



Human-Centered Data & AI

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MBA Professor, FIAP

Google Developer Expert – Machine Learning



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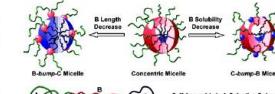
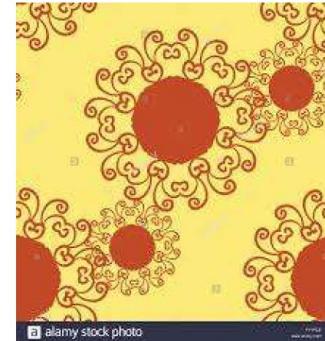
@vfcarida

“

# Convolution Neural Network (CNN)

# Convolution Neural Network (CNN)

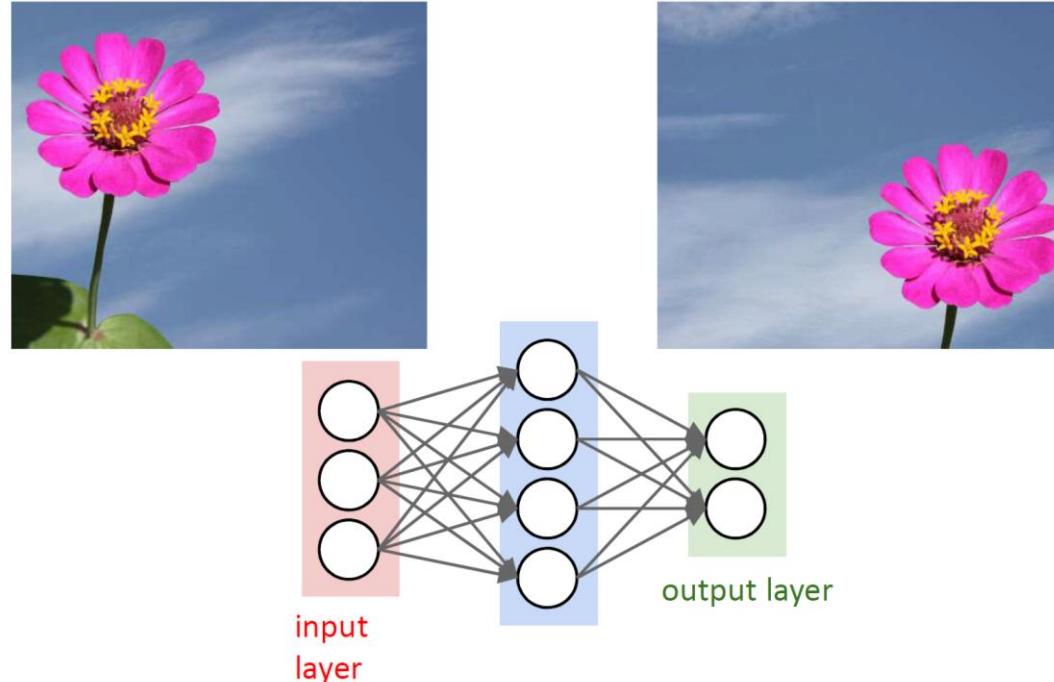
## Flowers



- Is there a flower in any of these images

# Convolution Neural Network (CNN)

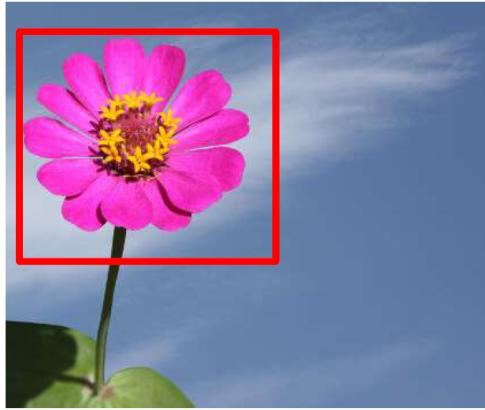
## A problem



- Will an MLP that recognizes the left image as a flower also recognize the one on the right as a flower?

# Convolution Neural Network (CNN)

## A problem



- Need a network that will “fire” regardless of the precise location of the target object

# Convolution Neural Network (CNN)

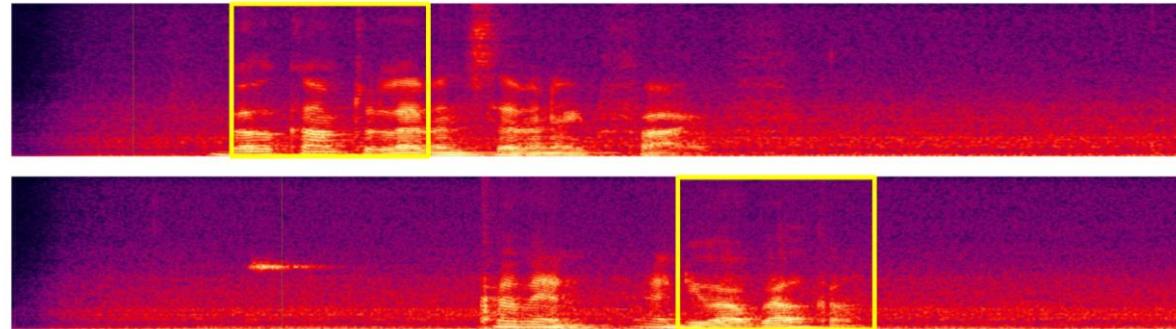
## The need for *shift invariance*



- In many problems the *location* of a pattern is not important
  - Only the presence of the pattern
- Conventional MLPs are sensitive to the location of the pattern
  - Moving it by one component results in an entirely different input that the MLP wont recognize
- Requirement: Network must be *shift invariant*

# Convolution Neural Network (CNN)

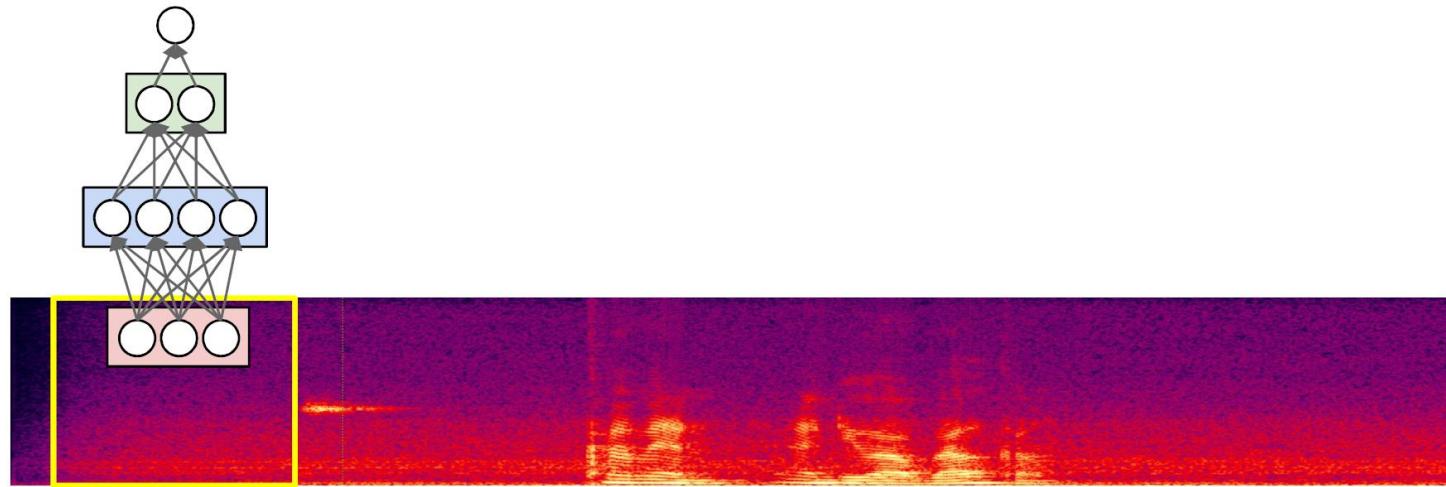
## The need for *shift invariance*



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# Convolution Neural Network (CNN)

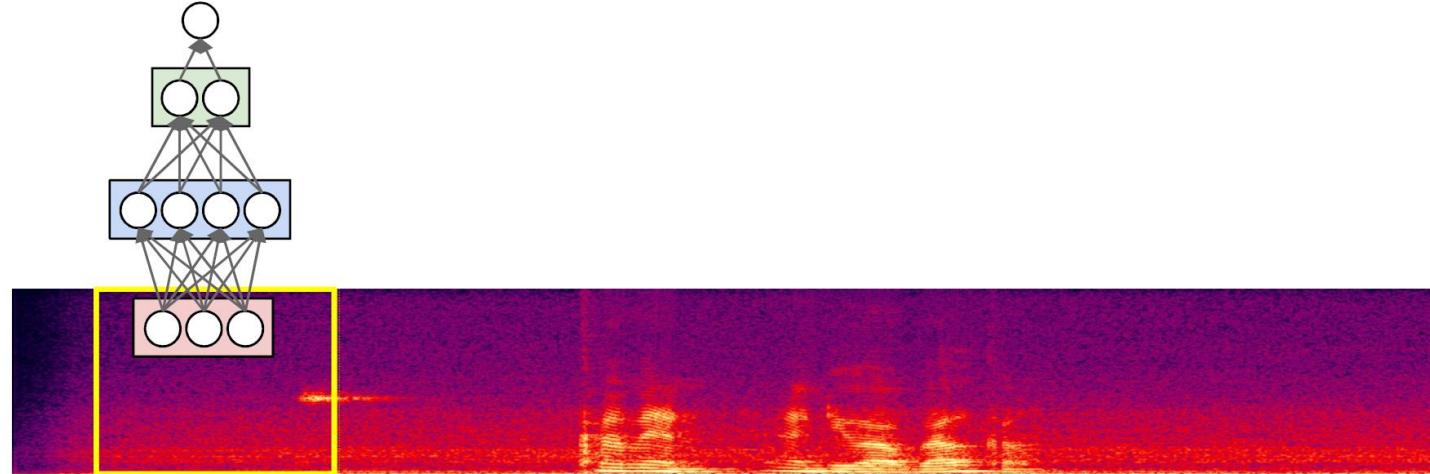
## Solution: Scan



- Scan for the target word
  - The spectral time-frequency components in a “window” are input to a “welcome-detector” MLP

# Convolution Neural Network (CNN)

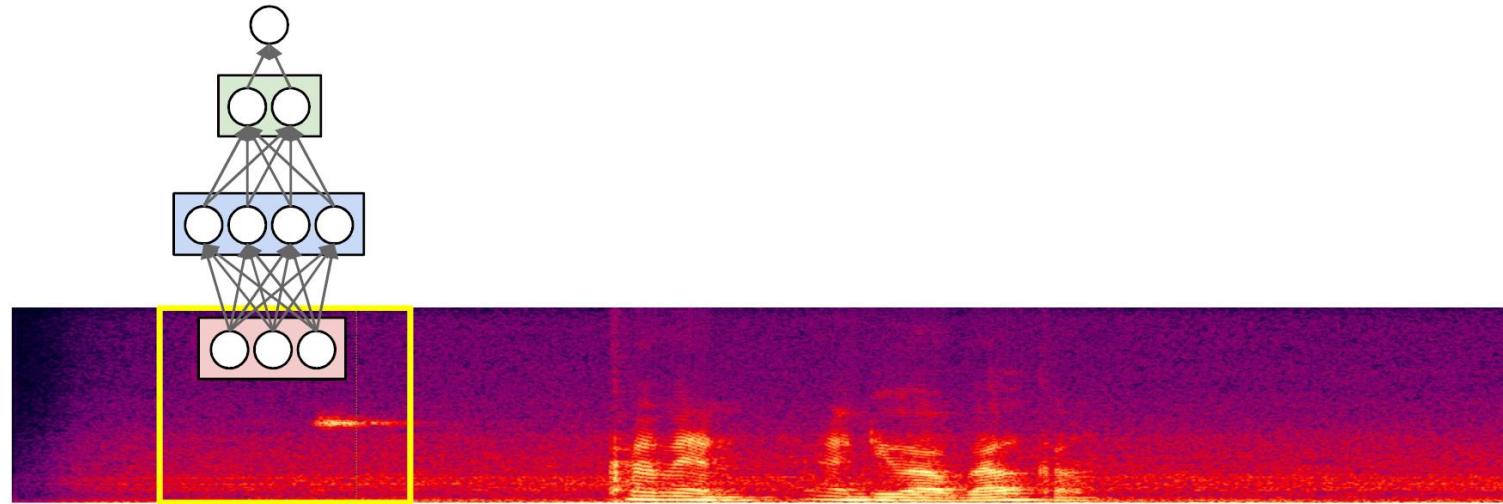
## Solution: Scan



- Scan for the target word
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# Convolution Neural Network (CNN)

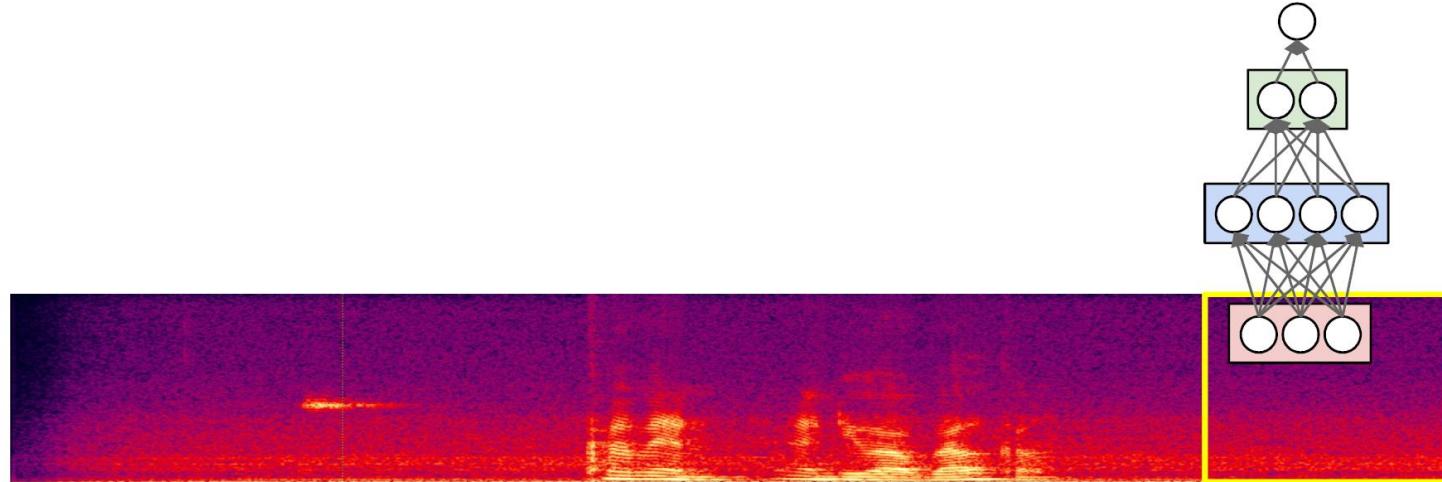
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# Convolution Neural Network (CNN)

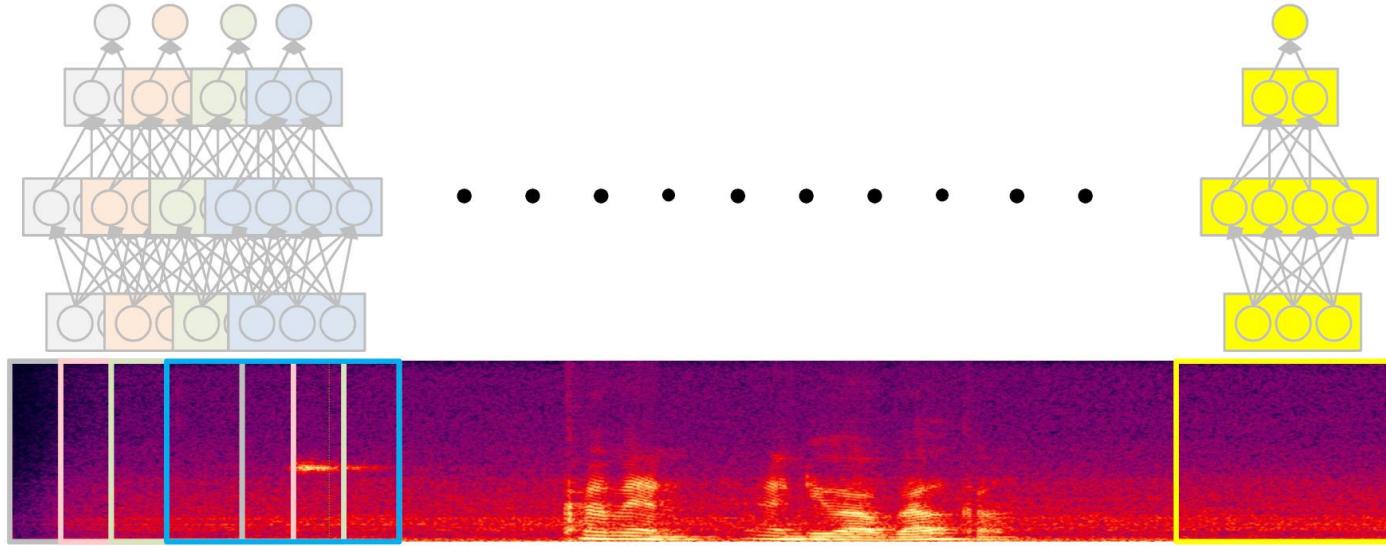
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# Convolution Neural Network (CNN)

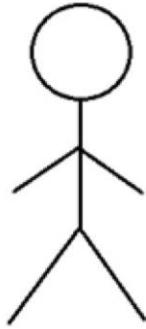
## Solution: Scan



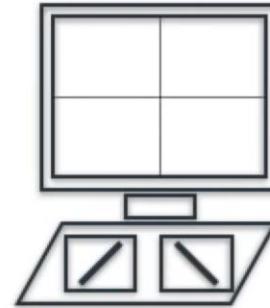
- “Does welcome occur in this recording?”
  - We have classified many “windows” individually
  - “Welcome” may have occurred in any of them

# Convolution Neural Network (CNN)

A simple world



Person



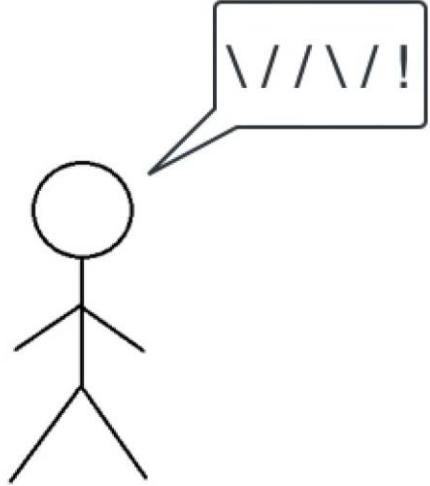
Computer



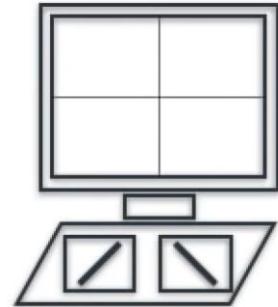
Alphabet

# Convolution Neural Network (CNN)

A simple world



Person



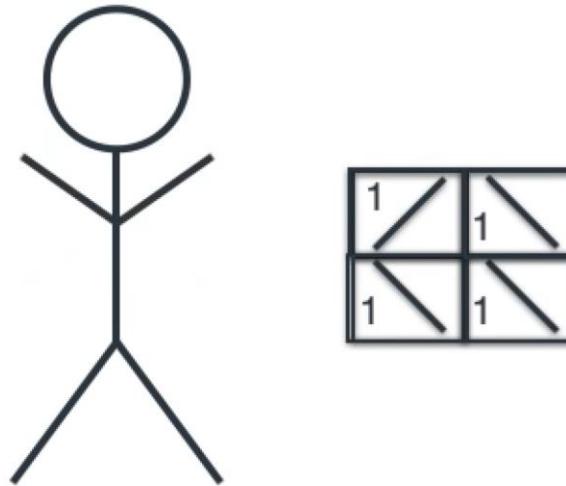
Computer



Alphabet

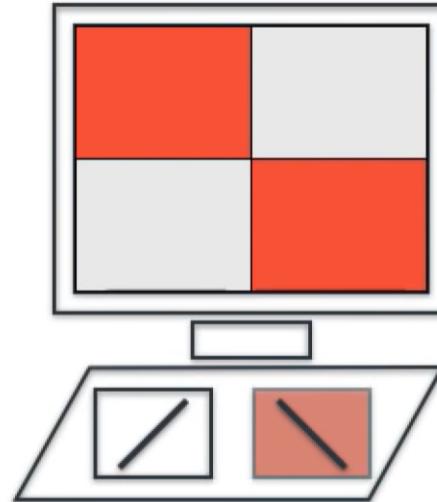
# Convolution Neural Network (CNN)

A simple world



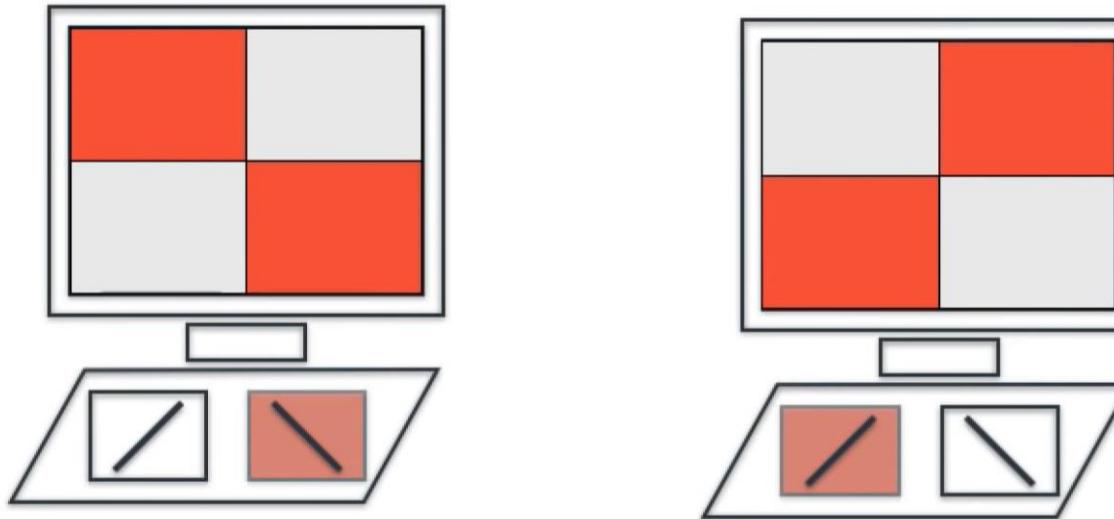
# Convolution Neural Network (CNN)

A simple world



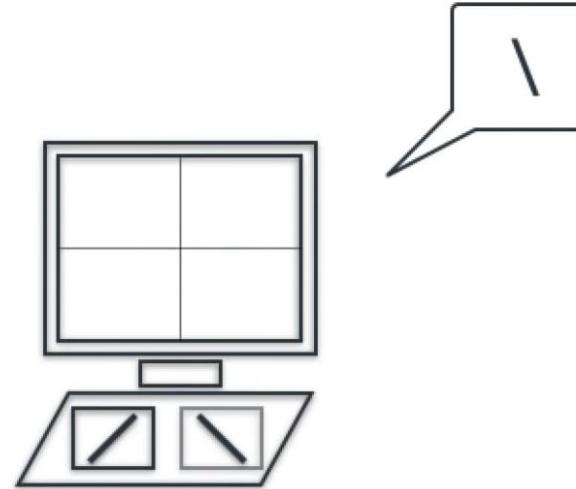
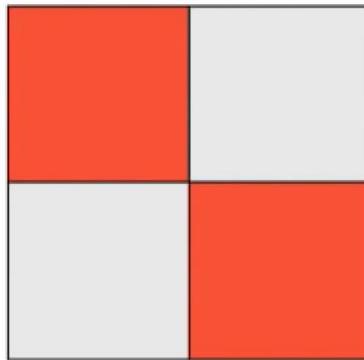
# Convolution Neural Network (CNN)

A simple world



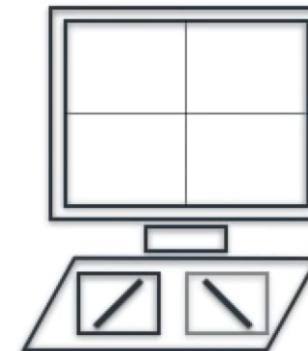
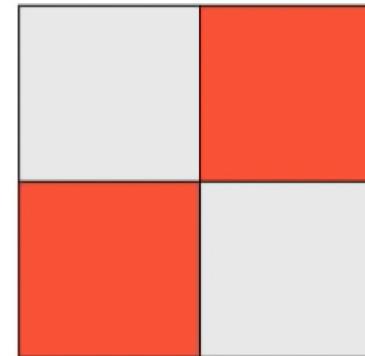
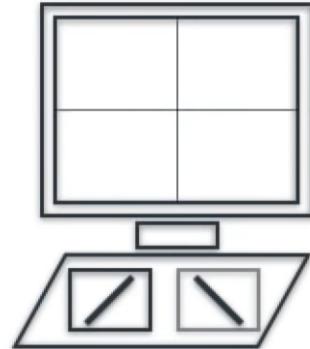
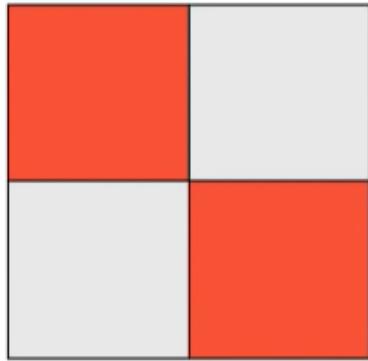
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A simple world



# Convolution Neural Network (CNN)

A simple world



# Convolution Neural Network (CNN)

A simple world



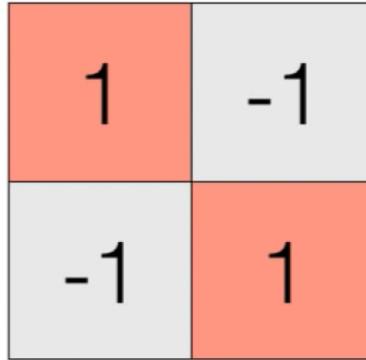
1	-1
-1	1



-1	1
1	-1

# Convolution Neural Network (CNN)

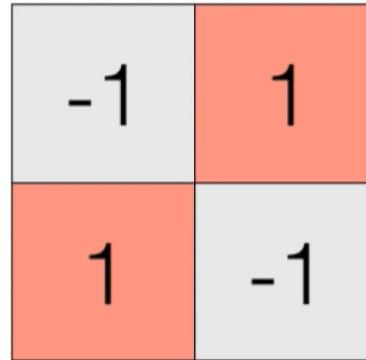
A simple world



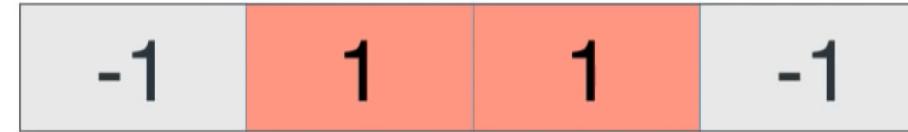
1	-1
-1	1



1	-1	-1	1
---	----	----	---



-1	1
1	-1



-1	1	1	-1
----	---	---	----

# Convolution Neural Network (CNN)

A simple world

$$\begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix}$$

$$\begin{bmatrix} 1 & + & -1 & + & -1 & + & 1 \end{bmatrix} = 0$$

$$\begin{bmatrix} -1 & 1 \\ 1 & -1 \end{bmatrix}$$

$$\begin{bmatrix} -1 & 1 & 1 & -1 \end{bmatrix}$$

# Convolution Neural Network (CNN)

A simple world

$$\begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix}$$

$$1 + -1 + -1 + 1 = 0$$

$$\begin{bmatrix} -1 & 1 \\ 1 & -1 \end{bmatrix}$$

$$-1 + 1 + 1 + -1 = 0$$

# Convolution Neural Network (CNN)

A simple world

1	-1
-1	1

$$\begin{matrix} 1 & \times & -1 & \times & -1 & \times & 1 \end{matrix} = 1$$

-1	1
1	-1

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

# Convolution Neural Network (CNN)

A simple world

$$\begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix}$$

$$1 \times -1 \times -1 \times 1 = 1$$

$$\begin{bmatrix} -1 & 1 \\ 1 & -1 \end{bmatrix}$$

$$-1 \times 1 \times 1 \times 1 \times -1 = 1$$

# Convolution Neural Network (CNN)

A simple world

$+1$	$-1$
$-1$	$+1$

$+1$	$-1$	$-1$	$+1$
------	------	------	------

$-1$	$+1$
$+1$	$-1$

$-1$	$+1$	$+1$	$-1$
------	------	------	------

# Convolution Neural Network (CNN)

A simple world

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

$$\begin{matrix} + & - & - & + \\ \begin{matrix} 1 & -1 & -1 & 1 \end{matrix} & = 4 \\ +1 & +1 & +1 & +1 \end{matrix}$$

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

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

# Convolution Neural Network (CNN)

A simple world

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

$$\begin{matrix} + & - & - & + \\ \begin{matrix} 1 & -1 & -1 & 1 \end{matrix} & = 4 \\ +1 & +1 & +1 & +1 \end{matrix}$$

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

$$\begin{matrix} + & - & - & + \\ \begin{matrix} -1 & 1 & 1 & -1 \end{matrix} & = -4 \\ -1 & -1 & -1 & -1 \end{matrix}$$

# Convolution Neural Network (CNN)

A simple world

## Image Recognition Classifier

+	-
-	+

If positive, “\”

If negative, “/”

# Convolution Neural Network (CNN)

A simple world

1	1
-1	1

-1	-1
1	-1

# Convolution Neural Network (CNN)

A simple world



1	1
-1	1



-1	-1
1	-1

# Convolution Neural Network (CNN)

A simple world

$+1$	$-1$
$-1$	$+1$

1	1	-1	1
---	---	----	---

$+ -1$	$- -1$
1	-1

-1	-1	1	-1
----	----	---	----

# Convolution Neural Network (CNN)

A simple world

$+1$	$-1$
$-1$	$+1$

$+1$	$-1$	$-1$	$+1$
$1$	$1$	$-1$	$1$
$+1$	$-1$	$+1$	$+1$

$+1$	$-1$
$-1$	$+1$

$+1$	$-1$	$-1$	$+1$
$-1$	$-1$	$1$	$-1$
$-1$	$+1$	$-1$	$-1$

# Convolution Neural Network (CNN)

A simple world

$$\begin{array}{|c|c|} \hline + & - \\ \hline 1 & 1 \\ \hline - & + \\ \hline -1 & 1 \\ \hline \end{array}$$

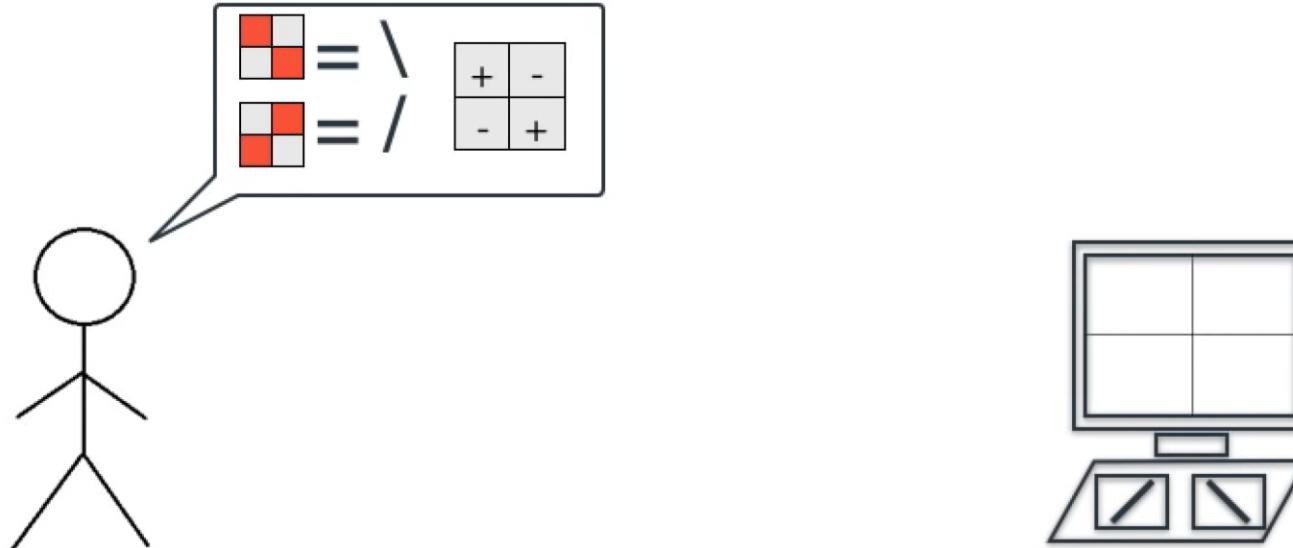
$$\begin{array}{cccc} + & - & - & + \\ \hline 1 & 1 & -1 & 1 \\ \hline +1 & -1 & +1 & +1 \\ \hline \end{array} = 2$$

$$\begin{array}{|c|c|} \hline + & - \\ \hline -1 & -1 \\ \hline - & + \\ \hline 1 & -1 \\ \hline \end{array}$$

$$\begin{array}{cccc} + & - & - & + \\ \hline -1 & -1 & 1 & -1 \\ \hline -1 & +1 & -1 & -1 \\ \hline \end{array} = -2$$

