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Classification

Motivations

Classification

Question	Answer "y"	
Is this email spam?	no	yes
Is the transaction fraudulent?	no	yes
Is the tumor malignant?	no	yes

y can only be one of two values

"binary classification"

class = category

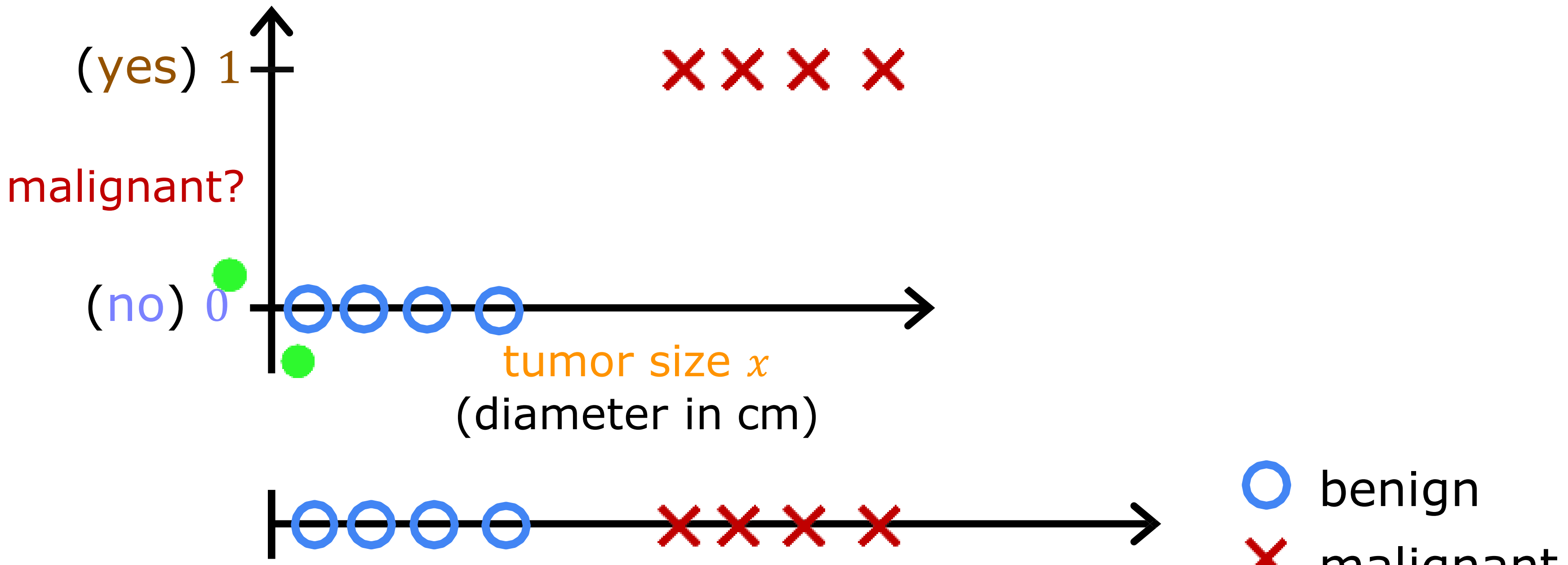
false true

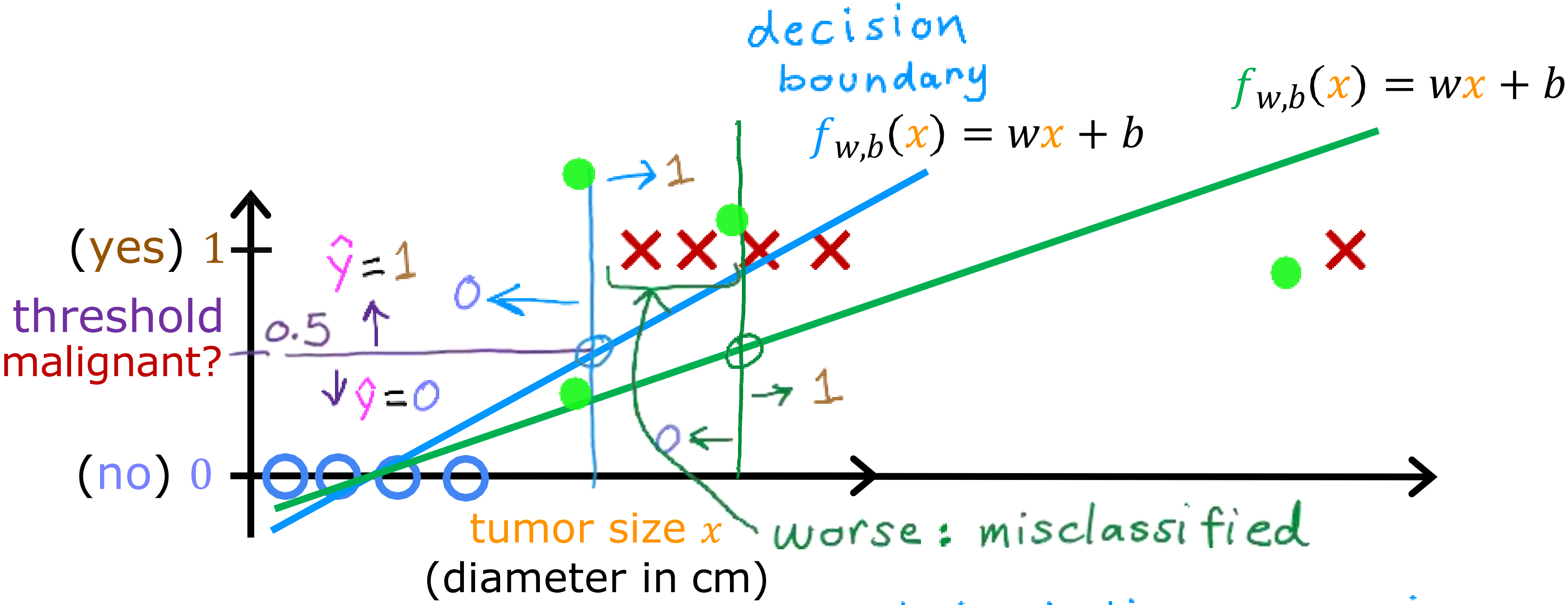
0 1

useful for classification

"negative class" ≠ "bad" absence

"positive class" ≠ "good" presence


(yes) 1
malignant?
(no) 0
tumor size x
(diameter in cm)
benign
malignant



if $f_{w,b}(x) < 0.5 \rightarrow \hat{y} = 0$

if $f_{w,b}(x) \geq 0.5 \rightarrow \hat{y} = 1$

next: logistic regression

$\underbrace{\text{logistic regression}}_{\text{classification}}$

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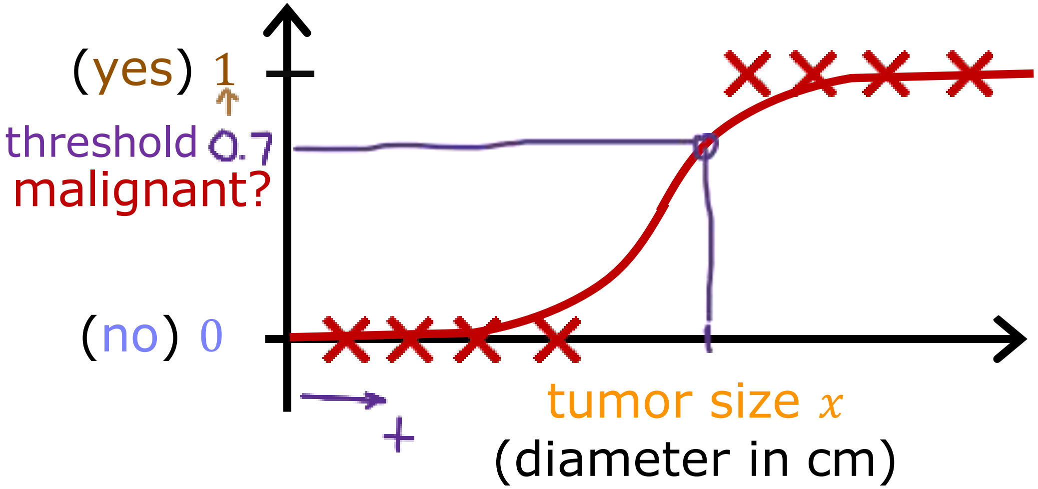
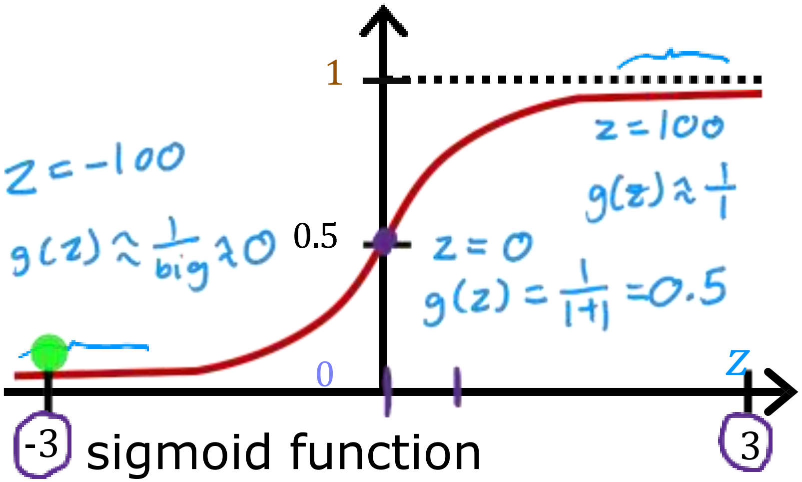
Classification

Logistic Regression



Want outputs between 0 and 1



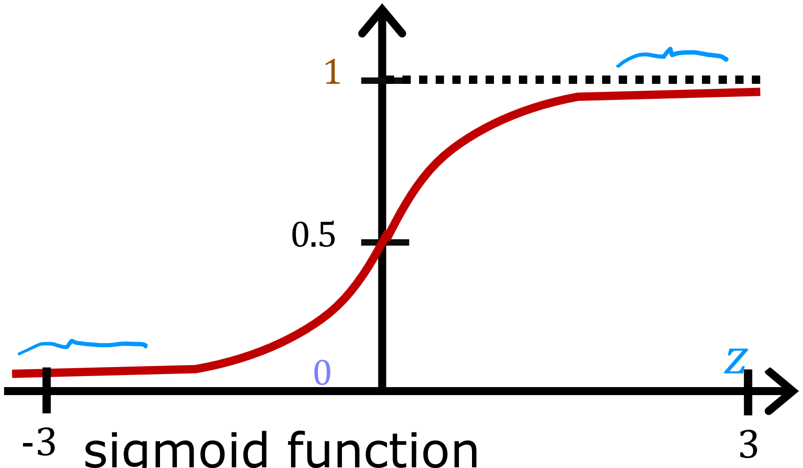
sigmoid function

logistic function

outputs between 0 and 1

$$g(z) = \frac{1}{1+e^{-z}} \qquad 0 < g(z) < 1$$

Want outputs between 0 and 1



sigmoid function

logistic function

$$\boxed{\begin{array}{l}\text{outputs between 0 and 1} \\ g(z) = \frac{1}{1+e^{-z}} \qquad 0 < g(z) < 1\end{array}}$$

