Convolutional Neural Networks

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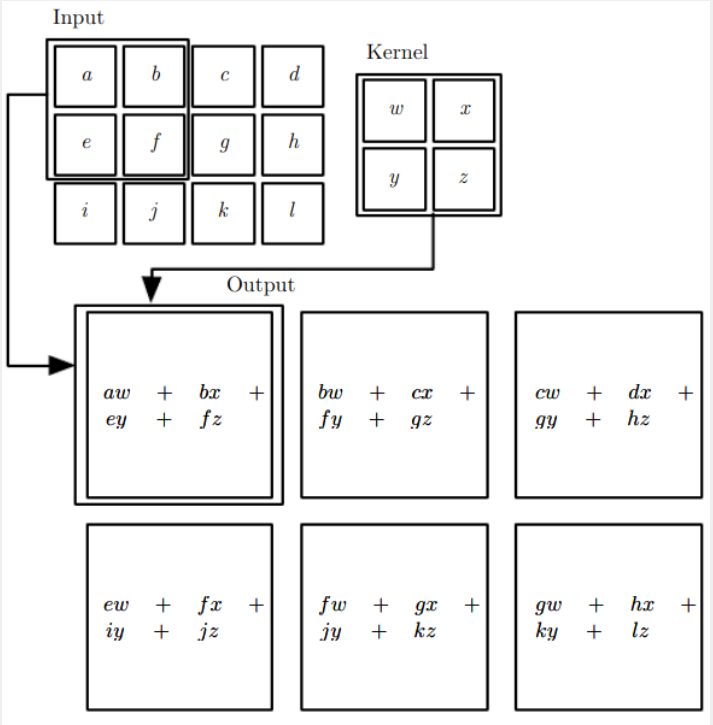
Outline

- Convolution
- Pooling
- Activation, Loss, Optimizer
- Example Networks
- Training Techniques
- Example Code

Convolution

- A type of neural network that can process known grid-structure data
  - Timeseries: 1-D grid
  - Image: 2-D grid
- "Convolution" represents a linear operation, which does not correspond precisely to the definition of convolution as used in other fields

- Three elements: grid-like data (input), kernel (filter), feature map (output)

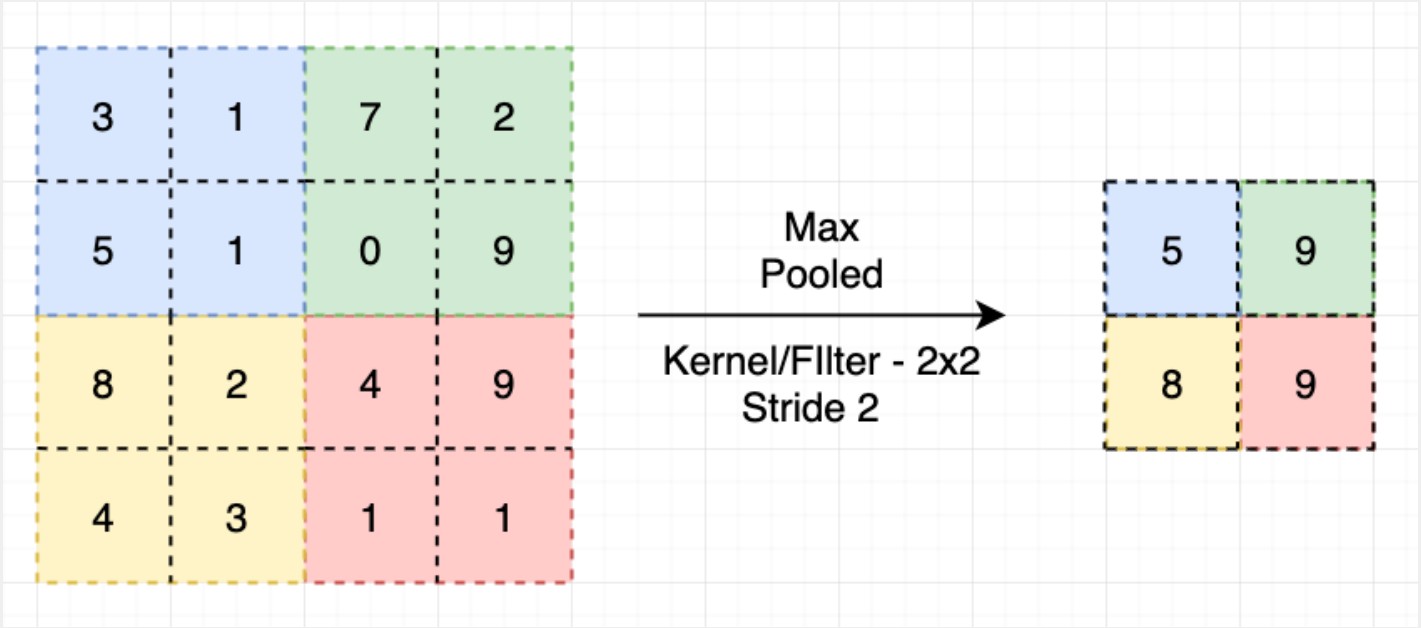


- A feature map is obtained by convolution of the input data with a kernel (image above), adding a bias term and then applying an activation function

