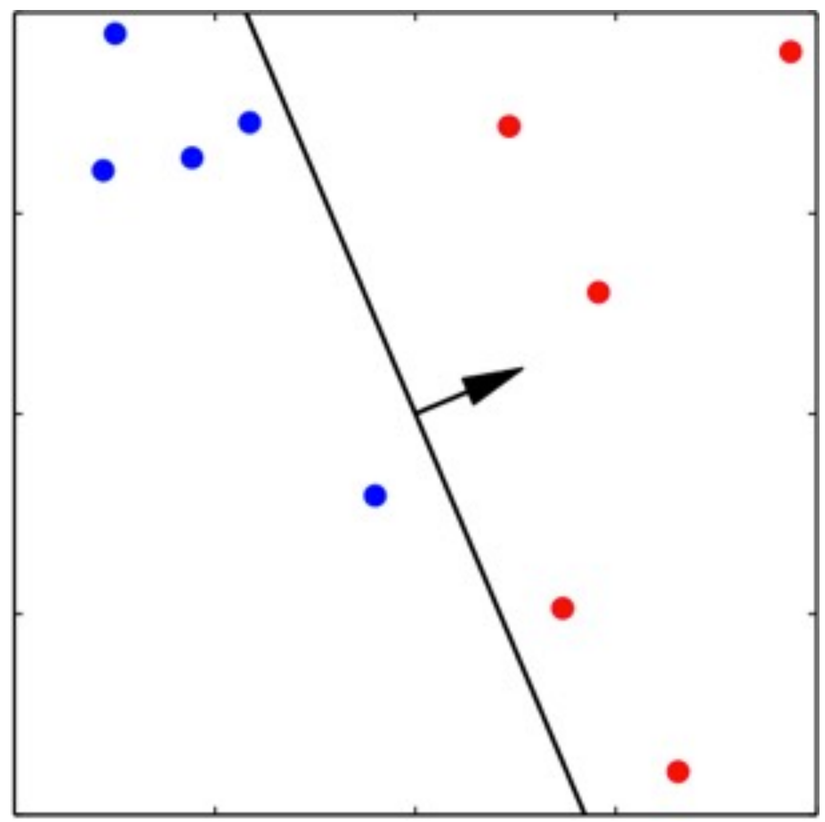
Applied Machine Learning

CIML Chaps 4-5 (A Geometric Approach)



"A ship in port is safe, but that is not what ships are for."

– Grace Hopper (1906-1992)

Week 3: Extensions and Variations of Perceptron; Practical Issues and HW1

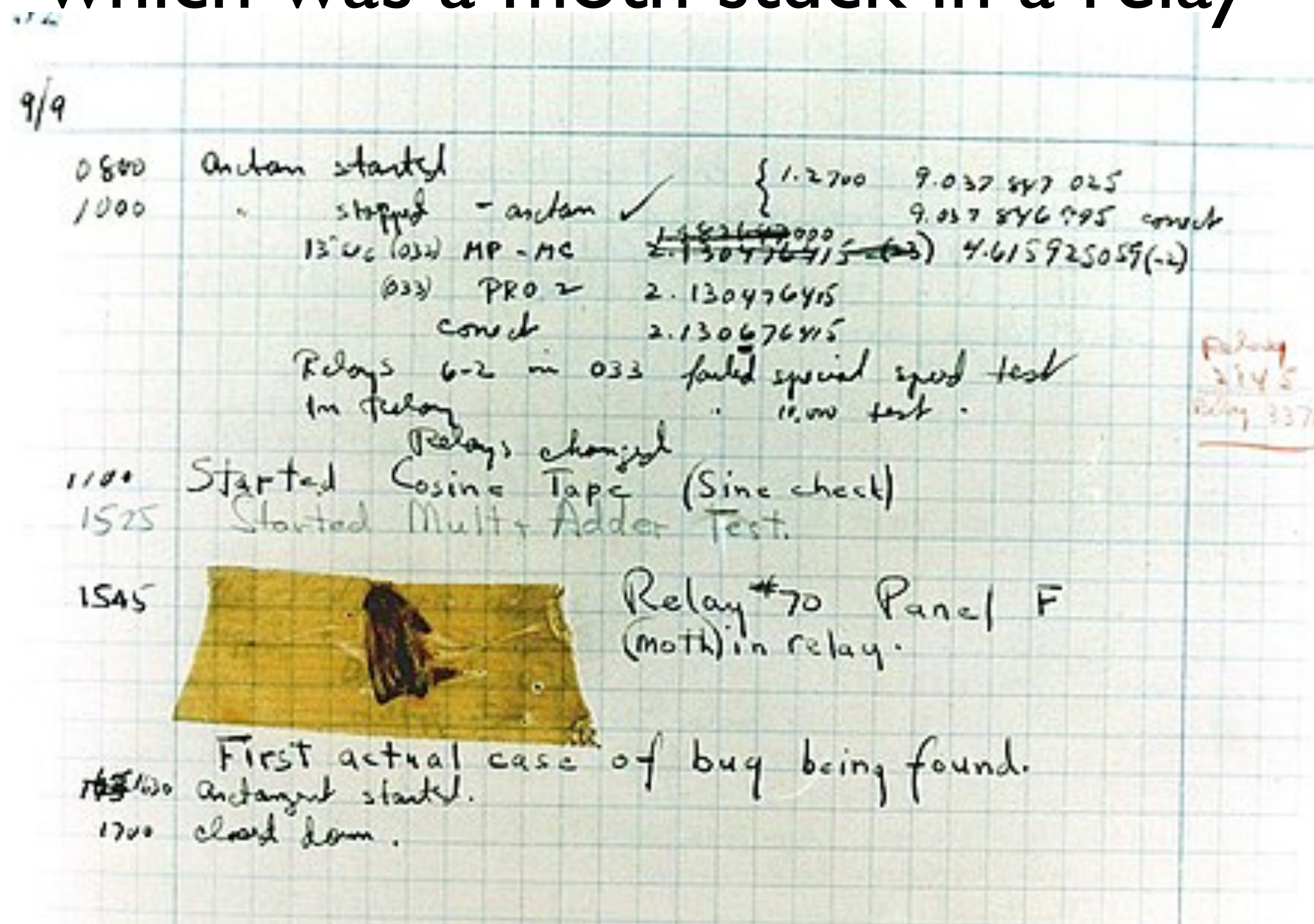
Professor Liang Huang

some slides from A. Zisserman (Oxford)

Trivia: Grace Hopper and the first bug

- Edison coined the term "bug" around 1878 and it had been widely used in engineering
- Hopper was associated with the discovery of the first computer bug in 1947 which was a moth stuck in a relay

ANITA BORG INSTITUTE
WOMEN TRANSFORMING TECHNOLOGY
GRACE HOPPER



Smithsonian National Museum of American History

Week 3: Perceptron in Practice

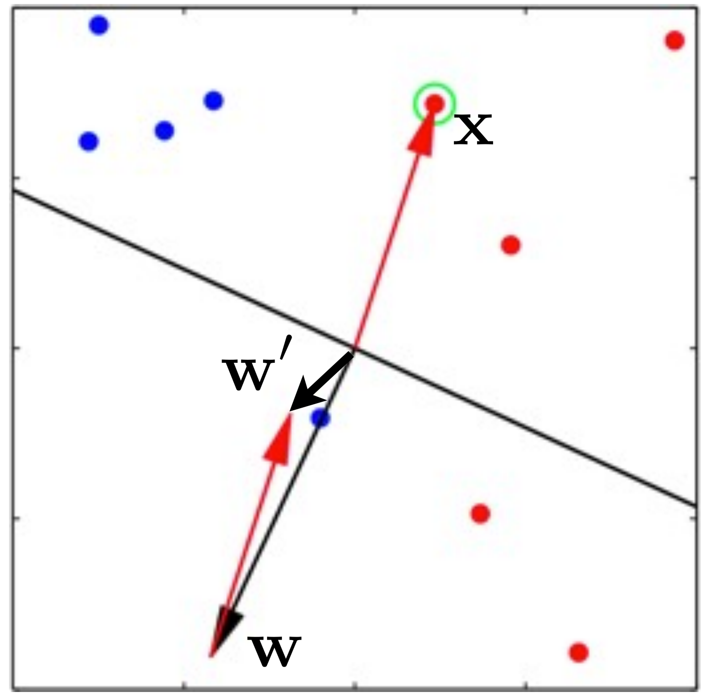
"A ship in port is safe, but that is not what ships are for."

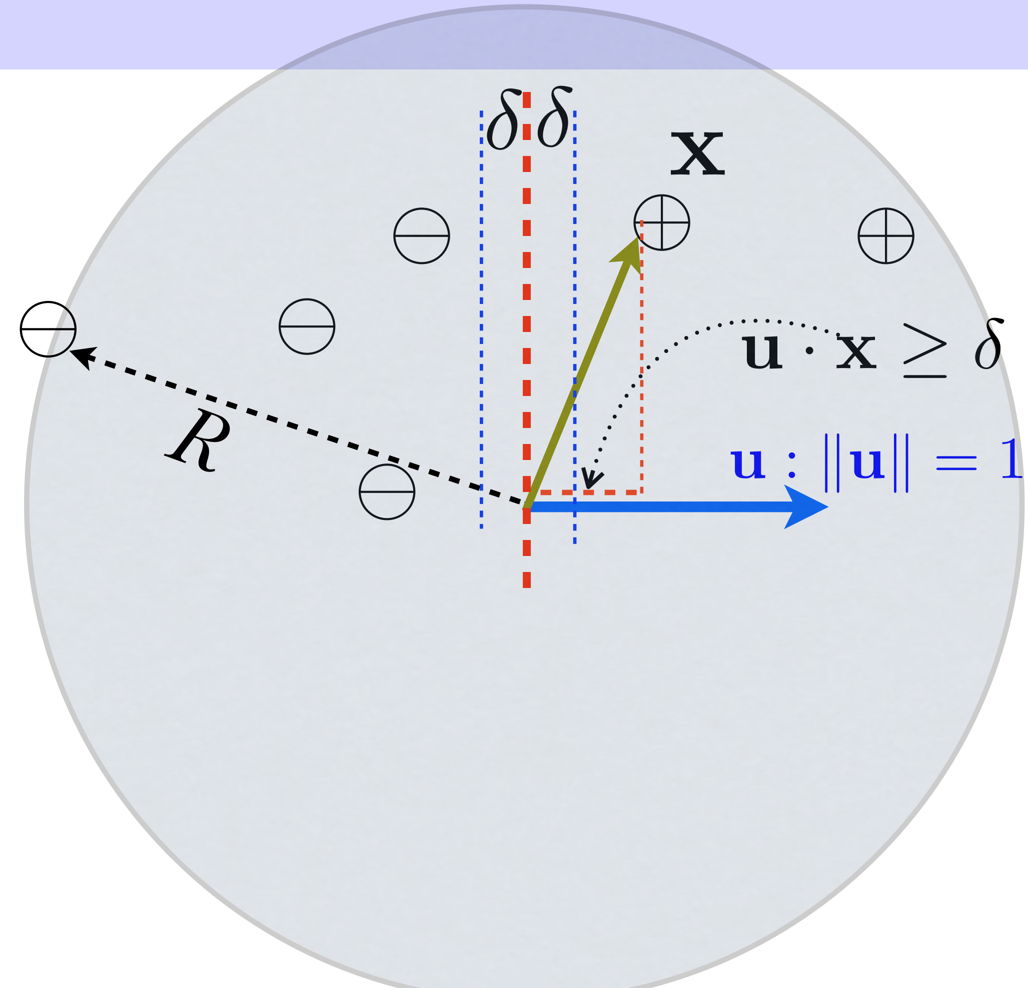
– Grace Hopper (1906-1992)

