Convolutional Neural Network (CNN)

Network Architecture designed for Image

Image Classification

100 x 100

Model

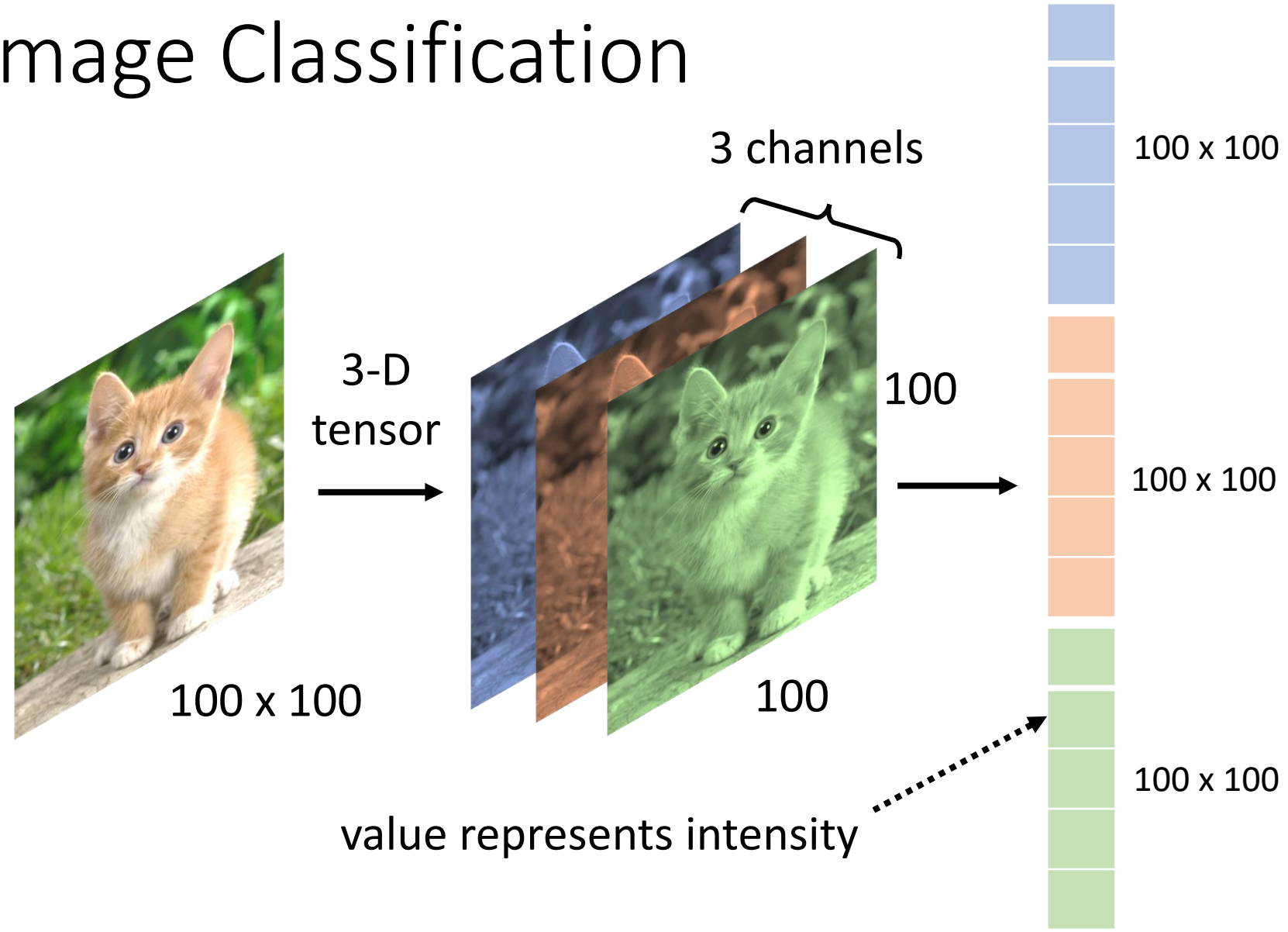
$$\begin{bmatrix} \vdots \\ 0.2 \\ 0.7 \\ 0.1 \\ \vdots \end{bmatrix} \quad y'$$

$$\begin{matrix} \\ \text{dog} \\ \text{cat} \\ \text{tree} \\ \\ \end{matrix} \begin{bmatrix} \vdots \\ 0 \\ 1 \\ 0 \\ \vdots \end{bmatrix} \quad \hat{y}$$

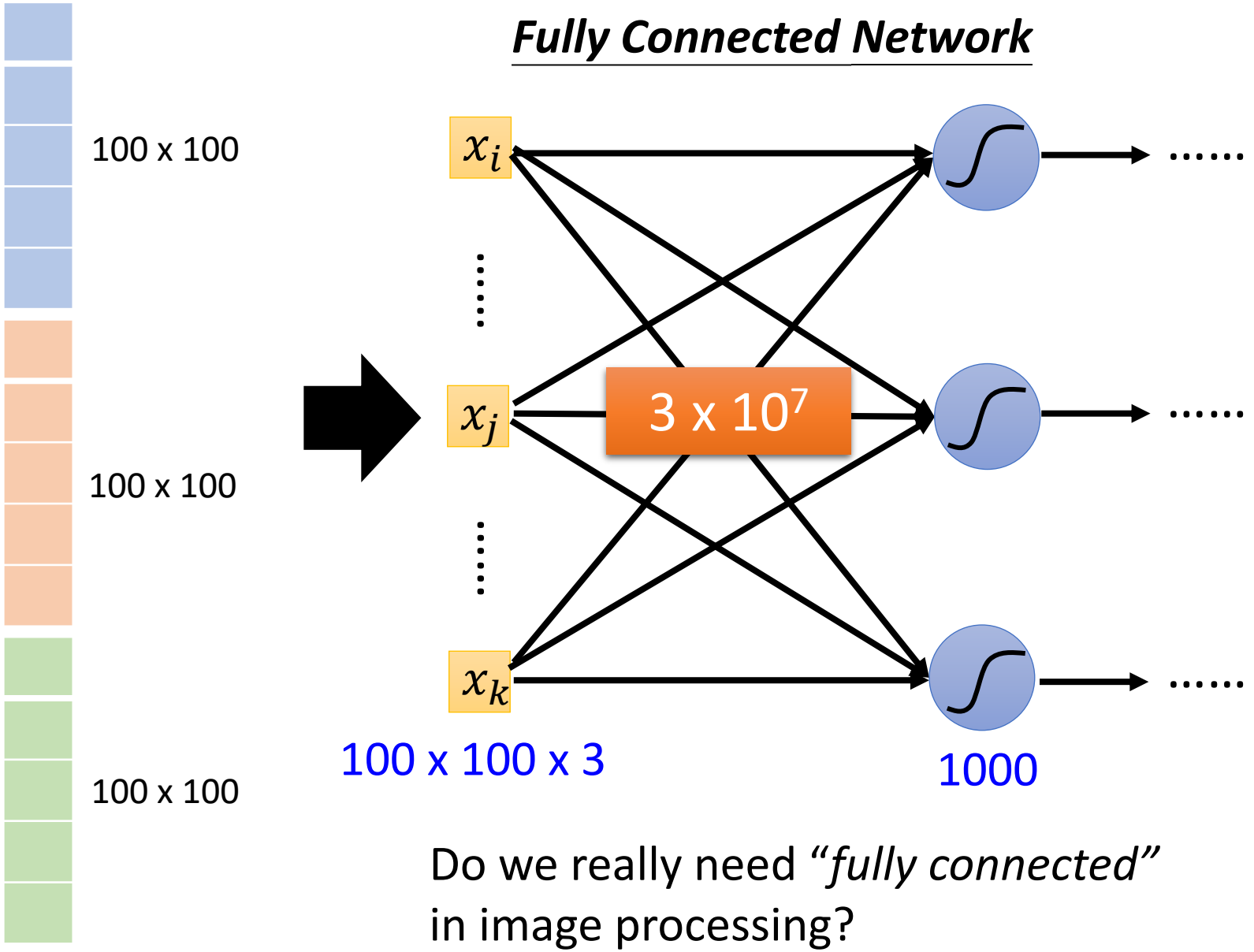
Cross entropy

(All the images to be classified have the same size.)

Image Classification

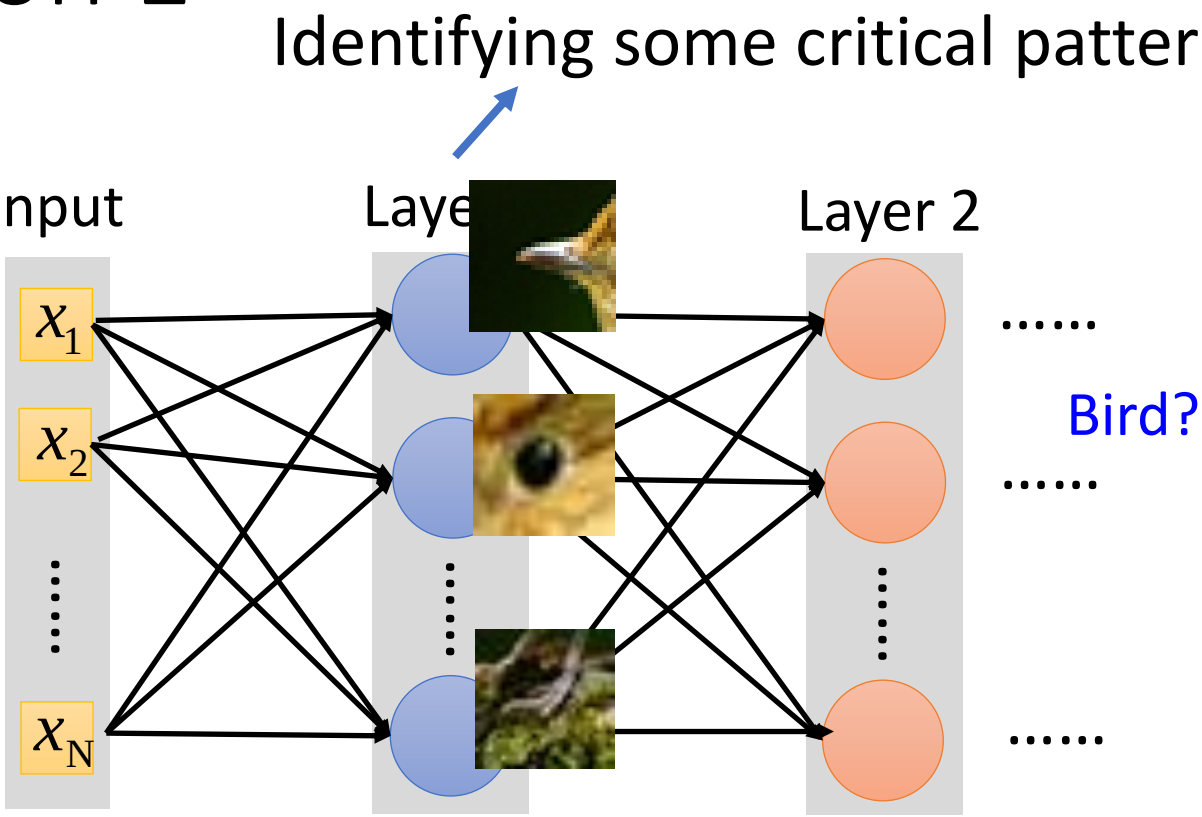


Fully Connected Network



Do we really need "*fully connected*" in image processing?

