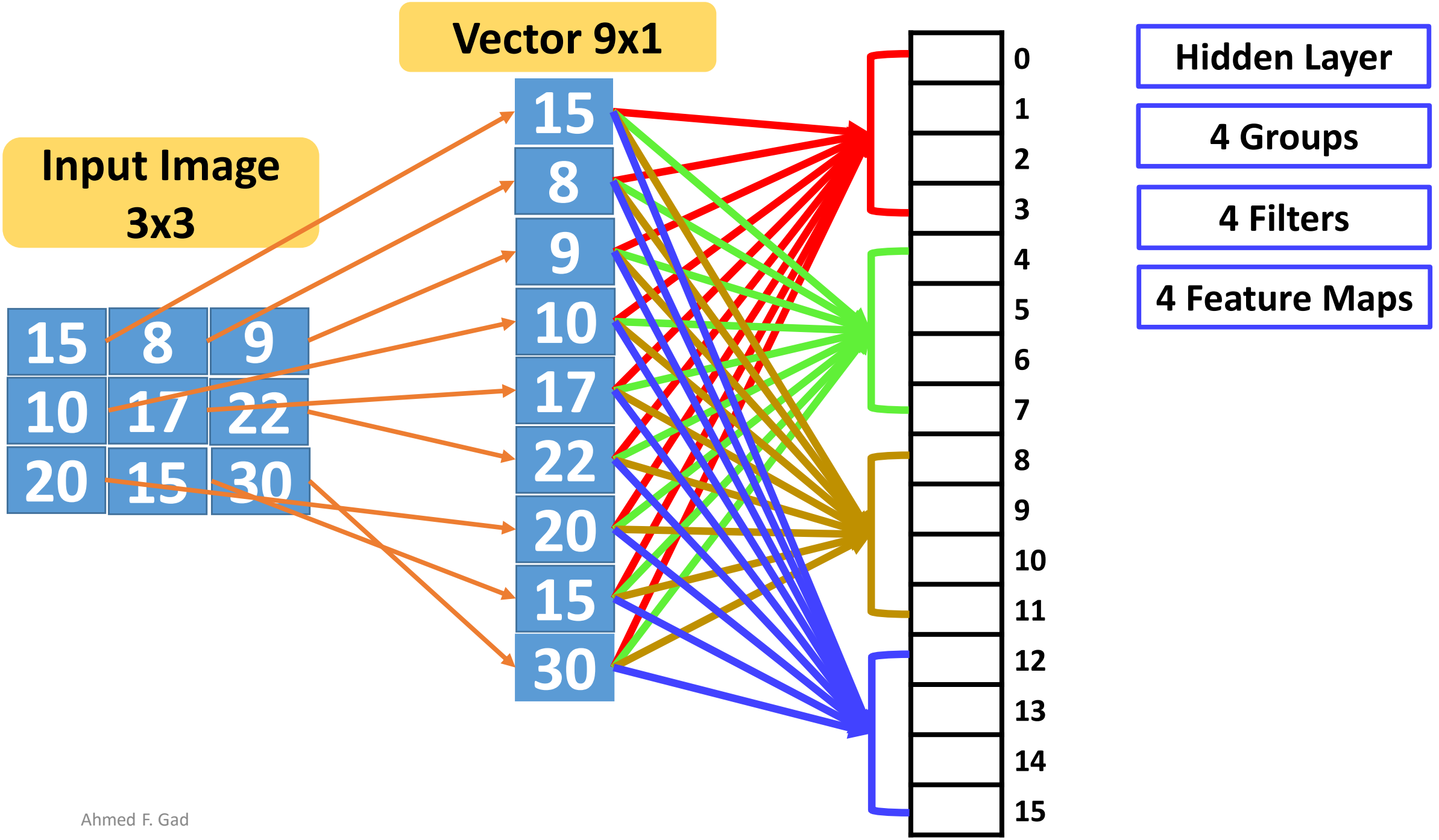
14
15


Vector 9x1
Input Image
3x3
15
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15
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17
22
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15
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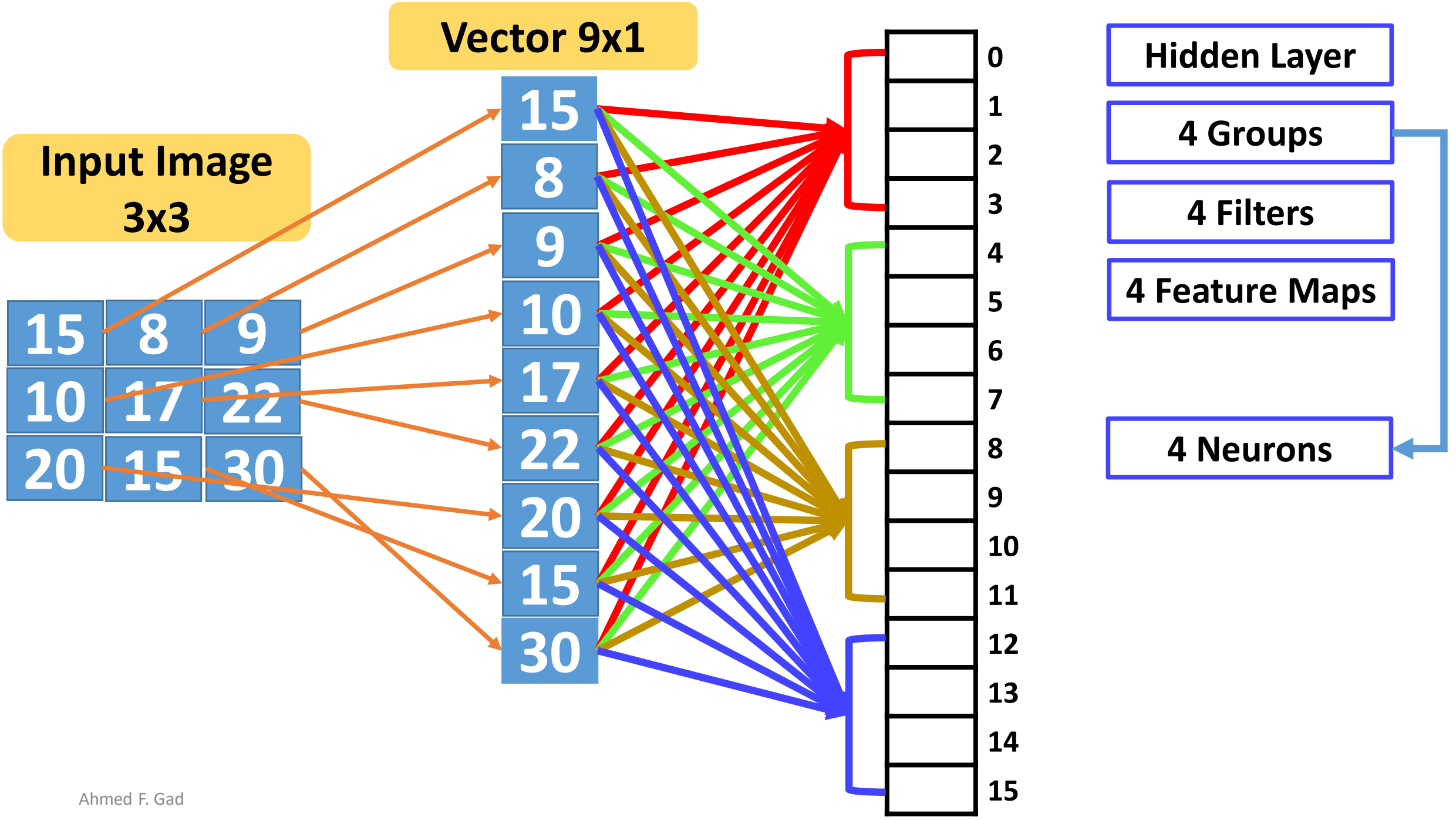
14
15
Hidden Layer
4 Groups
4 Filters
4 Feature Maps


Vector 9x1
Input Image
3x3
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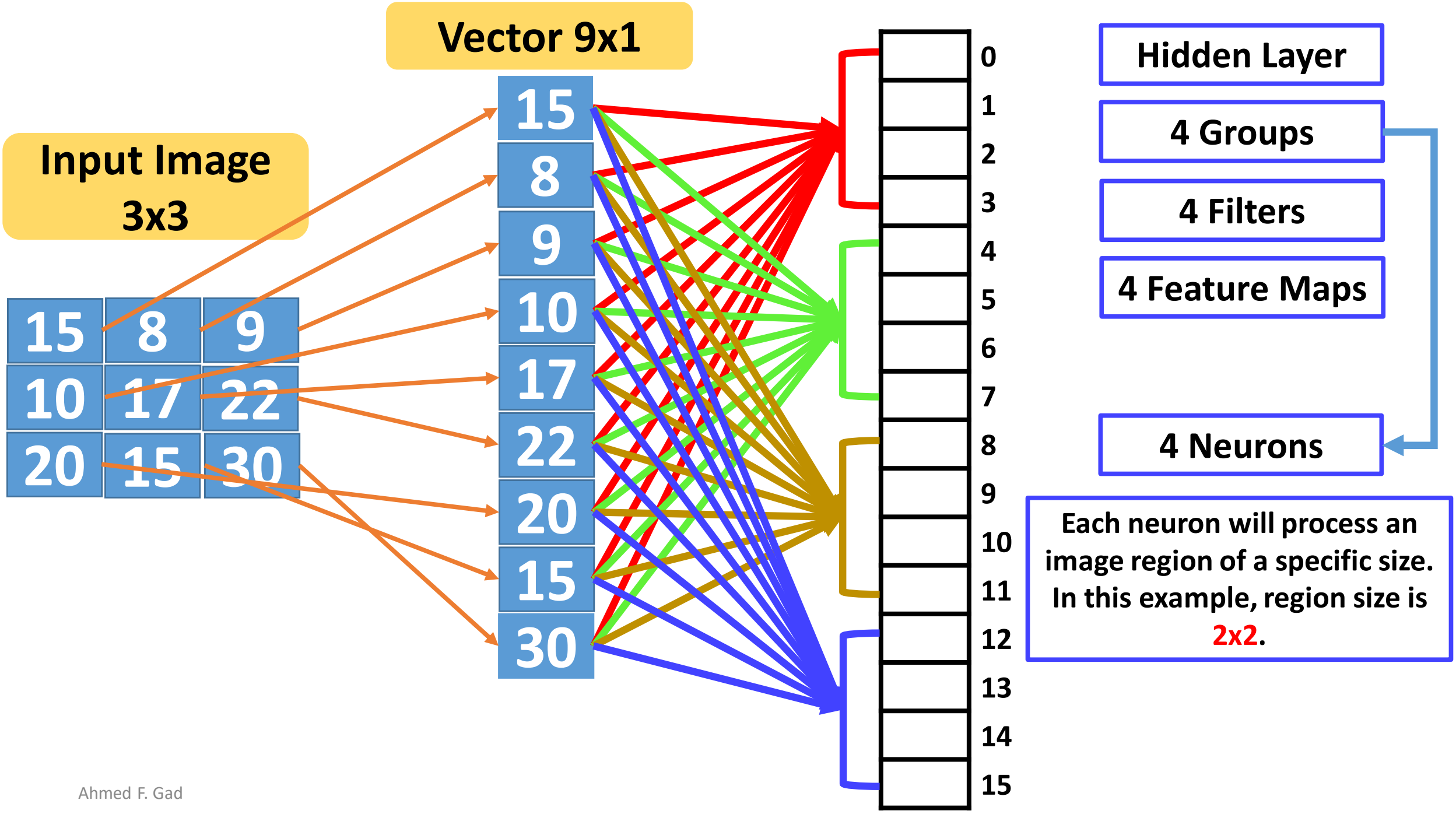
15
Hidden Layer
4 Groups
4 Filters
4 Feature Maps
4 Neurons


Vector 9x1
Input Image
3x3
15
8
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10
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22
20
15
30
0
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5
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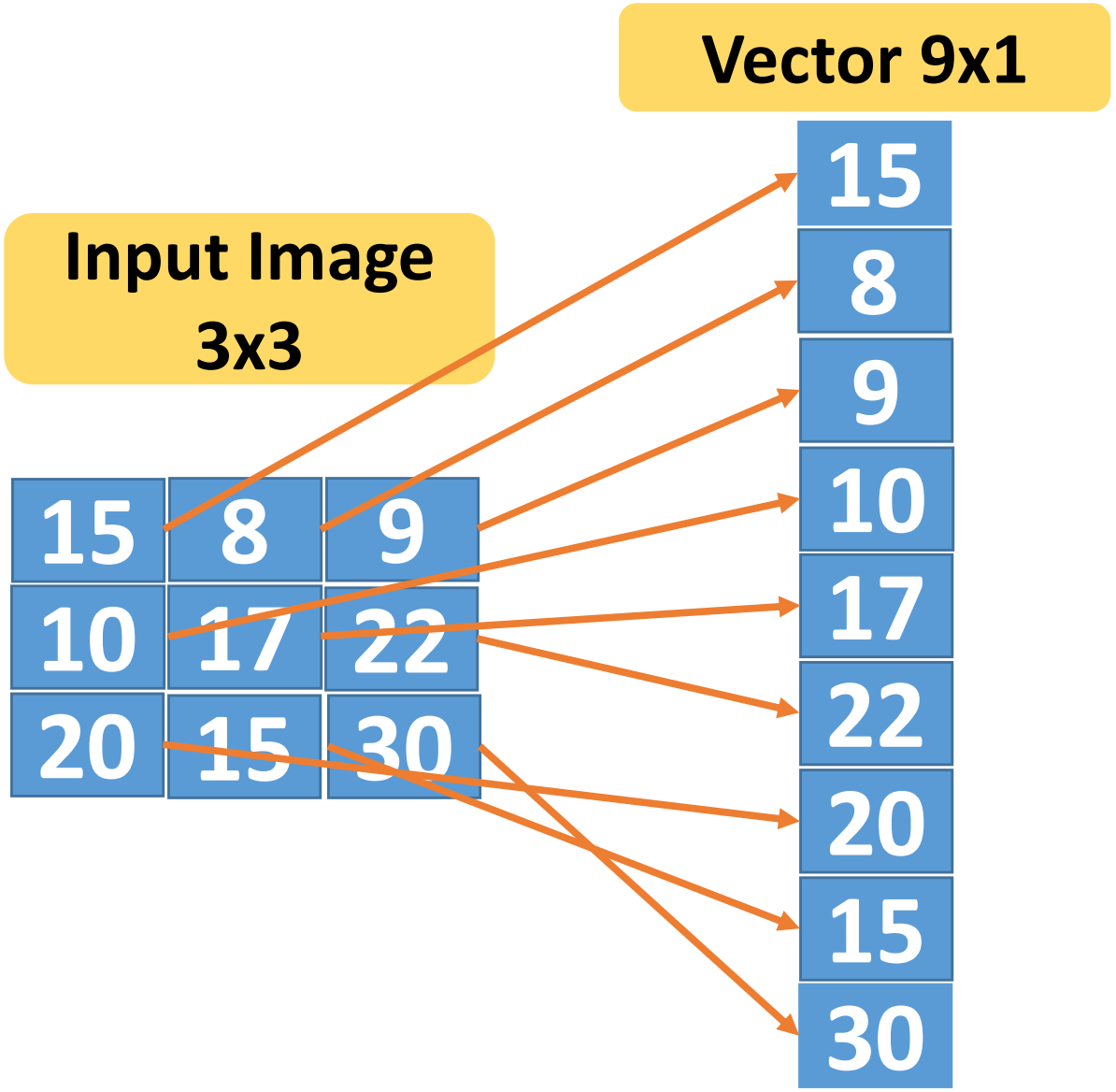
13
14
15
Hidden Layer
4 Groups
4 Filters
4 Feature Maps
4 Neurons
Each neuron will process an image region of a specific size. In this example, region size is 2x2.


Vector 9x1
Input Image
3x3
15
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22
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22
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15
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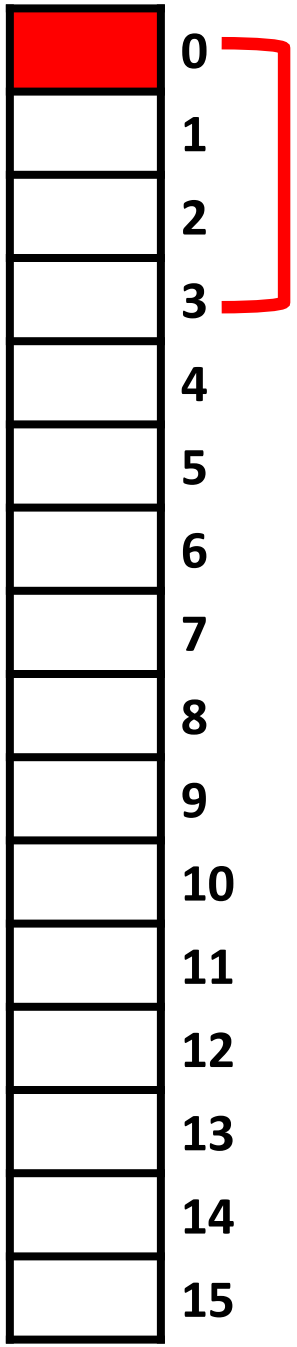
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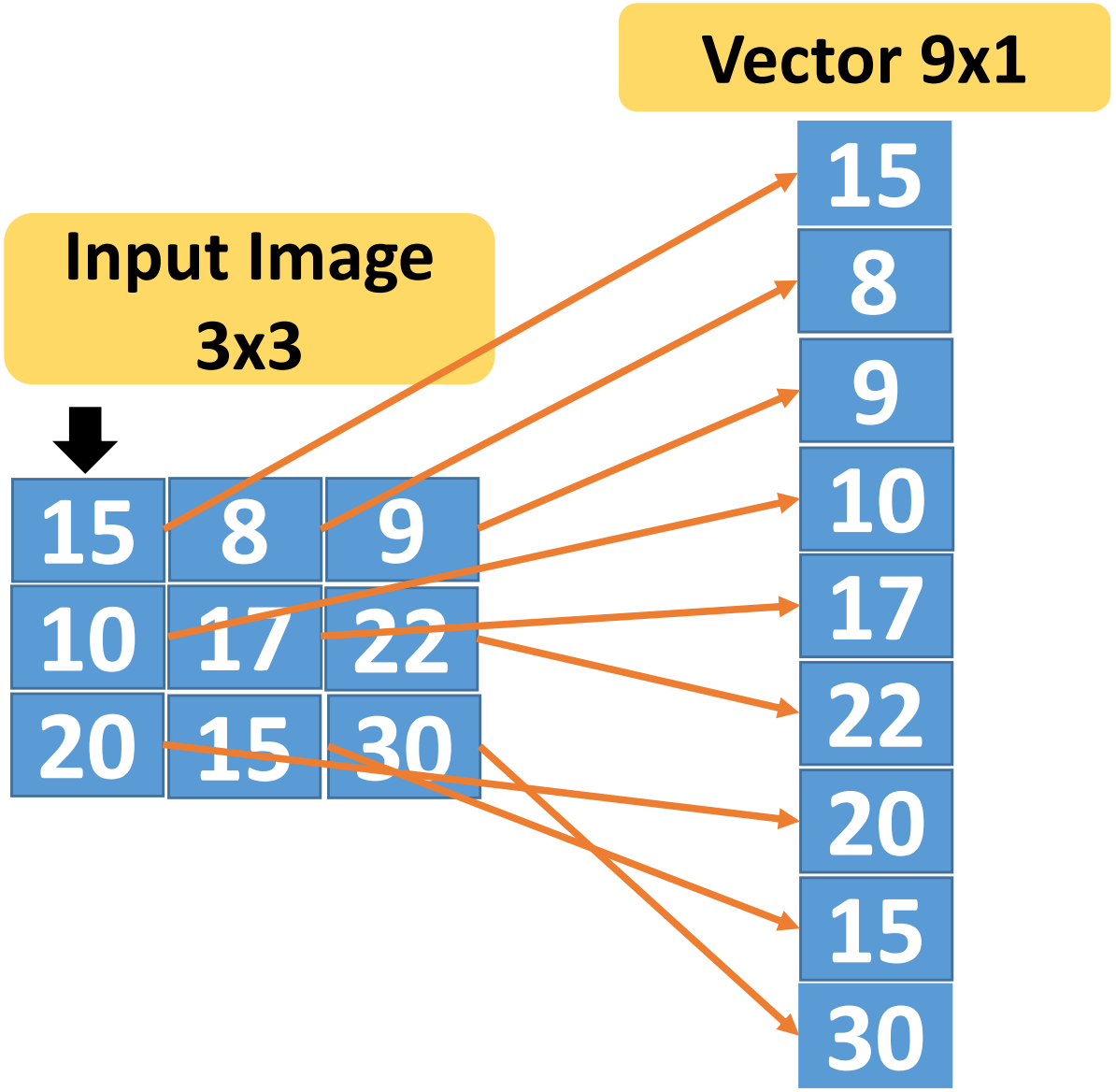
Vector 9x1
Input Image
3x3
15
8
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22
20
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8
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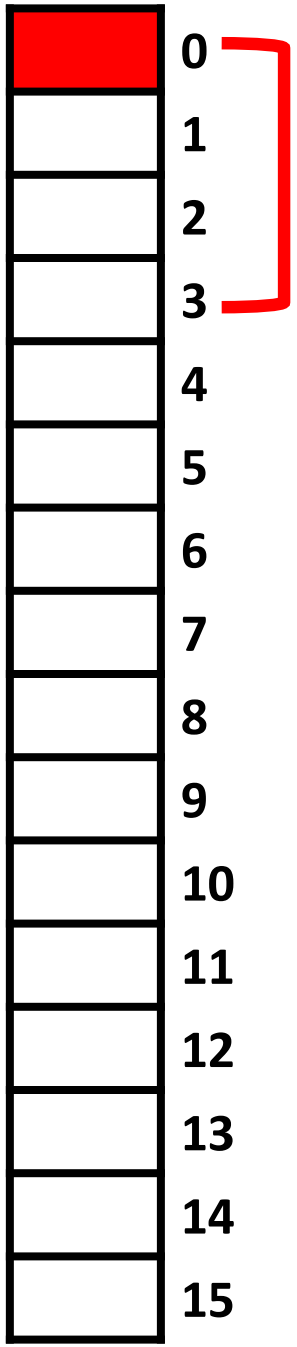
17
22
20
15
30


