# ED5340 - Data Science: Theory and Practise

## L27 - Convolution



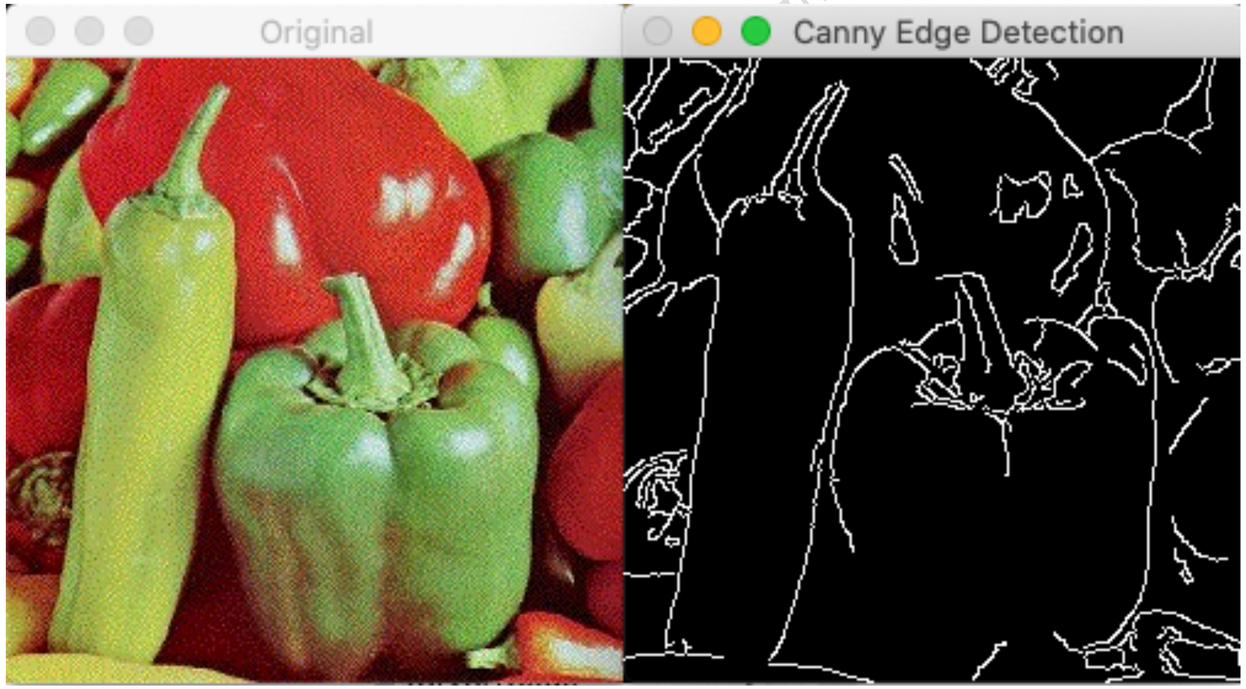
**Ramanathan Muthuganapathy (https://ed.iitm.ac.in/~raman)**
**Course web page: https://ed.iitm.ac.in/~raman/datascience.html**
**Moodle page: Available at https://courses.iitm.ac.in/**

# On Images

- Pixel (Picture element)
- Binary ({0, 255})
- Grayscale (One channel - 8-bit representation)
- RGB (Three channels, one for each colour)
- Discussion to one channel

# Observation

- Pixels close to one another represent same information
- ‘Edges’ that separate the information



# Hypothesis

- Train the NN for regions of same information
- Train to find ‘Edges’
- ‘Objects’ can be identified.