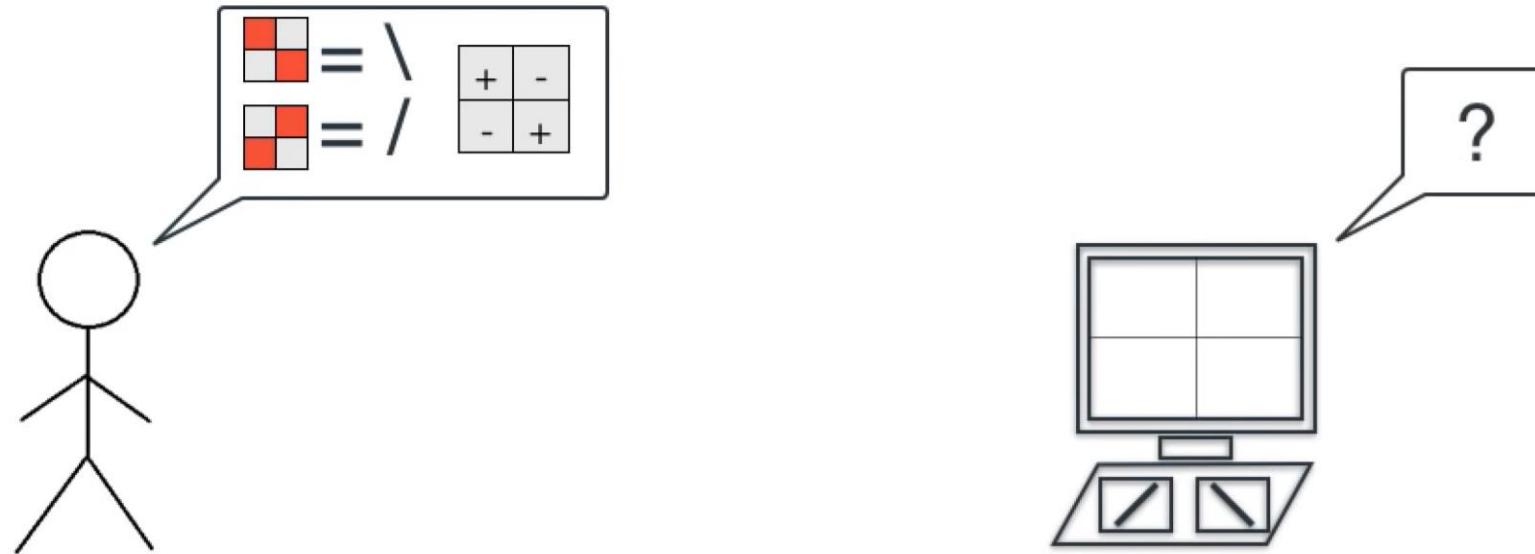
# Convolution Neural Network (CNN)

A simple world



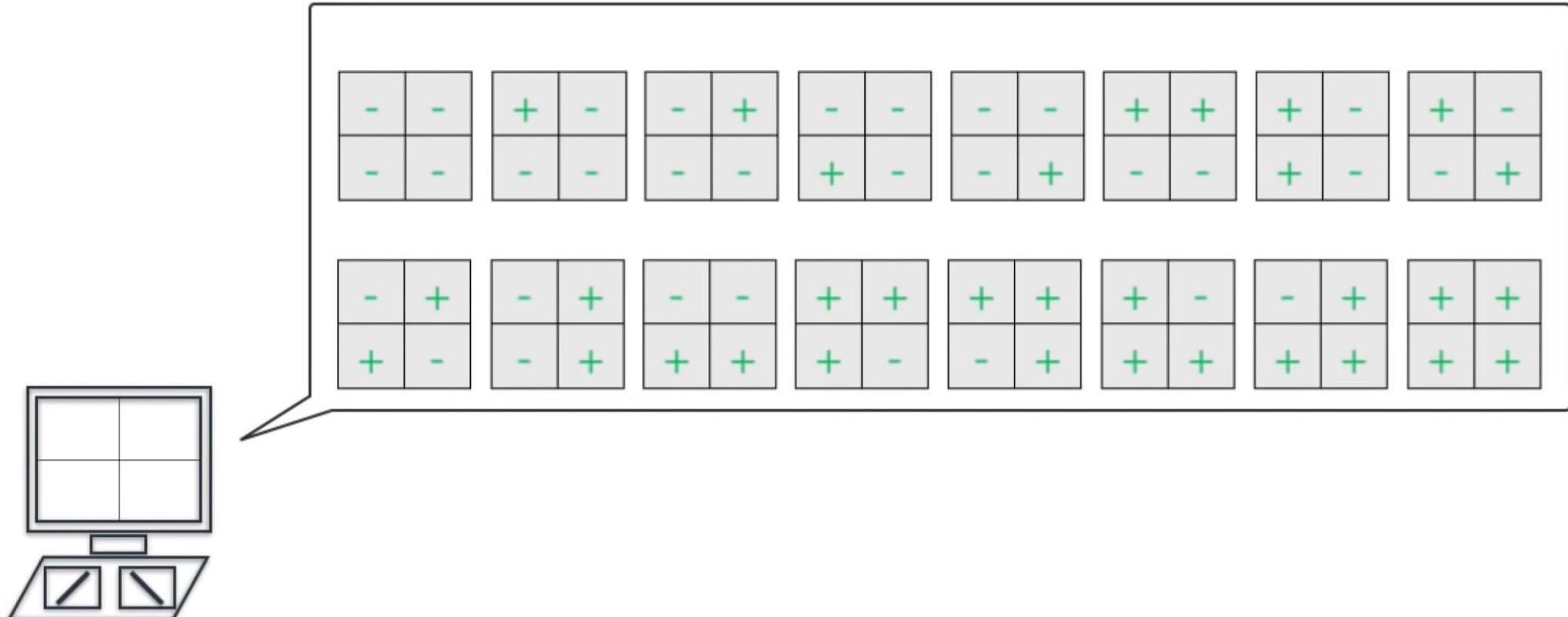
# Convolution Neural Network (CNN)

A simple world



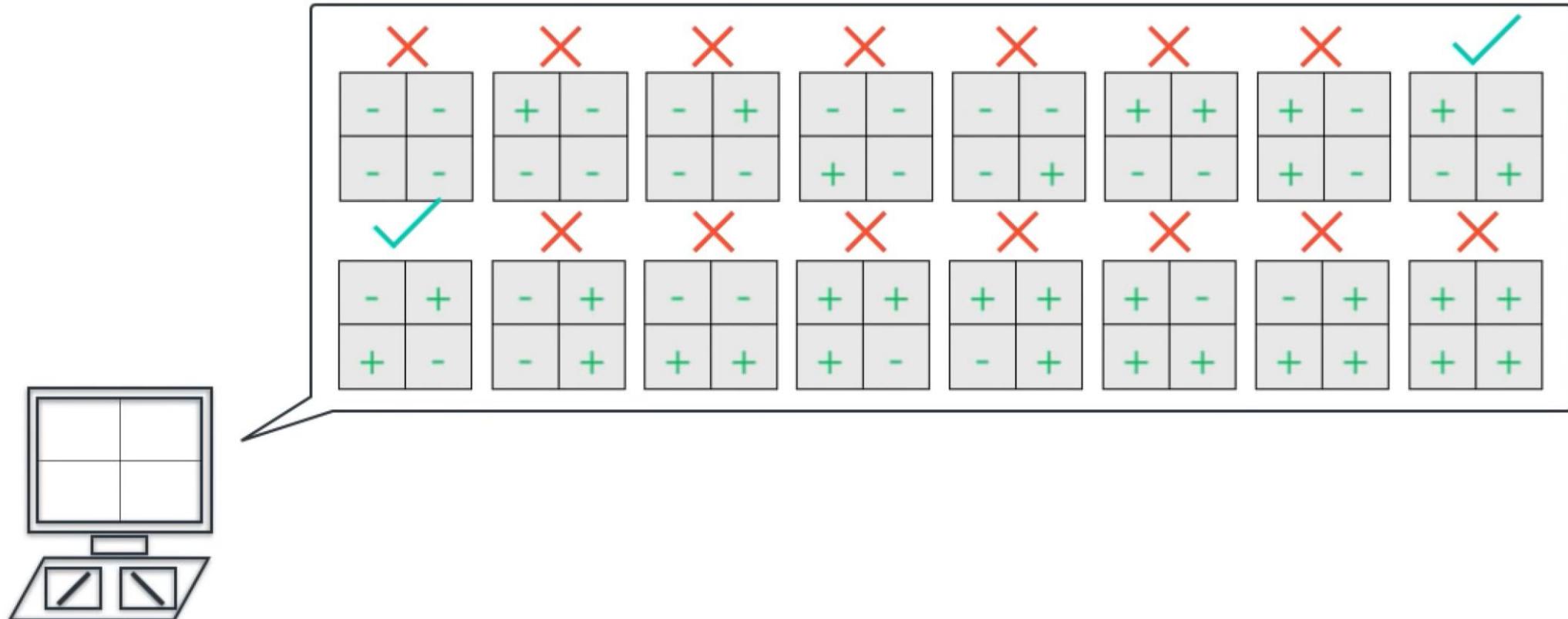
# Convolution Neural Network (CNN)

A simple world



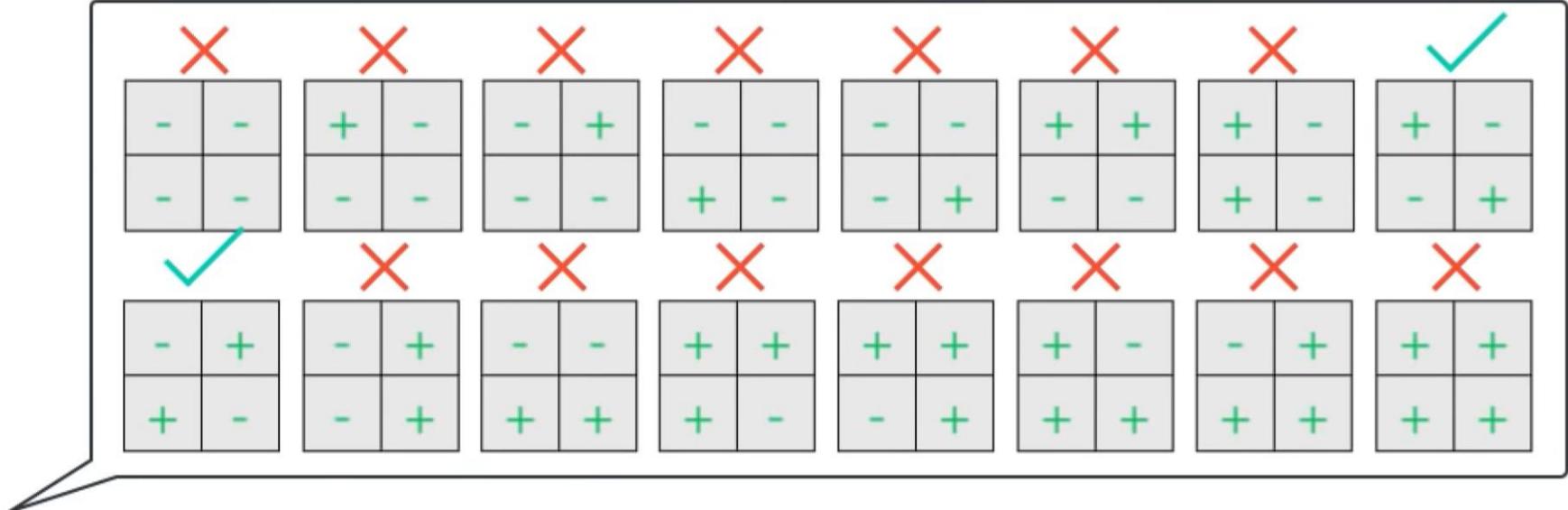
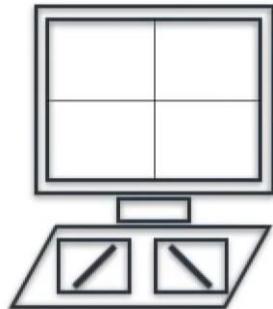
# Convolution Neural Network (CNN)

A simple world



# Convolution Neural Network (CNN)

A simple world



16 choices

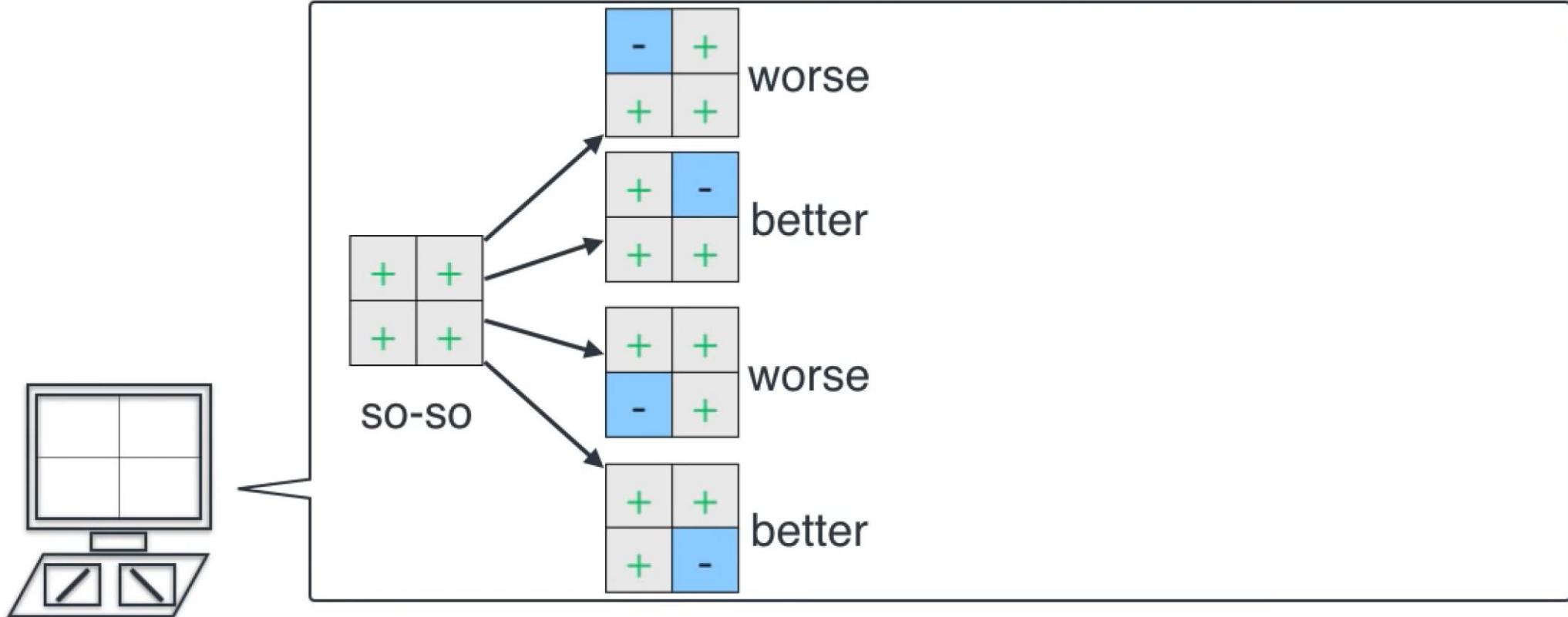
# Convolution Neural Network (CNN)

A simple world



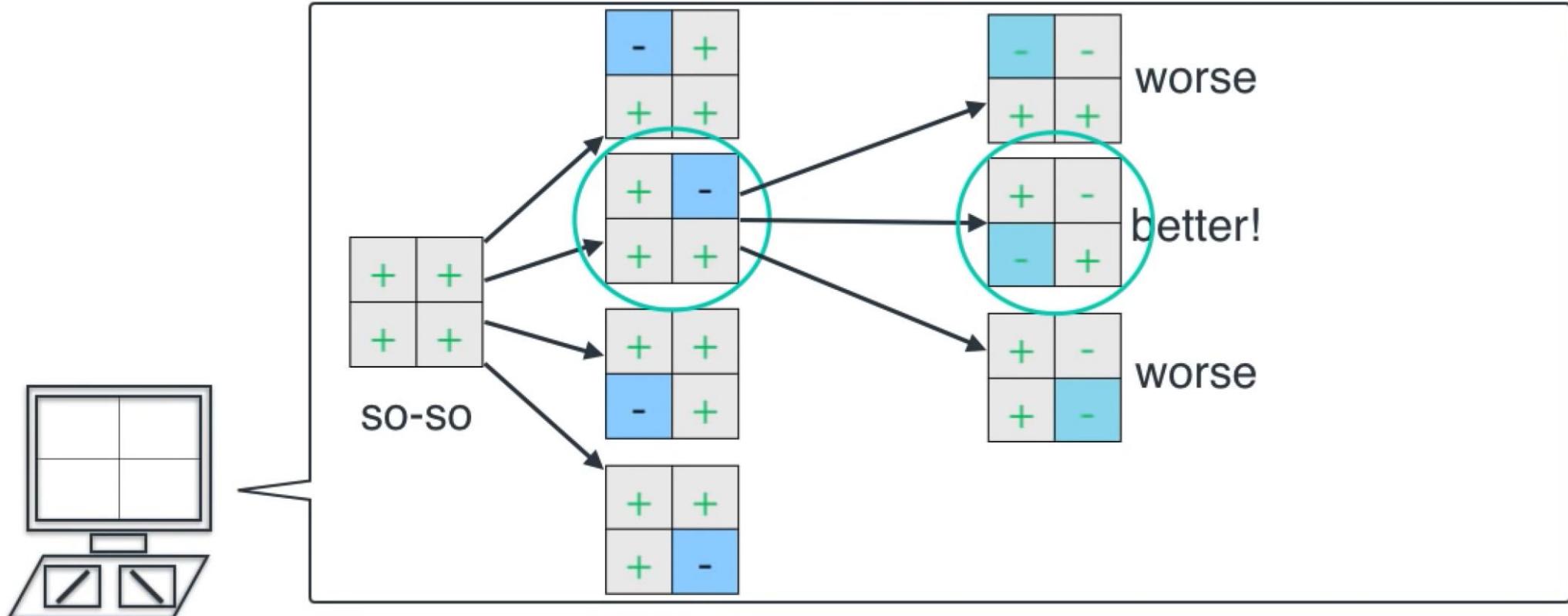
# Convolution Neural Network (CNN)

A simple world



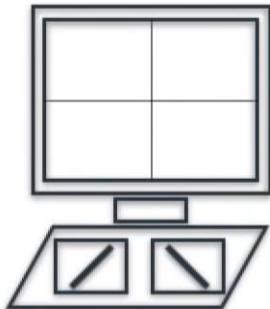
# Convolution Neural Network (CNN)

A simple world



# Convolution Neural Network (CNN)

A simple world



0.5	1.2
0.7	1.0

,

0.9	-0.7
-0.6	1.1

, etc...

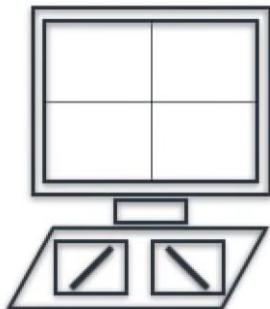
# Convolution Neural Network (CNN)

A simple world

0.5	1.2
0.7	1.0

0.9	-0.7
-0.6	1.1

, , etc...



Way too many choices

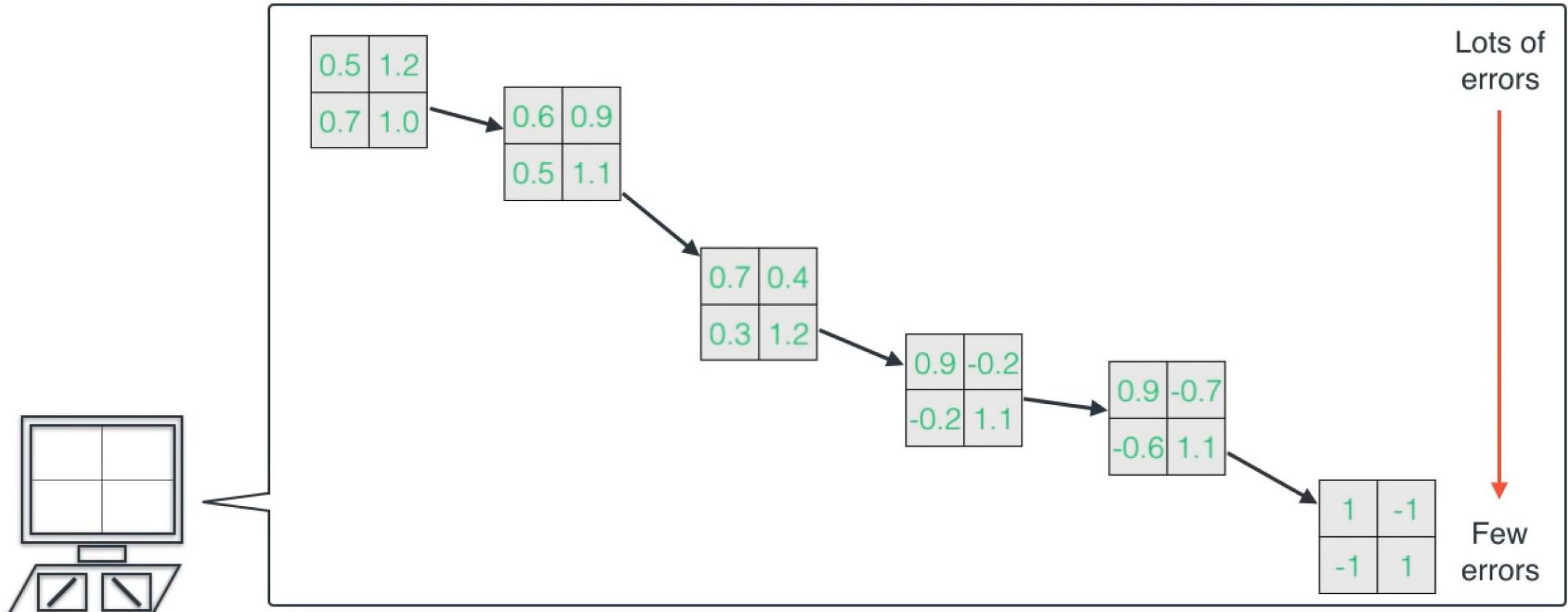
# Convolution Neural Network (CNN)

A simple world



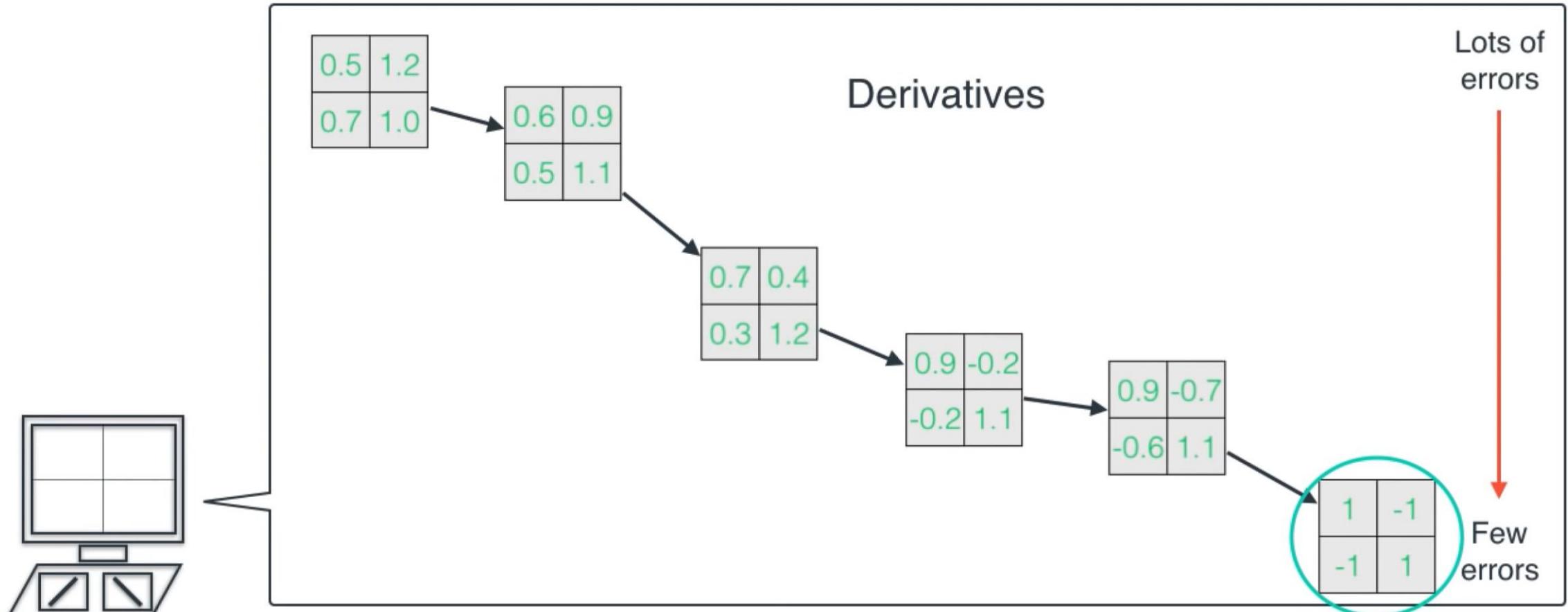
# Convolution Neural Network (CNN)

A simple world



# Convolution Neural Network (CNN)

A simple world

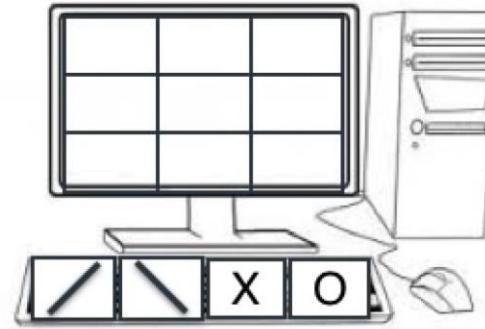


# Convolution Neural Network (CNN)

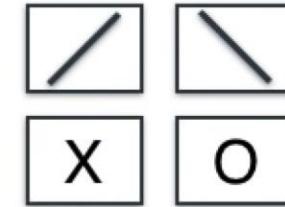
A little more complex world



Person



Computer



Alphabet

# Convolution Neural Network (CNN)

A little more complex world

1	-1	-1
-1	1	-1
-1	-1	1

\

1	-1	1
-1	1	-1
1	-1	1

X

-1	-1	1
-1	1	-1
1	-1	-1

/

-1	1	-1
1	-1	1
-1	1	-1

O

# Convolution Neural Network (CNN)

A little more complex world

1	-1	1
-1	1	-1
1	-1	1

# Convolution Neural Network (CNN)

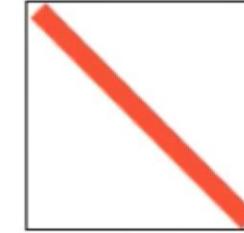
A little more complex world

+ 1	- -1	+ 1
- -1	+	- -1
+ 1	- -1	+ 1

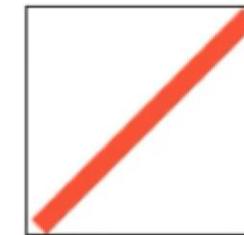
# Convolution Neural Network (CNN)

A little more complex world

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



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



# Convolution Neural Network (CNN)

A little more complex world

1	-1	1
-1	1	-1
1	-1	1

-1	1	-1
1	-1	1
-1	1	-1

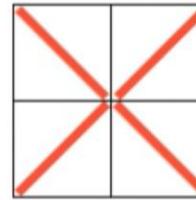
-1	-1	1
-1	1	-1
1	-1	-1

1	-1	-1
-1	1	-1
-1	-1	1

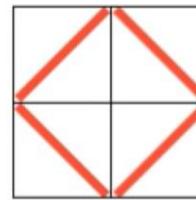
# Convolution Neural Network (CNN)

A little more complex world

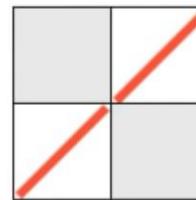
1	-1	1
-1	1	-1
1	-1	1



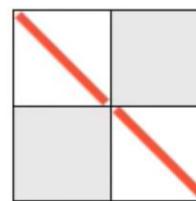
-1	1	-1
1	-1	1
-1	1	-1



-1	-1	1
-1	1	-1
1	-1	-1



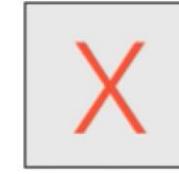
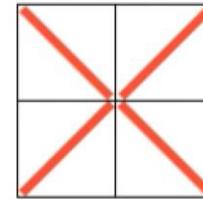
1	-1	-1
-1	1	-1
-1	-1	1



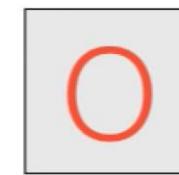
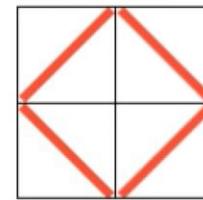
# Convolution Neural Network (CNN)

A little more complex world

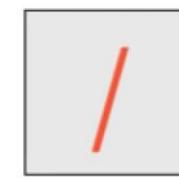
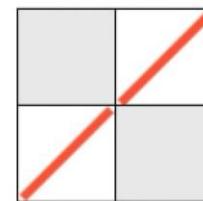
1	-1	1
-1	1	-1
1	-1	1



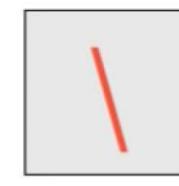
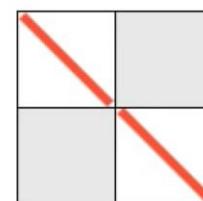
-1	1	-1
1	-1	1
-1	1	-1



-1	-1	1
-1	1	-1
1	-1	-1



1	-1	-1
-1	1	-1
-1	-1	1



# Convolution Neural Network (CNN)

A little more complex world

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



$$\begin{matrix} \times & \times \\ \times & \times \\ \times & \times \end{matrix}$$



$$X$$

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



$$\begin{matrix} \times & \times \\ \times & \times \\ \times & \times \end{matrix}$$



$$O$$

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

Convolution Layer  
Pooling Layer



$$\begin{matrix} \times & \times \\ \times & \times \\ \times & \times \end{matrix}$$



$$/$$

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



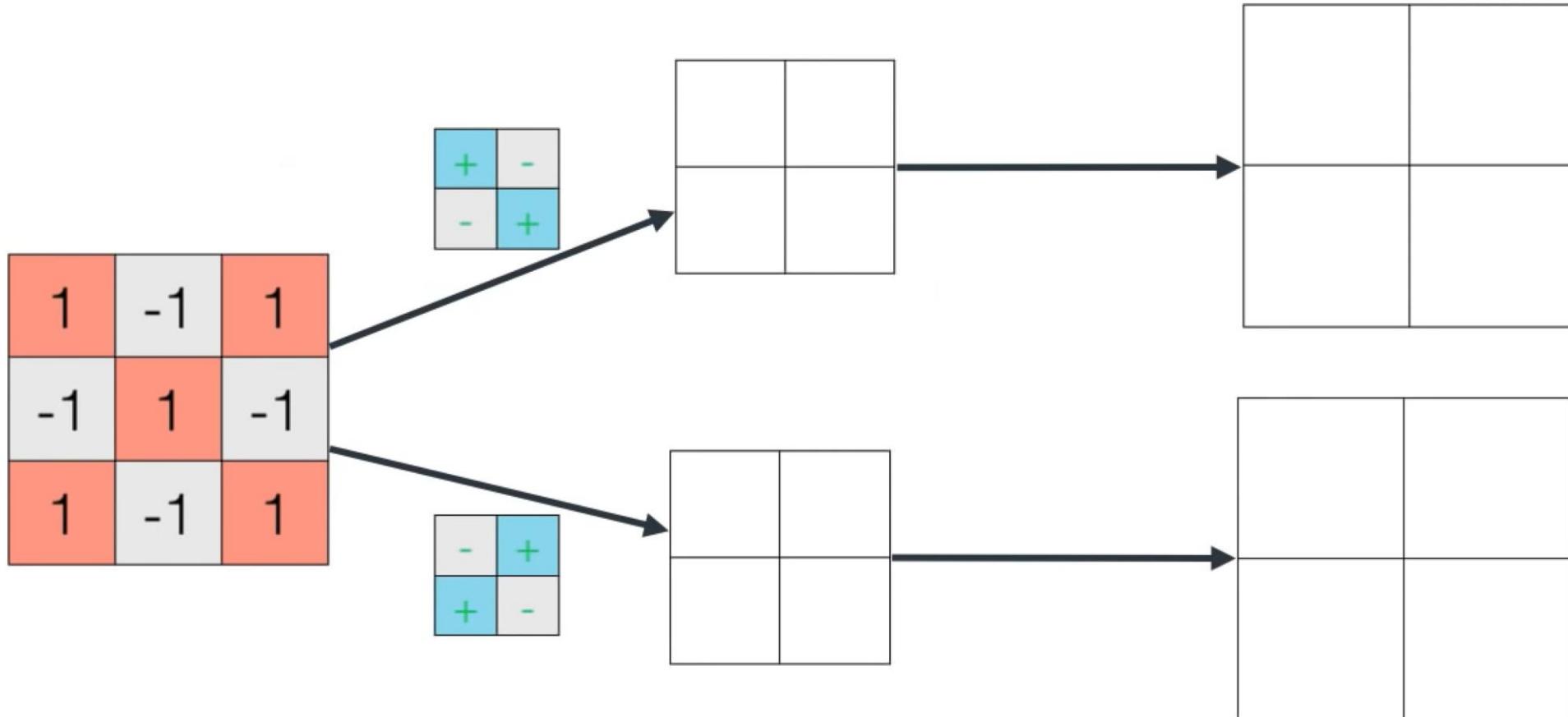
$$\begin{matrix} \times & \times \\ \times & \times \\ \times & \times \end{matrix}$$



$$/$$

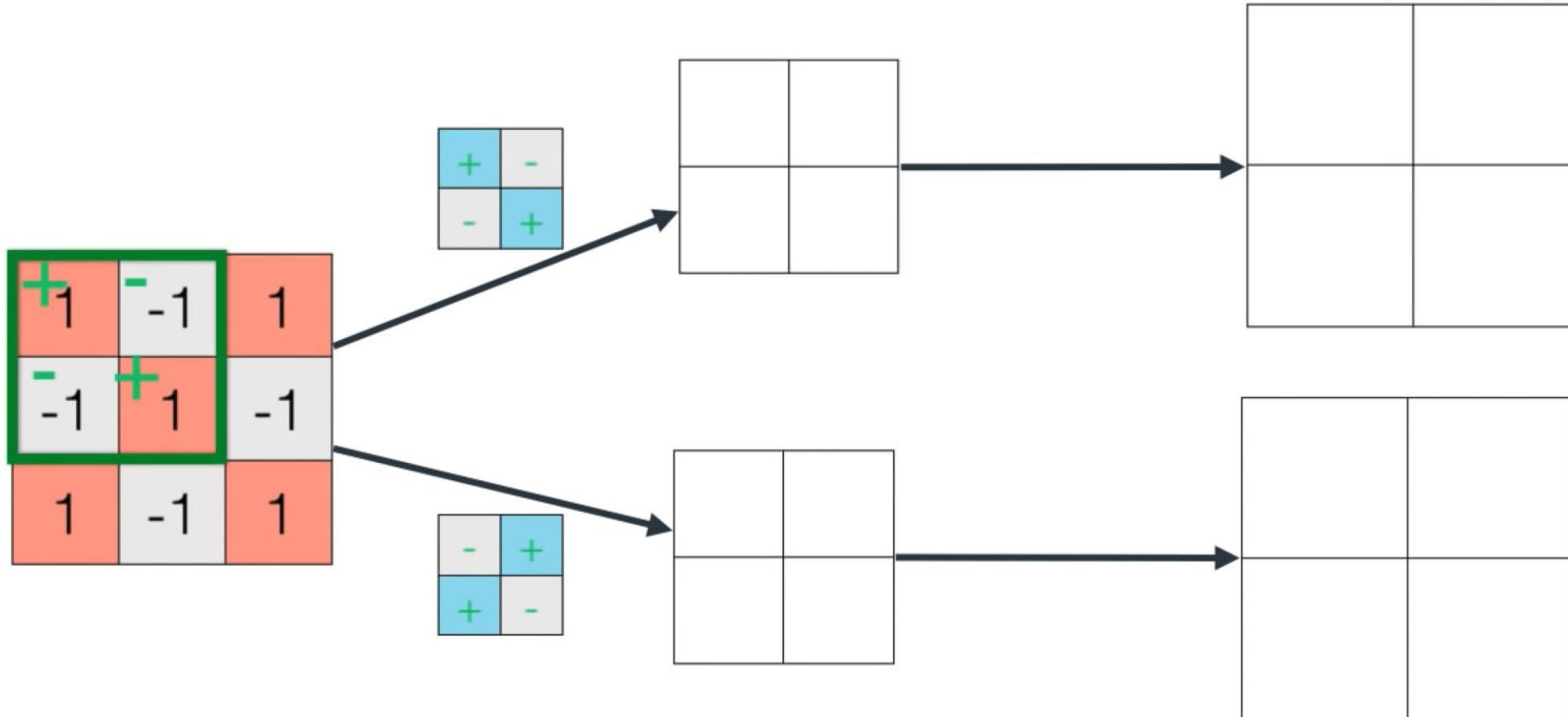
# Convolution Neural Network (CNN)

