

Machine Learning in Imaging

BME 590L
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Lecture 1: Machine Learning and Imaging in a nutshell

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?

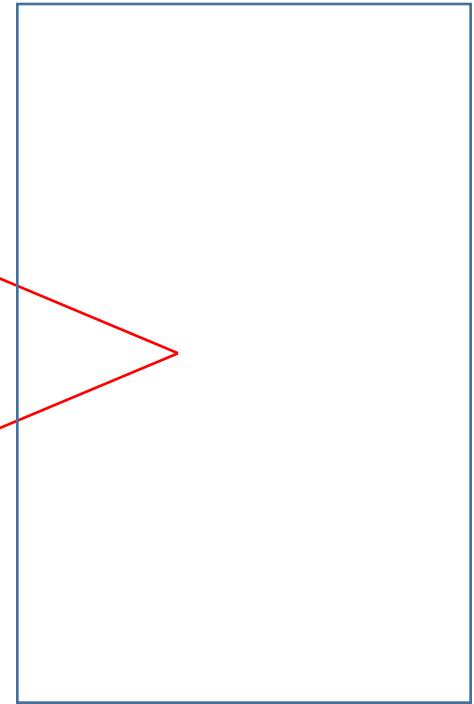
2. “Physical” Interpretation



Image plane

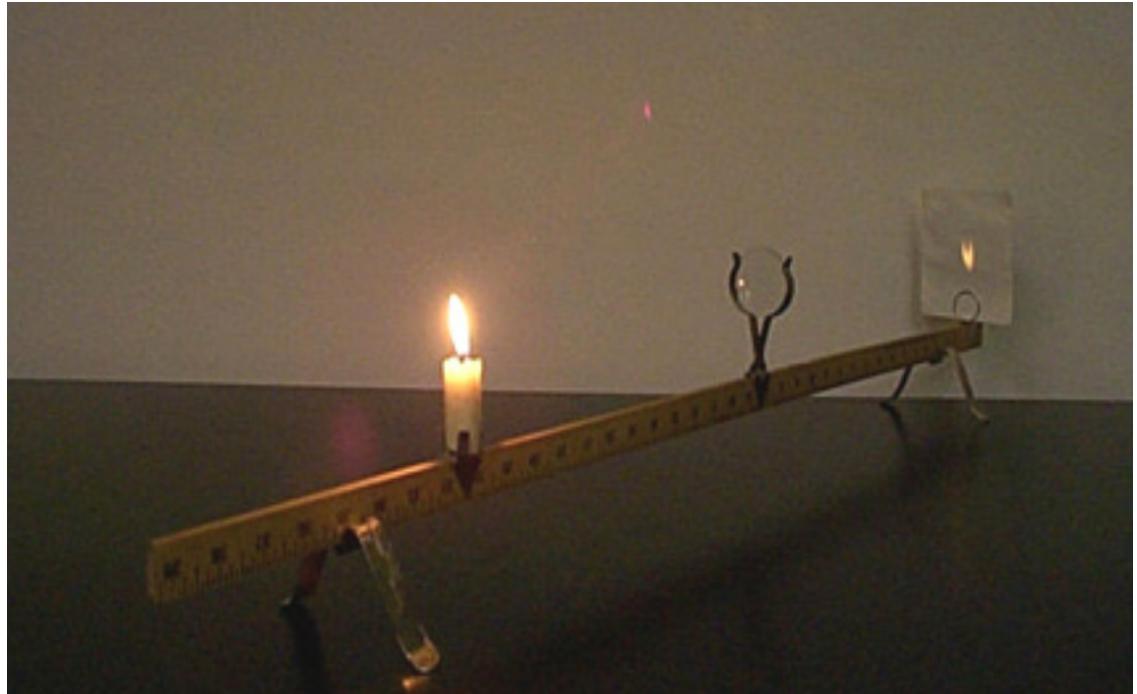
“Collection”
Element

Electromagnetic
radiation



Physical world
(Object plane)

What is an image?

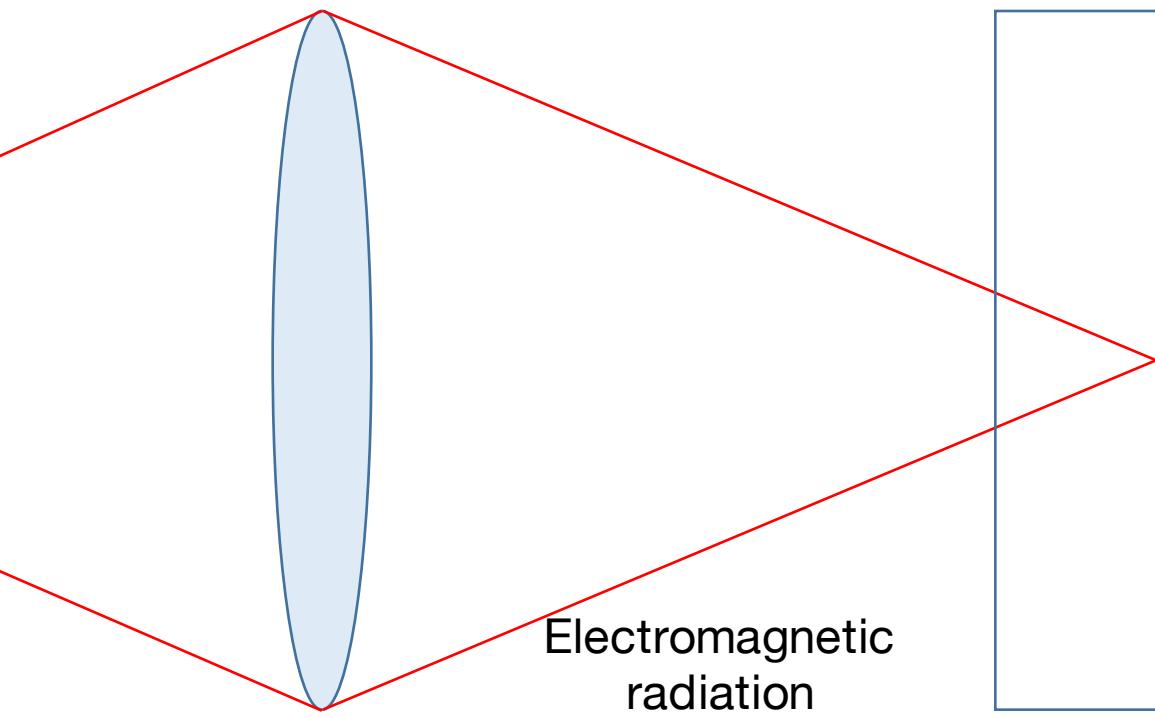


What is an image?