- Convolution leverages three important ideas.
  - Sparse interactions: kernel is smaller than input
  - Parameter sharing: one set of parameters for every location
  - Equivariant representations: if the input changes, the output changes in the same way
- Convolution is dramatically more efficient than dense matrix multiplication in terms of memory requirements and statistical efficiency

Pooling

- A pooling function replaces the output of a network at a certain location with a summary statistic of the nearby outputs.
- Examples: max pooling, average pooling, L2 norm pooling



- Pooling helps to make the representation approximately invariant to small translations of the input
- Pooling layers are usually used immediately after convolutional layers

- Padding options: VALID, SAME, etc

`"VALID"` = without padding:

```
inputs:         1  2  3  4  5  6  7  8  9  10 11 (12 13)
                |_________________|                dropped
                         |_________________|
```

`"SAME"` = with zero padding:

```
               pad|                                      |pad
inputs:         0 |1  2  3  4  5  6  7  8  9  10 11 12 13|0  0
                |_________________|
                         |_________________|
                                  |_________________|
```

Activation, Loss, Optimizer

- Keras activation function list (link)

- Regression
  - Linear: turn 1 real value to 1 real value
- Classification
  - Sigmoid: turn 1 real value to 1 real value between 0 and 1
  - Softmax: turn k real values to k real values that sum to 1

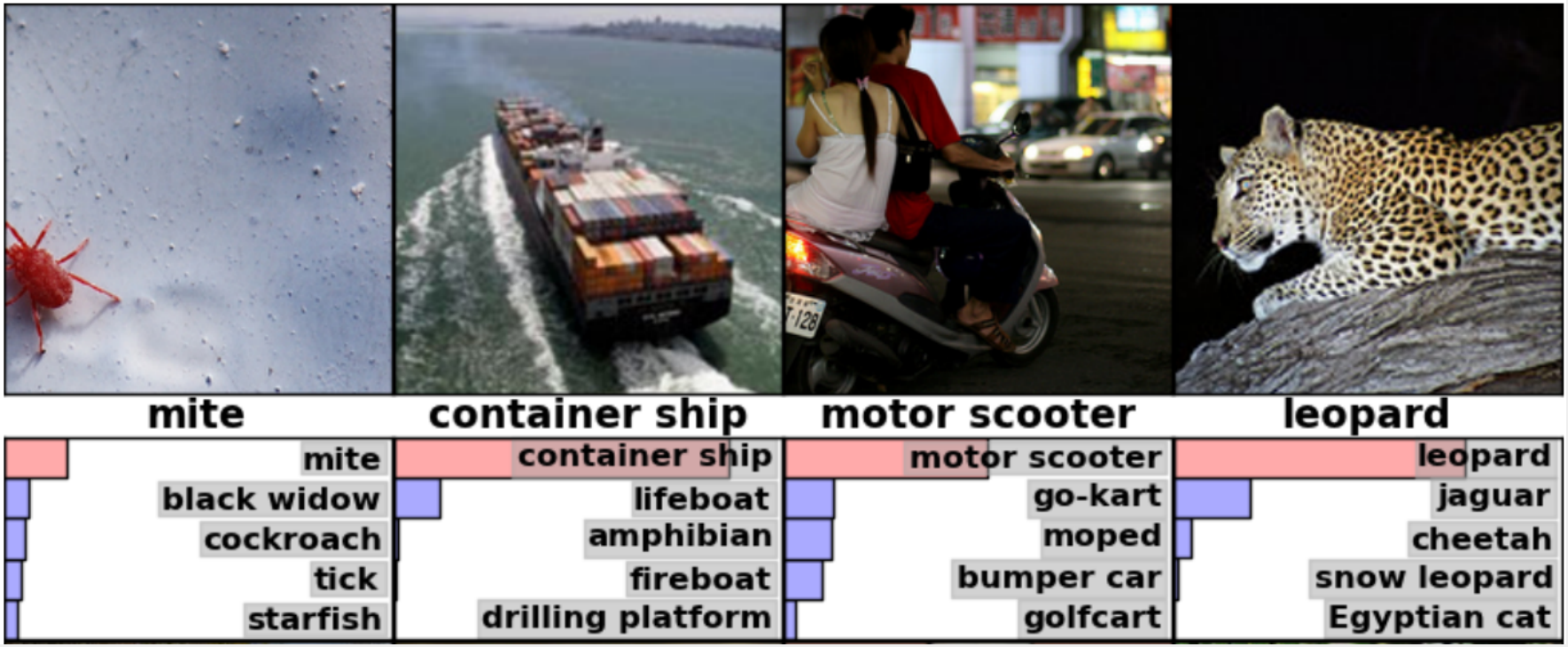
$$\sigma(\vec{z})_i = \frac{e^{z_i}}{\sum_{j=1}^{k} e^{z_j}}$$

