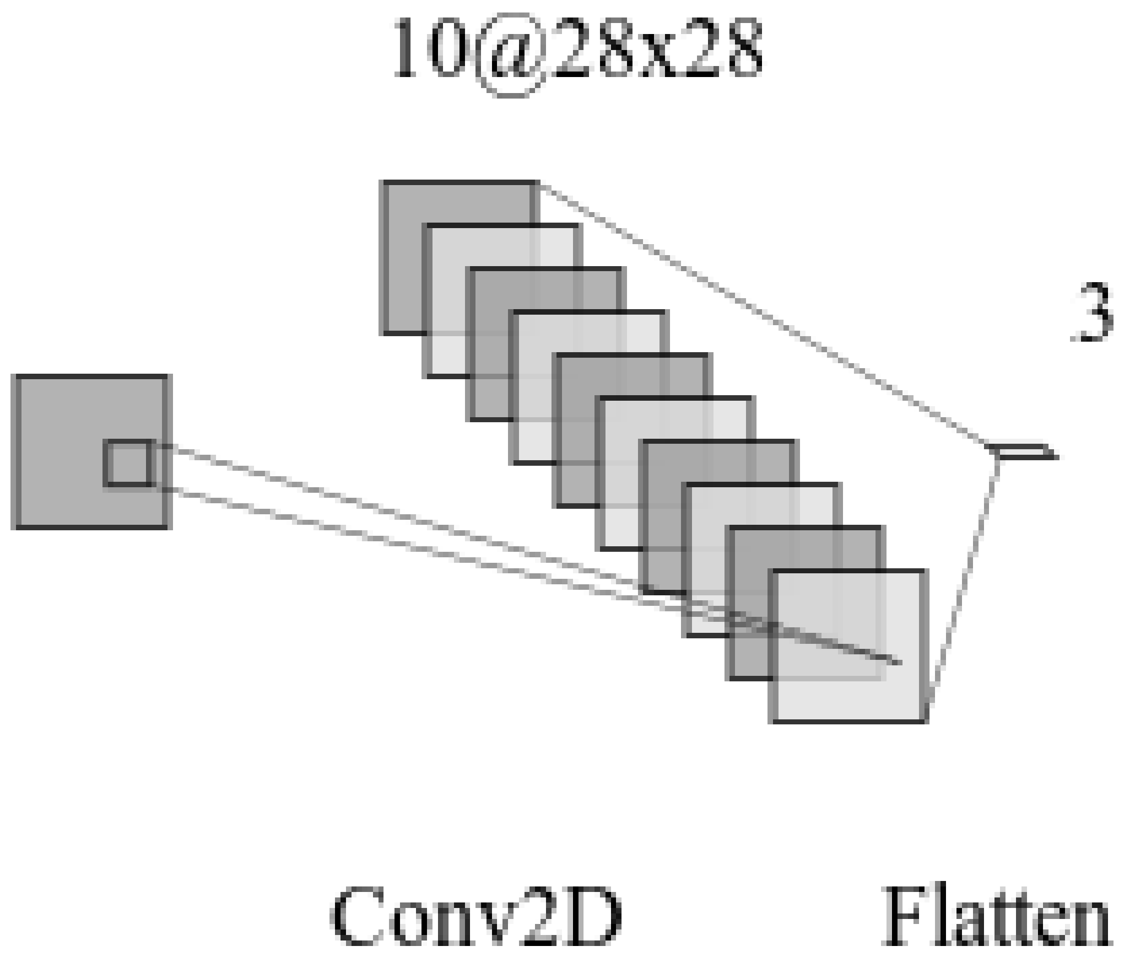
Going deeper

CONVOLUTIONAL NEURAL NETWORKS FOR IMAGE PROCESSING

Ariel Rokem
Senior Data Scientist, University of Washington

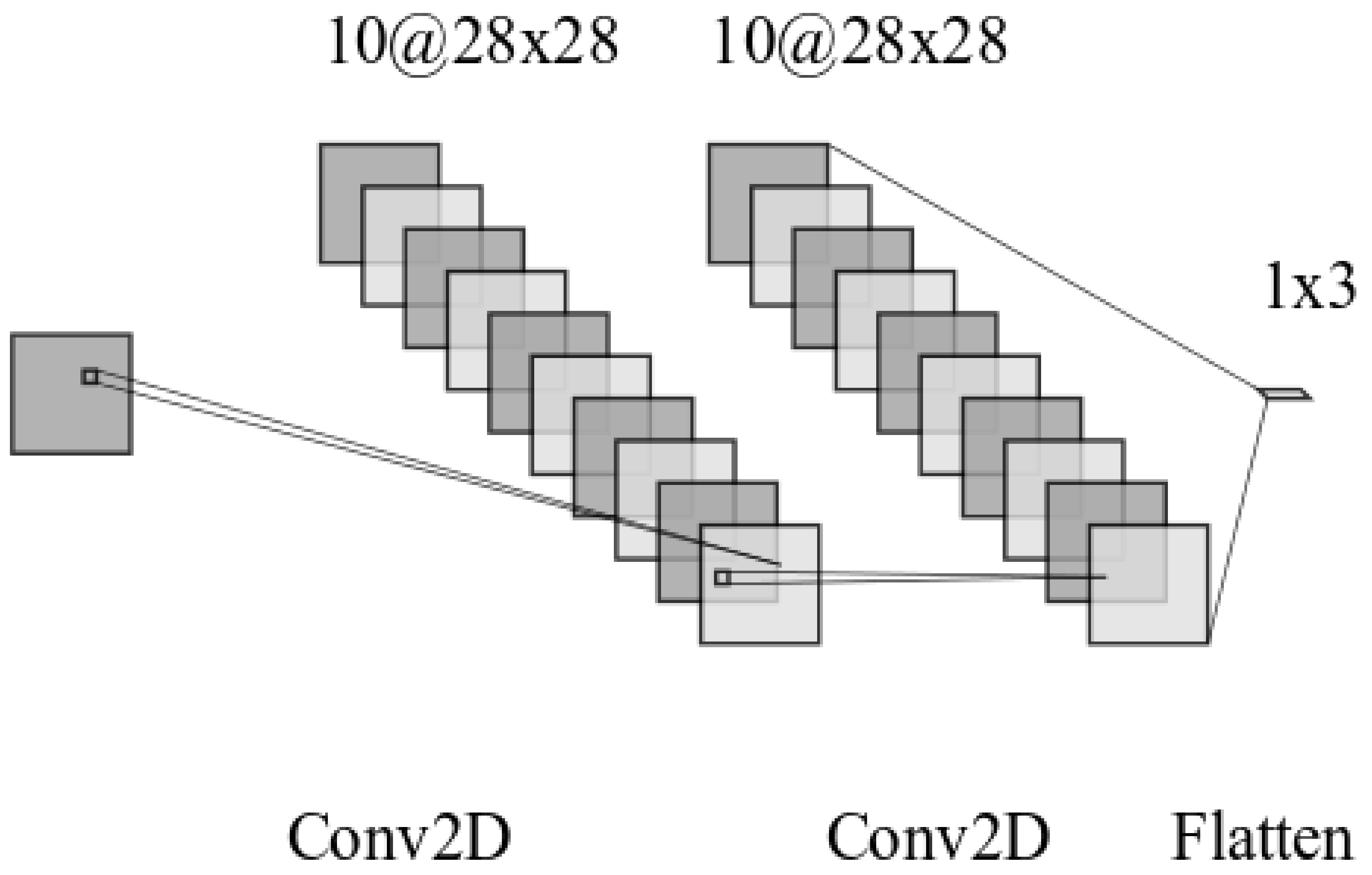
Network with one convolutional layer



Network with one convolutional layer: implementation

```
model = Sequential()
model.add(Conv2D(10, kernel_size=2, activation='relu',
                 input_shape=(img_rows, img_cols, 1)))
model.add(Flatten())
model.add(Dense(3, activation='softmax'))