Observation 1



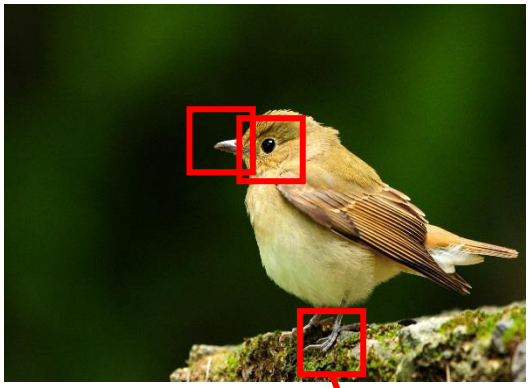
Perhaps human also identify birds in a similar way … ☺

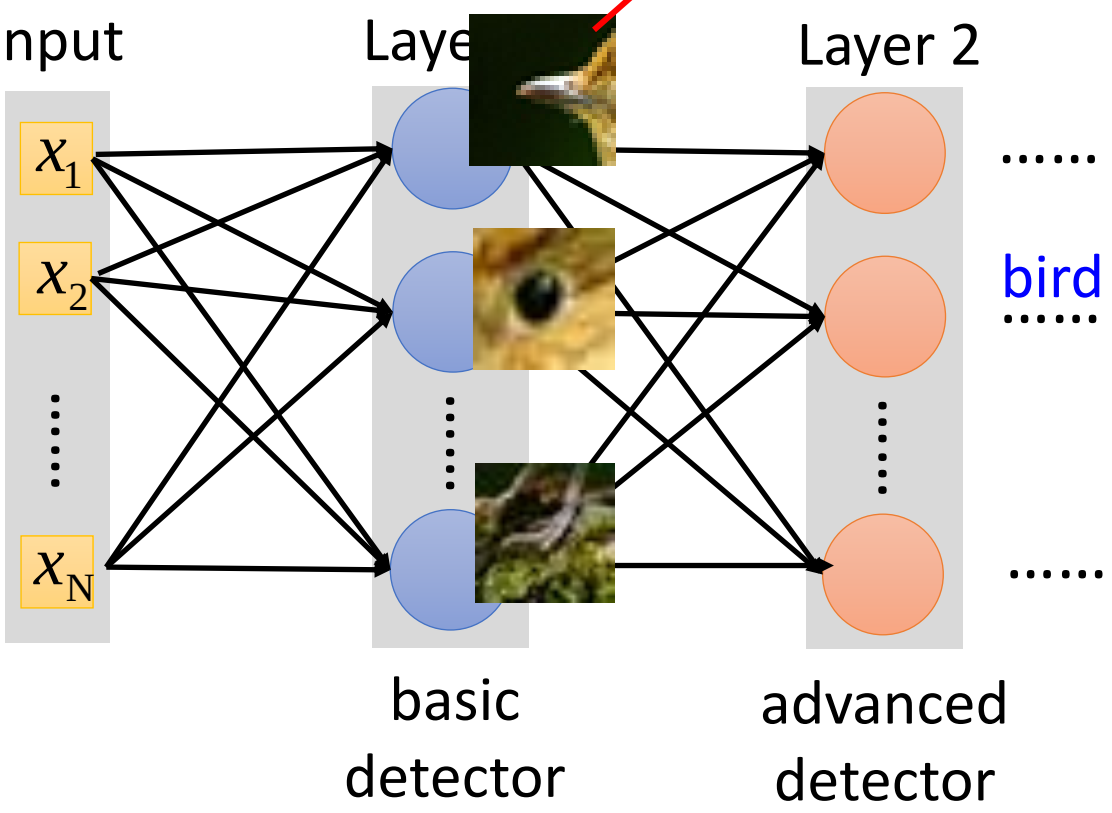
https://www.dcard.tw/f/funny/p/233833012

Observation 1

A neuron does not have to see the whole image.

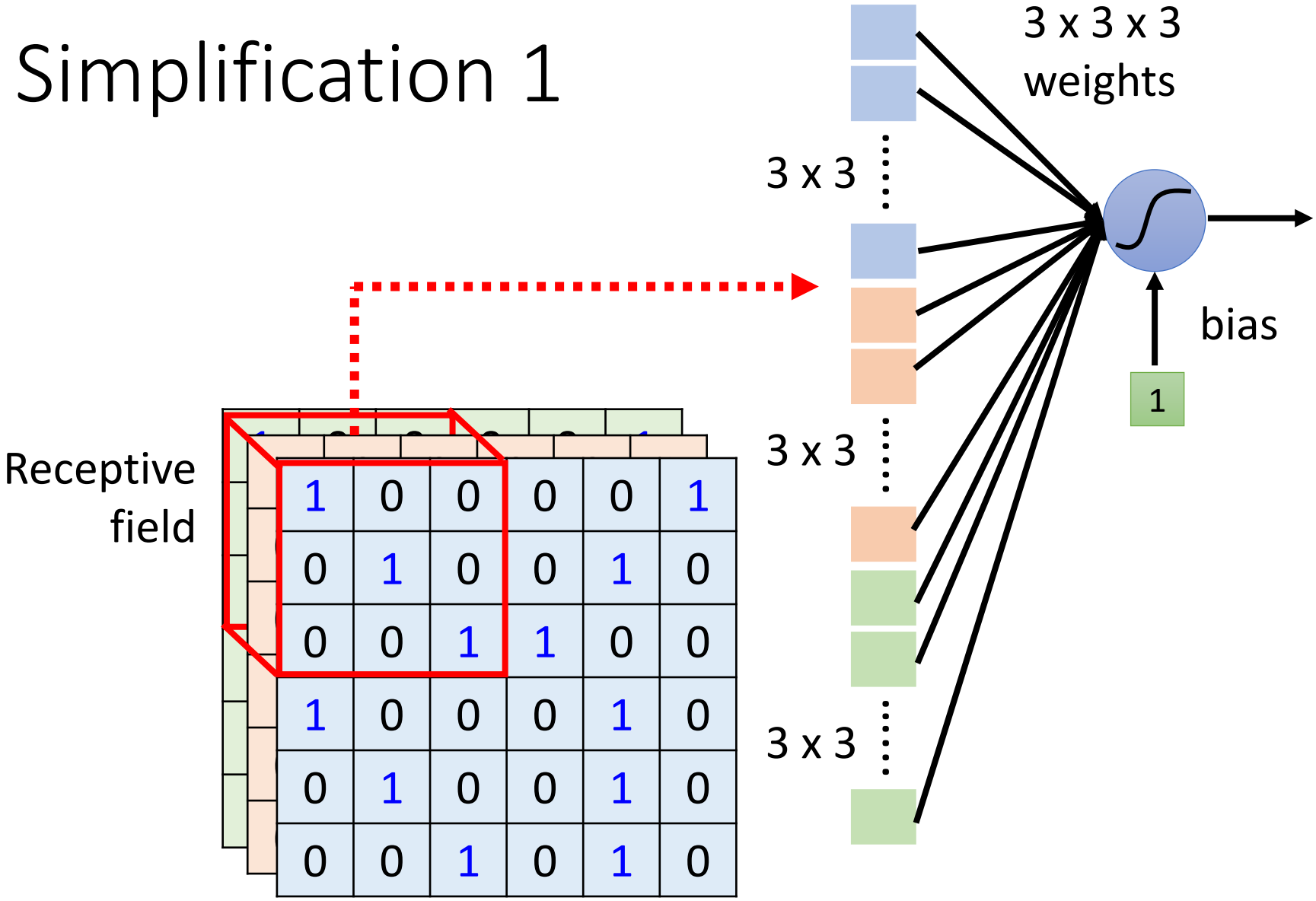
Need to see the whole image?





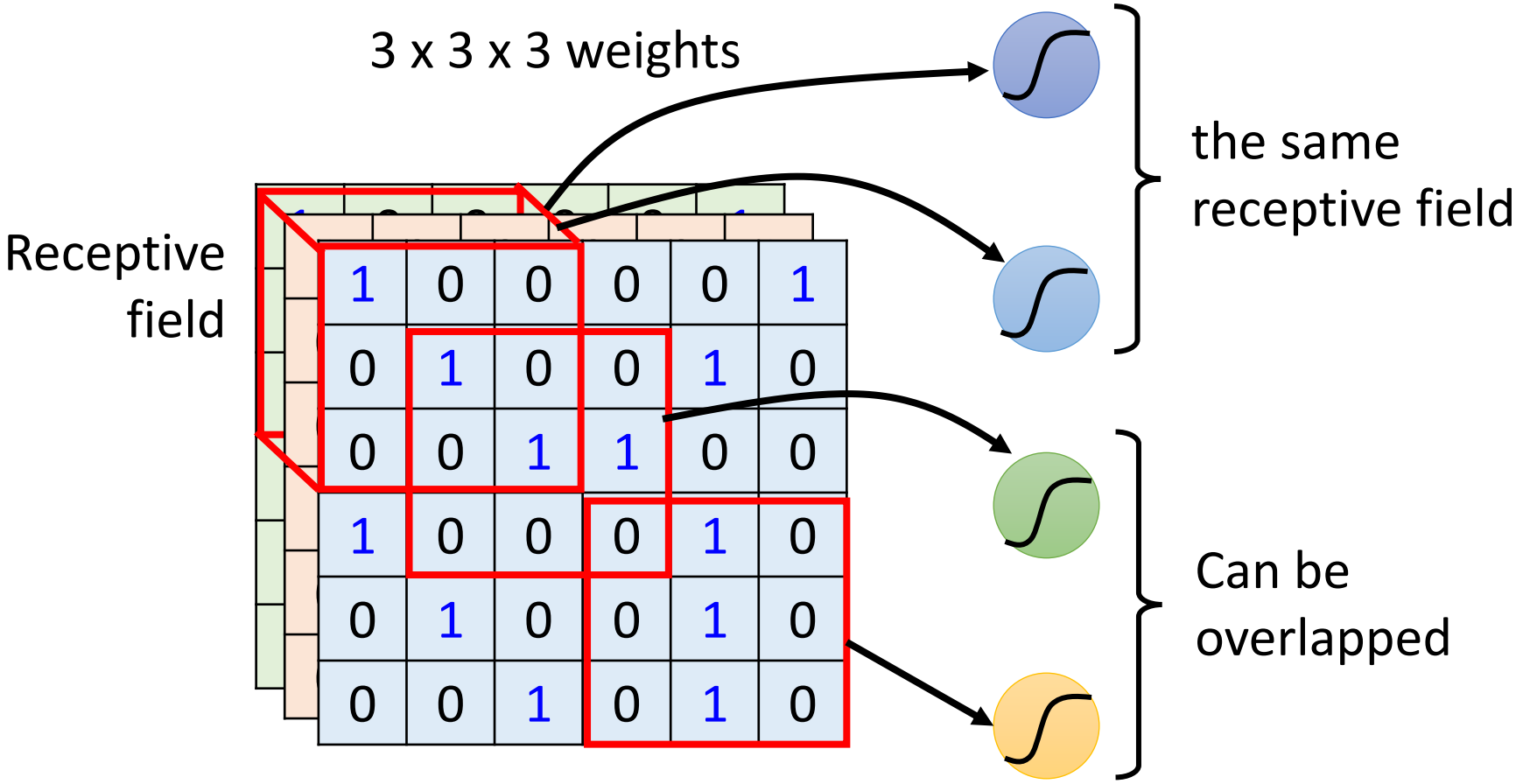
Some patterns are much smaller than the whole image.

