RWR 4013

Digital Twins for Smart Cities

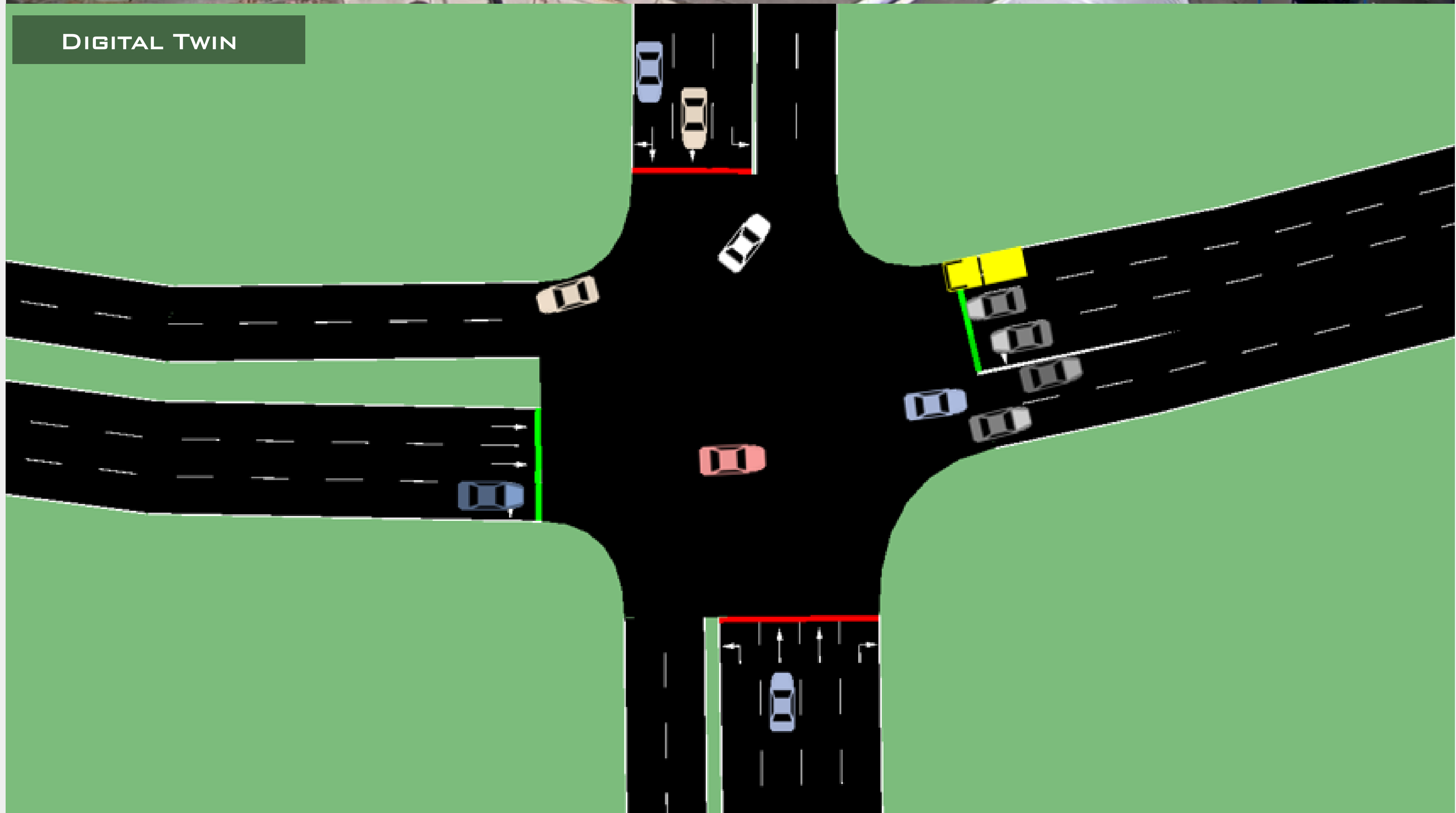
Dr. Ahmad Mohammadi

Week 1 | Session 2:
Introduction to Digital Twins
for Smart Cities

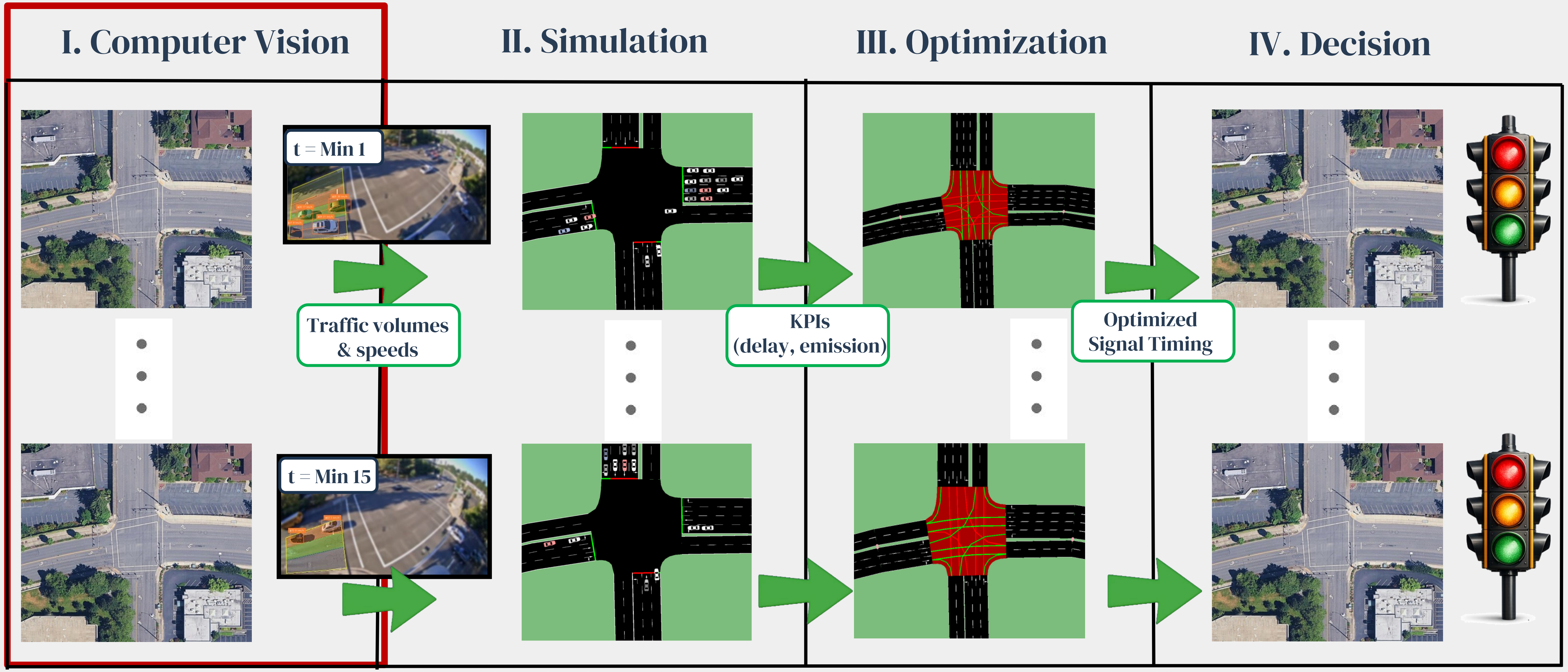
Fall 2026

RoadwayVR

roadwayvr.github.io/DigitalTwinsforSmartCities



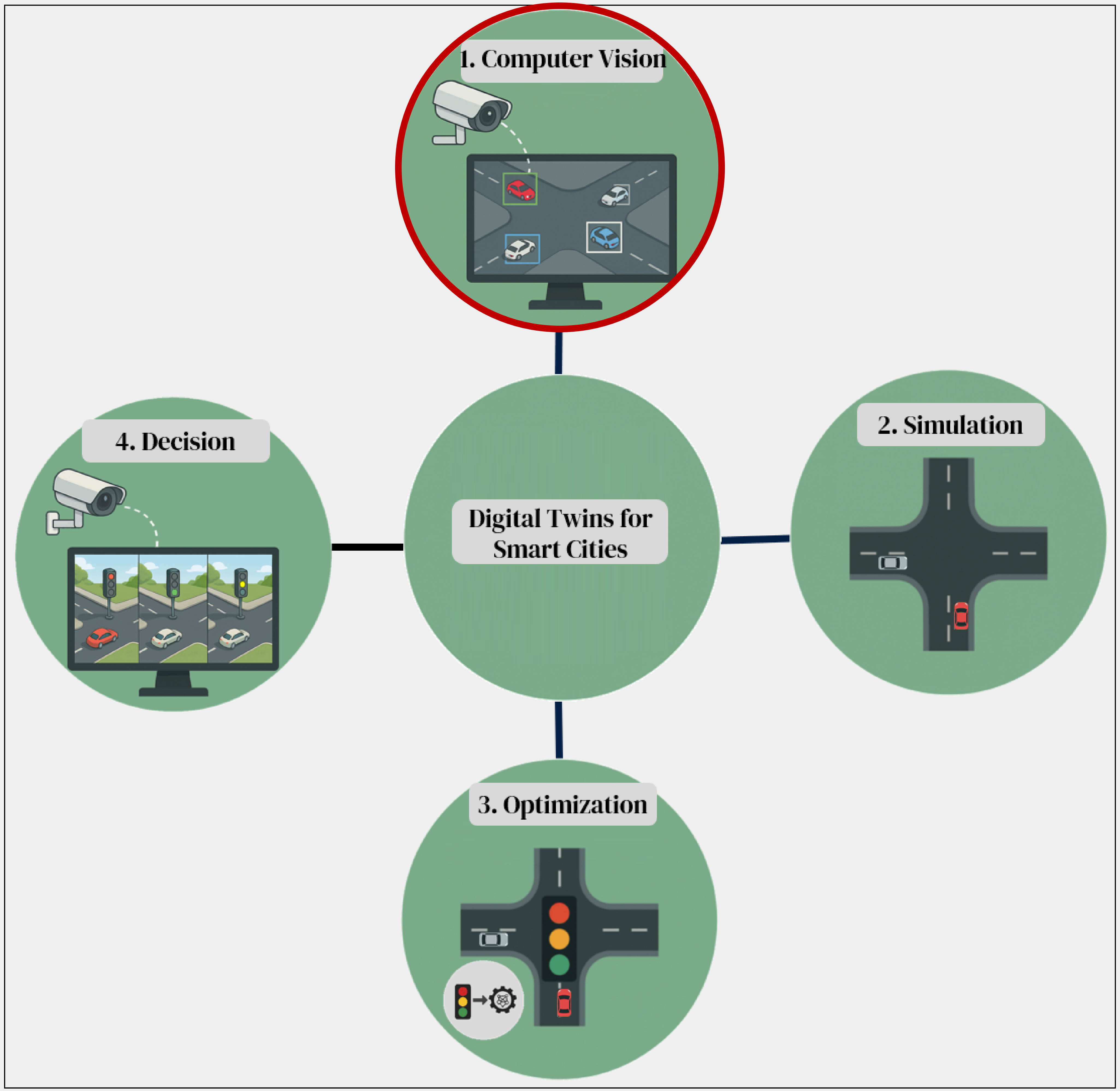
Overview of Course Syllabus in One Shot



Agenda

Fundamental of Computer Vision

- ❑ What is an Image?
- ❑ Pixel Data
- ❑ Resolution
- ❑ What are Videos?
- ❑ Convolutional Neural Network (CNN)
- ❑ What is Convolution?

