Deep Learning

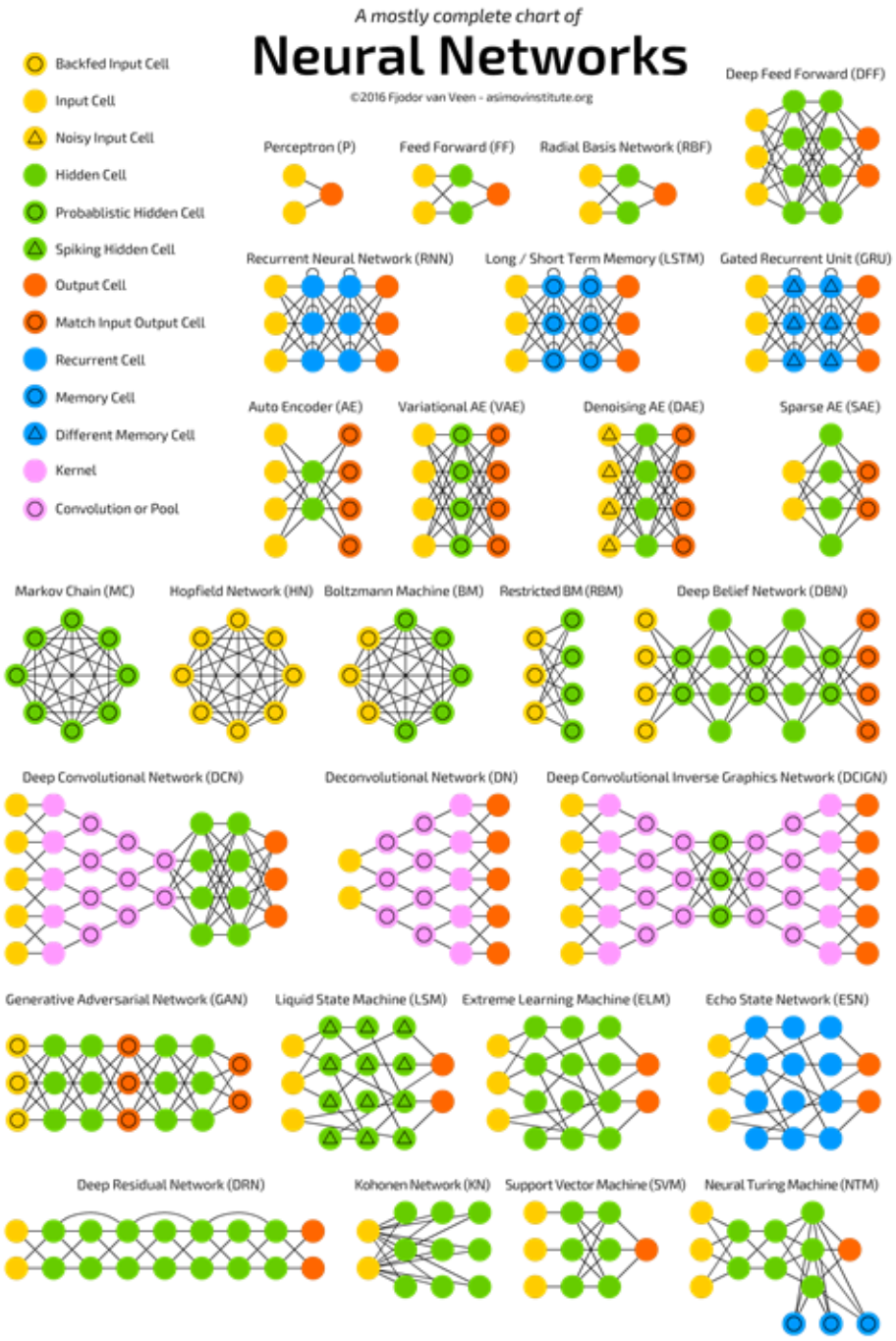
Deep learning

Representation learning with a hierarchy of concepts

Those concepts are represented by layers in a neural network model

Types of Deep Learning Tools

Azimov Institute:
http://www.asimovinstitute.org/neural-network-zoo/



Supervised learning models

- Image analysis:
  - Convolutional Neural Networks (CNNs)
  - Vision Transformers (ViTs)
- Text analysis and NLP
  - Transformers

Generative models

- Generative Adversarial Networks (GANs)
- Diffusion Models (e.g. DALL-E 2, Stable Diffusion)
- Generative Pre-trained Transformer (GPT)

Common Structure

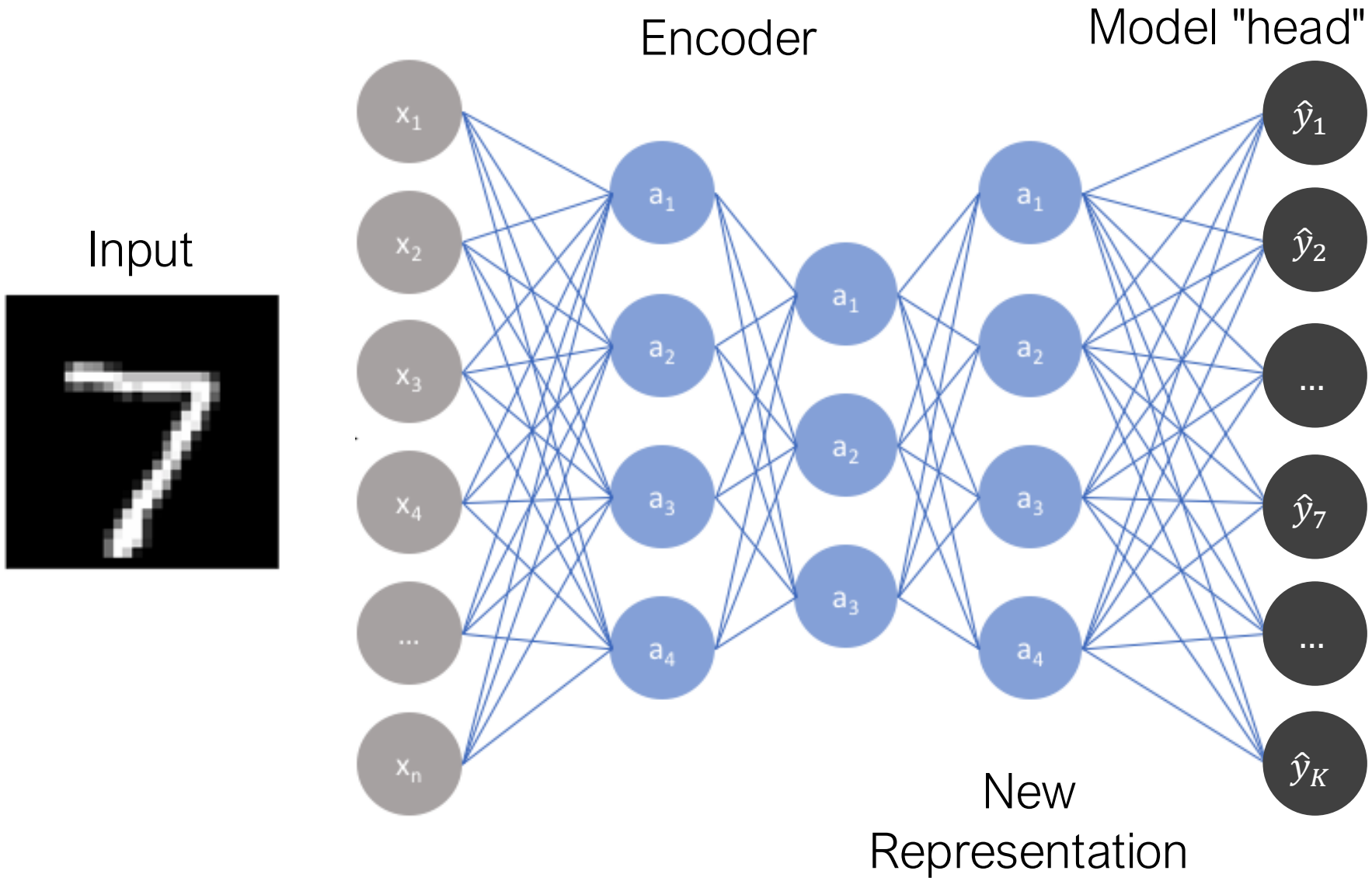
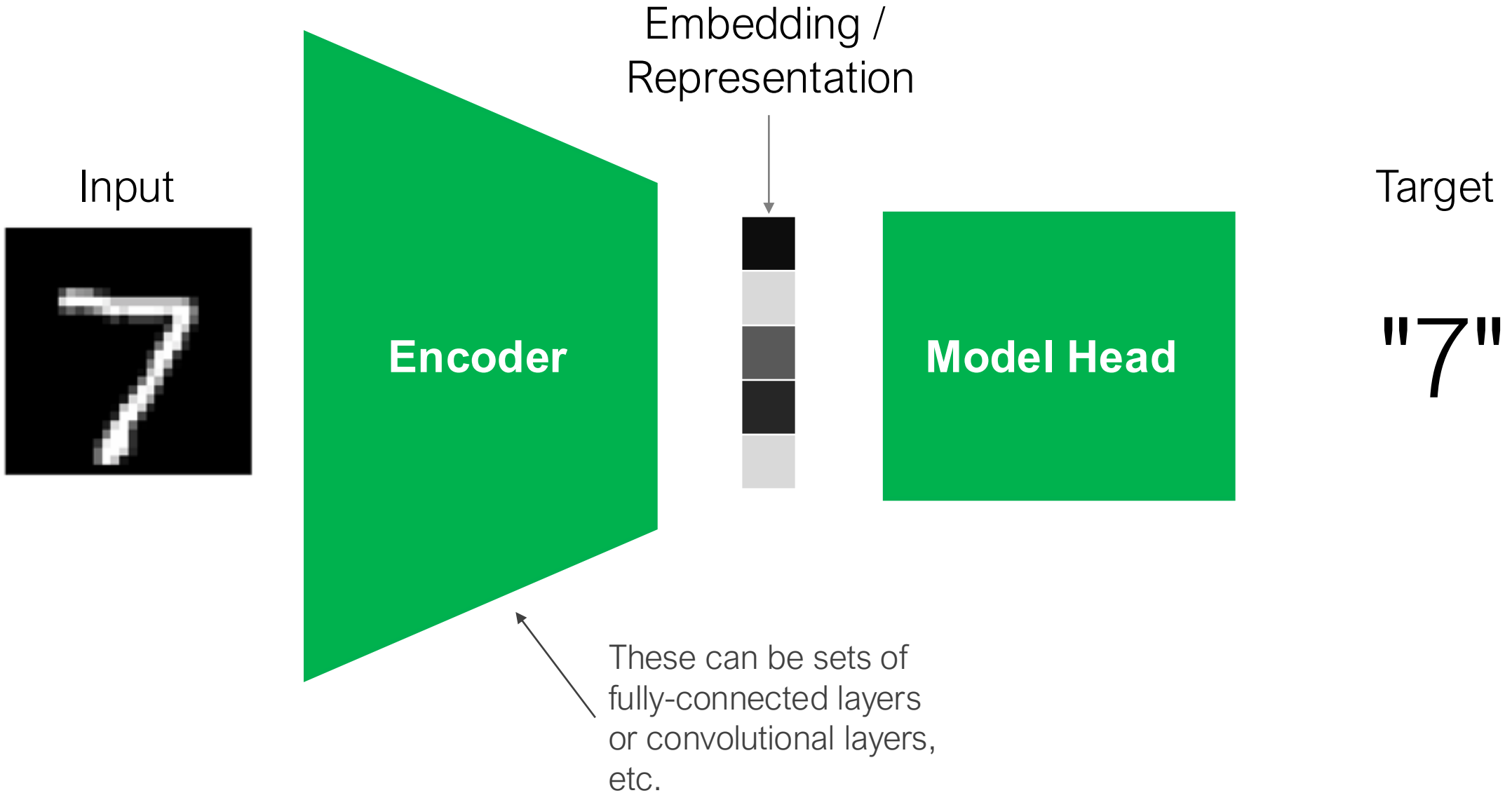


