Lecture 3 | Sensors & Sensor Abstractions

Secure Autonomous Systems

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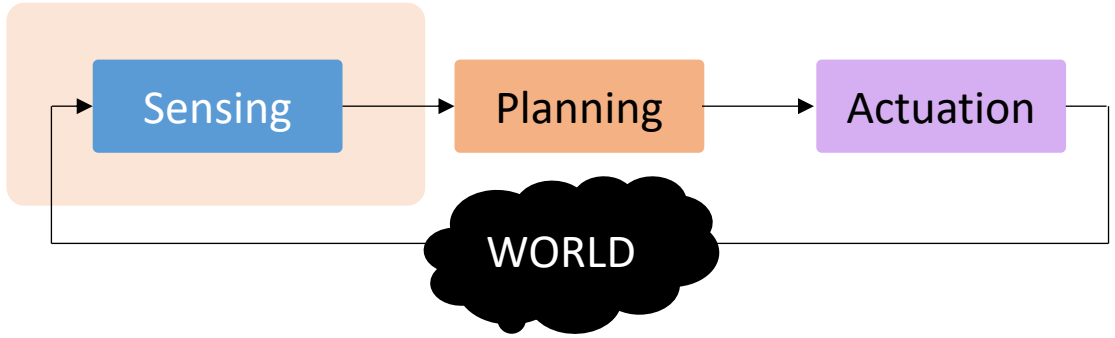
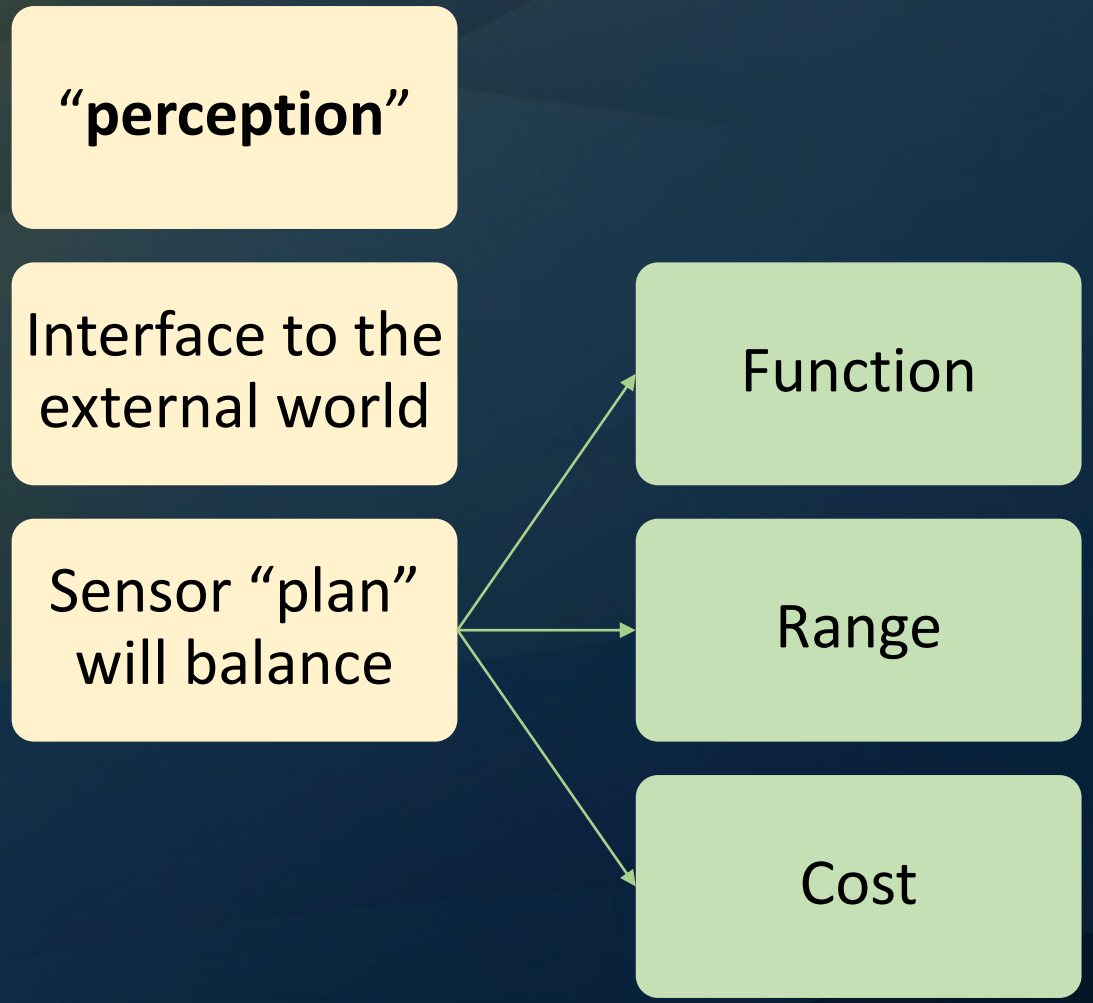
https://bit.ly/secureauto-spring24

Sensing, Planning, Actuation Loop



Sensors

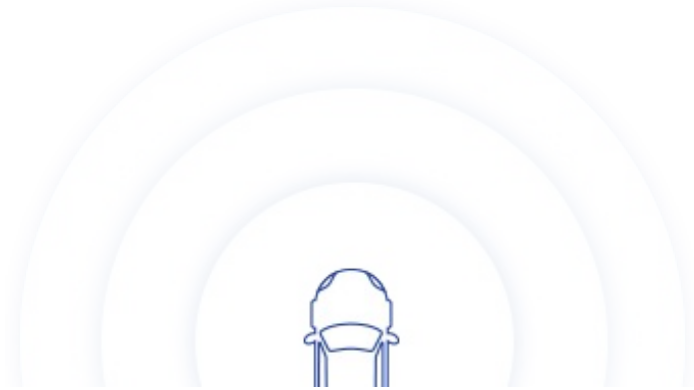

“perception”
Interface to the external world
Sensor “plan” will balance
Function
Range
Cost

Common Sensor Types

- **LiDAR/Millimeter Radar**
- **GPS**
- **Cameras**: lane, road, traffic light, stop line, surroundings
- **Stereo Vision**
- **Sonic**

LiDAR

- **Li**ght **D**etection **A**nd **R**anging
- Laser scanning/3D scanning
- Uses eye-safe laser beams ➔ create 3D representation of environment



