Week1: Lecture 2: CNN

Vertical edge detection examples

$$\begin{bmatrix} 10 & 10 & 10 & 0 & 0 & 0 \\ 10 & 10 & 10 & 0 & 0 & 0 \\ 10 & 10 & 10 & 0 & 0 & 0 \\ 10 & 10 & 10 & 0 & 0 & 0 \\ 10 & 10 & 10 & 0 & 0 & 0 \\ 10 & 10 & 10 & 0 & 0 & 0 \end{bmatrix} * \begin{bmatrix} 1 & 0 & -1 \\ 1 & 0 & -1 \\ 1 & 0 & -1 \end{bmatrix} = \boxed{\begin{bmatrix} 0 & 30 & 30 & 0 \\ 0 & 30 & 30 & 0 \\ 0 & 30 & 30 & 0 \\ 0 & 30 & 30 & 0 \end{bmatrix}}$$

$$\begin{bmatrix} 0 & 0 & 0 & 10 & 10 & 10 \\ 0 & 0 & 0 & 10 & 10 & 10 \\ 0 & 0 & 0 & 10 & 10 & 10 \\ 0 & 0 & 0 & 10 & 10 & 10 \\ 0 & 0 & 0 & 10 & 10 & 10 \\ 0 & 0 & 0 & 10 & 10 & 10 \end{bmatrix} * \begin{bmatrix} 1 & 0 & -1 \\ 1 & 0 & -1 \\ 1 & 0 & -1 \end{bmatrix} = \begin{bmatrix} 0 & -30 & -30 & 0 \\ 0 & -30 & -30 & 0 \\ 0 & -30 & -30 & 0 \\ 0 & -30 & -30 & 0 \end{bmatrix}$$

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Vertical and Horizontal Edge Detection

1	0	-1
1	0	-1
1	0	-1

Vertical

1	1	1
0	0	0
-1	-1	-1

Horizontal

Vertical and Horizontal Edge Detection

1	0	-1
1	0	-1
1	0	-1

Vertical

1	1	1
0	0	0
-1	-1	-1

Horizontal

10	10	10	0	0	0
10	10	10	0	0	0
10	10	10	0	0	0
0	0	0	10	10	10
0	0	0	10	10	10
0	0	0	10	10	10

6 x 6

*

1	1	1
0	0	0
-1	-1	-1

=

0	0	0	0
30	10	-10	-30
30	10	-10	-30
0	0	0	0

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Learning to detect edges

1	0	-1
1	0	-1
1	0	-1

1	0	-1
2	0	-2
1	0	-1

Sobel filter

3	0	-3
10	0	-10
3	0	-3

Scharr filter

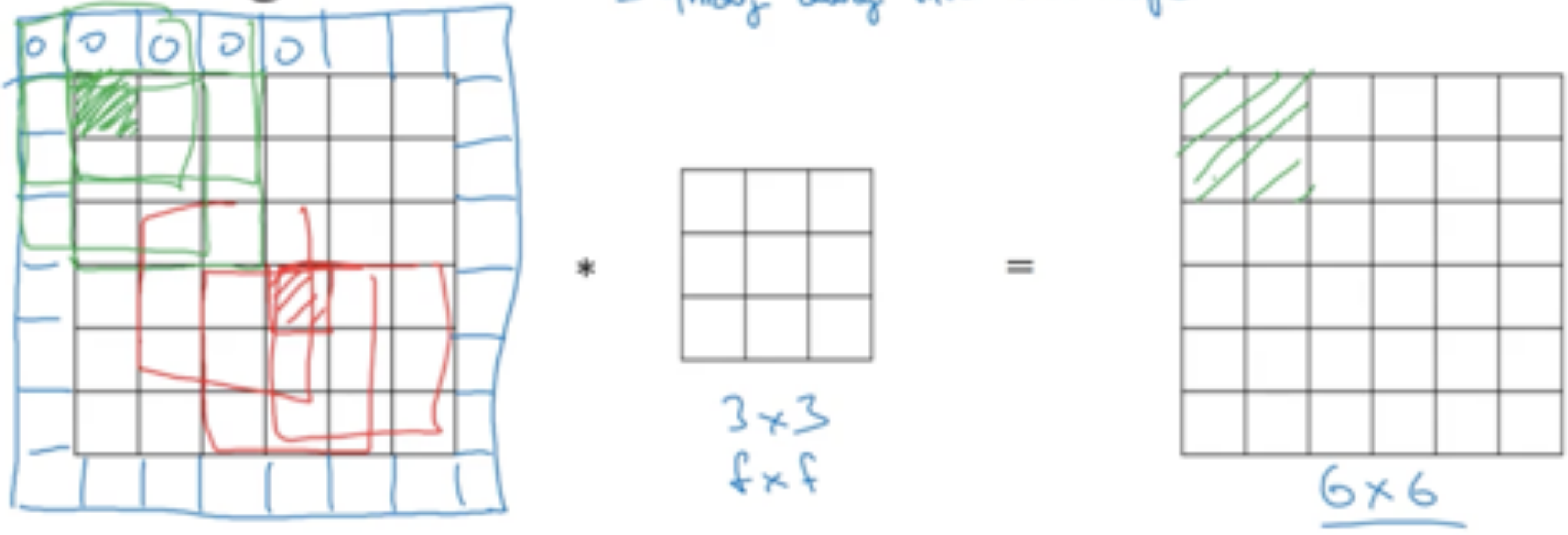
3	0	1	2	7	4
1	5	8	9	3	1
2	7	2	5	1	3
0	1	3	1	7	8
4	2	1	6	2	8
2	4	5	2	3	9

$*$

w_1	w_2	w_3
w_4	w_5	w_6
w_7	w_8	w_9

Padding

- shrinking output
- throw away info from edge



$6 \times 6 \rightarrow 8 \times 8$

$n \times n$

$n-f+1 \times n-f+1$ → ~~4×4~~

$6-3+1=4$

p = padding = 1

$n+2p-f+1 \times n+2p-f+1$

$6+2-3+1 \times \_\_\_ = 6 \times 6$

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Valid and Same convolutions

no padding

"Valid": $n \times n \quad * \quad f \times f \longrightarrow \underline{n-f+1} \times n-f+1$

$6 \times 6 \quad * \quad 3 \times 3 \longrightarrow 4 \times 4$

"Same": Pad so that output size is the same as the input size.

