
CS 232: Artificial Intelligence

Fall 2026

Prof. Carolyn Anderson
Wellesley College

Reminders

ONLINE

- ♦ I have help hours today ~~(W423)~~ and Monday from 3-4 (W323)
- ♦ Midterm 1 on Tuesday! I have notecards for you.
- ♦ Tutor hours:
 - Aeka: Thursdays 7:30-8:30 in H103
 - Amber: Friday 1:30-2:30 in Whiteboard Alley
 - Coco: Mondays 7-8 in Whiteboard Alley

Reminders

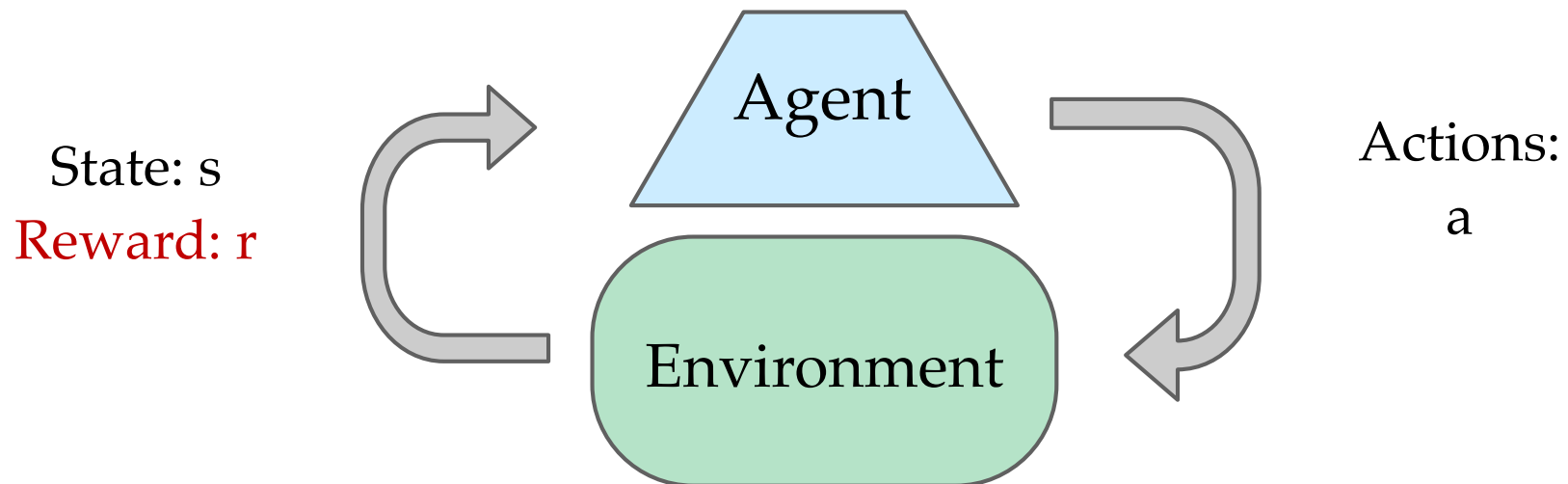
- ◆ There is a student in our class who requires the service of a note taker. If you take accurate and legible notes and attend class regularly, please apply for this position at <https://shasta.accessiblelearning.com/wellesley>. This is a paid position.

Recap

Reinforcement Learning

Basic idea:

- ♦ Agent receives feedback in the form of rewards
- ♦ Agent tries to learn to act in order to maximize expected rewards
- ♦ Agent learns from samples of observed outcomes (AKA: try something out and see what happens!)



RL Components

- ✦ Policy selection: how do we pick actions?
- ✦ Policy evaluation: how do we learn from the results of our actions?

