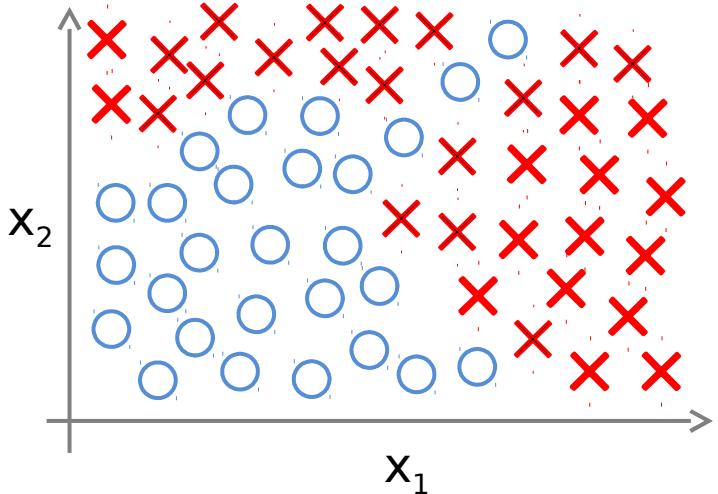


Machine Learning

Neural Networks: Representatio Non-linear hypotheses

Including only subset
of quadratic features

Non-linear Classification



$$g(\theta_0 + \theta_1 x_1 + \theta_2 x_2 + \theta_3 x_1 x_2 + \theta_4 x_1^2 x_2 + \theta_5 x_1^3 x_2 + \theta_6 x_1 x_2^2 + \dots)$$

$x_1 = \text{size}$

$x_2 = \# \text{ bedrooms}$

$x_3 = \# \text{ floors}$

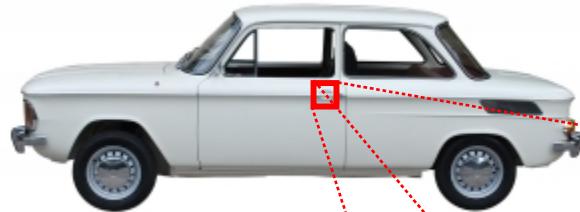
$x_4 = \text{age}$

\dots

x_{100}

What is this?

You see this:



But the camera sees this:

194	210	201	212	199	213	215	195	178	158	182	209
180	189	190	221	209	205	191	167	147	115	129	163
114	126	140	188	176	165	152	140	170	106	78	88
87	103	115	154	143	142	149	153	173	101	57	57
102	112	106	131	122	138	152	147	128	84	58	66
94	95	79	104	105	124	129	113	107	87	69	67
68	71	69	98	89	92	98	95	89	88	76	67
41	56	68	99	63	45	60	82	58	76	75	65
20	43	69	75	56	41	51	73	55	70	63	44
50	50	57	69	75	75	73	74	53	68	59	37
72	59	53	66	84	92	84	74	57	72	63	42
67	61	58	65	75	78	76	73	59	75	69	50

Computer Vision: Car detection



Cars

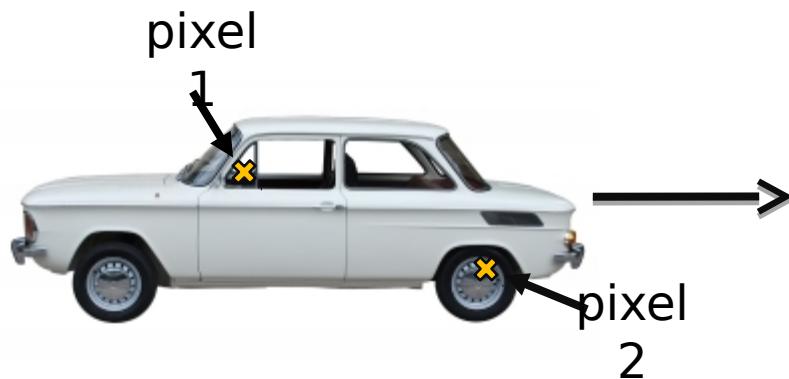


Not a
car

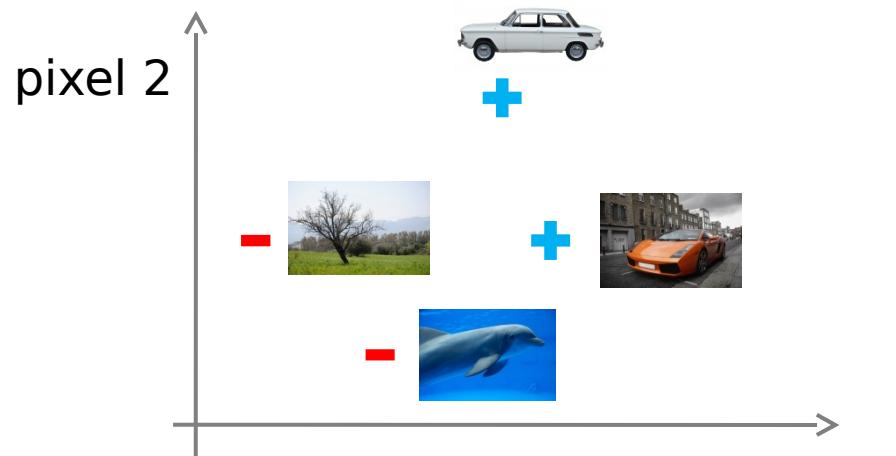
Testing:



What is this?