$n+2p-f+1 \times n+2p-f+1$

f is usually odd

$\cancel{n}+2p-f+1 = \cancel{n} \Rightarrow \underline{p} = \frac{f-1}{2}$

$3 \times 3 \quad p = \frac{3-1}{2} = 1 \quad \Big| \quad \underset{f=5}{5 \times 5} \quad p = 2$

Andrew Ng

7:59 / 9:49

Valid and Same convolutions

no padding

"Valid": $n \times n \quad * \quad f \times f \longrightarrow n-f+1 \times n-f+1$

$6 \times 6 \quad * \quad 3 \times 3 \longrightarrow 4 \times 4$

"Same": Pad so that output size is the same as the input size.

$n+2p-f+1 \times n+2p-f+1$

$\cancel{n}+2p-f+1 = \cancel{n} \Rightarrow \boxed{p = \frac{f-1}{2}}$

$3 \times 3 \quad p = \frac{3-1}{2} = 1 \quad \vert \quad \underset{f=5}{5 \times 5} \quad p=2$

f is usually odd

1×1

3×3

5×5

7×7

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Strided convolution

2	3	7^{3}	4^{4}	6^{4}	2	9
6	6	9^{1}	8^{0}	7^{2}	4	3
3	4	8^{-1}	3^{0}	8^{3}	9	7
7	8	3	6	6	3	4
4	2	1	8	3	4	6
3	2	4	1	9	8	3
0	1	3	9	2	1	4

7×7

*

3	4	4
1	0	2
-1	0	3

3×3

stride = 2

=

91	100	

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Strided convolution

2	3	7	4	6	2	9
6	6	9	8	7	4	3
3^{3}	4^{4}	8^{4}	3	8	9	7
7^{1}	8^{0}	3^{2}	6	6	3	4
4^{-1}	2^{0}	1^{3}	8	3	4	6
3	2	4	1	9	8	3
0	1	3	9	2	1	4

7×7

$*$

3	4	4
1	0	2
-1	0	3

3×3

stride = 2

$=$

91	100	83

Strided convolution

2	3	7	4	6	2	9
6	6	9	8	7	4	3
3	4	8	3	8	9	7
7	8	3	6	6	3	4
4	2	1	8	3^{3}	4^{4}	6^{4}
3	2	4	1	9^{1}	8^{0}	3^{2}
0	1	3	9	2^{-1}	1^{0}	4^{3}

7×7

*

3	4	4
1	0	2
-1	0	3

3×3

stride = 2

=

91	100	83
69	91	127
44	72	74

3×3

$n \times n$ * $f \times f$

padding p stride s

$s = 2$

$$\frac{n+2p-f}{s} + 1 \quad \times \quad \frac{n+2p-f}{s} + 1$$

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Summary of convolutions

$n \times n$ image $\quad f \times f$ filter

padding $p \quad$ stride s

Output size:

$$\left\lfloor \frac{n+2p-f}{s} + 1 \right\rfloor \times \left\lfloor \frac{n+2p-f}{s} + 1 \right\rfloor$$

Technical note on cross-correlation vs. convolution

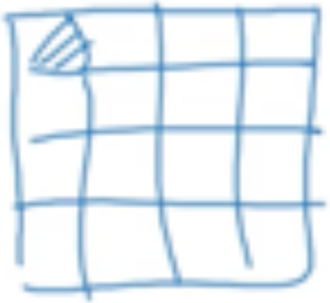
Convolution in math textbook:

2^{7}	3^{2}	7^{5}	4	6	2
6^{9}	6^{0}	9^{4}	8	7	4
3^{-1}	4^{1}	8^{3}	3	8	9
7	8	3	6	6	3
4	2	1	8	3	4
3	2	4	1	9	8

$*$

3	4	5
1	0	2
-1	9	7

=



At 4:44 when Andrew was explaining the technical note on cross-correlation vs convolution, the flipping of the filter was incorrect.

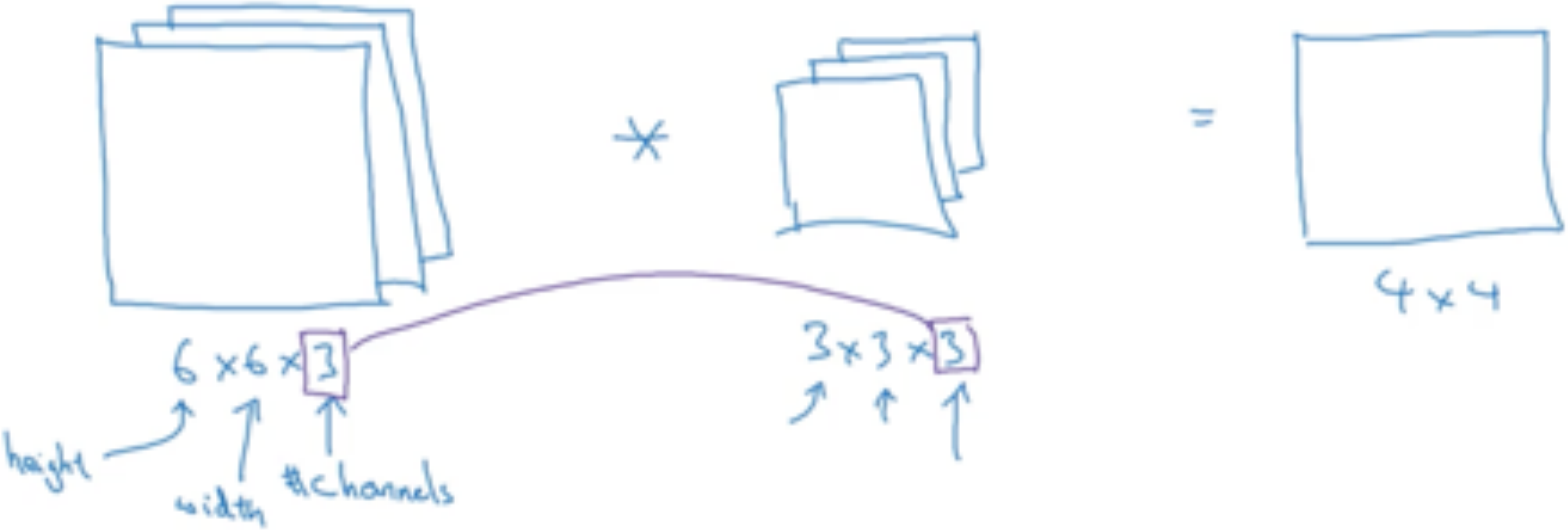
Originally, it was:

3	4	5
1	0	2
-1	9	7

The correct filter after flipping vertically and horizontally would be:

7	9	-1
2	0	1
5	4	3

Convolutions on RGB images



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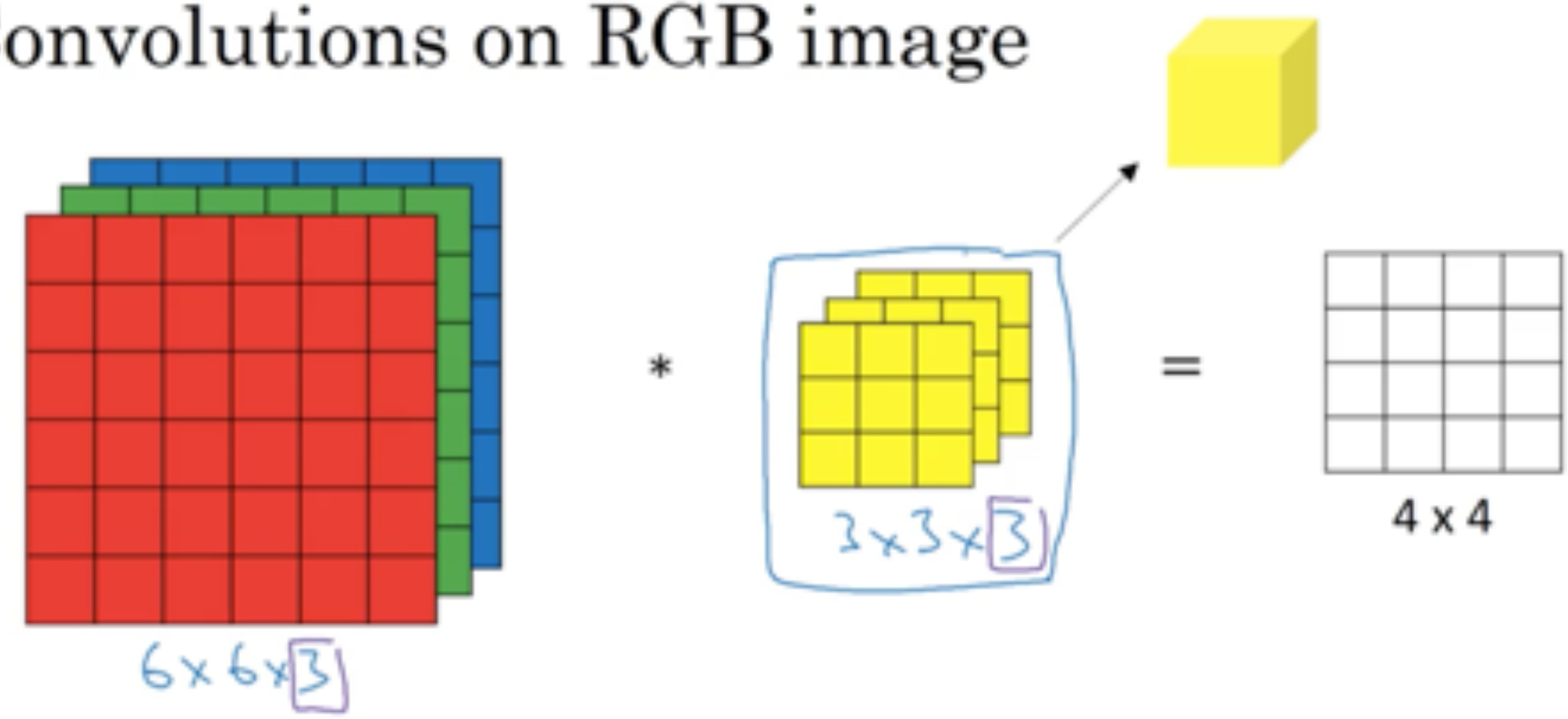
Convolutions on RGB image