- Problems with Perceptron
  - doesn't converge with inseparable data
  - update might often be too "bold"
  - doesn't optimize margin
  - result is sensitive to the order of examples
- Ways to alleviate these problems (without SVM/kernels)
  - Part II: voted perceptron and average perceptron
  - Part III: MIRA (margin-infused relaxation algorithm)
- Part IV: Practical Issues and HW1
- Part V: "Soft" Perceptron: Logistic Regression

Recap of Week 2

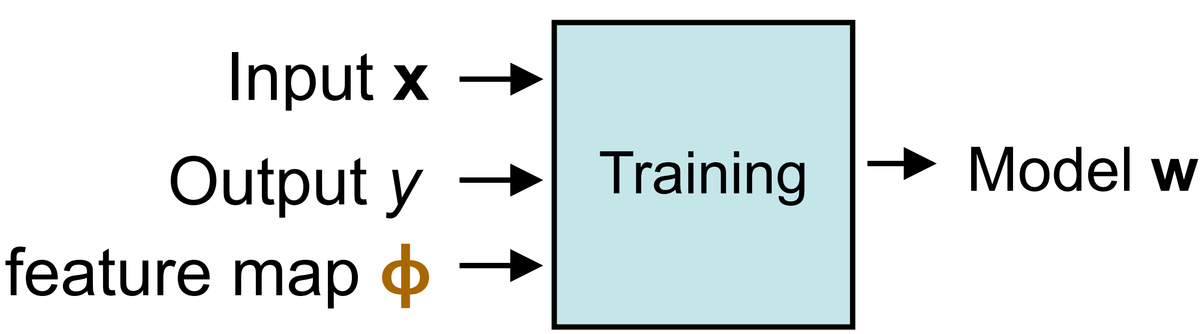
input: training data D
output: weights $\mathbf{w}$
initialize $\mathbf{w} \leftarrow \mathbf{0}$
while not converged
  for $(\mathbf{x}, y) \in D$
    if $y(\mathbf{w} \cdot \mathbf{x}) \leq 0$
      $\mathbf{w} \leftarrow \mathbf{w} + y\mathbf{x}$



