Convolutions

IMAGE PROCESSING WITH KERAS IN PYTHON

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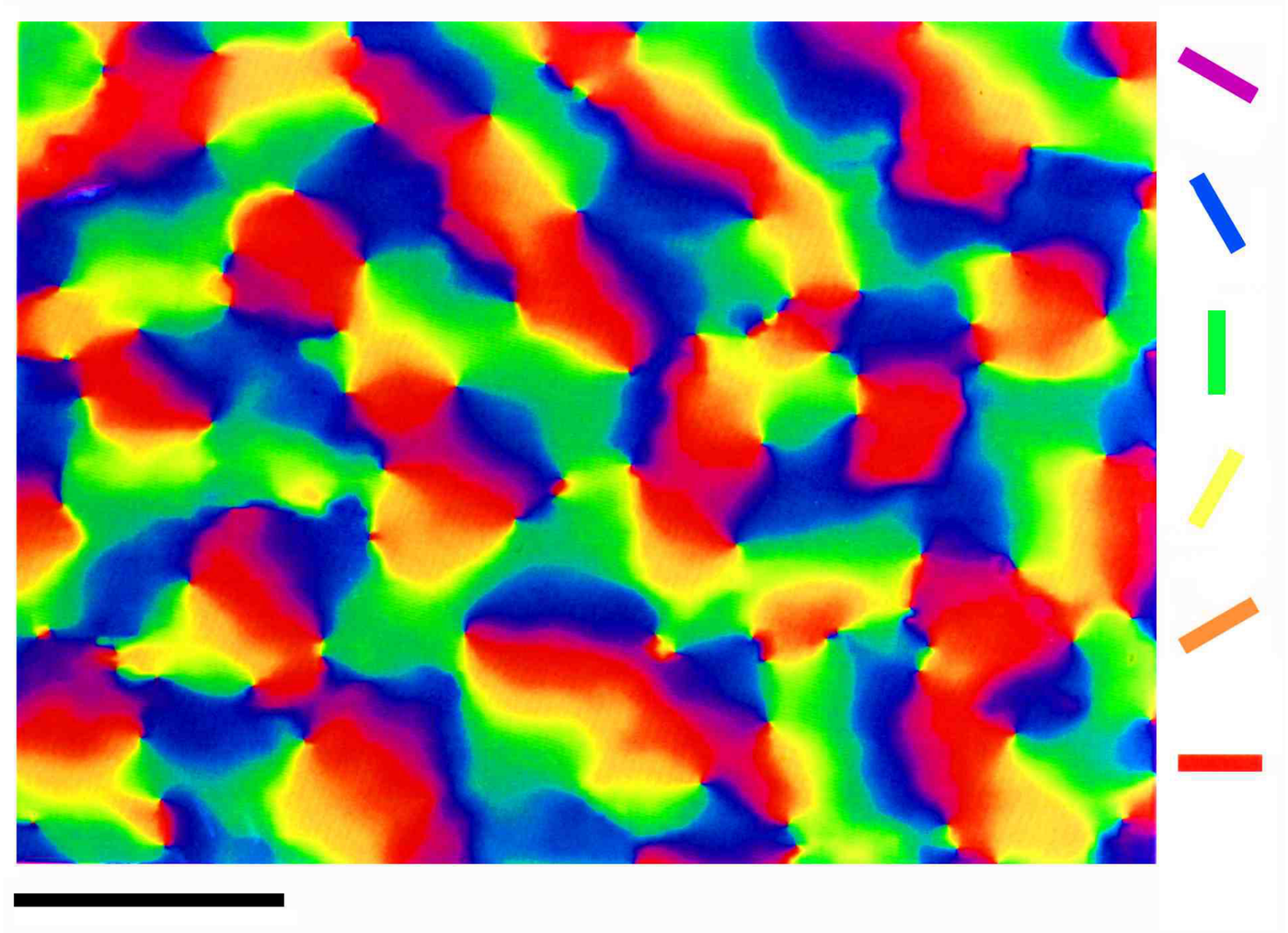
Using correlations in images

- Natural images contain spatial correlations
- For example, pixels along a contour or edge
- How can we use these correlations?

Biological inspiration



What is a convolution?

```
array = np.array([0, 0, 0, 0, 0, 1, 1, 1, 1, 1])

kernel = np.array([-1, 1])

conv = np.array([0, 0, 0, 0, 0, 0, 0, 0, 0])

conv[0] = (kernel * array[0:2]).sum()
conv[1] = (kernel * array[1:3]).sum()
conv[2] = (kernel * array[2:4]).sum()
...
for ii in range(8):
    conv[ii] = (kernel * array[ii:ii+2]).sum()
conv
```

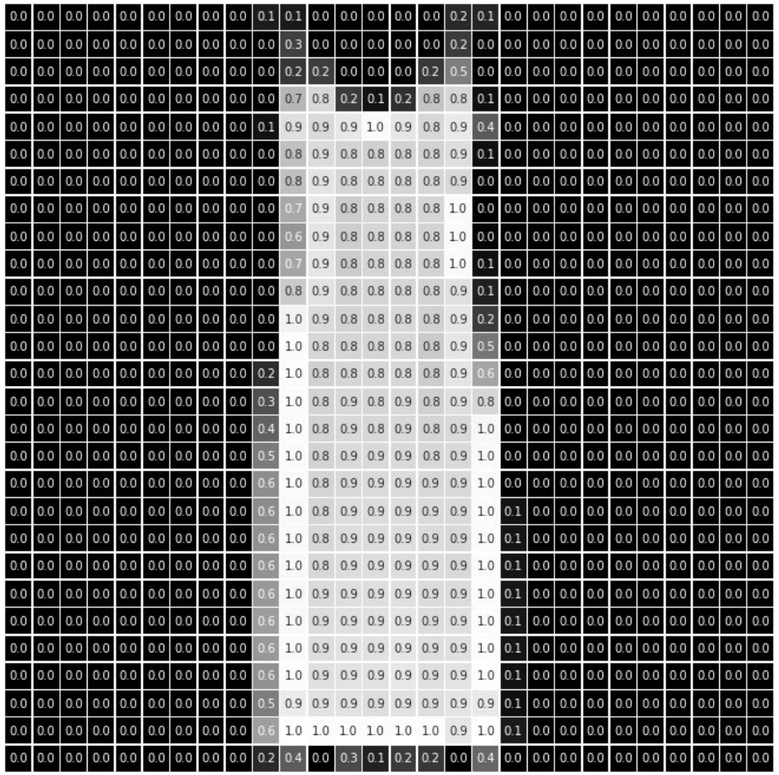
```
array([0, 0, 0, 0, 1, 0, 0, 0, 0])
```

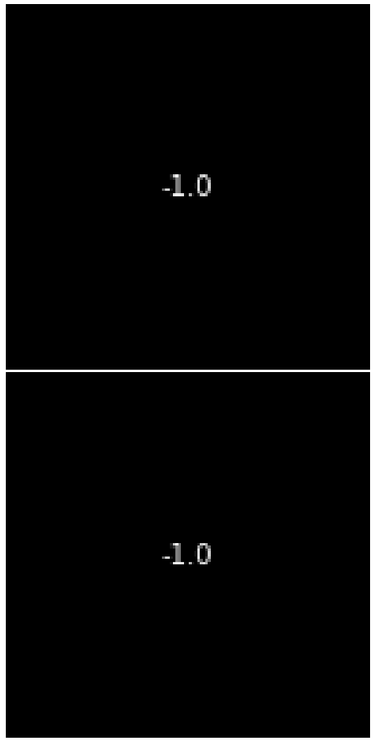
Convolution in one dimension

```
array = np.array([0, 0, 1, 1, 0, 0, 1, 1, 0, 0])
kernel = np.array([-1, 1])

conv = np.array([0, 0, 0, 0, 0, 0, 0, 0, 0])
for ii in range(8):
    conv[ii] = (kernel * array[ii:ii+2]).sum()

conv
```

```
array([ 0,  1,  0, -1,  0,  1,  0, -1,  0])
```