```

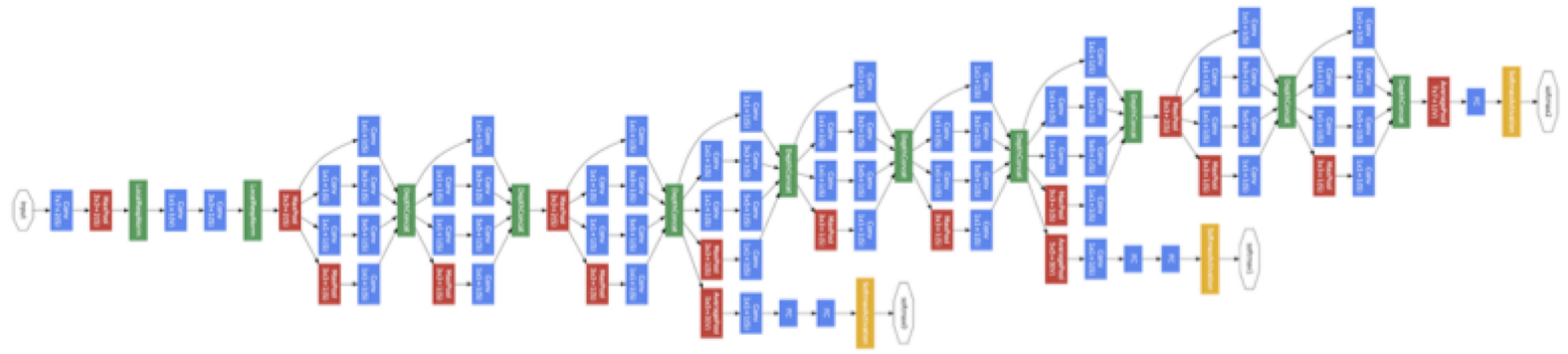
Building a deeper network



Building a deep network

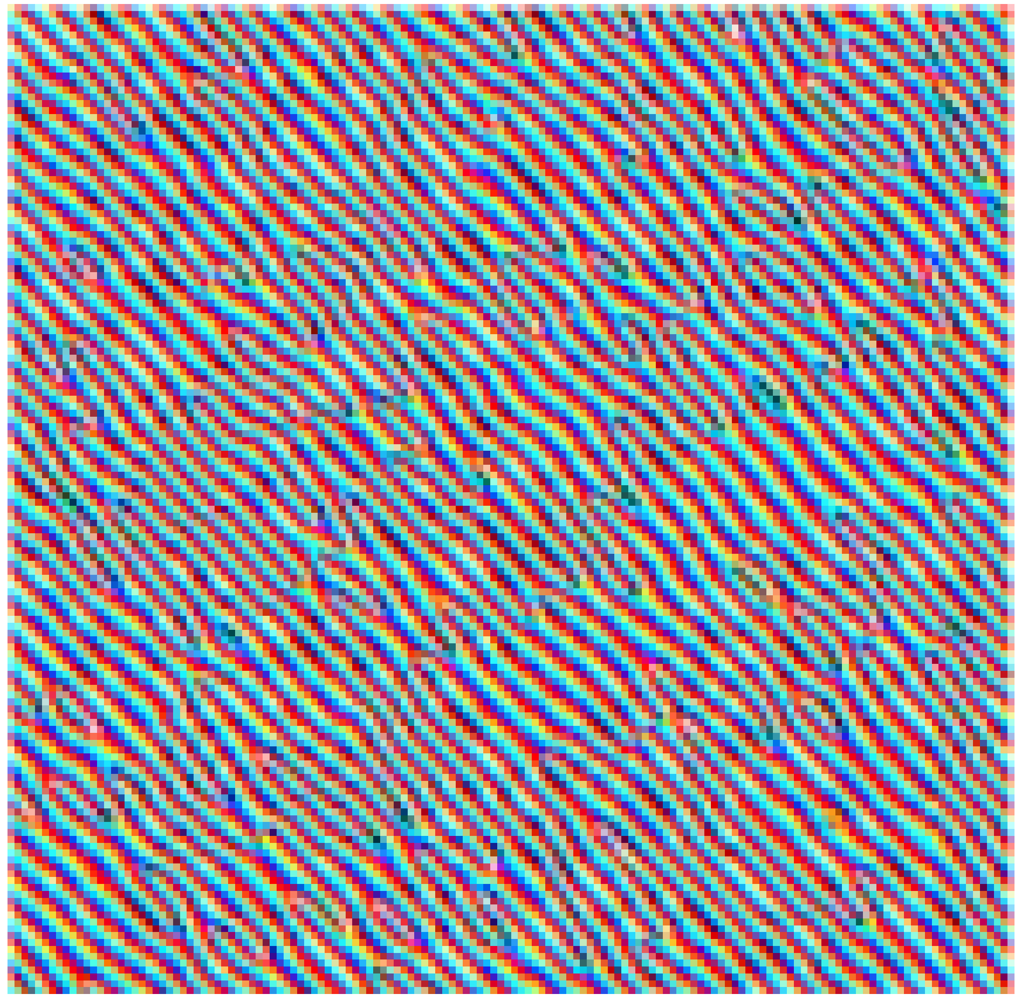
```
model = Sequential()
model.add(Conv2D(10, kernel_size=2, activation='relu',
                 input_shape=(img_rows, img_cols, 1),
                 padding='equal'))

# Second convolutional layer
model.add(Conv2D(10, kernel_size=2, activation='relu')

model.add(Flatten())
model.add(Dense(3, activation='softmax'))
```