0
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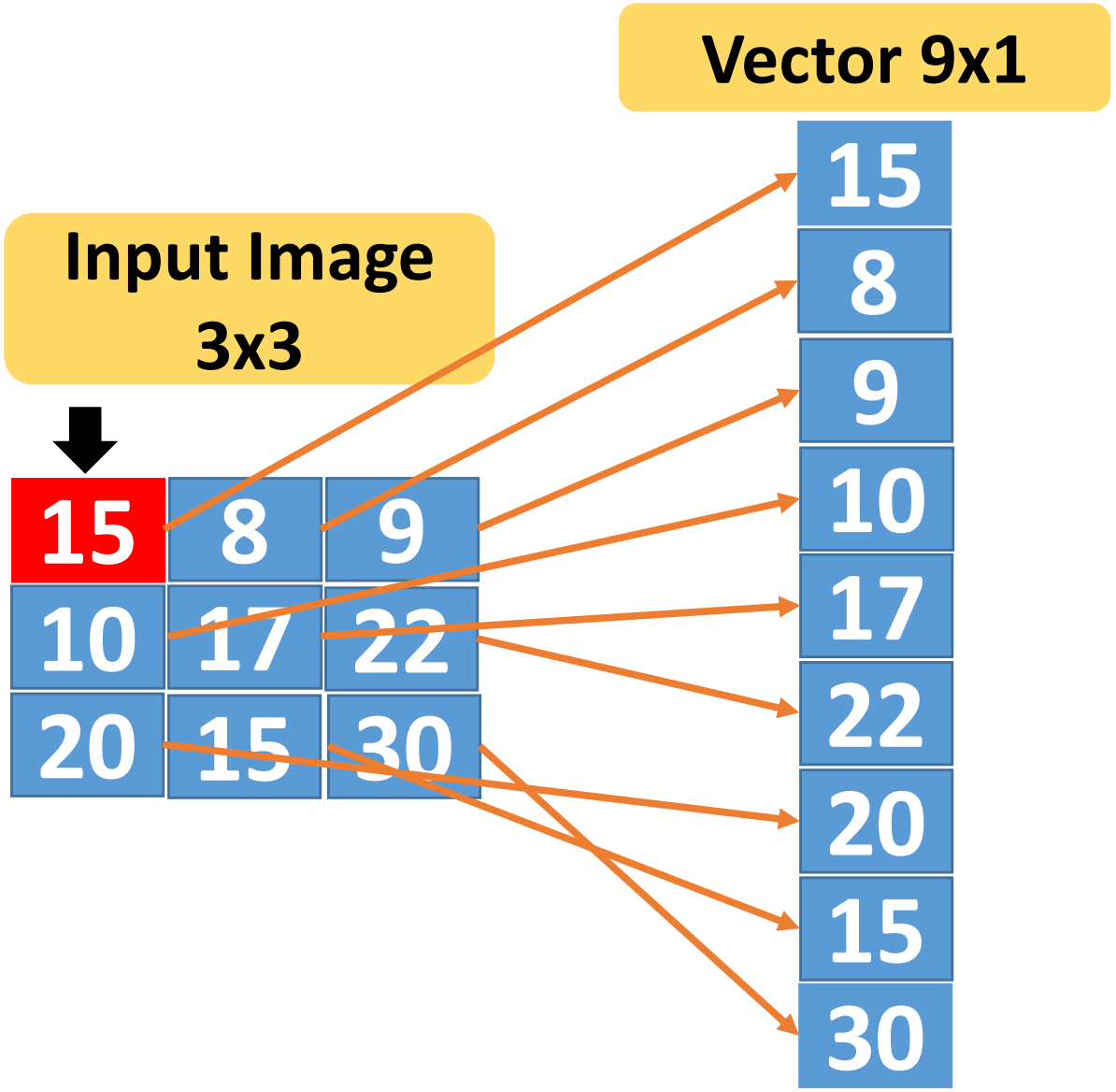
15


Vector 9x1
Input Image
3x3
15
8
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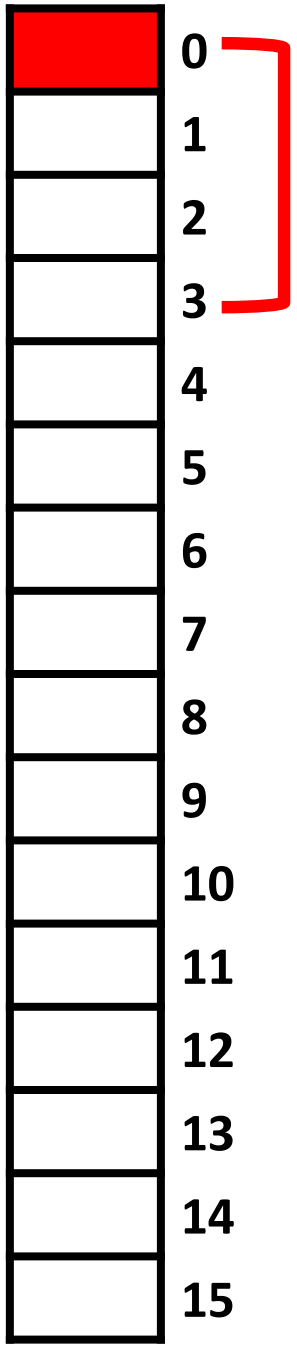
10
17
22
20
15
30


0
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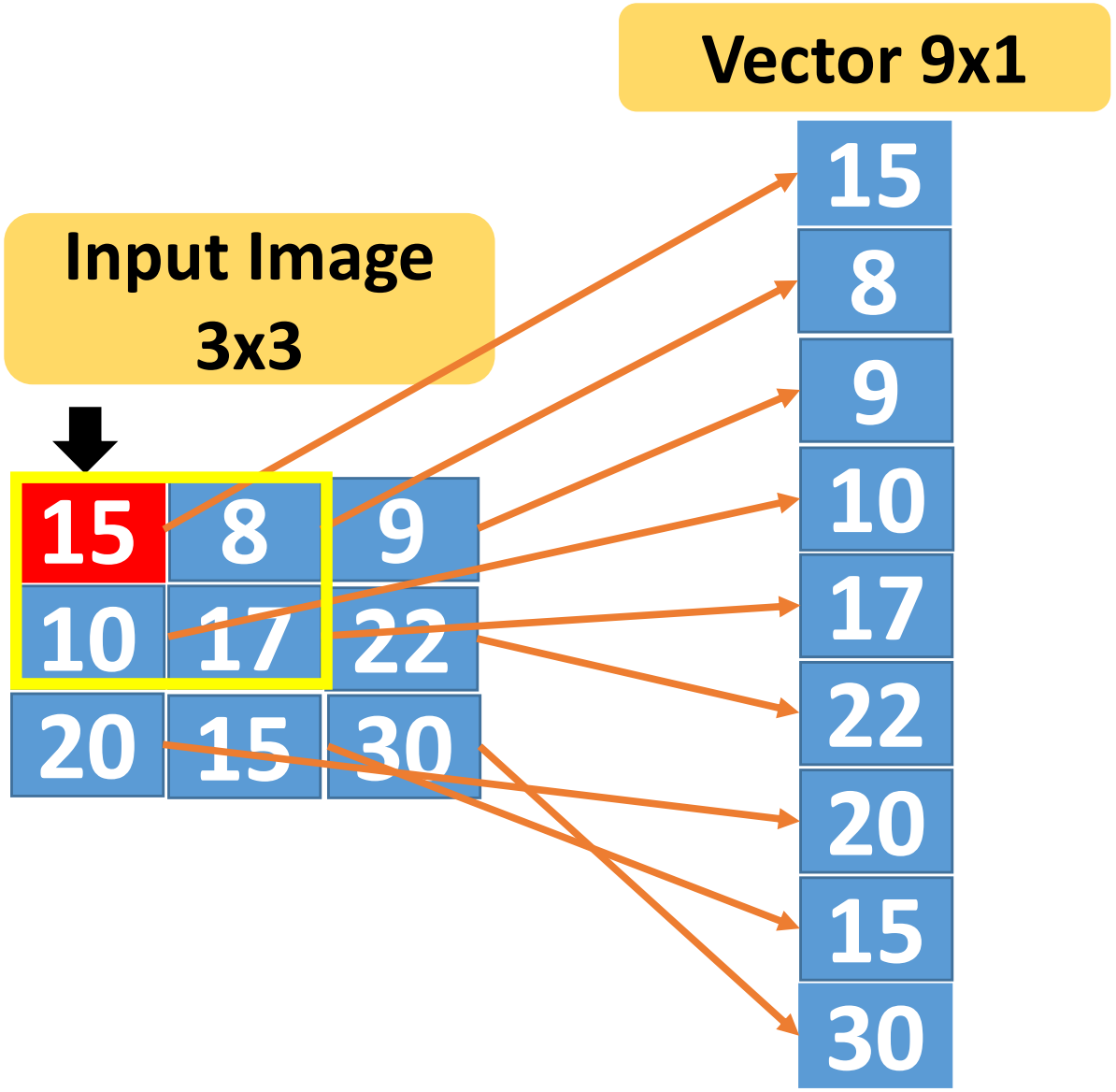
15


Vector 9x1
Input Image
3x3
15
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22
20
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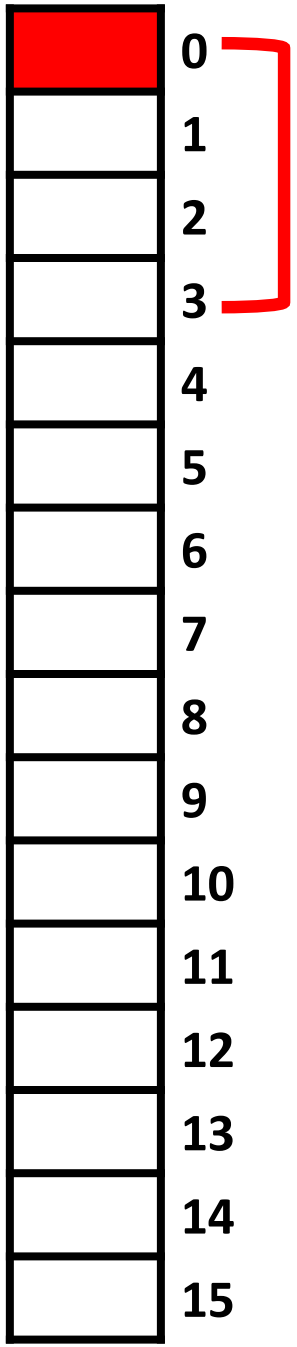
15
30


0
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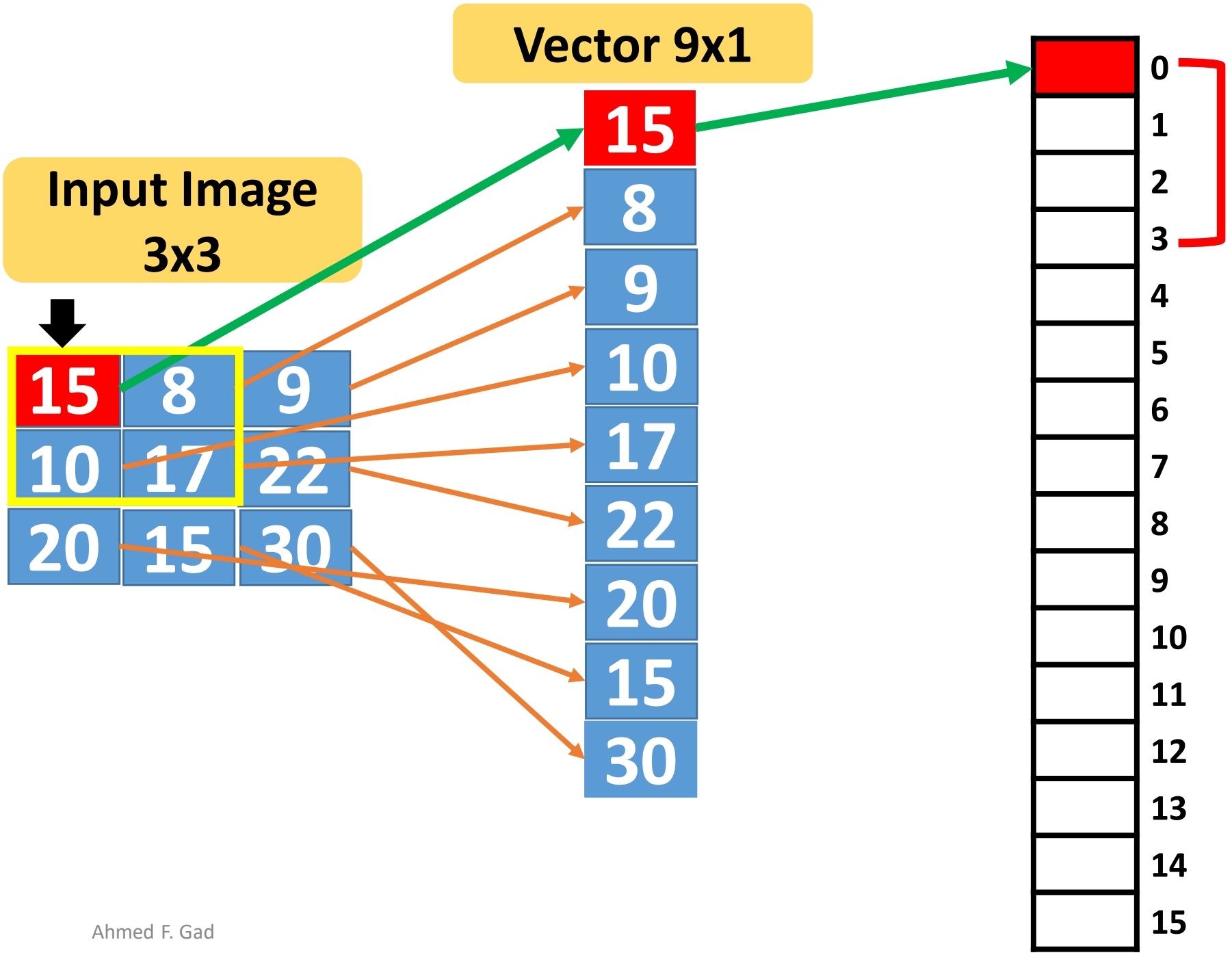
15


Vector 9x1
Input Image
3x3
15
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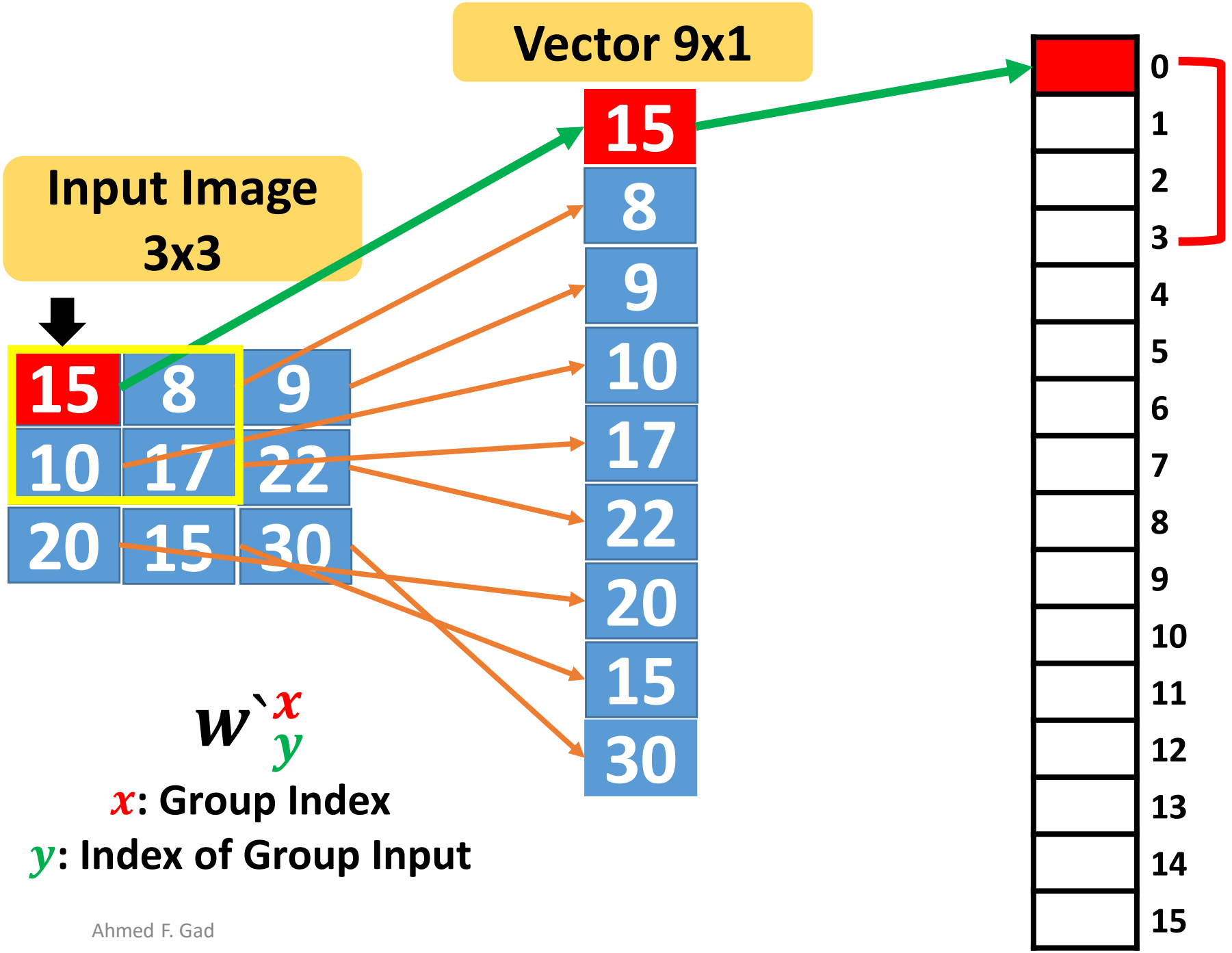
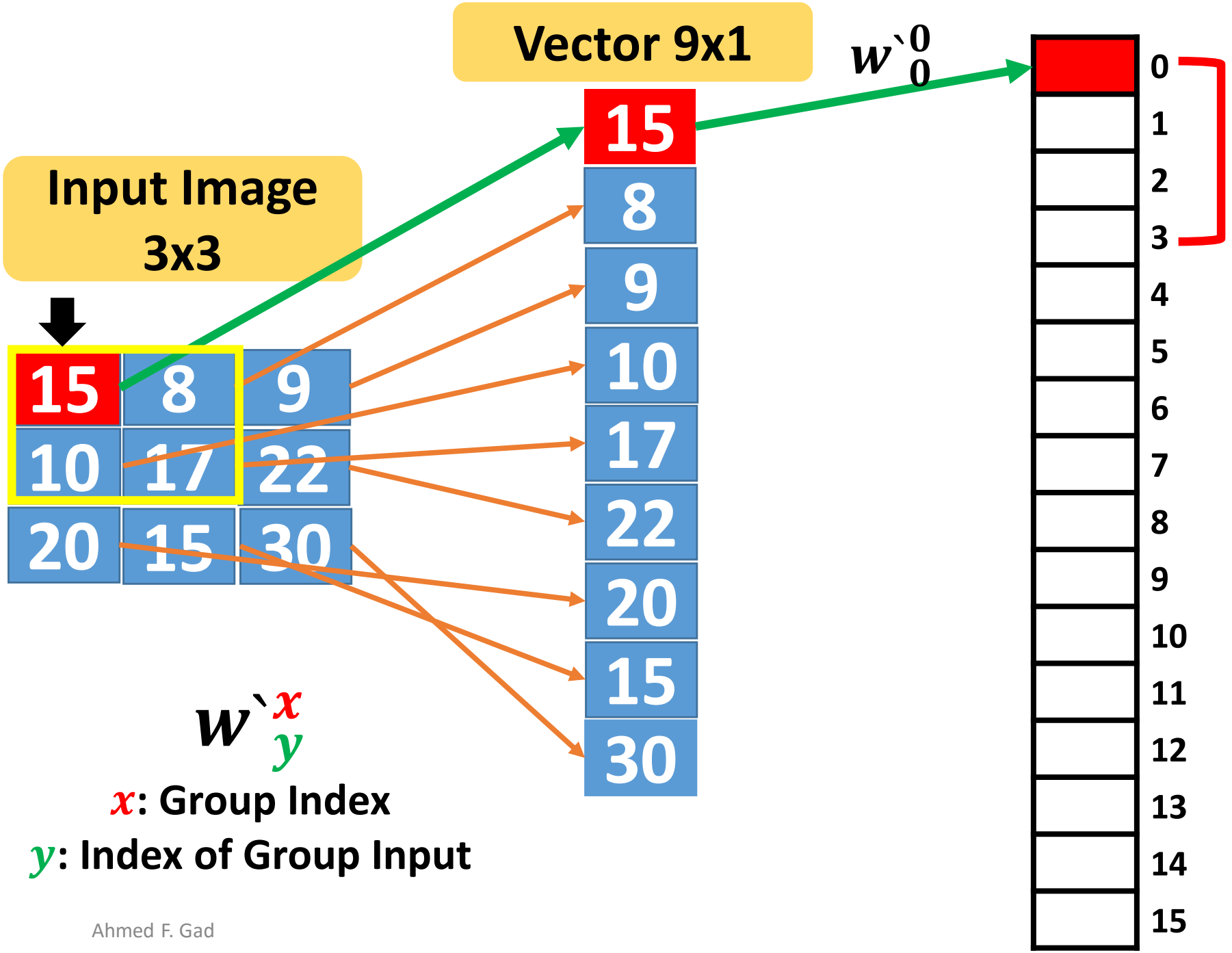
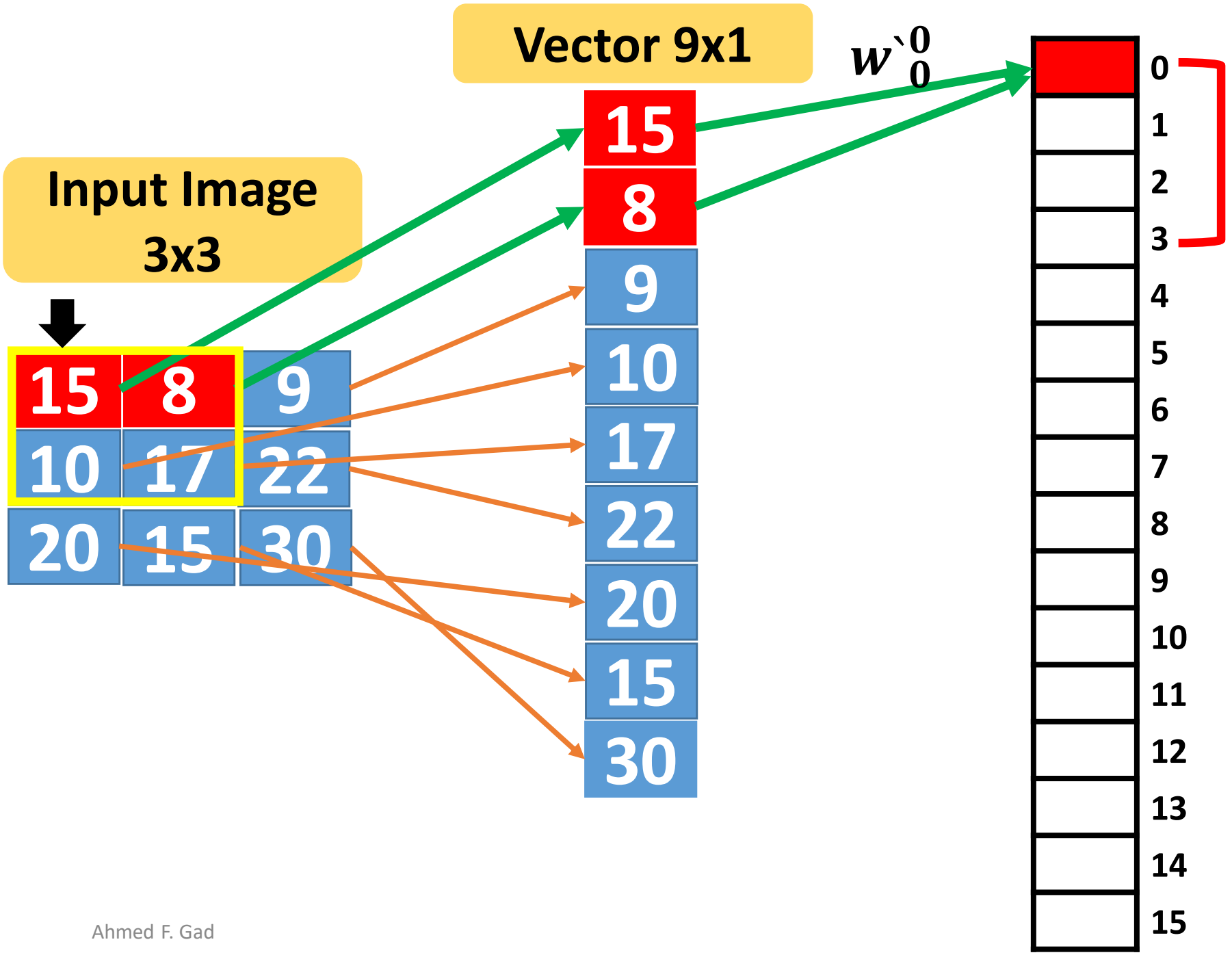