A little more complex world



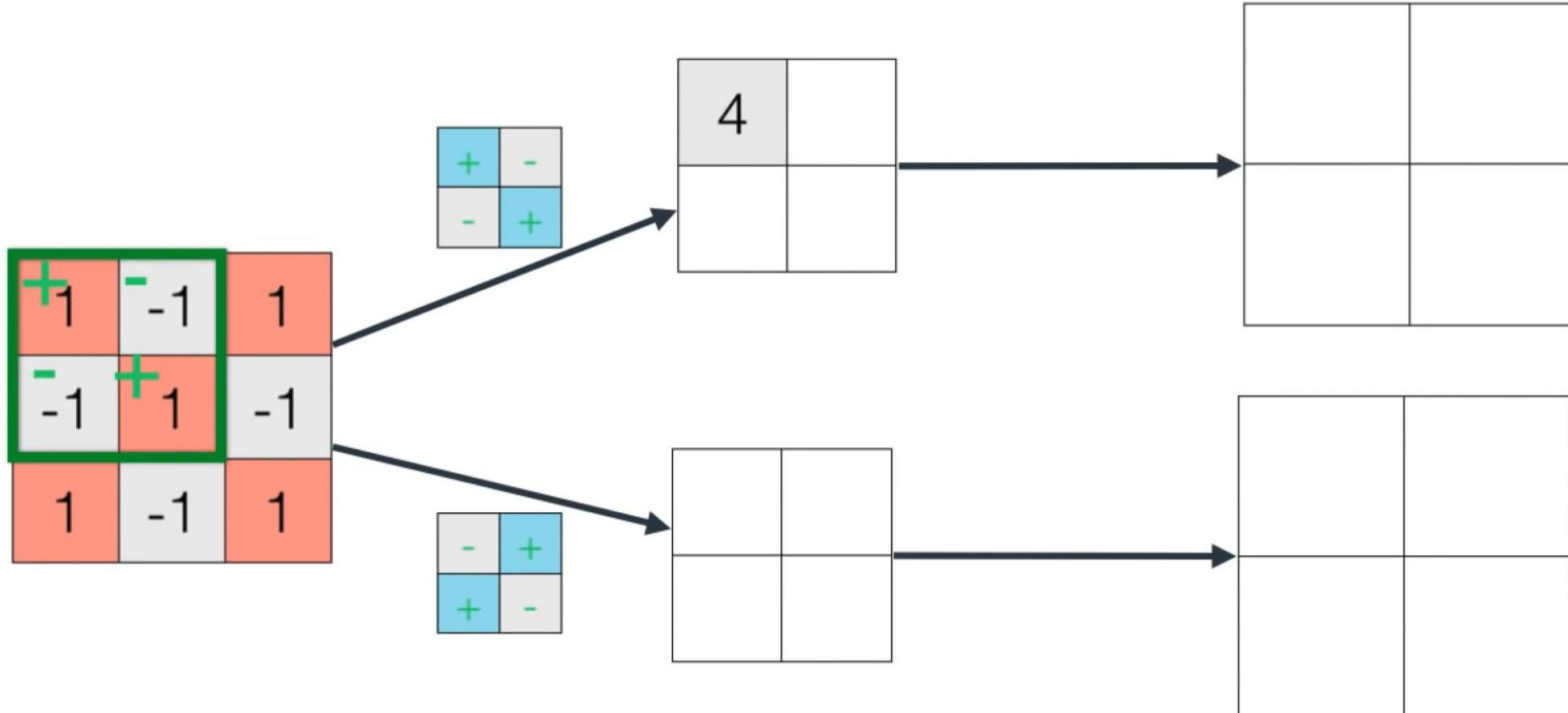
# Convolution Neural Network (CNN)

A little more complex world



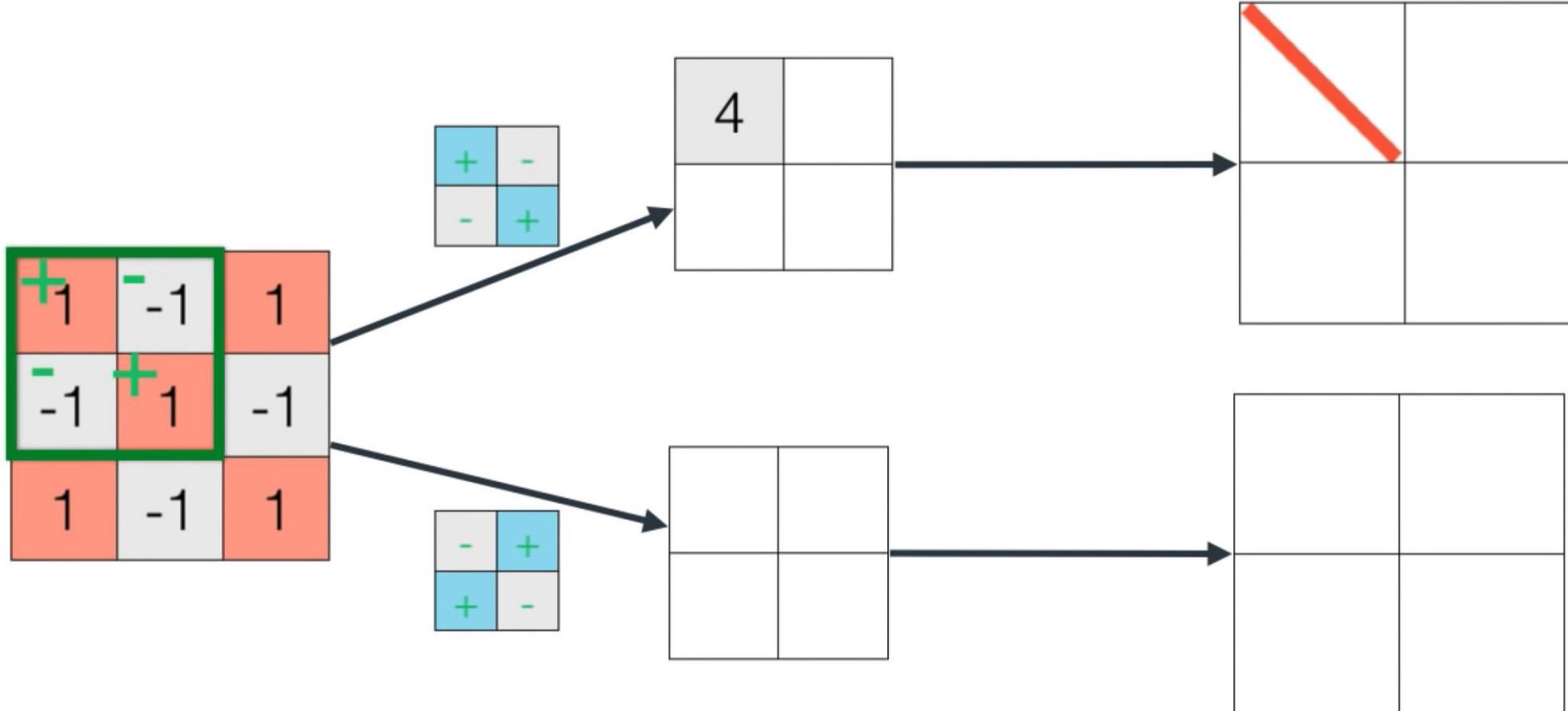
# Convolution Neural Network (CNN)

A little more complex world



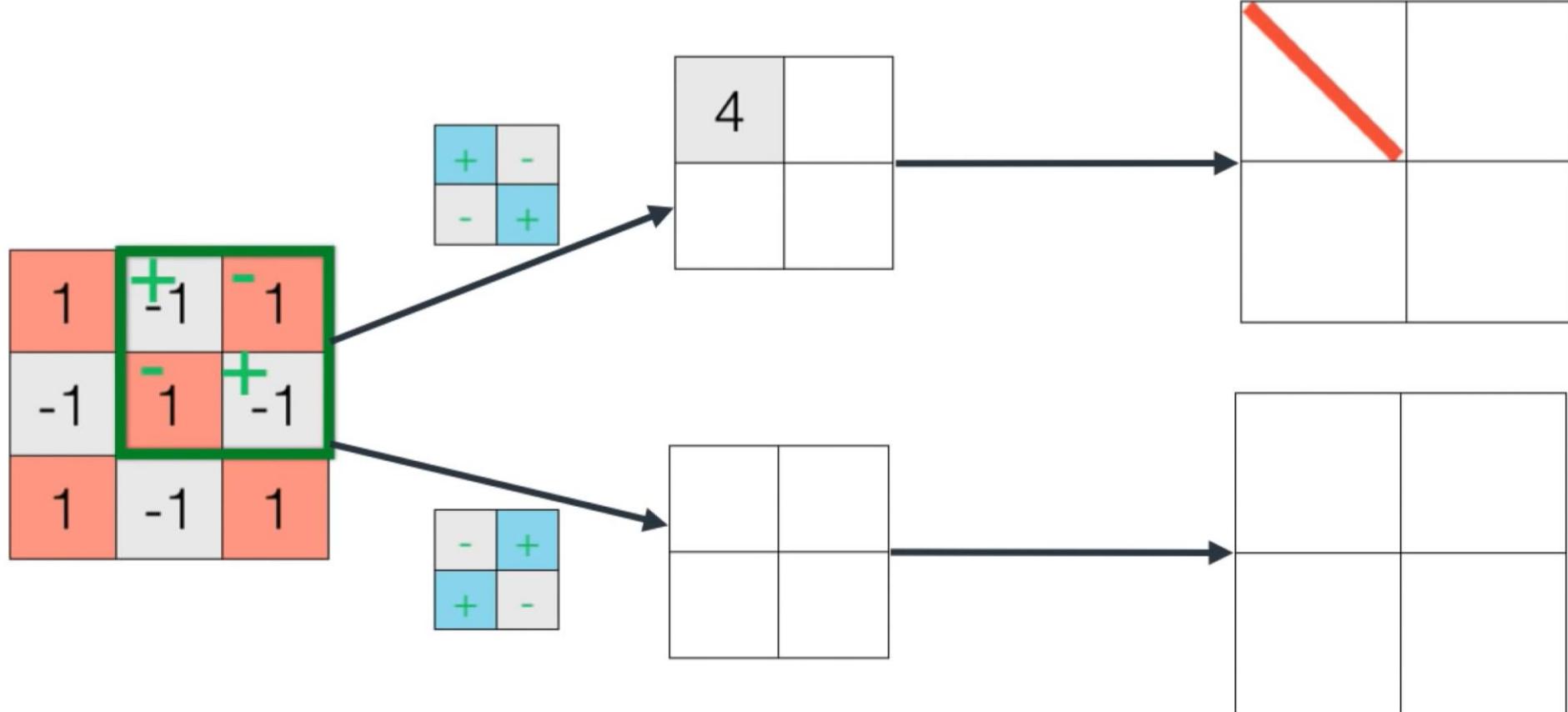
# Convolution Neural Network (CNN)

A little more complex world



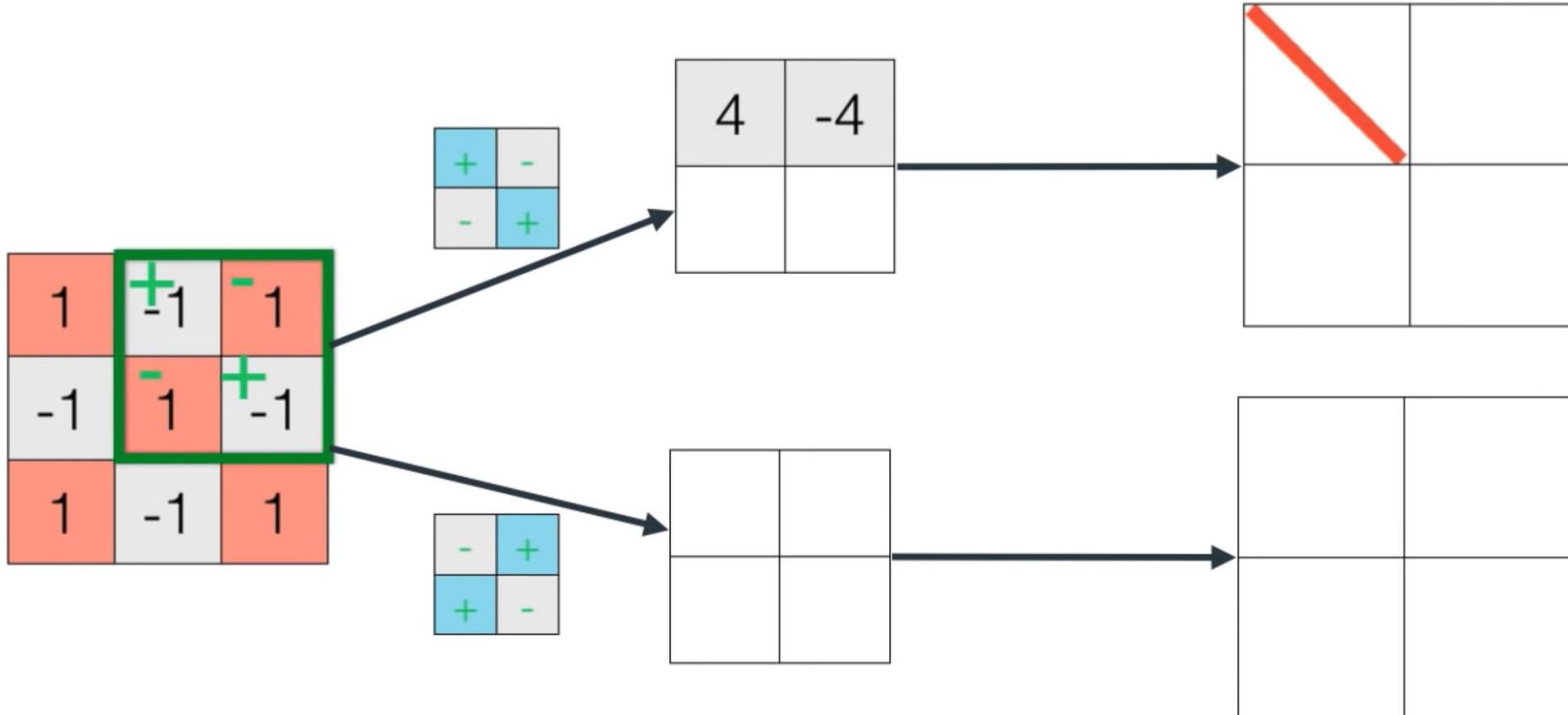
# Convolution Neural Network (CNN)

A little more complex world



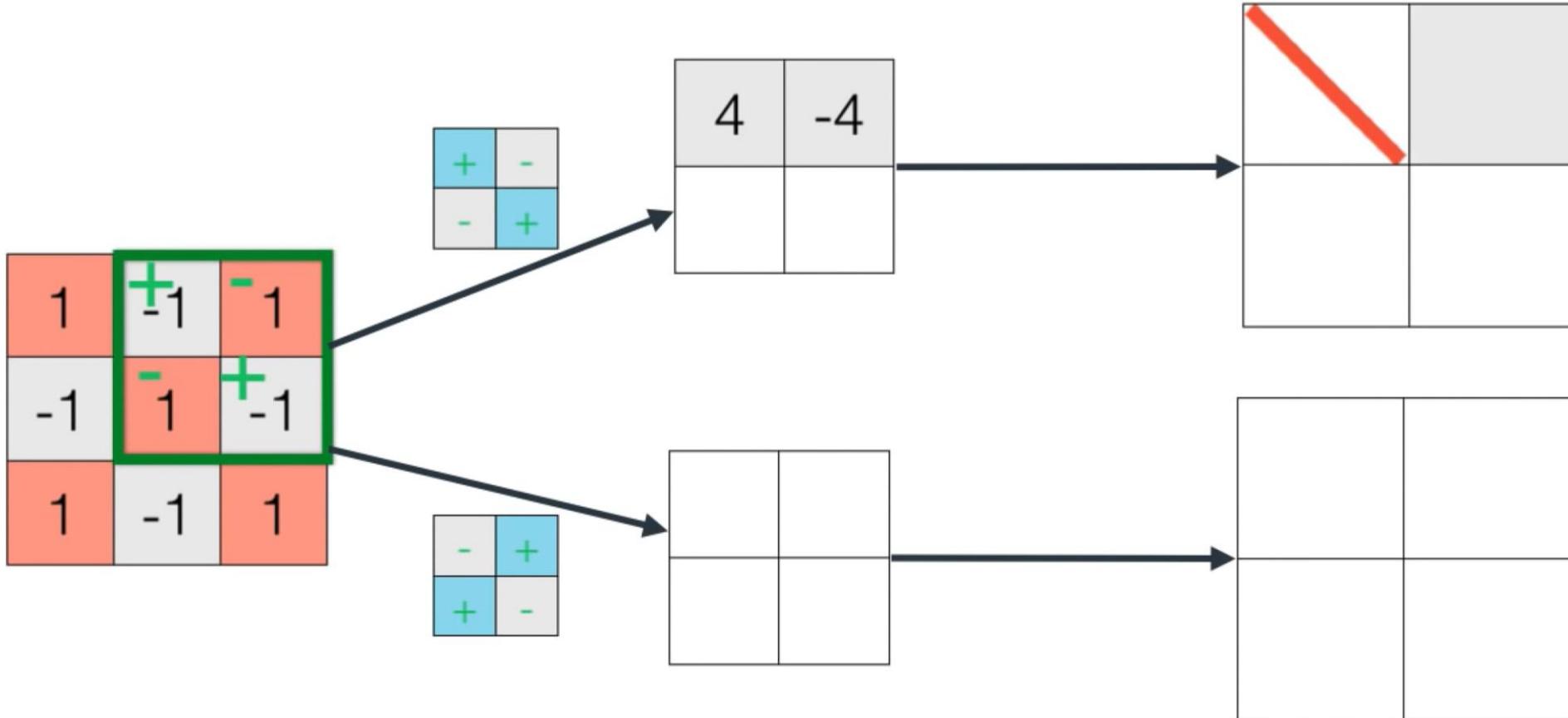
# Convolution Neural Network (CNN)

A little more complex world



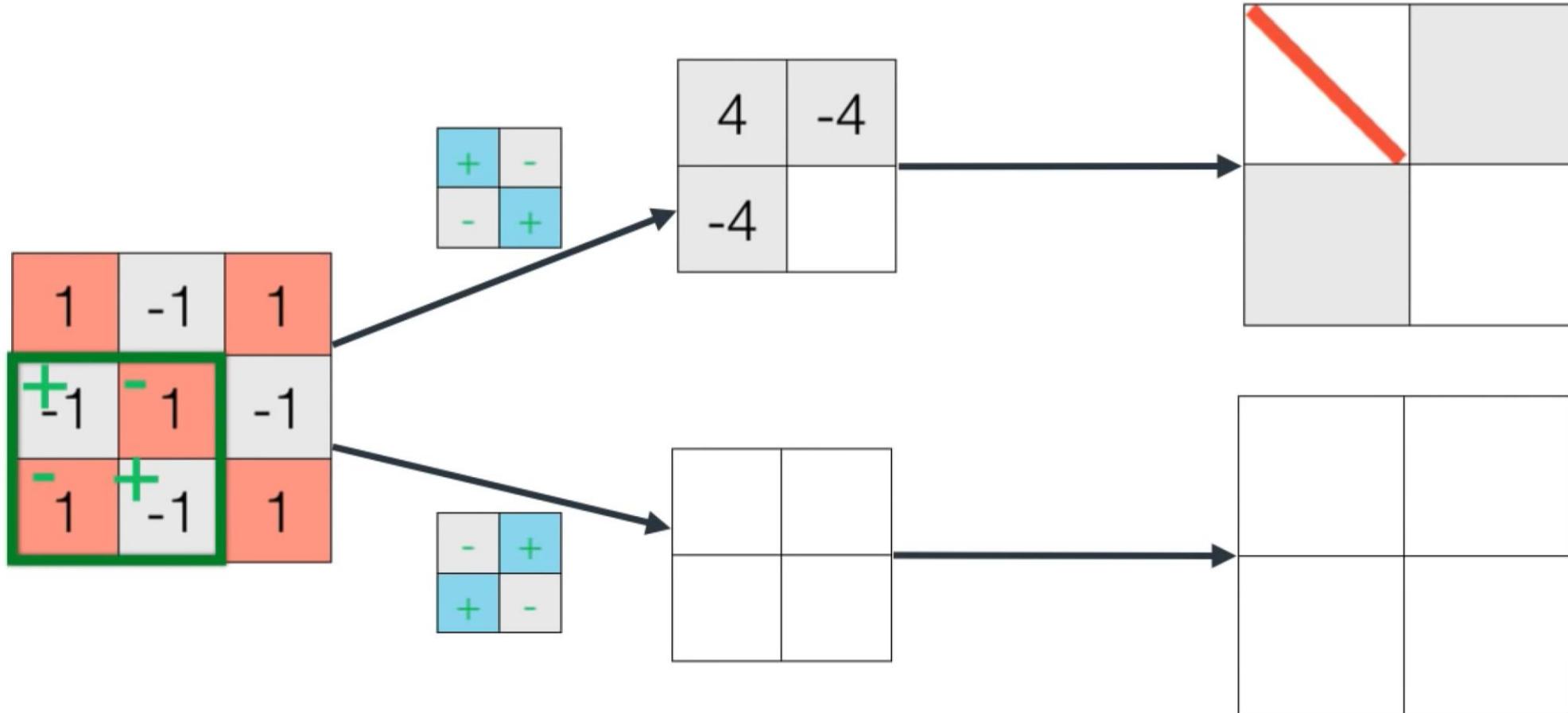
# Convolution Neural Network (CNN)

A little more complex world



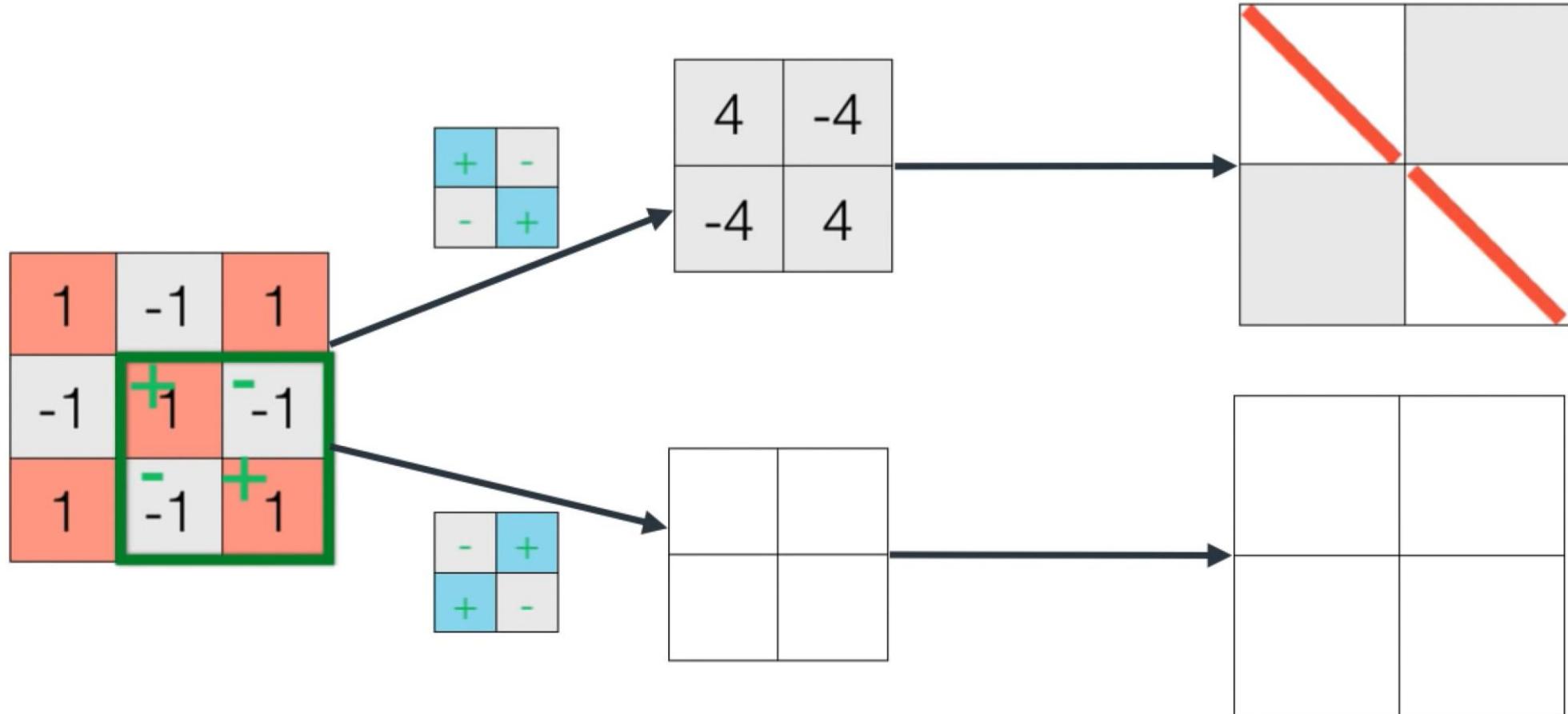
# Convolution Neural Network (CNN)

A little more complex world



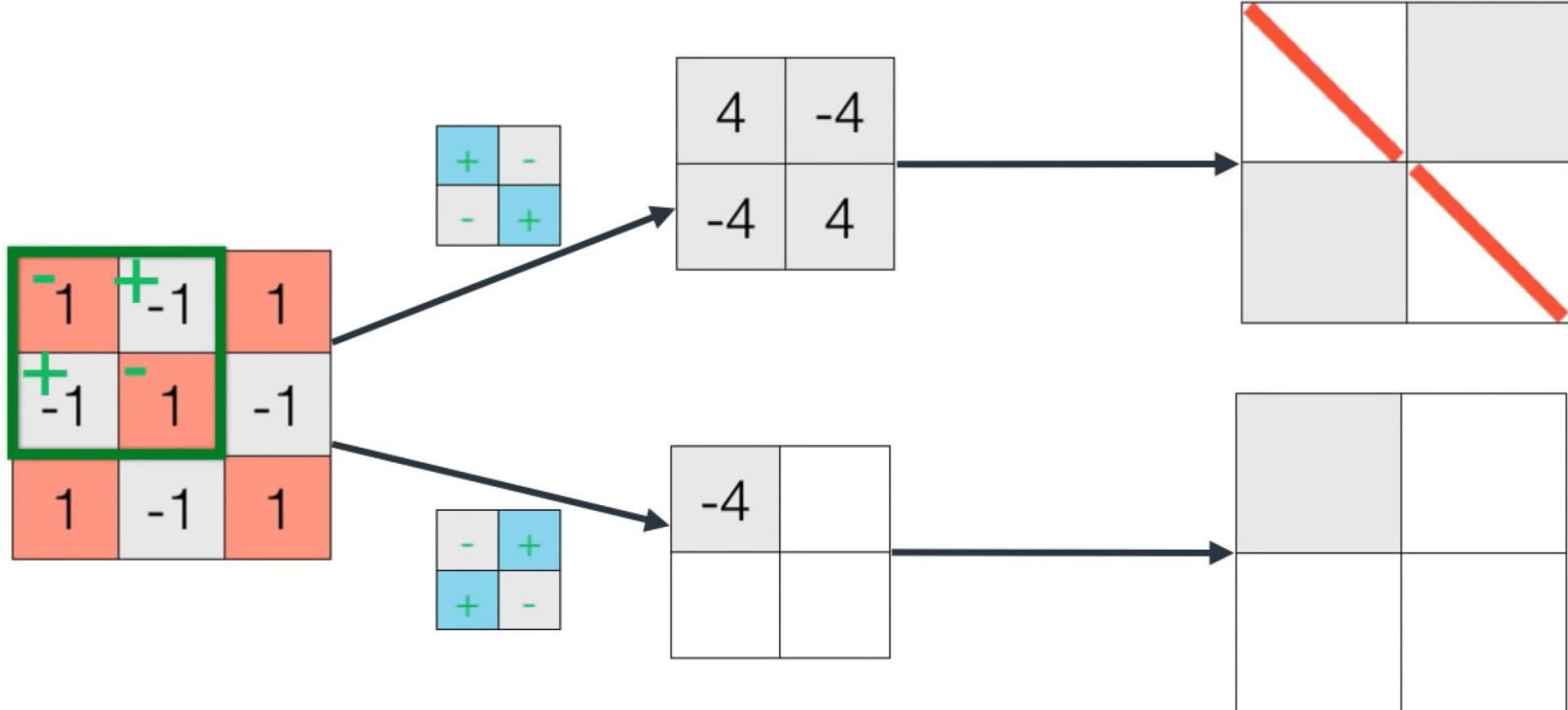
# Convolution Neural Network (CNN)