Simplification 1



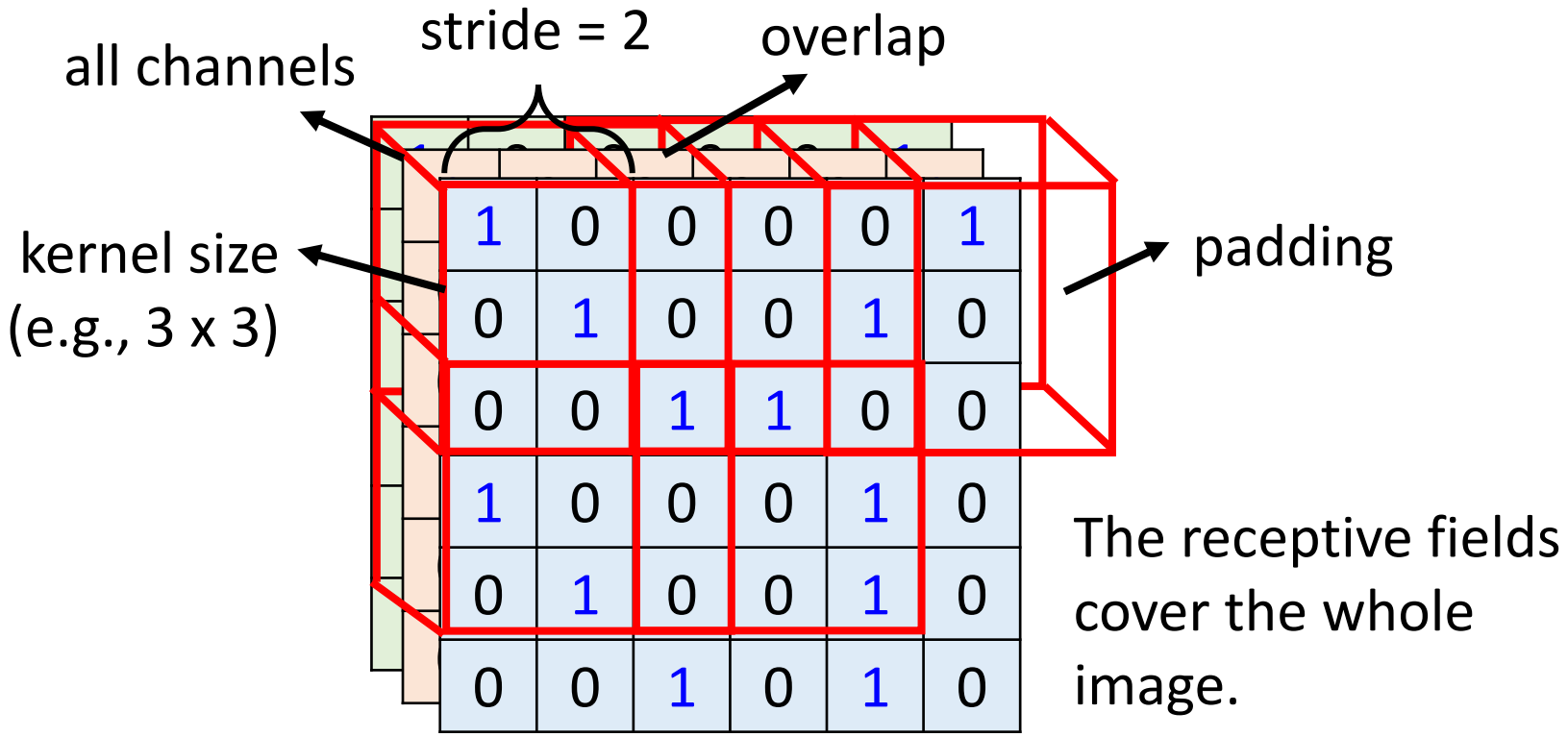
Simplification 1

- Can different neurons have different sizes of receptive field?
- Cover only some channels?
- Not square receptive field?



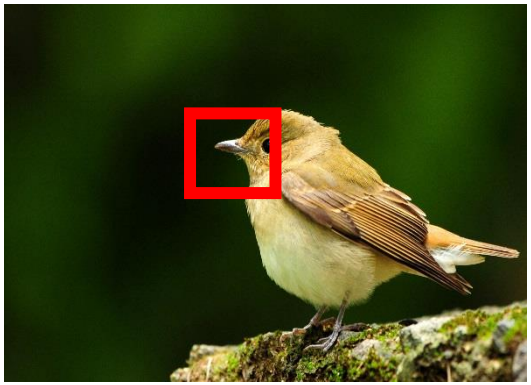
Simplification 1 – Typical Setting

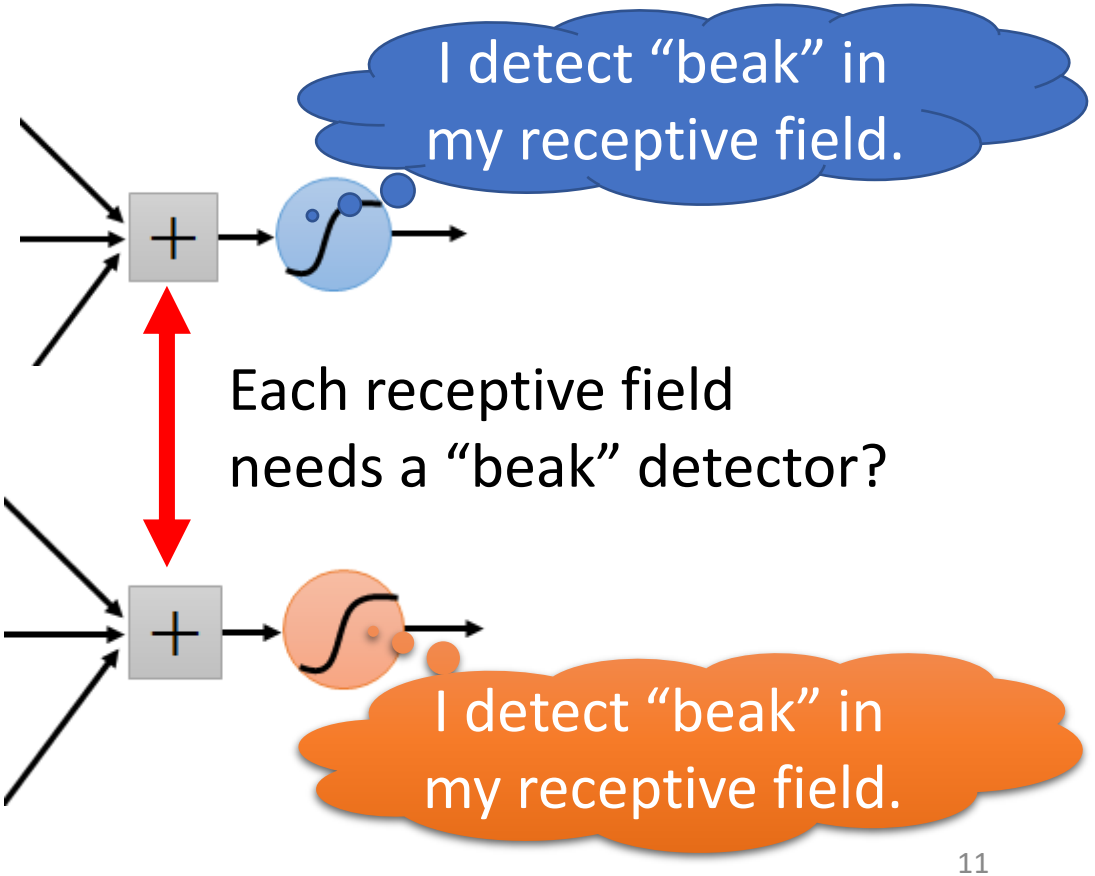
Each receptive field has a set of neurons (e.g., 64 neurons).



