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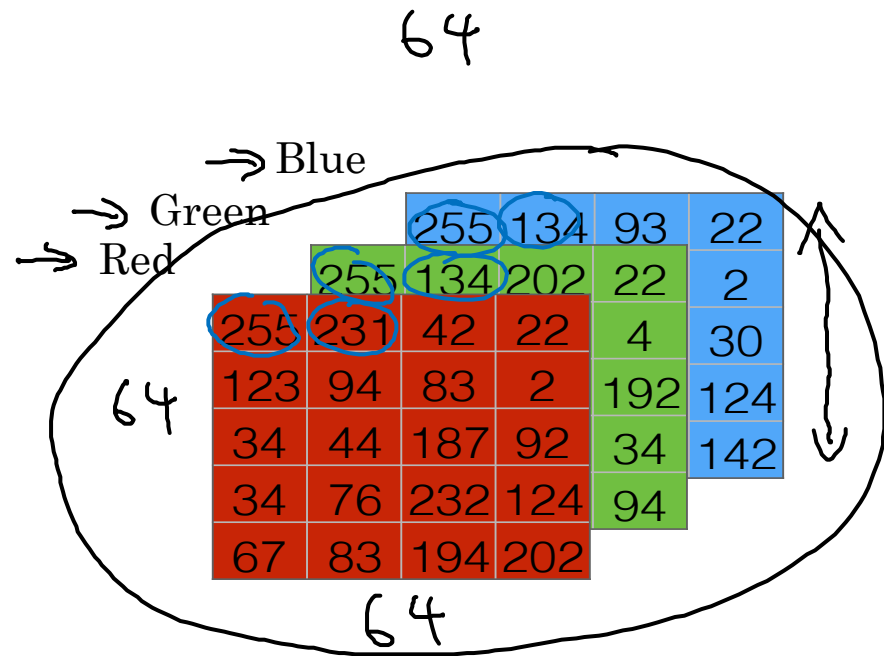
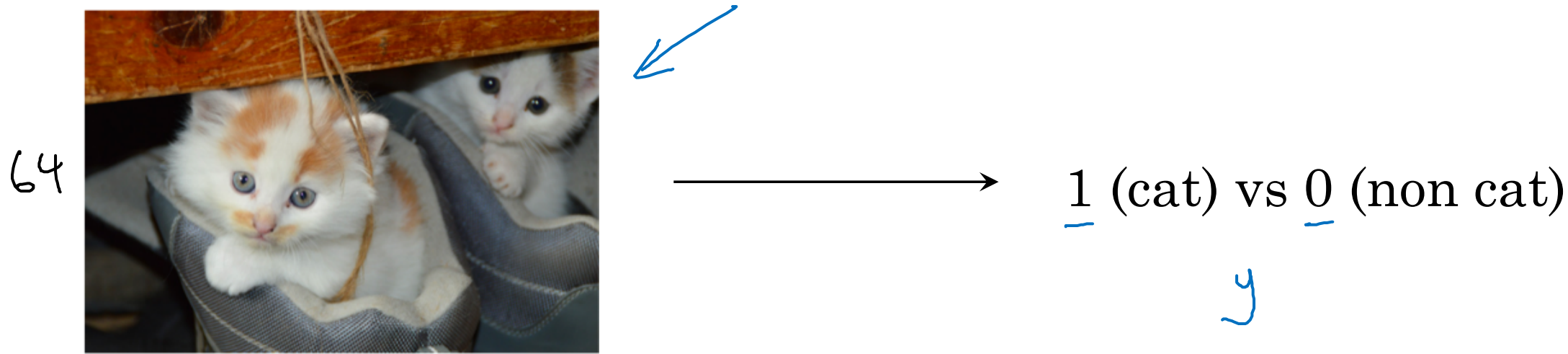


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Basics of Neural Network Programming

Binary Classification

Binary Classification



$X = \begin{bmatrix} 255 \\ 231 \\ \vdots \\ 255 \\ 134 \\ \vdots \end{bmatrix}$

$64 \times 64 \times 3 = 12288$

$n = n_x = 12288$

$X \longrightarrow y$

Notation

$$(x, y) \quad x \in \mathbb{R}^{n_x}, y \in \{0, 1\}$$

$$m \text{ training examples: } \{(\underline{x}^{(1)}, \underline{y}^{(1)}), (\underline{x}^{(2)}, \underline{y}^{(2)}), \dots, (\underline{x}^{(m)}, \underline{y}^{(m)})\}$$

$$M = M_{\text{train}}$$

$$M_{\text{test}} = \# \text{test examples.}$$

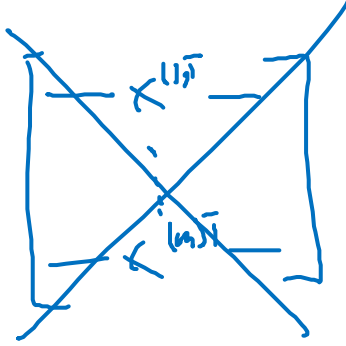
$$X = \begin{bmatrix} | & | & & | \\ x^{(1)} & x^{(2)} & \dots & x^{(m)} \\ | & | & & | \end{bmatrix}$$


Diagram illustrating the matrix X with dimensions n_x (vertical) and m (horizontal). The matrix contains columns $x^{(1)}, x^{(2)}, \dots, x^{(m)}$. A small square box to the right of the matrix is crossed out with a large X, containing the labels $x^{(1)}$ and $x^{(m)}$.

$$X \in \mathbb{R}^{n_x \times m}$$

$$X.\text{shape} = (n_x, m)$$

$$Y = [y^{(1)} \ y^{(2)} \ \dots \ y^{(m)}]$$

$$Y \in \mathbb{R}^{1 \times m}$$

$$Y.\text{shape} = (1, m)$$



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Basics of Neural Network Programming

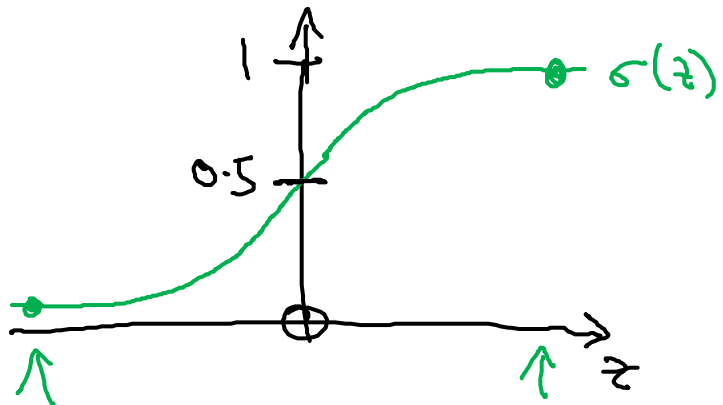
Logistic Regression

Logistic Regression

Given x , want $\hat{y} = \frac{P(y=1|x)}{0 \leq \hat{y} \leq 1}$
 $x \in \mathbb{R}^{n_x}$

Parameters: $\underline{w} \in \mathbb{R}^{n_x}$, $\underline{b} \in \mathbb{R}$.