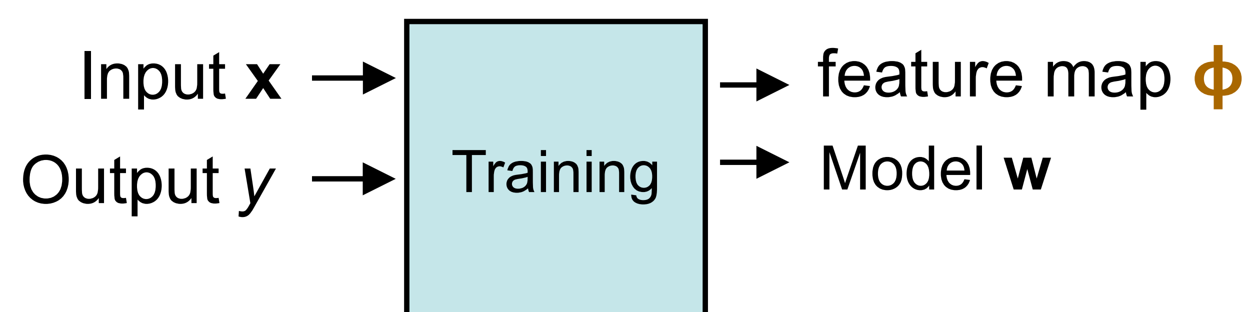


“idealized” ML

“actual” ML

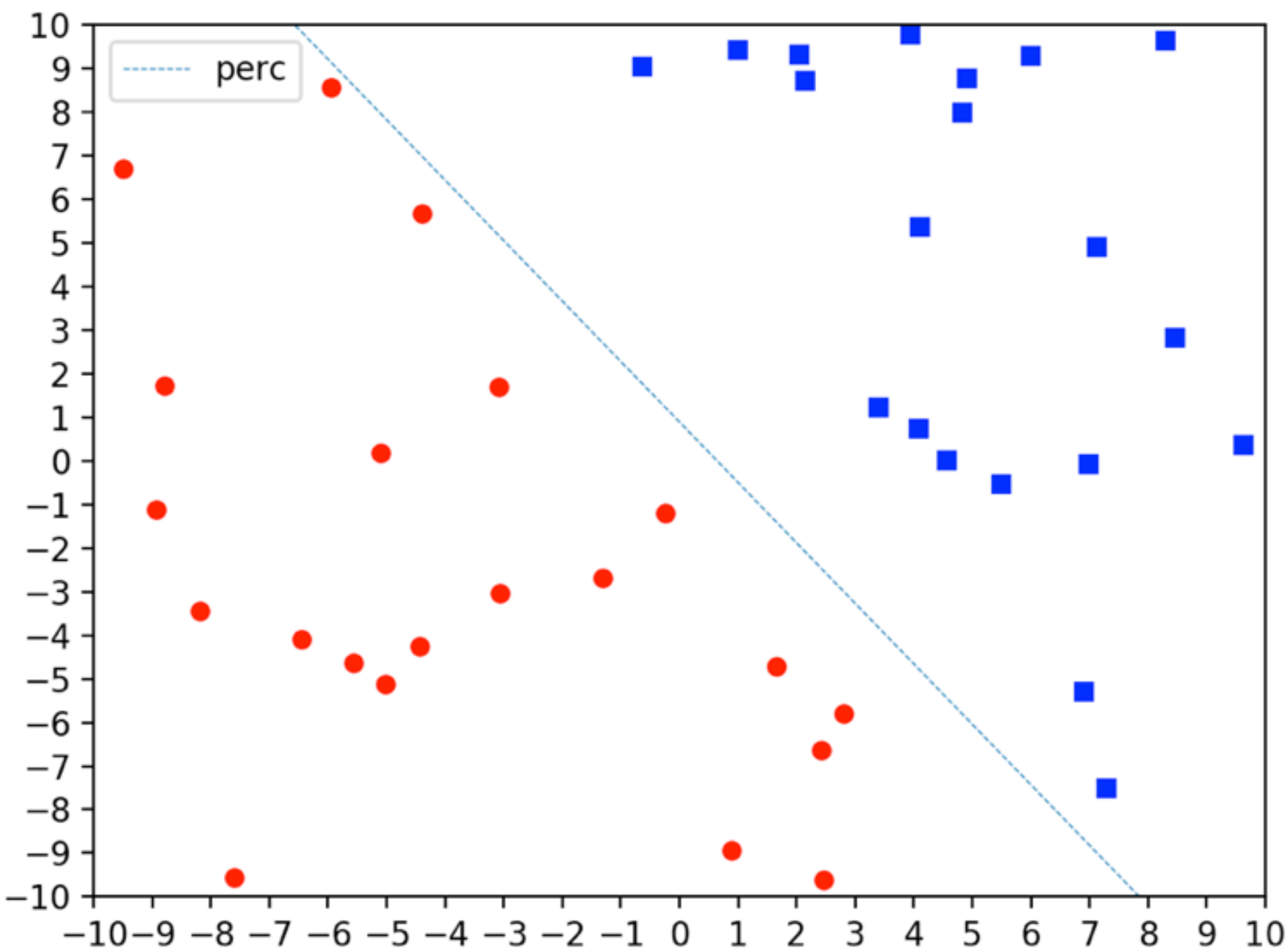


deep learning ≈ representation learning

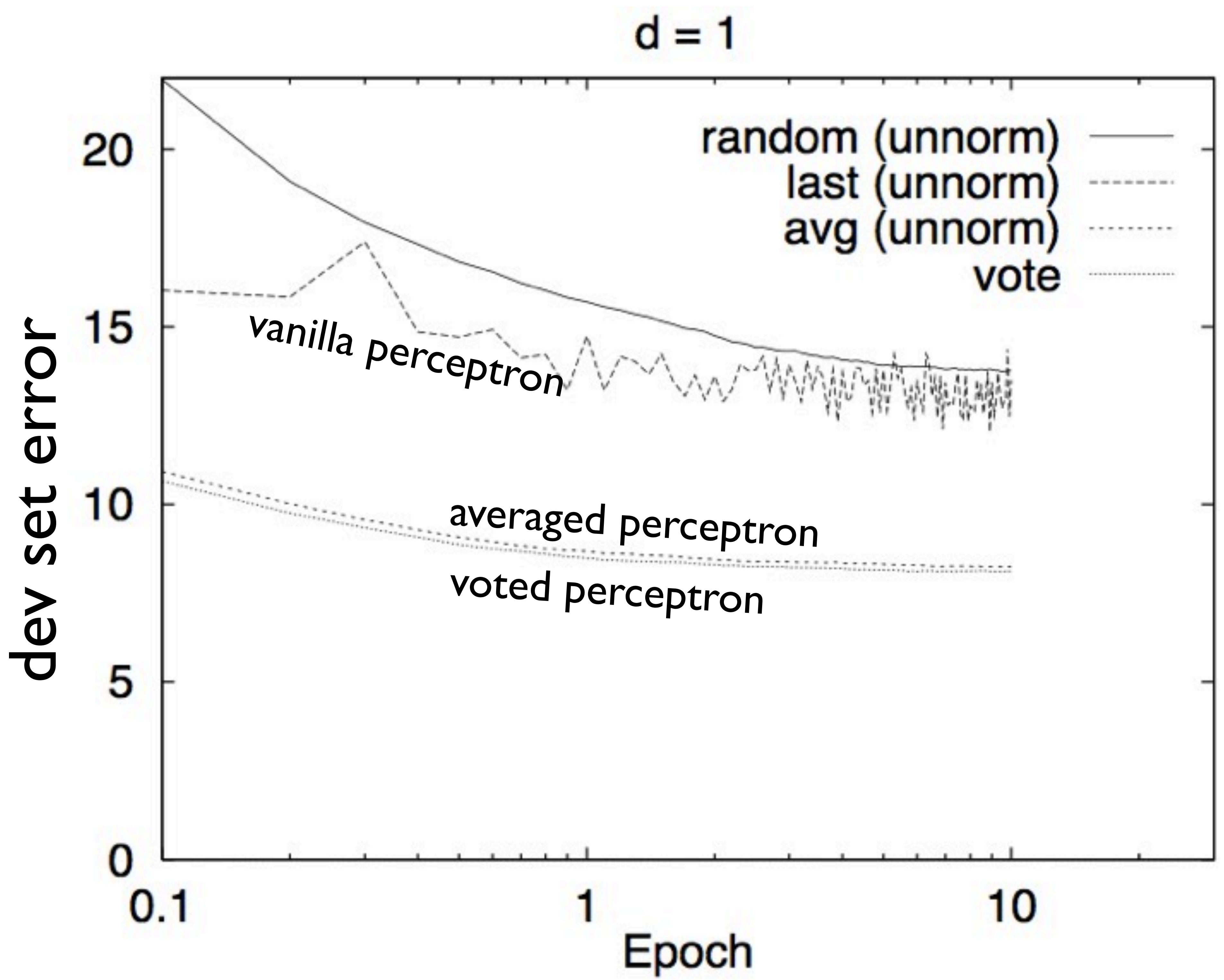


Python Demo

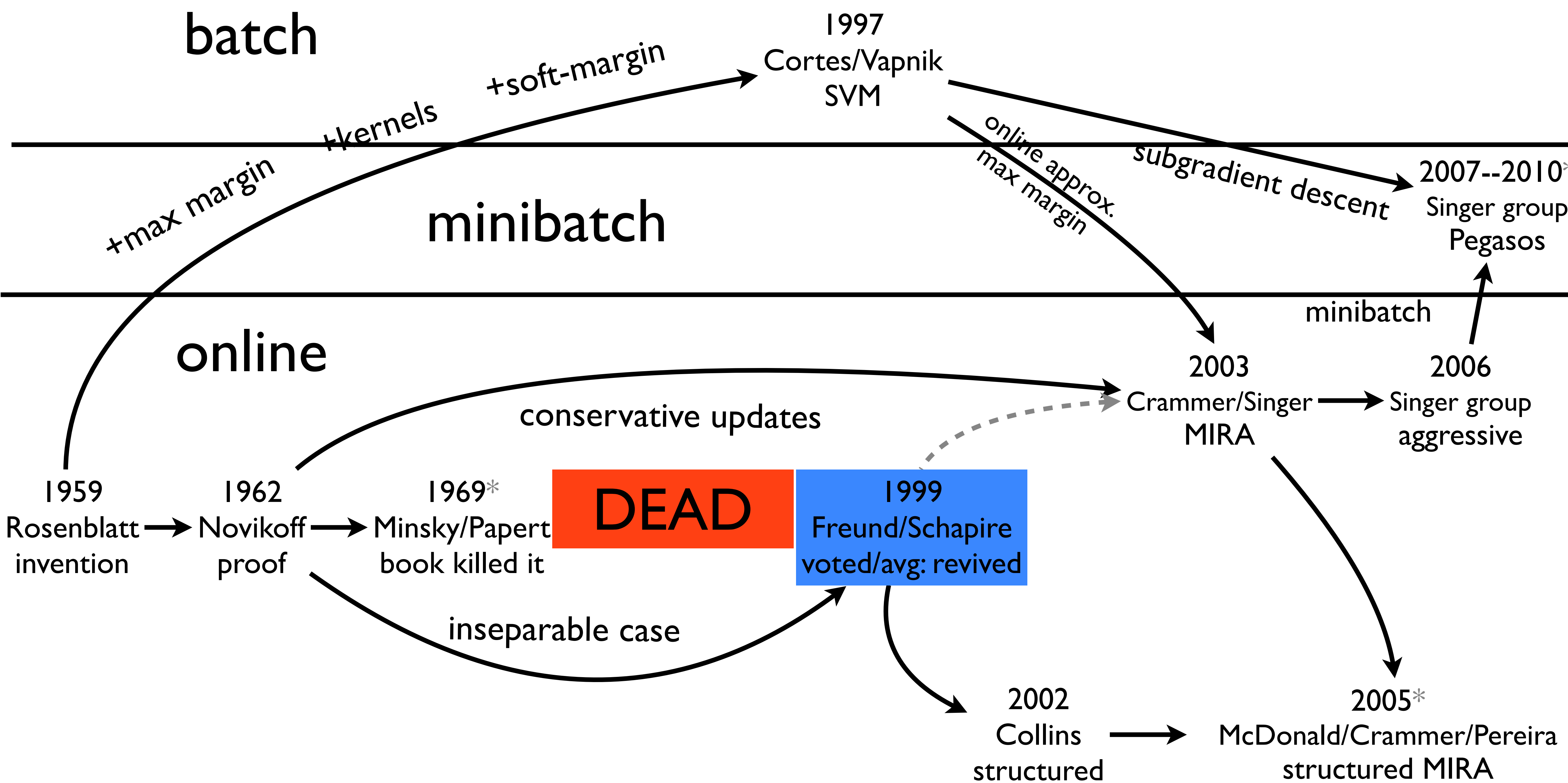
`$ python perc_demo.py` (requires numpy and matplotlib)



Part II: Voted and Averaged Perceptron



Voted/Avg. Perceptron Revives Perceptron



*mentioned in lectures but optional
(others papers all covered in detail)

Voted/Avged Perceptron

- problem: later examples dominate earlier examples
- solution: voted perceptron (Freund and Schapire, 1999)
  - record the weight vector after each example in D
    - not just after each update!
  - and vote on a new example using $|D|$ models
  - shown to have better generalization power
- averaged perceptron (from the same paper)
  - an approximation of voted perceptron
  - just use the average of all weight vectors
  - can be implemented efficiently

Voted Perceptron

Input: a labeled training set $\langle(\mathbf{x}_1, y_1), \ldots, (\mathbf{x}_m, y_m)\rangle$
number of epochs T

Output: a list of weighted perceptrons $\langle(\mathbf{v}_1, c_1), \ldots, (\mathbf{v}_k, c_k)\rangle$

our notation: $(\mathbf{x}^{(i)}, y^{(i)})$

$\mathbf{v}$ is weight,
c is its # of votes

- Initialize: $k := 0$, $\mathbf{v}_1 := \mathbf{0}$, $c_1 := 0$.
- Repeat T times:
  - For $i = 1, \ldots, m$:
    - Compute prediction: $\hat{y} := \text{sign}(\mathbf{v}_k \cdot \mathbf{x}_i)$
    - If $\hat{y} = y$ then $c_k := c_k + 1$.
      else $\mathbf{v}_{k+1} := \mathbf{v}_k + y_i \mathbf{x}_i$;
      $c_{k+1} := 1$;
      $k := k + 1$.

Large Margin Classification
Using the Perceptron Algorithm

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if correct, increase the current model's # of votes; otherwise create a new model with 1 vote

Voted Perceptron

Input: a labeled training set $\langle(\mathbf{x}_1, y_1), \ldots, (\mathbf{x}_m, y_m)\rangle$
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our notation: $(\mathbf{x}^{(1)}, y^{(1)})$

v is weight,

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- Initialize: $k := 0$, $\mathbf{v}_1 := \mathbf{0}$, $c_1 := 0$.
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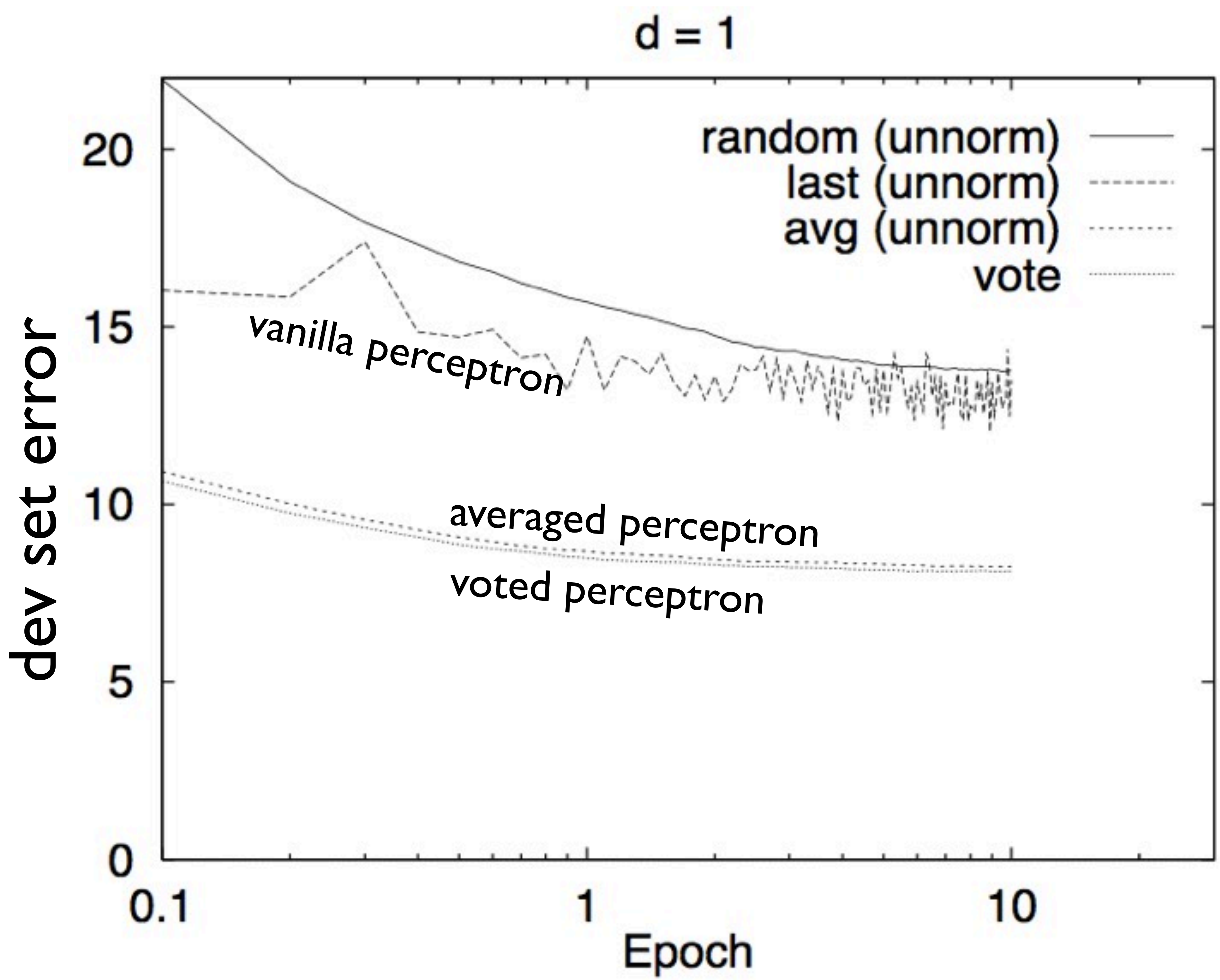
Prediction

