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# Convolutional Neural Networks
# CASA course
# (09/11/2018)

D. Freire-Obregón, PhD.

Edificio Central del Parque Tecnológico
Campus Universitario de Tafira
35017 Las Palmas de Gran Canaria
e-mail: info@siani.es · www.siani.es


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# Plan for TS4

- Deep Learning
- Convolutional Operation
- Understanding border effects
- Max-pooling operation
- Fully Connected Layer
- What is happening?
- Where to use CNN?

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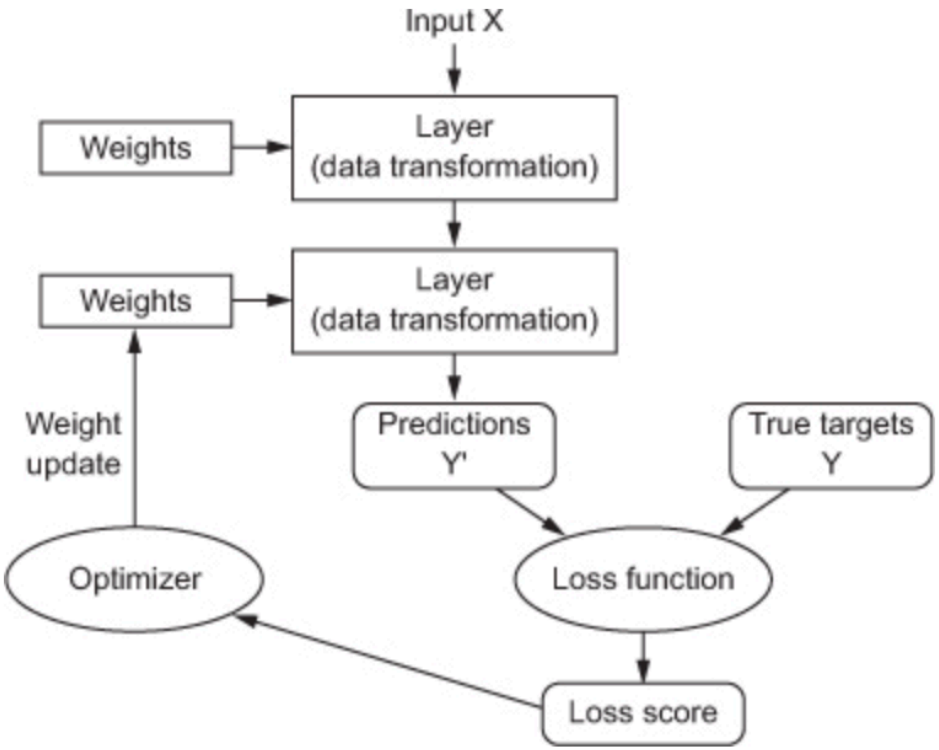
# Deep Learning

Does this scheme change? No!

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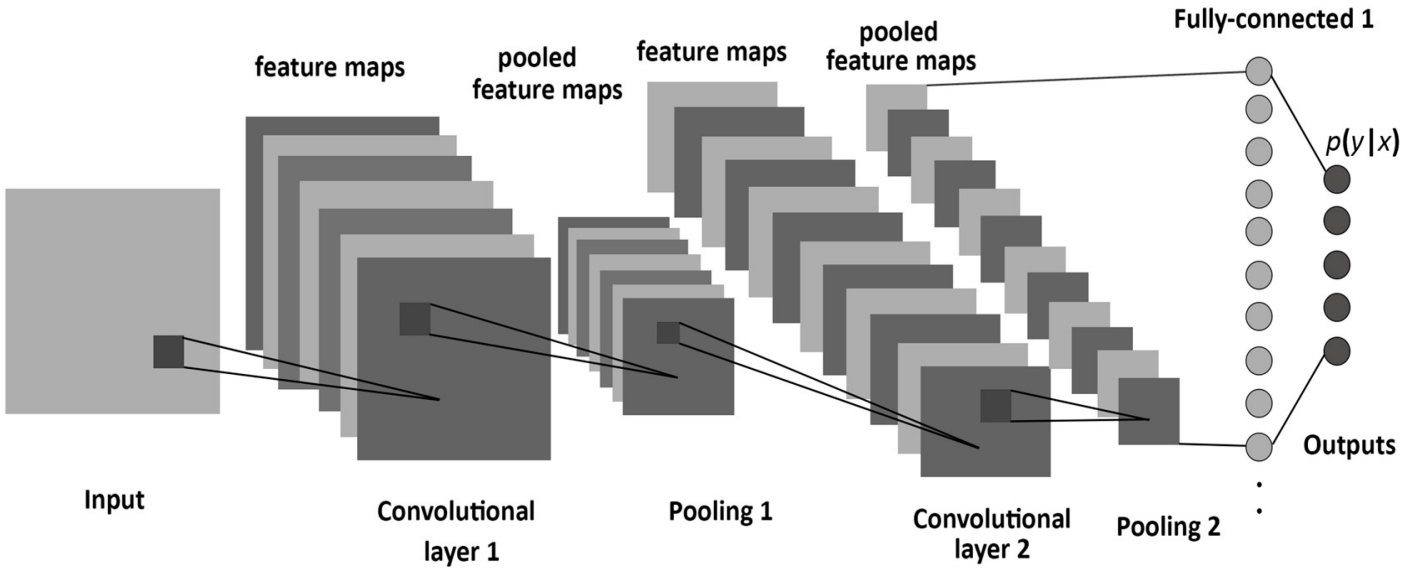
# Deep Learning

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# Convolutional Operation

What is the difference between a densely connected layer and a convolution layer?

- Dense layers → Learn global patterns in their input space.
- Convolutional layers → Learn local patterns

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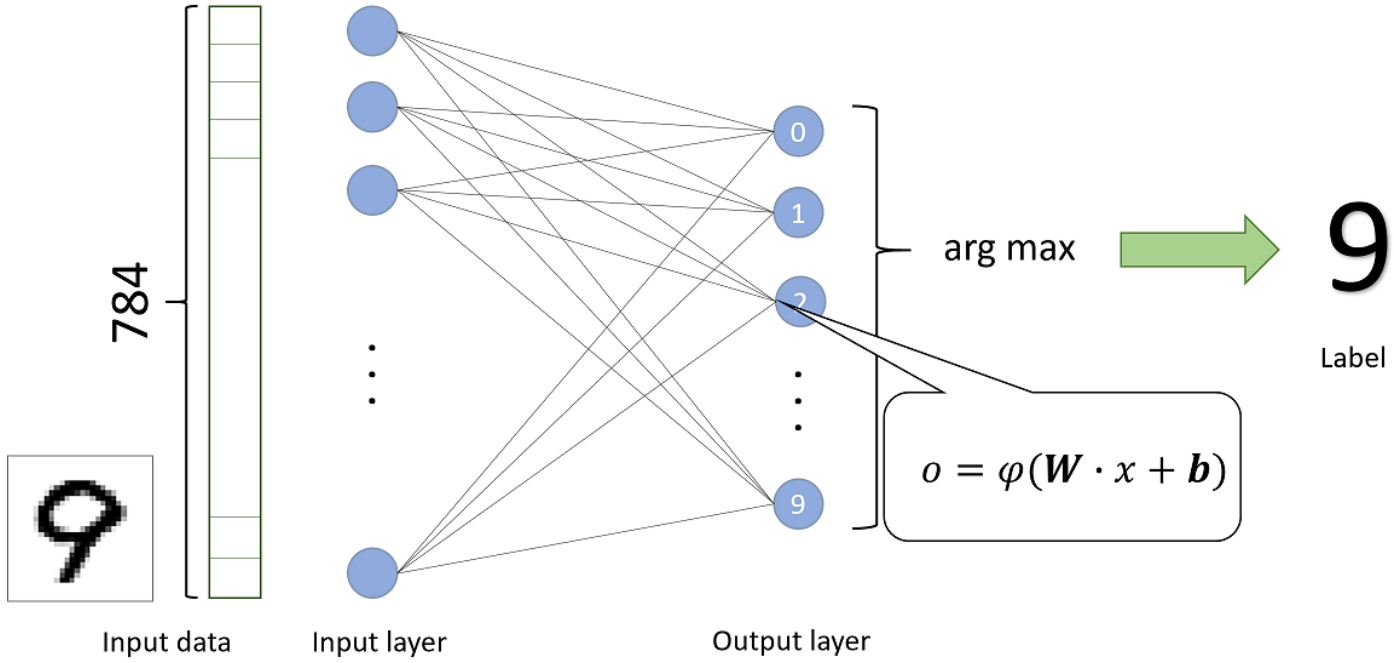
# Convolutional Operation

Dense layers:

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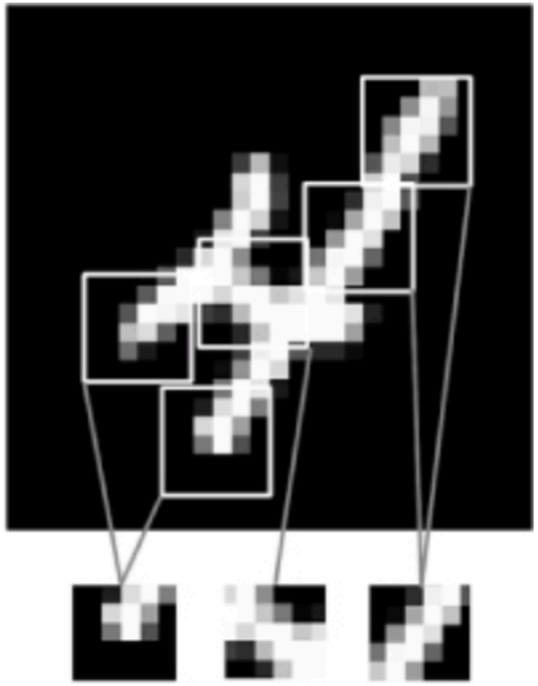
# Convolutional Operation

