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Convolutional Neural Networks

Computer vision

Computer Vision Problems

Image Classification



64x64



Cat? (0/1)



Neural Style Transfer



Object detection



Andrew Ng

Deep Learning on large images



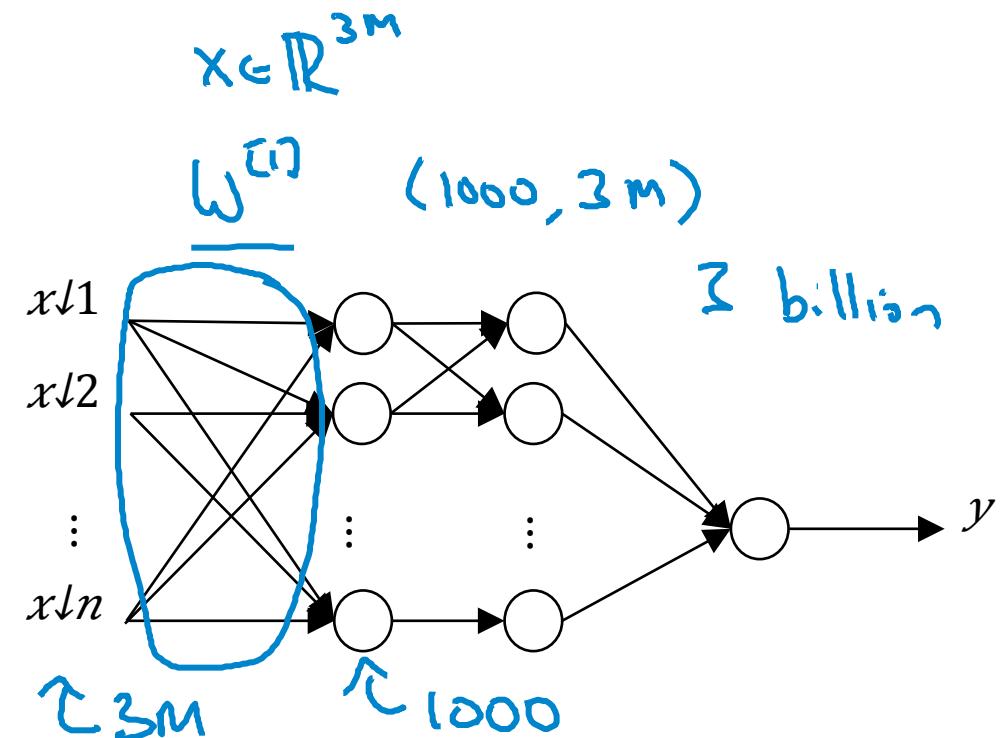
$64 \times 64 \times 3$

→ Cat? (0/1)

12288



$1000 \times 1000 \times 3$
= 3 million



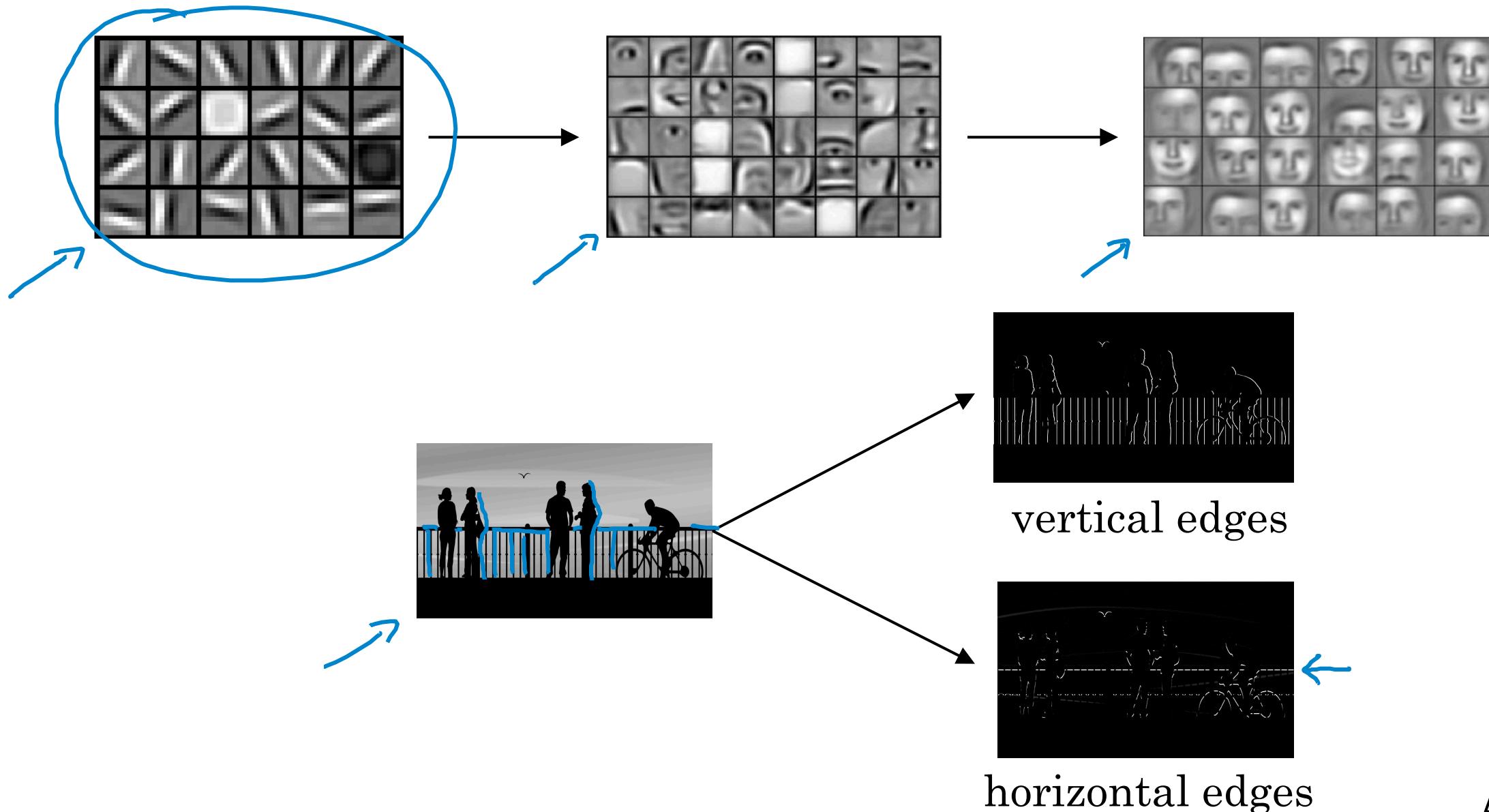


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Convolutional Neural Networks

