

# Going deeper

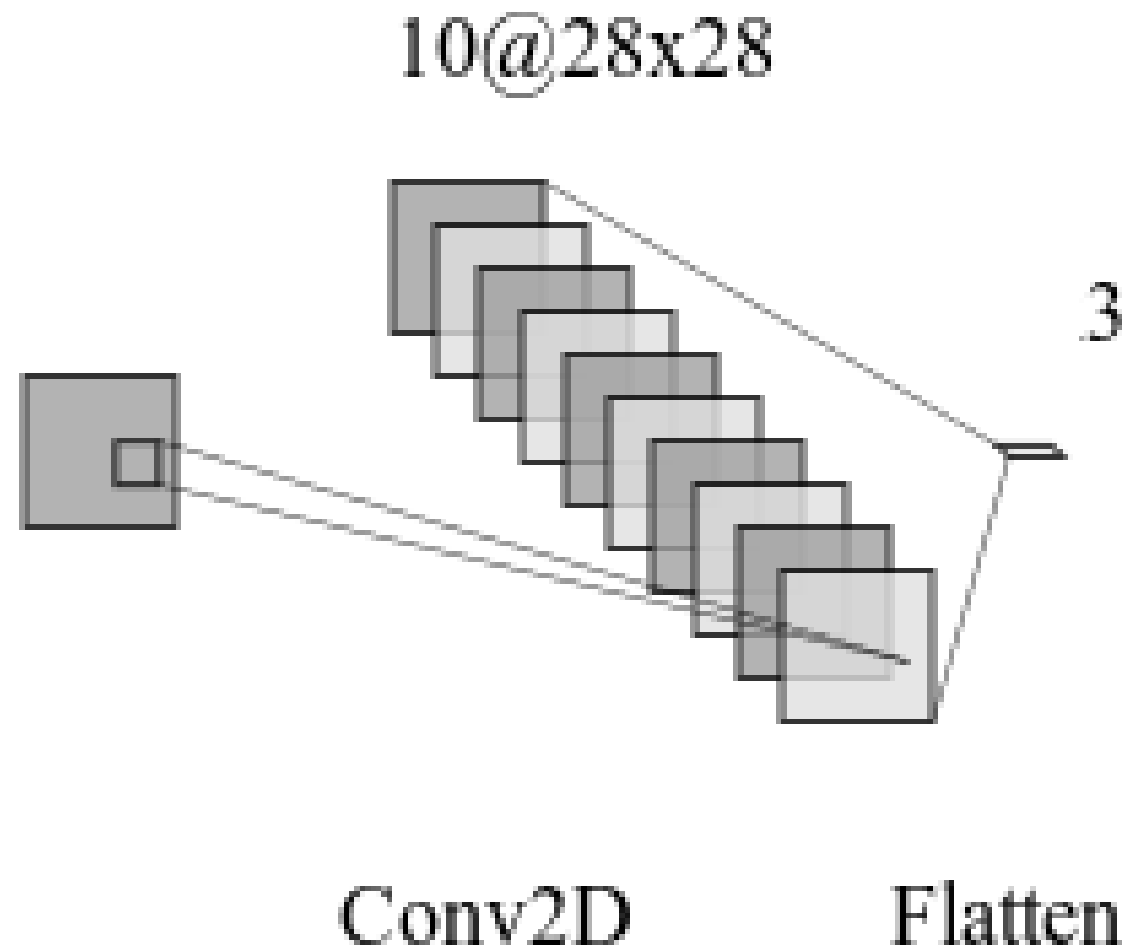
## IMAGE MODELING WITH KERAS



