deep imaging

Lecture 1: Machine Learning and Imaging in a Nutshell

Machine Learning and Imaging

BME 548L

Roarke Horstmeyer

Announcements

- No labs this week
  - First lab will be M/W 1/22 (1/24) at **4:30pm**

- Please complete pre-class survey:
  - https://forms.gle/moFWMQXY3cWRUDWq5
- Please complete Lab #1 pre-exercise before lab:
  - https://canvas.duke.edu/courses/26135/assignments/79632

What is an image?

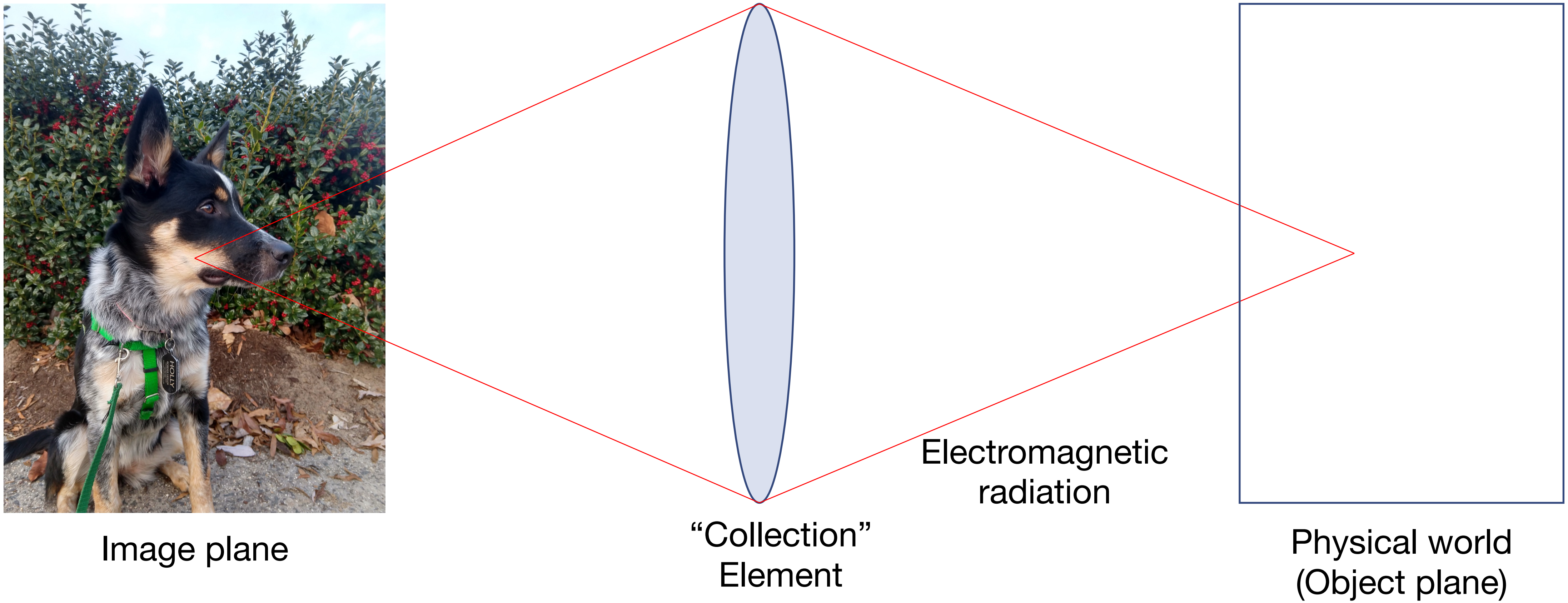
What is an image?

1. "Qualitative" Interpretation

- A re-creation of a visual scene
- A visible impression
- A mental representation or idea

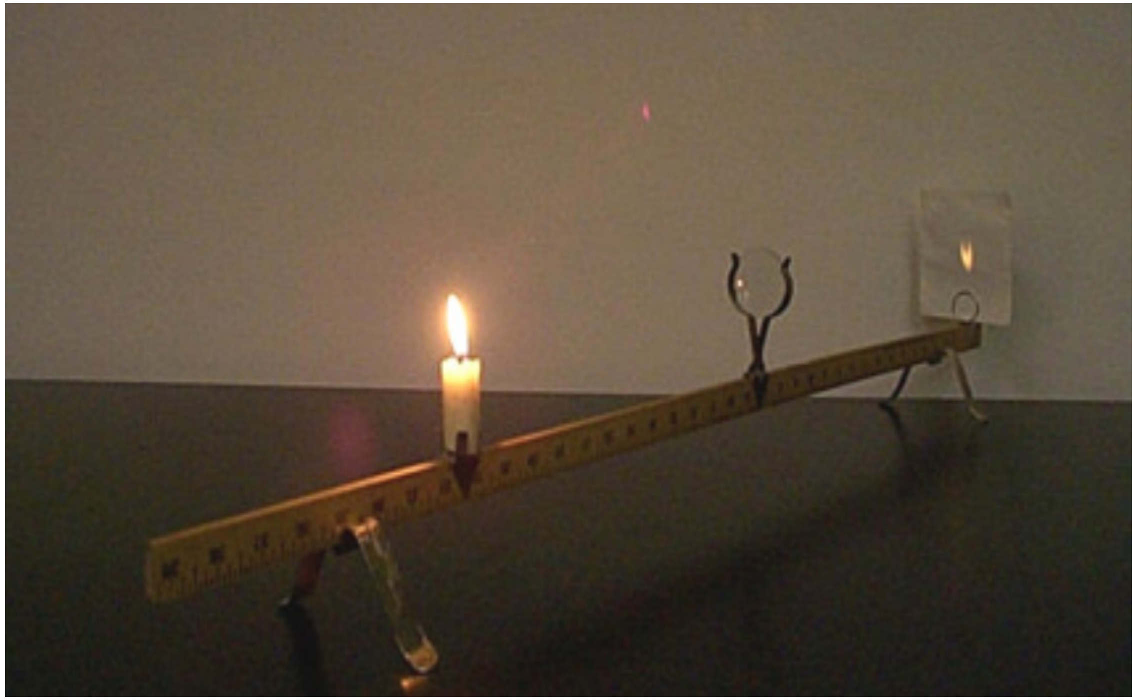
What is an image?

2. “Physical” Interpretation



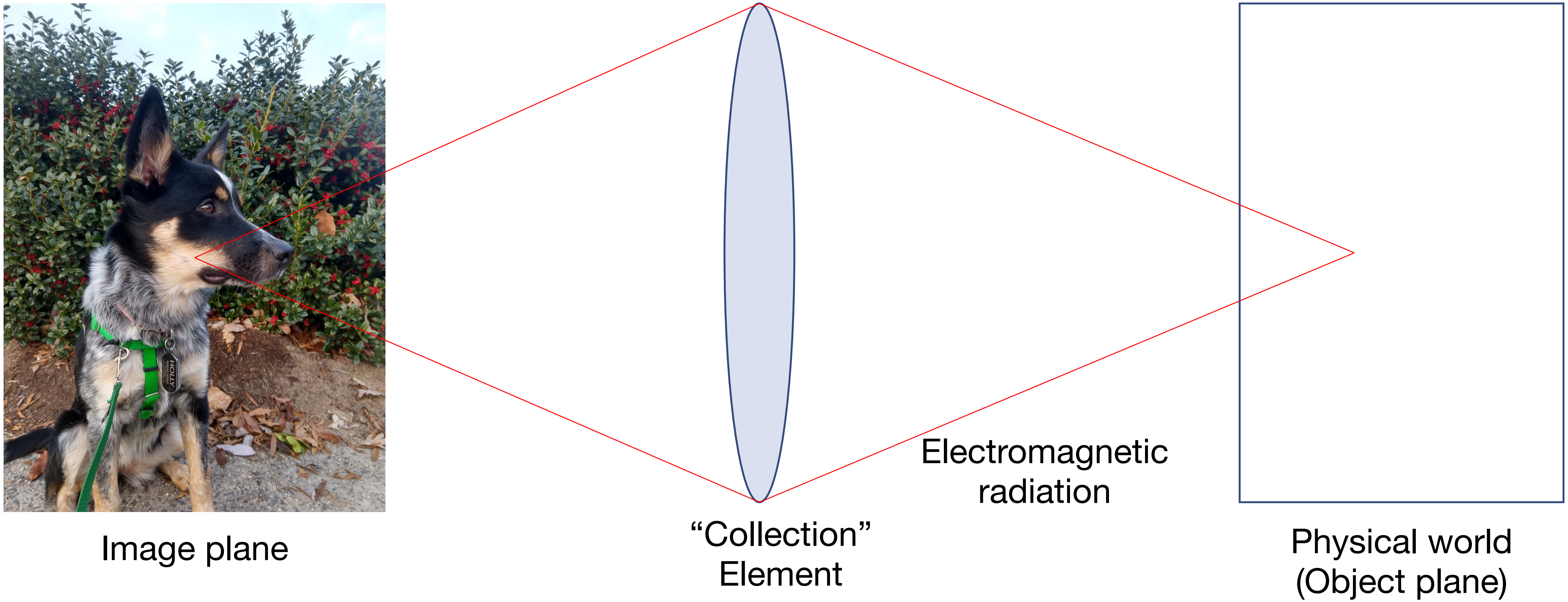
What is an image?

deep imaging



What is an image?