Image convolution

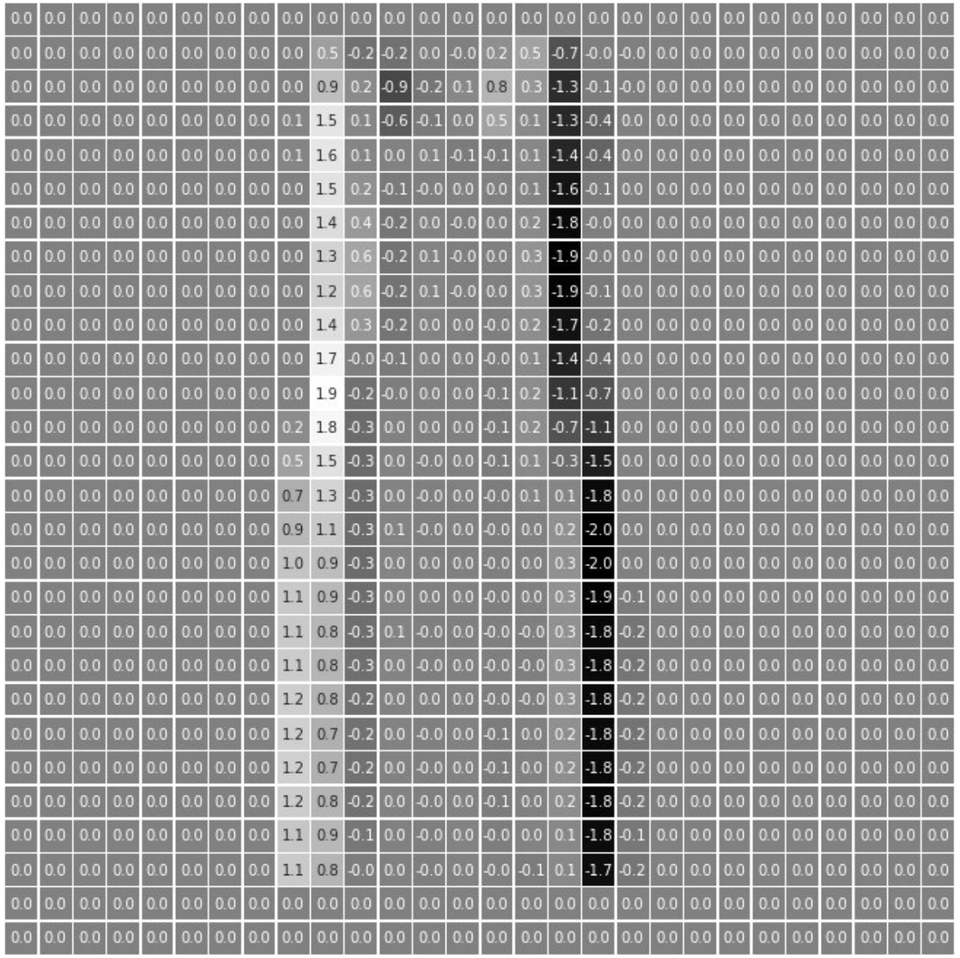




1.0

1.0

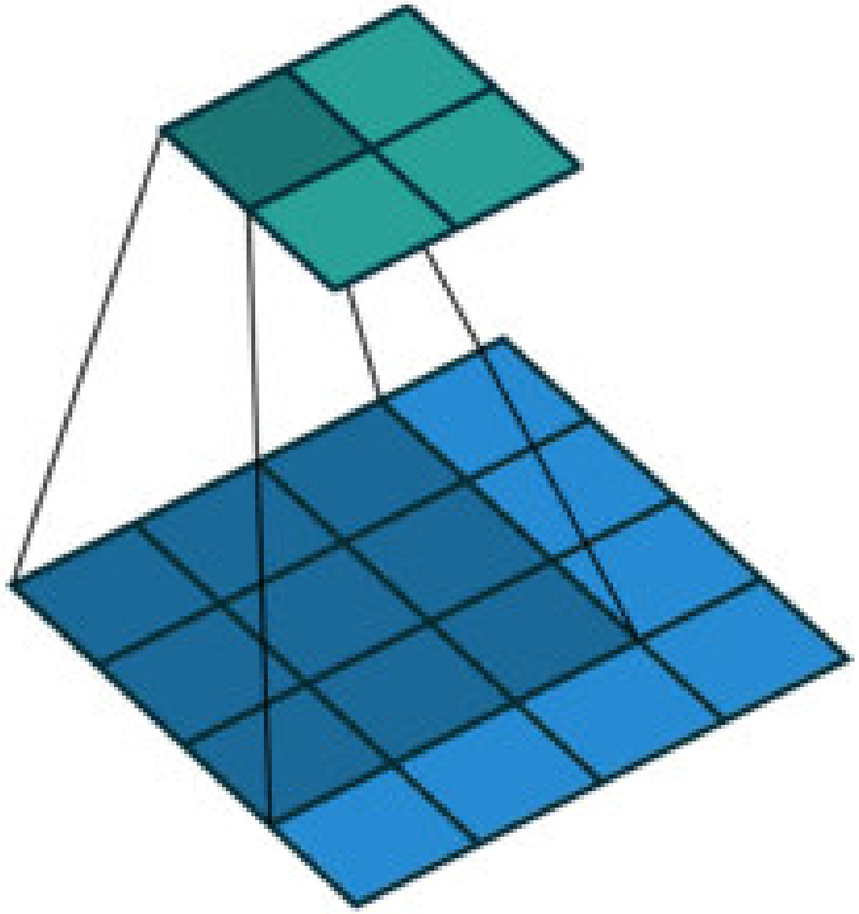
Image convolution



Two-dimensional convolution

```
kernel = np.array([[-1, 1],
                   [-1, 1]])


conv = np.zeros((27, 27)

for ii in range(27):
    for jj in range(27):
        window = image[ii:ii+2, jj:jj+2]
        conv[ii, jj] = np.sum(window * kernel)
```

Convolution



Let's practice!

IMAGE PROCESSING WITH KERAS IN PYTHON

Implementing convolutions in Keras

IMAGE PROCESSING WITH KERAS IN PYTHON

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Keras Convolution layer

```
from keras.layers import Conv2D
Conv2D(10, kernel_size=3, activation='relu')
```

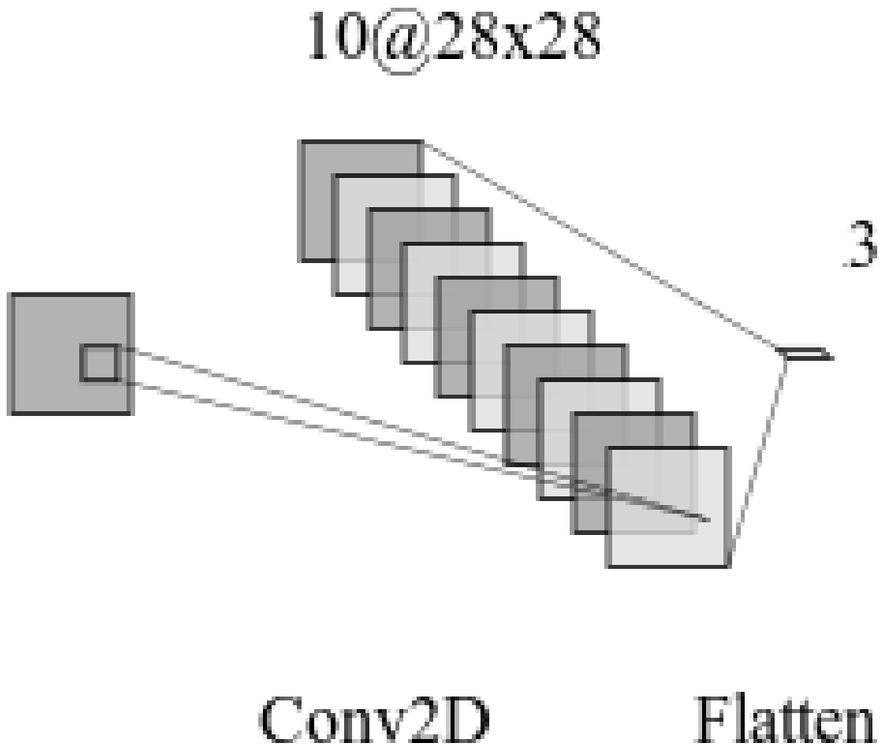
Integrating convolution layers into a network

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

model = Sequential()
model.add(Conv2D(10, kernel_size=3, activation='relu',
          input_shape=(img_rows, img_cols, 1)))

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

Our CNN



Fitting a CNN

```
model.compile(optimizer='adam',
              loss='categorical_crossentropy',
              metrics=['accuracy'])

train_data.shape
```

```
(50, 28, 28, 1)
```

```
model.fit(train_data, train_labels, validation_split=0.2,
          epochs=3)

model.evaluate(test_data, test_labels, epochs=3)
```

Let's practice!