Images can be broken into local patterns:
Edges, textures, etc…



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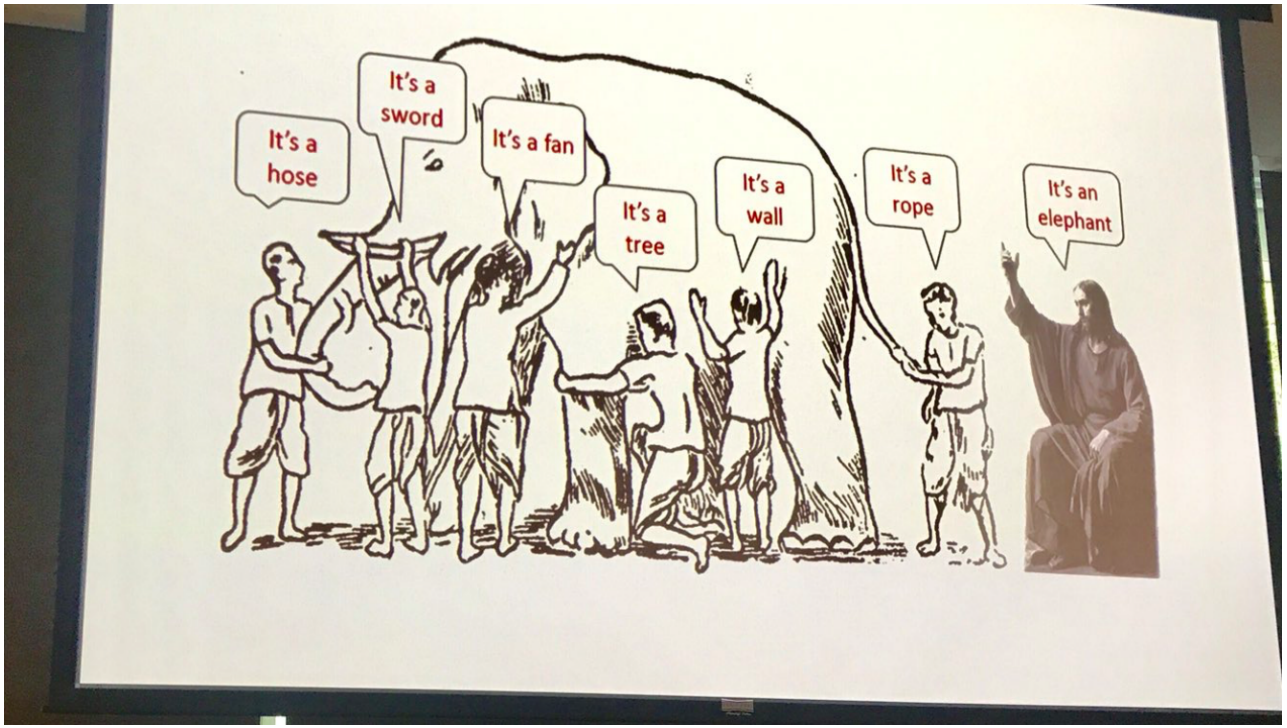
# Convolutional Operation

Convolutional layers:

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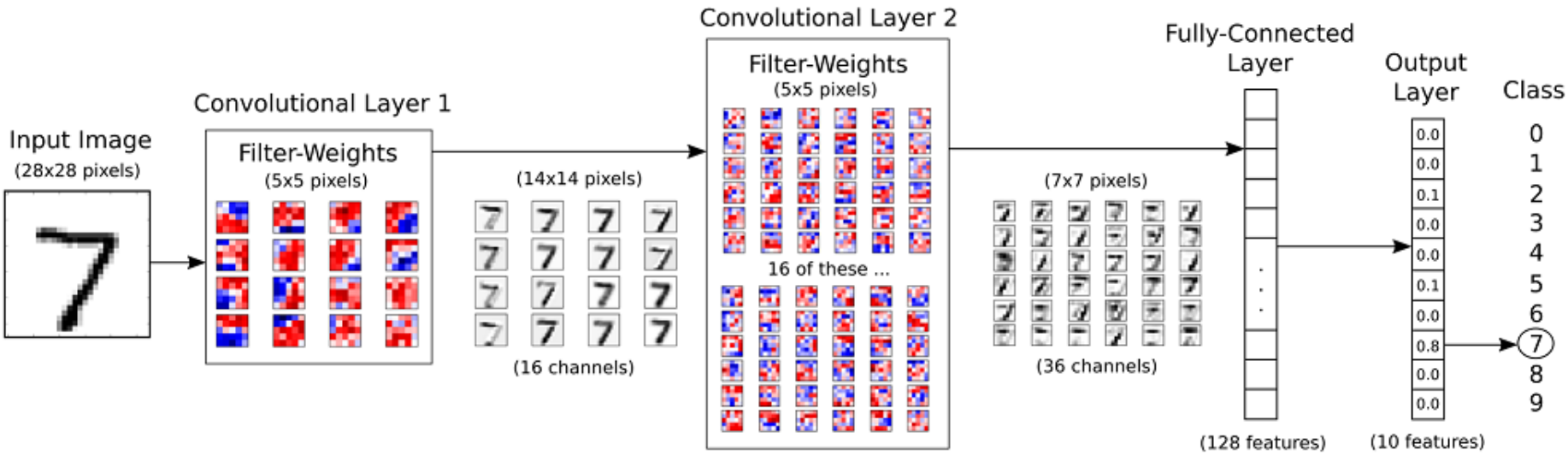
# Convolutional Operation

Convolutional layers:





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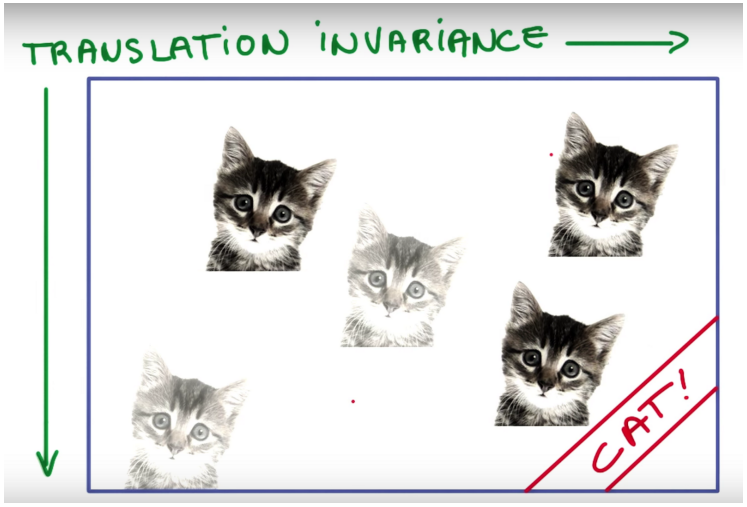
# Convolutional Operation

The hability to break the image into local patterns gives convnets two properties:

1.The learned patterns are translation invariant → After learning a certain pattern in the top-left corner of the picture, a convnet can recognize it anywhere (p.e. Lower-right corner)

The visual world is fundamentally translation invariant:

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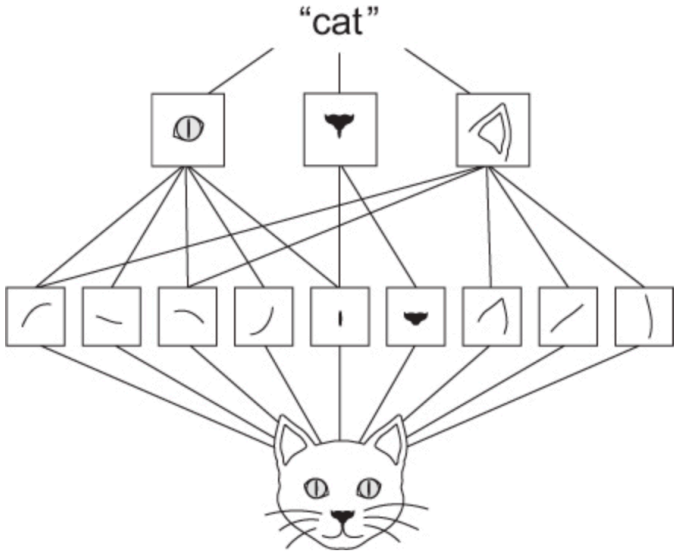
# Convolutional Operation

The hability to break the image into local patterns gives convnets two properties:

2. They can learn spatial hierarchies of patterns. A first Conv. Layer will learn a small local patterns such as edges, then a second Conv. Layer will learn larger patterns made of the features of the first layer, and so on.

   The visual world is fundamentally spatially hierarchical:

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# Convolutional Operation

Operates over 3D tensors known as → Featured maps (height x width x depth)

For RGB image → depth = 3 at the first feature map (input)

The convolutional operation:

1. extracts patches from its input feature map.
2. Applies the same transformation to all this patches
3. Generates an output feature map (height x width x depth)

   depth → no longer RGB colors, now number of filters.

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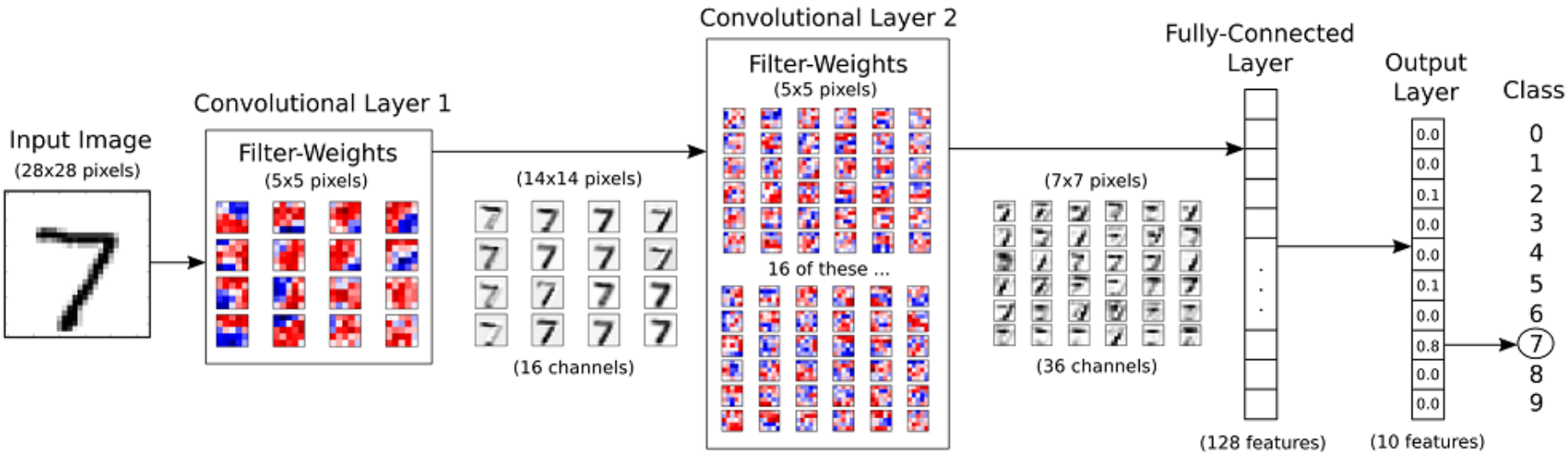
# Convolutional Operation

Convolutional layers:





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# Convolutional Operation

MNIST example:

...

*model = models.sequential()*

*model.add(layers.Conv2D(32, (3,3), activation='relu', input_shape=(28,28,1)))*

...

The first convolutional layer takes a feature map of (28, 28, 1)

And outputs a feature map of size (26, 26, 32):

It computes 32 filters over the input.