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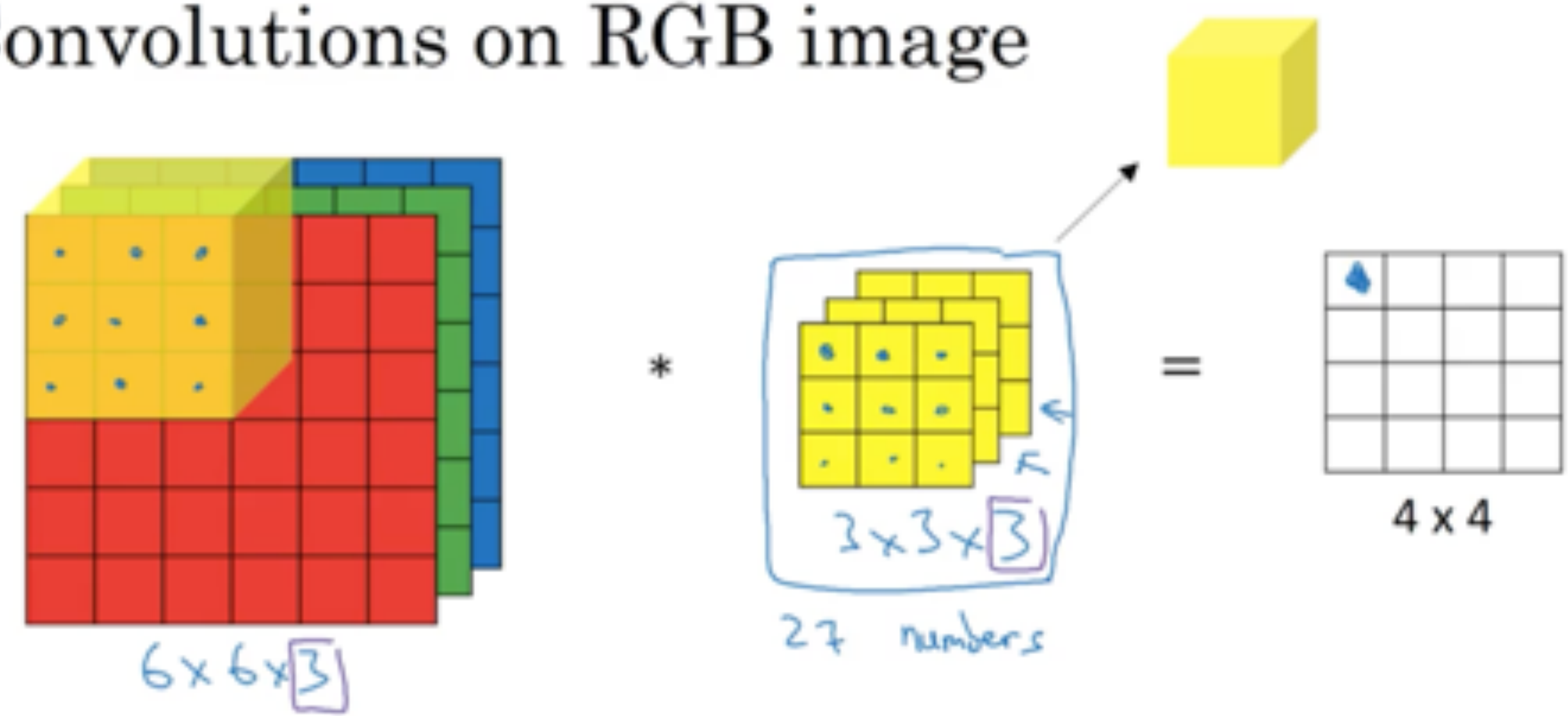
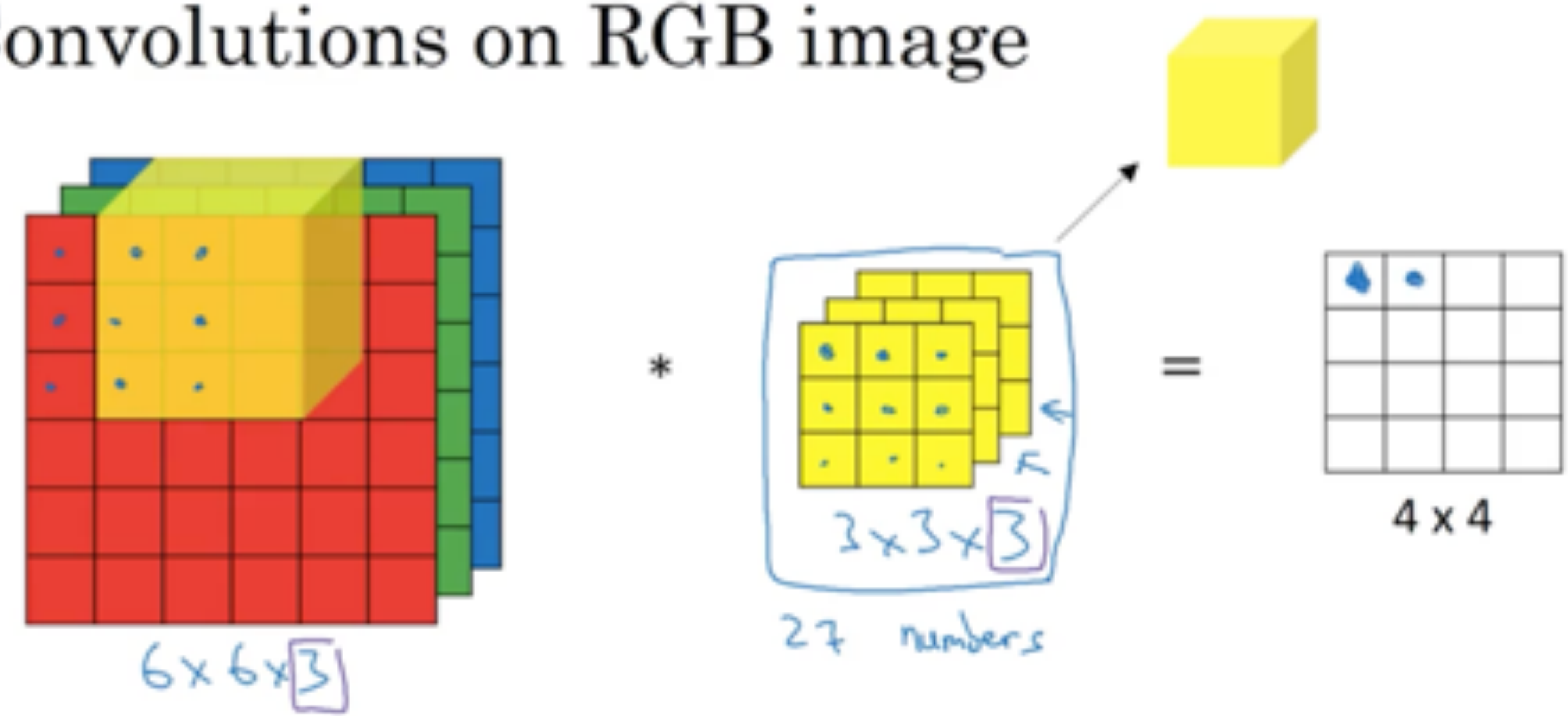
Convolutions on RGB image