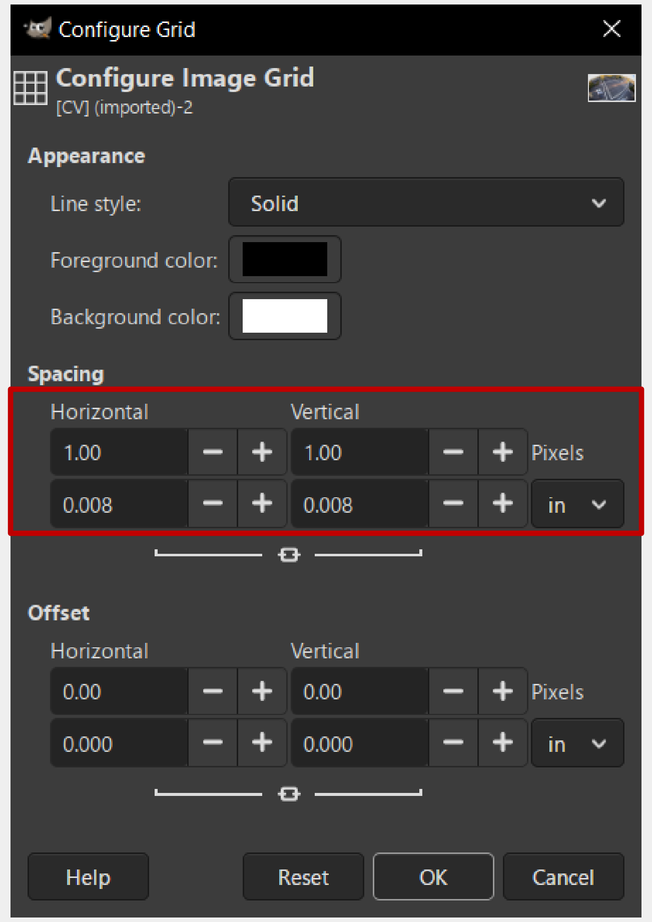


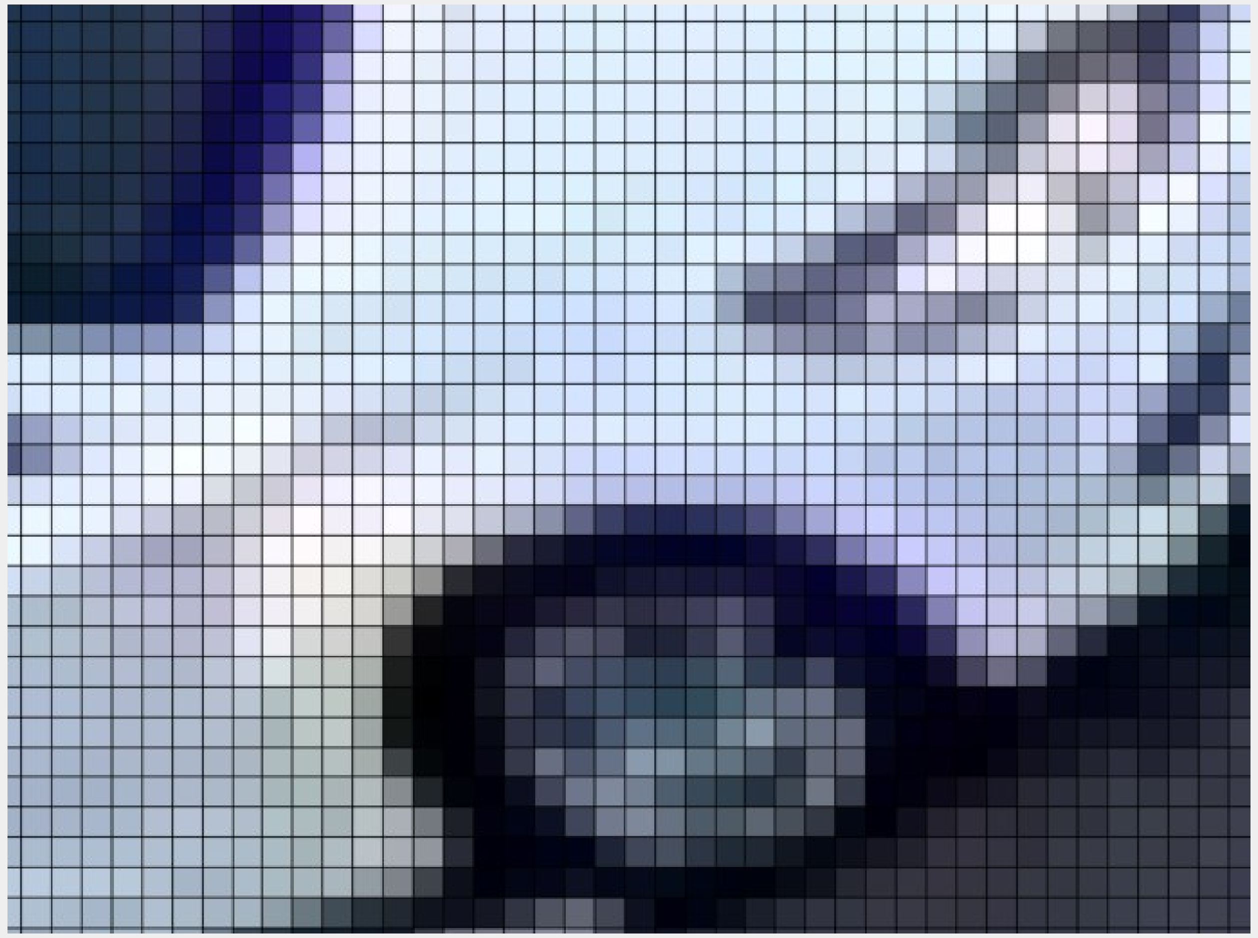
What is an Image?

- An image is a 2D grid of pixels, where each pixel stores a color value (intensity).

Observe Pixels in GIMP

- Download Week1b.Material.zip and extract the file
- Download Software GIMP (GIMP.org)→ Open GIMP
- File → Open → Select the CV.jpg from Folder "Week1b.Material"
- View → Show Grid
- Image → Configure Grid → Spacing → Set them to 1 and 1 → Select "Ok"
- Zoom in (Ctrl + Mouse Wheel) on the White Car

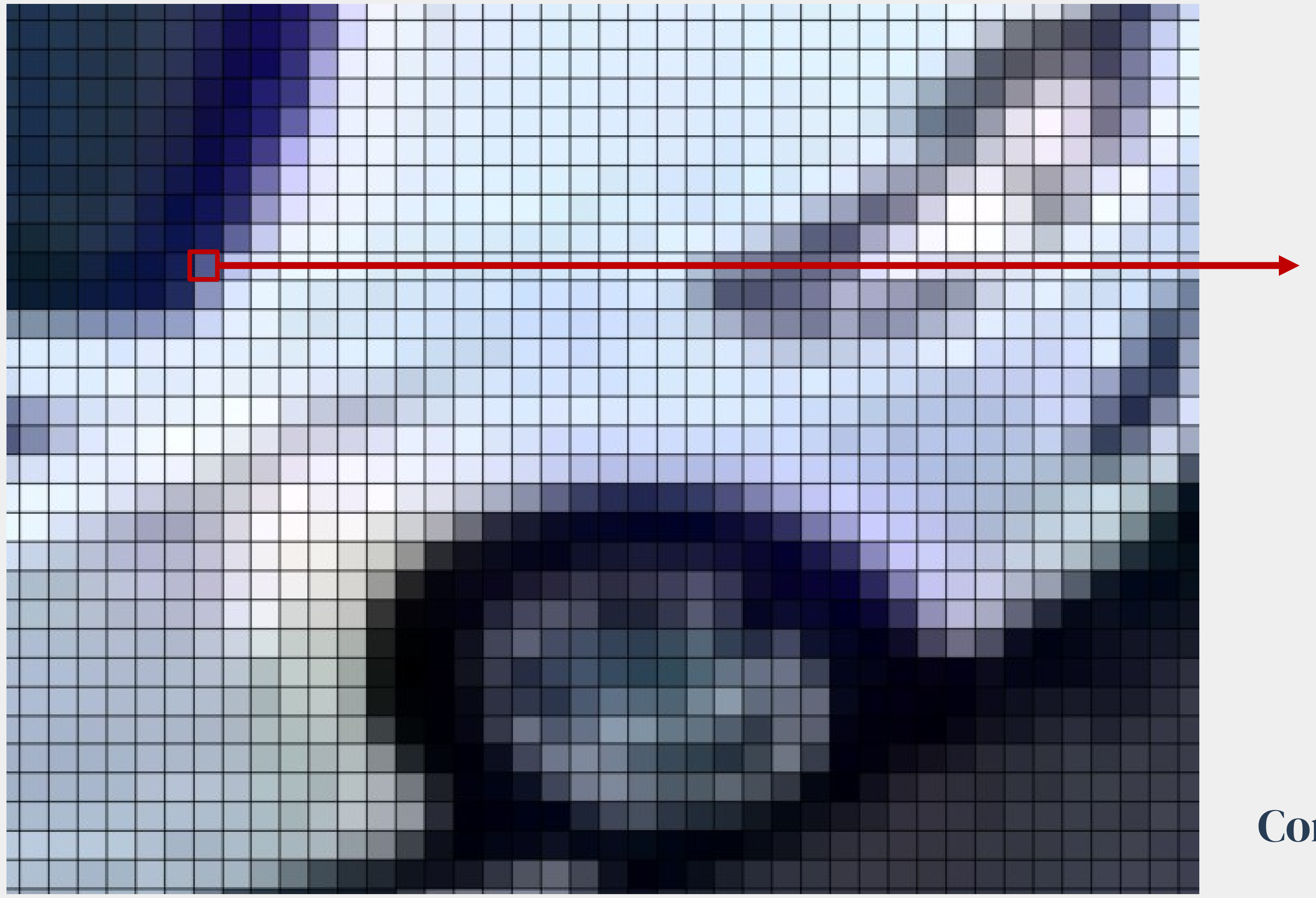


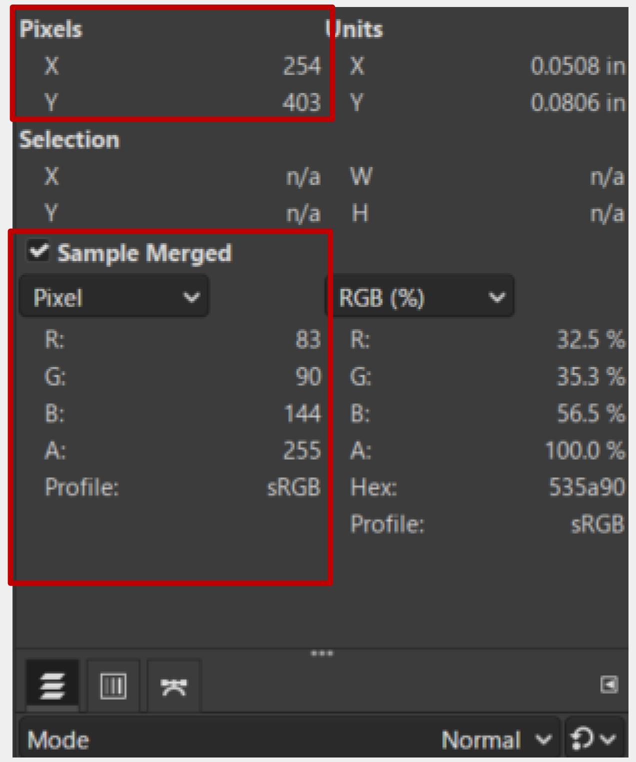


Observe Pixels in GIMP

- Windows → Dockable Dialogs → Pointer
- Hover your mouse over the exact pixel (red rectangle)

  It shows:
- X, Y coordinates
- RGB values



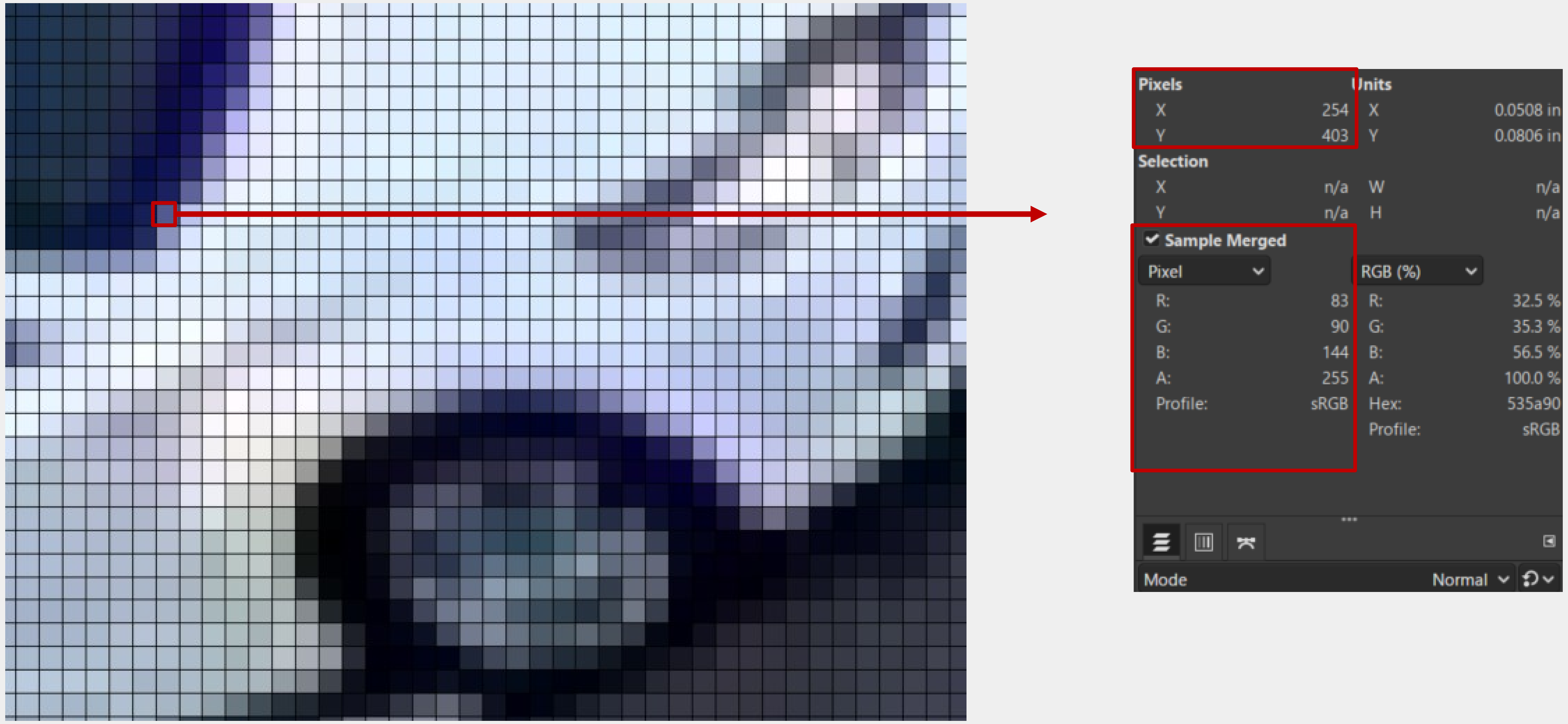


Computer sees this: (254,403,83,90,144)