Each filter contains a 26x26 grid of values (response map to the filter over the input)

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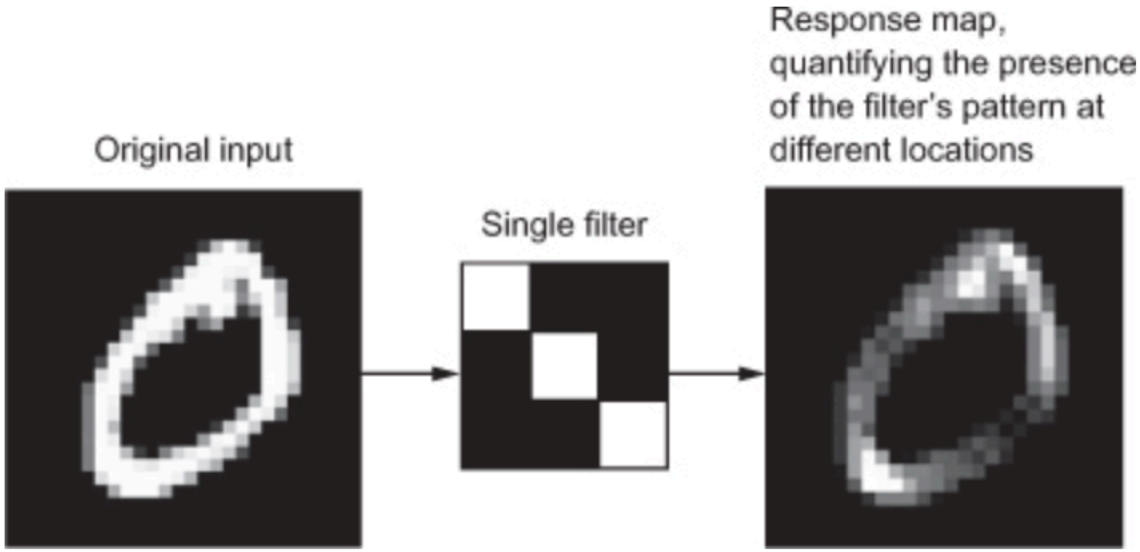
# Convolutional Operation

Feature map → is the 2D map of the response of this filter over the input.

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# Convolutional Operation

Convolutions are defined by two keys parameters:

1. Size of the patches extracted from the inputs → Typically 3x3 or 5x5.

2. Depth of the output feature map → Number of filters computed by the convolution. It is a very dynamic value, usually you start with a depth at the first layers and end with another depth at the final layers.

These parameters can be specified in Keras Conv2D function:

*Conv2D(output_depth, (height, width))*

***Must*** *read:* *http://cs231n.github.io/convolutional-networks/*

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# Convolutional Operation

MNIST example:

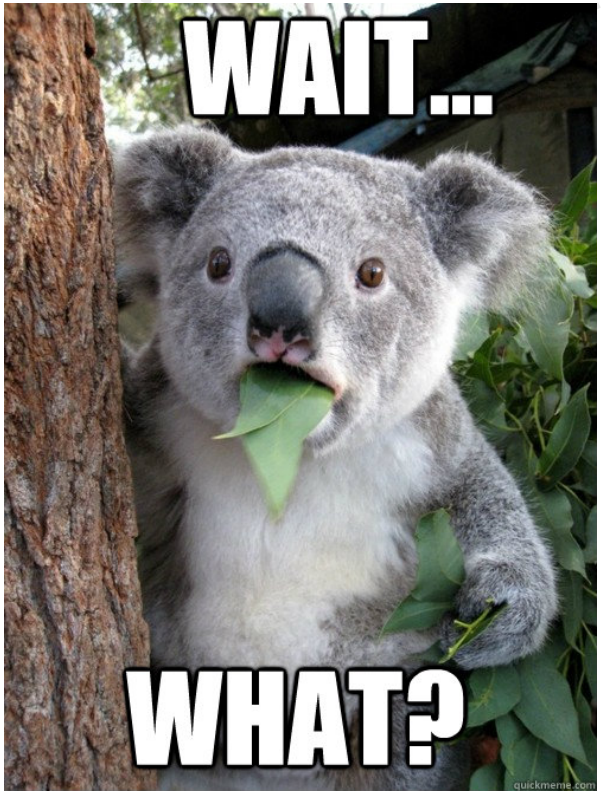
...

```
model = models.sequential()
model.add(layers.Conv2D(32, (3,3), activation='relu',
                        input_shape=(28,28,1)))
```

...

The first convolutional layer takes a feature map of (**28**, **28**, 1)
And outputs a feature map of size (26, 26, 32):

**26x26???**

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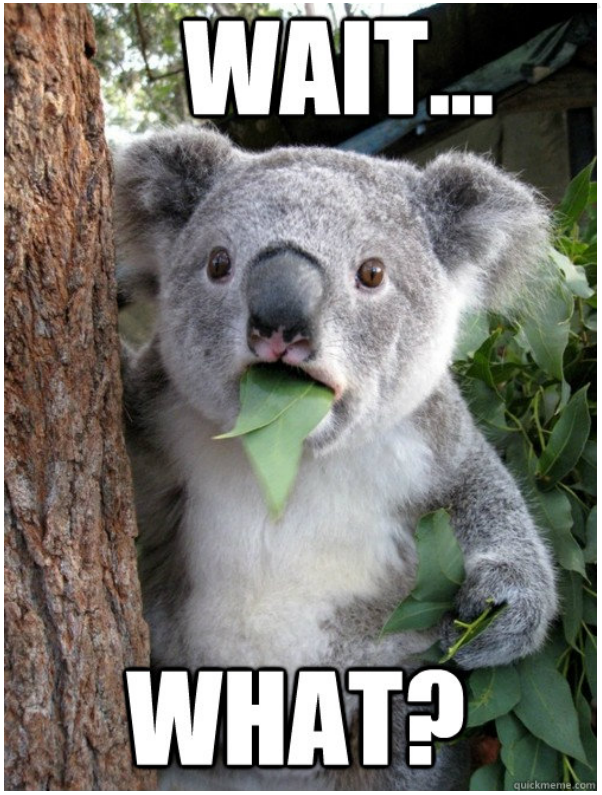
# Convolutional Operation

```
cnn_model.summary()
```

```
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_1 (Conv2D)            (None, 26, 26, 32)        320
_________________________________________________________________
max_pooling2d_1 (MaxPooling2 (None, 13, 13, 32)        0
_________________________________________________________________
conv2d_2 (Conv2D)            (None, 11, 11, 64)        18496
_________________________________________________________________
max_pooling2d_2 (MaxPooling2 (None, 5, 5, 64)          0
_________________________________________________________________
conv2d_3 (Conv2D)            (None, 3, 3, 64)          36928
_________________________________________________________________
flatten_1 (Flatten)          (None, 576)               0
_________________________________________________________________
dense_3 (Dense)              (None, 64)                36928
_________________________________________________________________
dense_4 (Dense)              (None, 10)                650
=================================================================
Total params: 93,322
Trainable params: 93,322
Non-trainable params: 0
_________________________________________________________________
```

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# Understanding border effects

Note that the output width and height may differ from the input width and height.

Two possible reasons:

1. Border effects due to the padding of the input feature map.
2. The use of strides

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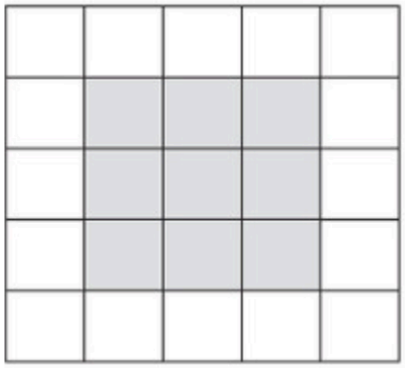
# Understanding border effects: Padding

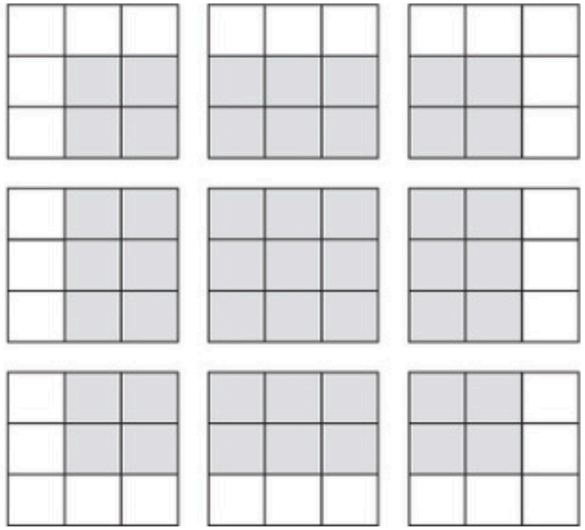
Let's consider:

A 5x5 feature map (25 pixels)

A 3x3 window

Then → There are only 9 possibilities to center the window.





The output feature map shrinks a little (2 pixels x dim)

Same for our 28x28 previous example → 26x26 output dim.

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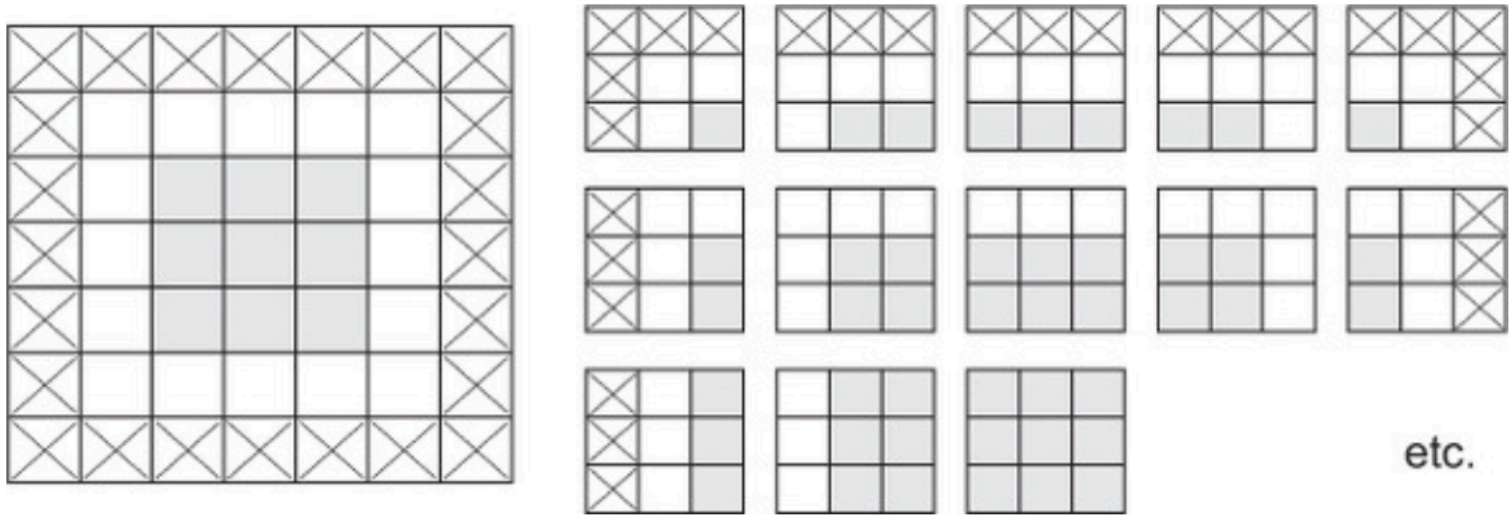
# Understanding border effects: Padding

But, let's assume that you want to generate an output feature map with the same spatial dimension as the input → use the parameter *padding*.