Convolutions on RGB image



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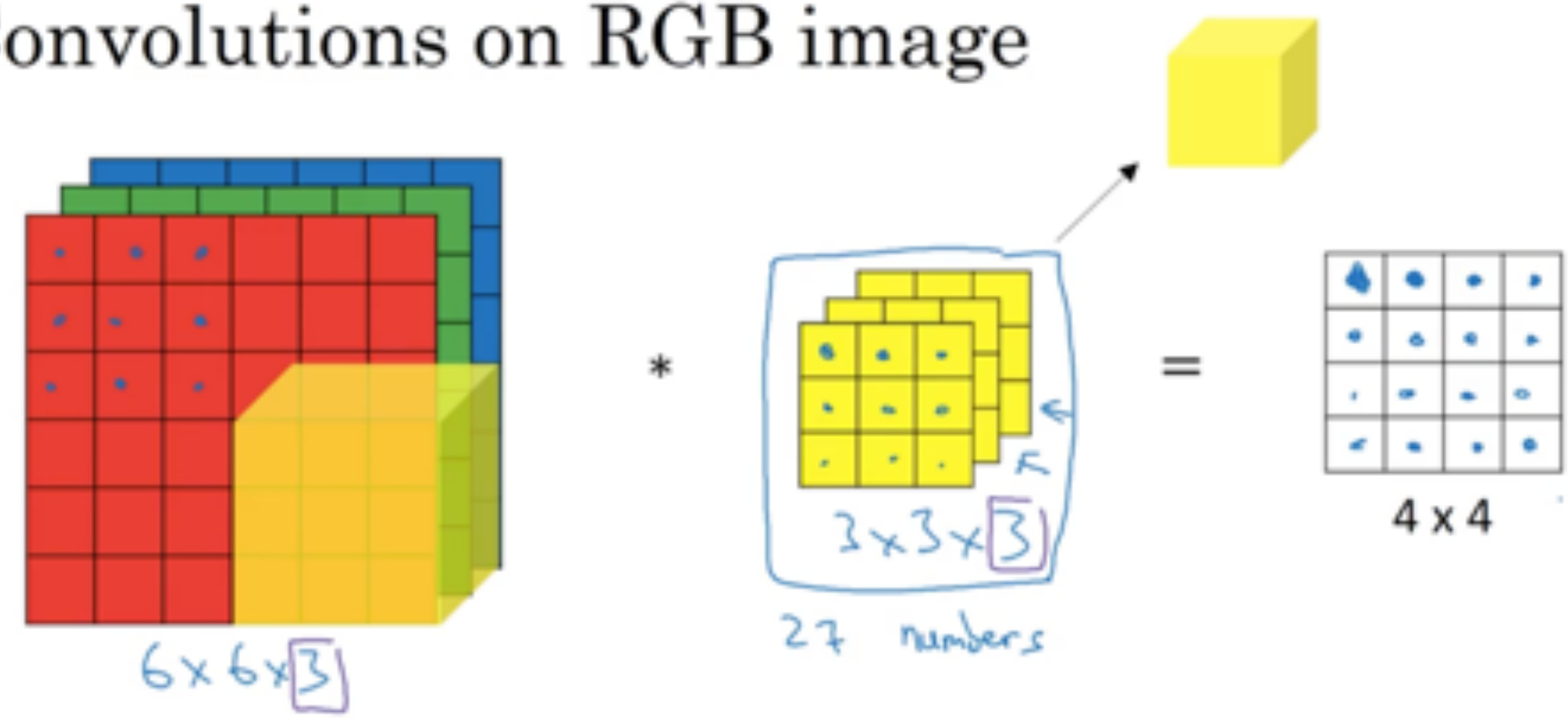
Convolutions on RGB image



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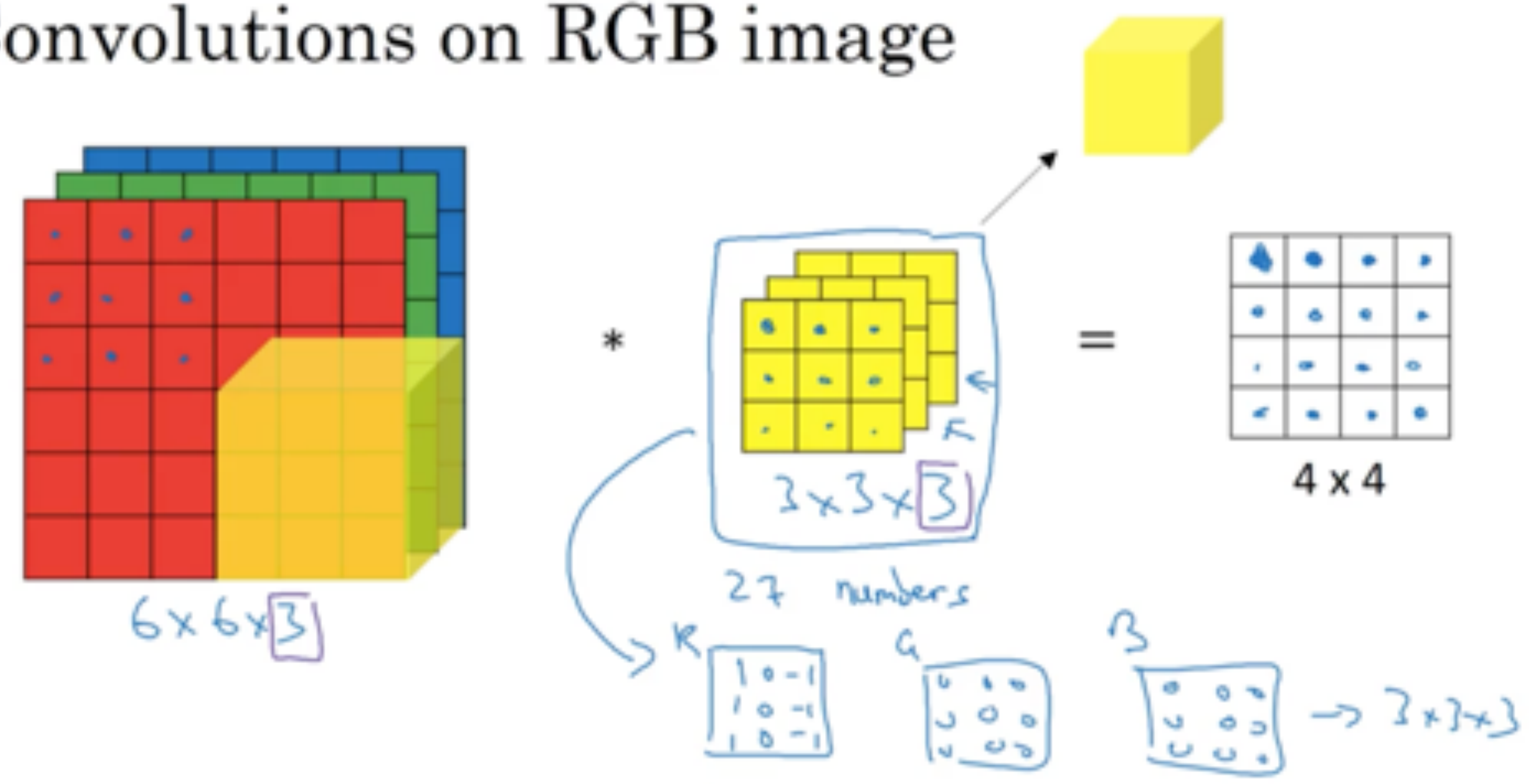
Convolutions on RGB image