2. “Physical” Interpretation

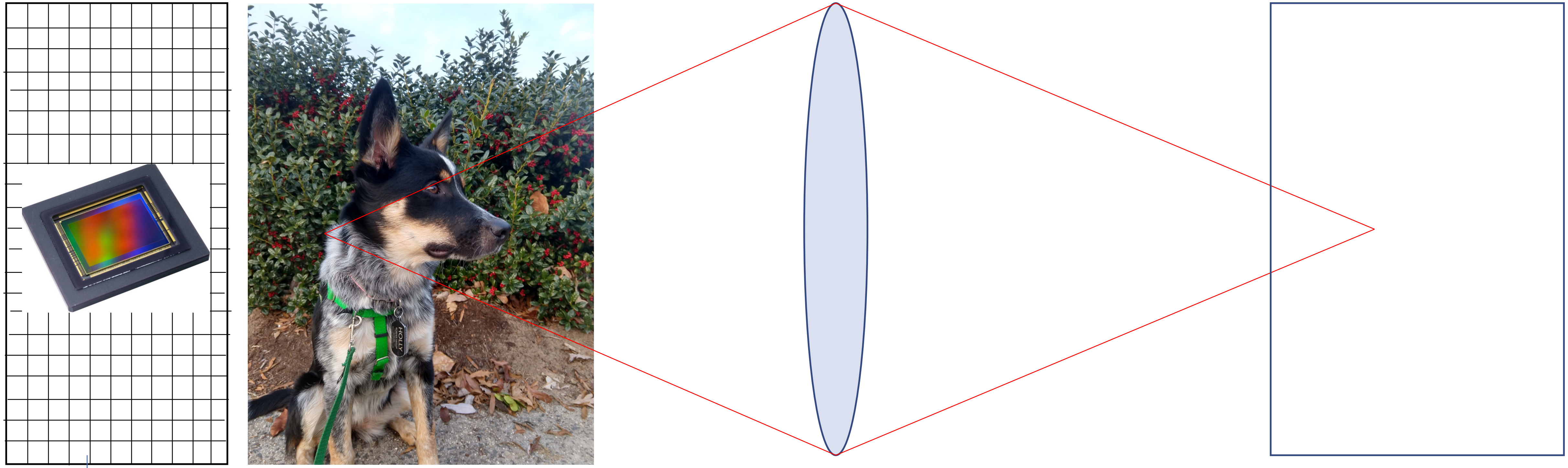


Continuous signal: $I(x, y), (x, y) \in (-\infty, \infty)$ (Physical wave)

What is an image?