Padding consists of adding an appropiate number of rows&columns each side of the input feature map in order to be able to centre perfectly the convolution window.

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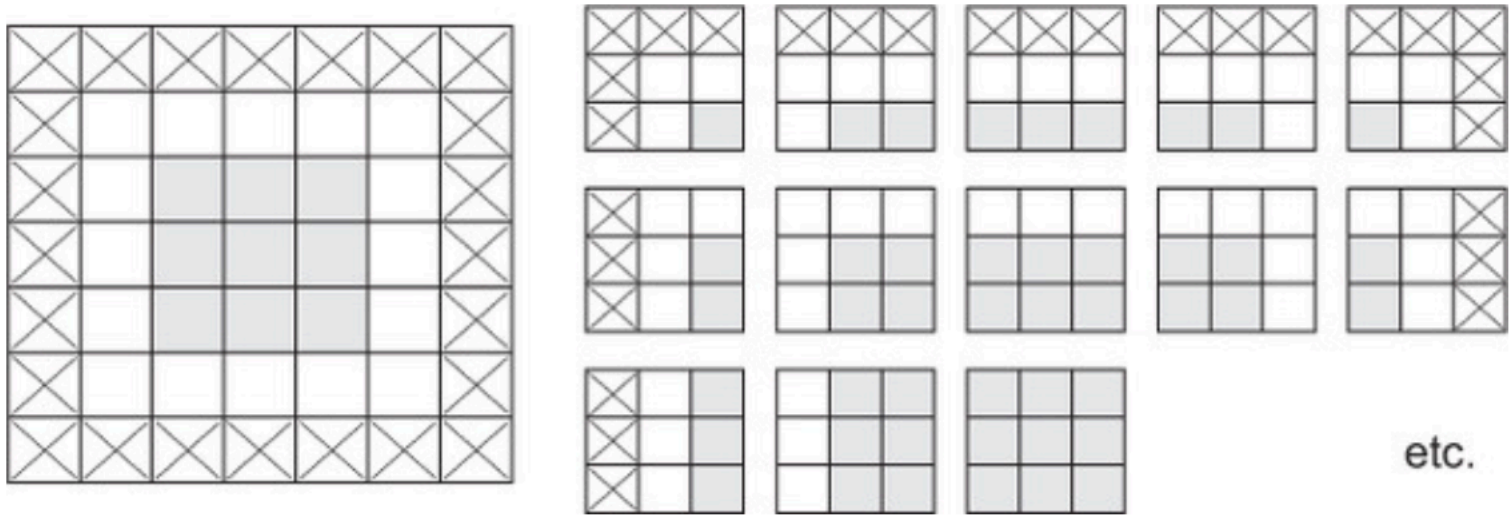
# Understanding border effects: Padding

In Keras → Conv2D layers are padding configurable through the padding argument, that takes two values:

'valid' → Means no padding (by default)

'same' → Means "pad in such way as to have the same width&height as the input

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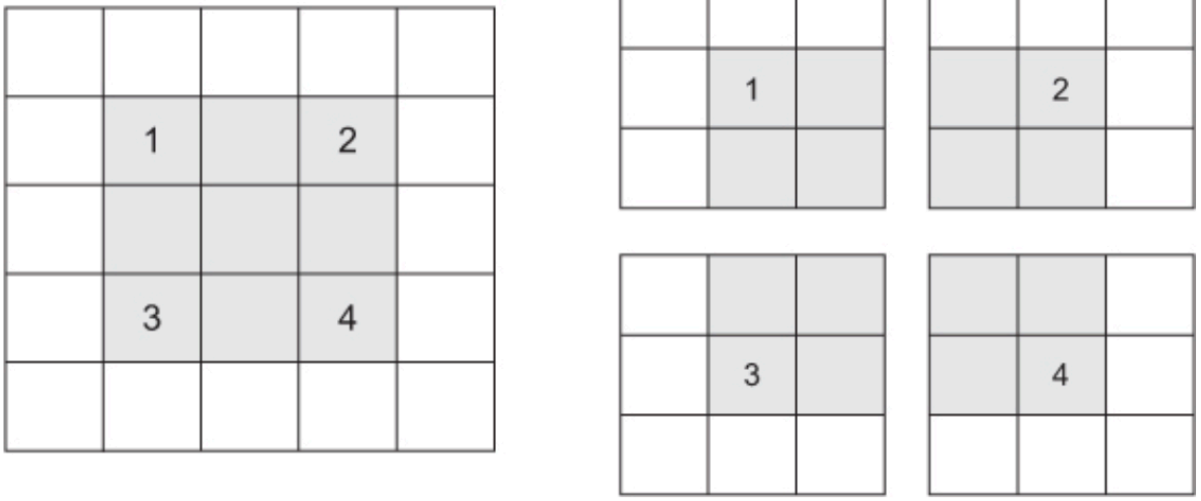
# Understanding border effects: Strides

A factor that can influence the output size.

The description of convolution so far has assumed that the filters move in a contiguous way.

But the distance between two succesive windows is a Conv2D parameter → *strides*

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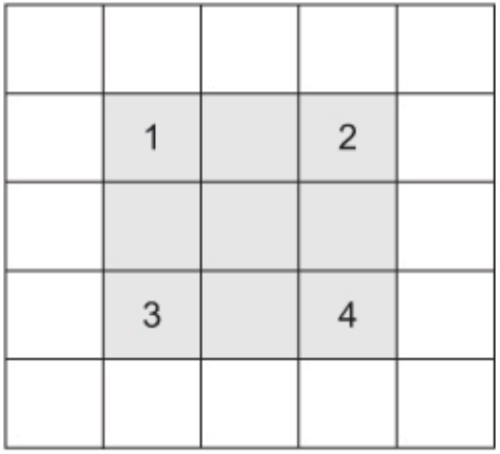
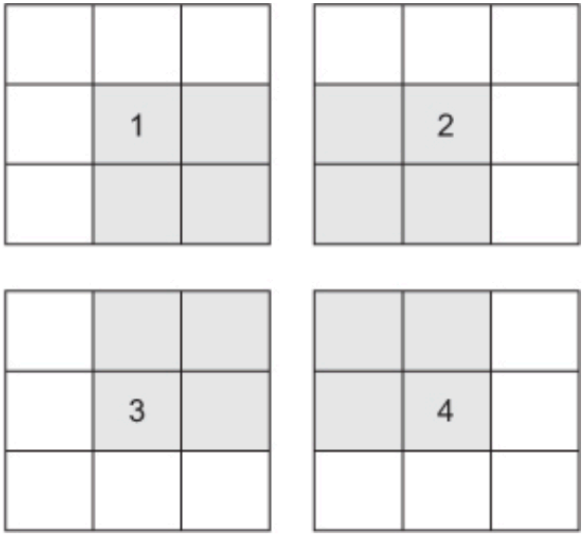
# Understanding border effects: Strides

It is possible to have convolutions with a stride higher than 1.

P.e. Using stride 2 means the width&height of the feature map are downsampled by 2.

This is rarely used in practice → instead of strides, we tend to use max-pooling operation.

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# Max-pooling operation

```
cnn_model.summary()
```

```
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_1 (Conv2D)            (None, 26, 26, 32)        320
_________________________________________________________________
max_pooling2d_1 (MaxPooling2 (None, 13, 13, 32)        0
_________________________________________________________________
conv2d_2 (Conv2D)            (None, 11, 11, 64)        18496
_________________________________________________________________
max_pooling2d_2 (MaxPooling2 (None, 5, 5, 64)          0
_________________________________________________________________
conv2d_3 (Conv2D)            (None, 3, 3, 64)          36928
_________________________________________________________________
flatten_1 (Flatten)          (None, 576)               0
_________________________________________________________________
dense_3 (Dense)              (None, 64)                36928
_________________________________________________________________
dense_4 (Dense)              (None, 10)                650
=================================================================
Total params: 93,322
Trainable params: 93,322
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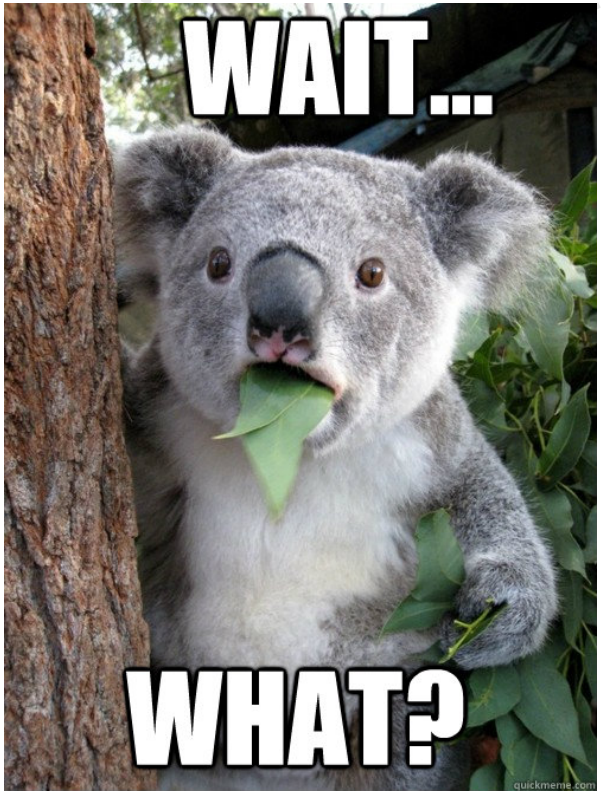


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# Max-pooling operation

MNIST example:

…

*model = models.sequential()*

*model.add(layers.Conv2D(32, (3,3), activation='relu', input_shape=(28,28,1)))*

model.add(layers.MaxPooling2D((2, 2)))

…

Max pooling → Aggressively downsample the feature maps (like strided convolutions)

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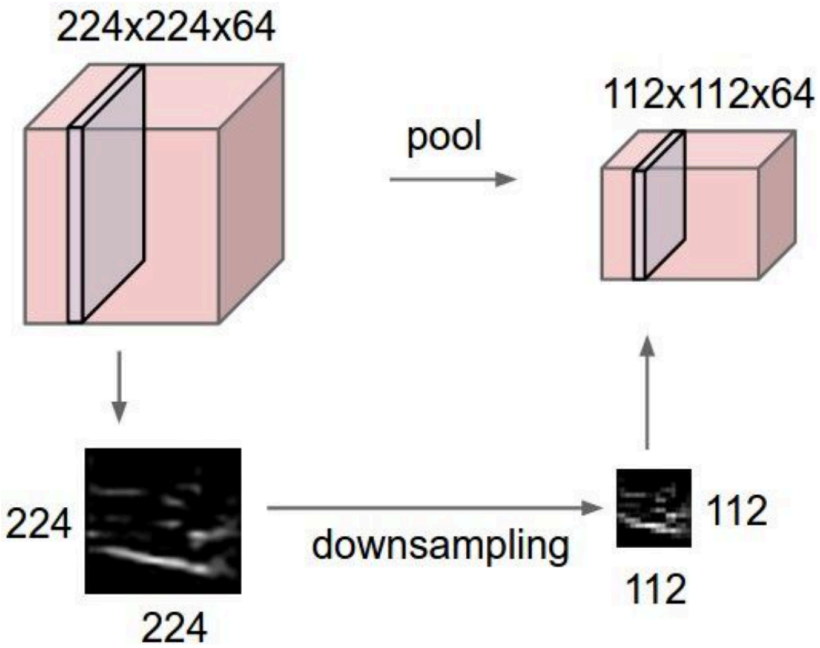
# Max-pooling operation

Makes the representation smaller and more manageable

Operates over each feature map independently:

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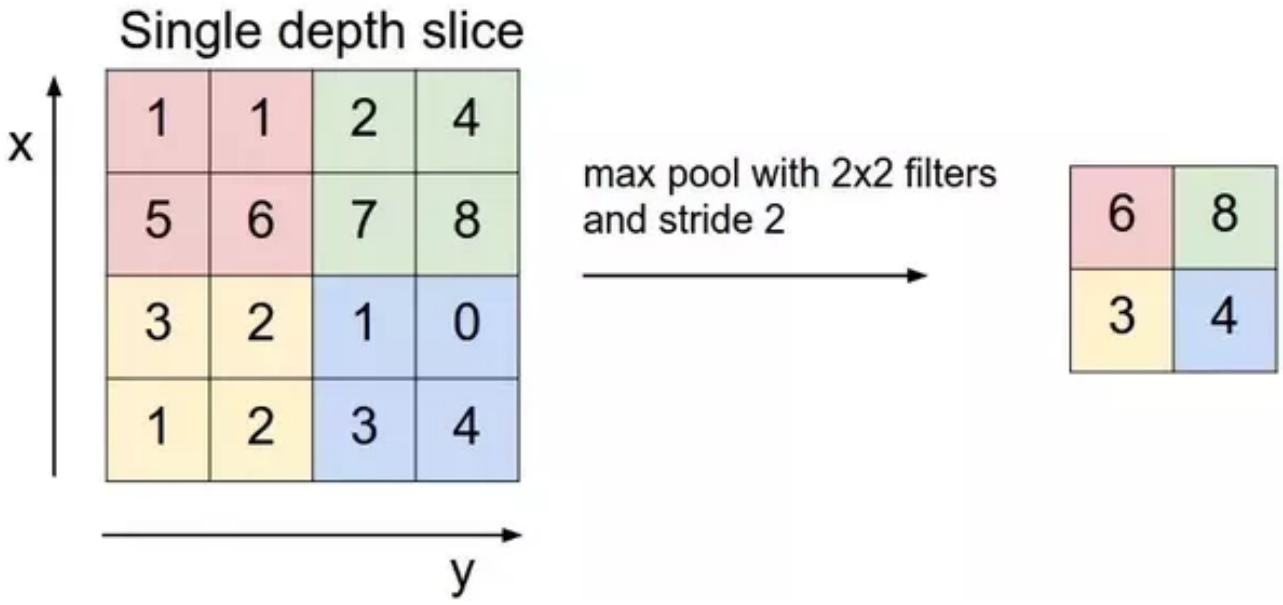
# Max-pooling operation

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# Max-pooling operation

Why downsample feature maps?

Why don't we remove the max-pooling layers and keep large feature maps all the way up?