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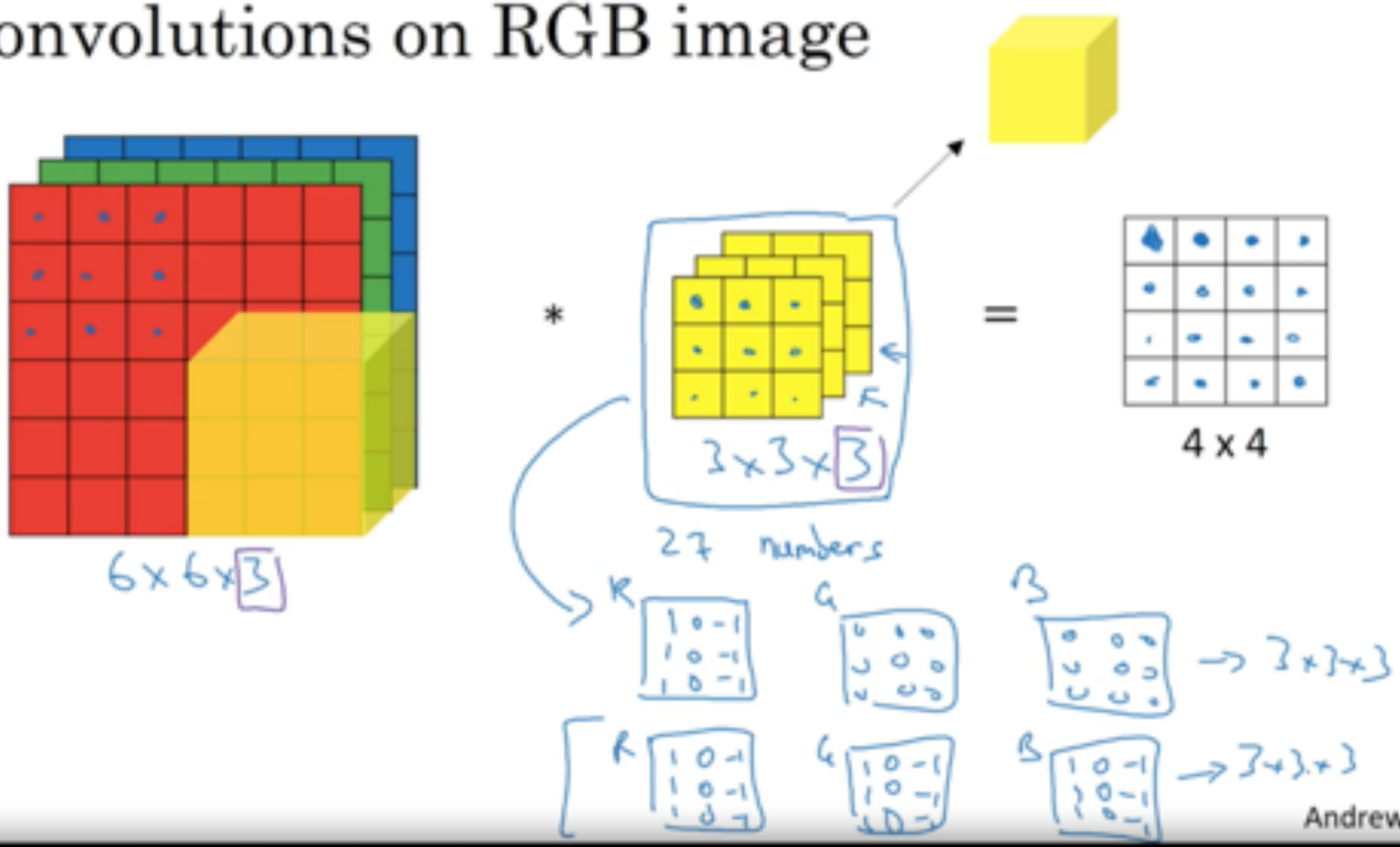
Convolutions on RGB image



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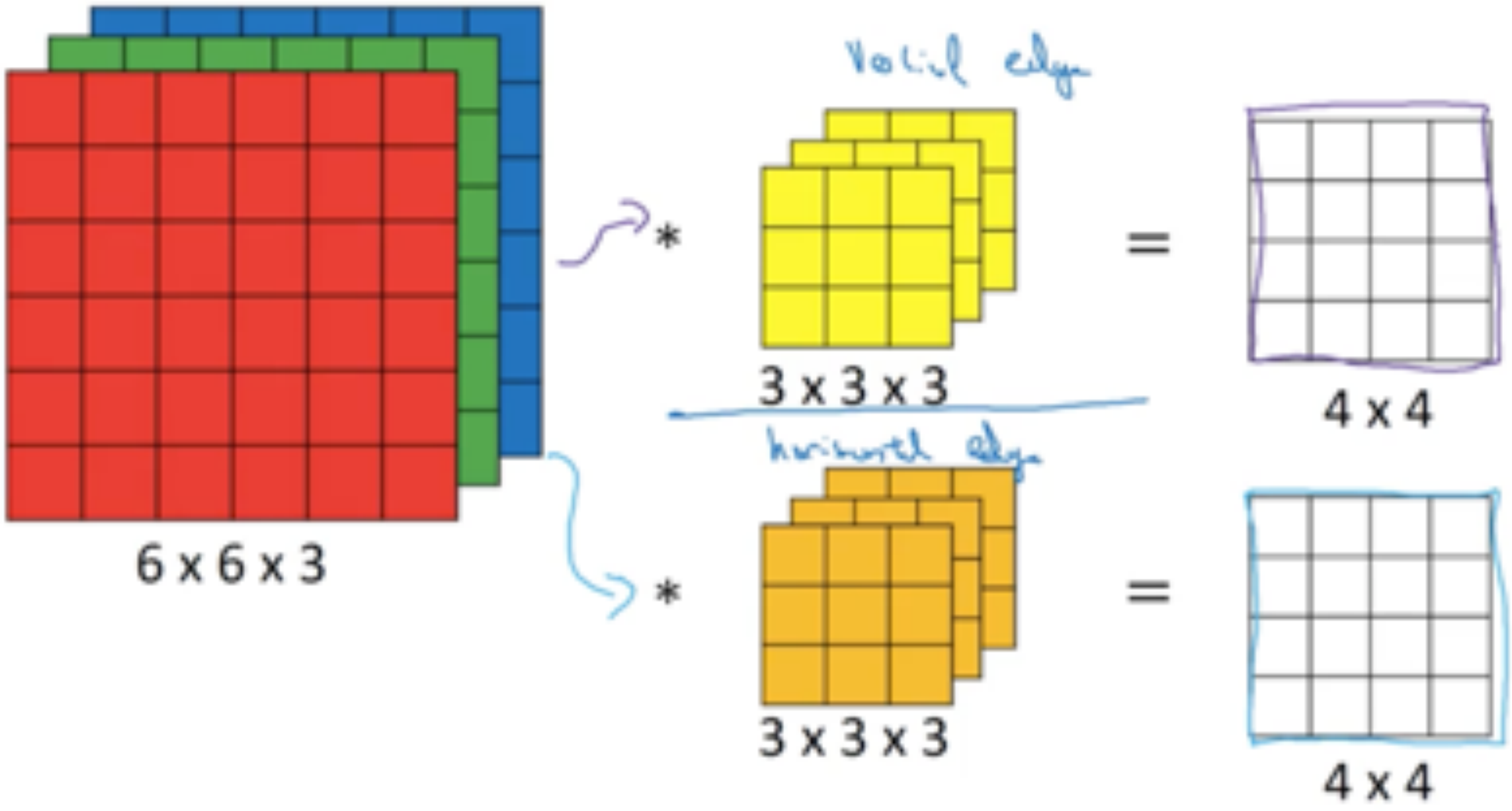
Multiple filters



