CS 2731
Introduction to Natural Language Processing

Session 11: Neural networks part 1

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University of Pittsburgh | School of Computing and Information

Quiz

- Go to **Quizzes > Quiz 10-01** on Canvas
- You have until **2:40pm** to complete it
- Allowed resources
  - Textbook
  - Your notes (on a computer or physical)
  - Course slides and website
- Resources not allowed
  - Generative AI
  - Internet searches

Course logistics: homework

- Homework 2 is **due next Thu Oct 9**
  - The Kaggle competition has been posted

Course logistics: project

- Next project deliverable: project proposal due Oct 16
  - Will include plans for **task, data, methods, evaluation**
  - Include example input and output
  - Literature review of at least 3 related papers
  - Feel free to email or book office hours with Michael to discuss
- We have $150 total as a class to use on OpenAI LLM credits
- Michael will let you know about open-source models set up on School of Computing and Information servers

Midterm course evaluation (OMETs)

- https://go.blueja.io/Iq36newH2UeDZRnTEA4pDg
- All types of feedback are welcome (critical and positive)
- **Completely anonymous, will not affect grades**
- Let me know what's working and what to improve on while the course is still running!
- Please be as specific as possible
- Available until **next Mon Oct 6**

Structure of this course

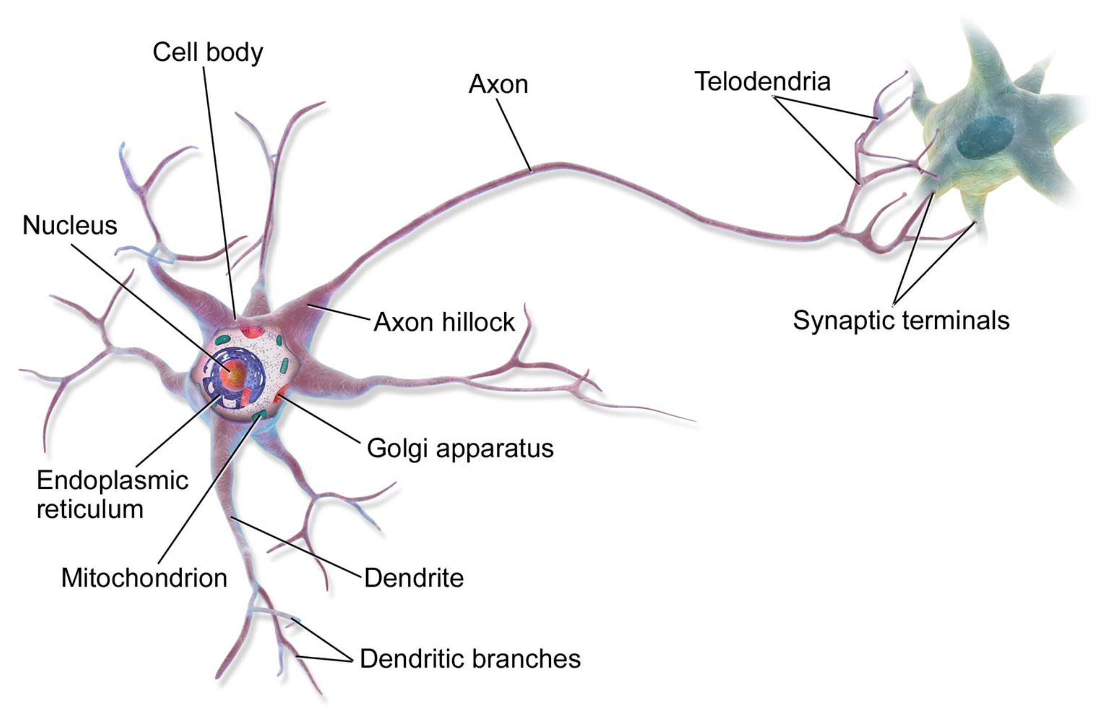
MODULE 1	Introduction and text processing	text normalization, machine learning, NLP tasks	
	Approaches	**How text is represented**	**NLP tasks**
MODULE 2	statistical machine learning	n-grams	language modeling text classification
MODULE 3	neural networks	static word vectors	text classification
MODULE 4	transformers and LLMs	contextual word vectors	language modeling text classification
MODULE 5	Sequence labeling and parsing		
MODULE 6	NLP applications and ethics		

Lecture overview: neural networks part 1

- Neural network fundamentals
- Non-linear activation functions
- Feedforward neural networks as classifiers
- Feedforward neural networks with word embedding input
- Coding activity

Neural network fundamentals

This is in your brain



Neural network unit: This is not in your brain

Output value

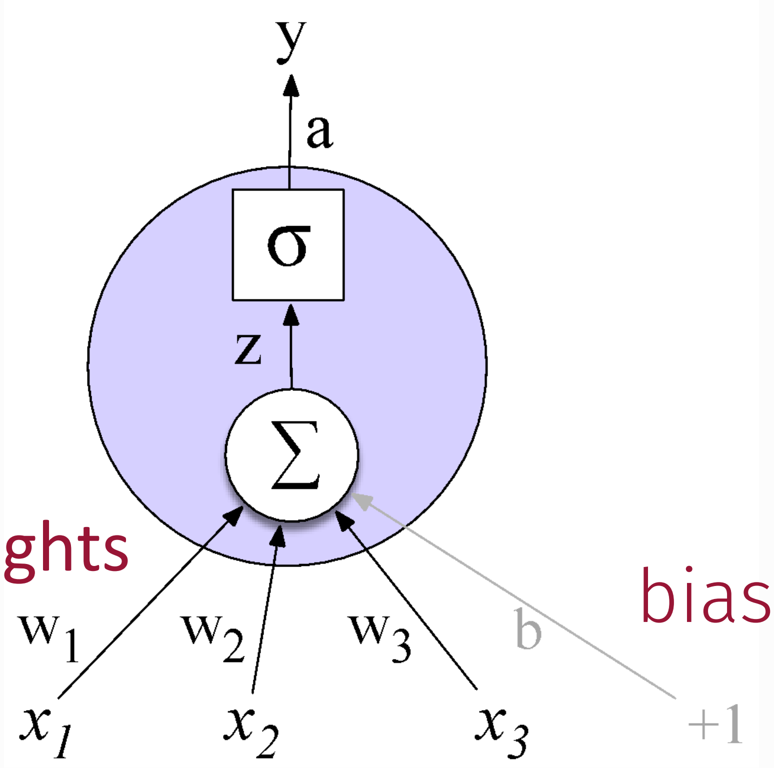
Non-linear transform

Weighted sum

Weights

Input layer

bias



Slide adapted from Jurafsky & Martin

The Variables in Our Very Important Formula

- $\mathbf{x}$ A vector of features of n dimensions (like number of positive sentiment words, length of document, etc.)
- $\mathbf{w}$ A vector of weights of n dimensions specifying how discriminative each feature is
- b A scalar bias term that shifts z
- z The raw score
- y A random variable (e.g., $y = 1$ means positive sentiment and $y = 0$ means negative sentiment