$f_{\vec{w},b}(\vec{x})$

$$\boxed{\vec{w} \cdot \vec{x} + b}$$

$\downarrow$

z

$\downarrow$

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

$$f_{\vec{w},b}(\vec{x}) = g(\underbrace{\vec{w} \cdot \vec{x} + b}_{z}) = \frac{1}{1 + e^{-(\vec{w} \cdot \vec{x} + b)}}$$

$e \approx 2.7$

"logistic regression"

Interpretation of logistic regression output

$$f_{\vec{w},b}(\vec{x}) = \frac{1}{1+e^{-(\vec{w}\cdot\vec{x}+b)}}$$

"probability" that class is 1

Example:

x is "tumor size"

y is 0 (not malignant)

or 1 (malignant)

$$f_{\vec{w},b}(\vec{x}) = 0.7$$

70% chance that y is 1

P(1)

$$f_{\vec{w},b}(\vec{x}) = P(y=1|\vec{x};\vec{w},b)$$

Probability that y is 1,
given input $\vec{x}$, parameters $\vec{w}$,b

$$P(y=0)+P(y=1)=1$$

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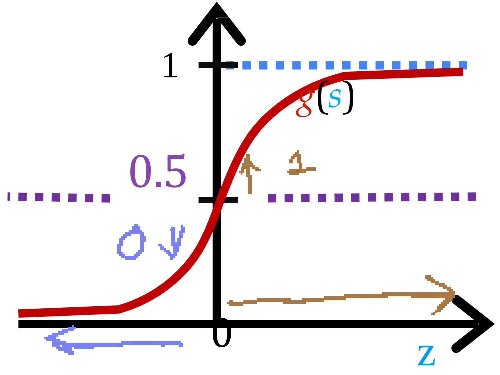
Classification

Decision Boundary



$f_{\vec{w},b}(\vec{x})$

$\boxed{s = \vec{w} \cdot \vec{x} + b}$

$\downarrow$

z

$\downarrow$

$\boxed{g(s) = \dfrac{1}{1 + e^{-s}}}$

$$f_{\vec{w},b}(\vec{x}) = g(\underbrace{\vec{w} \cdot \vec{x} + b}_{z}) = \frac{1}{1 + e^{-(\vec{w} \cdot \vec{x} + b)}}$$

$$= P(y = 1 \mid x; \vec{w}, b) \quad 0.7 \quad 0.3$$

0 or 1 ? threshold

Is $f_{\vec{w},b}(\vec{x}) \geq 0.5$?