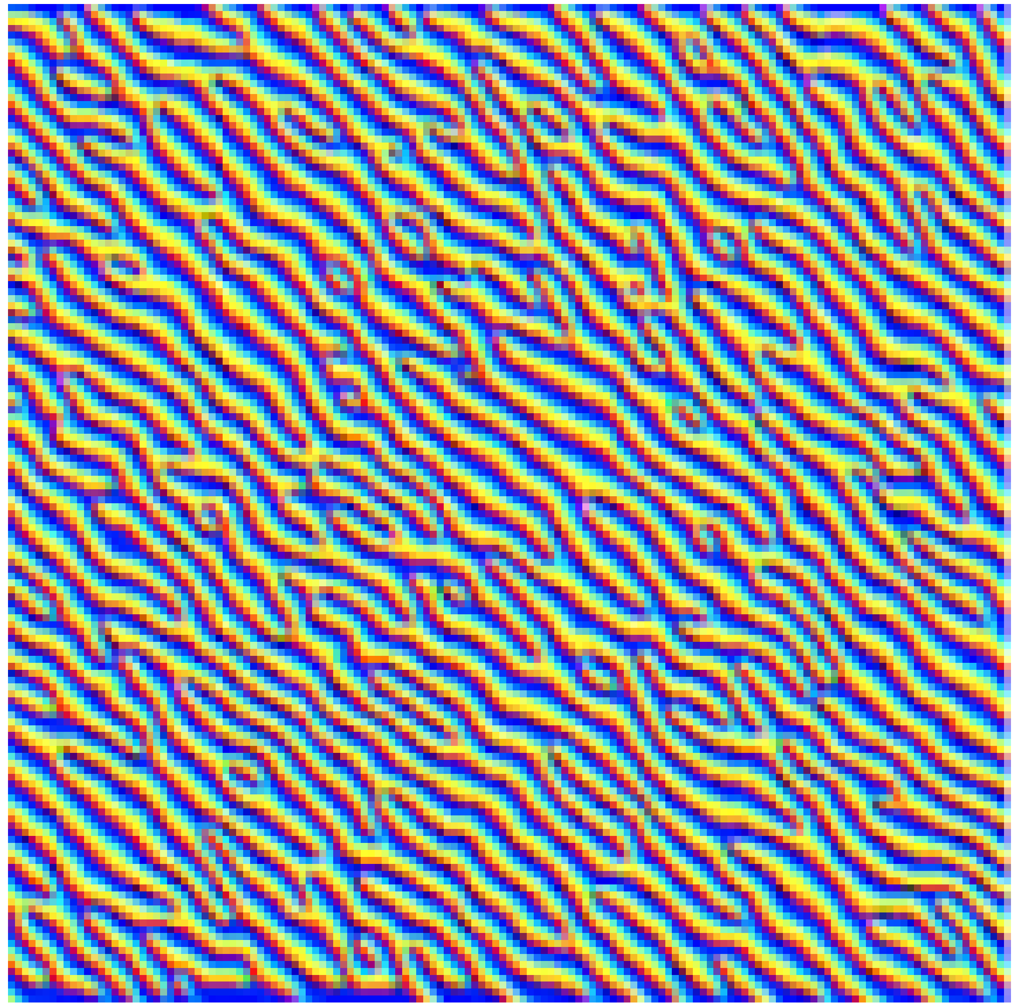
Why do we want deep networks?