Edge detection
example

Computer Vision Problem

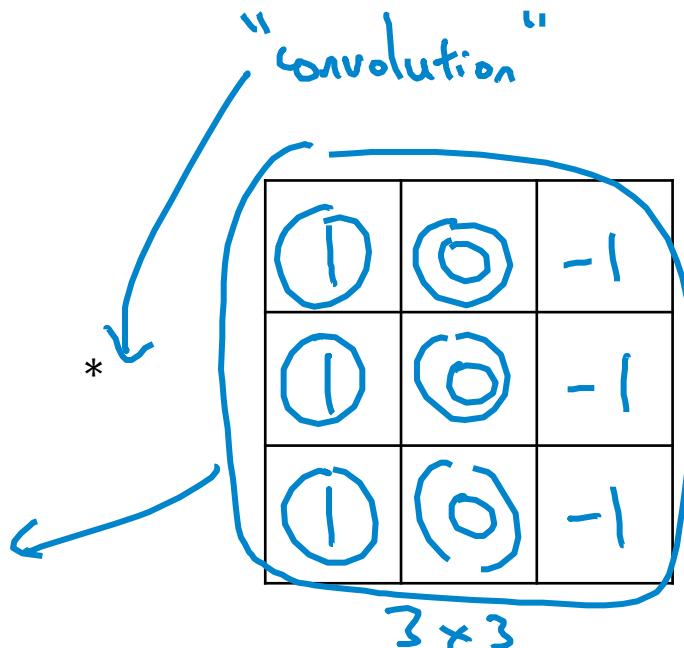


Vertical edge detection

$$3 \times 1 + 1 \times 1 + 2 \times 1 + 0 \times 0 + 5 \times 0 + 7 \times 0 + 1 \times 1 + 8 \times -1 + 2 \times -1 = -5$$

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

6×6



=

-5	-4	0	8
-10	-2	2	3
0	-2	-4	-7
-3	-2	-3	-16

4×4

Vertical edge detection

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

*

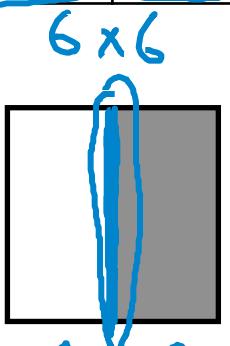
$$\begin{matrix} 1 & 0 & -1 \\ 1 & 0 & -1 \\ 1 & 0 & -1 \end{matrix}$$

3x3

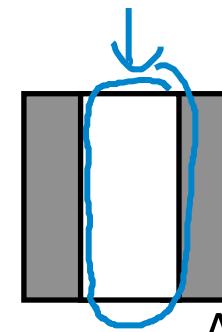
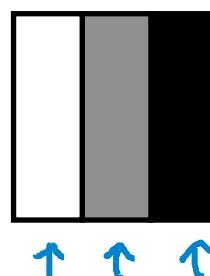
=

$$\begin{matrix} 0 & 30 & 30 & 0 \\ 0 & 30 & 30 & 0 \\ 0 & 30 & 30 & 0 \\ 0 & 30 & 30 & 0 \end{matrix}$$

4x4



*



Andrew Ng



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Convolutional Neural Networks

More edge
detection

Vertical edge detection examples

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



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



*

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



=

0	30	30	0
0	30	30	0
0	30	30	0
0	30	30	0



*

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



=

0	-30	-30	0
0	-30	-30	0
0	-30	-30	0
0	-30	-30	0



Vertical and Horizontal Edge Detection

A 3x3 input matrix with values 1, 0, -1 in each row. A blue arrow points from the left to the first column. The first column is circled in blue.

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

Vertical

A 3x3 input matrix with values 1, 1, 1 in the top row. A blue arrow points from the right to the last column. The last column is circled in blue.

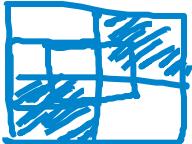
1	1	1
0	0	0
-1	-1	-1

Horizontal

A 6x6 input matrix with values 10, 10, 10 in the first three columns of the first three rows. A blue arrow points from the left to the first column. The first column is circled in blue.

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

6×6



*

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

Learning to detect edges

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

→

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

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

↑

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

Sobel filter

convolution



=

45°
70°
73°

Scharr filter



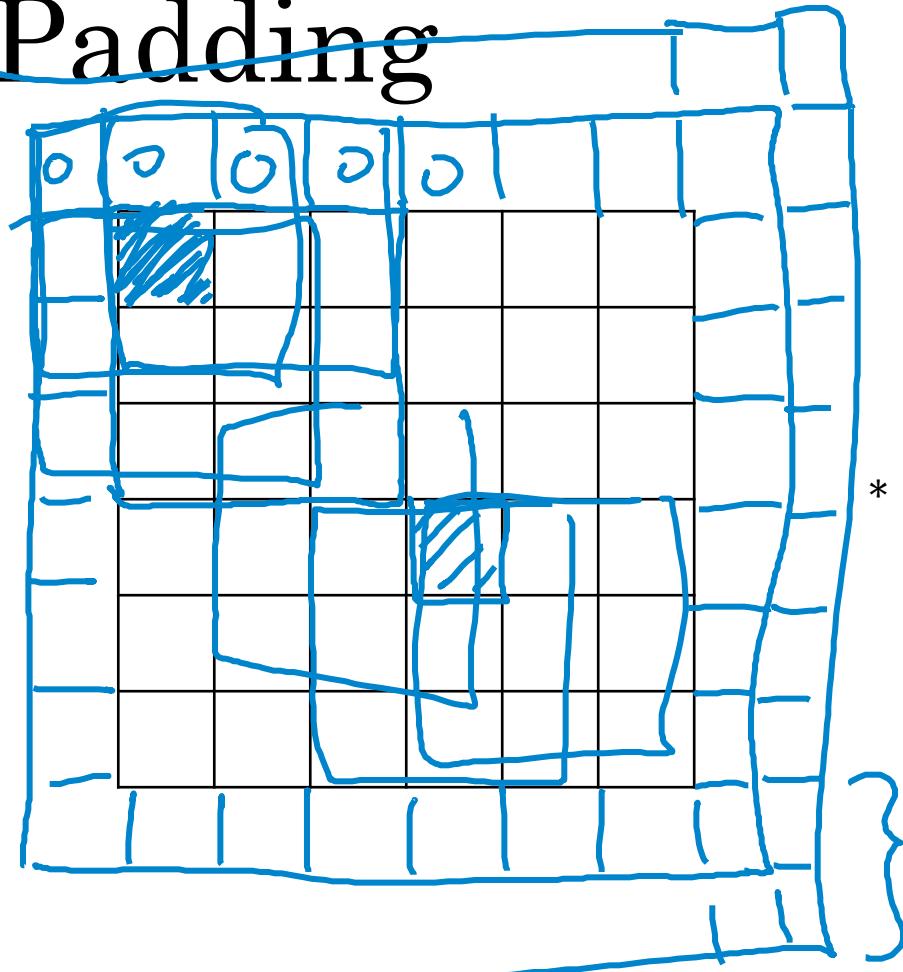
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Convolutional Neural Networks