A typical lidar sensor emits pulsed light waves into the surrounding environment

These pulses bounce off surrounding objects and return to the sensor

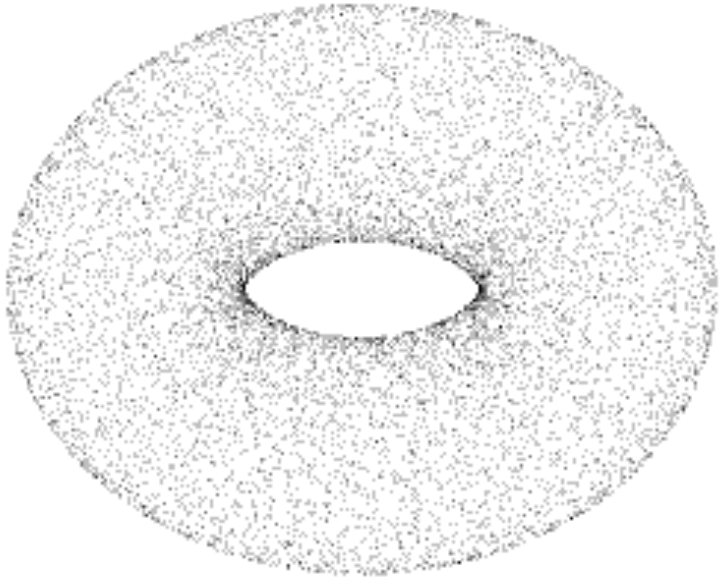
The sensor uses the time it took for each pulse to return to the sensor to calculate the distance it traveled

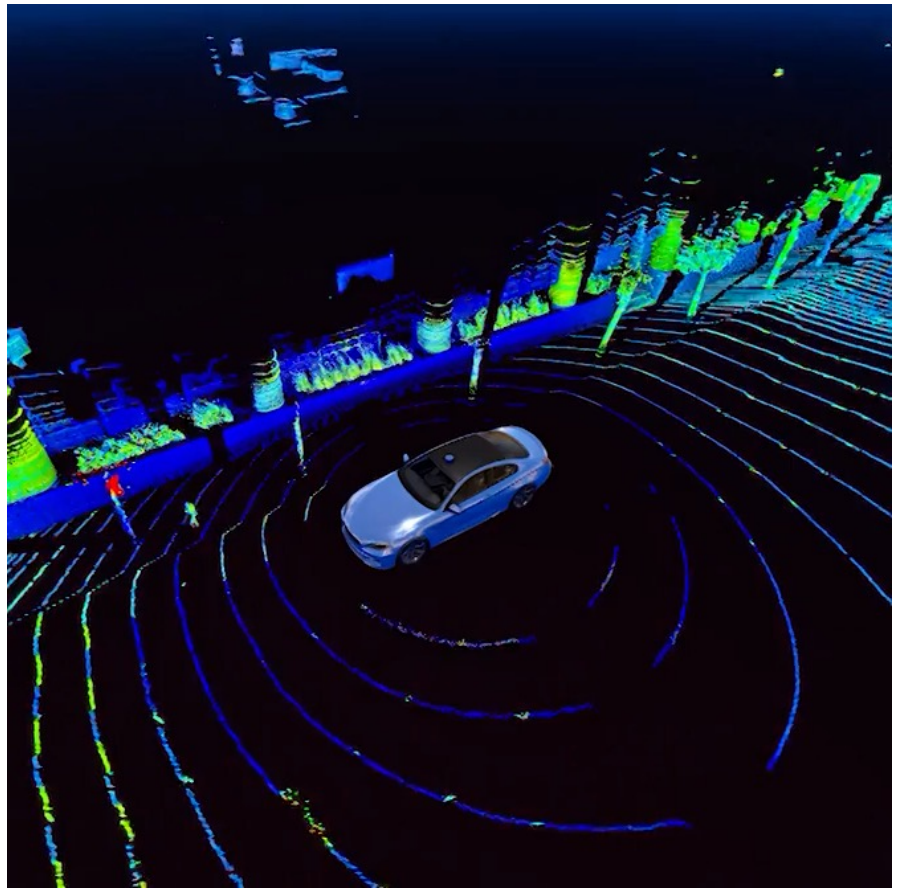
LiDAR Output

Point clouds In 3D

Range: **70-100** m

View: **360 degrees**





Millimeter Wave Radar [mmWave]

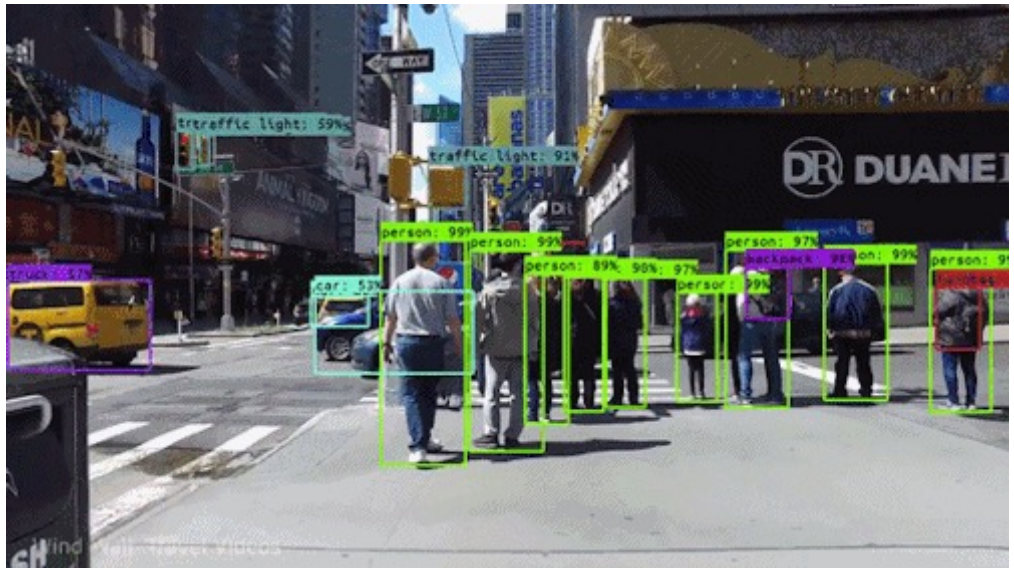
- Radar technology
- short-wavelength electromagnetic waves
- Measures reflected radar signals

- **High accuracy**
- 76-81 GHz ➔ detect movements in a **fraction of a millimeter**!
- Limited distance [< 80m]