IMAGE PROCESSING WITH KERAS IN PYTHON

Tweaking your convolutions

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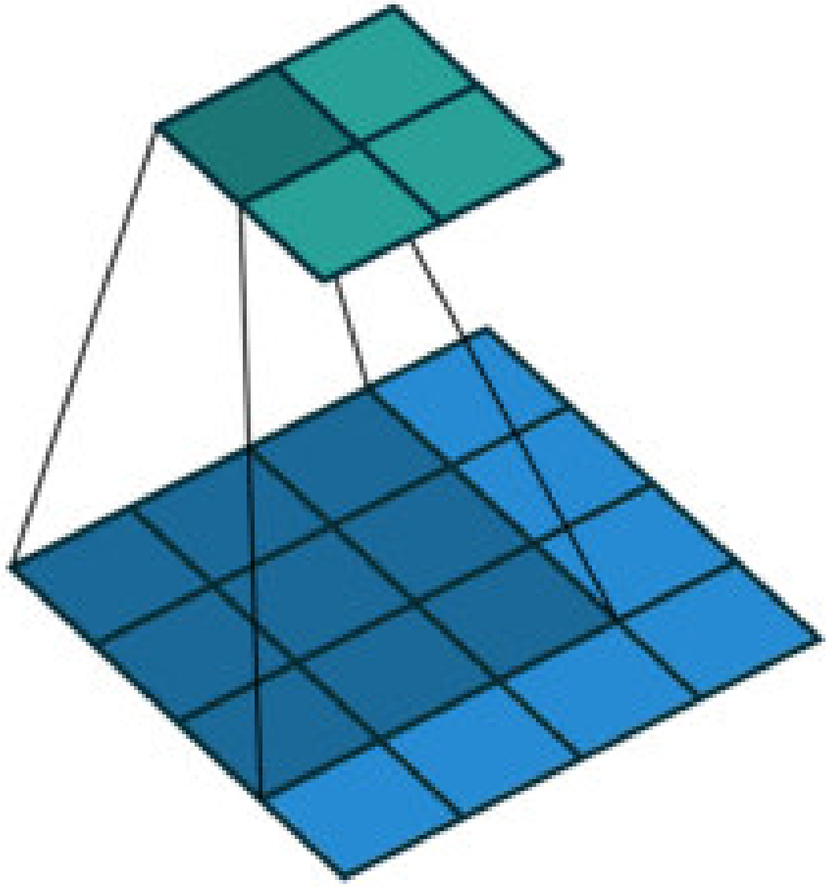
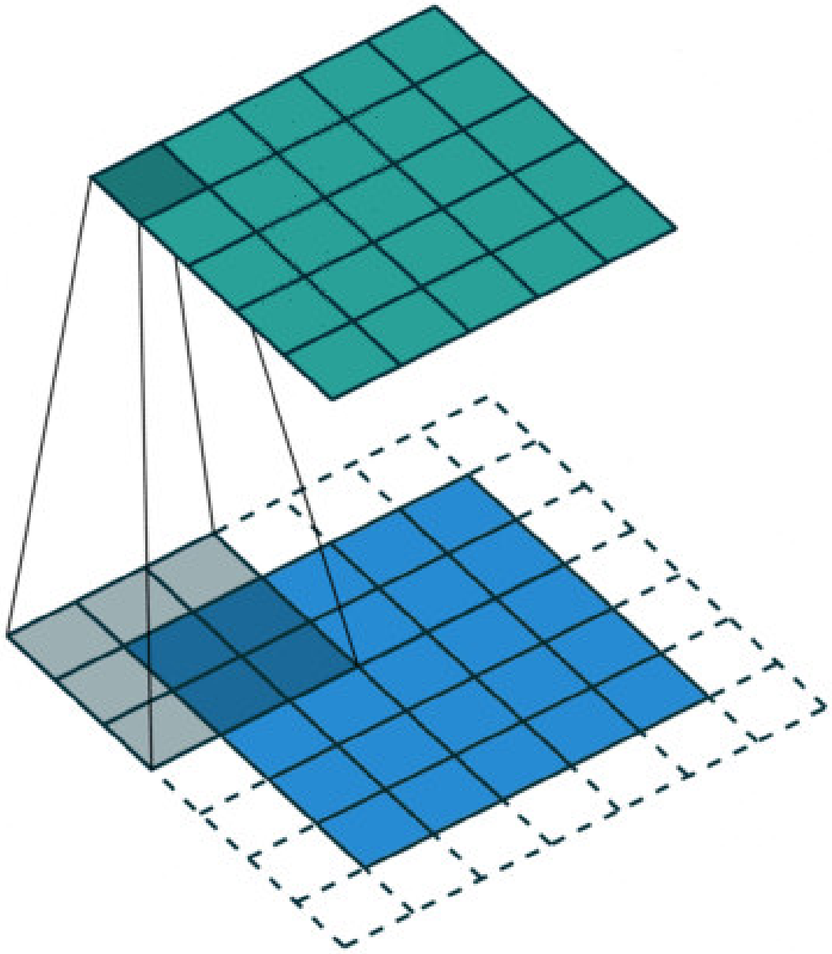
Convolution



Convolution with zero padding



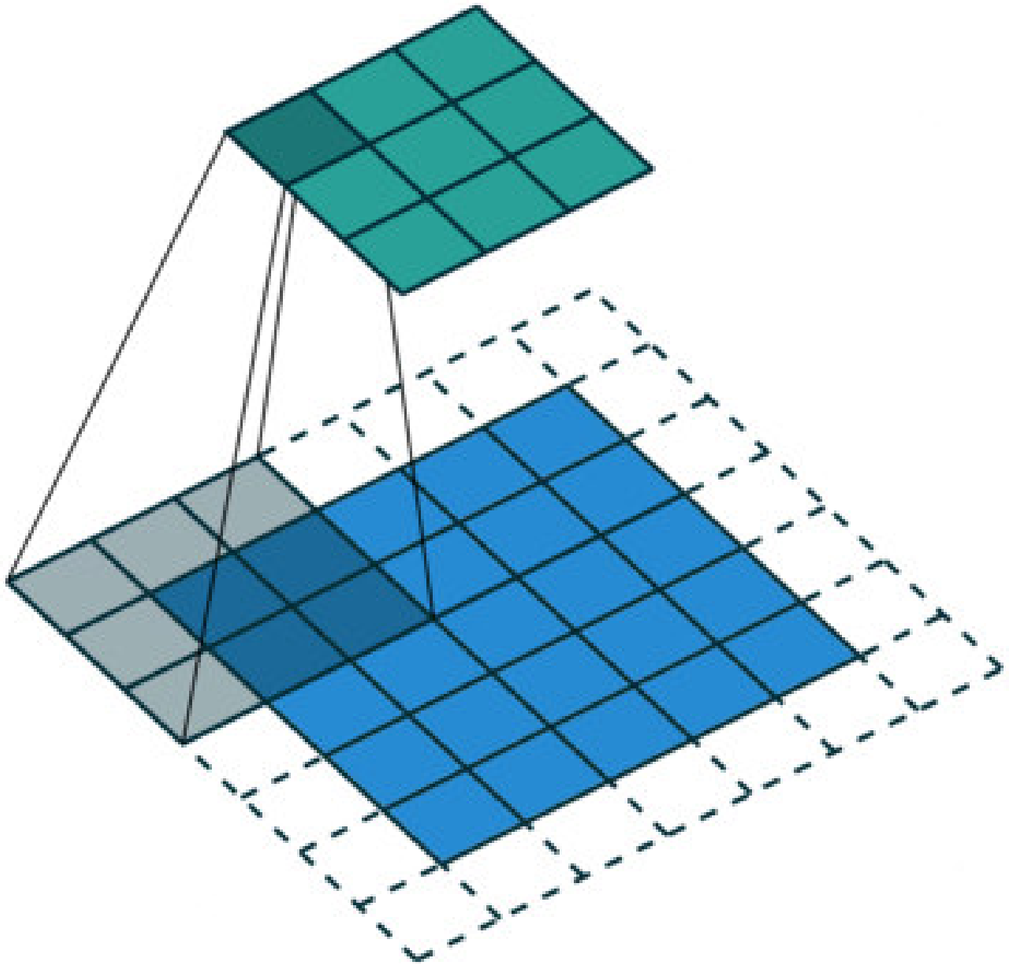
Zero padding in Keras

```
model.add(Conv2D(10, kernel_size=3, activation='relu',
                 input_shape=(img_rows, img_cols, 1)),
                 padding='valid')
```