A little more complex world



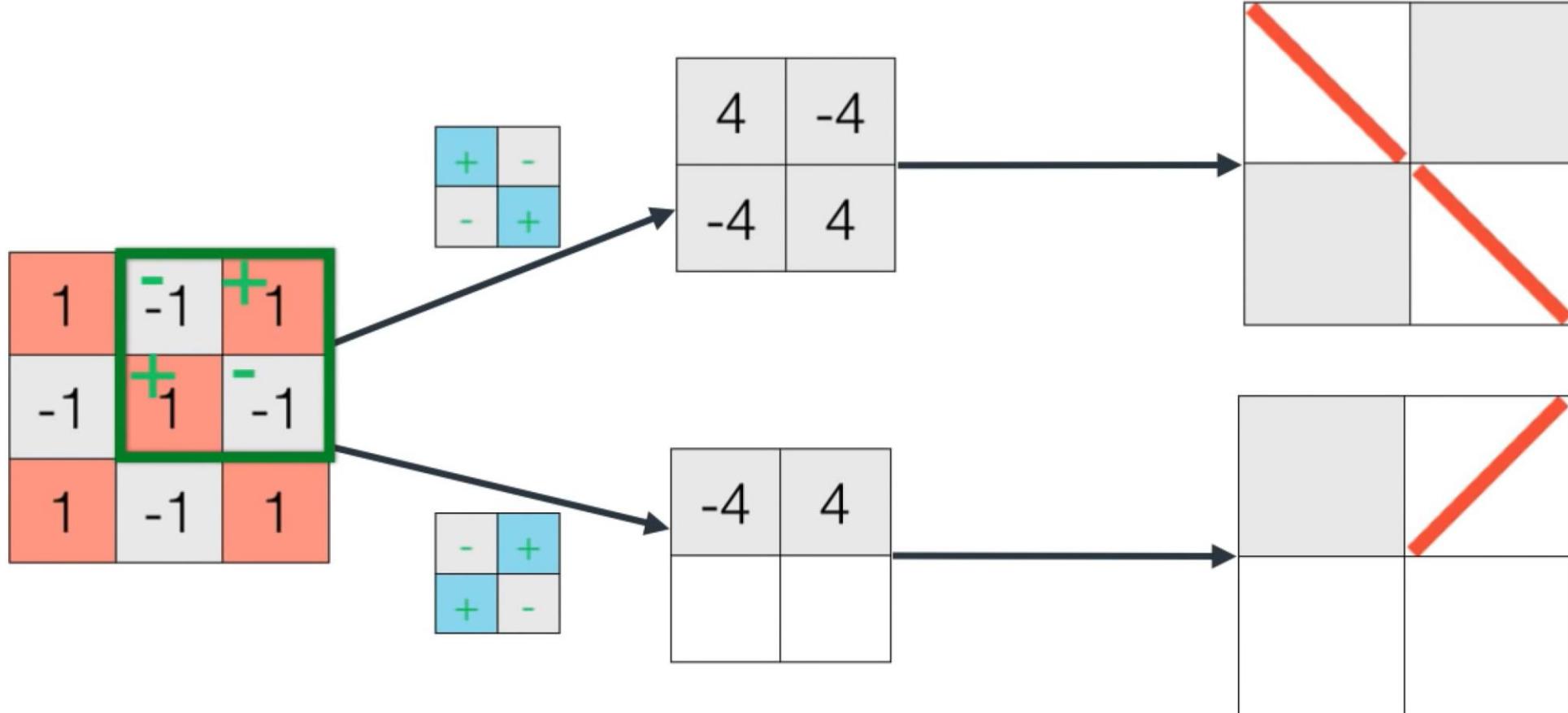
# Convolution Neural Network (CNN)

A little more complex world



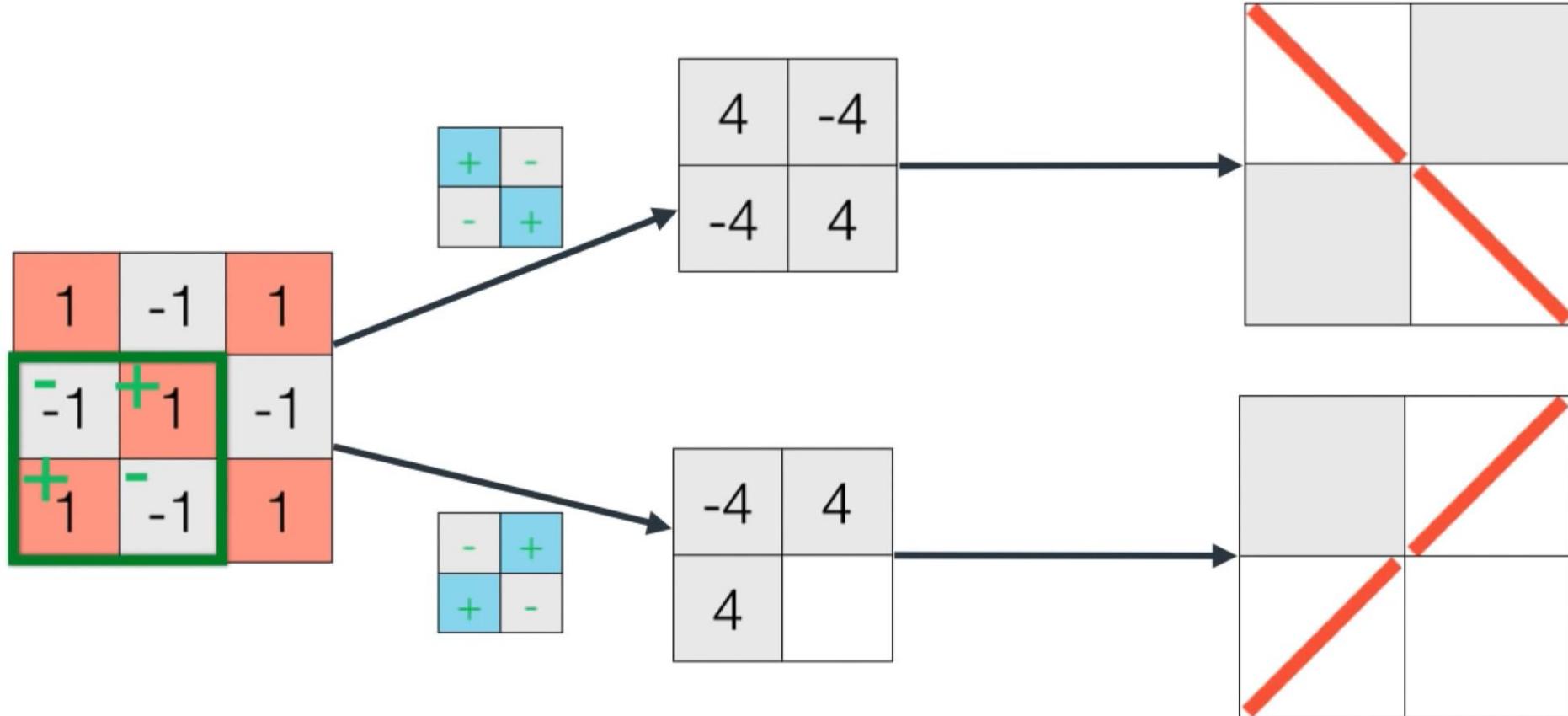
# Convolution Neural Network (CNN)

A little more complex world



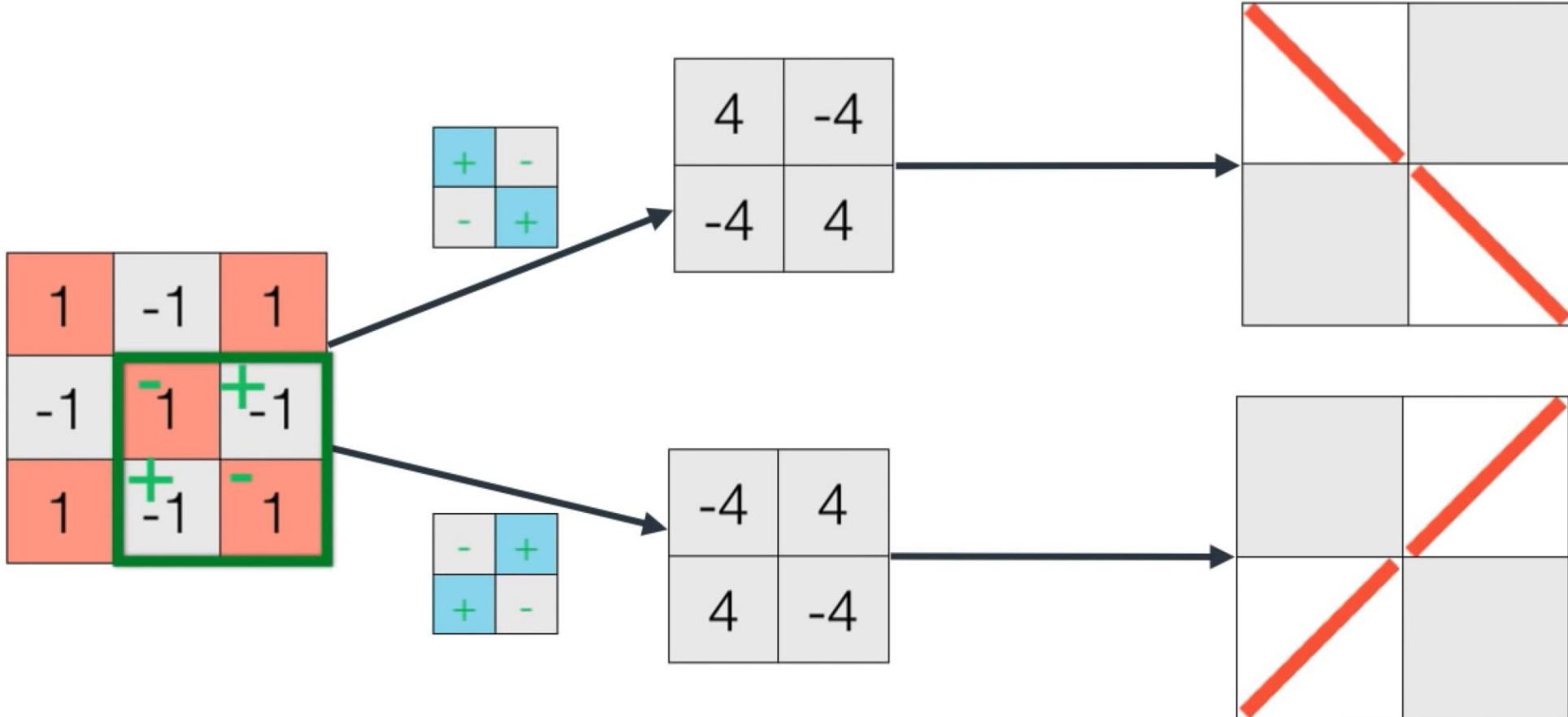
# Convolution Neural Network (CNN)

A little more complex world



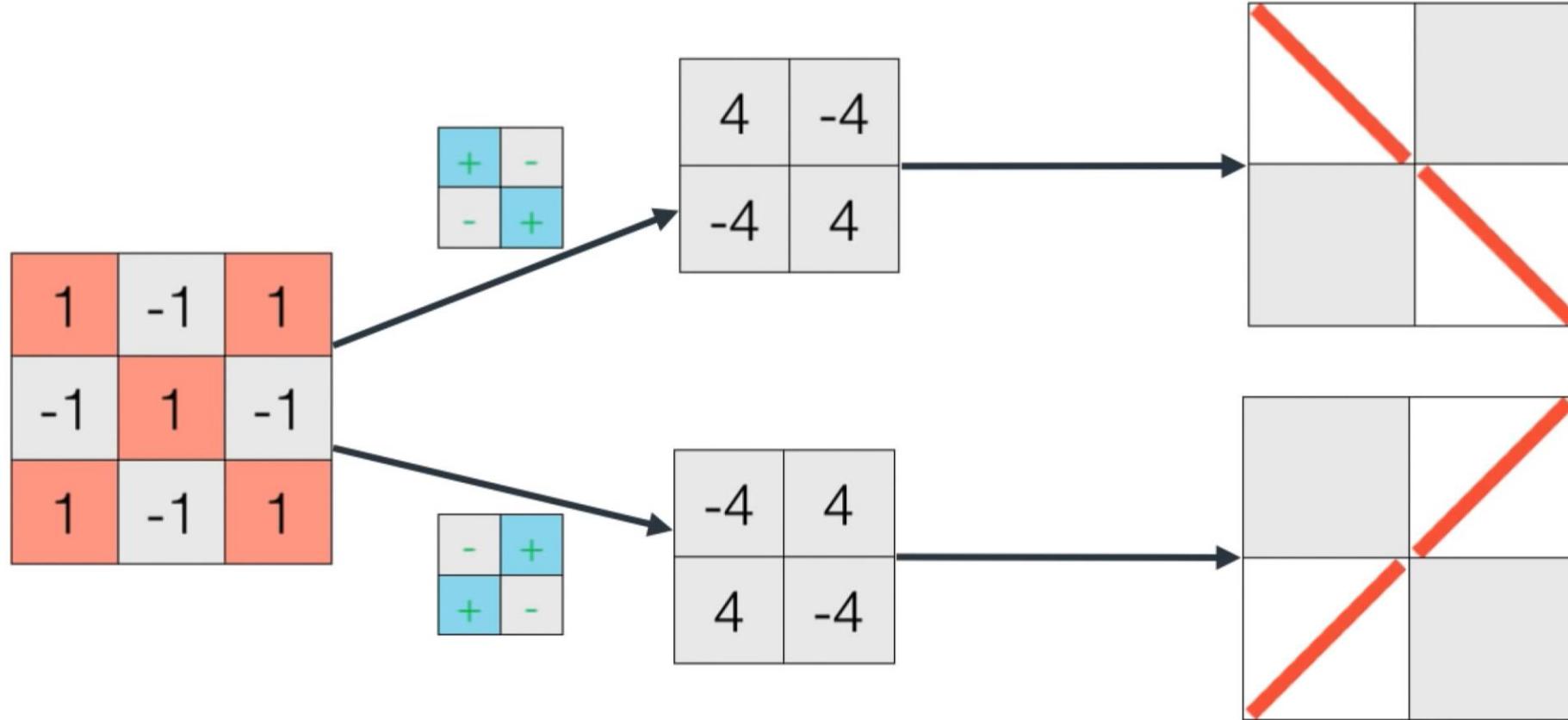
# Convolution Neural Network (CNN)

A little more complex world



# Convolution Neural Network (CNN)

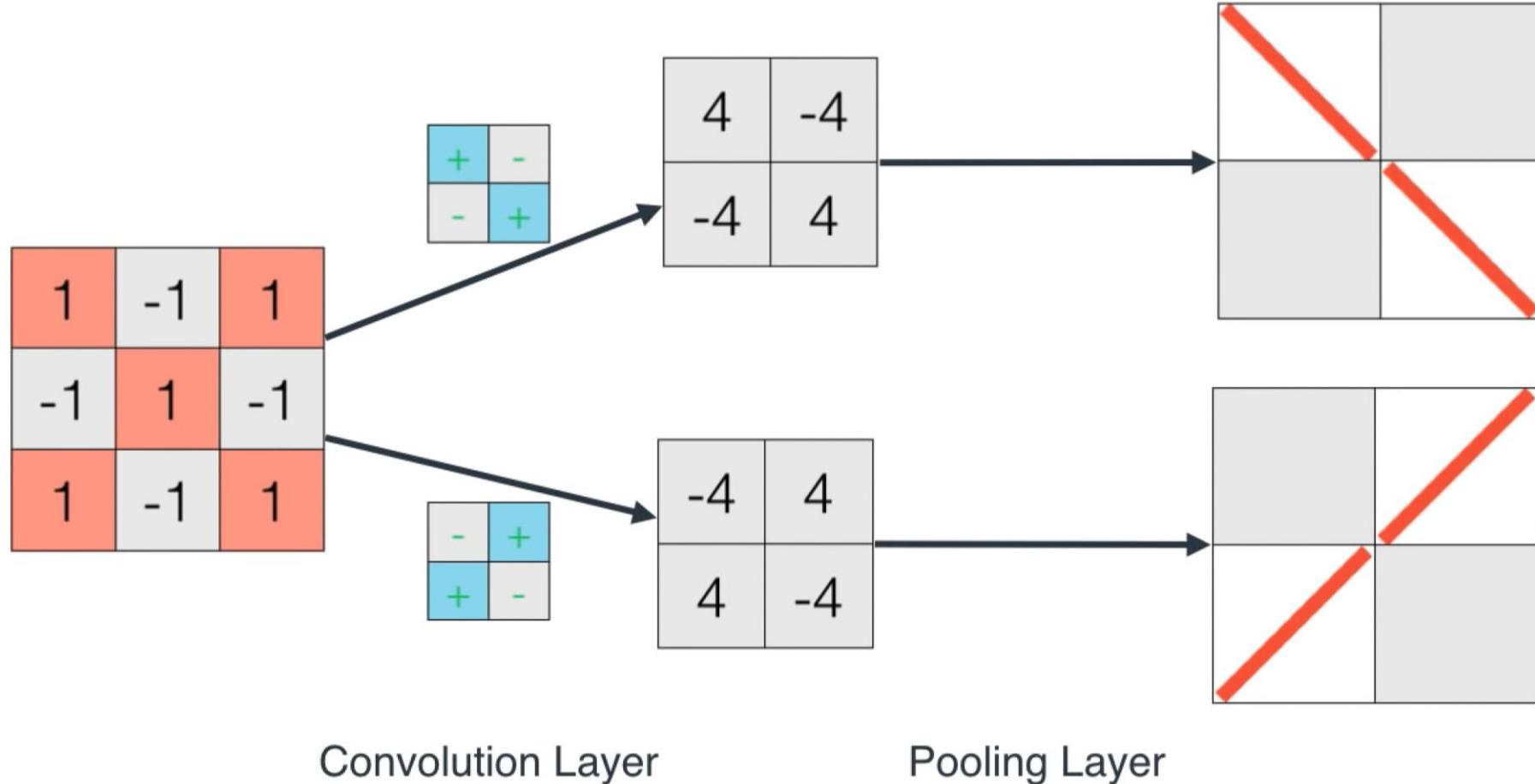
A little more complex world



Convolution Layer

# Convolution Neural Network (CNN)

A little more complex world

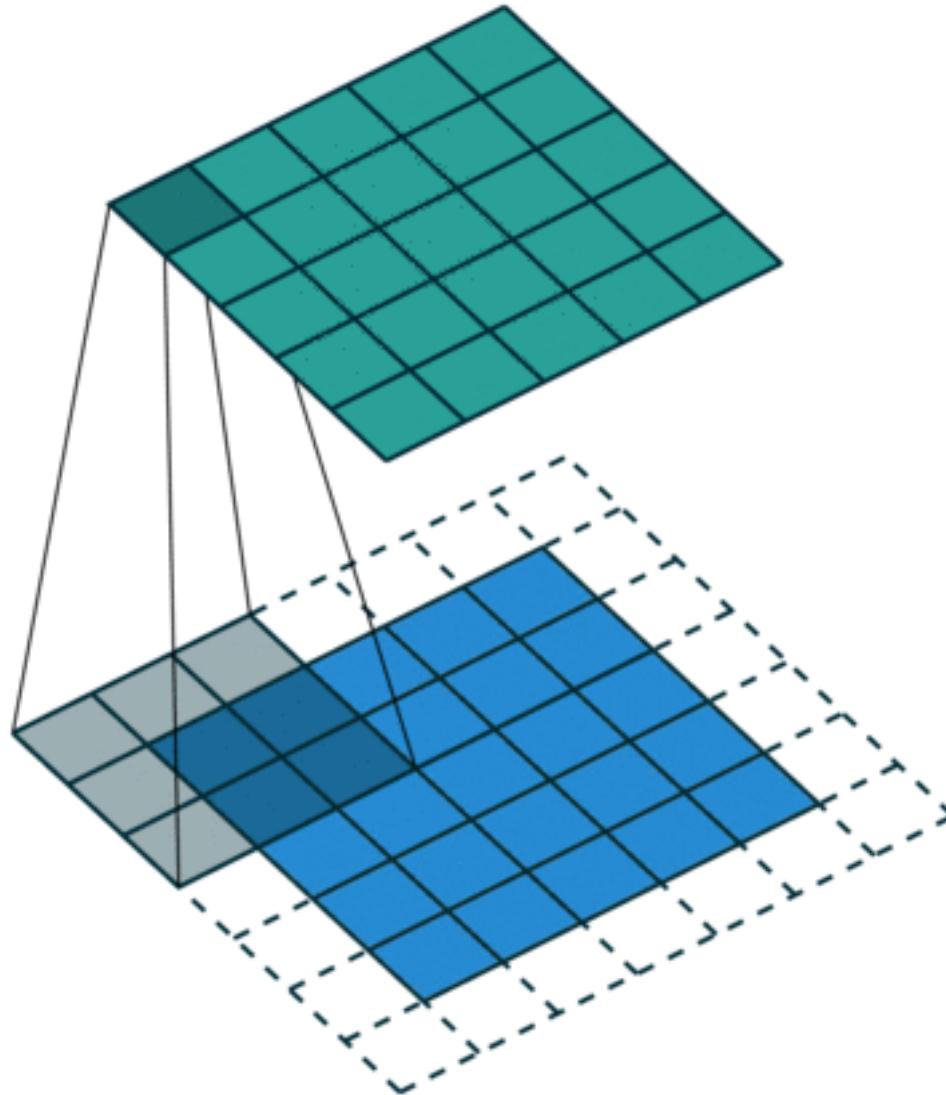


Convolution Layer

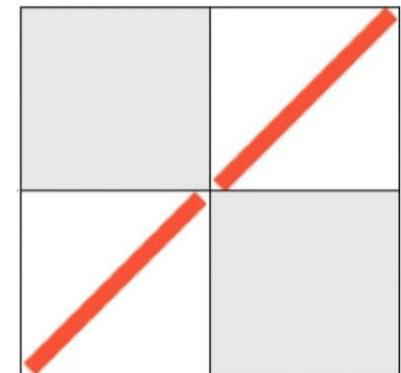
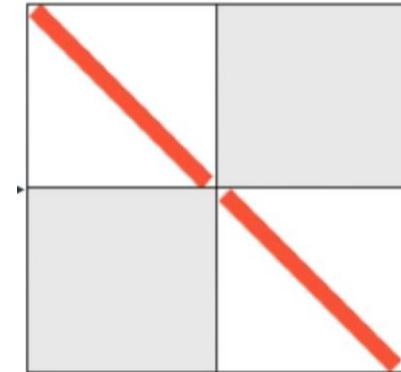
Pooling Layer

Con

1	-1	1
-1	1	-1
1	-1	1

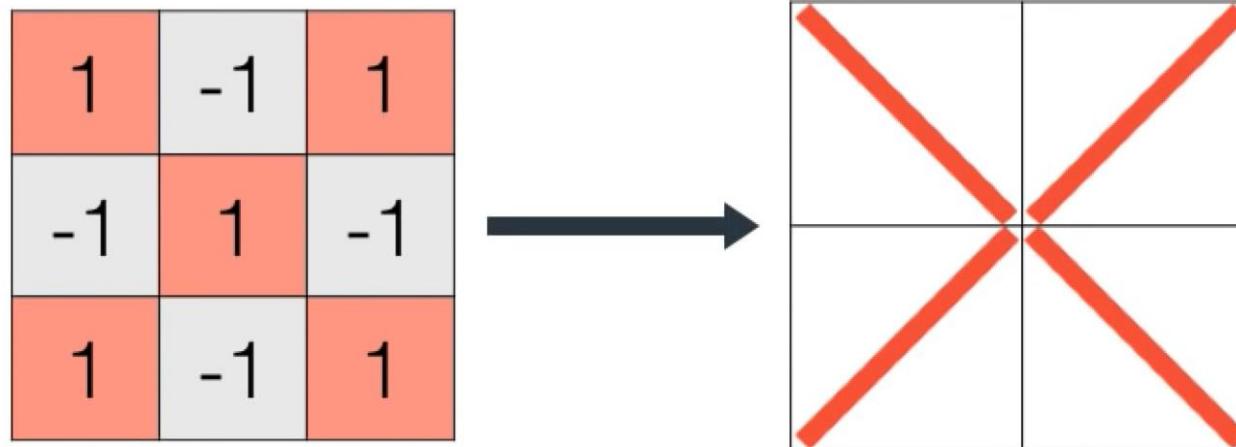


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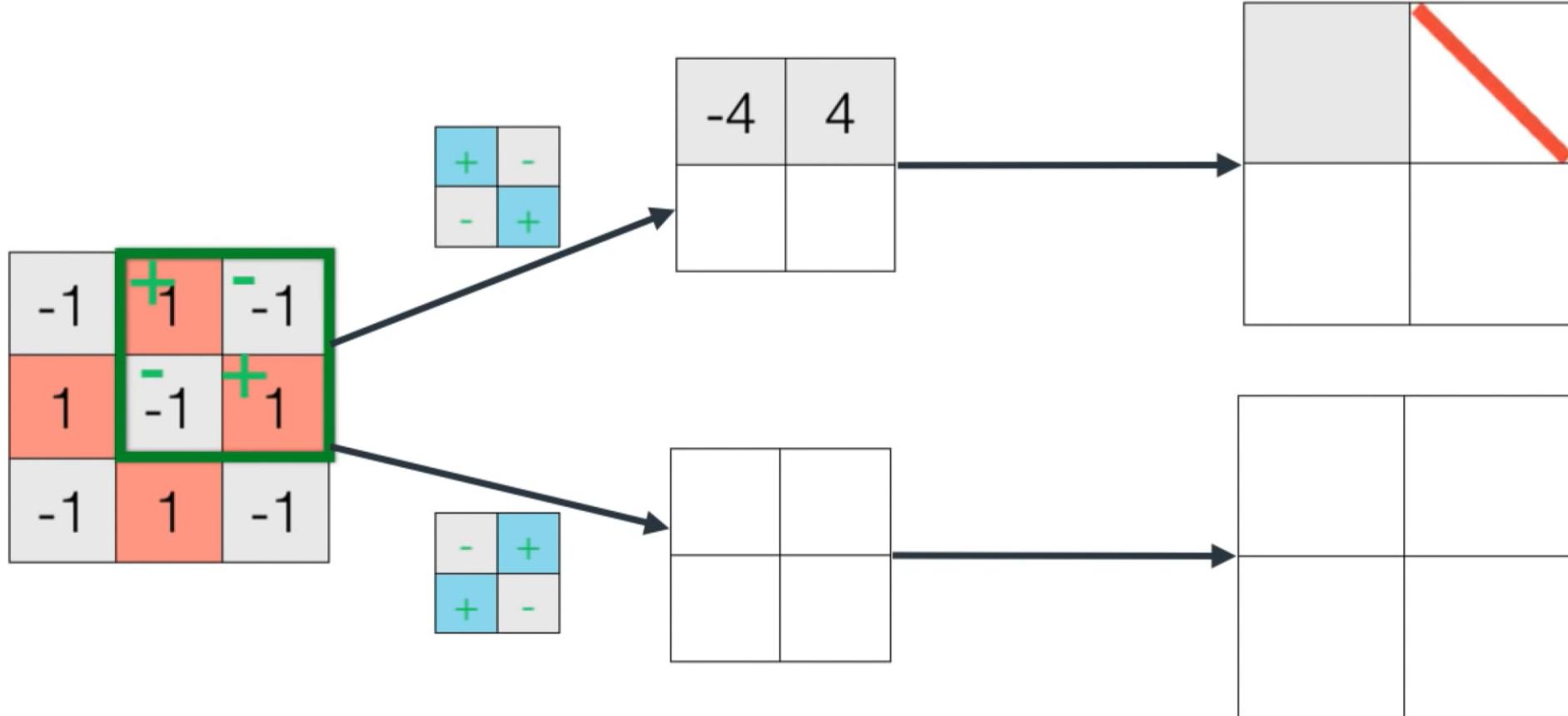
# Convolution Neural Network (CNN)

A little more complex world



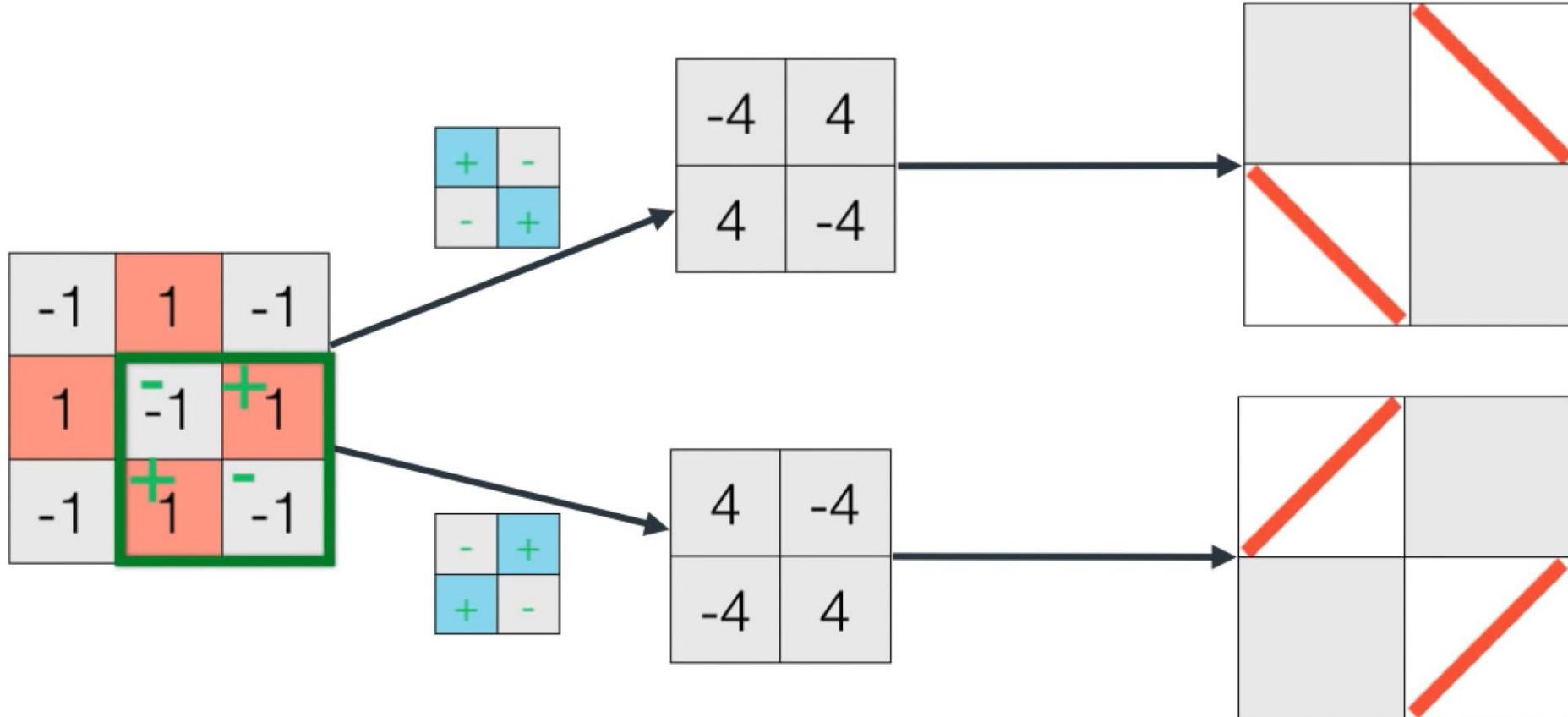
# Convolution Neural Network (CNN)

A little more complex world



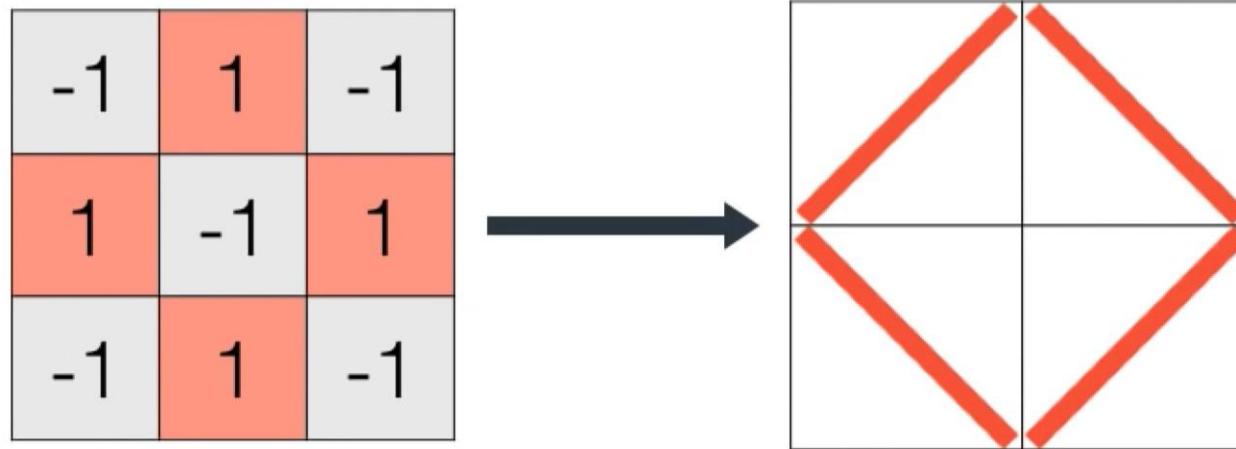
# Convolution Neural Network (CNN)

A little more complex world



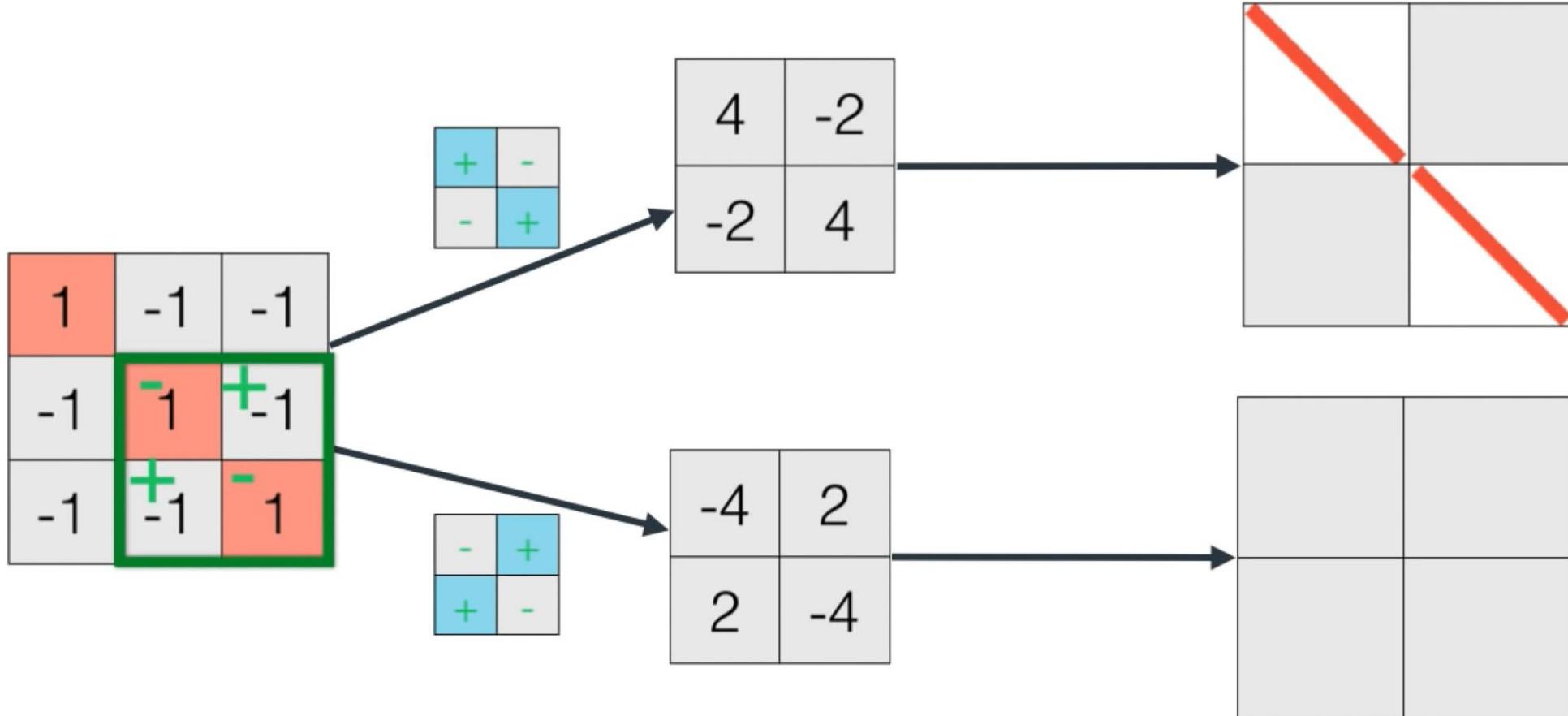
# Convolution Neural Network (CNN)