# Idea

- Capture ‘local’ information
- Split the image into patches (square)
- Use a ‘moving window’ approach

# Patch

- Patch - Array of numbers
- 4 X 4 Array of numbers

| | | | |
|---|---|---|---|
| **2** | **4** | **3** | **6** |
| **2** | 1 | 3 | 0 |
| **9** | 0 | 1 | 2 |
| **7** | 5 | 1 | 2 |

# Convolution

- Uses a filter F (a.k.a Kernel)
  - 3 X 3
  - 2 X 2
  - 1 X 1
- Operates on the patches.
- If the numbers from convolution are larger, then the ‘region’ (or the patch) resembles the filter.

| | | |
|---|---|---|
| **1** | **0** | **-1** |
| **1** | 0 | -1 |
| **1** | 0 | -1 |

# Convolution

| | | | |
|---|---|---|---|
| **2** | **4** | **3** | **6** |
| **2** | 1 | 3 | 0 |
| **9** | 0 | 1 | 2 |
| **7** | 5 | 1 | 2 |

| | | |
|---|---|---|
| **1** | **0** | **-1** |
| **1** | 0 | -1 |
| **1** | 0 | -1 |

# Convolution

## Superimpose, multiply and add

| | | | |
|---|---|---|---|
| **2 1** | **4 0** | **3 -1** | **6** |
| **2 1** | 1 0 | 3 -1 | 0 |
| **9 1** | 0 0 | 1 -1 | 2 |
| **7** | 5 | 1 | 2 |

$$2*1 + 2*1 + +9*1 + 1*0 + 1*0 + 0*0 + 3*(-1) + 3*(-1) + 1*(-1) = 6$$

# Convolution

## Then stride (slide) by 1 to right

| | | | |
|---|---|---|---|
| **2** | **4 1** | **3 0** | **6 -1** |
| **2** | 1 **1** | 3 0 | 0 -1 |
| **9** | 0 **1** | 1 0 | 2 -1 |
| **7** | 5 | 1 | 2 |

$$4*1 + 1*1 + +0*1 + 3*0 + 3*0 + 1*0 + 6*(-1) + 0*(-1) + 2*(-1)$$
$$= -3$$

# Convolution

## Then stride (slide) by 1 to right (not possible)

| | | | | |
|---|---|---|---|---|
| **2** | **4** | **3** **1** | **6** **0** | **-1** |
| **2** | 1 | 3 **1** | 0 0 | -1 |
| **9** | 0 | 1 **1** | 2 0 | -1 |
| **7** | 5 | 1 | 2 | |

# Convolution

## Then stride (slide) down by 1

| 2 | 4 | 3 | 6 |
|---|---|---|---|
| **2** **1** | 1 **0** | 3 **-1** | 0 |
| **9** **1** | 0 0 | 1 -1 | 2 |
| **7** **1** | 5 0 | 1 -1 | 2 |



13

# Convolution

## Then stride (slide) right by 1

| 2 | 4 | 3 | 6 |
|---|---|---|---|
| 2 | 1 **1** | 3 **0** | 0 **-1** |
| 9 | 0 **1** | 1 0 | 2 -1 |
| 7 | 5 **1** | 1 0 | 2 -1 |



2

# Convolution

| | | | |
|---|---|---|---|
| **2** | **4** | **3** | **6** |
| **2** | 1 | 3 | 0 |
| **9** | 0 | 1 | 2 |
| **7** | 5 | 1 | 2 |

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| | | |
|---|---|---|
| **1** | **0** | **-1** |
| **1** | 0 | -1 |
| **1** | 0 | -1 |



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| | |
|---|---|
| **6** | **-3** |
| **13** | 2 |

| **2** | **4** | **3** | **6** | | |
|---|---|---|---|---|---|
| **2** | 1 | 3 | 0 | | |
| **9** | 0 | 1 | 2 | | |
| **7** | 5 | 1 | 2 | | |
| | | | | | |
| | | | | | |

| **1** | **0** | **-1** |
|---|---|---|
| **1** | 0 | -1 |
| **1** | 0 | -1 |

# Larger images

## Stride as 1

| | | | | | |
|---|---|---|---|---|---|
| **2 1** | **4 0** | **3 -1** | **6** | | |
| **2 1** | 1 0 | 3 -1 | 0 | | |
| **9 1** | 0 0 | 1 -1 | 2 | | |
| **7** | 5 | 1 | 2 | | |
| | | | | | |
| | | | | | |