Zero padding in Keras

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

Strides



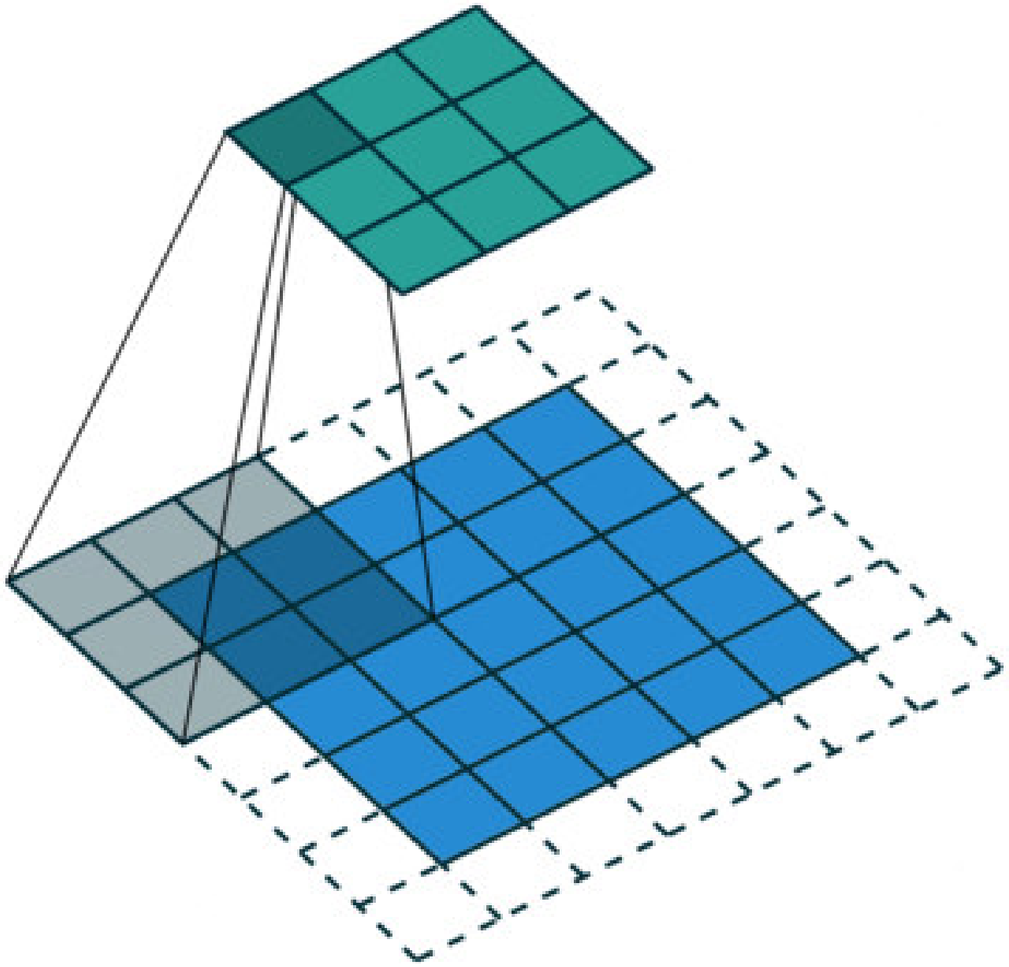
Strides in Keras

```
model.add(Conv2D(10, kernel_size=3, activation='relu',
                 input_shape=(img_rows, img_cols, 1)),
          strides=1)
```

Strides in Keras

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

Example



Calculating the size of the output

$$O = ((I - K + 2P)/S) + 1$$

where

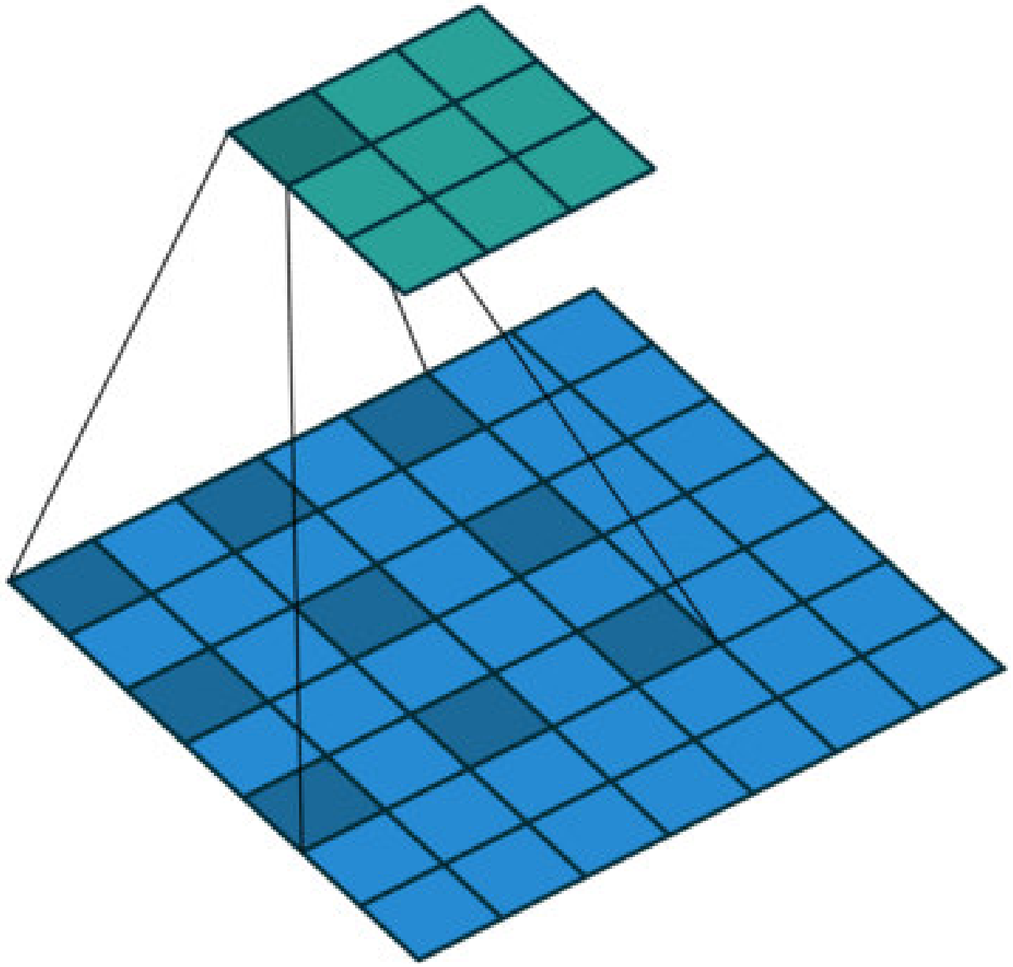
- I = size of the input
- K = size of the kernel
- P = size of the zero padding
- S = strides