Direct Evaluation

Main Idea:

- ♦ Act according to **policy** π
- ♦ In each state, write down the **sum of discounted rewards**: the value of a state s is equal to the expected immediate reward at s plus the **expected future reward** from the successor state s'
- ♦ **Average multiple samples**

Sample of $V(s)$: $sample = R(s, \pi(s), s') + \gamma V^\pi(s')$

discounting parameter

Temporal Difference Learning

Main Idea: learn from every experience

TD Learning

- ♦ Update $V(s)$ every time we make a transition $T(s,a,s',r)$
- ♦ Most likely outcomes (s') will contribute more updates
- ♦ Use a *learning rate* to control how quickly we update values

Sample of $V(s)$:

$$sample = R(s, \pi(s), s') + \gamma V^\pi(s')$$

Update to $V(s)$:

$$V^\pi(s) \leftarrow (1 - \alpha)V^\pi(s) + (\alpha)sample$$

Same update:

$$V^\pi(s) \leftarrow V^\pi(s) + \alpha(sample - V^\pi(s))$$

Policy Selection

RL policy selection must balance two things:

- ♦ **Exploitation**: choose the action with highest reward (according to current information)
- ♦ **Exploration**: choose a new action to discover new information more quickly.
- ♦ Different strategies for exploring:
 - Choose the action that has been tried least often in the current state.
 - Choose an action that leads to states that have been unexplored.
 - Choose a random action.

Semester Road Map

Almost all AI tasks can be grouped into one of three main categories:

- ♦ Search
- ♦ Classification
- ♦ Generation

AI Needs You Discussion

- ◆ What lessons does this chapter have for how we think about AI?
- ◆ What differences do you see between this era's technology debate and the current debate over AI?

Classification Methods

Classification Methods: Supervised Machine Learning

Lots of kinds!

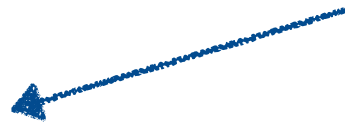
- Naïve Bayes
- Logistic regression
- Neural networks
- k-Nearest Neighbors
- random forests
- ...

Classification Methods: Supervised Machine Learning

Lots of kinds!

- Naïve Bayes
- Logistic regression
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- ...

we'll cover these



Classification Methods: Supervised Machine Learning

Input:

- a input d
- a fixed set of classes $C = \{c_1, c_2, \dots, c_j\}$
- A training set of m hand-labeled examples
 $(d_1, c_1) \dots (d_m, c_m)$

Output:

- a learned classifier $y: d \rightarrow c$

Defining a Machine Learning Classifier

Given m input/output pairs $(x^{(i)}, y^{(i)})$:

1. A feature representation of the input

$$x = [x_1, x_2 \dots x_n]$$

vector of features
expressing information
about input

2. A classification function

$$f(x) \rightarrow p(y | x)$$

$\hat{y}$ = predicted
class

3. An objective function for learning, like cross-entropy loss

Scoring the performance of the classifier

4. An algorithm for optimizing the objective function:
stochastic gradient descent.

A technique for updating the classifier

Selecting Features

Leslie L.F 6 years ago

This is my favorite sandwich on earth. I usually use basil instead of chives/tarragon. Sometimes i add a sprinkle of shredded parmesean. So good. I love it so much.

[Reply](#) [Is this helpful?](#)  1

Kayla 7 years ago

This sandwich is outrageous. Make it now. I did it once begrudgingly and ate it 4 days that week for lunch.

[Is this helpful?](#)  7

Lynne 10 years ago

Really wanted to love this sandwich. Of course, I love the butter and the baguette (and the salt), but the radishes just don't do anything for me.

[Reply](#) [Is this helpful?](#) 

SonomaSMB 10 years ago

No! Butter is the essence of this. The radishes DO mind.

[Is this helpful?](#)  51

Radish Sandwiches With Butter and Salt

Recipe from "Root to Leaf"
Adapted by Sam Sifton
Updated June 10, 2021



Total Time 10 minutes
Rating 5 ★★★★★ (1,212)
Comments [Read 123 comments](#) 

Steven Satterfield, the chef at Miller Union in Atlanta, included this very French picnic recipe in his cookbook, "Root to Leaf." As he points out, the key is to use a lot of butter, a lot of radishes and plenty of salt. The recipe yields four sturdy desk- or school-lunch sandwiches, or you can divide them further, into a dozen little bites for hors d'oeuvres. — Sam Sifton

franw 9 years ago

What a simple taste sensation! This is really a very filling and go-to sandwich when you are short on supply. That said, it makes for very pretty sandwiches when serving tea as well. Replace butter with cream cheese-wonderful!

The baguette is a very nice presentation but I have used Hawaiian sweet bread to shepherders and its all good. The versatility is key here.

I would recommend to try and save your judgement on this sandwich till you do.

[Is this helpful?](#)  12

 Save

Logistic Regression Classifiers

Is this spam?