# Larger images

## Stride as 1

| | | | | | |
|---|---|---|---|---|---|
| **2** | **4 1** | **3 0** | **6 -1** | | |
| **2** | 1 **1** | 3 0 | 0 -1 | | |
| **9** | 0 **1** | 1 0 | 2 -1 | | |
| **7** | 5 | 1 | 2 | | |
| | | | | | |
| | | | | | |

# Larger images

## Stride as 1

| | | | | | |
|---|---|---|---|---|---|
| **2** | **4** | **3** **1** | **6** **0** | **-1** | |
| **2** | 1 | 3 **1** | 0 0 | -1 | |
| **9** | 0 | 1 **1** | 2 0 | -1 | |
| **7** | 5 | 1 | 2 | | |
| | | | | | |
| | | | | | |

# Larger images

## Stride as 1

| | | | | | |
|---|---|---|---|---|---|
| **2** | **4** | **3** | **6** | **1** | **0** | **-1** |
| **2** | 1 | 3 | 0 | **1** | 0 | -1 |
| **9** | 0 | 1 | 2 | **1** | 0 | -1 |
| **7** | 5 | 1 | 2 | | | |
| | | | | | | |
| | | | | | | |

# Larger images

## Stride as 1

| | | | | | |
|---|---|---|---|---|---|
| **2** | **4** | **3** | **6** | | |
| **2 1** | 1 **0** | 3 **-1** | 0 | | |
| **9 1** | 0 0 | 1 -1 | 2 | | |
| **7 1** | 5 0 | 1 -1 | 2 | | |
| | | | | | |
| | | | | | |

# Larger images

## Stride as 1

| **2** | **4** | **3** | **6** | | |
|---|---|---|---|---|---|
| **2** | 1 **1** | 3 **0** | 0 **-1** | | |
| **9** | 0 **1** | 1 0 | 2 -1 | | |
| **7** | 5 **1** | 1 0 | 2 -1 | | |
| | | | | | |
| | | | | | |

# Larger images

## Stride as 1

| **2** | **4** | **3** | **6** | | |
|---|---|---|---|---|---|
| **2** | 1 | 3 **1** | 0 **0** | **-1** | |
| **9** | 0 | 1 **1** | 2 0 | -1 | |
| **7** | 5 | 1 **1** | 2 0 | -1 | |
| | | | | | |
| | | | | | |

# Larger images

## Stride as 1

| **2** | **4** | **3** | **6** | | |
|---|---|---|---|---|---|
| **2** | 1 | 3 | 0 **1** | **0** | **-1** |
| **9** | 0 | 1 | 2 **1** | 0 | -1 |
| **7** | 5 | 1 | 2 **1** | 0 | -1 |
| | | | | | |
| | | | | | |

# Larger images

## Stride as 1

| | | | | | |
|---|---|---|---|---|---|
| **2** | **4** | **3** | **6** | | |
| **2** | 1 | 3 | 0 | | |
| **9** **1** | 0 **0** | 1 **-1** | 2 | | |
| **7** **1** | 5 0 | 1 -1 | 2 | | |
| **1** | 0 | -1 | | | |
| | | | | | |

# Larger images

## Stride as 1

| | | | | | |
|---|---|---|---|---|---|
| **2** | **4** | **3** | **6** | | |
| **2** | 1 | 3 | 0 | | |
| **9** | 0 **1** | 1 **0** | 2 **-1** | | |
| **7** | 5 **1** | 1 0 | 2 -1 | | |
| | **1** | 0 | -1 | | |
| | | | | | |