A little more complex world



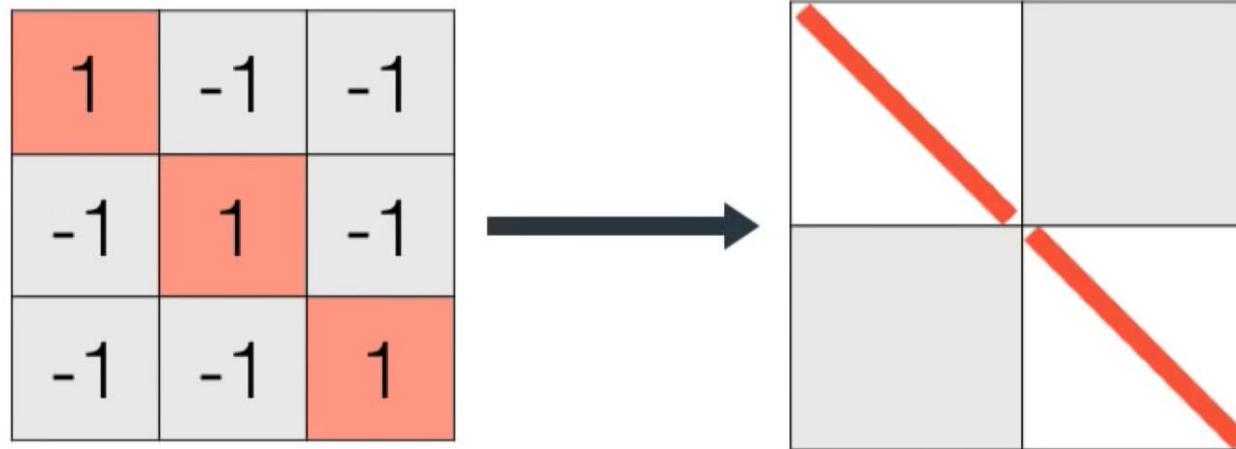
# Convolution Neural Network (CNN)

A little more complex world



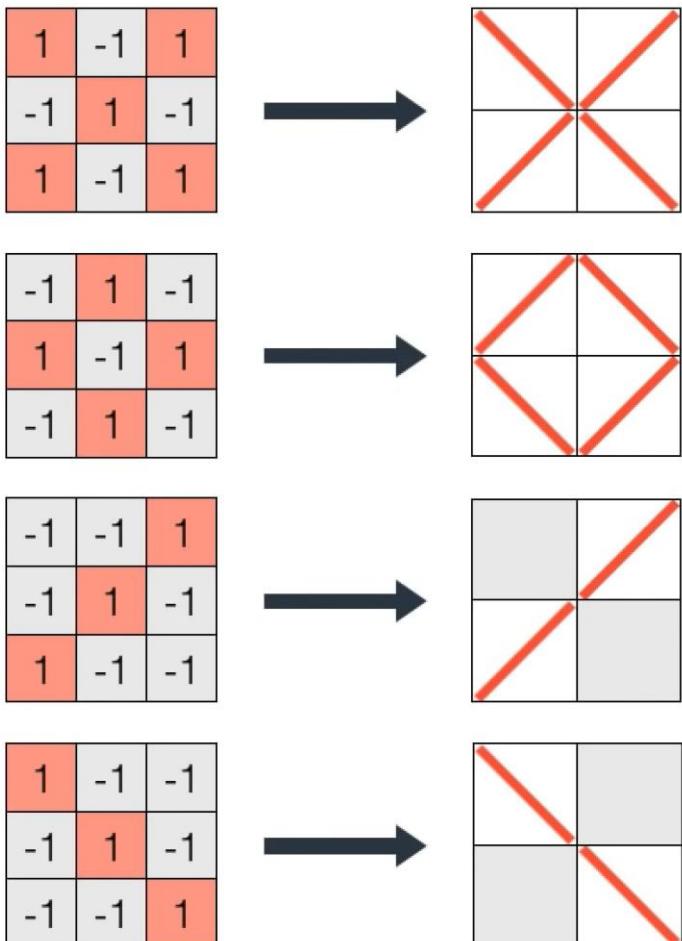
# Convolution Neural Network (CNN)

A little more complex world



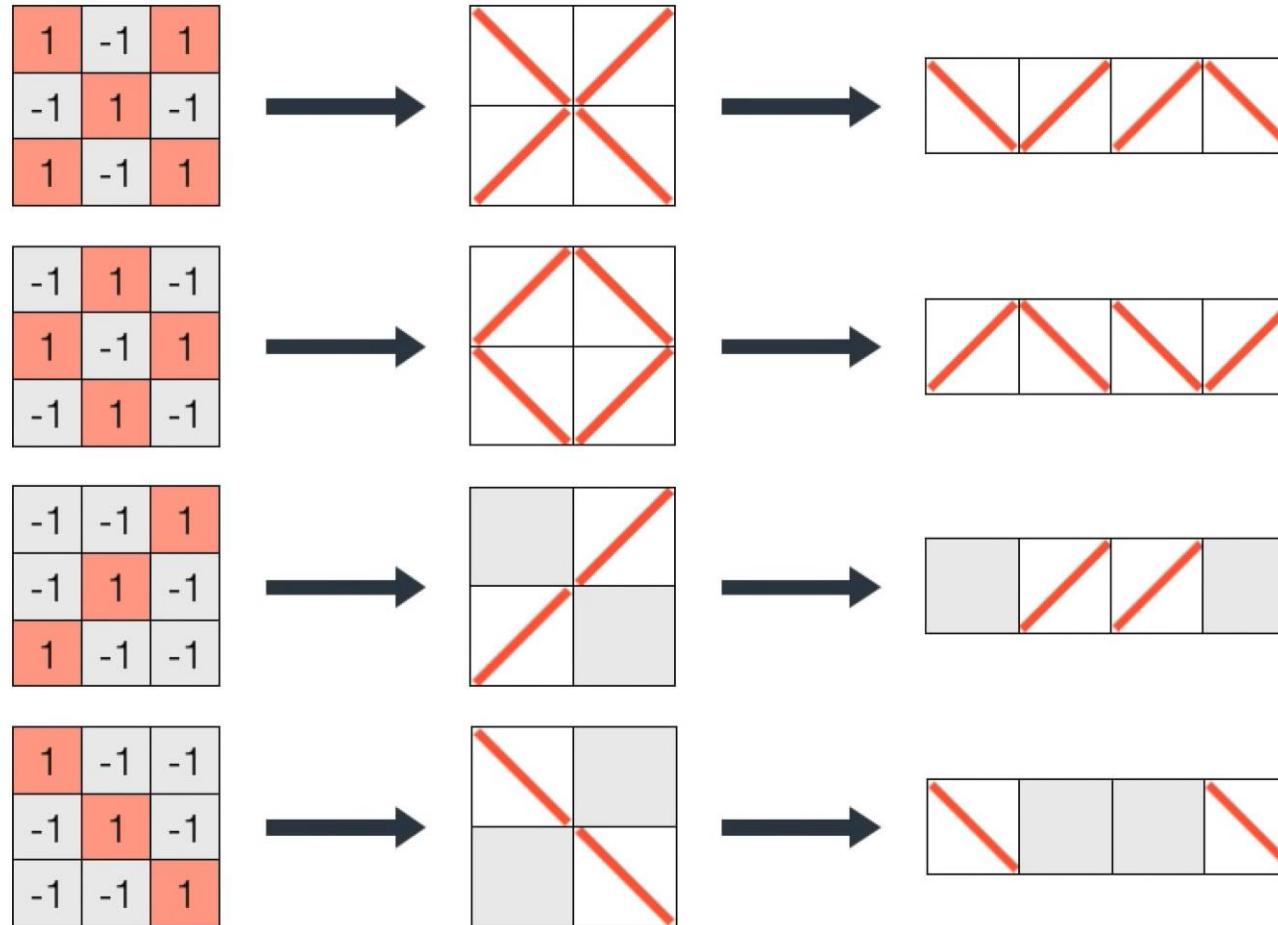
# Convolution Neural Network (CNN)

A little more complex world



# Convolution Neural Network (CNN)

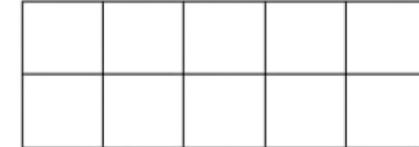
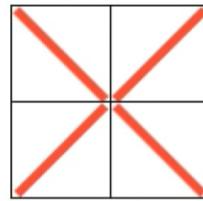
A little more complex world



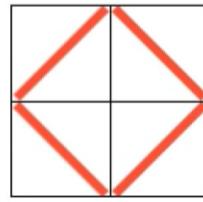
# Convolution Neural Network (CNN)

A little more complex world

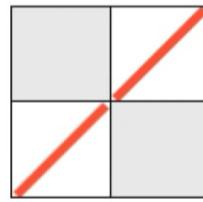
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-1	1	-1
1	-1	1



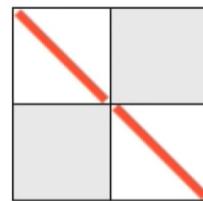
-1	1	-1
1	-1	1
-1	1	-1



-1	-1	1
-1	1	-1
1	-1	-1

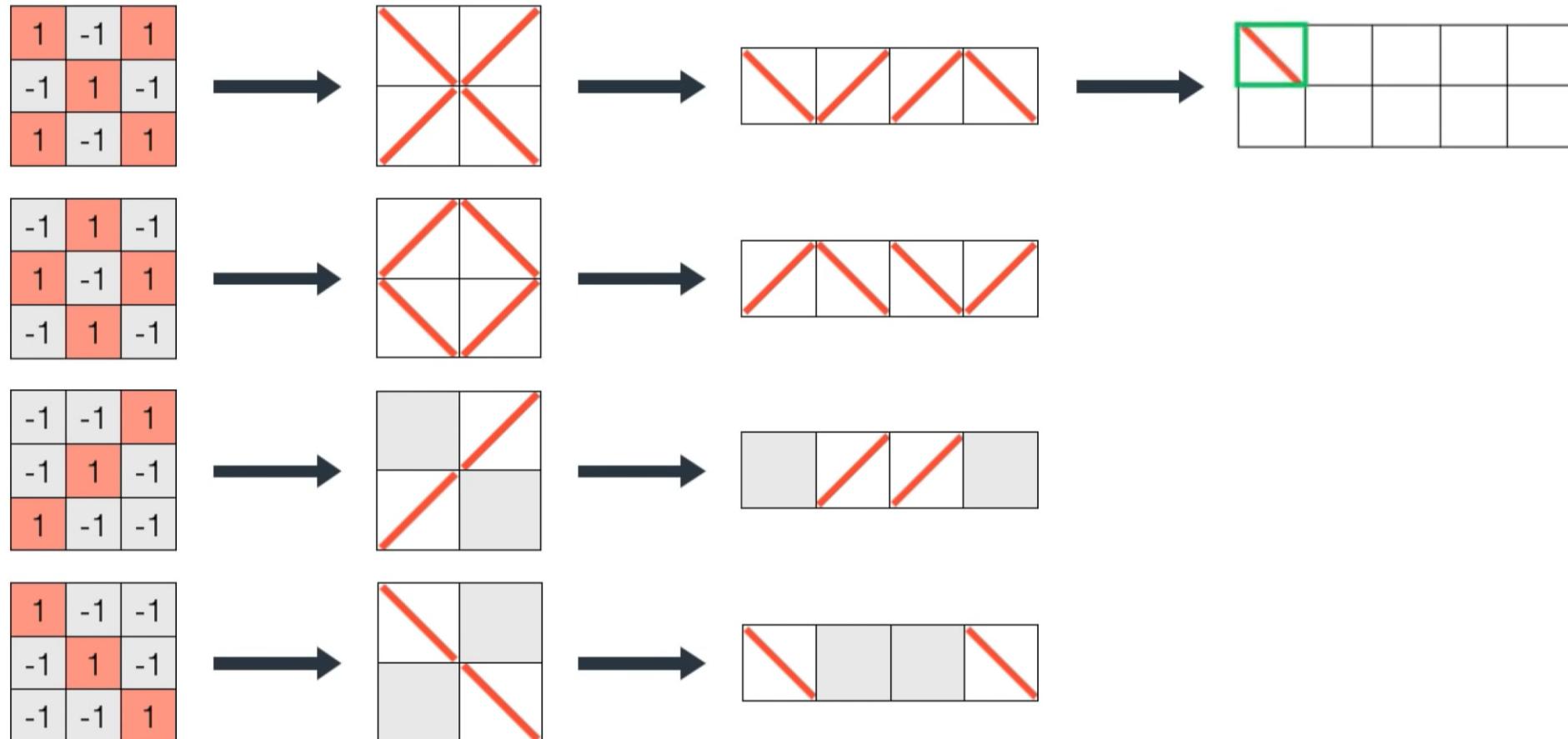


1	-1	-1
-1	1	-1
-1	-1	1



# Convolution Neural Network (CNN)

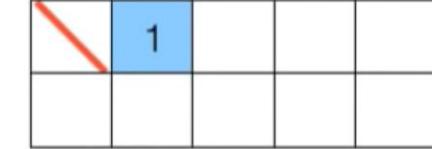
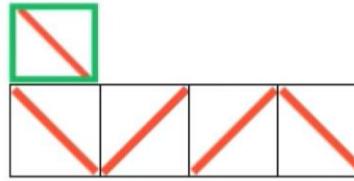
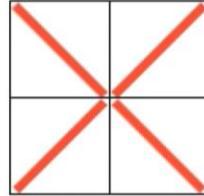
A little more complex world



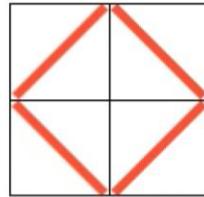
# Convolution Neural Network (CNN)

A little more complex world

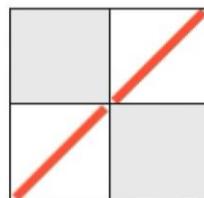
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-1	1	-1
1	-1	1



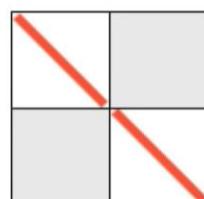
-1	1	-1
1	-1	1
-1	1	-1



-1	-1	1
-1	1	-1
1	-1	-1

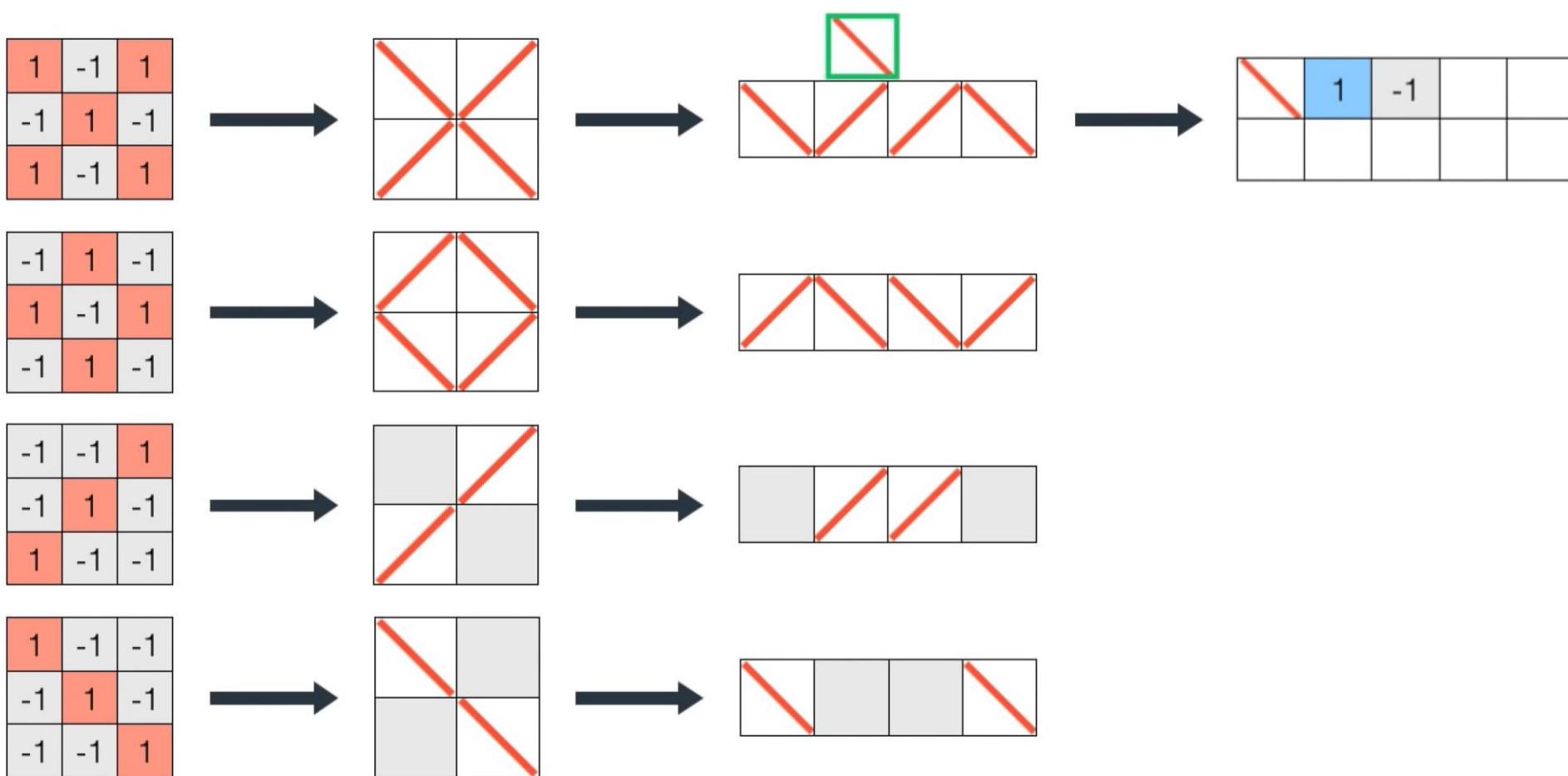


1	-1	-1
-1	1	-1
-1	-1	1



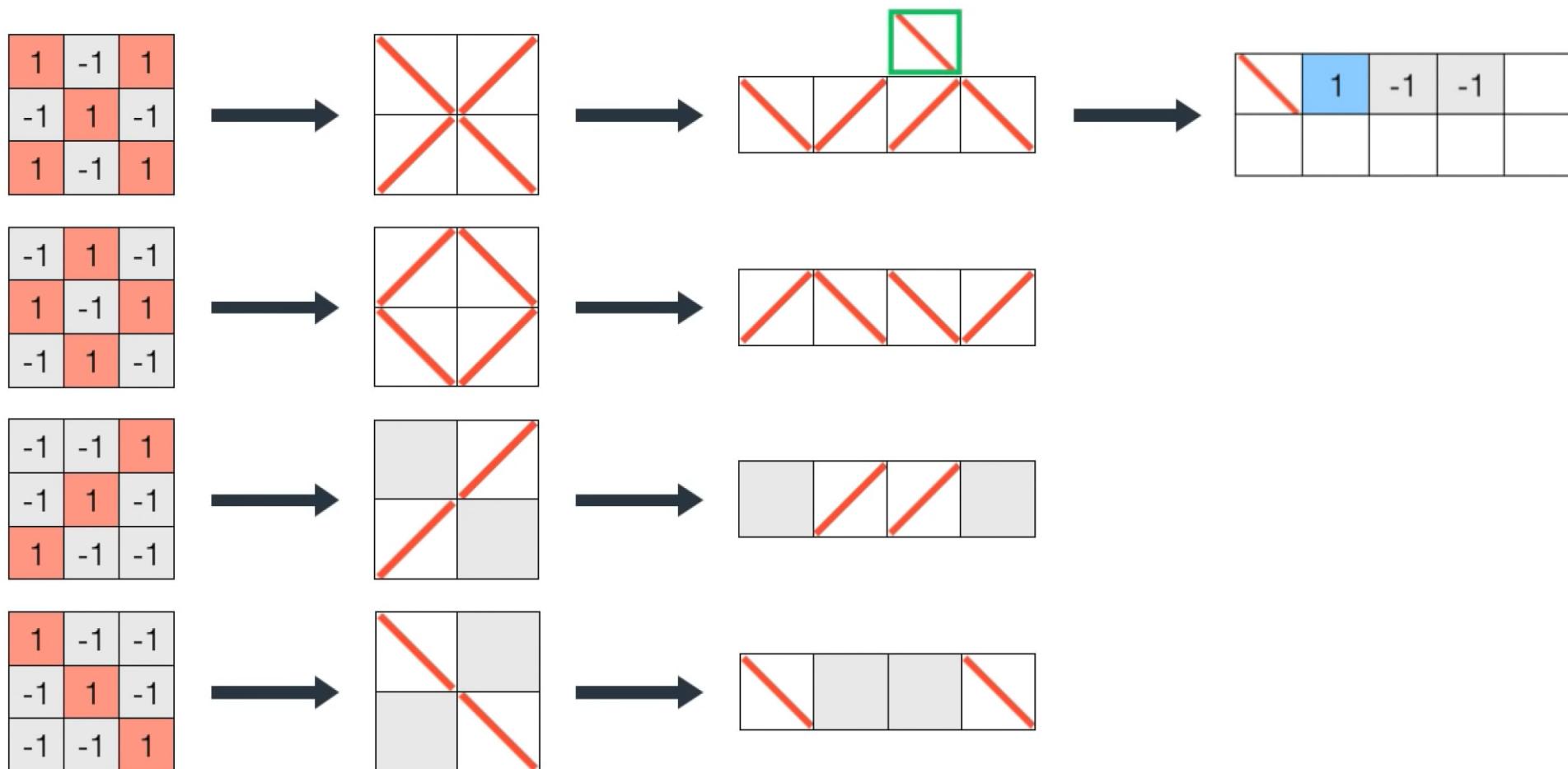
# Convolution Neural Network (CNN)

A little more complex world



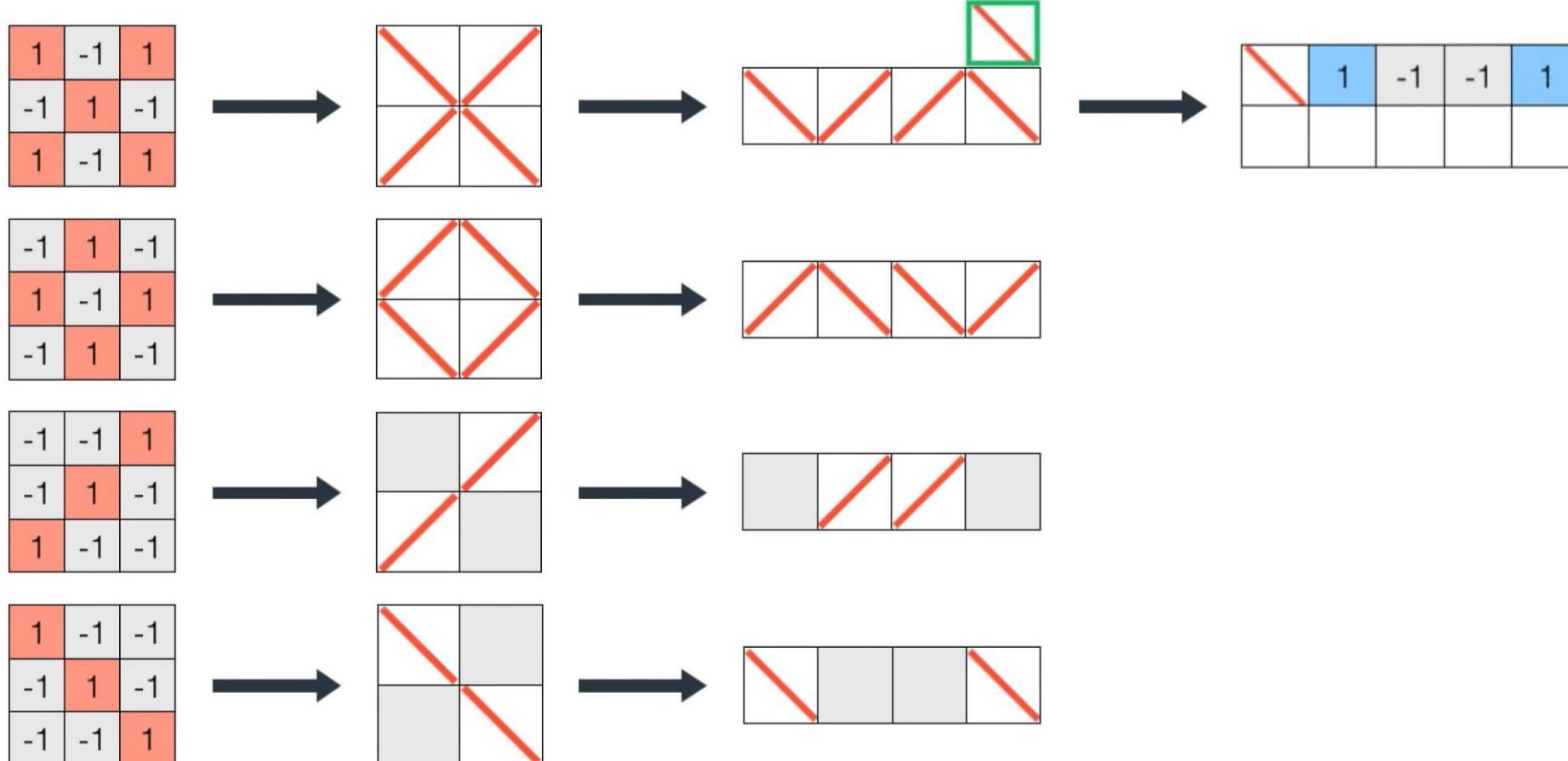
# Convolution Neural Network (CNN)

A little more complex world



# Convolution Neural Network (CNN)

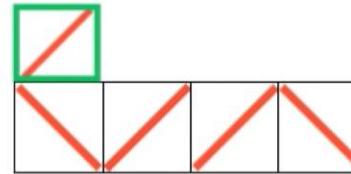
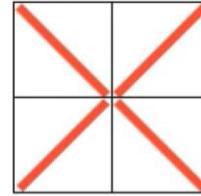
A little more complex world



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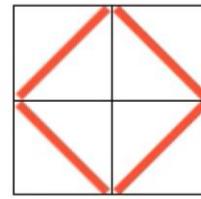
A little more complex world

1	-1	1
-1	1	-1
1	-1	1

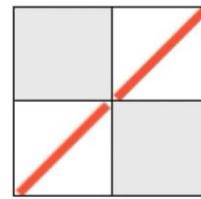


	1	-1	-1	1
	-1			

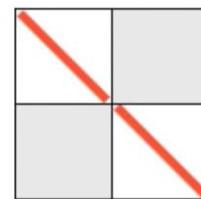
-1	1	-1
1	-1	1
-1	1	-1



-1	-1	1
-1	1	-1
1	-1	-1

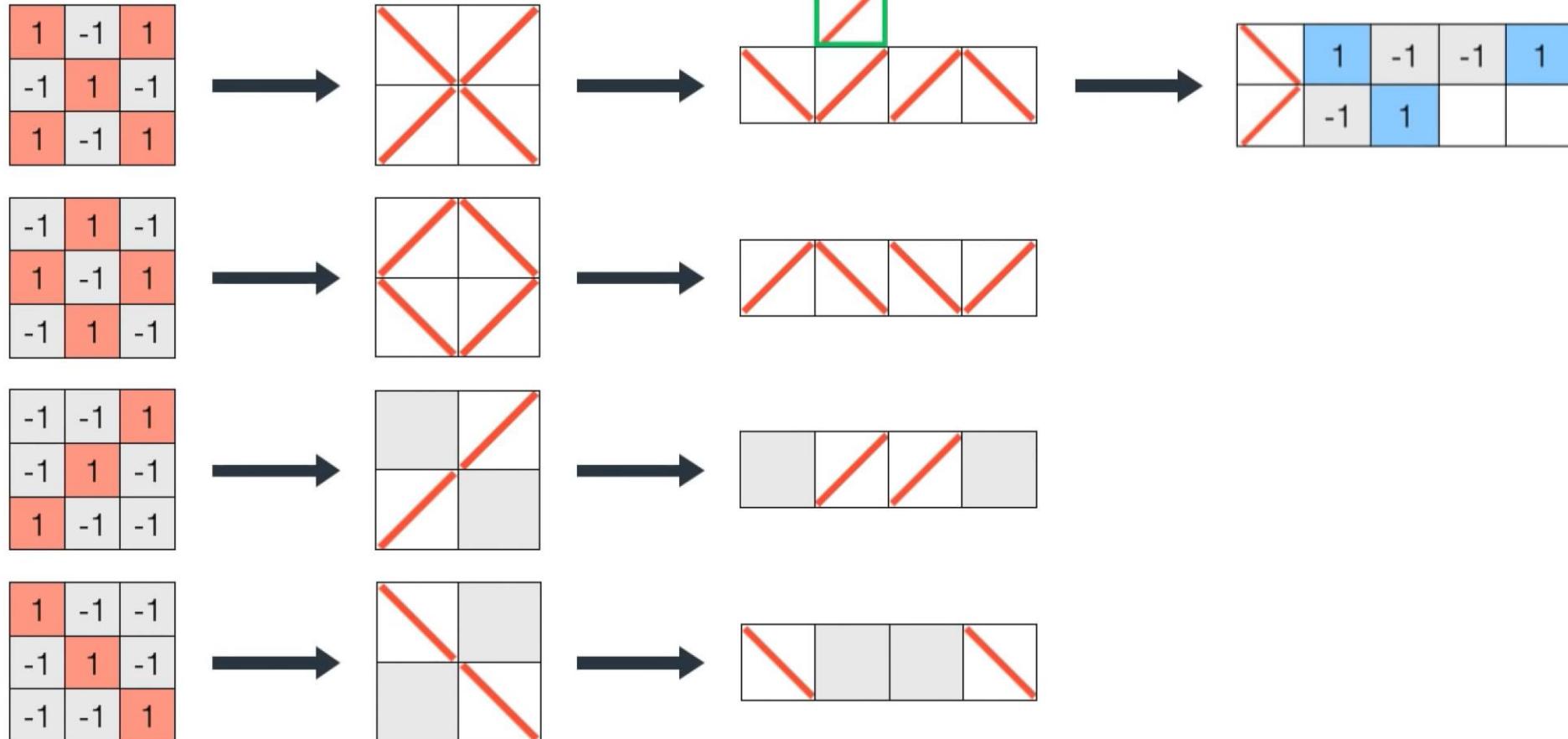


1	-1	-1
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-1	-1	1



# Convolution Neural Network (CNN)

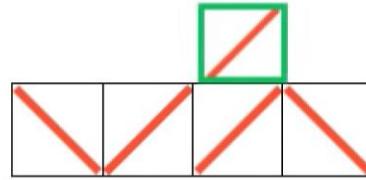
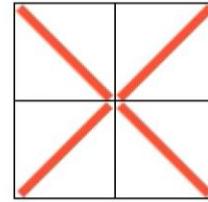
A little more complex world



# Convolution Neural Network (CNN)

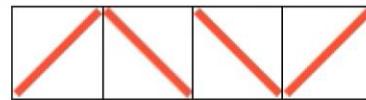
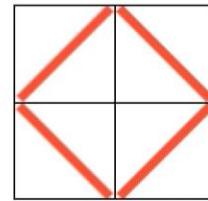
A little more complex world