$W`_{y}^{x}$

x: Group Index

y: Index of Group Input


Vector 9x1
$w`_0^0$
Input Image
3x3
15
8
9
10
17
22
20
15
30
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
$w`_y^x$
x: Group Index
y: Index of Group Input


Vector 9x1
$w`_0^0$
Input Image
3x3
15
8
9
10
17
22
20
15
30
0
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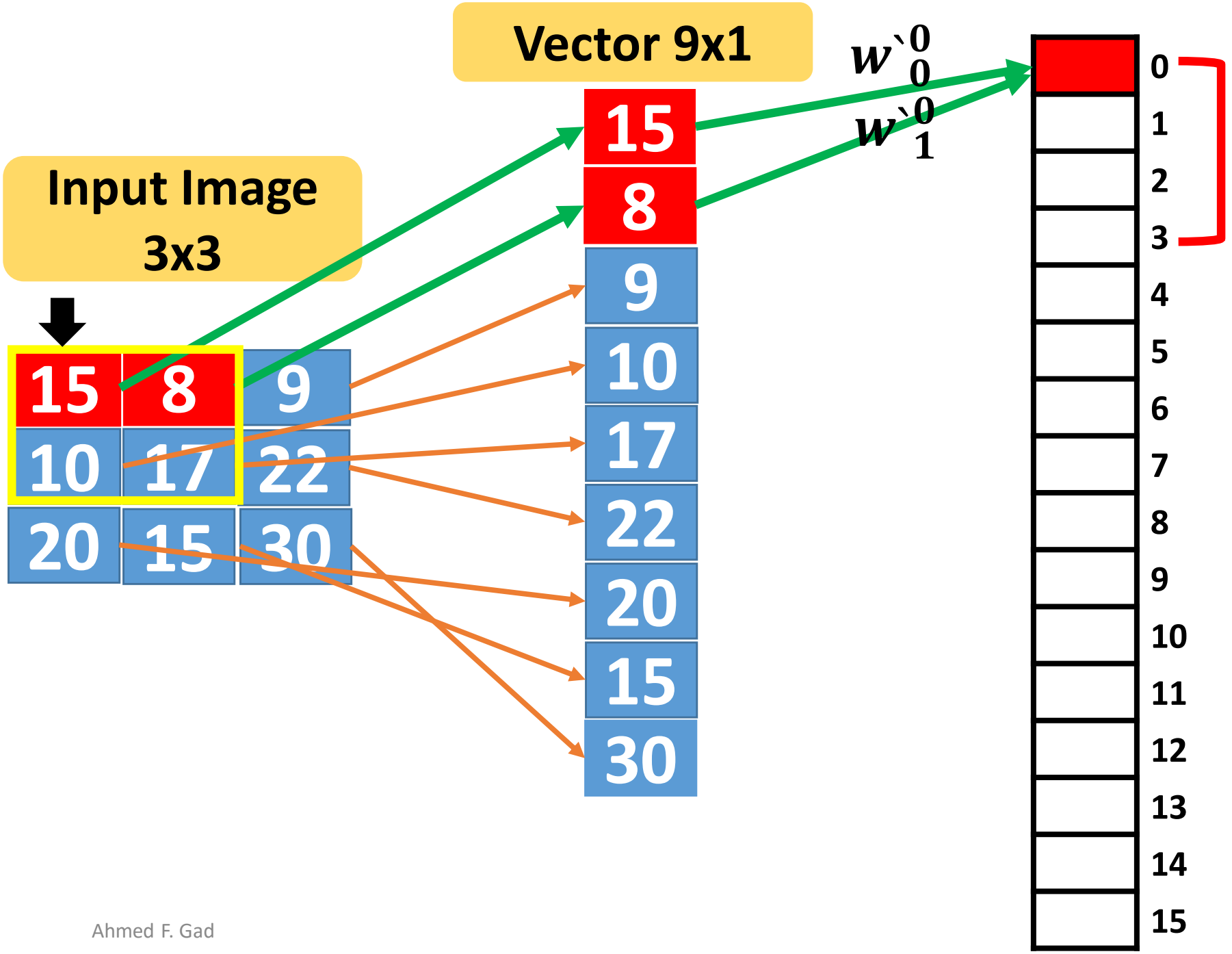
15


Vector 9x1
Input Image
3x3
15
8
9
10
17
22
20
15
30
$w`_0^0$
$w`_1^0$
0
1
2
3
4
5
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7
8
9
10
11
12
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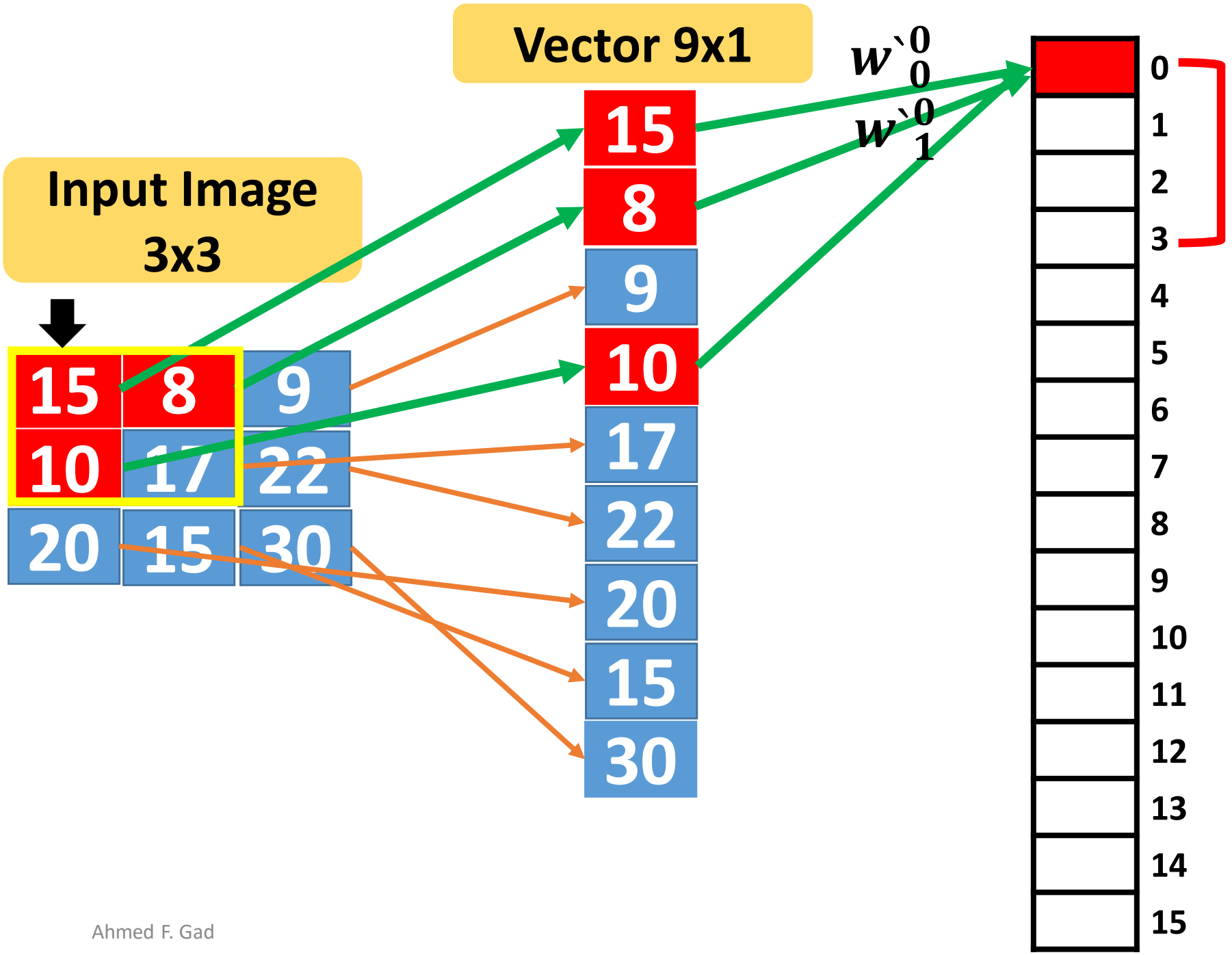
14
15


Vector 9x1
Input Image
3x3
15
8
9
10
17
22
20
15
30
$w`_{0}^{0}$
$w`_{1}^{0}$
0
1
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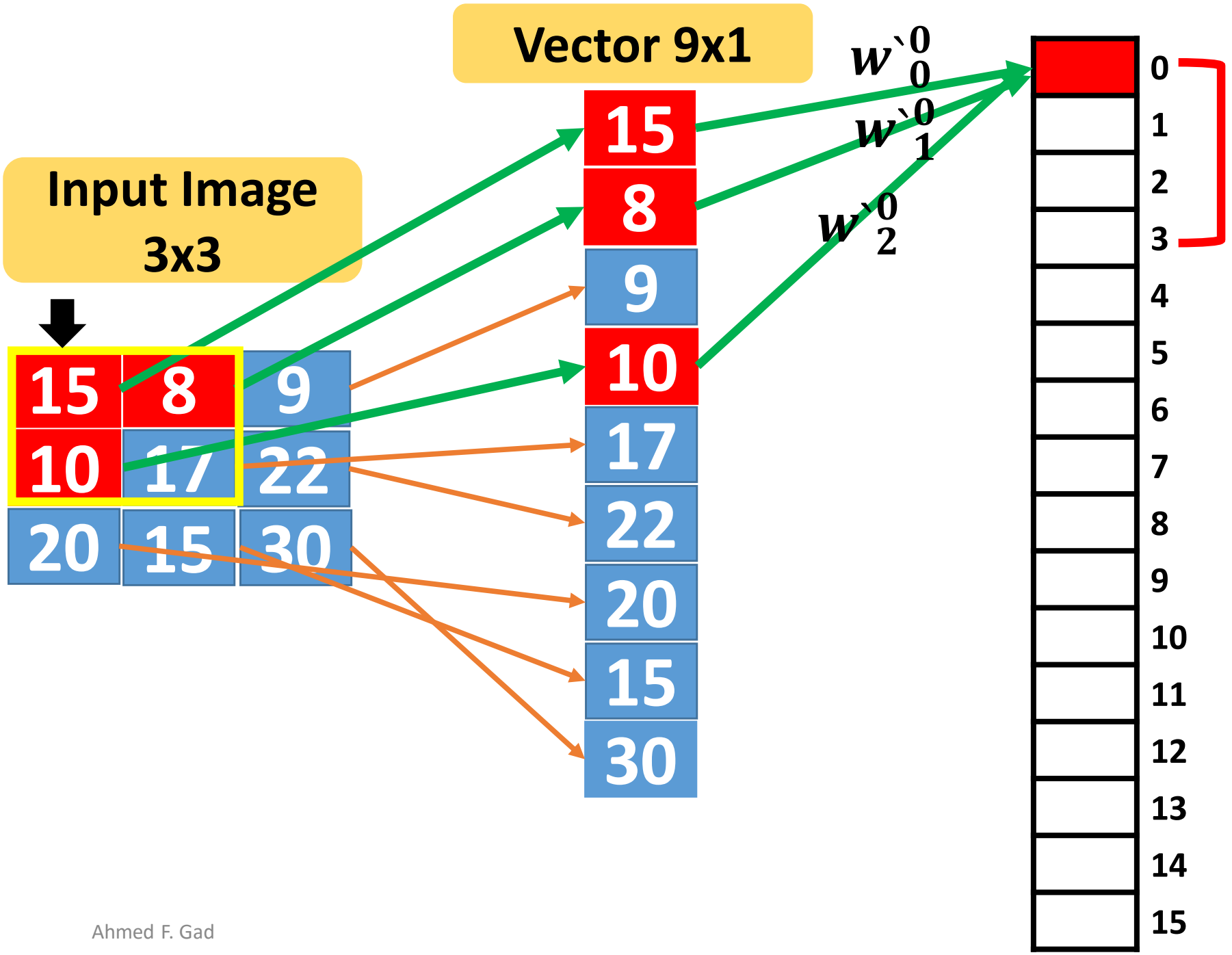
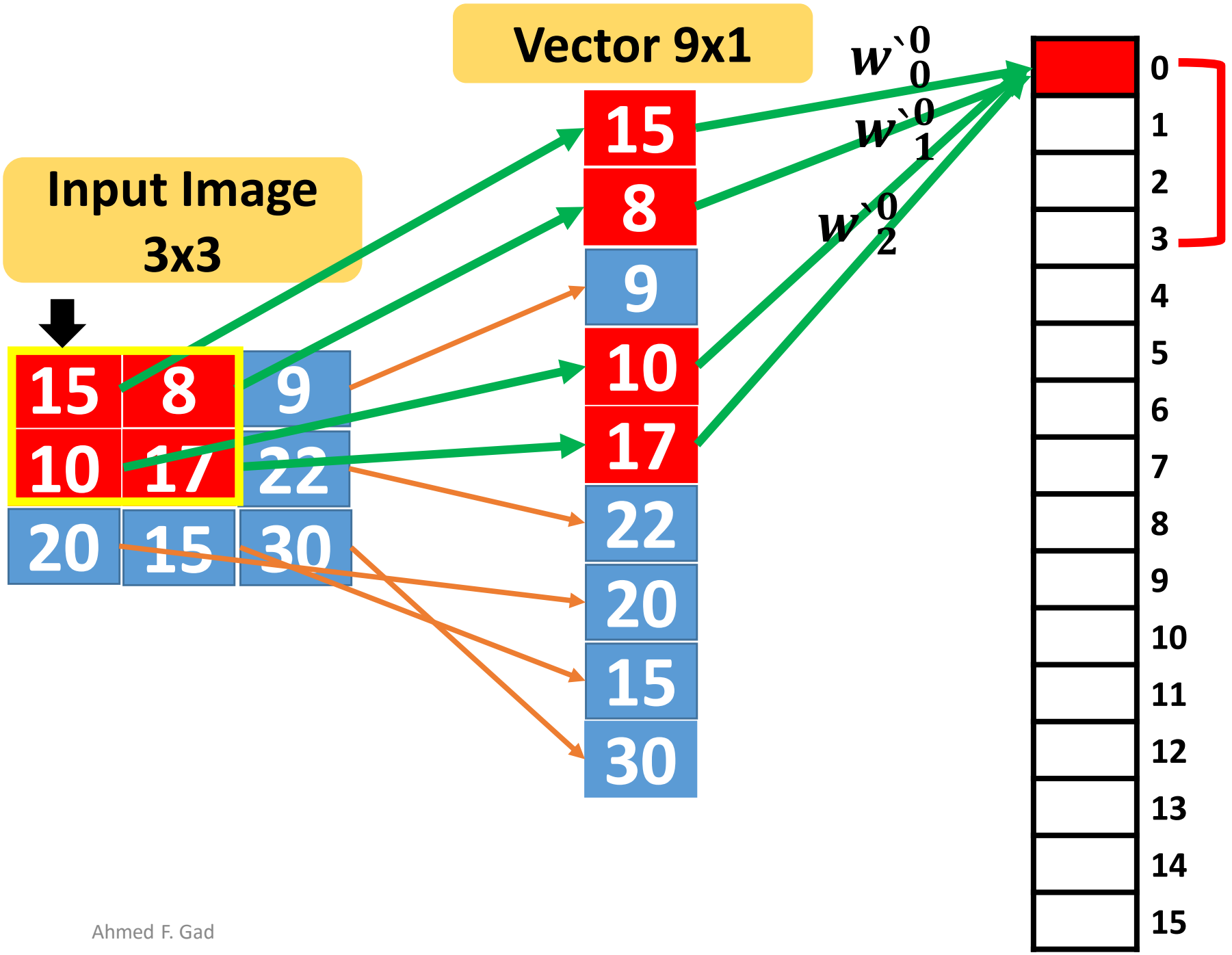
3
4
5
6
7
8
9
10
11
12
13
14
15


Vector 9x1
Input Image
3x3
15
8
9
10
17
22
20
15
30
$w`^0_0$
$w`^0_1$
$w`^0_2$
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15


Vector 9x1
Input Image
3x3
15
8
9
10
17
22
20
15
30
$w`^0_0$
$w`^0_1$
$w`^0_2$
0
1
2
3
4
5
6
7
8
9
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11
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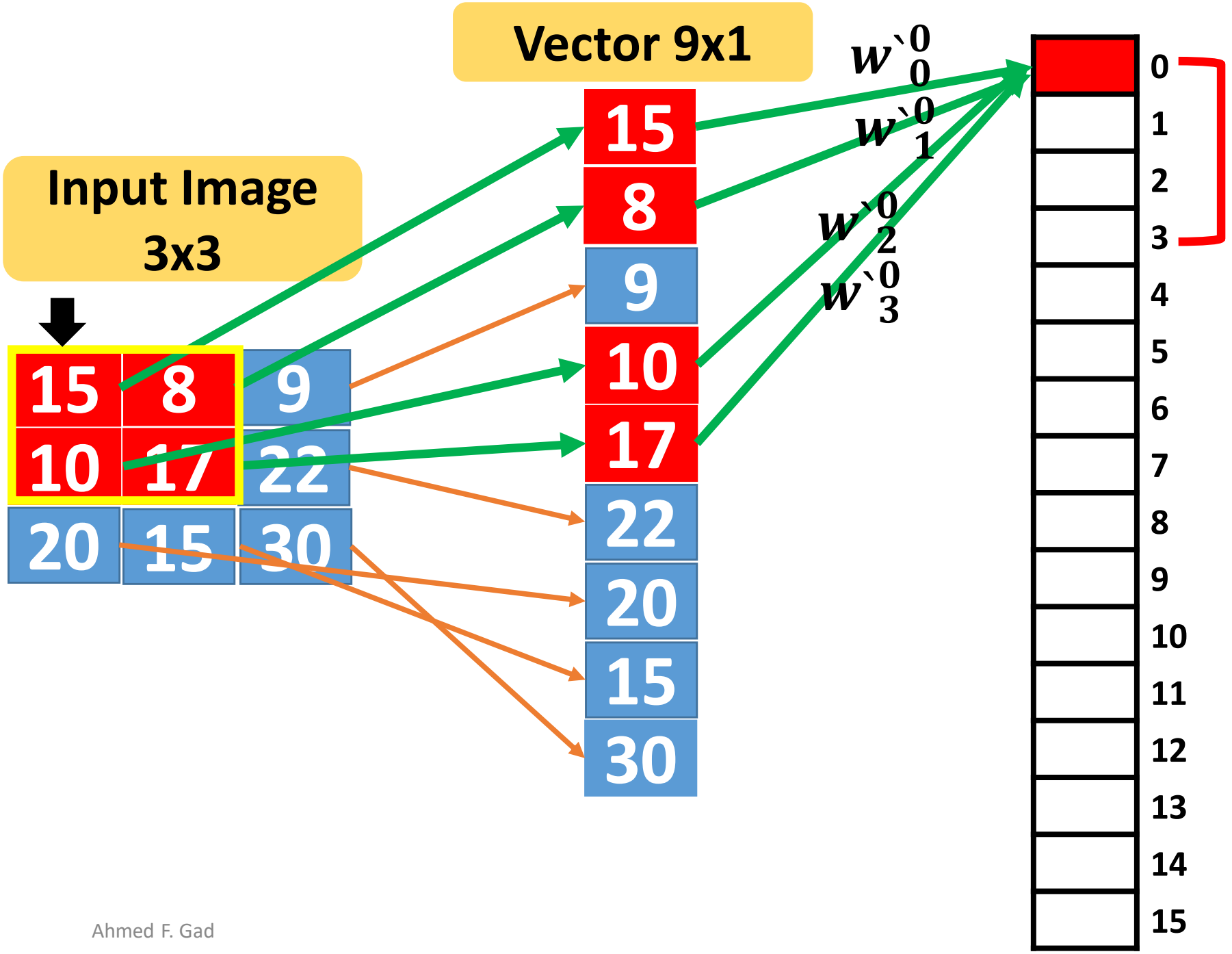
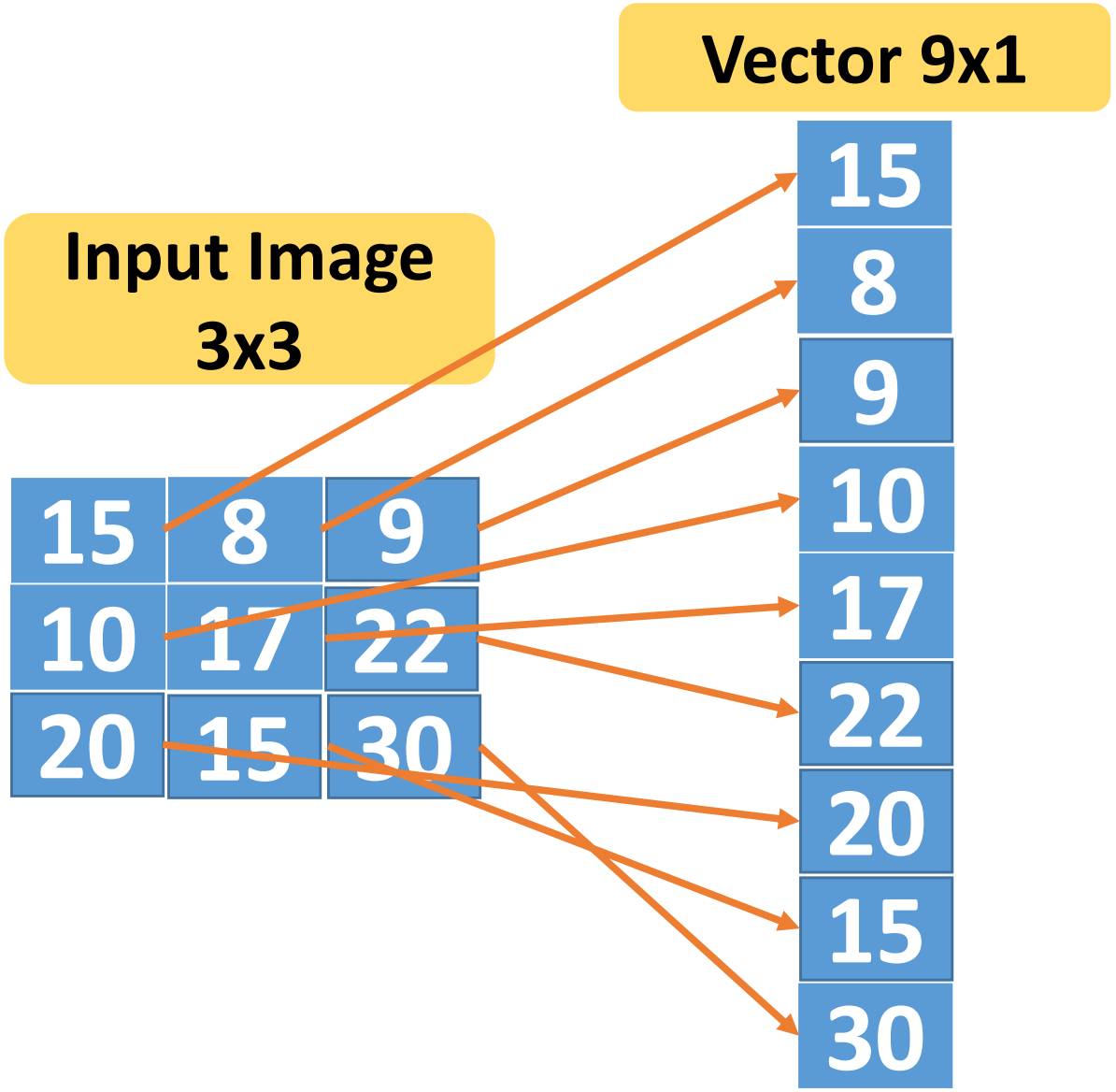
15