- Also, used for in-cabin monitoring of drivers

Cameras

- Accurate way to create visual representations
- Front, left, right, rear cameras
  - to create **a 360-degree view**
- Main focus ➔ **object detection**

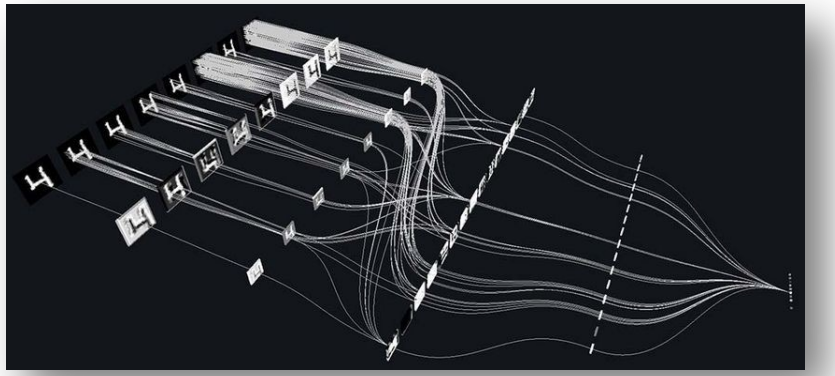


Cameras | Computer Vision

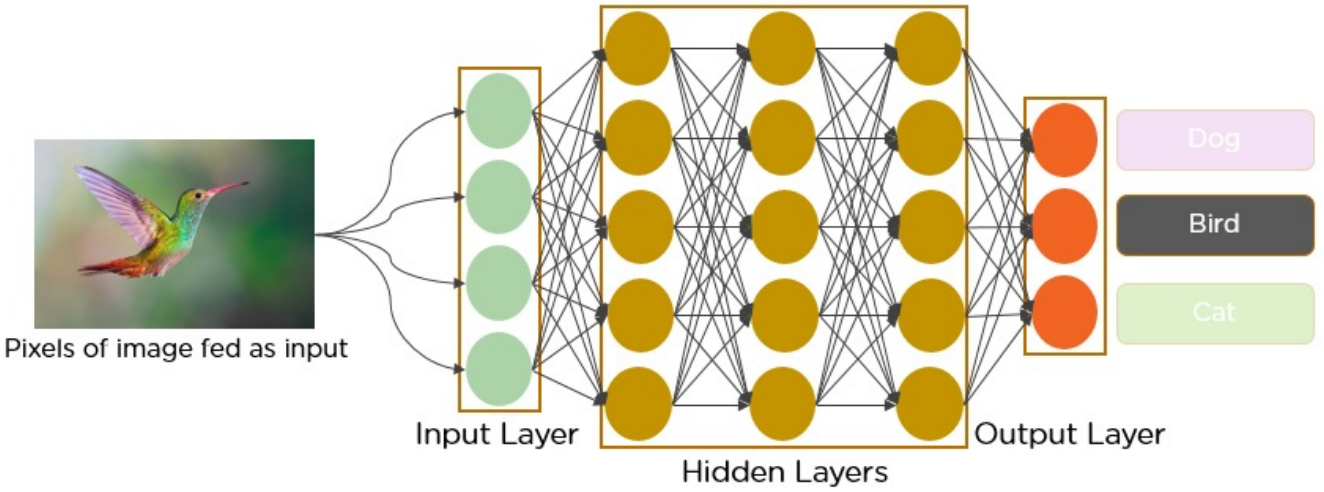
- Computer Vision algorithms for object detection
    1. Image classification → determine **what** the objects in an image are
    2. Image localizations → providing specific **locations** of image [bounding box]

Cameras | Image Classification

- Convolutional Neural Networks (CNNs)
  - **trained** to recognize objects like cars, pedestrians, etc.
  - performs **convolution operations at runtime**
    - to classify images from camera