Subject: Important notice!
From: Stanford University <newsforum@stanford.edu>
Date: October 28, 2011 12:34:16 PM PDT
To: undisclosed-recipients;;

Greats News!

You can now access the latest news by using the link below to login to Stanford University News Forum.

<http://www.123contactform.com/contact-form-StanfordNew1-236335.html>

Click on the above link to login for more information about this new exciting forum. You can also copy the above link to your browser bar and login for more information about the new services.

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Who wrote which Federalist papers?

Anonymous essays try to convince New York to ratify U.S Constitution.
Authorship of 12 of the letters in dispute.

Solved by Mosteller and Wallace (1963) using Bayesian methods



What is the subject of this research article?

MEDLINE Article



?

Blood Supply
Chemistry
Drug Therapy
Embryology
Epidemiology
...

Text Classification: definition

Input:

- a document $\mathbf{x} = [x_1, \dots, x_n]$
- a fixed set of classes $C = \{c_1, c_2, \dots, c_j\}$
pos, neg

Output: a predicted class

$$\hat{y} \in C$$

y = true class label

$\hat{y}$ = predicted class label

Binary Classification in Logistic Regression

Given a series of input / output pairs:

$$x^i, y^i$$

For each observation $x^{(i)}$

- We represent $x^{(i)}$ by: $[x_1, x_2 \dots x_n]$
- We compute an output: $\hat{y}^i \in \{pos, neg\}$
 $1, 0$

Sentiment example: does $y=1$ or $y=0$?

Leslie L.F 6 years ago

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Features in logistic regression

For feature x_i , weight w_i tells is how important is x_i

- x_i = "review contains love": $w_i = +10$
- x_j = "review contains disappointing": $w_j = -5$
- x_k = "review contains outrageous": $w_k = -2$

Logistic Regression for one observation x

Input observation: $x = [x_1, x_2 \dots x_n]$

Weights (one per feature): $W = [w_1, w_2 \dots w_n]$

Output: a predicted class
 $\hat{y} \in \{0, 1\}$

How to do classification

For each feature x_i , weight $\underline{w_i}$ tells us importance of x_i

We also have a special term : $b = \text{bias}$

We'll sum up all the weighted features and the bias:

$$z = \left(\sum_{i=1}^n w_i x_i \right) + b$$

$$z = \underline{w \cdot x} + b$$

If the sum is high, we predict $\hat{y} = 1$
If low, $\hat{y} = 0$

But we want a probabilistic classifier

We need to formalize “sum is high”.

We want a model that can tell us:

$$p(y=1 \mid x; w)$$

$$p(y=0 \mid x; w)$$

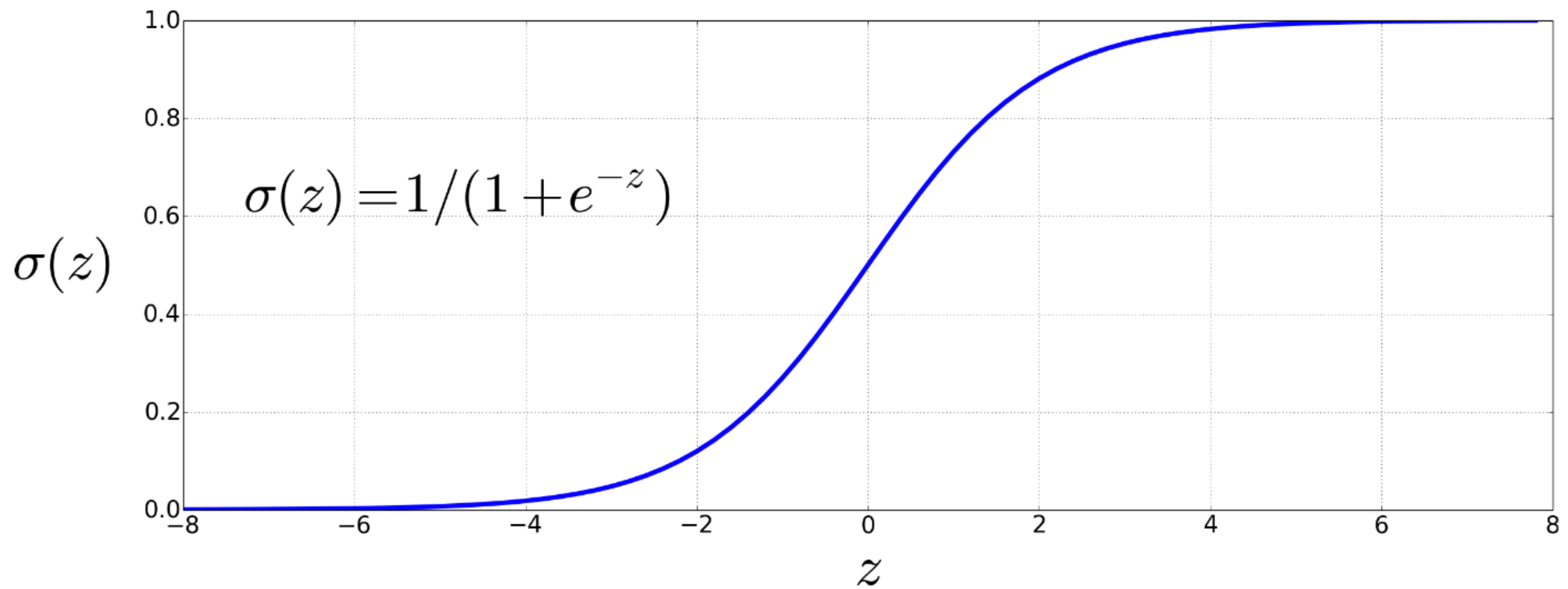
The problem: z isn't a probability, it's just a number!