Learning
Algorithm
m

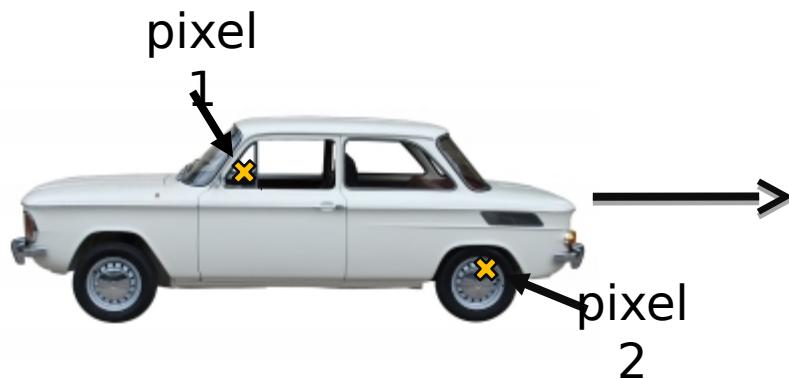


+

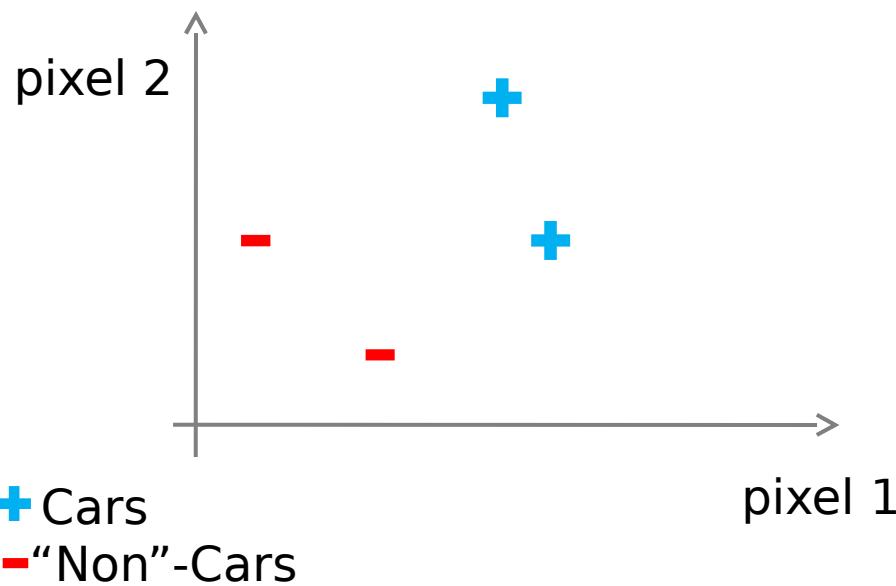
Cars

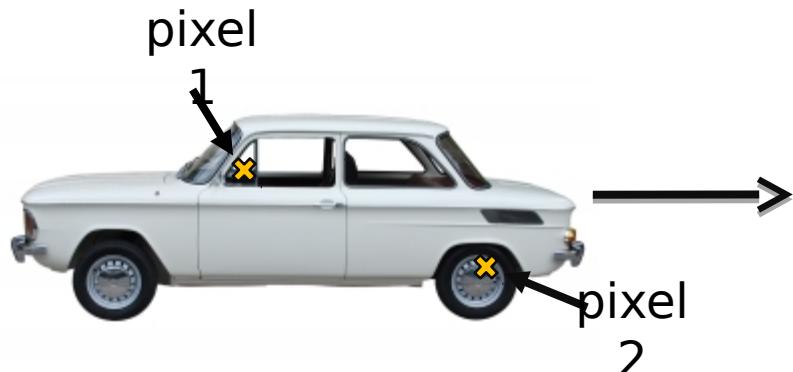
-

"Non"-Cars

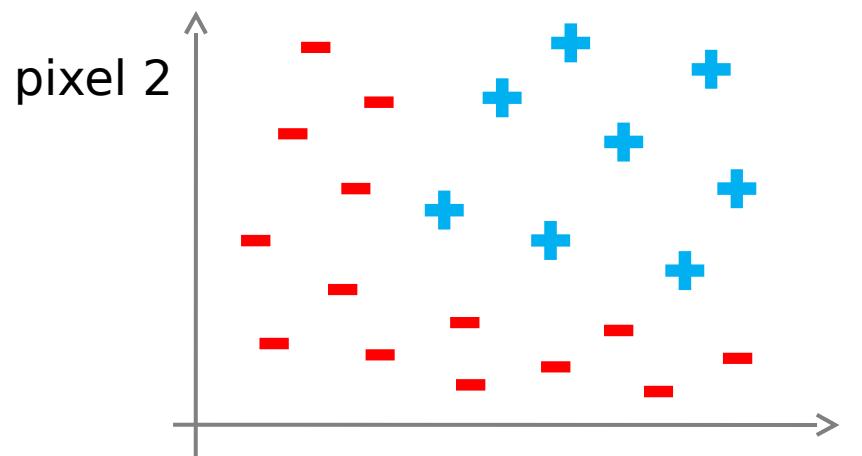


Learning
Algorithm
m





Learning
Algorithm
m



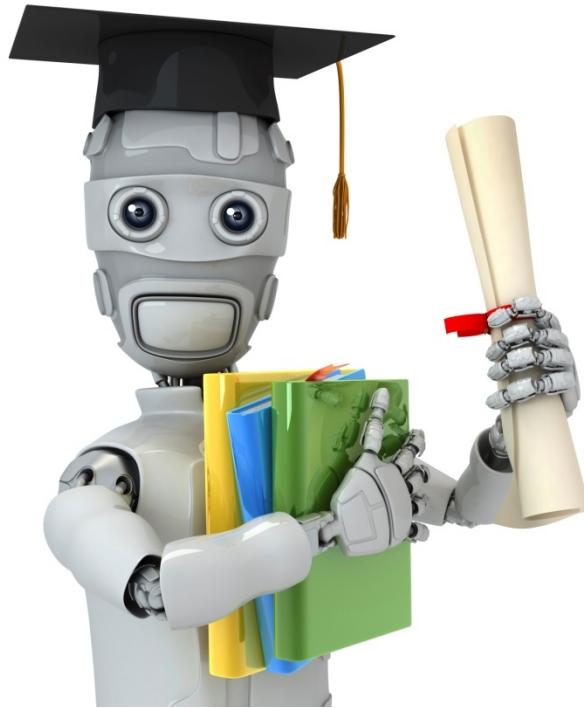
+ Cars
- '\"Non\"-Cars'

50 x 50 pixel images \rightarrow 2500

$$r = \begin{bmatrix} \text{pixel 1} \\ \text{pixel 2} \\ \text{intensity} \\ \vdots \\ \text{pixel 2500} \\ \text{intensity} \end{bmatrix}$$

(7500 if RGB)

$\approx 3^{2/2}$ million features



Machine Learning

Neural Networks: Representation Neurons and the brain

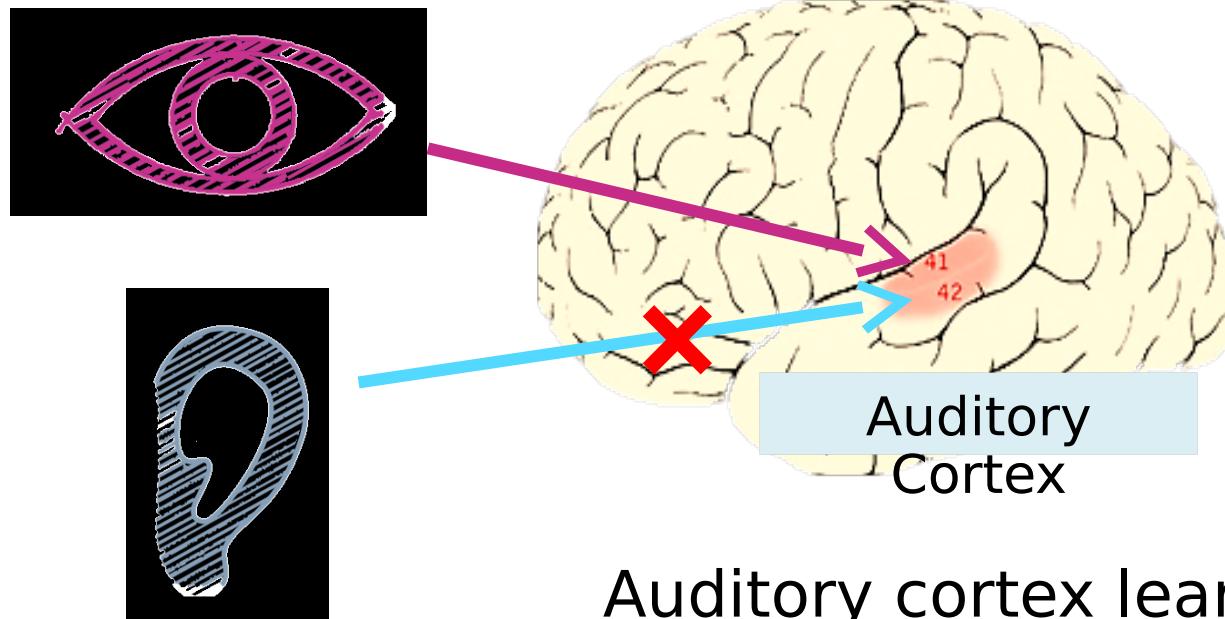
Neural Networks

Origins: Algorithms that try to mimic the brain.

Was very widely used in 80s and early 90s; popularity diminished in late 90s.

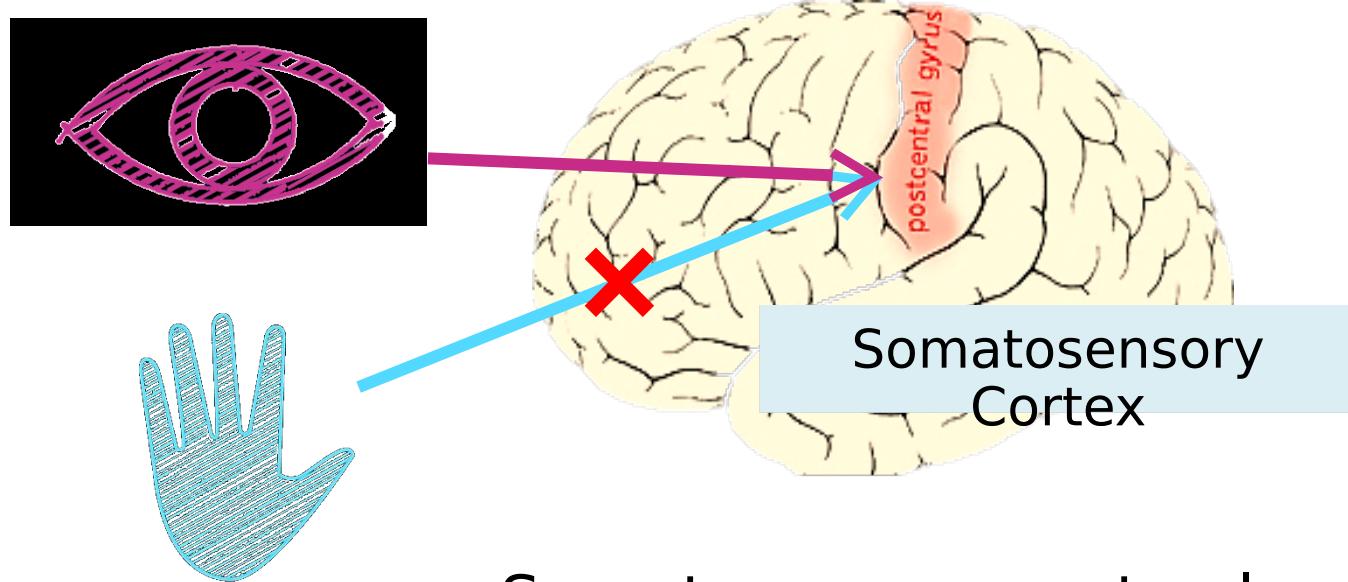
Recent resurgence: State-of-the-art technique for many applications

