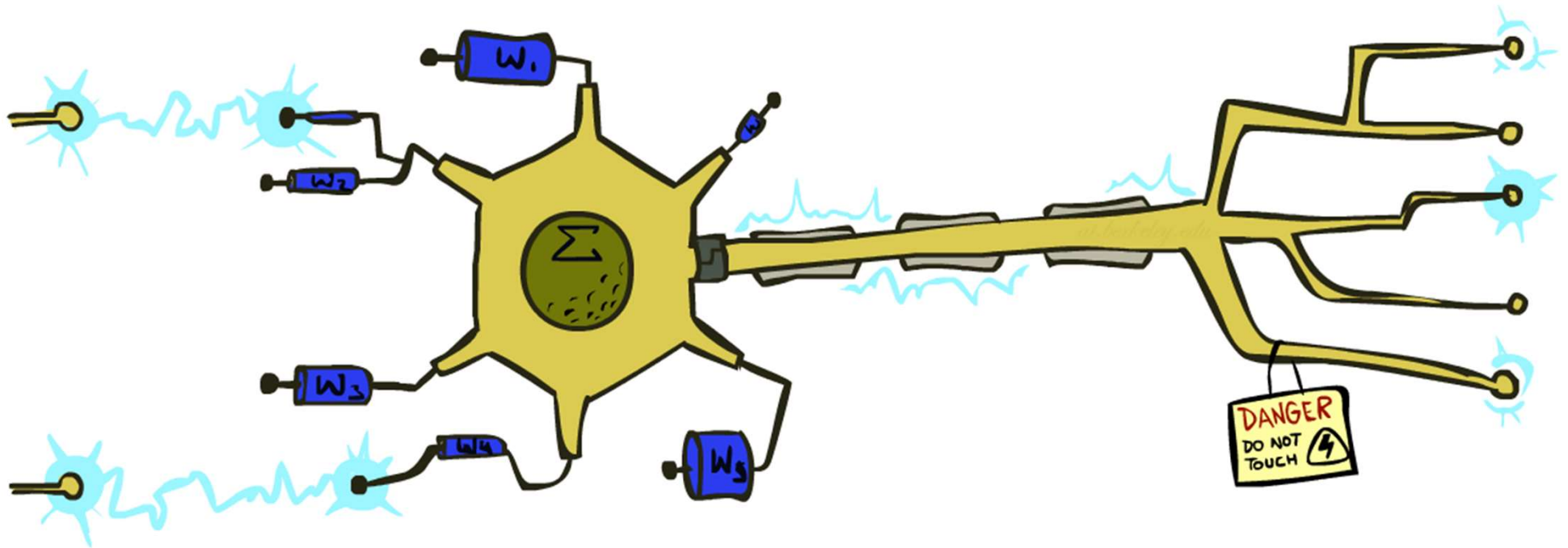


# CSE 473: Artificial Intelligence

## Perceptrons



Steve Tanimoto --- University of Washington

[These slides were created by Dan Klein and Pieter Abbeel for CS188 Intro to AI at UC Berkeley. All CS188 materials are available at <http://ai.berkeley.edu>.]

# Error-Driven Classification

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# Errors, and What to Do

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- Examples of errors

Dear GlobalSCAPE Customer,

GlobalSCAPE has partnered with ScanSoft to offer you the latest version of OmniPage Pro, for just \$99.99\* - the regular list price is \$499! The most common question we've received about this offer is - Is this genuine? We would like to assure you that this offer is authorized by ScanSoft, is genuine and valid. You can get the . . .

. . . To receive your \$30 Amazon.com promotional certificate, click through to

<http://www.amazon.com/apparel>

and see the prominent link for the \$30 offer. All details are there. We hope you enjoyed receiving this message. However, if you'd rather not receive future e-mails announcing new store launches, please click . . .

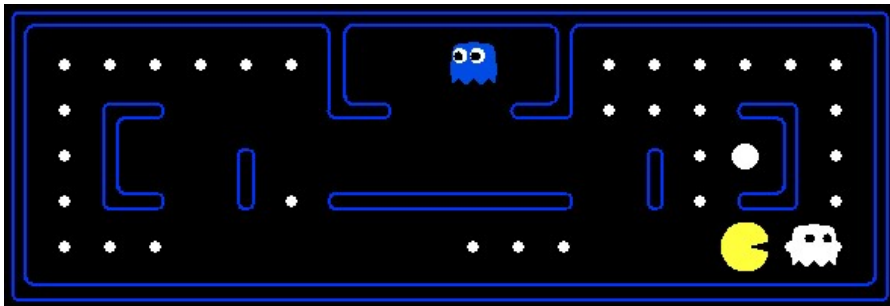
# What to Do About Errors

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- Problem: there's still spam in your inbox
- Need more **features** – words aren't enough!
  - Have you emailed the sender before?
  - Have 1M other people just gotten the same email?
  - Is the sending information consistent?
  - Is the email in ALL CAPS?
  - Do inline URLs point where they say they point?
  - Does the email address you by (your) name?
- Naïve Bayes models can incorporate a variety of features, but tend to do best in homogeneous cases (e.g. all features are word occurrences)

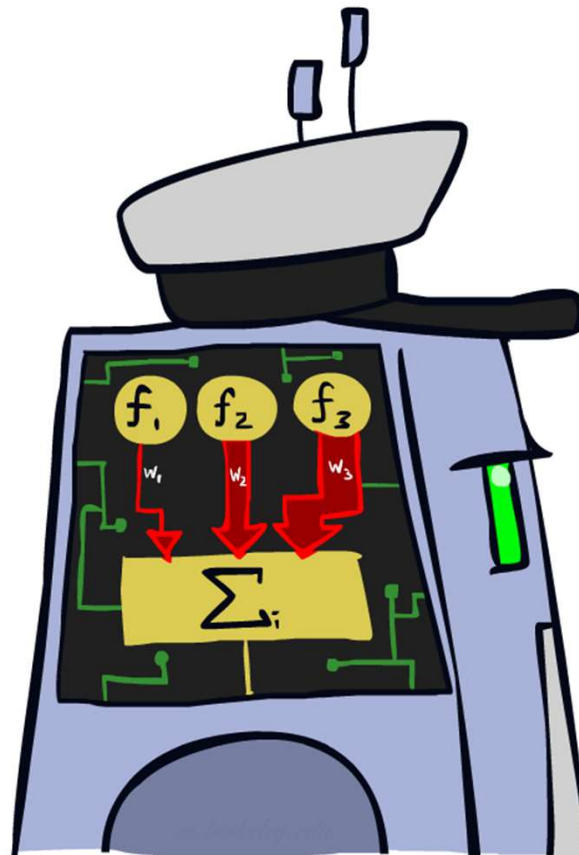
# Later On...