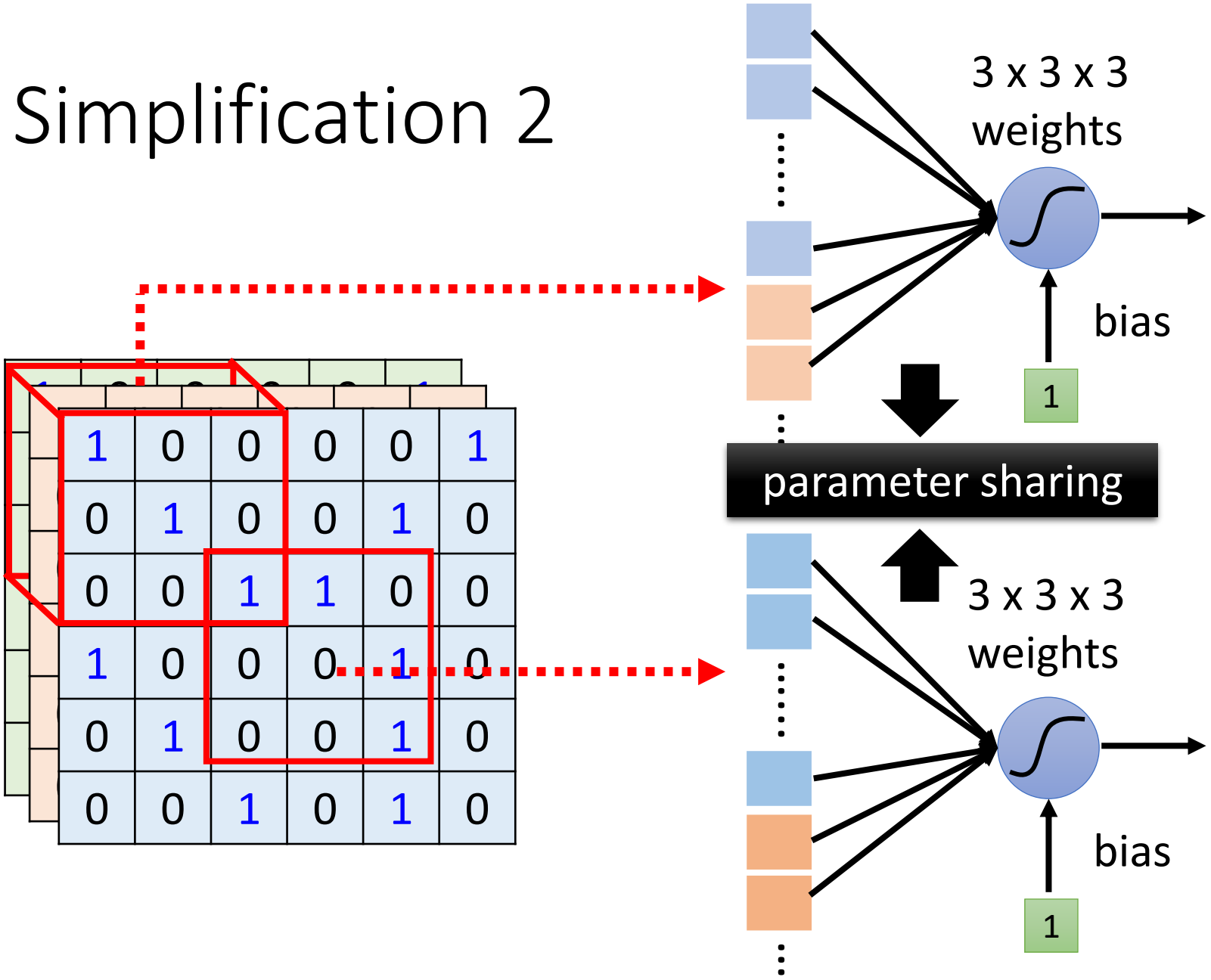
Observation 2

- The same patterns appear in different regions.

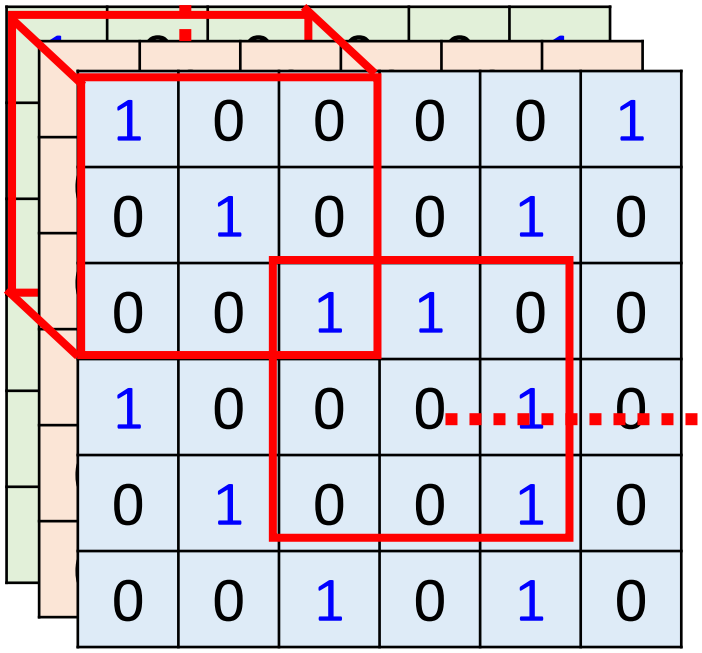


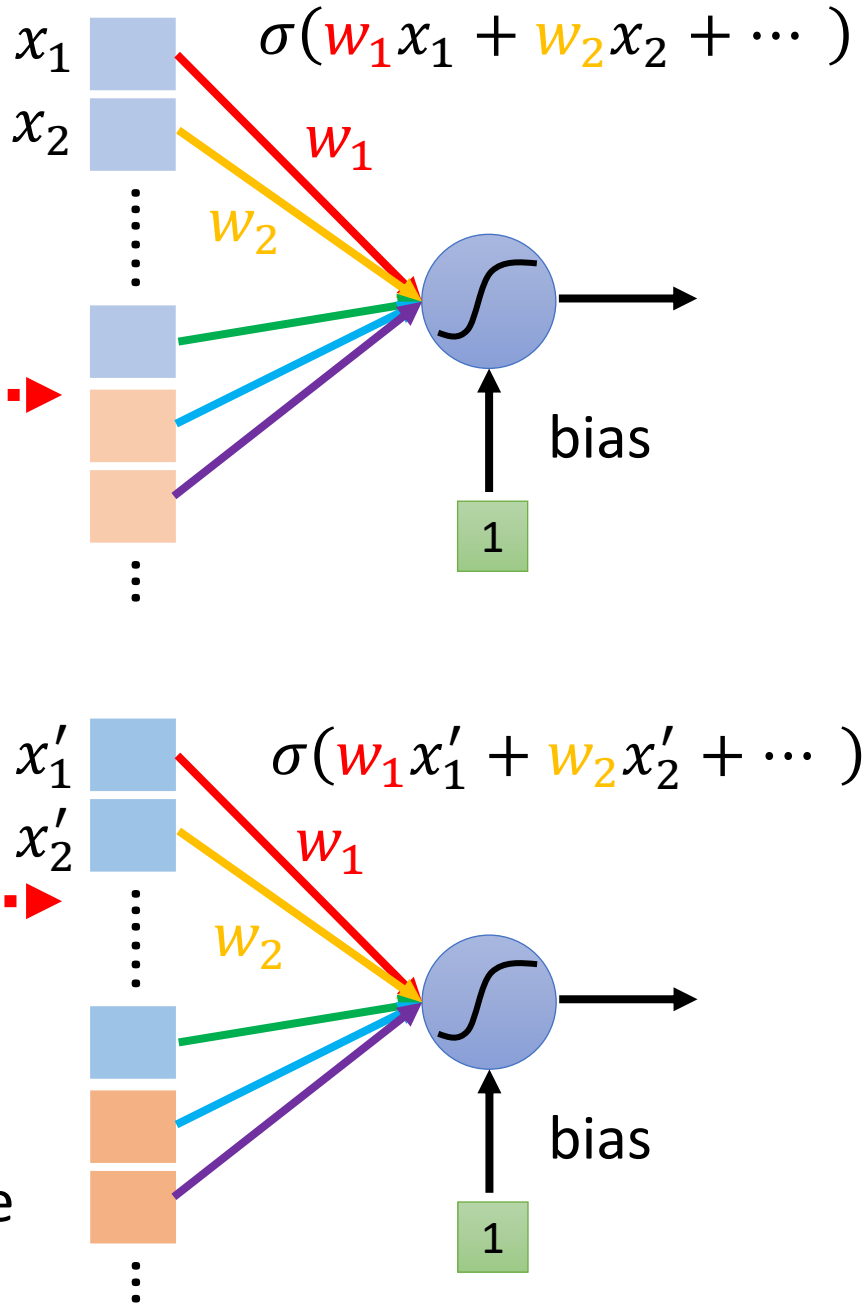


Simplification 2



Simplification 2

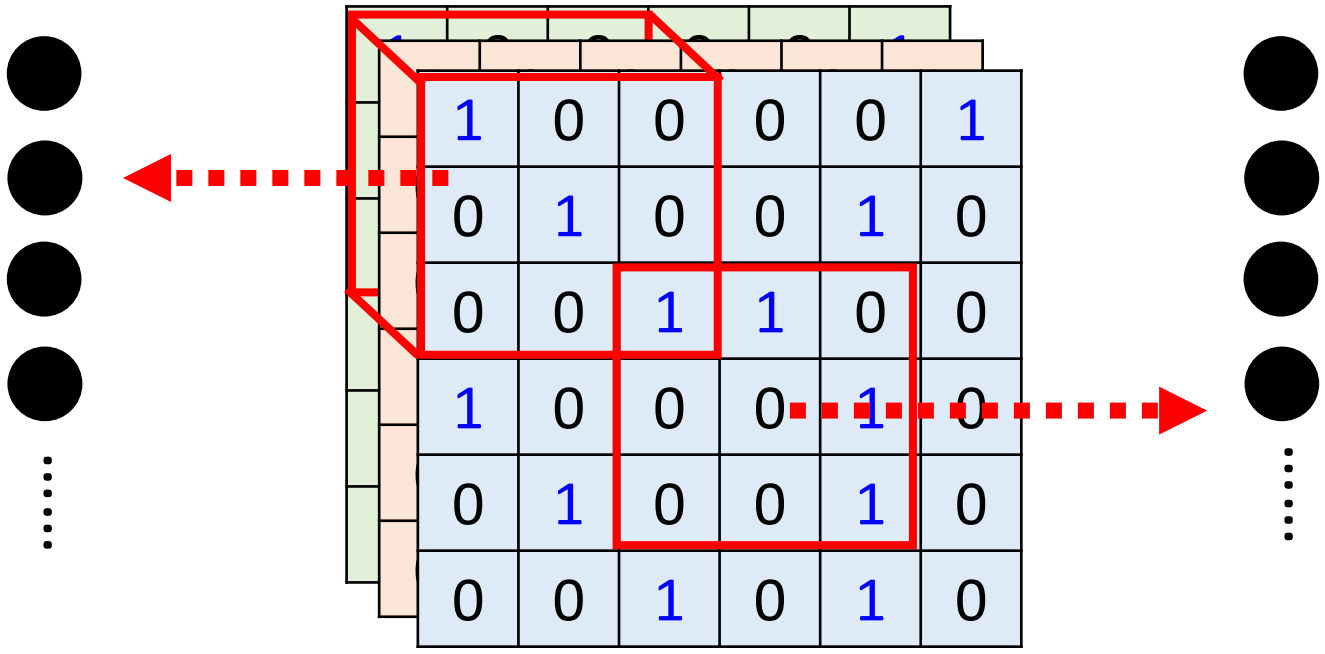




Two neurons with the same receptive field would not share parameters.