$$z = w \cdot x + b$$

Use a function that goes from
0 to 1

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

The very useful sigmoid or logistic function



Idea of logistic regression

Compute $w \cdot x + b$

Then pass it through the sigmoid function:

$$\sigma(w \cdot x + b)$$

Treat it as a probability

Making probabilities with sigmoids

$$\begin{aligned} P(y = 1) &= \sigma(w \cdot x + b) \\ &= \frac{1}{1 + \exp(-(w \cdot x + b))} \end{aligned}$$

$$\begin{aligned} P(y = 0) &= 1 - \sigma(w \cdot x + b) \\ &= 1 - \frac{1}{1 + \exp(-(w \cdot x + b))} \end{aligned}$$

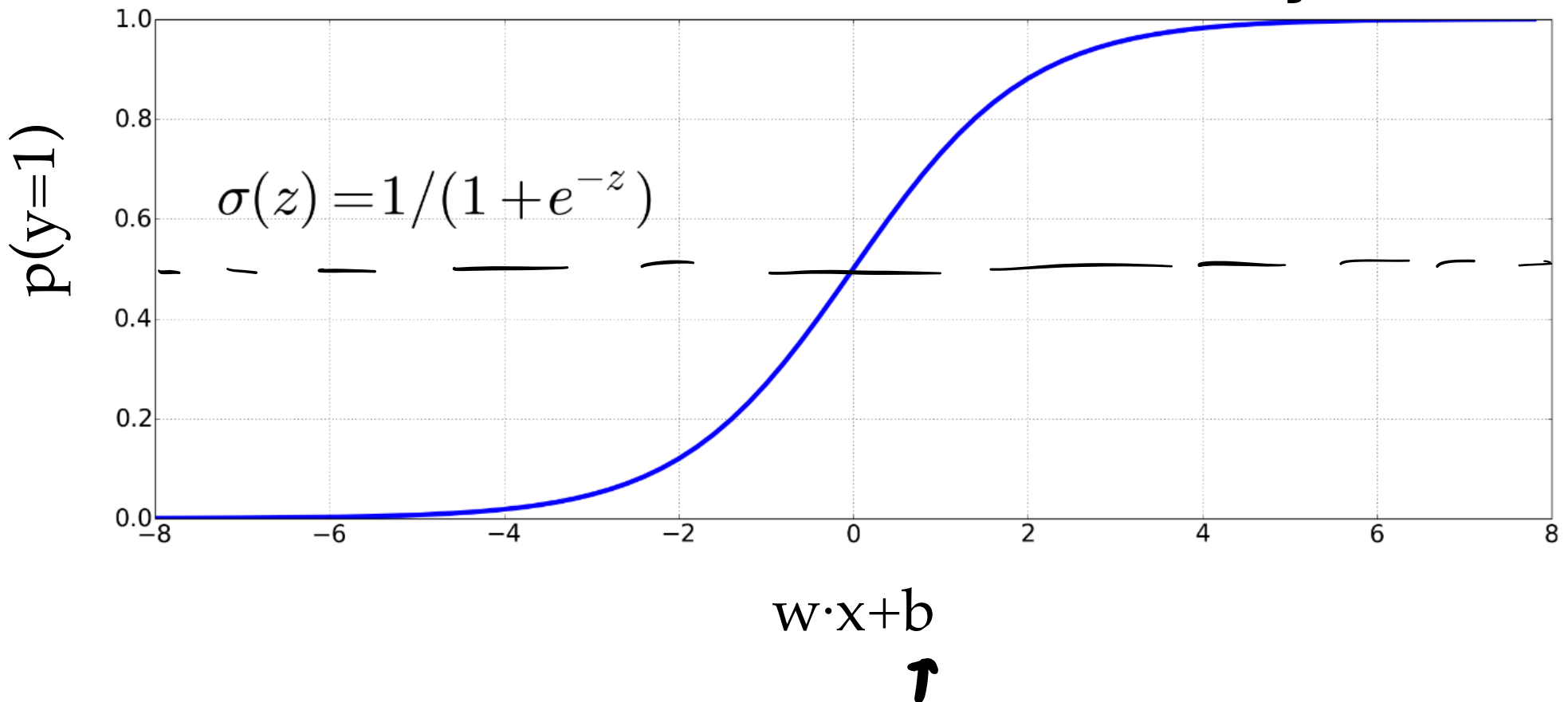
Turning a probability into a classifier

$$\text{decision}(x) = \begin{cases} 1 & \text{if } P(y = 1|x) > 0.5 \\ 0 & \text{otherwise} \end{cases}$$

0.5 is our decision boundary

Turning a probability into a classifier

0.5 is the **decision boundary**



The bias term b can be used to shift the intercept!

Logistic Regression Example: Text Classification

Sentiment example: does $y=1$ or $y=0$?

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Ricki Snyder for The New York Times

Total Time 10 minutes
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Comments [Read 123 comments](#) ↴

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Sam Sifton

Features

Var	Definition	Value
x_1	count(positive words)	2
x_2	count(negative words)	0
x_3	1 if "no" or "n't" in doc else 0	1
x_4	1 if ! in doc else 0	0
x_5	log(word count)	3.33

Weights

Var	Definition	Value	<u>w</u>