```
model_no_max_pool = models.Sequential()
model_no_maxpool.add(layers.Conv2D(32, (3, 3), activation='relu',input_shape=(28, 28, 1)))
model_no_max_pool.add(layers.Conv2D(64, (3, 3), activation='relu'))
model_no_max_pool.add(layers.Conv2D(64, (3, 3), activation='relu'))
```

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# Max-pooling operation

Why downsample feature maps?

Why don't we remove the max-pooling layers and keep large feature maps all the way up?

```
>>> model_no_max_pool.summary()

Layer (type)                 Output Shape              Param #
=================================================================
conv2d_4 (Conv2D)            (None, 26, 26, 32)        320
_________________________________________________________________
conv2d_5 (Conv2D)            (None, 24, 24, 64)        18496
_________________________________________________________________
conv2d_6 (Conv2D)            (None, 22, 22, 64)        36928
=================================================================
Total params: 55,744
Trainable params: 55,744
Non-trainable params: 0
```

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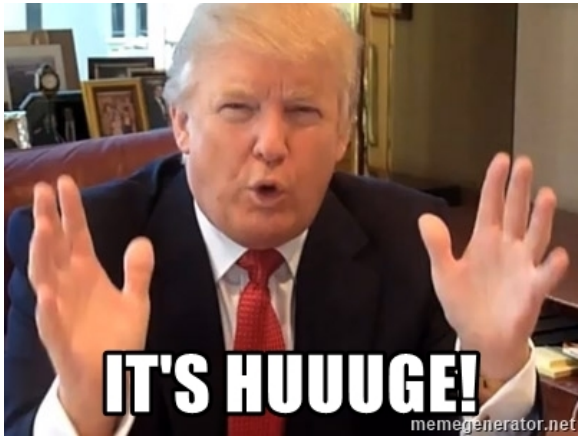
# Max-pooling operation

What is wrong with that setup?