3. "Digital" Interpretation

n x *m* array



Photons to electrons → Digitazation → *Discrete signal*

$$I_s(x,y), (x,y) \in Z^{n\times m}$$

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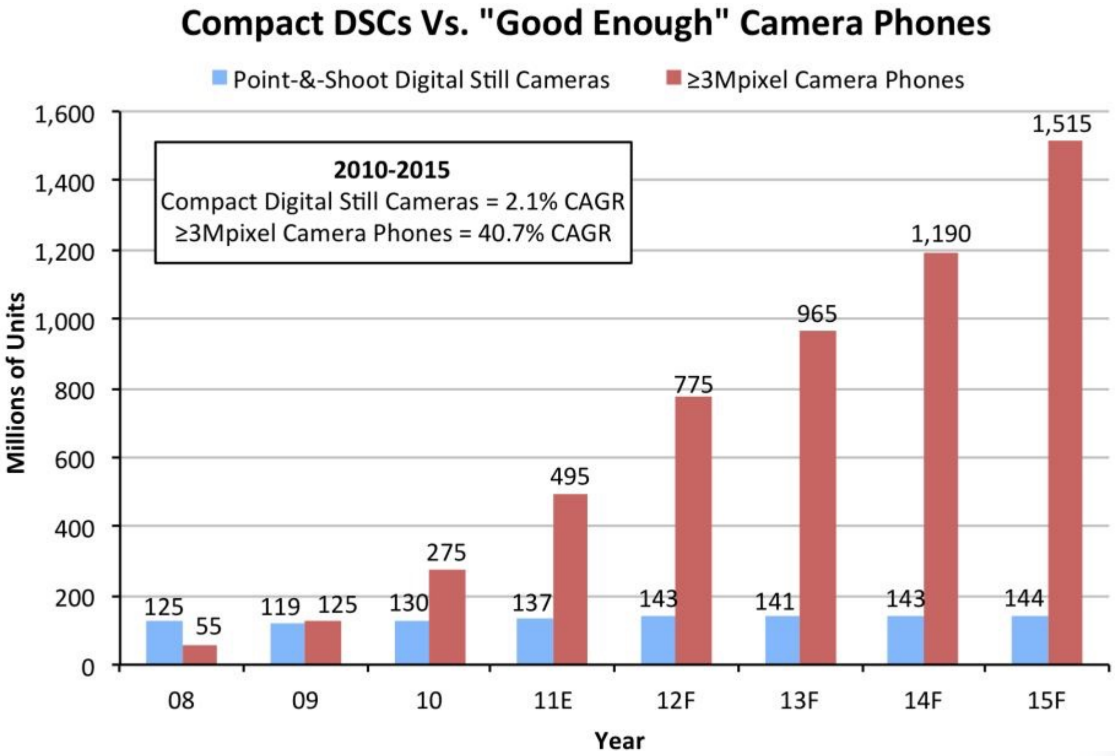
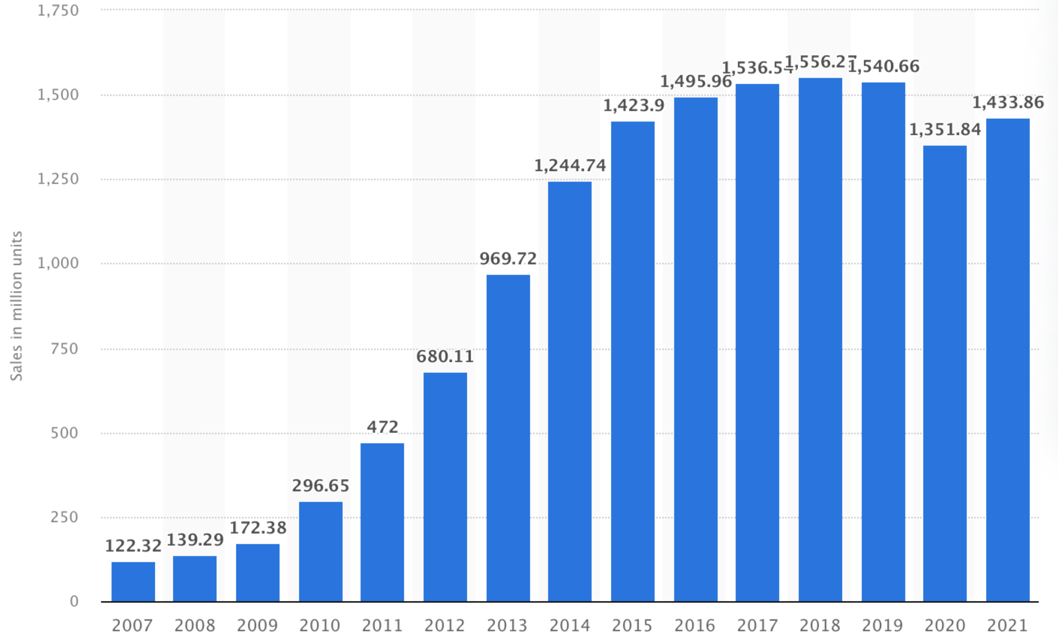
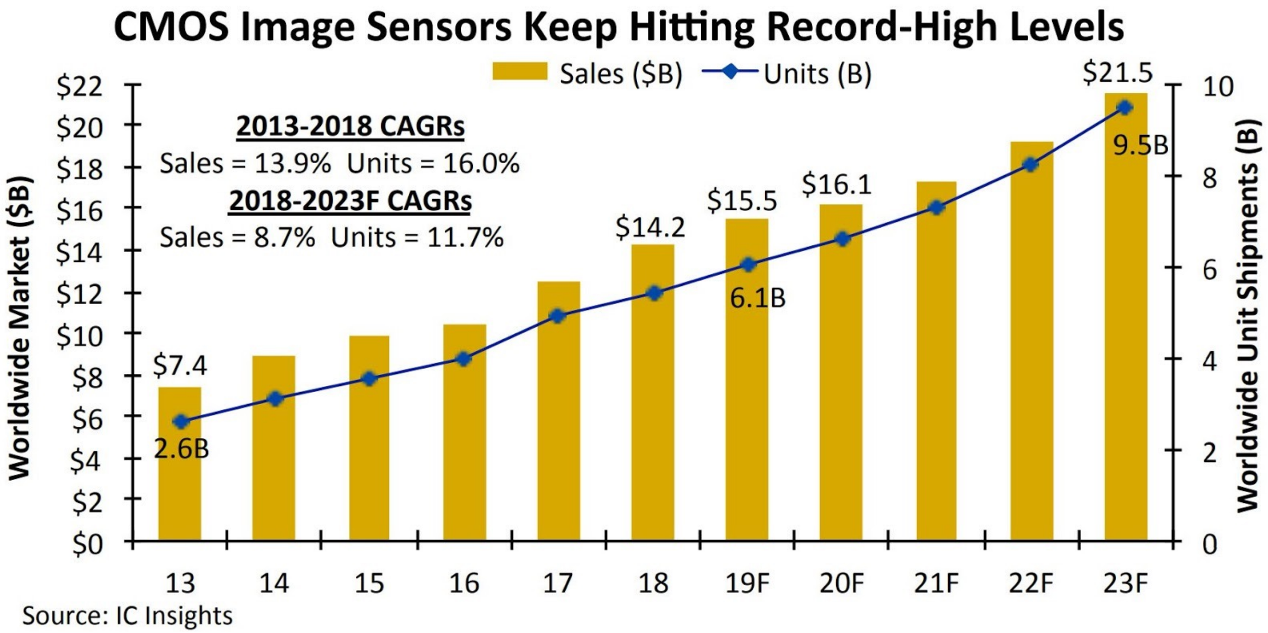
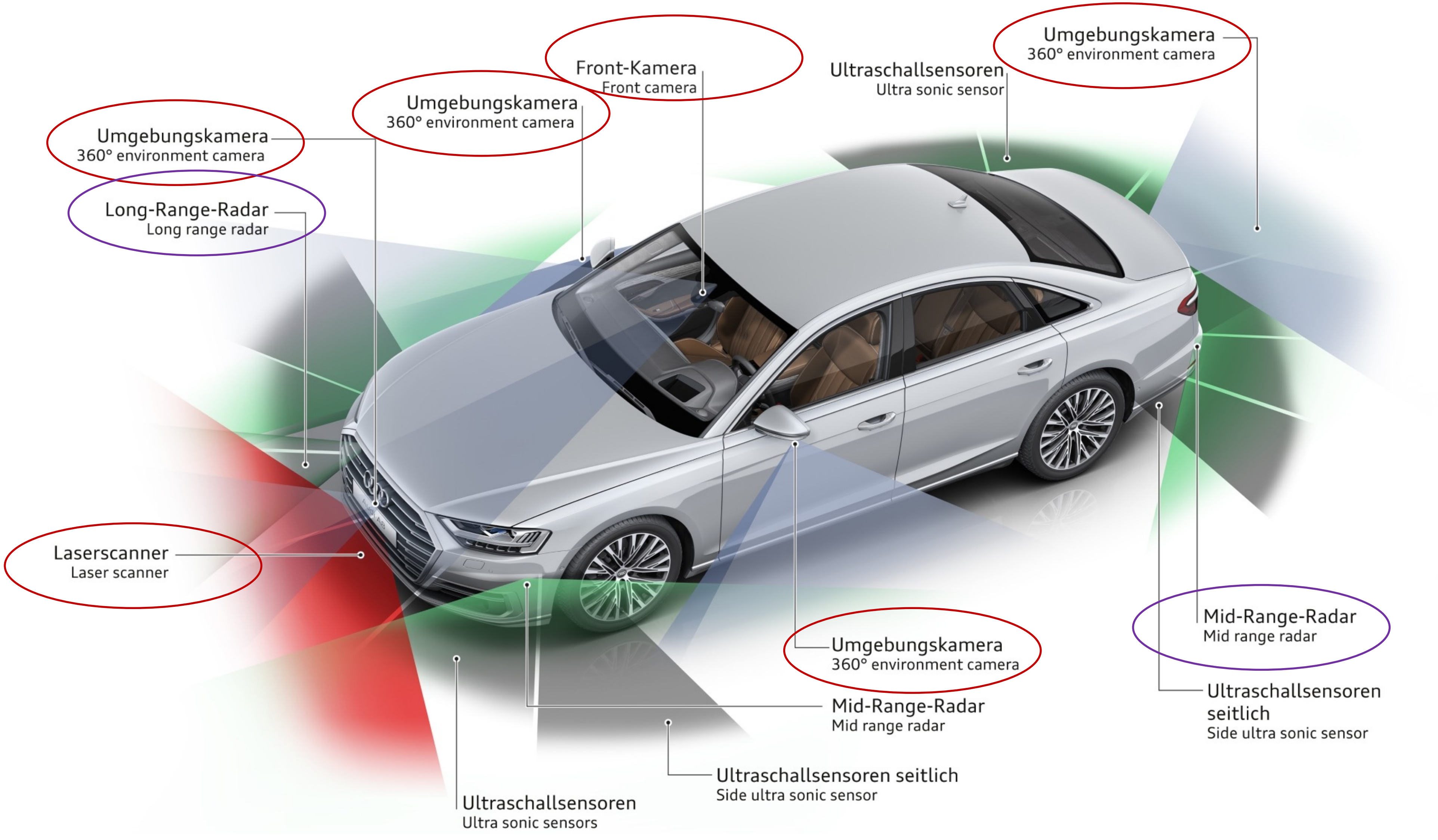






A hypothesis: there are now more discretized images than continuous images in the world!