2. “Physical” Interpretation



Image plane



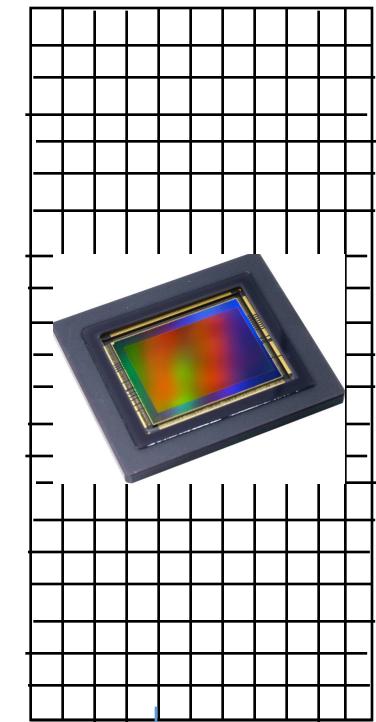
Continuous signal:

$$I(x, y), (x, y) \in (-\infty, \infty)$$

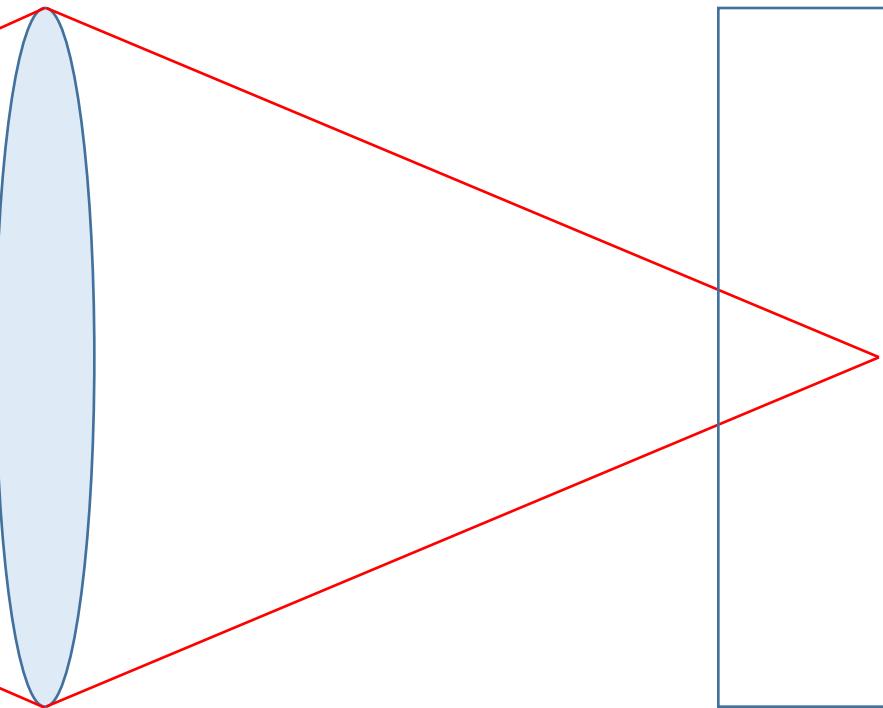
(Physical wave)

What is an image?