  - E.g., $\vec{z} = [8, 5, 0] \rightarrow [0.9523, 0.0474, 0.0003]$

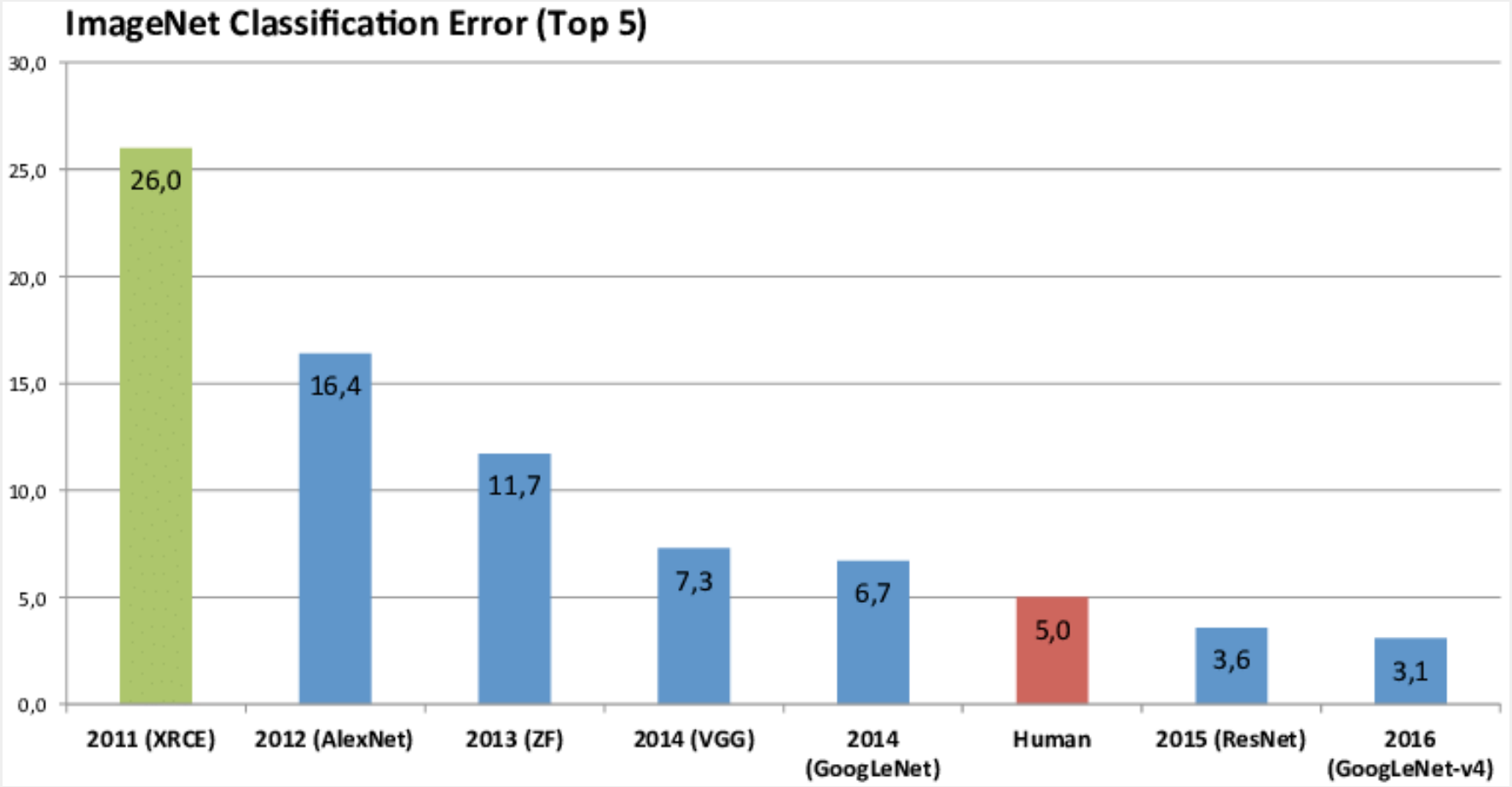
- Keras loss function list (link)

- Keras optimizer list (link)