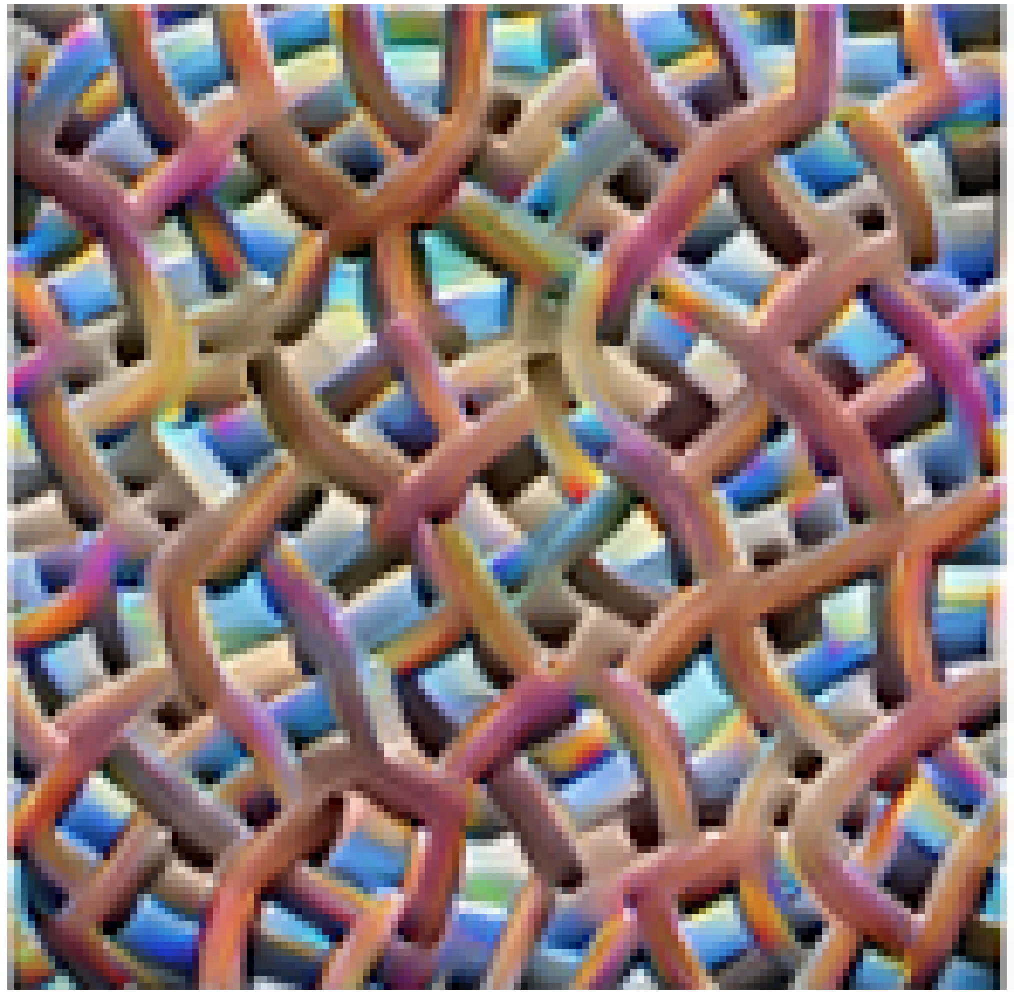
Convolution
Pooling
Softmax
Other

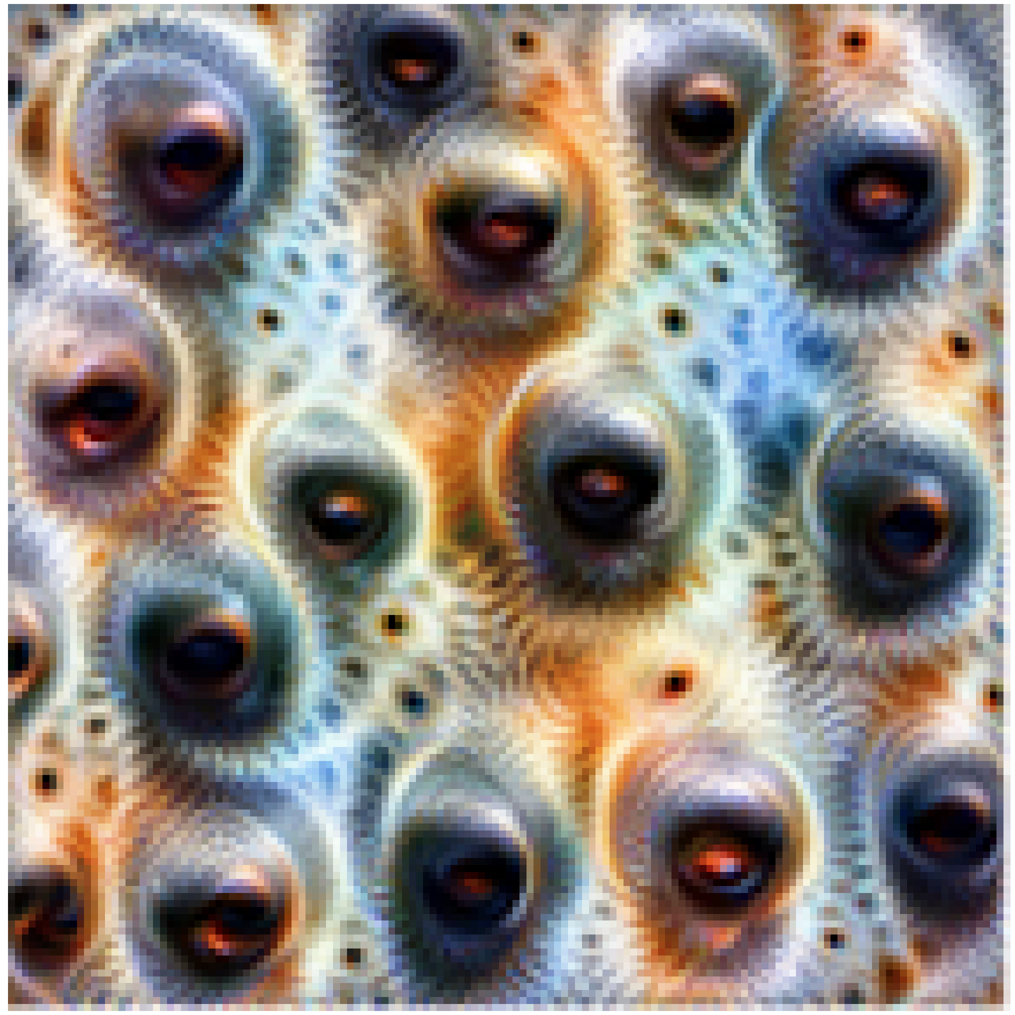
Features in early layers



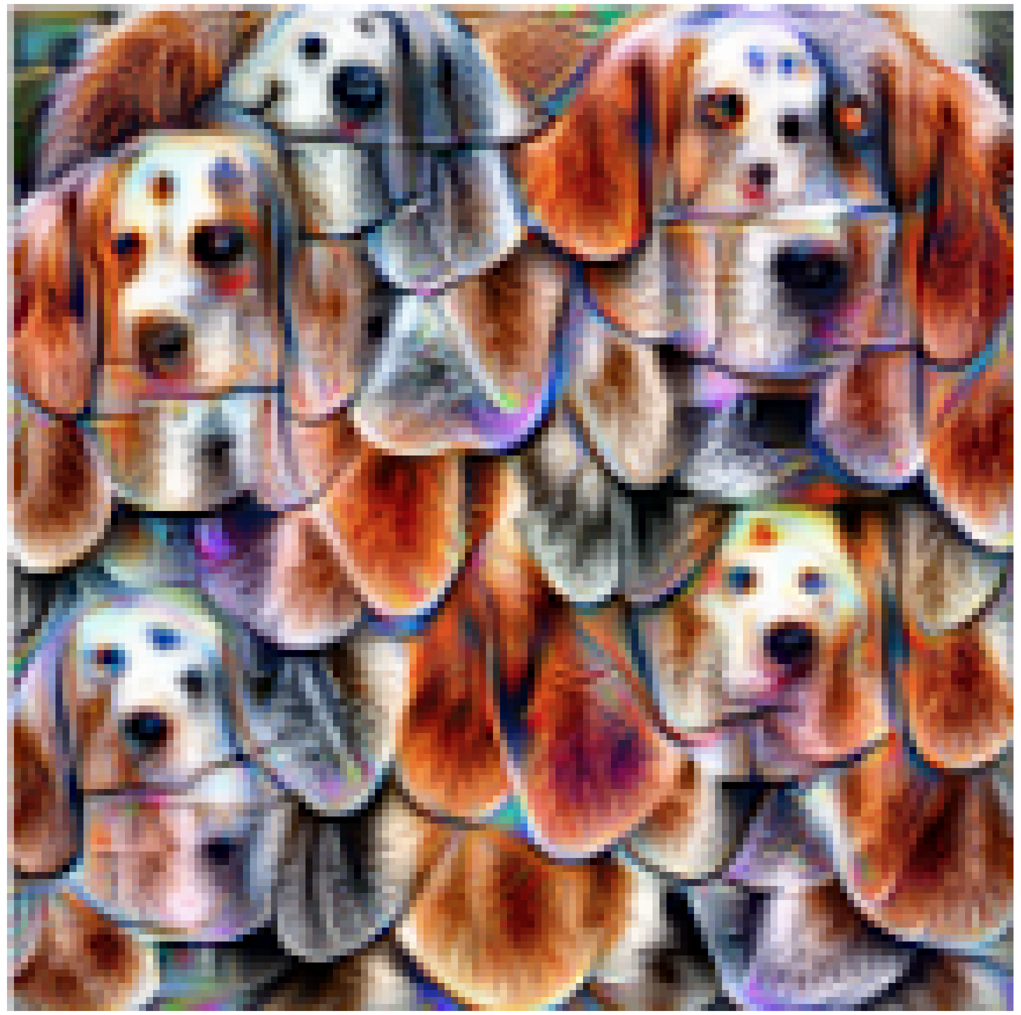


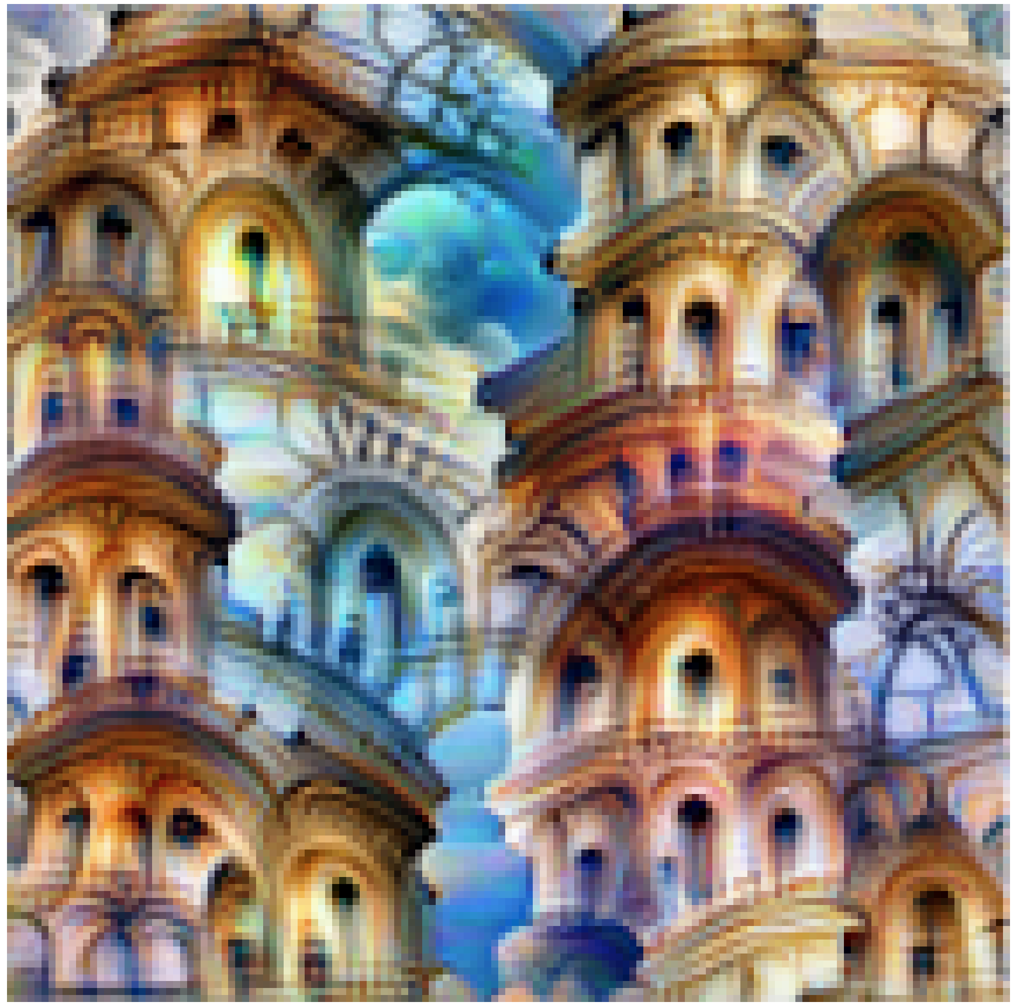
Features in intermediate layers





Features in late layers





How deep?

- Depth comes at a computational cost
- May require more data

Let's practice!

CONVOLUTIONAL NEURAL NETWORKS FOR IMAGE PROCESSING

How many parameters?

CONVOLUTIONAL NEURAL NETWORKS FOR IMAGE PROCESSING

Ariel Rokem
Senior Data Scientist, University of Washington

Counting parameters

```
model = Sequential()

model.add(Dense(10, activation='relu',
                input_shape=(784,)))

model.add(Dense(10, activation='relu'))

model.add(Dense(3, activation='softmax'))
```

```
# Call the summary method
model.summary()
```

```
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
dense_1 (Dense)              (None, 10)                7850
_________________________________________________________________
dense_2 (Dense)              (None, 10)                110
_________________________________________________________________
dense_3 (Dense)              (None, 3)                 33
=================================================================
Total params: 7,993
Trainable params: 7,993
Non-trainable params: 0
_________________________________________________________________
```

Counting parameters

```
model.add(Dense(
        10, activation='relu',
        input_shape=(784,)))
```

$$parameters = 784 * 10 + 10$$

$$= 7850$$

```
model.add(Dense(
        10, activation='relu'))
```

$$parameters = 10 * 10 + 10$$

$$= 110$$

```
model.add(Dense(
        3, activation='softmax'))
```

$$parameters = 10 * 3 + 3$$

$$= 33$$

$$7850 + 110 + 33 = 7993$$

```
model.summary()
```

```
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
dense_1 (Dense)              (None, 10)                7850
_________________________________________________________________
dense_2 (Dense)              (None, 10)                110
_________________________________________________________________
dense_3 (Dense)              (None, 3)                 33
=================================================================
Total params: 7,993
Trainable params: 7,993
Non-trainable params: 0
_________________________________________________________________
```

The number of parameters in a CNN

```
model = Sequential()

model.add(Conv2D(10, kernel_size=3, activation='relu',
                 input_shape=(28, 28, 1), padding='same'))

model.add(Conv2D(10, kernel_size=3, activation='relu',
                 padding='same'))

model.add(Flatten())

model.add(Dense(3, activation='softmax'))
model.summary()
```

```
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_1 (Conv2D)           (None, 28, 28, 10)       100
_________________________________________________________________
conv2d_2 (Conv2D)           (None, 28, 28, 10)       910