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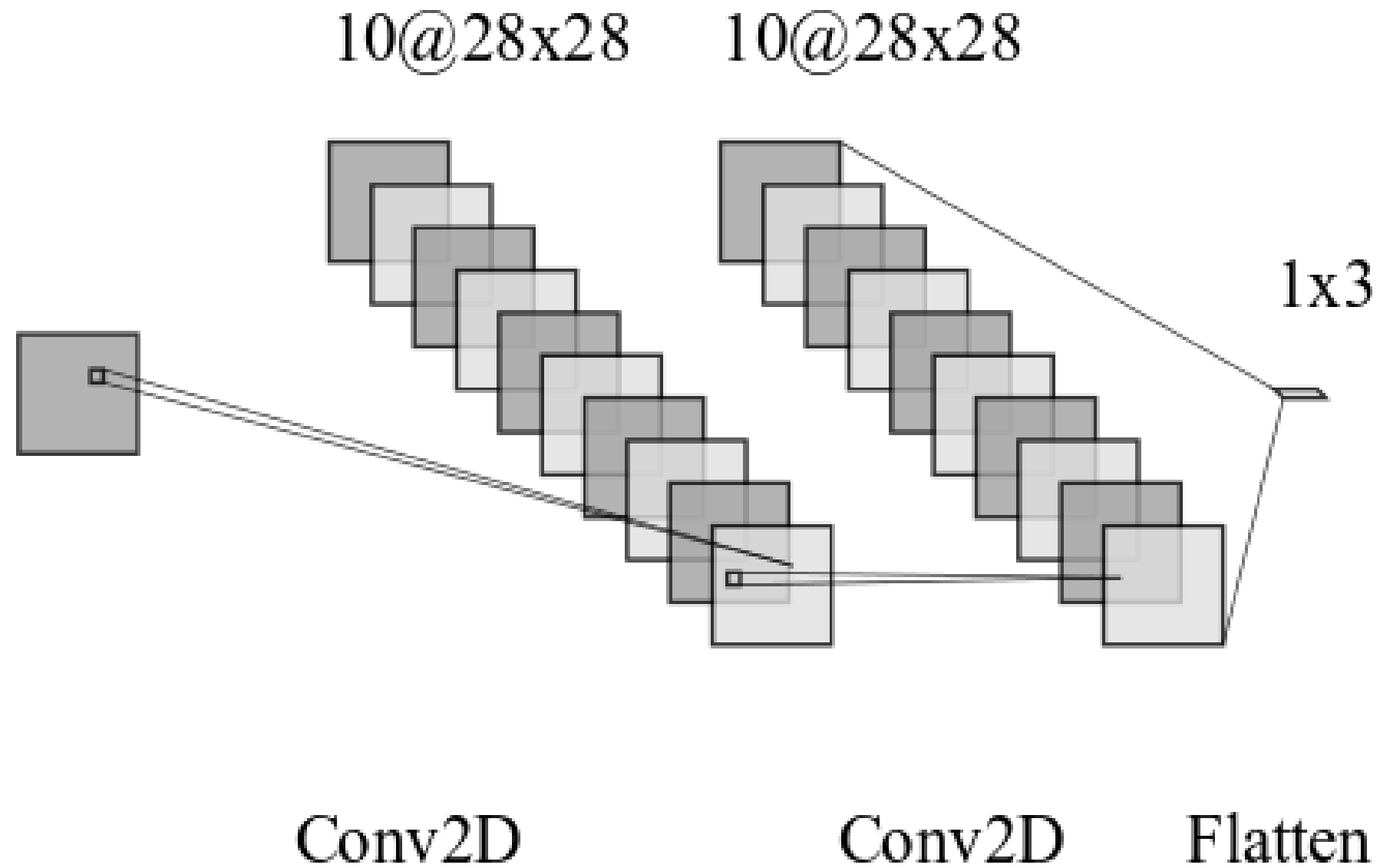
# Network with one convolutional layer