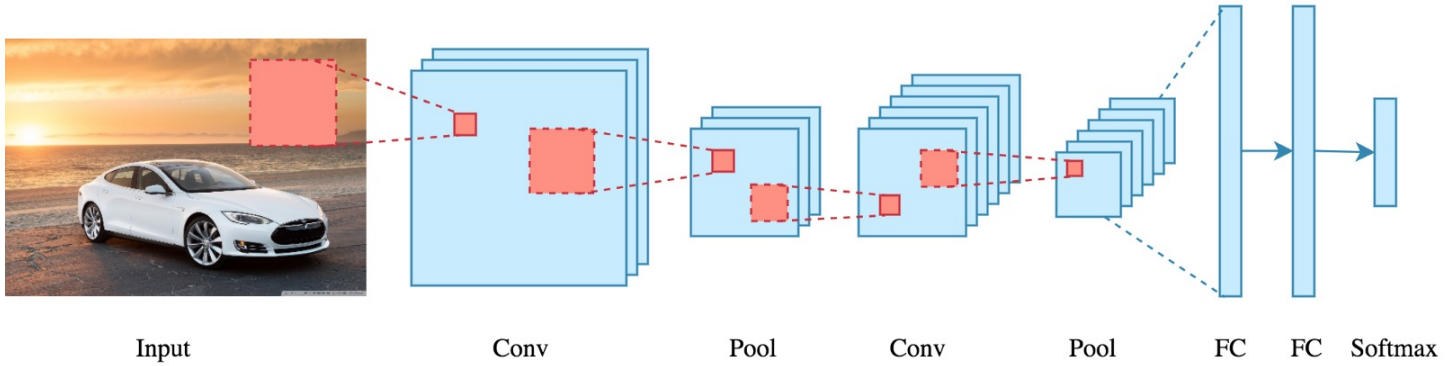


Deep Learning



CNNs

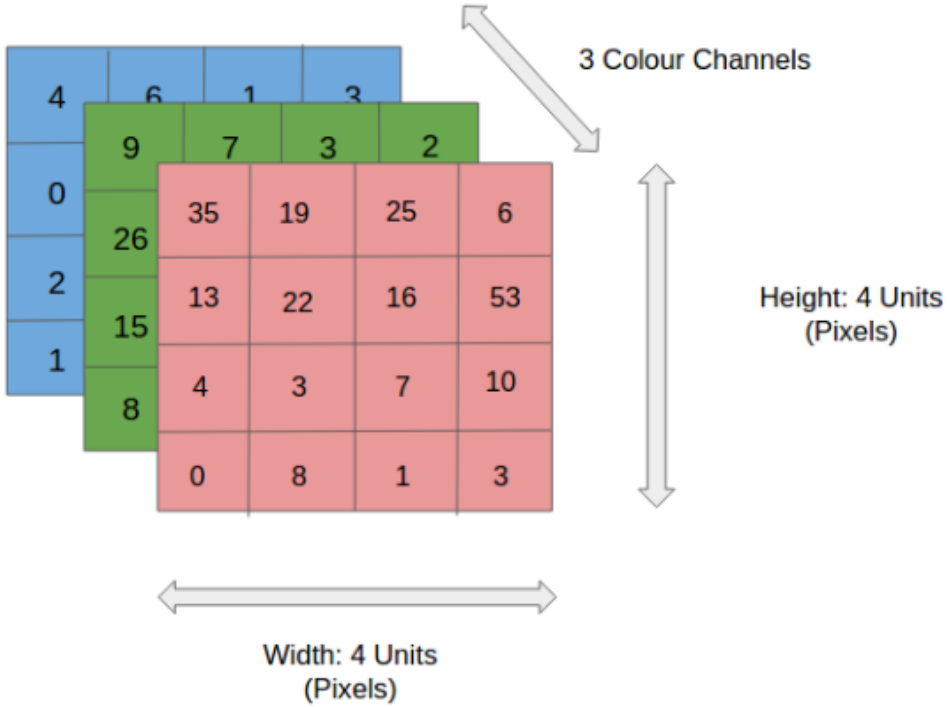
- A class of deep neural networks
- Mostly applied for visual imagery
- Uses **mathematical convolutions**
  - operation on two functions
  - produces a third function
  - expresses shape of how one modifies the other



How Do Convolutions Work?