Given: the list of weighted perceptrons: $\langle(\mathbf{v}_1, c_1), \ldots, (\mathbf{v}_k, c_k)\rangle$
an unlabeled instance: $\mathbf{x}$

compute a predicted label $\hat{y}$ as follows:

$$s = \sum_{i=1}^{k} c_i \,\mathrm{sign}(\mathbf{v}_i \cdot \mathbf{x}); \qquad \hat{y} = \mathrm{sign}(s)\ .$$

Experiments



Averaged Perceptron

- voted perceptron is not scalable
  - and does not output a single model
- avg perceptron is an approximation of voted perceptron
  - actually, summing all weight vectors is enough; no need to divide

$$
\begin{array}{l}
\textbf{initialize } \mathbf{w} \leftarrow \mathbf{0};\ \mathbf{w}_s \leftarrow \mathbf{0} \\
\textbf{while} \text{ not converged} \\
\quad \textbf{for } (\mathbf{x}, y) \in D \\
\quad\quad \textbf{if } y(\mathbf{w} \cdot \mathbf{x}) \leq 0 \\
\quad\quad\quad \mathbf{w} \leftarrow \mathbf{w} + y\mathbf{x} \\
\quad\quad \mathbf{w}_s \leftarrow \mathbf{w}_s + \mathbf{w} \\
\textbf{output: } \text{summed weights } \mathbf{w}_s
\end{array}
$$

after each example, not after each update!

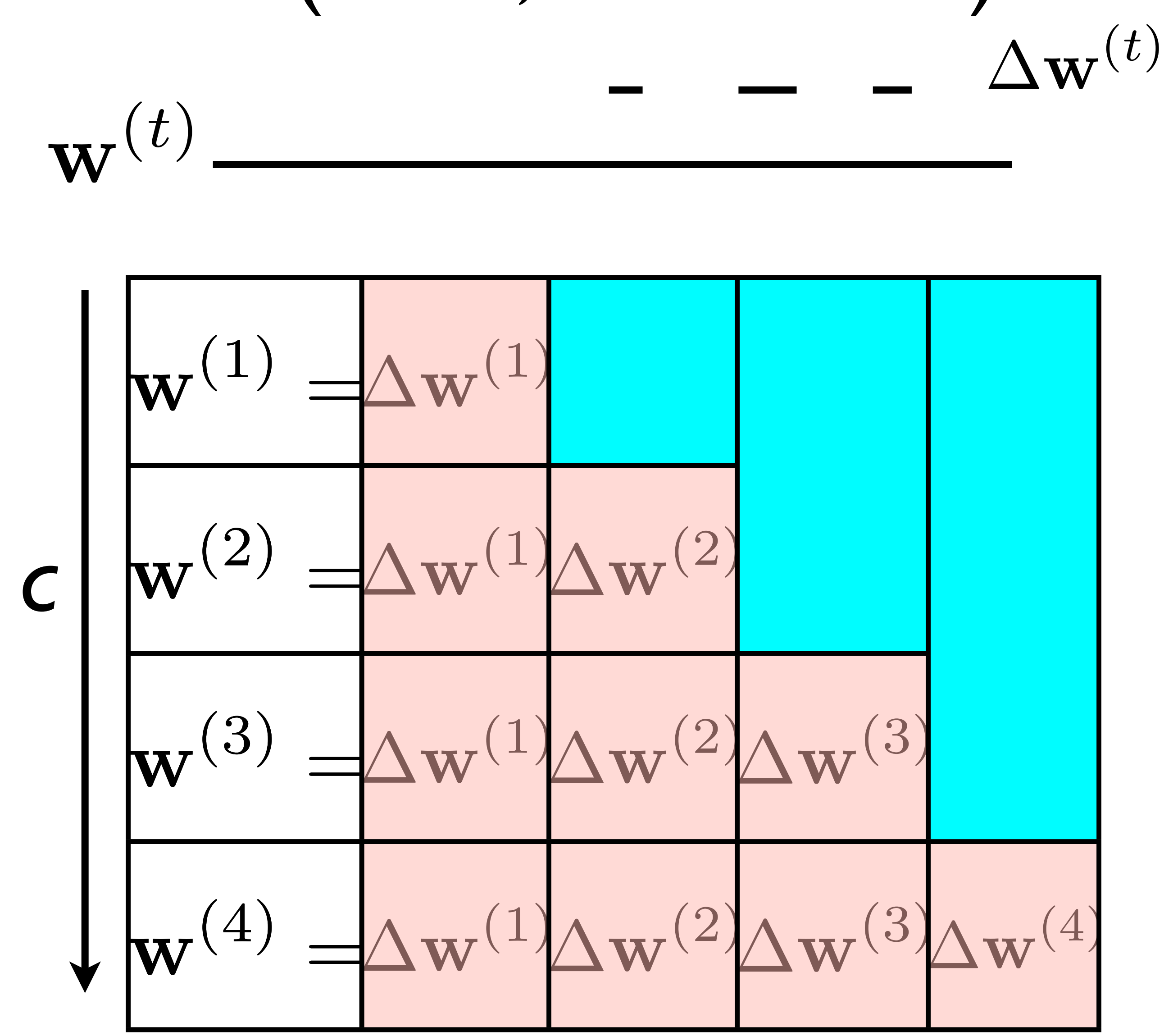
$$
\begin{array}{l}
\mathbf{w}^{(1)} = \Delta\mathbf{w}^{(1)} \\
\mathbf{w}^{(2)} = \Delta\mathbf{w}^{(1)} \Delta\mathbf{w}^{(2)} \\
\mathbf{w}^{(3)} = \Delta\mathbf{w}^{(1)} \Delta\mathbf{w}^{(2)} \Delta\mathbf{w}^{(3)} \\
\mathbf{w}^{(4)} = \Delta\mathbf{w}^{(1)} \Delta\mathbf{w}^{(2)} \Delta\mathbf{w}^{(3)} \Delta\mathbf{w}^{(4)}
\end{array}
$$

Efficient Implementation of Averaging

- naive implementation (running sum $\mathbf{w}_s$) doesn't scale
  - OK for low dim. (HW1); too slow for high-dim. (HW3)
- very clever trick from Hal Daumé (2006, PhD thesis)

$$
\begin{array}{l}
\textbf{initialize } \mathbf{w} \leftarrow \mathbf{0};\ \mathbf{w}_a \leftarrow \mathbf{0};\ c \leftarrow 0 \\
\textbf{while} \text{ not converged} \\
\quad \textbf{for } (\mathbf{x}, y) \in D \\
\quad\quad \textbf{if } y(\mathbf{w} \cdot \mathbf{x}) \leq 0 \\
\quad\quad\quad \mathbf{w} \leftarrow \mathbf{w} + y\mathbf{x} \\
\quad\quad\quad \mathbf{w}_a \leftarrow \mathbf{w}_a + cy\mathbf{x} \\
\quad\quad c \leftarrow c + 1 \\
\textbf{output: } c\mathbf{w} - \mathbf{w}_a
\end{array}
$$

after each update, not after each example!

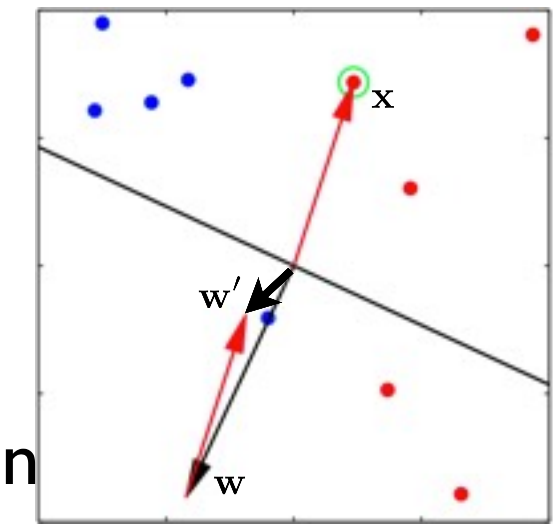


Part III: MIRA

- perceptron often makes bold updates (over-correction)
  - and sometimes too small updates (under-correction)
  - but hard to tune learning rate
- "just enough" update to correct the mistake?