Web Search



Decision Problems

# Linear Classifiers



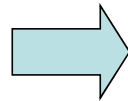
# Feature Vectors

$x$

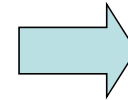
$f(x)$

$y$

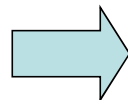
```
Hello,  
  
Do you want free print  
cartridges? Why pay more  
when you can get them  
ABSOLUTELY FREE! Just
```



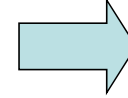
```
# free      : 2  
YOUR_NAME   : 0  
MISSPELLED  : 2  
FROM_FRIEND : 0  
...
```



SPAM  
or  
+



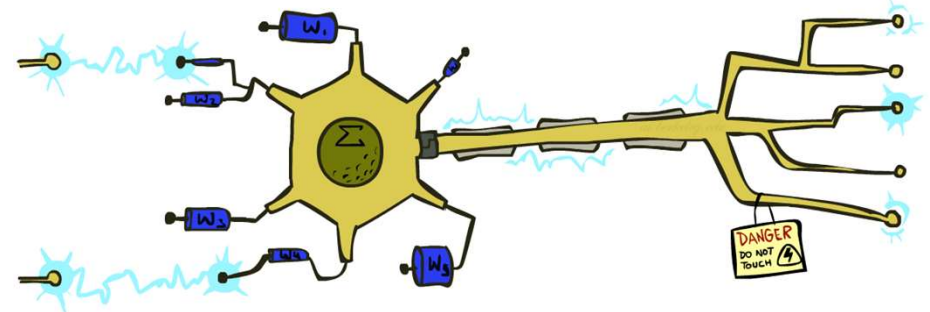
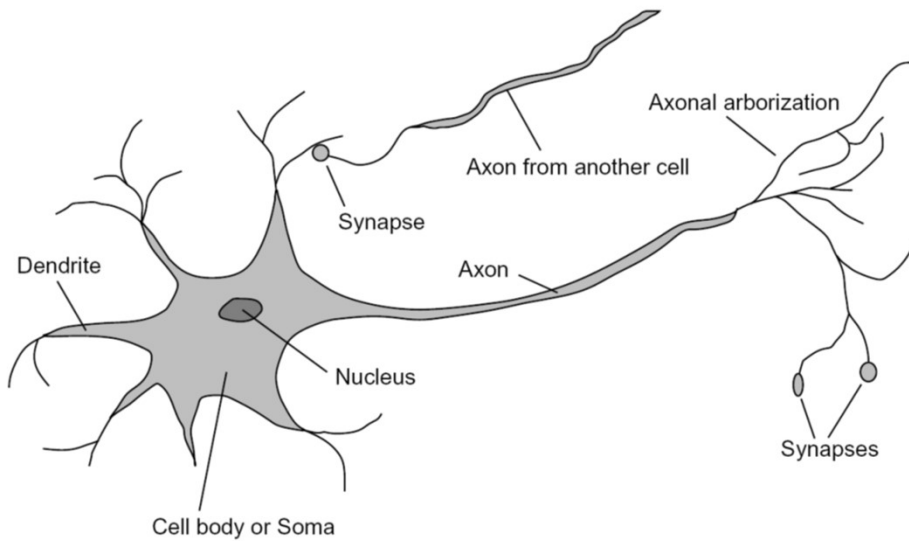
```
PIXEL-7,12  : 1  
PIXEL-7,13  : 0  
...  
NUM_LOOPS   : 1  
...
```



"2"

# Some (Simplified) Biology

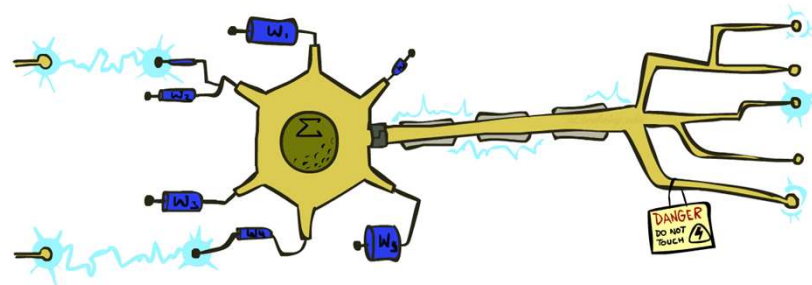
- Very loose inspiration: human neurons





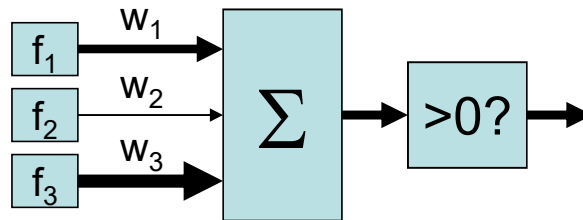
# Linear Classifiers

- Inputs are **feature values**
- Each feature has a **weight**
- Sum is the **activation**



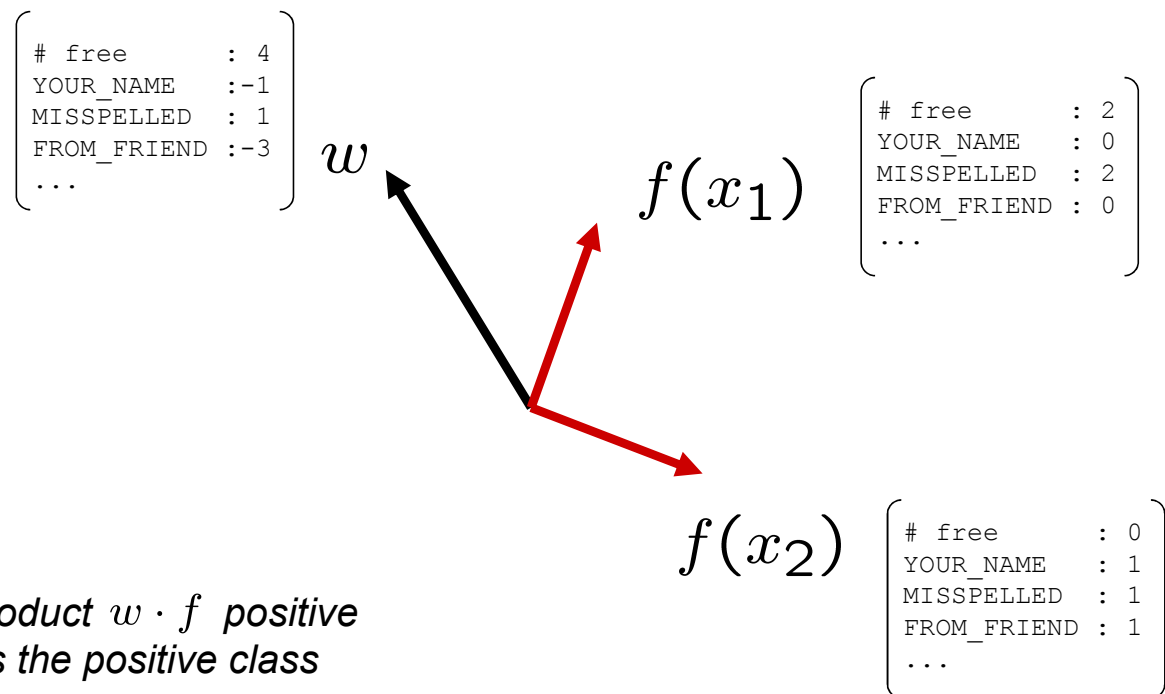
$$\text{activation}_w(x) = \sum_i w_i \cdot f_i(x) = w \cdot f(x)$$