Consider an image

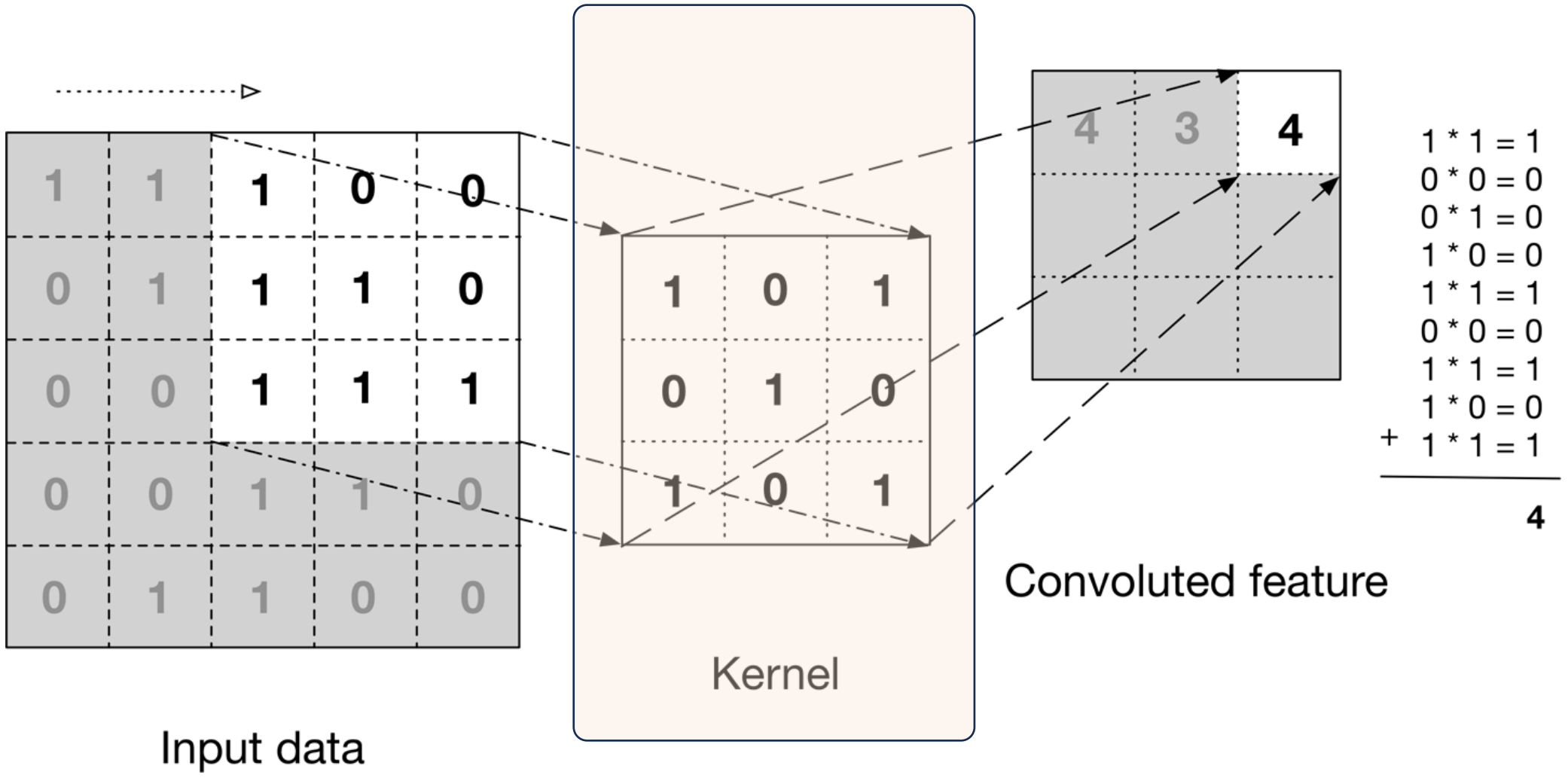
Input



for simplicity, consider a **grayscale** version

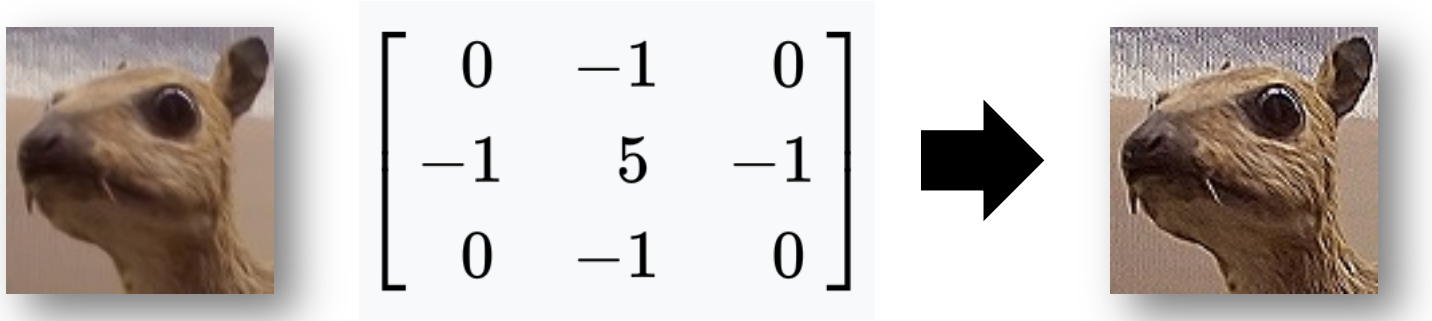
Input

[Greyscale] Convolution



Kernel/Filters

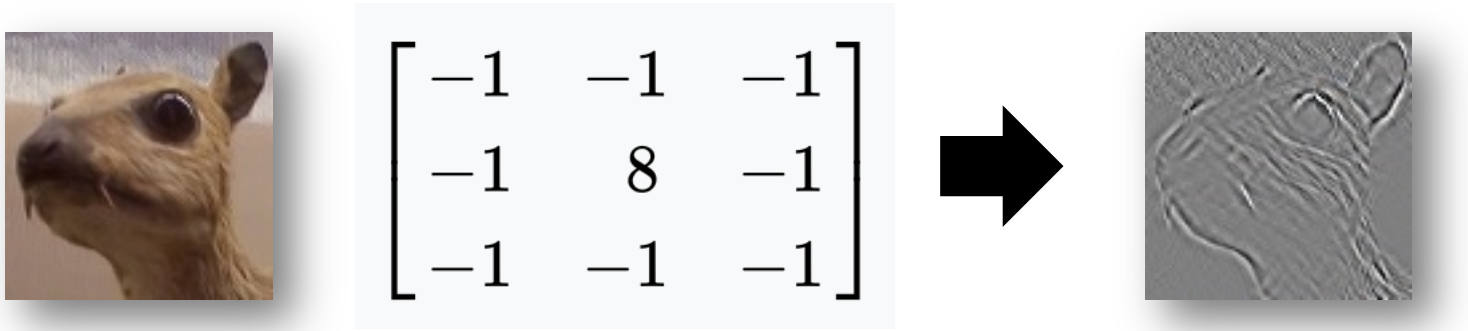
- Filters exploit **spatial locality** of a particular image
- A small matrix used for ➔ *blurring, sharpening, edge detection*, etc.
- **Enforcing connectivity** between neurons



$$\begin{bmatrix} 0 & -1 & 0 \\ -1 & 5 & -1 \\ 0 & -1 & 0 \end{bmatrix}$$

“**sharpen**” kernel

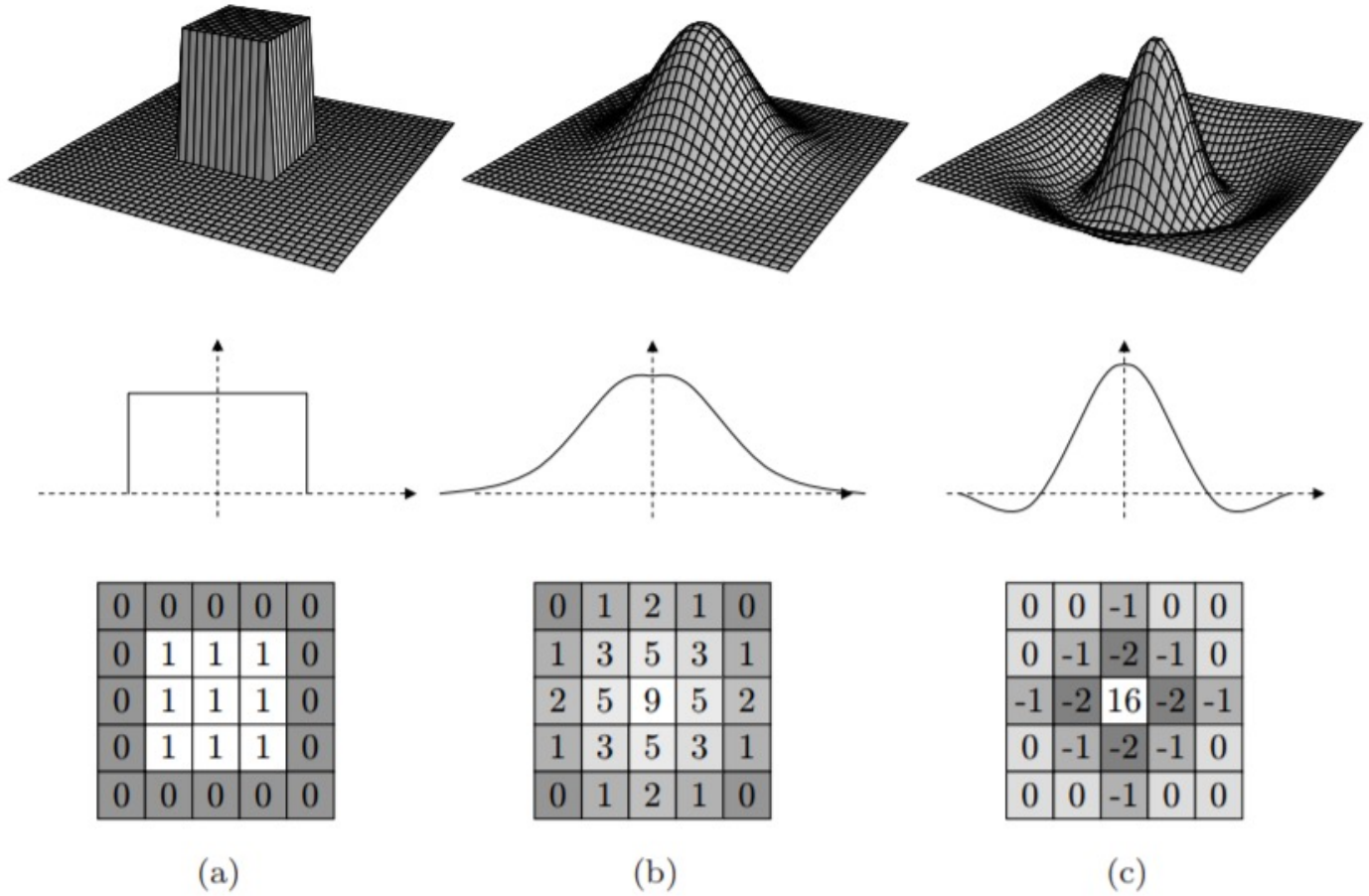
Kernel/Filter Example [contd.]