The “one learning algorithm” hypothesis



Auditory cortex learns
to see

The “one learning algorithm” hypothesis



Somatosensory cortex learns
to see

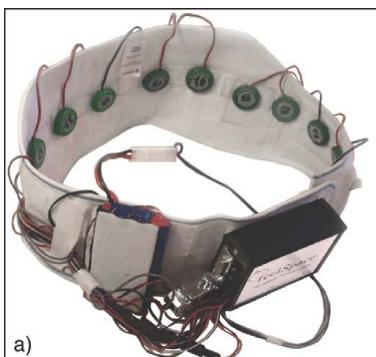
Sensor representations in the brain



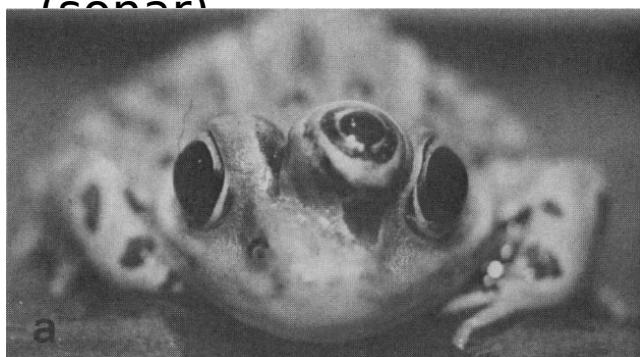
Seeing with your tongue



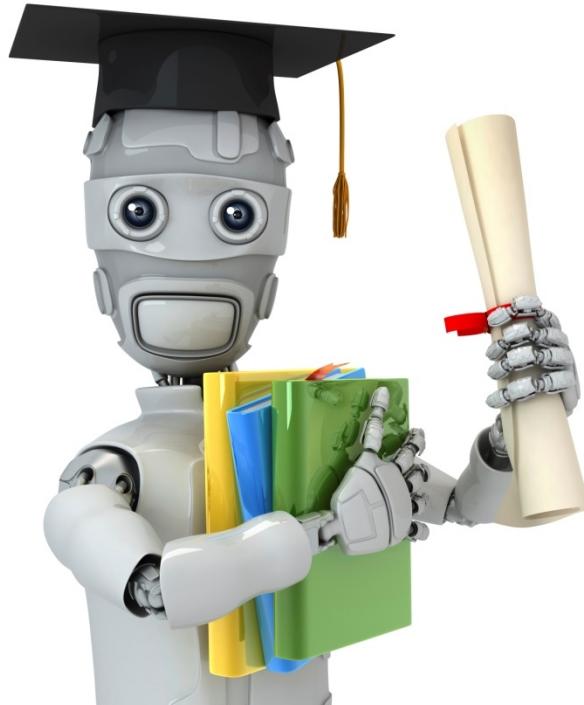
Human echolocation
(sonar)