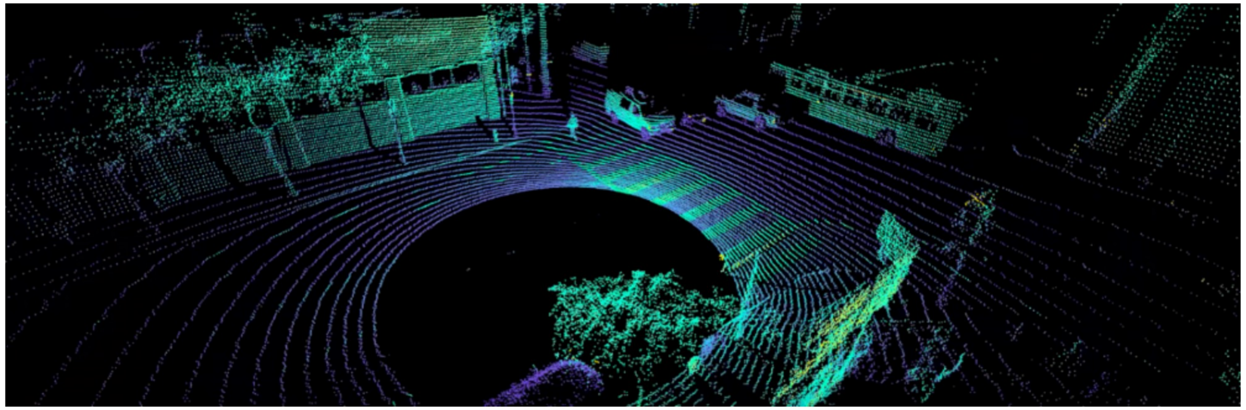
Audi A8

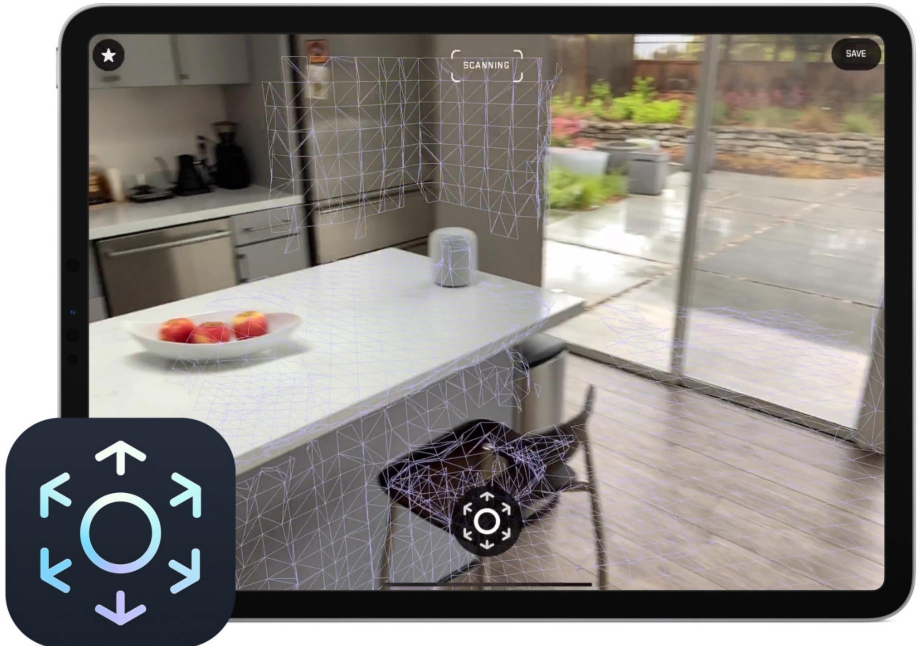

Umgebungskamera
360° environment camera
Front-Kamera
Front camera
Ultraschallsensoren
Ultra sonic sensor
Umgebungskamera
360° environment camera
Umgebungskamera
360° environment camera
Long-Range-Radar
Long range radar
Laserscanner
Laser scanner
Umgebungskamera
360° environment camera
Mid-Range-Radar
Mid range radar
Ultraschallsensoren seitlich
Side ultra sonic sensor
Ultraschallsensoren
Ultra sonic sensors
Mid-Range-Radar
Mid range radar
Ultraschallsensoren seitlich
Side ultra sonic sensor

Da Vinci Xi Surgical Robot

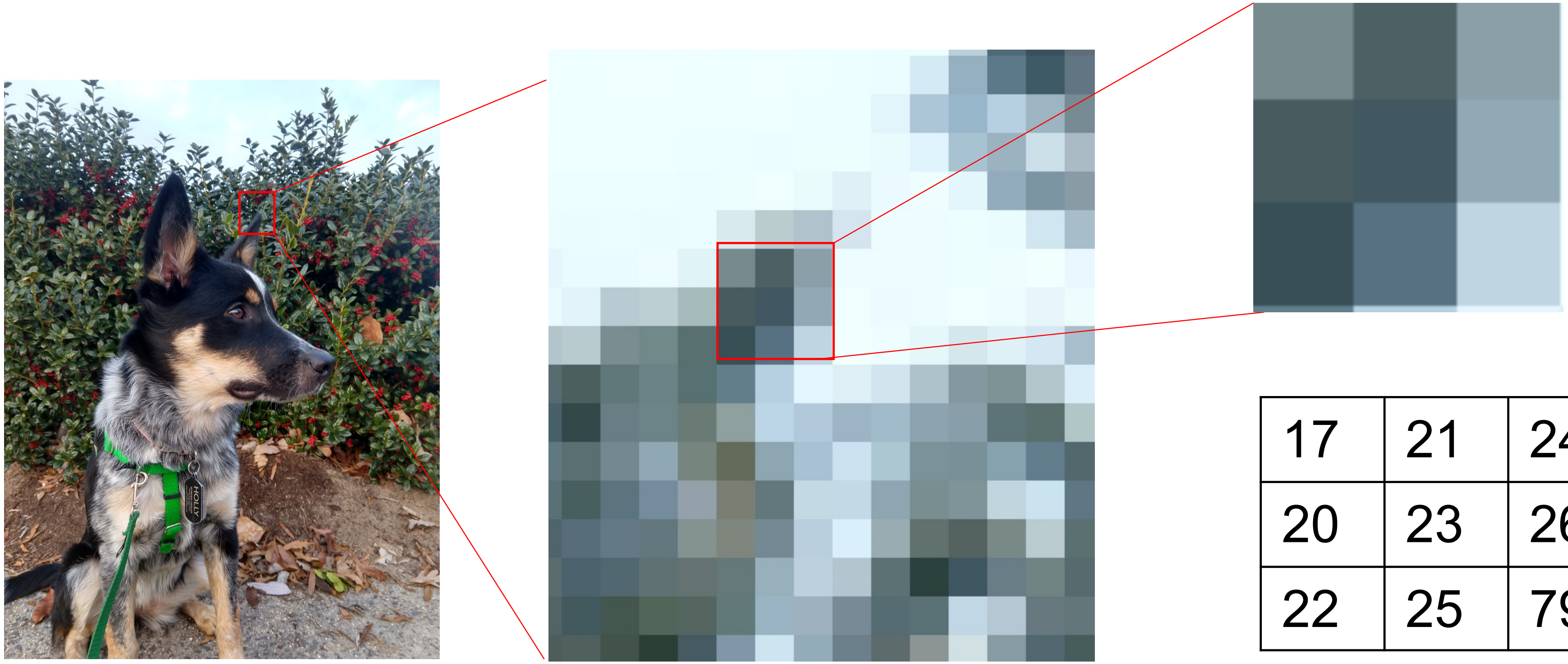
New digital image sensor arrays can now also detect depth...

SPAD array sensors – are here now…





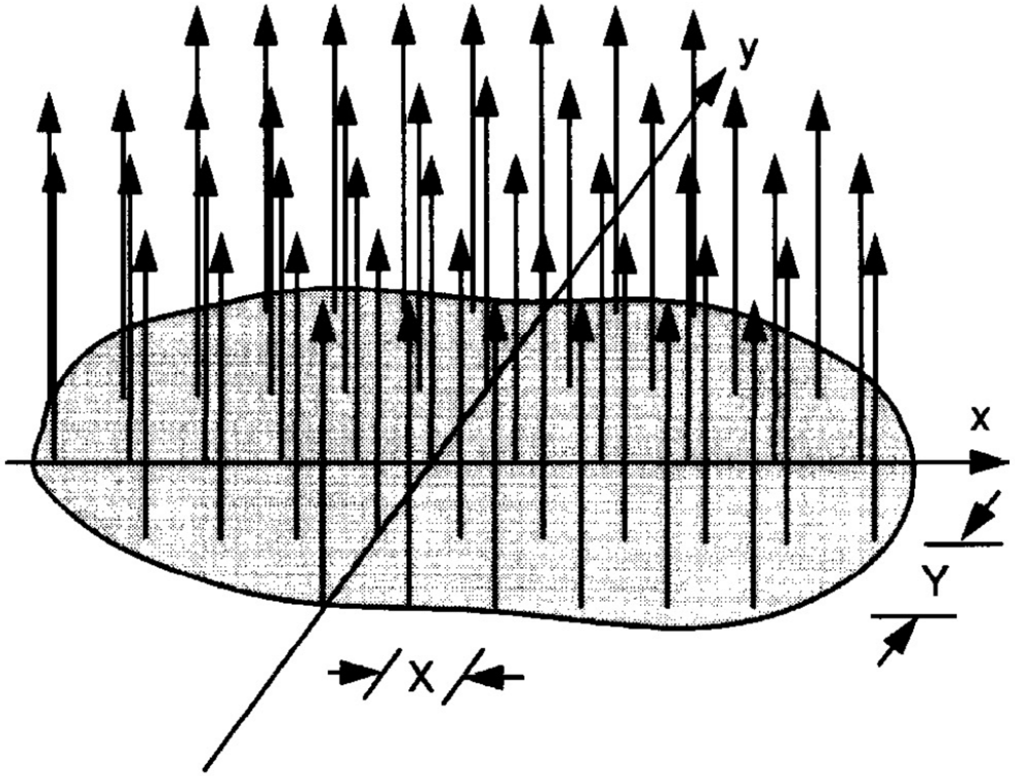
Images as matrices and vectors



17	21	24
20	23	26
22	25	79

Continuous versus discrete representation

$$I_s(x, y) = \text{comb}(x/X)\text{comb}(y/Y)I(x, y)$$



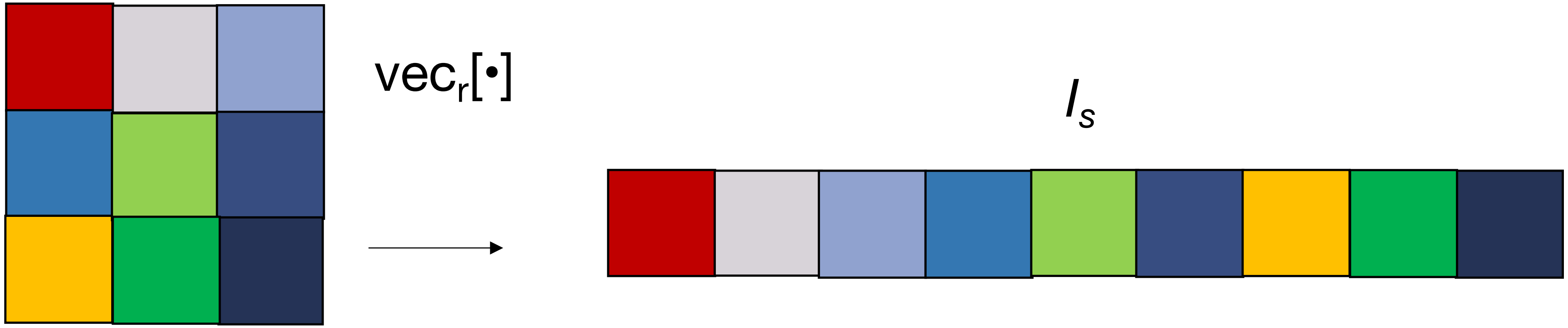
From J. Goodman, *Introduction to Fourier Optics*