Simplification 2 – Typical Setting

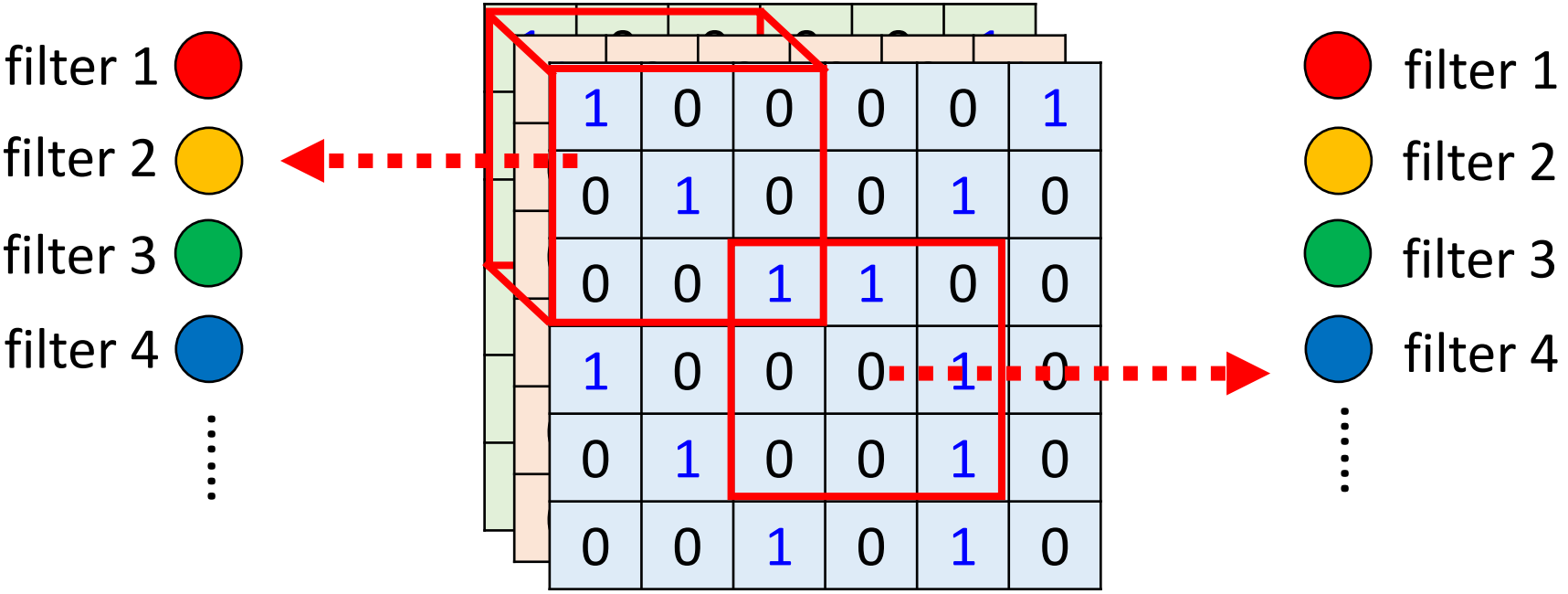
Each receptive field has a set of neurons (e.g., 64 neurons).



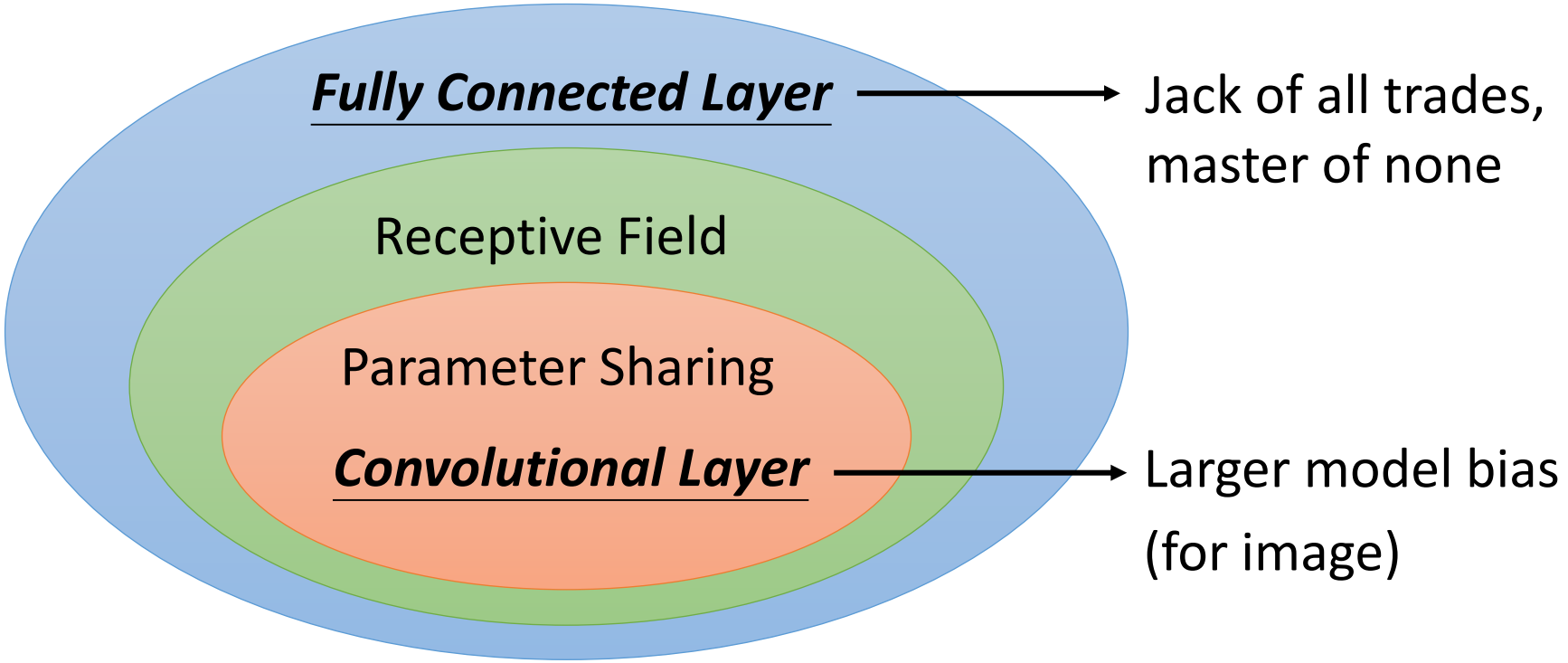
Simplification 2 – Typical Setting

Each receptive field has a set of neurons (e.g., 64 neurons).

Each receptive field has the neurons with the same set of parameters.



Benefit of Convolutional Layer

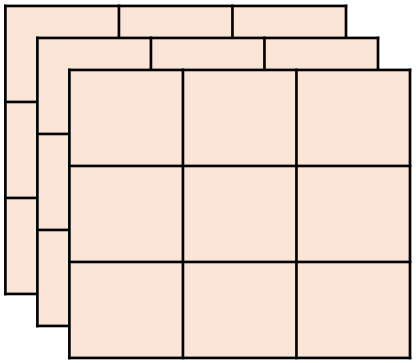


- Some patterns are much smaller than the whole image.
- The same patterns appear in different regions.

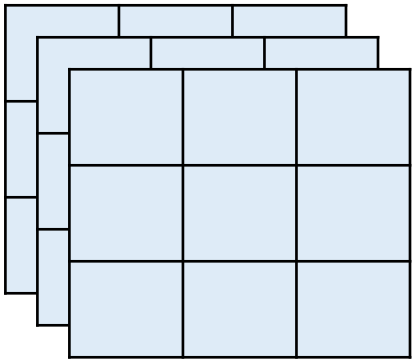
Another story based on ***filter*** ☺

Convolutional Layer

Convolution



Filter 1
3 x 3 x channel
tensor



Filter 2
3 x 3 x channel
tensor

channel = 3 (colorful)

channel = 1 (black and white)

Each filter detects a small pattern (3 x 3 x channel).

Convolutional Layer

Consider channel = 1
(black and white image)

1	0	0	0	0	1
0	1	0	0	1	0
0	0	1	1	0	0
1	0	0	0	1	0
0	1	0	0	1	0
0	0	1	0	1	0

6 x 6 image

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

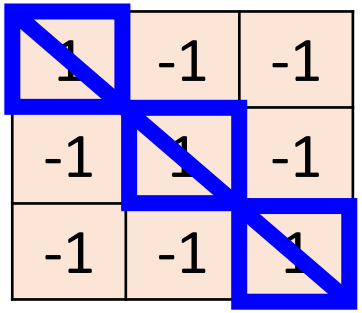
Filter 1

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

Filter 2

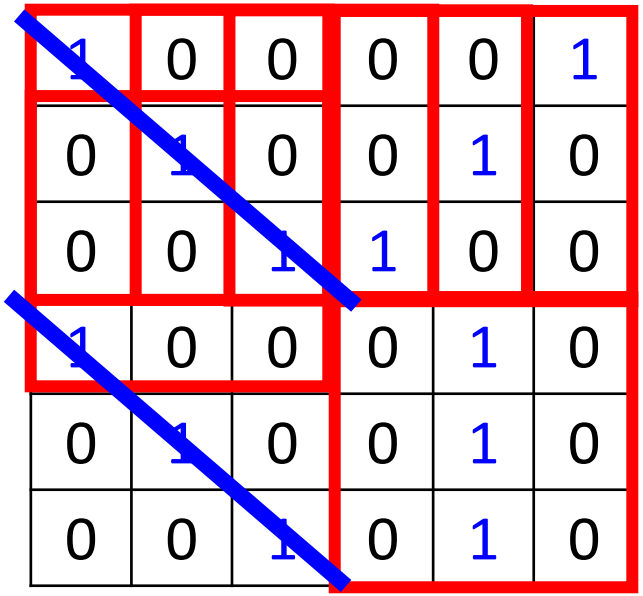
(The values in the filters are unknown parameters.)