Yes: $\hat{y} = 1$ No: $\hat{y} = 0$

When is $f_{\vec{w},b}(\vec{x}) \geq 0.5$?

$g(s) \geq 0.5$

$s \geq 0$	< 0
$\vec{w} \cdot \vec{x} + b \geq 0$	$\vec{w} \cdot \vec{x} + b < 0$
$\hat{y} = 1$	$\hat{y} = 0$

Decision boundary

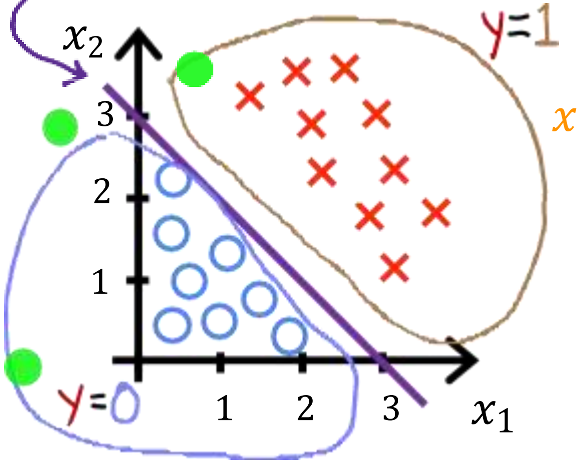
$$f_{\vec{w},b}(\vec{x}) = g(z) = g(\overbrace{\underset{1}{w_1}x_1 + \underset{1}{w_2}x_2 + \underset{-3}{b}})$$

Decision boundary $z = \vec{w} \cdot \vec{x} + b = 0$

$z = x_1 + x_2 - 3 = 0$

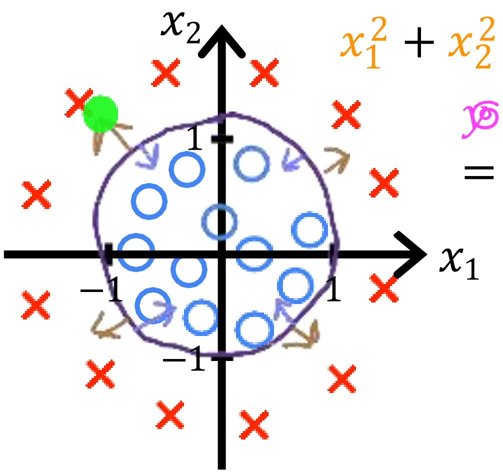
$x_1 + x_2 = 3$

$x_1 + x_2 < 3$



$x_1 + x_2 \geq 3$

Non-linear decision boundaries



$x_1^2 + x_2^2 \geq 1$

$\hat{y} = 1$

decision boundary

$x_1^2 + x_2^2 < 1$

$\hat{y} = 0$

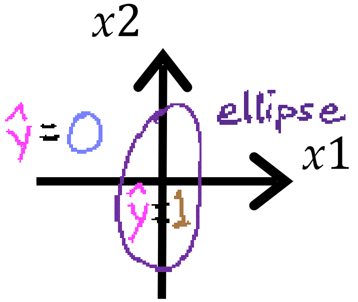
$z = x_1^2 + x_2^2 - 1 = 0$

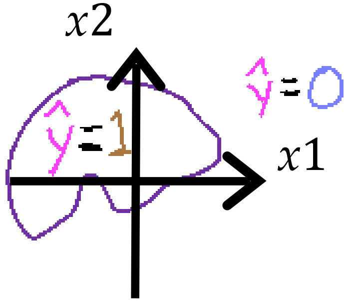
$x_1^2 + x_2^2 = 1$

$\overbrace{w_1 x_1^2 + w_2 x_2^2 + b}^{z}$

$1 \quad 1 \quad -1$

Non-linear decision boundaries





$$f_{\vec{w},b}(\vec{x}) = g(z) = g(w_1 x_1 + w_2 x_2 + w_3 x_1^2 + w_4 x_1 x_2 + w_5 x_2^2 + w_6 x_1^3 + \cdots + b)$$

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Cost Function

Cost Function for Logistic Regression

Training set

tumor size (cm) x_1	...	patient's age x_n	malignant? y
$i=1$ 10		52	1
2		73	0
5		55	0
12		49	1
$i=m$ ...		...	...

$i = 1, \dots, m$ ← training examples

$j = 1, \dots, n$ ← features

$\boxed{\text{target } y \text{ is } 0 \text{ or } 1}$

$$f_{\vec{w},b}(\vec{x}) = \frac{1}{1 + e^{-(\vec{w}\cdot\vec{x}+b)}}$$

How to choose $\vec{w} = [w_1 \quad w_2 \quad \cdots \quad w_n]$ and b?

Squared error cost

cost

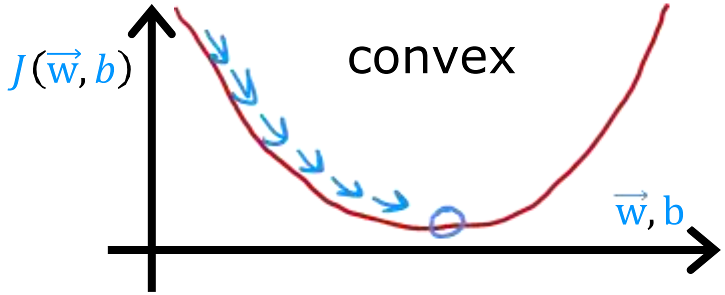
$$J(\vec{w},b) = \frac{1}{m}\sum_{i=1}^{m} \boxed{\frac{1}{2}\left(f_{\vec{w},b}(\vec{x}^{(i)}) - y^{(i)}\right)^2}$$