Padding

Padding

- shrinky output
- throw away info from edge



$$\frac{6 \times 6}{n \times n} \rightarrow 8 \times 8$$

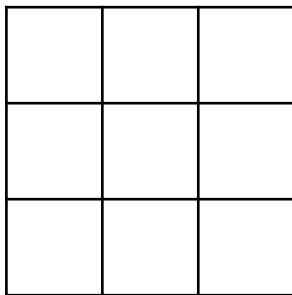
$$p = \text{padding} = 1$$

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

$$6-3+1 = 4$$

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

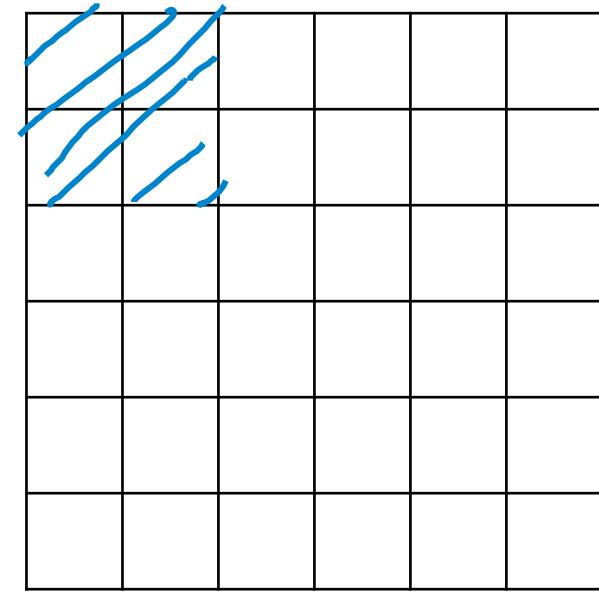
$$6+2-3+1 \times \underline{\quad} = 6 \times 6$$



$$3 \times 3$$

$$f \times f$$

=



$$\underline{6 \times 6}$$

$$\xrightarrow{\quad} \underline{4 \times 4}$$

Valid and Same convolutions

→ n → padding

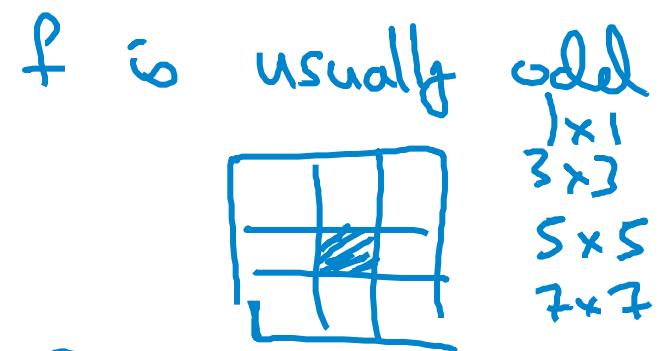
“Valid”: $n \times n \quad * \quad f \times f \quad \rightarrow \frac{n-f+1}{4} \times \frac{n-f+1}{4}$

$$\begin{array}{ccc} 6 \times 6 & * & 3 \times 3 \\ \downarrow & & \downarrow \\ 4 \times 4 & & 4 \times 4 \end{array}$$

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

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

$$3 \times 3 \quad p = \frac{3-1}{2} = 1 \quad | \quad \begin{matrix} S \times S \\ f \times f \end{matrix} \quad p=2$$



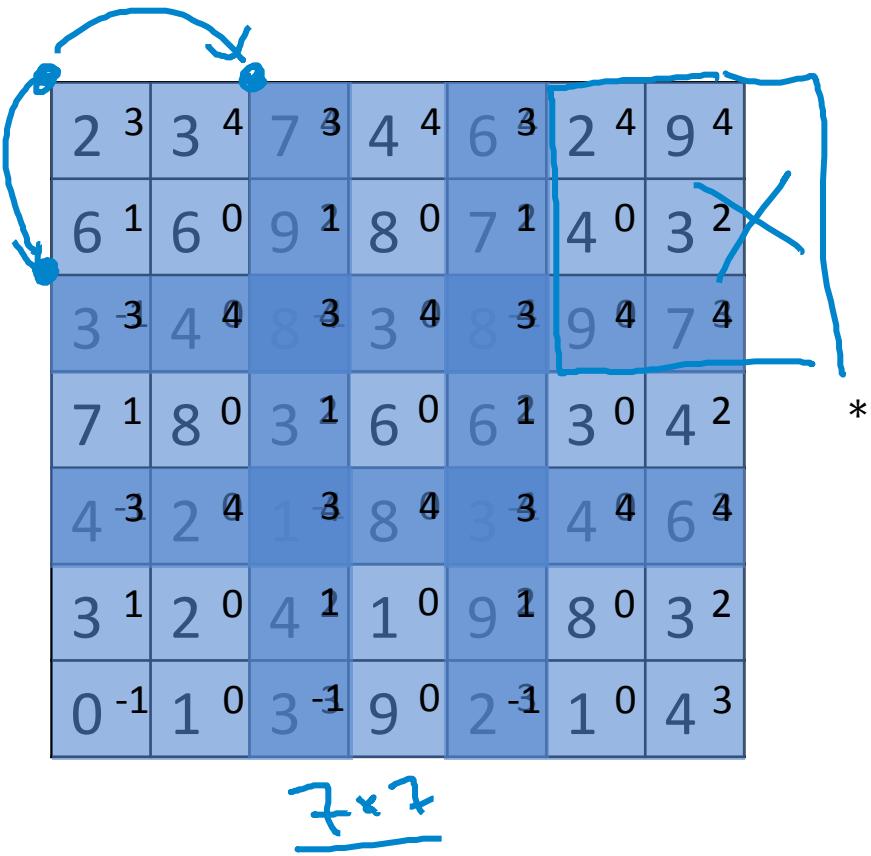


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Convolutional Neural Networks

Strided
convolutions

Strided convolution



$n \times n$ * $f \times f$
 padding p stride s
 $s=2$

$$\begin{array}{|c|c|c|} \hline 3 & 4 & 4 \\ \hline 1 & 0 & 2 \\ \hline -1 & 0 & 3 \\ \hline \end{array}$$

3×3

stride = 2

=

$$\begin{array}{|c|c|c|} \hline 91 & 100 & 83 \\ \hline 69 & 91 & 127 \\ \hline 44 & 72 & 74 \\ \hline \end{array}$$