Observe Pixels in GIMP

- A digital image contains many pixels.
- Each pixel has:
  - a location (x, y)
  - color values (R, G, B)

Computer sees this: (254,403,83,90,144)



How a Computer Represents an Image

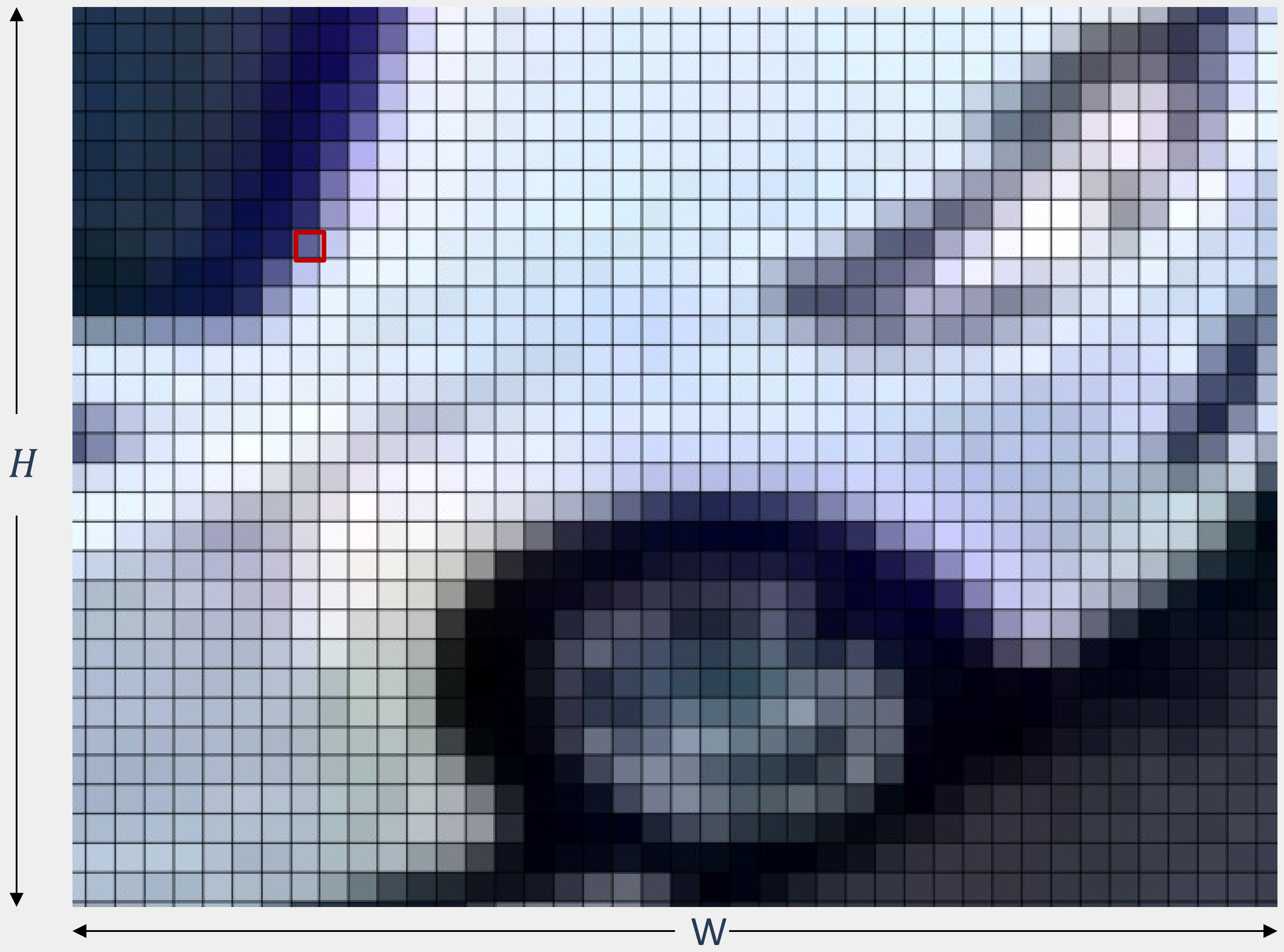
An image can be represented as a table of pixel data.
Each pixel becomes one row in the table:

$$(x, y, R, G, B)$$

- Number of pixels:

$$H \times W$$

- where H = image height (pixels) and W = image width (pixels).



What Computer Vision Does with Pixels

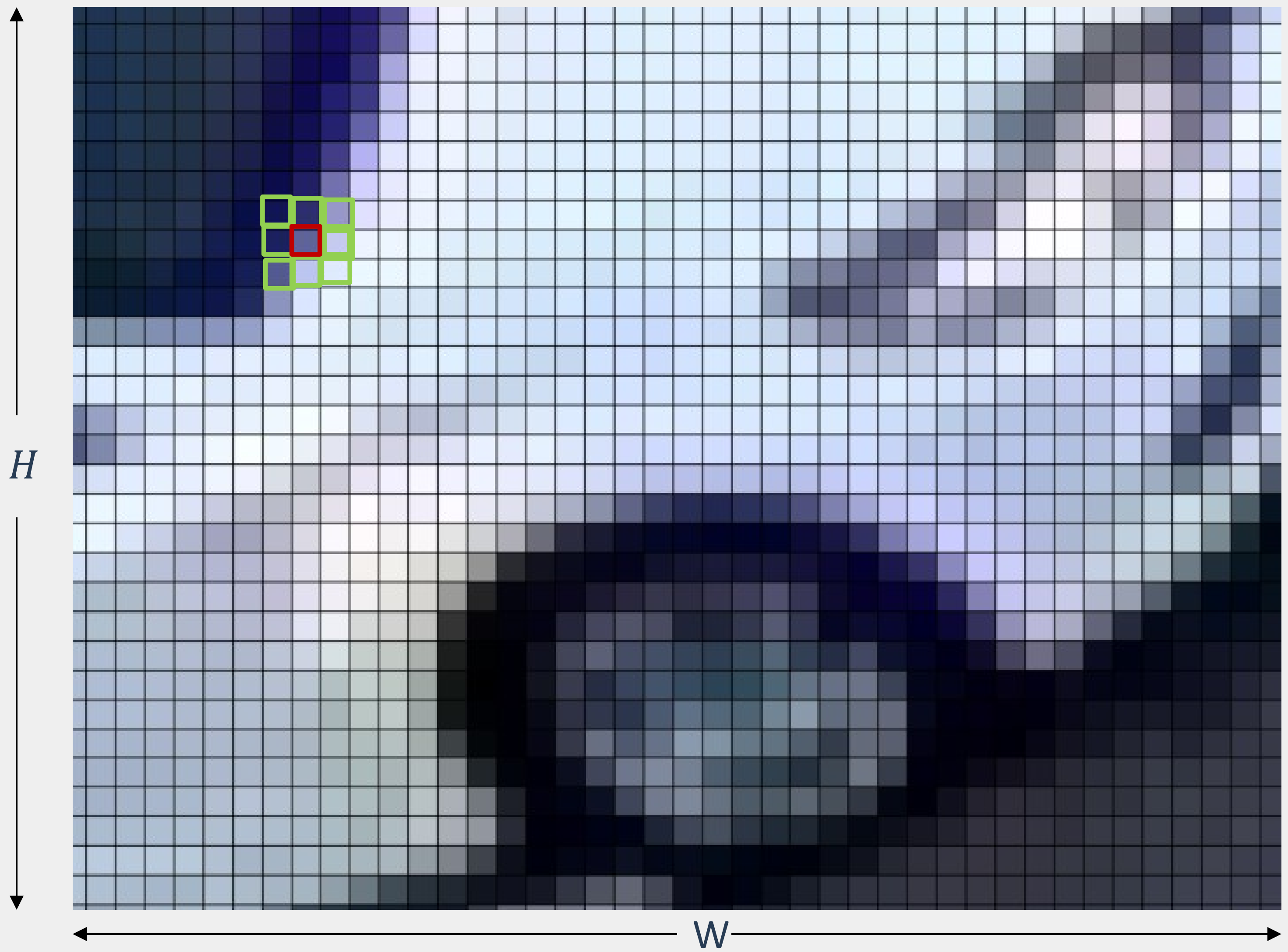
- Computer vision typically analyzes local neighborhoods of pixels (nearby pixels), not pixels in isolation.

Local neighborhood example

- For a pixel at (x, y) ,nearby pixels include (shown in green):

$$(x, \pm 1\ y \pm 1)$$

- This is the idea behind a 3×3 neighborhood



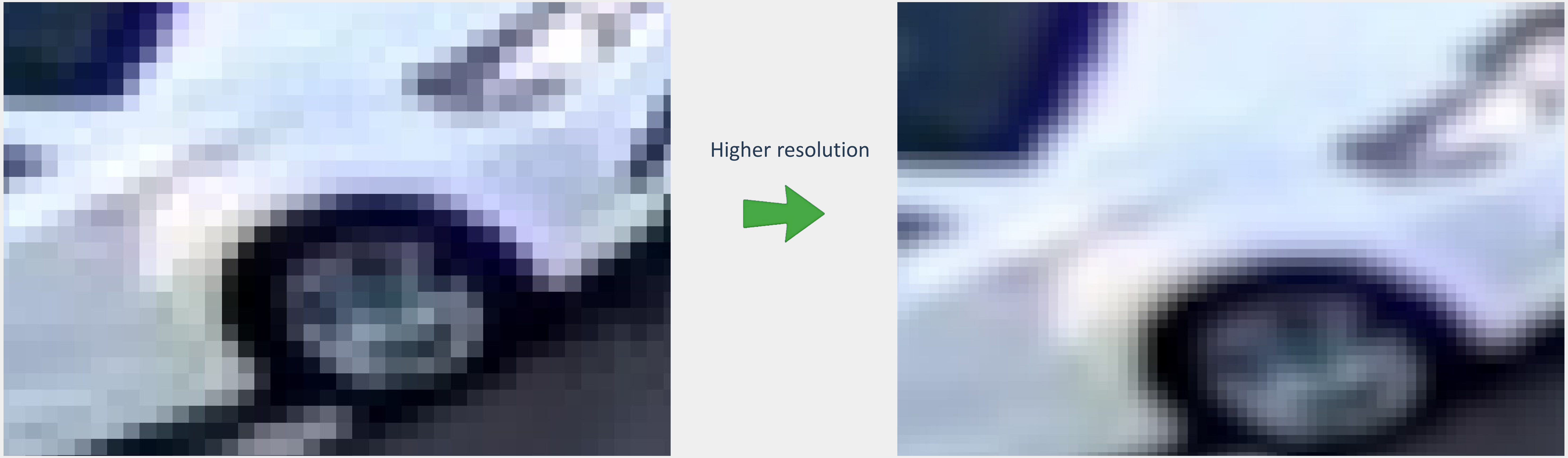
What Computer Vision Does with Pixels

- In GIMP: Image → Scale Image → Increase Height to 2000 px (use +/-) → Select "Scale"
- This increases the number of pixels in the image.
- This relates to resolution (image size in pixels).

More Pixels

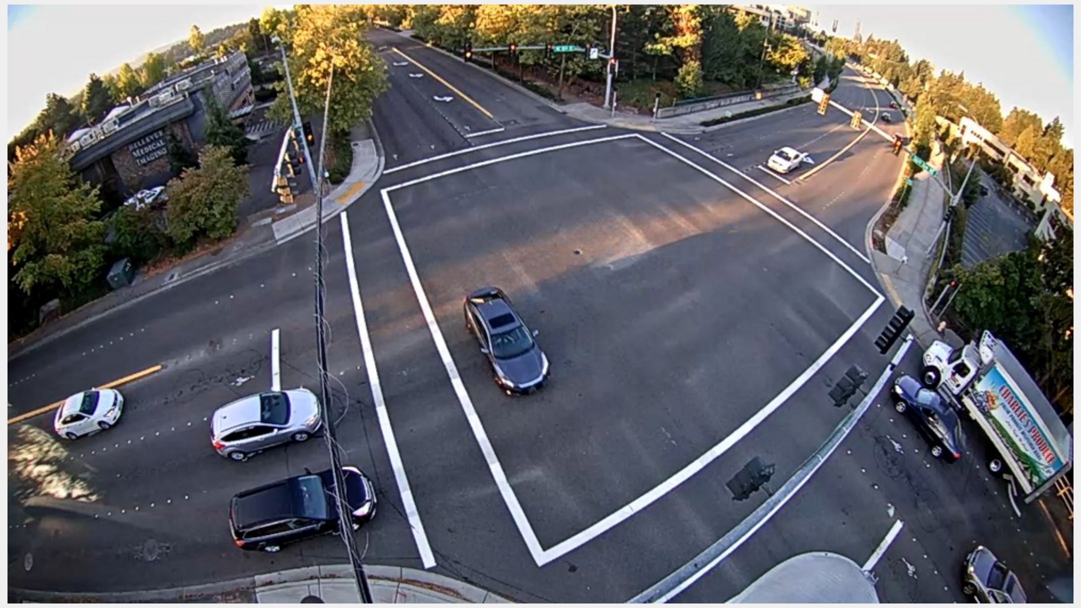
Resolution

- ❑ Resolution: the image's pixel dimensions (how many pixels it has).
- ❑ Usually written as Width × Height (in pixels).
- ❑ Example: 1920 × 1080 (Full HD) where W = 1920 px and H = 1080 px.
- ❑ Total pixels = W×H
- ❑ Higher resolution → more pixels, but also more storage and computation.