Output $\hat{y} = \sigma(\underbrace{w^T x + b}_z)$



$$x_0 = 1, \quad x \in \mathbb{R}^{n_x+1}$$
$$\hat{y} = \sigma(\theta^T x)$$

$$\theta = \begin{bmatrix} \theta_0 \\ \theta_1 \\ \theta_2 \\ \vdots \\ \theta_{n_x} \end{bmatrix} \quad \left. \begin{array}{l} \} b \leftarrow \\ \} w \leftarrow \end{array} \right\}$$

$$\sigma(z) = \frac{1}{1 + e^{-z}}$$

If z large $\sigma(z) \approx \frac{1}{1+0} = 1$

If z large negative number

$$\sigma(z) = \frac{1}{1 + e^{-z}} \approx \frac{1}{1 + \text{Big num}} \approx 0$$



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Basics of Neural Network Programming

Logistic Regression cost function

Logistic Regression cost function

$$\rightarrow \hat{y}^{(i)} = \sigma(\underline{w^T x^{(i)}} + b), \text{ where } \underline{\sigma(z^{(i)})} = \frac{1}{1+e^{-z^{(i)}}}$$

$$z^{(i)} = w^T x^{(i)} + b$$

Given $\{(x^{(1)}, y^{(1)}), \dots, (x^{(m)}, y^{(m)})\}$, want $\hat{y}^{(i)} \approx y^{(i)}$.

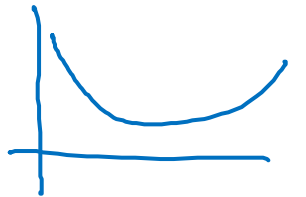
$x^{(i)}$
 $y^{(i)}$
 $z^{(i)}$

i -th
example.

Loss (error) function:

$$\underline{\mathcal{L}(\hat{y}, y)} = \frac{1}{2} (\hat{y} - y)^2$$

~~~~~



We do not use this in the context of Logistic Regression since this loss function is more suitable for regression problems !!

$$\underline{\mathcal{L}(\hat{y}, y)} = - (y \log \hat{y}) + \underline{(1-y) \log (1-\hat{y})} \leftarrow$$

If  $\underline{y=1}$ :  $\mathcal{L}(\hat{y}, y) = -\log \hat{y} \leftarrow$  Want  $\log \hat{y}$  large, want  $\hat{y}$  large.

If  $\underline{y=0}$ :  $\mathcal{L}(\hat{y}, y) = -\log (1-\hat{y}) \leftarrow$  Want  $\log (1-\hat{y})$  large ... want  $\hat{y}$  small

Cost function:  $\underline{J(w, b)} = \frac{1}{m} \sum_{i=1}^m \mathcal{L}(\hat{y}^{(i)}, y^{(i)}) = \frac{1}{m} \sum_{i=1}^m [y^{(i)} \log \hat{y}^{(i)} + (1-y^{(i)}) \log (1-\hat{y}^{(i)})]$





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# Basics of Neural Network Programming

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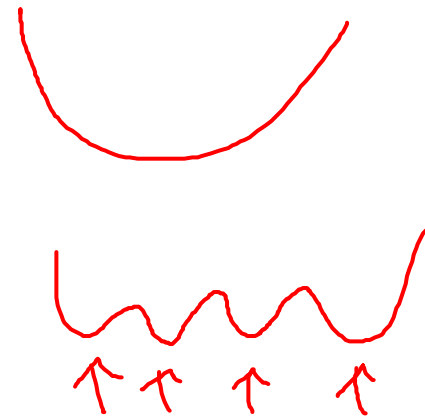
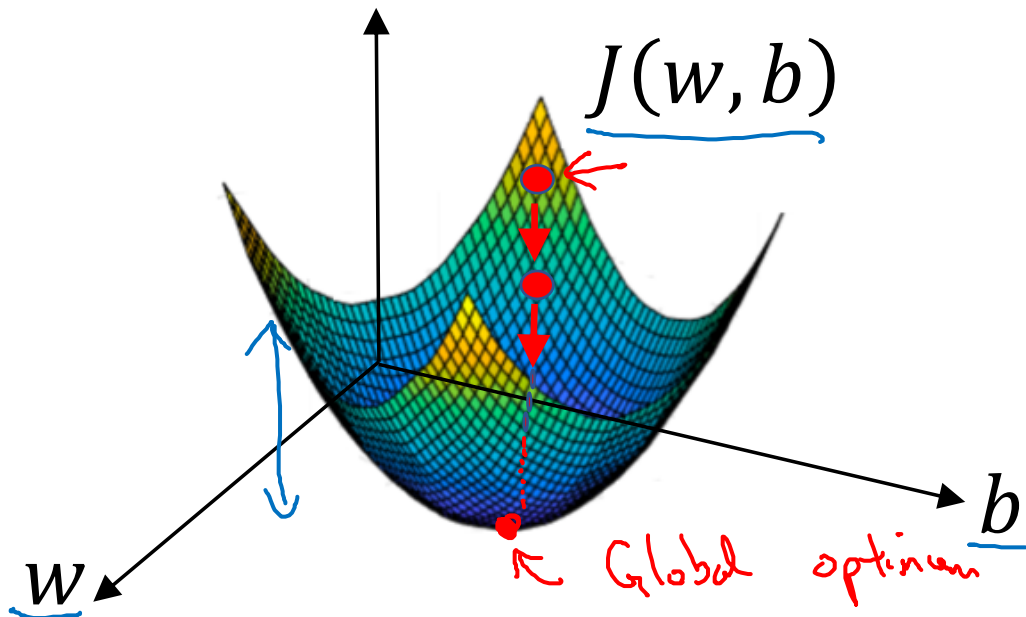
## Gradient Descent

# Gradient Descent

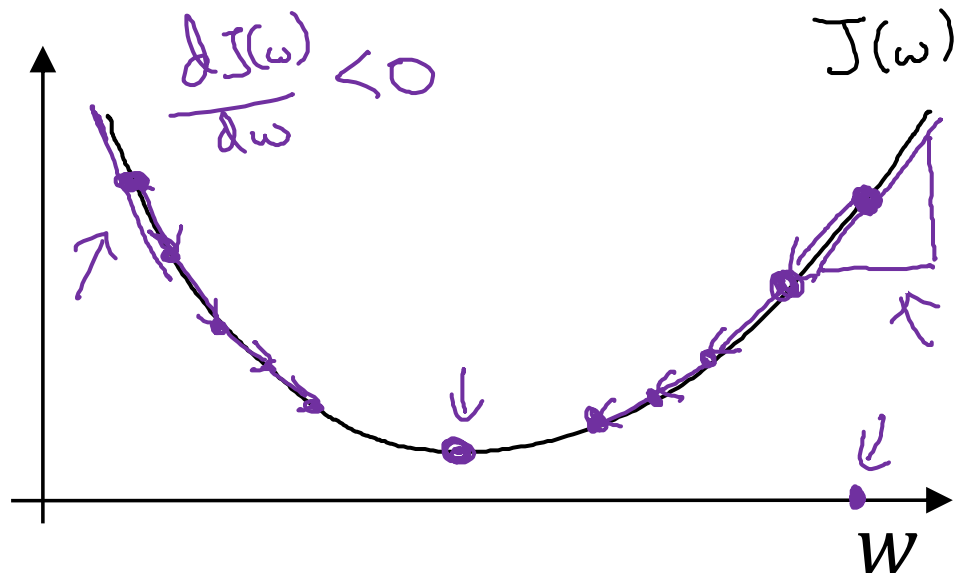
Recap:  $\hat{y} = \sigma(w^T x + b)$ ,  $\sigma(z) = \frac{1}{1+e^{-z}}$   $\leftarrow$

$$\underline{J(w, b)} = \frac{1}{m} \sum_{i=1}^m \mathcal{L}(\underline{\hat{y}^{(i)}} , \underline{y^{(i)}}) = -\frac{1}{m} \sum_{i=1}^m y^{(i)} \log \hat{y}^{(i)} + (1 - y^{(i)}) \log(1 - \hat{y}^{(i)})$$

Want to find  $w, b$  that minimize  $J(w, b)$



# Gradient Descent



Repeat {

$$w := w - \alpha \frac{dJ(w)}{dw}$$

learning rate

}

$$w := w - \alpha \underbrace{\frac{dJ(w)}{dw}}_{\text{"dw"}}$$

$$\frac{dJ(w)}{dw} = ?$$

$$J(w, b)$$

$$w := w - \alpha \frac{\partial J(w, b)}{\partial w}$$

$$b := b - \alpha \frac{\partial J(w, b)}{\partial b}$$

$$\frac{\partial J(w, b)}{\partial w}$$

$$\frac{\partial J(w, b)}{\partial b}$$

$$\partial$$

$$\partial$$

"partial derivative"  
J

dw

db



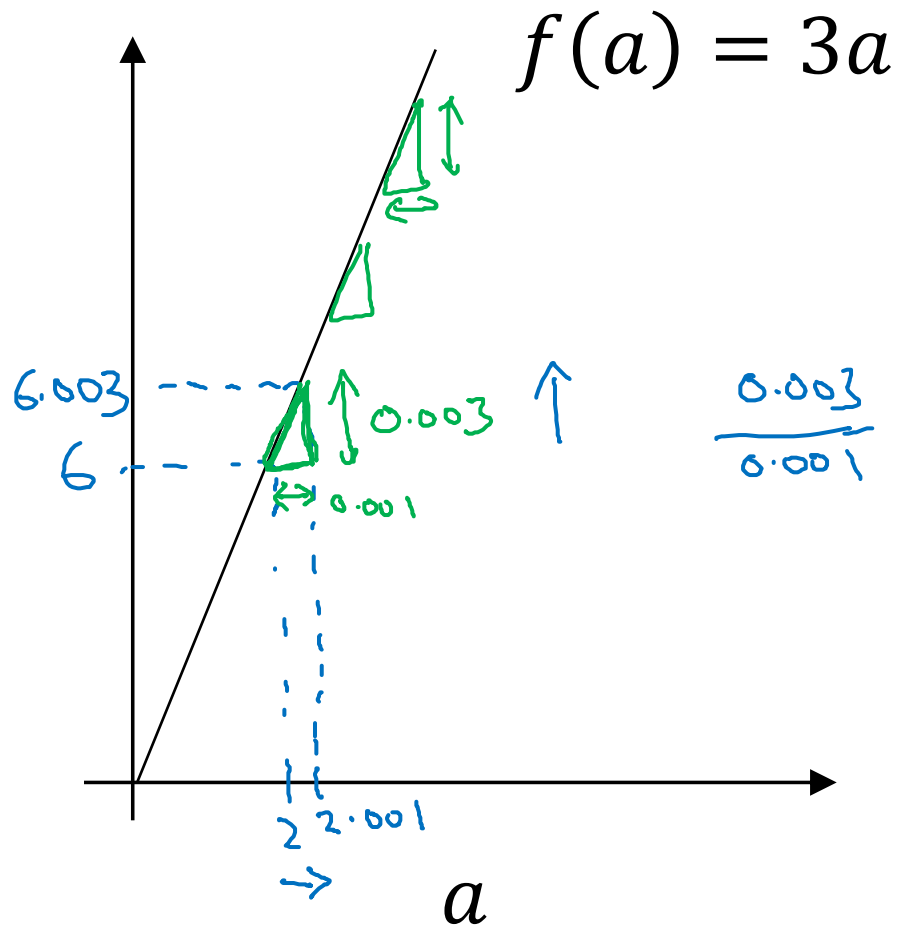
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# Basics of Neural Network Programming

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## Derivatives

# Intuition about derivatives



$\rightarrow a = 2$        $f(a) = 6$   
 $a = 2.001$        $f(a) = 6.003$

$\rightarrow$  slope (derivative) of  $f(a)$   