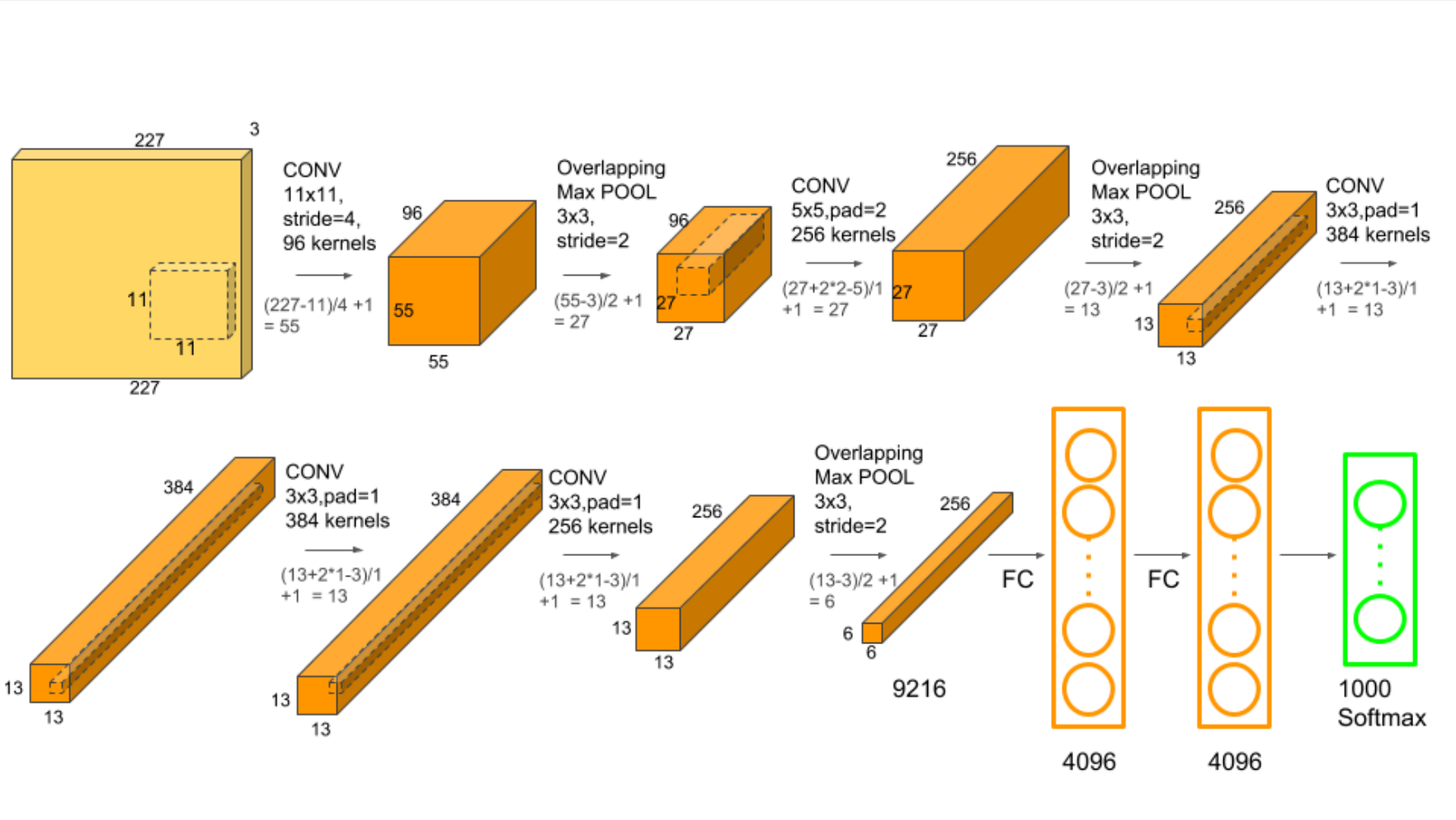
Example Networks


mite
container ship
motor scooter
leopard
mite
black widow
cockroach
tick
starfish
container ship
lifeboat
amphibian
fireboat
drilling platform
motor scooter
go-kart
moped
bumper car
golfcart
leopard
jaguar
cheetah
snow leopard
Egyptian cat