- If the activation is:
  - Positive, output +1
  - Negative, output -1



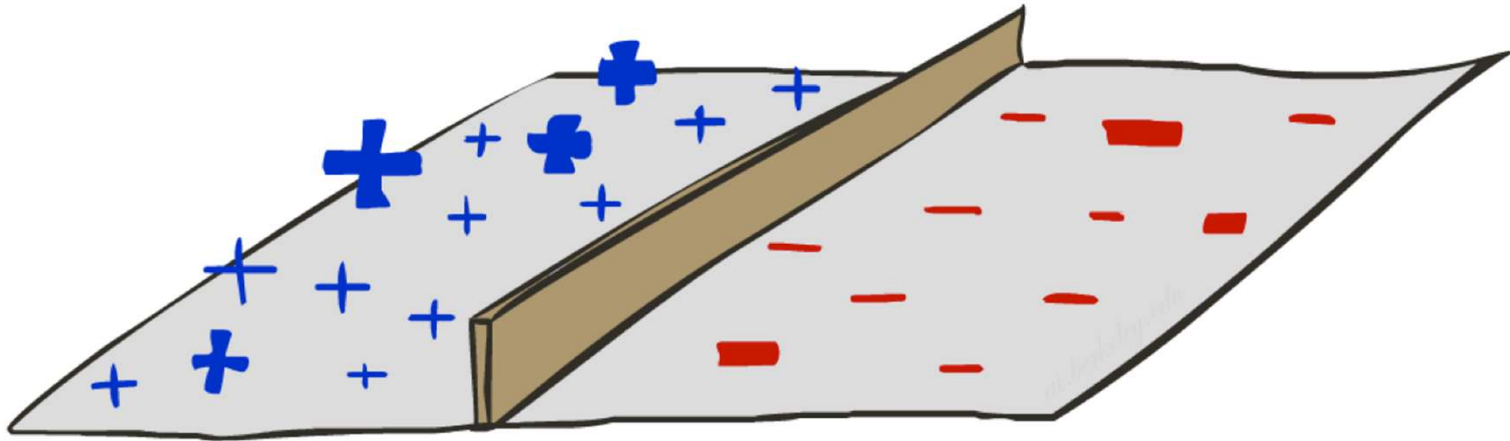
# Weights

- Binary case: compare features to a weight vector
- Learning: figure out the weight vector from examples



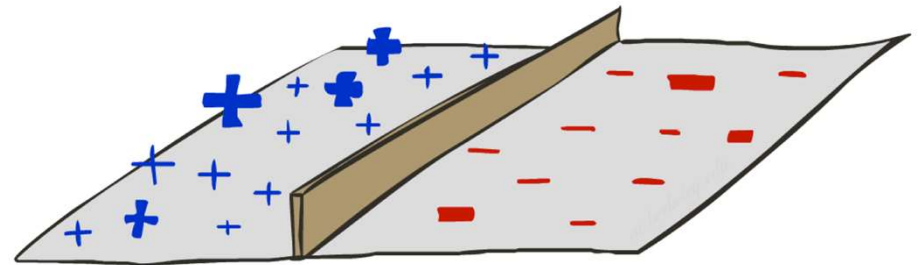
# Decision Rules

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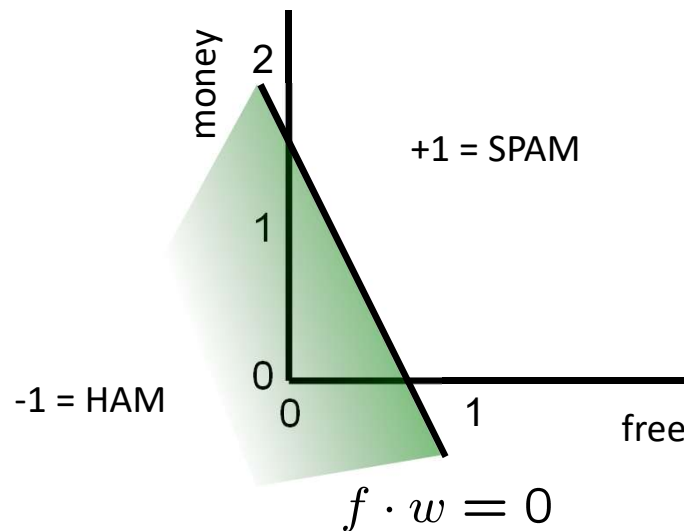
# Binary Decision Rule

- In the space of feature vectors
  - Examples are points
  - Any weight vector is a hyperplane
  - One side corresponds to  $Y=+1$
  - Other corresponds to  $Y=-1$



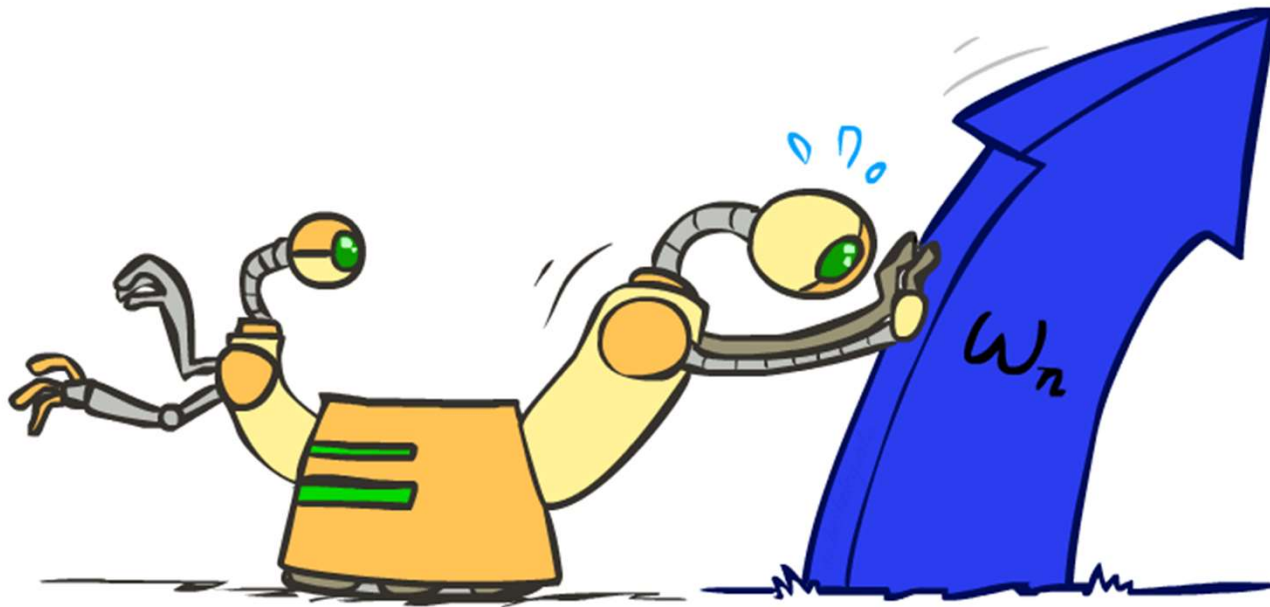
$w$

BIAS	:	-3
free	:	4
money	:	2
...	:	