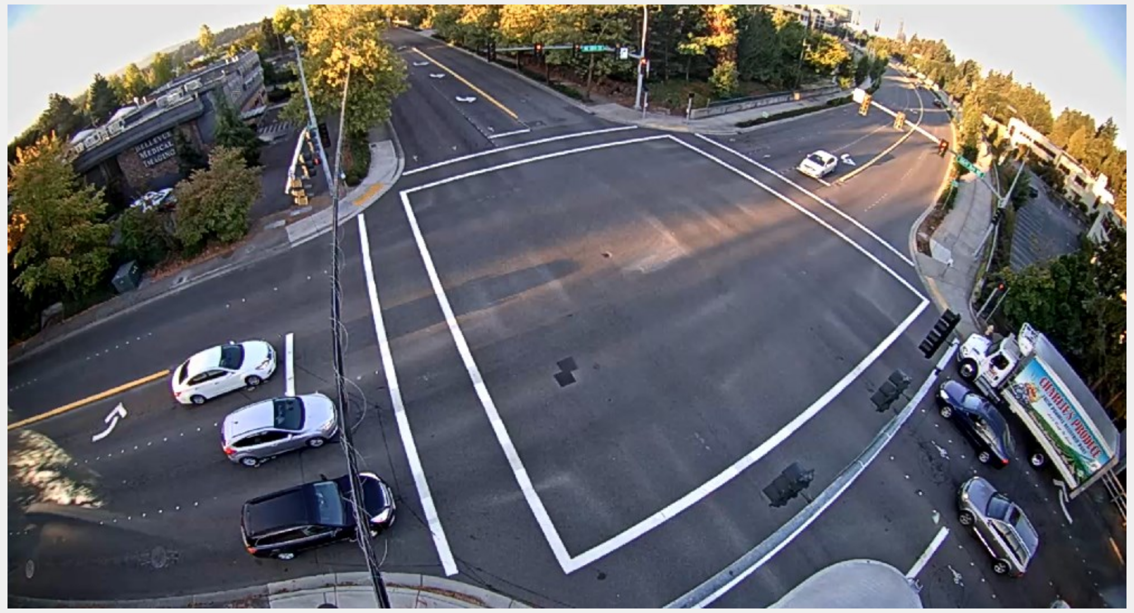
What are Videos?

- Videos are a sequence of images (frames).



Frame (Image) 1

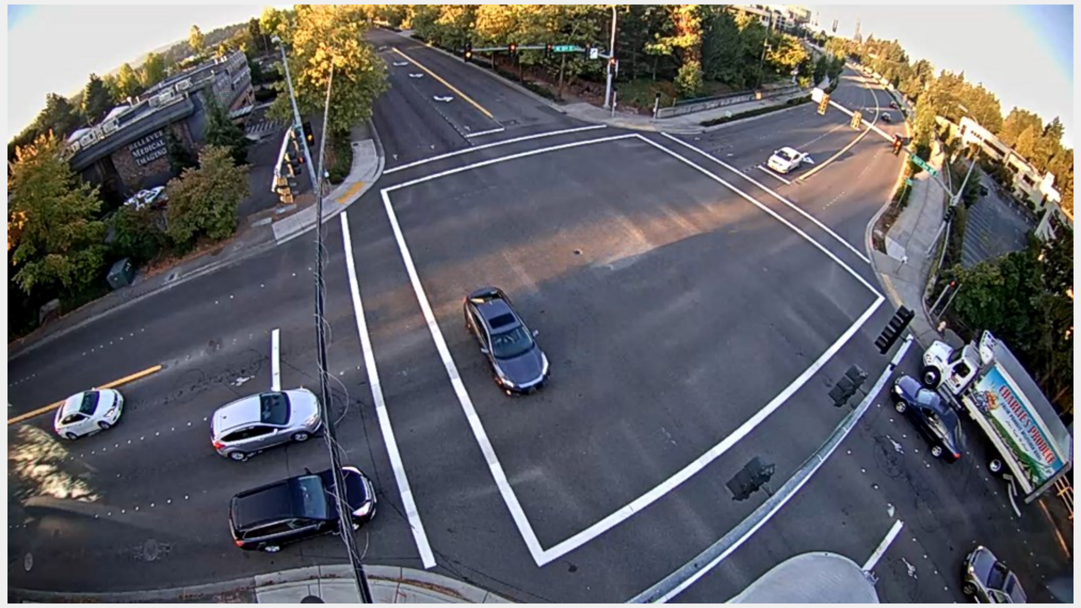
Frame (Image) 2



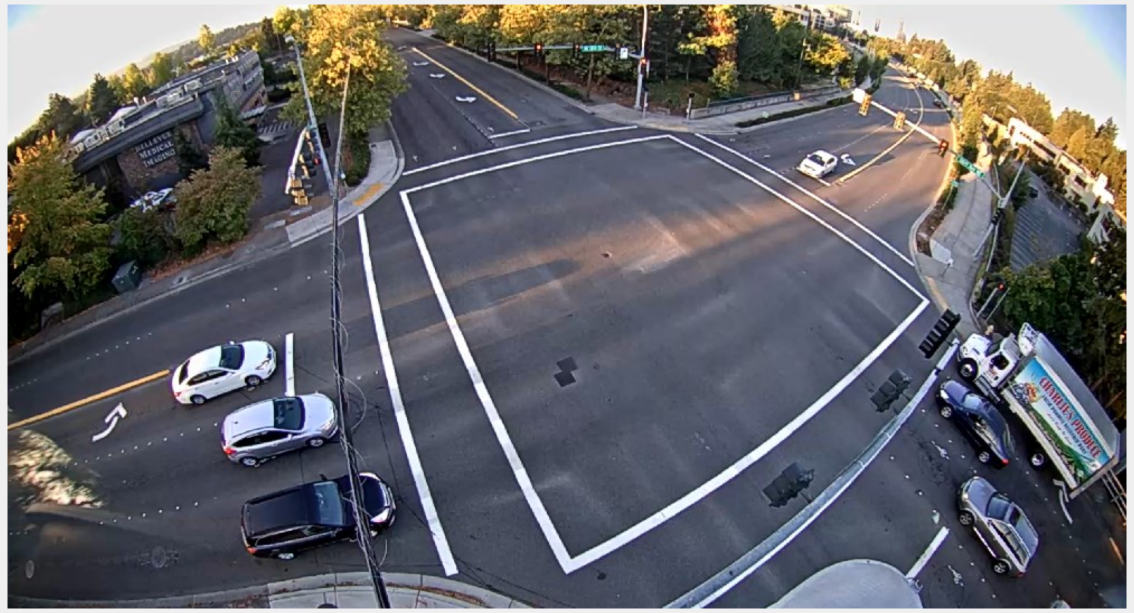
Frame (Image) 3

What is Frame Rate per Second in Video?

- Frame rate (FPS) is the number of frames (images) shown or processed each second.
- Example: 30 FPS = 30 frames per second.
- Higher FPS → smoother motion, but more storage and computation.


Frame (Image) 1


Frame (Image) 2

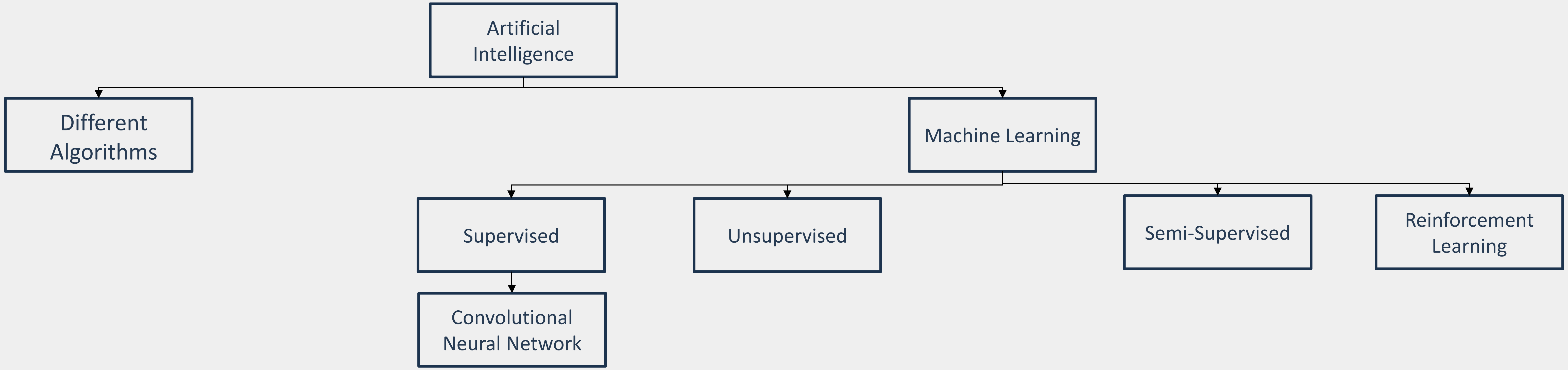

Frame (Image) 3

Resolution vs FPS

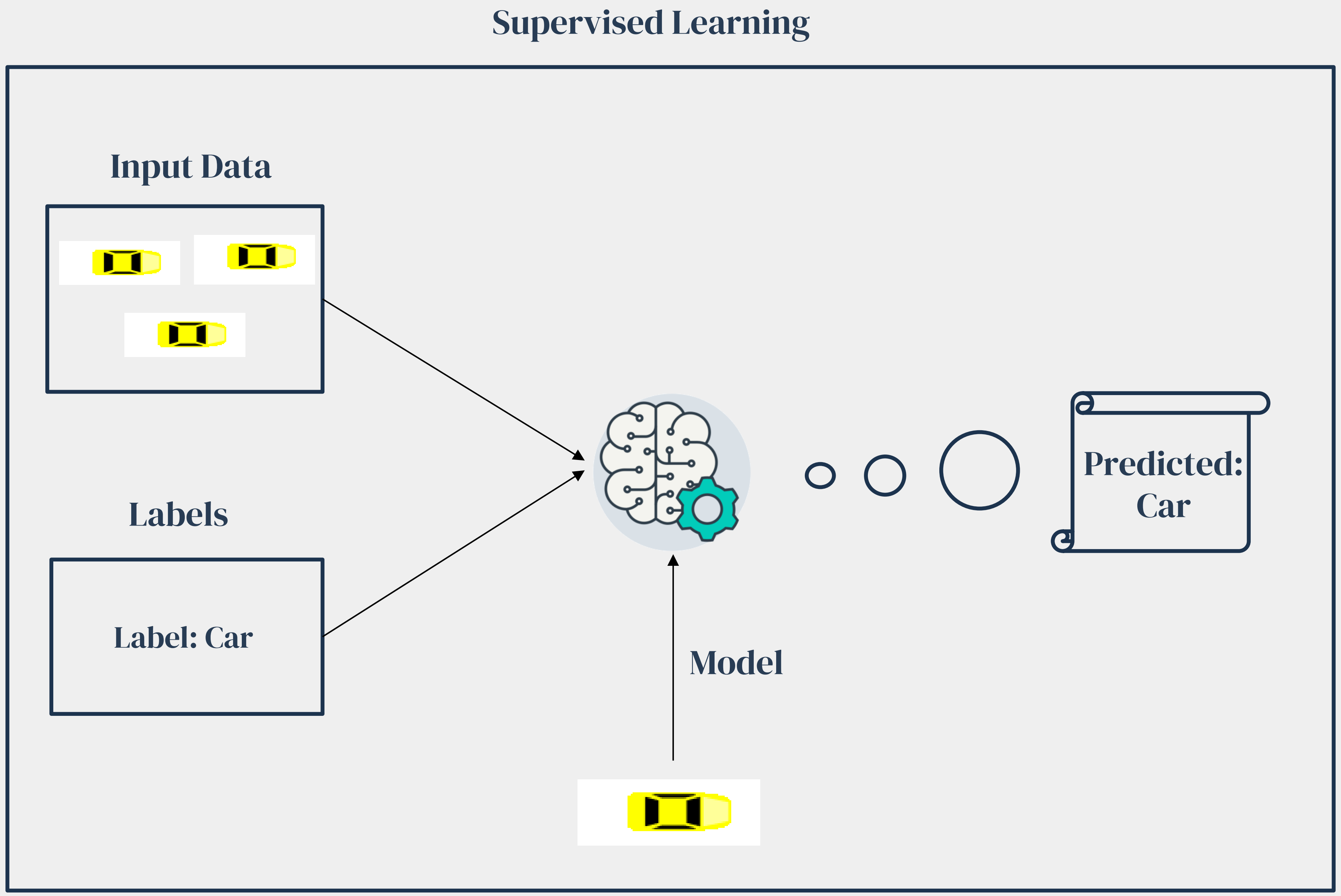
- Resolution = how much detail is in one frame (image).
- FPS (frames per second) = how many frames are shown each second.