Haptic belt: Direction sense



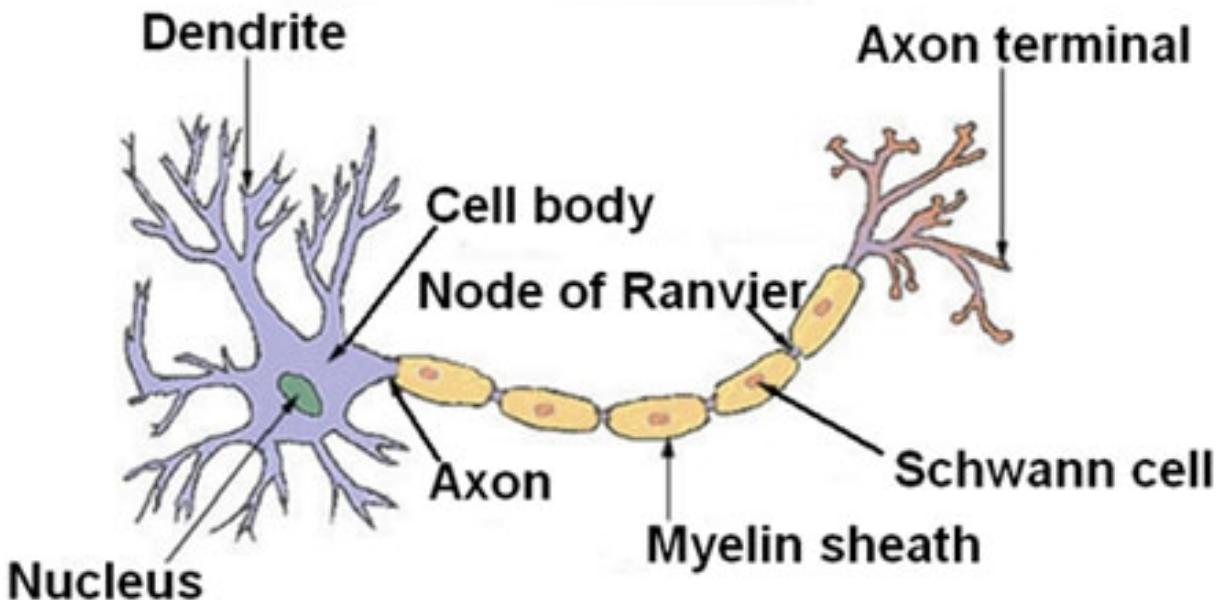
Implanting a 3rd eye



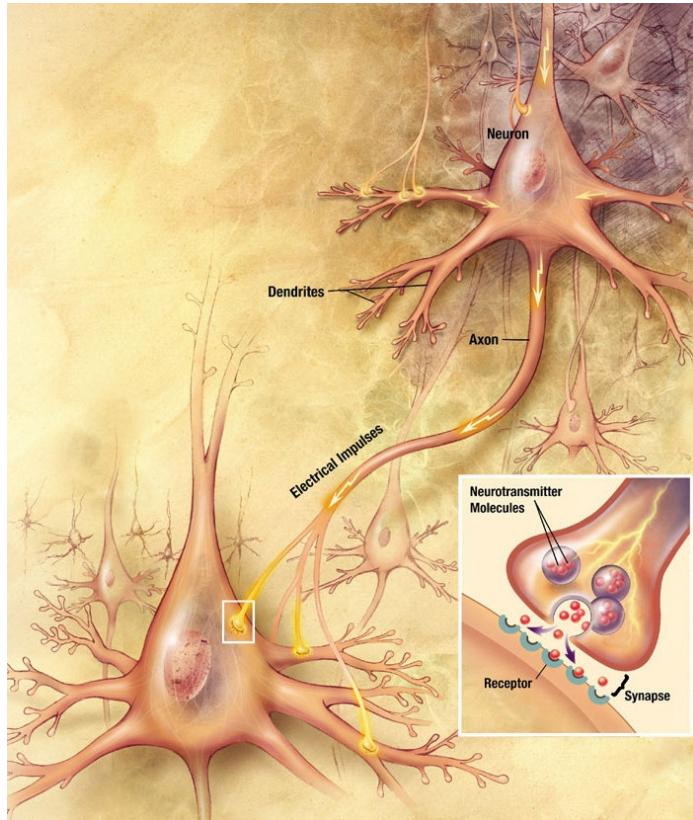
Machine Learning

Neural Networks: Model representation

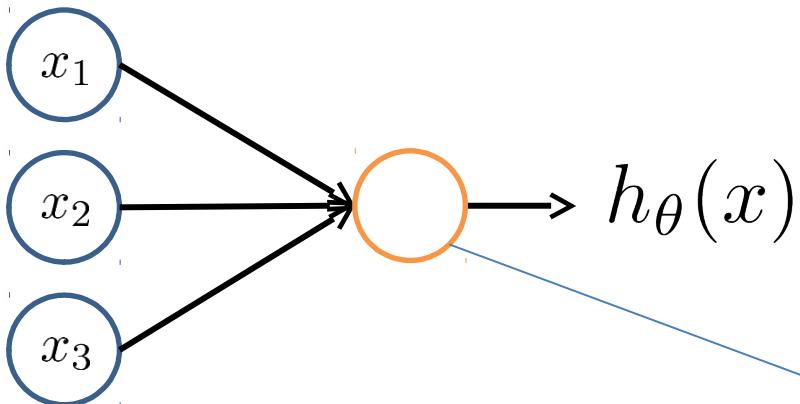
Neuron in the brain



Neurons in the brain



Neuron model: Logistic unit

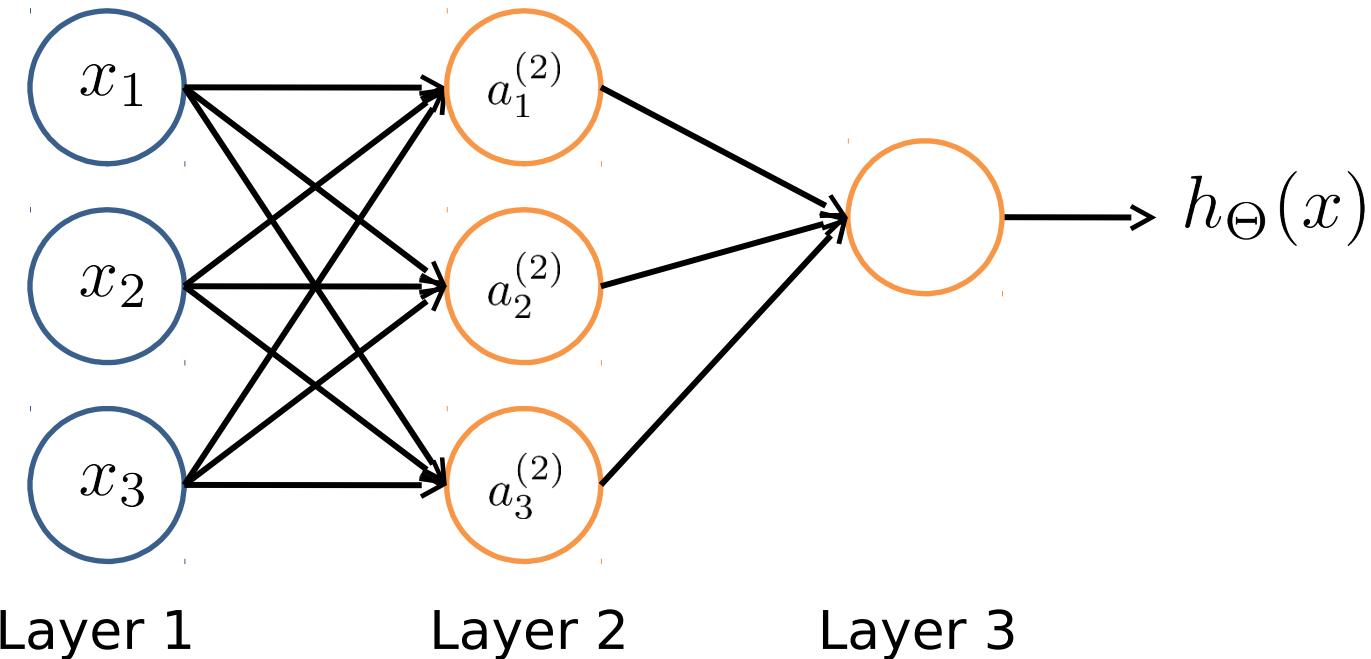


$$x = \begin{bmatrix} x_0 \\ x_1 \\ x_2 \\ x_3 \end{bmatrix} \quad \theta = \begin{bmatrix} \theta_0 \\ \theta_1 \\ \theta_2 \\ \theta_3 \end{bmatrix}$$

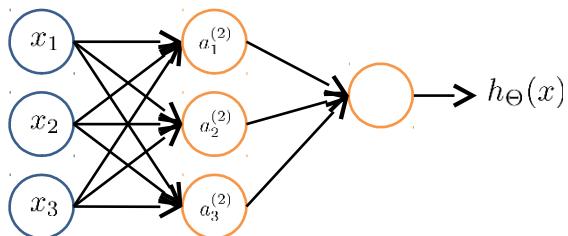
Sigmoid (logistic) activation function.

(neuron [say]) Analogous to neurons body

Neural Network



Neural Network



$a_i^{(j)}$ = “activation” of unit in layer

$\Theta^{(j)}$ = matrix of weights controlling function mapping from layer to layer

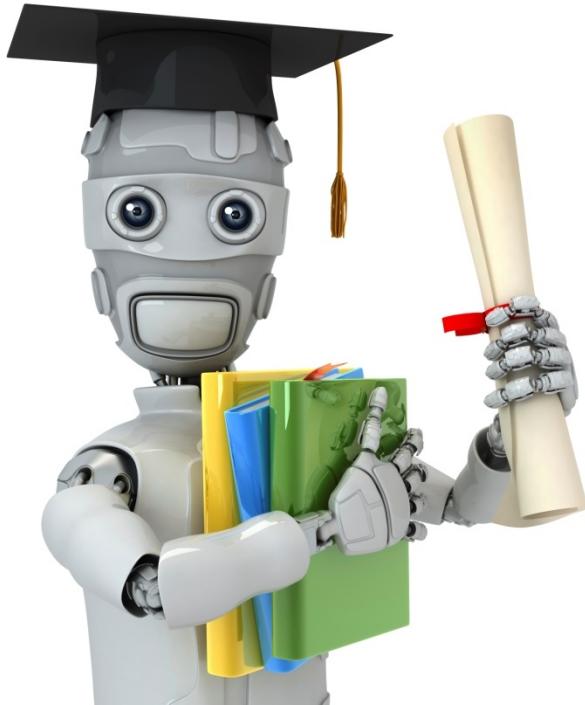
$$a_1^{(2)} = g(\Theta_{10}^{(1)}x_0 + \Theta_{11}^{(1)}x_1 + \Theta_{12}^{(1)}x_2 + \Theta_{13}^{(1)}x_3)$$

$$a_2^{(2)} = g(\Theta_{20}^{(1)}x_0 + \Theta_{21}^{(1)}x_1 + \Theta_{22}^{(1)}x_2 + \Theta_{23}^{(1)}x_3)$$

$$a_3^{(2)} = g(\Theta_{30}^{(1)}x_0 + \Theta_{31}^{(1)}x_1 + \Theta_{32}^{(1)}x_2 + \Theta_{33}^{(1)}x_3)$$

$$h_{\Theta}(x) = a_1^{(3)} = g(\Theta_{10}^{(2)}a_0^{(2)} + \Theta_{11}^{(2)}a_1^{(2)} + \Theta_{12}^{(2)}a_2^{(2)} + \Theta_{13}^{(2)}a_3^{(2)})$$

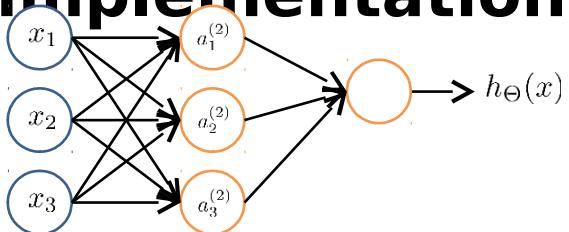
If network has units in layer , units in layer ,
then $s_{j+1} \times (s_j + 1)$
will be of dimension .