1	-1	1
-1	1	-1
1	-1	1

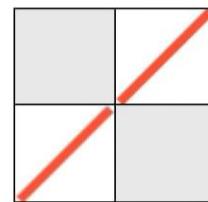


	1	-1	-1	1
	-1	1	1	
	1	-1	1	

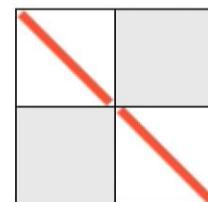
-1	1	-1
1	-1	1
-1	1	-1



-1	-1	1
-1	1	-1
1	-1	-1

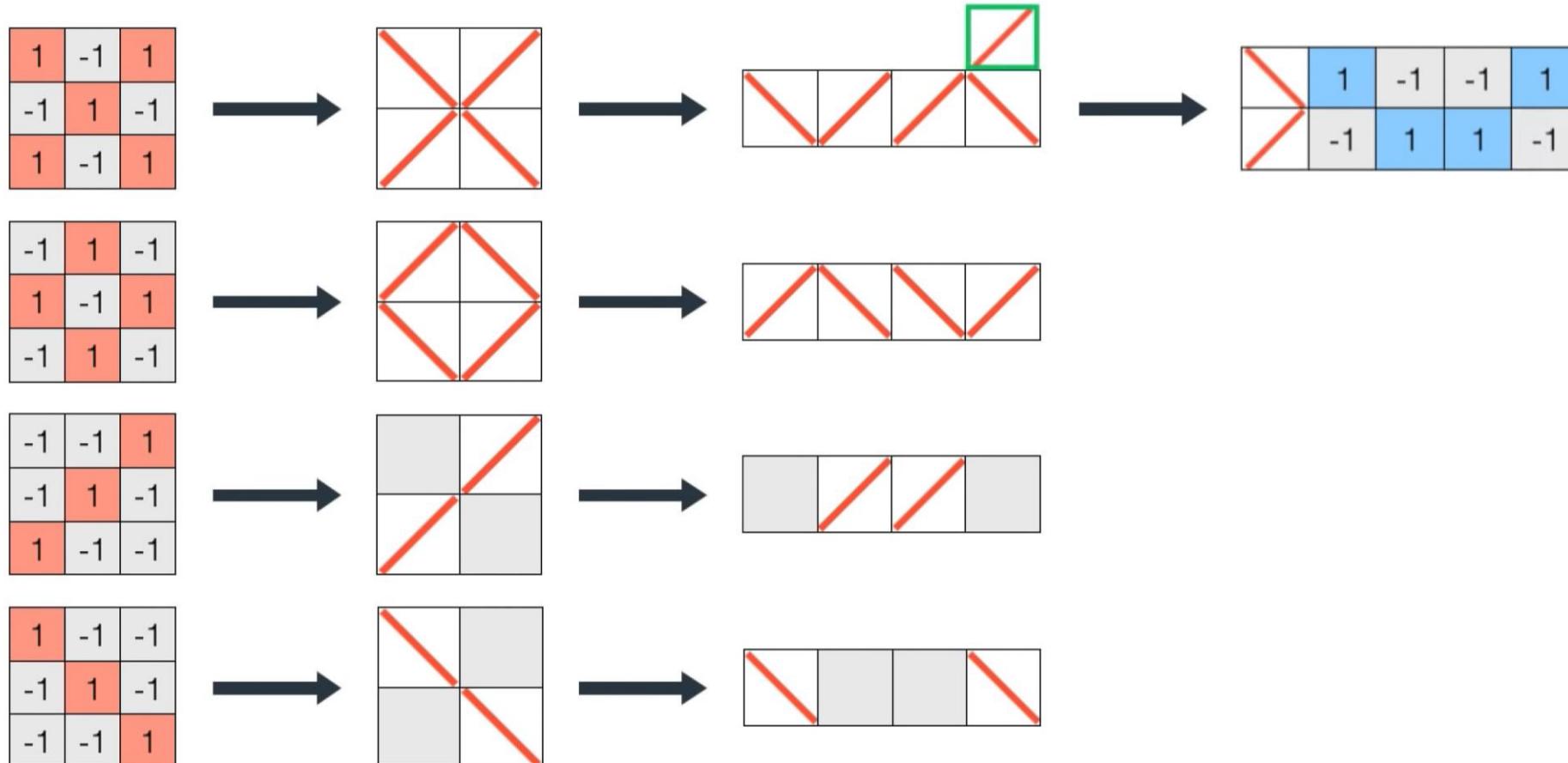


1	-1	-1
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-1	-1	1



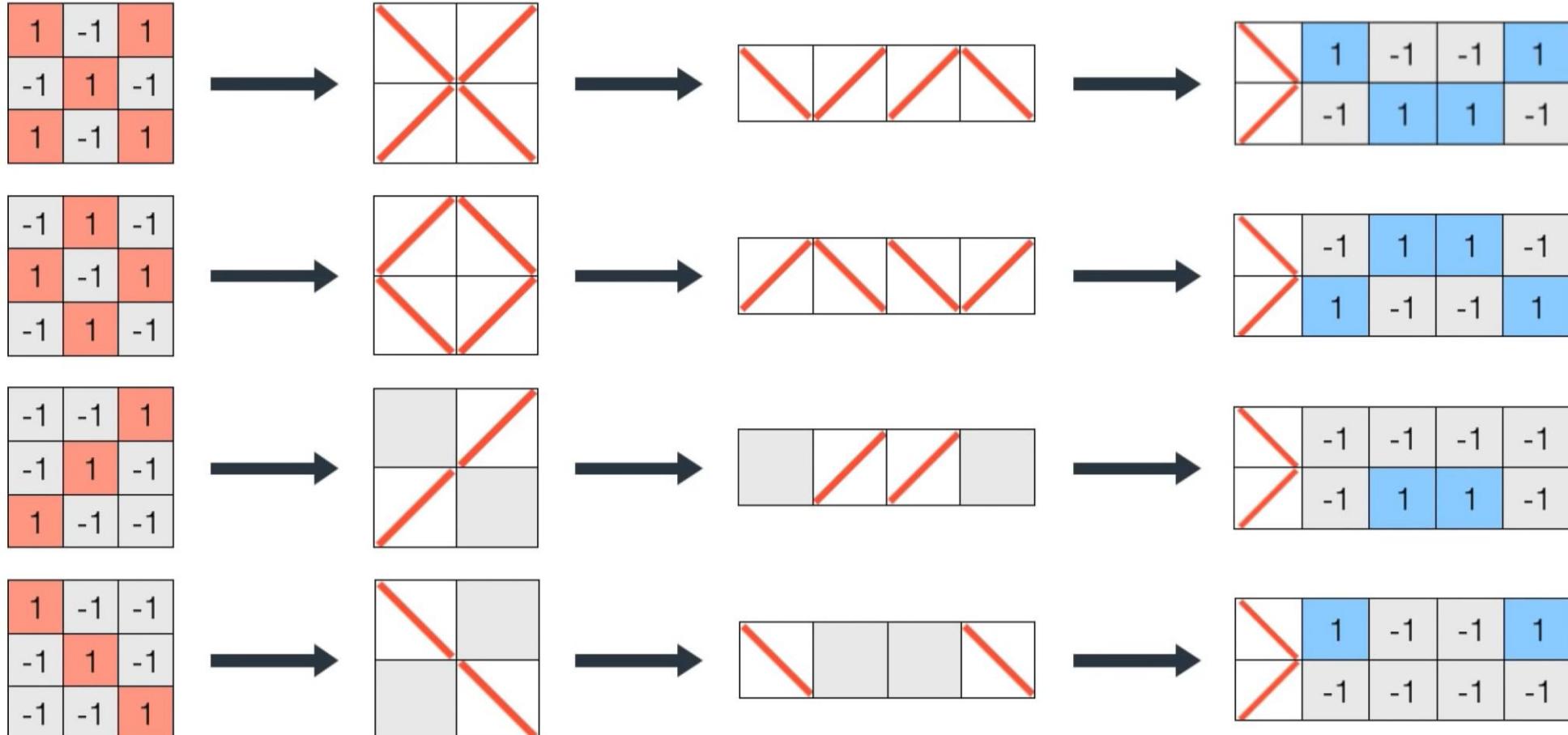
# Convolution Neural Network (CNN)

A little more complex world



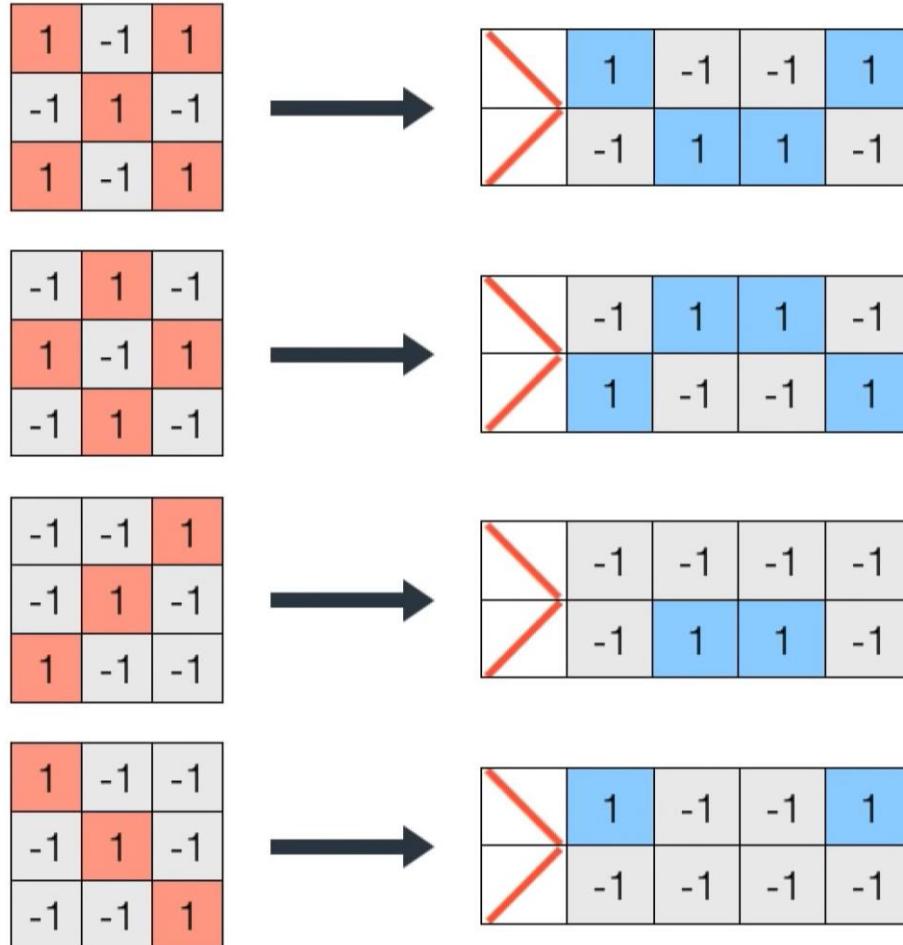
# Convolution Neural Network (CNN)

A little more complex world



# Convolution Neural Network (CNN)

A little more complex world



# Convolution Neural Network (CNN)

A little more complex world

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



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

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



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

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



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

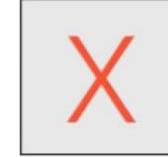
$$\begin{matrix} 1 & -1 & -1 \\ -1 & 1 & -1 \\ -1 & -1 & 1 \end{matrix}$$



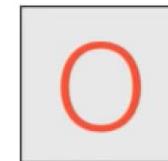
$$\begin{matrix} & 1 & -1 & -1 & 1 \\ -1 & & & & \\ -1 & & & & \end{matrix}$$

## Filters

$$\begin{matrix} + & - & - & + \\ - & + & + & - \end{matrix}$$



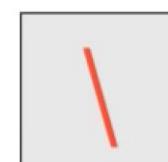
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$$\begin{matrix} - & - & - & - \\ - & + & + & - \end{matrix}$$

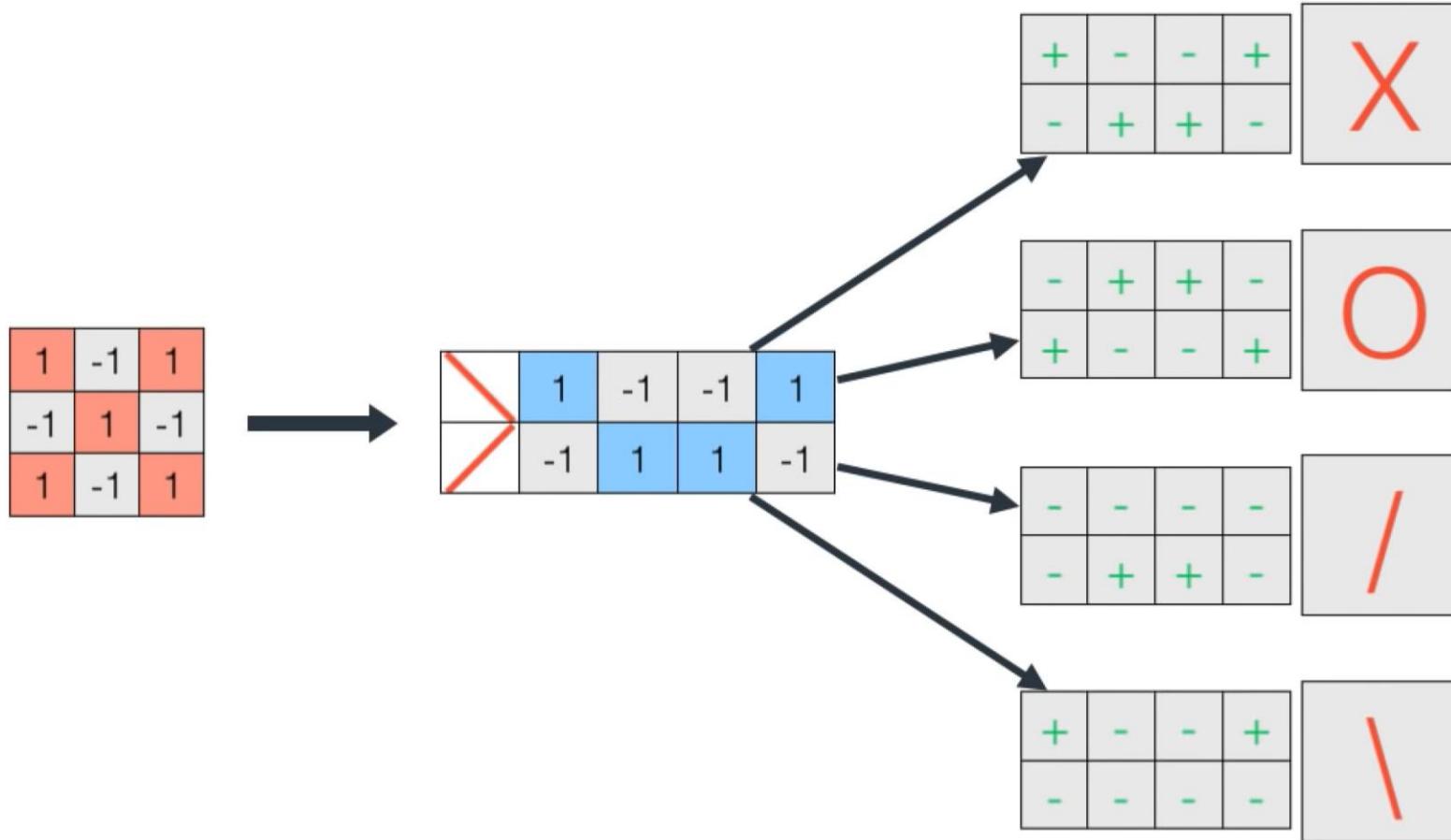


$$\begin{matrix} + & - & - & + \\ - & - & - & - \end{matrix}$$



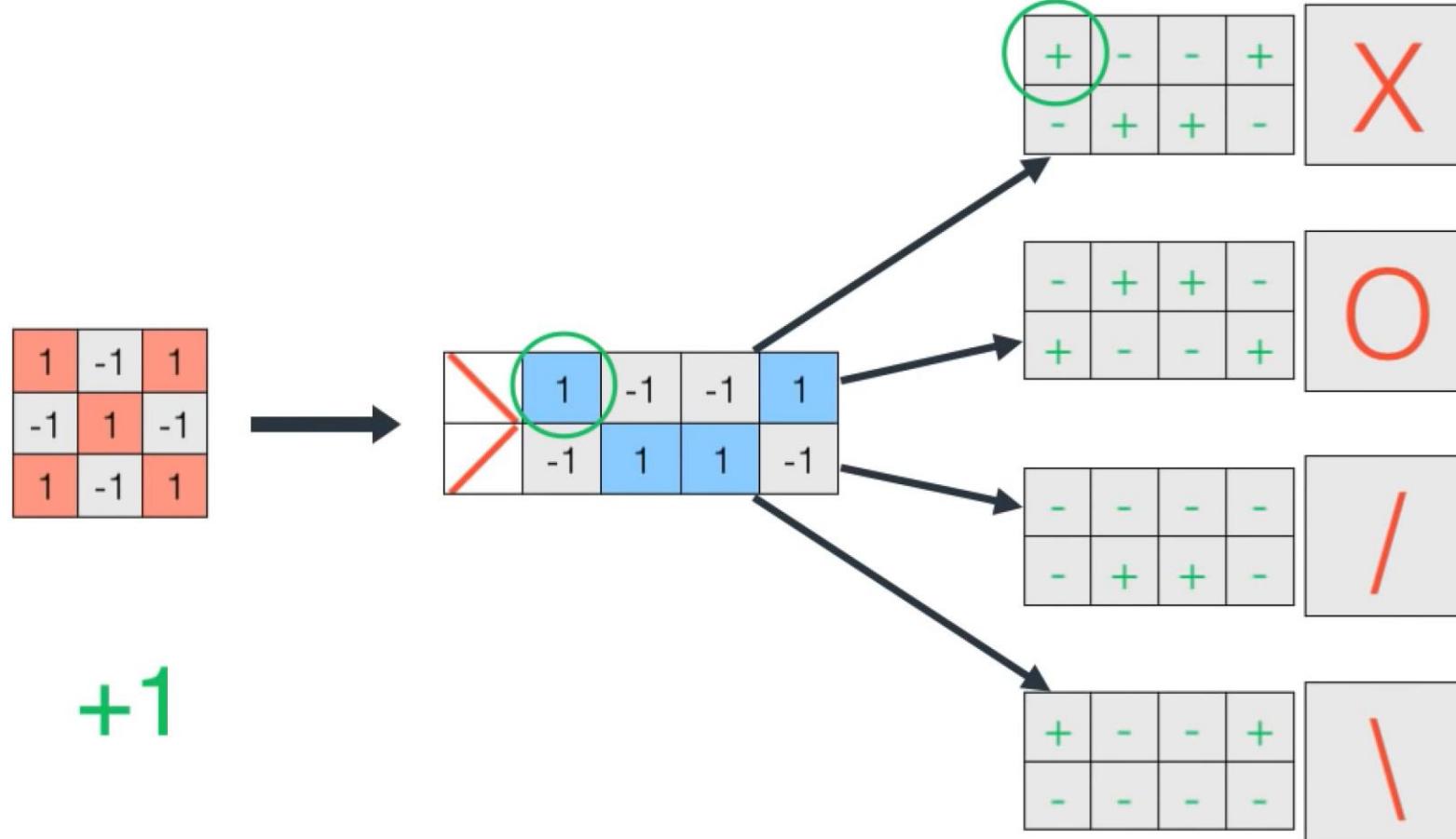
# Convolution Neural Network (CNN)

A little more complex world



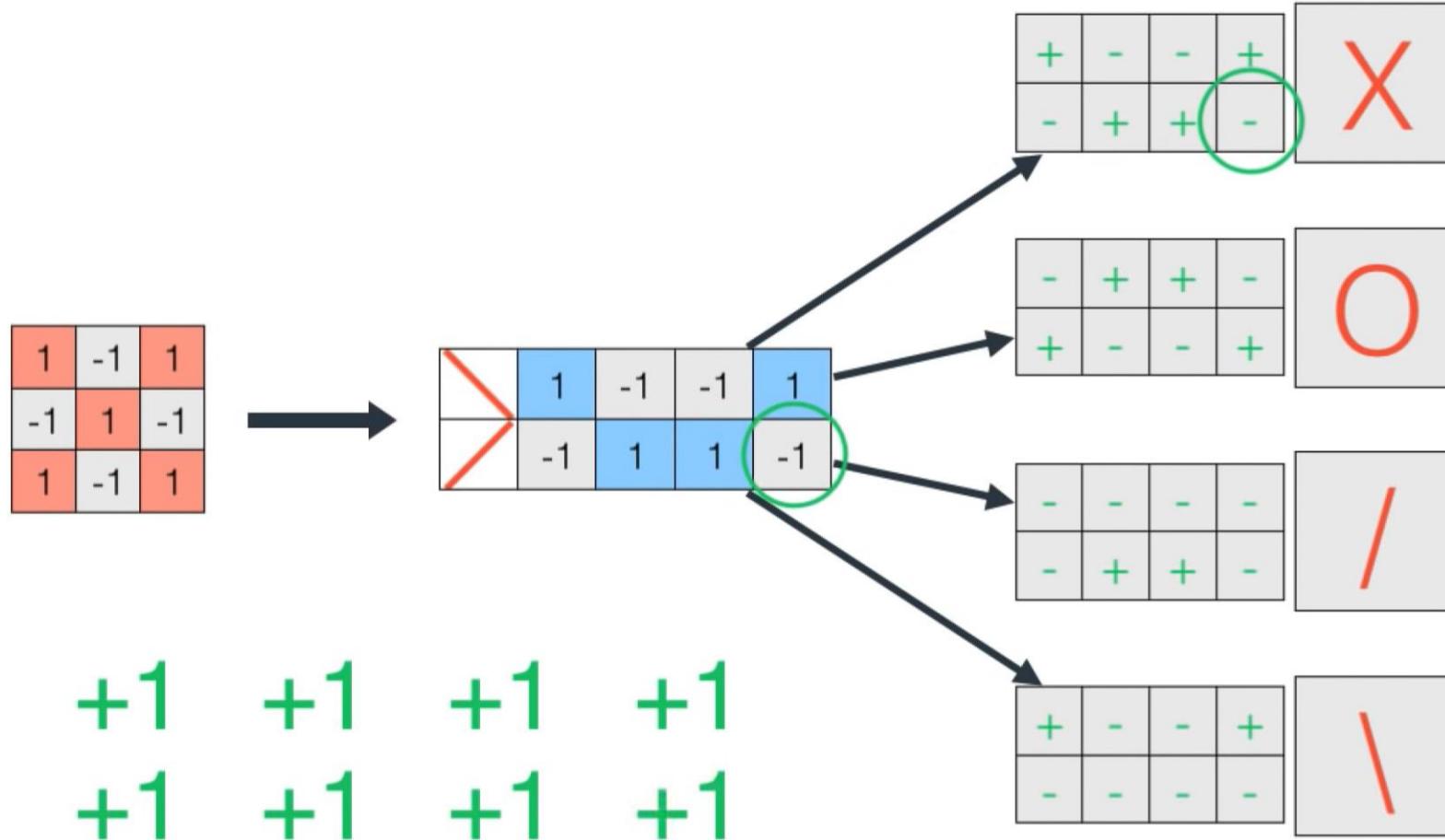
# Convolution Neural Network (CNN)

A little more complex world



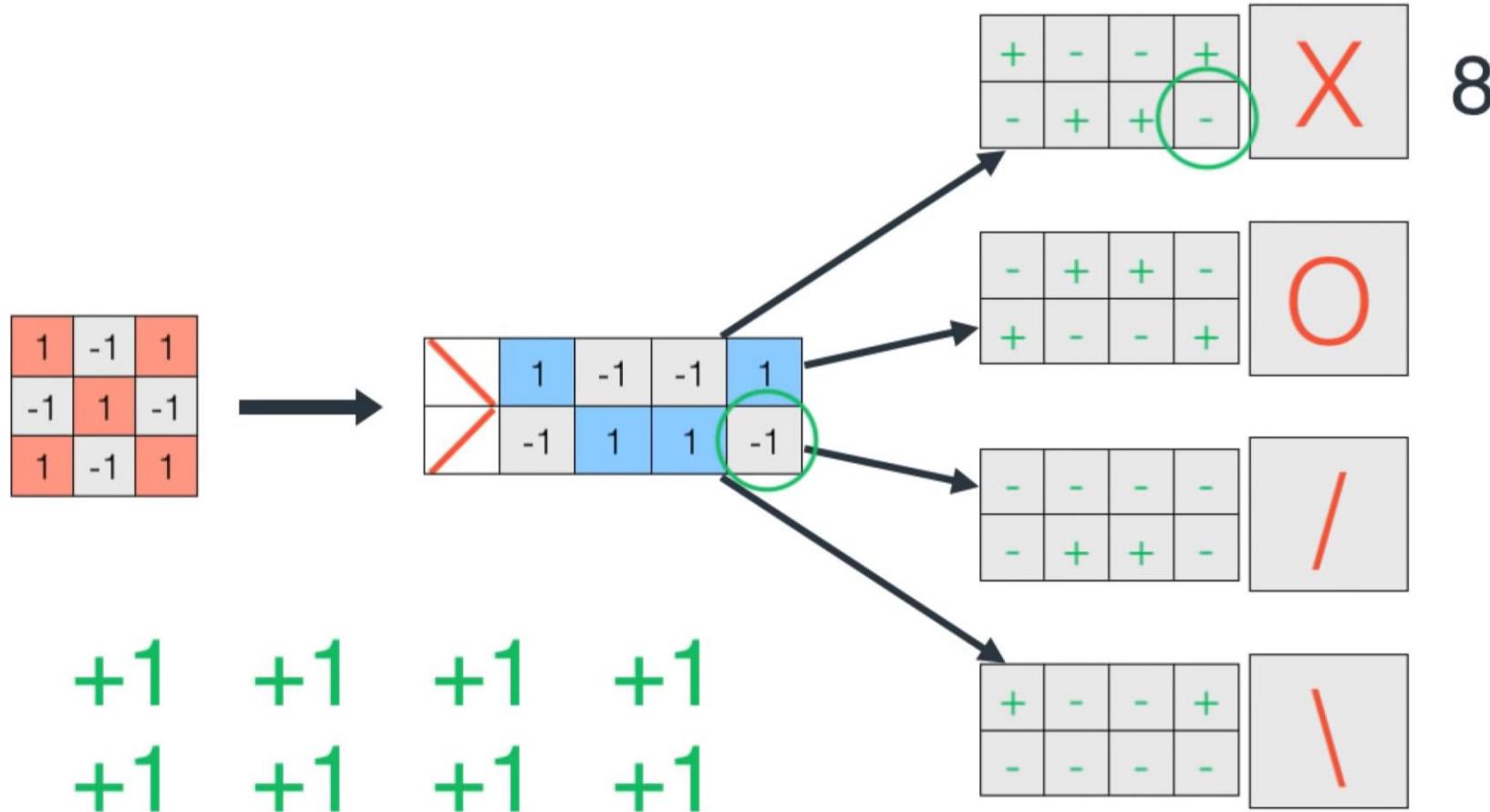
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A little more complex world



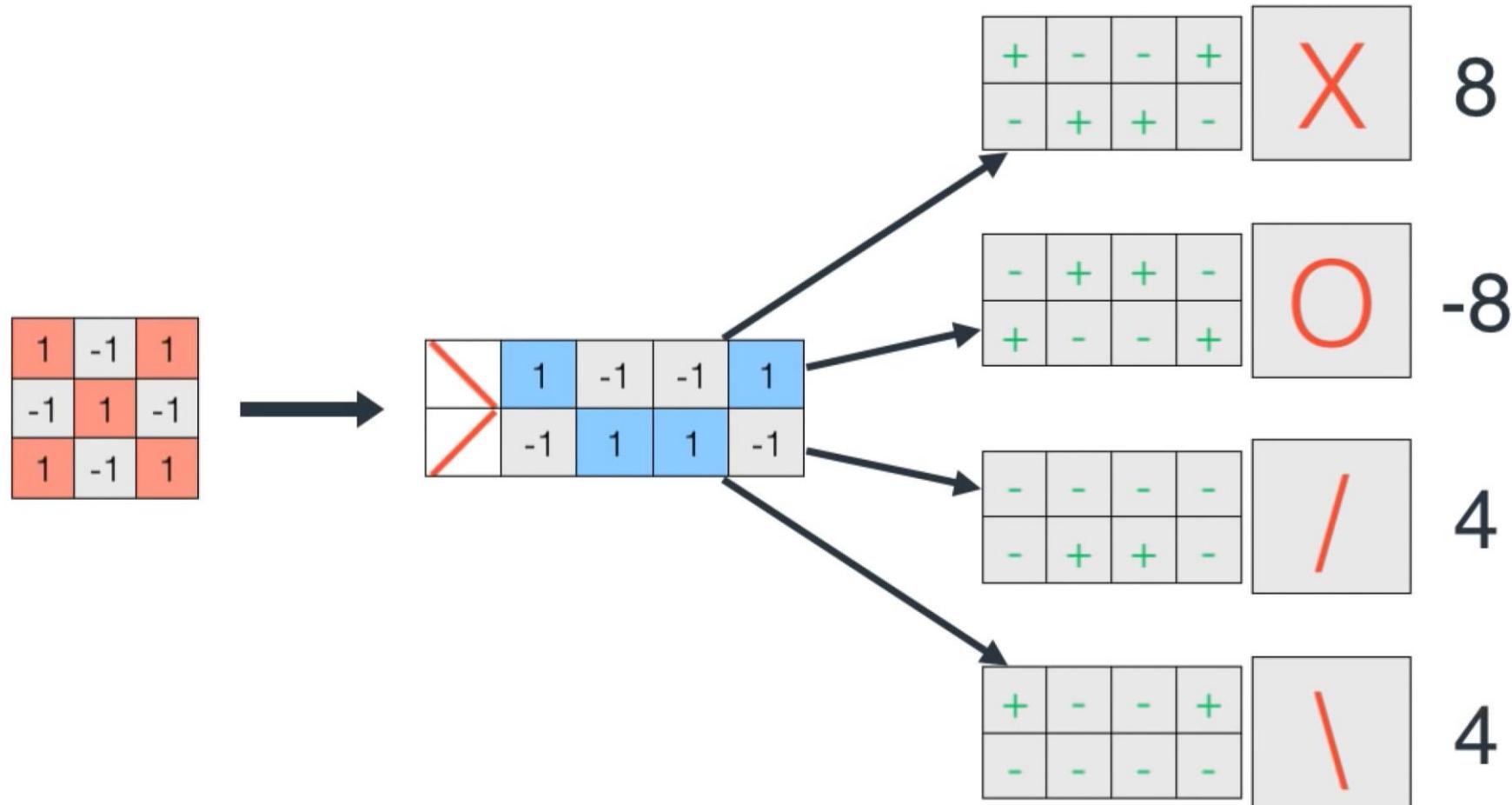
# Convolution Neural Network (CNN)

A little more complex world



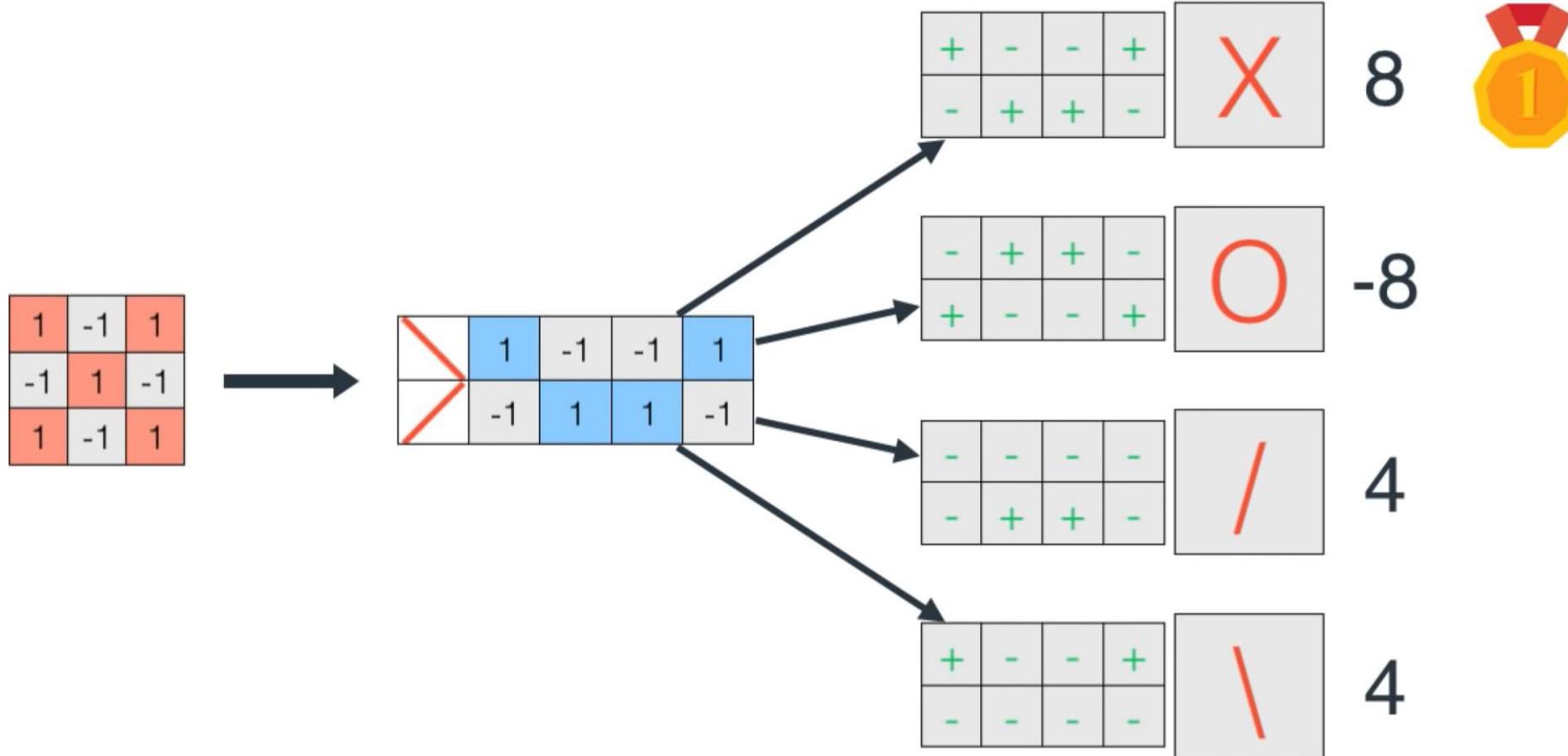
# Convolution Neural Network (CNN)