 at  $a = 2$  is  $3$

$\rightarrow a = 5$        $f(a) = 15$   
 $a = 5.001$        $f(a) = 15.003$   
 slope at  $a = 5$  is also  $3$

$\downarrow$   
 $\frac{df(a)}{da} = 3 = \frac{d}{da} f(a)$   
 $\uparrow$

$0.001 \leftarrow$   
 $0.000000001$   
 $0.000000000001$



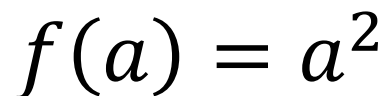
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# Basics of Neural Network Programming

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More derivatives  
examples

0.001 ←  
0.000000...01 ←


$$\frac{\text{height}}{\text{width}}$$

$$\frac{d}{da} a^2 = 2a$$

$$0.001$$

$$(2a) \times 0.001$$

$$\begin{aligned} a &= 2 & f(a) &= 4 \\ a &= 2.001 & f(a) &\approx 4.004 \\ & & & (4.004 \text{ } \boxed{004}) \end{aligned}$$

$$\frac{d}{da} f(a) = 4 \quad \text{when } a=2$$

$$a = 5 \quad f(a) = 25$$
$$a = 5.001 \quad f(a) \approx 25.010$$

$$\frac{d}{da} f(a) = 10 \quad \text{when} \quad a = 5$$

$$\frac{d}{da} f(a) = \frac{d}{da} a^2 = 2a$$

# More derivative examples

$$f(a) = a^2$$

$$\frac{d}{da} f(a) = \frac{2a}{4}$$

$$a = 2$$

$$f(a) = 4$$

$$a = 2.001$$

$$f(a) \approx 4.004$$

$$f(a) = a^3$$

$$\frac{d}{da} f(a) = \frac{3a^2}{3 \times 2^2 = 12}$$

$$a = 2$$

$$f(a) = 8$$

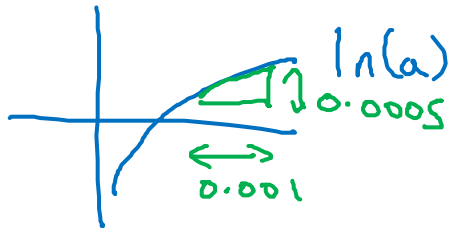
$$a = \underline{2.001}$$

$$f(a) \approx \underline{8.012}$$

$$f(a) = \log_e(a)$$
  

$$\ln(a)$$

$$\frac{d}{da} f(a) = \frac{1}{a}$$



$$\frac{d}{da} f(a) = \boxed{\frac{1}{2}}$$

$$a = 2$$

$$f(a) \approx 0.69315$$

$$\downarrow$$
  

$$a = \underline{2.001}$$

$$\downarrow$$
  

$$\underline{f(a) \approx 0.69365}$$

$$\downarrow$$
  

$$0.0005$$
  

$$\swarrow$$
  

$$\underline{0.0005}$$





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# Basics of Neural Network Programming

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## Computation Graph

# Computation Graph

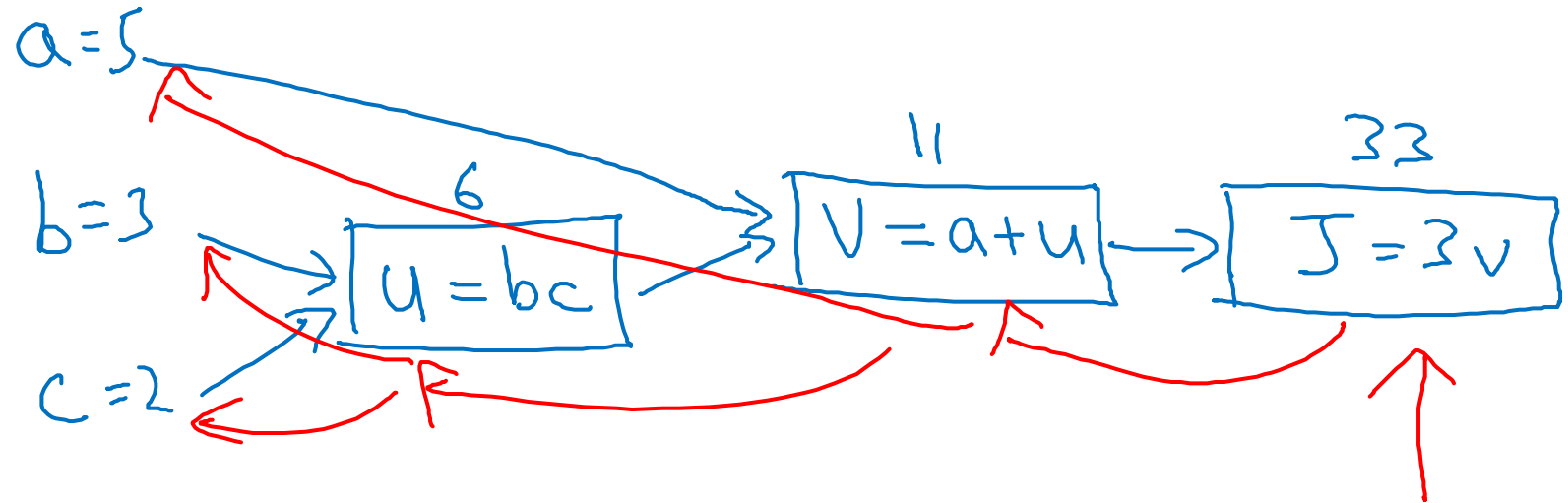
$$J(a,b,c) = 3(a + \underbrace{bc}_u) = 3(5 + 3 \times 2) = 33$$

$$\underbrace{\underbrace{a + u}_v}_J$$

$$u = bc$$

$$V = a + u$$

$$J = 3V$$





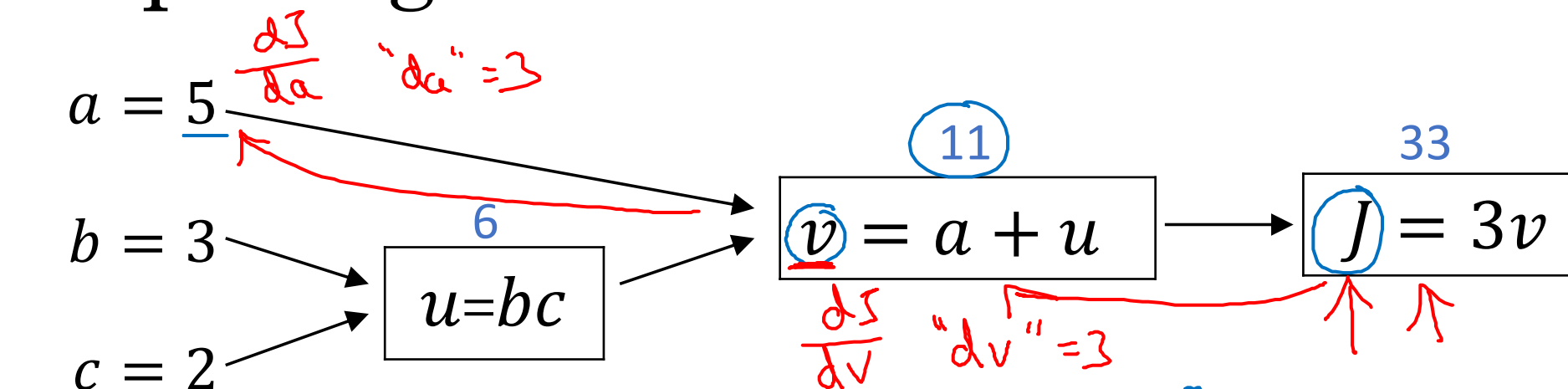
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# Basics of Neural Network Programming

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## Derivatives with a Computation Graph