Slide adapted from David Mortensen

The Fundamentals

The fundamental equation that describes a unit of a neural network should look very familiar:

$$z = b + \sum_i w_i x_i \tag{1}$$

Which we will represent as

$$z = \mathbf{w} \cdot \mathbf{x} + b \tag{2}$$

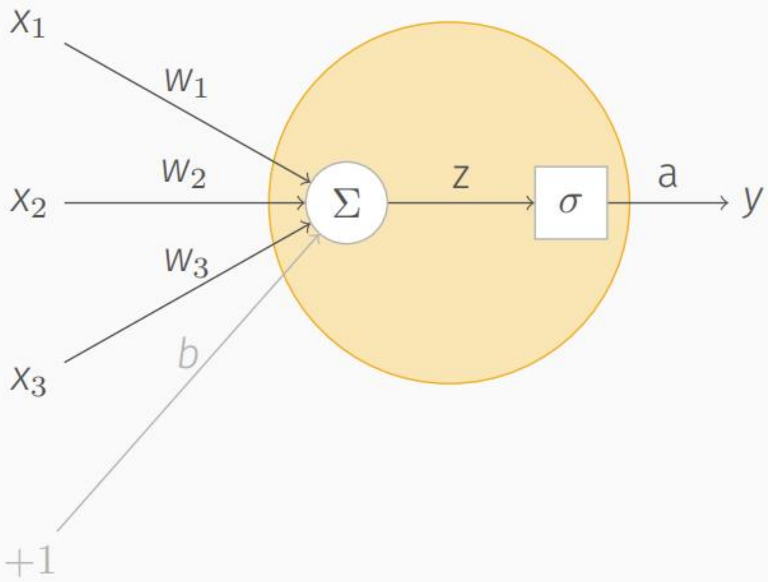
But we do not use z directly. Instead, we pass it through a non-linear function, like the sigmoid function:

$$y = \sigma(z) = \frac{1}{1 + e^{-z}} \tag{3}$$

(which has some nice properties even though, in practice, we will prefer other functions like tanh and ReLU).

Slide adapted from David Mortensen

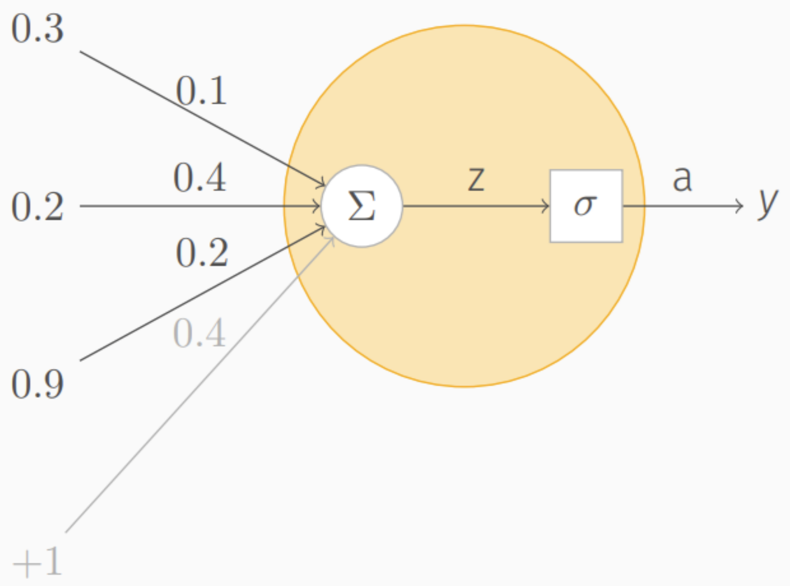
A Unit Illustrated



Take, for example, a scenario in which our unit has the weights [0.1, 0.4, 0.2] and the bias term 0.4 and the input vector x has the values [0.3, 0.2, 0.9].

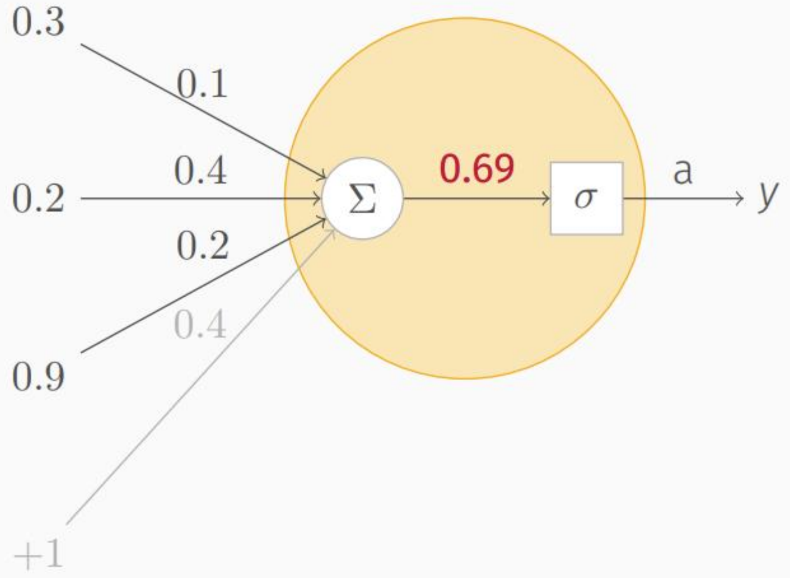
Slide adapted from David Mortensen

Filling in the Input Values and Weights



Slide adapted from David Mortensen

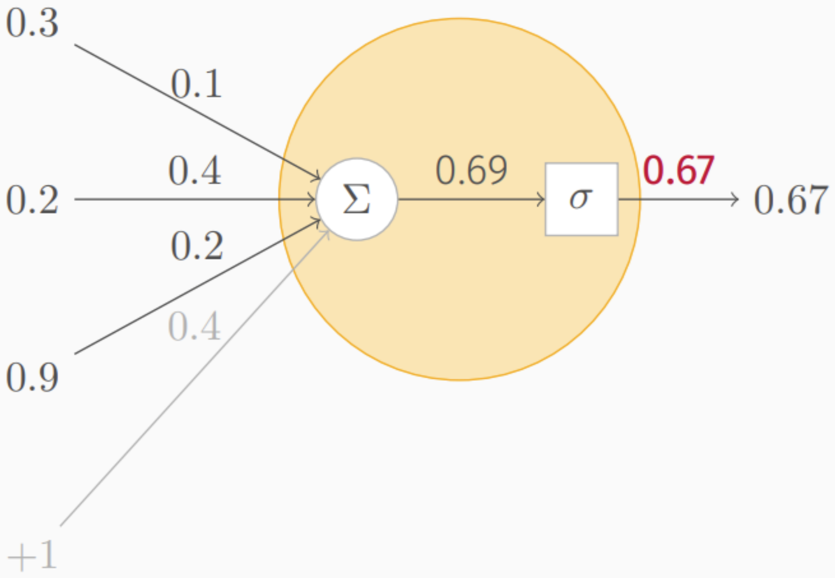
Multiplying the Input Values and Weights and Summing Them (with the Bias Term)



$$z = x_1 w_1 + x_2 w_2 + x_3 w_3 + b = 0.1(0.3) + 0.4(0.2) + 0.2(0.9) + 0.4 = 0.69 \tag{4}$$