# Larger images

## Stride as 1

| | | | | | |
|---|---|---|---|---|---|
| **2** | **4** | **3** | **6** | | |
| **2** | 1 | 3 | 0 | | |
| **9** | 0 | 1 **1** | 2 **0** | **-1** | |
| **7** | 5 | 1 **1** | 2 0 | -1 | |
| | | **1** | 0 | -1 | |
| | | | | | |

# Larger images

## Stride as 1

| | | | | | |
|---|---|---|---|---|---|
| **2** | **4** | **3** | **6** | | |
| **2** | 1 | 3 | 0 | | |
| **9** | 0 | 1 | 2 **1** | **0** | **-1** |
| **7** | 5 | 1 | 2 **1** | 0 | -1 |
| | | | **1** | 0 | -1 |
| | | | | | |

# Larger images

## Stride as 1

| | | | | | |
|---|---|---|---|---|---|
| **2** | **4** | **3** | **6** | | |
| **2** | 1 | 3 | 0 | | |
| **9** | 0 | 1 | 2 | | |
| **7** **1** | 5 **0** | 1 **-1** | 2 | | |
| **1** | 0 | -1 | | | |
| **1** | 0 | -1 | | | |

# Larger images

## Stride as 1

| | | | | | |
|---|---|---|---|---|---|
| **2** | **4** | **3** | **6** | | |
| **2** | 1 | 3 | 0 | | |
| **9** | 0 | 1 | 2 | | |
| **7** | 5 **1** | 1 **0** | 2 **-1** | | |
| | **1** | 0 | -1 | | |
| | **1** | 0 | -1 | | |

# Larger images

## Stride as 1

| | | | | | |
|---|---|---|---|---|---|
| **2** | **4** | **3** | **6** | | |
| **2** | 1 | 3 | 0 | | |
| **9** | 0 | 1 | 2 | | |
| **7** | 5 | 1 **1** | 2 **0** | **-1** | |
| | | **1** | 0 | -1 | |
| | | **1** | 0 | -1 | |

# Larger images

## Stride as 1

| | | | | | |
|---|---|---|---|---|---|
| **2** | **4** | **3** | **6** | | |
| **2** | 1 | 3 | 0 | | |
| **9** | 0 | 1 | 2 | | |
| **7** | 5 | 1 | 2 **1** | **0** | **-1** |
| | | | **1** | 0 | -1 |
| | | | **1** | 0 | -1 |

# Larger images

## Stride as 2

| | | | | | |
|---|---|---|---|---|---|
| **2 1** | **4 0** | **3 -1** | **6** | | |
| **2 1** | 1 0 | 3 -1 | 0 | | |
| **9 1** | 0 0 | 1 -1 | 2 | | |
| **7** | 5 | 1 | 2 | | |
| | | | | | |
| | | | | | |

# Larger images

## Stride as 2

| | | | | | |
|---|---|---|---|---|---|
| **2** | **4** | **3** **1** | **6** **0** | **-1** | |
| **2** | 1 | 3 **1** | 0 0 | -1 | |
| **9** | 0 | 1 **1** | 2 0 | -1 | |
| **7** | 5 | 1 | 2 | | |
| | | | | | |
| | | | | | |

# Larger images

## Stride as 2

| | | | | | |
|---|---|---|---|---|---|
| **2** | **4** | **3** | **6** | | |
| **2** | 1 | 3 | 0 | | |
| **9 1** | 0 **0** | 1 **-1** | 2 | | |
| **7 1** | 5 0 | 1 -1 | 2 | | |
| **1** | 0 | -1 | | | |
| | | | | | |

# Larger images

## Stride as 2

| | | | | | |
|---|---|---|---|---|---|
| **2** | **4** | **3** | **6** | | |
| **2** | 1 | 3 | 0 | | |
| **9** | 0 | 1 **1** | 2 **0** | **-1** | |
| **7** | 5 | 1 **1** | 2 0 | -1 | |
| | | **1** | 0 | -1 | |
| | | | | | |