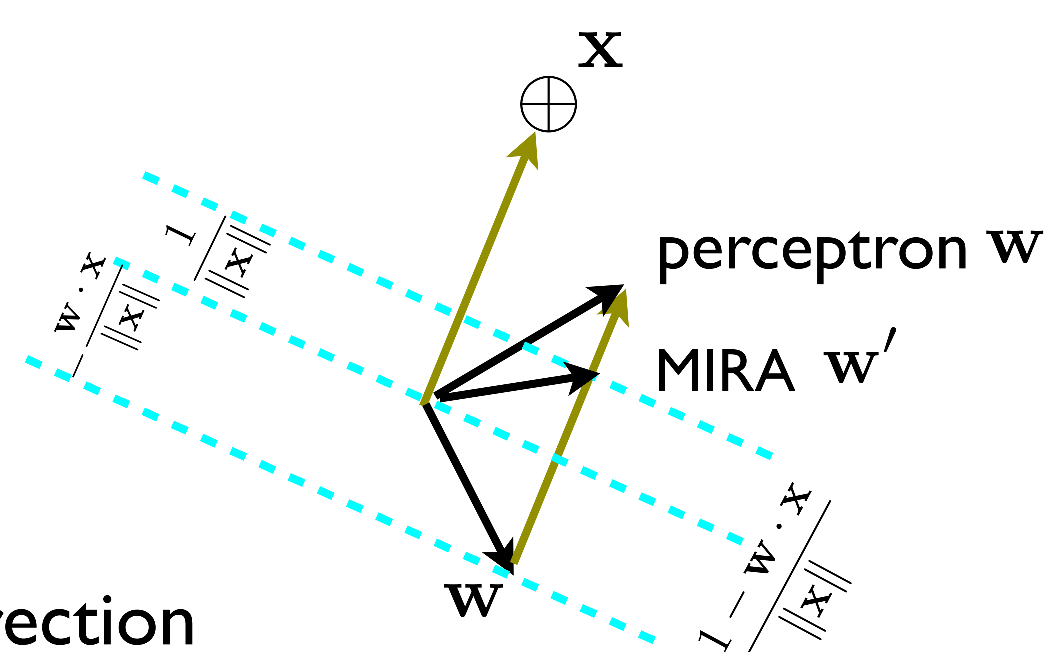
$$\mathbf{w}' \leftarrow \mathbf{w} + \frac{y - \mathbf{w} \cdot \mathbf{x}}{\|\mathbf{x}\|^2} \mathbf{x}$$

under-correction



easy to show:

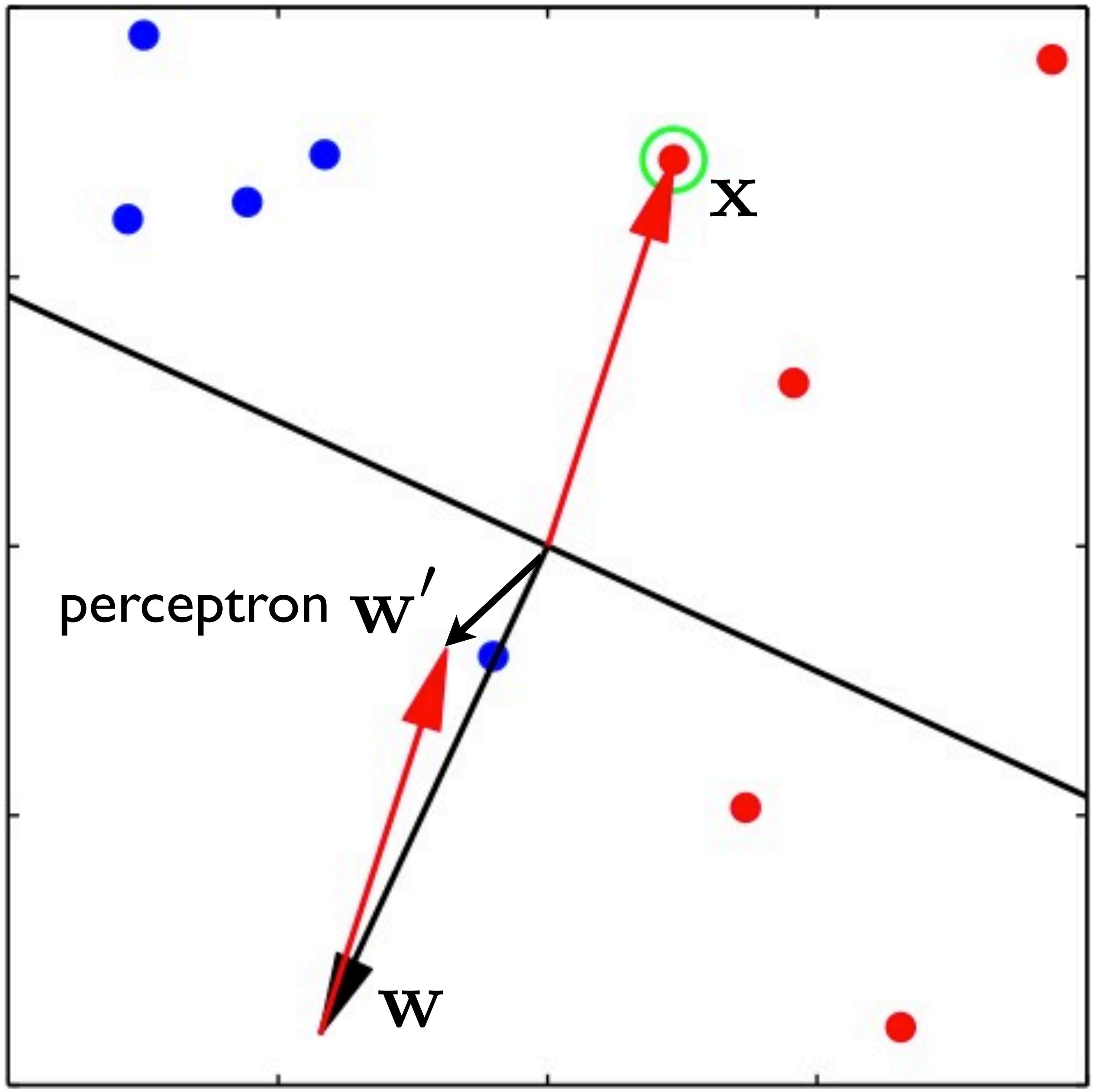
$$\mathbf{w}' \cdot \mathbf{x} = (\mathbf{w} + \frac{y - \mathbf{w} \cdot \mathbf{x}}{\|\mathbf{x}\|^2} \mathbf{x}) \cdot \mathbf{x} = y$$



over-correction

margin-infused relaxation algorithm (MIRA)

Example: Perceptron under-correction

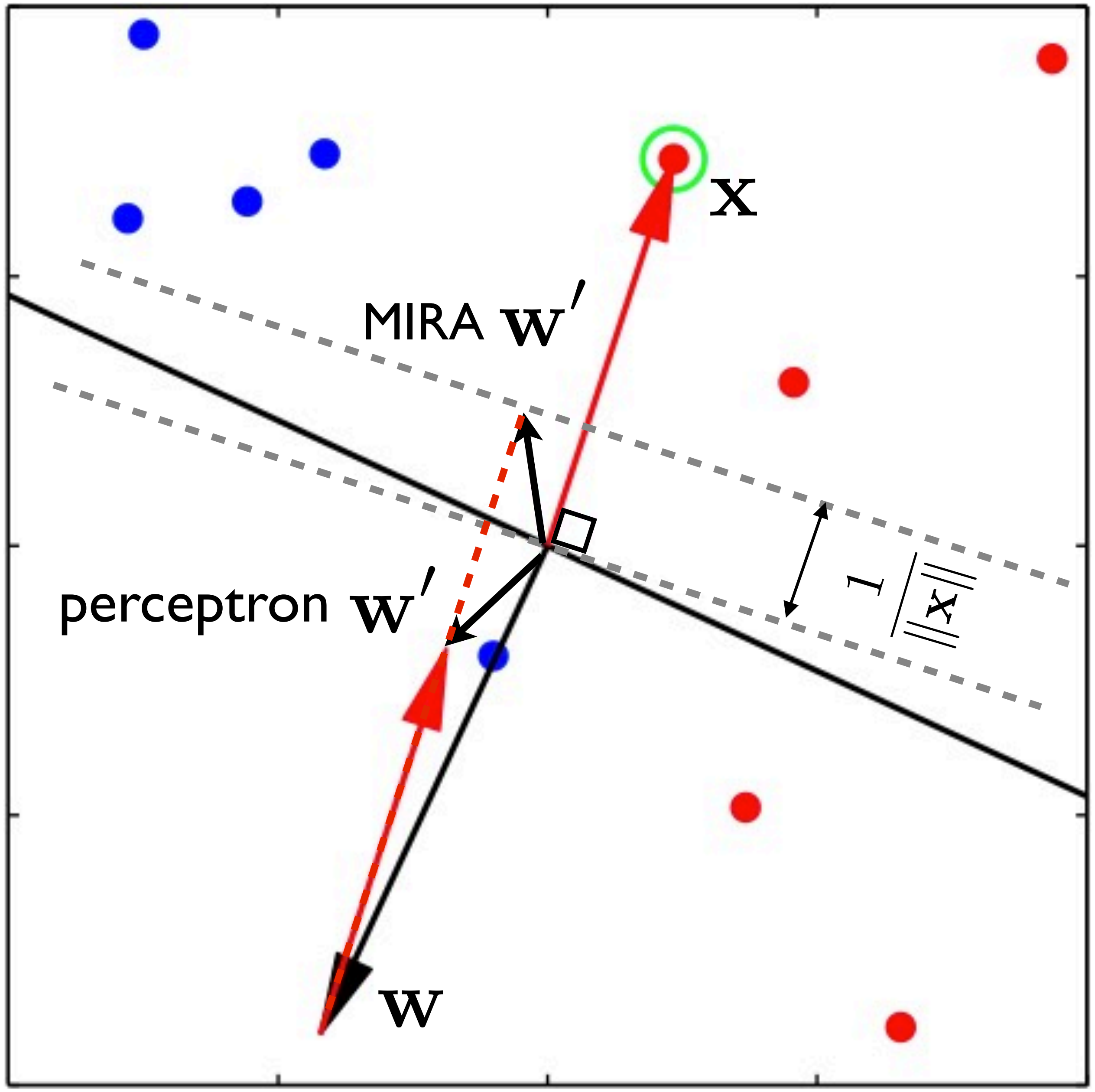


MIRA: just enough

$$\min_{\mathbf{w}'} \|\mathbf{w}' - \mathbf{w}\|^2$$
$$\text{s.t. } \mathbf{w}' \cdot \mathbf{x} \geq 1$$

minimal change to ensure functional margin of 1 (dot-product **w' · x**=1)