Vector 9x1
Input Image
3x3
15
8
9
10
17
22
20
15
30
$w`_0^0$
$w`_1^0$
$w`_2^0$
$w`_3^0$
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15


Vector 9x1
Input Image
3x3
15
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9
10
17
22
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15
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10
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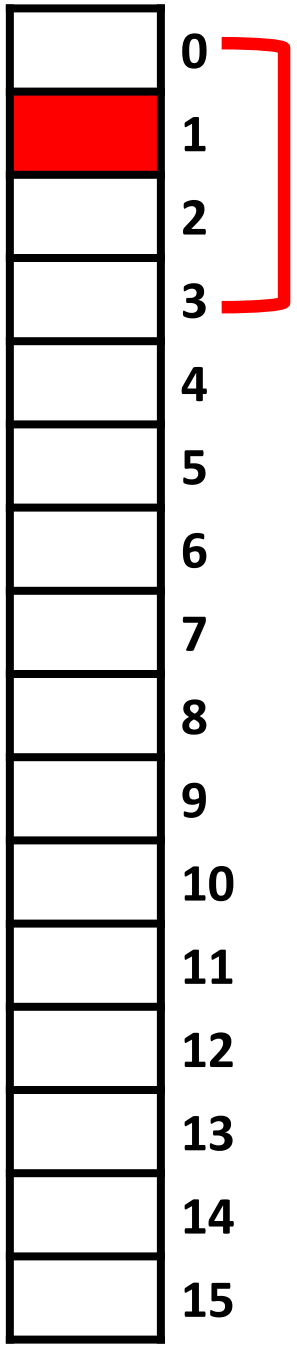
22
20
15
30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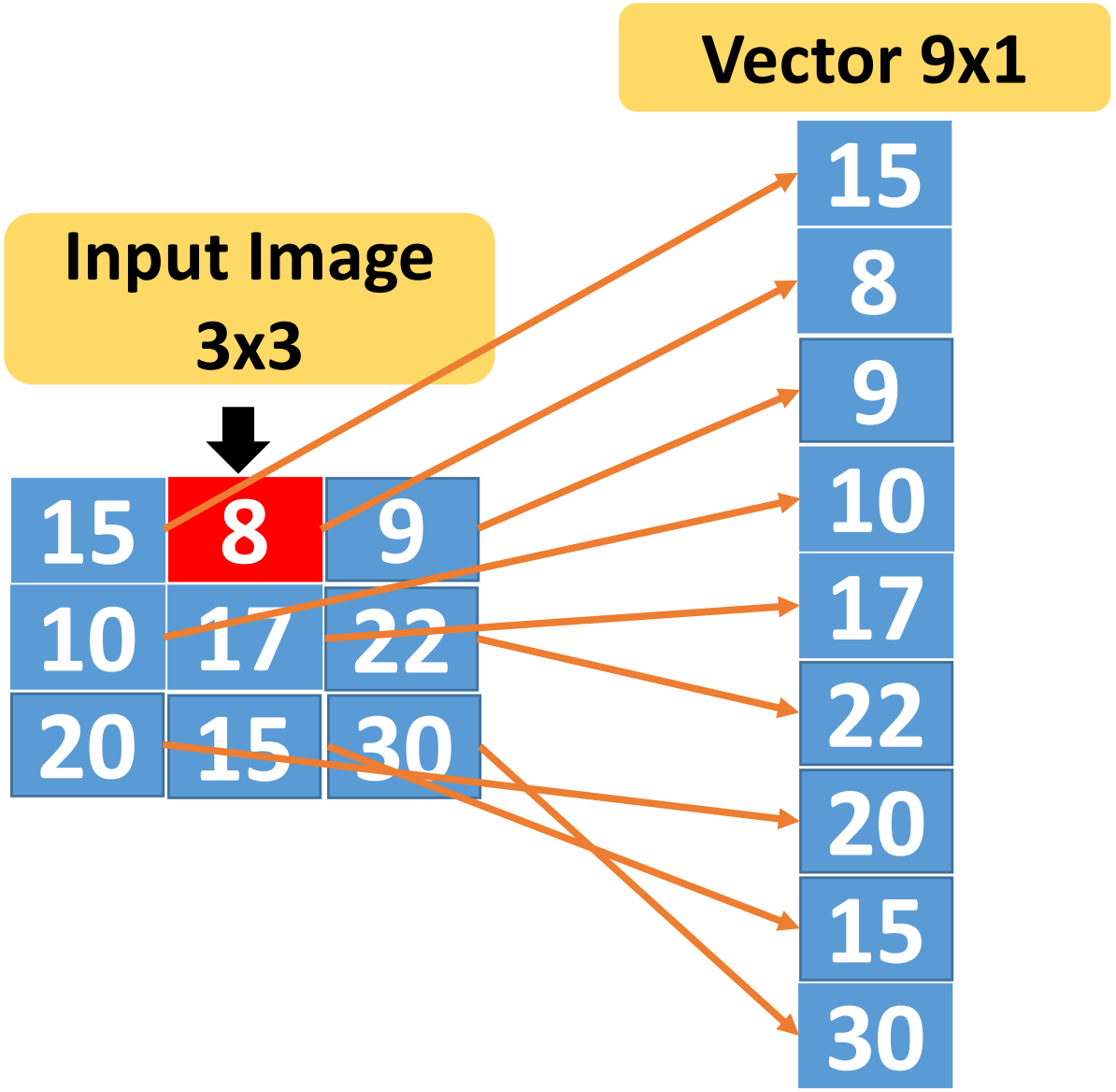
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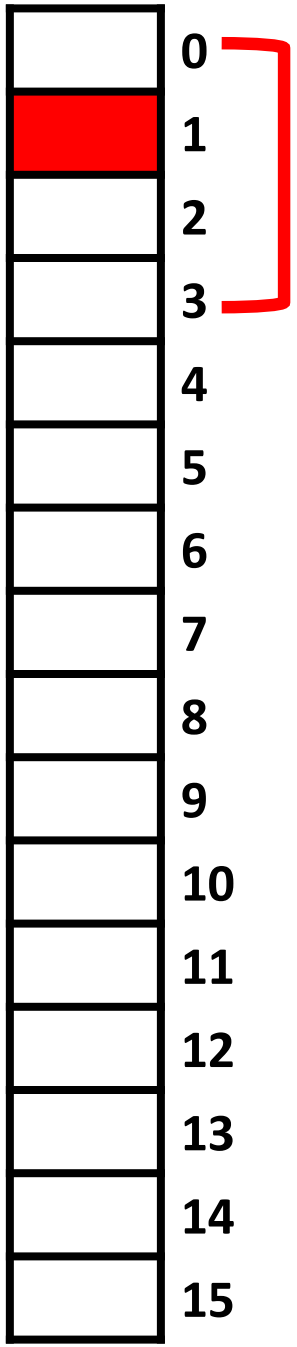
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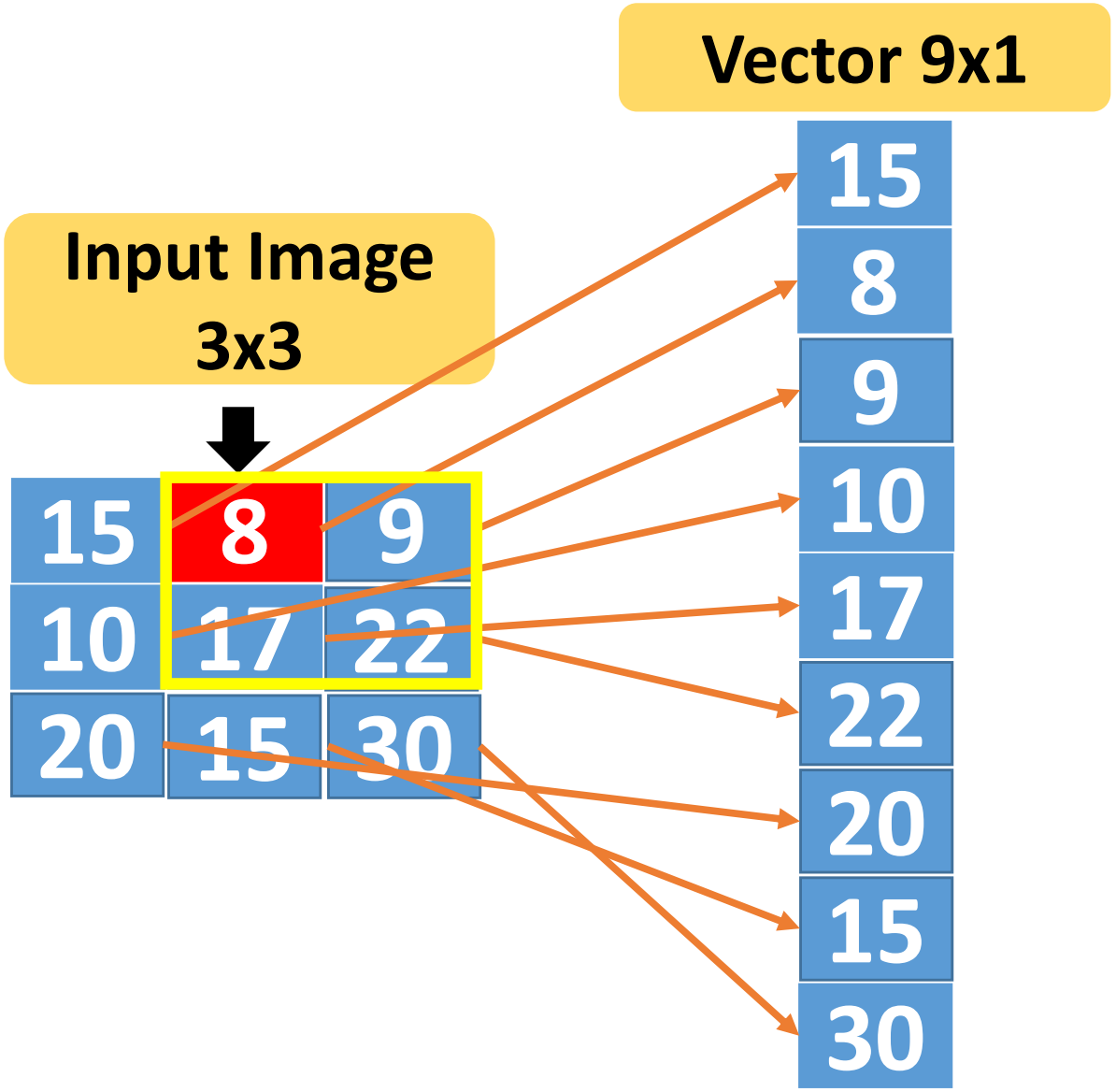
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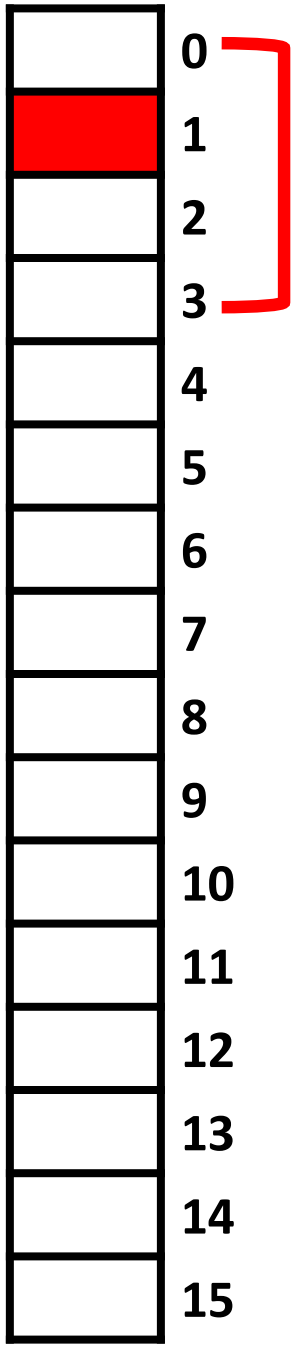
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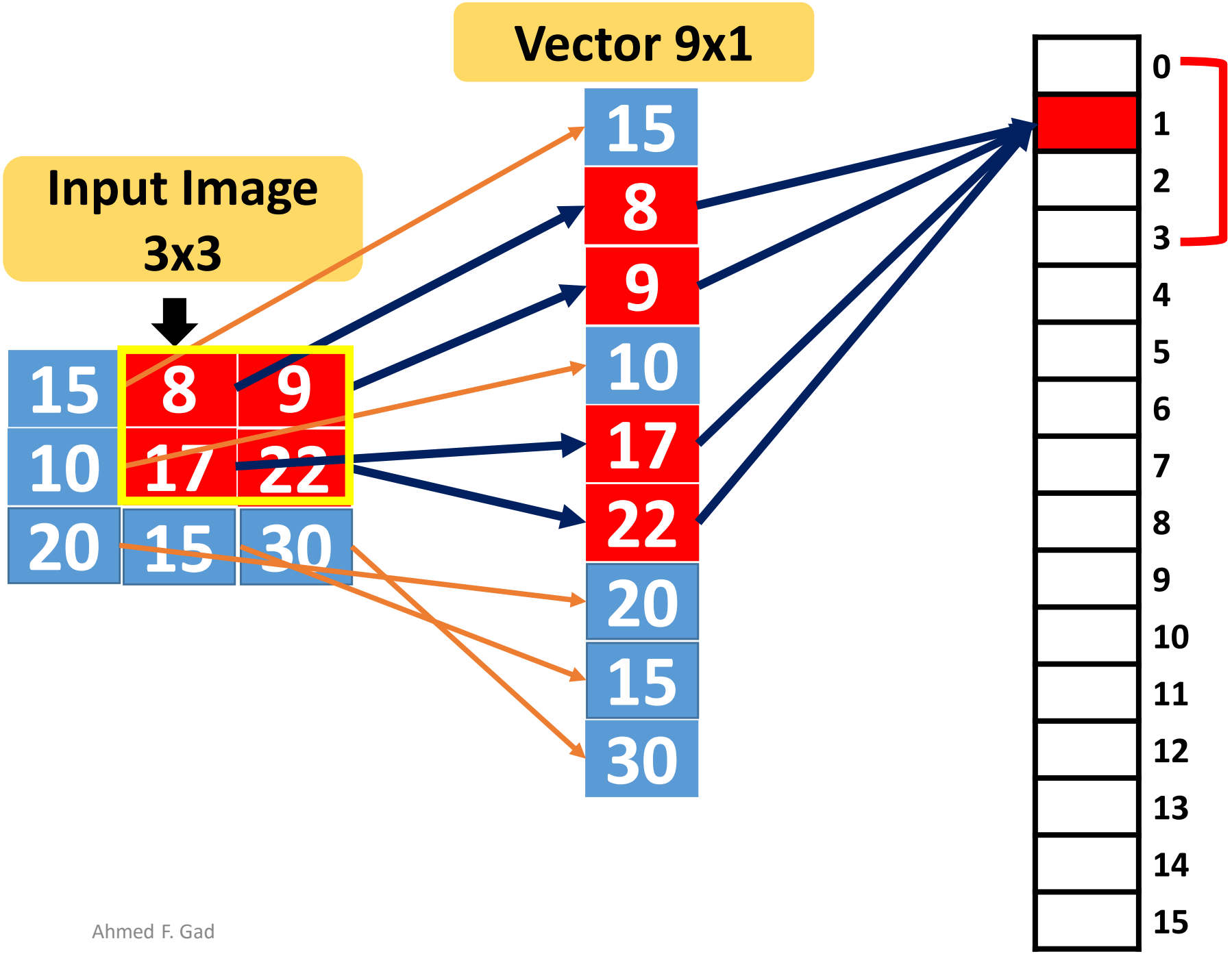
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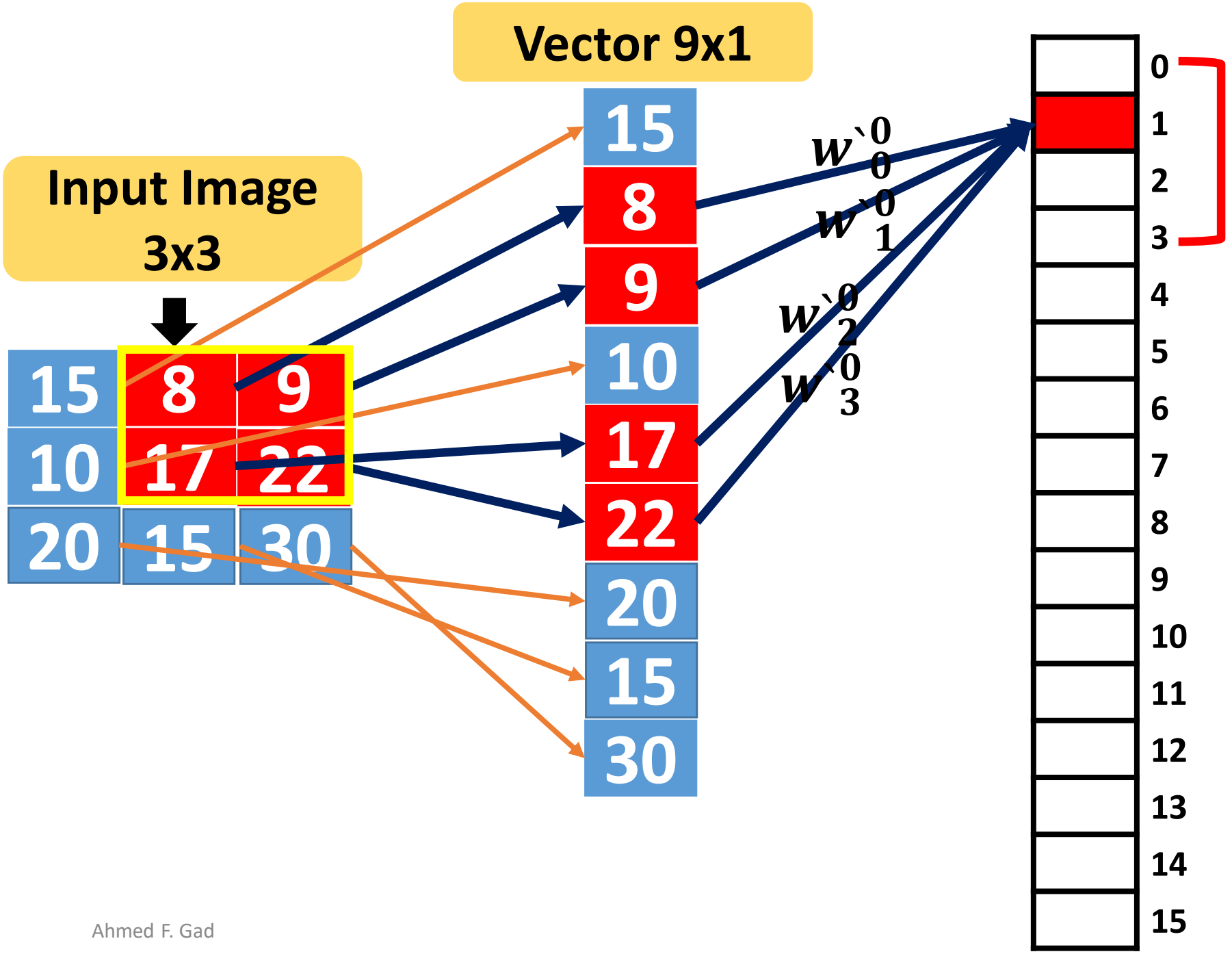
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$w`_{2}^{0}$
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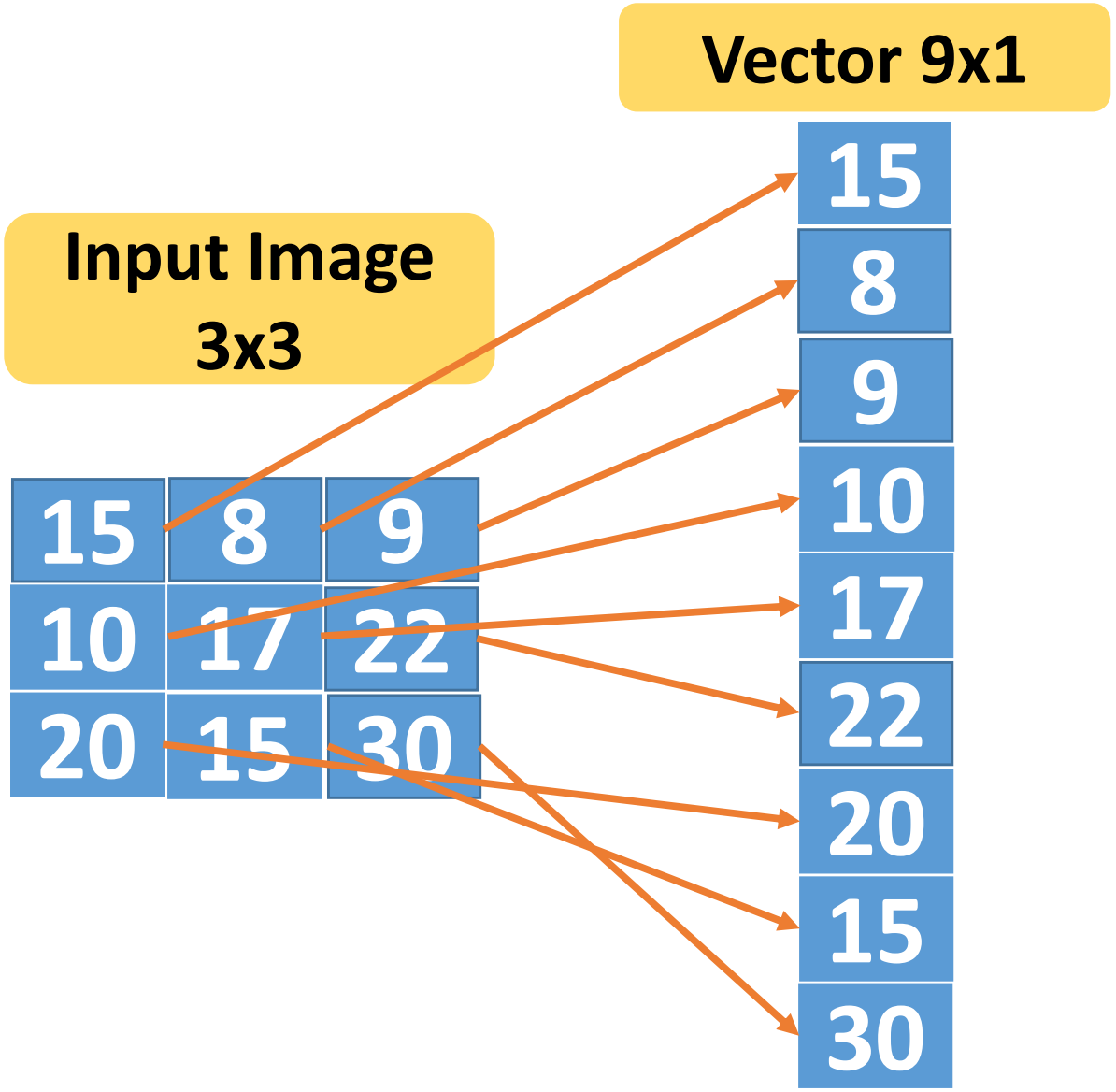
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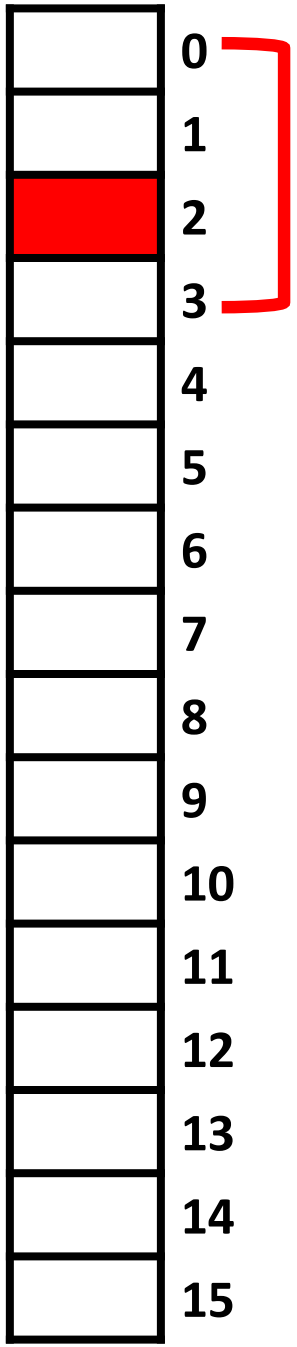
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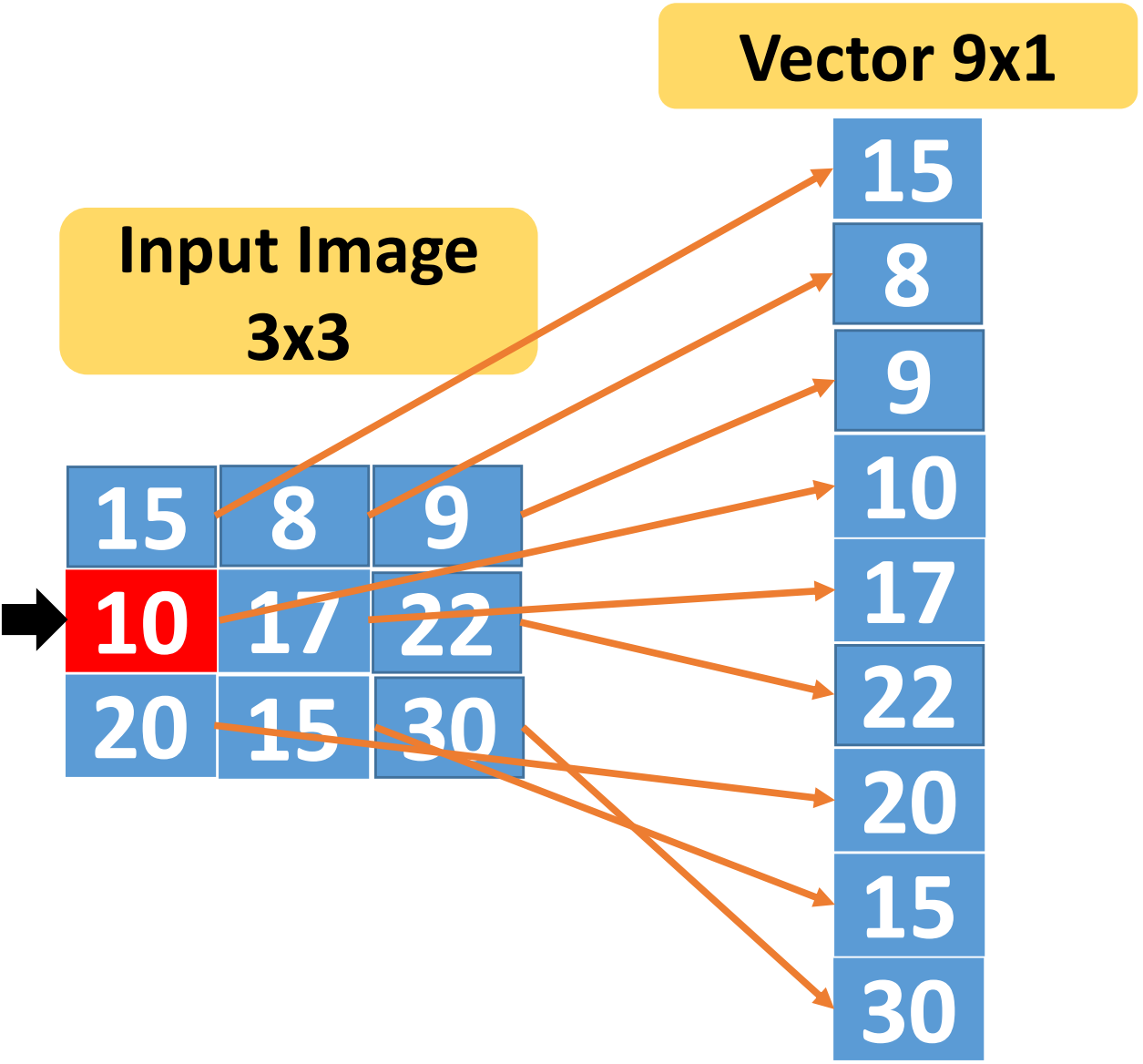
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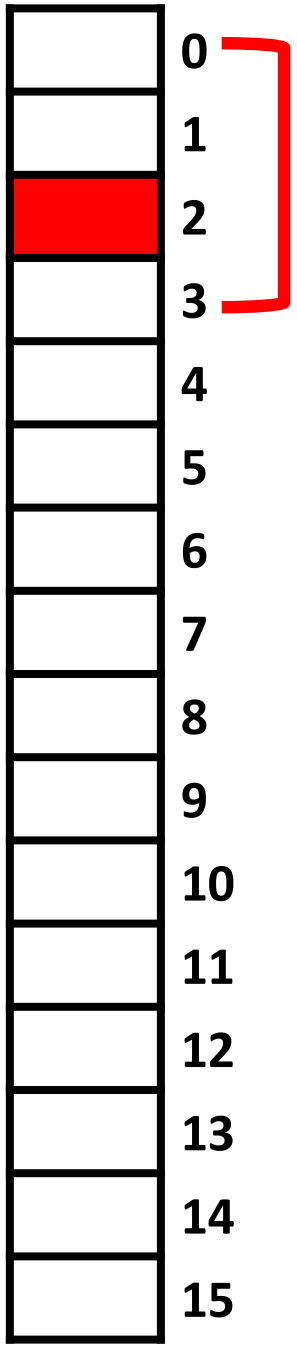
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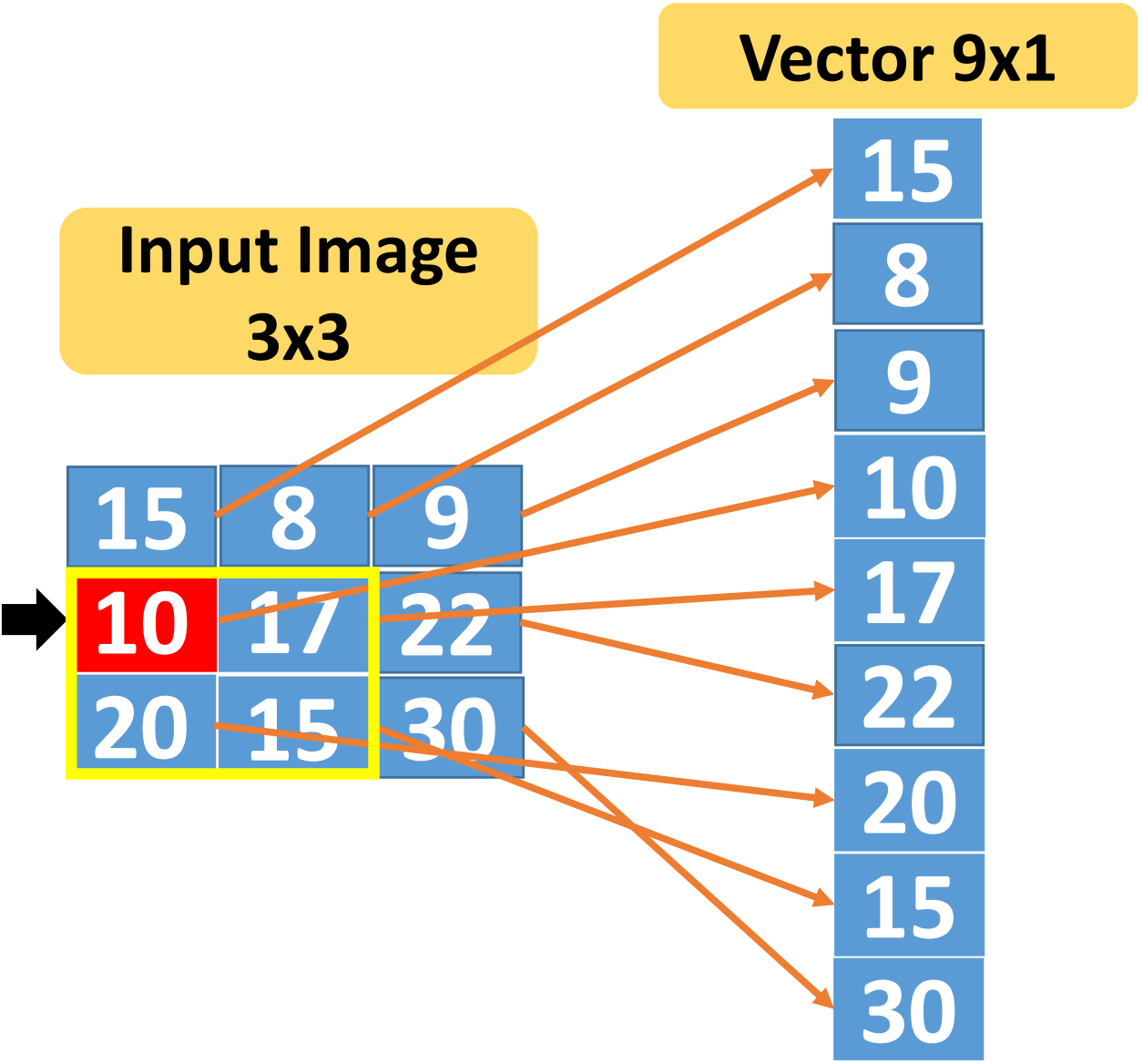
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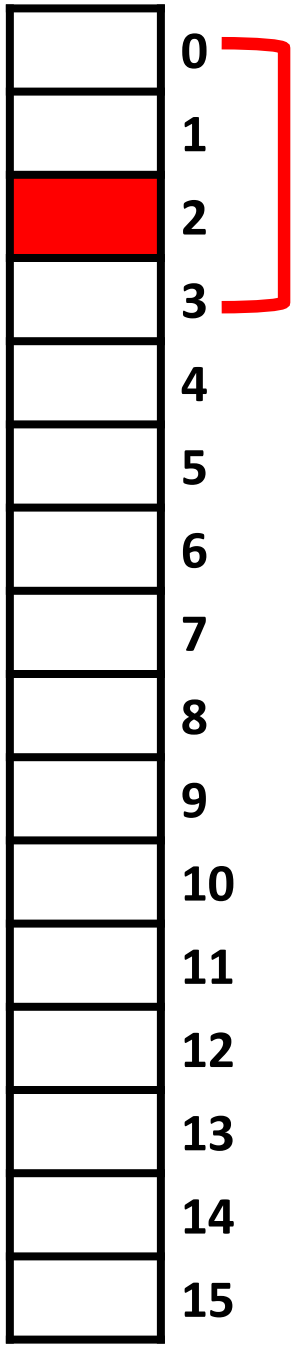
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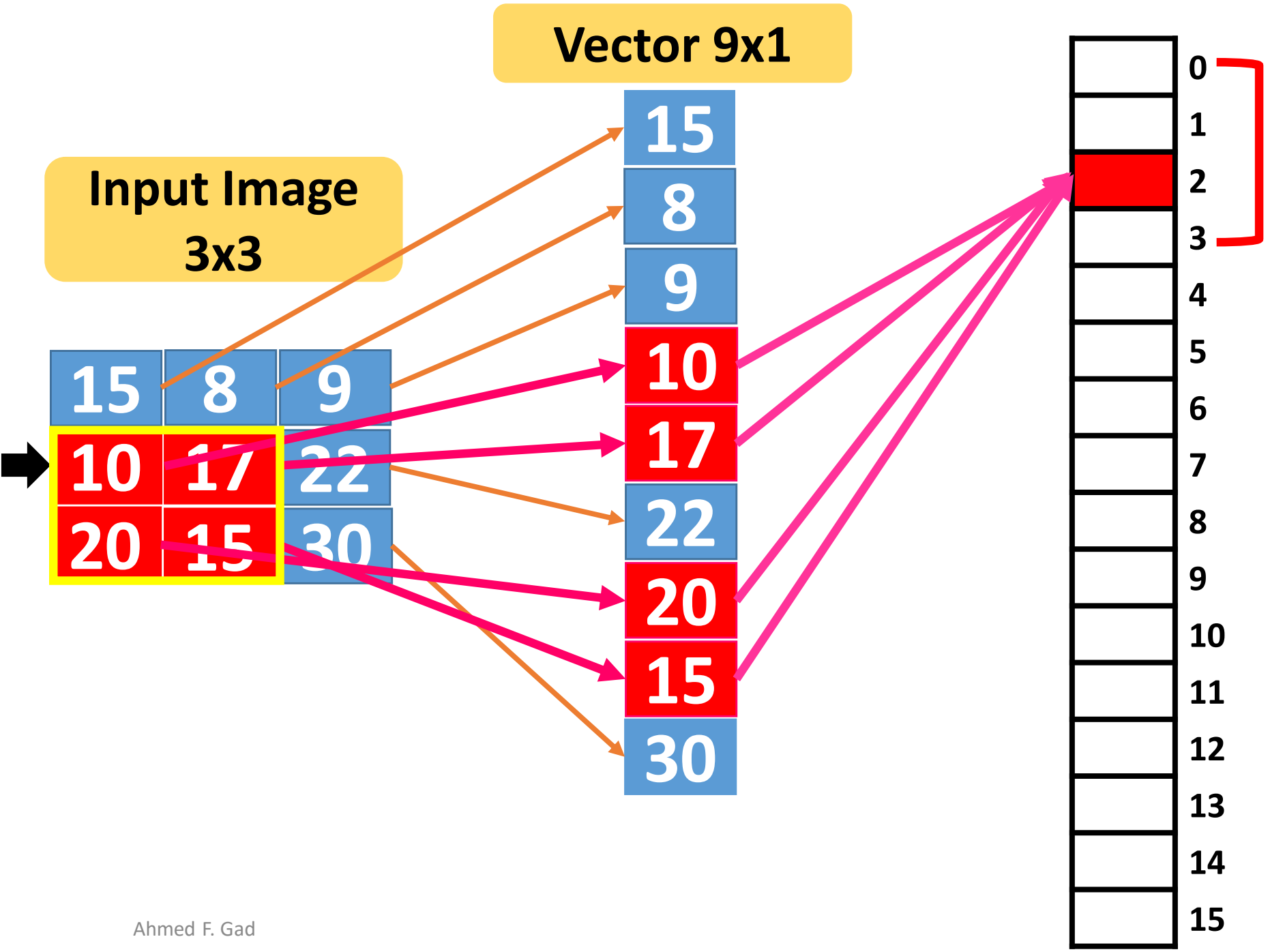
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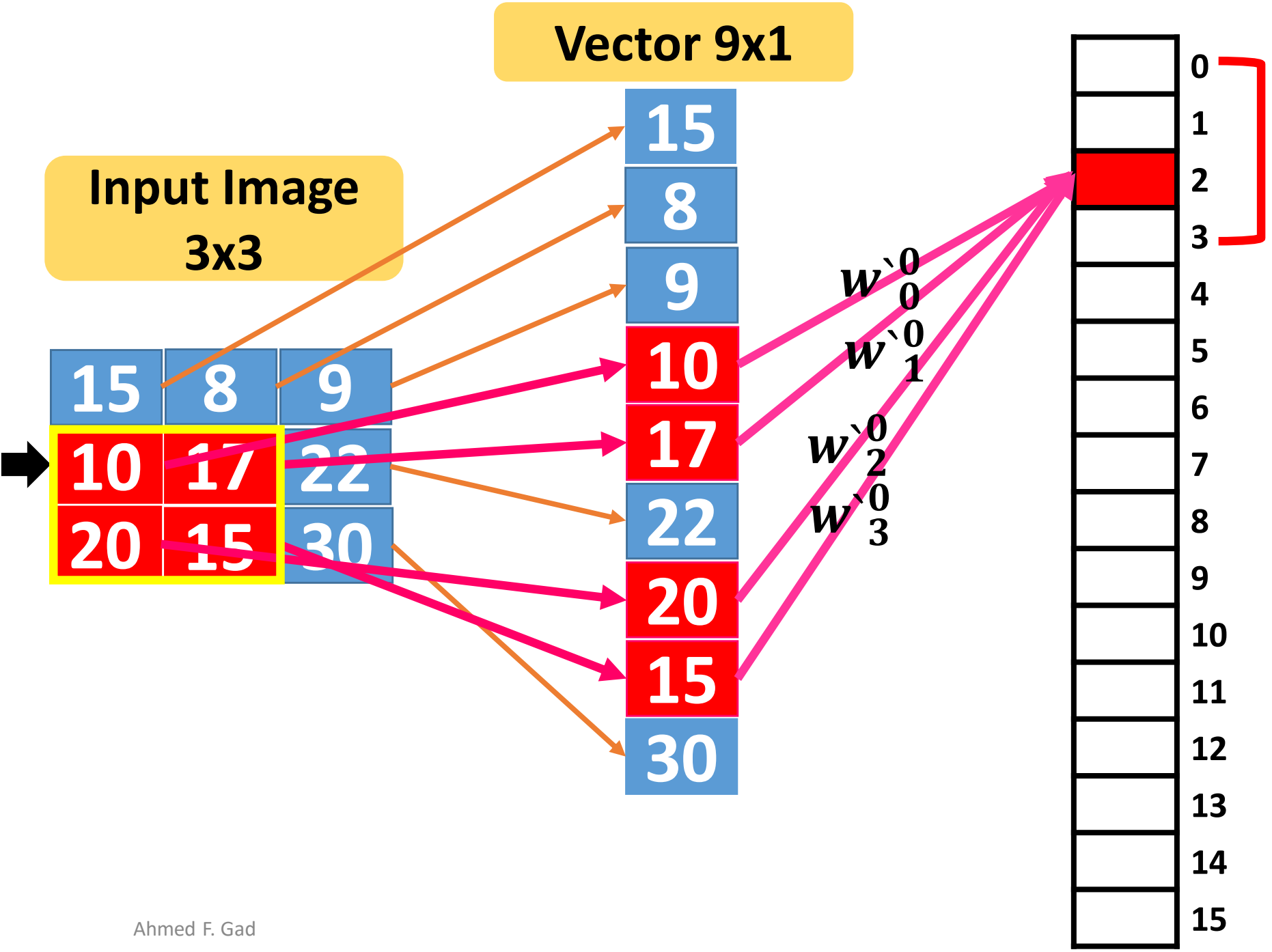
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Input Image
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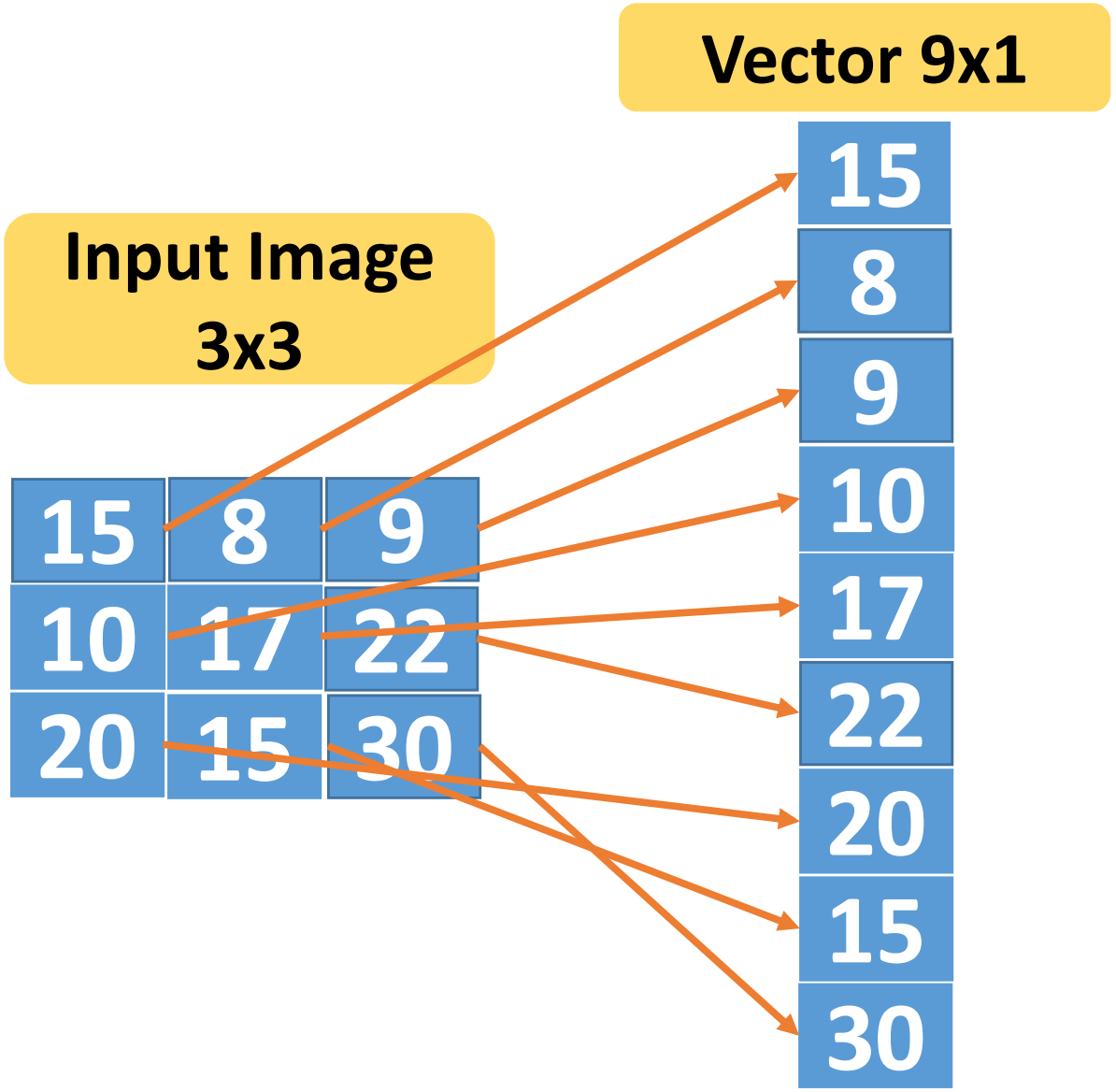