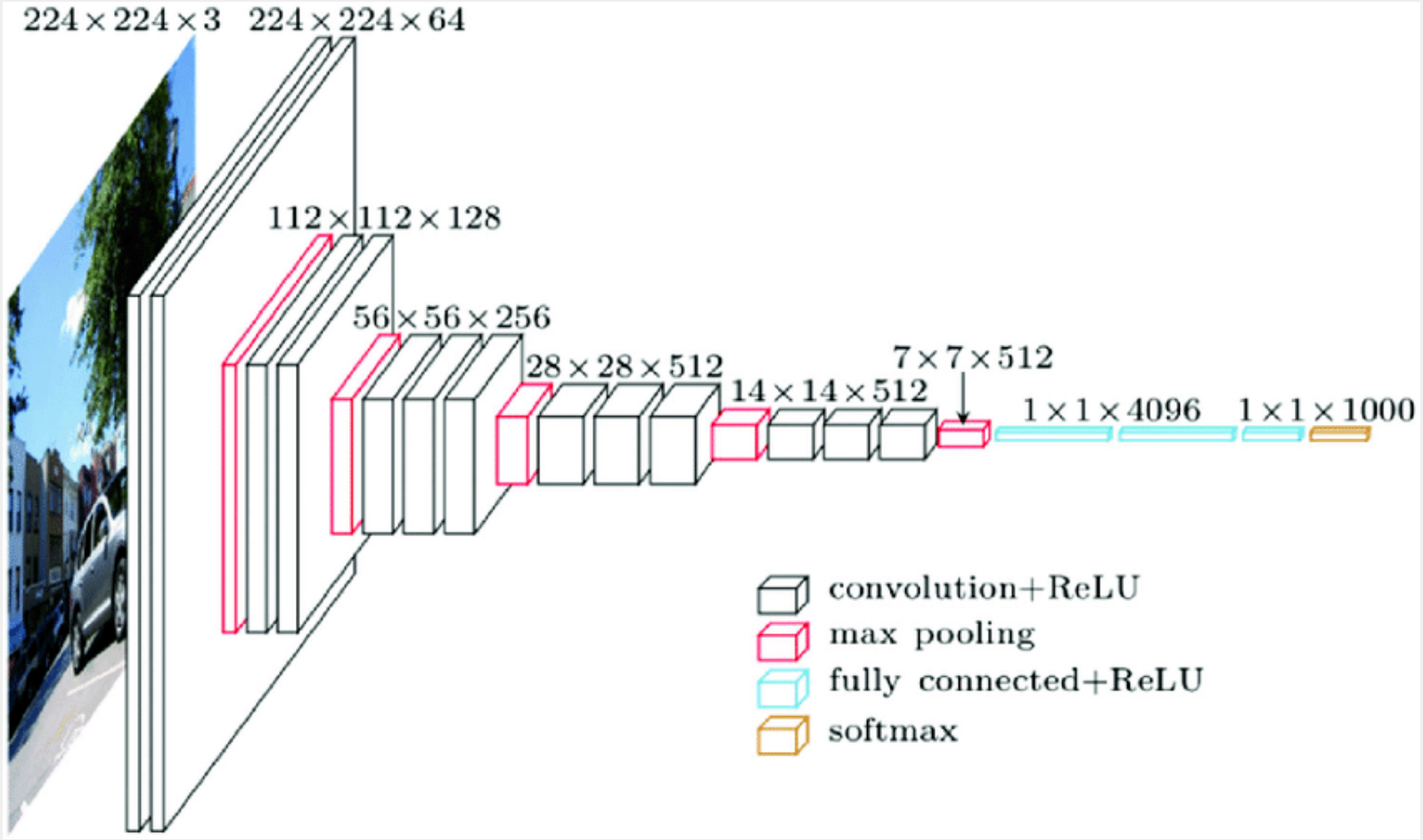
Recall ImageNet Competition



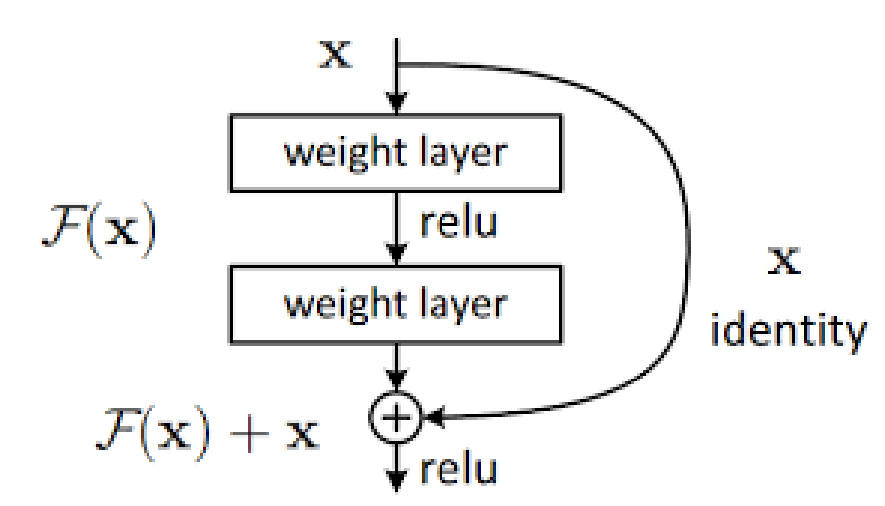
CNN Example for ImageNet (AlexNet)