_________________________________________________________________
flatten_3 (Flatten)          (None, 7840)              0
_________________________________________________________________
dense_4 (Dense)              (None, 3)                 23523
=================================================================
Total params: 24,533
Trainable params: 24,533
Non-trainable params: 0
_________________________________________________________________
```

The number of parameters in a CNN

```
model.add(
 Conv2D(10, kernel_size=3,
        activation='relu',
        input_shape=(28, 28, 1),
        padding='same'))
```

$$parameters = 9 * 10 + 10$$

$$= 100$$

```
model.add(
 Conv2D(10, kernel_size=3,
        activation='relu',
        padding='same'))
```

$$parameters = 10 * 9 * 10 + 10$$

$$= 910$$

```
model.add(Flatten())
```

$$parameters = 0$$

```
model.add(Dense(
       3, activation='softmax'))
```

$$parameters = 7840 * 3 + 3$$

$$= 23523$$

Increasing the number of units in each layer

```
model = Sequential()

model.add(Dense(5, activation='relu',
                input_shape=(784,), padding='same'))

model.add(Dense(15, activation='relu', padding='same'))

model.add(Dense(3, activation='softmax'))
model.summary()
```

```
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
dense_1 (Dense)              (None, 5)                 3925
_________________________________________________________________
dense_2 (Dense)              (None, 15)                90
_________________________________________________________________
dense_3 (Dense)              (None, 3)                 48
=================================================================
Total params: 4,063
Trainable params: 4,063
Non-trainable params: 0
_________________________________________________________________
```

Increasing the number of units in each layer

```
model = Sequential()

model.add(Conv2D(5, kernel_size=3, activation='relu',
                 input_shape=(28, 28, 1),
                 padding="same"))

model.add(Conv2D(15, kernel_size=3, activation='relu',
                 padding="same"))

model.add(Flatten())

model.add(Dense(3, activation='softmax'))
model.summary()
```

```
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_12 (Conv2D)           (None, 28, 28, 5)         50
_________________________________________________________________
conv2d_13 (Conv2D)           (None, 28, 28, 15)        690
_________________________________________________________________
flatten_6 (Flatten)          (None, 11760)             0
_________________________________________________________________
dense_9 (Dense)              (None, 3)                 35283
=================================================================
Total params: 36,023
Trainable params: 36,023
Non-trainable params: 0
_________________________________________________________________
```

Let's practice!