average of training set

loss $\boxed{L\left(f_{\vec{w},b}(\vec{x}^{(i)}), y^{(i)}\right)}$

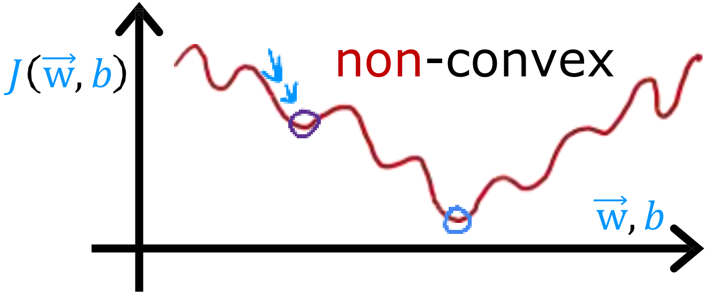
linear regression

$$f_{\vec{w},b}(\vec{x}) = \vec{w} \cdot \vec{x} + b$$



logistic regression

$$f_{\vec{w},b}(\vec{x}) = \frac{1}{1 + e^{-(\vec{w}\cdot\vec{x}+b)}}$$

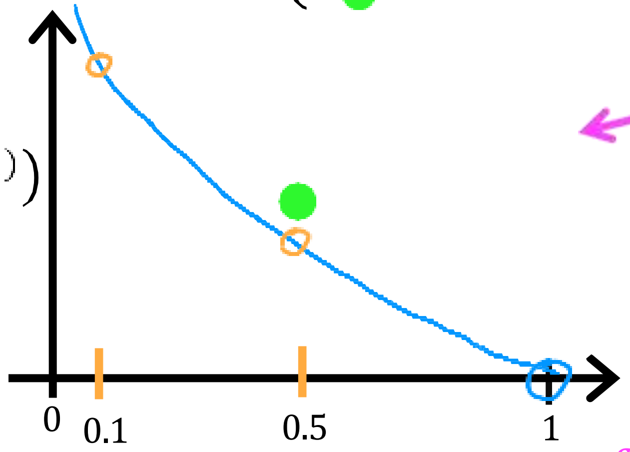


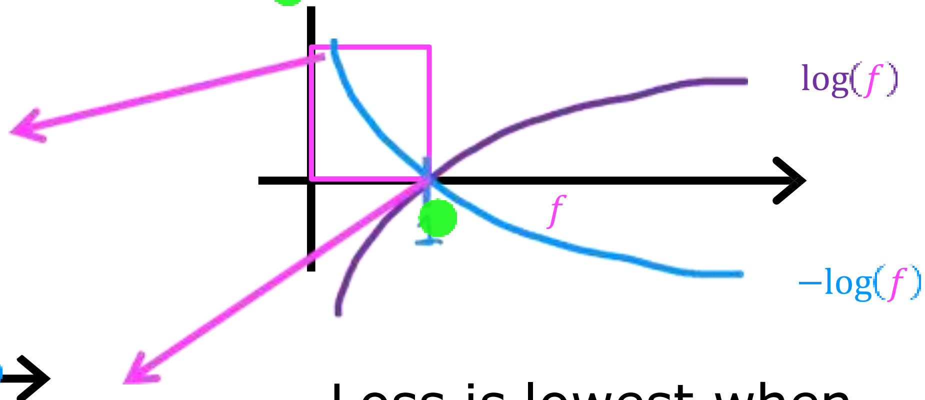
Logistic loss function

$$L\left(f_{\vec{w},b}\left(\vec{x}^{(i)}\right), y^{(i)}\right) = \begin{cases} -\log\left(f_{\vec{w},b}\left(\vec{x}^{(i)}\right)\right) & \text{if } y^{(i)} = 1 \\ -\log\left(1 - f_{\vec{w},b}\left(\vec{x}^{(i)}\right)\right) & \text{if } y^{(i)} = 0 \end{cases}$$

$L\left(f_{\vec{w},b}\left(\vec{x}^{(i)}\right), y^{(i)}\right)$

if $y^{(i)} = 1$





$f_{\vec{w},b}\left(\vec{x}^{(i)}\right)$

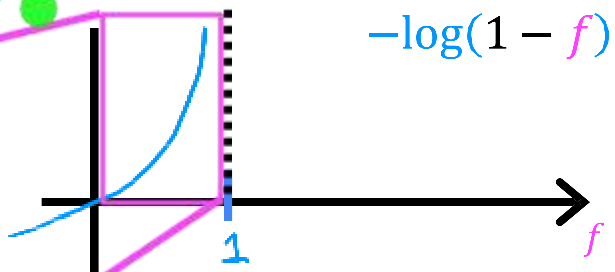
As $f_{\vec{w},b}\left(\vec{x}^{(i)}\right) \rightarrow 1$ then loss $\rightarrow 0$

As $f_{\vec{w},b}\left(\vec{x}^{(i)}\right) \rightarrow 0$ then loss $\rightarrow \infty$

Loss is lowest when $f_{\vec{w},b}\left(\vec{x}^{(i)}\right)$ predicts close to true label $y^{(i)}$.

Logistic loss function

$$L\left(f_{\vec{w},b}(\vec{x}^{(i)}), y^{(i)}\right) = \begin{cases} -\log\left(f_{\vec{w},b}(\vec{x}^{(i)})\right) & \text{if } y^{(i)} = 1 \\ -\log\left(1 - f_{\vec{w},b}(\vec{x}^{(i)})\right) & \text{if } y^{(i)} = 0 \end{cases}$$

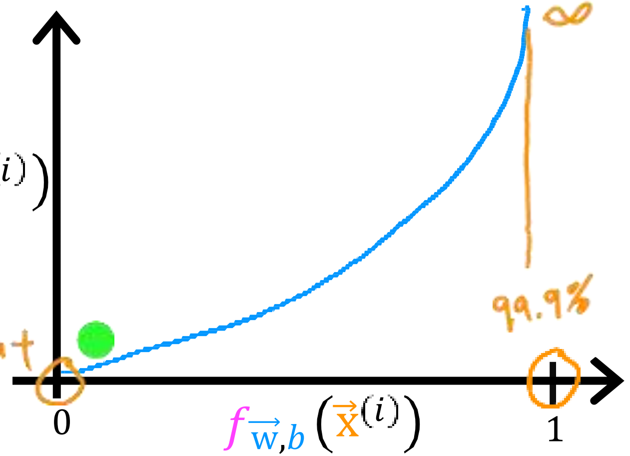


As $f_{\vec{w},b}(\vec{x}^{(i)}) \rightarrow 0$ then loss $\rightarrow 0$

$L\left(f_{\vec{w},b}(\vec{x}^{(i)}), y^{(i)}\right)$

if $y^{(i)} = 0$

not malignant



As $f_{\vec{w},b}(\vec{x}^{(i)}) \rightarrow 1$ then loss $\rightarrow \infty$

The further prediction $f_{\vec{w},b}(\vec{x}^{(i)})$ is from target $y^{(i)}$, the higher the loss.