$n \times m$ array



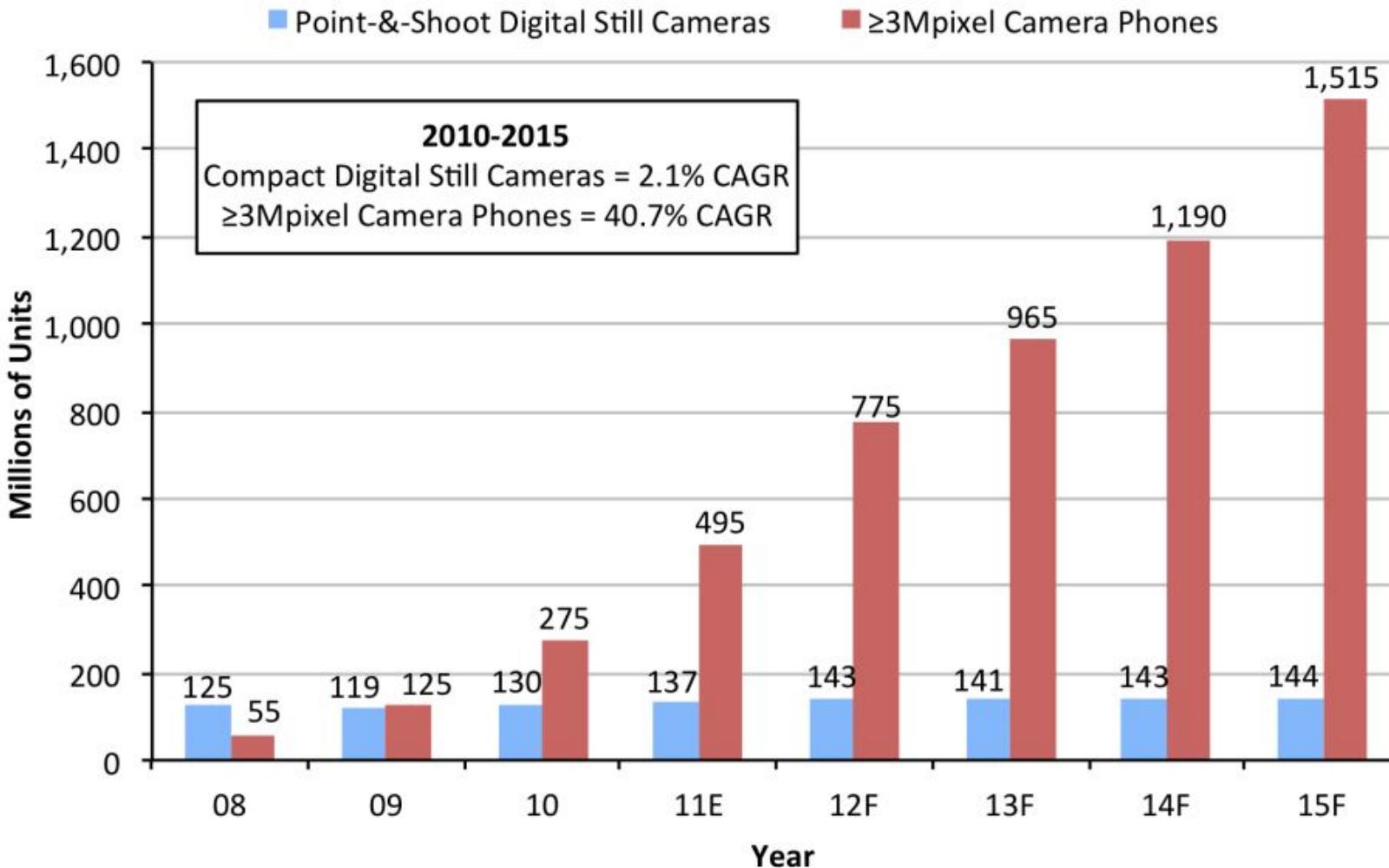
3. “Digital” Interpretation



Photons to electrons → Digitization → *Discrete signal*

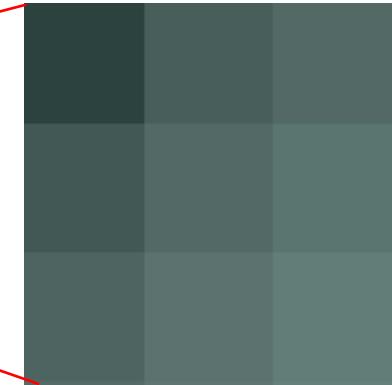
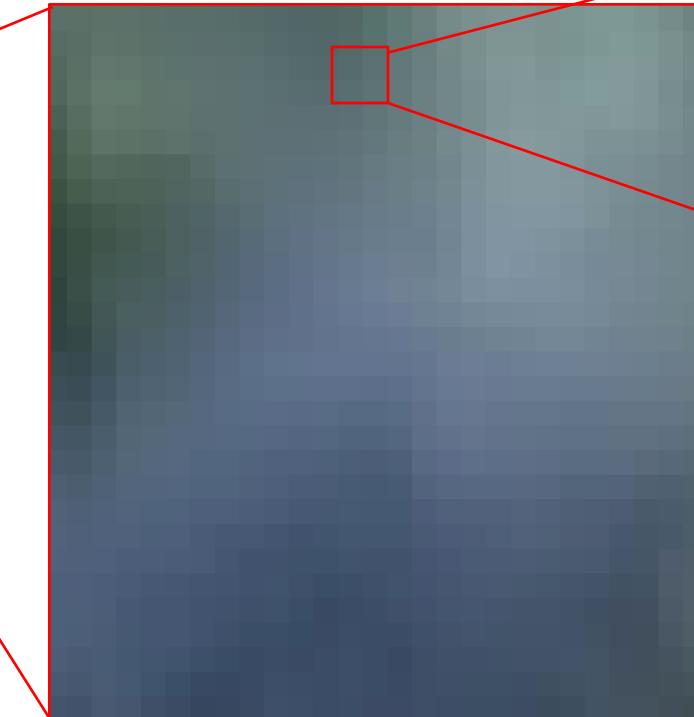
$$I_s(x, y), (x, y) \in Z^{n \times m}$$

Compact DSCs Vs. "Good Enough" Camera Phones



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

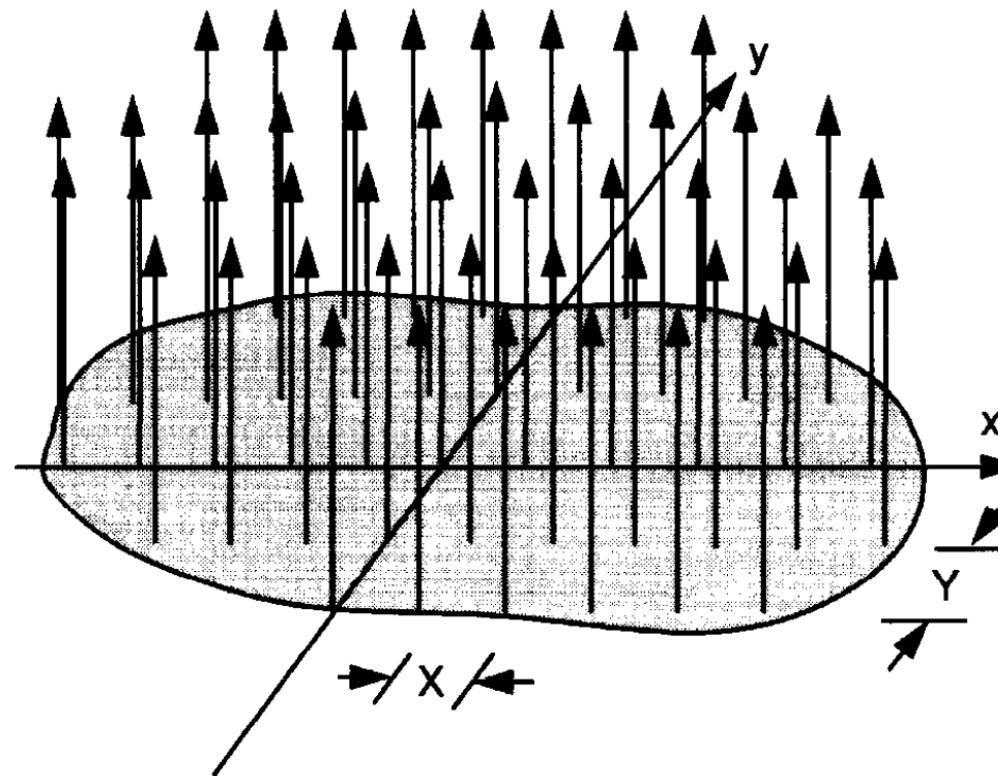
Images as matrices and vectors



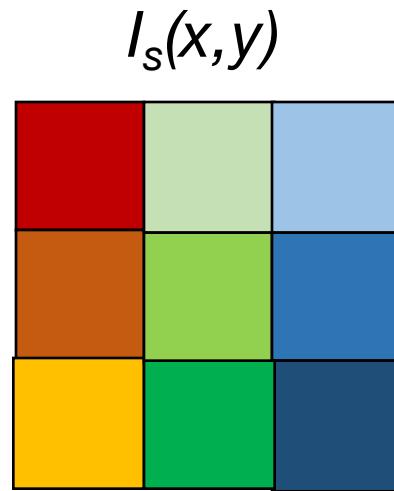
17	21	24
20	23	26
22	25	29

Continuous versus discrete representation

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



Images unrolled into vectors



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



I_s

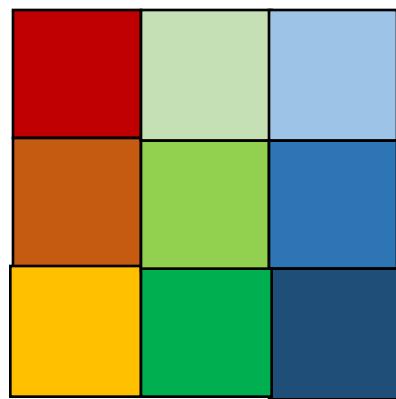


17	21	24
20	23	26
22	25	29

17	21	24	20	23	26	22	25	29
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Images unrolled into vectors