Slide adapted from David Mortensen

Applying the Activation Function (Sigmoid)



$$y = \sigma(0.69) = \frac{1}{1 + e^{-0.69}} = 0.67 \tag{5}$$

Slide adapted from David Mortensen

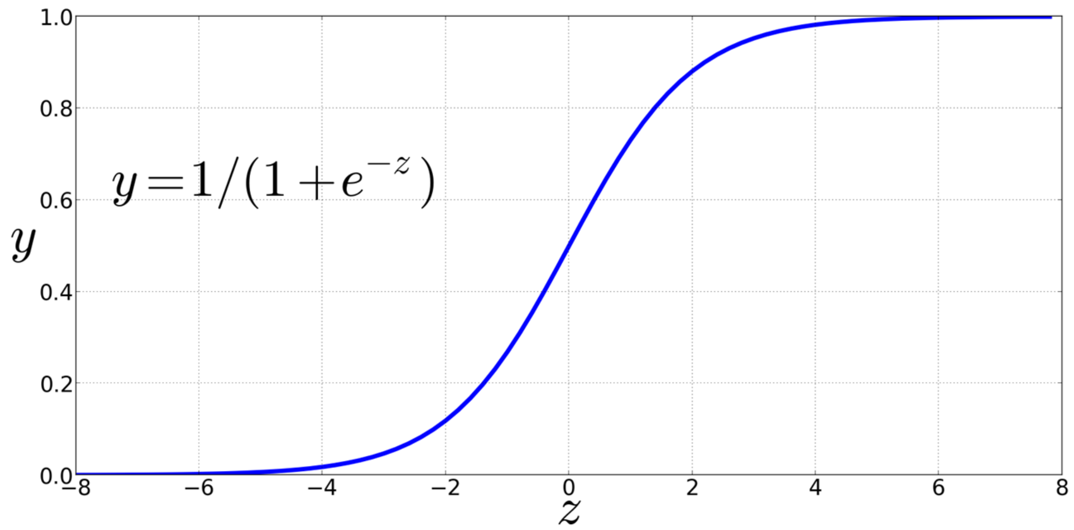
Non-linear activation functions

Non-Linear Activation Functions

We're already seen the sigmoid for logistic regression:

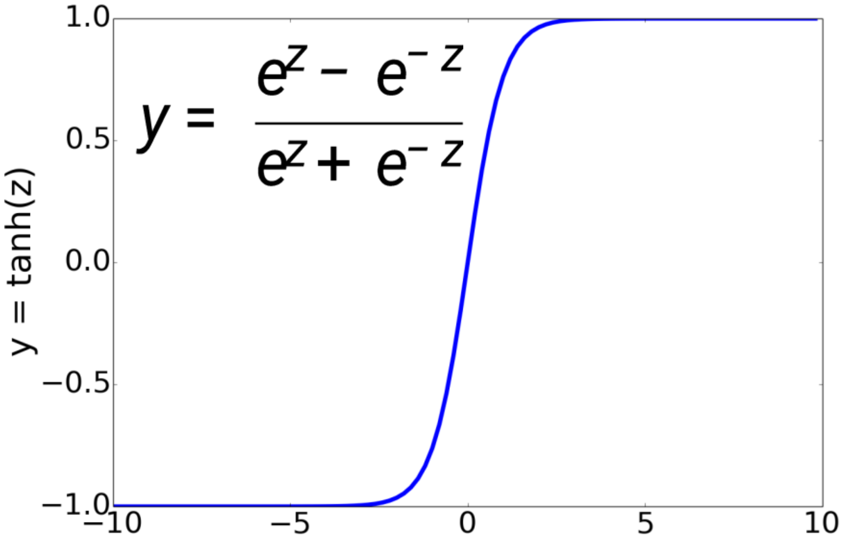
Sigmoid

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



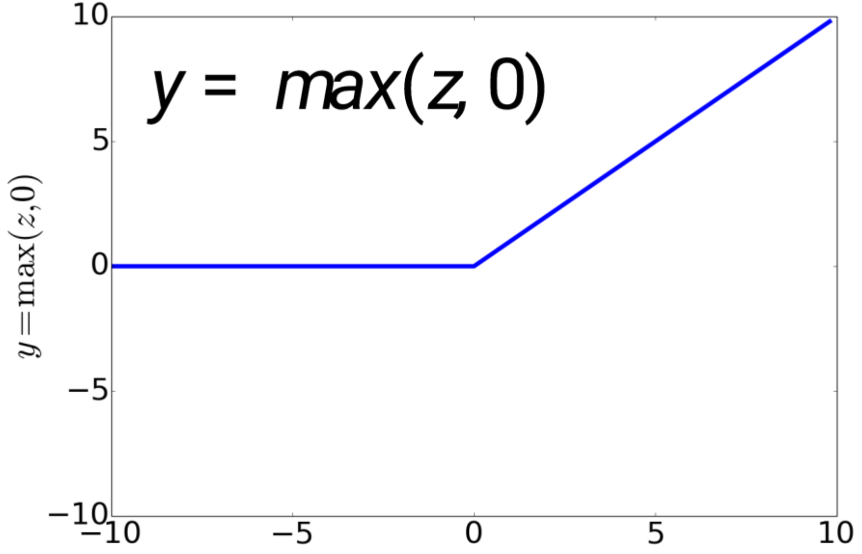
Slide adapted from Jurafsky & Martin

Nonlinear activation functions besides sigmoid



tanh

Most common:



ReLU
Rectified Linear

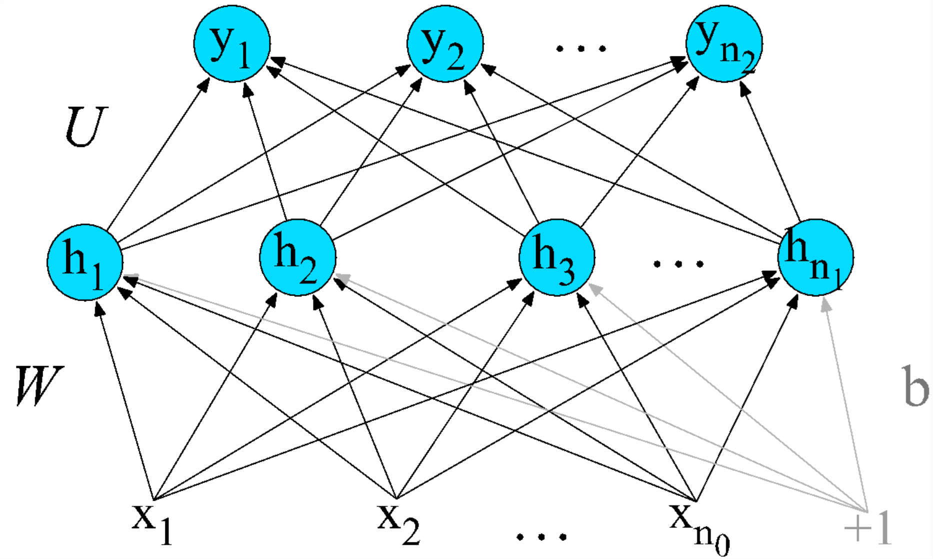
Feedforward neural networks

Adding multiple units to a neural network increases its power to learn patterns in data. **Feedforward Neural Nets (FFNNs or MLPs)**

Slide adapted from David Mortensen

Feedforward Neural Networks

Can also be called **multi-layer perceptrons** (or **MLPs**) for historical reasons