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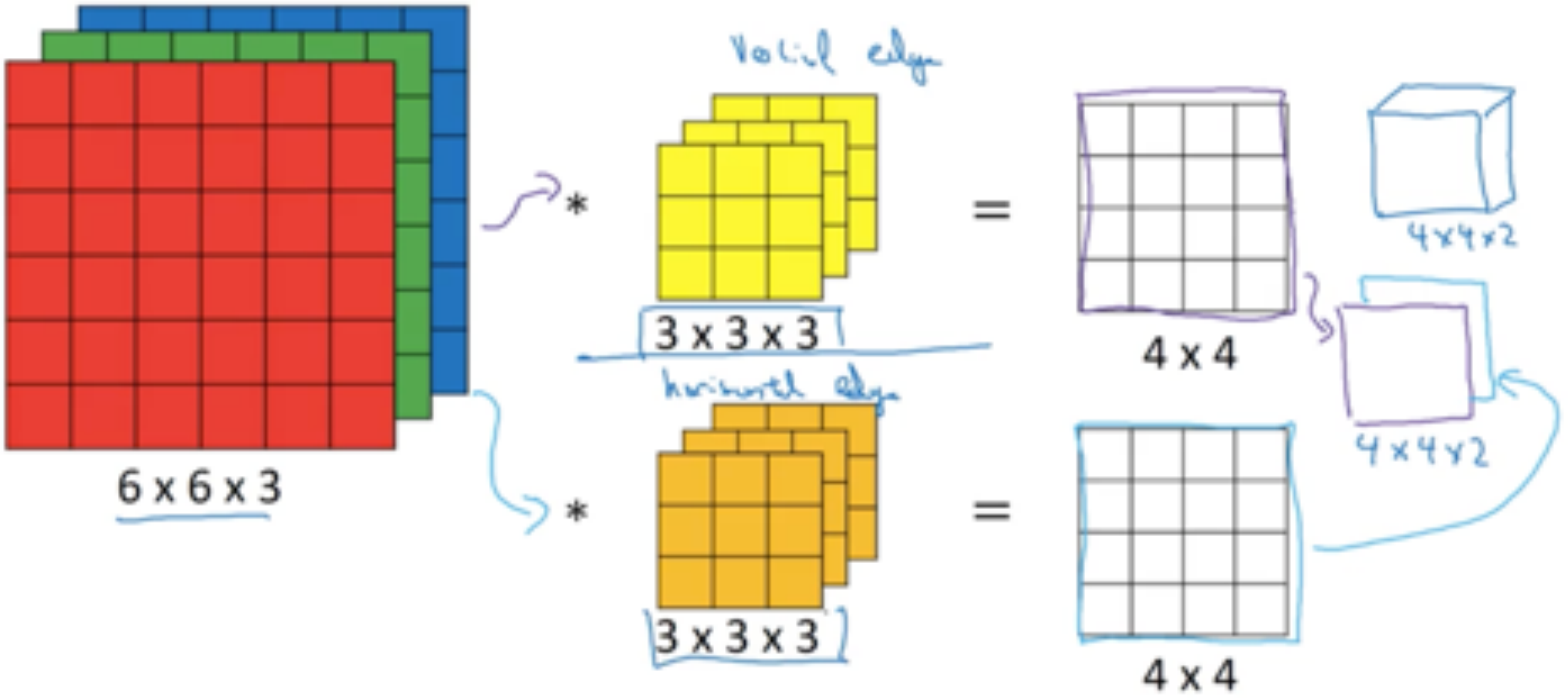
Multiple filters