# 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

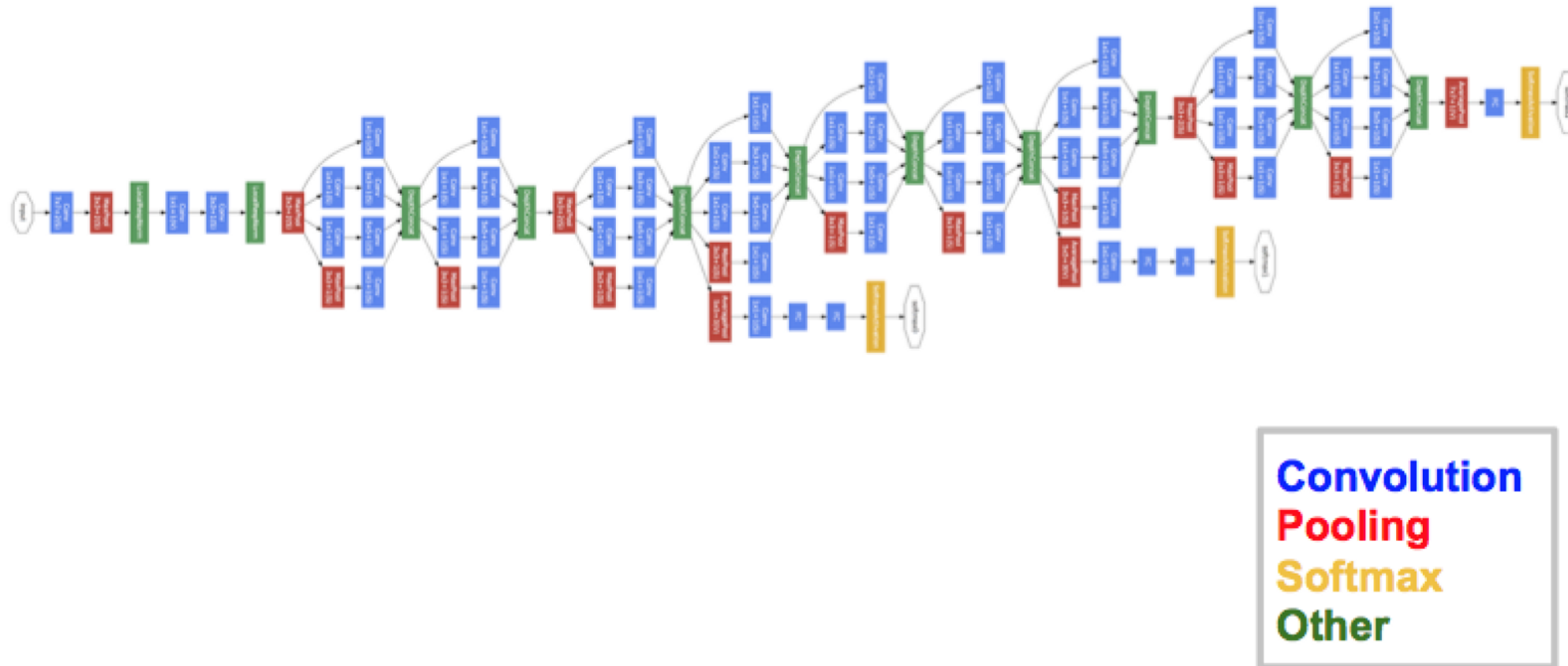


# Building a deep network

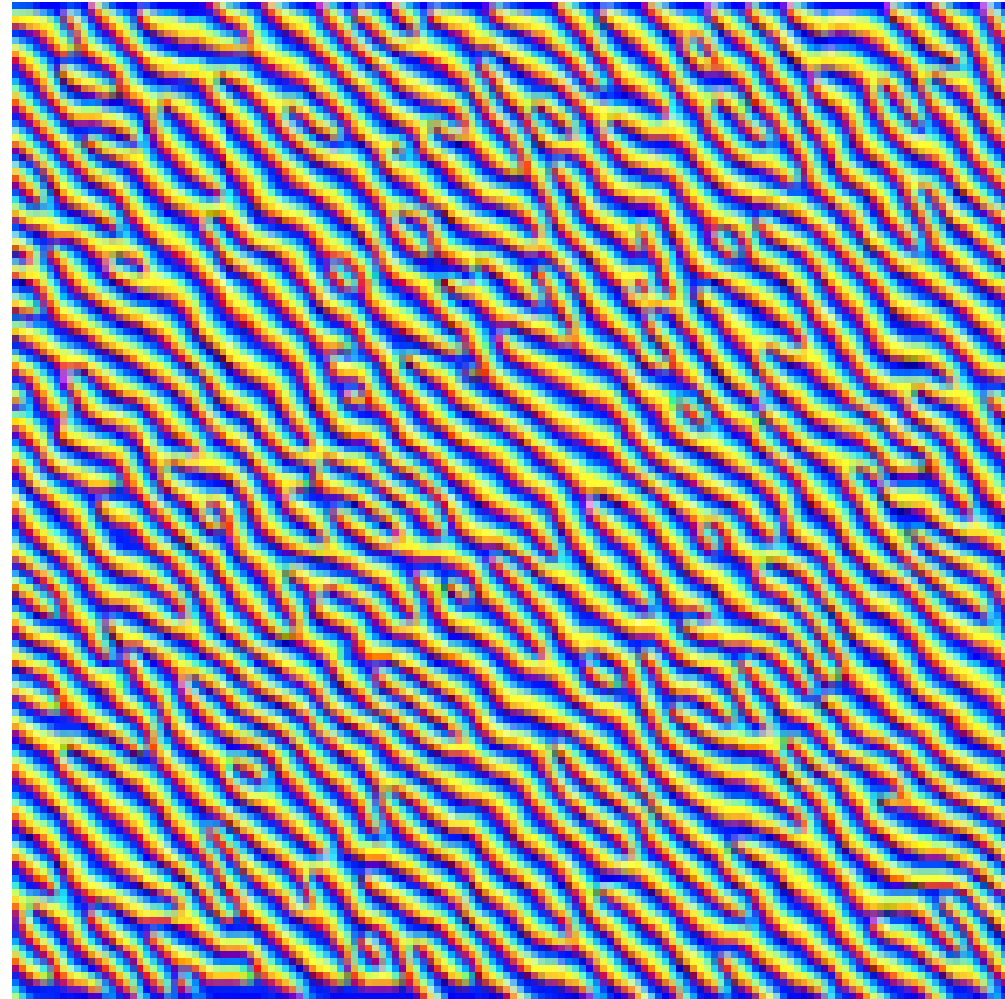
```
model = Sequential()
model.add(Conv2D(10, kernel_size=2, activation='relu',
                 input_shape=(img_rows, img_cols, 1),
                 padding='equal'))

# Second convolutional layer
model.add(Conv2D(10, kernel_size=2, activation='relu'))
model.add(Flatten())
model.add(Dense(3, activation='softmax'))
```