w_1	weight on positive words	2	2.5
w_2	weight on negative words	0	-2.5
w_3	weight on negation value	1	-3
w_4	weight on ! value	0	4
w_5	weight on length	3.33	0.1

$$b = 0.2$$

Classifying sentiment for input x

$$\begin{aligned} p(y=1|x) &= \sigma(w \cdot x + b) \\ &= \sigma([2.5, -2.5, -3, 4, 0.1] \cdot \\ &\quad [2, 0, 1, 0, 3.33] + 0.2) \\ &= \sigma(2.53) \\ &= 0.926 \end{aligned}$$

$$p(y=0|x) = 1 - 0.926 = 0.074$$

Classification in (binary) logistic regression: summary

Given:

- a set of classes: (+ sentiment, - sentiment)
- a vector $\mathbf{x}$ of features $[x_1, x_2, x_3, \dots, x_n]$
 - $x_1 = \text{count}(\text{"awesome"})$ in document
 - $x_3 = 1$ if "no" in document else 0
- A vector $\mathbf{w}$ of weights $[w_1, w_2, \dots, w_n]$
 - w_i for each feature f_i

$$\begin{aligned} P(y = 1) &= \sigma(w \cdot x + b) \\ &= \frac{1}{1 + \exp(-(w \cdot x + b))} \end{aligned}$$

Turning a probability into a classifier

$$\text{decision}(x) = \begin{cases} 1 & \text{if } P(y = 1|x) > 0.5 \\ 0 & \text{otherwise} \end{cases} \quad \begin{array}{l} \text{if } w \cdot x + b > 0 \\ \text{if } w \cdot x + b \leq 0 \end{array}$$

What do we conclude about this review?

$$p(y=1) = 92.6\%$$

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The two phases of logistic regression

Training: We learn W and b using
stochastic gradient descent & cross-entropy
loss

Test:

Given a test example x we
compute $p(y|x)$ using learned weights
 W & b and return whichever label
($y=1$ or $y=0$) has highest probability.