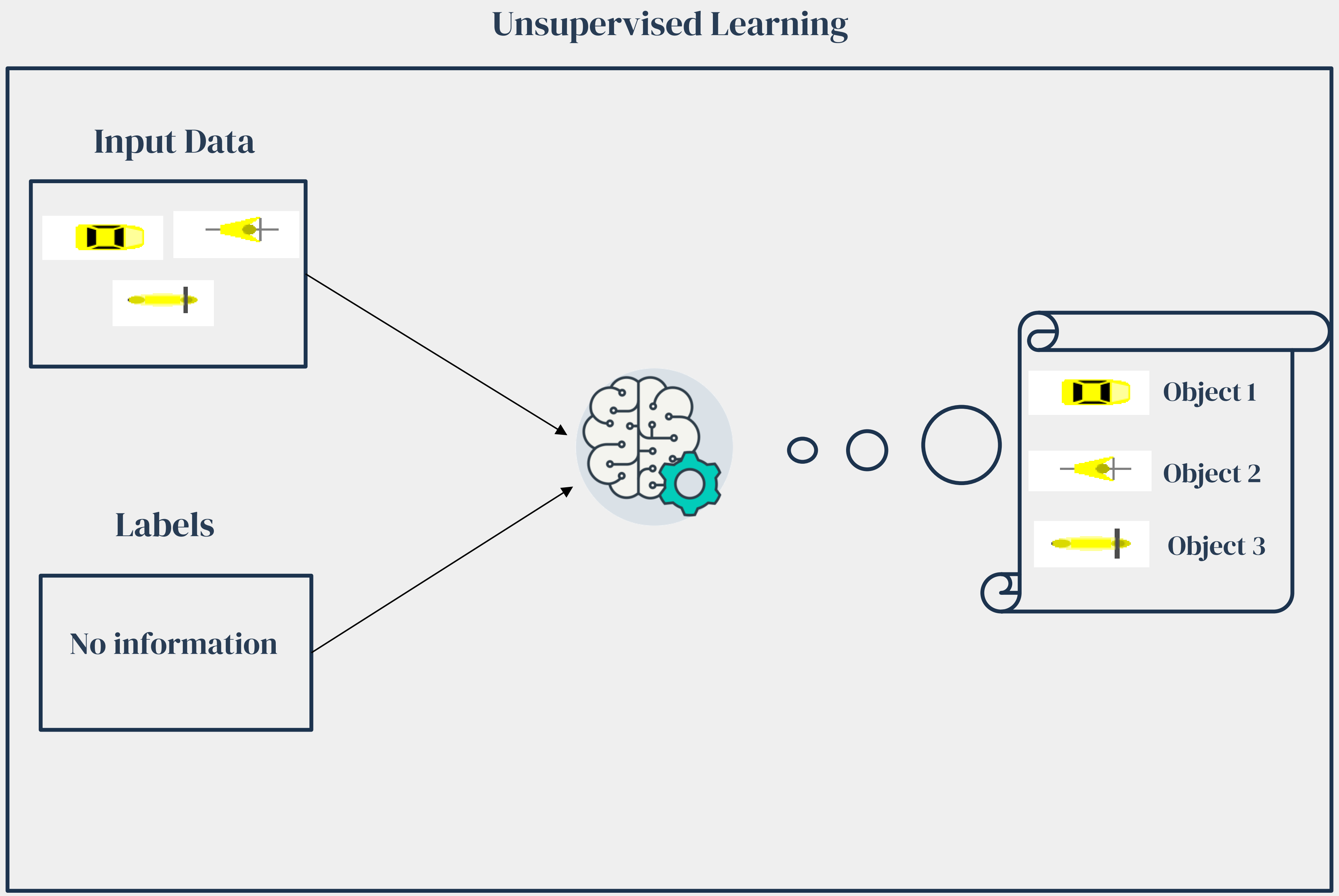
AI vs Machine Learning vs Deep Learning

- ***AI:*** Making machines perform tasks that require "intelligence"
- ***Machine Learning:*** A way to build AI systems by learning patterns from data (examples of inputs and outputs).
- ***Supervised learning:*** You have inputs (X) and labels/outputs (y).
- ***Unsupervised learning:*** You have inputs (X) but no labels (y).
- ***Semi-supervised learning:*** You have many inputs, but only some are labeled (a mix of labeled + unlabeled data).
- ***Reinforcement learning (RL):*** You have inputs and it learns step by step through trial and error to achieve output



Supervised/Unsupervised Learning





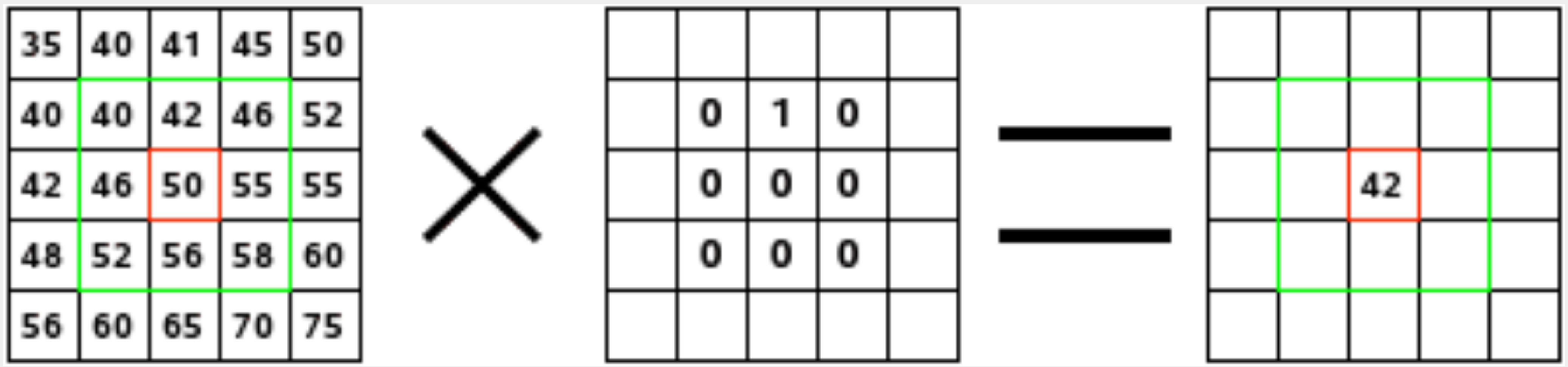
Convolutional Neural Network

$\boxed{\text{Convolution}}$ + Neural Network

What is Convolution?

➢ **Convolution** = Repeat this 3-step process at every location in the image:

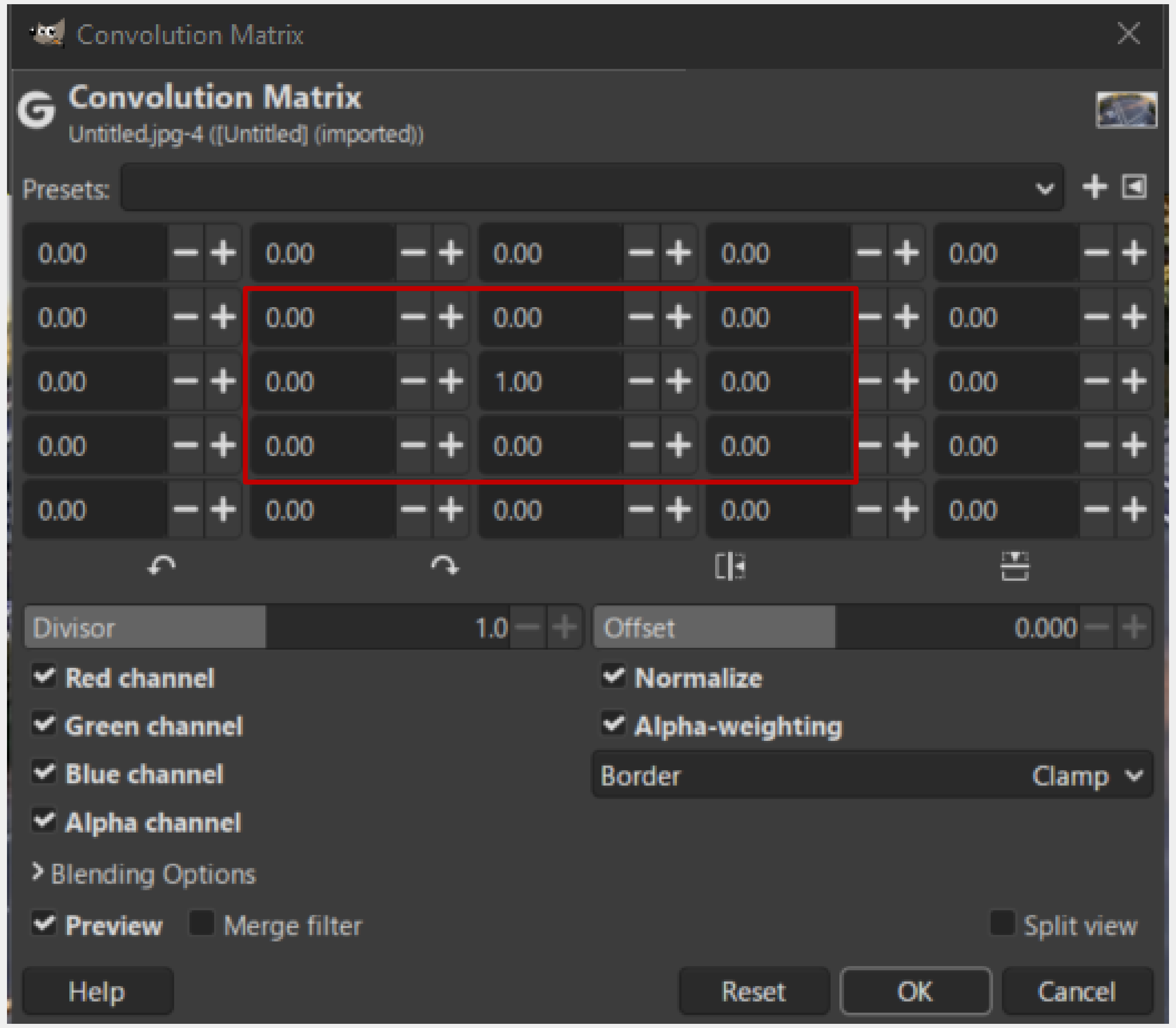
1. **Input patch:** Select a small neighborhood of pixels (e.g., 3×3) around location (x, y)
2. **Filter:** Multiply each pixel by the corresponding weight and sum them
3. **Output pixel:** Write the summed value as the new pixel at (x, y) in the output (feature map)



https://docs.gimp.org/2.10/en/gimp-filter-convolution-matrix.html

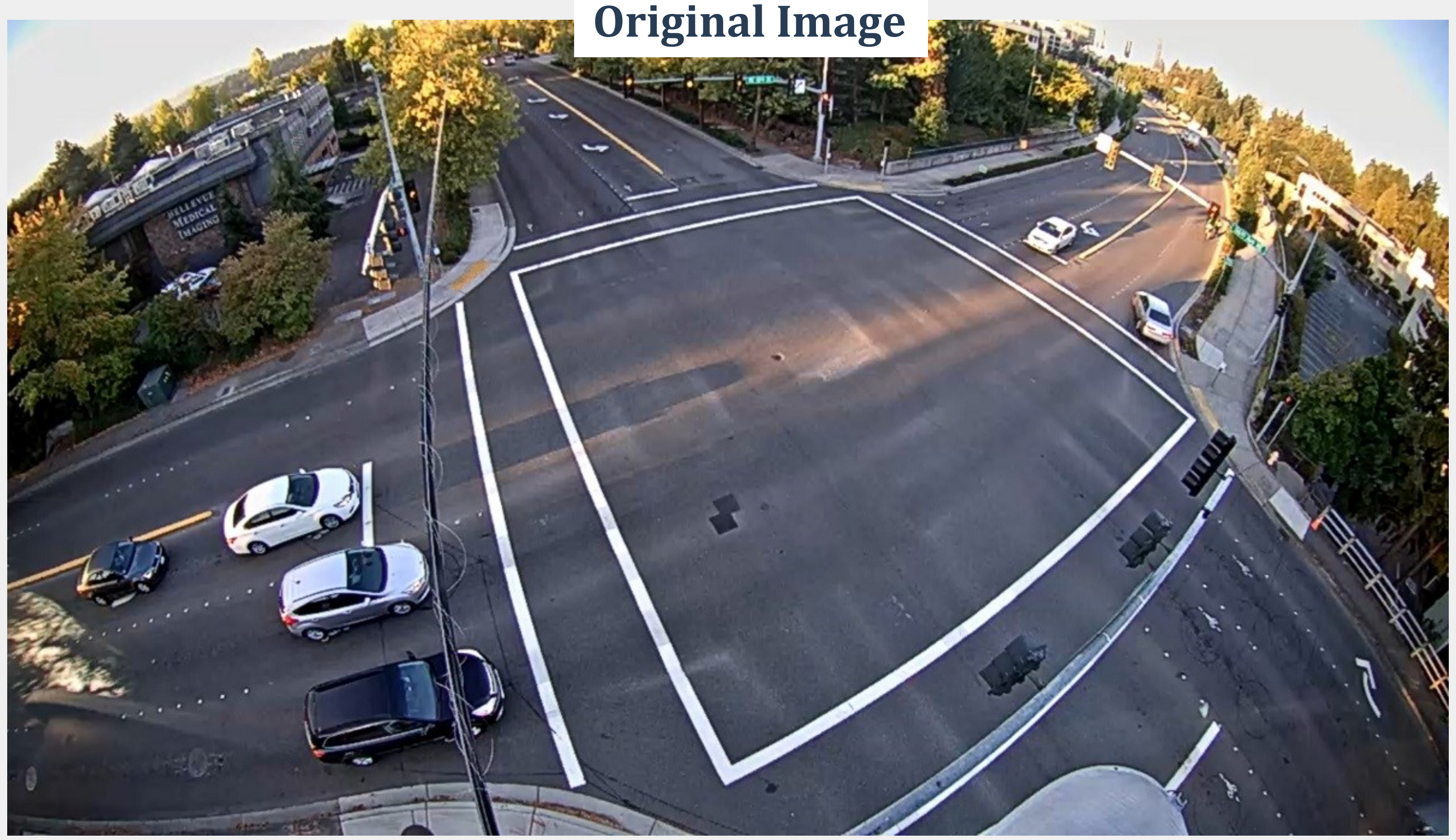
Convolutional Matrix Concept

- Filters are often implemented as a convolution matrix (kernel).
- At each location (x,y), the kernel looks at a small neighborhood (e.g., 3×3) and combines those pixel values to compute a new output value.
- Filters → Generic → Convolution Matrix
- The red box shows the 3×3 kernel weights we will use in the next slides.