MIRA ≈ 1-step SVM



functional margin: $y(\mathbf{w} \cdot \mathbf{x})$

geometric margin: $\dfrac{y(\mathbf{w} \cdot \mathbf{x})}{\|\mathbf{w}\|}$

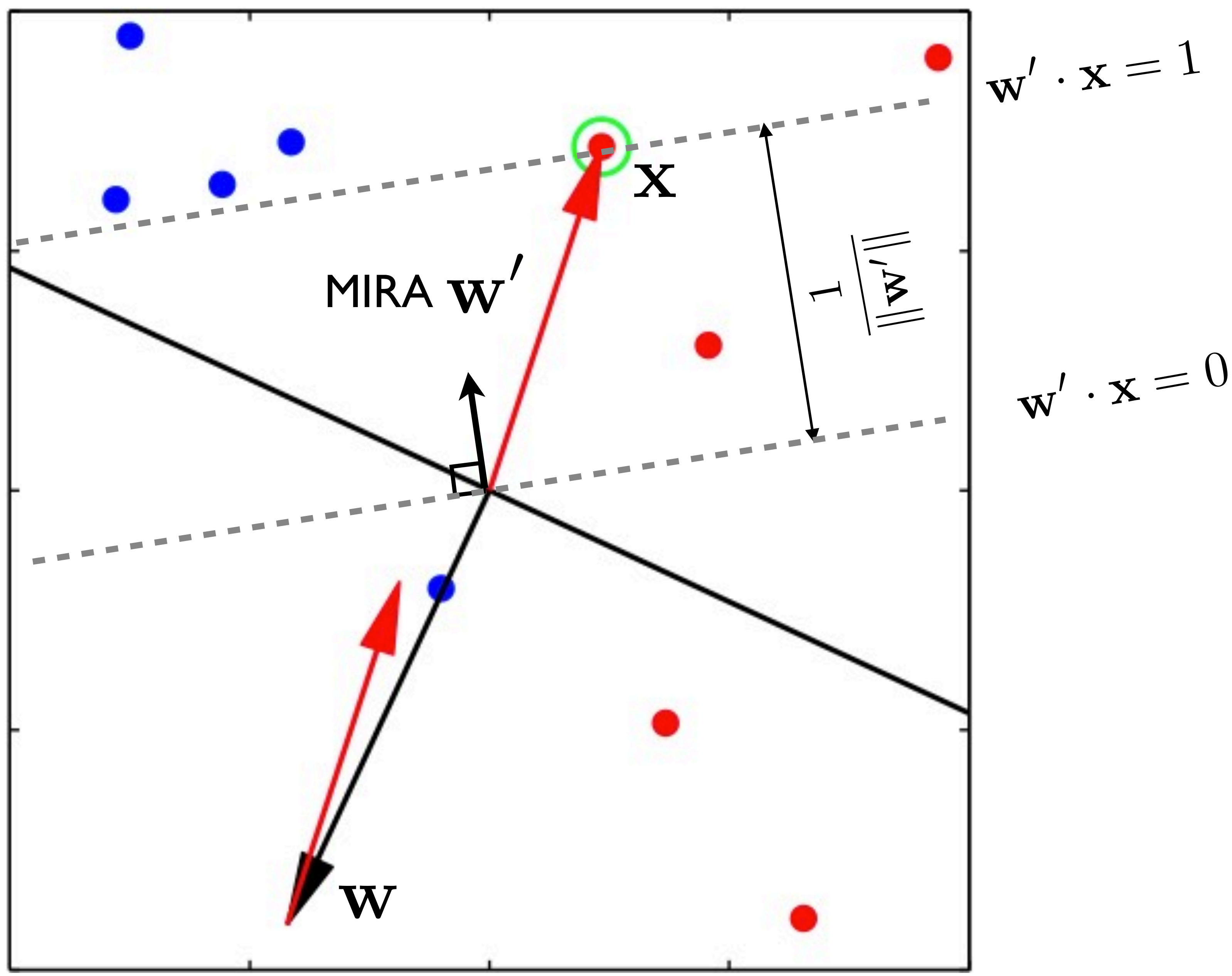
MIRA: functional vs geom. margin

$$\min_{\mathbf{w}'} \|\mathbf{w}' - \mathbf{w}\|^2$$

$$\text{s.t. } \mathbf{w}' \cdot \mathbf{x} \geq 1$$

minimal change to ensure functional margin of 1 (dot-product **w**' · **x**=1)

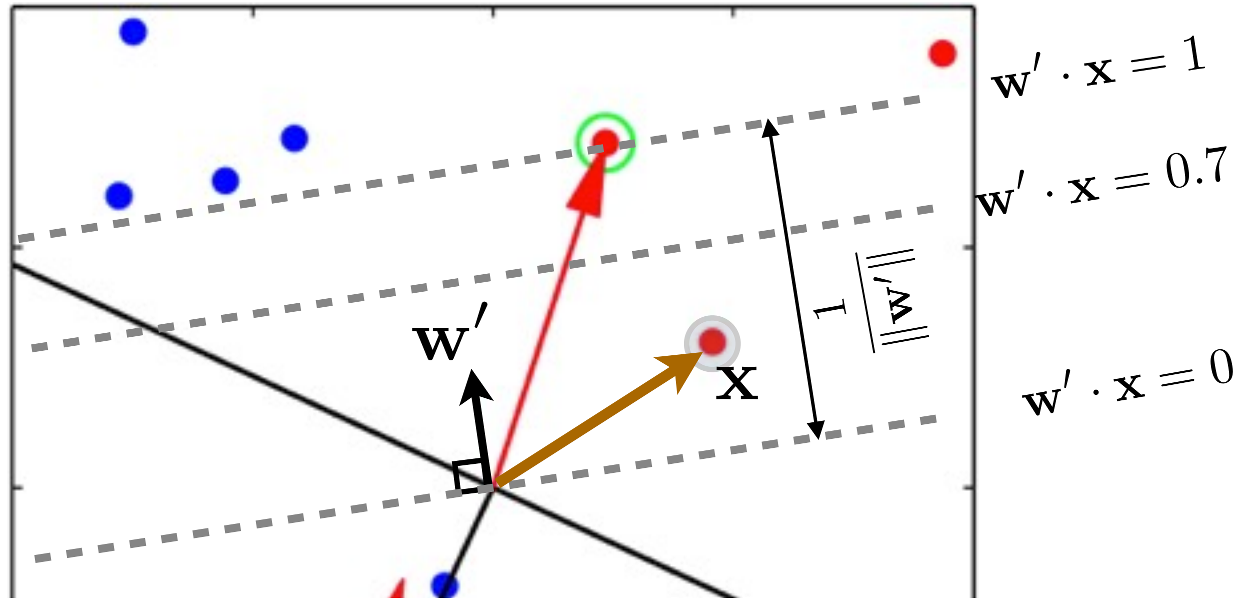
MIRA ≈ 1-step SVM



functional margin: $y(\mathbf{w} \cdot \mathbf{x})$

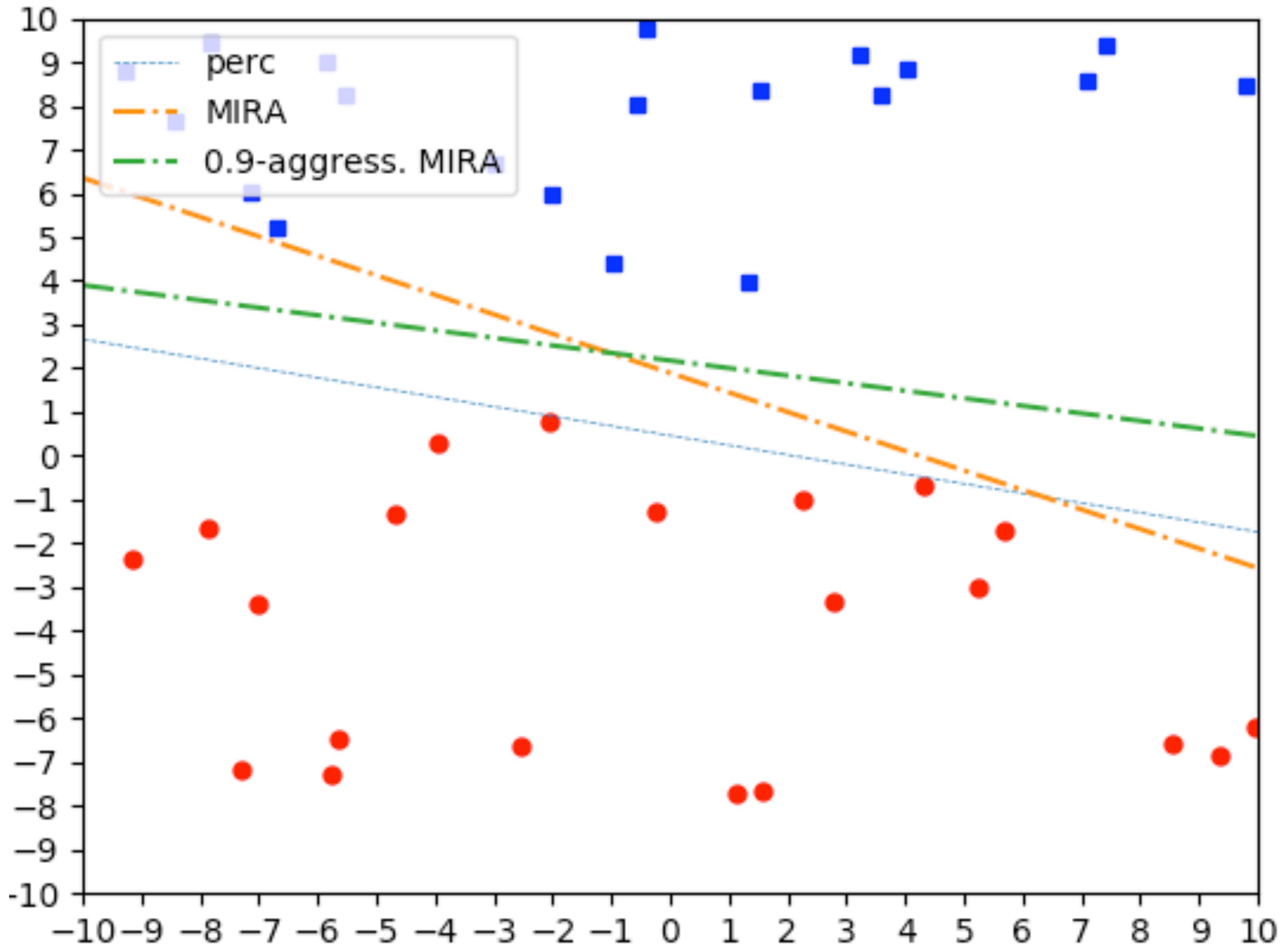
geometric margin: $\dfrac{y(\mathbf{w} \cdot \mathbf{x})}{\|\mathbf{w}\|}$