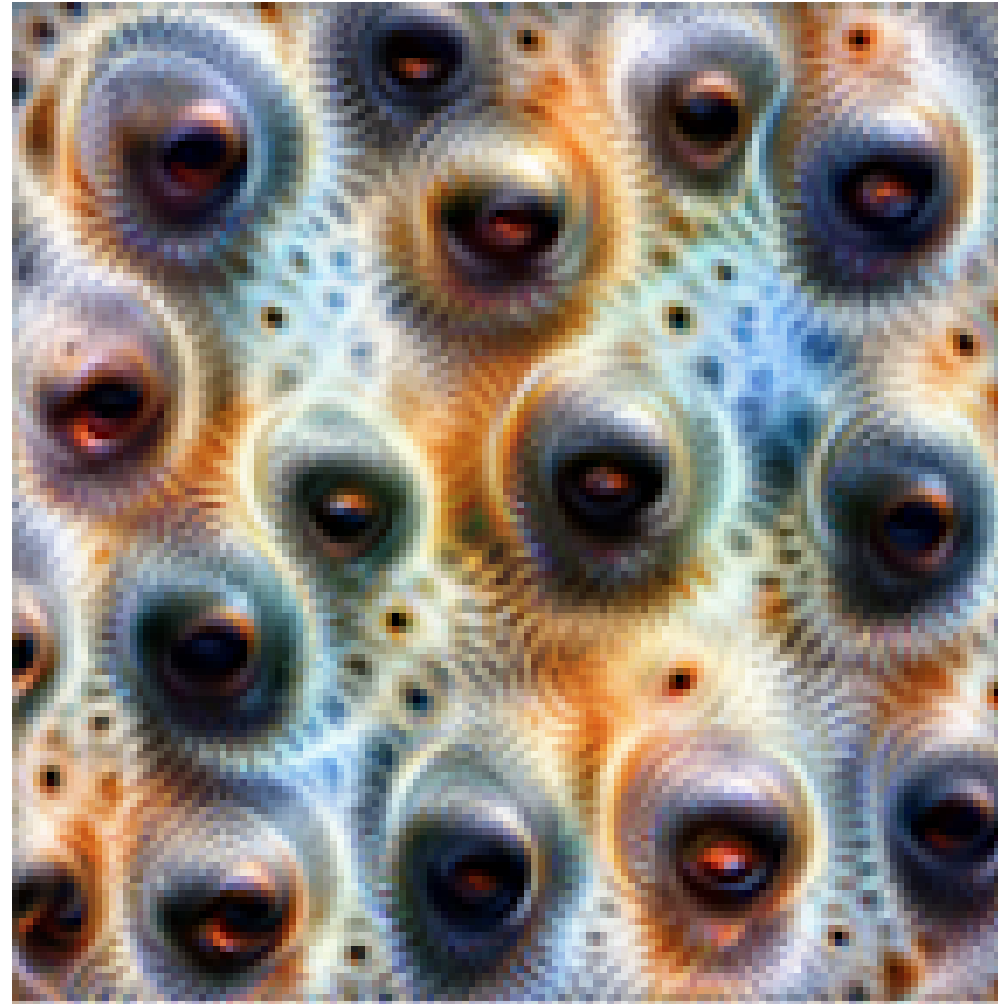
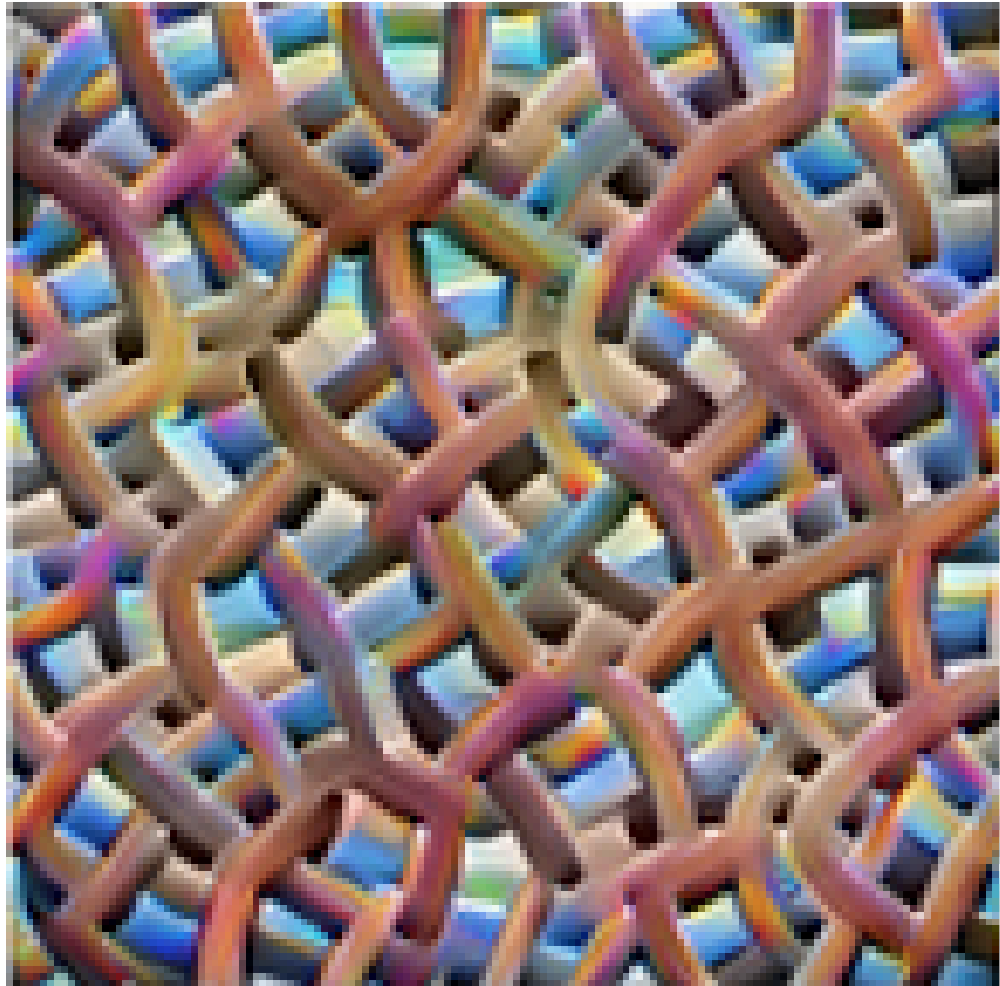
# Why do we want deep networks?