https://docs.gimp.org/2.10/en/gimp-filter-convolution-matrix.html

Convolutional Matrix Concept

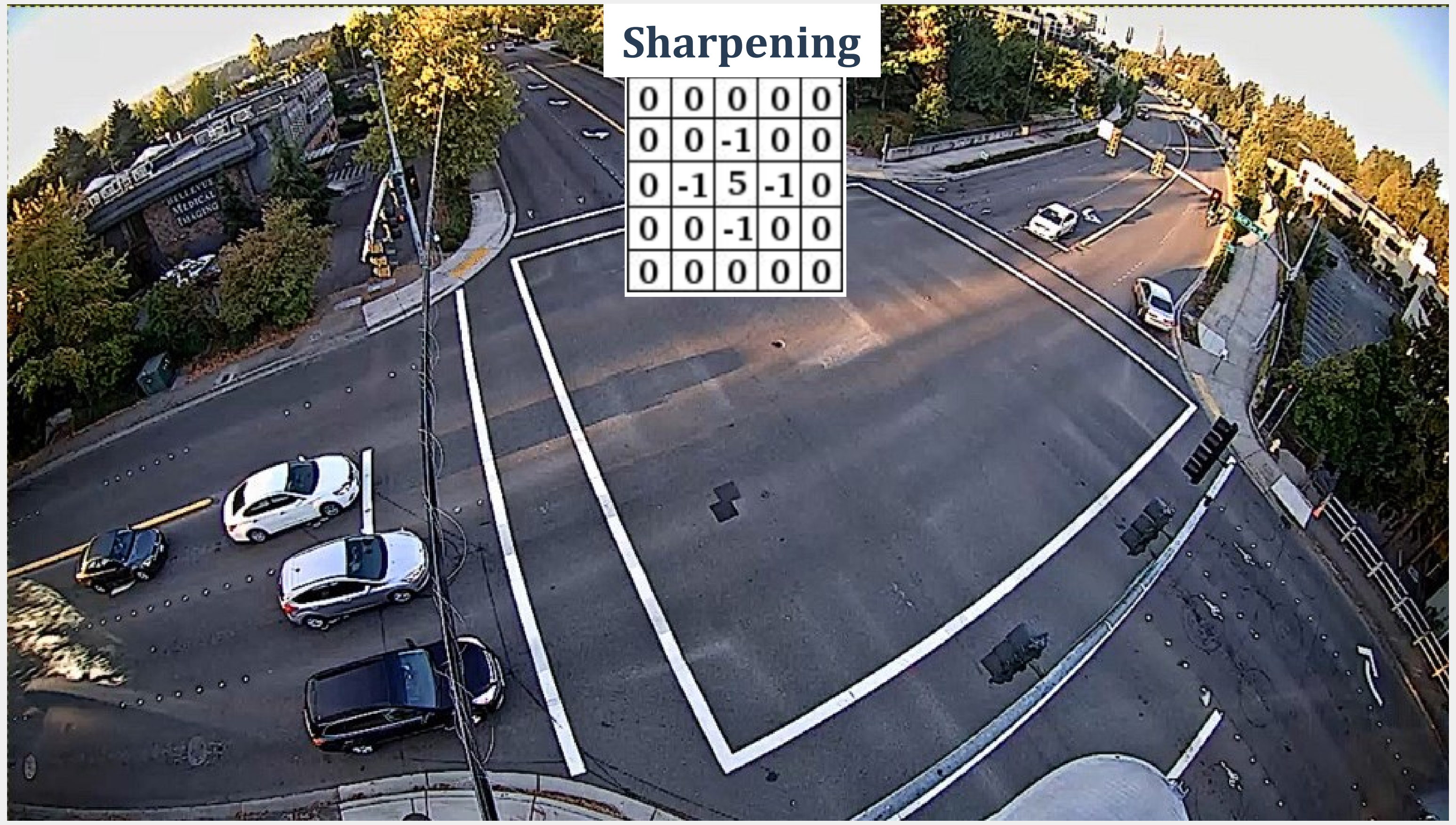


Feature Maps (Filtered Outputs)

Reduces noise and smooths small details

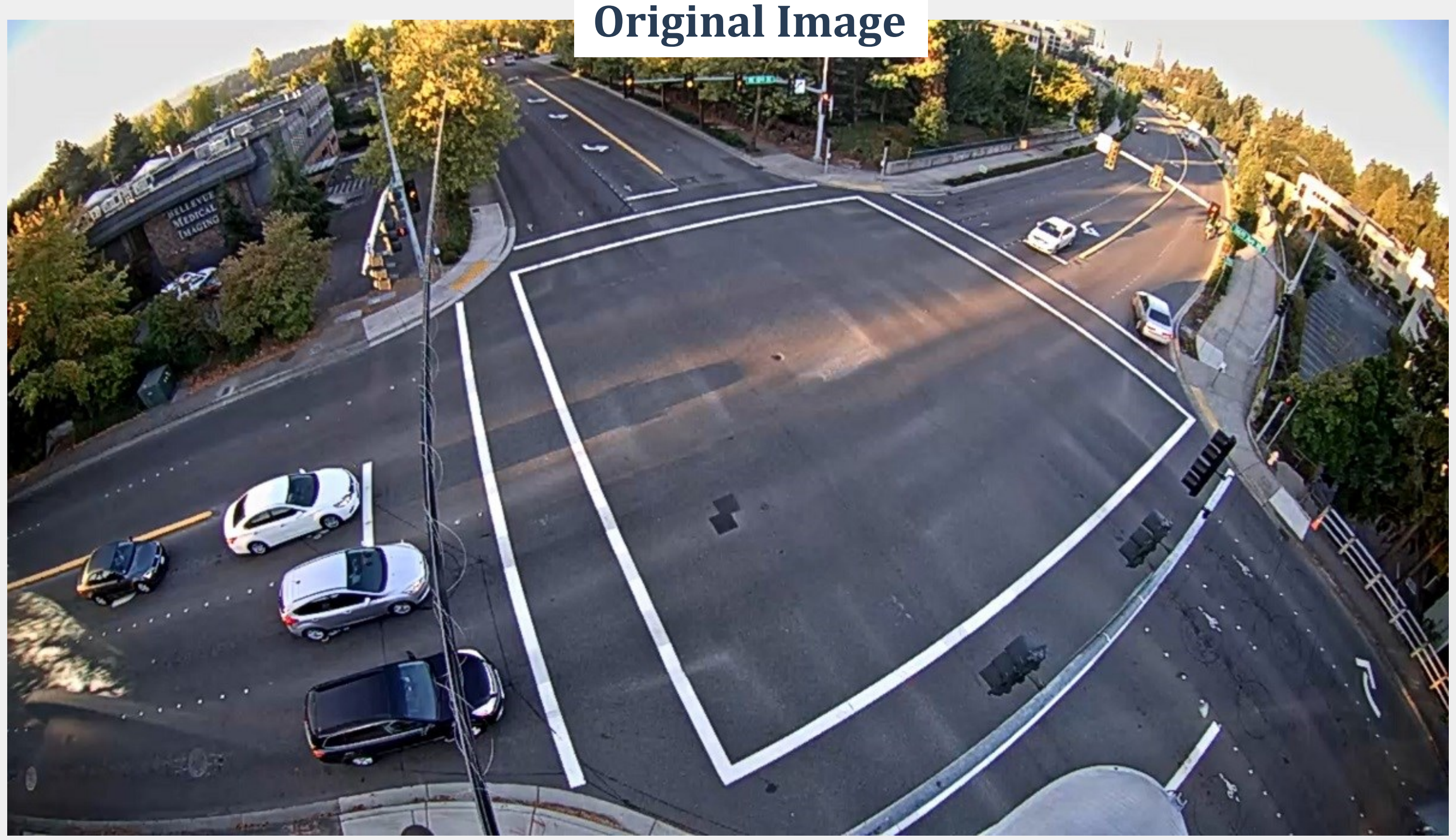
$$\begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 1 & 1 & 0 \\ 0 & 1 & 1 & 1 & 0 \\ 0 & 1 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Enhances edges and boosts local contrast



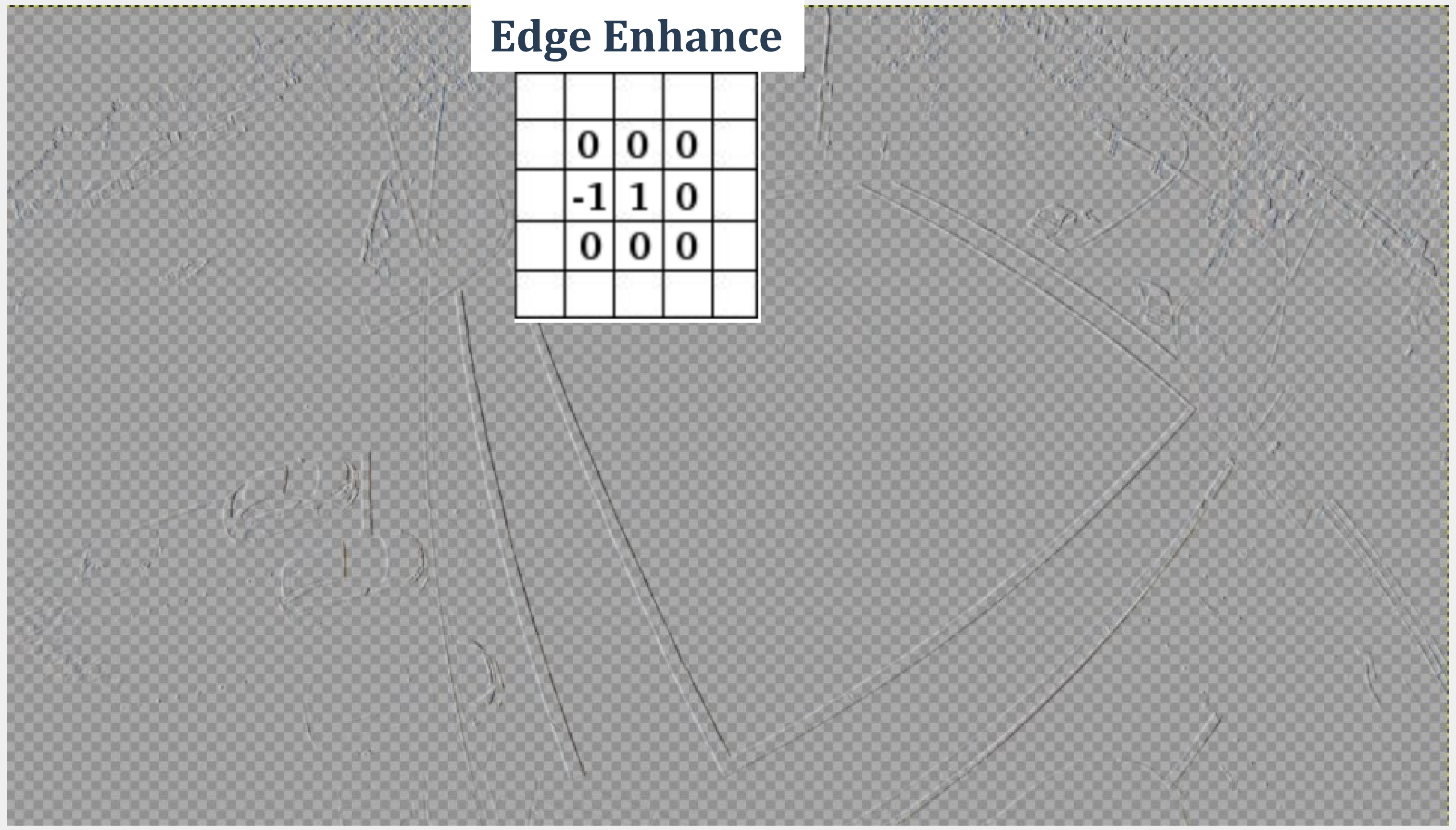
$$\begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 & 0 \\ 0 & -1 & 5 & -1 & 0 \\ 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Convolutional Matrix Concept