Cost

cost

$$J(\vec{w},b) = \frac{1}{m}\sum_{i=1}^{m} \underbrace{L\left(f_{\vec{w},b}\left(\vec{x}^{(i)}\right), y^{(i)}\right)}_{\text{loss}}$$

$$= \begin{cases} -\log\left(f_{\vec{w},b}\left(\vec{x}^{(i)}\right)\right) & \text{if } y^{(i)} = 1 \\ -\log\left(1 - f_{\vec{w},b}\left(\vec{x}^{(i)}\right)\right) & \text{if } y^{(i)} = 0 \end{cases}$$

convex

↳ can reach a global minimum

find w, b that minimize cost J

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Cost Function

Simplified Cost Function for Logistic Regression

Simplified loss function

$$L\left(f_{\vec{w},b}\left(\vec{x}^{(i)}\right), y^{(i)}\right) = \begin{cases} \boxed{-\log\left(f_{\vec{w},b}\left(\vec{x}^{(i)}\right)\right)} & \text{if } y^{(i)} = 1 \\ -\log\left(1 - f_{\vec{w},b}\left(\vec{x}^{(i)}\right)\right) & \text{if } y^{(i)} = 0 \end{cases}$$

$$\boxed{L\left(f_{\vec{w},b}\left(\vec{x}^{(i)}\right), y^{(i)}\right) = -\underset{1}{y^{(i)}}\log\left(f_{\vec{w},b}\left(\vec{x}^{(i)}\right)\right) \cancel{- \underbrace{\left(1 - y^{(i)}\right)}_{\underbrace{(1-1)}_{0}}\log\left(1 - f_{\vec{w},b}\left(\vec{x}^{(i)}\right)\right)}}$$

if $y^{(i)} = 1$:

$$L\left(f_{\vec{w},b}\left(\vec{x}^{(i)}\right), y^{(i)}\right) = \underbrace{-1 \log\left(f(\vec{x})\right)}$$

Simplified loss function

$$L\left(f_{\vec{w},b}\left(\vec{x}^{(i)}\right), y^{(i)}\right) = \begin{cases} -\log\left(f_{\vec{w},b}\left(\vec{x}^{(i)}\right)\right) & \text{if } y^{(i)} = 1 \\ \boxed{-\log\left(1 - f_{\vec{w},b}\left(\vec{x}^{(i)}\right)\right)} & \text{if } y^{(i)} = 0 \end{cases}$$

$$\boxed{L\left(f_{\vec{w},b}\left(\vec{x}^{(i)}\right), y^{(i)}\right) = -\underbrace{\cancel{y^{(i)}\log\left(f_{\vec{w},b}\left(\vec{x}^{(i)}\right)\right)}}_{0} - \underbrace{\left(1 - y^{(i)}\right)}_{(1-0)}\log\left(1 - f_{\vec{w},b}\left(\vec{x}^{(i)}\right)\right)}$$

if $y^{(i)} = 1$:

$$L\left(f_{\vec{w},b}\left(\vec{x}^{(i)}\right), y^{(i)}\right) = -1 \log\left(f(\vec{x})\right)$$

if $y^{(i)} = 0$:

$$L\left(f_{\vec{w},b}\left(\vec{x}^{(i)}\right), y^{(i)}\right) = \underline{-(1-0)\log\left(1 - f(\vec{x})\right)}$$

Simplified cost function

loss

$$L\left(f_{\vec{w},b}\left(\vec{x}^{(i)}\right), y^{(i)}\right) = \underbrace{-y^{(i)}\log\left(f_{\vec{w},b}\left(\vec{x}^{(i)}\right)\right) - \left(1-y^{(i)}\right)\log\left(1-f_{\vec{w},b}\left(\vec{x}^{(i)}\right)\right)}$$

cost

$$J(\vec{w},b) = \frac{1}{m}\sum_{i=1}^{m}\left[\underbrace{L\left(f_{\vec{w},b}\left(\vec{x}^{(i)}\right), y^{(i)}\right)}\right]$$

convex

(single global minimum)

$$= -\frac{1}{m}\sum_{i=1}^{m}\left[y^{(i)}\log\left(f_{\vec{w},b}\left(\vec{x}^{(i)}\right)\right) + \left(1-y^{(i)}\right)\log\left(1-f_{\vec{w},b}\left(\vec{x}^{(i)}\right)\right)\right]$$

maximum likelihood

(don't worry about it!)

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Gradient Descent

Gradient Descent Implementation

Training logistic regression

Find $\vec{w}, b$

Given new $\vec{x}$, output $f_{\vec{w},b}(\vec{x}) = \frac{1}{1+e^{-(\vec{w}\cdot\vec{x}+b)}}$

$$P(y = 1|\vec{x}; \vec{w}, b)$$

Gradient descent

cost

$$J(\vec{w},b) = -\frac{1}{m}\sum_{i=1}^{m}\left[y^{(i)}\log\left(f_{\vec{w},b}(\vec{x}^{(i)})\right) + (1-y^{(i)})\log\left(1-f_{\vec{w},b}(\vec{x}^{(i)})\right)\right]$$

repeat {

$j=1 \ldots n$

$$w_j = w_j - \alpha \underbrace{\frac{\partial}{\partial w_j} J(\vec{w},b)}$$

$$\frac{\partial}{\partial w_j} J(\vec{w},b) = \frac{1}{m}\sum_{i=1}^{m}\left(f_{\vec{w},b}(\vec{x}^{(i)}) - y^{(i)}\right)\underbrace{x_j^{(i)}}$$

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

$$\frac{\partial}{\partial b} J(\vec{w},b) = \frac{1}{m}\sum_{i=1}^{m}\underbrace{\left(f_{\vec{w},b}(\vec{x}^{(i)}) - y^{(i)}\right)}$$

} simultaneous updates

Gradient descent for logistic regression

repeat {

looks like linear regression!

$$w_j = w_j - \alpha \left[\frac{1}{m} \sum_{i=1}^{m} \left(f_{\vec{w},b}\left(\vec{x}^{(i)}\right) - y^{(i)} \right) x_j^{(i)} \right]$$

$$b = b - \alpha \left[\frac{1}{m} \sum_{i=1}^{m} \left(f_{\vec{w},b}\left(\vec{x}^{(i)}\right) - y^{(i)} \right) \right]$$

} simultaneous updates

Same concepts:

- Monitor gradient descent (learning curve)
- Vectorized implementation
- Feature scaling

Linear regression $f_{\vec{w},b}(\vec{x}) = \vec{w} \cdot \vec{x} + b$

Logistic regression $f_{\vec{w},b}(\vec{x}) = \dfrac{1}{1 + e^{(-\vec{w} \cdot \vec{x} + b)}}$

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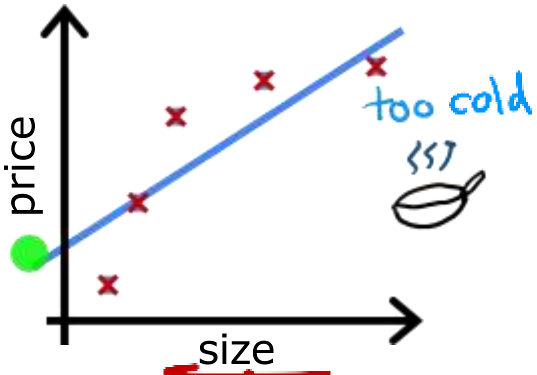
Regularization to Reduce Overfitting