# Padding

- Adding rows and columns outside your main data
- Typically zeros are added.
- Capture the boundaries (edges) better



| **2** | **4** | **3** | **6** |
|---|---|---|---|
| **2** | 1 | 3 | 0 |
| **9** | 0 | 1 | 2 |
| **7** | 5 | 1 | 2 |

# Padding

- Adding rows and columns outside your main data
- Typically zeros are added.
- Capture the boundaries (edges) better



| | | | | | |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 2 | 4 | 3 | 6 | 0 |
| 0 | 2 | 1 | 3 | 0 | 0 |
| 0 | 9 | 0 | 1 | 2 | 0 |
| 0 | 7 | 5 | 1 | 2 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 |

# Apply Stride

| | | | | | |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 2 | 4 | 3 | 6 | 0 |
| 0 | 2 | 1 | 3 | 0 | 0 |
| 0 | 9 | 0 | 1 | 2 | 0 |
| 0 | 7 | 5 | 1 | 2 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 |



| | | |
|---|---|---|
| **1** | **0** | **-1** |
| **1** | 0 | -1 |
| **1** | 0 | -1 |

# Apply Stride

| | | | | | |
|---|---|---|---|---|---|
| 0 **1** | 0 **0** | 0 **-1** | 0 | 0 | 0 |
| 0 **1** | 2 0 | 4 -1 | 3 | 6 | 0 |
| 0 **1** | 2 0 | 1 -1 | 3 | 0 | 0 |
| 0 | 9 | 0 | 1 | 2 | 0 |
| 0 | 7 | 5 | 1 | 2 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 |



| | | | |
|---|---|---|---|
| **-5** | | | |
| | | | |
| | | | |
| | | | |

# Apply Stride

| | | | | | |
|---|---|---|---|---|---|
| 0 | 0 **1** | 0 **0** | 0 **-1** | 0 | 0 |
| 0 | 2 **1** | 4 0 | 3 -1 | 6 | 0 |
| 0 | 2 **1** | 1 0 | 3 -1 | 0 | 0 |
| 0 | 9 | 0 | 1 | 2 | 0 |
| 0 | 7 | 5 | 1 | 2 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 |



| | | | |
|---|---|---|---|
| **-5** | **-2** | | |
| | | | |
| | | | |
| | | | |

# Apply Stride

| | | | | | |
|---|---|---|---|---|---|
| 0 | 0 | 0 **1** | 0 **0** | 0 **-1** | 0 |
| 0 | 2 | 4 **1** | 3 0 | 6 -1 | 0 |
| 0 | 2 | 1 **1** | 3 0 | 0 -1 | 0 |
| 0 | 9 | 0 | 1 | 2 | 0 |
| 0 | 7 | 5 | 1 | 2 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 |



| | | | |
|---|---|---|---|
| **-5** | **-2** | **-1** | |
| | | | |
| | | | |
| | | | |

# Apply Stride

| | | | | | |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 **1** | 0 **0** | 0 **-1** |
| 0 | 2 | 4 | 3 **1** | 6 0 | 0 -1 |
| 0 | 2 | 1 | 3 **1** | 0 0 | 0 -1 |
| 0 | 9 | 0 | 1 | 2 | 0 |
| 0 | 7 | 5 | 1 | 2 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 |



| | | | |
|---|---|---|---|
| **-5** | **-2** | **-1** | **6** |
| | | | |
| | | | |
| | | | |

# Apply Stride

| | | | | | |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 |
| 0 **1** | 2 **0** | 4 **-1** | 3 | 6 | 0 |
| 0 **1** | 2 0 | 1 -1 | 3 | 0 | 0 |
| 0 **1** | 9 0 | 0 -1 | 1 | 2 | 0 |
| 0 | 7 | 5 | 1 | 2 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 |



| | | | |
|---|---|---|---|
| **-5** | **-2** | **-1** | **6** |
| **-5** | | | |
| | | | |
| | | | |