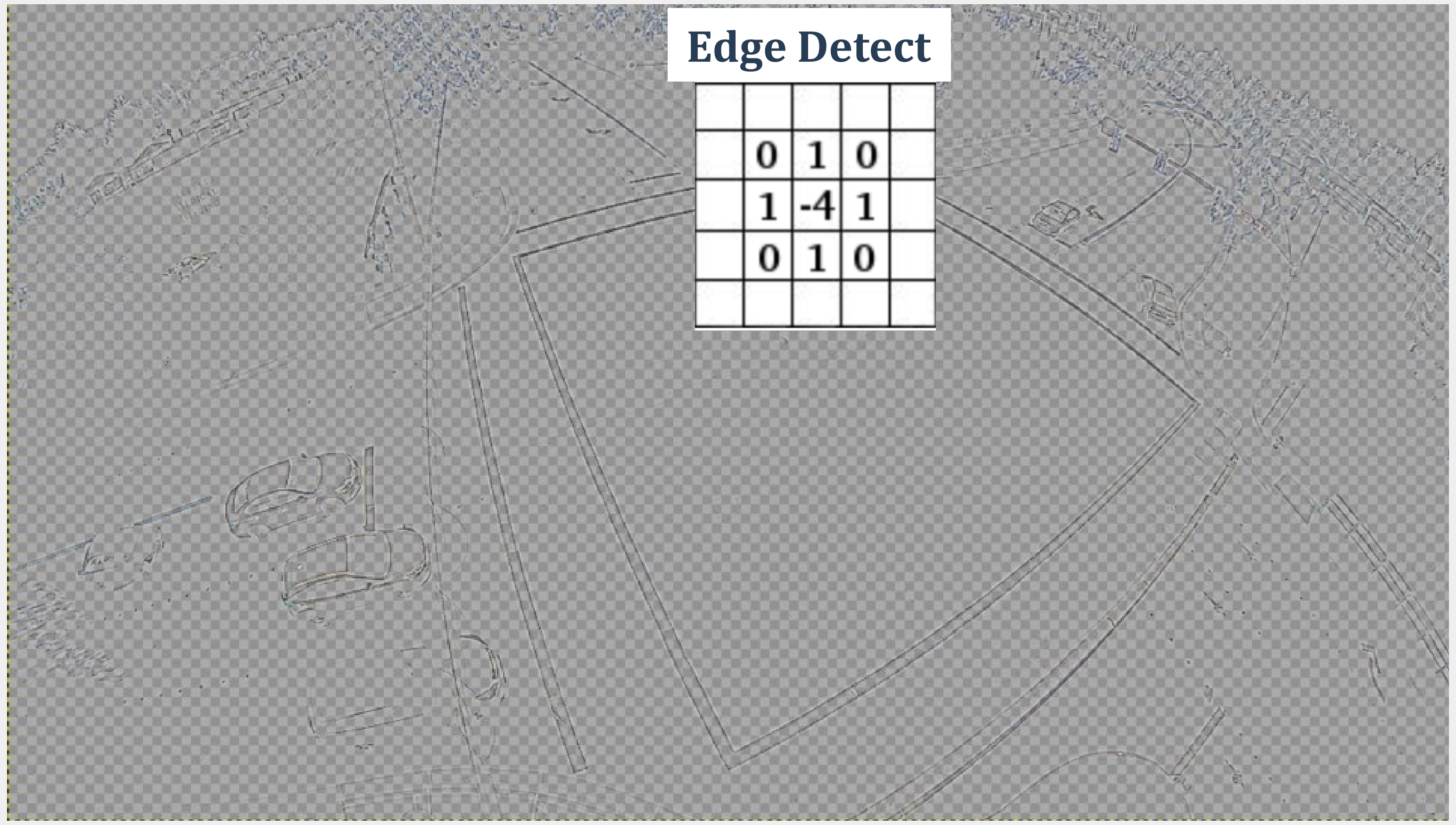


Feature Maps

Edge enhancement: strengthens edges

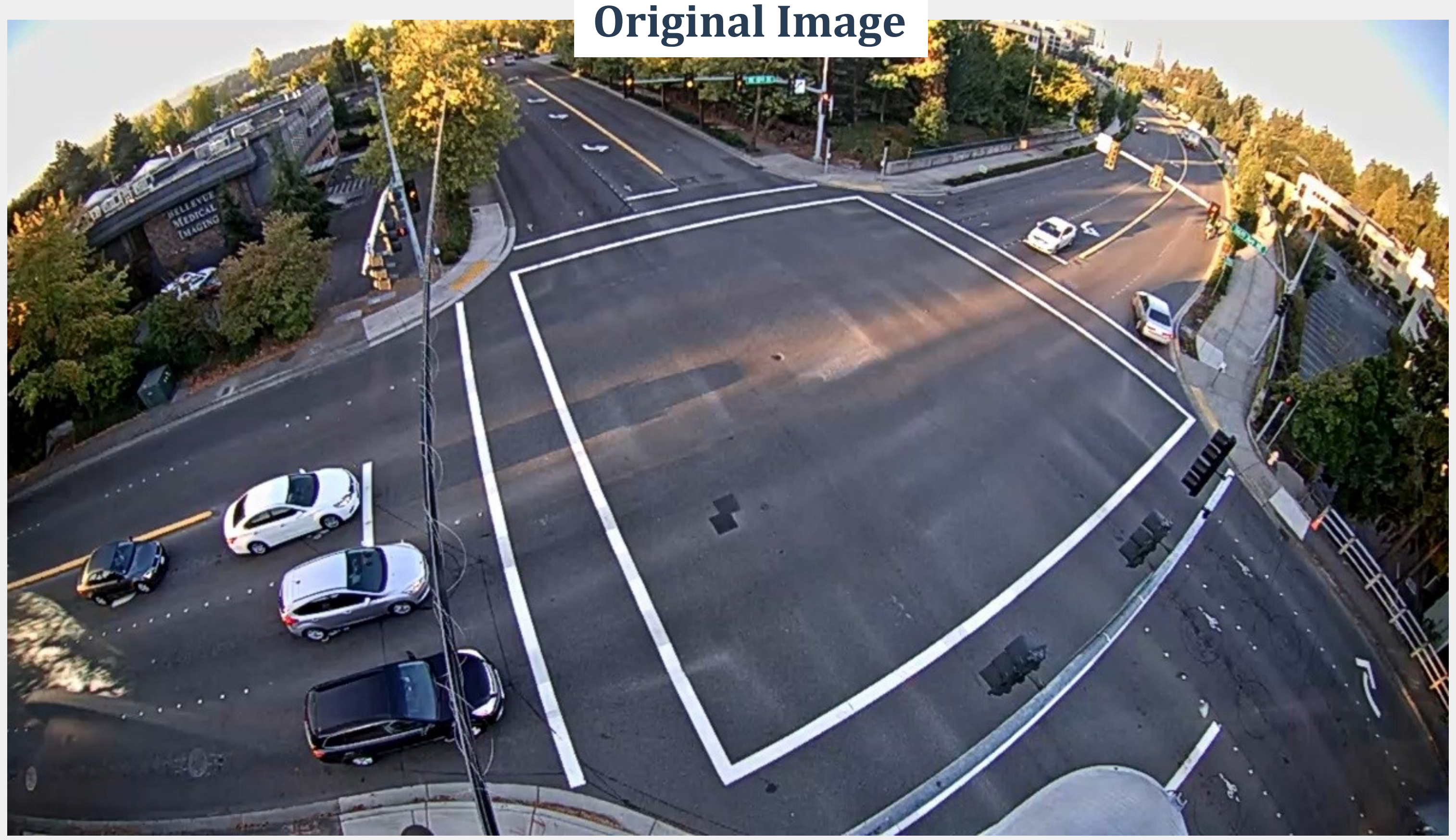


Edge detection: highlights boundaries (lane lines, vehicles)