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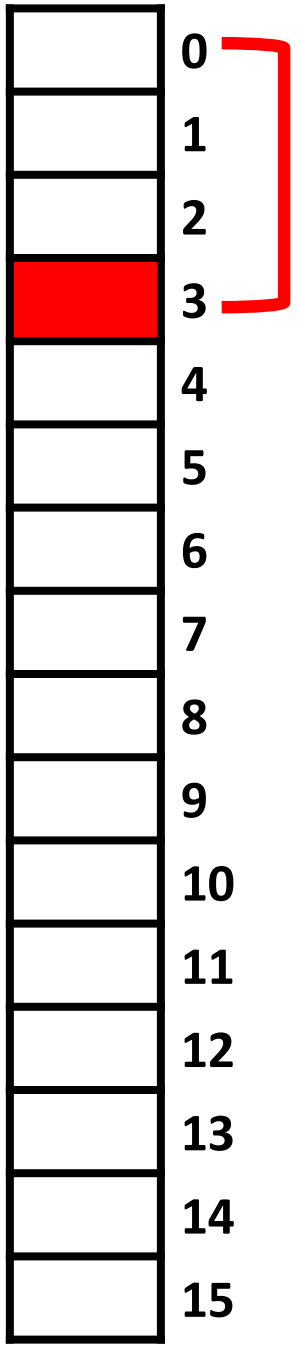
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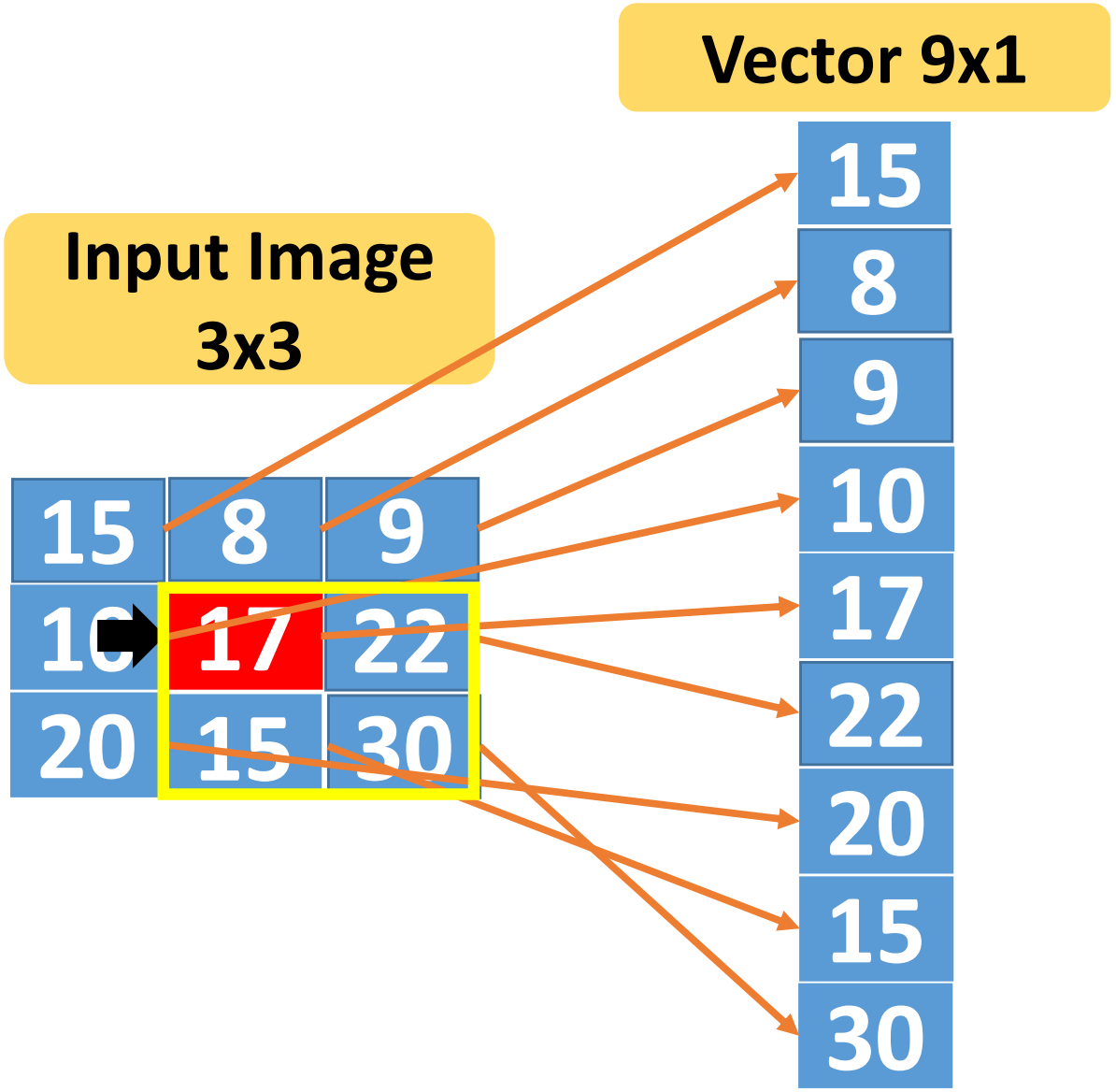
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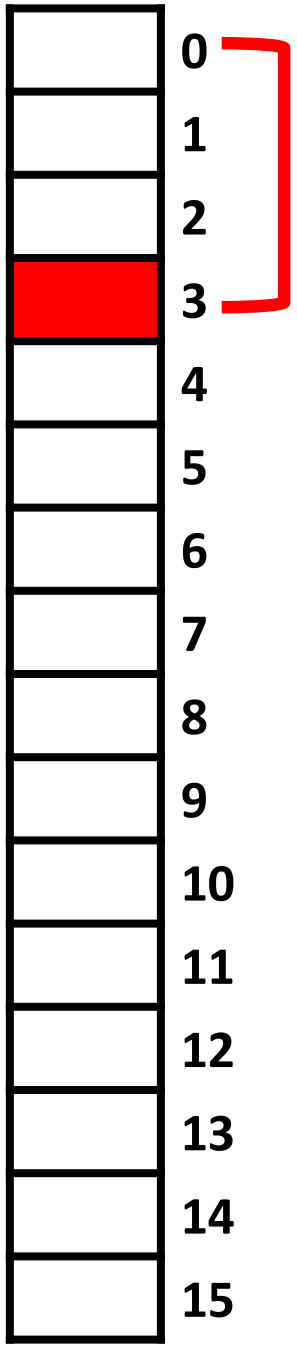
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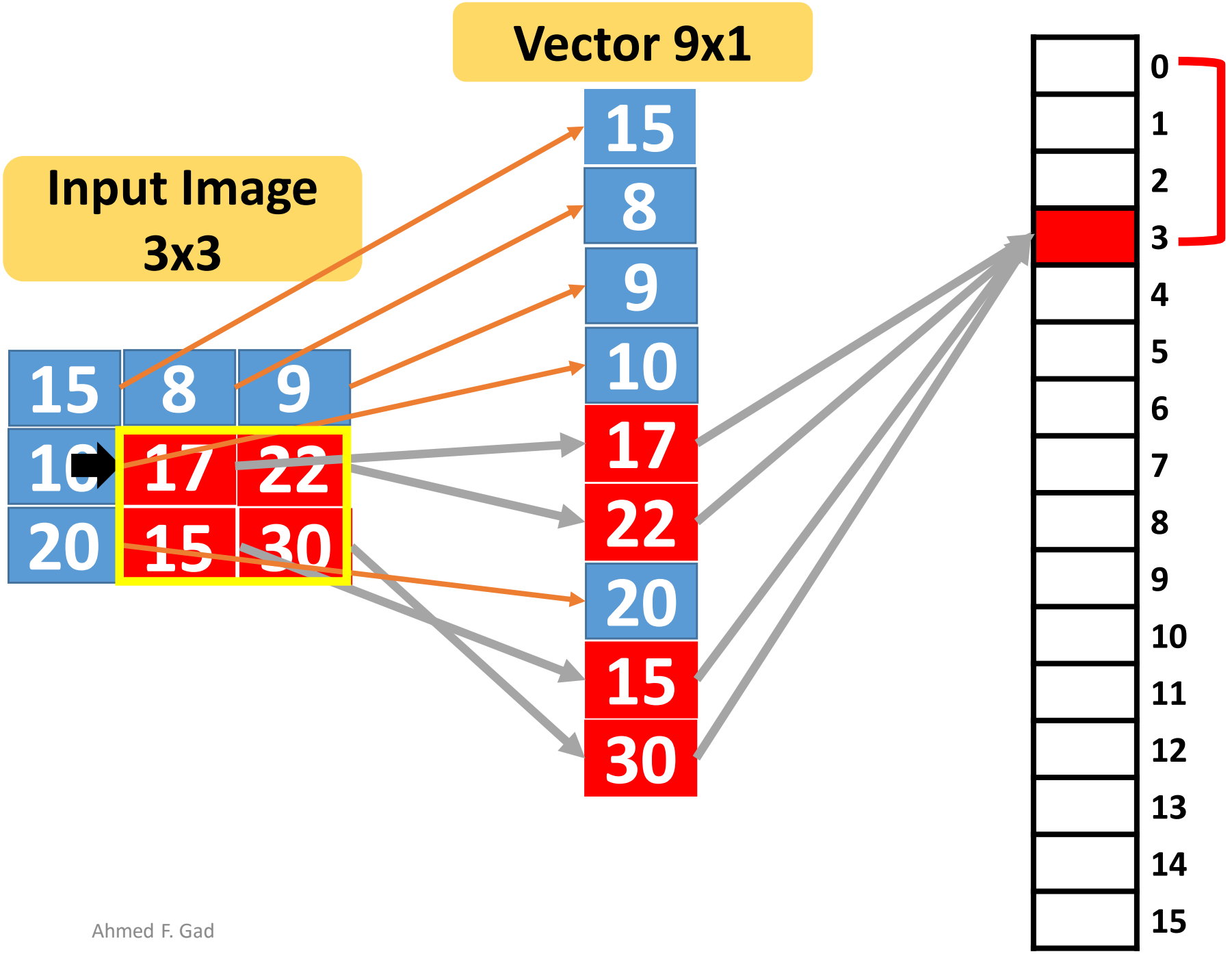
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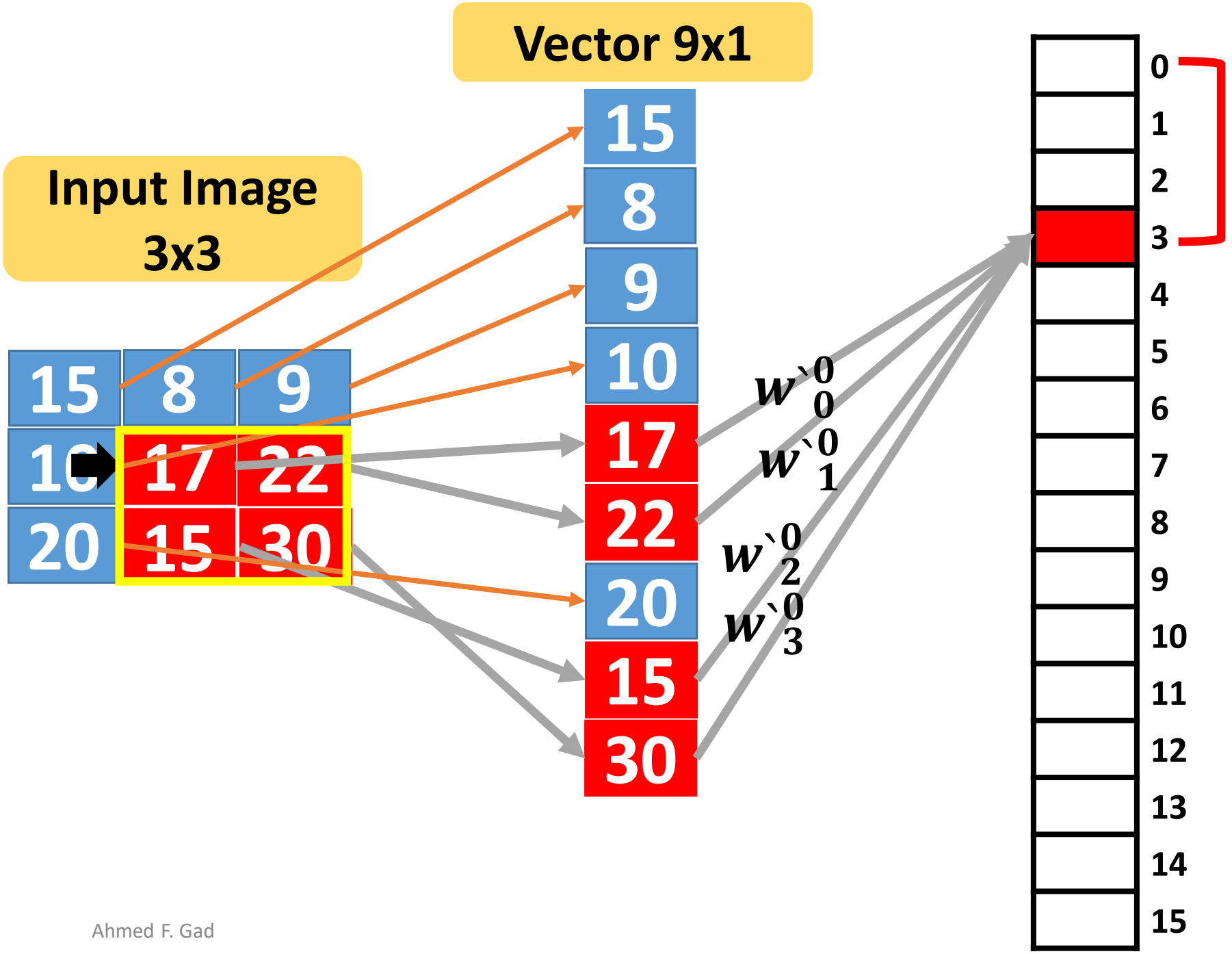
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$w`_1^0$
$w`_2^0$
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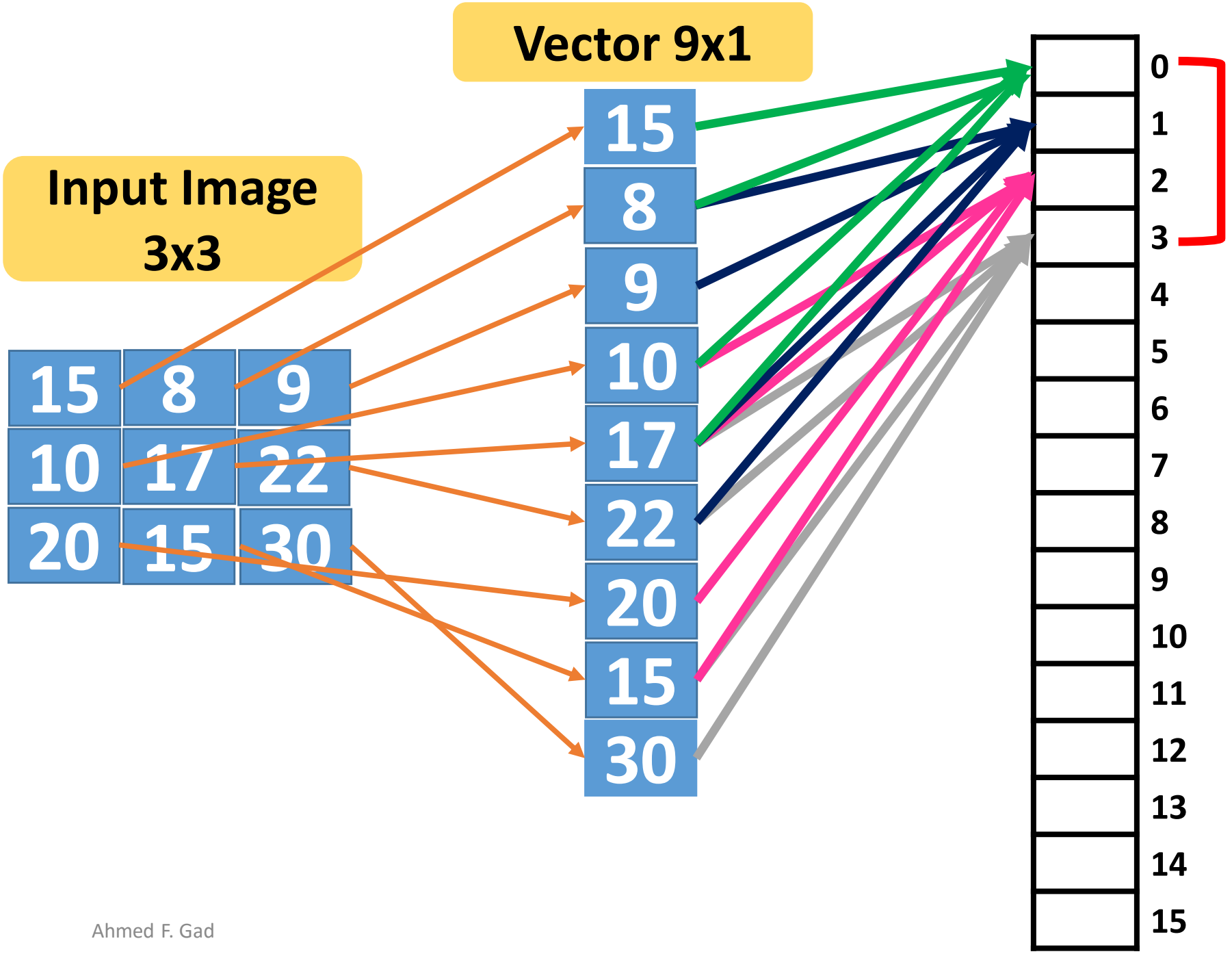
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Input Image
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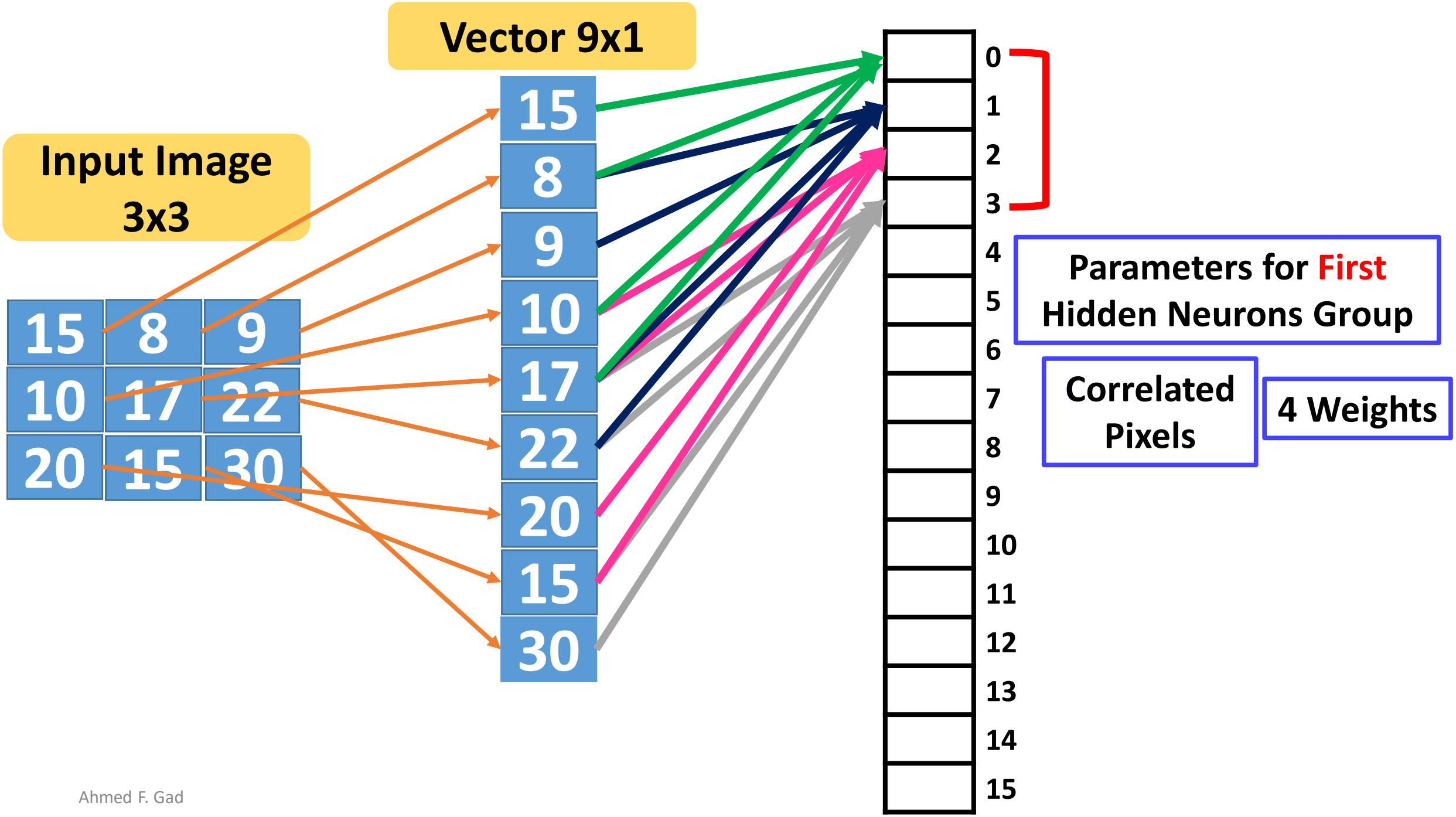
Vector 9x1
Input Image
3x3
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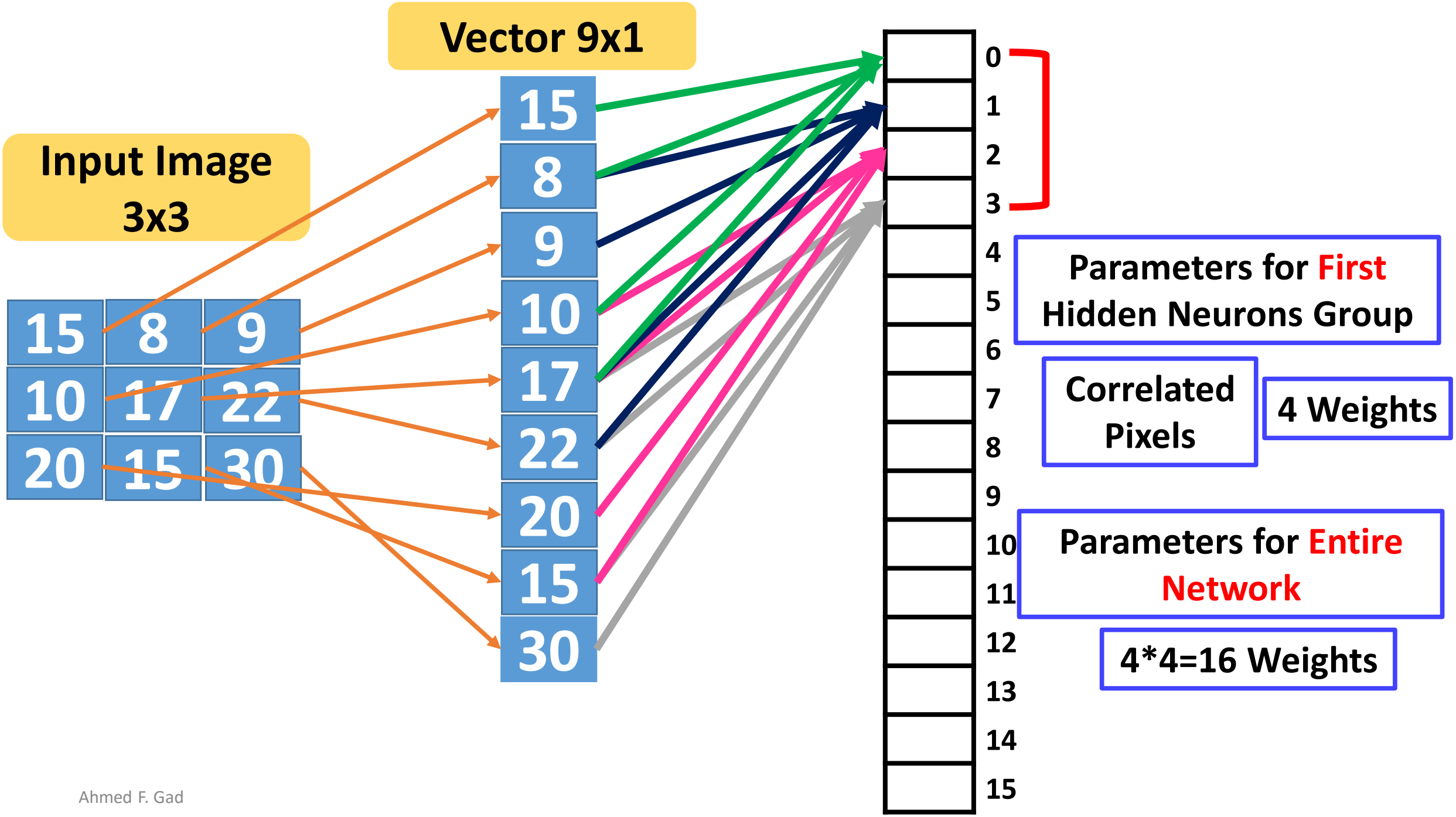
Parameters for First
Hidden Neurons Group
Correlated
Pixels
4 Weights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Input Image
3x3
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14
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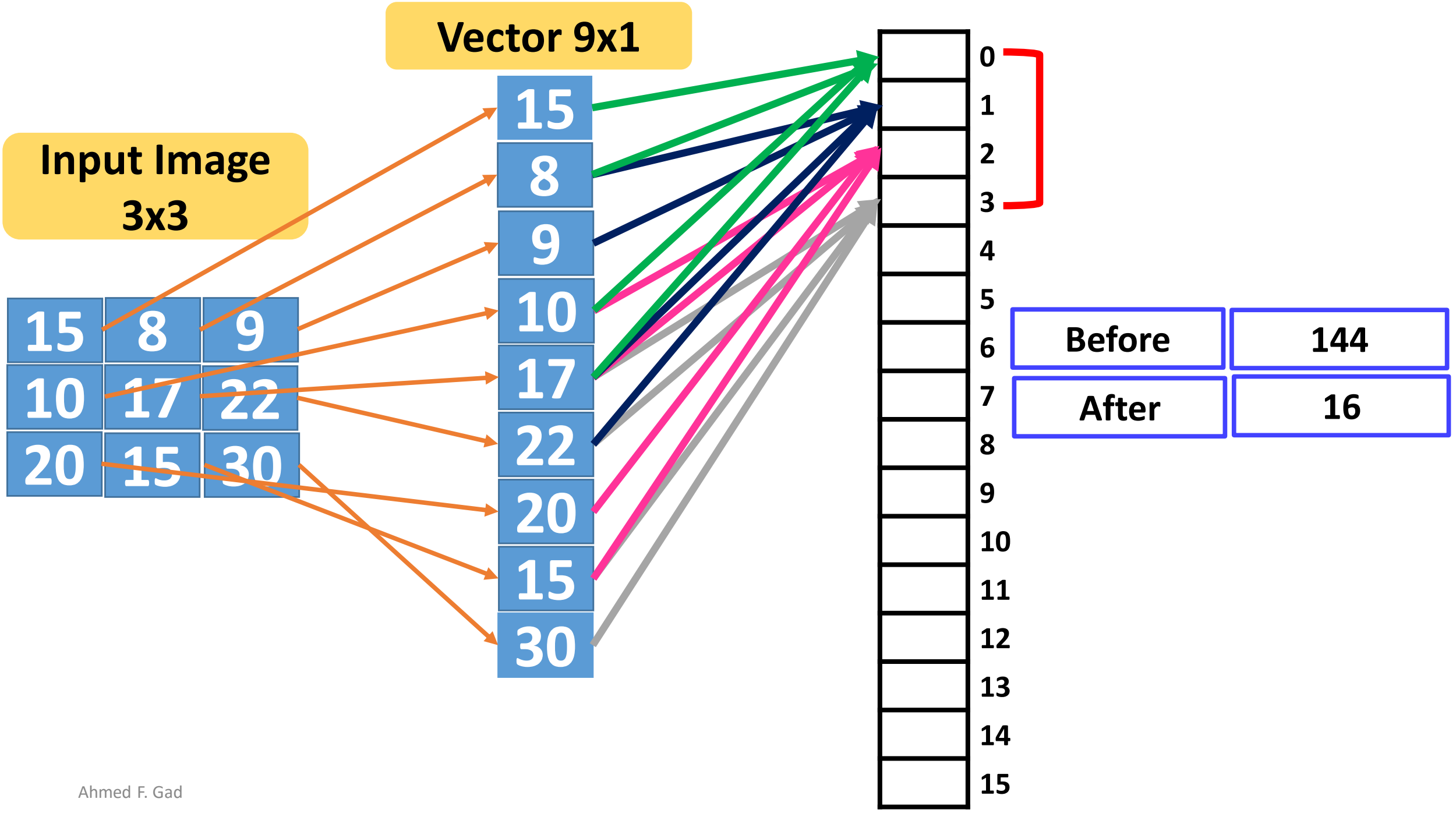
Parameters for First Hidden Neurons Group
Correlated Pixels
4 Weights
Parameters for Entire Network
4*4=16 Weights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Input Image
3x3
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8
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17
22
20
15
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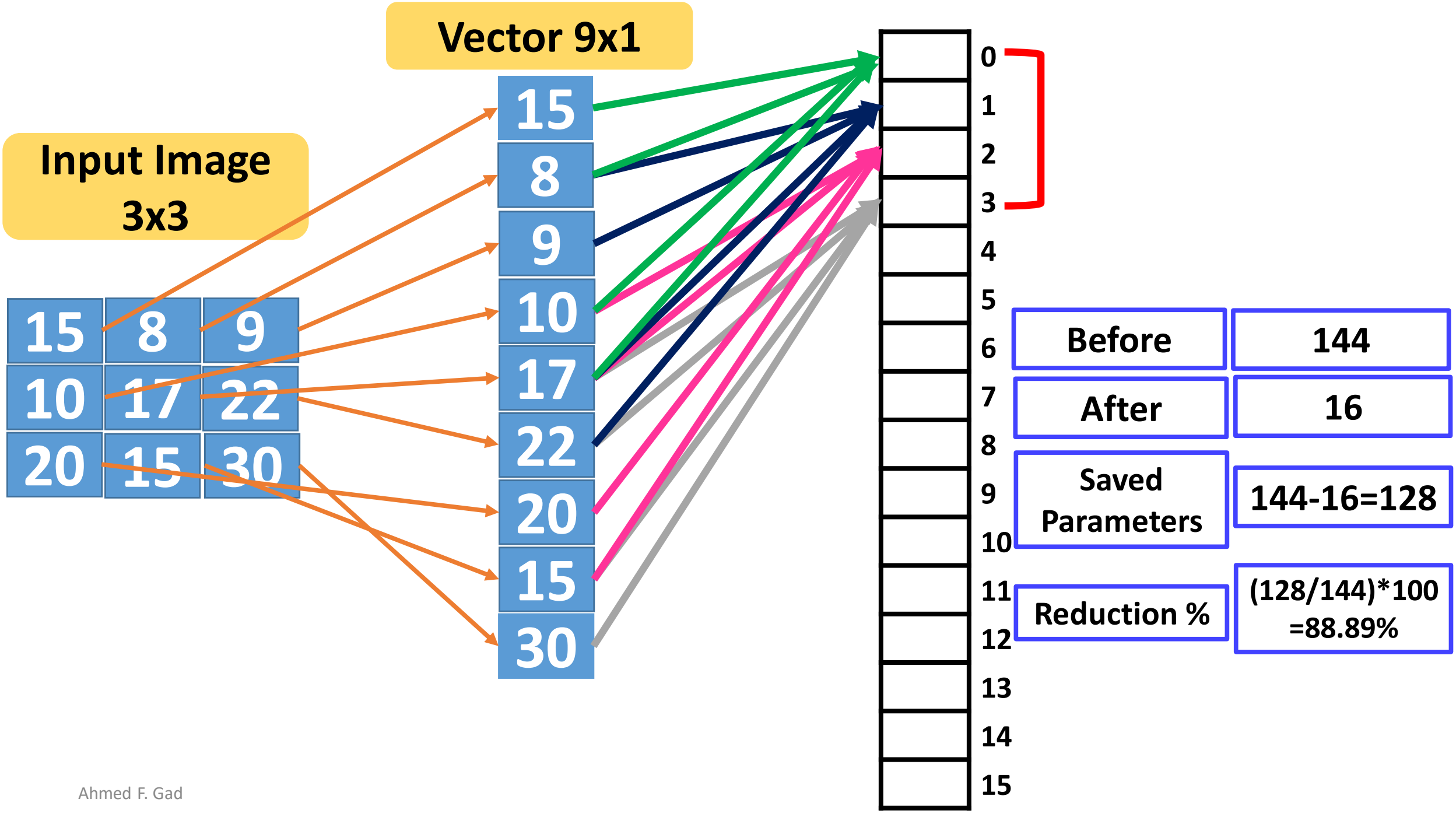
12
13
14
15
Before
144
After
16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Input Image
3x3
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10
17
22
20
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30
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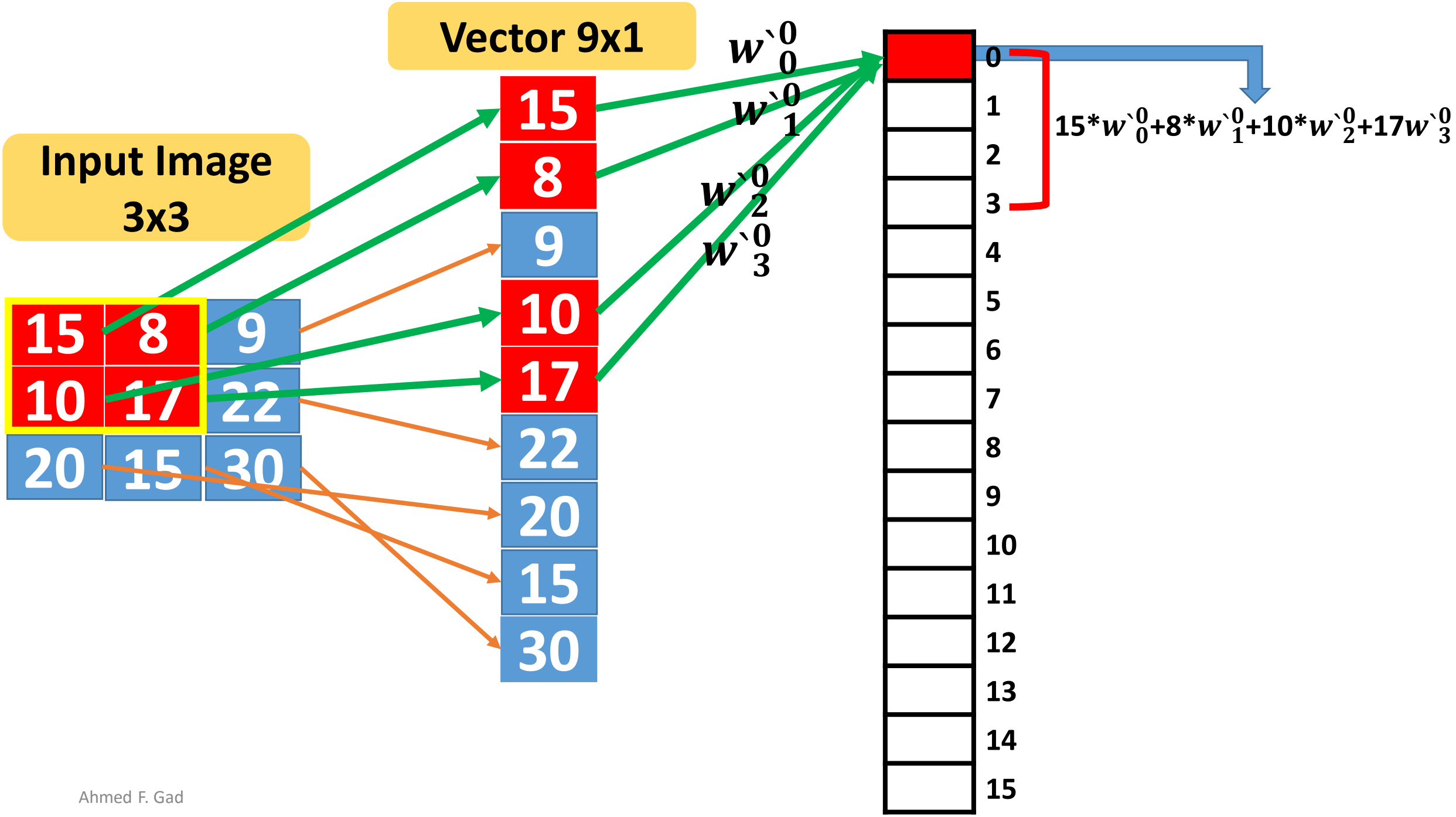
4
5
6
7
8
9
10
11
12
13
14
15
Before
144
After
16
Saved Parameters
144-16=128
Reduction %
(128/144)*100
=88.89%