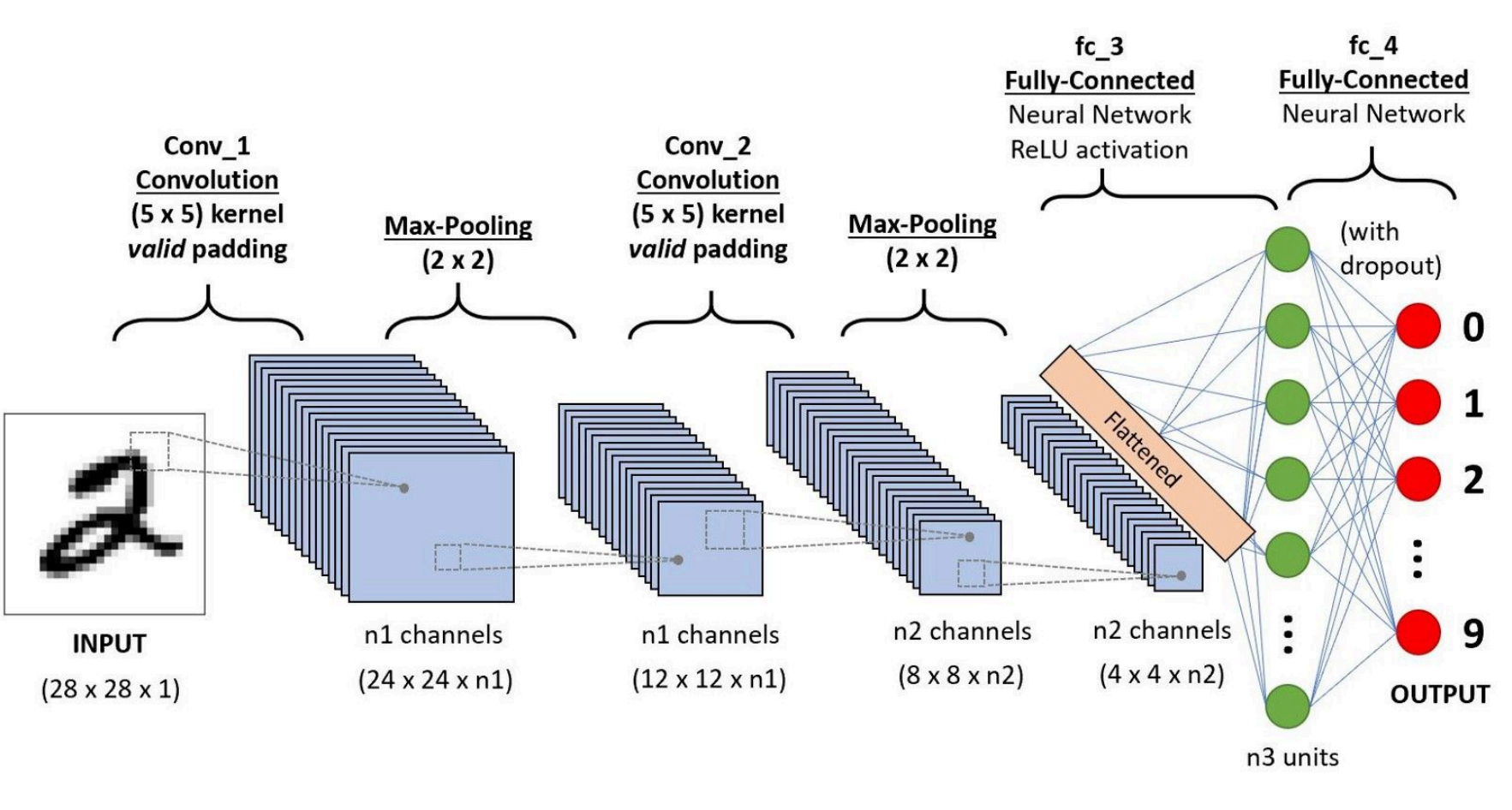
- 2 Conv + 2 Conv + 3 Conv + 3 Conv + 3 Conv + 3 Dense



- Original version: 152 layers (first network beat human performance)
- Many variants, e.g., ResNet-18, ResNet-50
- Residual learning (skip operation) helps train very deep networks by addressing the vanishing/exploding gradient problem



CNN Example for MNIST



- NVIDIA's model
- Paper (link)
- Video (link)
- Blog (link)

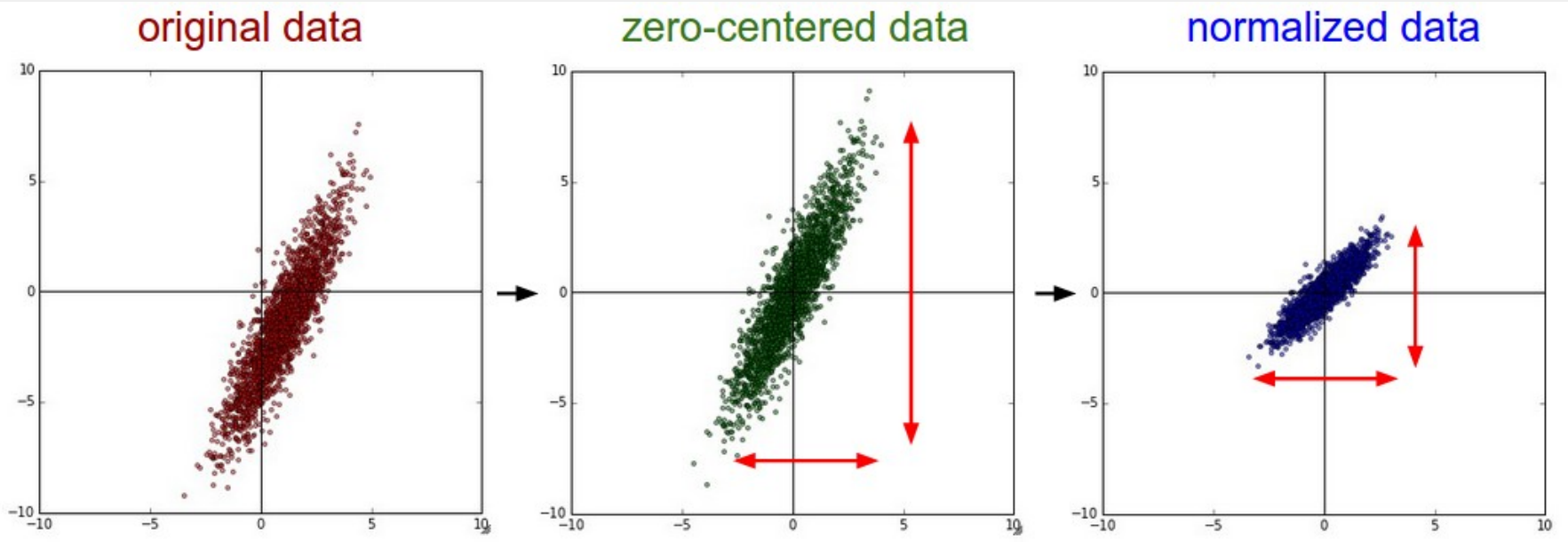
CNN Parameter Counting


```
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_1 (Conv2D)            (None, 26, 26, 32)        320
_________________________________________________________________
conv2d_2 (Conv2D)            (None, 24, 24, 64)        18496
_________________________________________________________________
max_pooling2d_1 (MaxPooling2 (None, 12, 12, 64)        0
_________________________________________________________________
dropout_1 (Dropout)          (None, 12, 12, 64)        0
_________________________________________________________________
flatten_1 (Flatten)          (None, 9216)              0
_________________________________________________________________
dense_1 (Dense)              (None, 128)               1179776
_________________________________________________________________
dropout_2 (Dropout)          (None, 128)               0
_________________________________________________________________
dense_2 (Dense)              (None, 10)                1290
=================================================================
Total params: 1,199,882
Trainable params: 1,199,882
Non-trainable params: 0
_________________________________________________________________
```