3×3

$\lfloor z \rfloor = \text{floor}(z)$

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

$$\left\lfloor \frac{7+0-3}{2} + 1 \right\rfloor = \frac{4}{2} + 1 = 3$$

Summary of convolutions

$n \times n$ image

$f \times f$ filter

padding p

stride s

Output size:

$$\lfloor n + 2p - f/s + 1 \rfloor$$

\times

$$\lfloor n + 2p - f/s + 1 \rfloor$$

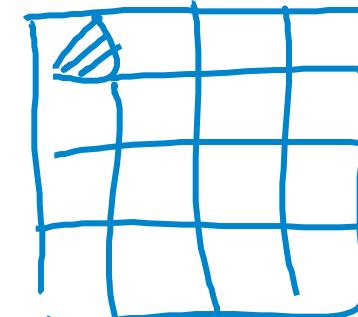


Technical note on cross-correlation vs. convolution

Convolution in math textbook:

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

$$\begin{matrix} & * & \begin{matrix} 3 & 4 & 5 \\ 1 & 0 & 2 \\ -1 & 9 & 7 \end{matrix} \\ \begin{matrix} 7 & 2 & 5 \\ 9 & 0 & 4 \\ -1 & 1 & 3 \end{matrix} & \end{matrix}$$

$$=$$


$$(A * B) * C = A * (B * C)$$

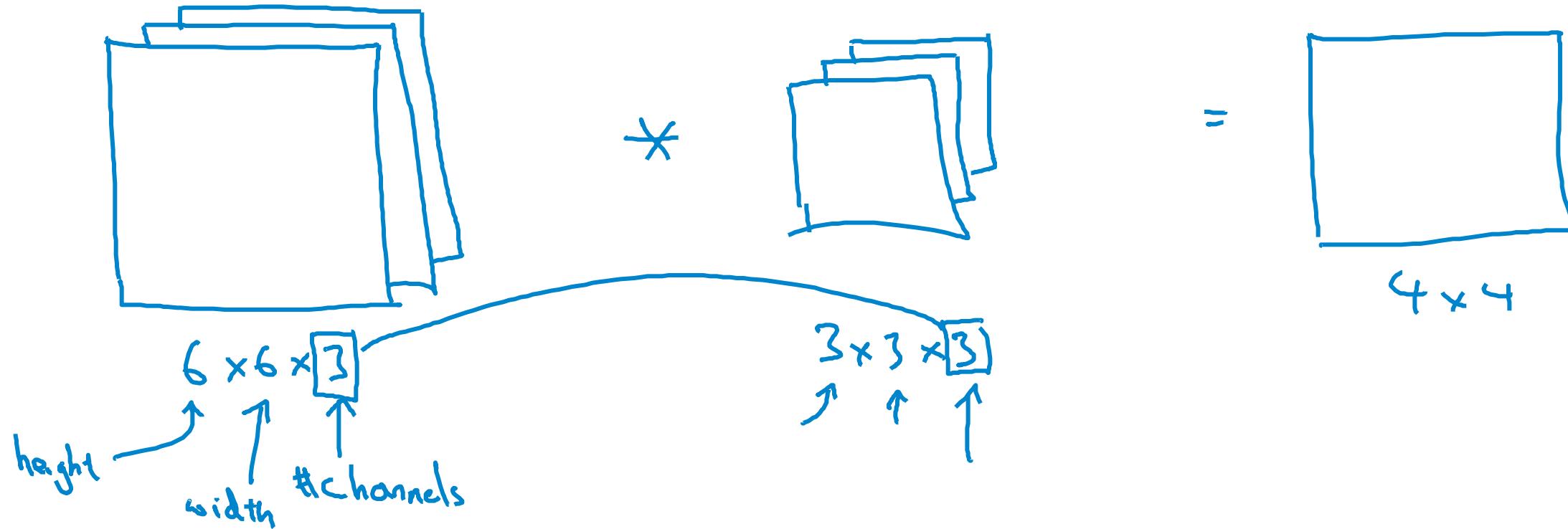


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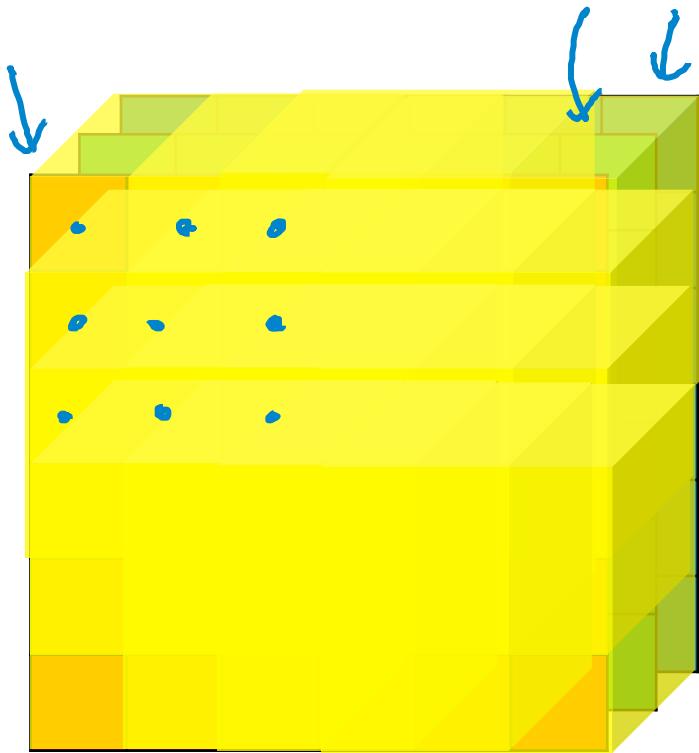
Convolutional Neural Networks