The Problem of Overfitting

Regression example

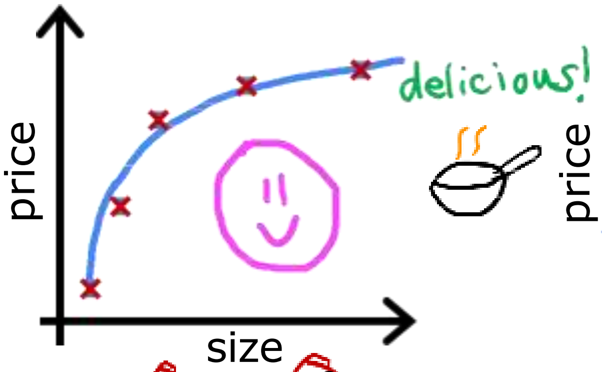


$w_1 x + b$

underfit

- Does not fit the training set well

high bias

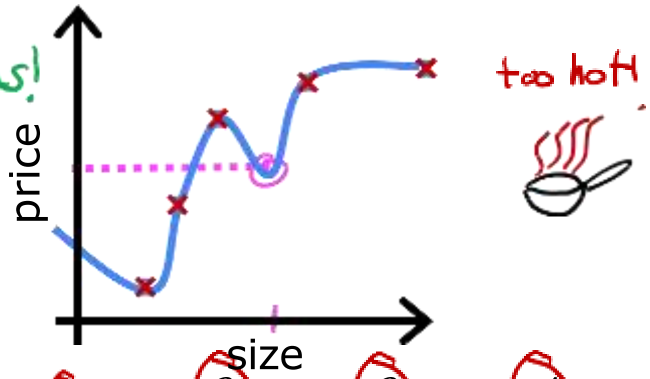


$w_1 x + w_2 x^2 + b$

just right

- Fits training set pretty well

generalization



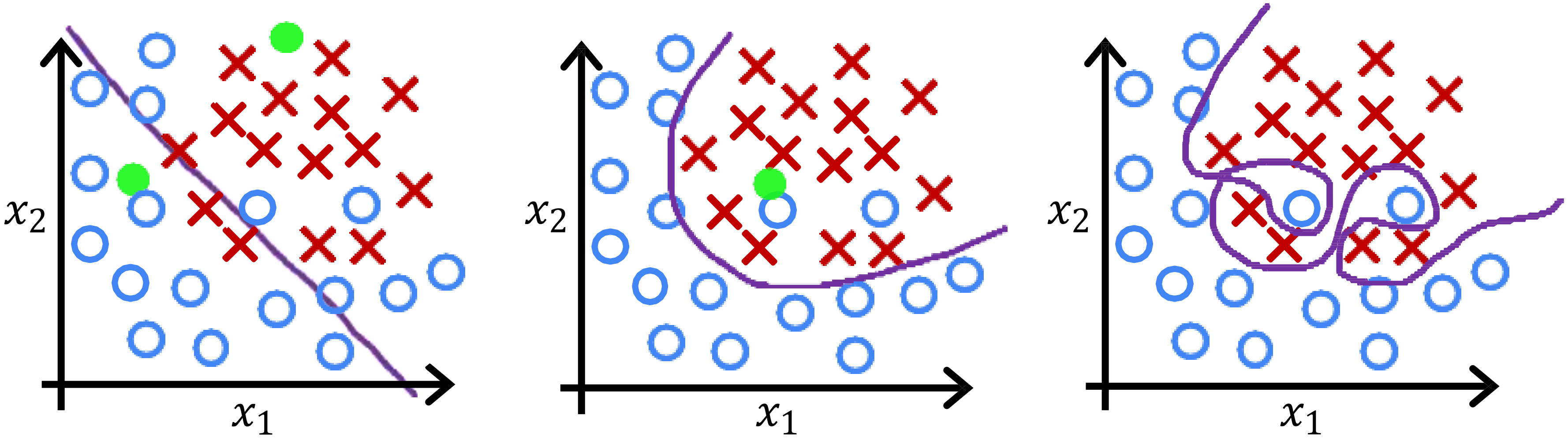
$w_1 x + w_2 x^2 + w_3 x^3 + w_4 x^4 + b$

overfit

- Fits the training set extremely well

high variance

Classification



$z = w_1 x_1 + w_2 x_2 + b$

$f_{\vec{w},b}(\vec{x}) = g(z)$

g is the sigmoid function

underfit high bias

$z = w_1 x_1 + w_2 x_2$
$+ w_3 x_1^2 + w_4 x_2^2$
$+ w_5 x_1 x_2 + b$

just right

$z = w_1 x_1 + w_2 x_2$
$+ w_3 x_1^2 x_2 + w_4 x_1^2 x_2^2$
$+ w_5 x_1^2 x_2^3 + w_6 x_1^3 x_2$
$+ \cdots + b$

overfit

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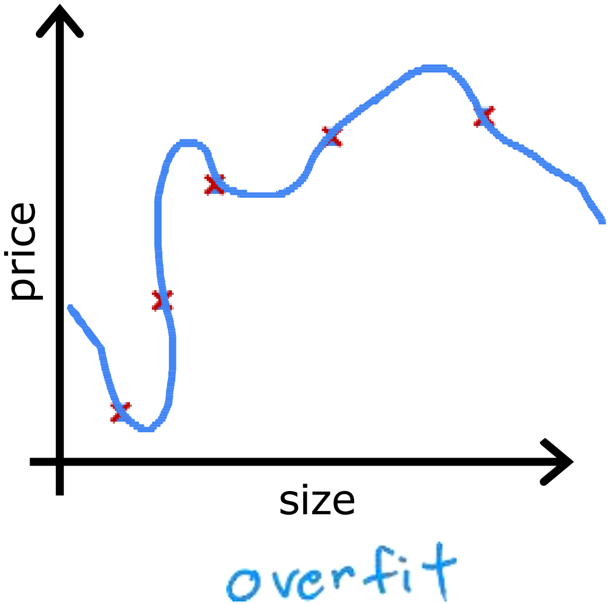
Regularization to Reduce Overfitting

Addressing Overfitting

Collect more training examples



Select features to include/exclude

size	bedrooms	floors	age	avg income	…	distance to coffee shop	price
x_1	x_2	x_3	x_4	x_5		x_{100}	y