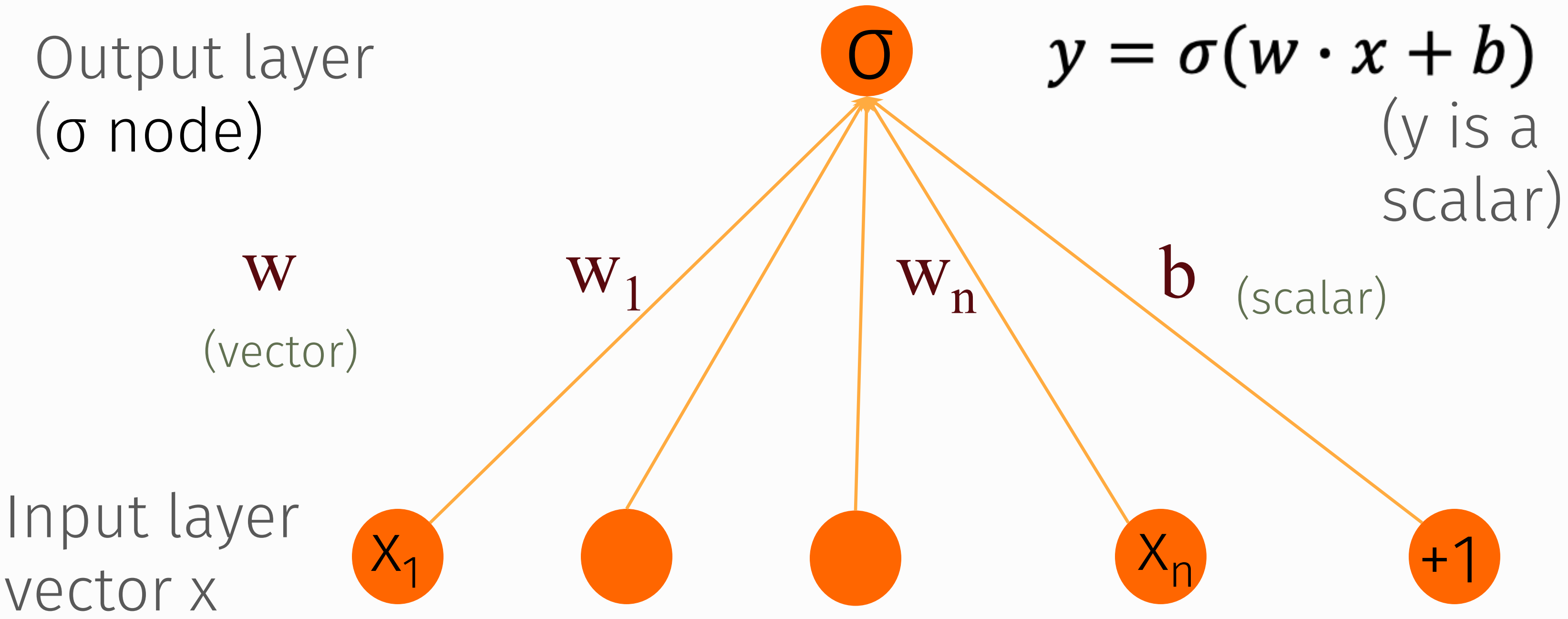


The simplest FFNN is just binary logistic regression
(INPUT LAYER = feature vector)

Slide adapted from David Mortensen

Binary Logistic Regression as a 1-layer Network

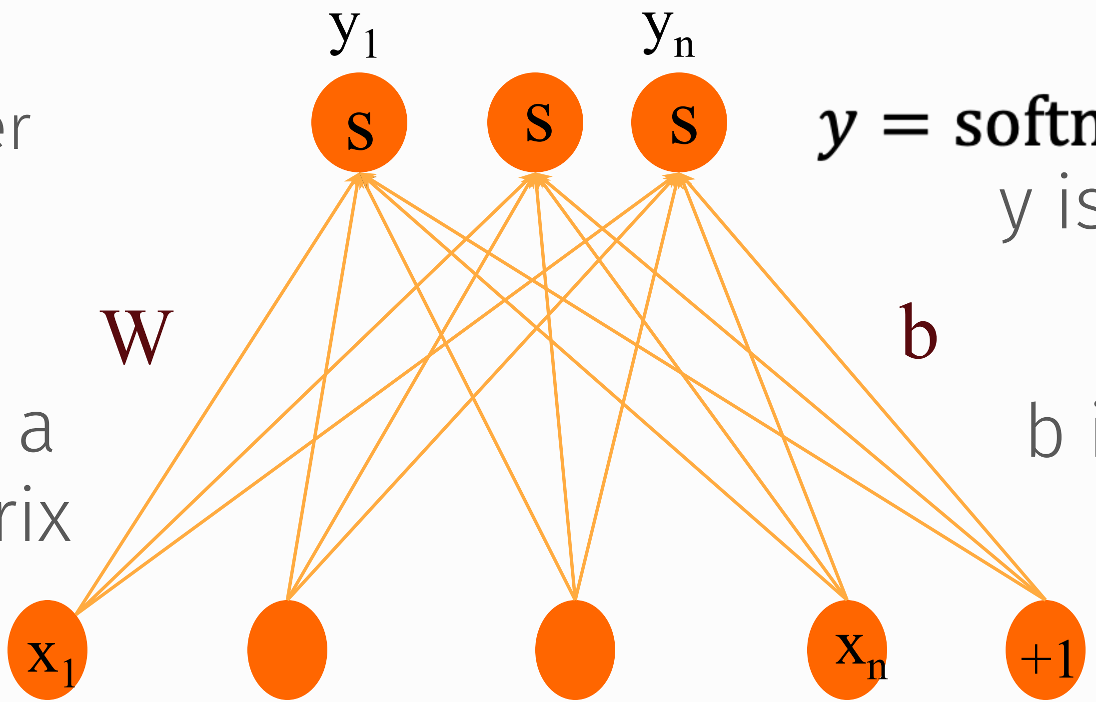
(we don't count the input layer in counting layers!)



Multinomial Logistic Regression as a 1-layer Network

Fully connected single layer network

Output layer (softmax nodes)



$$y = \text{softmax}(Wx + b)$$

y is a vector

W is a matrix

b is a vector

Input layer scalars

Slide adapted from Jurafsky & Martin

The real power comes when multiple layers are added

Slide adapted from David Mortensen

Two-Layer Network with scalar output

Output layer
(σ node)