$$\begin{bmatrix} -1 & -1 & -1 \\ -1 & 8 & -1 \\ -1 & -1 & -1 \end{bmatrix}$$

“**ridge/edge detection**” kernel

Kernels Come in Various Shapes



0	0	0	0	0
0	1	1	1	0
0	1	1	1	0
0	1	1	1	0
0	0	0	0	0

(a)

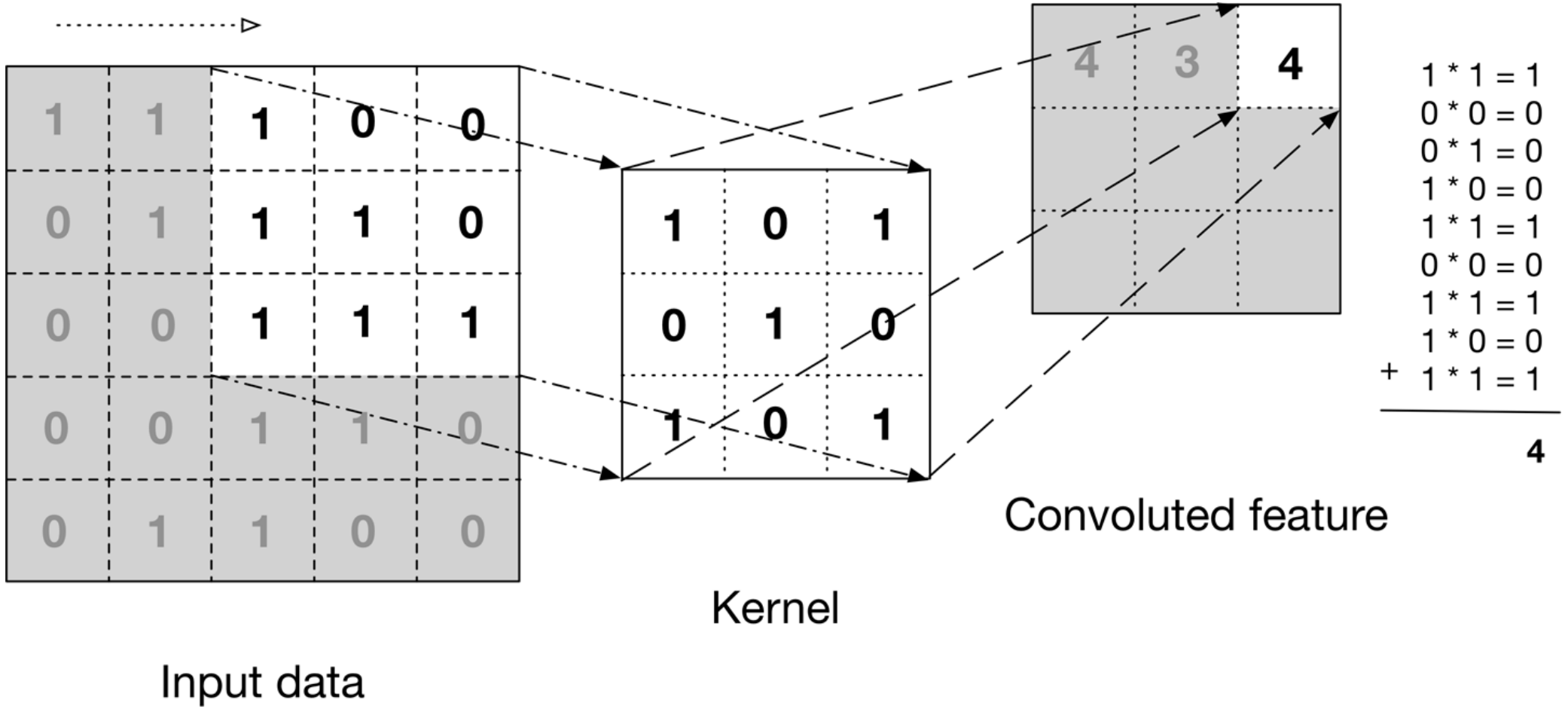
0	1	2	1	0
1	3	5	3	1
2	5	9	5	2
1	3	5	3	1
0	1	2	1	0

(b)

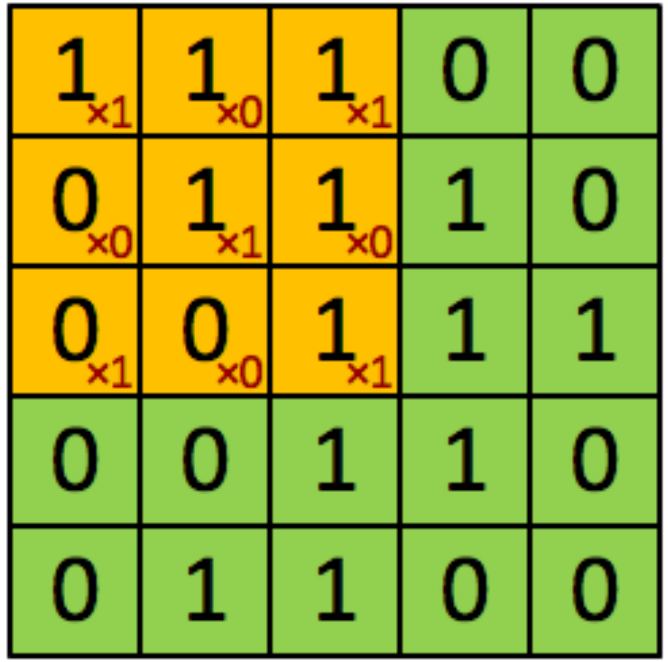
0	0	-1	0	0
0	-1	-2	-1	0
-1	-2	16	-2	-1
0	-1	-2	-1	0
0	0	-1	0	0

(c)

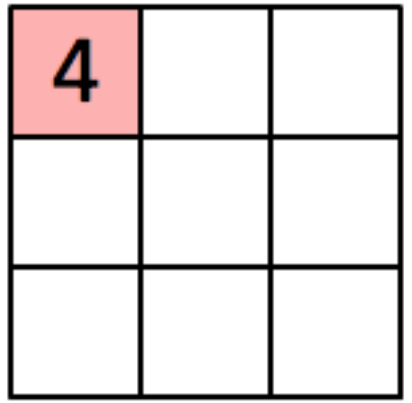
[Greyscale] Convolution



[Greyscale] Convolution [contd.]