# Features in early layers

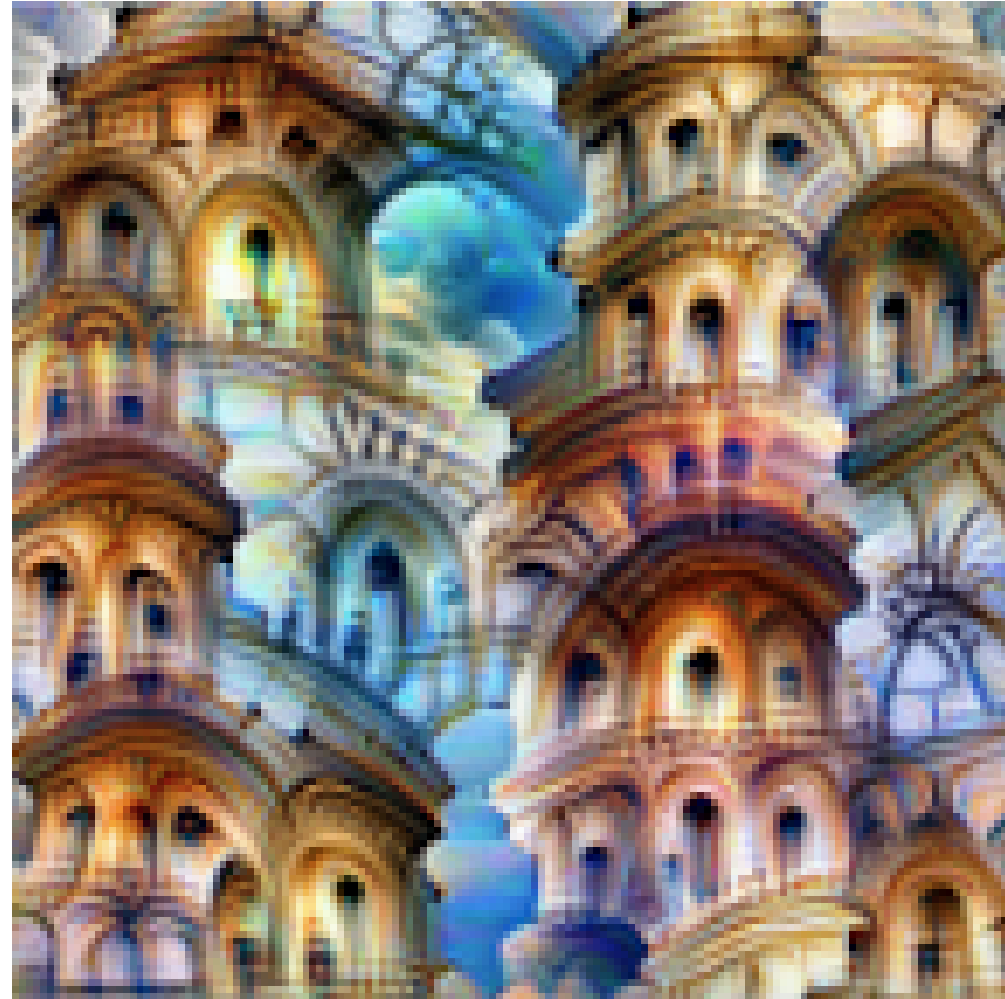
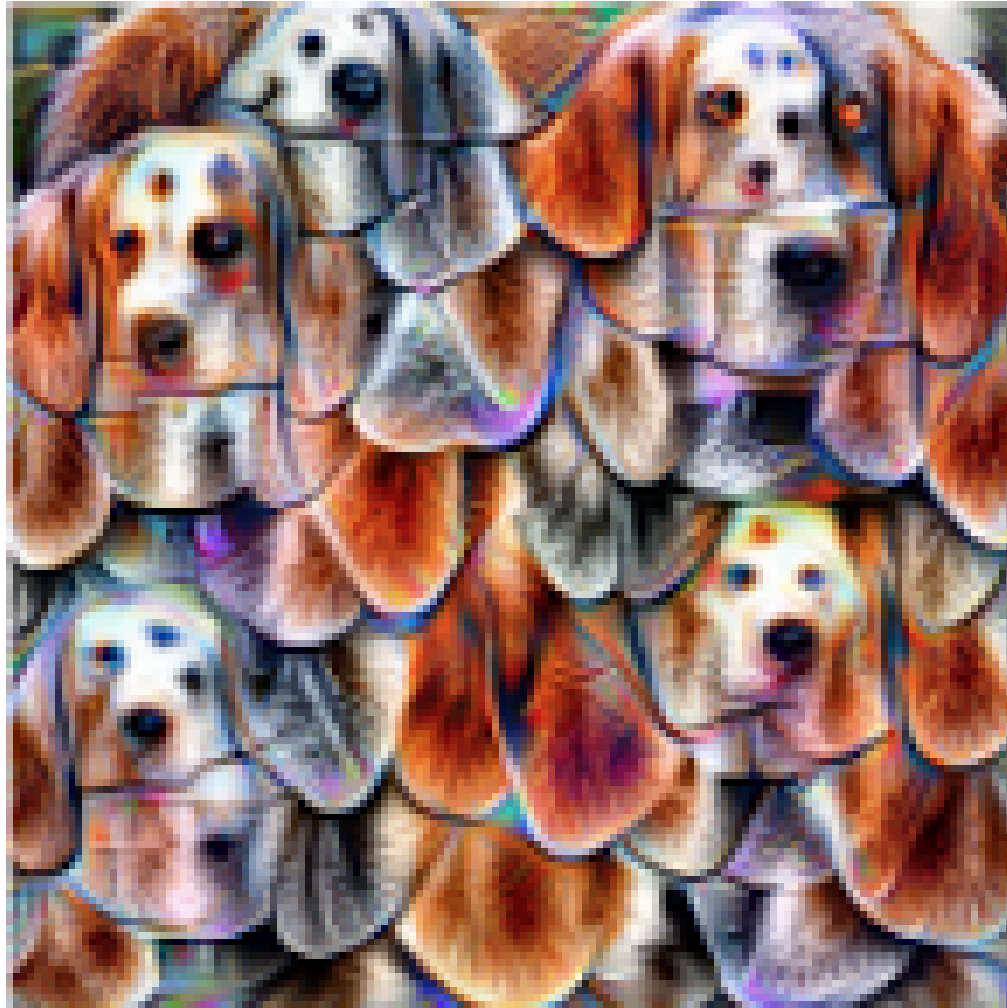