Images unrolled into vectors

$I_s(x,y)$

$\text{vec}_r[\bullet]$

I_s

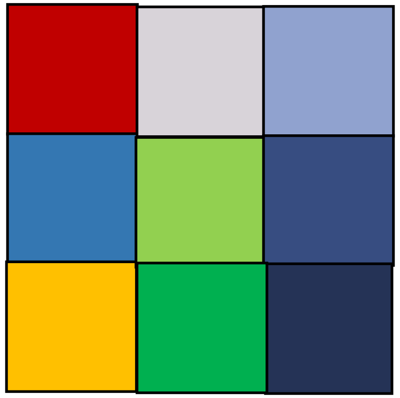


17	21	24
20	23	26
22	25	29

17	21	24	20	23	26	22	25	29

Images unrolled into vectors

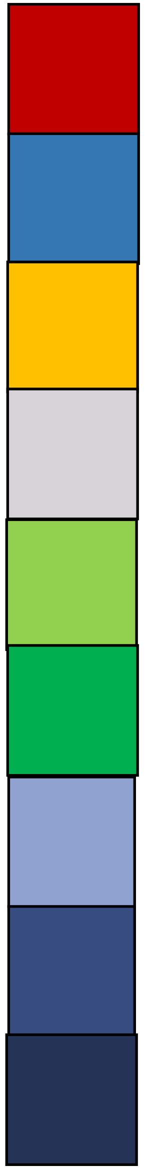
$I_s(x,y)$



17	21	24
20	23	26
22	25	29

$\text{vec}_c[\cdot]$

I_s



17
20
22
21
23
25
24
26
29

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Example manipulations of images

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1. Image addition/subtraction

$$I_o = I_1 + I_2$$

2. Image multiplication

$$I_o = I_1 \odot I_2$$

3. Image transformation: matrix-vector multiplication

$$I_o = \mathbf{W} I_1$$

4. Non-linear image operations

$$I_o = |I_1|^2$$

5. Convolution

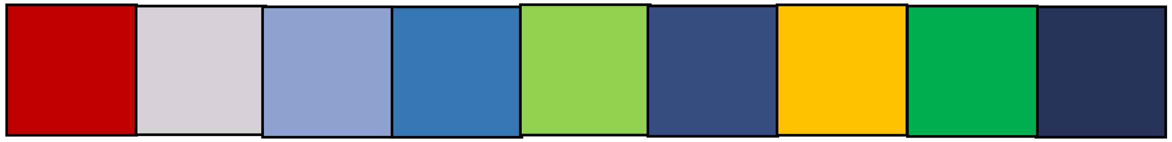
$$I_o = I_1 * I_2$$

Important image manipulation: convolution

$$I_o = I_1 * I_2$$

$$I_o[n] = \sum_{m=-M}^{M} I_1[n-m] I_2[m]$$

I_1



17	21	24	20	23	26	22	25	29

$*$

I_2

1	1	1

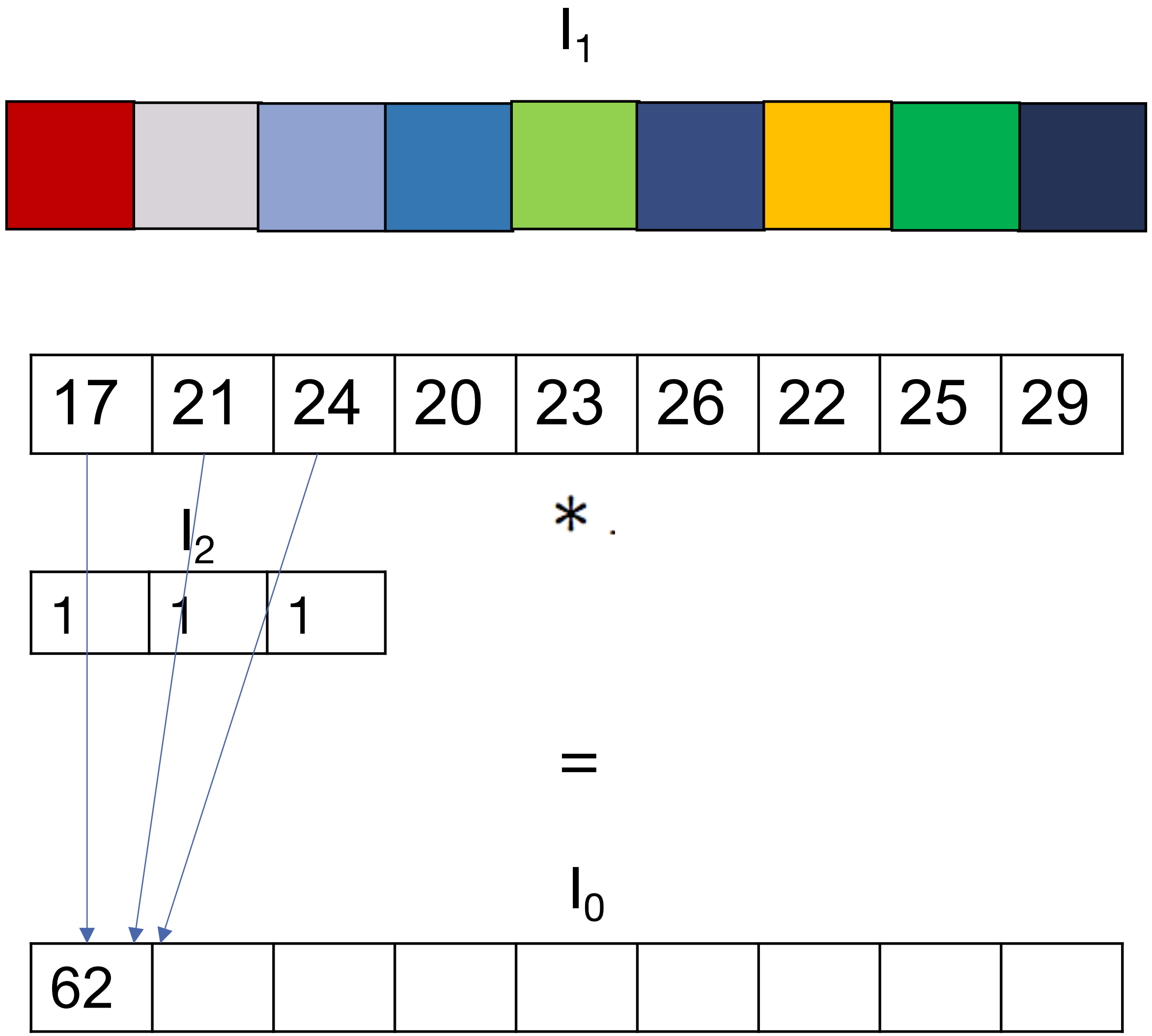
$=$

I_0

Important image manipulation: convolution

$$I_o = I_1 * I_2$$

$$I_o[n] = \sum_{m=-M}^{M} I_1[n-m] I_2[m]$$



Important image manipulation: convolution

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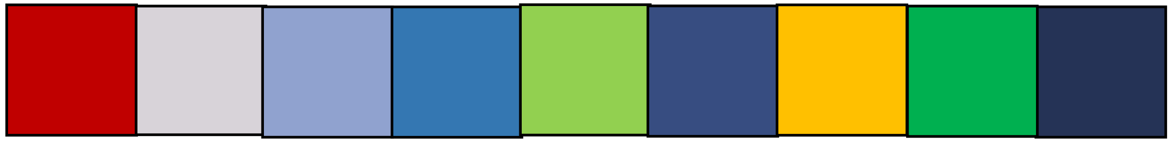
$$I_o = I_1 * I_2$$