Calculating the size of the output

$$28 = ((28 - 3 + 2)/1) + 1$$

$$10 = ((28 - 3 + 2)/3) + 1$$

Dilated convolutions



Dilation in Keras

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

Going deeper

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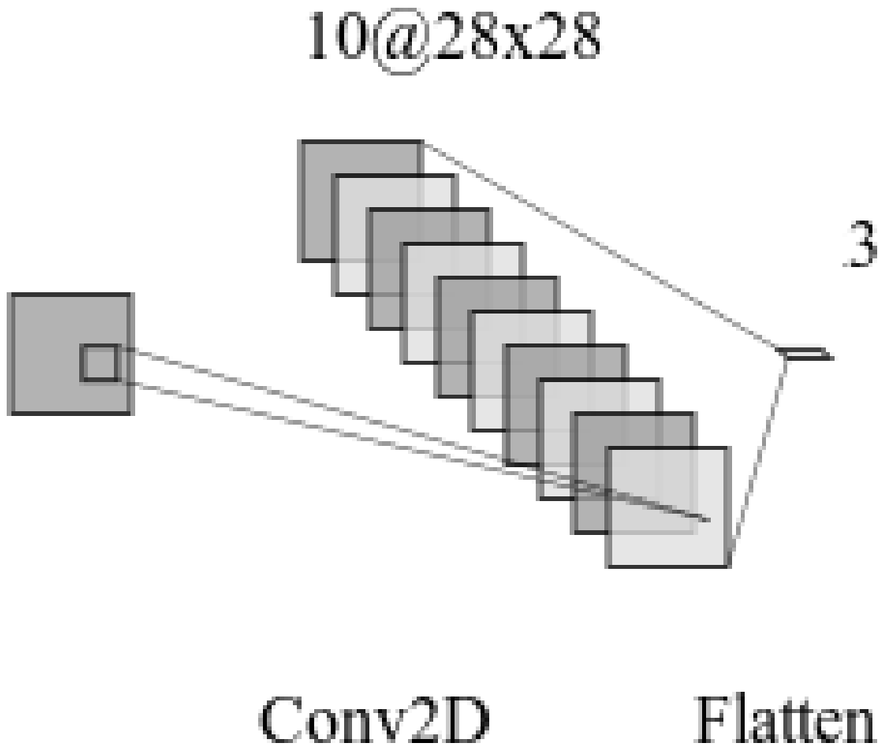
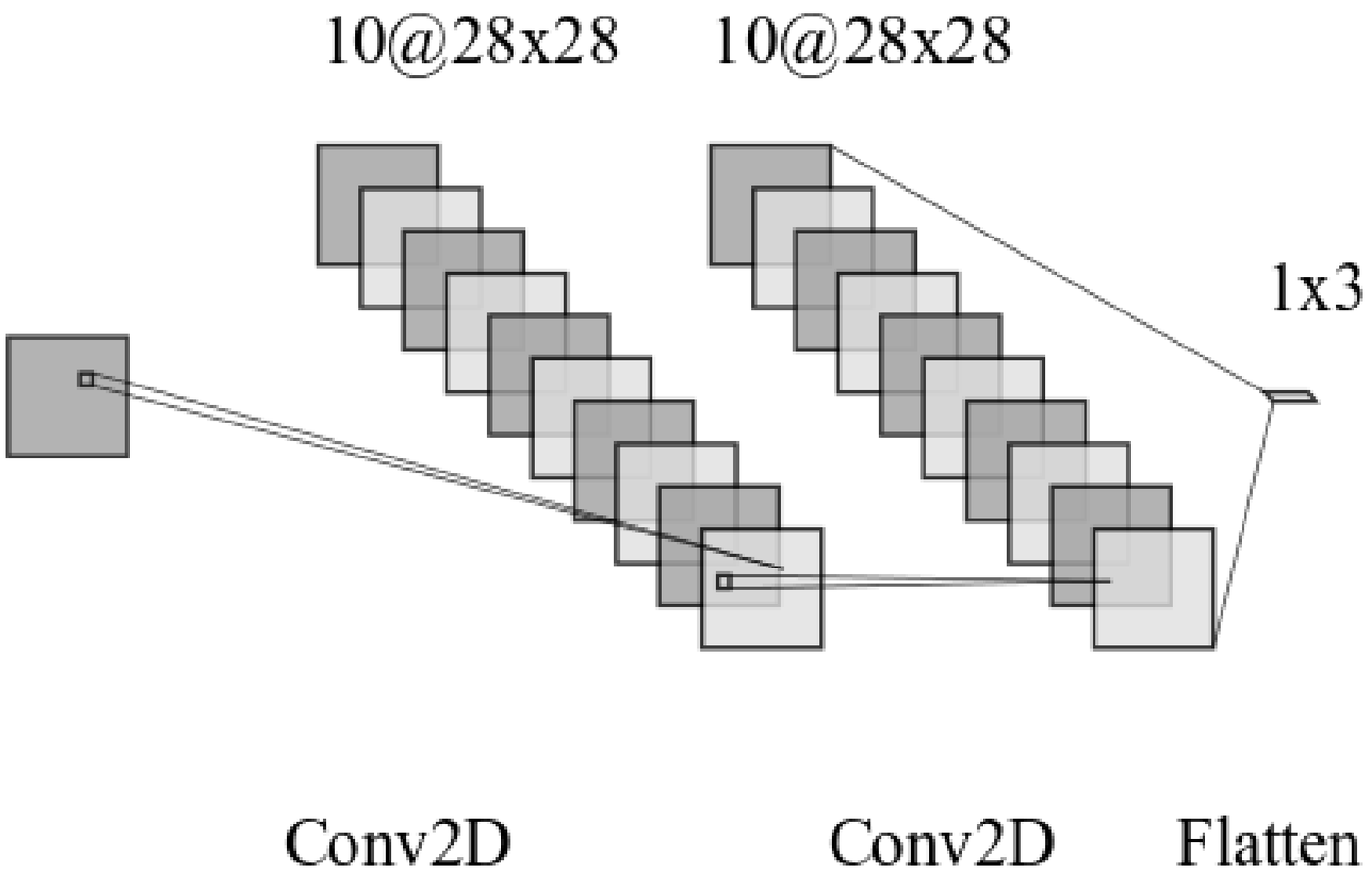
Network with one convolutional layer