Vector 9x1
Input Image
3x3
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8
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10
17
22
20
15
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$w`_1^0$
$w`_2^0$
$w`_3^0$
0
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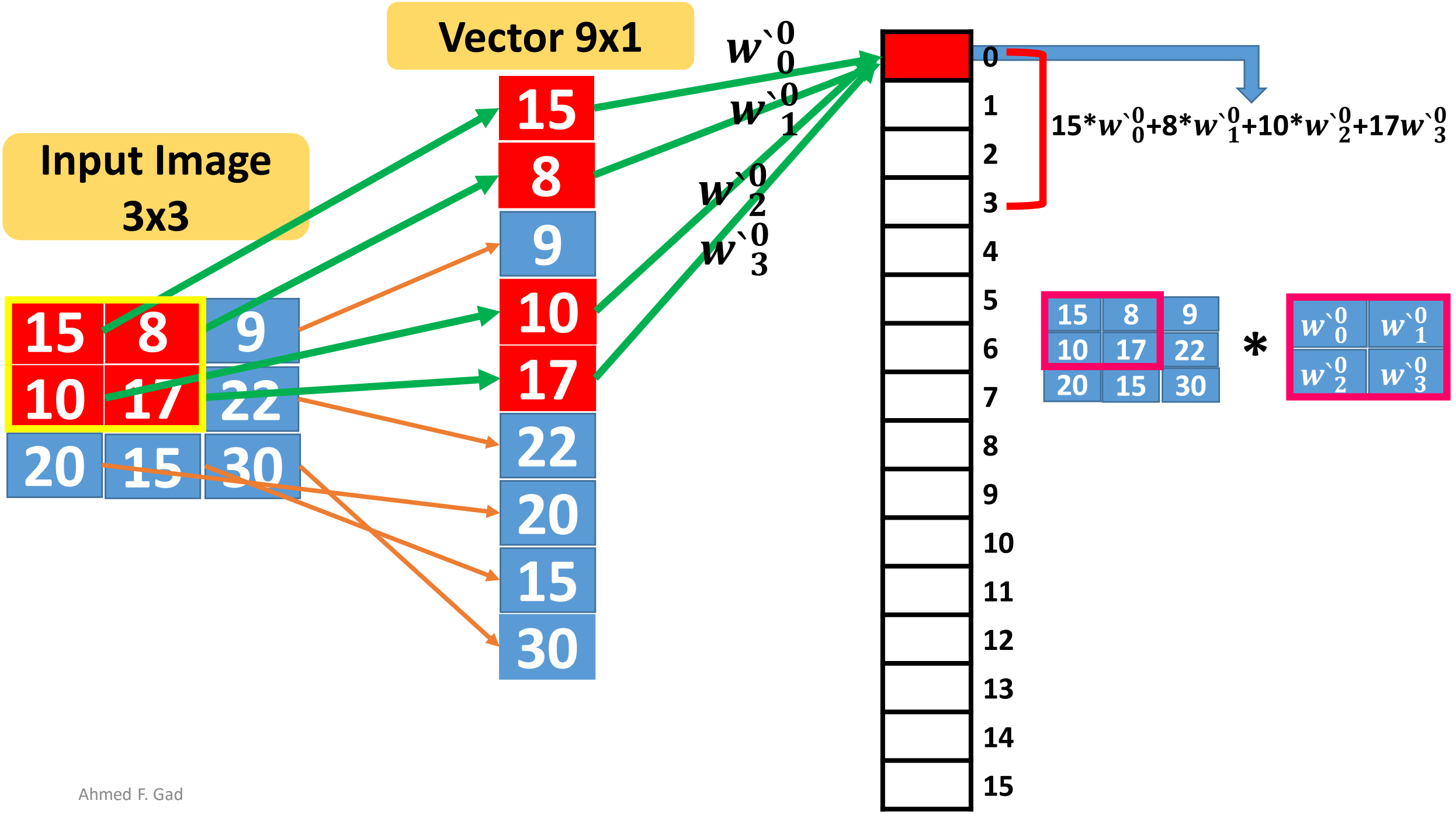
4
5
6
7
8
9
10
11
12
13
14
15
$15*w`_0^0+8*w`_1^0+10*w`_2^0+17w`_3^0$