The final feature map is 22 x 22 x 64 = 30,976 total coefficients per sample!!
That is huge!

If we want to flatten it to stick a Dense layer of 512 units,




we would have **15.800.000** parameters

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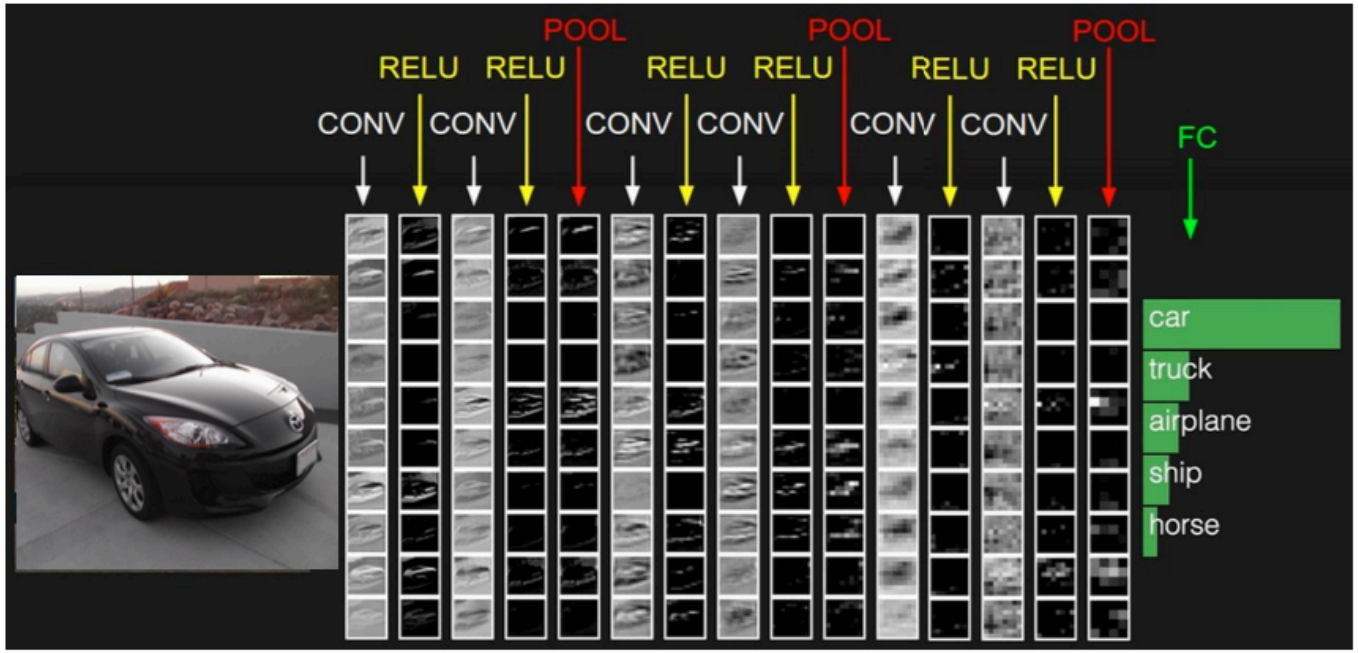
# Fully Connected Layer

Contains neurons that connect to the entire input volume, as an ordinary NN.

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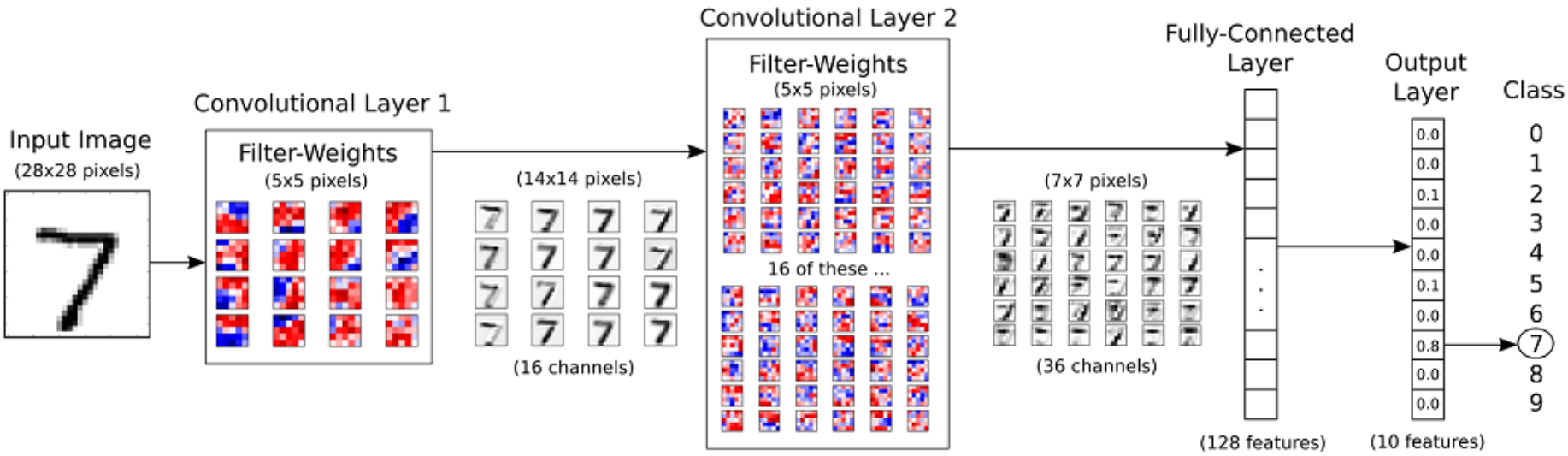
# What is happening?

Convolutional layers:





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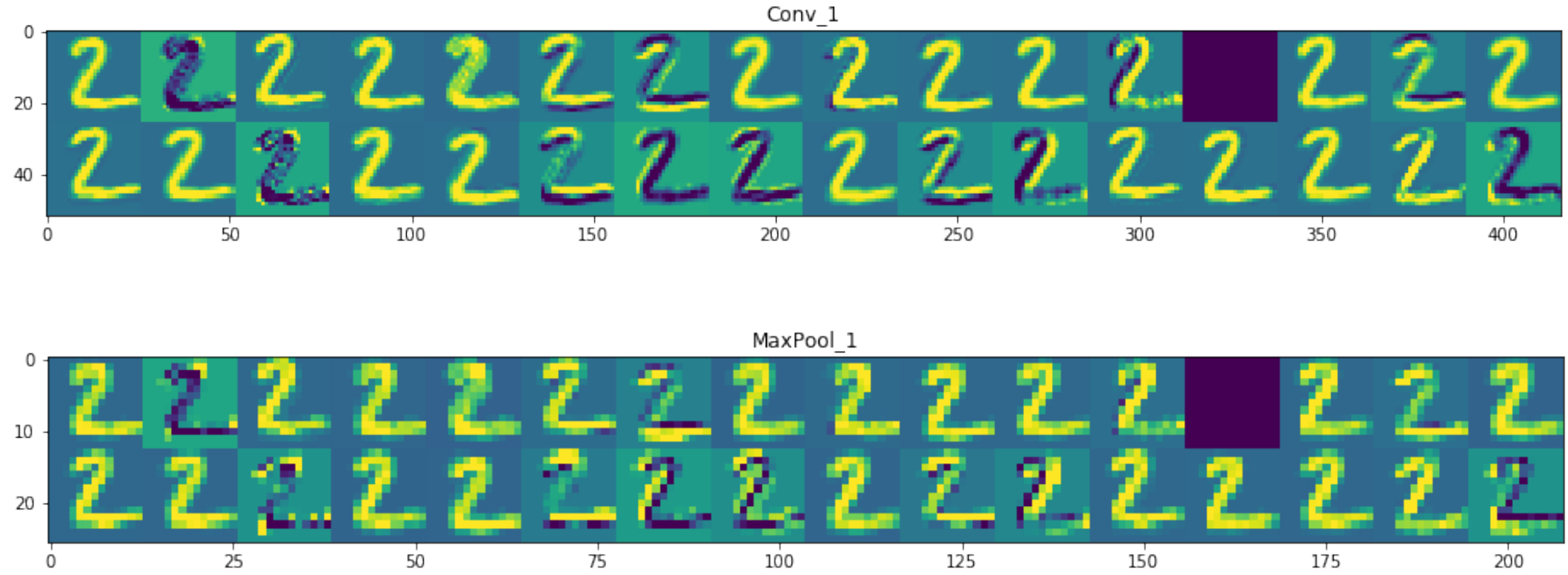
# What is happening?
# Feature Maps





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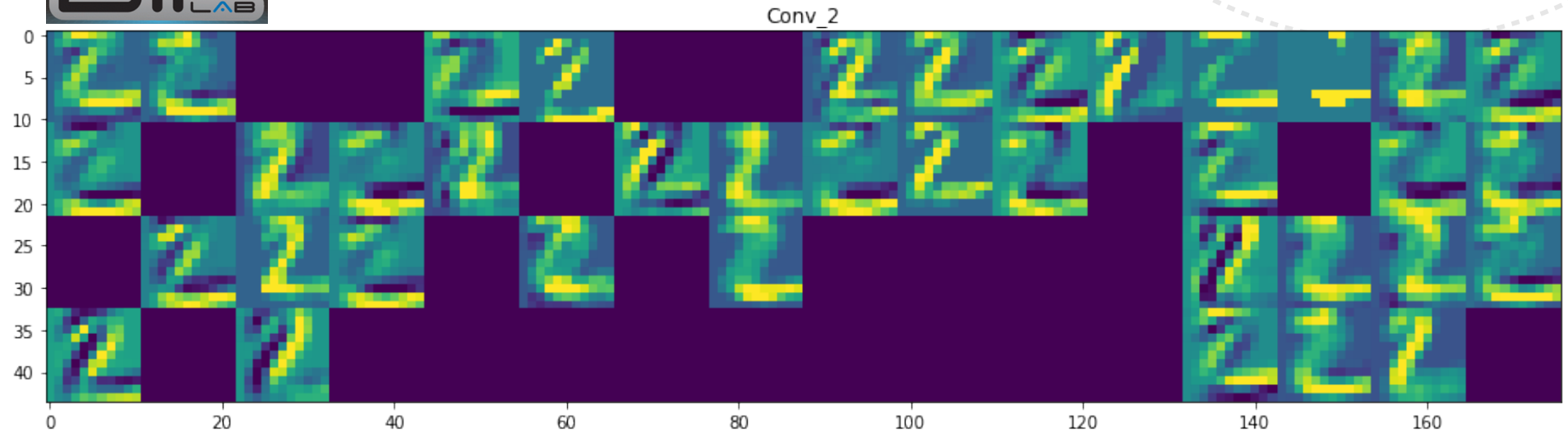
# What is happening?
# Feature Maps

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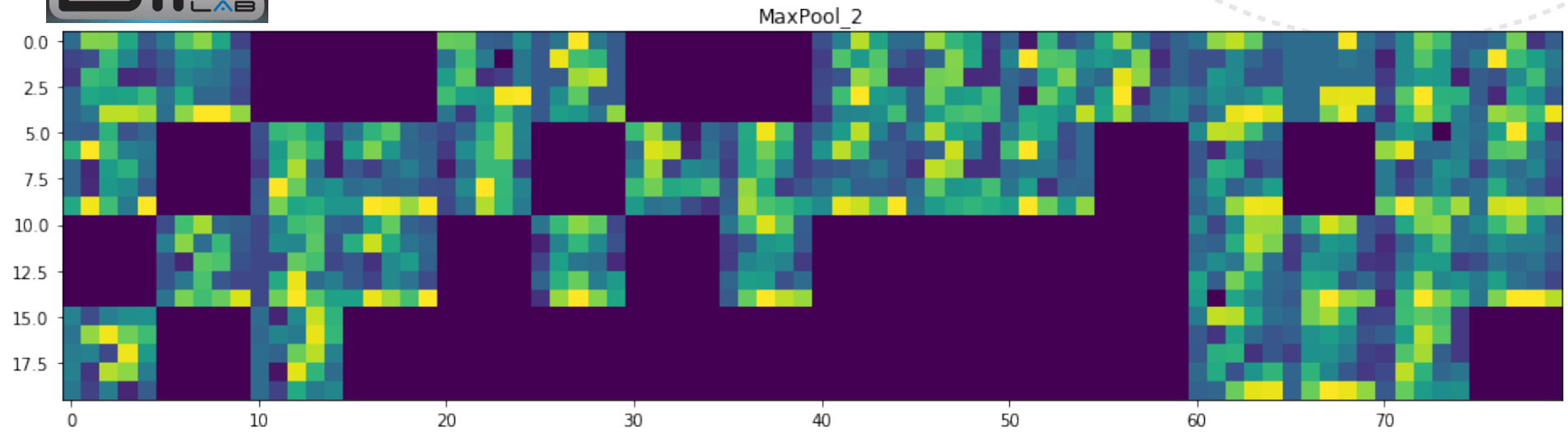
# What is happening?
# Feature Maps

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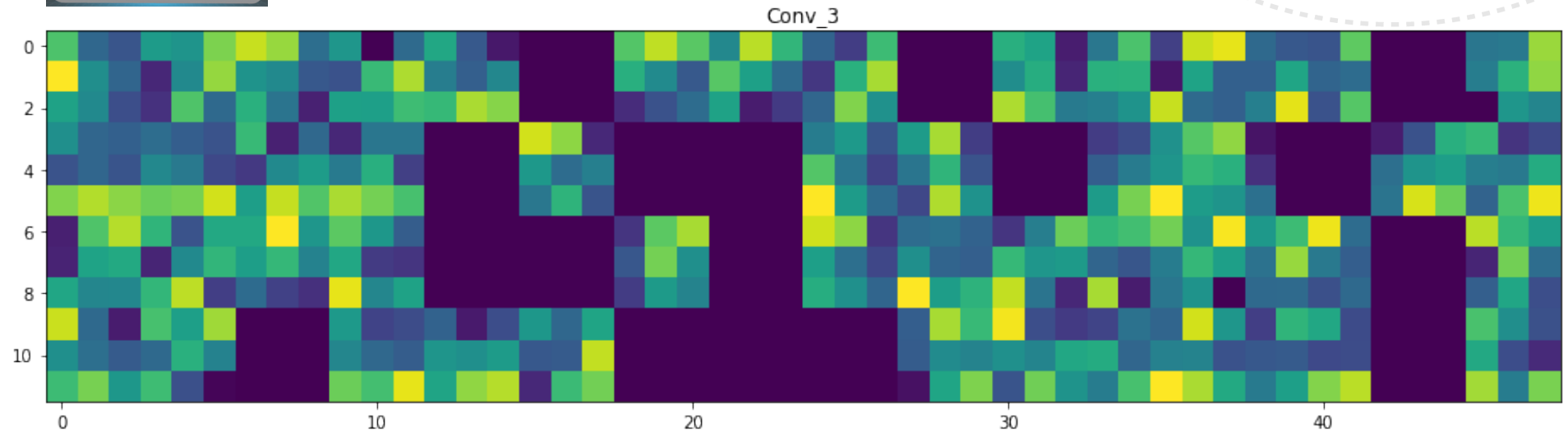
# What is happening?
# Feature Maps




These feature maps are flattened and stick into the Fully Connected layer!!

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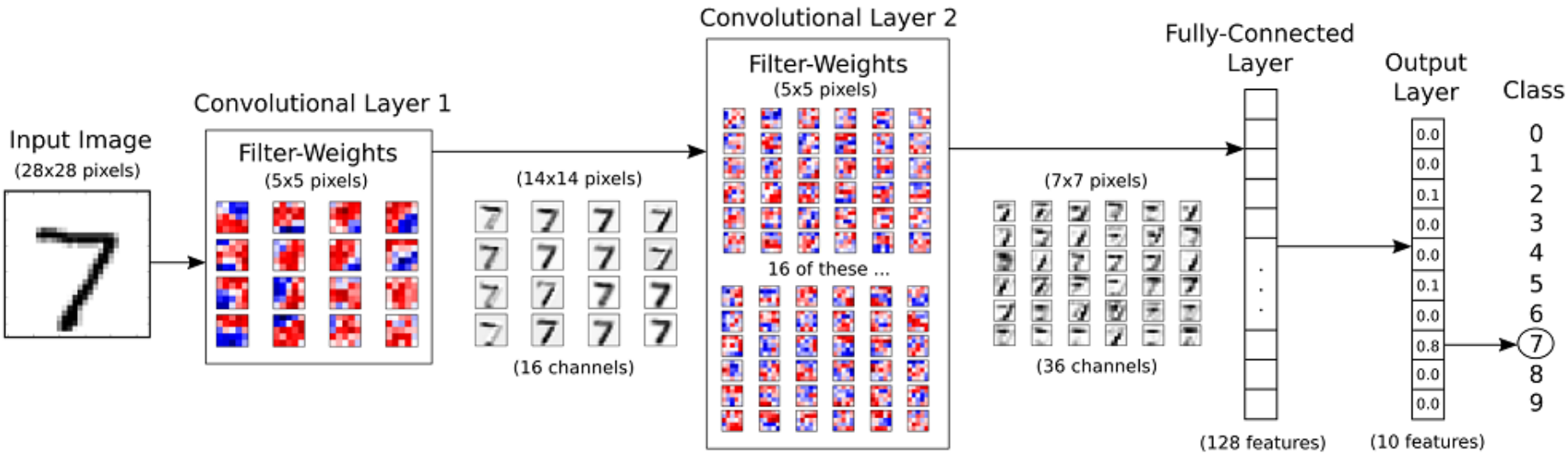