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'))
```

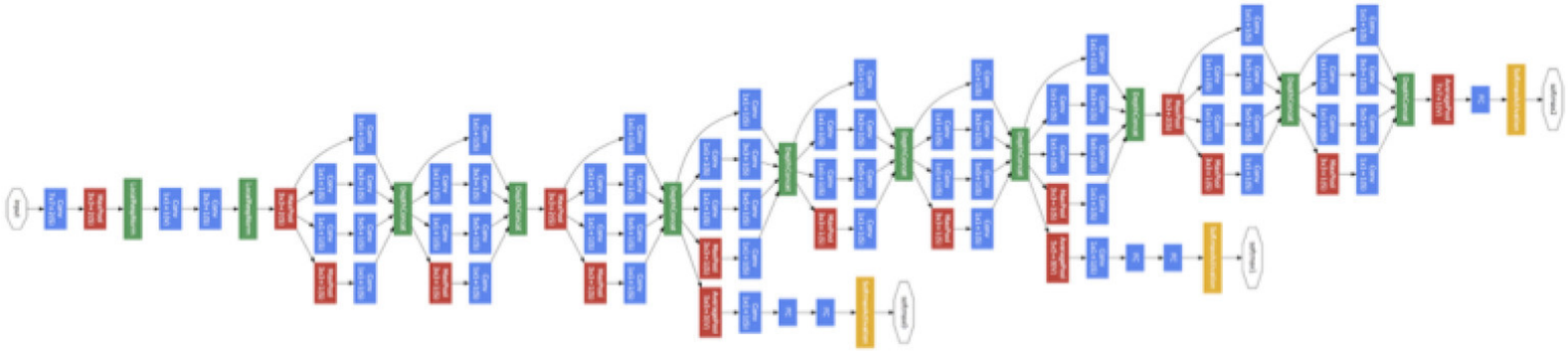
Building a deeper network



Building a deep network

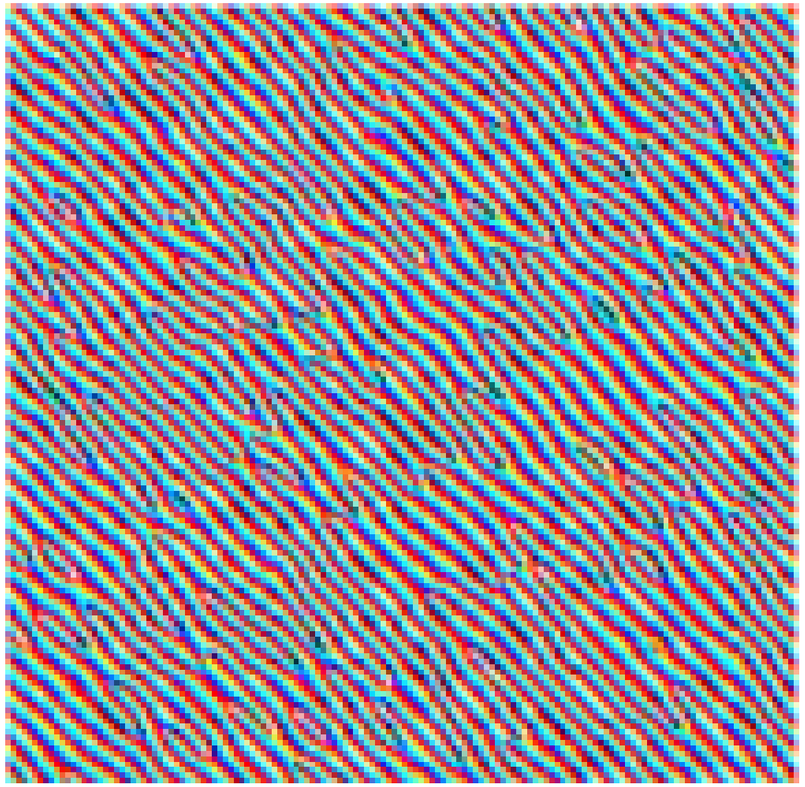
```
model = Sequential()
model.add(Conv2D(10, kernel_size=2, activation='relu',
                 input_shape=(img_rows, img_cols, 1),
                 padding='equal'))

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

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

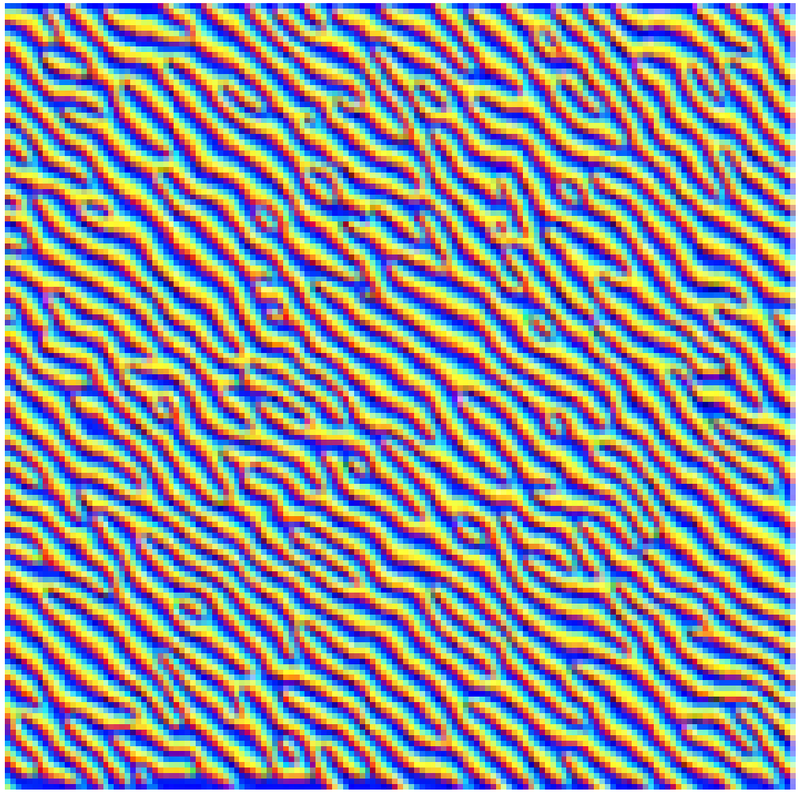
Why do we want deep networks?