Image from: https://www.jeremyjordan.me/autoencoders/

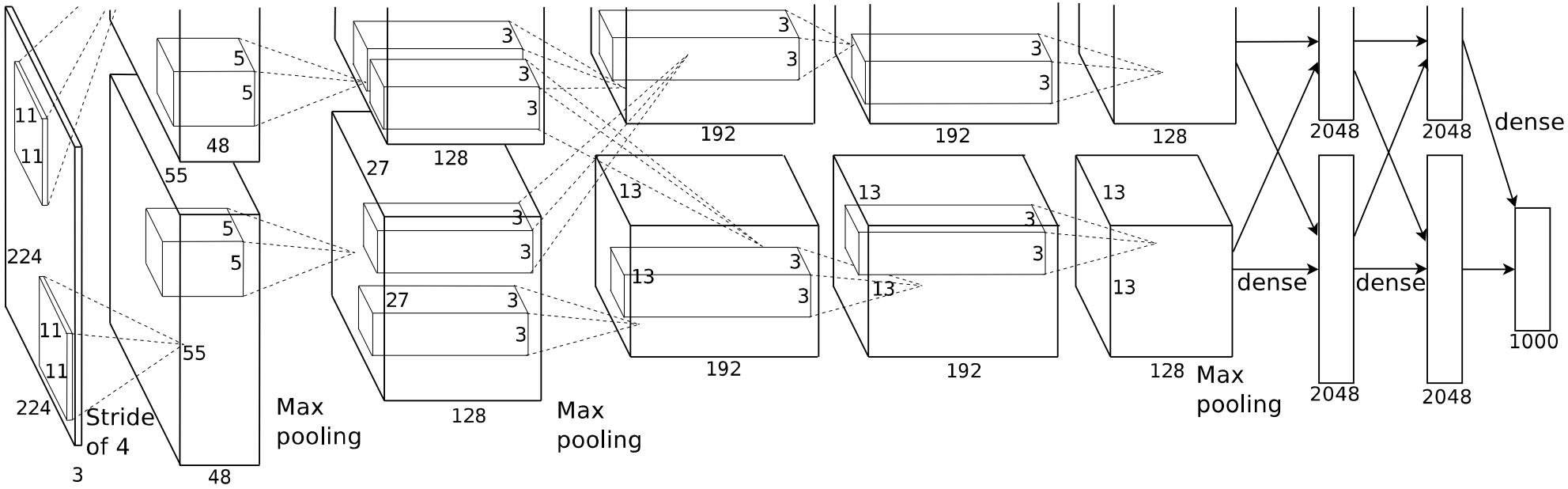
Common Structure

Our goal is often to develop a good **encoder** that represents our features well



Convolutional Neural Networks

AlexNet



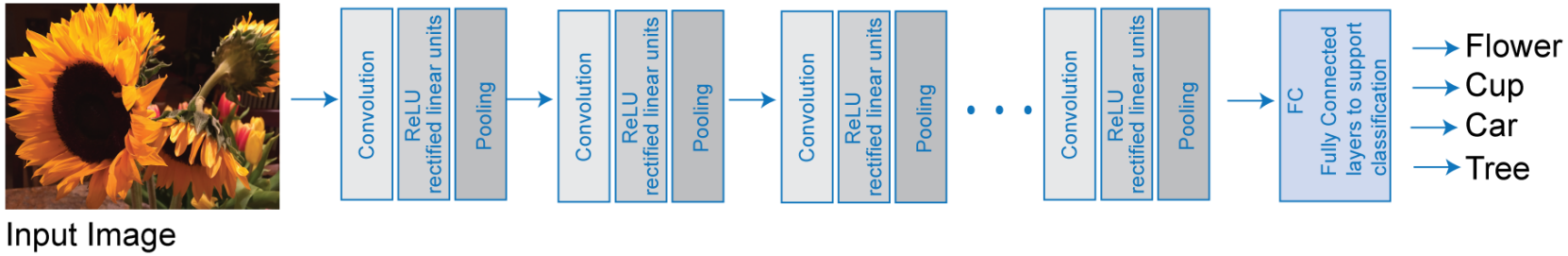
Input
11x11 conv, 96
5x5 conv, 256
max pool
3x3 conv, 384
max pool
3x3 conv, 384
3x3 conv, 256
max pool
FC 4096
FC 4096
FC 1000
softmax

Krizhevsky, Alex, Ilya Sutskever, and Geoffrey E. Hinton. "Imagenet classification with deep convolutional neural networks." Advances in neural information processing systems. 2012.

Key

Input or output layer
Convolutional Layer
Fully Connected Layer
max pooling layer

Convolutional Neural Networks



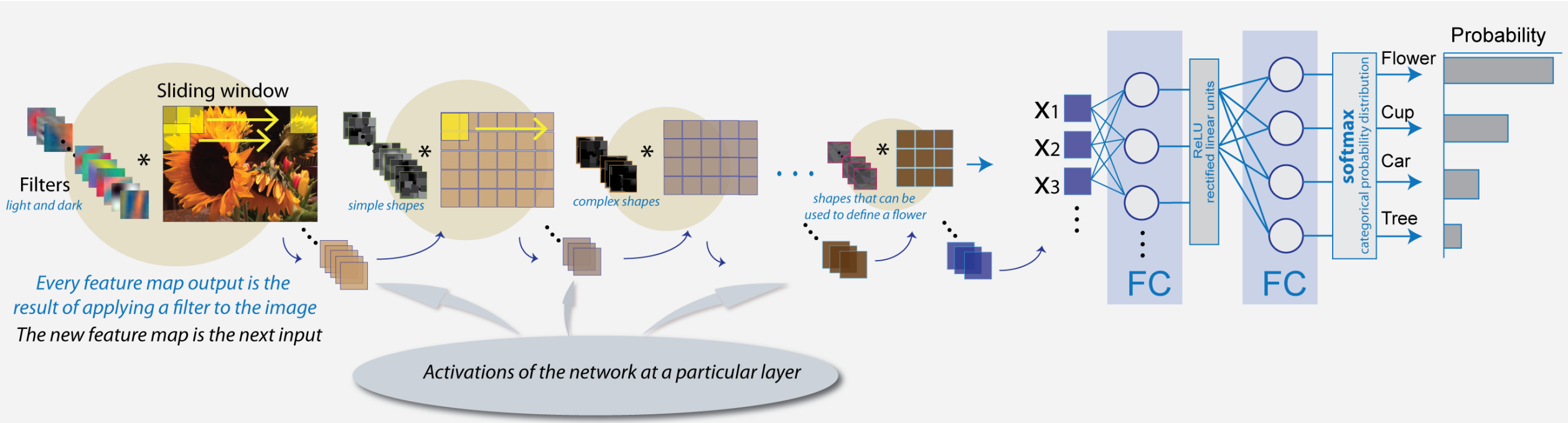
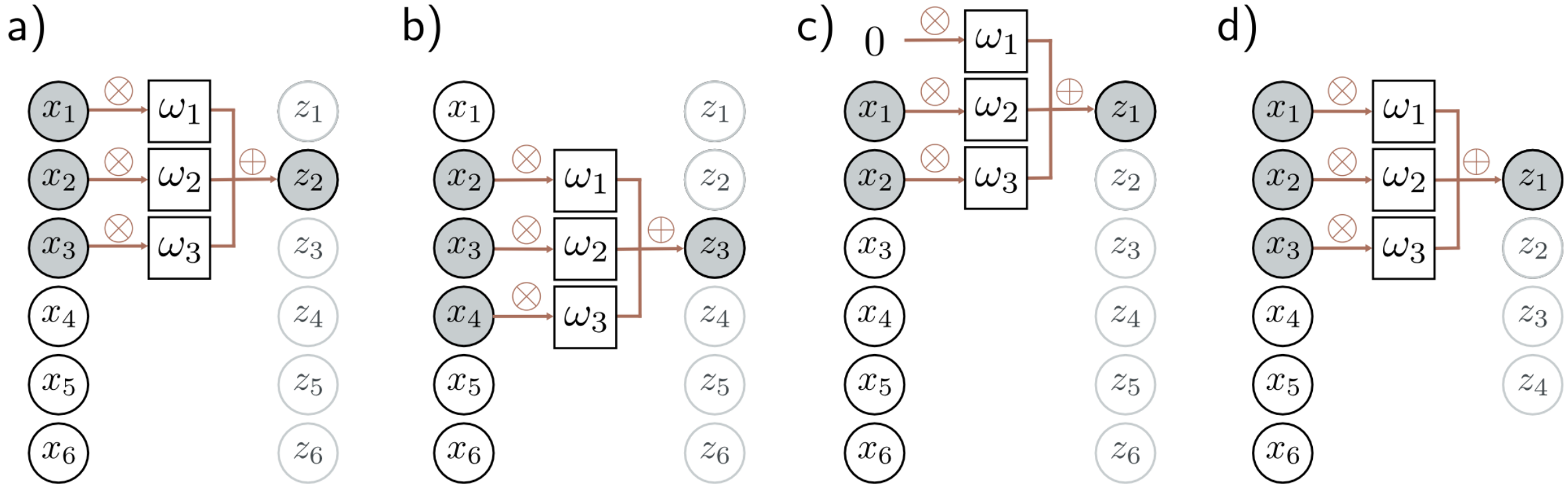


Image from the Mathworks

Image from Prince, 2024

Convolution in 1 dimension



$$z_2 = x_1w_1 + x_2w_2 + x_3w_3$$

$$z_3 = x_2w_1 + x_3w_2 + x_4w_3$$

$$z_1 = 0w_1 + x_1w_2 + x_2w_3$$

$$z_1 = x_1w_1 + x_2w_2 + x_3w_3$$

Data: $\boldsymbol{x}$

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

$*$

Weights: $\boldsymbol{w}$

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

$=$

Output: $\boldsymbol{x} * \boldsymbol{w}$

2D Convolution

Data: $\boldsymbol{x}$

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

$*$

Weights: $\boldsymbol{w}$

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

$=$

Output: $\boldsymbol{x} * \boldsymbol{w}$

Computing one output value:

$1 \cdot 1 + 1 \cdot 2 + 1 \cdot 5 +$

$0 \cdot 0 + 0 \cdot 2 + 0 \cdot 3 +$

$(-1) \cdot 4 + (-1) \cdot 5 + (-1) \cdot 5$

2D Convolution

Data: $\boldsymbol{x}$

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

$*$

Weights: $\boldsymbol{w}$

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

$=$

Output: $\boldsymbol{x} * \boldsymbol{w}$

-6			

Computing one output value:

$1 \cdot 1 + 1 \cdot 2 + 1 \cdot 5 +$

$0 \cdot 0 + 0 \cdot 2 + 0 \cdot 3 +$

$(-1) \cdot 4 + (-1) \cdot 5 + (-1) \cdot 5 = \mathbf{-6}$

2D Convolution

Data: $\boldsymbol{X}$

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

$*$

Weights: $\boldsymbol{w}$

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

$=$

Output: $\boldsymbol{X} * \boldsymbol{w}$

-6	**-11**		

Computing one output value:

$1 \cdot 2 + 1 \cdot 5 + 1 \cdot 1 +$

$0 \cdot 2 + 0 \cdot 3 + 0 \cdot 2 +$

$(-1) \cdot 5 + (-1) \cdot 5 + (-1) \cdot 9 = \mathbf{-11}$

2D Convolution

Data: $\boldsymbol{X}$

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

$*$

Weights: $\boldsymbol{w}$

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

$=$

Output: $\boldsymbol{X} * \boldsymbol{w}$

-6	**-11**	**-12**	

Computing one output value:

$1 \cdot 5 + 1 \cdot 1 + 1 \cdot 4 +$

$0 \cdot 3 + 0 \cdot 2 + 0 \cdot 0 +$

$(-1) \cdot 5 + (-1) \cdot 9 + (-1) \cdot 8 = \mathbf{-12}$

2D Convolution

Data: $\boldsymbol{X}$

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

$*$

Weights: $\boldsymbol{w}$

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

$=$

Output: $\boldsymbol{X} * \boldsymbol{w}$

-6	**-11**	**-12**	**-11**

Computing one output value:

$1 \cdot 1 + 1 \cdot 4 + 1 \cdot 2 +$

$0 \cdot 2 + 0 \cdot 0 + 0 \cdot 0 +$

$(-1) \cdot 9 + (-1) \cdot 8 + (-1) \cdot 1 = \mathbf{-11}$

2D Convolution

Data: $\boldsymbol{X}$

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

$*$

Weights: $\boldsymbol{w}$

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

$=$

Output: $\boldsymbol{X} * \boldsymbol{w}$

-6	**-11**	**-12**	**-11**
-7			

Computing one output value:

$1 \cdot 0 + 1 \cdot 2 + 1 \cdot 3 +$

$0 \cdot 4 + 0 \cdot 5 + 0 \cdot 5 +$

$(-1) \cdot 6 + (-1) \cdot 3 + (-1) \cdot 4 = \mathbf{-7}$

2D Convolution

Data: $\boldsymbol{X}$

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

6 x 6

$*$

Weights: $\boldsymbol{w}$

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

3 x 3

$=$

Output: $\boldsymbol{X} * \boldsymbol{w}$

-6	**-11**	**-12**	**-11**
-7	**-2**	**-2**	**-4**
4	**1**	**-2**	**1**
3	**-4**	**-6**	**-10**

4 x 4

2D Convolution

What features do layers respond to?

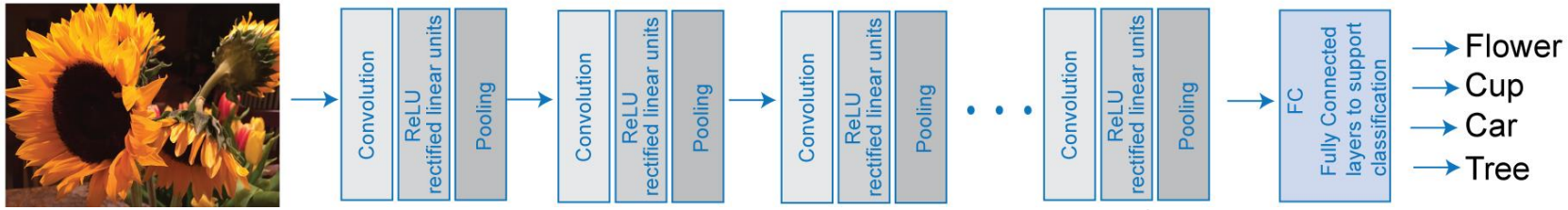
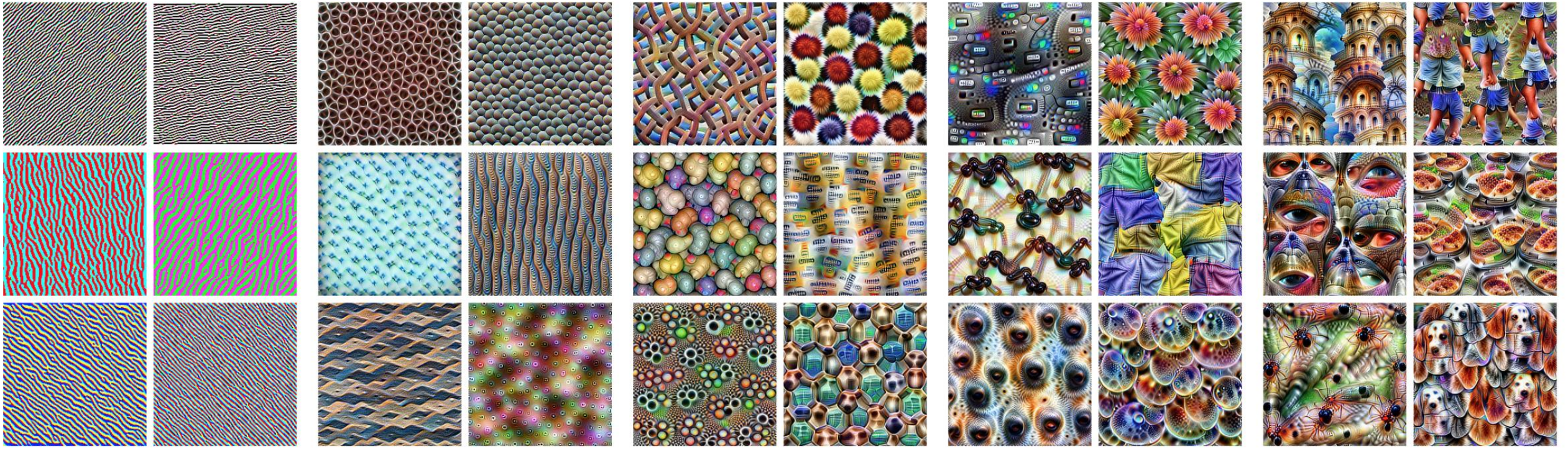


Image from the Mathworks



Edges (layer conv2d0) **Textures** (layer mixed3a) **Patterns** (layer mixed4a) **Parts** (layers mixed4b & mixed4c) **Objects** (layers mixed4d & mixed4e)

Olah et al, 2017: https://distill.pub/2017/feature-visualization/

Features

Dataset Examples show us what neurons respond to in practice

Optimization isolates the causes of behavior from mere correlations. A neuron may not be detecting what you initially thought.

Baseball—or stripes?
mixed4a, Unit 6

Animal faces—or snouts?
mixed4a, Unit 240

Clouds—or fluffiness?
mixed4a, Unit 453

Buildings—or sky?
mixed4a, Unit 492

Olah et al, 2017: https://distill.pub/2017/feature-visualization/

Resources on Visualization of Features

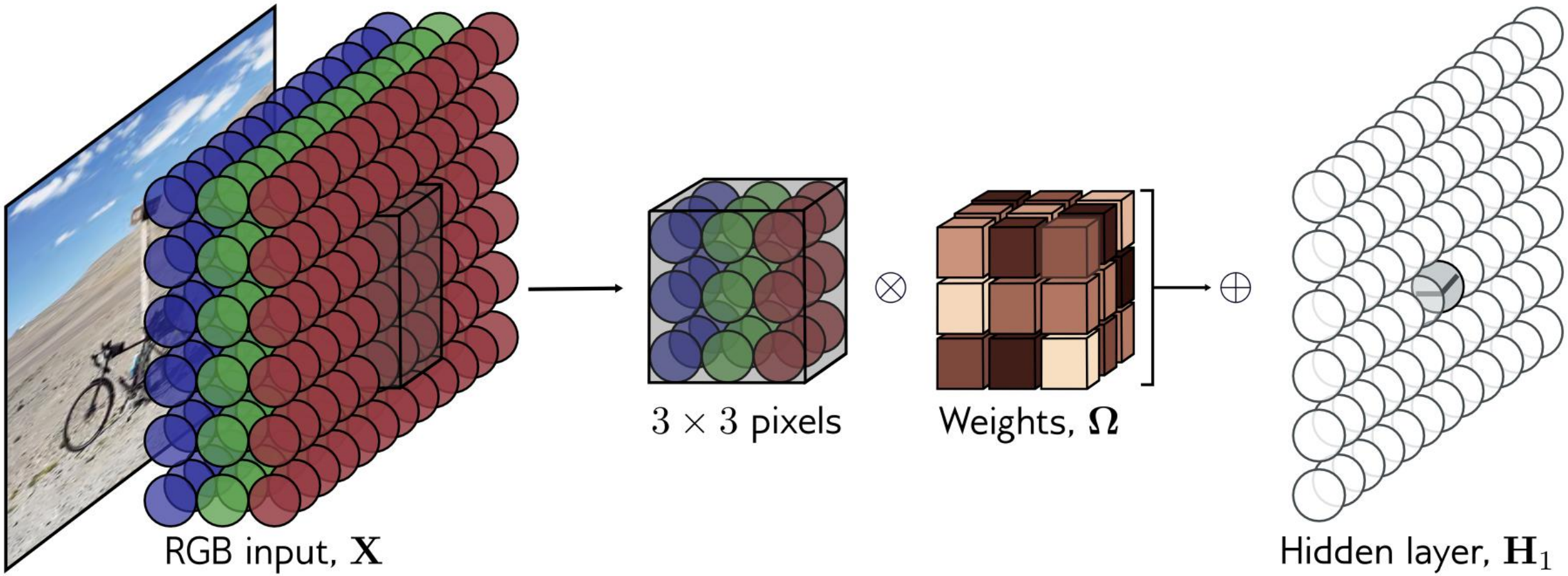
Feature visualization: https://distill.pub/2017/feature-visualization/

Building blocks of interpretability: https://distill.pub/2018/building-blocks/

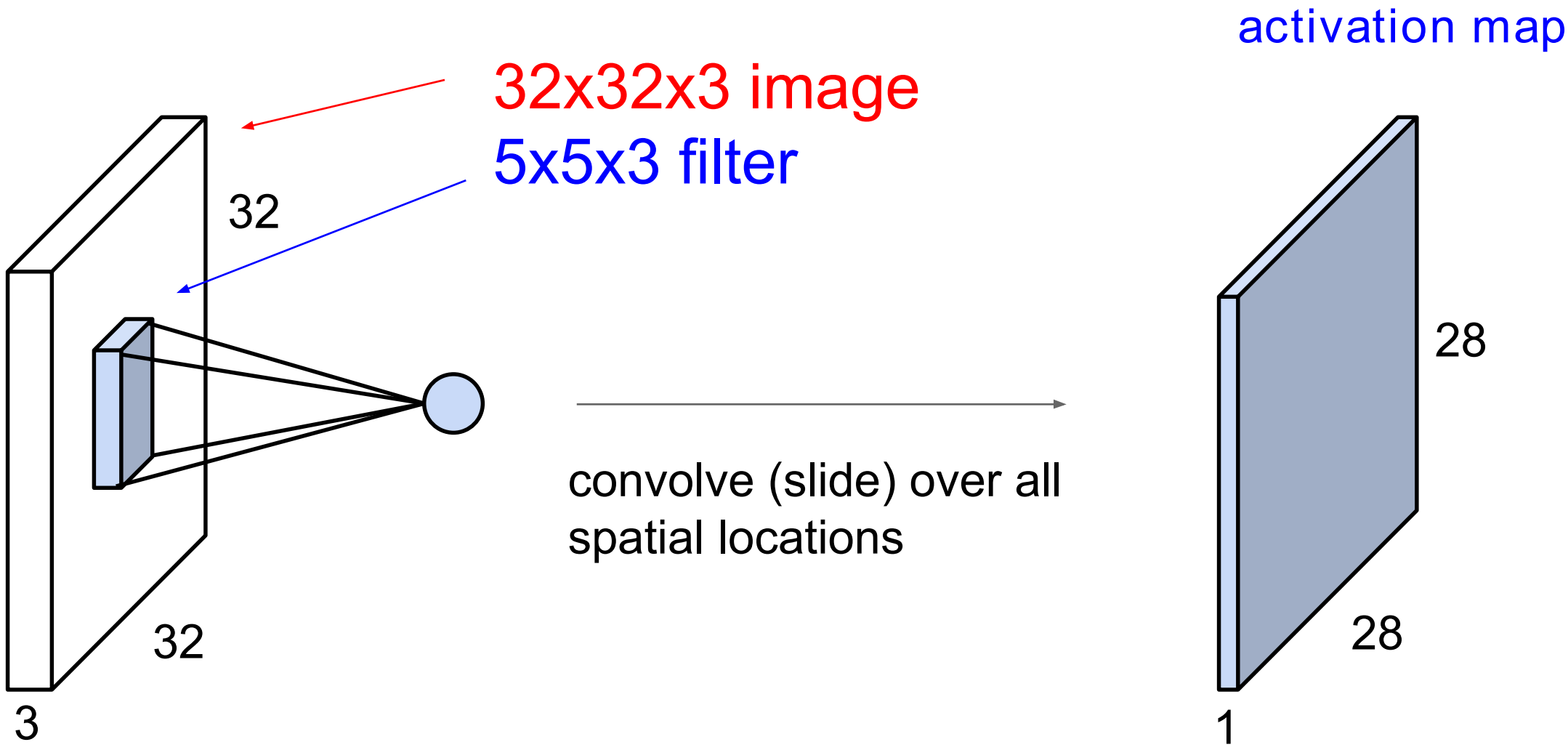
Activation Activation Atlases: https://distill.pub/2019/activation-atlas/