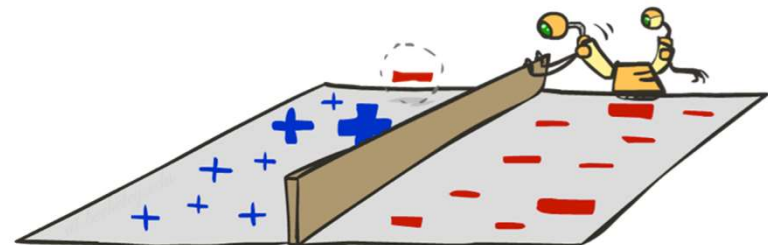
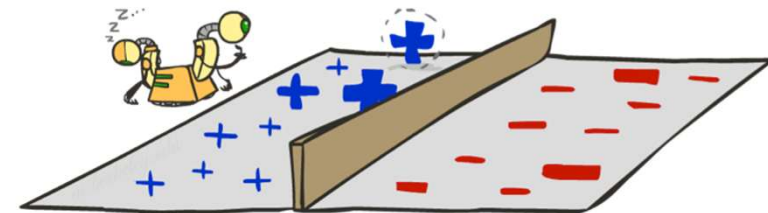
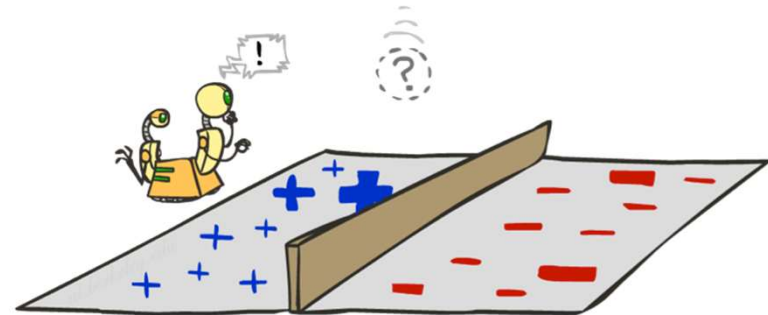
# Weight Updates

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# Learning: Binary Perceptron

- Start with weights = 0
- For each training instance:
  - Classify with current weights
- If correct (i.e.,  $y=y^*$ ), no change!
- If wrong: adjust the weight vector



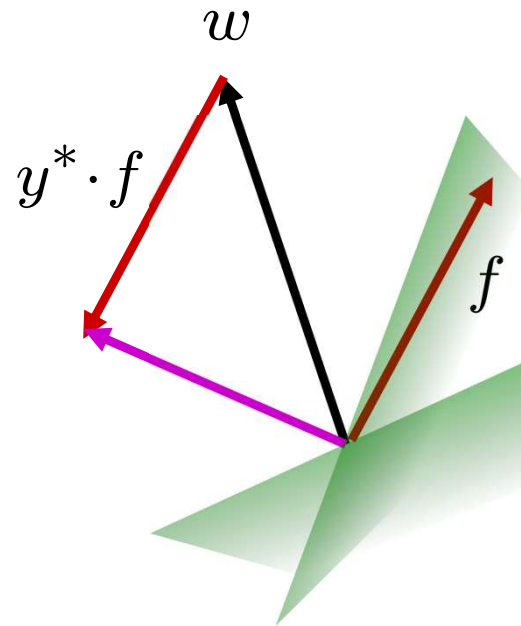
# Learning: Binary Perceptron

- Start with weights = 0
- For each training instance:
  - Classify with current weights

$$y = \begin{cases} +1 & \text{if } w \cdot f(x) \geq 0 \\ -1 & \text{if } w \cdot f(x) < 0 \end{cases}$$

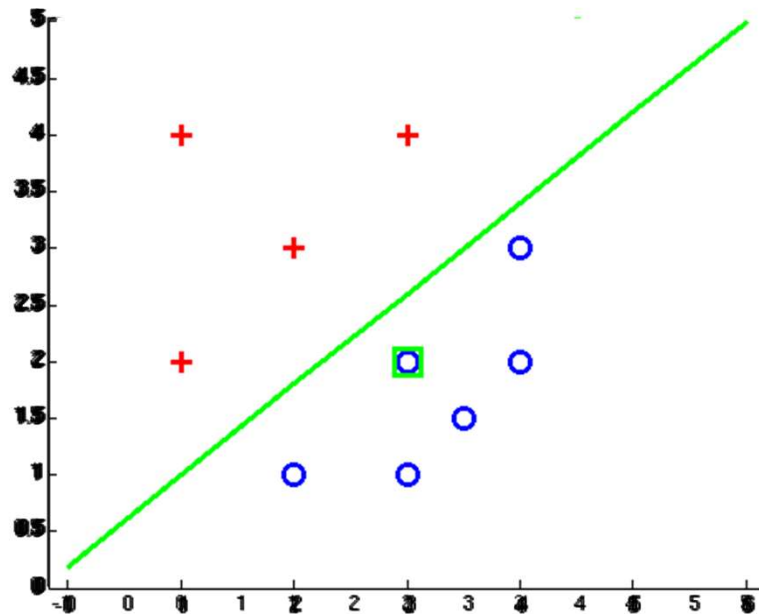
- If correct (i.e.,  $y=y^*$ ), no change!
- If wrong: adjust the weight vector by adding or subtracting the feature vector. Subtract if  $y^*$  is -1.

$$w = w + y^* \cdot f$$



# Examples: Perceptron

- Separable Case





# Multiclass Decision Rule

- If we have multiple classes:

- A weight vector for each class:

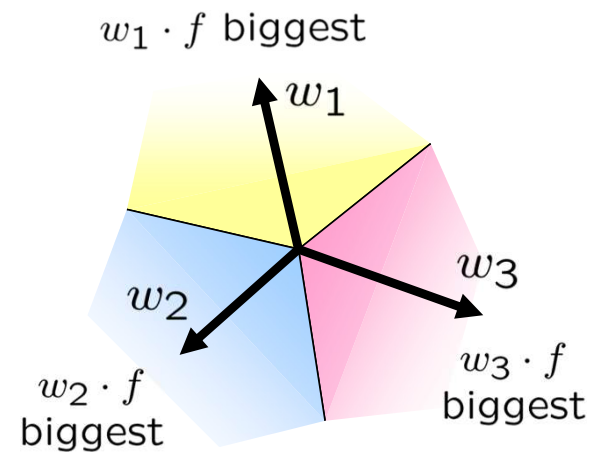
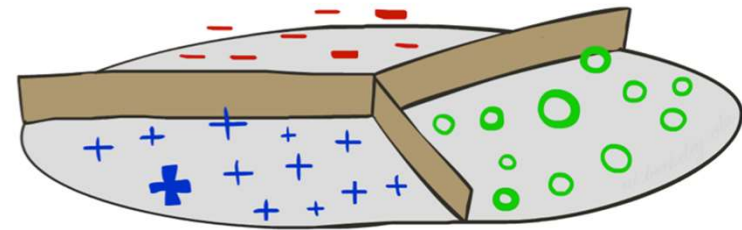
$$w_y$$

- Score (activation) of a class  $y$ :

$$w_y \cdot f(x)$$

- Prediction highest score wins

$$y = \arg \max_y w_y \cdot f(x)$$



*Binary = multiclass where the negative class has weight zero*

# Learning: Multiclass Perceptron

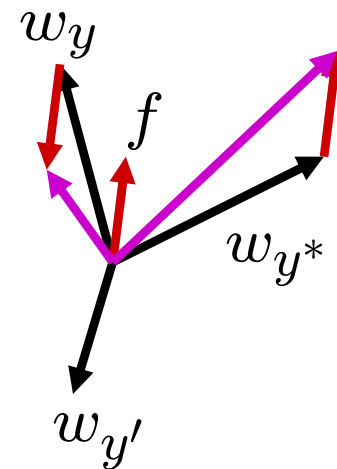
- Start with all weights = 0
- Pick up training examples one by one
- Predict with current weights

$$y = \arg \max_y w_y \cdot f(x)$$

- If correct, no change!
- If wrong: lower score of wrong answer, raise score of right answer

$$w_y = w_y - f(x)$$

$$w_{y^*} = w_{y^*} + f(x)$$



# Example: Multiclass Perceptron

---

“win the vote”

“win the election”

“win the game”

$w_{SPORTS}$

BIAS	:	1
win	:	0
game	:	0
vote	:	0
the	:	0
...		