$y = \sigma(z)$ y is a scalar

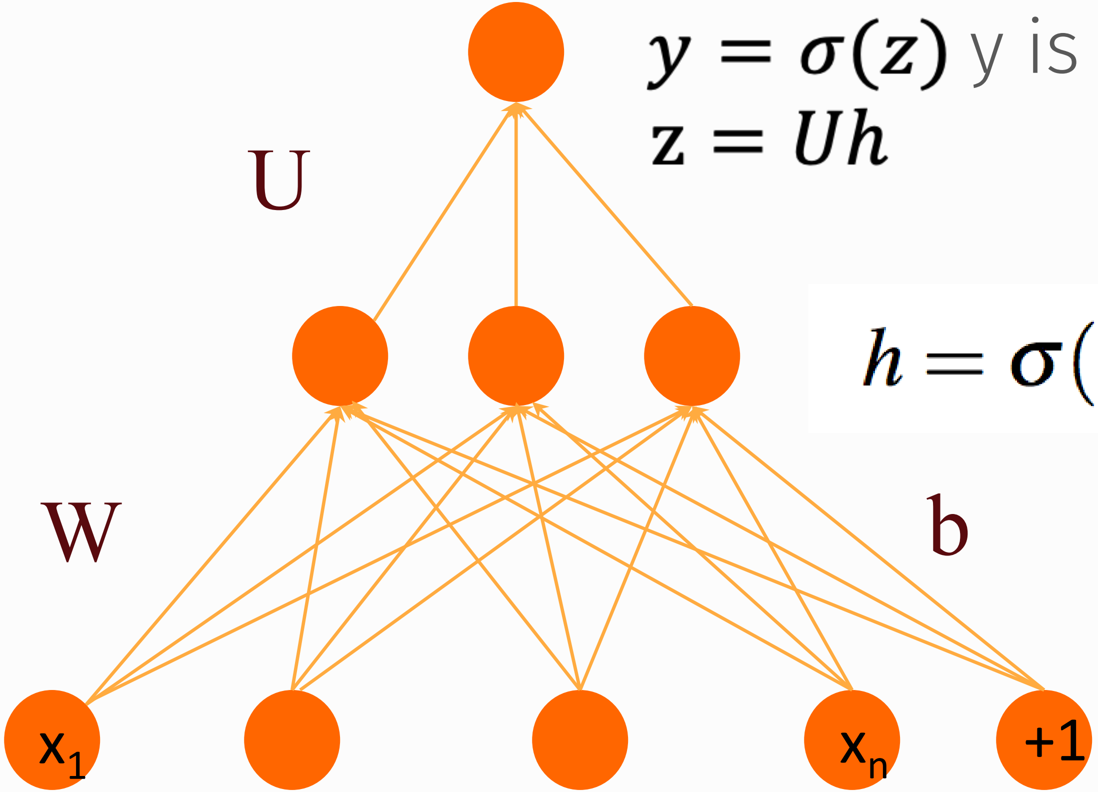
$z = Uh$

hidden units
(σ node)

$h = \sigma(Wx + b)$

Could be
ReLU
or tanh

Input layer
(vector)



Slide adapted from Jurafsky & Martin

Two-Layer Network with scalar output

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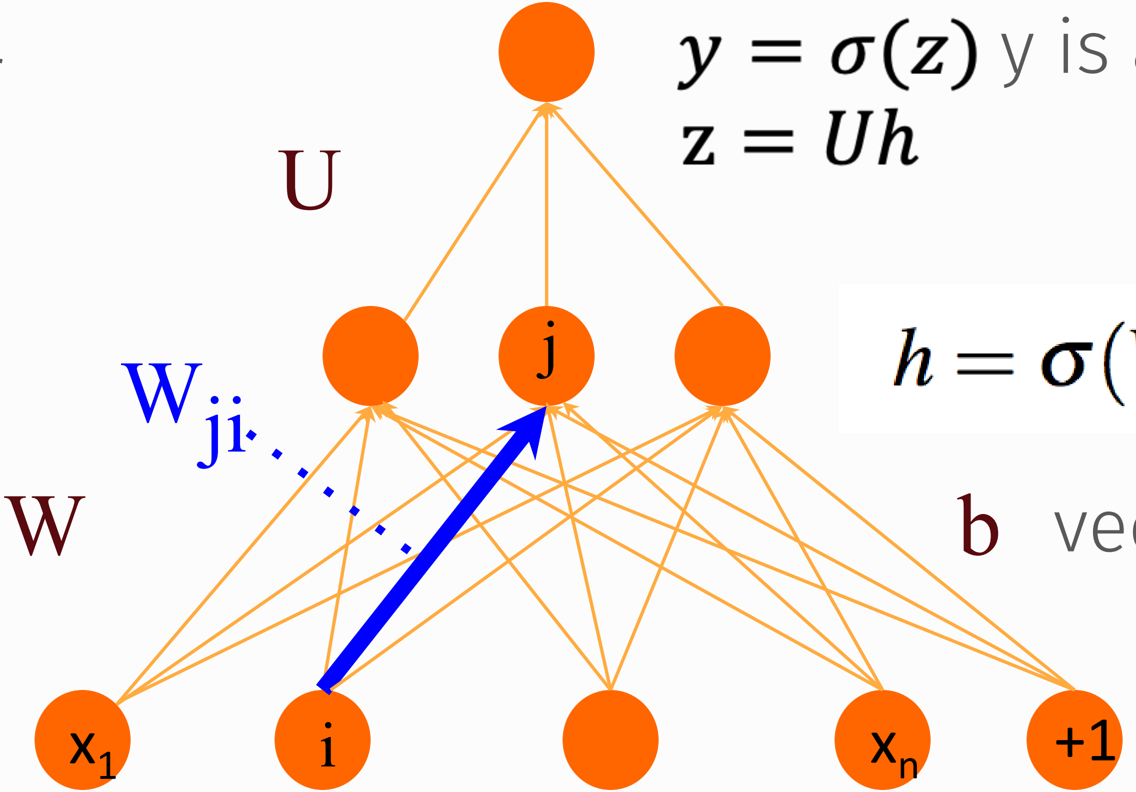


b vector

Input layer
(vector)

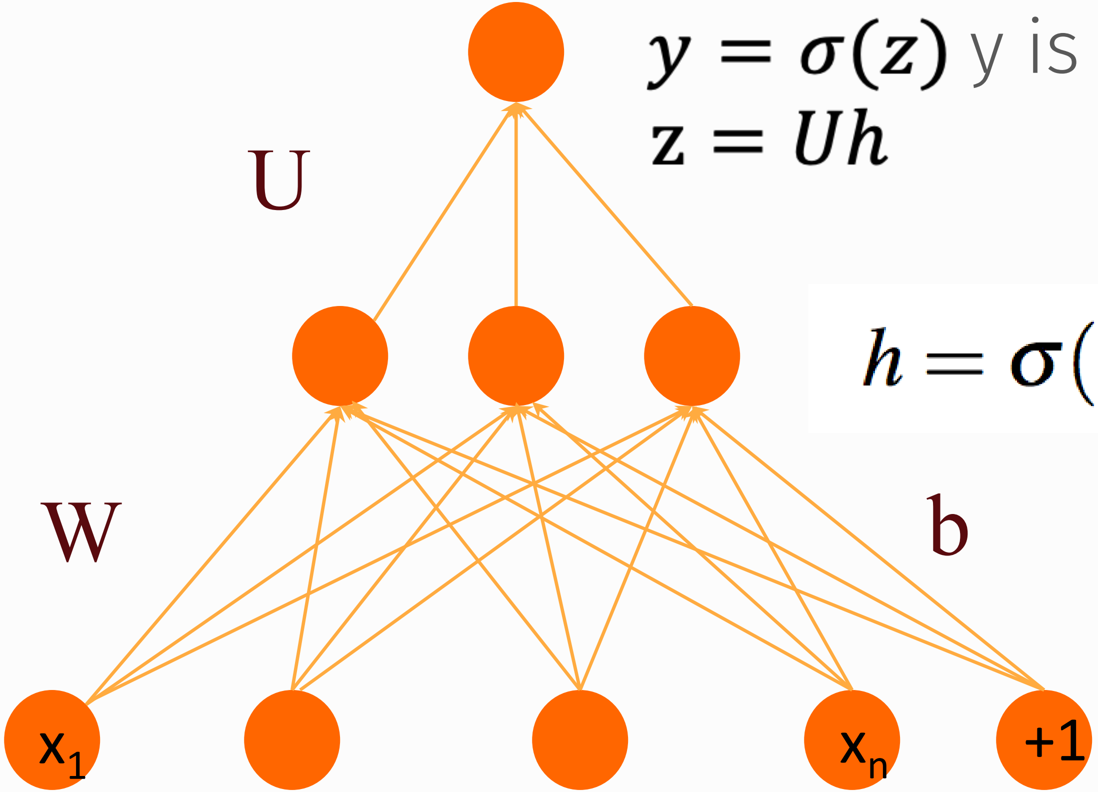
Slide adapted from Jurafsky & Martin

Two-Layer Network with scalar output

Output layer
(σ node)

hidden units
(σ node)