Image from Prince, 2024

Convolution Example

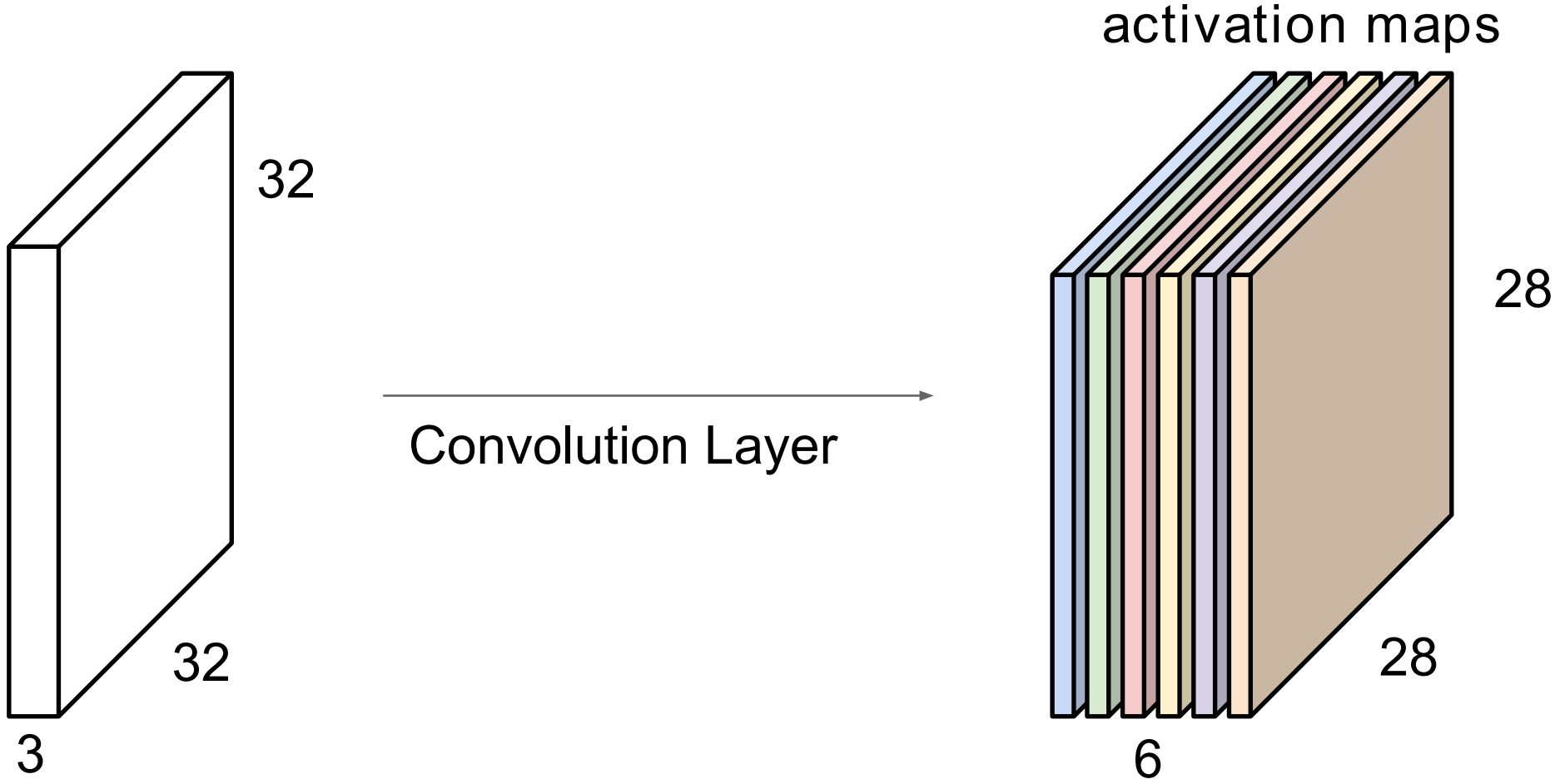


Convolution Layer



From Fei-Fei Li, Justin Johnson, and Serena Young. CS231n, 2018

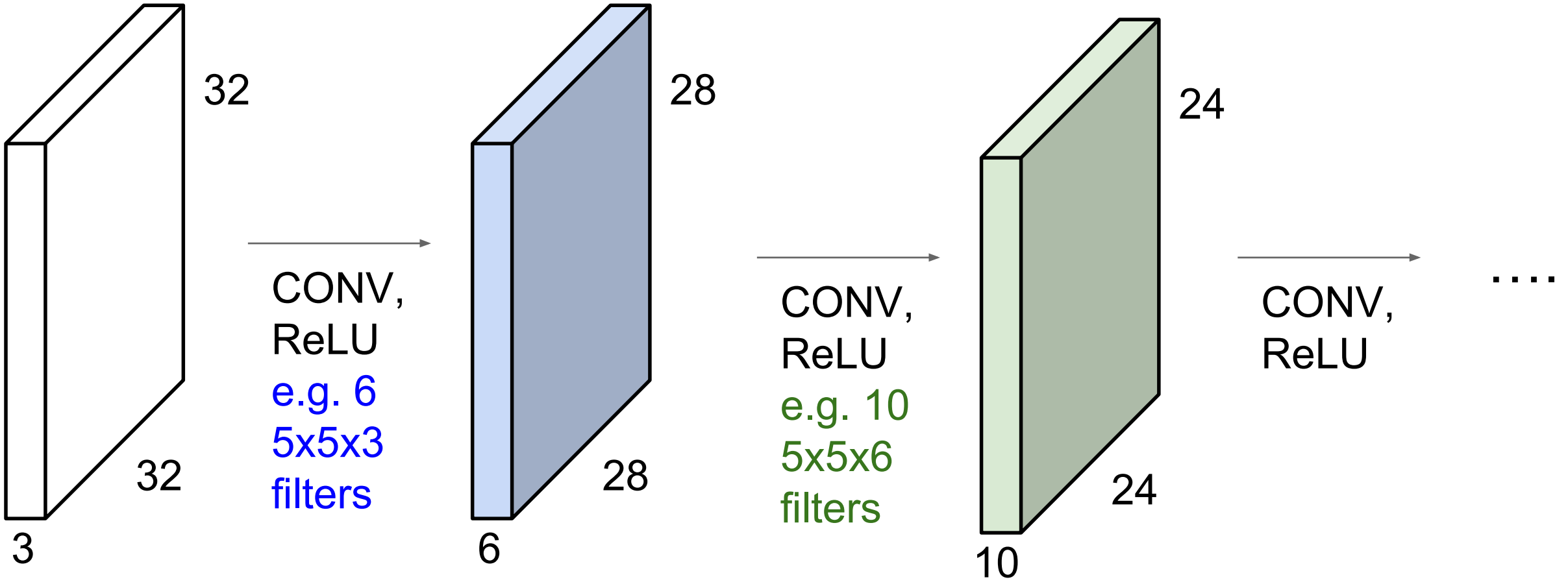
For example, if we had 6 5x5 filters, we'll get 6 separate activation maps:



We stack these up to get a "new image" of size 28x28x6!

From Fei-Fei Li, Justin Johnson, and Serena Young. CS231n, 2018

Preview: ConvNet is a sequence of Convolution Layers, interspersed with activation functions