# Apply Stride

| | | | | | |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 2 **1** | 4 **0** | 3 **-1** | 6 | 0 |
| 0 | 2 **1** | 1 0 | 3 -1 | 0 | 0 |
| 0 | 9 **1** | 0 0 | 1 -1 | 2 | 0 |
| 0 | 7 | 5 | 1 | 2 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 |



| | | | |
|---|---|---|---|
| **-5** | **-2** | **-1** | **6** |
| **-5** | 6 | | |
| | | | |
| | | | |

# Apply Stride

| | | | | | |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 2 | 4 **1** | 3 **0** | 6 **-1** | 0 |
| 0 | 2 | 1 **1** | 3 0 | 0 -1 | 0 |
| 0 | 9 | 0 **1** | 1 0 | 2 -1 | 0 |
| 0 | 7 | 5 | 1 | 2 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 |



| | | | |
|---|---|---|---|
| **-5** | **-2** | **-1** | **6** |
| **-5** | 6 | -3 | |
| | | | |
| | | | |

# Apply Stride

| | | | | | |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 2 | 4 | 3 **1** | 6 **0** | 0 **-1** |
| 0 | 2 | 1 | 3 **1** | 0 0 | 0 -1 |
| 0 | 9 | 0 | 1 **1** | 2 0 | 0 -1 |
| 0 | 7 | 5 | 1 | 2 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 |

| | | | |
|---|---|---|---|
| **-5** | **-2** | **-1** | **6** |
| **-5** | 6 | -3 | 7 |
| | | | |
| | | | |

# Apply Stride

| | | | | | |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 2 | 4 | 3 | 6 | 0 |
| 0 **1** | 2 **0** | 1 **-1** | 3 | 0 | 0 |
| 0 **1** | 9 0 | 0 -1 | 1 | 2 | 0 |
| 0 **1** | 7 0 | 5 -1 | 1 | 2 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 |



| | | | |
|---|---|---|---|
| **-5** | **-2** | **-1** | **6** |
| **-5** | 6 | -3 | 7 |
| **-6** | | | |
| | | | |

# Apply Stride

| | | | | | |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 2 | 4 | 3 | 6 | 0 |
| 0 | 2 **1** | 1 **0** | 3 **-1** | 0 | 0 |
| 0 | 9 **1** | 0 0 | 1 -1 | 2 | 0 |
| 0 | 7 **1** | 5 0 | 1 -1 | 2 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 |



| | | | |
|---|---|---|---|
| **-5** | **-2** | **-1** | **6** |
| **-5** | 6 | -3 | 7 |
| **-6** | 18 | | |
| | | | |

# Apply Stride

| | | | | | |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 2 | 4 | 3 | 6 | 0 |
| 0 | 2 | 1 **1** | 3 **0** | 0 **-1** | 0 |
| 0 | 9 | 0 **1** | 1 0 | 2 -1 | 0 |
| 0 | 7 | 5 **1** | 1 0 | 2 -1 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 |

| | | | |
|---|---|---|---|
| **-5** | **-2** | **-1** | **6** |
| **-5** | 6 | -3 | 7 |
| **-6** | 18 | 2 | |
| | | | |

# Apply Stride

| | | | | | |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 2 | 4 | 3 | 6 | 0 |
| 0 | 2 | 1 | 3 **1** | 0 **0** | 0 **-1** |
| 0 | 9 | 0 | 1 **1** | 2 0 | 0 -1 |
| 0 | 7 | 5 | 1 **1** | 2 0 | 0 -1 |
| 0 | 0 | 0 | 0 | 0 | 0 |

| | | | |
|---|---|---|---|
| **-5** | **-2** | **-1** | **6** |
| **-5** | 6 | -3 | 7 |
| **-6** | 18 | 2 | 5 |
| | | | |