Machine Learning

Neural Networks: Representation Model representation II

Forward propagation: Vectorized implementation



$$a_1^{(2)} = g(\Theta_{10}^{(1)} x_0 + \Theta_{11}^{(1)} x_1 + \Theta_{12}^{(1)} x_2 + \Theta_{13}^{(1)} x_3)$$

$$a_2^{(2)} = g(\Theta_{20}^{(1)} x_0 + \Theta_{21}^{(1)} x_1 + \Theta_{22}^{(1)} x_2 + \Theta_{23}^{(1)} x_3)$$

$$a_3^{(2)} = g(\Theta_{30}^{(1)} x_0 + \Theta_{31}^{(1)} x_1 + \Theta_{32}^{(1)} x_2 + \Theta_{33}^{(1)} x_3)$$

$$h_\Theta(x) = g(\Theta_{10}^{(2)} a_0^{(2)} + \Theta_{11}^{(2)} a_1^{(2)} + \Theta_{12}^{(2)} a_2^{(2)} + \Theta_{13}^{(2)} a_3^{(2)})$$

$$x = \begin{bmatrix} x_0 \\ x_1 \\ x_2 \\ x_3 \end{bmatrix} \quad z^{(2)} = \begin{bmatrix} z_1^{(2)} \\ z_2^{(2)} \\ z_3^{(2)} \end{bmatrix}$$