Vector 9x1
Input Image
3x3
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17
22
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15
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$w`_0^0$
$w`_1^0$
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$w`_3^0$
0
1
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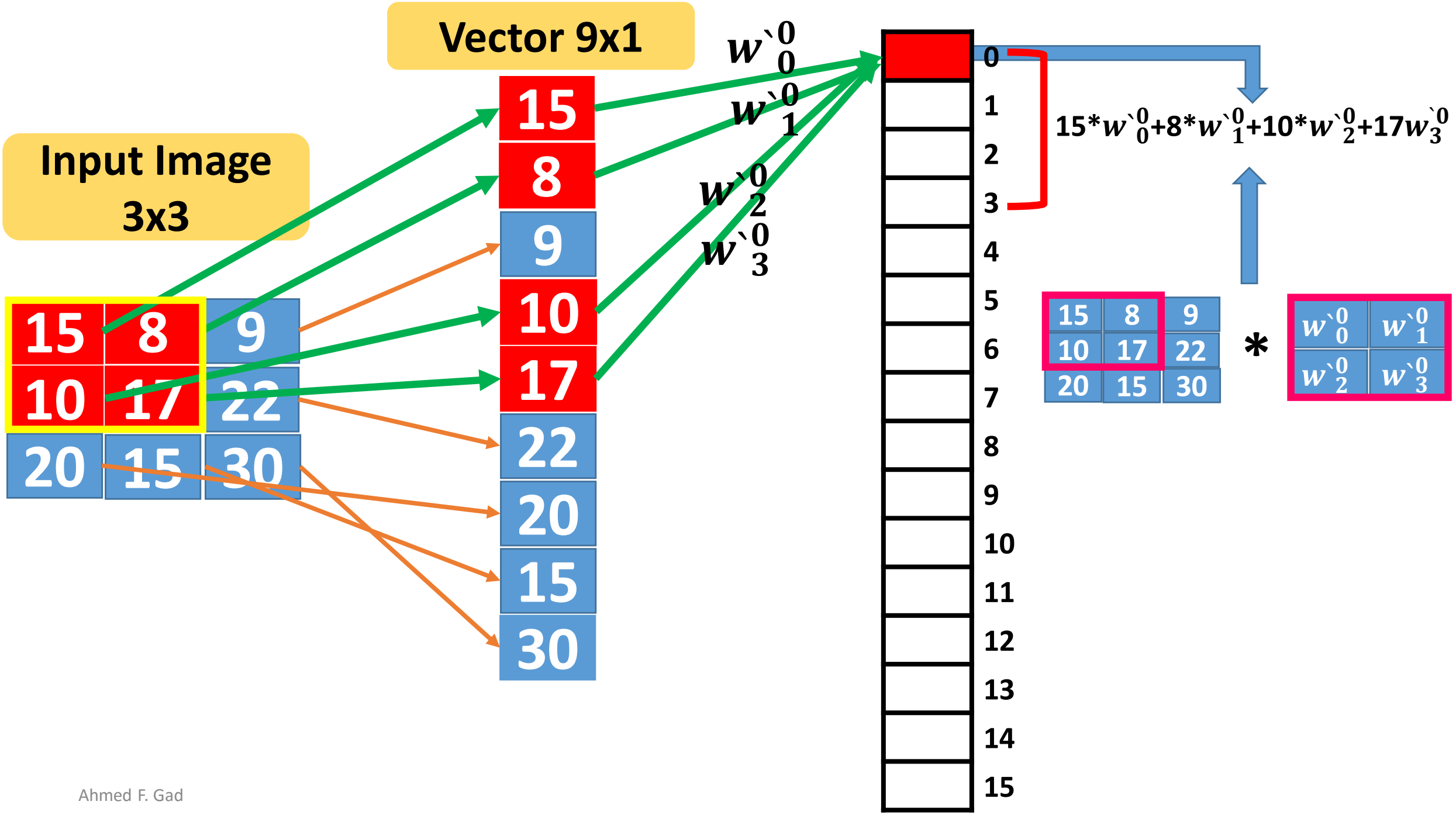
4
5
6
7
8
9
10
11
12
13
14
15
$15*w`_0^0+8*w`_1^0+10*w`_2^0+17w`_3^0$
15 8 9
10 17 22
20 15 30
*
$w`_0^0$ $w`_1^0$
$w`_2^0$ $w`_3^0$