$I_s(x, y)$

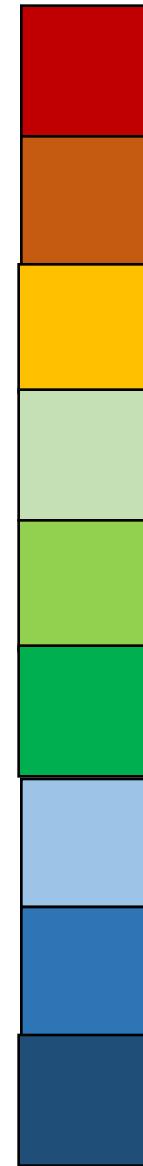


17	21	24
20	23	26
22	25	29

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



I_s



17
20
22
21
23
25
24
26
29

Example manipulations of images

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

$$I_o = |I_1|^2$$

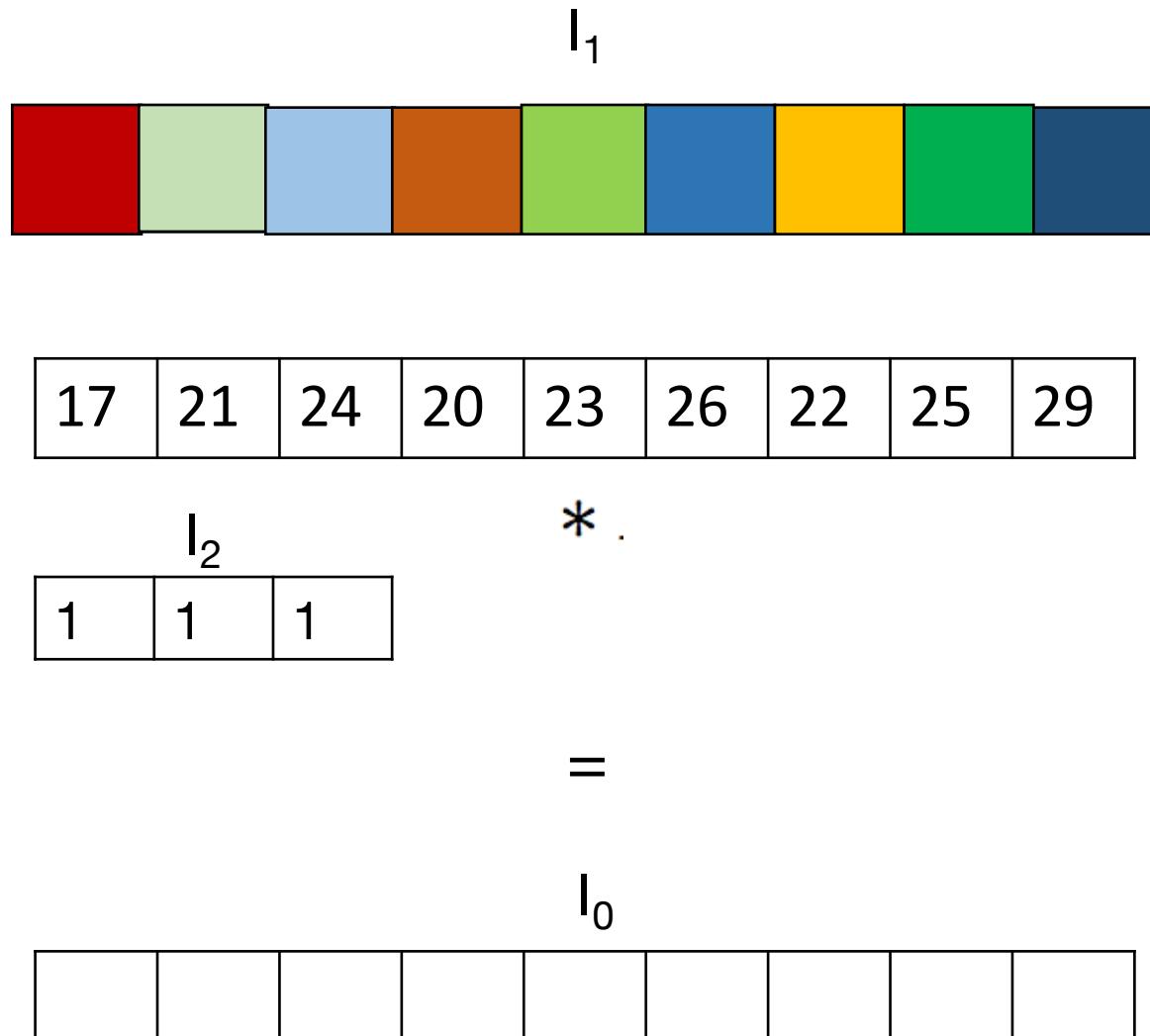