Convolutional Layer

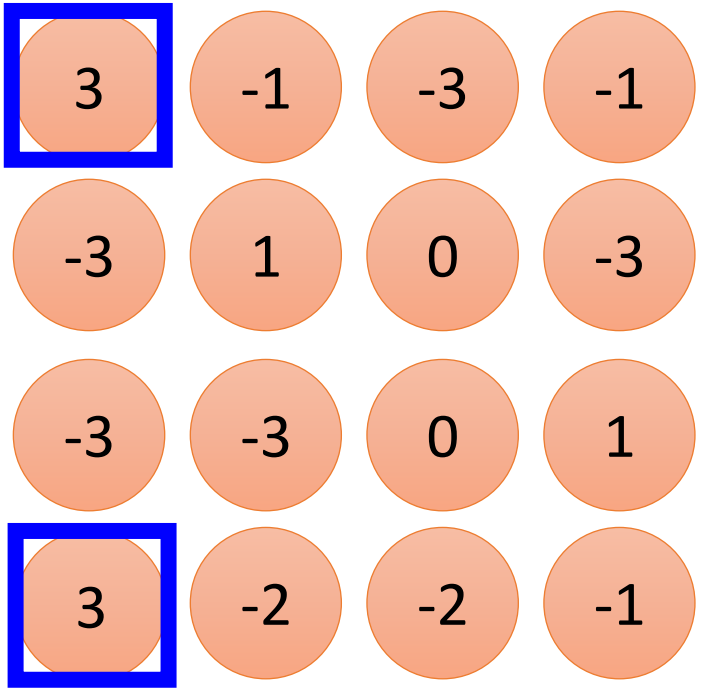


Filter 1

stride=1



6 x 6 image



Convolutional Layer

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

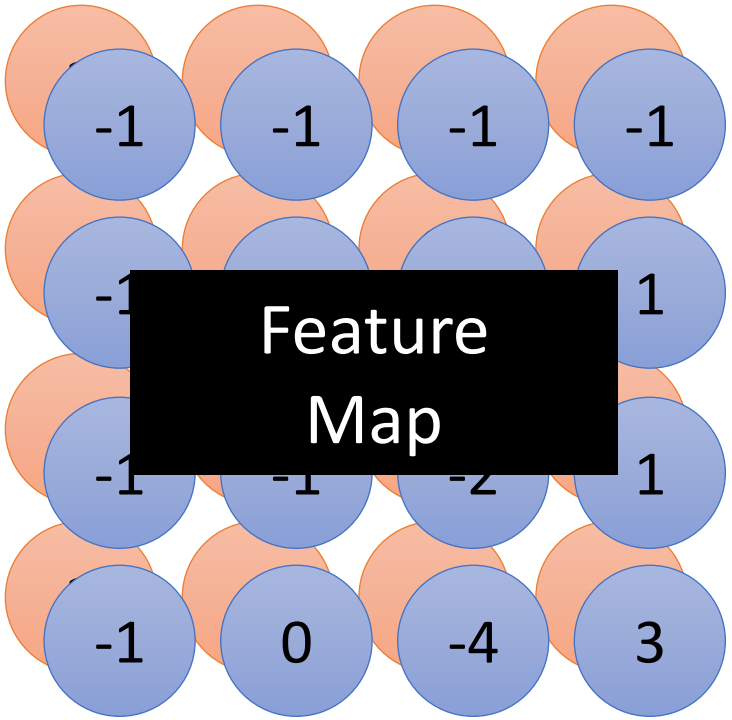
Filter 2

stride=1

1	0	0	0	0	1
0	1	0	0	1	0
0	0	1	1	0	0
1	0	0	0	1	0
0	1	0	0	1	0
0	0	1	0	1	0

6 x 6 image

Do the same process for every filter

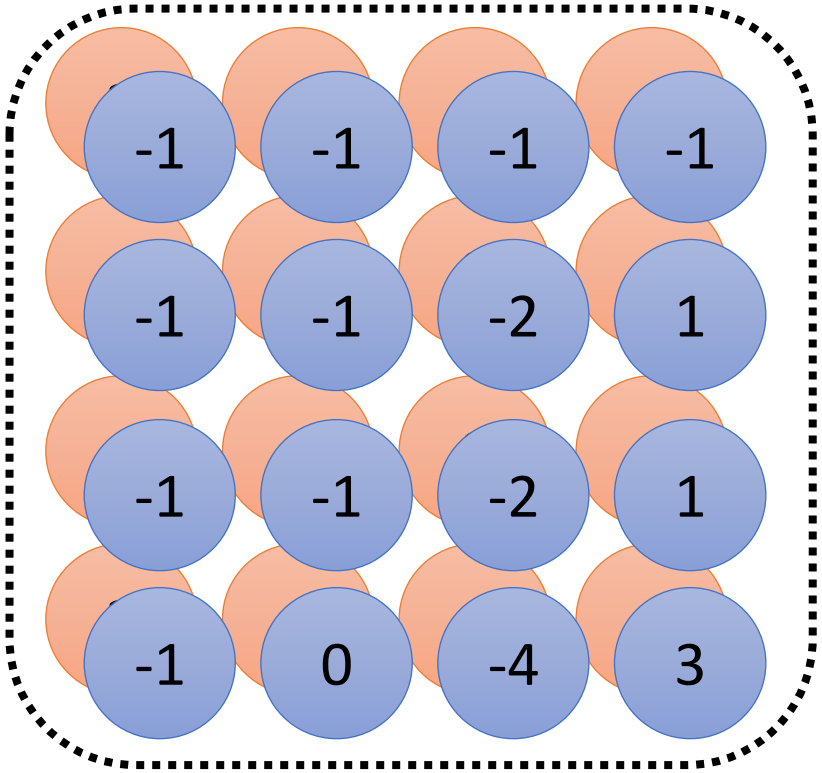


Convolutional Layer

64 filters

Convolution

Convolution



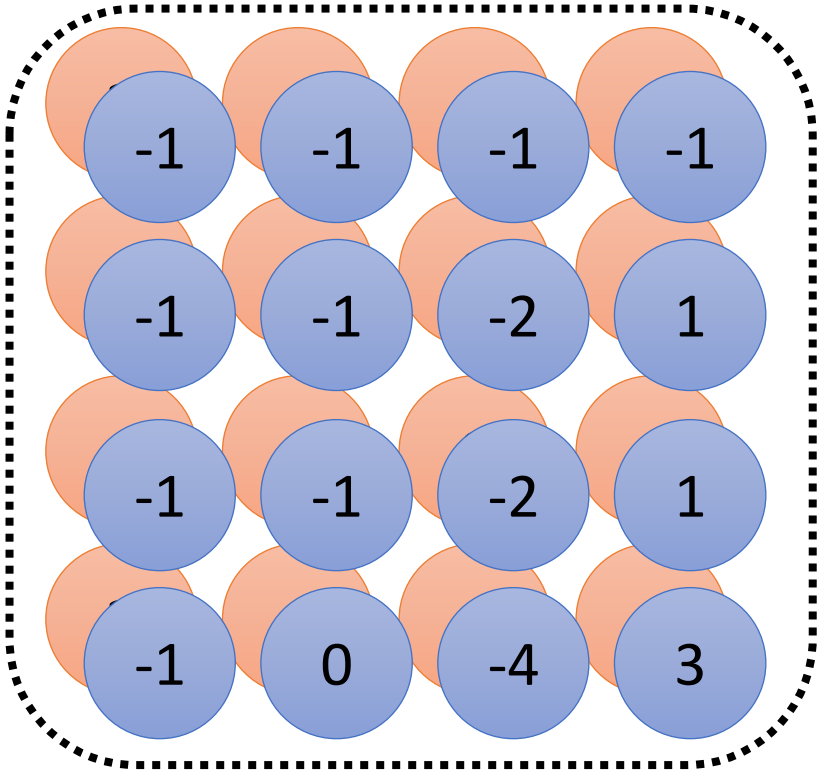
"Image" with 64 channels

Multiple Convolutional Layers

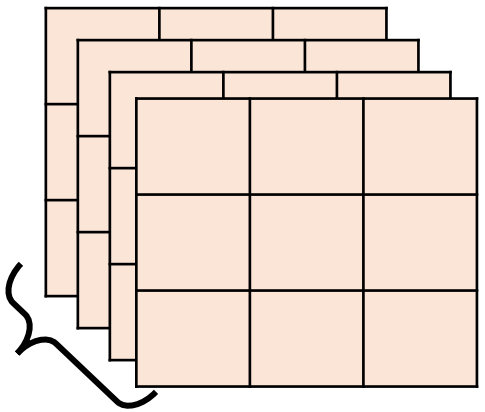
64 filters

Convolution

Convolution



"Image" with 64 channels



Filter:
3 x 3 x 64

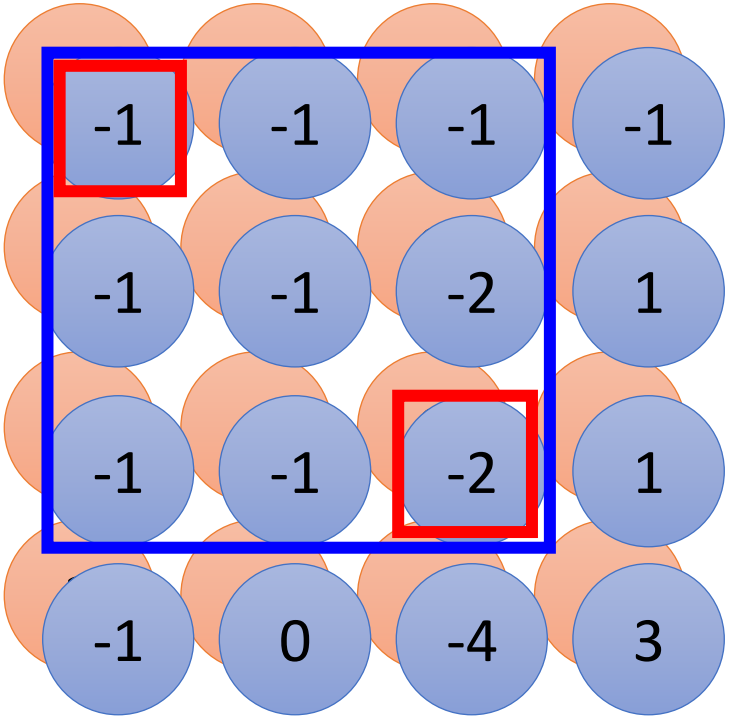
Multiple Convolutional Layers

64 filters

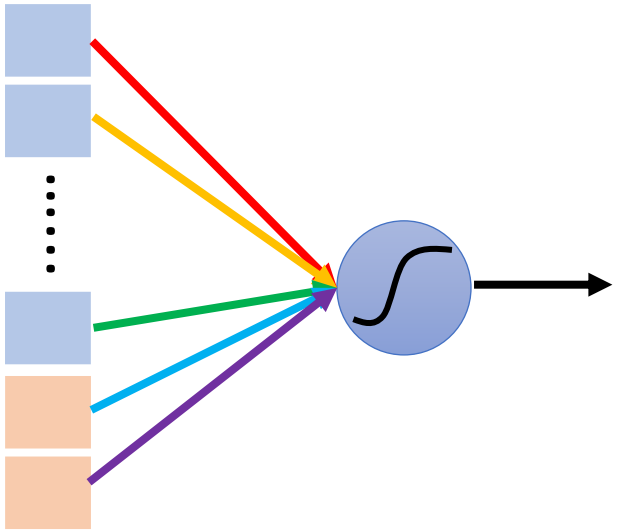
Convolution

Convolution

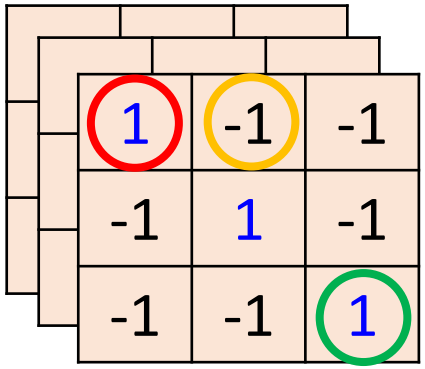
1	0	0	0	0	1
0	1	0	0	1	0
0	0	1	1	0	0
1	0	0	0	1	0
0	1	0	0	1	0
0	0	1	0	1	0