all features

+

insufficient data

↓

overfit

selected features

size

bedrooms

age

just right

feature selection

course 2

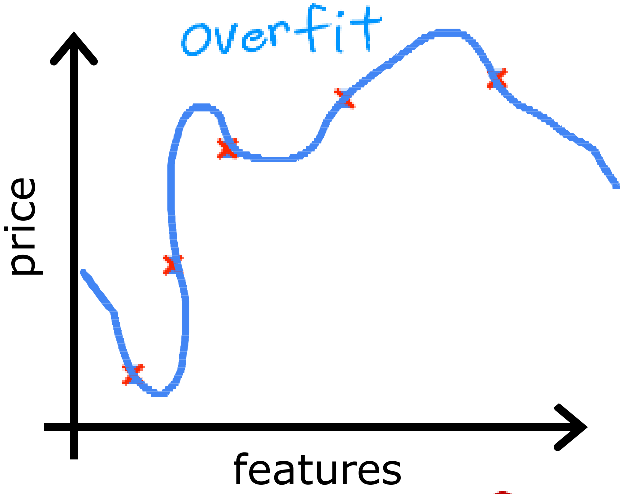
disadvantage

↓

useful features could be lost

Regularization

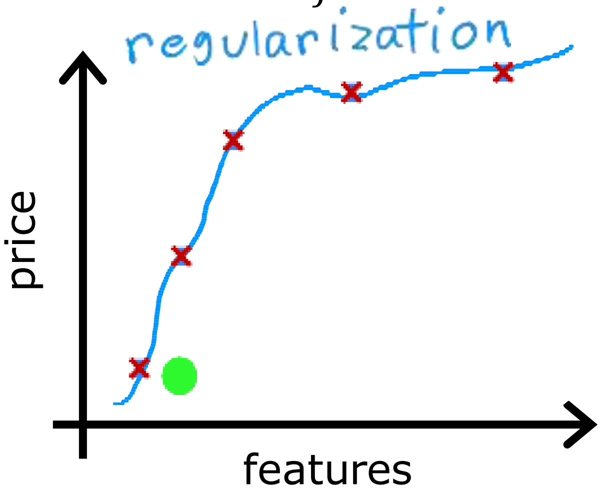
Reduce the size of parameters w_j



$$f(x) = 28x - 385x^2 + 39x^3 - \underbrace{\cancel{174x^4}}_{0} + 100$$

← eliminate feature

large values for w_j



$$f(x) = 13x - 0.23x^2 + \underbrace{0.000014x^3}_{} - \underbrace{0.0001\,x^4}_{} + 10$$

small values for w_j

Addressing overfitting

Options

1. Collect more data

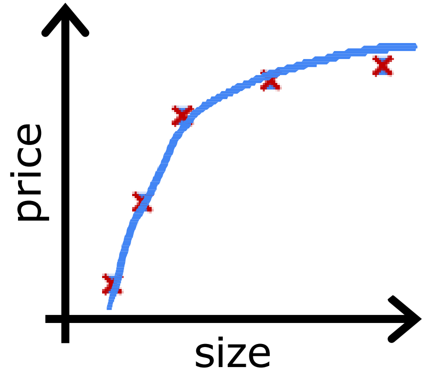
2. Select features
   – Feature selection in course 2

3. Reduce size of parameters
   – "Regularization" next videos!

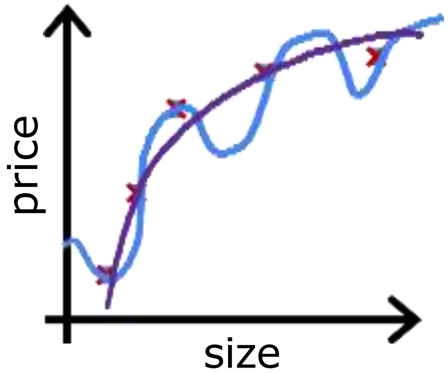
Regularization to Reduce Overfitting

Cost Function with Regularization

Intuition



$w_1x + w_2x^2 + b$



$w_1x + w_2x^2 + \underbrace{\cancel{w_3x^3}}_{\approx 0} + \underbrace{\cancel{w_4x^4}}_{\approx 0} + b$

make w_3, w_4 really small (≈ 0)

$$\min_{\vec{w},b} \frac{1}{2m} \sum_{i=1}^{m} \left(f_{\vec{w},b}\left(\vec{x}^{(i)}\right) - y^{(i)} \right)^2 \cancel{+ 1000 \underbrace{w_3^2}_{0.001}} \cancel{+ 1000 \underbrace{w_4^2}_{0.002}}$$

Regularization

small values $w_1, w_2, \cdots, w_n, b$

simpler model $w_3 \approx 0$

less likely to overfit $w_4 \approx 0$

size	bedrooms	floors	age	avg income	...	distance to coffee shop	price
x_1	x_2	x_3	x_4	x_5		x_{100}	y

n features

$n = 100$

$w_1, w_1, w_2, \cdots, w_{100}, b$

$$J(\vec{w}, b) = \frac{1}{2m}\left[\sum_{i=1}^{m}\left(f_{\vec{w},b}\left(\vec{x}^{(i)}\right) - y^{(i)}\right)^2 + \underbrace{\frac{\lambda}{2m}\sum_{j=1}^{n} w_j^2}_{\text{regularization term}} + \frac{\lambda}{2m} b^2\right]$$

regularization term

"lambda"

regularization parameter

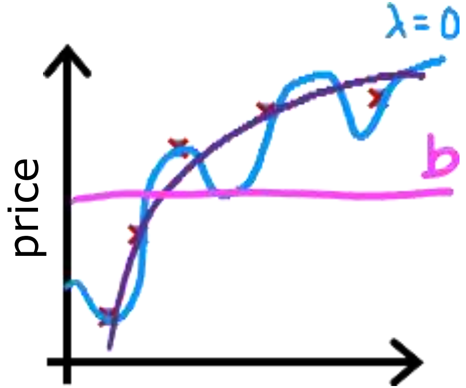
$\lambda > 0$

can include or exclude b

Regularization

$$\min_{\vec{w},b} J(\vec{w},b) = \min_{\vec{w},b}\left[\overbrace{\frac{1}{2m}\sum_{i=1}^{m}\left(f_{\vec{w},b}(\vec{x}^{(i)}) - y^{(i)}\right)^2}^{\text{mean squared error}} + \overbrace{\frac{\lambda}{2m}\sum_{j=1}^{n} w_j^2}^{\text{regularization term}}\right]$$

fit data → λ balances both goals ← Keep w_j small



choose $\lambda = 10^{10}$

$$f_{\vec{w},b}(\vec{x}) = \underbrace{\cancel{w_1 x}}_{\approx 0} + \underbrace{\cancel{w_2 x^2}}_{\approx 0} + \underbrace{\cancel{w_3 x^3}}_{\approx 0} + \underbrace{\cancel{w_4 x^4}}_{\approx 0} + b$$

$f(x) = b$

Choose λ

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Regularization to Reduce Overfitting

Regularized Linear Regression

Regularized linear regression

$$\min_{\vec{w},b} J(\vec{w},b) = \min_{\vec{w},b}\left[\frac{1}{2m}\sum_{i=1}^{m}\left(f_{\vec{w},b}(\vec{x}^{(i)}) - y^{(i)}\right)^2 + \frac{\lambda}{2m}\sum_{j=1}^{n} w_j^2\right]$$

Gradient descent

repeat {

$$w_j = w_j - \alpha \frac{\partial}{\partial w_j} J(\vec{w},b) \qquad = \frac{1}{m}\sum_{i=1}^{m}\left(f_{\vec{w},b}(\vec{x}^{(i)}) - y^{(i)}\right)x_j^{(i)} + \frac{\lambda}{m} w_j$$