CONVOLUTIONAL NEURAL NETWORKS FOR IMAGE PROCESSING

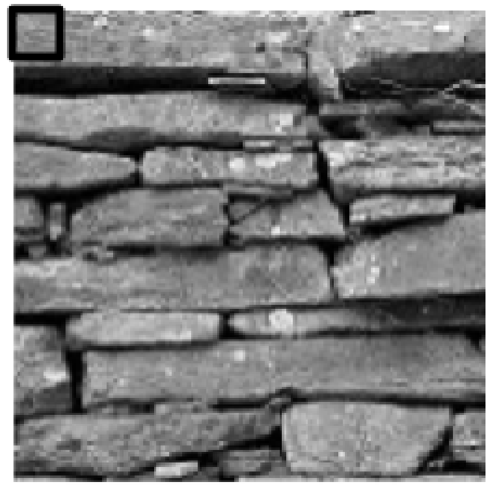
Reducing parameters with pooling

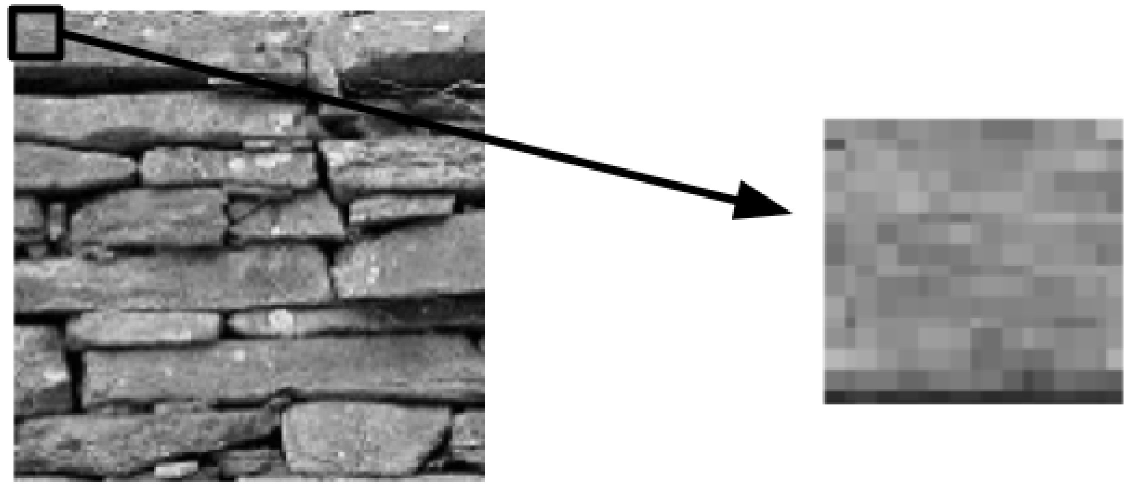
CONVOLUTIONAL NEURAL NETWORKS FOR IMAGE PROCESSING

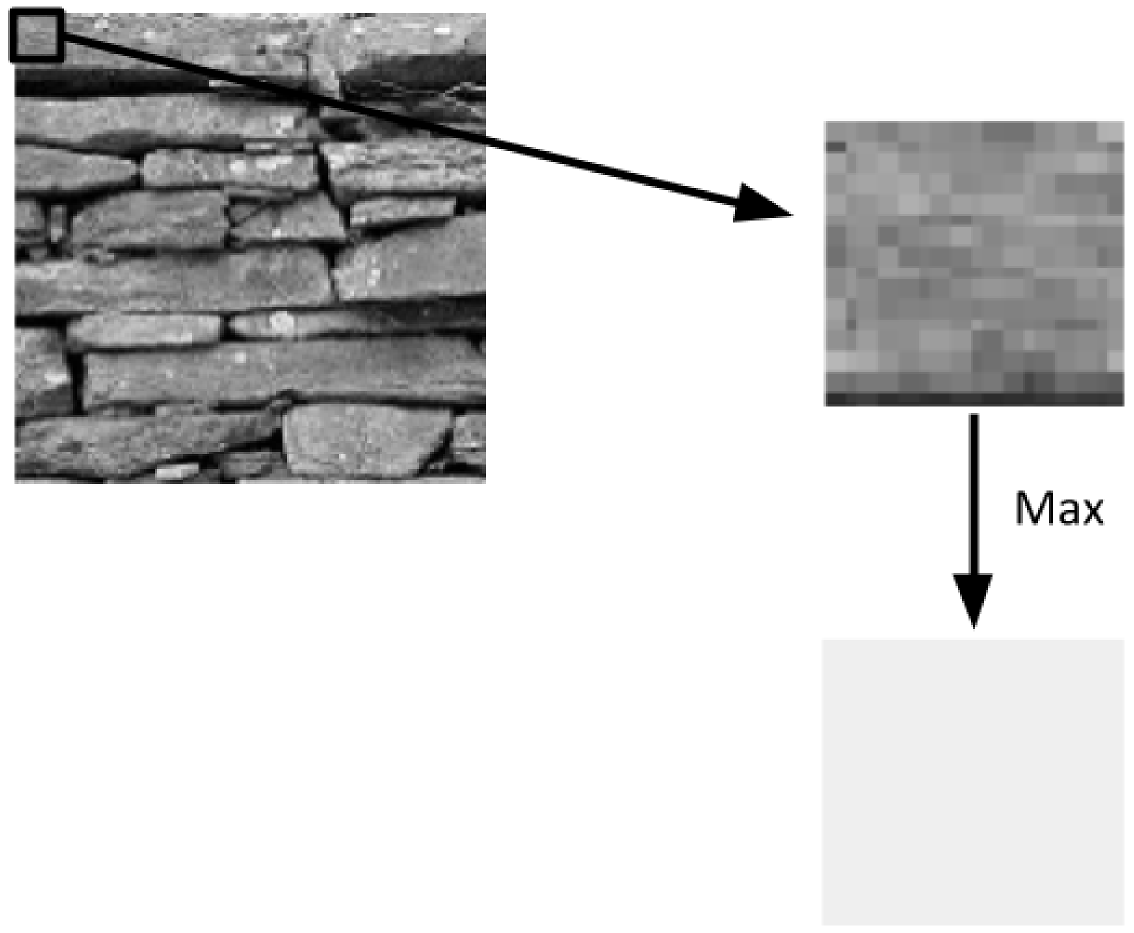
Ariel Rokem
Senior Data Scientist, University of Washington