$$z^{(2)} = \Theta^{(1)} x$$

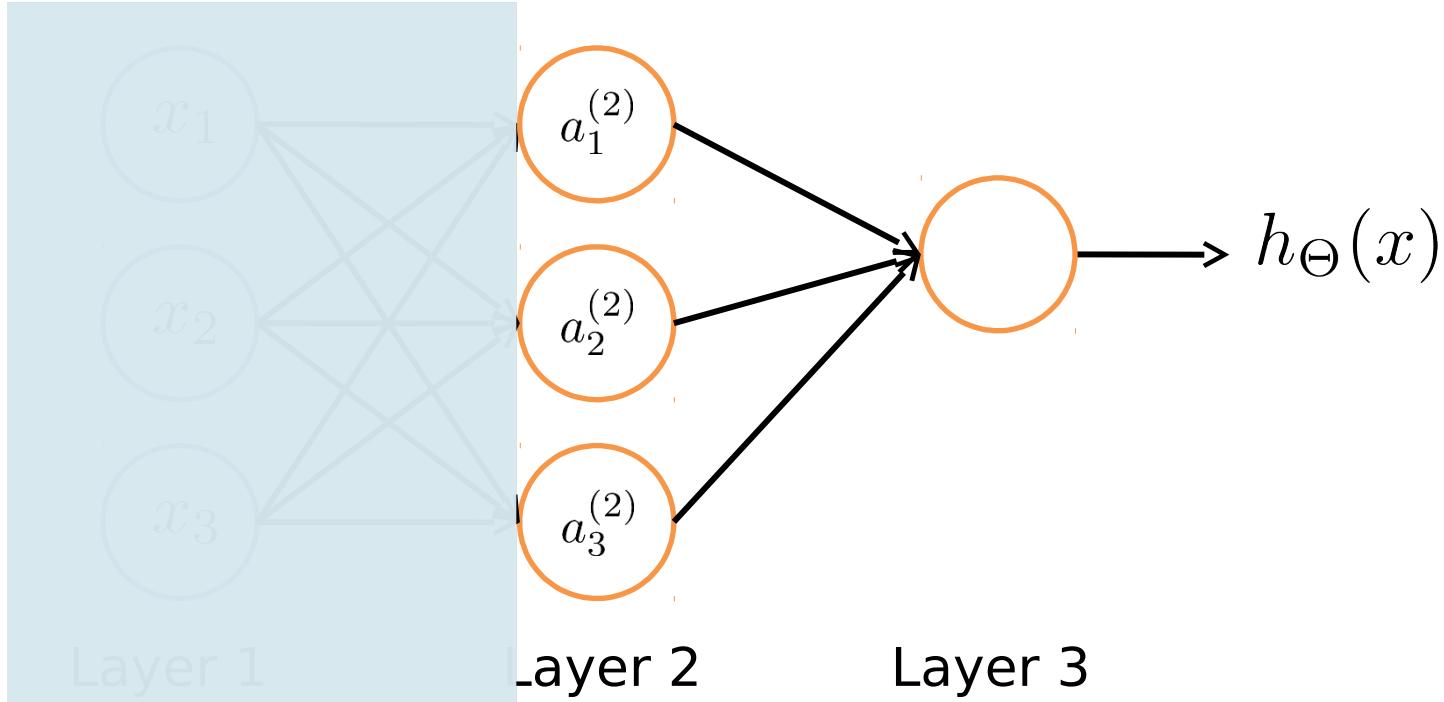
$$a^{(2)} = g(z^{(2)})$$

$$\text{Add } a_0^{(2)} = 1$$

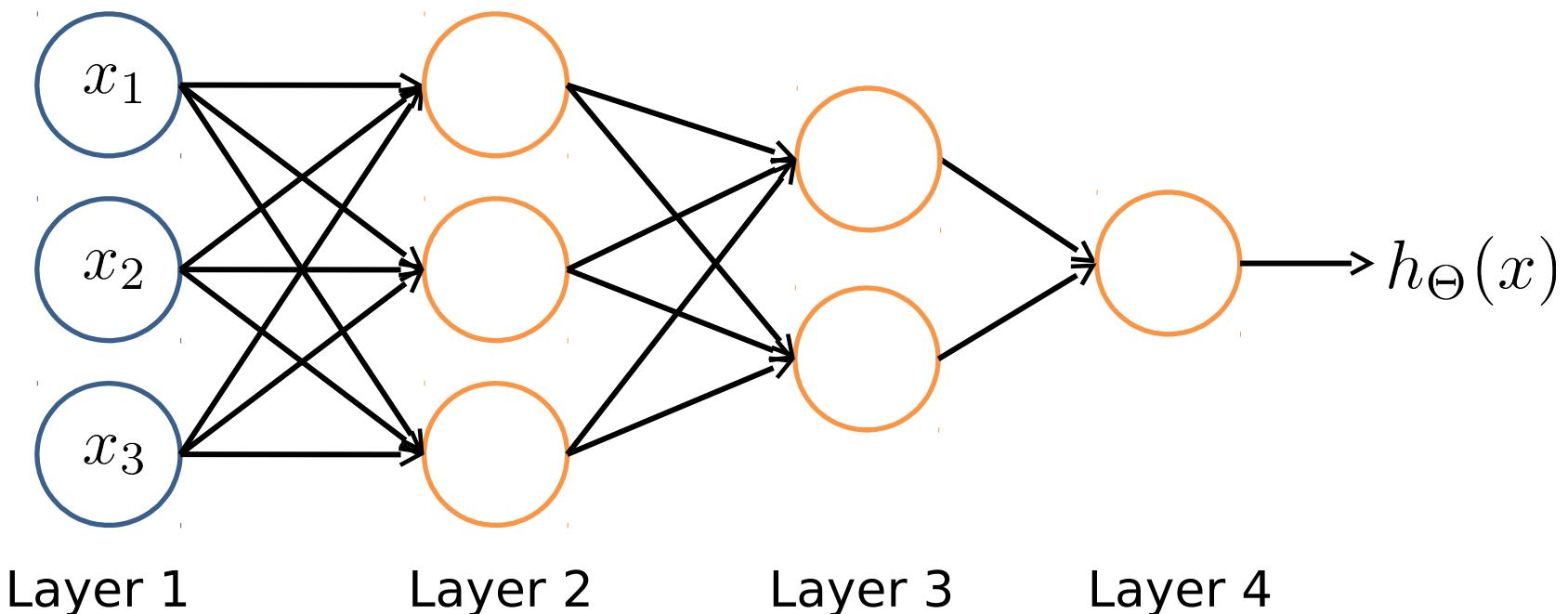
$$z^{(3)} = \Theta^{(2)} a^{(2)}$$

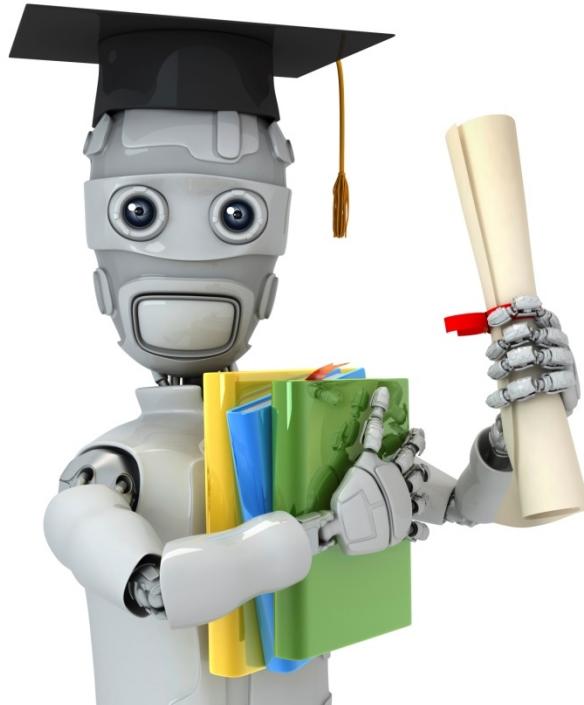
$$h_\Theta(x) = a^{(3)} = g(z^{(3)})$$

Neural Network learning its own features



Other network architectures



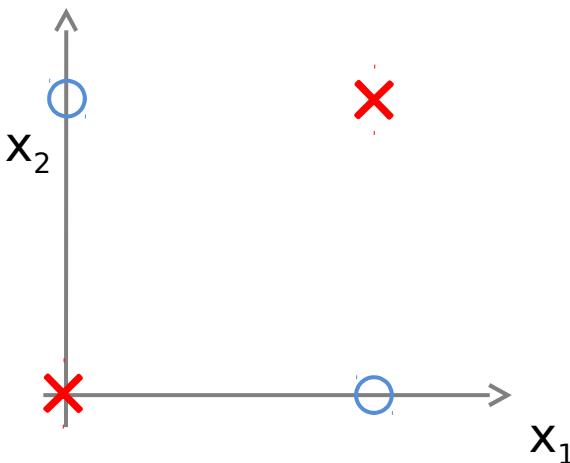


Machine Learning

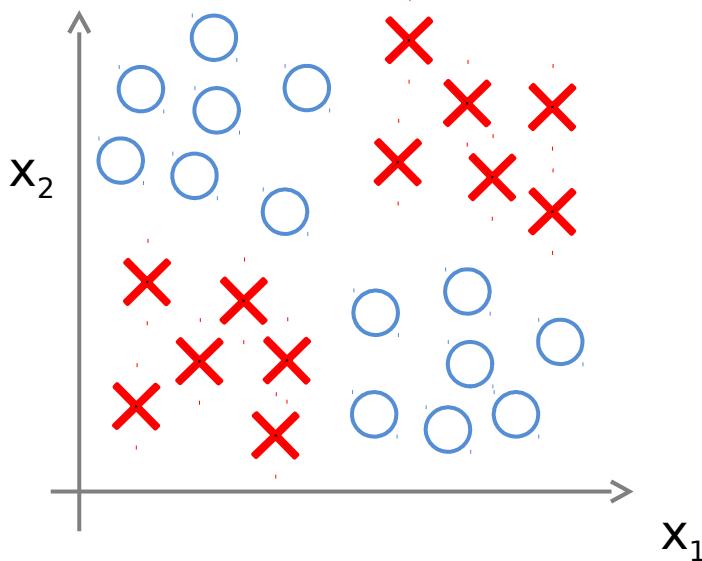
Neural Networks: Representatio n Examples and intuitions I

Non-linear classification example: x_1, x_2 Features

x_1, x_2 are binary (0 or 1).



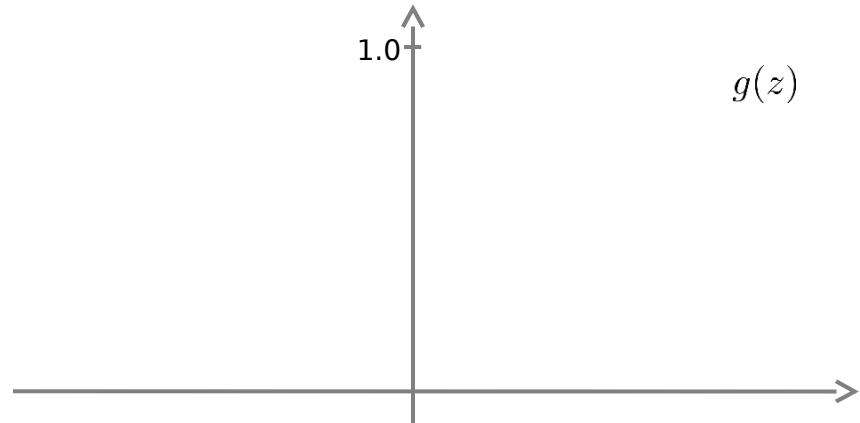
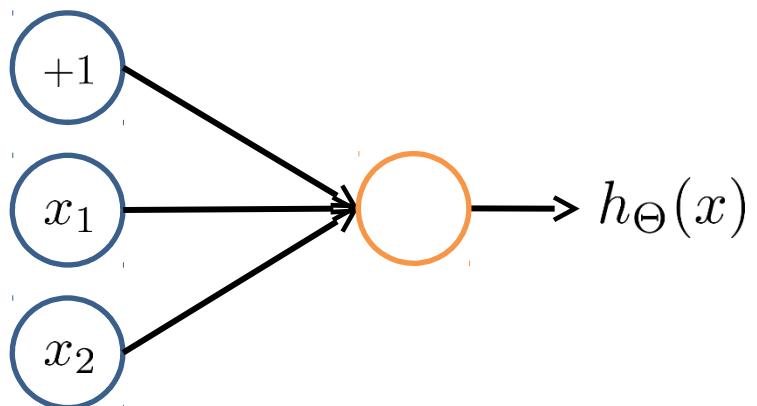
$$y = x_1 \text{ XOR } x_2$$
$$x_1 \text{ XNOR } x_2$$
$$\text{NOT } (x_1 \text{ XOR } x_2)$$



Simple example: AND

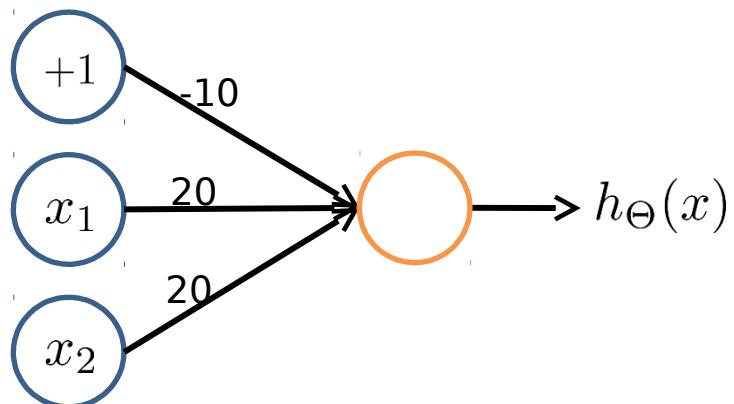
$$x_1, x_2 \in \{0, 1\}$$

$$y = x_1 \text{ AND } x_2$$

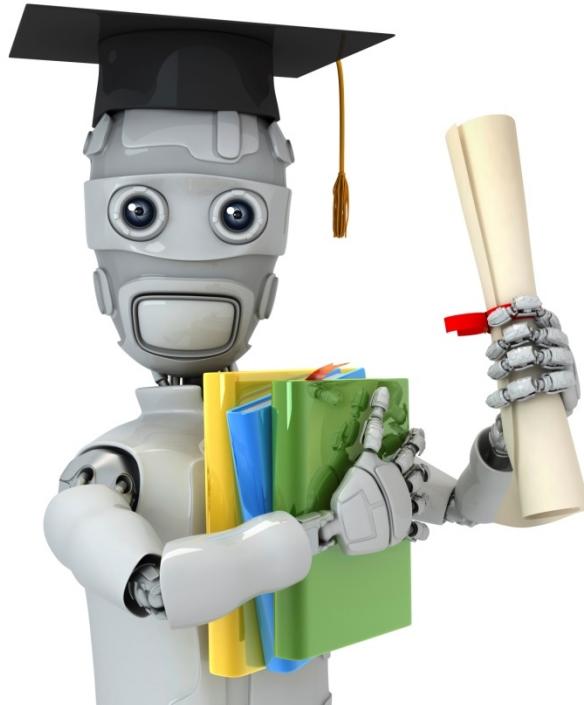


x_1	x_2	$h_{\Theta}(x)$
0	0	0
0	1	0
1	0	0
1	1	1

Example: OR function



x_1	x_2	$h_{\Theta}(x)$
0	0	0
0	1	1
1	0	1
1	1	1

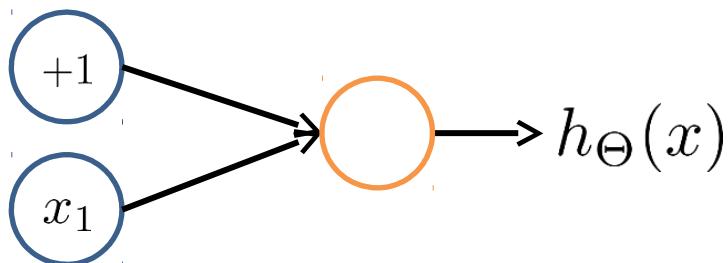


Machine Learning

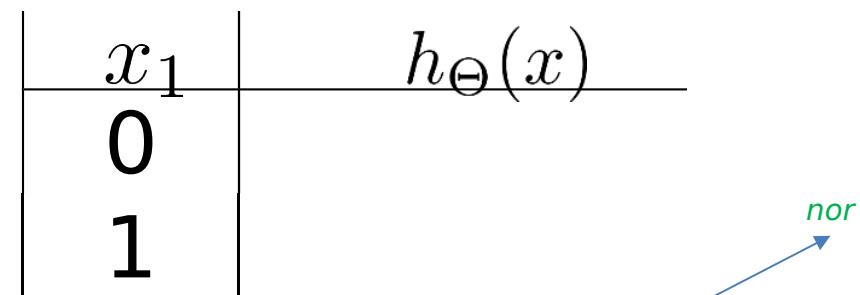
Neural Networks: Representation Examples and intuitions II