$j = 1, \ldots, n$

$$b = b - \alpha \frac{\partial}{\partial b} J(\vec{w},b) \qquad = \frac{1}{m}\sum_{i=1}^{m}\left(f_{\vec{w},b}(\vec{x}^{(i)}) - y^{(i)}\right)$$

} simultaneous update

don't have to regularize b

Implementing gradient descent

repeat {

- $$w_j = w_j - \alpha \left[\frac{1}{m} \sum_{i=1}^{m} \left[\left(f_{\vec{w},b}(\vec{x}^{(i)}) - y^{(i)} \right) x_j^{(i)} \right] + \frac{\lambda}{m} w_j \right]$$

$$b = b - \alpha \frac{1}{m} \sum_{i=1}^{m} \left(f_{\vec{w},b}(\vec{x}^{(i)}) - y^{(i)} \right)$$

} simultaneous update $j = 1 \ldots n$

Implementing gradient descent

repeat {

$$w_j = w_j - \alpha \left[\frac{1}{m} \sum_{i=1}^{m} \left[\left(f_{\vec{\mathrm{w}},b}\left(\vec{\mathrm{x}}^{(i)}\right) - y^{(i)} \right) x_j^{(i)} \right] + \frac{\lambda}{m} w_j \right]$$

$$b = b - \alpha \frac{1}{m} \sum_{i=1}^{m} \left(f_{\vec{\mathrm{w}},b}\left(\vec{\mathrm{x}}^{(i)}\right) - y^{(i)} \right)$$

} simultaneous update $j = 1 \ldots n$

$$w_j = \underbrace{1 w_j - \alpha \frac{\lambda}{m} w_j}_{w_j \underbrace{\left(1 - \alpha \frac{\lambda}{m}\right)}_{\text{shrink } w_j}} \underbrace{- \alpha \frac{1}{m} \sum_{i=1}^{m} \left(f_{w,b}\left(\vec{x}^{(i)}\right) - y^{(i)} \right) x_j^{(i)}}_{\text{usual update}}$$

$$\alpha \frac{\lambda}{m}$$

$$0.01 \frac{1}{50} = 0.0002$$

$$w_j \underbrace{(1 - 0.0002)}_{0.9998}$$

How we get the derivative term (optional)

$$\frac{\partial}{\partial w_j} J(\vec{w}, b) = \frac{\partial}{\partial w_j}\left[\frac{1}{2m} \sum_{i=1}^{m} \left(\underbrace{f(\vec{x}^{(i)})}_{\vec{w}\cdot\vec{x}^{(i)}+b} - y^{(i)} \right)^2 + \frac{\lambda}{2m} \sum_{j=1}^{n} w_j^2 \right]$$

$$= \frac{1}{\cancel{2}m} \sum_{i=1}^{m} \left[\left(\vec{w}\cdot\vec{x}^{(i)} + b - y^{(i)} \right) \cancel{2} x_j^{(i)} \right] + \frac{\lambda}{\cancel{2}m} \cancel{2} w_j \quad \text{No } \sum_{j=1}^{n}$$

$$= \frac{1}{m} \sum_{i=1}^{m} \left[\left(\underbrace{\vec{w}\cdot\vec{x}^{(i)} + b}_{f(\vec{x})} - y^{(i)} \right) x_j^{(i)} \right] + \frac{\lambda}{m} w_j$$

$$= \frac{1}{m} \sum_{i=1}^{m} \left[\left(f_{\vec{w},b}(\vec{x}^{(i)}) - y^{(i)} \right) x_j^{(i)} \right] + \frac{\lambda}{m} w_j$$

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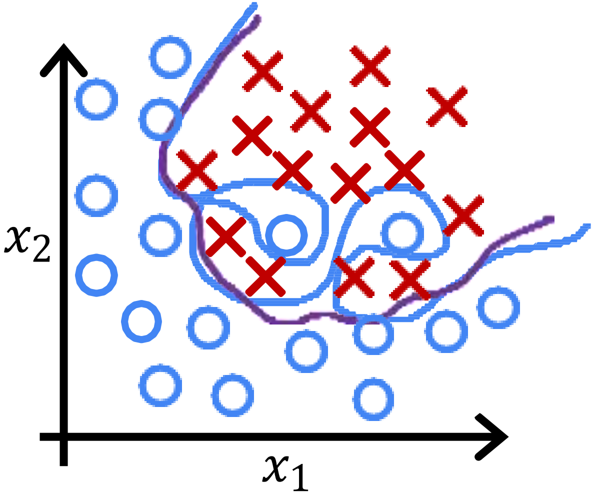
Regularization to Reduce Overfitting

Regularized Logistic Regression

Regularized logistic regression



$$z = w_1x_1 + w_2x_2 + w_3x_1^2x_2 + w_4x_1^2x_2^2 + w_5x_1^2x_2^3 + \cdots + b$$

$$f_{\vec{\mathrm{w}},b}(\vec{\mathrm{x}}) = \frac{1}{1+e^{-z}}$$

Cost function

$$\underbrace{J(\vec{\mathrm{w}},b) = -\frac{1}{m}\sum_{i=1}^{m}\left[y^{(i)}\log\left(f_{\vec{\mathrm{w}},b}(\vec{\mathrm{x}}^{(i)})\right) + (1-y^{(i)})\log\left(1-f_{\vec{\mathrm{w}},b}(\vec{\mathrm{x}}^{(i)})\right)\right] + \frac{\lambda}{2m}\sum_{j=1}^{n} w_j^2}_{\min_{\vec{w},b} J(\vec{\mathrm{w}},b) \;\rightarrow\; w_j \downarrow}$$

Regularized logistic regression

$$J(\vec{w},b) = -\frac{1}{m}\sum_{i=1}^{m}\left[y^{(i)}\log\left(f_{\vec{w},b}(\vec{x}^{(i)})\right) + (1-y^{(i)})\log\left(1-f_{\vec{w},b}(\vec{x}^{(i)})\right)\right] + \frac{\lambda}{2m}\sum_{j=1}^{n} w_j^2$$

$\min_{\vec{w},b}$

Gradient descent

Looks same as for linear regression!

repeat {

$$w_j = w_j - \alpha\frac{\partial}{\partial w_j}J(\vec{w},b) \quad = \frac{1}{m}\sum_{i=1}^{m}\left[\left(f_{\vec{w},b}(\vec{x}^{(i)}) - y^{(i)}\right)x_j^{(i)}\right] + \frac{\lambda}{m}w_j$$

$j = 1 \ldots n$

$$b = b - \alpha\frac{\partial}{\partial b}J(\vec{w},b) \quad = \frac{1}{m}\sum_{i=1}^{m}\left(f_{\vec{w},b}(\vec{x}^{(i)}) - y^{(i)}\right)$$

}

logistic regression

don't have to regularize b