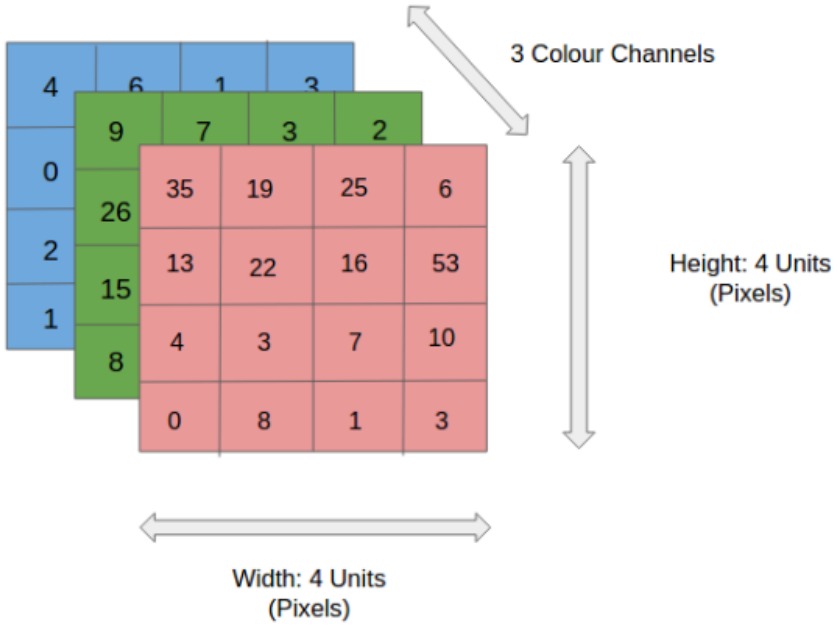


Image

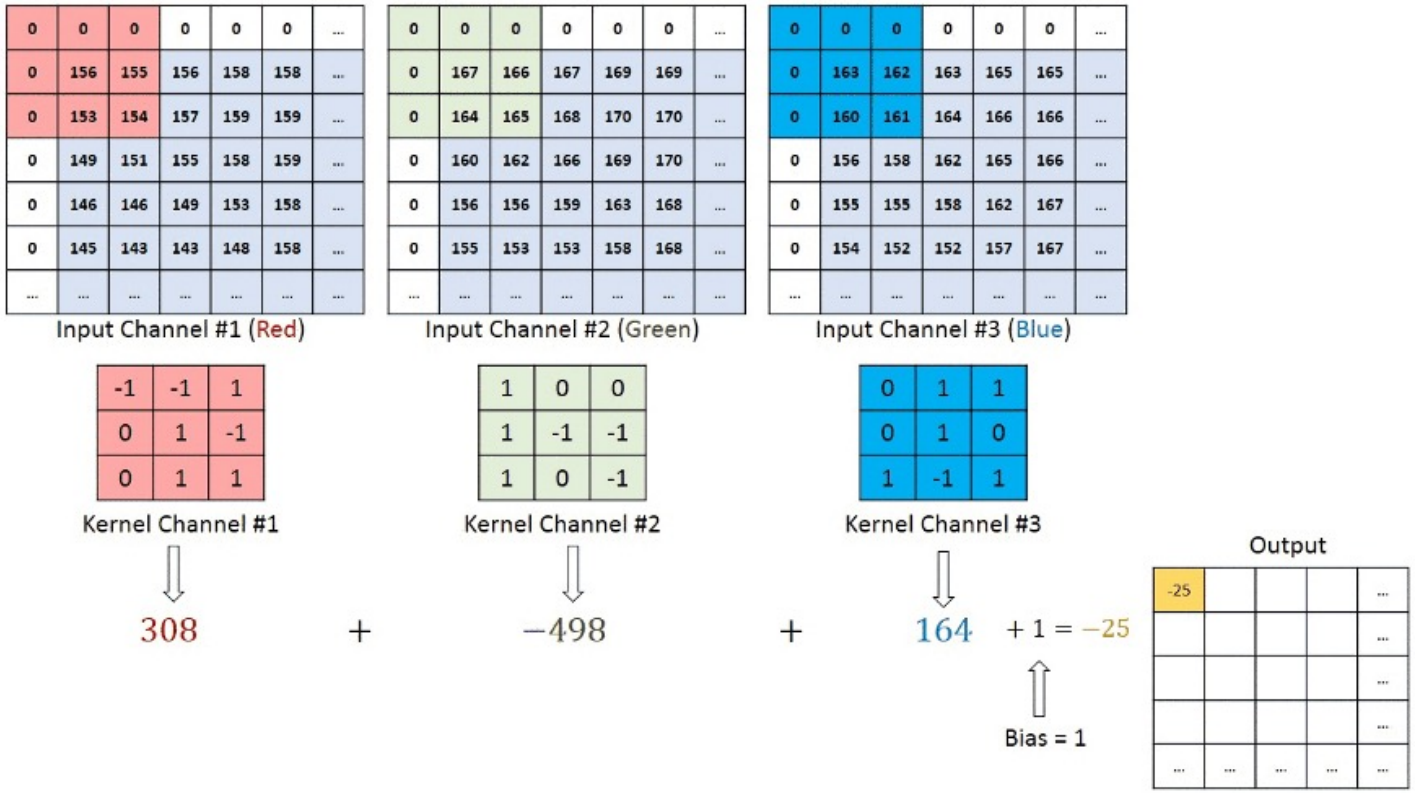


Convolved Feature

but we deal with **color** images!