Input layer
(vector)



$y = \sigma(z)$ y is a scalar

$z = Uh$

$$h = \sigma(Wx + b)$$

Could be
ReLU
Or tanh

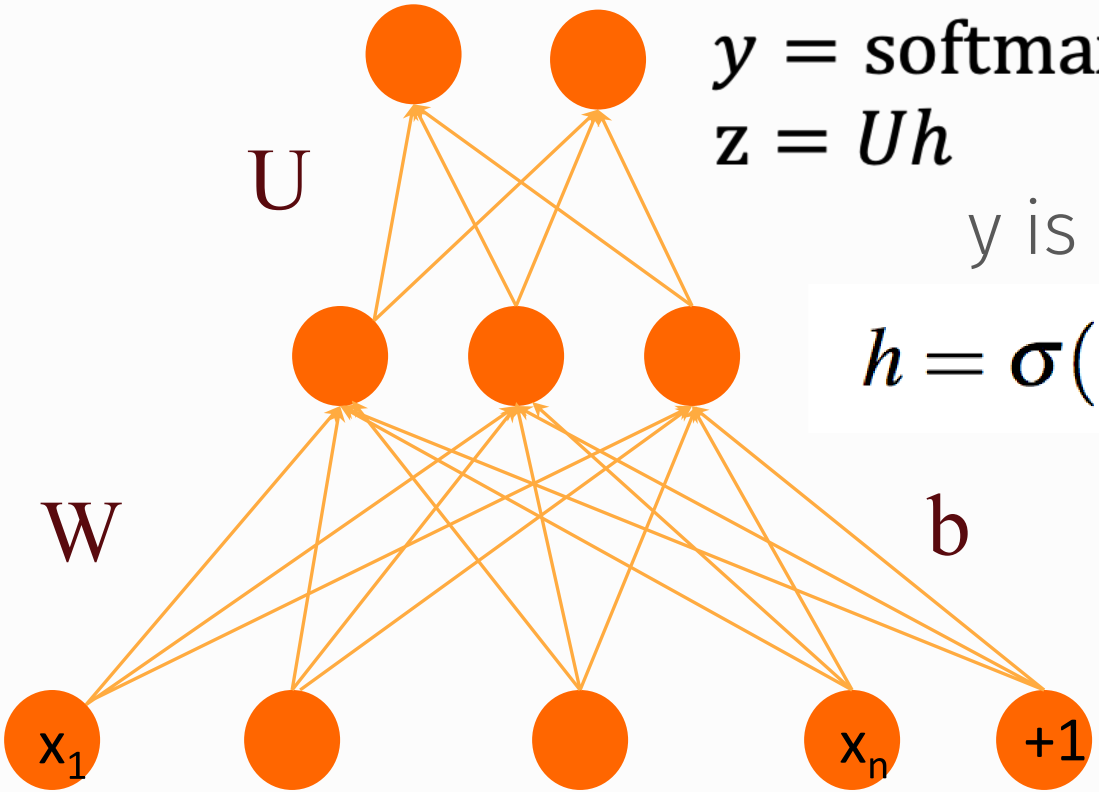
Slide adapted from Jurafsky & Martin

Two-Layer Network with softmax output

Output layer (σ node)

hidden units (σ node)

Input layer (vector)