# Features in intermediate layers





# Features in late layers



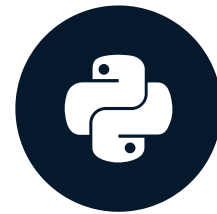
# How deep?

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

**Let's practice!**  
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# How many parameters?

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# 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,)))
```

$$\begin{aligned} \text{parameters} &= 784 * 10 + 10 \\ &= 7850 \end{aligned}$$

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

$$\begin{aligned} \text{parameters} &= 10 * 10 + 10 \\ &= 110 \end{aligned}$$

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

$$\begin{aligned} \text{parameters} &= 10 * 3 + 3 \\ &= 33 \end{aligned}$$

$$7850 + 110 + 33 = 7993$$

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

model.add(Flatten())
```

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

$$parameters = 9 * 10 + 10$$

$$= 100$$

.

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

$$= 910$$

$$parameters = 0$$

$$parameters = 7840 * 3 + 3$$

$$= 23523$$

$$100 + 910 + 0 + 23523 = 24533$$

# 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!**  
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# Reducing parameters with pooling

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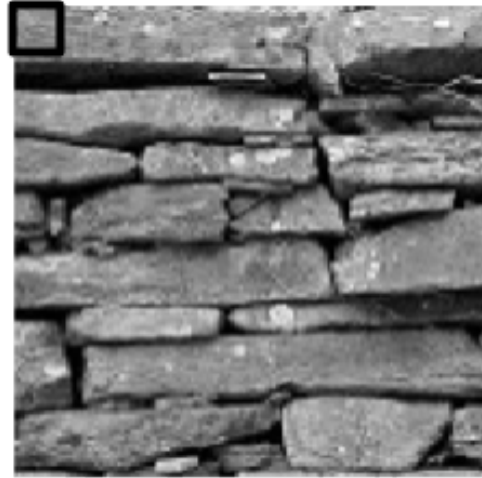
**Ariel Rokem**

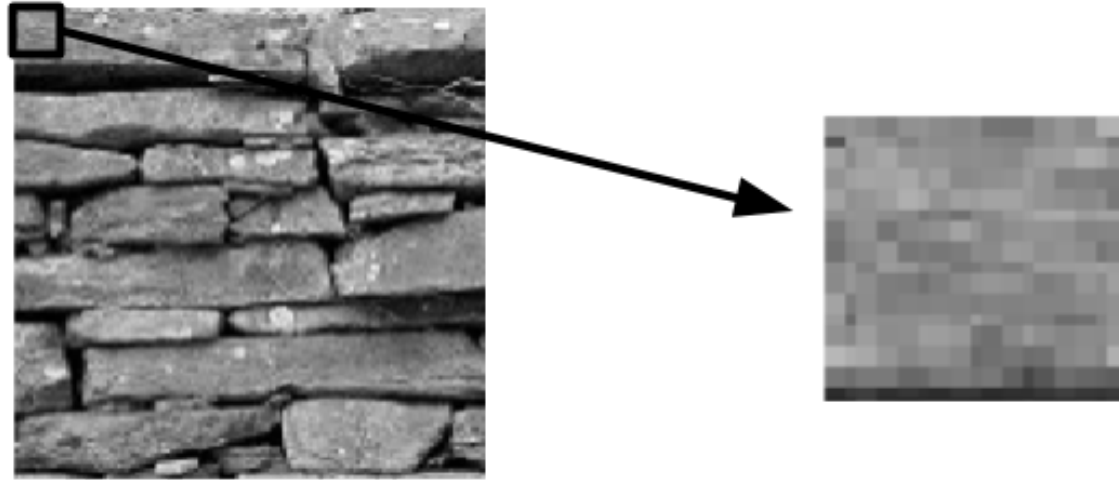
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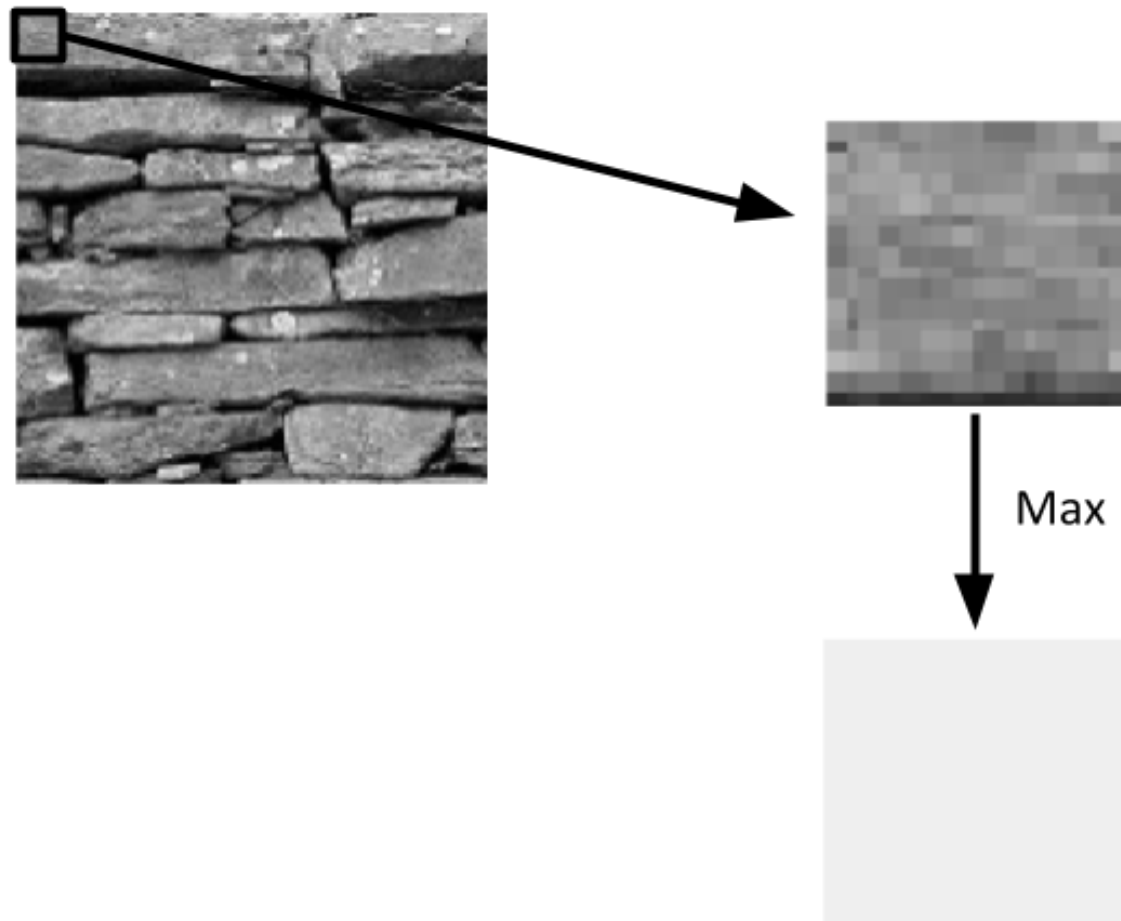
```
model.summary()
```