[Color] Convolutions



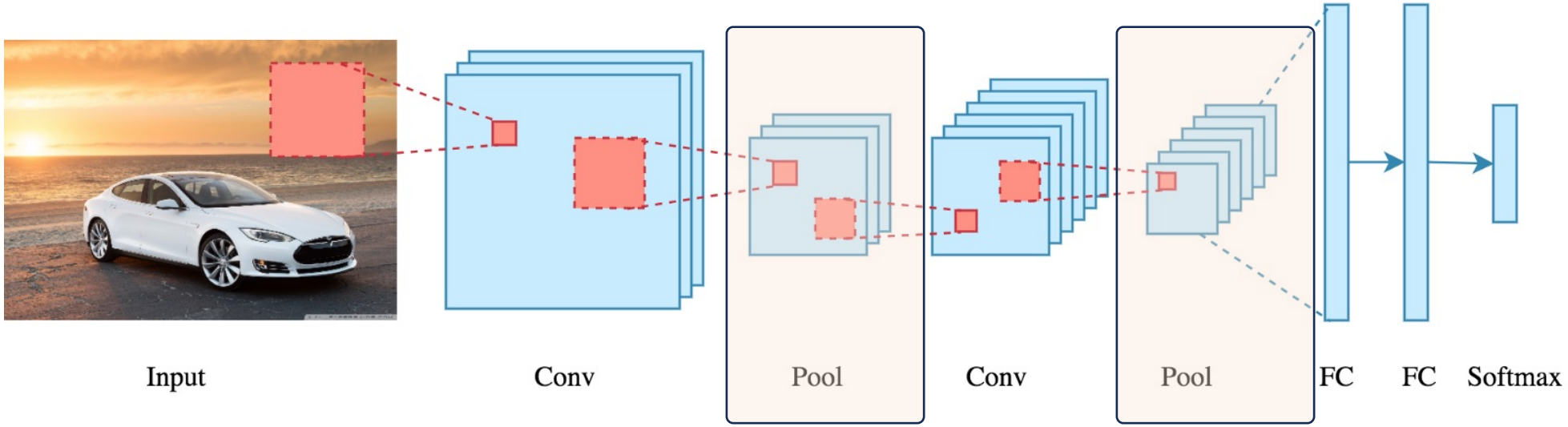
So, then…what are CNNs?

- multiple layers of **artificial neurons**
- mathematical functions ➔ calculate weighted sum of inputs/outputs
- on **activation value**

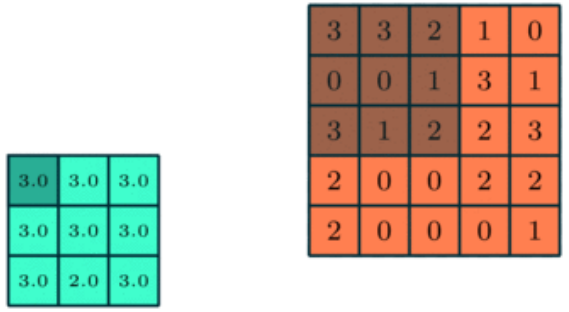
Why **Multiple** layers?

Each layer has a unique function

Pooling Layer?



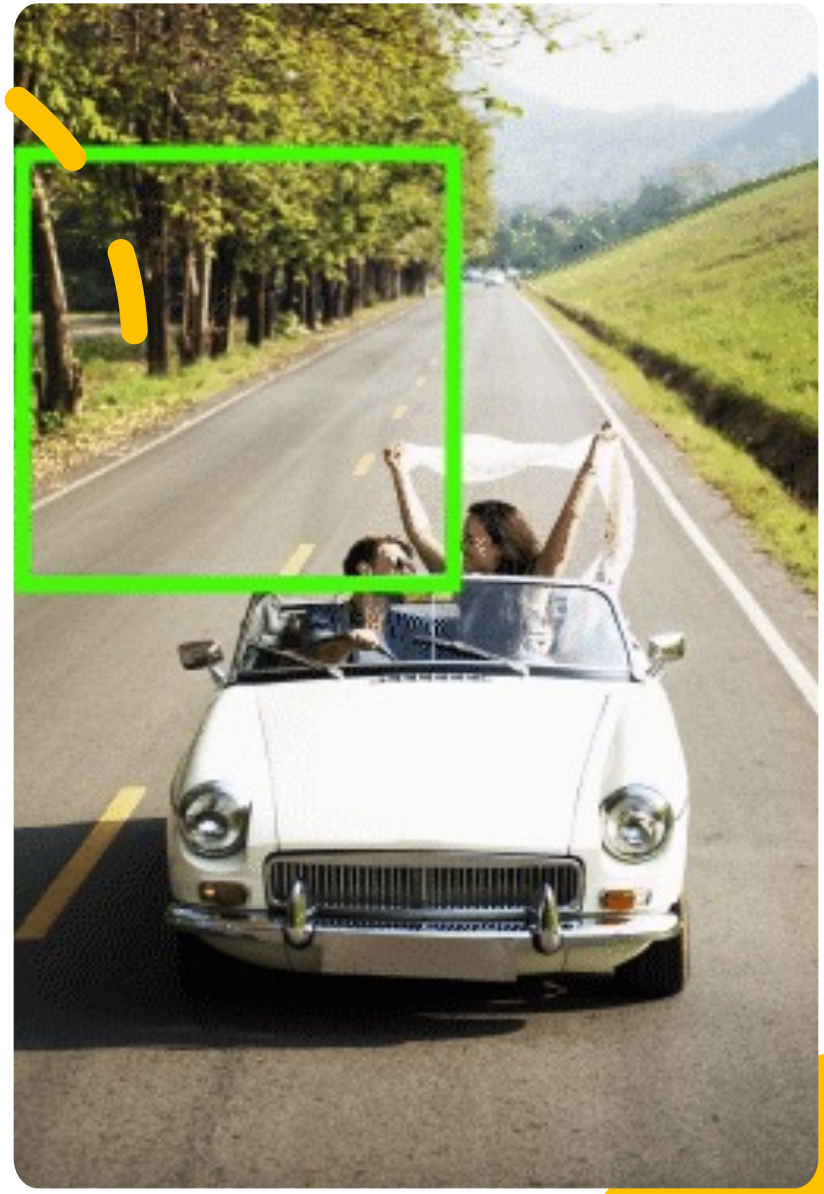
- **reduce spatial size** of convolution layer
- reduce computational loads



"**max**" pool

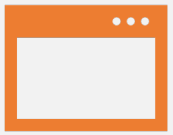
Issues with CNNs

- limited to single objects taking up entire image
- multiple objects in image?
- **sliding windows!**



Cameras | Sliding Window Algorithm

Issues to Consider



what is the **window size**?

- start with large/small window and keep increasing?

accuracy?

- bounding box may not be accurate
- rectangular boxes?

computational cost!

References

- Velodyne LiDAR Video:

https://sibin.github.io/teaching/csci6907_88-gwu-secure_autonomous/fall_2022/other_docs/What-is-Lidar-video.mp4

- mmWave Documentation

https://www.ti.com/lit/wp/spyy005a/spyy005a.pdf?ts=1641417836995&ref_url=https%253A%252F%252Fwww.google.com%252F