A little more complex world



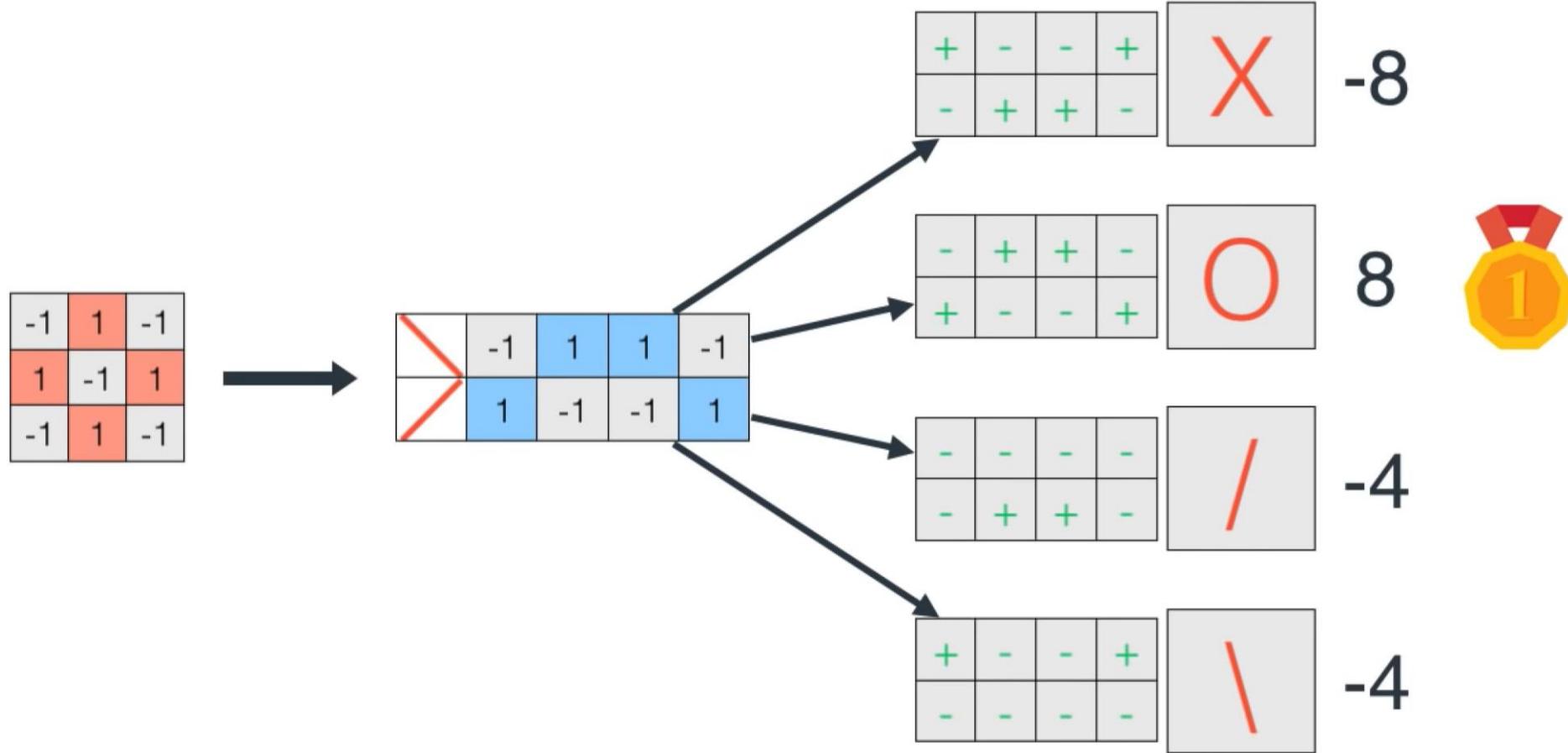
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A little more complex world



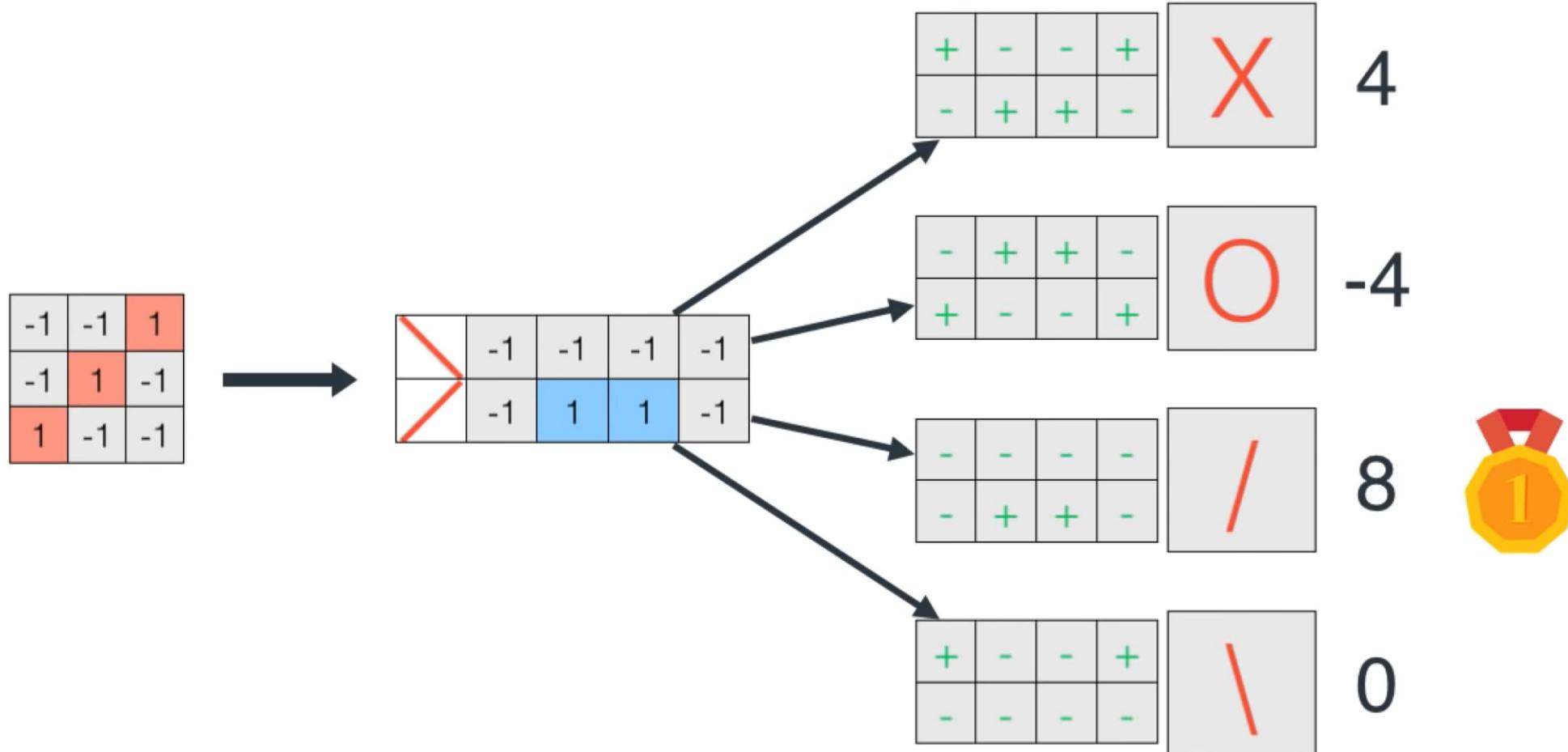
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A little more complex world



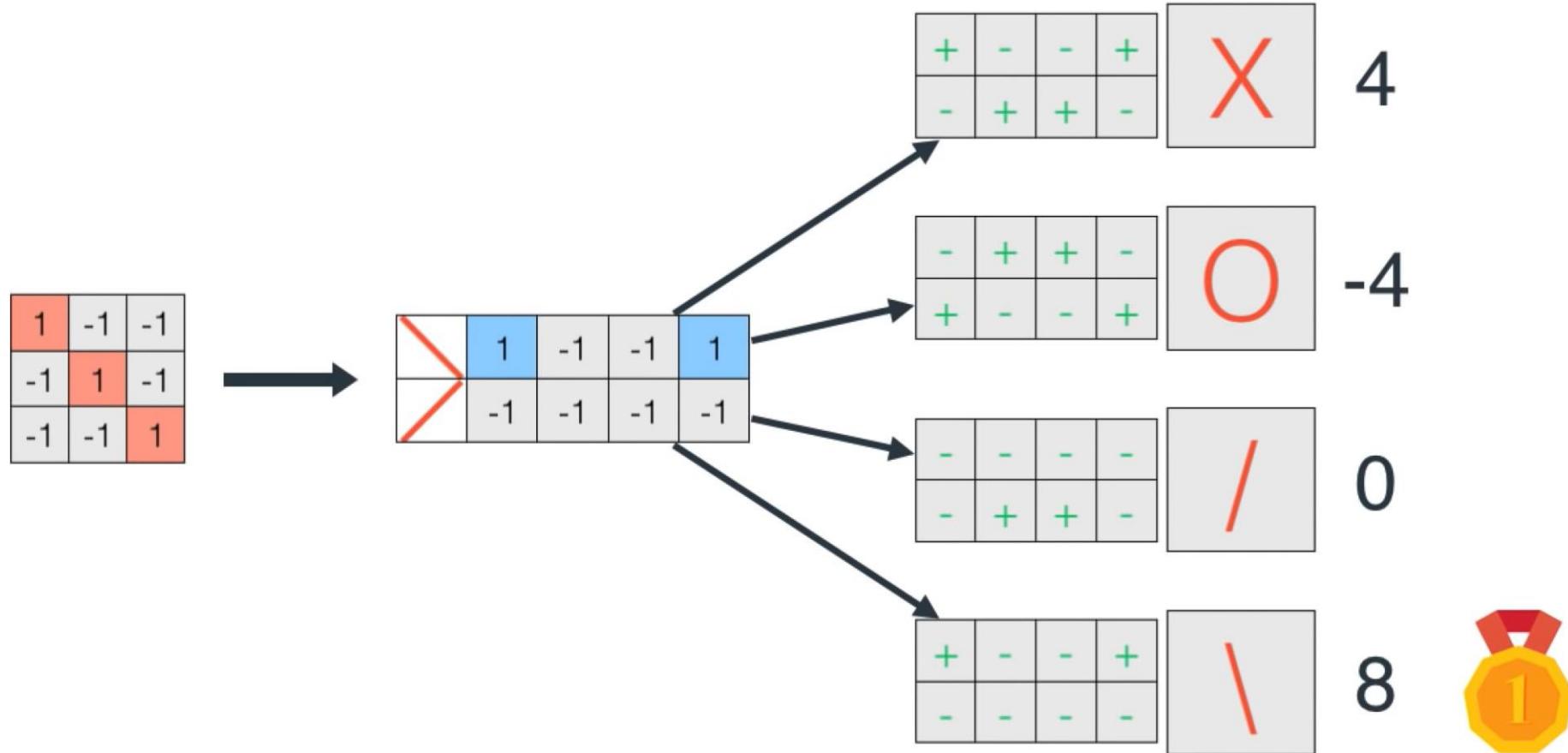
# Convolution Neural Network (CNN)

A little more complex world



# Convolution Neural Network (CNN)

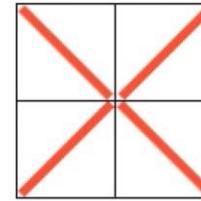
A little more complex world



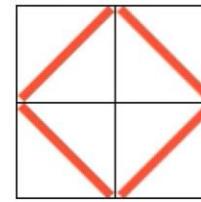
# Convolution Neural Network (CNN)

A little more complex world

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

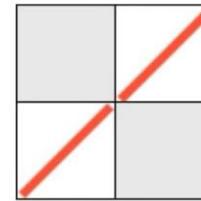


$$\begin{matrix} -1 & 1 & -1 \\ 1 & -1 & 1 \\ -1 & 1 & -1 \end{matrix}$$

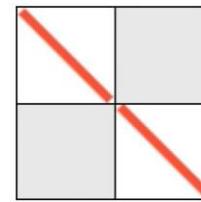


$$\begin{matrix} -1 & -1 & 1 \\ -1 & 1 & -1 \\ 1 & -1 & -1 \end{matrix}$$

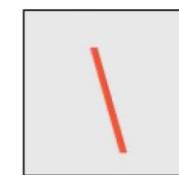
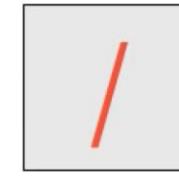
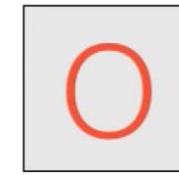
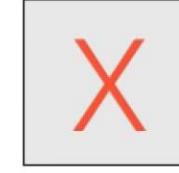
Convolution Layer  
Pooling Layer



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

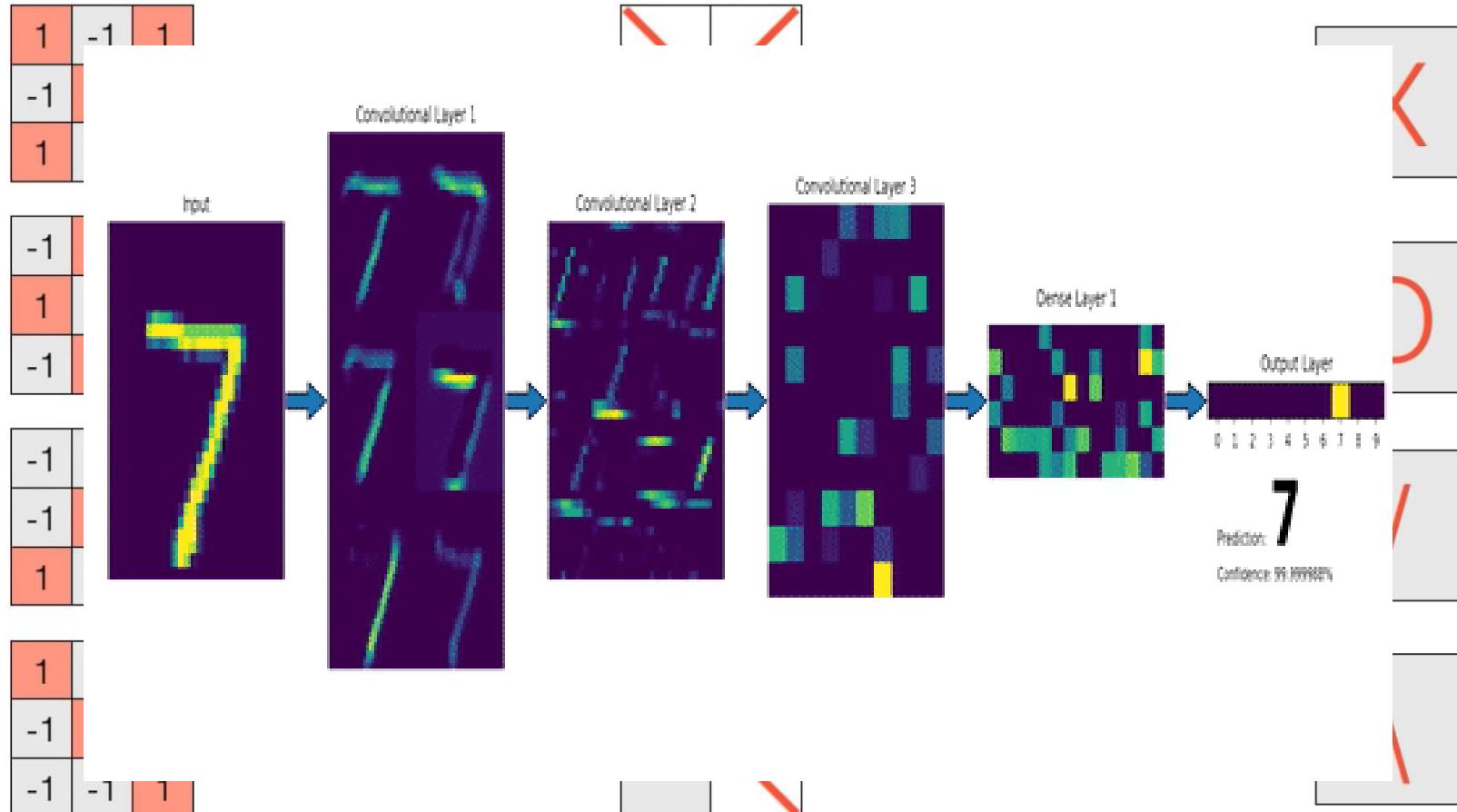


Fully Connected  
Layer



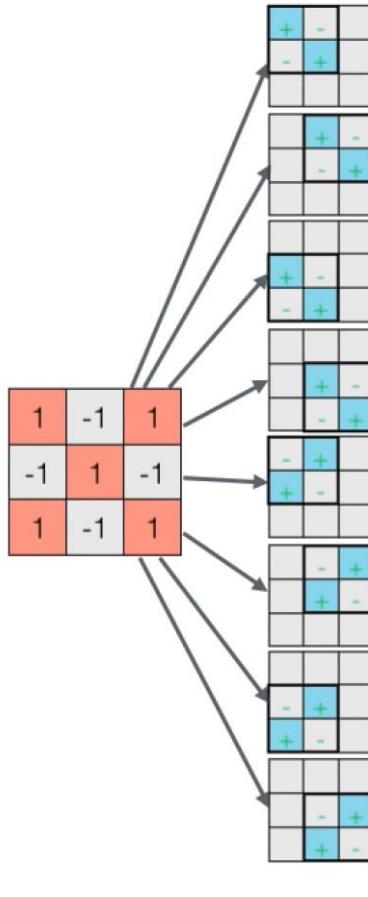
# Convolution Neural Network (CNN)

A little more complex world



# Convolution Neural Network (CNN)

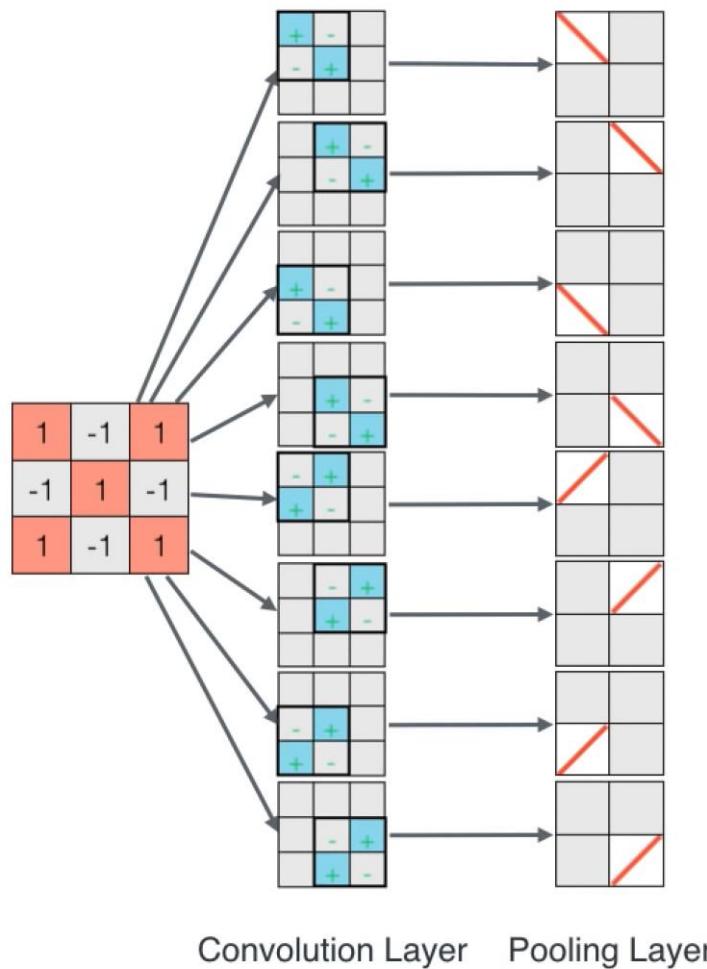
A little more complex world



Convolution Layer

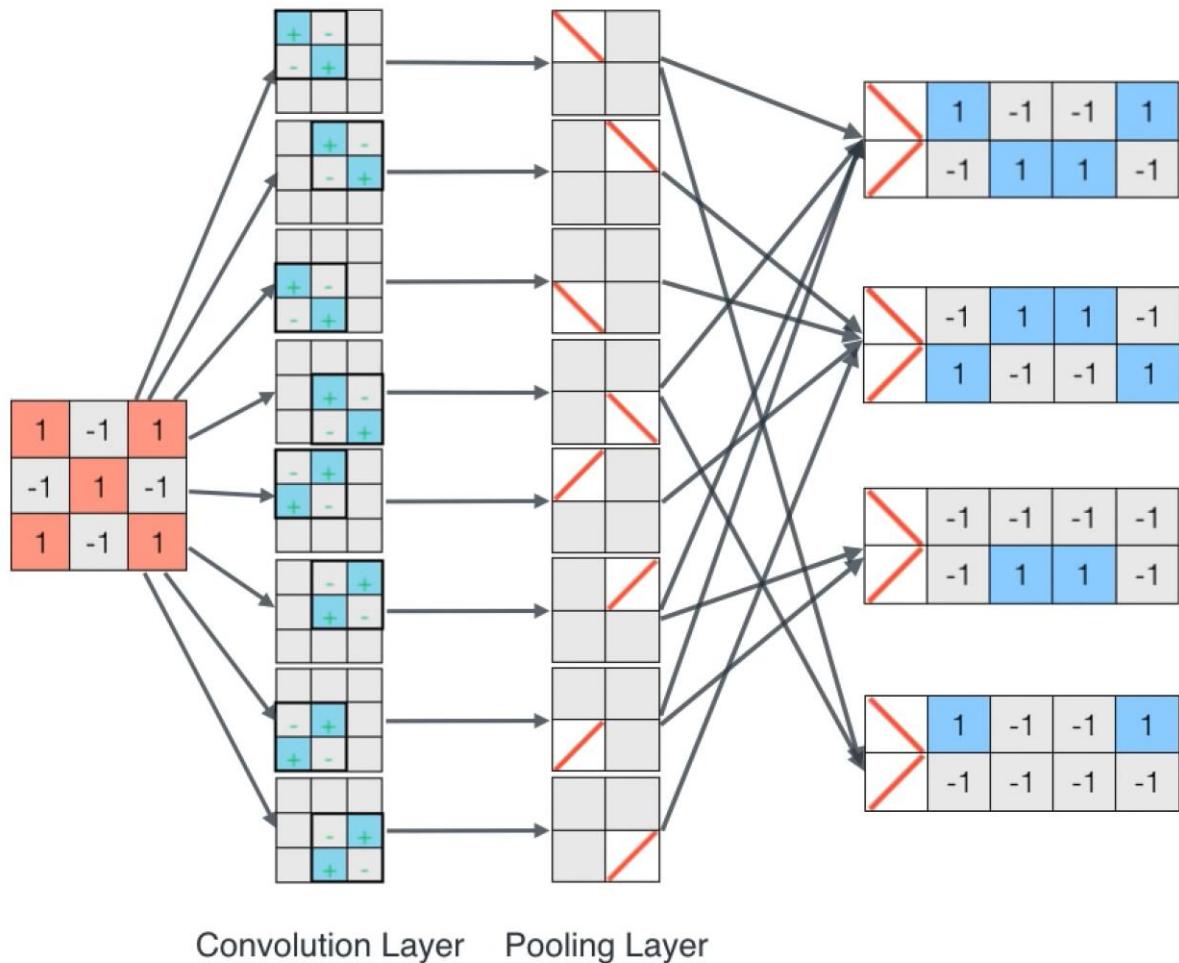
# Convolution Neural Network (CNN)

A little more complex world



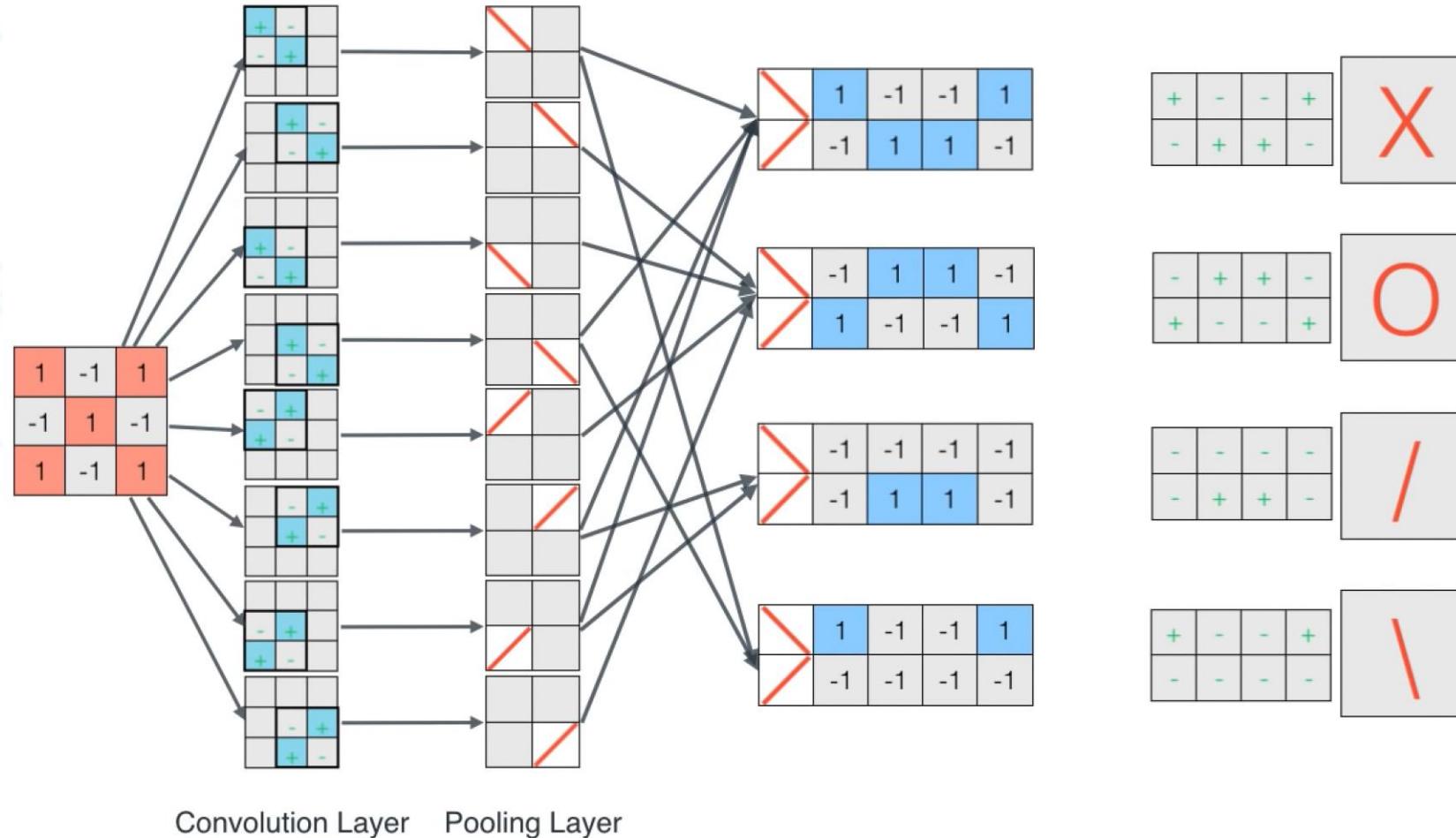
# Convolution Neural Network (CNN)

A little more complex world



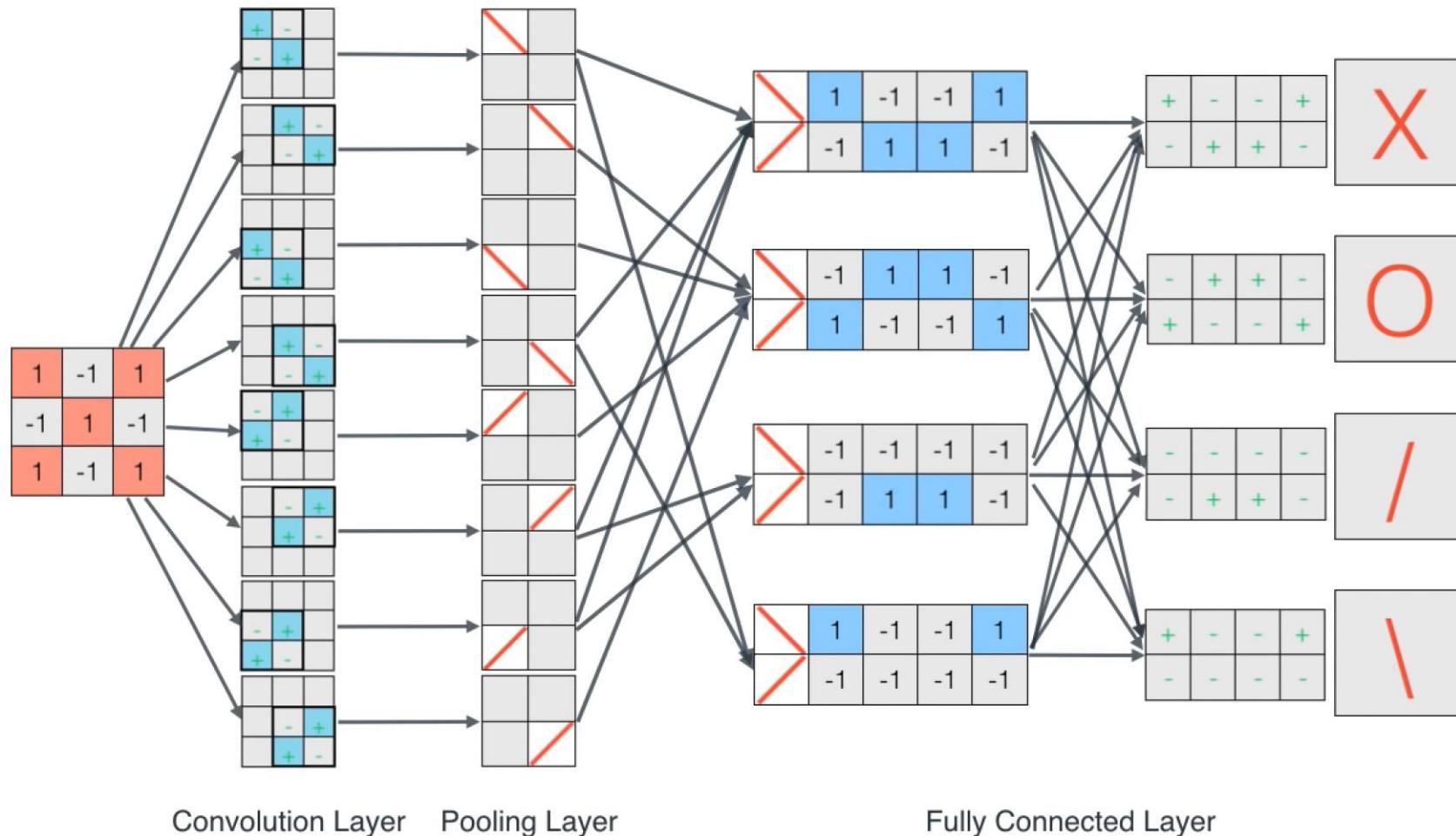
# Convolution Neural Network (CNN)