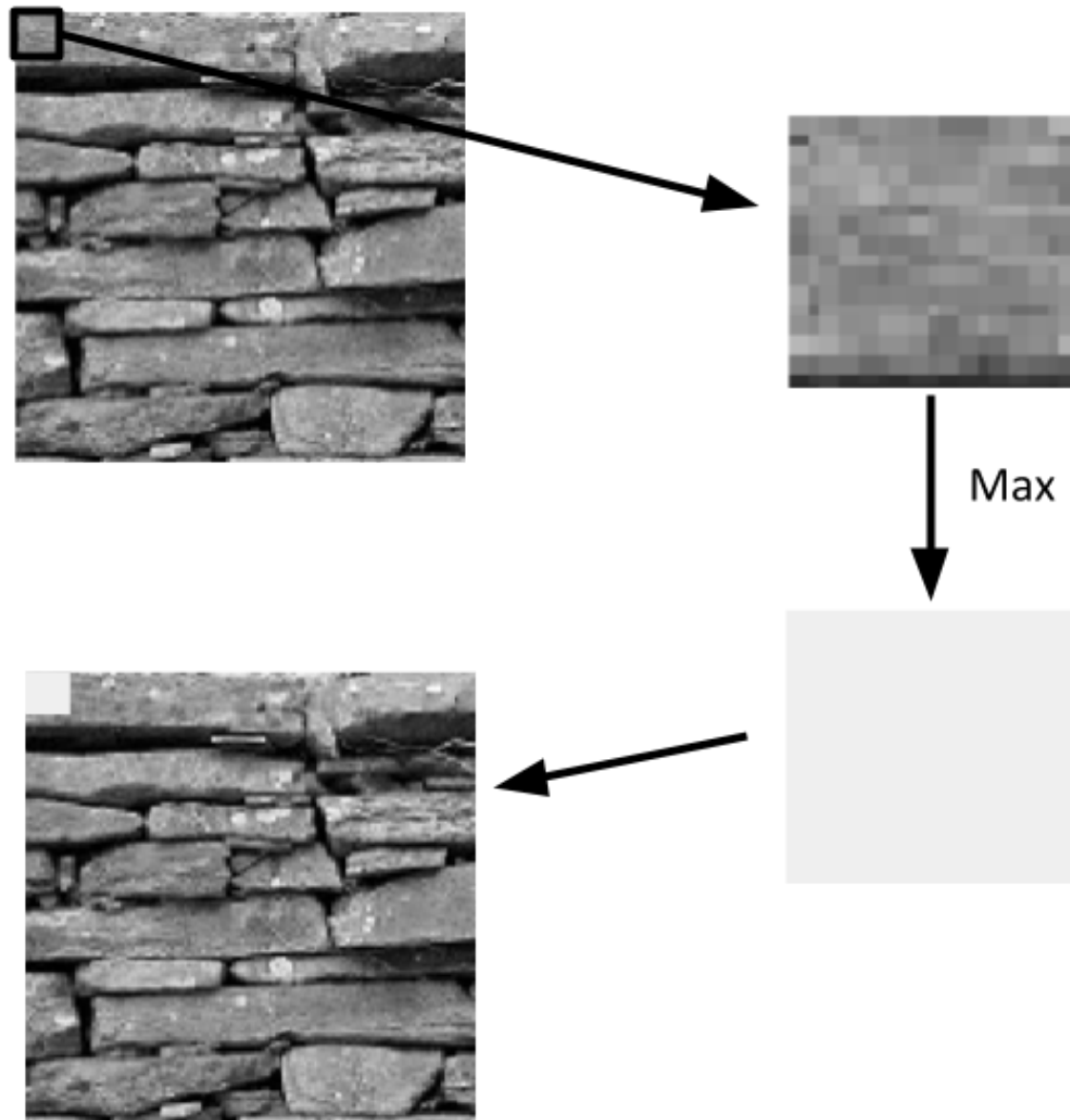
```
-----  
Layer (type)                 Output Shape                 Param #  
-----  
conv2d_12 (Conv2D)           (None, 28, 28, 5)           50  
-----  
conv2d_13 (Conv2D)           (None, 28, 28, 15)          690  
-----  