5. Convolution

$$I_o = I_1 * I_2$$

Important image manipulation: convolution

$$I_o = I_1 * I_2$$

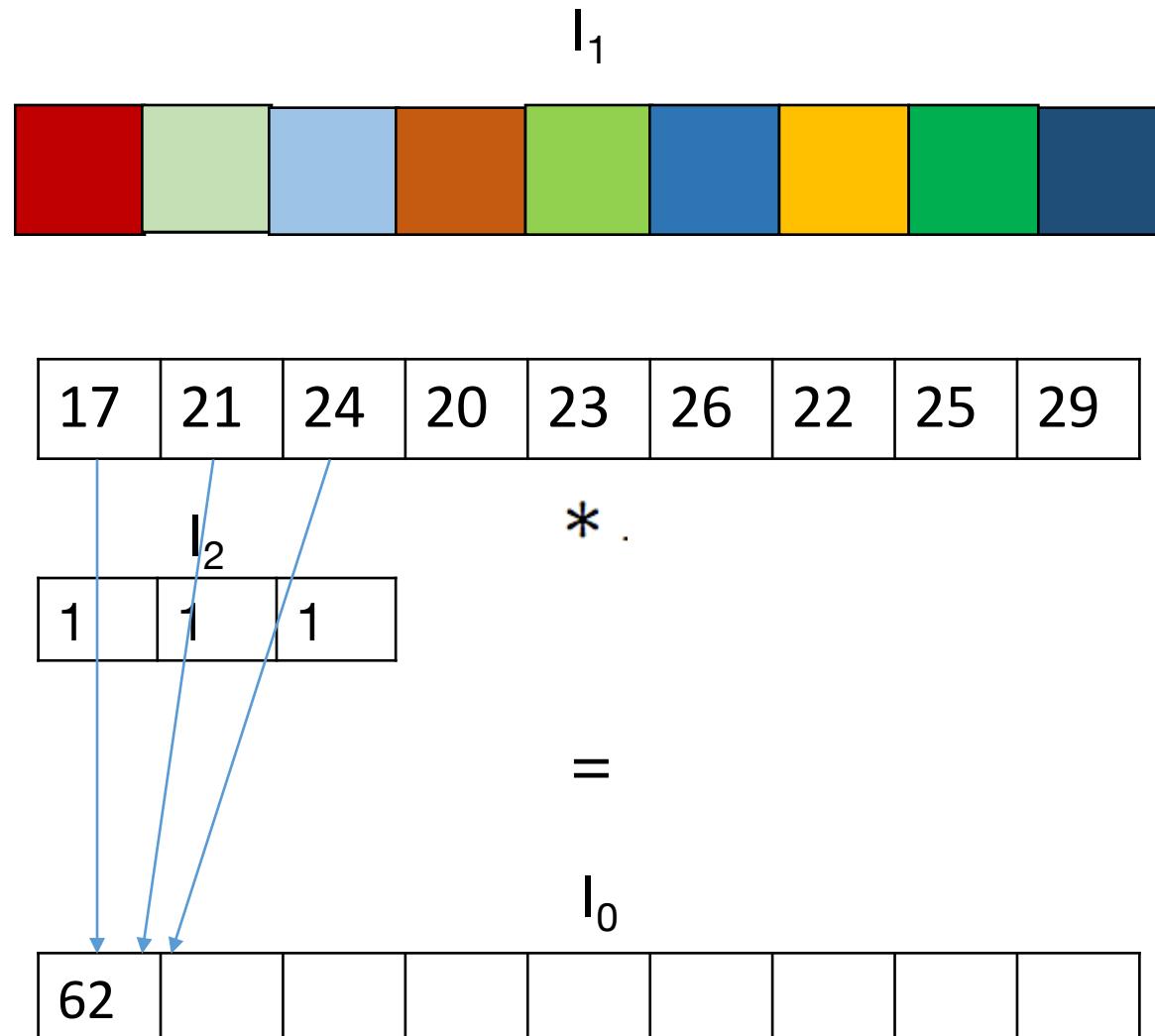
$$I_o[n] = \sum_{m=-M}^M I_1[n-m]I_2[m]$$



Important image manipulation: convolution

$$I_o = I_1 * I_2$$

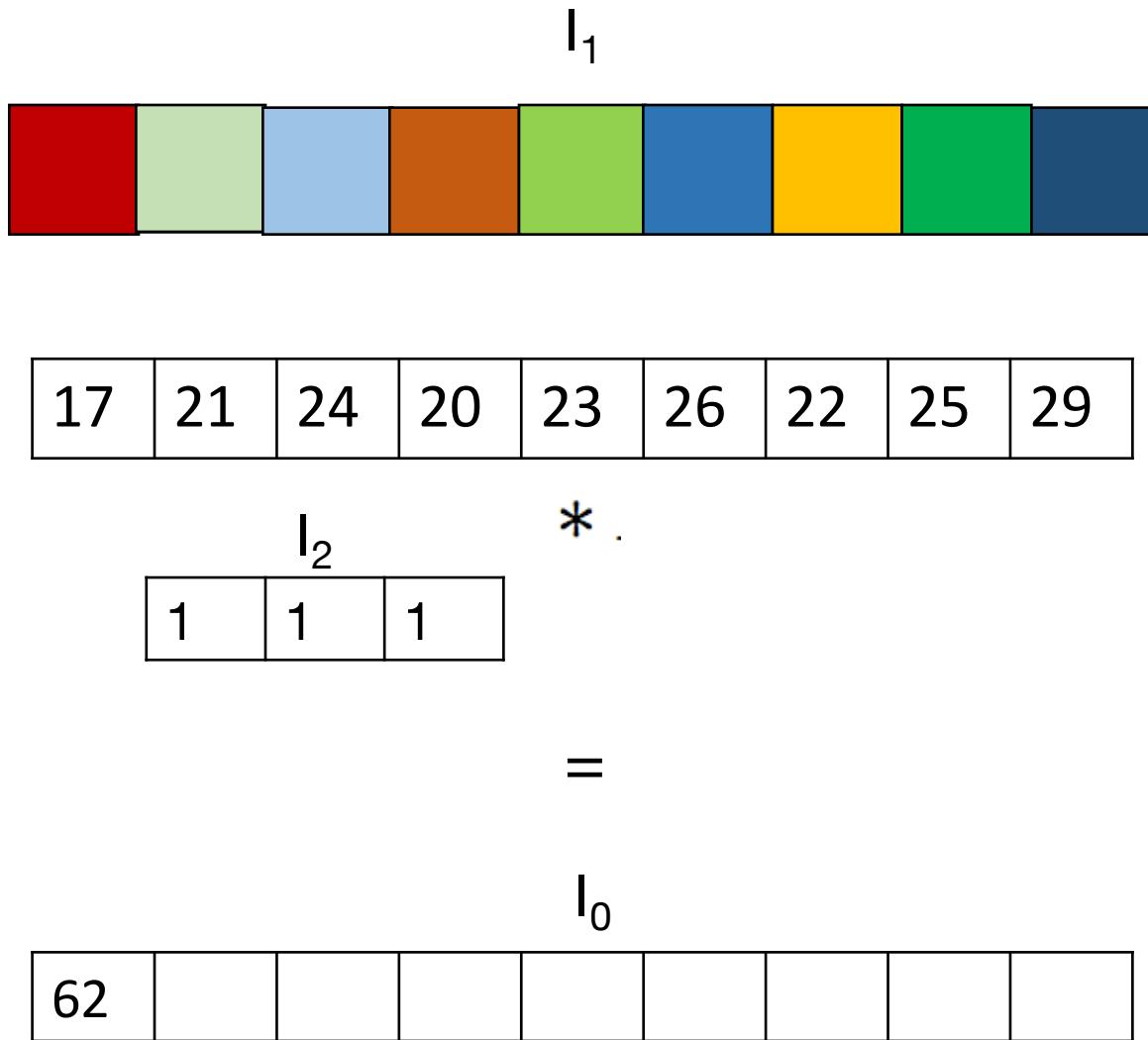
$$I_o[n] = \sum_{m=-M}^M I_1[n-m]I_2[m]$$