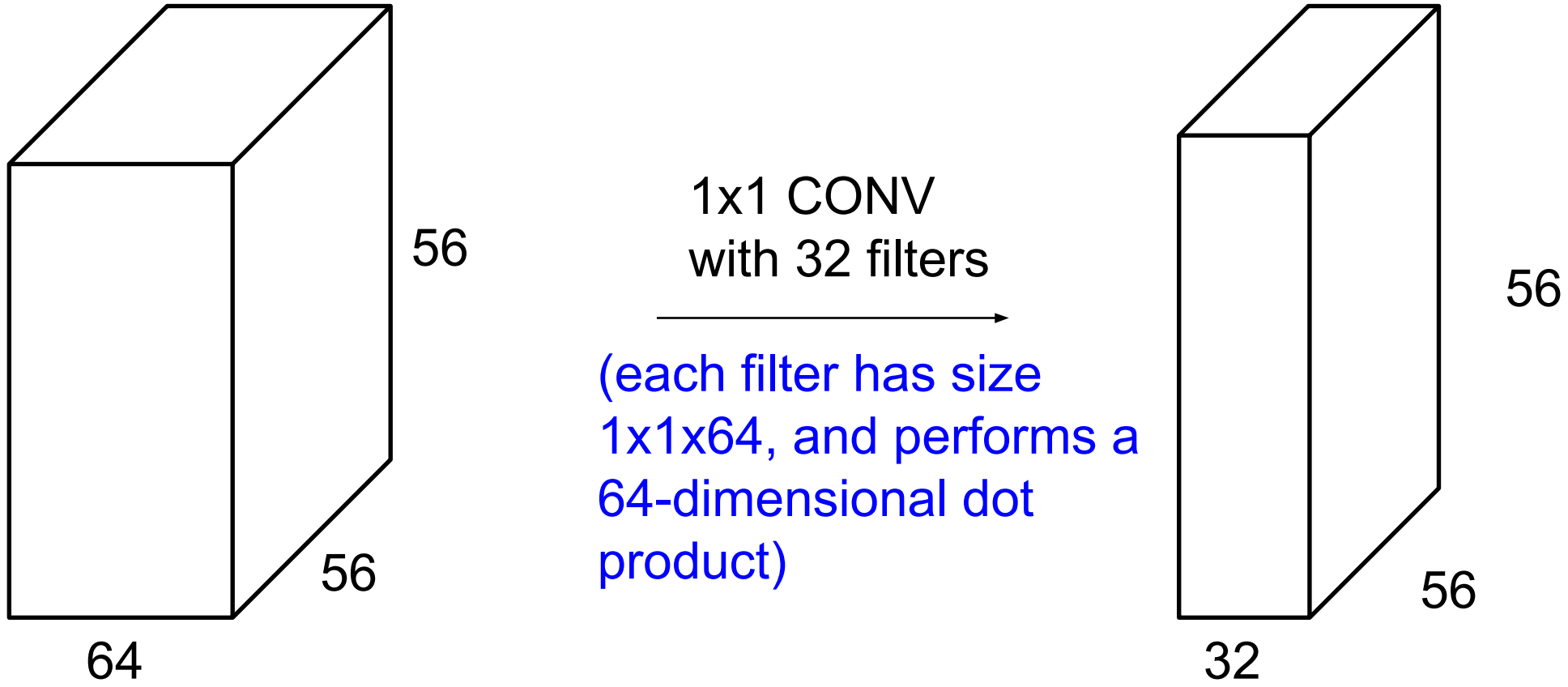


Parameters = (5*5*3)*6 = 450

(5*5*6)*10 = 1,500

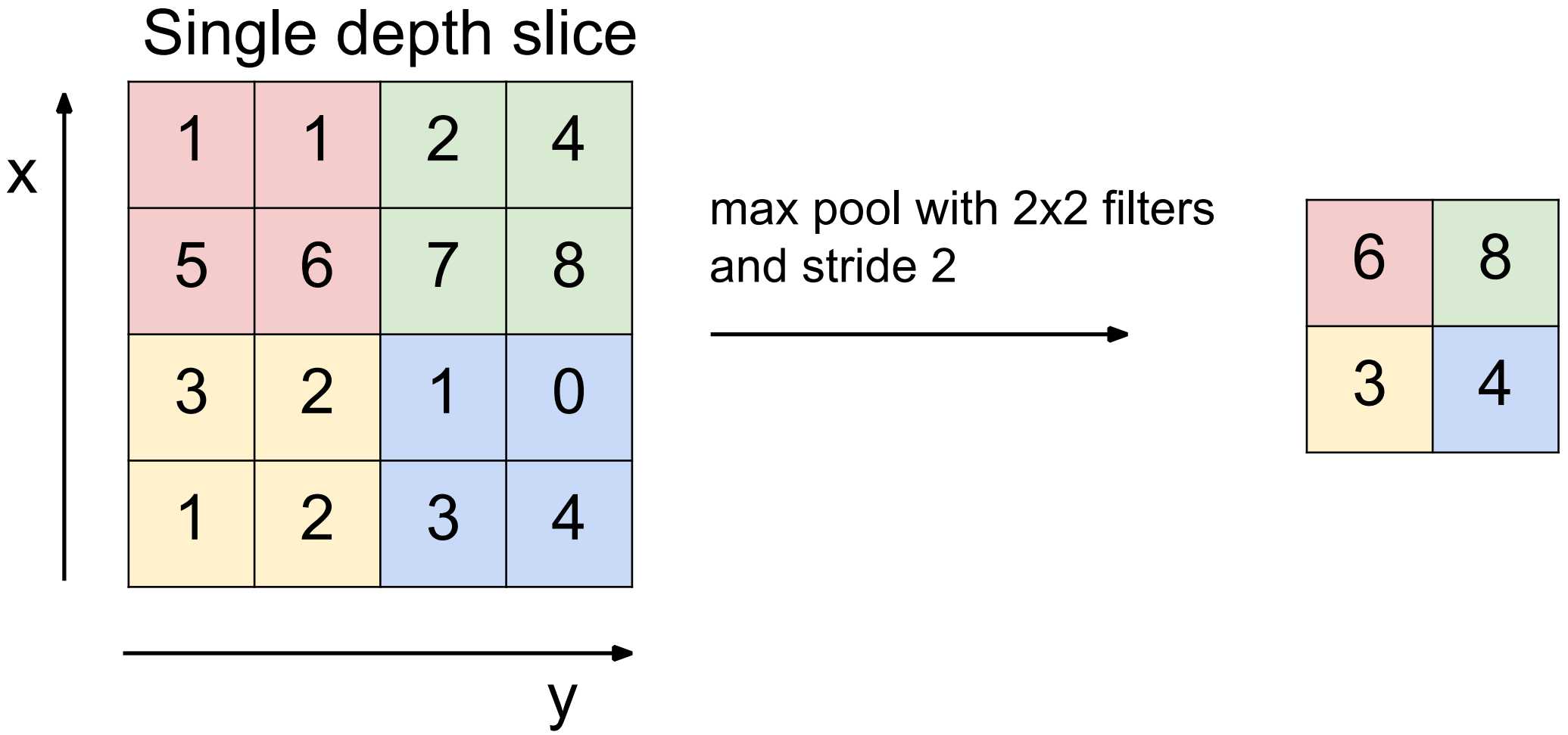
From Fei-Fei Li, Justin Johnson, and Serena Young. CS231n, 2018

1 x 1 Convolution Explained



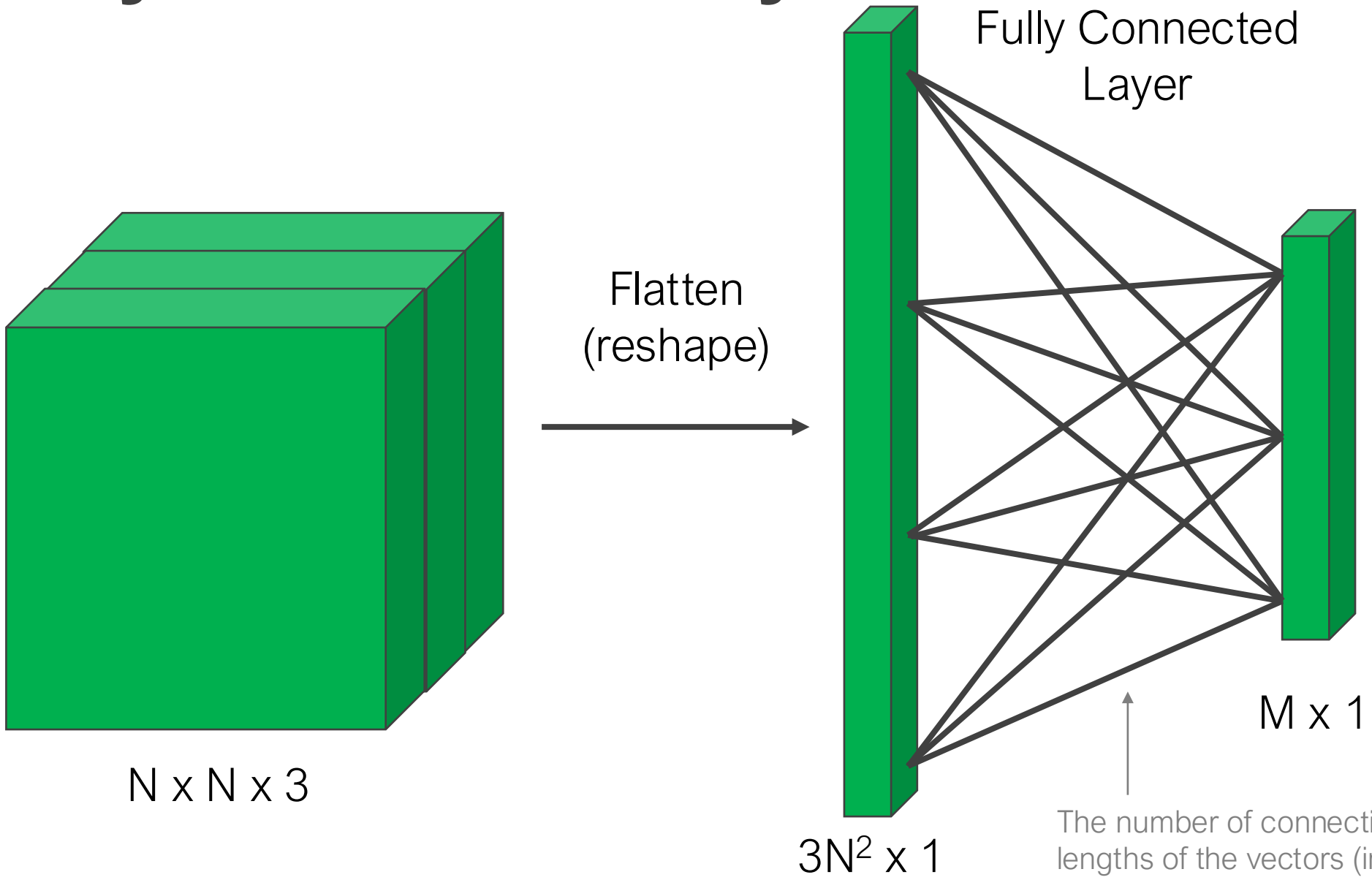
From Fei-Fei Li, Justin Johnson, and Serena Young. CS231n, 2018

Max Pooling

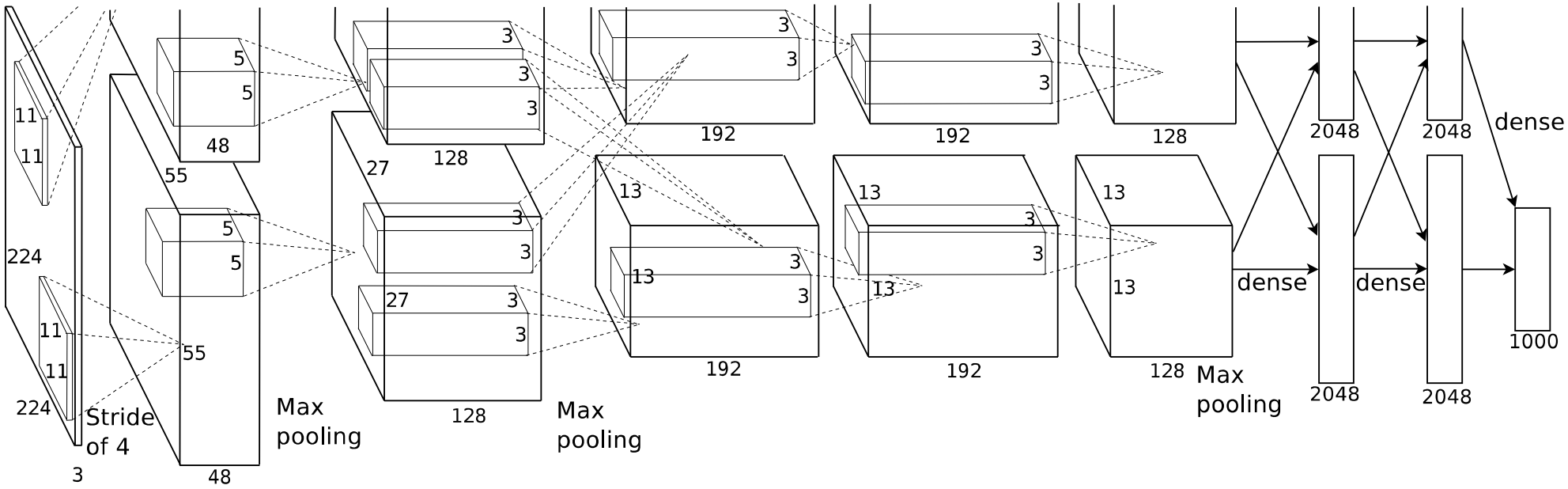


From Fei-Fei Li, Justin Johnson, and Serena Young. CS231n, 2018

Fully Connected Layer



AlexNet



Input
11x11 conv, 96
5x5 conv, 256
max pool
3x3 conv, 384
max pool
3x3 conv, 384
3x3 conv, 256
max pool
FC 4096
FC 4096
FC 1000
softmax

Krizhevsky, Alex, Ilya Sutskever, and Geoffrey E. Hinton. "Imagenet classification with deep convolutional neural networks." Advances in neural information processing systems. 2012.