# Computing derivatives



$$\frac{dJ}{dv} = ? = 3$$

$$\frac{dJ}{da} = 3 = \frac{dJ}{dv} \frac{dv}{da}$$

$$\frac{dv}{da} = 1$$

Handwritten notes in green boxes:

- $\frac{dJ}{dv} = ? = 3$
- $\frac{dv}{da} = 1$

$$a \rightarrow v \rightarrow J$$

$$J = 3v$$

$$v = 11 \rightarrow 11.001$$

$$J = 33 \rightarrow 33.003$$

$$a = 5 \rightarrow 5.001$$

$$\rightarrow v = 11 \rightarrow 11.001$$

$$J = 33 \rightarrow 33.003$$

$$\frac{d \text{ Final Output Var}}{d \text{ var}}$$

$$\frac{dJ}{d \text{ var}}$$

Handwritten note: "dvar"

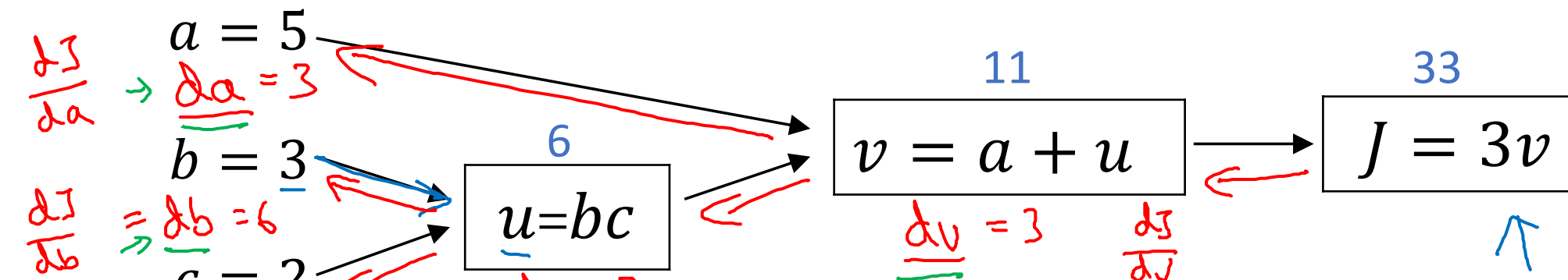
$$f(a) = 3a$$

$$\frac{df(a)}{da} = \frac{df}{da} = 3$$

$$J = 3v$$

$$\frac{dJ}{dv} = 3$$

# Computing derivatives



$$\frac{dJ}{du} = 3 = \frac{dJ}{dv} \cdot \frac{dv}{du}$$

$\underbrace{\quad}_{3} \quad \underbrace{\quad}_{1}$

$$\frac{dJ}{db} = \frac{dJ}{du} \cdot \frac{du}{db} = 6$$

$\underbrace{\quad}_{\rightarrow 3} \quad \underbrace{\quad}_{=2}$

$$\frac{dJ}{dc} = \frac{dJ}{du} \cdot \frac{du}{dc} = 9$$

$\underbrace{\quad}_{\rightarrow 3} \quad \underbrace{\quad}_{=3}$

$$\begin{aligned} u = 6 &\rightarrow 6.001 \\ v = 11 &\rightarrow 11.001 \\ J = 33 &\rightarrow 33.003 \end{aligned}$$

$$\begin{aligned} b = 3 &\rightarrow 3.001 \\ u = b \cdot c = 6 &\rightarrow 6.002 \\ J = 33.006 & \end{aligned} \quad c = 2$$

$$\begin{aligned} v = 11.002 \\ J = 3v \end{aligned}$$



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# Basics of Neural Network Programming

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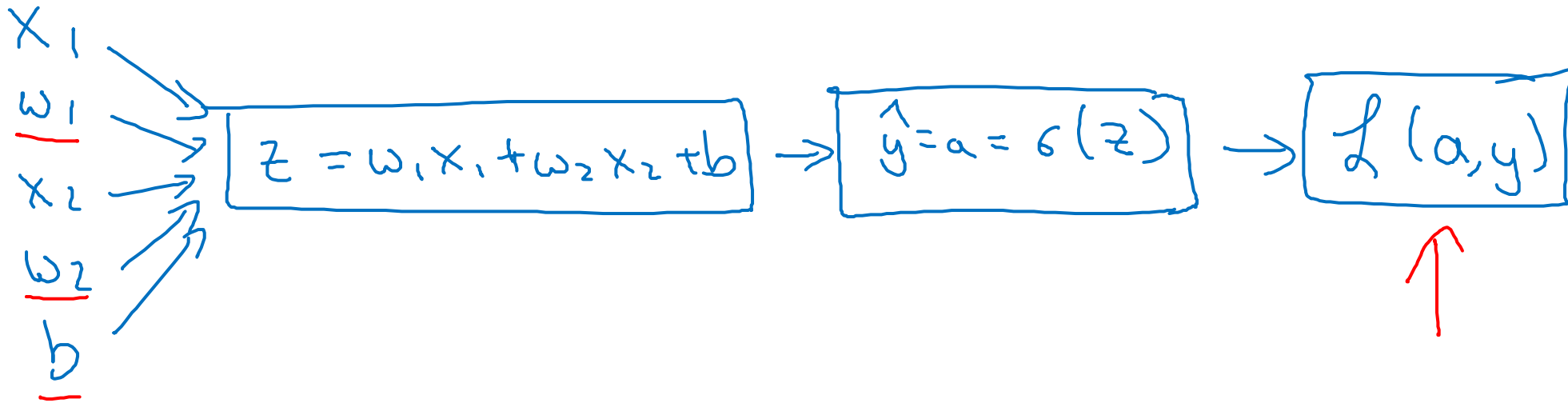
Logistic Regression  
Gradient descent

# Logistic regression recap

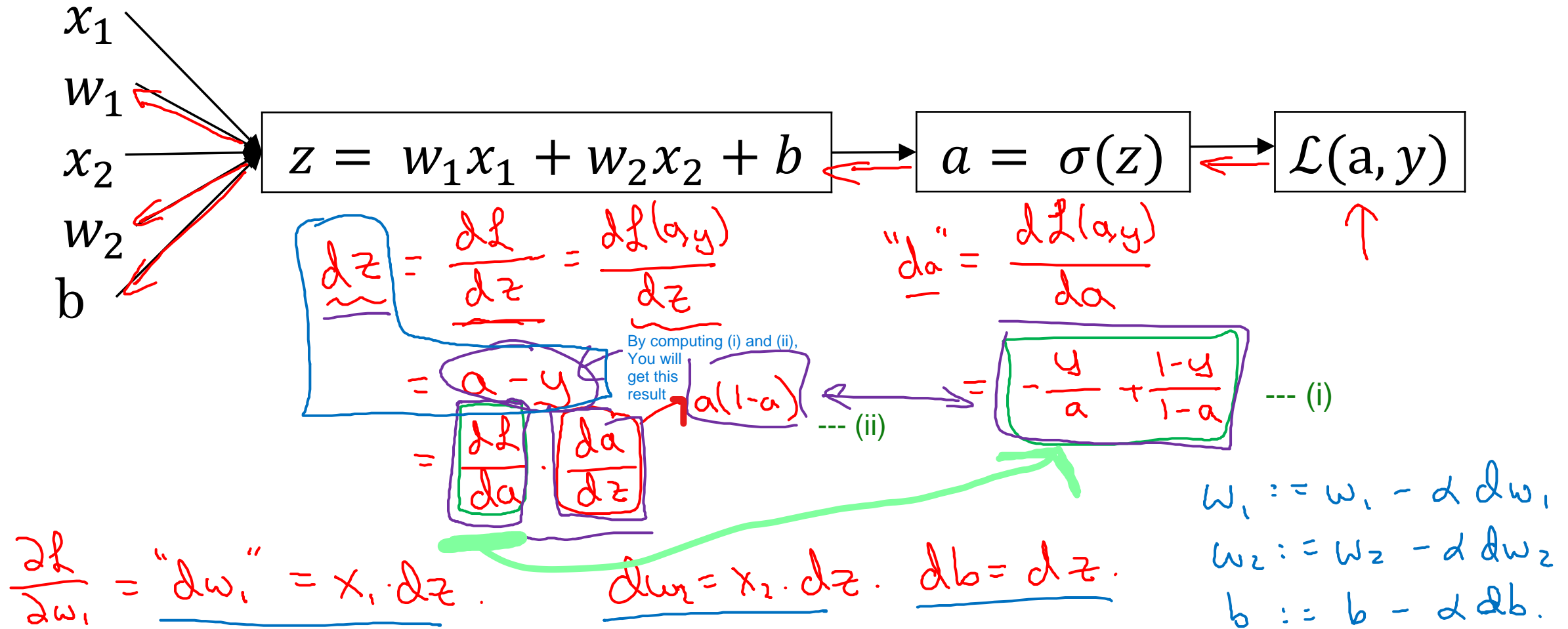
→  $z = w^T x + b$

→  $\hat{y} = a = \sigma(\underline{z})$

→  $\mathcal{L}(a, y) = -(y \log(a) + (1 - y) \log(1 - a))$



# Logistic regression derivatives







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# Basics of Neural Network Programming

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Gradient descent  
on  $m$  examples

# Logistic regression on $m$ examples

$$\underline{J(w, b)} = \frac{1}{m} \sum_{i=1}^m \ell(a^{(i)}, y^{(i)})$$

$$\rightarrow a^{(i)} = \hat{y}^{(i)} = \sigma(z^{(i)}) = \sigma(w^T x^{(i)} + b)$$

$$(x^{(i)}, y^{(i)})$$

$$\underline{dw_1^{(i)}}, \underline{dw_2^{(i)}}, \underline{db^{(i)}}$$