A little more complex world



# Convolution Neural Network (CNN)

A little more complex world

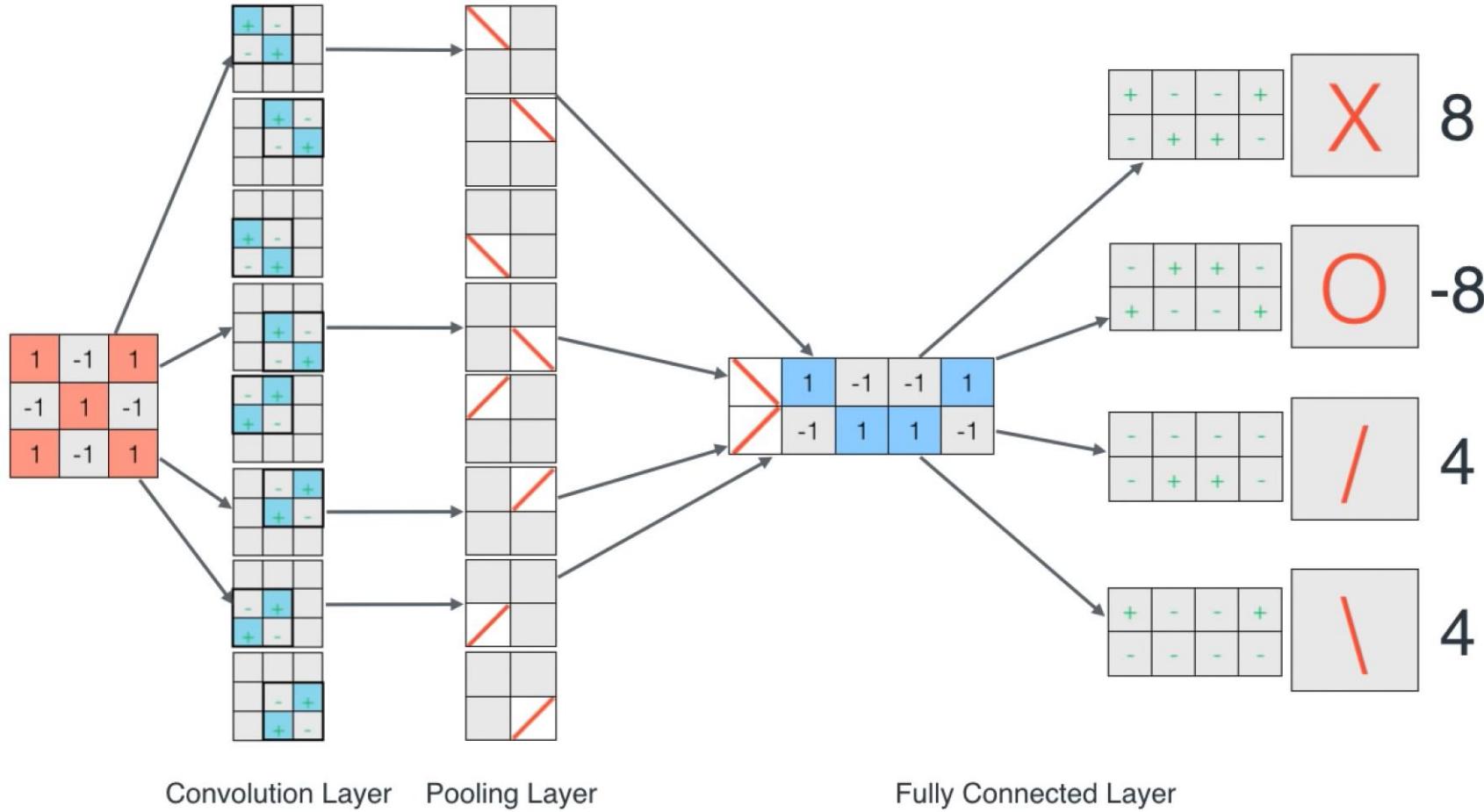


Convolution Layer    Pooling Layer

Fully Connected Layer

# Convolution Neural Network (CNN)

A little more complex world



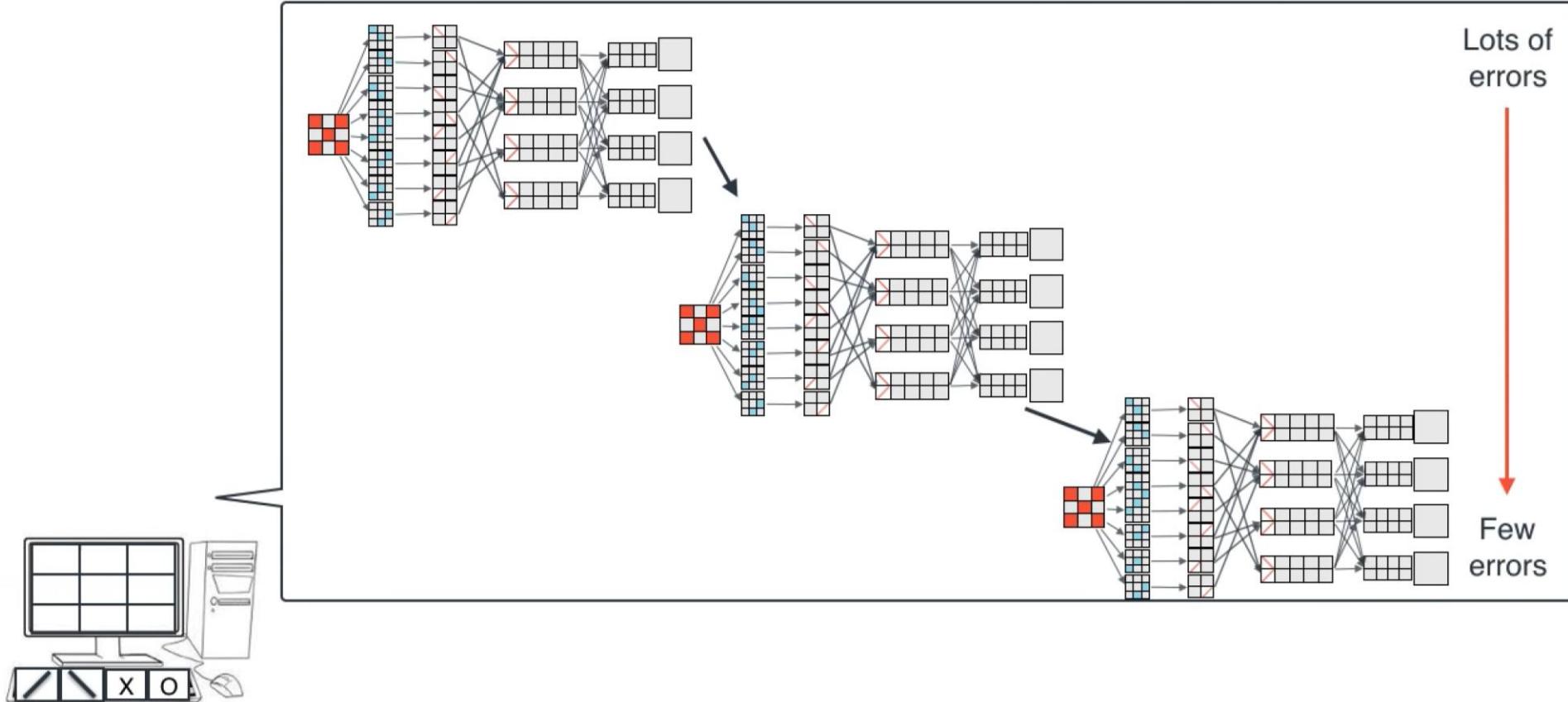
# Convolution Neural Network (CNN)

A little more complex world



# Convolution Neural Network (CNN)

A little more complex world



# Convolution Neural Network (CNN)

Advanced world



People

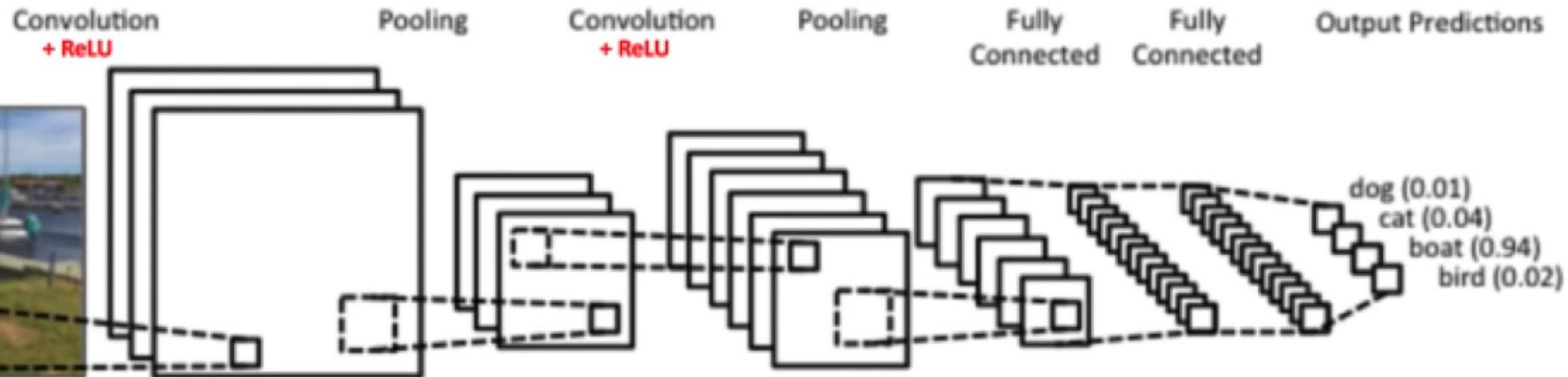


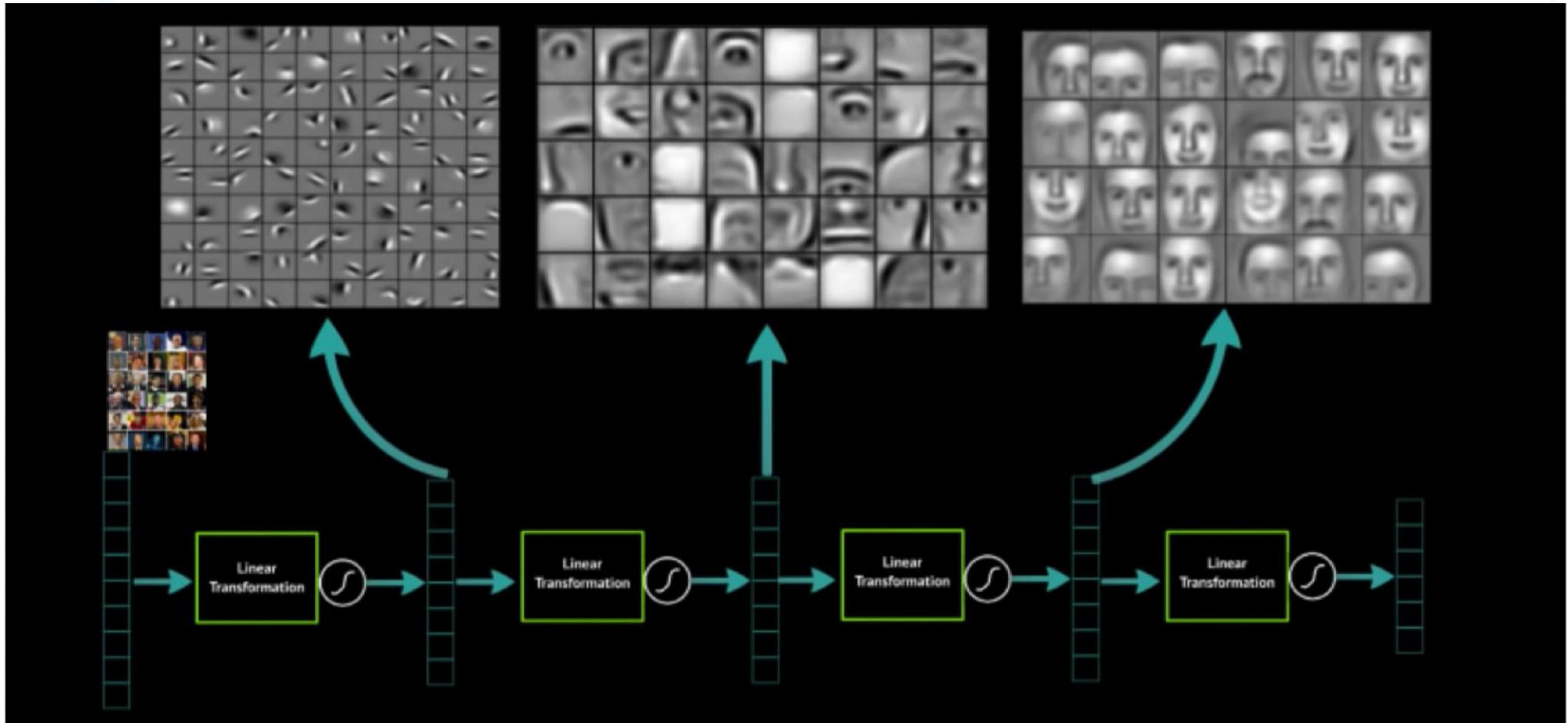
Computer



Alphabet

# Convolution Neural Network (CNN)





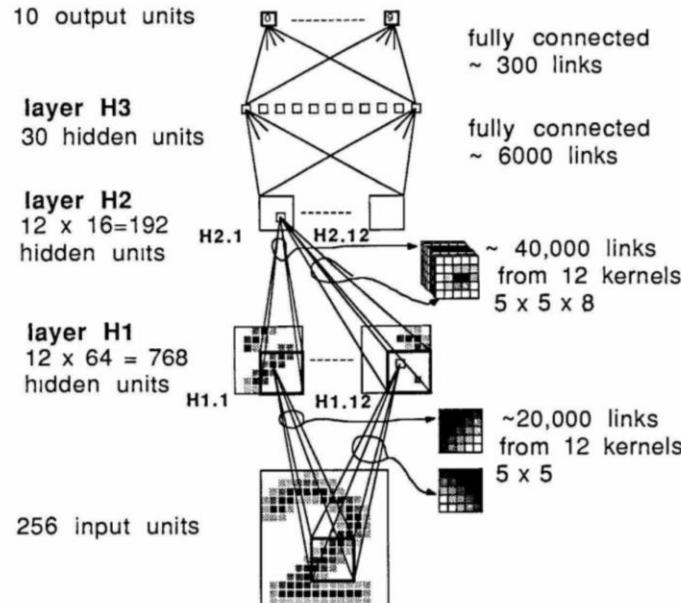
# Convolution Neural Network (CNN)



# Convolution Neural Network (CNN)

## Year 1989 Kicked-Off Convolution Neural Nets

Ten-Digit Classifier using a Modest Neural Network with Three Hidden Layers



*Backpropagation Applied to Handwritten Zip Code*

*Recognition*. LeCun, et. al.

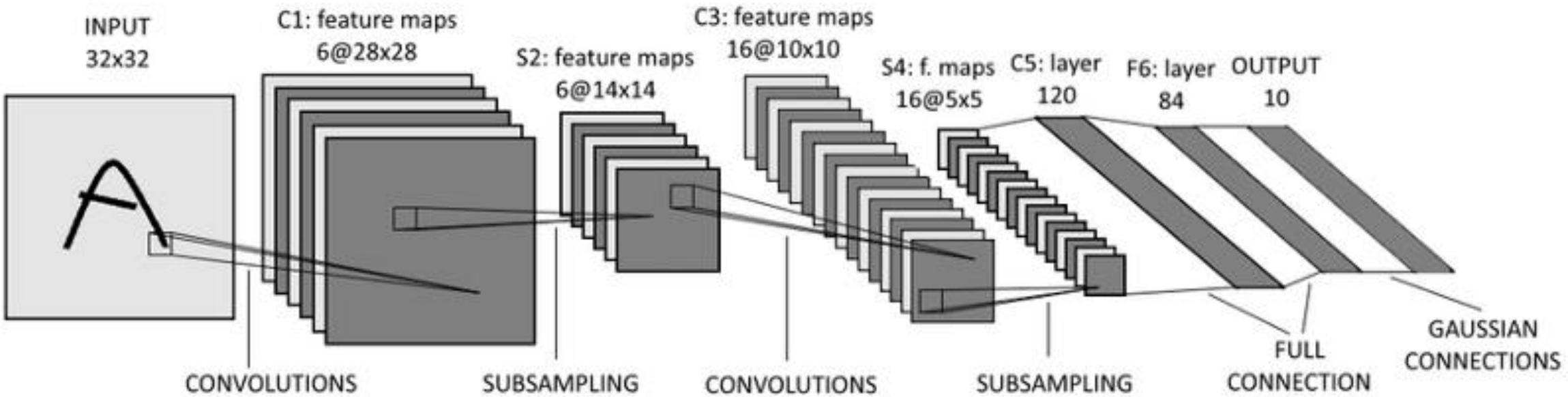
<http://yann.lecun.com/exdb/publis/pdf/lecun-89e.pdf>

[www.shatterline.com](http://www.shatterline.com)

Each of the units in H2 combines local information coming from 8 of the 12 different feature maps in H1.

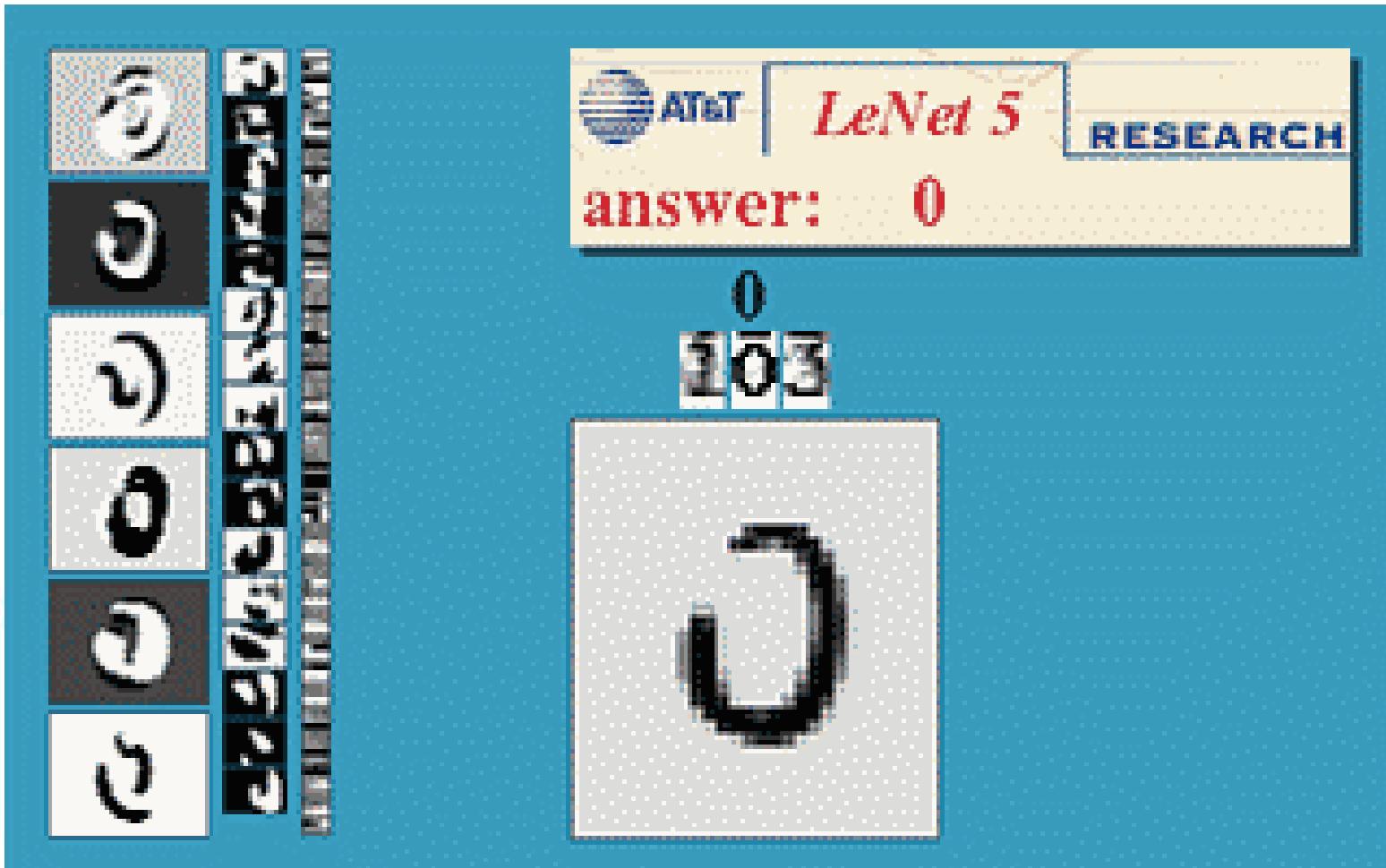
# Convolution Neural Network (CNN)

LeNet - Architecture



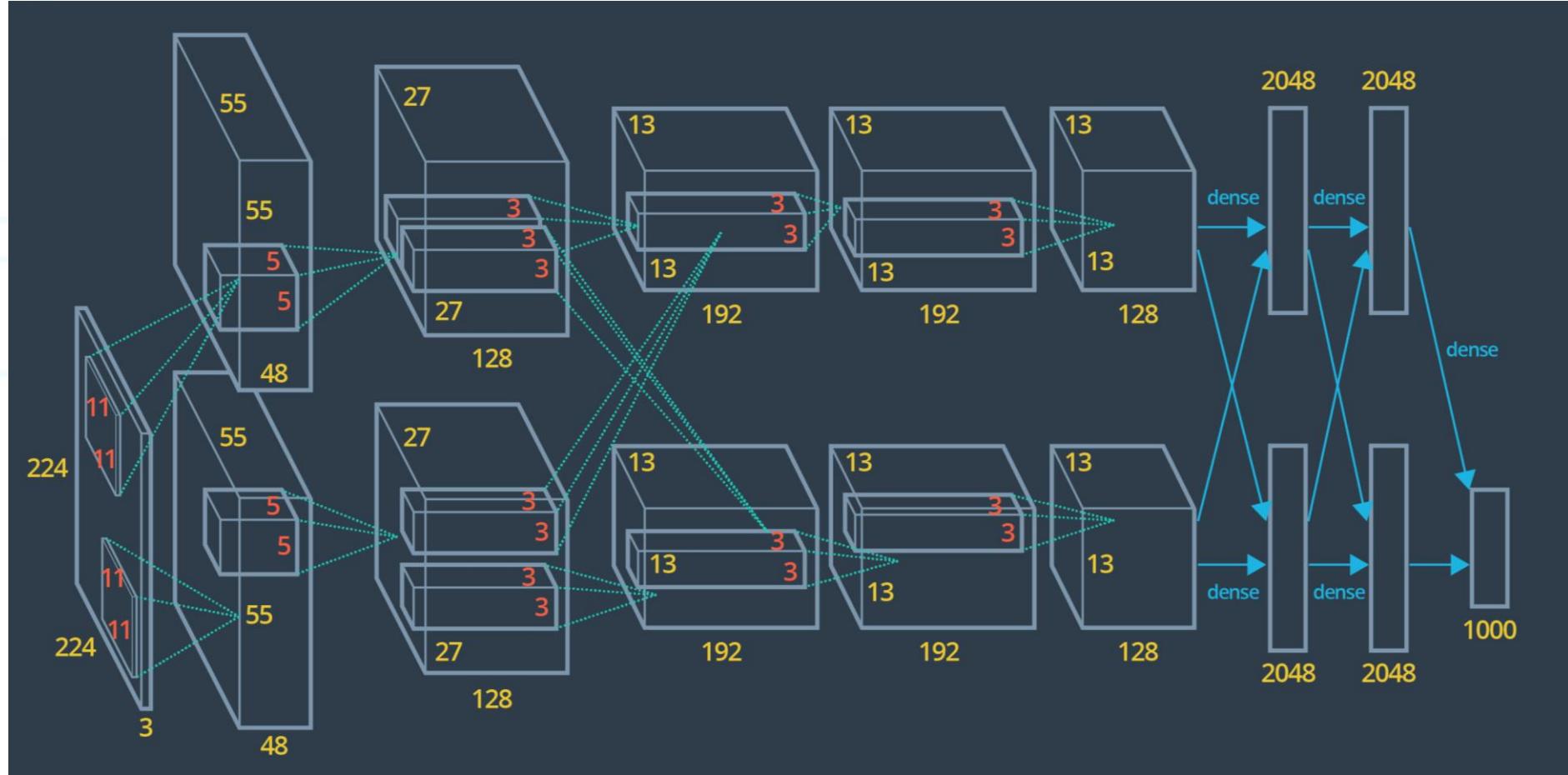
# Convolution Neural Network (CNN)

LeNet - Application



# Convolution Neural Network (CNN)

AlexNet - Architecture



# Convolution Neural Network (CNN)

AlexNet - Application

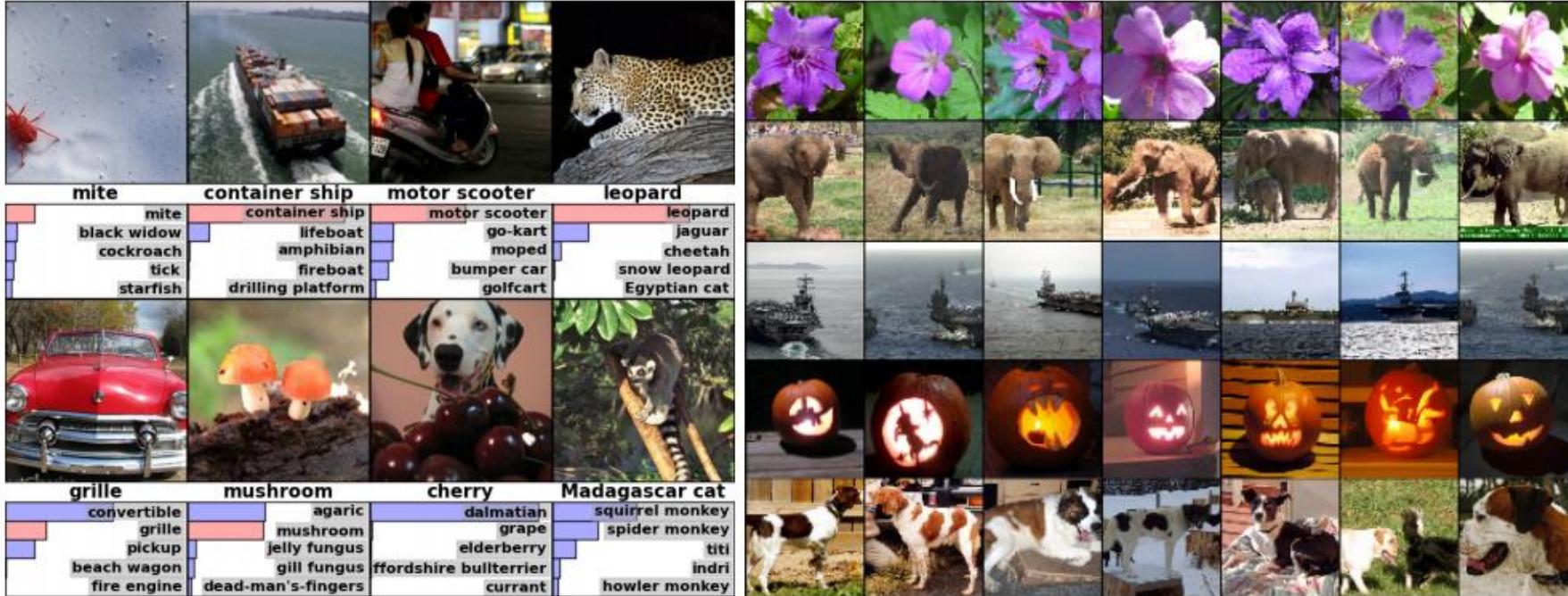
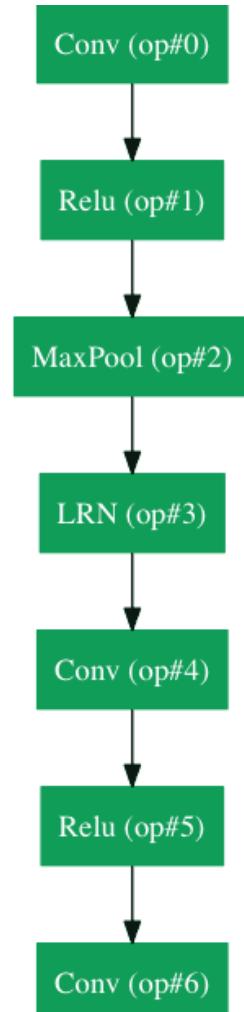


Figure 4: **(Left)** Eight ILSVRC-2010 test images and the five labels considered most probable by our model. The correct label is written under each image, and the probability assigned to the correct label is also shown with a red bar (if it happens to be in the top 5). **(Right)** Five ILSVRC-2010 test images in the first column. The remaining columns show the six training images that produce feature vectors in the last hidden layer with the smallest Euclidean distance from the feature vector for the test image.

# Convolution Neural Network (CNN)

GoogLeNet (Inception)

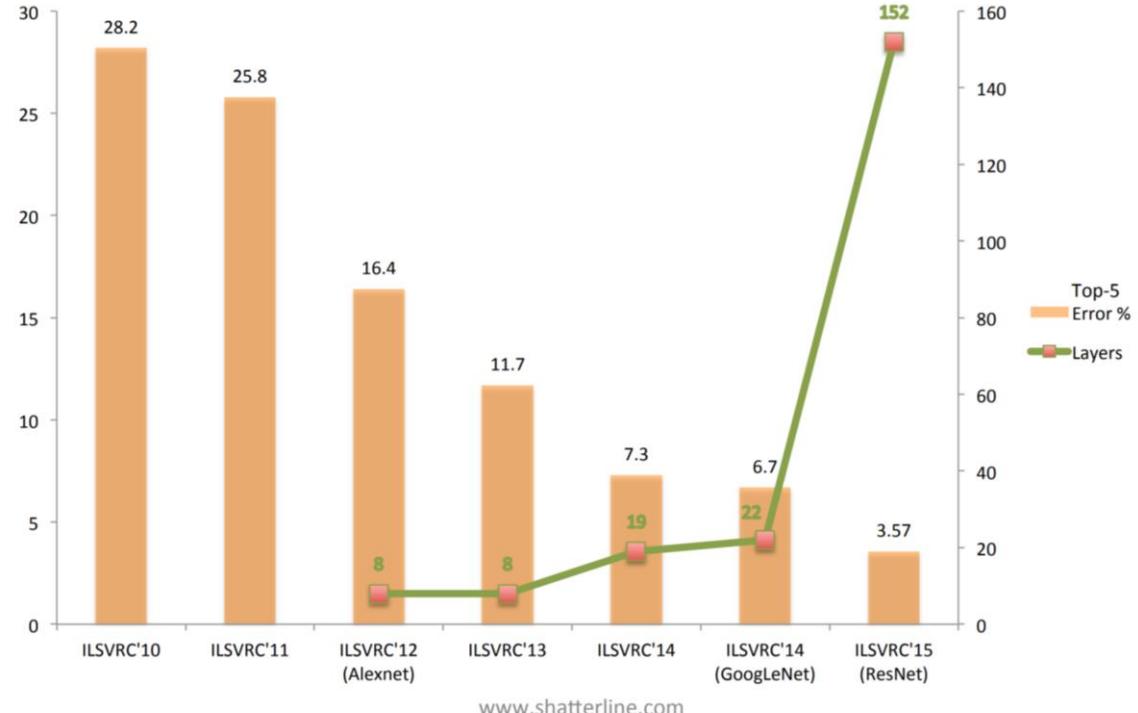


# Convolution Neural Network (CNN)

Advanced world

## Year 2012 Marked The Inflection Point

Reintroducing CNNs Led to Big Drop in Error for Image Classification.  
Since Then, Deeper Networks Continued to Reduce Error



# Convolution Neural Network (CNN)

Advanced world

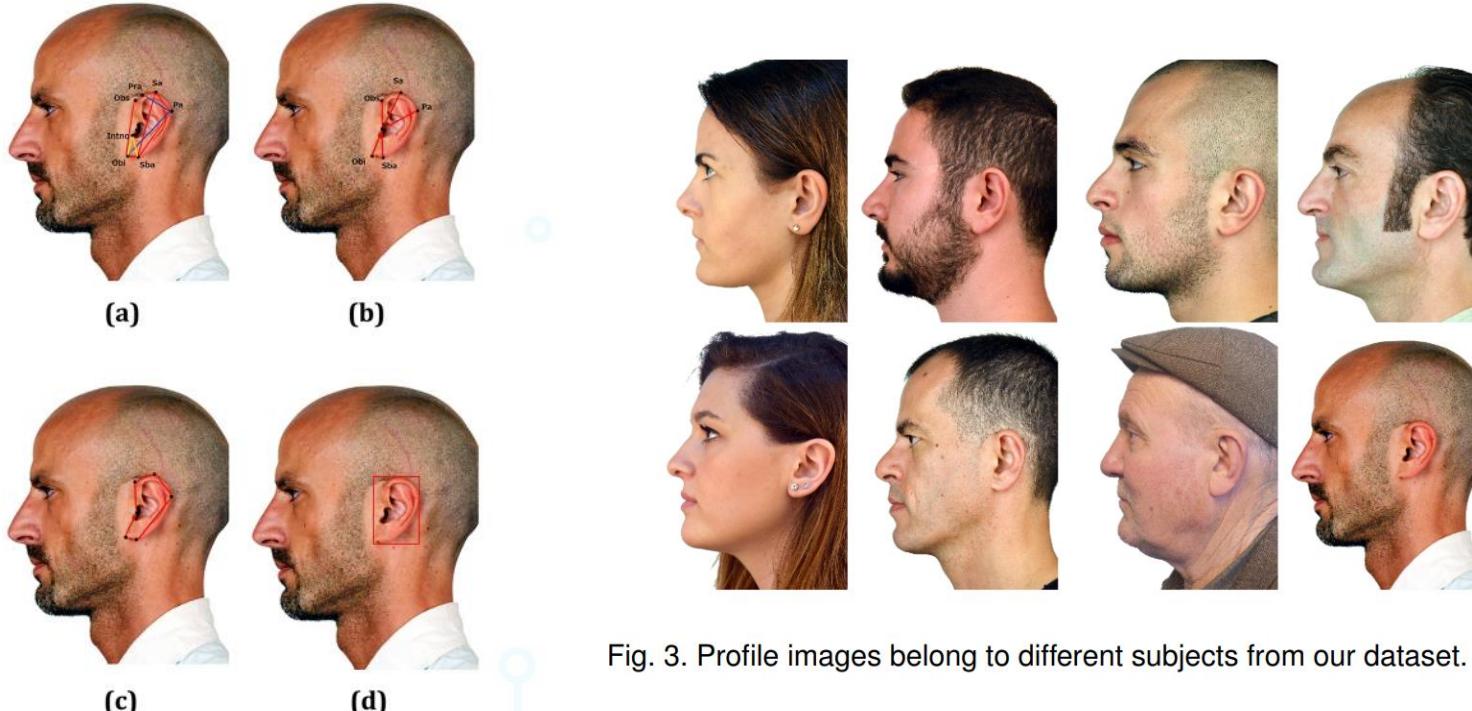


Fig. 3. Profile images belong to different subjects from our dataset.

Fig. 1. Used landmarks and measurements for geometric features. (a)-(b) Landmarks and calculated distances, (c)-(d) Calculated areas.

## Gender classification results

Approach	Test Result
Logistic Regression	47% (Geometric)
Random Forest	47% (Geometric)
SVM	65% (Geometric)
3 hidden layers NN	58% (Geometric)
AlexNet	88% (Appearance)
VGG-16	89% (Appearance)
GoogLeNet	94% (Appearance)
SqueezeNet	89% (Appearance)

## Age estimation results

Approach	Test Result
Logistic Regression	43% (Geometric)
Random Forest	34% (Geometric)
SVM	39% (Geometric)
3 hidden layers NN	43% (Geometric)
AlexNet	45% (Appearance)
VGG-16	39% (Appearance)
GoogLeNet	52% (Appearance)
SqueezeNet	39% (Appearance)

# Thanks !



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