# What is happening?

Convolutional layers:





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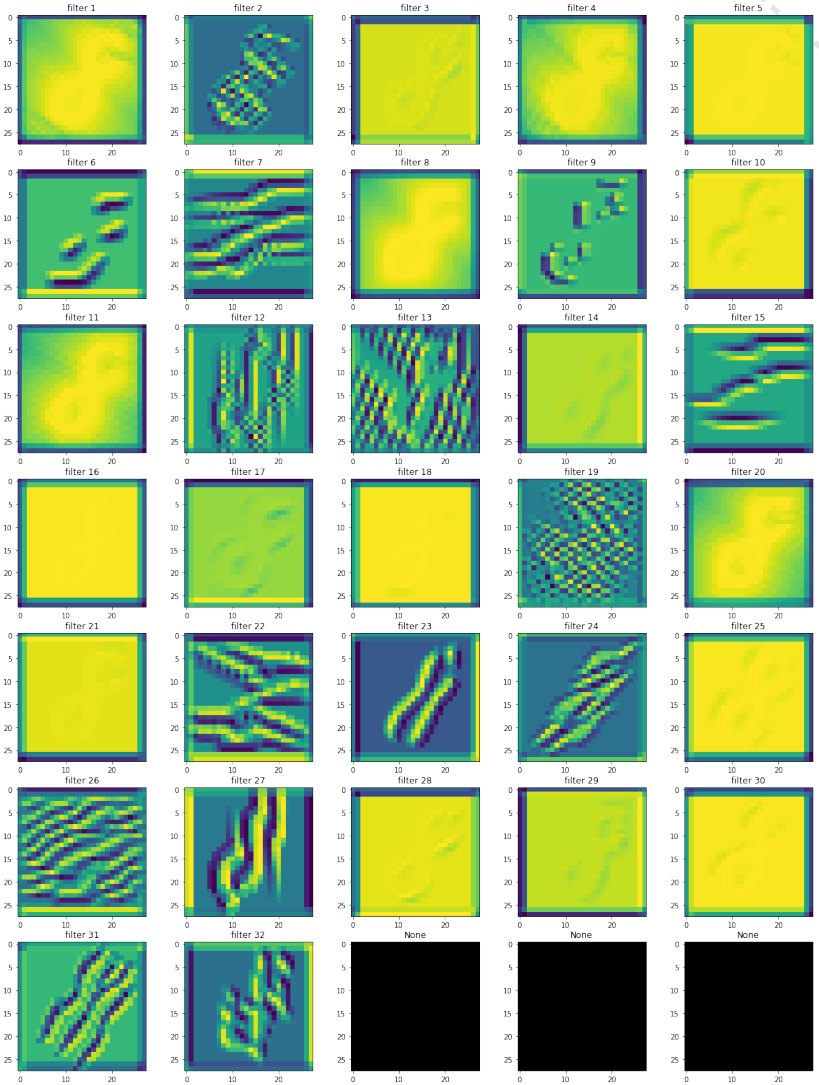
# What is happening?
# Filters Conv1

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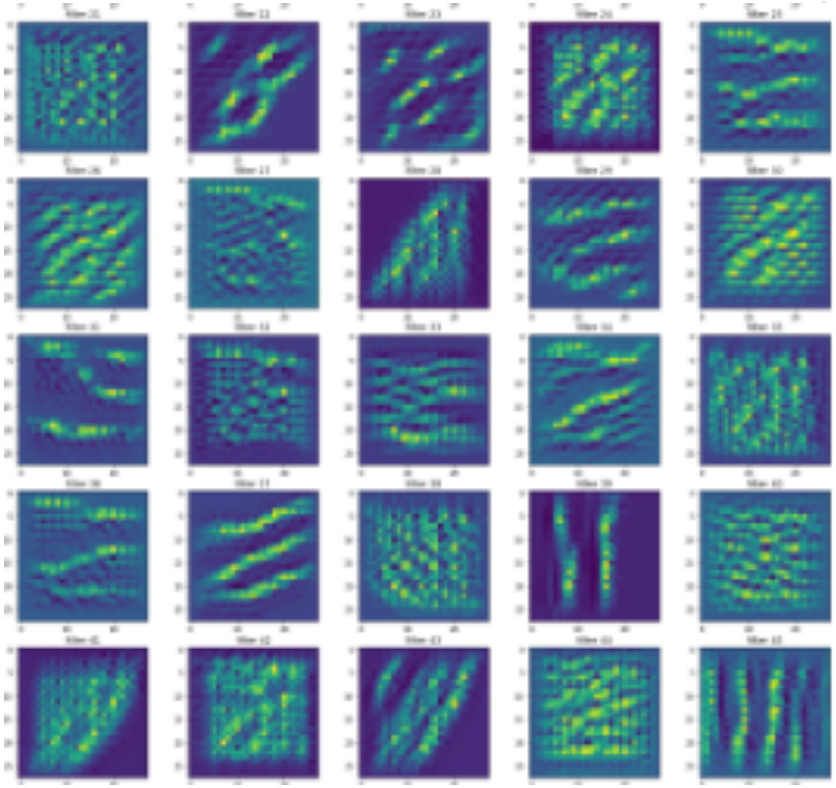
# What is happening?
# Filters Conv2



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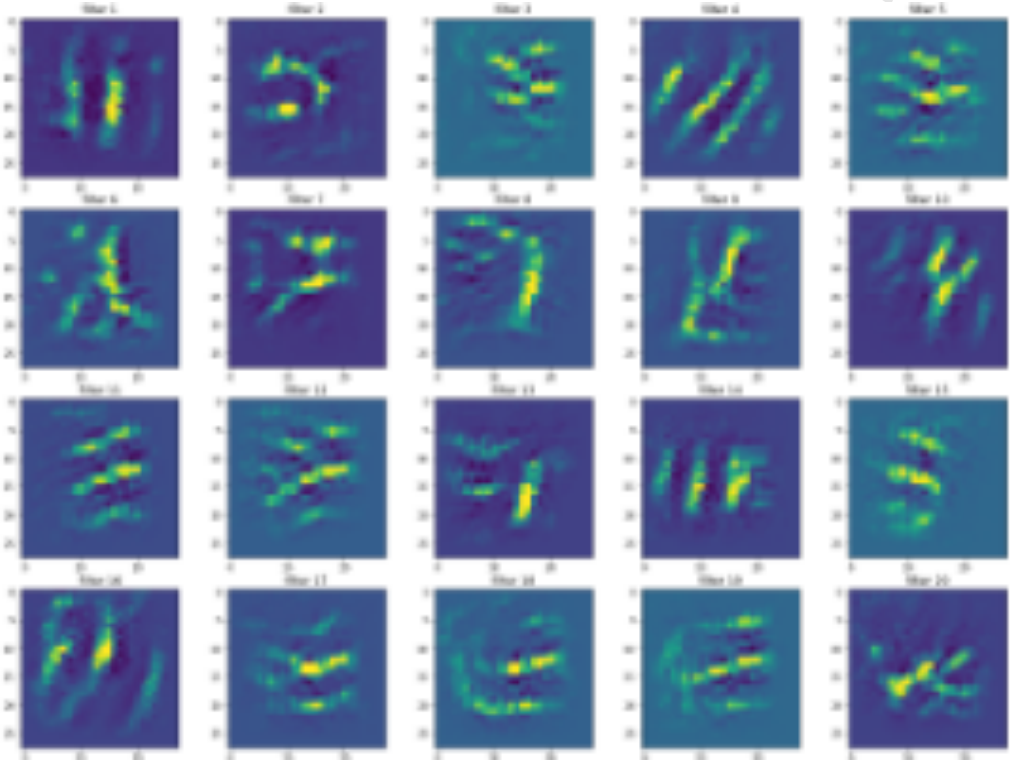
# What is happening?
# Filters Conv3



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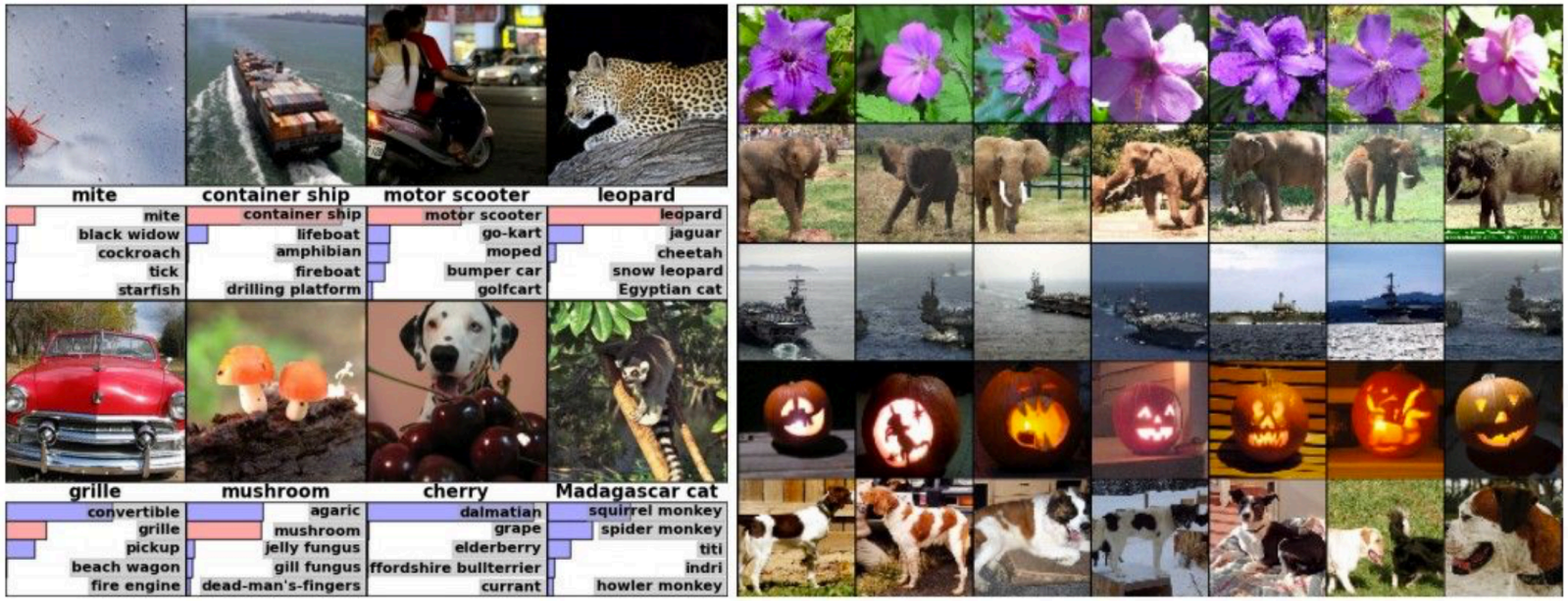
# Where to use CNN?

Classification

Retrieval



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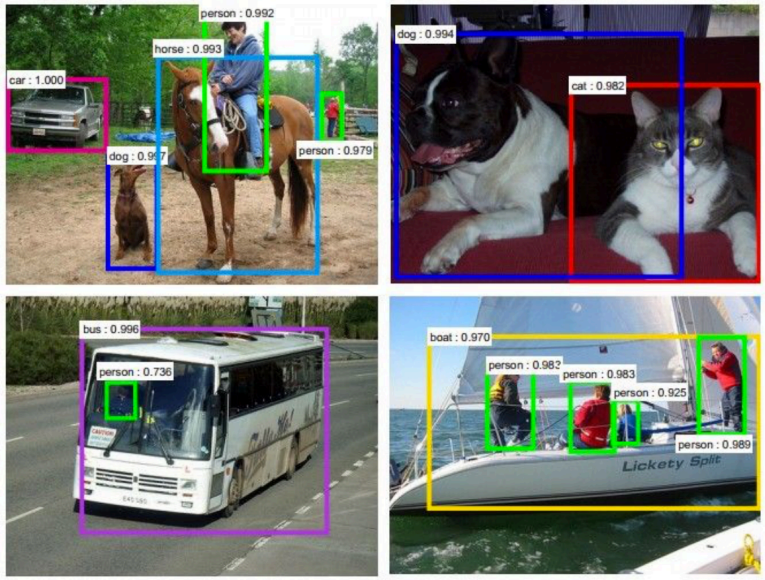
# Where to use CNN?

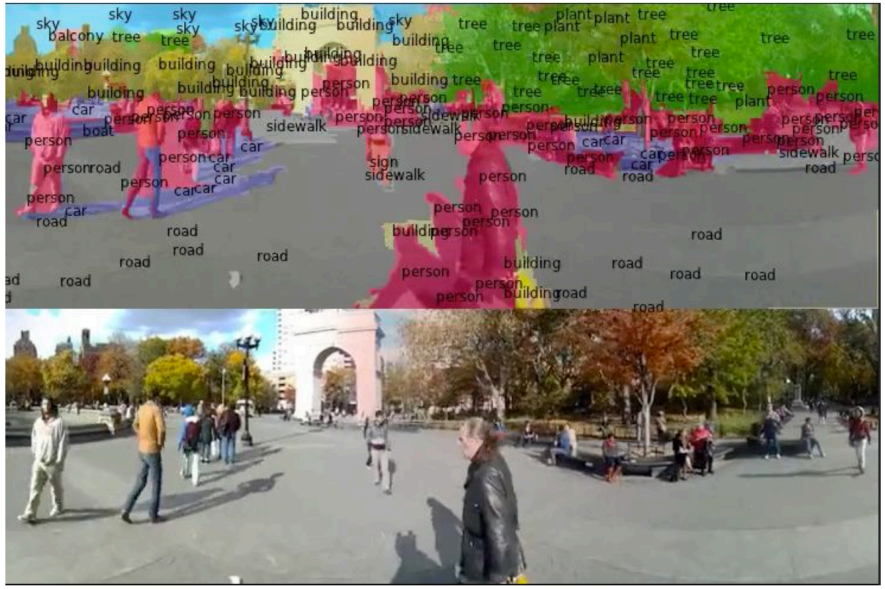
## Detection




Figures copyright Shaoqing Ren, Kaiming He, Ross Girschick, Jian Sun, 2015. Reproduced with permission.

*[Faster R-CNN: Ren, He, Girshick, Sun 2015]*

## Segmentation



Figures copyright Clement Farabet, 2012. Reproduced with permission.

*[Farabet et al., 2012]*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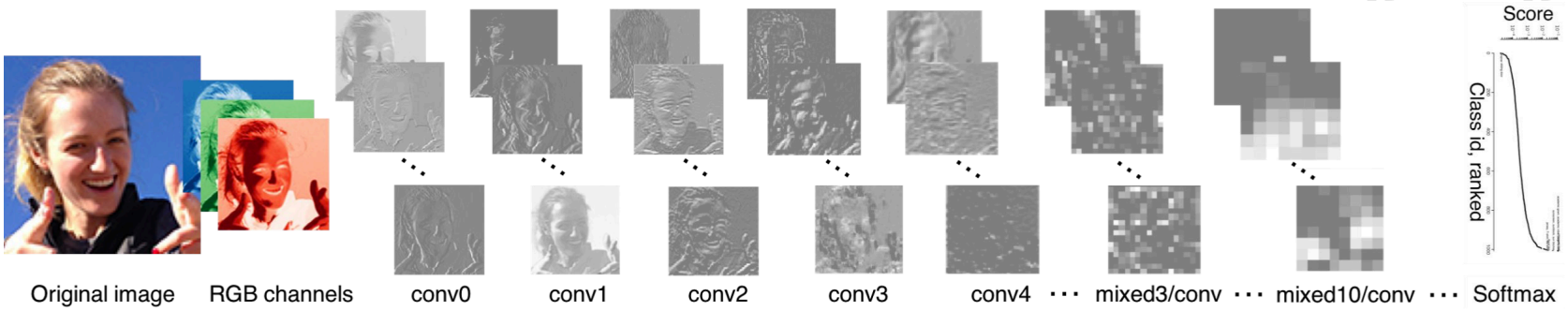
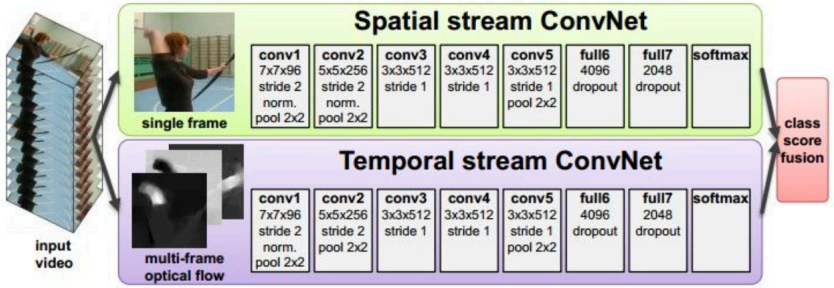
# Where to use CNN?




*[Taigman et al. 2014]*