Convolutions over volumes

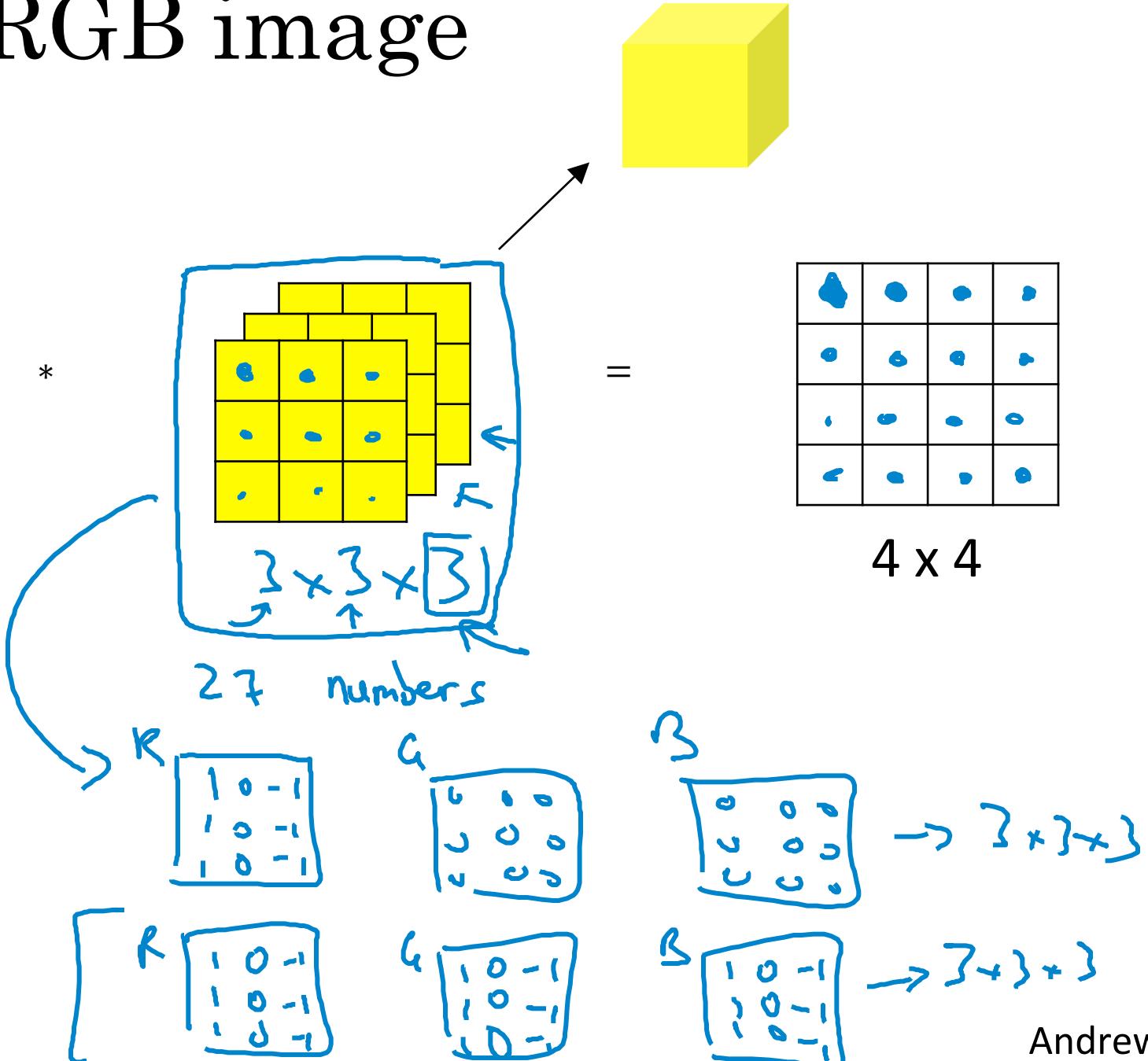
Convolutions on RGB images



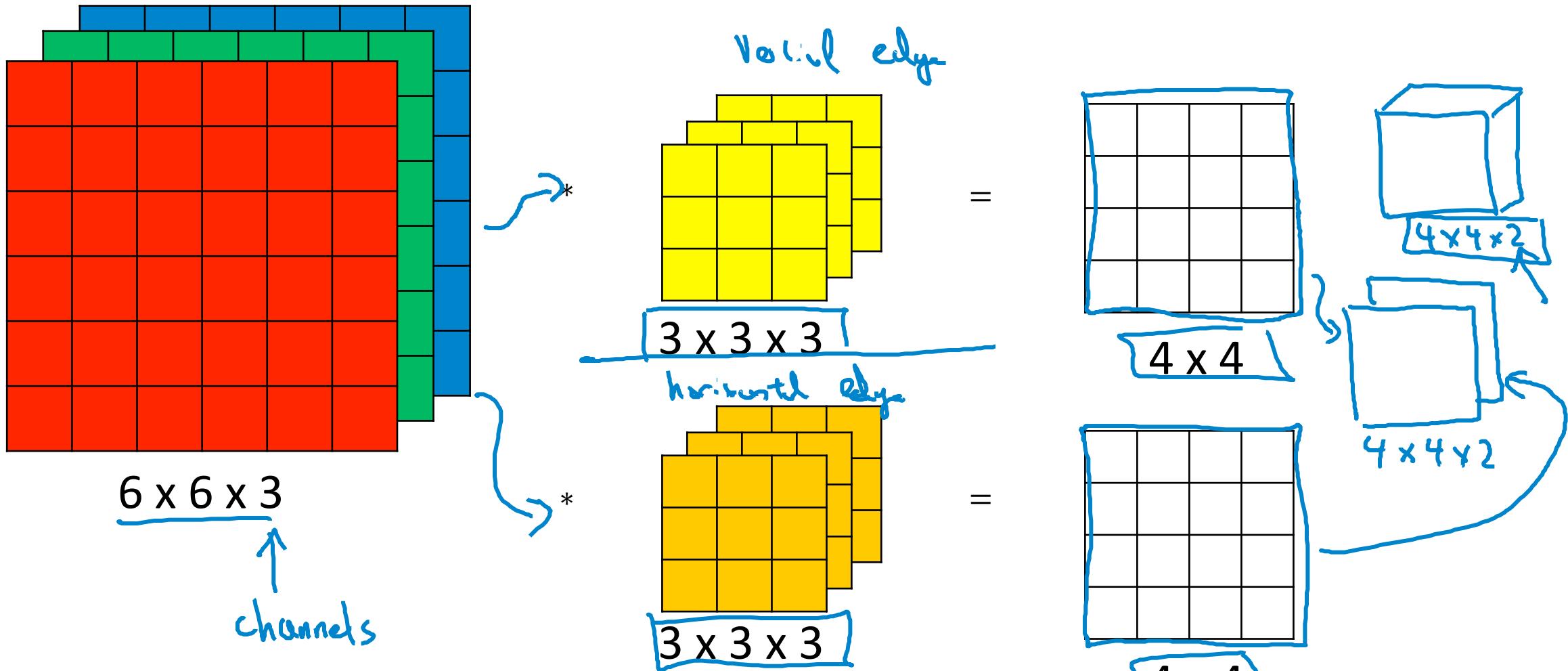
Convolutions on RGB image



$$\begin{matrix} & 6 \times 6 \times 3 \\ \uparrow & \uparrow & \uparrow \\ \boxed{\text{ }} \quad * \quad \boxed{\text{ }} & = & \boxed{\text{ }} \end{matrix}$$



Multiple filters



Summary: $n \times n \times n_c$ $\times f \times f \times n_c$ $\rightarrow \frac{n-f+1}{4} \times \frac{n-f+1}{4} \times \frac{n'_c}{2} \# \text{filters}$