$$\underline{\frac{\partial}{\partial w_1} J(w, b)} = \frac{1}{m} \sum_{i=1}^m \underbrace{\frac{\partial}{\partial w_1} \ell(a^{(i)}, y^{(i)})}_{\underline{dw_1^{(i)}} - (x^{(i)}, y^{(i)})}$$

# Logistic regression on $m$ examples

$$J=0; \underline{dw_1}=0; \underline{dw_2}=0; \underline{db}=0$$

→ For  $i=1$  to  $m$

$$z^{(i)} = w^T x^{(i)} + b$$

$$a^{(i)} = \sigma(z^{(i)})$$

$$J += -[y^{(i)} \log a^{(i)} + (1-y^{(i)}) \log(1-a^{(i)})]$$

$$\underline{dz^{(i)}} = a^{(i)} - y^{(i)}$$

$$dw_1 += x_1^{(i)} dz^{(i)}$$

$$dw_2 += x_2^{(i)} dz^{(i)}$$

$$db += dz^{(i)}$$

$n=2$

$dw_3$   
 $\vdots$   
 $dw_n$

$$J /= m \leftarrow$$

$$dw_1 /= m; dw_2 /= m; db /= m. \leftarrow$$

$$dw_1 = \frac{\partial J}{\partial w_1}$$

$$w_1 := w_1 - \alpha \underline{dw_1}$$

$$w_2 := w_2 - \alpha \underline{dw_2}$$

$$b := b - \alpha \underline{db}$$

Vectorization



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# Basics of Neural Network Programming

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## Vectorization

# What is vectorization?

$$z = \underbrace{w^T x}_{\text{dot product}} + b$$

Non-vectorized:

$$z = 0$$

for  $i$  in  $\text{range}(n-x)$ :

$$z += w[i] * x[i]$$

$$z += b$$

$$w = \begin{bmatrix} \vdots \\ \vdots \\ \vdots \end{bmatrix} \quad x = \begin{bmatrix} \vdots \\ \vdots \\ \vdots \end{bmatrix}$$

$$w \in \mathbb{R}^{n_x}$$

$$x \in \mathbb{R}^{n_x}$$

Vectorized

$$z = \underbrace{\text{np.dot}(w, x)}_{w^T x} + b$$

$\Rightarrow$  GPU } SIMD - single instruction  
 $\Rightarrow$  CPU } multiple data.



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# Basics of Neural Network Programming

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## More vectorization examples

# Neural network programming guideline

Whenever possible, avoid explicit for-loops.

$$u = Av$$

$$u_i = \sum_j A_{ij} v_j$$

$$u = \text{np.zeros}(n, 1)$$

for i ... ←

for j ... ←

$$u[i] += A[i][j] * v[j]$$

$$u = \text{np.dot}(A, v)$$

# Vectors and matrix valued functions

Say you need to apply the exponential operation on every element of a matrix/vector.

$$v = \begin{bmatrix} v_1 \\ \vdots \\ v_n \end{bmatrix} \rightarrow u = \begin{bmatrix} e^{v_1} \\ e^{v_2} \\ \vdots \\ e^{v_n} \end{bmatrix}$$