Comparison of Two Stories



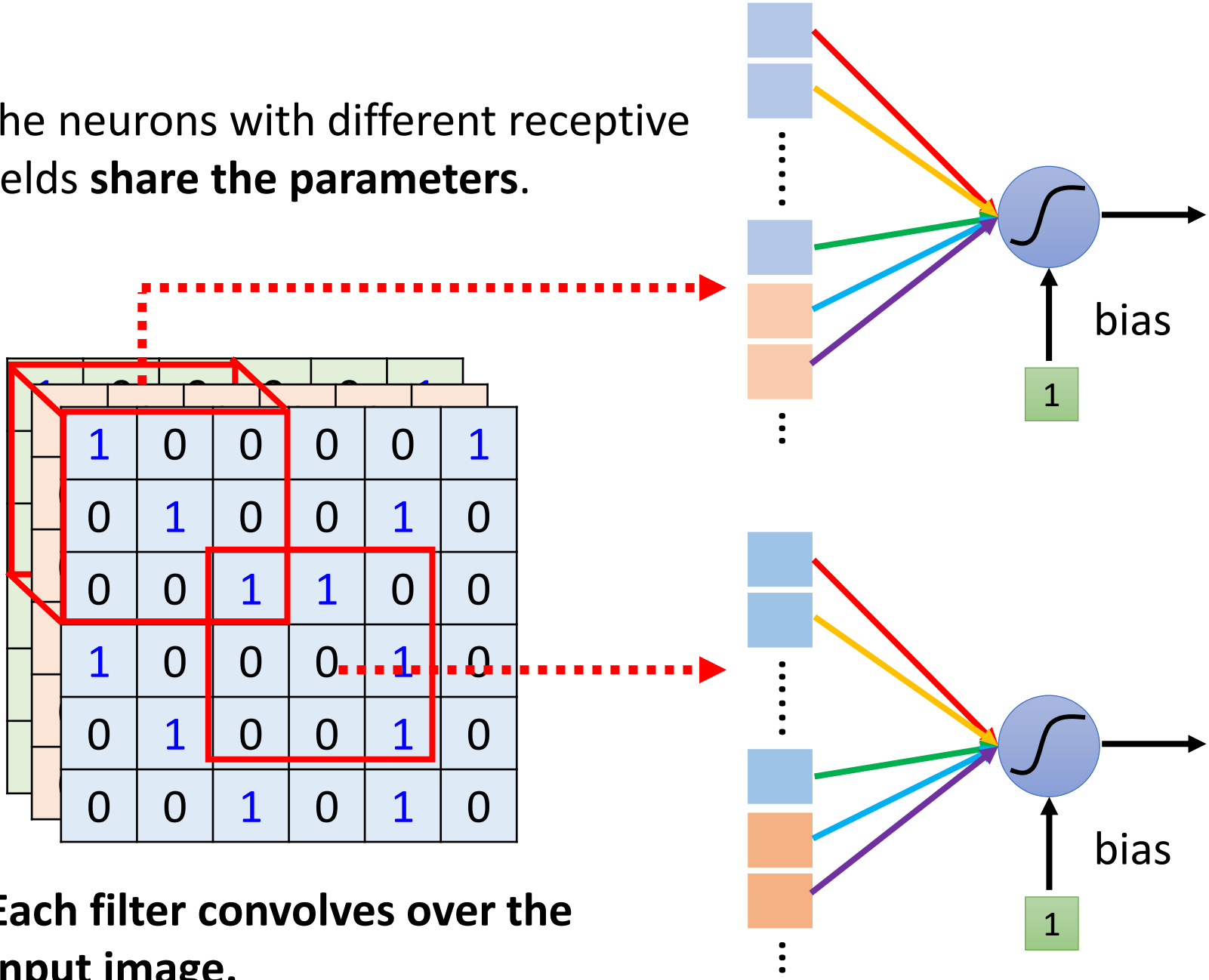
Receptive field



Filter
3 x 3 x channel tensor

(ignore bias in this slide)

The neurons with different receptive fields **share the parameters**.



Each filter convolves over the input image.

Convolutional Layer

Neuron Version Story	***Filter Version Story***
Each neuron only considers a receptive field.	There are a set of filters detecting small patterns.
The neurons with different receptive fields share the parameters.	Each filter convolves over the input image.

They are the same story.