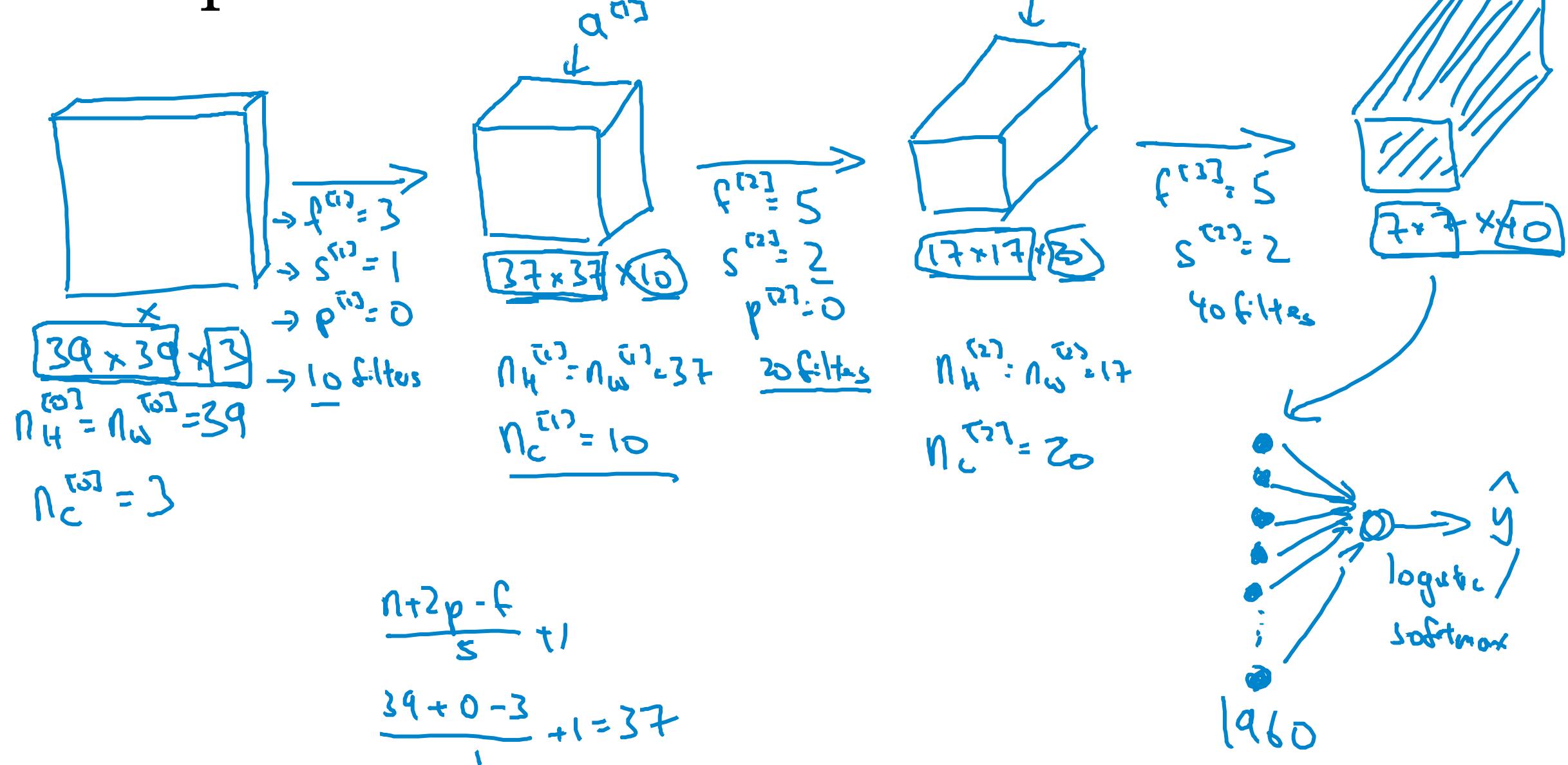


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Convolutional Neural Networks

A simple convolution
network example

Example ConvNet



Types of layer in a convolutional network:

- Convolution (conv) ←
- Pooling (pool) ←
- Fully connected (Fc) ←



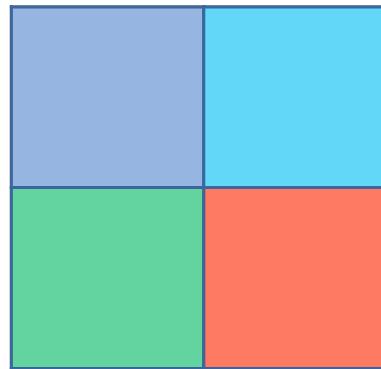
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Convolutional Neural Networks