# Apply Stride

| | | | | | |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 2 | 4 | 3 | 6 | 0 |
| 0 | 2 | 1 | 3 | 0 | 0 |
| 0 **1** | 9 **0** | 0 **-1** | 1 | 2 | 0 |
| 0 **1** | 7 0 | 5 -1 | 1 | 2 | 0 |
| 0 **1** | 0 0 | 0 -1 | 0 | 0 | 0 |



| | | | |
|---|---|---|---|
| **-5** | **-2** | **-1** | **6** |
| **-5** | 6 | -3 | 7 |
| **-6** | 18 | 2 | 5 |
| **-5** | | | |

# Apply Stride

| | | | | | |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 2 | 4 | 3 | 6 | 0 |
| 0 | 2 | 1 | 3 | 0 | 0 |
| 0 | 9 **1** | 0 **0** | 1 **-1** | 2 | 0 |
| 0 | 7 **1** | 5 0 | 1 -1 | 2 | 0 |
| 0 | 0 **1** | 0 0 | 0 -1 | 0 | 0 |



| | | | |
|---|---|---|---|
| **-5** | **-2** | **-1** | **6** |
| **-5** | 6 | -3 | 7 |
| **-6** | 18 | 2 | 5 |
| **-5** | 14 | | |

# Apply Stride

| | | | | | |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 2 | 4 | 3 | 6 | 0 |
| 0 | 2 | 1 | 3 | 0 | 0 |
| 0 | 9 | 0 **1** | 1 **0** | 2 **-1** | 0 |
| 0 | 7 | 5 **1** | 1 0 | 2 -1 | 0 |
| 0 | 0 | 0 **1** | 0 0 | 0 -1 | 0 |



| | | | |
|---|---|---|---|
| **-5** | **-2** | **-1** | **6** |
| **-5** | 6 | -3 | 7 |
| **-6** | 18 | 2 | 5 |
| **-5** | 14 | 1 | |

# Apply Stride

| | | | | | |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 2 | 4 | 3 | 6 | 0 |
| 0 | 2 | 1 | 3 | 0 | 0 |
| 0 | 9 | 0 | 1 **1** | 2 **0** | 0 **-1** |
| 0 | 7 | 5 | 1 **1** | 2 0 | 0 -1 |
| 0 | 0 | 0 | 0 **1** | 0 0 | 0 -1 |



| | | | |
|---|---|---|---|
| **-5** | **-2** | **-1** | **6** |
| **-5** | 6 | -3 | 7 |
| **-6** | 18 | 2 | 5 |
| **-5** | 14 | 1 | 2 |

# Padding + Apply Stride + Convolution

## with a Kernel (filter)

| | | | | | |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 2 | 4 | 3 | 6 | 0 |
| 0 | 2 | 1 | 3 | 0 | 0 |
| 0 | 9 | 0 | 1 | 2 | 0 |
| 0 | 7 | 5 | 1 | 2 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 |

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| | | |
|---|---|---|
| **1** | **0** | **-1** |
| **1** | 0 | -1 |
| **1** | 0 | -1 |



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| | | | |
|---|---|---|---|
| **-5** | **-2** | **-1** | **6** |
| **-5** | 6 | -3 | 7 |
| **-6** | 18 | 2 | 5 |
| **-5** | 14 | 1 | 2 |

# Pooling

- Fixed operator - Max or Average pooling.
- Filter size and stride are hyper-parameters.
- Capture the boundaries (edges) better

# Filter with size 2 X 2

## Max. pooling

| | | | |
|---|---|---|---|
| **-5** | **-2** | **-1** | **6** |
| **-5** | 6 | -3 | 7 |
| **-6** | 18 | 2 | 5 |
| **-5** | 14 | 1 | 2 |