Important image manipulation: convolution

$$I_o = I_1 * I_2$$

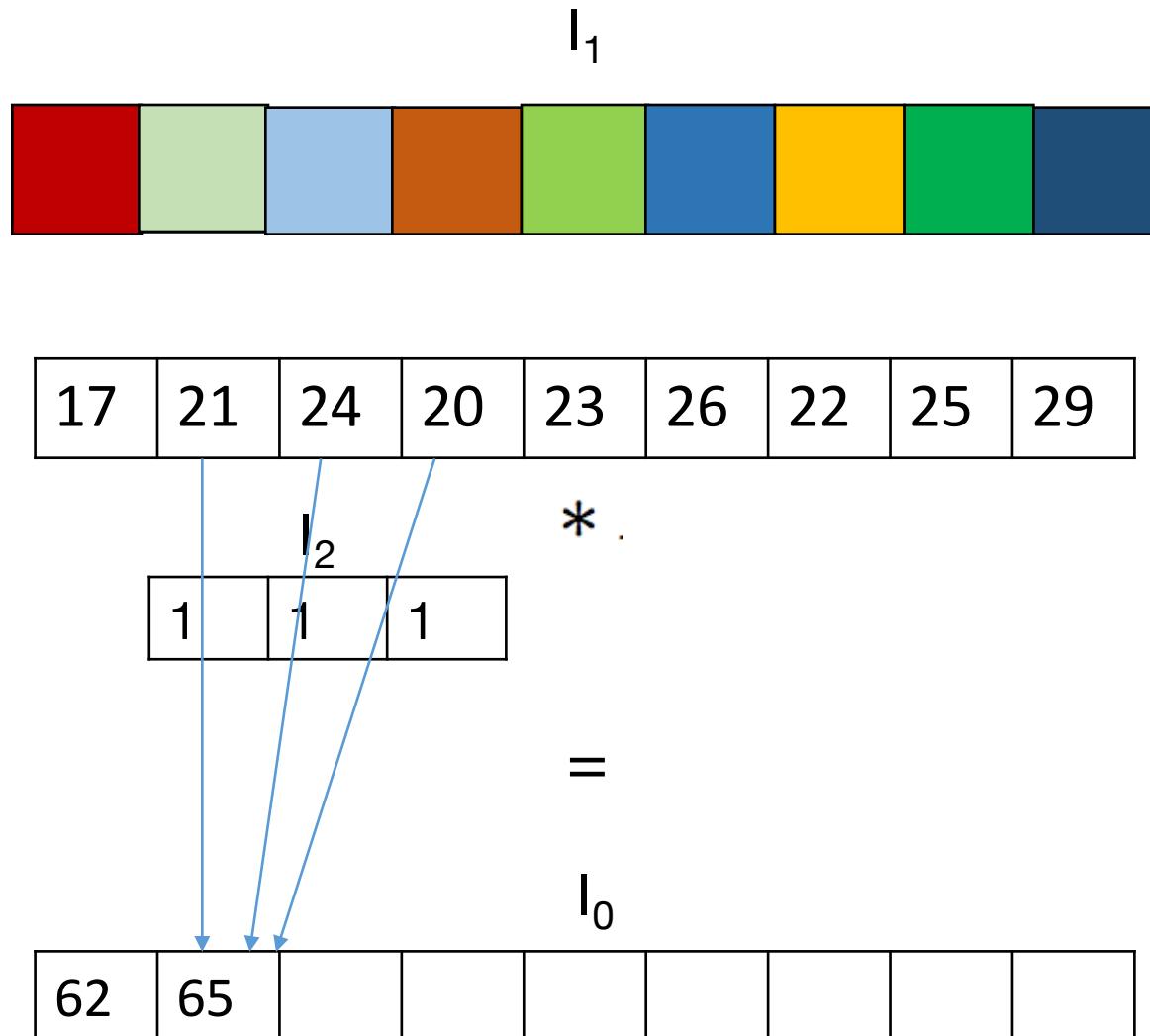
$$I_o[n] = \sum_{m=-M}^M I_1[n-m]I_2[m]$$



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_0



I_2

*

1	1	1
1	1	1
1	1	1

=

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_0



I_2

$$\begin{matrix} * & \begin{matrix} -1 & 0 & -1 \\ -2 & 0 & -2 \\ -1 & 0 & -1 \end{matrix} & = & \end{matrix}$$

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

Machine learning: “dynamic” image manipulations

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



I_1

$$I_1 \cdot W = \text{Most useful information possible for computer to use}$$

w1	w2	w3
w4	w5	w6
w7	w8	w9

Machine learning: “dynamic” image manipulations

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



I_1

$$I_1 \cdot W = \text{Most useful information possible for computer to use}$$

w1	w2	w3
w4	w5	w6
w7	w8	w9



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

Physical world



$n \times m$ image I_1



$$I_1 = W_0 I_0$$

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



$n \times m$ image I_1



Processed image I_2



ML
Task

$$I_1 = W_0 I_0$$

$$I_2 = W_1 I_1$$

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



$n \times m$ image I_1



Processed image I_2



ML
Task

$$I_2 = W_1 I_1 W_0 I_0$$

Linear mapping

Bringing together physical and digital image representations

Physical world



$n \times m$ image I_1



Convolutional
neural network

ML
Task

“Image of
a man”