$x_1 \text{ AND } x_2$ $x_1 \text{ OR } x_2$

Negation:

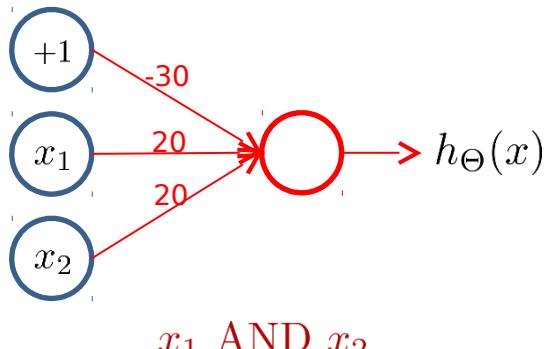


$$h_{\Theta}(x) = g(10 - 20x_1)$$

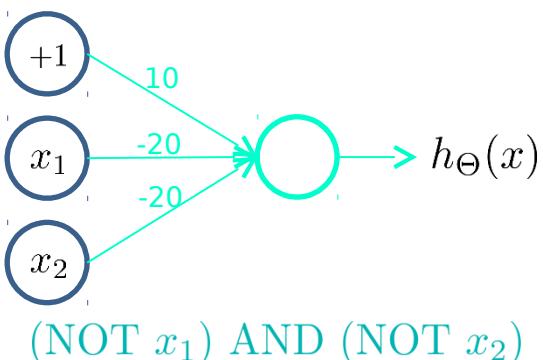


$$(\text{NOT } x_1) \text{ AND } (\text{NOT } x_2)$$

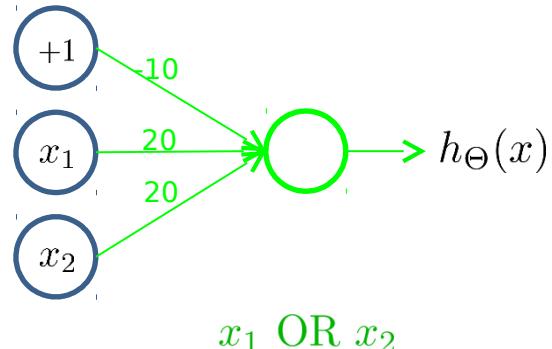
Putting it together



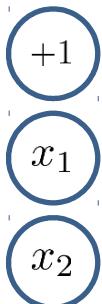
x_1 AND x_2



(NOT x_1) AND (NOT x_2)