Activations of inception-v3 architecture [Szegedy et al. 2015] to image of Emma McIntosh, used with permission. Figure and architecture not from Taigman et al. 2014.




*[Simonyan et al. 2014]*

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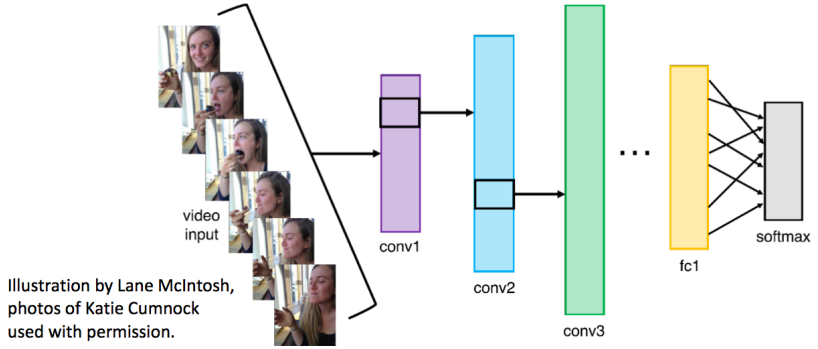


Illustration by Lane McIntosh, photos of Katie Cumnock used with permission.

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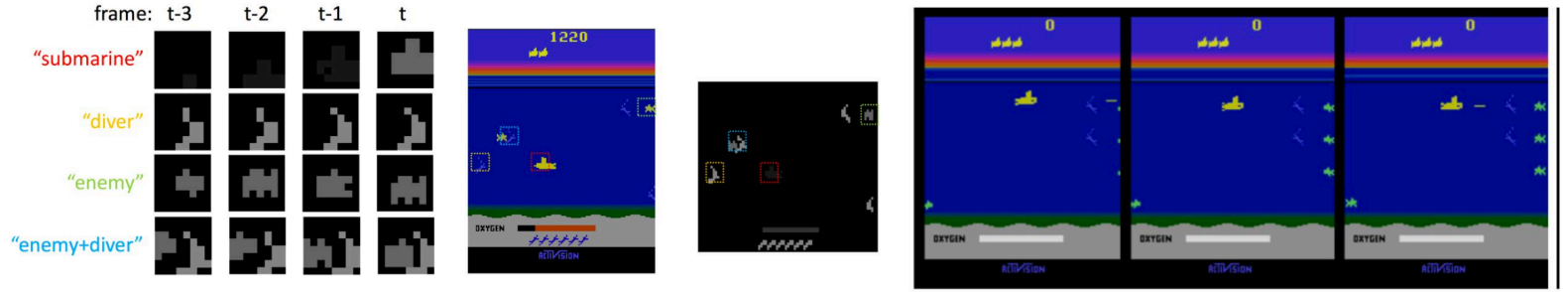
Images are examples of pose estimation, not actually from Toshev & Szegedy 2014. Copyright Lane McIntosh.

*[Toshev, Szegedy 2014]*




*[Guo et al. 2014]*

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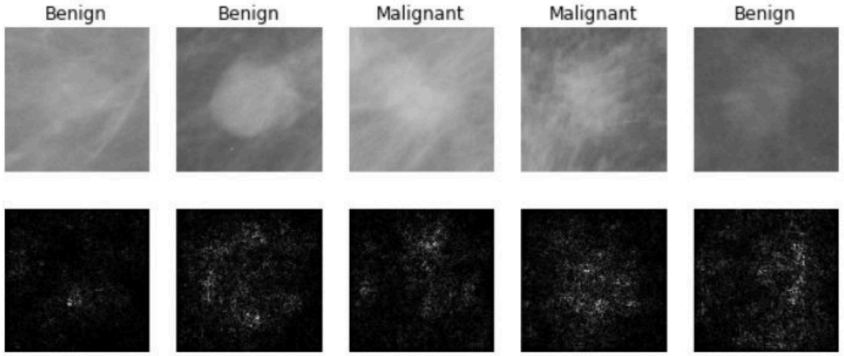
# Where to use CNN?




*[Levy et al. 2016]*



*[Dieleman et al. 2014]*




*[Sermanet et al. 2011]*
*[Ciresan et al.]*



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# Applications

https://www.youtube.com/watch?v=kkha3sPoU70

https://www.youtube.com/watch?v=U1vb-NI9sKE

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# Credits

**The ‘Where to use CNN?’ section is partially based on the Lecture 5: Convolutional Neural Networks. By Fei-Fei, Johnson and Yeung. April 18, 2017**

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