$w_{POLITICS}$

BIAS	:	0
win	:	0
game	:	0
vote	:	0
the	:	0
...		

$w_{TECH}$

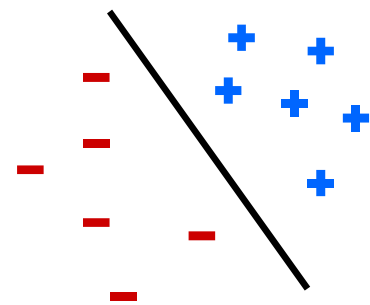
BIAS	:	0
win	:	0
game	:	0
vote	:	0
the	:	0
...		

# Properties of Perceptrons

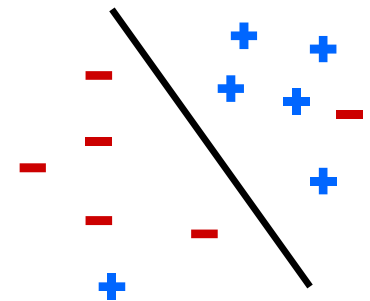
- Separability: true if some parameters get the training set perfectly correct
- Convergence: if the training is separable, perceptron will eventually converge (binary case)
- Mistake Bound: the maximum number of mistakes (binary case) related to the *margin* or degree of separability

$$\text{mistakes} < \frac{k}{\delta^2}$$

Separable

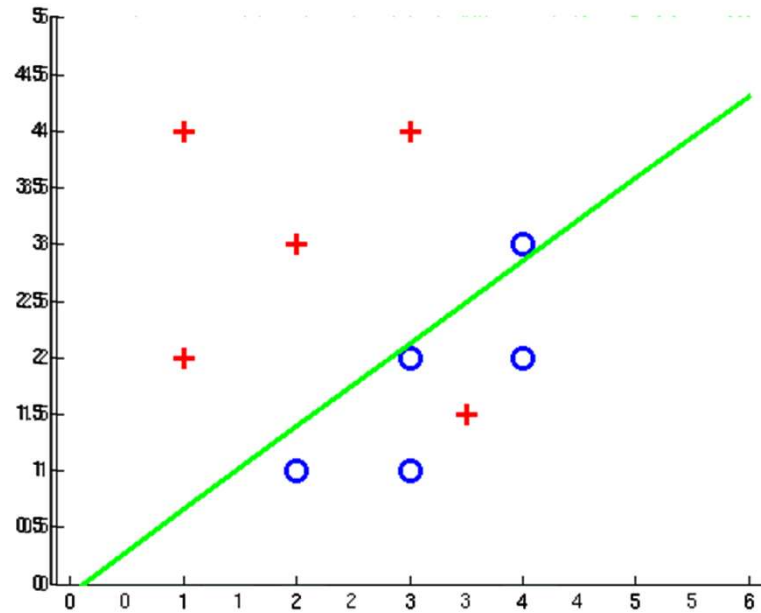


Non-Separable

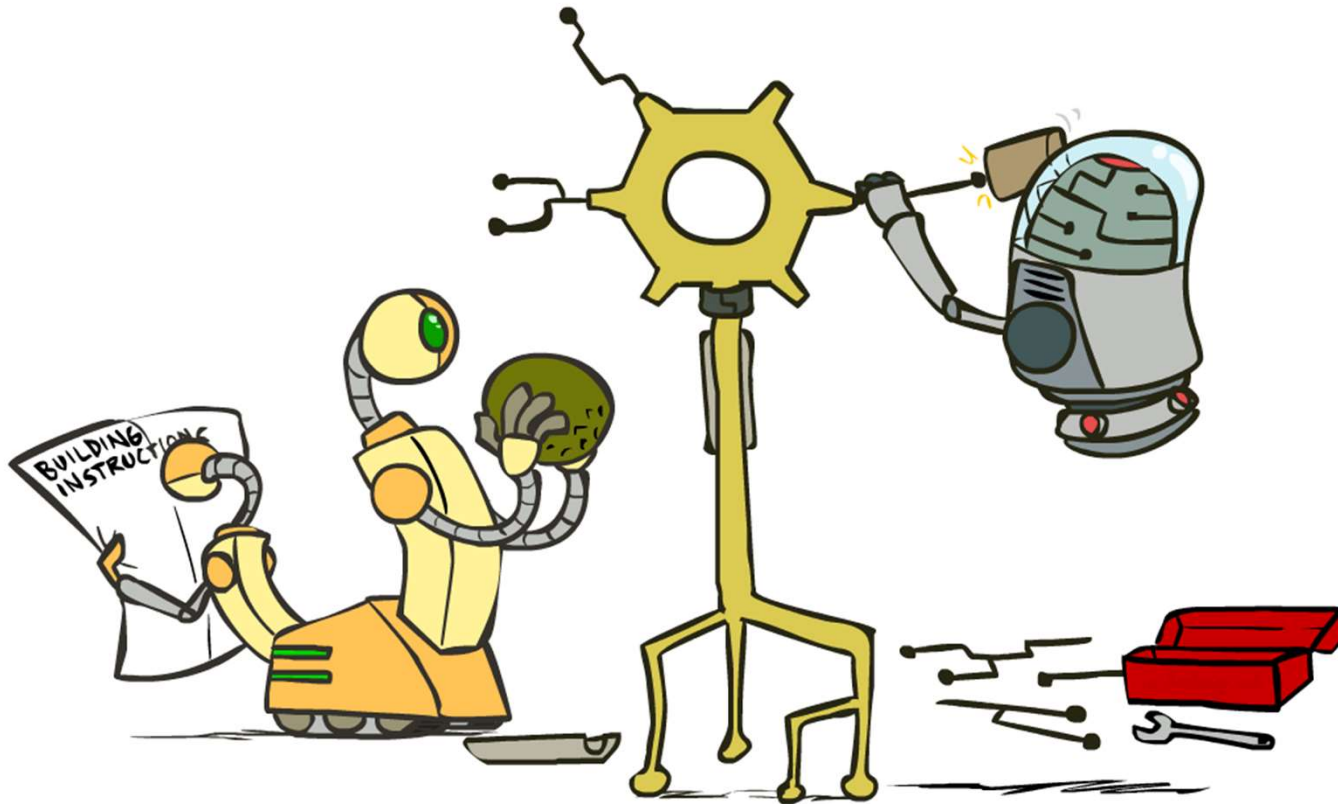


# Examples: Perceptron

- Non-Separable Case

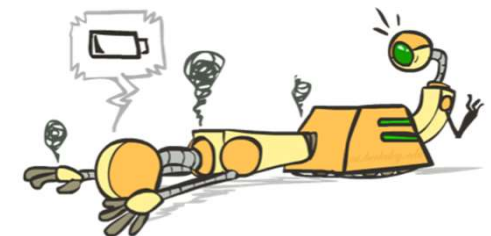
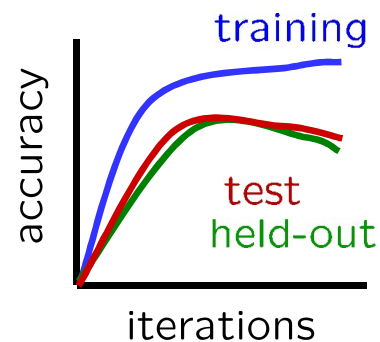
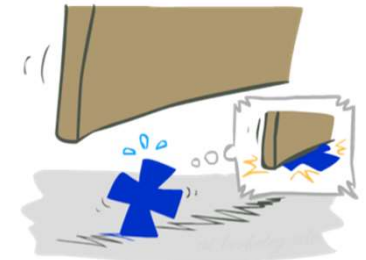
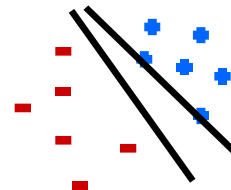
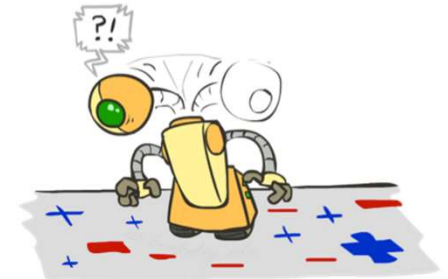
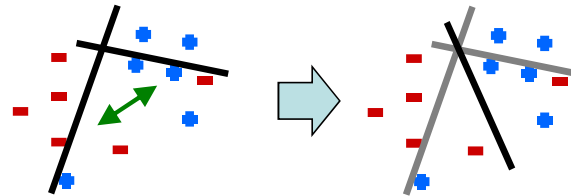


# Improving the Perceptron



# Problems with the Perceptron

- Noise: if the data isn't separable, weights might thrash
  - Averaging weight vectors over time can help (averaged perceptron)
- Mediocre generalization: finds a "barely" separating solution
- Overtraining: test / held-out accuracy usually rises, then falls
  - Overtraining is a kind of overfitting



# Fixing the Perceptron

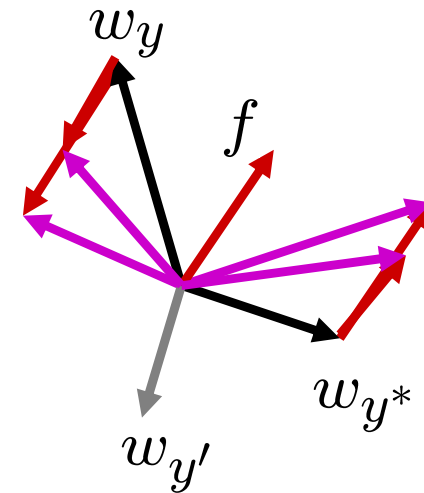