Optional: Aggressive MIRA



- aggressive version of MIRA
  - also update if correct but not confident enough
    - i.e., functional margin ($y\ \mathbf{w} \cdot \mathbf{x}$) not big enough
  - p-aggressive MIRA: update if $y\ (\mathbf{w} \cdot \mathbf{x}) < p$ $(0 <= p < 1)$
    - MIRA is a special case with p=0: only update if misclassified!
    - update equation is same as MIRA
      - i.e., after update, functional margin becomes 1
  - larger p leads to a larger geometric margin but slower convergence

Demo



perc
MIRA
0.9-aggress. MIRA
10
9
8
7
6
5
4
3
2
1
0
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−4
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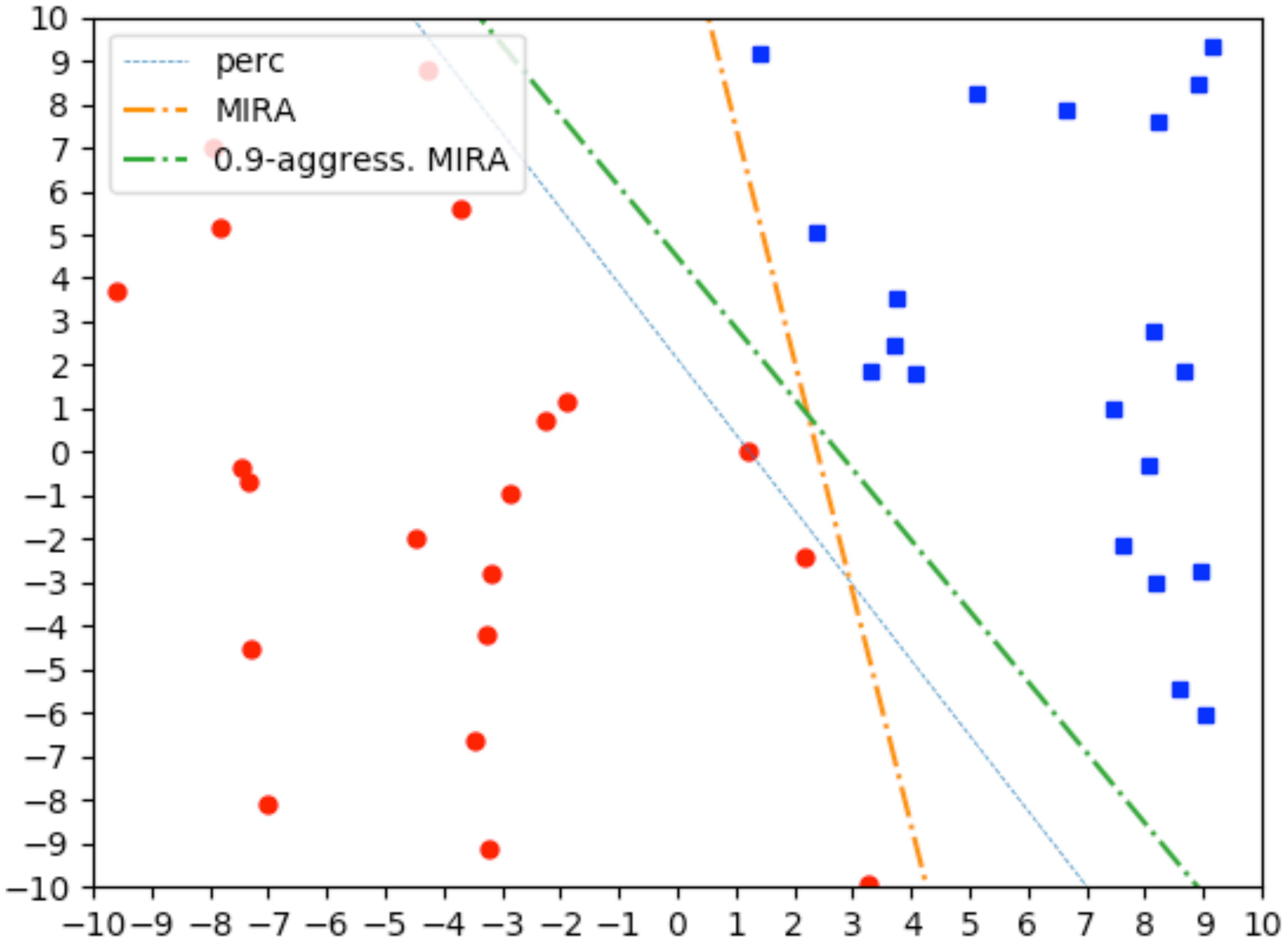
-10
−10 −9 −8 −7 −6 −5 −4 −3 −2 −1 0 1 2 3 4 5 6 7 8 9 10

Demo



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Part IV: Practical Issues and HW1

"A ship in port is safe, but that is not what ships are for."

– Grace Hopper (1906-1992)

- you will build your own linear classifiers for HW1 data

HW1: Adult Income >50K?

training/dev sets:

Age,	*Sector,*	*Education,*	*Marital_Status,*	*Occupation,*	*Race,*	*Sex,*	*Hours,*	*Country,*	***Target***
40,	Private,	Doctorate,	Married-civ-spouse,	Prof-specialty,	White,	Female,	60,	United-States,	>50K
44,	Local-gov,	Some-college,	Married-civ-spouse,	Exec-managerial,	Black,	Male,	38,	United-States,	>50K
55,	Private,	HS-grad,	Divorced,	Sales,	White,	Male,	40,	England,	<=50K
test data (semi-blind):									
30,	Private,	Assoc-voc,	Married-civ-spouse,	Tech-support,	White,	Female,	40,	Canada,	???

- 2 numerical features: age and hours-per-week
  - option 1: keep them as numerical features
    - but is older and more hours always better?
  - option 2: (better) treat them as <u>binary</u> features
    - e.g., age=22, hours=38, ...
- 7 categorical features: convert to <u>binary</u> features
  - country, race, occupation, etc.
  - e.g., country=United_States, education=Doctorate,...
- perceptron: ~19% dev error, avg. perceptron: ~15% dev error

Interesting Facts in HW1 Data

- only ~25% positive (>50K); data was from 1994 (~$27K per capita)
- education is probably the single most important factor
  - education=Doctorate is extremely positive (80%)
  - education=Prof-school is also very positive (75%)
  - education=Masters is also positive (55%)
  - education=9th (high school dropout) is extremely negative (6%)
- "married" is good (45%), "never married" is extremely bad (5%)
- "self-emp-inc" is the best sector (59%), but "self-emp-not-inc" 30%
- hours-per-week=1 is 100% positive; country=Iran is 70% positive
- exec-managerial and prof-specialty are best occupations (48% / 46%)
- interesting combinations (e.g. "edu=Doc and sector=self-emp-inc": 100%)

Looking at HW1 data on terminal

- you are highly recommended to use Linux or Mac terminals
- basic familiarity with the terminal is a must for a data scientist!

```
$ cat income.train.txt.5k | cut -f 2 -d ','| sort | uniq -c
 150  Federal-gov
 340  Local-gov
3694  Private
 183  Self-emp-inc
 424  Self-emp-not-inc
 208  State-gov
   1  Without-pay
```

```
sector=Self-emp-inc: 59.02%
education=Masters: 55.38%
education=Prof-school: 74.70%
education=Doctorate: 80.00%
hours-per-week=99: 60.00%
hours-per-week=68: 100.00%
hours-per-week=1: 100.00%
country-of-origin=Taiwan: 58.33%
country-of-origin=Iran: 70.00%
country-of-origin=Cambodia: 66.67%
```

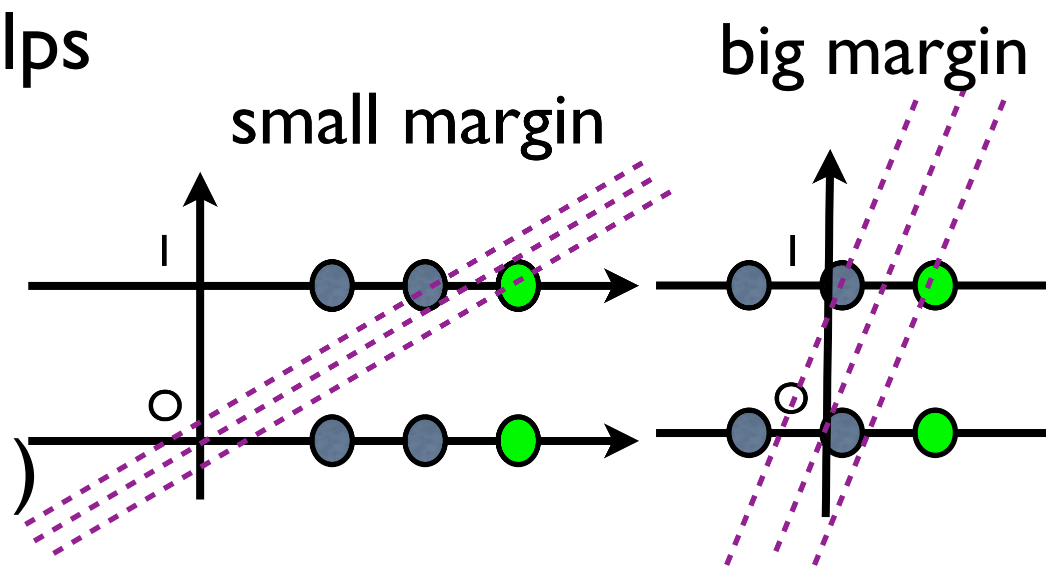
```
$ cat income.train.txt.5k | grep "Prof-spec" | wc -l
646
$ cat income.train.txt.5k | grep "Prof-spec" | grep -c ">"
294
```