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

Nonlinear mapping

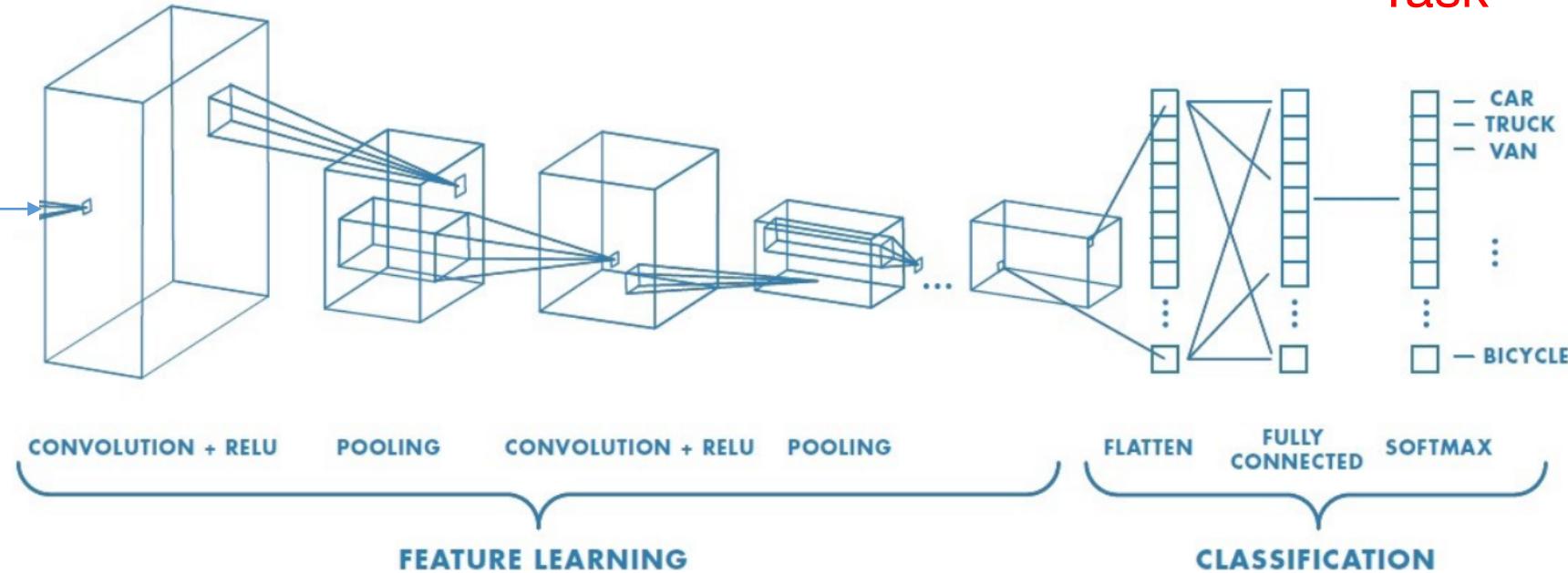
Bringing together physical and digital image representations

Physical world I_0



Hardware

Image I_1



$$\text{Task} = \mathbf{W}_n \dots \mathbf{T}_1 [\mathbf{W}_1 \mathbf{T}_0 [\mathbf{W}_0 I_0] \dots]$$

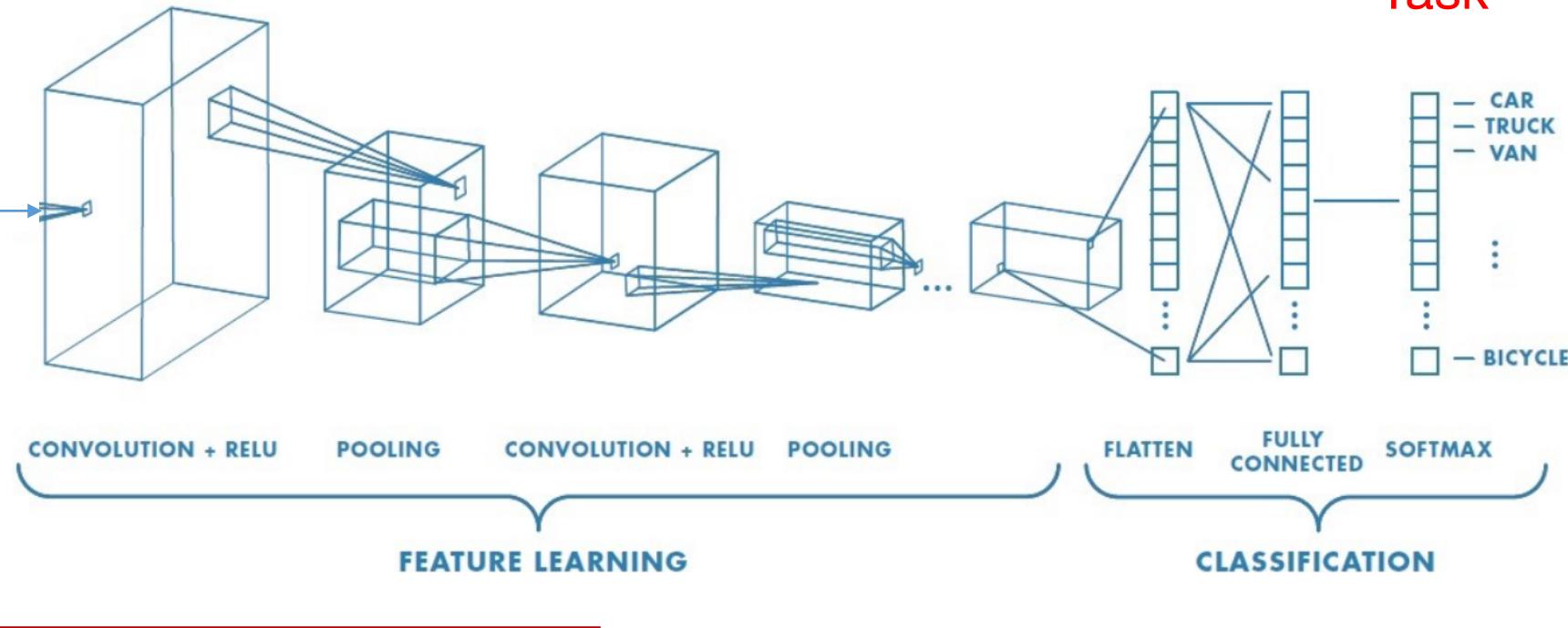
Bringing together physical and digital image representations