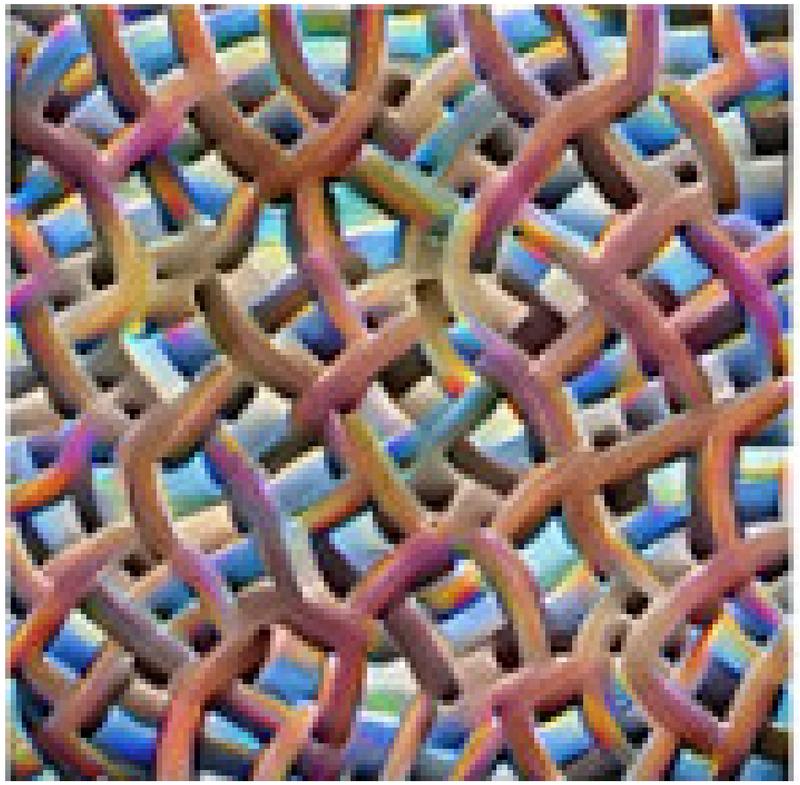
Convolution
Pooling
Softmax
Other

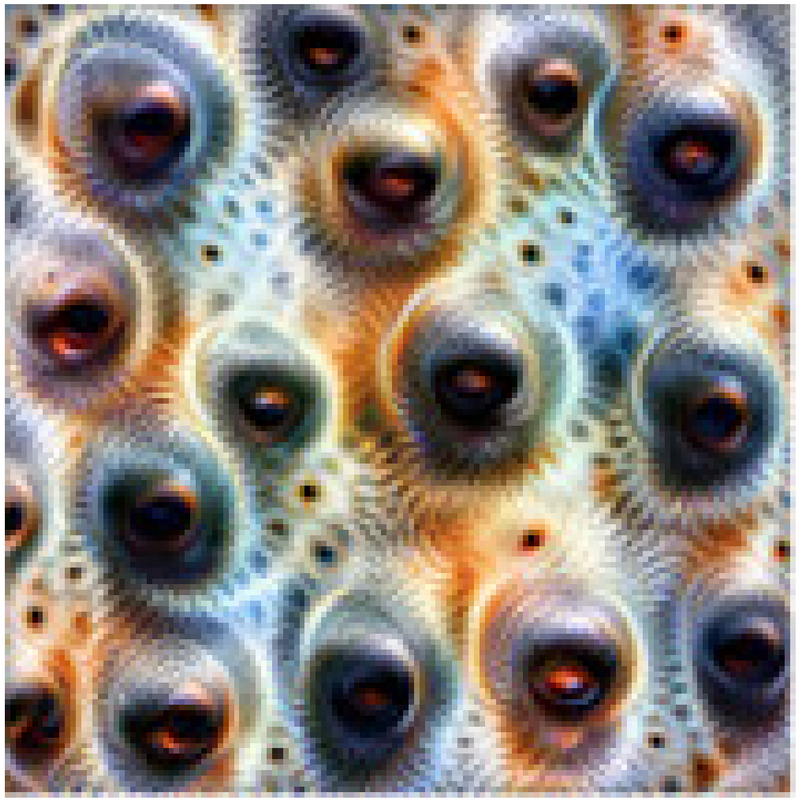
Features in early layers



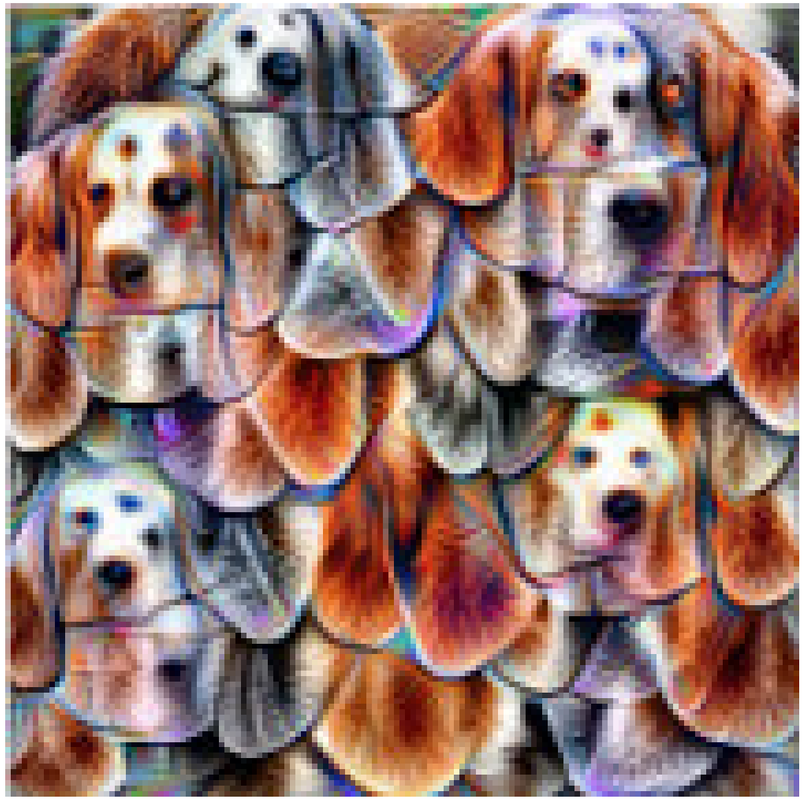


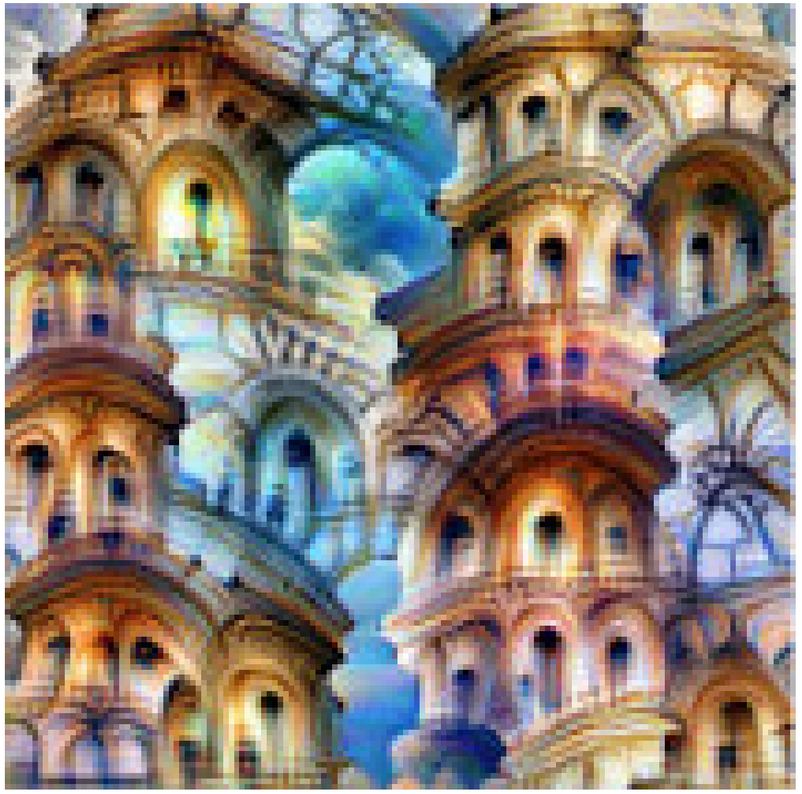
Features in intermediate layers





Features in late layers





How deep?

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

Let's practice!

IMAGE PROCESSING WITH KERAS IN PYTHON

How many parameters?

IMAGE PROCESSING WITH KERAS IN PYTHON

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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,)))
```

$$parameters = 784 * 10 + 10$$

$$= 7850$$

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



model.add(Flatten())
```

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

$$parameters = 9 * 10 + 10$$

$$= 100$$

.