- Idea: adjust the weight update to mitigate these effects
- MIRA\*: choose an update size that fixes the current mistake...
- ... but, minimizes the change to  $w$

$$\min_w \frac{1}{2} \sum_y \|w_y - w'_y\|^2$$

$$w_{y^*} \cdot f(x) \geq w_y \cdot f(x) + 1$$

- The +1 helps to generalize

\* Margin Infused Relaxed Algorithm



Guessed  $y$  instead of  $y^*$  on example  $x$  with features  $f(x)$

$$w_y = w'_{y'} - \tau f(x)$$
$$w_{y^*} = w'_{y^*} + \tau f(x)$$



# Minimum Correcting Update

$$\min_w \frac{1}{2} \sum_y \|w_y - w'_y\|^2$$

$$w_{y^*} \cdot f \geq w_y \cdot f + 1$$



$$\min_{\tau} \|\tau f\|^2$$

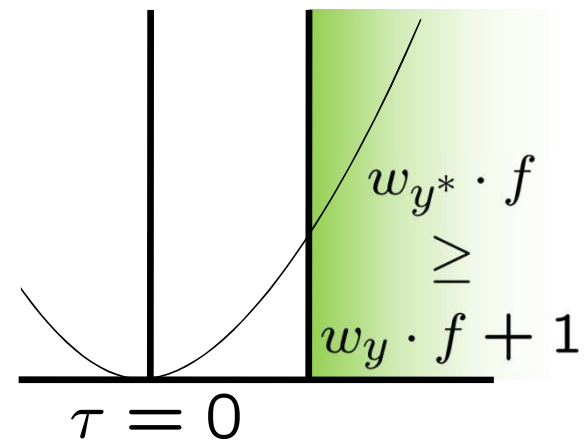
$$w_{y^*} \cdot f \geq w_y \cdot f + 1$$



$$(w'_{y^*} + \tau f) \cdot f = (w'_y - \tau f) \cdot f + 1$$

$$\tau = \frac{(w'_y - w'_{y^*}) \cdot f + 1}{2f \cdot f}$$

$$\begin{aligned} w_y &= w'_y - \tau f(x) \\ w_{y^*} &= w'_{y^*} + \tau f(x) \end{aligned}$$



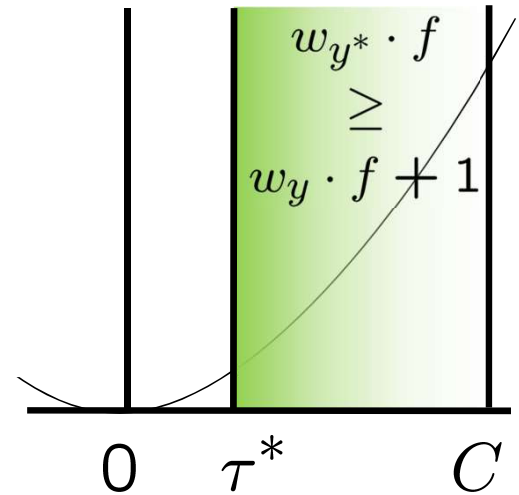
min not  $\tau=0$ , or would not have made an error, so min will be where equality holds

# Maximum Step Size

- In practice, it's also bad to make updates that are too large
  - Example may be labeled incorrectly
  - You may not have enough features
  - Solution: cap the maximum possible value of  $\tau$  with some constant  $C$

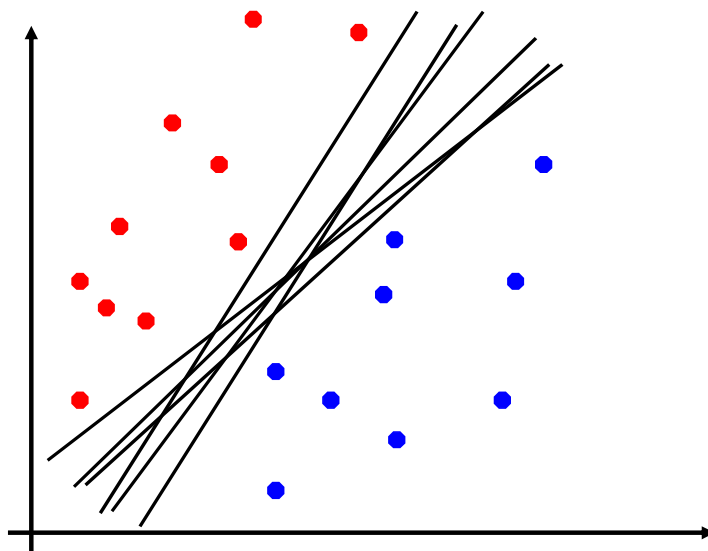
$$\tau^* = \min \left( \frac{(w'_y - w'_{y^*}) \cdot f + 1}{2f \cdot f}, C \right)$$