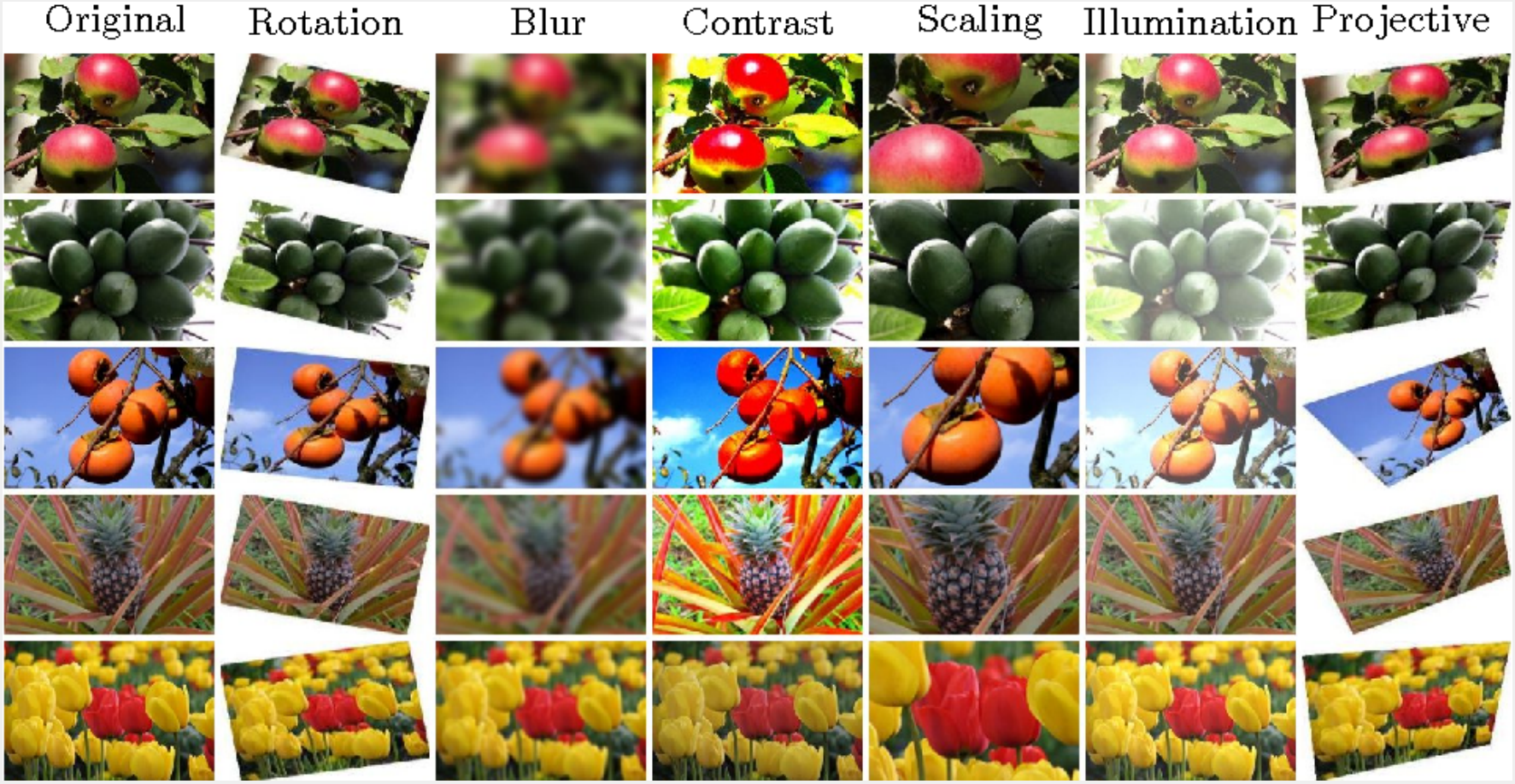
- Input shape is 28x28x1 (this is data, not trainable parameters)
- conv2d_1: 32x3x3+32 = 320 (32 2-D kernels, each is 3x3, plus a bias term for each kernel)
- conv2d_2: 32x3x3x64+64 = 18496 (64 3-D kernels, each is 32x3x3, plus a bias term for each kernel)
- dense_1: 9216x128+128 = 1179776
- dense_2: 128x10+10 = 1290
- Total number of trainable parameters: 1,199,882