Convolutional Matrix Concept

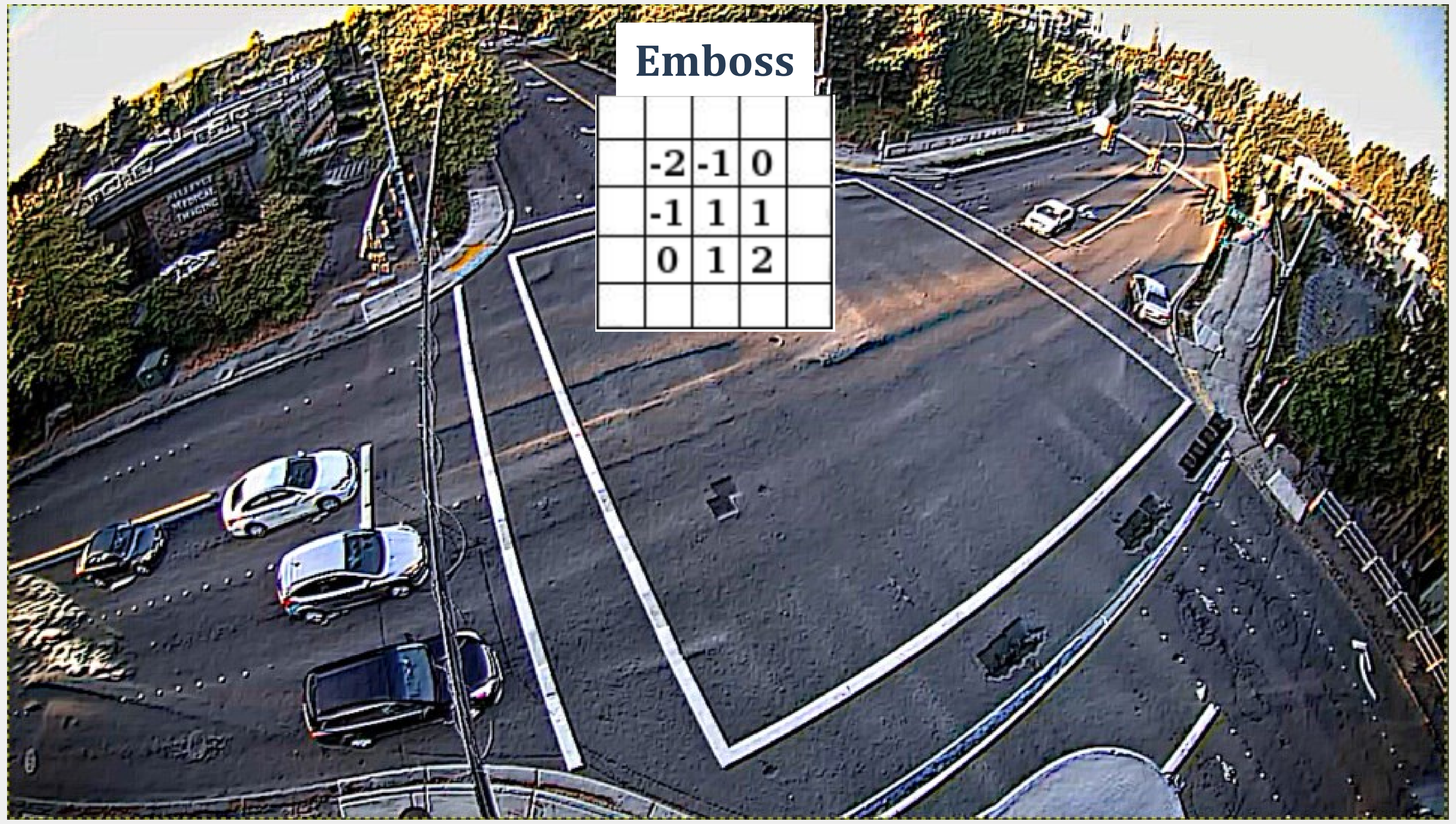
Original Image



Feature Maps

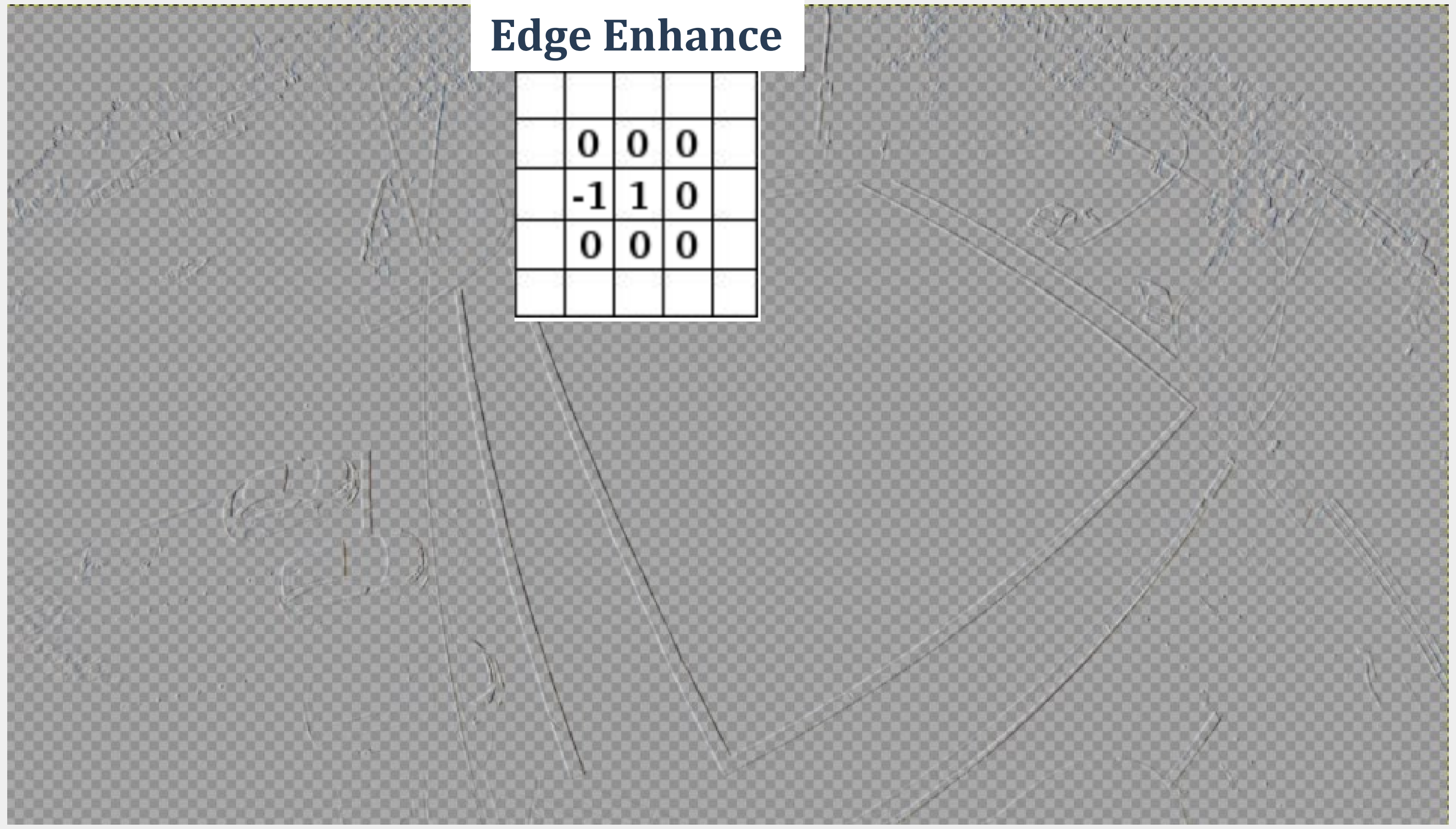
Many More Feature Maps

Turns edges into highlights and shadows, creating a 3D relief look



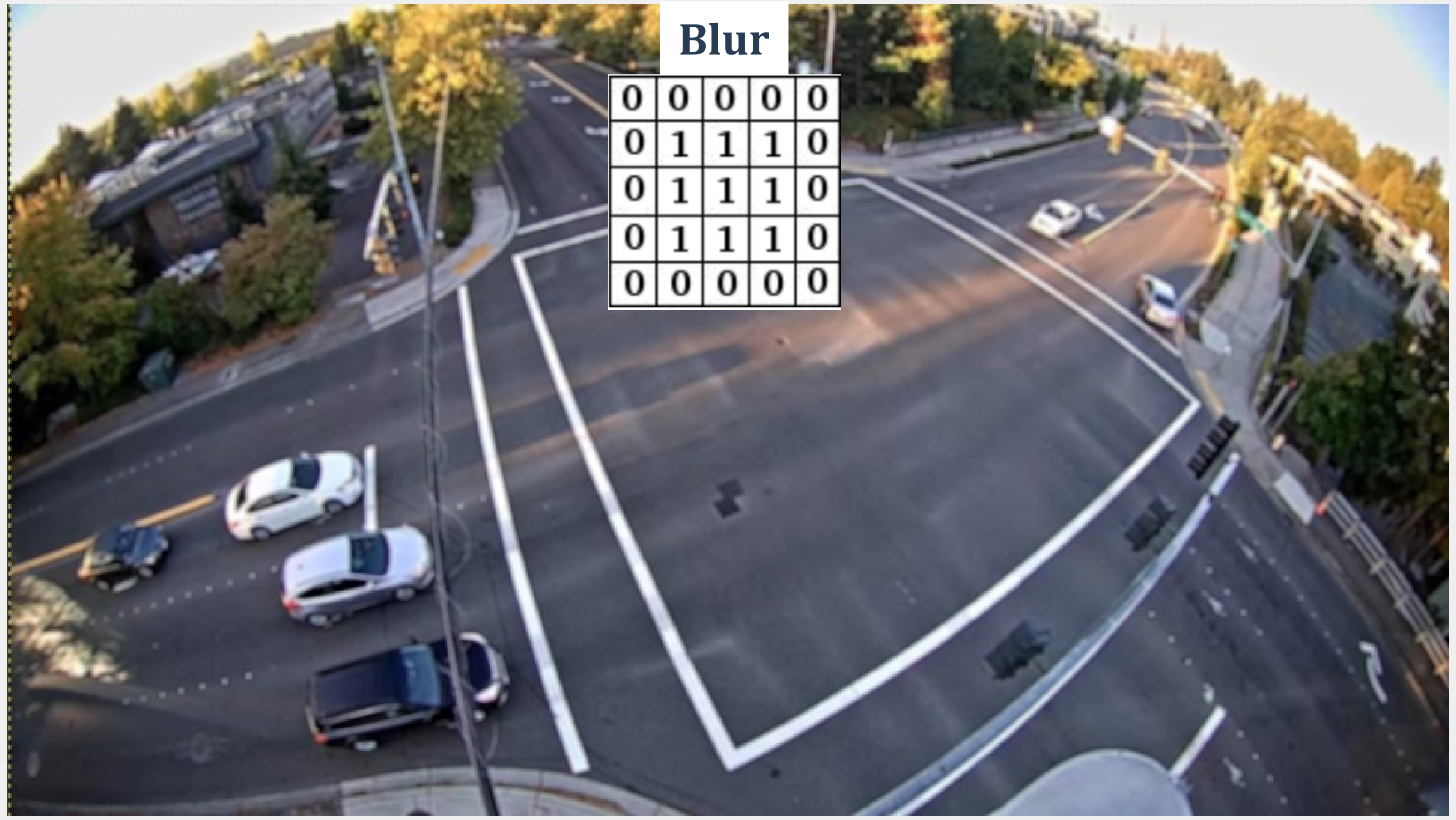
-2	-1	0
-1	1	1
0	1	2

Combining Feature Maps → Create Feature Map in Middle Layer



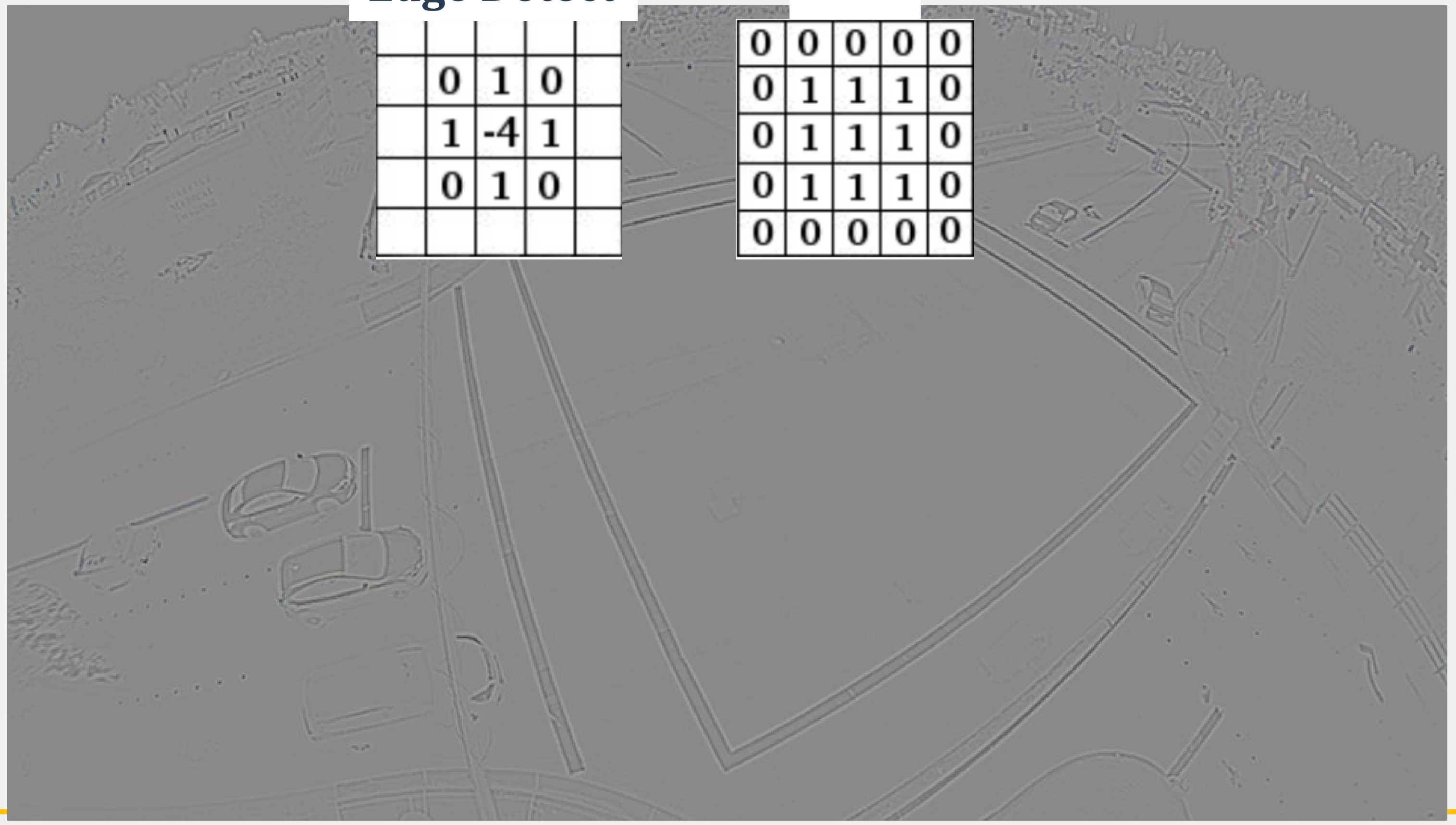
Edge Enhance

	0	0	0	
	-1	1	0	
	0	0	0	



Blur

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



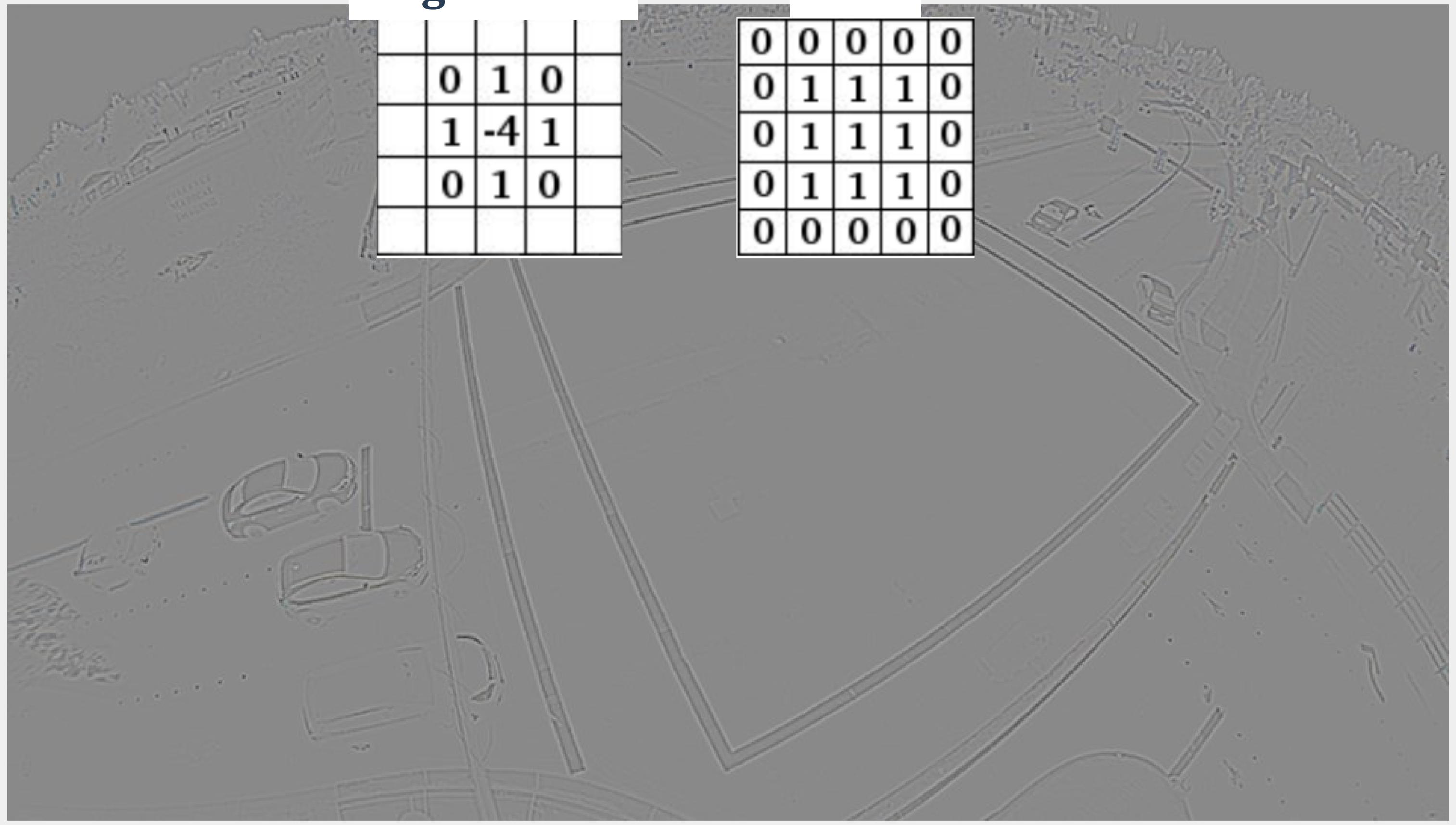
Edge Detect

	0	1	0	
	1	-4	1	
	0	1	0	

Blur

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

Combining Feature Maps → Create Feature Map in Deep Layer



Edge Detect

	0	1	0	
	1	-4	1	
	0	1	0	

Blur

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

Many More Feature Maps

Create Feature Map in Deep Layer