- Corresponds to an optimization that assumes non-separable data
- Usually converges faster than perceptron
- Usually better, especially on noisy data



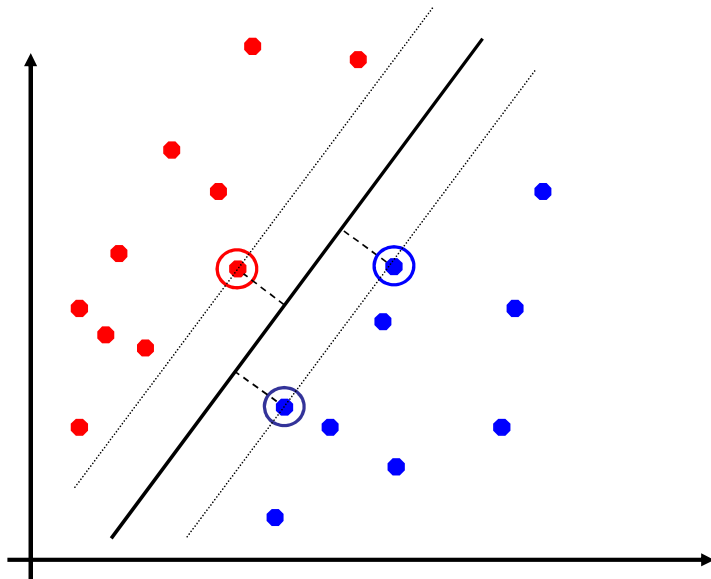
# Linear Separators

- Which of these linear separators is optimal?



# Support Vector Machines

- **Maximizing the margin:** good according to intuition, theory, practice
- Only **support vectors** matter; other training examples are ignorable
- Support vector machines (SVMs) find the separator with max margin
- Basically, SVMs are MIRA where you optimize over all examples at once



MIRA

$$\min_w \frac{1}{2} \|w - w'\|^2$$
$$w_{y^*} \cdot f(x_i) \geq w_y \cdot f(x_i) + 1$$

SVM

$$\min_w \frac{1}{2} \|w\|^2$$
$$\forall i, y \quad w_{y^*} \cdot f(x_i) \geq w_y \cdot f(x_i) + 1$$

# Classification: Comparison

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- Naïve Bayes

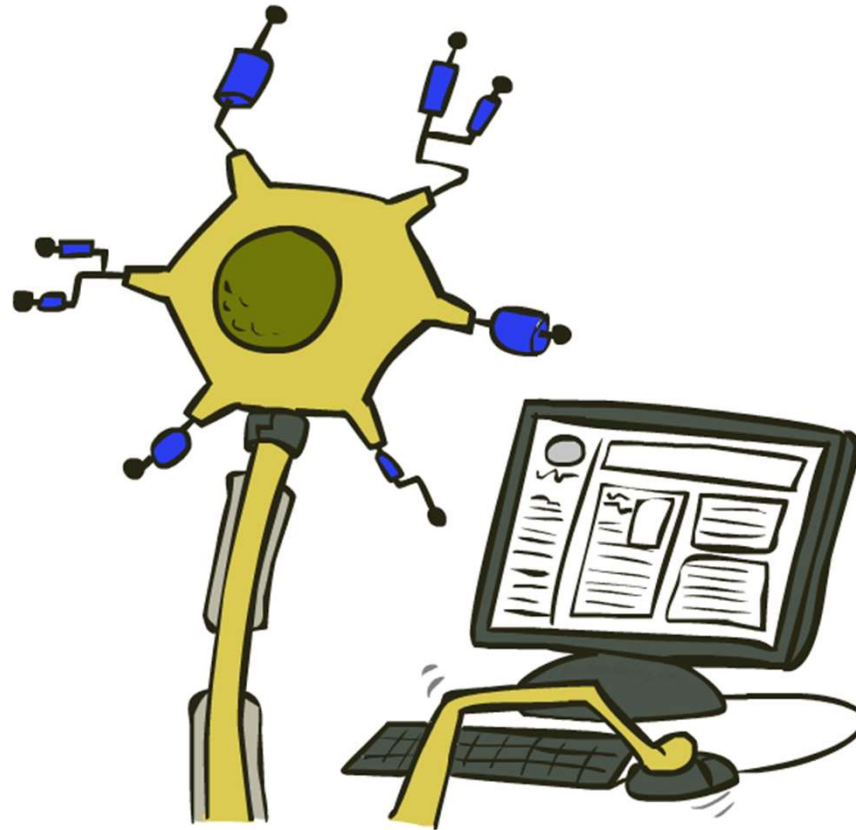
- Builds a model training data
- Gives prediction probabilities
- Strong assumptions about feature independence
- One pass through data (counting)

- Perceptrons / MIRA:

- Makes less assumptions about data
- Mistake-driven learning
- Multiple passes through data (prediction)
- Often more accurate

# Web Search

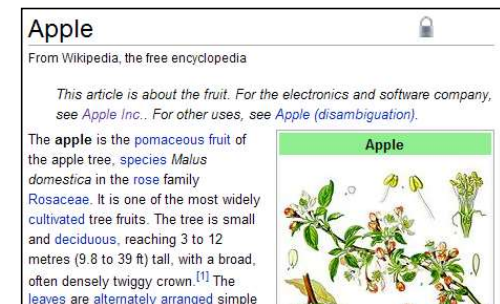
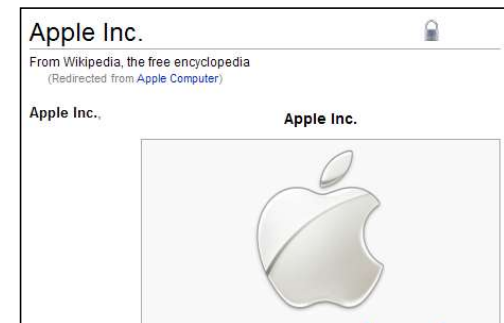
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# Extension: Web Search

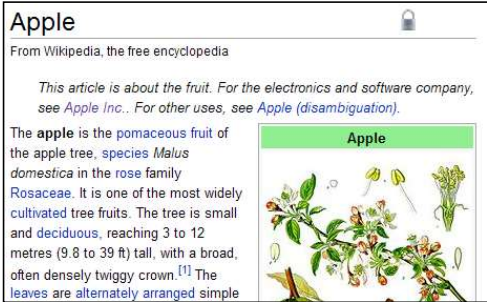
- Information retrieval:
  - Given information needs, produce information
  - Includes, e.g. web search, question answering, and classic IR
- Web search: not exactly classification, but rather ranking

$x = \text{“Apple Computers”}$

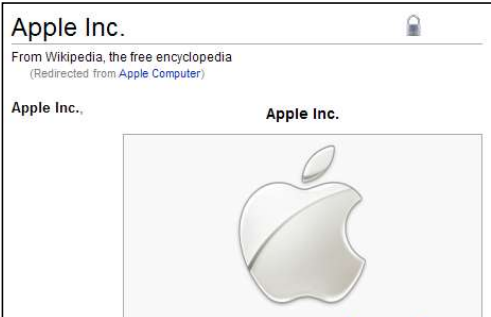


# Feature-Based Ranking

$x = \text{"Apple Computer"}$

$$f(x, \text{Apple}) = [0.3 \ 5 \ 0 \ 0 \ \dots]$$


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$$f(x, \text{Apple Inc.}) = [0.8 \ 4 \ 2 \ 1 \ \dots]$$