Physical world I_0



Hardware

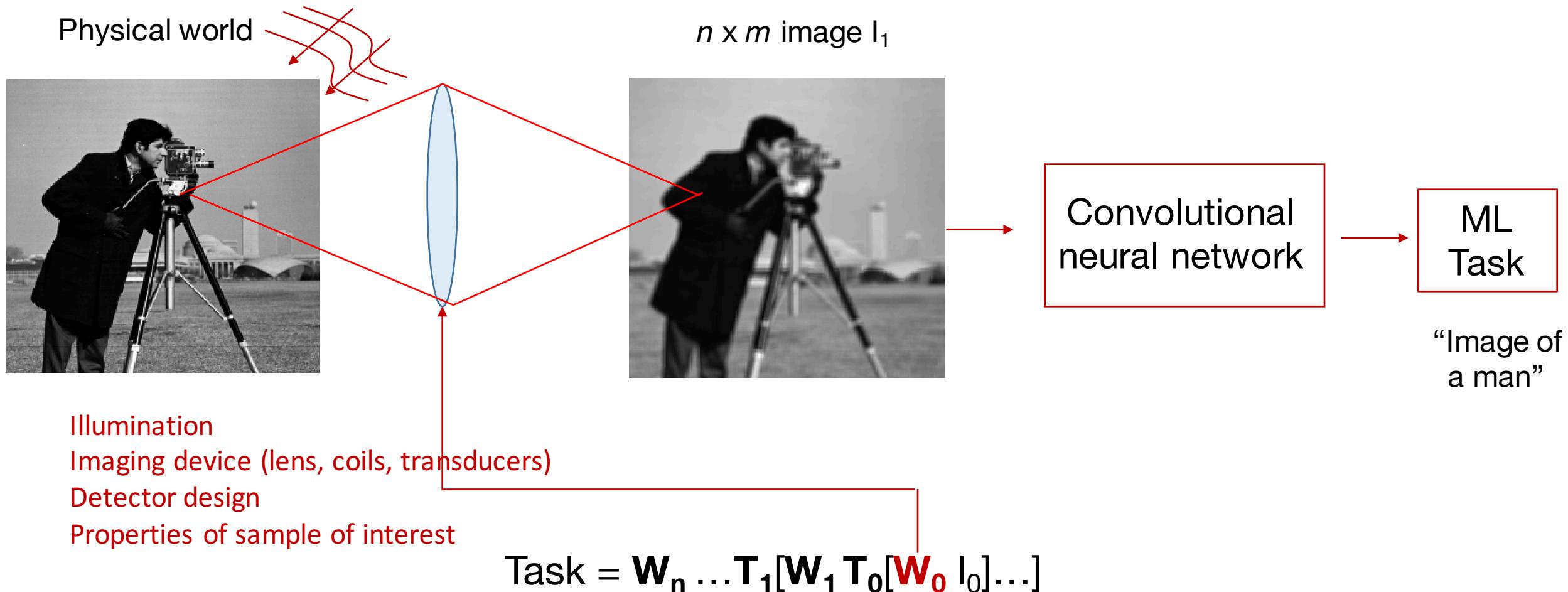
Image I_1



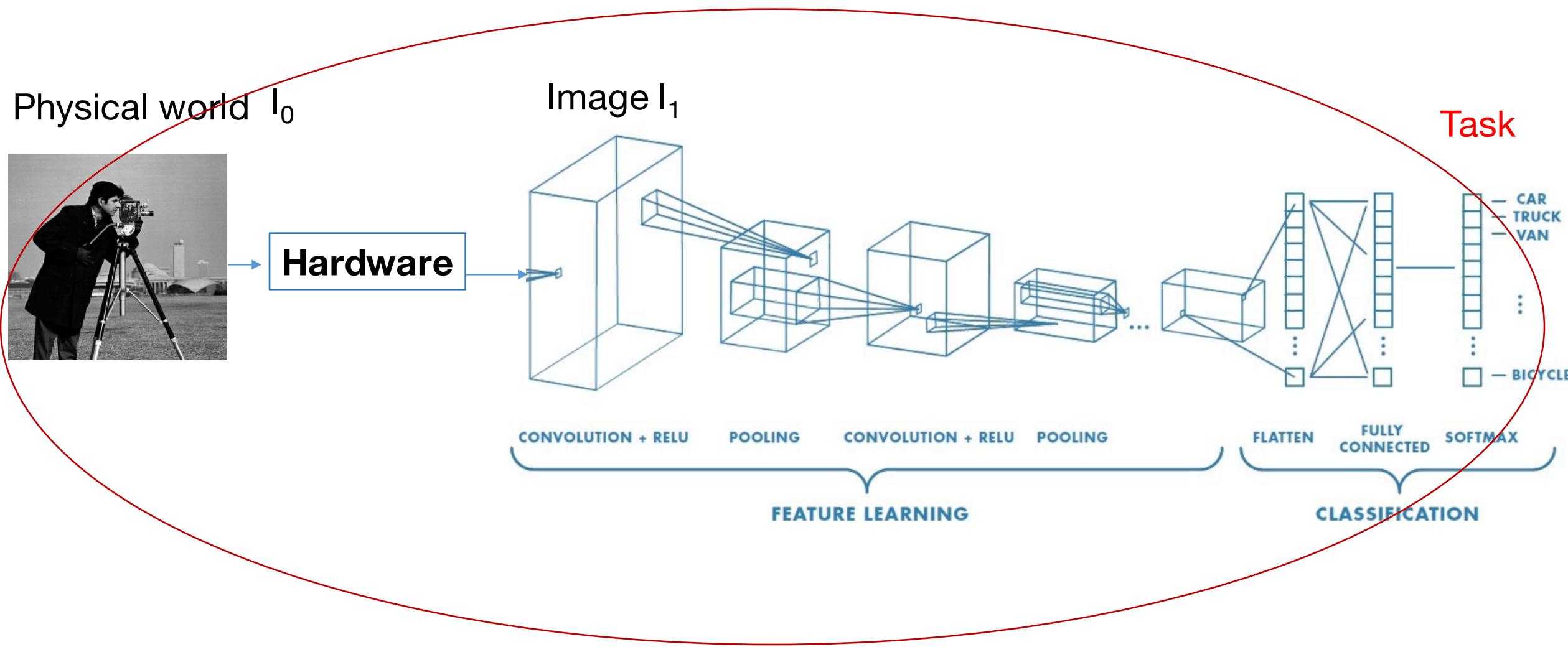
Account for or
modify imaging
hardware

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

Bringing together physical and digital image representations



Bringing together physical and digital image representations



Final project: try to optimize all of this together!