$$y = \text{softmax}(z)$$
$$z = Uh$$

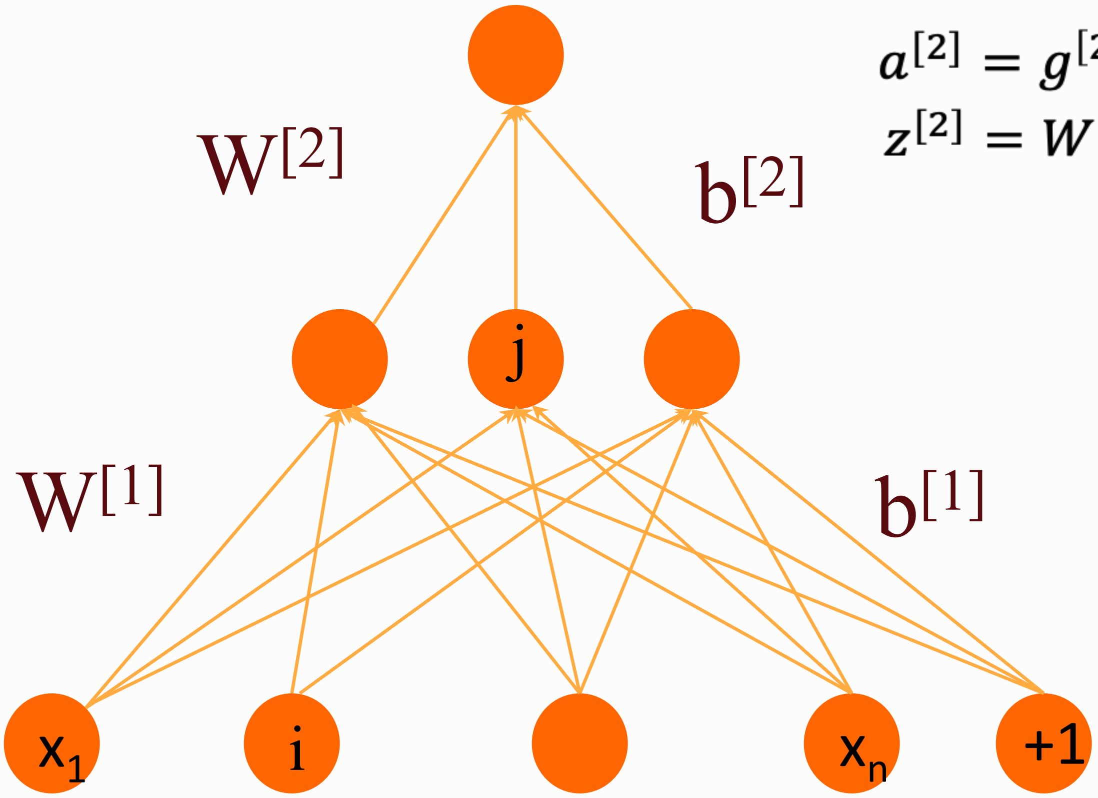
y is a vector

$$h = \sigma(Wx + b)$$

Could be ReLU Or tanh

Slide adapted from Jurafsky & Martin

Multi-layer Notation



$y = a^{[2]}$

$a^{[2]} = g^{[2]}(z^{[2]})$ sigmoid or softmax

$z^{[2]} = W^{[2]}a^{[1]} + b^{[2]}$

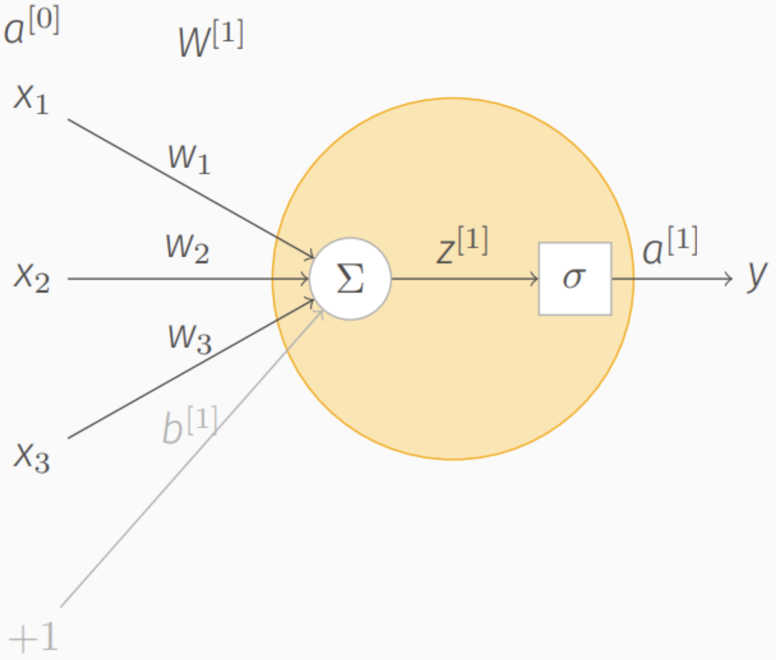
$a^{[1]} = g^{[1]}(z^{[1]})$ ReLU

$z^{[1]} = W^{[1]}a^{[0]} + b^{[1]}$

$a^{[0]}$

Slide adapted from Jurafsky & Martin

A Forward Pass in Terms of Multi-Layer Notation



for each $i \in 1..n$ **do**

$z^{[i]} \leftarrow W^{[i]} a^{[i-1]} + b^{[i]}$

$a^{[i]} \leftarrow g^{[i]}(z^{[i]})$

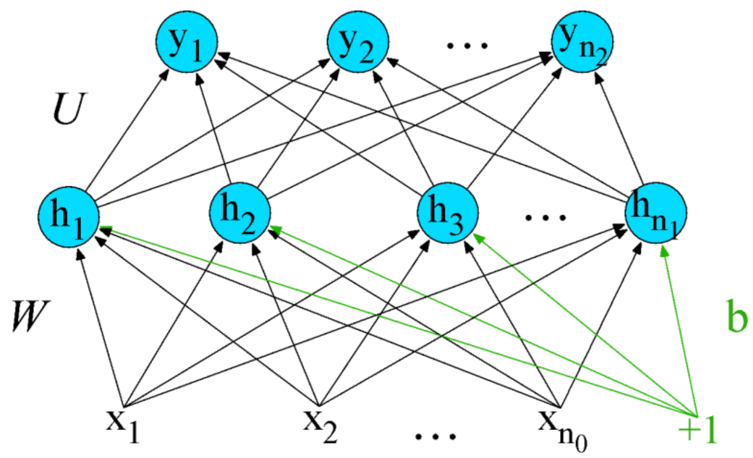
end for

$\hat{y} \leftarrow a^{[n]}$

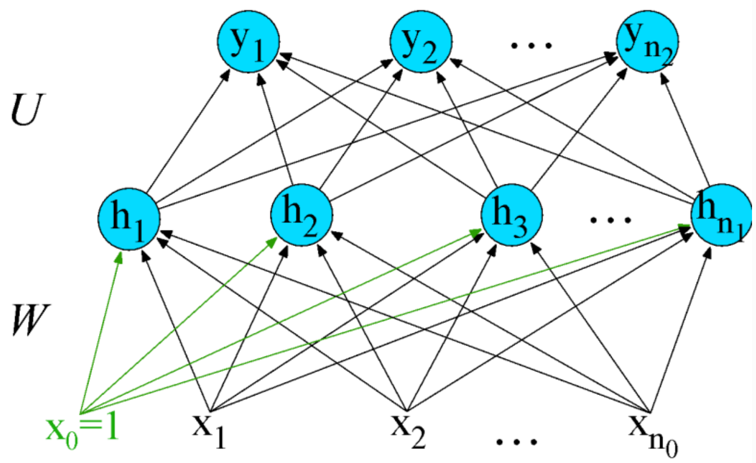
Slide credit: David Mortensen

Replacing the bias unit

Instead of:



We'll do this:



Slide adapted from Jurafsky & Martin

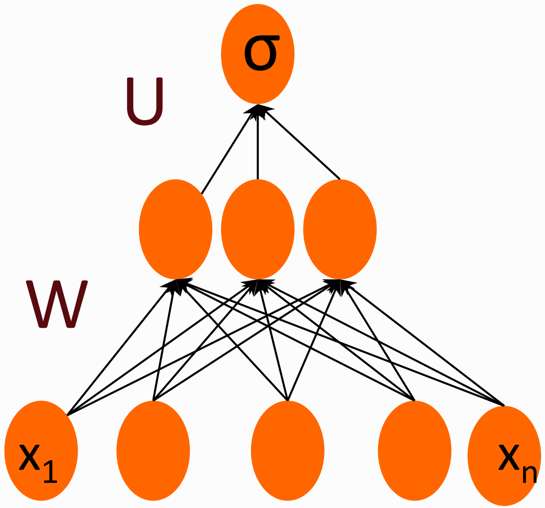
Feedforward neural nets as classifiers

Classification: Sentiment Analysis

We could do exactly what we did with logistic regression

Input layer are binary features as before

Output layer is 0 or 1



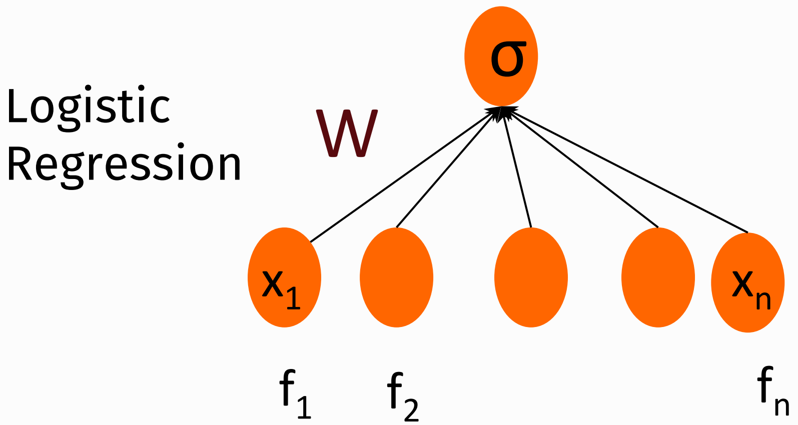
Slide adapted from Jurafsky & Martin

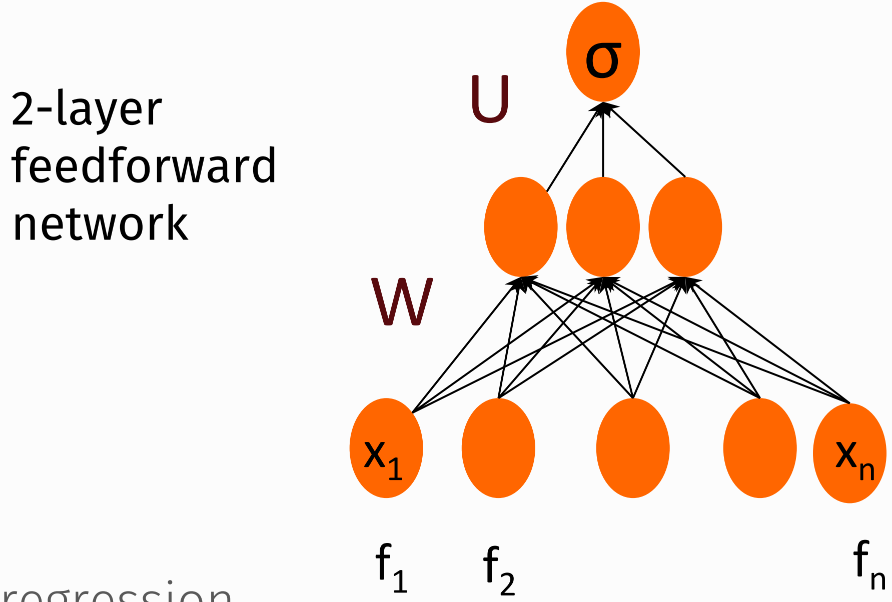
Sentiment Features

Var	Definition
x_1	count(positive lexicon) $\in$ doc)
x_2	count(negative lexicon) $\in$ doc)
x_3	$\begin{cases} 1 & \text{if ``no''} \in \text{doc} \\ 0 & \text{otherwise} \end{cases}$
x_4	count(1st and 2nd pronouns $\in$ doc)
x_5	$\begin{cases} 1 & \text{if ``!''} \in \text{doc} \\ 0 & \text{otherwise} \end{cases}$
x_6	log(word count of doc)