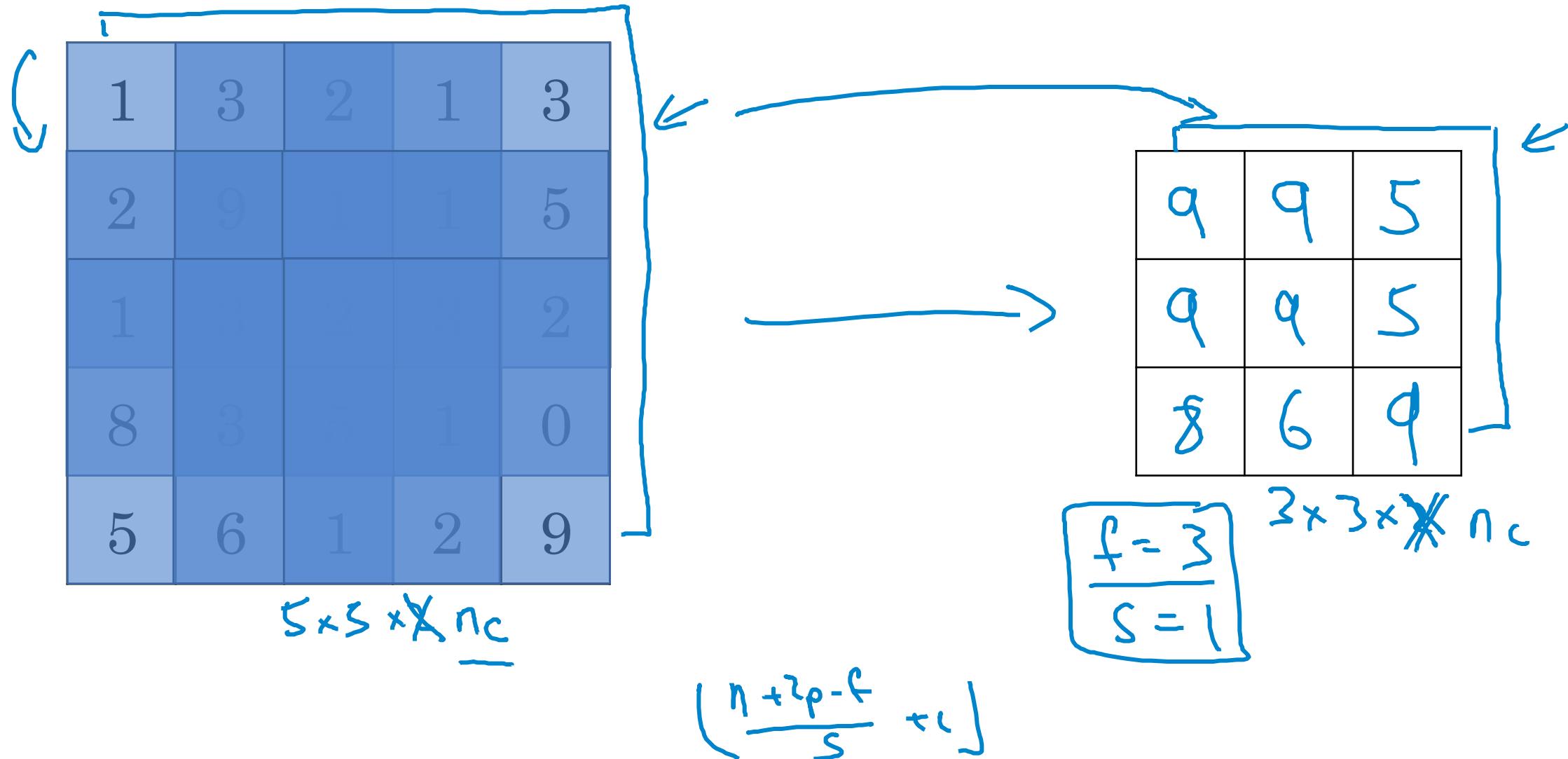
Pooling layers

Pooling layer: Max pooling

1	3	2	1
2	9	1	1
1	3	2	3
5	6	1	2



Pooling layer: Max pooling



Pooling layer: Average pooling

1	3	2	1
2	9	1	1
1	4	2	3
5	6	1	2



3.75	1.25
4	2

$$f=2$$

$$s=2$$

$$\underbrace{7 \times 7 \times 1000}_{\text{Input}} \rightarrow 1 \times 1 \times 1000$$

Summary of pooling

Hyperparameters:

f : filter size

$$f=2, s=2$$

s : stride

$$f=3, s=2$$

Max or average pooling

$\rightarrow p: \text{padding}$

No parameters to learn!

$$n_H \times n_w \times n_c$$

$$\downarrow$$
$$\left\lfloor \frac{n_H-f}{s} + 1 \right\rfloor \times \left\lfloor \frac{n_w-f}{s} + 1 \right\rfloor \times n_c$$



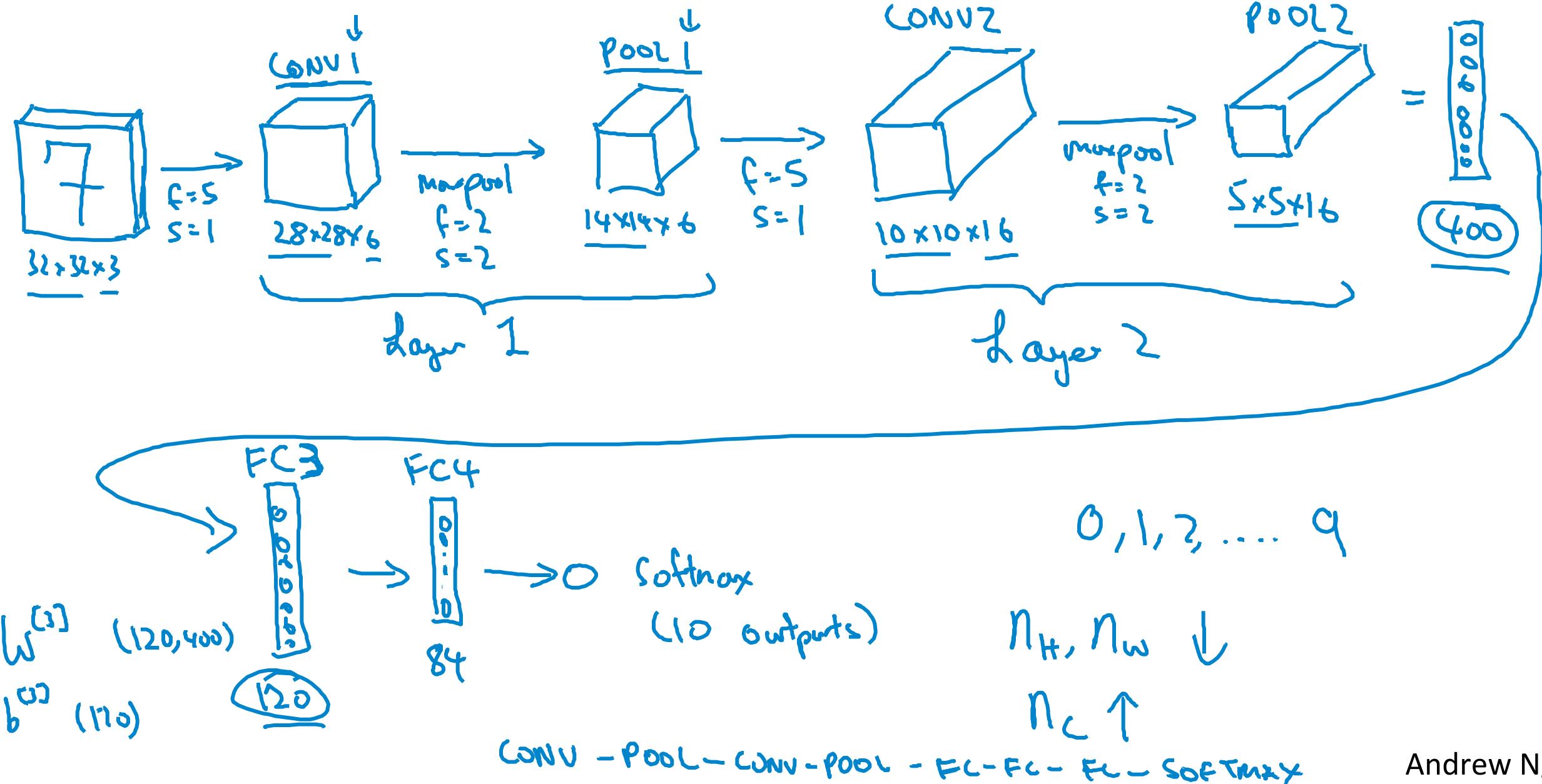
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Convolutional Neural Networks

Convolutional neural
network example

Neural network example

(LeNet-5)