# Filter with size 2 X 2 and stride 1

## Max. pooling

| | | | |
|---|---|---|---|
| **-5** | **-2** | **-1** | **6** |
| **-5** | 6 | -3 | 7 |
| **-6** | 18 | 2 | 5 |
| **-5** | 14 | 1 | 2 |



| | | |
|---|---|---|
| **6** | | |
| | | |
| | | |

# Filter with size 2 X 2 and stride 1

## Max. pooling

| | | | |
|---|---|---|---|
| **-5** | **-2** | **-1** | **6** |
| **-5** | 6 | -3 | 7 |
| **-6** | 18 | 2 | 5 |
| **-5** | 14 | 1 | 2 |



| | | |
|---|---|---|
| **6** | **6** | |
| | | |
| | | |

# Filter with size 2 X 2 and stride 1

## Max. pooling

| | | | |
|---|---|---|---|
| **-5** | **-2** | **-1** | **6** |
| **-5** | 6 | -3 | 7 |
| **-6** | 18 | 2 | 5 |
| **-5** | 14 | 1 | 2 |



| | | |
|---|---|---|
| **6** | **6** | **7** |
| | | |
| | | |

# Filter with size 2 X 2 and stride 1

## Max. pooling

| | | | |
|---|---|---|---|
| **-5** | **-2** | **-1** | **6** |
| **-5** | 6 | -3 | 7 |
| **-6** | 18 | 2 | 5 |
| **-5** | 14 | 1 | 2 |



| | | |
|---|---|---|
| **6** | **6** | **7** |
| **18** | | |
| | | |

# Filter with size 2 X 2 and stride 1

## Max. pooling

| | | | |
|---|---|---|---|
| **-5** | **-2** | **-1** | **6** |
| **-5** | 6 | -3 | 7 |
| **-6** | 18 | 2 | 5 |
| **-5** | 14 | 1 | 2 |



| | | |
|---|---|---|
| **6** | **6** | **7** |
| **18** | 18 | |
| | | |

# Filter with size 2 X 2 and stride 1

## Max. pooling

| | | | |
|---|---|---|---|
| **-5** | **-2** | **-1** | **6** |
| **-5** | 6 | -3 | 7 |
| **-6** | 18 | 2 | 5 |
| **-5** | 14 | 1 | 2 |



| | | |
|---|---|---|
| **6** | **6** | **7** |
| **18** | 18 | 7 |
| | | |

# Filter with size 2 X 2 and stride 1

## Max. pooling

| | | | |
|---|---|---|---|
| **-5** | **-2** | **-1** | **6** |
| **-5** | 6 | -3 | 7 |
| **-6** | 18 | 2 | 5 |
| **-5** | 14 | 1 | 2 |



| | | |
|---|---|---|
| **6** | **6** | **7** |
| **18** | 18 | 7 |
| **18** | | |

# Filter with size 2 X 2 and stride 1

## Max. pooling

| | | | |
|---|---|---|---|
| **-5** | **-2** | **-1** | **6** |
| **-5** | 6 | -3 | 7 |
| **-6** | 18 | 2 | 5 |
| **-5** | 14 | 1 | 2 |



| | | |
|---|---|---|
| **6** | **6** | **7** |
| **18** | 18 | 7 |
| **18** | 18 | |

# Filter with size 2 X 2 and stride 1

## Max. pooling

| | | | |
|---|---|---|---|
| **-5** | **-2** | **-1** | **6** |
| **-5** | 6 | -3 | 7 |
| **-6** | 18 | 2 | 5 |
| **-5** | 14 | 1 | 2 |



| | | |
|---|---|---|
| **6** | **6** | **7** |
| **18** | 18 | 7 |
| **18** | 18 | 5 |

# Pooling

- Filter (size)
- Padding
- Strides
- Pooling

# Edge detection filters

| | | |
|---|---|---|
| **0** | **-1** | **0** |
| **-1** | 4 | -1 |
| **0** | -1 | 0 |

| | | |
|---|---|---|
| **-1** | **-1** | **-1** |
| **-1** | 8 | -1 |
| **-1** | -1 | -1 |

# CNN

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