```
→ u = np.zeros((n,1))  
→ for i in range(n):  
    → u[i]=math.exp(v[i])
```

```
import numpy as np  
u = np.exp(v)  
  
np.log(v)  
np.abs(v)  
np.maximum(v, 0)  
v**2  
1/v
```



# Logistic regression derivatives

$$J = 0, \quad \boxed{\cancel{dw_1 = 0, dw_2 = 0}}, \quad db = 0$$

$$dw = np.zeros((n-x, 1))$$

→ for i = 1 to n:

$$z^{(i)} = w^T x^{(i)} + b$$

$$a^{(i)} = \sigma(z^{(i)})$$

$$J += -[y^{(i)} \log \hat{y}^{(i)} + (1 - y^{(i)}) \log(1 - \hat{y}^{(i)})]$$

$$dz^{(i)} = a^{(i)}(1 - a^{(i)})$$

$$\cancel{dw_1 += x_1^{(i)} dz^{(i)}}$$

$$\cancel{dw_2 += x_2^{(i)} dz^{(i)}}$$

$$db += dz^{(i)}$$

$$n_x = 2$$

$$dw += x^{(i)} dz^{(i)}$$

$$J = J/m, \quad \boxed{\cancel{dw_1 = dw_1/m, dw_2 = dw_2/m}}, \quad db = db/m$$

$$dw /= m.$$



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# Basics of Neural Network Programming

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## Vectorizing Logistic Regression

# Vectorizing Logistic Regression

$z^{(1)} = w^T x^{(1)} + b$

$a^{(1)} = \sigma(z^{(1)})$

$$\underline{z^{(2)}} = w^T x^{(2)} + b$$
$$\underline{a^{(2)}} = \sigma(z^{(2)})$$

$$\begin{aligned} \underline{z^{(3)}} &= w^T x^{(3)} + b \\ \underline{a^{(3)}} &= \sigma(\underline{z^{(3)}}) \end{aligned}$$

$$\underline{\underline{X}} = \begin{bmatrix} | & | & & | \\ X^{(1)} & X^{(2)} & \dots & X^{(m)} \\ | & | & & | \end{bmatrix}$$

$$\frac{(n_{x,m})}{R^{n_x \times m}}$$

$$\vec{1} \rightarrow \omega \left[ \begin{array}{c} | \\ x^{(1)} \\ | \end{array} \quad \begin{array}{c} | \\ x^{(2)} \\ | \end{array} \quad \dots \quad \begin{array}{c} | \\ x^{(m)} \\ | \end{array} \right]$$

$$\underline{Z} = \begin{bmatrix} \underline{z}^{(1)} & \underline{z}^{(2)} & \dots & \underline{z}^{(m)} \end{bmatrix} = \underbrace{w^T X}_{1 \times m} + \underbrace{[b \ b \dots b]}_{1 \times m} = \boxed{w^T x^{(1)} + b} \quad \boxed{w^T x^{(2)} + b} \quad \dots \quad \boxed{w^T x^{(m)} + b}$$

$$\rightarrow \underline{z = np.dot(w.T, x) + b} \quad (1.1) \quad \mathbb{R}$$

$$\underline{A} = [\underline{a^{(1)}} \quad \underline{a^{(2)}} \quad \dots \quad \underline{a^{(m)}}] = \underline{\sigma(z)}$$

"Broadcasting"



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# Basics of Neural Network Programming

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## Vectorizing Logistic Regression's Gradient Computation

# Vectorizing Logistic Regression

$$dz^{(1)} = a^{(1)} - y^{(1)}$$

$$dz^{(2)} = a^{(2)} - y^{(2)}$$

.....

$$dz = [dz^{(1)} \quad dz^{(2)} \quad \dots \quad dz^{(m)}]$$

$1 \times m$

$$A = [a^{(1)} \quad \dots \quad a^{(m)}] \quad Y = [y^{(1)} \quad \dots \quad y^{(m)}]$$

$$\rightarrow dz = A - Y = [a^{(1)} - y^{(1)} \quad a^{(2)} - y^{(2)} \quad \dots]$$

$$\rightarrow dw = 0$$

$$dw += \frac{x^{(1)} dz^{(1)}}{m}$$

$$dw += \frac{x^{(2)} dz^{(2)}}{m}$$

$\vdots$

$$dw /= m$$

$$db = 0$$

$$db += dz^{(1)}$$

$$db += dz^{(2)}$$

$\vdots$

$$db += dz^{(m)}$$

$$db /= m$$

$$db = \frac{1}{m} \sum_{i=1}^m dz^{(i)}$$

$$= \frac{1}{m} \text{np.sum}(dz)$$

$$dw = \frac{1}{m} X dz^T$$

$$= \frac{1}{m} \begin{bmatrix} x^{(1)} & \dots & x^{(m)} \\ 1 & & 1 \end{bmatrix} \begin{bmatrix} dz^{(1)} \\ \vdots \\ dz^{(m)} \end{bmatrix}$$

$$= \frac{1}{m} \left[ \frac{x^{(1)} dz^{(1)}}{n \times 1} + \dots + \frac{x^{(m)} dz^{(m)}}{n \times 1} \right]$$

# Implementing Logistic Regression

$J = 0, dw_1 = 0, dw_2 = 0, db = 0$

for  $i = 1$  to  $m$ :

$$z^{(i)} = w^T x^{(i)} + b \leftarrow$$

$$a^{(i)} = \sigma(z^{(i)}) \leftarrow$$

$$J += -[y^{(i)} \log a^{(i)} + (1 - y^{(i)}) \log(1 - a^{(i)})]$$

$$dz^{(i)} = a^{(i)} - y^{(i)} \leftarrow$$

$$\left[ \begin{array}{l} dw_1 += x_1^{(i)} dz^{(i)} \\ dw_2 += x_2^{(i)} dz^{(i)} \end{array} \right] \left\{ dw += x^{(i)} * dz^{(i)} \right.$$

$$db += dz^{(i)}$$

$$J = J/m, dw_1 = dw_1/m, dw_2 = dw_2/m$$

$$db = db/m$$

for iter in range(1000):  $\leftarrow$

$$Z = w^T X + b$$

$$= \text{np.dot}(w.T, X) + b$$

$$A = \sigma(Z)$$

$$dZ = A - Y$$

$$dw = \frac{1}{m} X dZ^T$$

$$db = \frac{1}{m} \text{np.sum}(dZ)$$

$$w := w - \alpha dw$$

$$b := b - \alpha db$$



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# Basics of Neural Network Programming

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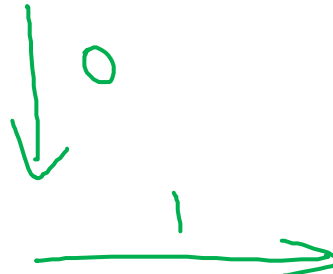
## Broadcasting in Python

# Broadcasting example

Calories from Carbs, Proteins, Fats in 100g of different foods:

|         | ↓<br>Apples | ↓<br>Beef | ↓<br>Eggs | ↓<br>Potatoes |              |
|---------|-------------|-----------|-----------|---------------|--------------|
| Carb    | 56.0        | 0.0       | 4.4       | 68.0          | = A<br>(3,4) |
| Protein | 1.2         | 104.0     | 52.0      | 8.0           |              |
| Fat     | 1.8         | 135.0     | 99.0      | 0.9           |              |

59 cal  $\frac{56}{59} \approx 94.9\%$



Calculate % of calories from Carb, Protein, Fat. Can you do this without explicit for-loop?