Key

Input or output layer
Convolutional Layer
Fully Connected Layer
max pooling layer

CNN Architectures

AlexNet (2012)

- Input
- 11x11 conv, 96
- 5x5 conv, 256
- max pool
- 3x3 conv, 384
- max pool
- 3x3 conv, 384
- 3x3 conv, 256
- max pool
- FC 4096
- FC 4096
- FC 1000
- softmax

VGG16 (2014)

- Input
- 3x3 conv, 64
- 3x3 conv, 64
- max pool
- 3x3 conv, 128
- 3x3 conv, 128
- max pool
- 3x3 conv, 256
- 3x3 conv, 256
- 3x3 conv, 256
- max pool
- 3x3 conv, 512
- 3x3 conv, 512
- 3x3 conv, 512
- max pool
- 3x3 conv, 512
- 3x3 conv, 512
- 3x3 conv, 512
- max pool
- FC 4096
- FC 4096
- FC 1000
- softmax

VGG19 (2014)

- Input
- 3x3 conv, 64
- 3x3 conv, 64
- max pool
- 3x3 conv, 128
- 3x3 conv, 128
- max pool
- 3x3 conv, 256
- 3x3 conv, 256
- 3x3 conv, 256
- 3x3 conv, 256
- max pool
- 3x3 conv, 512
- 3x3 conv, 512
- 3x3 conv, 512
- 3x3 conv, 512
- max pool
- 3x3 conv, 512
- 3x3 conv, 512
- 3x3 conv, 512
- 3x3 conv, 512
- max pool
- FC 4096
- FC 4096
- FC 1000
- softmax

Note: an activation function is applied to the output of each layer

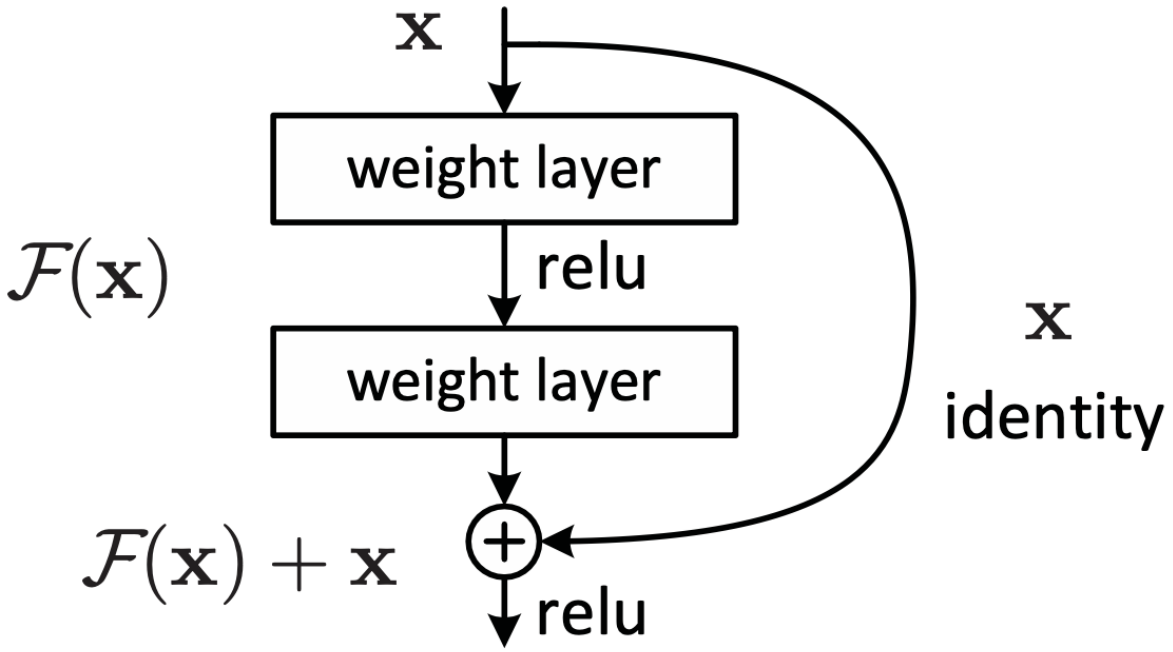
Fewer layers, larger filters

Key

- Input or output layer
- Convolutional Layer
- Fully Connected Layer
- max pooling layer

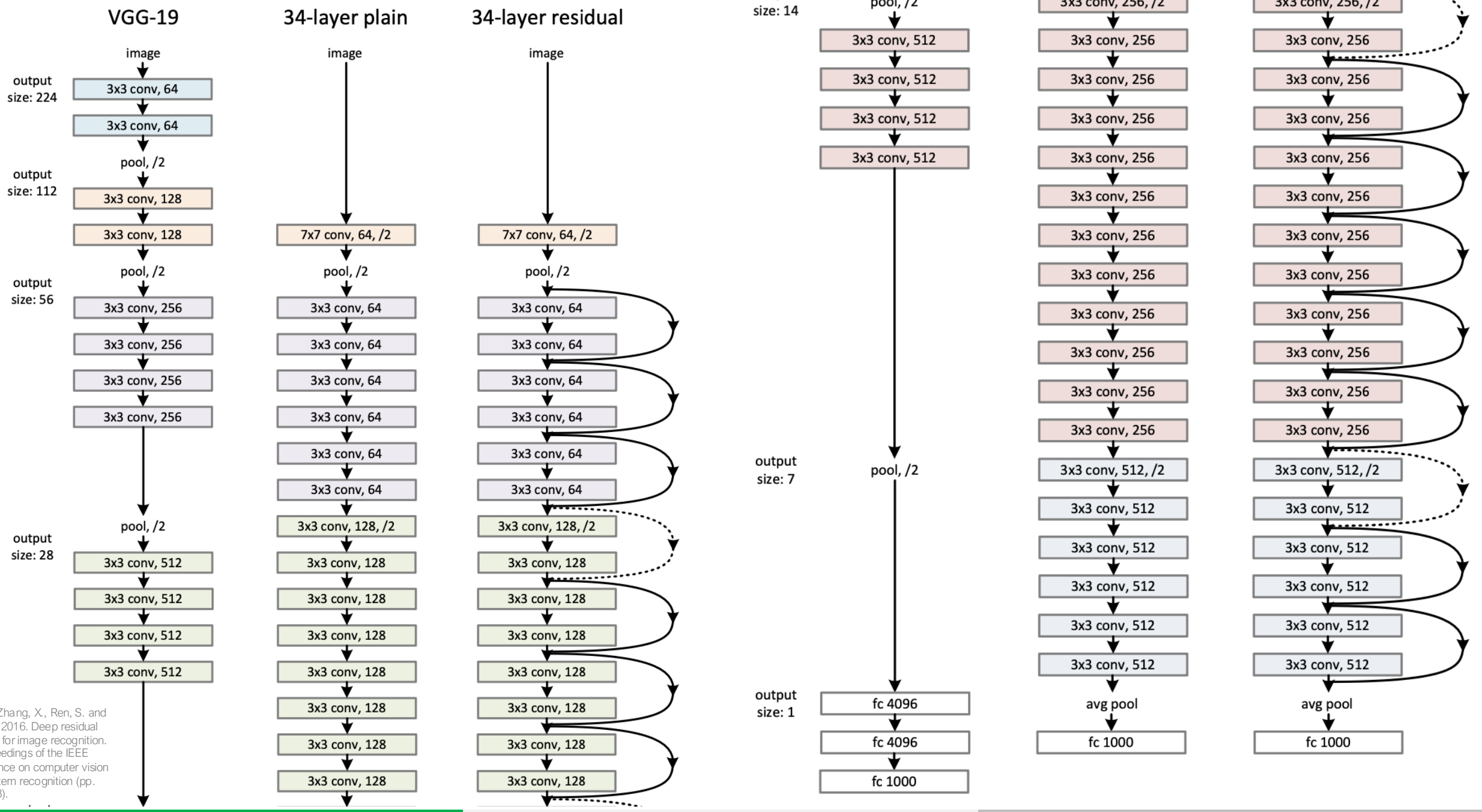
Adapted from Fei-Fei Li, Justin Johnson, and Serena Young. CS231n, 2018

Residual Networks (ResNet)



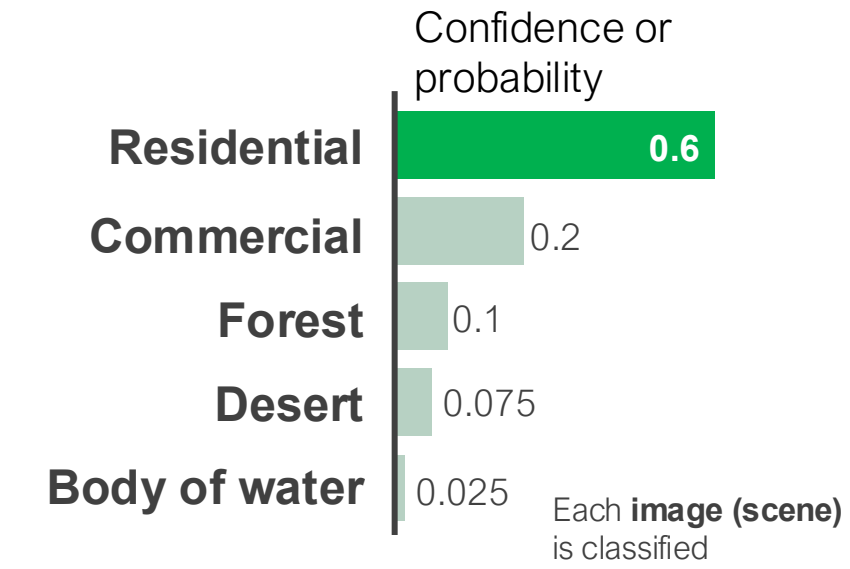
Skip Connection enable faster convergence, more effectively backpropate the error signal (avoiding vanishing gradients)

He, K., Zhang, X., Ren, S. and Sun, J., 2016. Deep residual learning for image recognition. In Proceedings of the IEEE conference on computer vision and pattern recognition (pp. 770-778).



He, K., Zhang, X., Ren, S. and Sun, J., 2016. Deep residual learning for image recognition. In Proceedings of the IEEE conference on computer vision and pattern recognition (pp. 770-778).