$$I_o[n] = \sum_{m=-M}^{M} I_1[n-m] I_2[m]$$

I_1



17	21	24	20	23	26	22	25	29

$*$

I_2

1	1	1

=

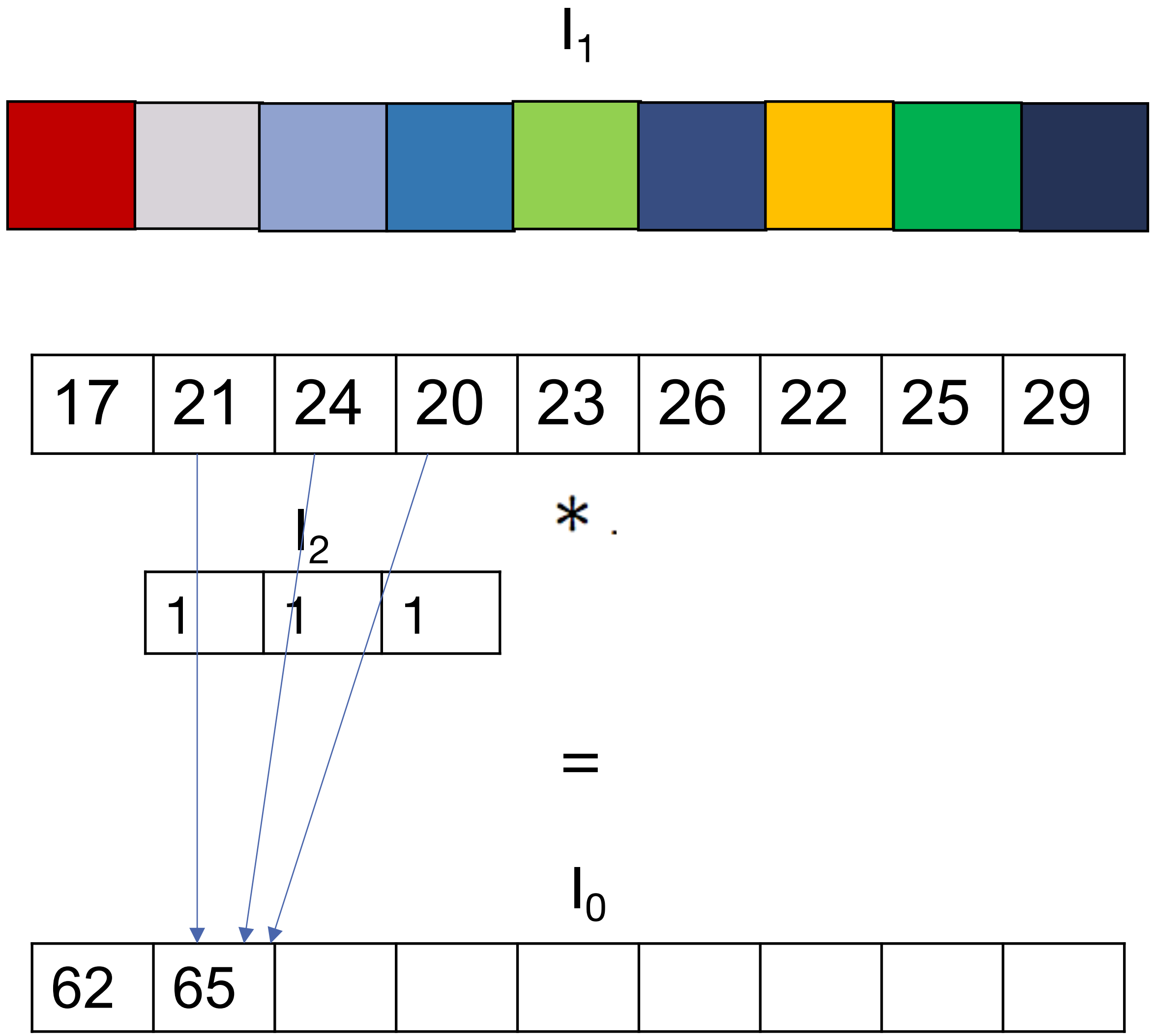
I_0

62								

Important image manipulation: convolution

$$I_o = I_1 * I_2$$

$$I_o[n] = \sum_{m=-M}^{M} I_1[n-m]I_2[m]$$



Important image manipulation: convolution

$$I_o[s,t] = \sum_{l=-L}^{L} \sum_{m=-M}^{M} I_1[s-l, t-m] I_2[l,m]$$

I_1

$*$

I_2

1	1	1
1	1	1
1	1	1

$=$

I_0

Important image manipulation: convolution

$$I_o[s,t] = \sum_{l=-L}^{L} \sum_{m=-M}^{M} I_1[s-l, t-m] I_2[l,m]$$

I_1

$*$

I_2

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

=

I_0

Machine learning: "dynamic" image manipulations

Current goal in machine learning : determine image manipulations to highlight features of interest

I_1

$*$

W

w1	w2	w3
w4	w5	w6
w7	w8	w9

=

Most useful information possible for computer to use

Machine learning: "dynamic" image manipulations

Current goal in machine learning : determine image manipulations to highlight features of interest

I_1

$*$

W

w1	w2	w3
w4	w5	w6
w7	w8	w9

= Most useful information possible for computer to use

Determine weights w for particular task: image segmentation, object detection, bw-to-color, etc.

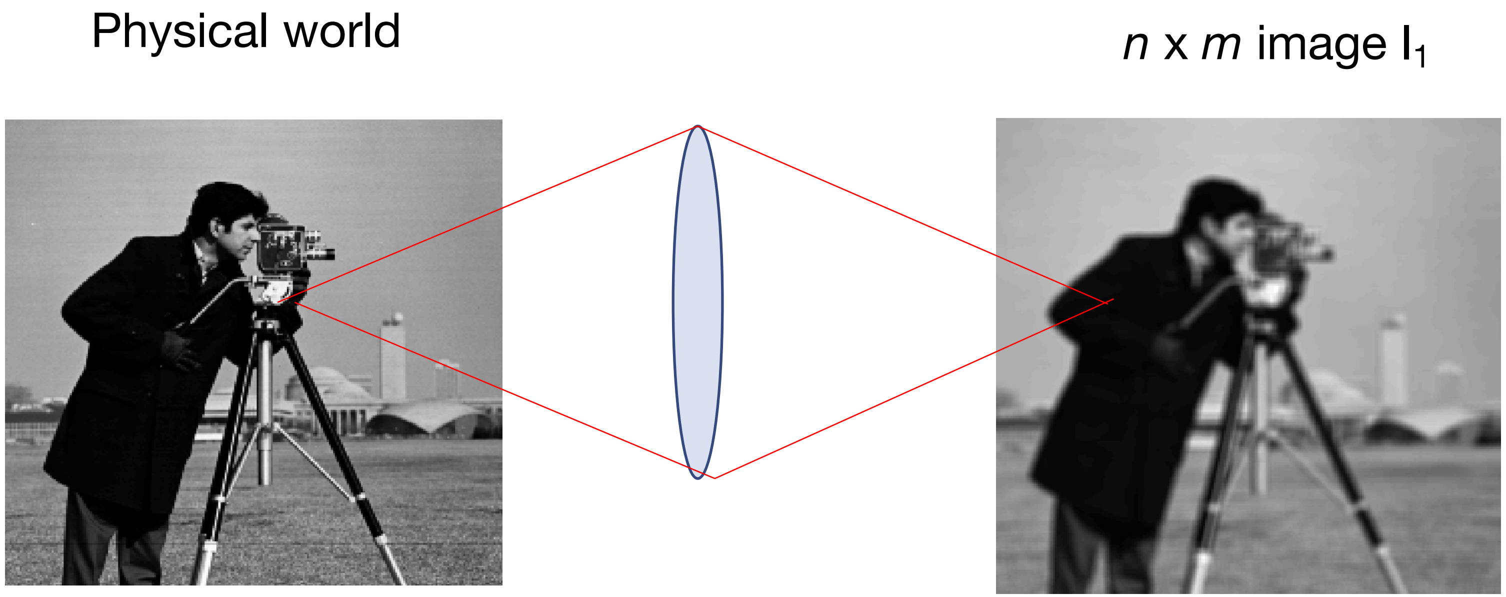
Example tasks for machine learning

Common ML transformations for detected image:

- A vector of different categories (image is of a man, not a dog)
- A vector of coordinates highlighting features of interest (the man's head is contained in the box of pixels from (x,y,x+a,y+b)
- A segmentation map (the line denoting the boundary of the man is 1, rest is 0)