Slide adapted from Jurafsky & Martin

Feedforward nets for simple classification





Just adding a hidden layer to logistic regression

- allows the network to use non-linear interactions between features
- which may (or may not) improve performance.

Slide adapted from Jurafsky & Martin

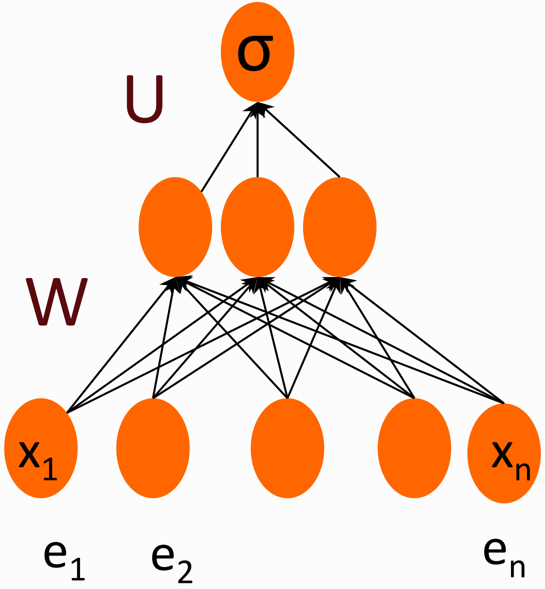
Feedforward neural networks with word embedding input

Even better: representation learning

The real power of deep learning comes from the ability to **learn** features from the data

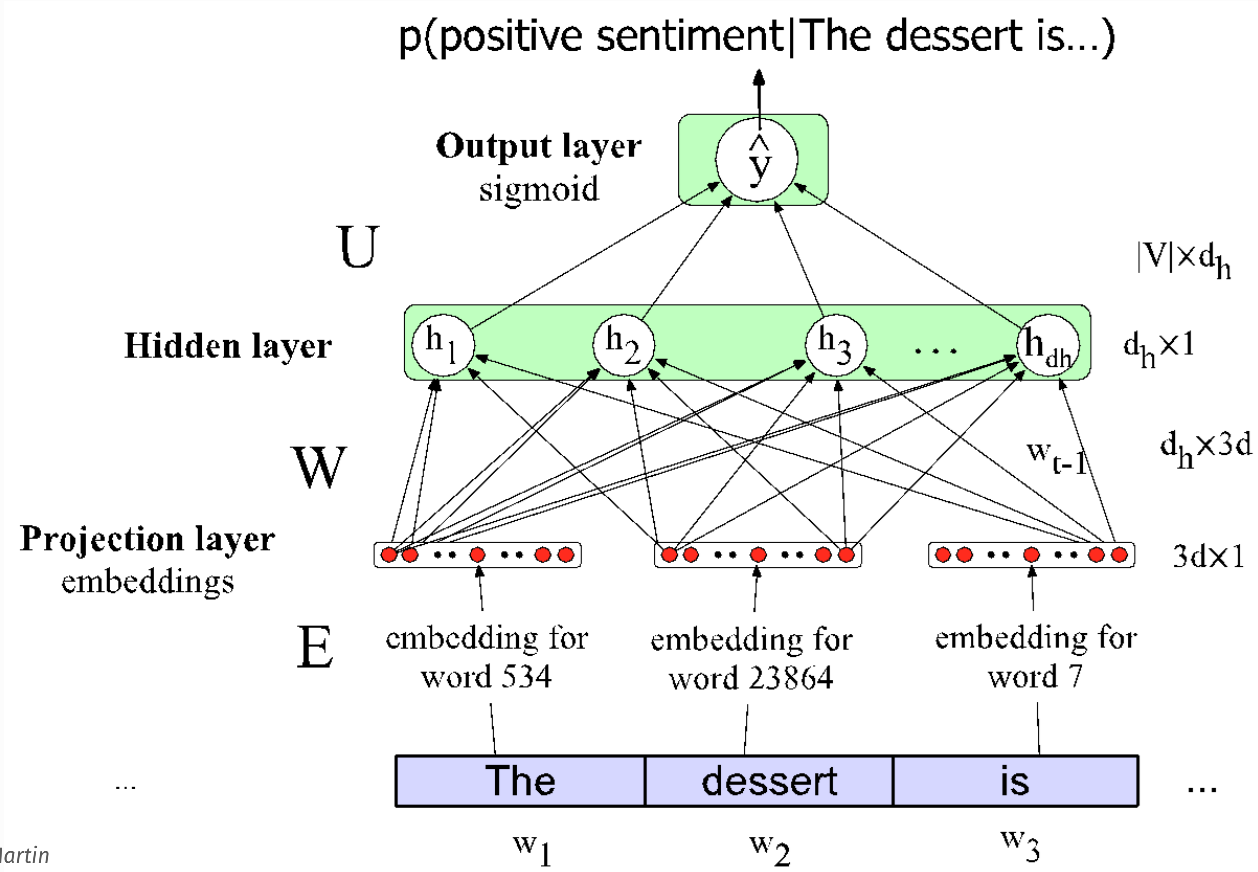
Instead of using hand-built human-engineered features for classification

Use learned representations like embeddings!



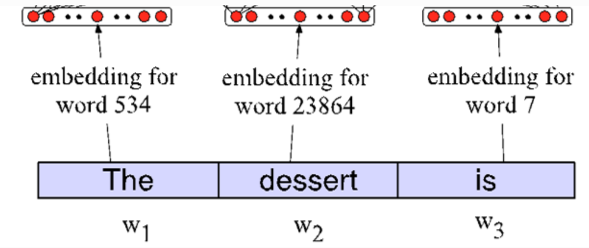
Slide adapted from Jurafsky & Martin

Neural net classification with embeddings as input features!



Slide adapted from Jurafsky & Martin

Issue: texts come in different sizes



This assumes a fixed size length (3)!
Kind of unrealistic.
Some simple solutions:

1. Make the input the length of the longest review
   - If shorter then pad with zero embeddings
   - Truncate if you get longer reviews at test time

2. Create a single "sentence embedding" (the same dimensionality as a word) to represent all the words
   - Take the mean of all the word embeddings
   - Take the element-wise max of all the word embeddings
     - For each dimension, pick the max value from all words

Slide adapted from Jurafsky & Martin

Coding activity

Notebook: feedforward neural network

- Click on this nbgitpuller link
  - Or find the link on the course website
- Open **session11_ffnn.ipynb**

Questions?