# Perceptron for Ranking

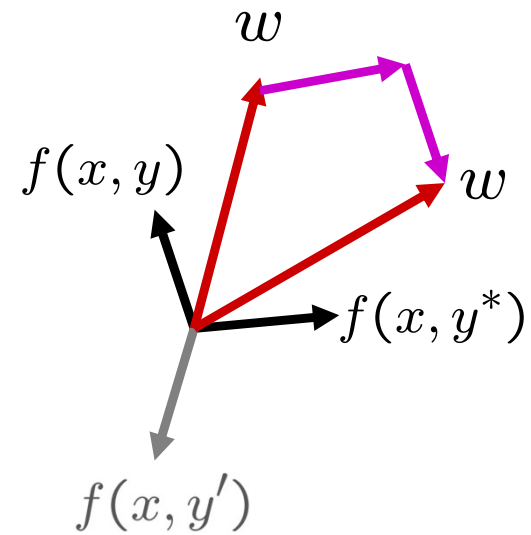
- Inputs  $x$
- Candidates  $y$
- Many feature vectors:  $f(x, y)$
- One weight vector:  $w$

- Prediction:

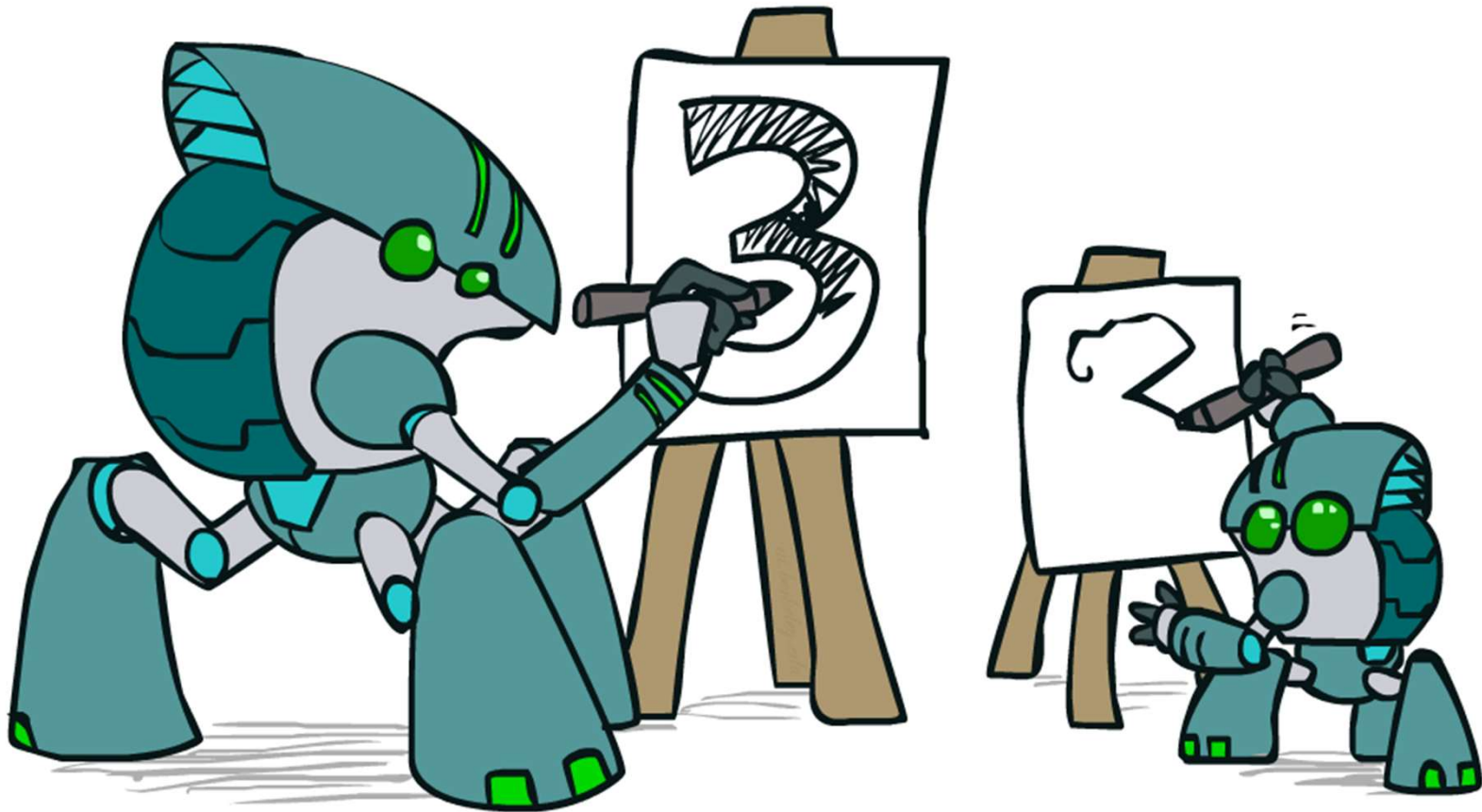
$$y = \arg \max_y w \cdot f(x, y)$$

- Update (if wrong):

$$w = w + f(x, y^*) - f(x, y)$$

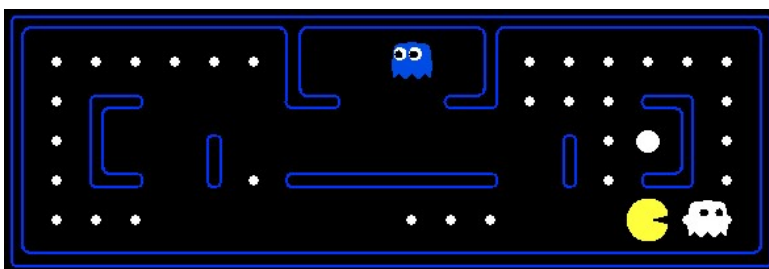


# Apprenticeship



# Pacman Apprenticeship!

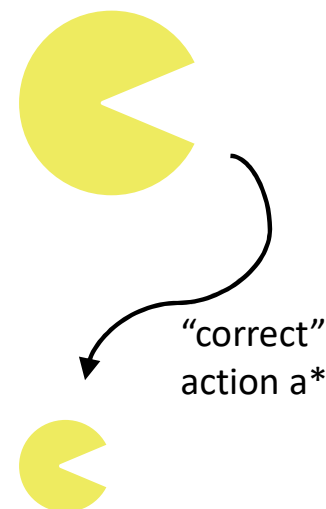
- Examples are states  $s$



- Candidates are pairs  $(s,a)$
- “Correct” actions: those taken by expert
- Features defined over  $(s,a)$  pairs:  $f(s,a)$
- Score of a q-state  $(s,a)$  given by:

$$w \cdot f(s, a)$$

- How is this VERY different from reinforcement learning?



$$\forall a \neq a^*, \\ w \cdot f(a^*) > w \cdot f(a)$$

[Demo: Pacman Apprentice (L22D1,2,3)]

# Video of Demo Pacman Apprentice

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