```
cal = A.sum(axis = 0)  
percentage = 100 * A / (cal.reshape(1,4))
```

↑(3,4) / (1,4)



# Broadcasting example

$$\begin{bmatrix} 1 \\ 2 \\ 3 \\ 4 \end{bmatrix} + \begin{bmatrix} 100 \\ 100 \\ 100 \\ 100 \end{bmatrix} \quad \text{100}$$

$$\begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \end{bmatrix} + \begin{bmatrix} 100 & 200 & 300 \\ 100 & 200 & 300 \end{bmatrix}$$

$(m,n) \quad (2,3) \quad (1,n) \rightsquigarrow (m,n) \quad (2,3)$

↓   ↓   ↓

$$\begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \end{bmatrix} + \begin{bmatrix} 100 & 100 & 100 \\ 200 & 200 & 200 \end{bmatrix} =$$

$(m,n) \quad (m,1) \rightsquigarrow (m,n)$

←  
←

# General Principle

$$\begin{array}{ccc} (m, n) & + & (1, n) \\ \text{matrix} & \times & \rightsquigarrow (m, n) \\ \hline & / & \end{array}$$

$$\begin{array}{ccc} (m, 1) & + & \mathbb{R} \\ \begin{bmatrix} 1 \\ 2 \\ 3 \end{bmatrix} & + & 100 \\ [1 \ 2 \ 3] & + & 100 \end{array} = \begin{bmatrix} 101 \\ 102 \\ 103 \end{bmatrix} = [101 \quad 102 \quad 103]$$

Matlab/Octave: bsxfun



deeplearning.ai

# Basics of Neural Network Programming

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Explanation of logistic  
regression cost function  
(Optional)

# Logistic regression cost function

$$\hat{y} = \sigma(w^T x + b) \quad \text{where} \quad \sigma(z) = \frac{1}{1 + e^{-z}}$$

Interpret  $\hat{y} = p(y=1|x)$

If  $y=1$  :  $p(y|x) = \hat{y}$

If  $y=0$  :  $\underline{p(y|x)} = \underline{1 - \hat{y}}$

# Logistic regression cost function

$$\begin{aligned} \rightarrow & \text{If } y = 1: p(y|x) = \hat{y} \\ \rightarrow & \text{If } y = 0: p(y|x) = 1 - \hat{y} \end{aligned} \quad \left. \vphantom{\begin{aligned} \rightarrow & \text{If } y = 1: p(y|x) = \hat{y} \\ \rightarrow & \text{If } y = 0: p(y|x) = 1 - \hat{y} \end{aligned}} \right\} p(y|x)$$

$$p(y|x) = \hat{y}^y (1 - \hat{y})^{(1-y)} \quad \leftarrow$$

$$\text{If } y=1: p(y|x) = \hat{y} \underbrace{(1-\hat{y})^0}_{=1}$$

$$\text{If } y=0: p(y|x) = \hat{y}^0 \underbrace{(1-\hat{y})^{(1-0)}}_{=1} = 1 \times (1-\hat{y}) = \underline{1-\hat{y}}$$

$$\begin{aligned} \uparrow \log p(y|x) &= \log \hat{y}^y (1-\hat{y})^{(1-y)} = y \log \hat{y} + (1-y) \log (1-\hat{y}) \\ &= - \underbrace{\ell(\hat{y}, y)}_{\downarrow} \end{aligned}$$

# Cost on $m$ examples

$$\log p(\text{labels in training set}) = \log \prod_{i=1}^m p(y^{(i)} | x^{(i)}) \leftarrow$$

$$\log p(\text{-----}) = \sum_{i=1}^m \underbrace{\log p(y^{(i)} | x^{(i)})}_{- \mathcal{L}(\hat{y}^{(i)}, y^{(i)})}$$

$$= - \sum_{i=1}^m \mathcal{L}(\hat{y}^{(i)}, y^{(i)})$$

Maximum likelihood  
estimator  $\nwarrow$

$$\text{Cost:} \quad \underbrace{J(w, b)}_{\uparrow \text{(minimize)}} = \frac{1}{m} \sum_{i=1}^m \mathcal{L}(\hat{y}^{(i)}, y^{(i)})$$