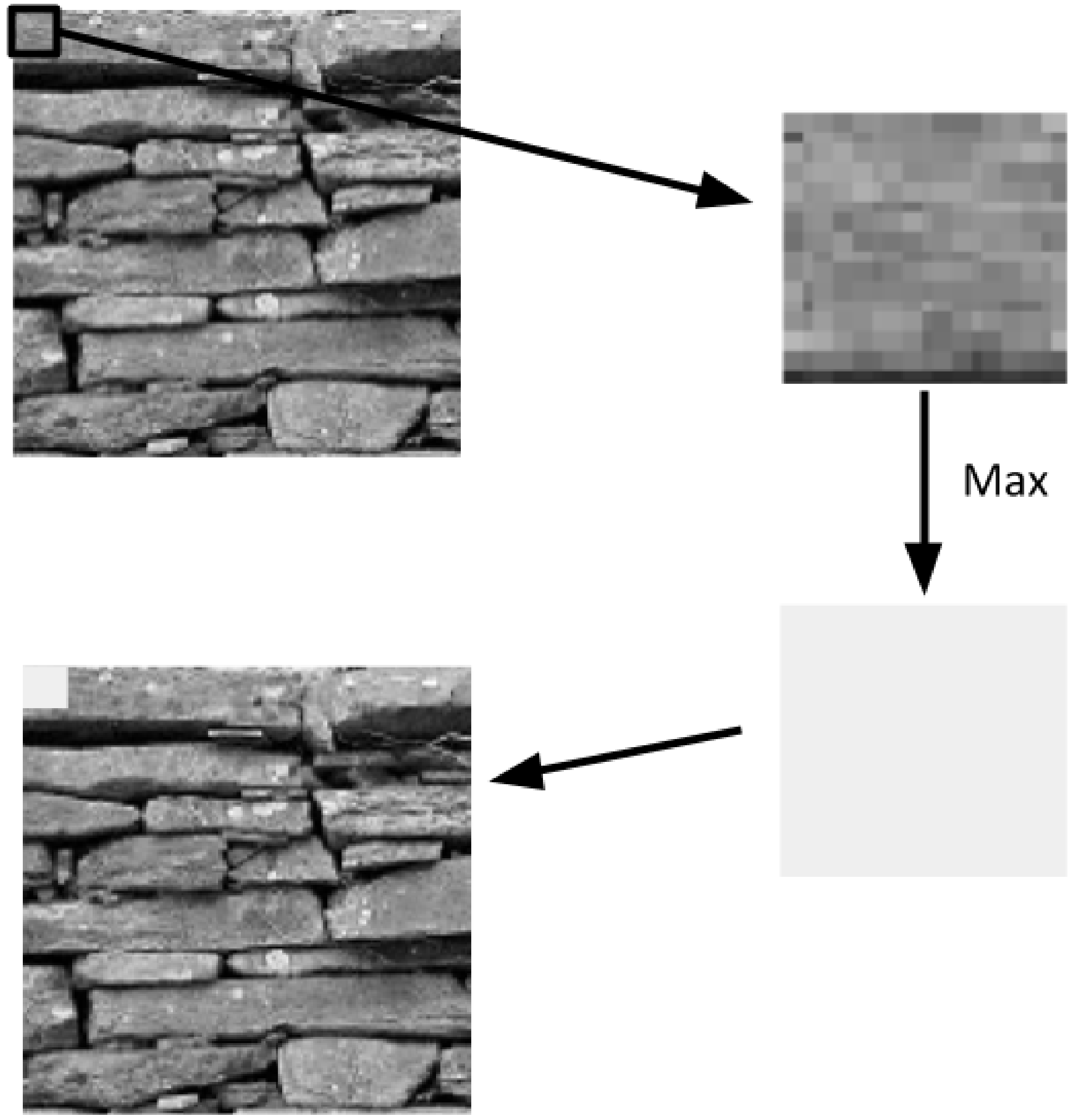
```
model.summary()
```

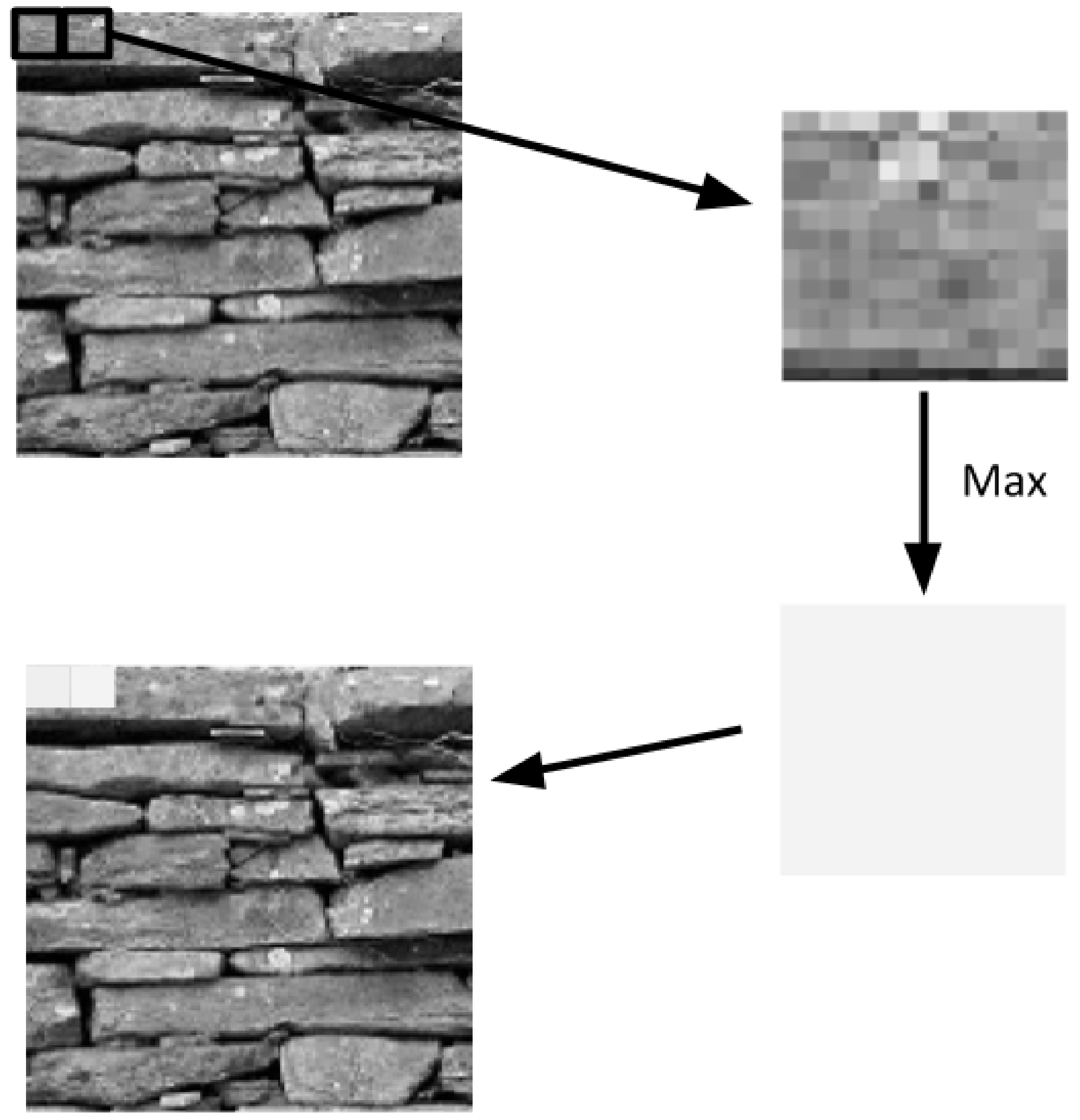
```
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_12 (Conv2D)           (None, 28, 28, 5)         50
_________________________________________________________________
conv2d_13 (Conv2D)           (None, 28, 28, 15)        690
_________________________________________________________________
flatten_6 (Flatten)          (None, 11760)             0
_________________________________________________________________
dense_9 (Dense)              (None, 3)                 35283
=================================================================
Total params: 36,023
Trainable params: 36,023
Non-trainable params: 0
_________________________________________________________________
```