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

$$= 910$$

$$parameters = 0$$

$$parameters = 7840 * 3 + 3$$

$$= 23523$$

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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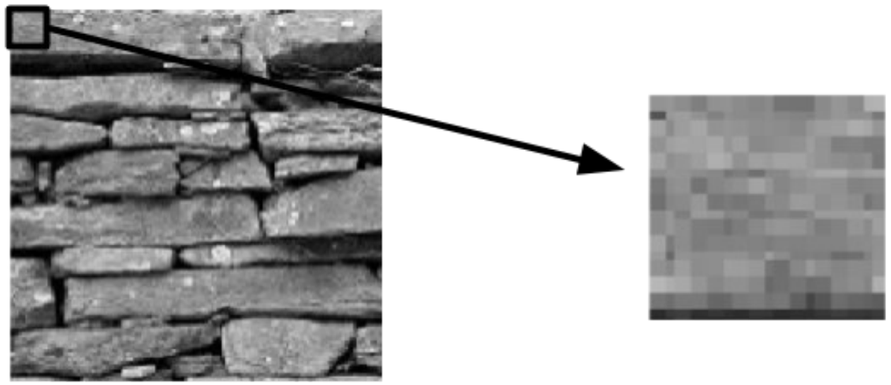
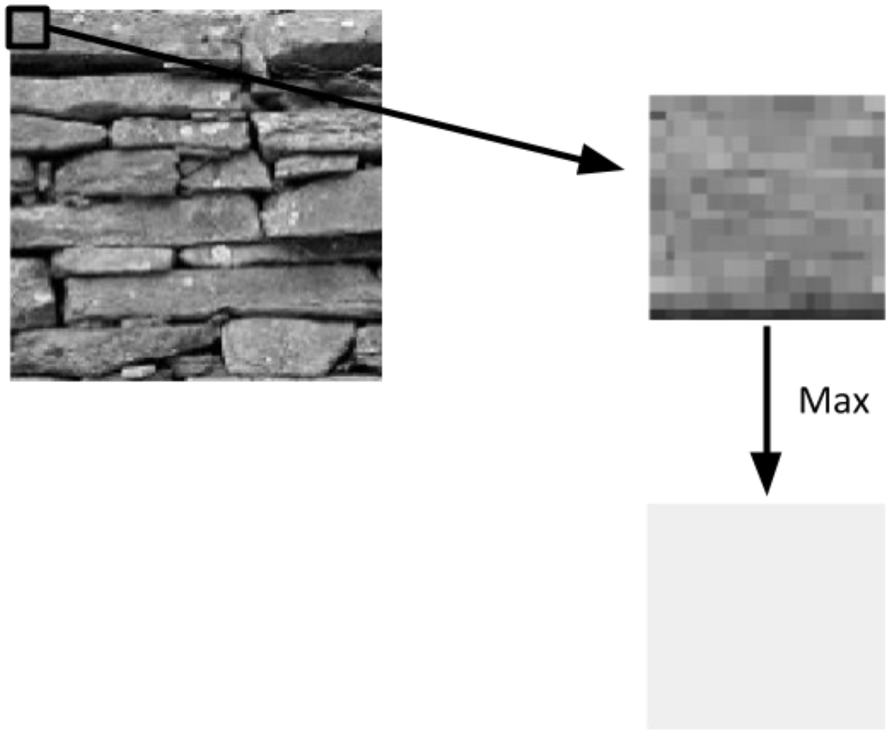
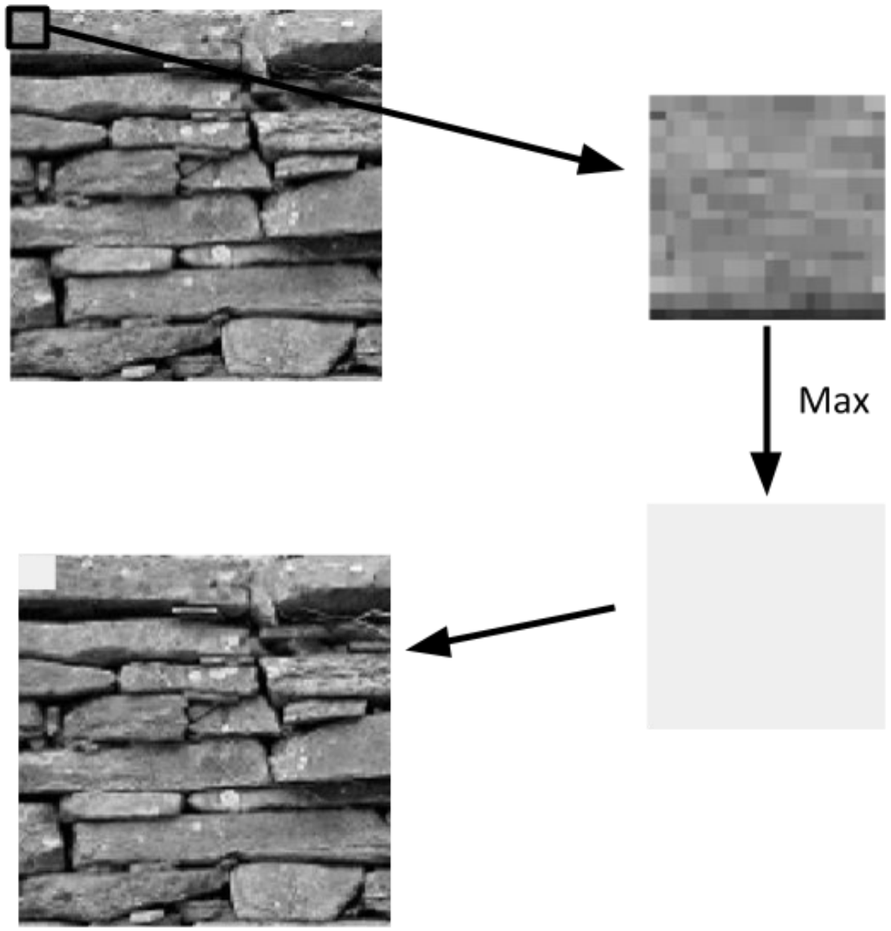
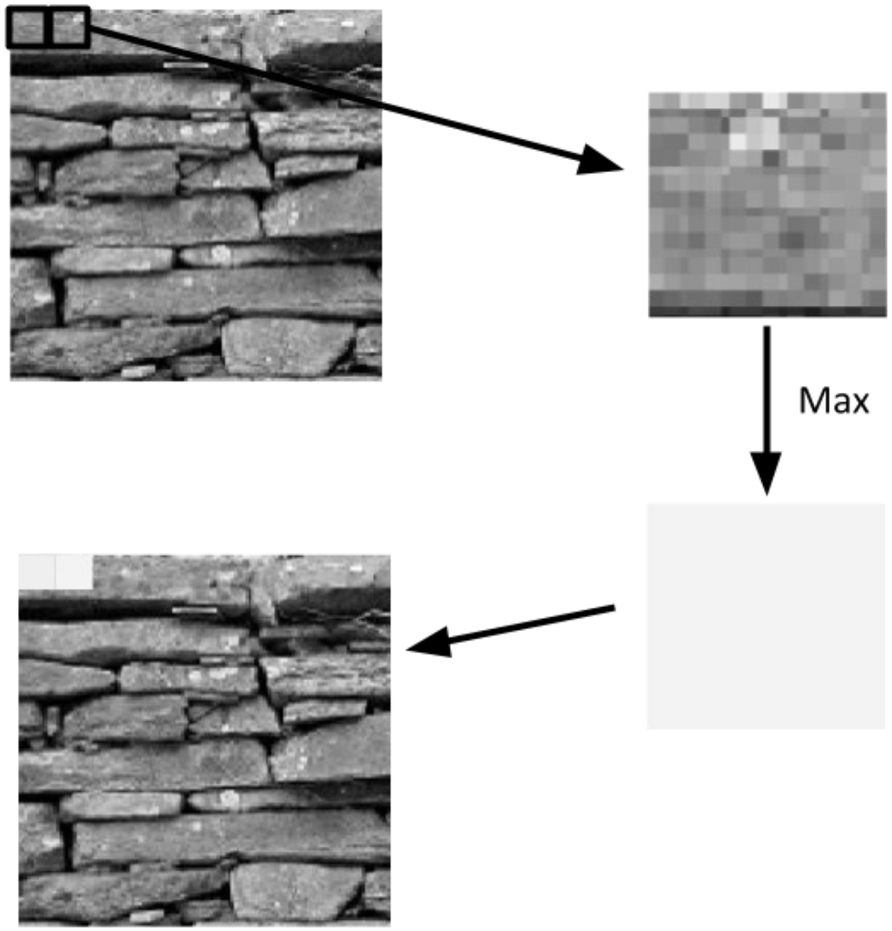
```
model.summary()
```

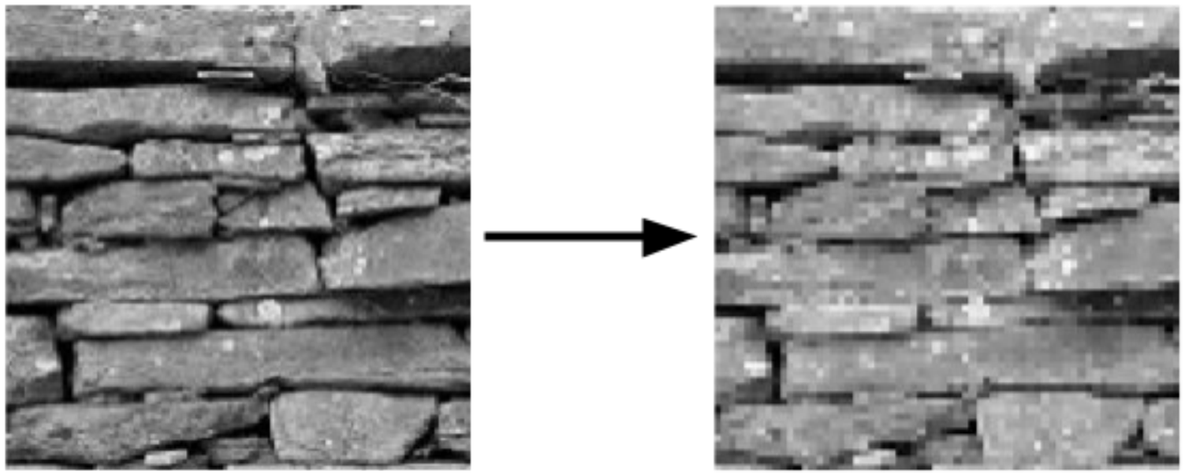
```
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_12 (Conv2D)           (None, 28, 28, 5)         50
_________________________________________________________________
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
=================================================================
```