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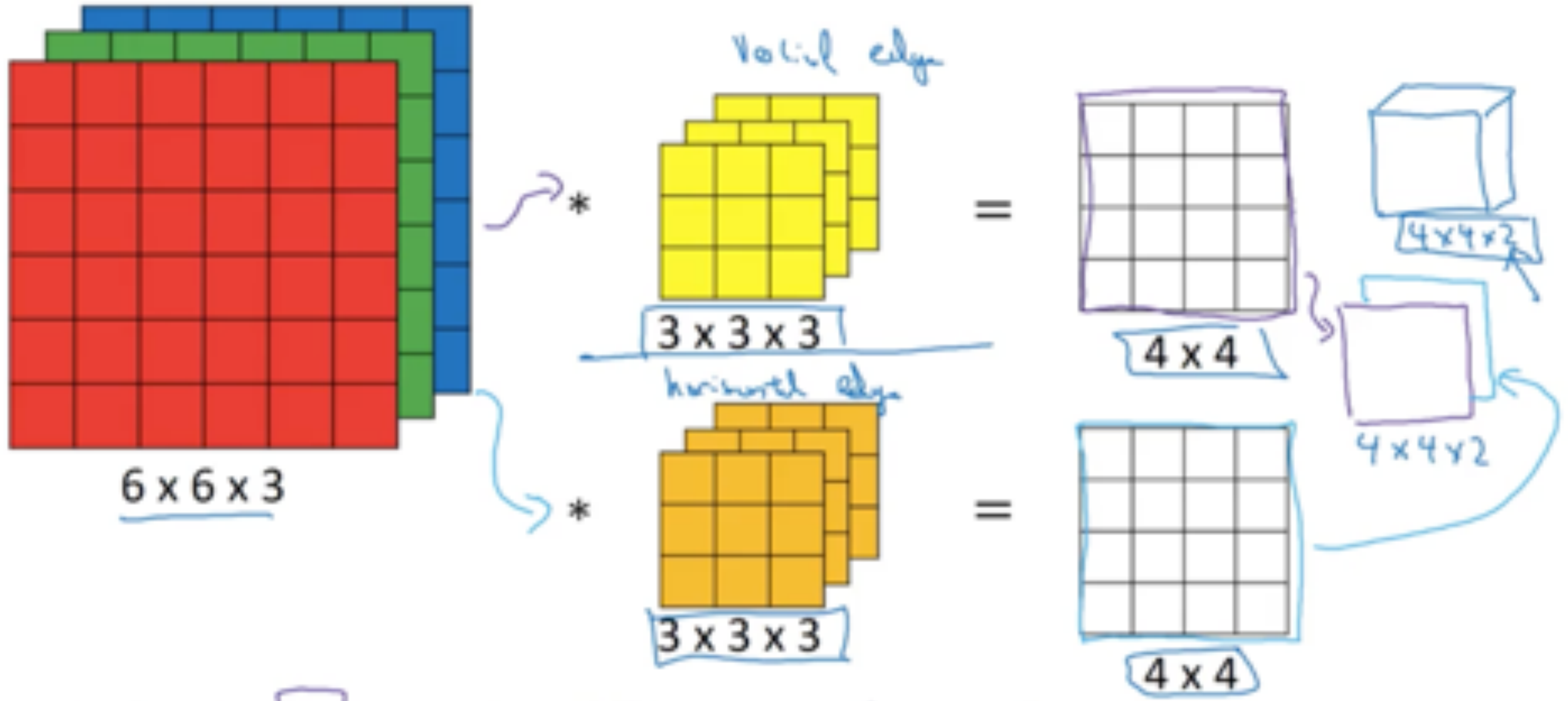
Multiple filters



Summary: $n \times n \times \boxed{n_c} \ * \ f \times f \times \boxed{n_c} \ \rightarrow \ \underline{n-f+1} \times \underline{n-f+1} \times n_c'$

$6 \times 6 \times 3 \qquad 3 \times 3 \times 3 \qquad 4 \times 4 \times 2$ ↑ #filters

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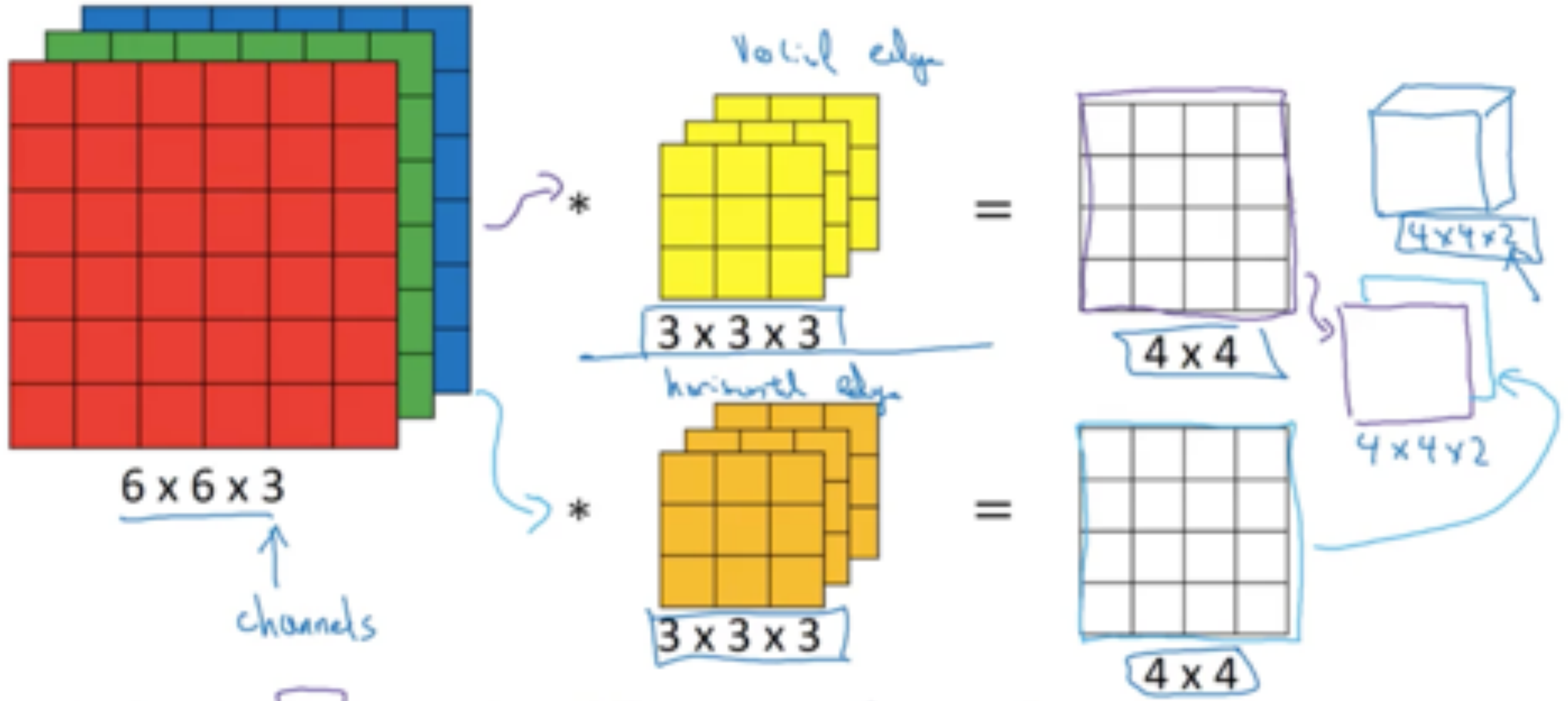
9:17 / 10:44

Multiple filters



Summary: $n \times n \times \boxed{n_c}$ $*$ $f \times f \times \boxed{n_c}$ $\rightarrow$ $\underline{n-f+1} \times \underline{n-f+1} \times n_c'$

$6 \times 6 \times 3$ $\qquad$ $3 \times 3 \times 3$ $\qquad$ $4 \times 4 \times 2$ # filters

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