Scene classification



Object detection

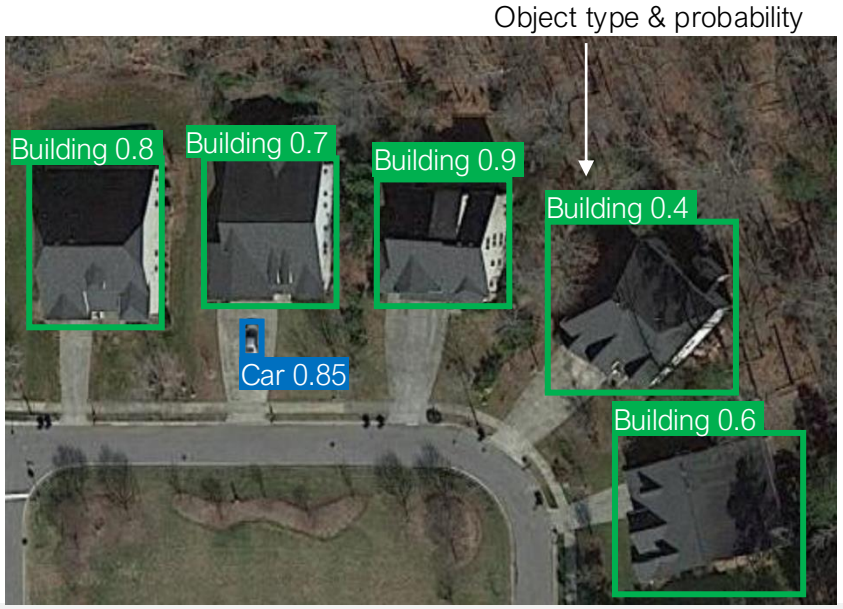
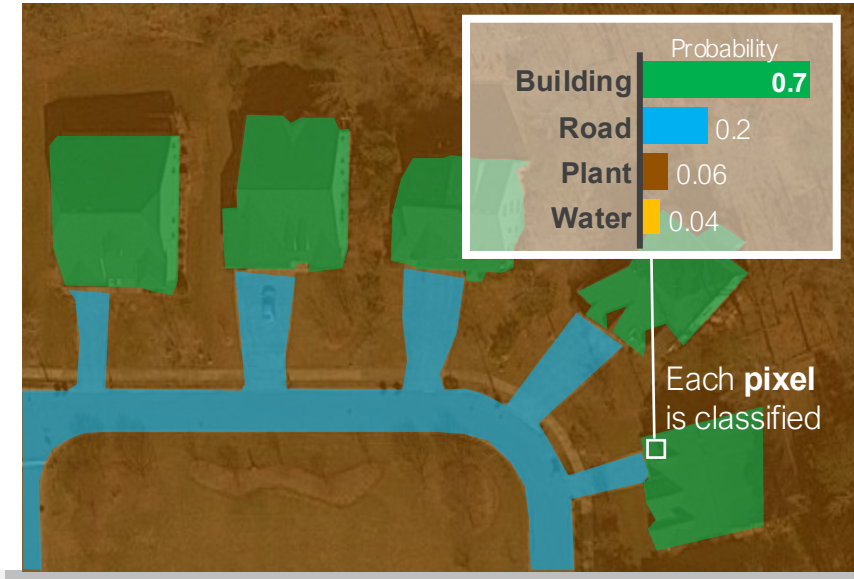
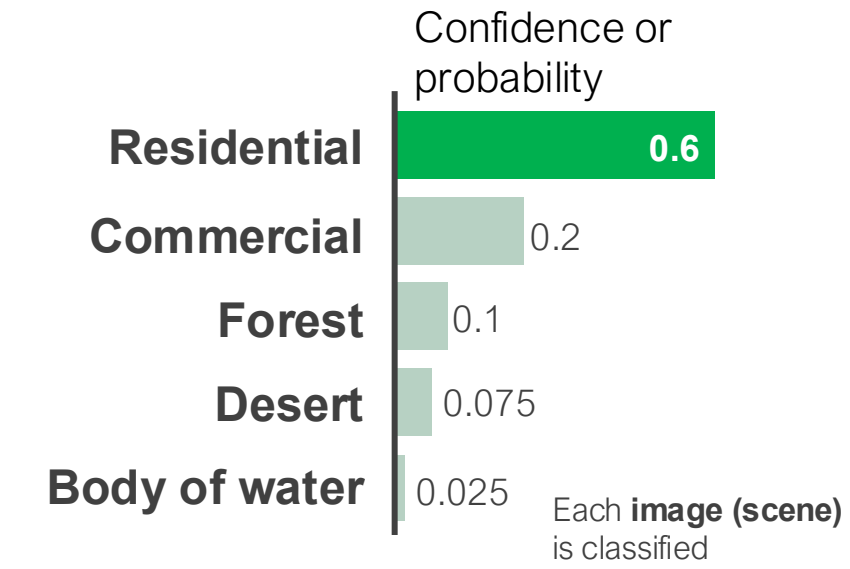


Image segmentation



Scene classification

AlexNet
VGG
GoogLeNet
ResNet
Inception
DenseNet
SqueezeNet
EfficientNet



Each **image (scene)** is classified

Object detection

Faster/Fast/R-CNN
Mask R-CNN
YOLO
Single Shot Detector (SSD)
RetinaNet

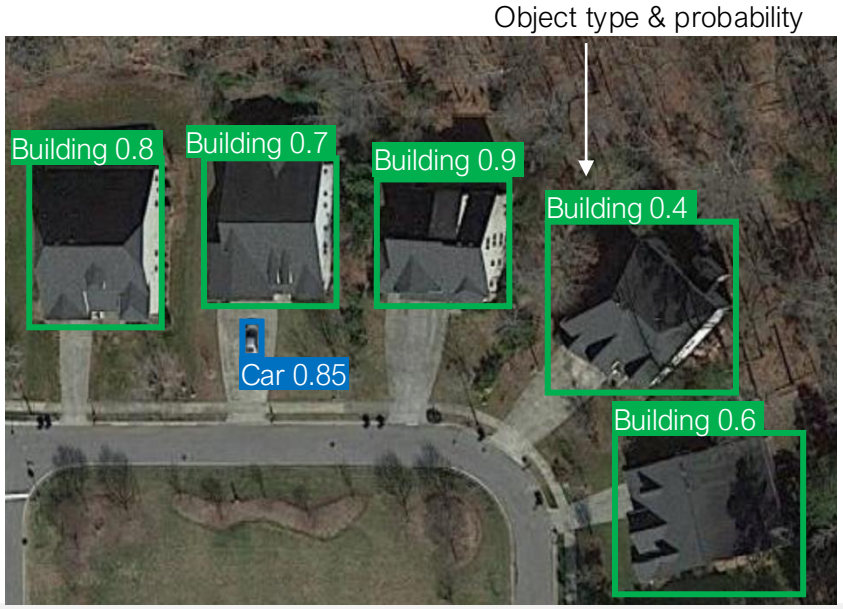
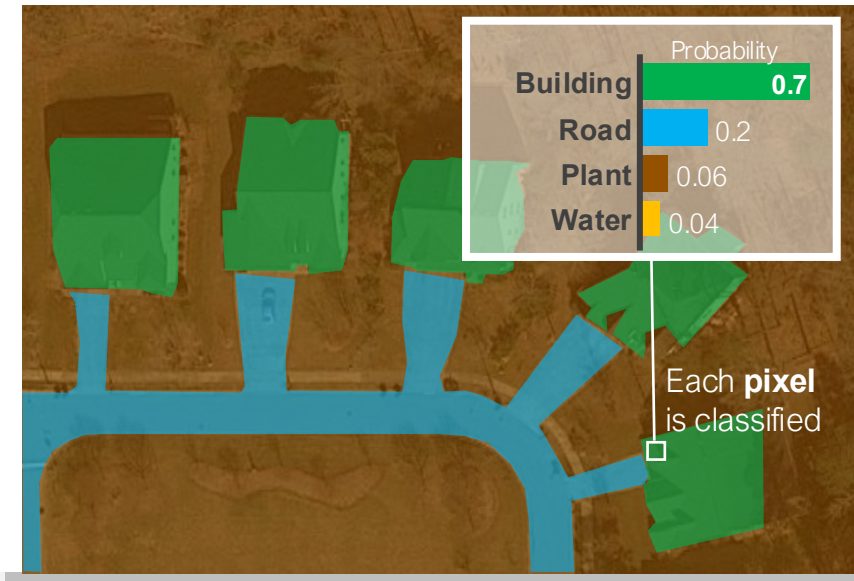


Image segmentation

U-Net (2015)
SegNet (2016)
DeepLab (2017)
FCN (2016)

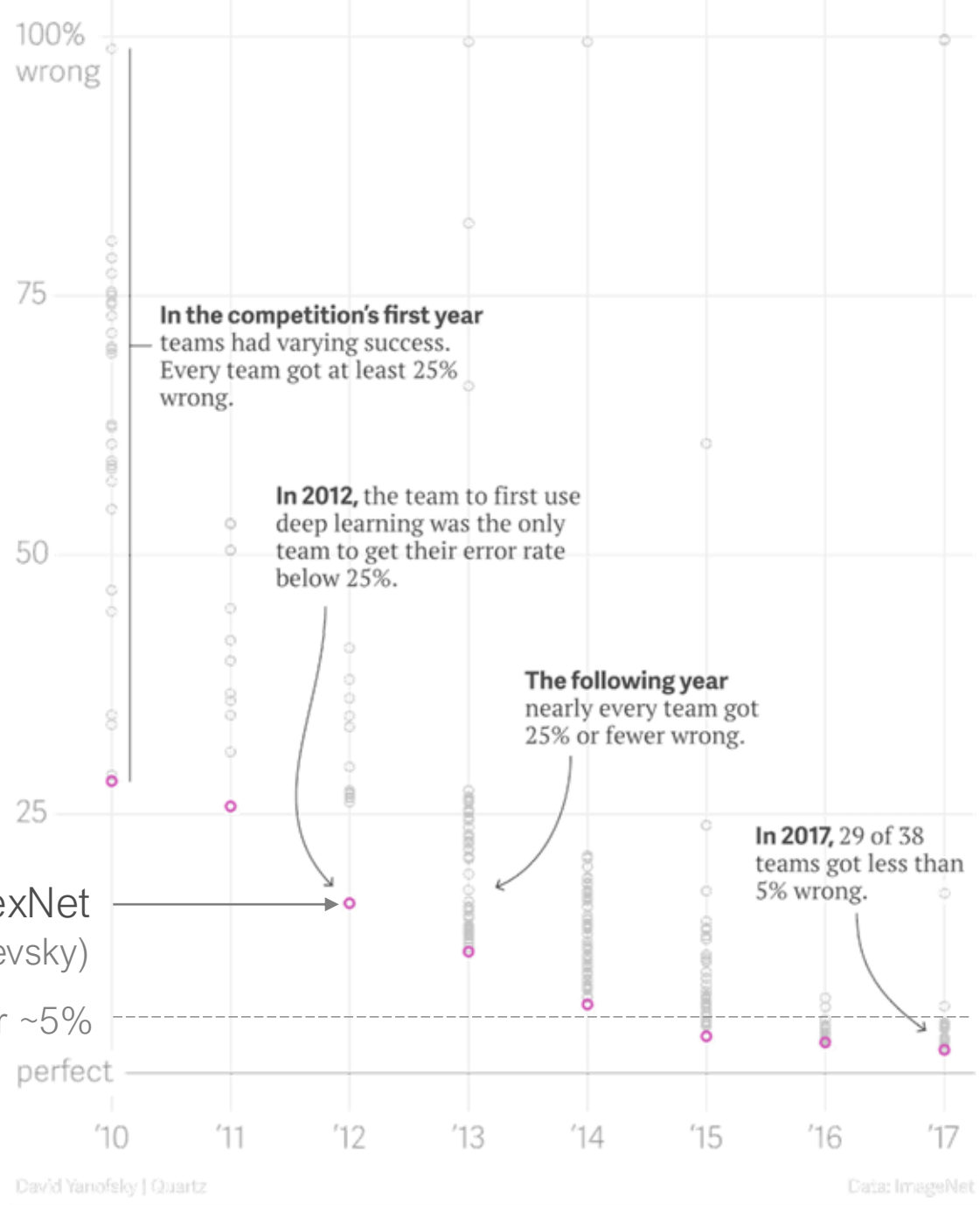


ImageNet Large Scale Visual Recognition Challenge (ILSVRC)

Fei-Fei Li et al. 2010 (link)