flatten_6 (Flatten)          (None, 11760)               0  
-----  
dense_9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

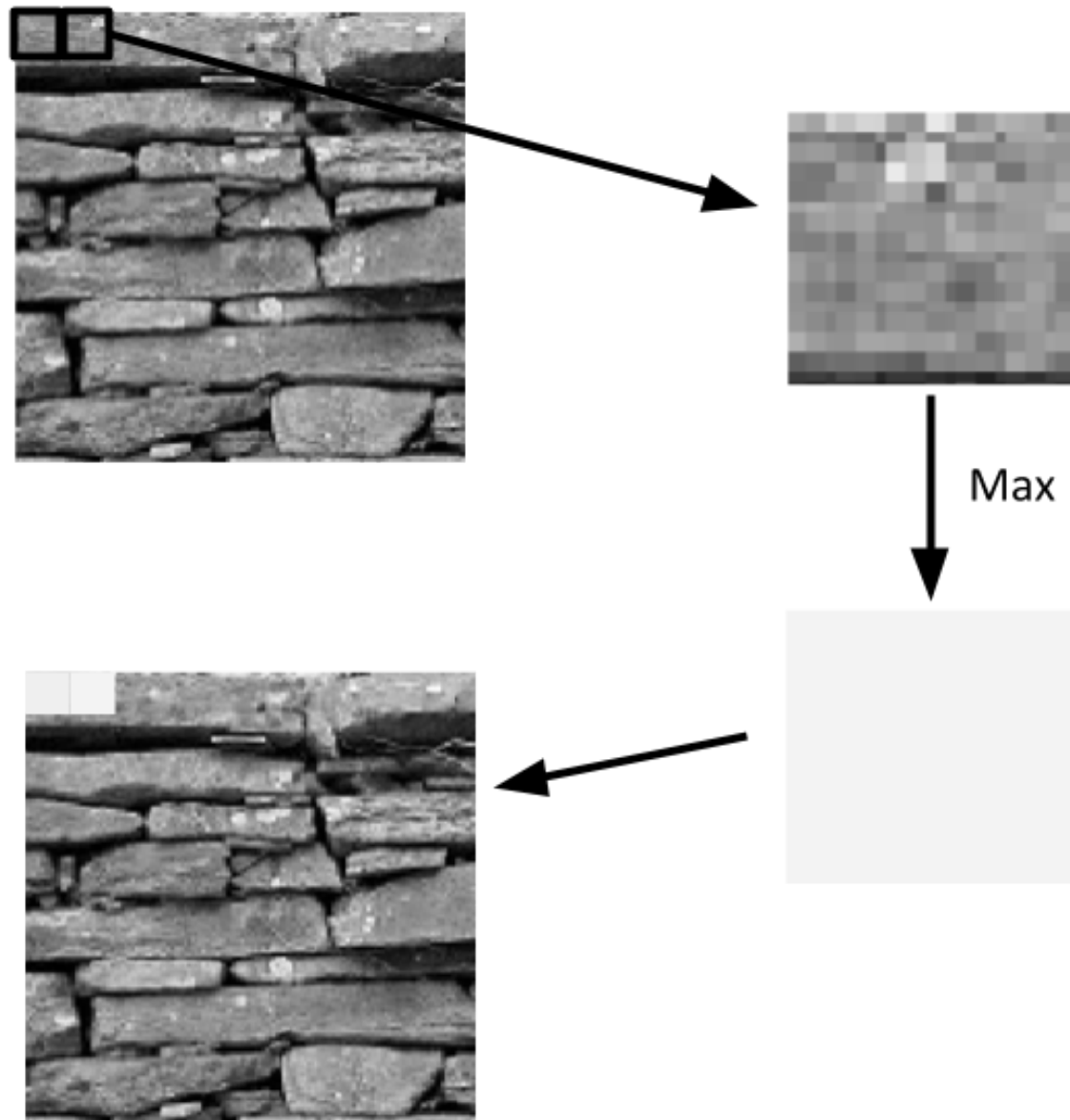
















# Implementing max pooling

```
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!

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