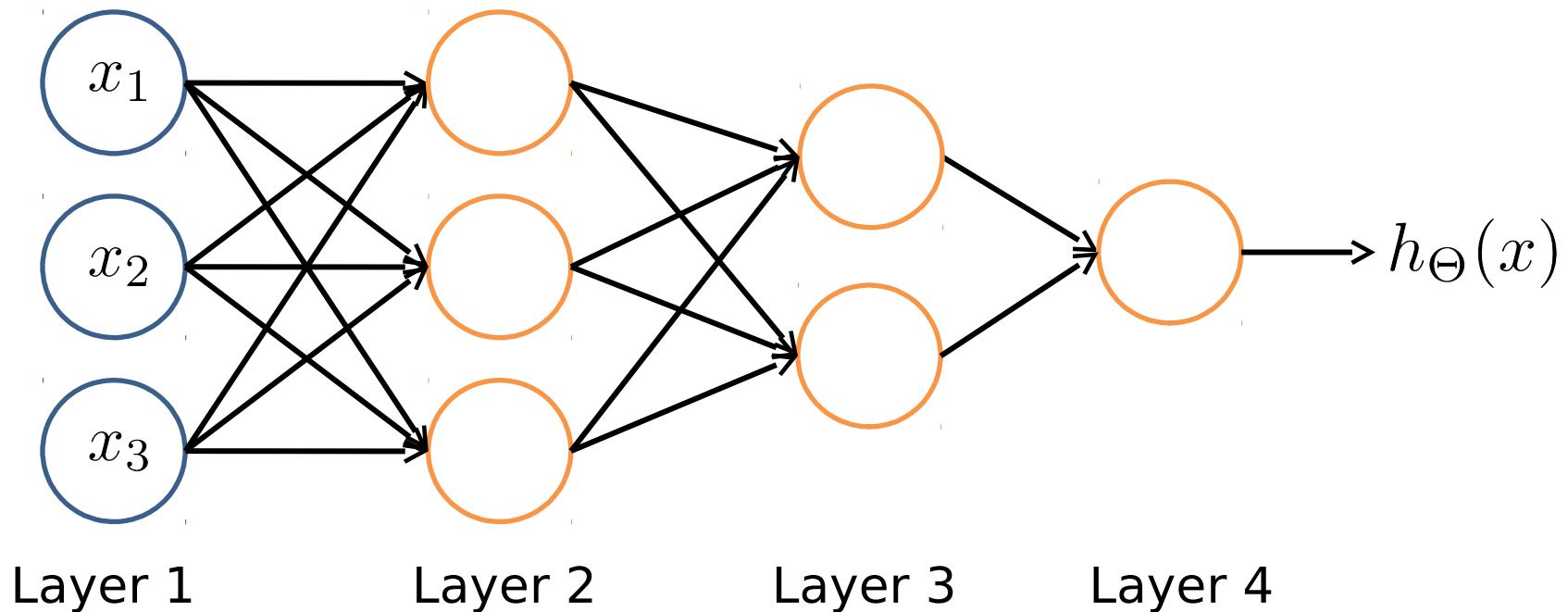


x_1 OR x_2

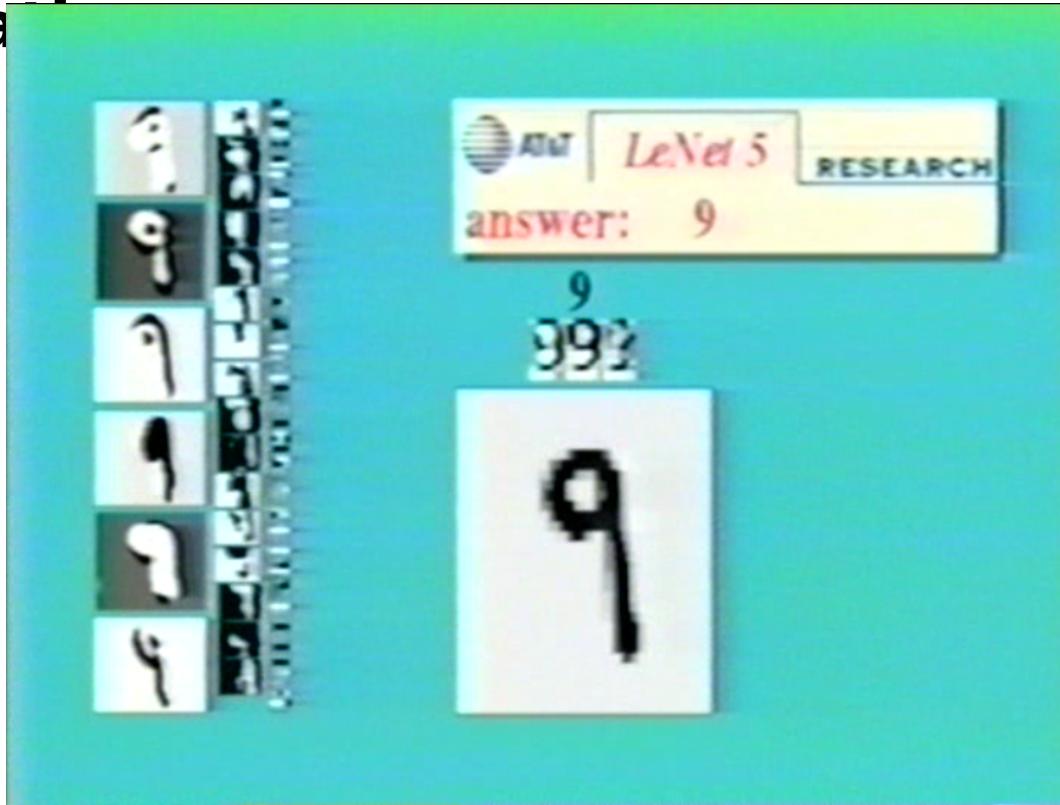


x_1	x_2	$a_1^{(2)}$	$a_2^{(2)}$	$h_{\Theta}(x)$
0	0			
0	1			
1	0			
1	1			

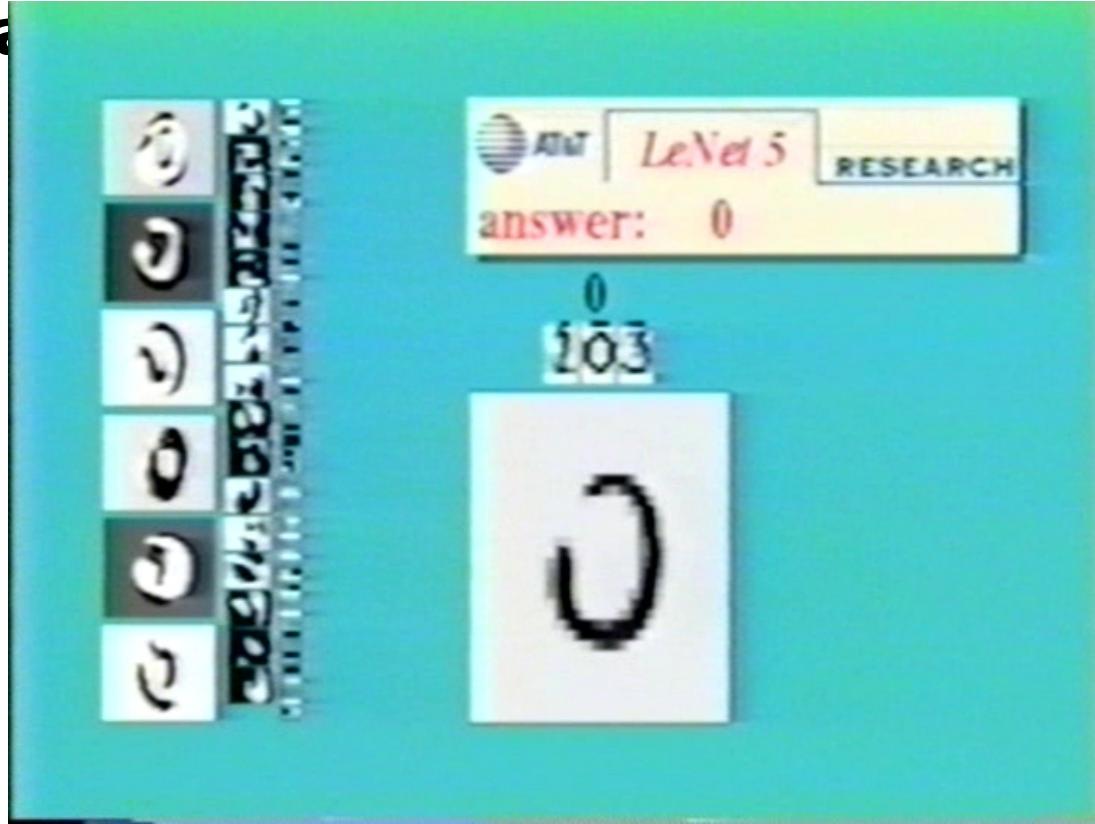
Neural Network intuition

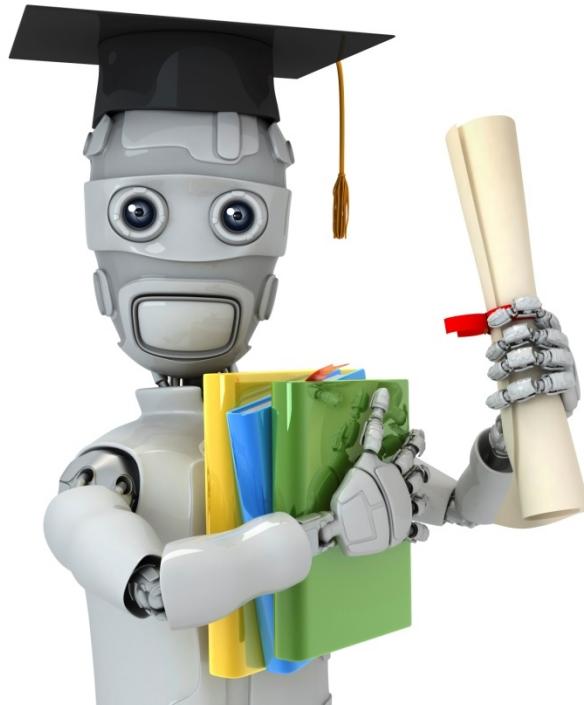


Handwritten digit classification



Handwritten digit classification





Machine Learning

Neural Networks: Representatio

n Multi-class
classification

Multiple output units: One-

vs-

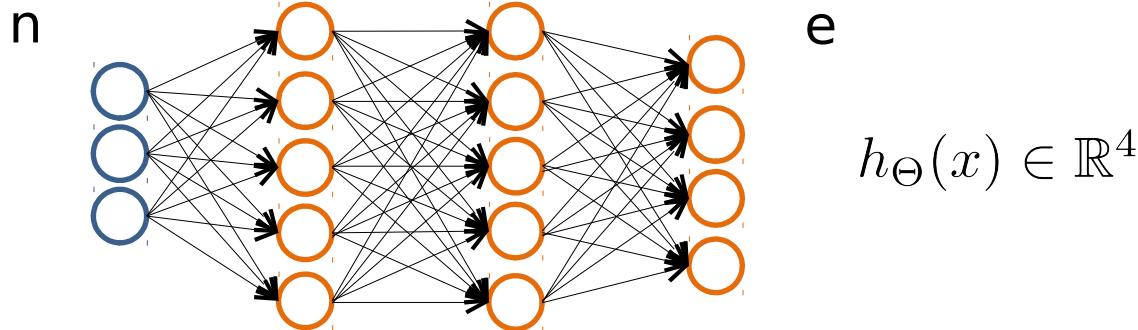


Pedestria

Car

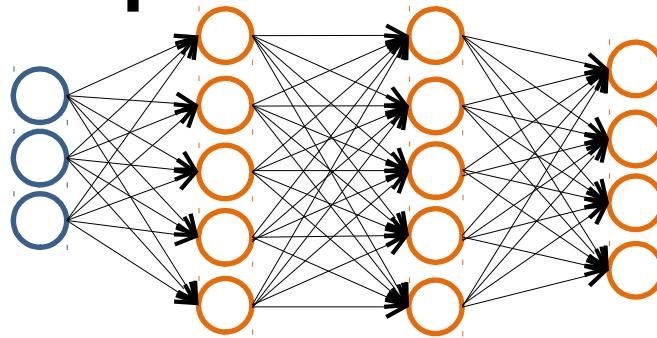
Motorcycl

Truck



Want $h_{\Theta}(x) \approx \begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \end{bmatrix}$ $h_{\Theta}(x) \approx \begin{bmatrix} 0 \\ 1 \\ 0 \\ 0 \end{bmatrix}$ $h_{\Theta}(x) \approx \begin{bmatrix} 0 \\ 0 \\ 1 \\ 0 \end{bmatrix}$
, etc. when pedestrian when car when motorcycle

Multiple output units: One-vs-all.



$$h_{\Theta}(x) \in \mathbb{R}^4$$

Want $h_{\Theta}(x) \approx \begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \end{bmatrix}$ $h_{\Theta}(x) \approx \begin{bmatrix} 0 \\ 1 \\ 0 \\ 0 \end{bmatrix}$ $h_{\Theta}(x) \approx \begin{bmatrix} 0 \\ 0 \\ 1 \\ 0 \end{bmatrix}$
etc. when pedestrian when car when
motorcycle

Training set $(x^{(1)}, y^{(1)}), (x^{(2)}, y^{(2)}), \dots, (x^{(m)}, y^{(m)})$

$y^{(i)}$ one of $\begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \end{bmatrix}, \begin{bmatrix} 0 \\ 1 \\ 0 \\ 0 \end{bmatrix}, \begin{bmatrix} 0 \\ 0 \\ 1 \\ 0 \end{bmatrix}, \begin{bmatrix} 0 \\ 0 \\ 0 \\ 1 \end{bmatrix}$
pedestrian car motorcycle truck