Image formation as a set of discrete equations

- Can also model the behavior of the imaging system before the radiation hits the image detector



$$I_1 = \mathbf{W_0}\, I_0$$

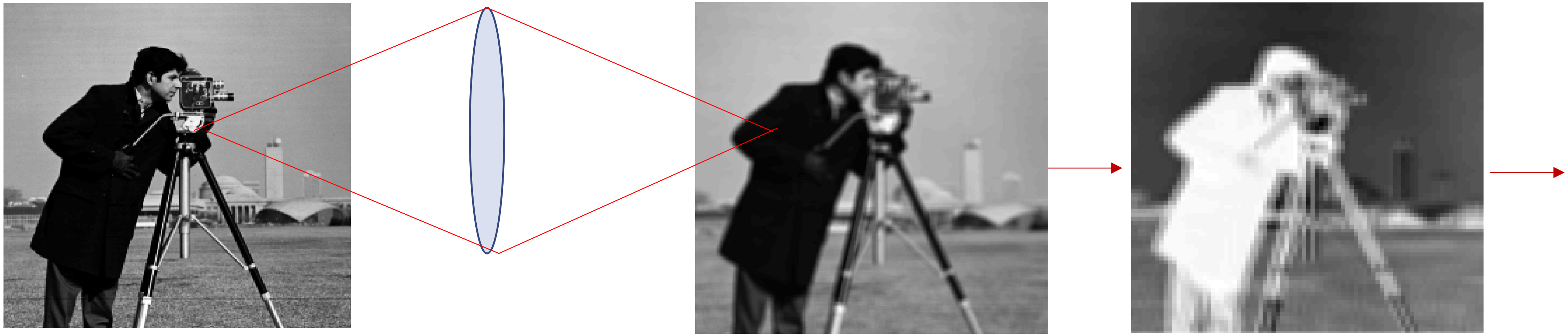
Image formation as a set of discrete equations

- Can also model the behavior of the imaging system before the radiation hits the image detector

Physical world

n x *m* image I_1

Processed image I_2



ML Task

$$I_1 = \mathbf{W_0}\ I_0$$

$$I_2 = \mathbf{W_1}\ I_1$$

Image formation as a set of discrete equations

- Can also model the behavior of the imaging system before the radiation hits the image detector

Physical world

n x m image I_1

Processed image I_2

$I_2 = \mathbf{W_1 W_0}\ I_0$

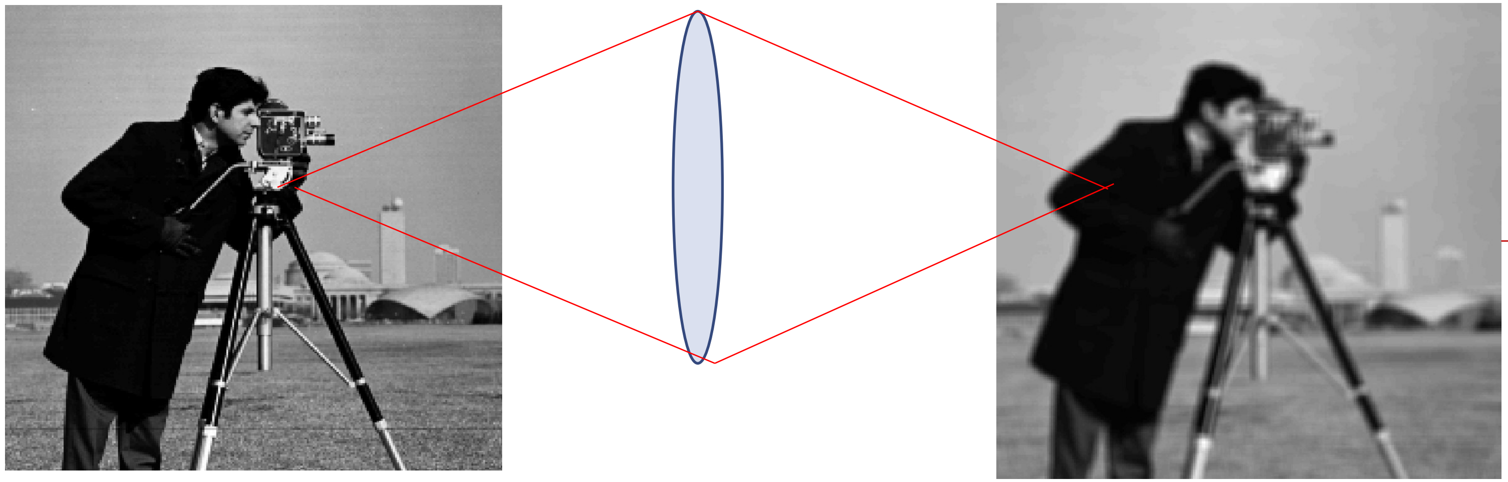
Linear mapping

Bringing together physical and digital image representations

deep imaging

Physical world

n x *m* image I_1



Convolutional neural network → ML Task

"Image of a man"

$$\text{Task} = \mathbf{W_n} \ldots \mathbf{T_1}[\mathbf{W_1}\, \mathbf{T_0}[\mathbf{W_0}\, I_0]\ldots]$$

Nonlinear mapping

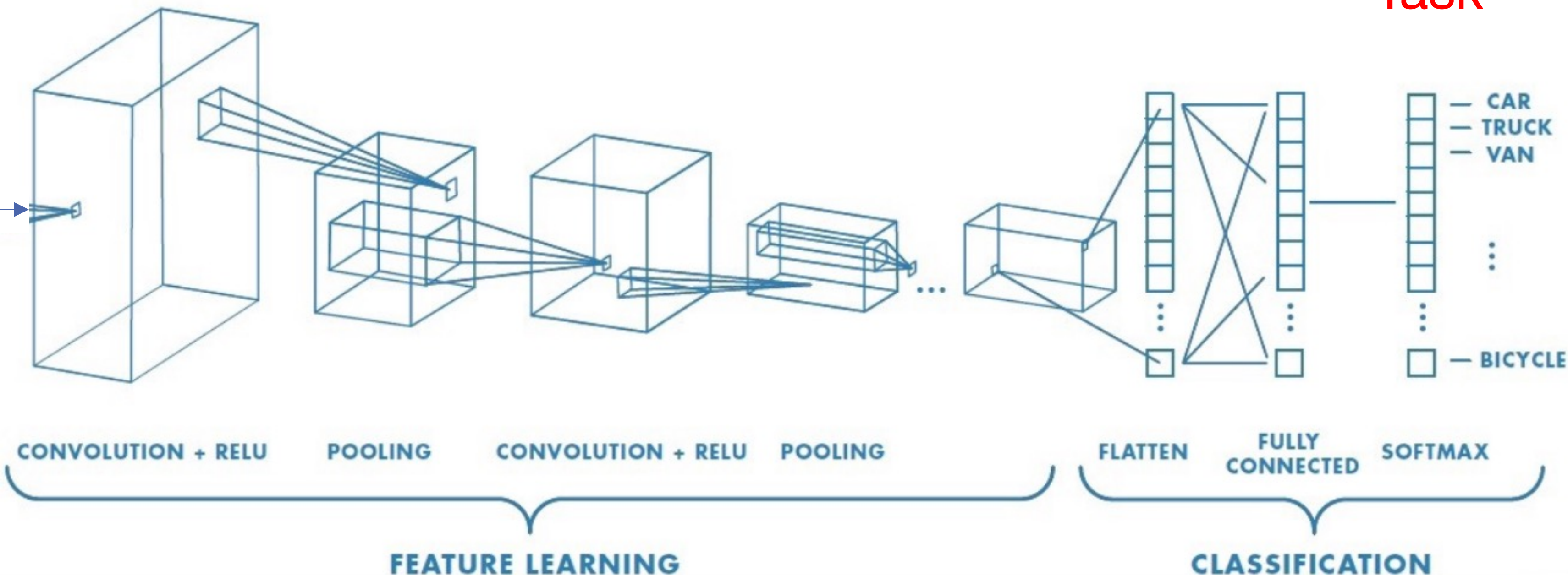
Bringing together physical and digital image representations

Physical world I_0

Hardware

Image I_1

Task



$$\text{Task} = \mathbf{W_n} \ldots \mathbf{T_1}[\mathbf{W_1}\, \mathbf{T_0}[\mathbf{W_0}\, I_0]\ldots]$$