Vector 9x1
Input Image
3x3
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17
22
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$w`_0^0$
$w`_1^0$
$w`_2^0$
$w`_3^0$
0
1
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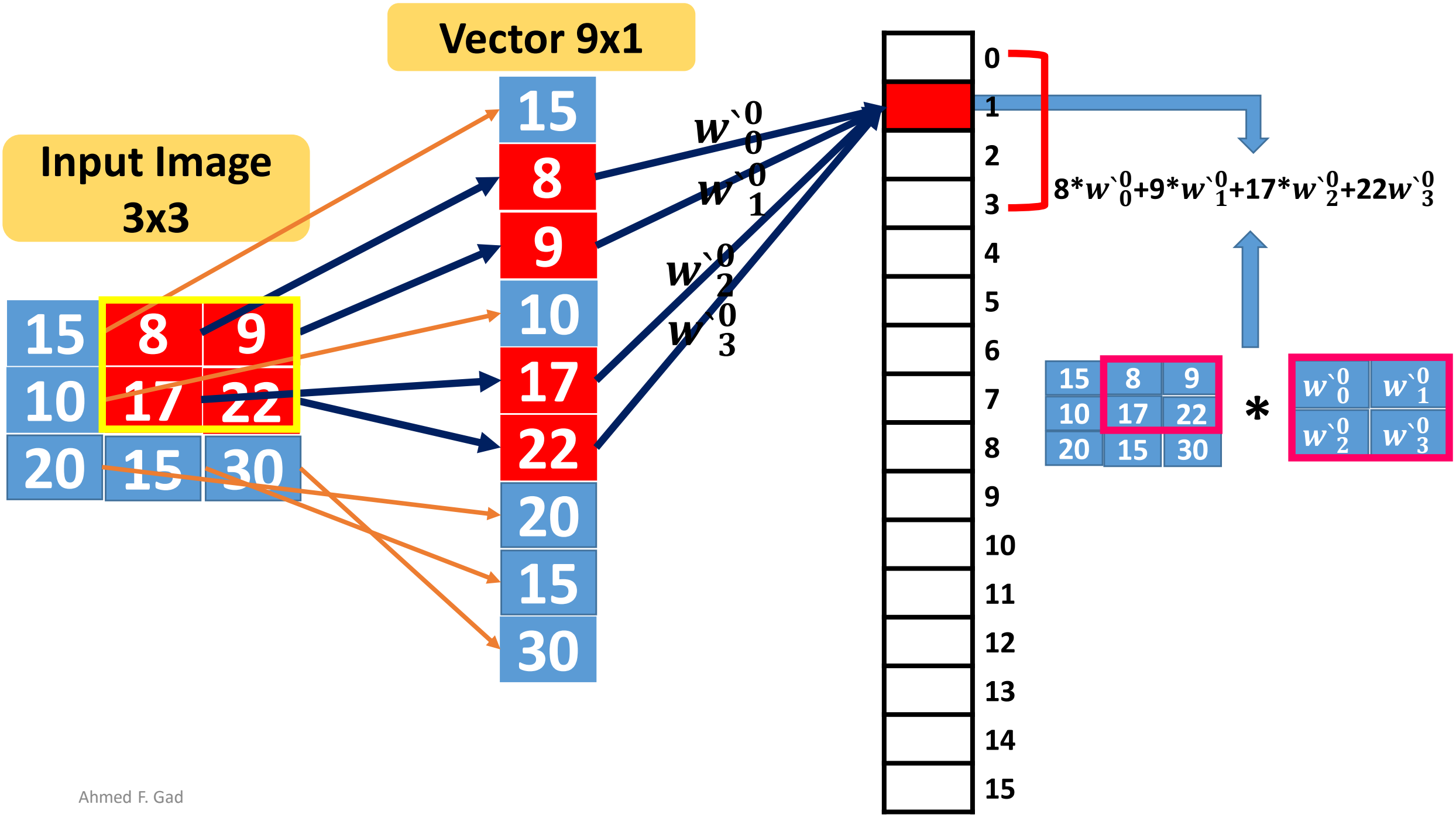
6
7
8
9
10
11
12
13
14
15
$15*w`_0^0+8*w`_1^0+10*w`_2^0+17w_3^{`0}$
15
8
9
10
17
22
20
15
30
*
$w`_0^0$
$w`_1^0$
$w`_2^0$
$w`_3^0$


Vector 9x1
Input Image
3x3
15
8
9
10
17
22
20
15
30
$w`_0^0$
$w`_1^0$
$w`_2^0$
$w`_3^0$
0
1
2
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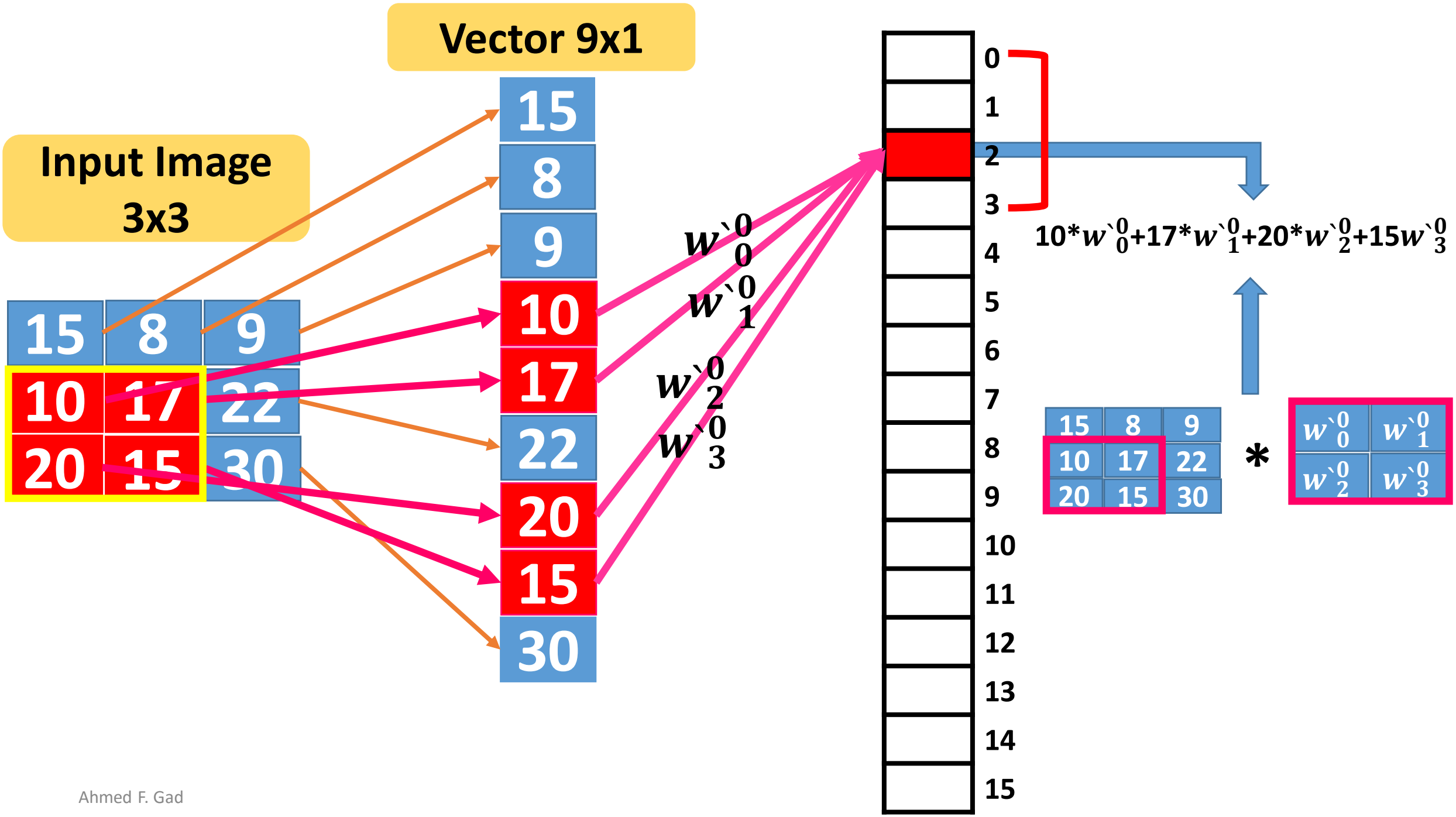
4
5
6
7
8
9
10
11
12
13
14
15
$8*w`_0^0+9*w`_1^0+17*w`_2^0+22w`_3^0$
*


Vector 9x1
Input Image
3x3
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10
17
22
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15
30
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$w`^0_1$
$w`^0_2$
$w`^0_3$
0
1
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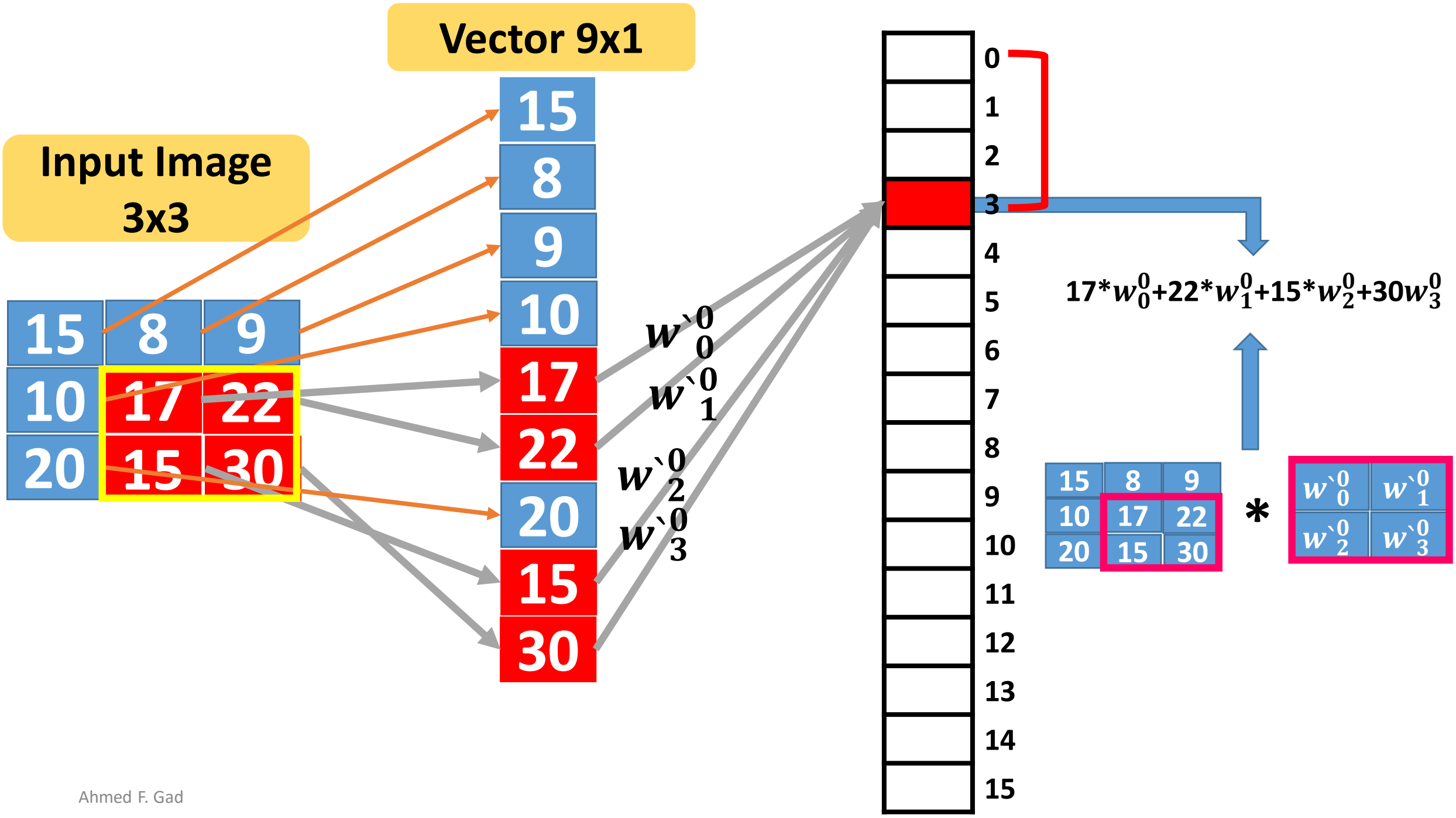
3
4
5
6
7
8
9
10
11
12
13
14
15
$10*w`^0_0+17*w`^0_1+20*w`^0_2+15w`^0_3$
15 8 9
10 17 22
20 15 30
*
$w`^0_0$ $w`^0_1$
$w`^0_2$ $w`^0_3$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Input Image
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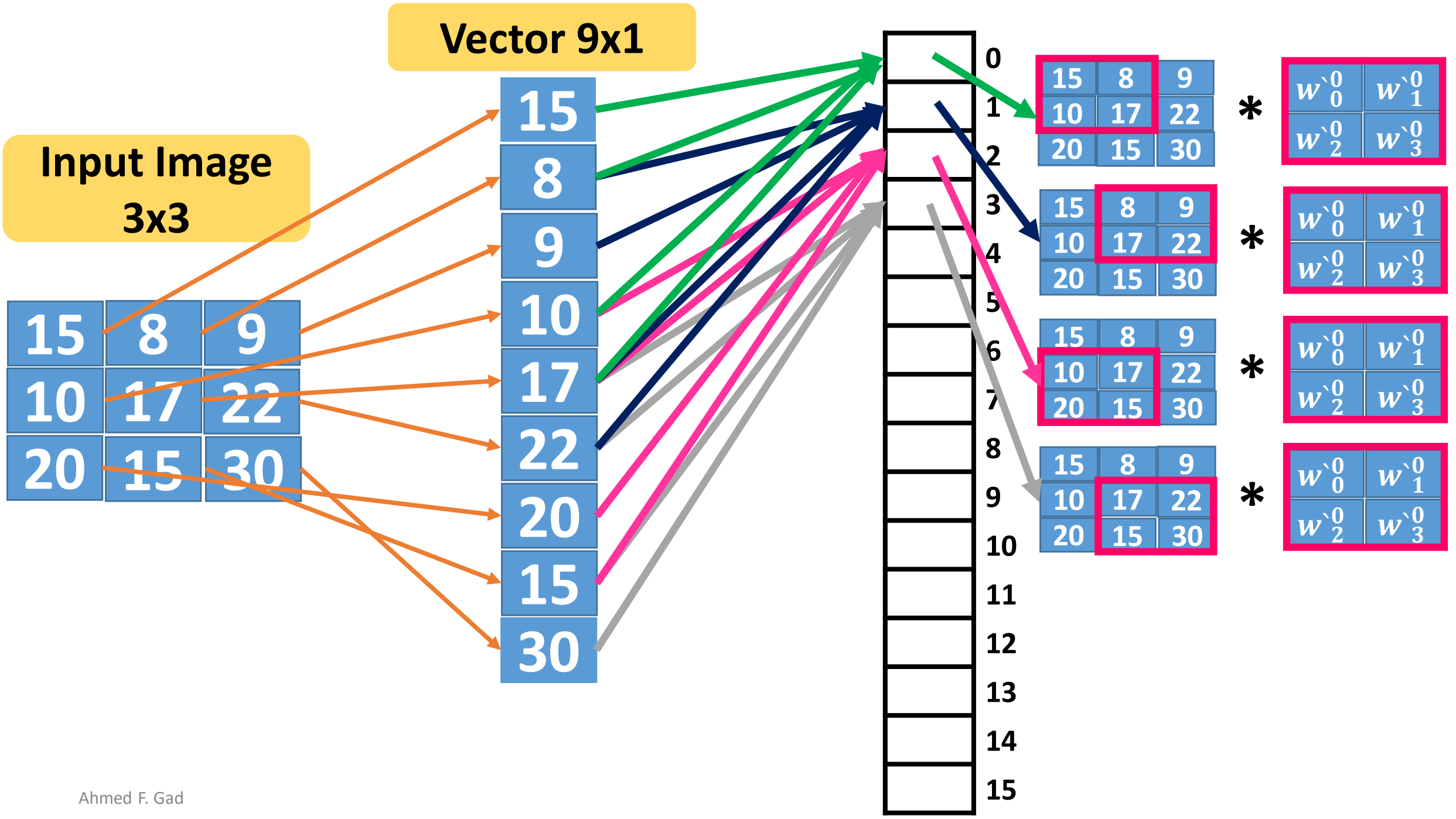
12
13
14
15
$w`_0^0$
$w`_1^0$
$w`_2^0$
$w`_3^0$
$17*w_0^0+22*w_1^0+15*w_2^0+30w_3^0$
*

Ahmed F. Gad


Vector 9x1
Input Image
3x3
15 8 9
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15 8 9
10 17 22
20 15 30
*
$w`_0^0$ $w`_1^0$
$w`_2^0$ $w`_3^0$
15 8 9
10 17 22
20 15 30
*
$w`_0^0$ $w`_1^0$
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10 17 22
20 15 30
*
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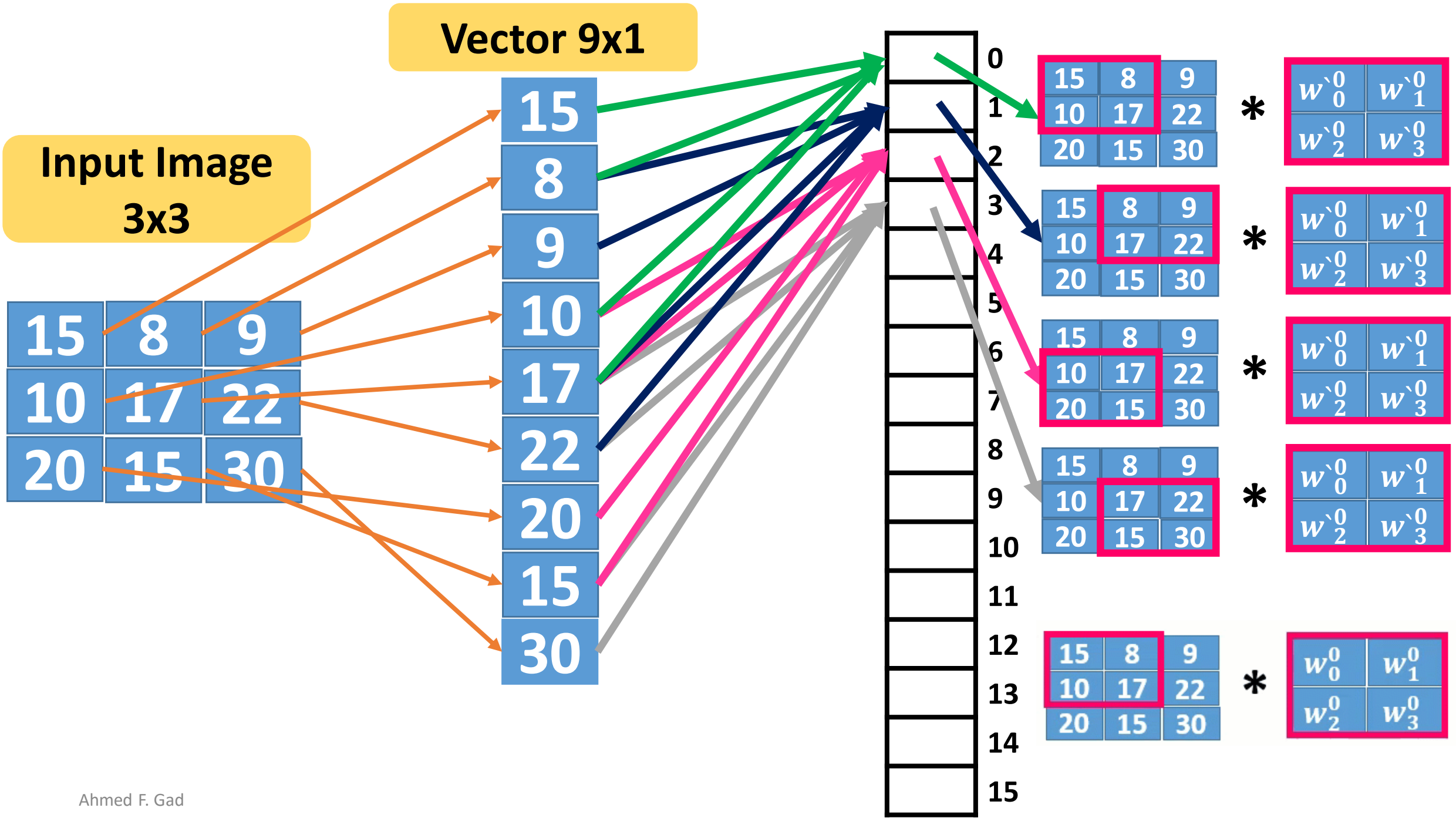
15 8 9
10 17 22
20 15 30
*
$w`_0^0$ $w`_1^0$
$w`_2^0$ $w`_3^0$


Vector 9x1
Input Image
3x3
15 8 9
10 17 22
20 15 30
15
8
9
10
17
22
20
15
30
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
15 8 9
10 17 22
20 15 30
*
$w`_0^0$ $w`_1^0$
$w`_2^0$ $w`_3^0$
15 8 9
10 17 22
20 15 30
*
$w`_0^0$ $w`_1^0$
$w`_2^0$ $w`_3^0$
15 8 9
10 17 22
20 15 30
*
$w`_0^0$ $w`_1^0$
$w`_2^0$ $w`_3^0$
15 8 9
10 17 22
20 15 30
*
$w`_0^0$ $w`_1^0$
$w`_2^0$ $w`_3^0$
15 8 9
10 17 22
20 15 30
*
w_0^0 w_1^0
w_2^0 w_3^0