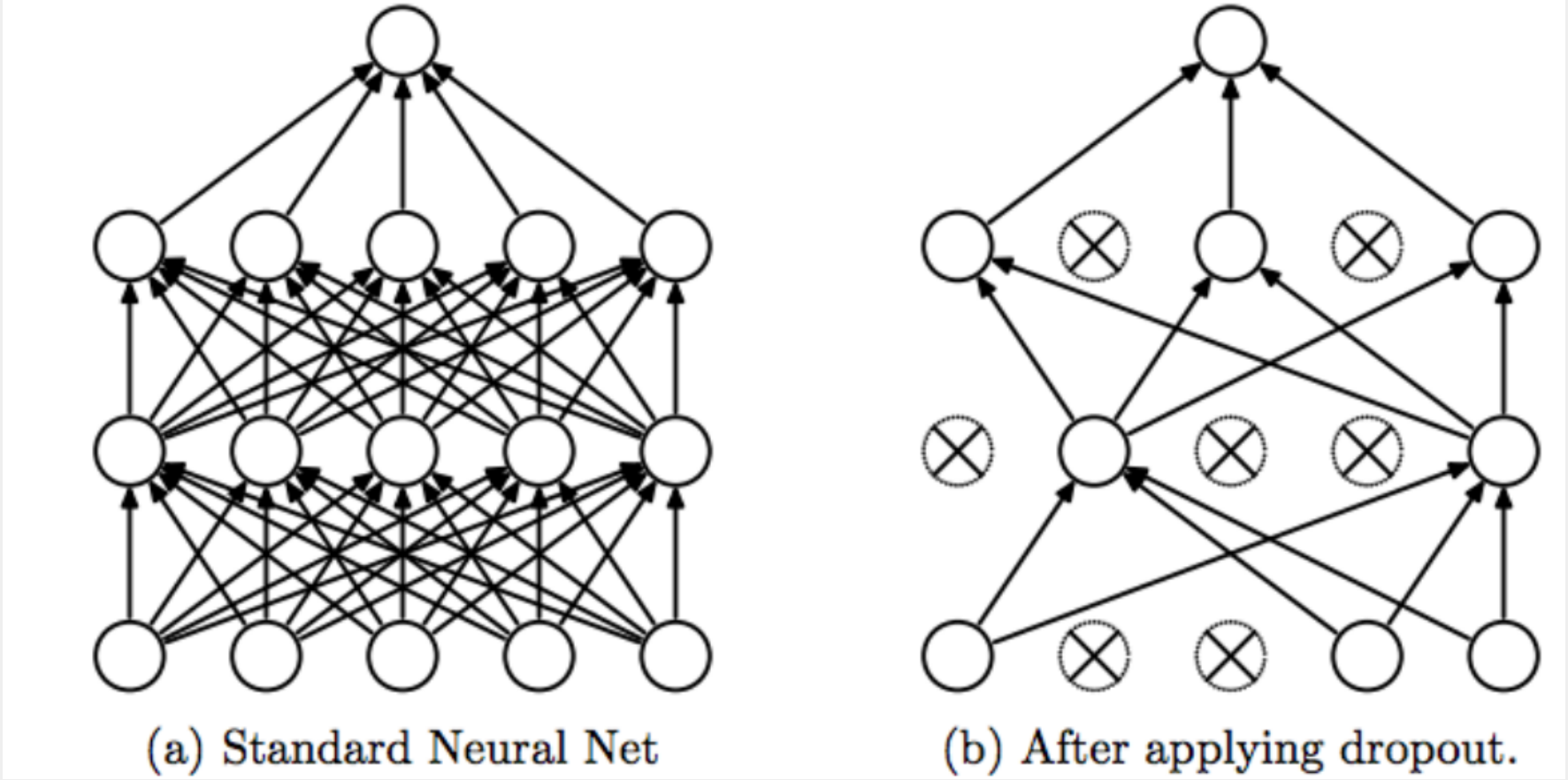
Training Techniques

- Linear normalization (know min and max): $\frac{x-min}{max-min}$, e.g., pixel values
- Z-score normalization: $\frac{x-mean(x)}{std(x)}$



Data Augmentation





(a) Standard Neural Net

(b) After applying dropout.

- grid search: simplest technique
- random search: may perform better than grid search
- coarse to fine: start with broad sweep, then zero in

Example Code

- link

- Tensorflow (link)
- Keras (link)
- Pytorch (link)