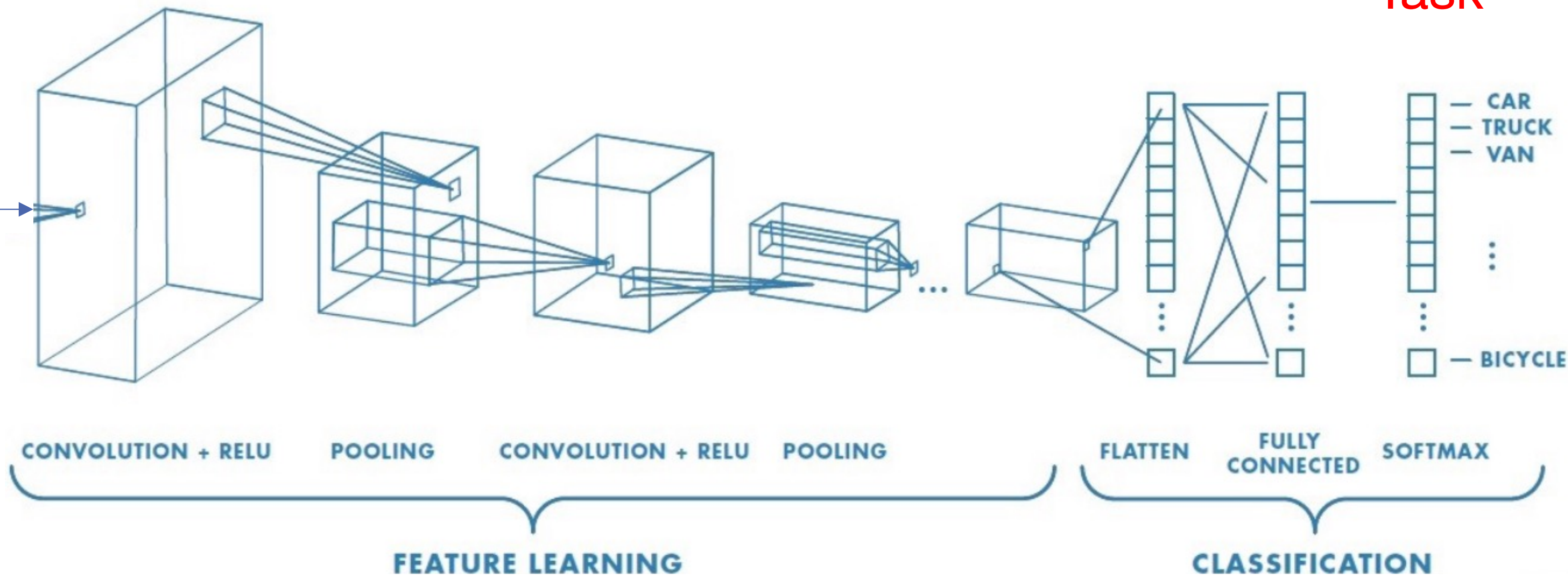
From https://towardsdatascience.com/

Bringing together physical and digital image representations

Physical world I_0

Hardware

Image I_1



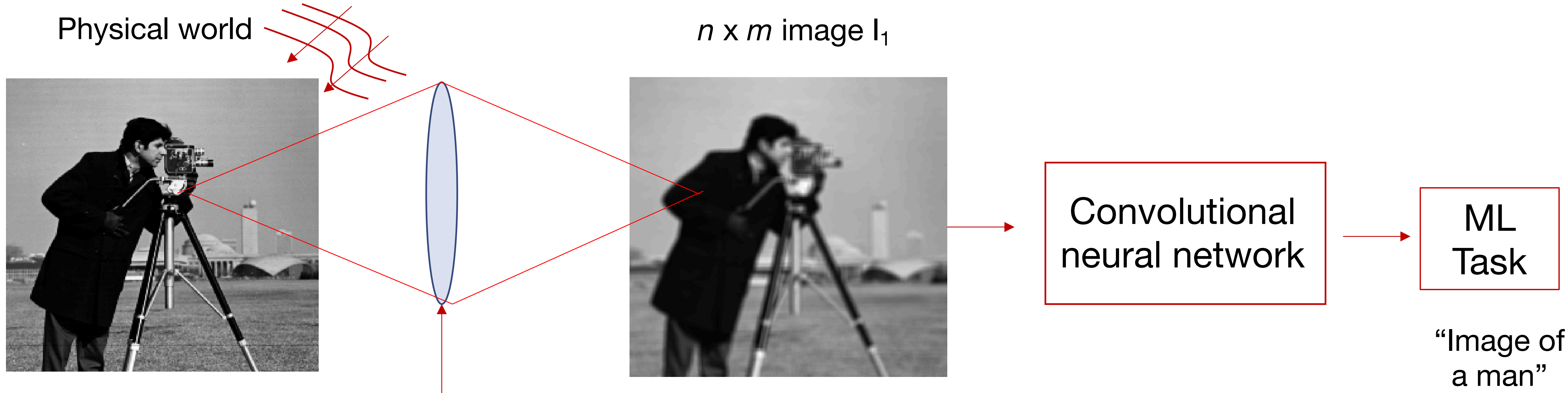
Task

Account for or modify imaging hardware

$$\text{Task} = \mathbf{W_n} \ldots \mathbf{T_1}[\mathbf{W_1}\ \mathbf{T_0}[\mathbf{W_0}\ I_0]\ldots]$$

From https://towardsdatascience.com/

Bringing together physical and digital image representations



Illumination
Imaging device (lens, coils, transducers)
Detector design
Properties of sample of interest

$$\text{Task} = \mathbf{W_n} \ldots \mathbf{T_1}[\mathbf{W_1}\ \mathbf{T_0}[\mathbf{W_0}\ I_0]\ldots]$$

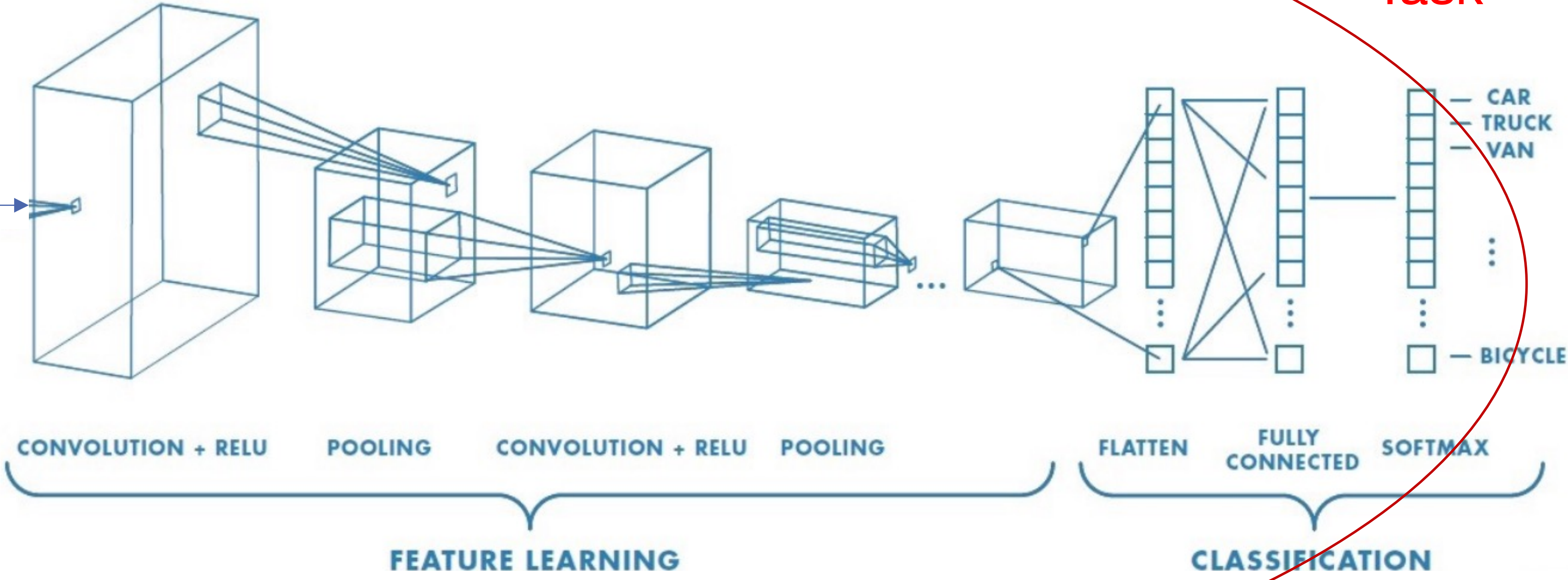
Bringing together physical and digital image representations

Physical world I_0

Hardware

Image I_1

Task



Final project: try to optimize all of this together!

From https://towardsdatascience.com/