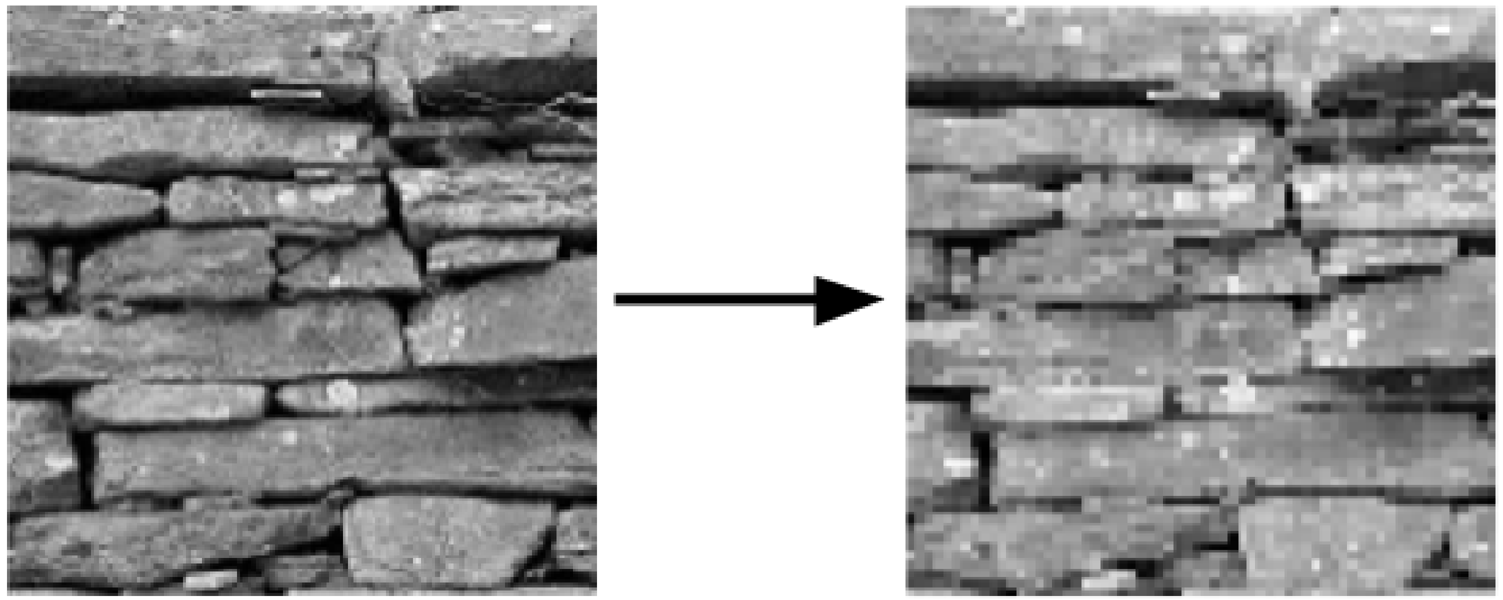





Max


Max


Max



Implementing max pooling

```
result = np.zeros((im.shape[0]//2, im.shape[1]//2))

result[0, 0] = np.max(im[0:2, 0:2])

result[0, 1] = np.max(im[0:2, 2:4])

result[0, 2] = np.max(im[0:2, 4:6])
```

...

```
result[1, 0] = np.max(im[2:4, 0:2])

result[1, 1] = np.max(im[2:4, 2:4])
```

...

Implementing max pooling

```
for ii in range(result.shape[0]):
    for jj in range(result.shape[1]):
        result[ii, jj] = np.max(im[ii*2:ii*2+2, jj*2:jj*2+2
```

Max pooling in Keras

```
from keras.models import Sequential
from keras.layers import Dense, Conv2D, Flatten, MaxPool2D

model = Sequential()
model.add(Conv2D(5, kernel_size=3, activation='relu',
                 input_shape=(img_rows, img_cols, 1)))

model.add(MaxPool2D(2))

model.add(Conv2D(15, kernel_size=3, activation='relu',
                 input_shape=(img_rows, img_cols, 1)))

model.add(MaxPool2D(2))

model.add(Flatten())
model.add(Dense(3, activation='softmax'))
model.summary()
```

```
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_1 (Conv2D)            (None, 26, 26, 5)         50
_________________________________________________________________
max_pooling2d_1 (MaxPooling2 (None, 13, 13, 5)         0
_________________________________________________________________
conv2d_2 (Conv2D)            (None, 11, 11, 15)        690
_________________________________________________________________
max_pooling2d_2 (MaxPooling2 (None, 5, 5, 15)          0
_________________________________________________________________
flatten_1 (Flatten)          (None, 375)               0
_________________________________________________________________
dense_1 (Dense)              (None, 3)                 1128
=================================================================
```

Let's practice!

CONVOLUTIONAL NEURAL NETWORKS FOR IMAGE PROCESSING