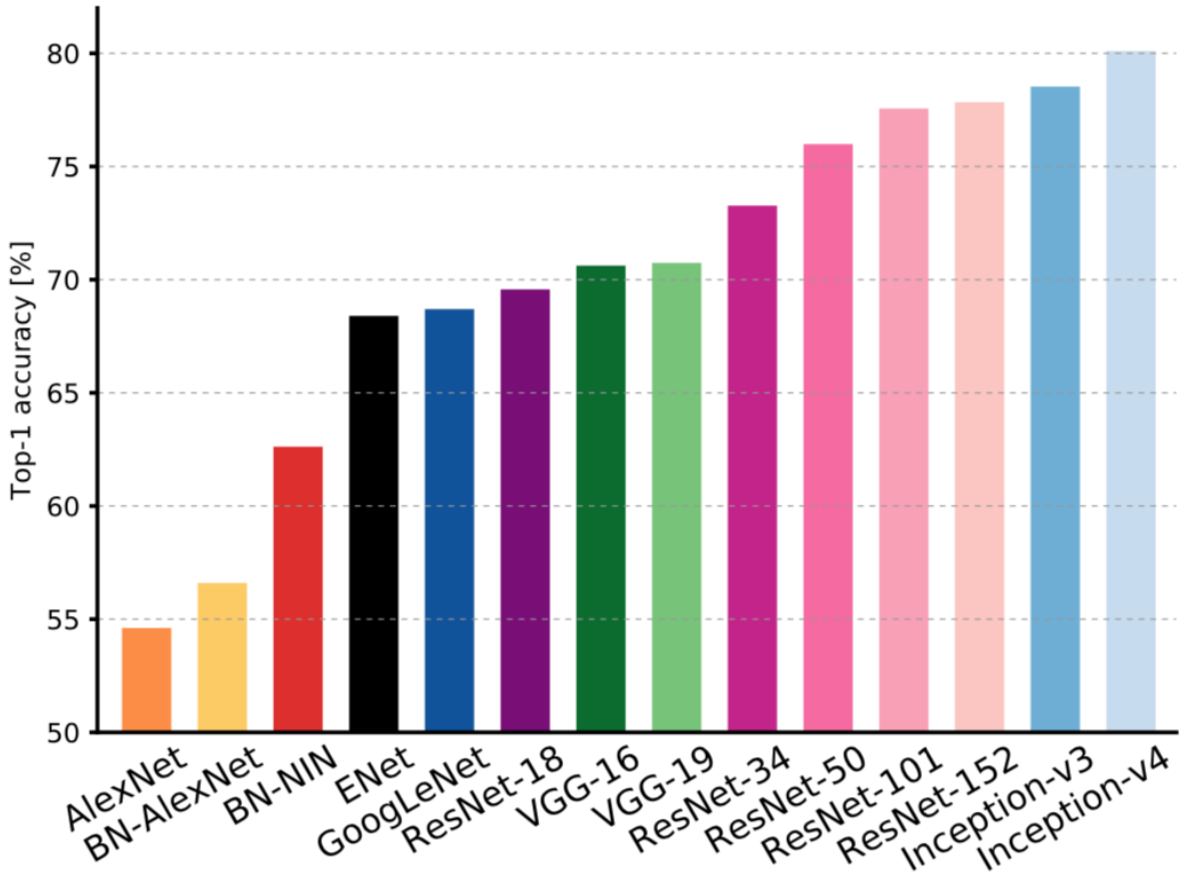
Competition at:
Conference on Computer Vision and Pattern Recognition (CVPR)

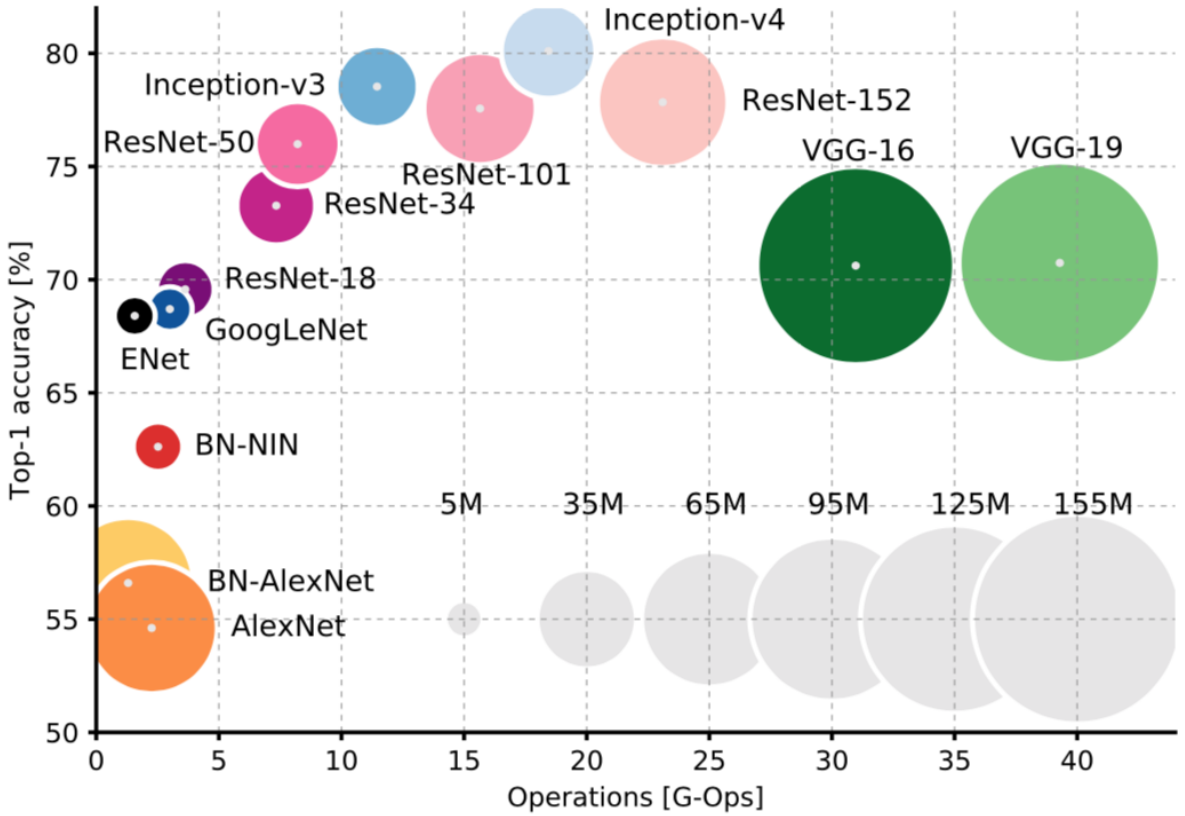
USED FOR MODEL PRETRAINING



Source: Quartz, link

Deep Learning Models Compared





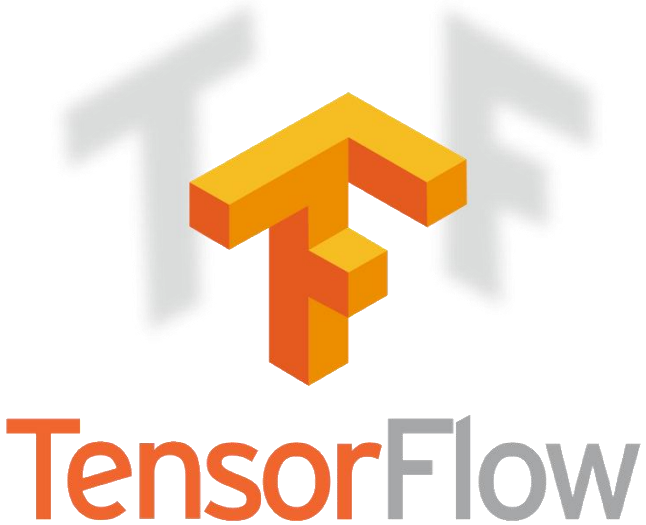
Models compared for ImageNet

Many of these models are available through Keras (link)

A. Canziani, E. Culurciello and A. Paszke, "Evaluation of neural network architectures for embedded systems," *2017 IEEE International Symposium on Circuits and Systems (ISCAS)*, Baltimore, MD, 2017, pp. 1-4.

Deep learning frameworks

Tensorflow (link)
Framework for implementing graphical models, such as neural networks



Keras (link)
Wrapper for Tensorflow to make coding easier: higher level and excellent API

PyTorch (link)
Framework for implementing graphical models, such as neural networks

KERAS DEMO

```
model = keras.Sequential(
    [
        keras.Input(shape=input_shape),
        layers.Conv2D(32, kernel_size=(3, 3), activation="relu"),
        layers.MaxPooling2D(pool_size=(2, 2)),
        layers.Conv2D(64, kernel_size=(3, 3), activation="relu"),
        layers.MaxPooling2D(pool_size=(2, 2)),
        layers.Flatten(),
        layers.Dropout(0.5),
        layers.Dense(num_classes, activation="softmax"),
    ]
)

model.summary()
```

```
Model: "sequential"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d (Conv2D)              (None, 26, 26, 32)        320
_________________________________________________________________
max_pooling2d (MaxPooling2D) (None, 13, 13, 32)        0
_________________________________________________________________
conv2d_1 (Conv2D)            (None, 11, 11, 64)        18496
_________________________________________________________________
max_pooling2d_1 (MaxPooling2 (None, 5, 5, 64)          0
_________________________________________________________________
flatten (Flatten)            (None, 1600)              0
_________________________________________________________________
dropout (Dropout)            (None, 1600)              0
_________________________________________________________________
dense (Dense)                (None, 10)                16010
=================================================================
Total params: 34,826
Trainable params: 34,826
Non-trainable params: 0
_________________________________________________________________
```

Generative Adversarial Networks

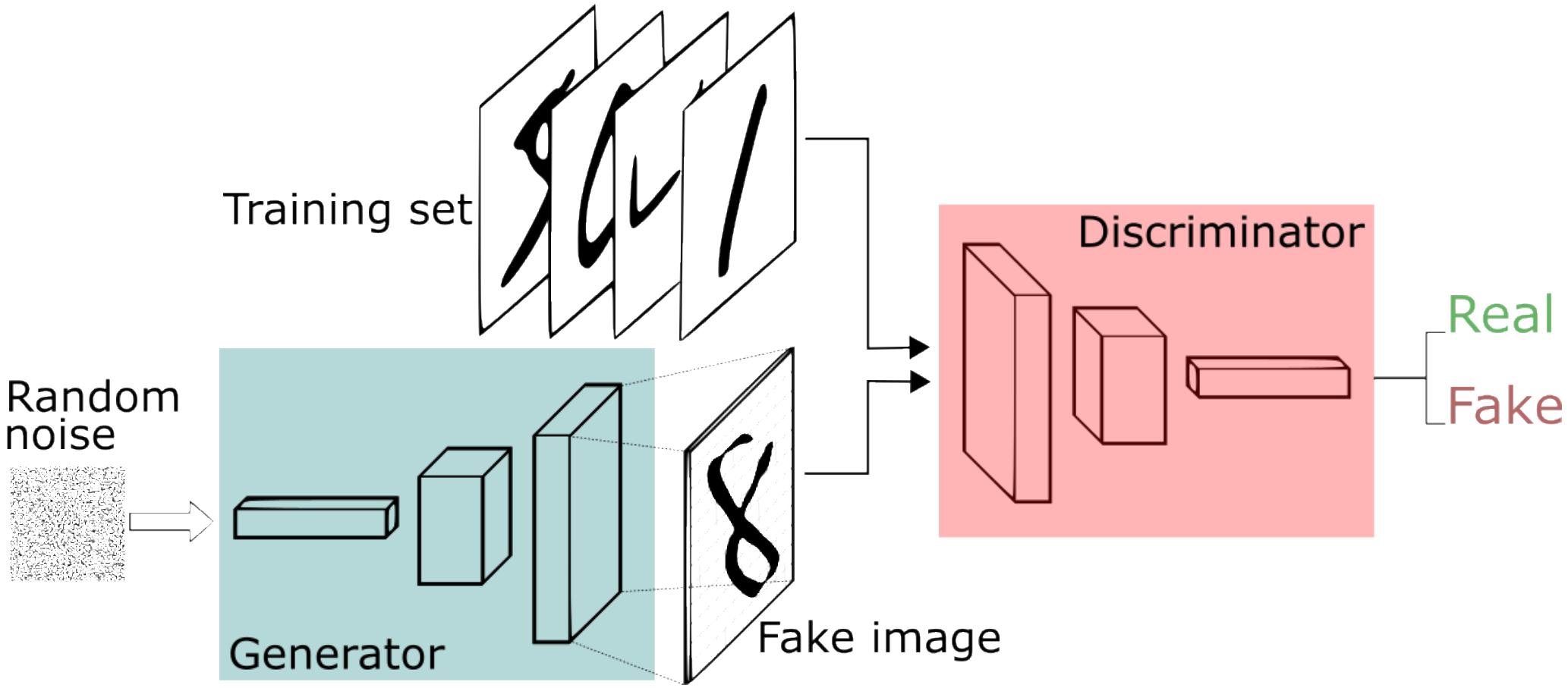


Image from: https://skymind.ai/wiki/generative-adversarial-network-gan