Observation 3

- Subsampling the pixels will not change the object

bird

subsampling

bird

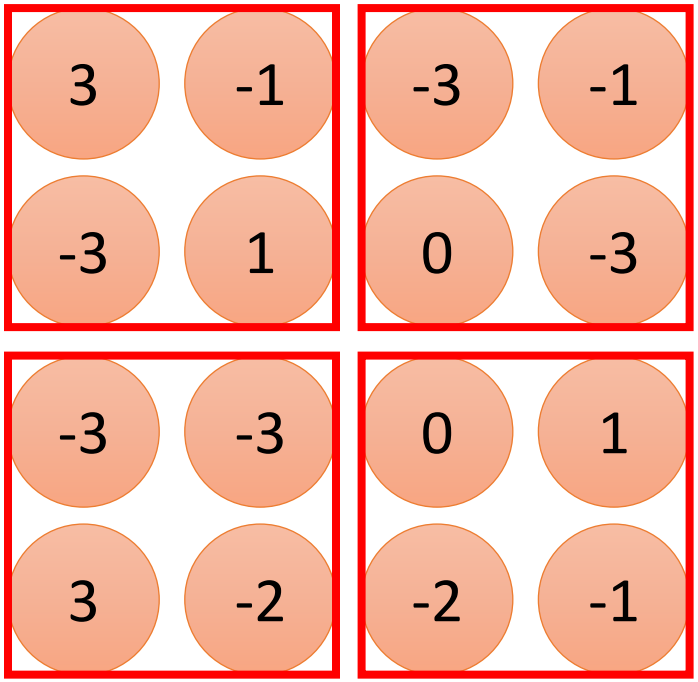
Pooling – Max Pooling

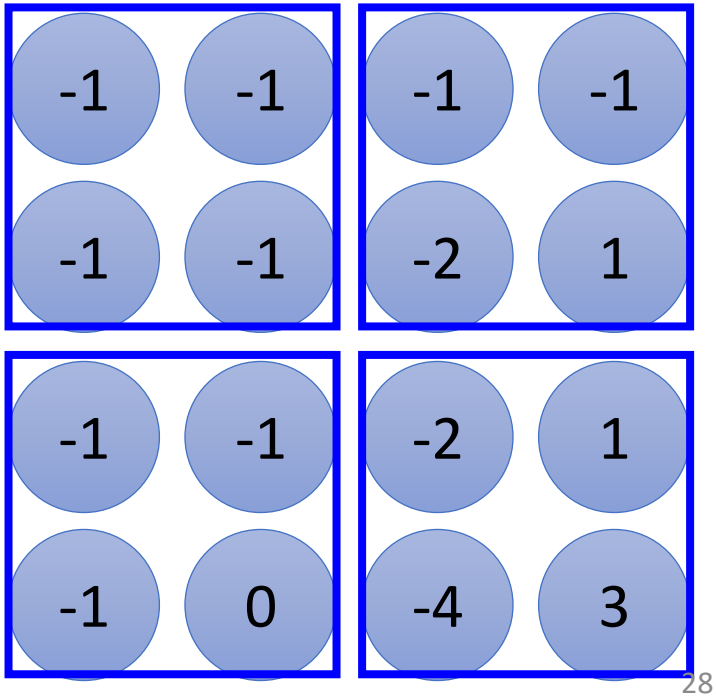
1	-1	-1
-1	1	-1
-1	-1	1

Filter 1

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

Filter 2



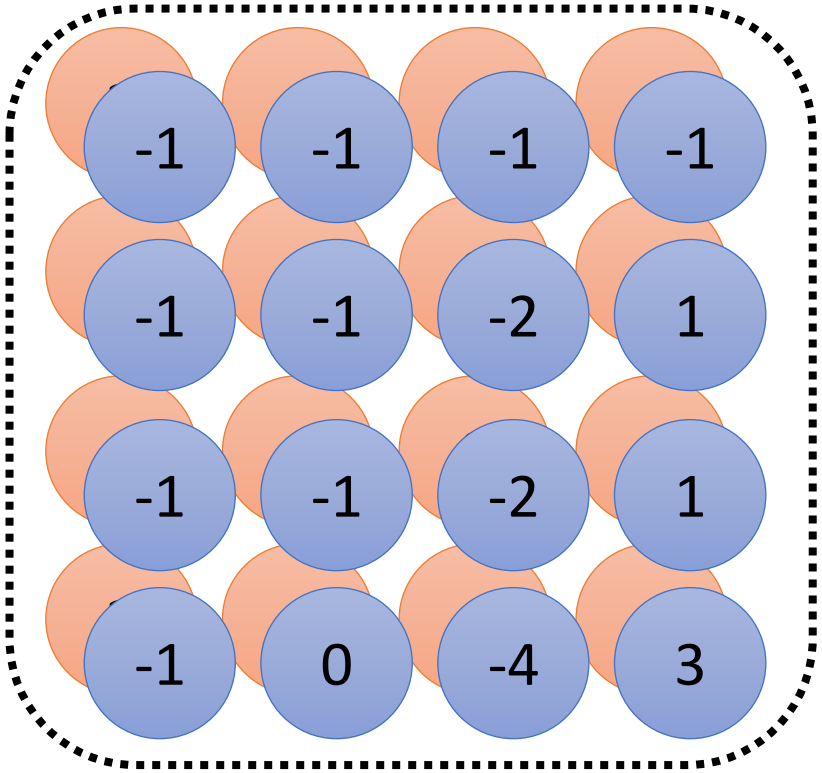


Convolutional Layers + Pooling

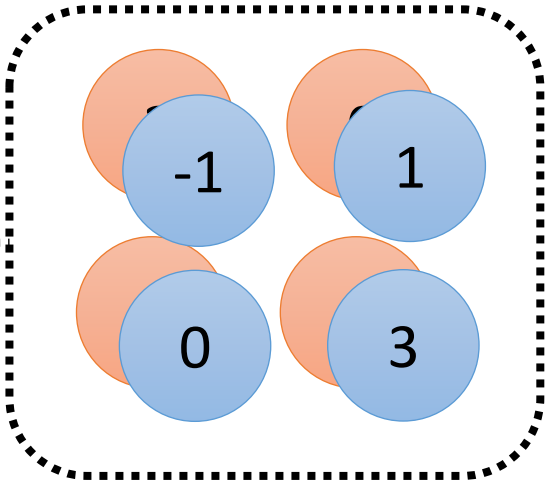
Repeat

Convolution

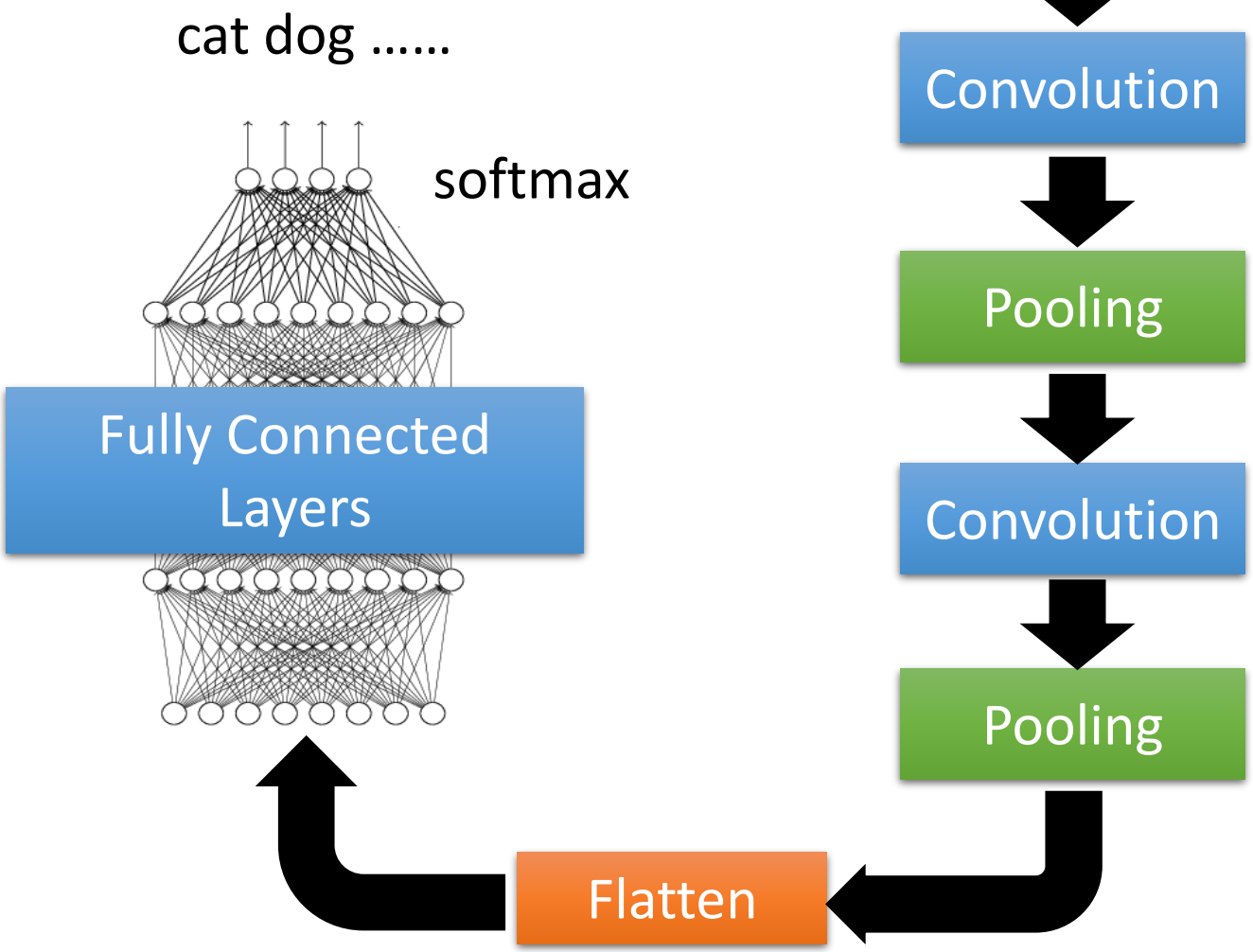
Pooling



"Image" with 64 channels



The whole CNN



Application: Playing Go

19 x 19 matrix (image)

Network

Next move (19 x 19 positions)

19 x 19 classes

48 channels in Alpha Go

Black: 1

white: -1

none: 0

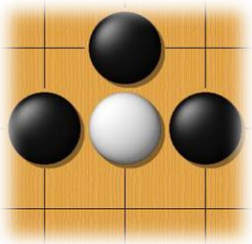
Fully-connected network can be used

But CNN performs much better.

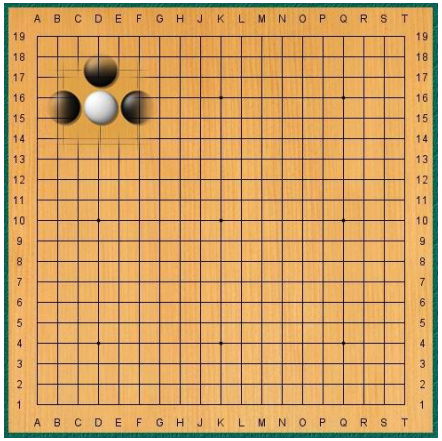
Why CNN for Go playing?

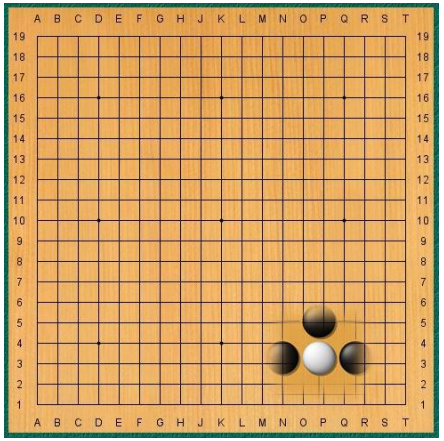
- Some patterns are much smaller than the whole image

  Alpha Go uses 5 x 5 for first layer



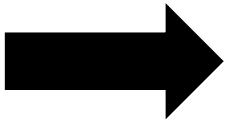
- The same patterns appear in different regions.





Why CNN for Go playing?

- Subsampling the pixels will not change the object



Pooling

How to explain this???

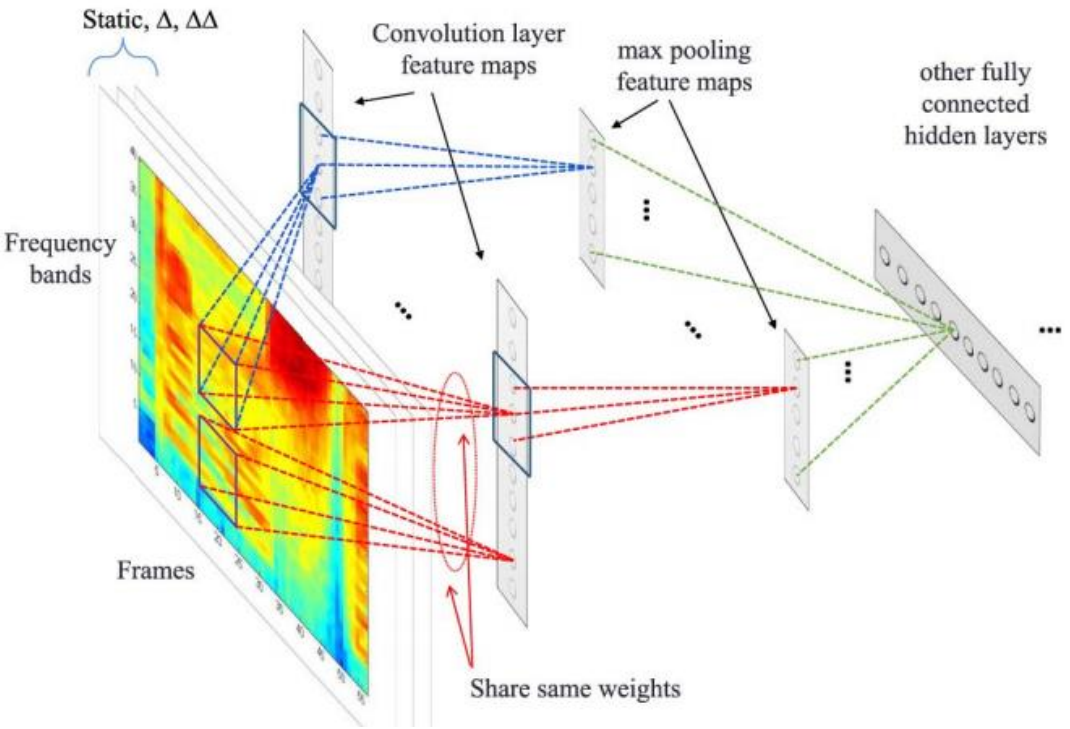
Neural network architecture. The input to the policy network is a $19 \times 19 \times 48$ image stack consisting of 48 feature planes. The first hidden layer zero pads the input into a 23×23 image, then convolves k filters of kernel size 5×5 with stride 1 with the input image and applies a rectifier nonlinearity. Each of the subsequent hidden layers 2 to 12 zero pads the respective previous hidden layer into a 21×21 image, then convolves k filters of kernel size 3×3 with stride 1, again followed by a rectifier nonlinearity. The final layer convolves 1 filter of kernel size 1×1 with stride 1, with a different bias for each position, and applies a softmax function. The match version of AlphaGo used $k = 192$ filters; Fig. 2b and Extended Data Tabl 256 and 384 filters

Alpha Go does not use Pooling ……

More Applications

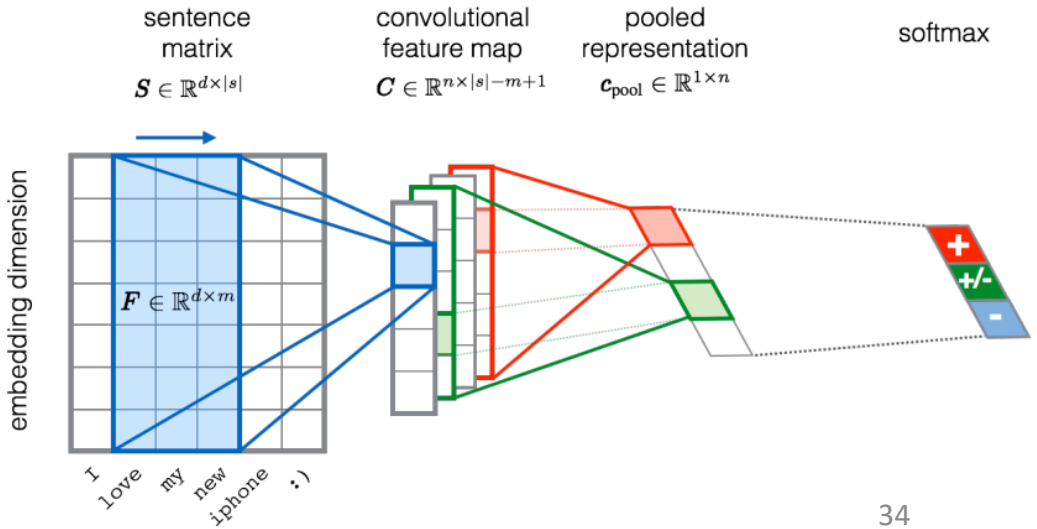
Speech

https://dl.acm.org/doi/10.1109/TASLP.2014.2339736



Natural Language Processing

https://www.aclweb.org/anthology/S15-2079/



To learn more …

- CNN is not invariant to scaling and rotation (we need data augmentation ☺).

Spatial Transformer Layer

https://youtu.be/SoCywZ1hZak

(in Mandarin)