Neural network example

	Activation shape	Activation Size	# parameters
Input:	(32,32,3)	— 3,072 $a^{[3]}$	0
		—	←
		—	←
		—	←
		—	←
		—	←
		—	—
		—	—
		—	—
		—	—

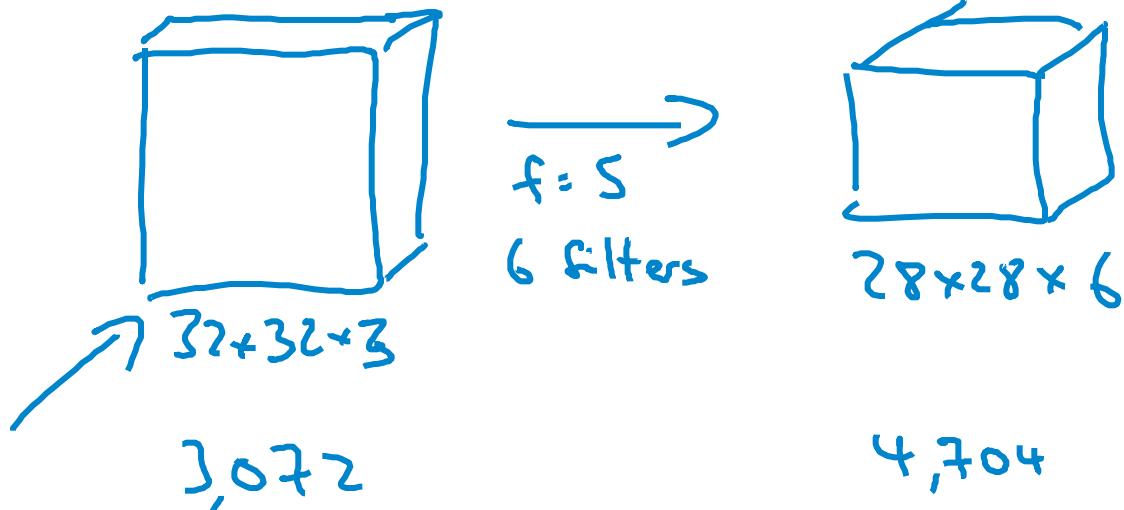


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Convolutional Neural Networks

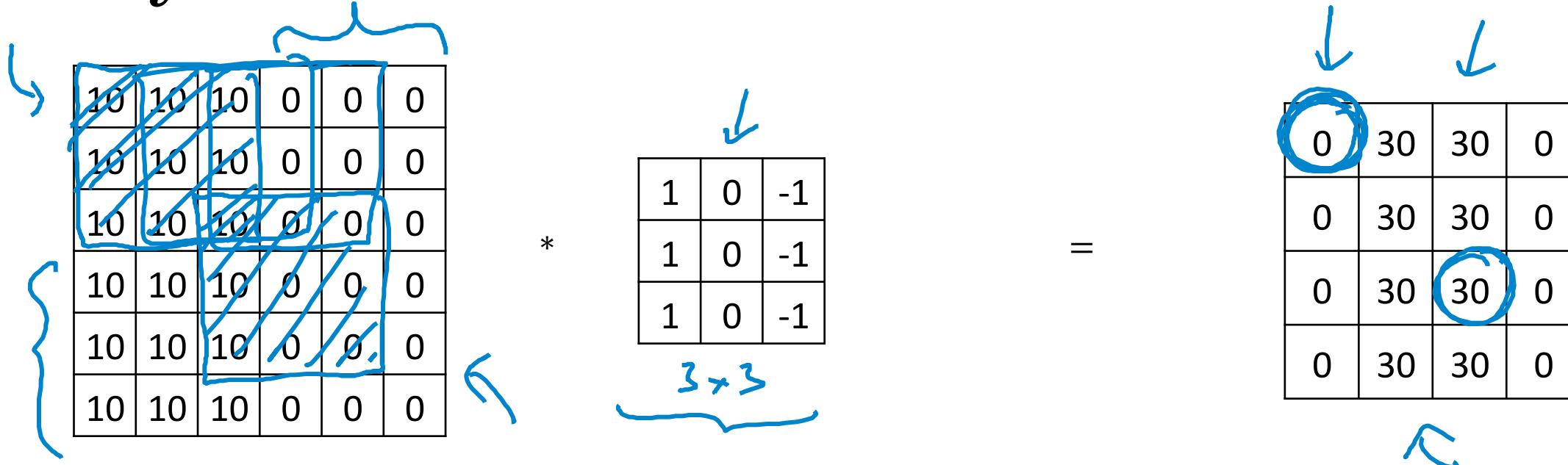
Why convolutions?

Why convolutions



$$\begin{aligned} & 5 \times 5 - 25 \\ & 26 \\ & 6 \times 26 = 156 \text{ Parameters} \\ & 3,072 \times 4,704 \approx 14M \end{aligned}$$

Why convolutions

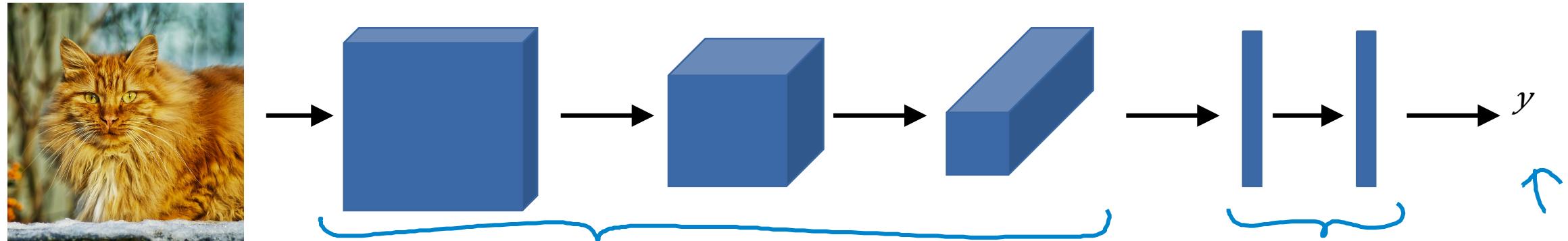


Parameter sharing: A feature detector (such as a vertical edge detector) that's useful in one part of the image is probably useful in another part of the image.

→ **Sparsity of connections:** In each layer, each output value depends only on a small number of inputs.

Putting it together

Training set $(x^{\uparrow(1)}, y^{\uparrow(1)}) \dots (x^{\uparrow(m)}, y^{\uparrow(m)})$.



$$\text{Cost } J = \frac{1}{m} \sum_{i=1}^{m} \mathcal{L}(y^{\uparrow(i)}, \hat{y}^{\uparrow(i)})$$

Use gradient descent to optimize parameters to reduce J