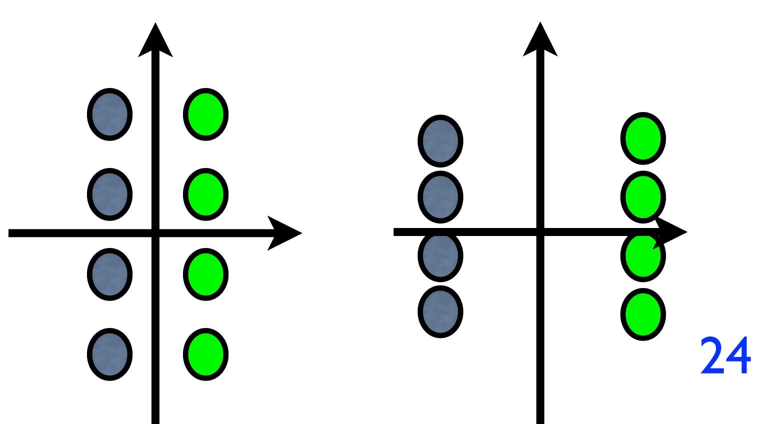
```
$ cat income.train.txt.5k | sort -nk1 | head -1
17
$ cat income.train.txt.5k | sort -nk1 | tail -1
90
```

Useful Engineering Tips:

averaging, shuffling, variable learning rate, fixing feature scale

- averaging helps significantly; MIRA helps a tiny little bit
  - perceptron < MIRA < avg. perceptron ≈ avg. MIRA ≈ SVM
- shuffling the data helps hugely if classes were ordered (HW1)
  - shuffling before each epoch helps a little bit
- variable (decaying) learning rate often helps a little
  - 1/(total#updates) or 1/(total#examples) helps
  - any requirement in order to converge?
    - how to prove convergence now?
- centering of each dimension helps (Ex1/HW1)
  - why? => smaller radius, bigger margin!
- unit variance also helps (why?) (Ex1/HW1)
  - 0-mean, 1-var => each feature ≈ a unit Gaussian



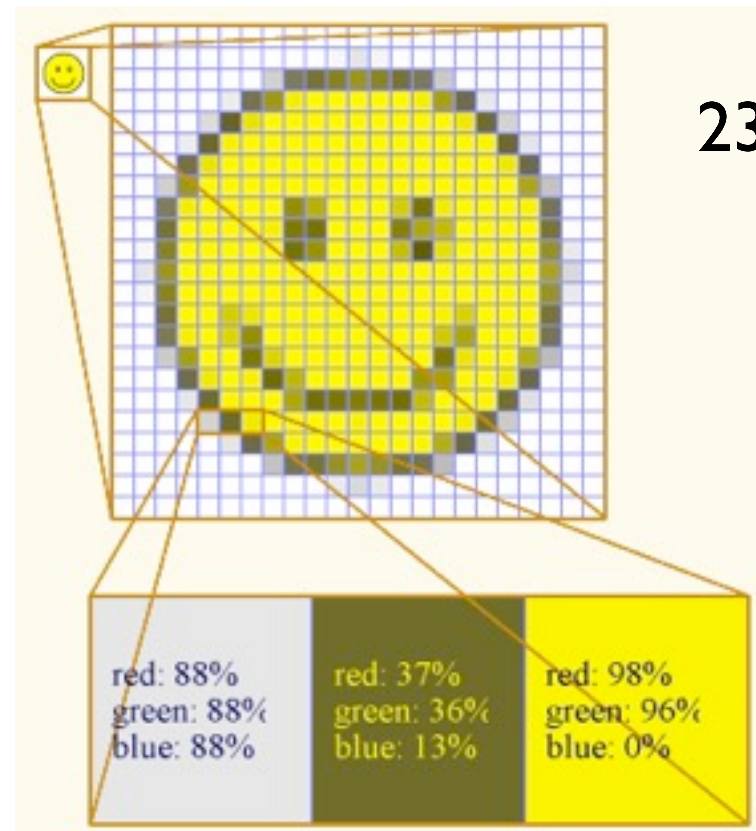


Feature Maps in Other Domains

- how to convert an image or text to a vector?

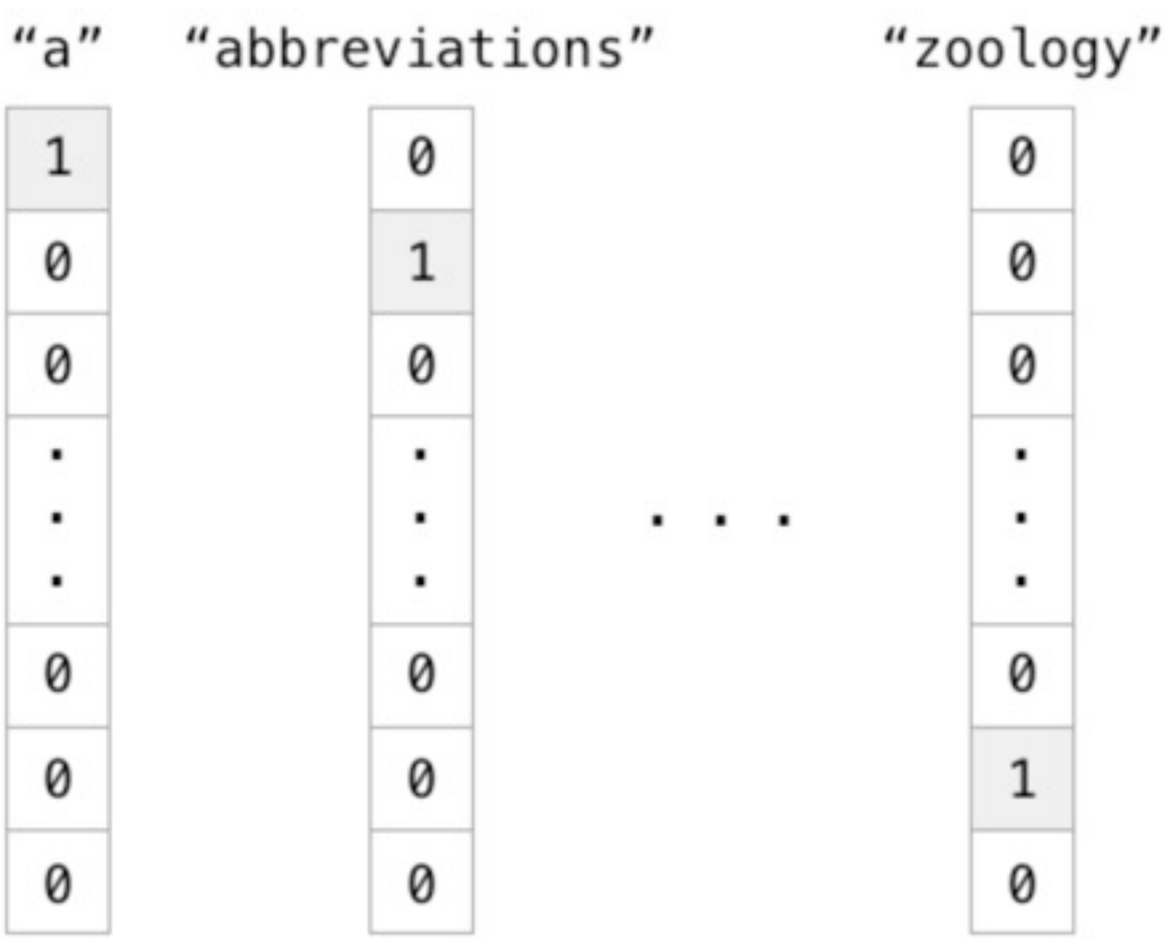
28x28 grayscale image

$\mathbf{x} \in \mathbb{R}^{784}$



23x23 RGB image

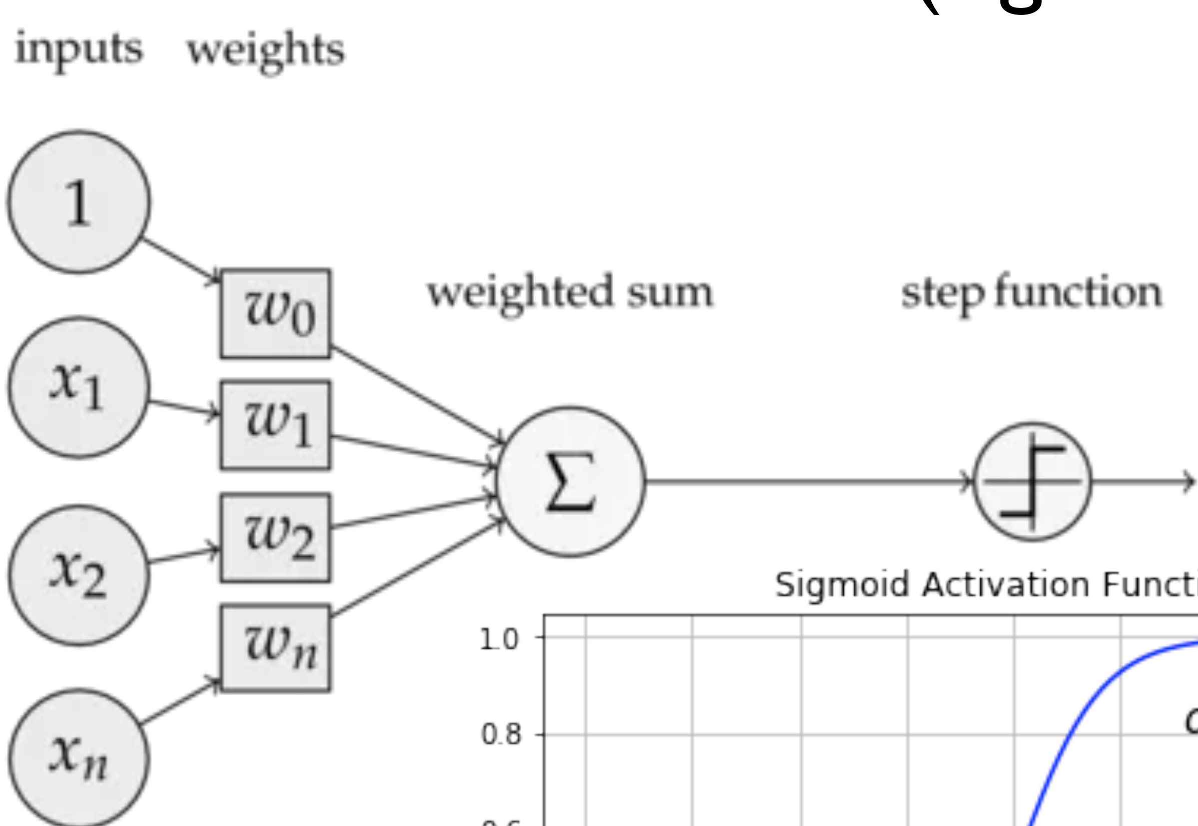
$\mathbf{x} \in \mathbb{R}^{23\text{x}23\text{x}3}$

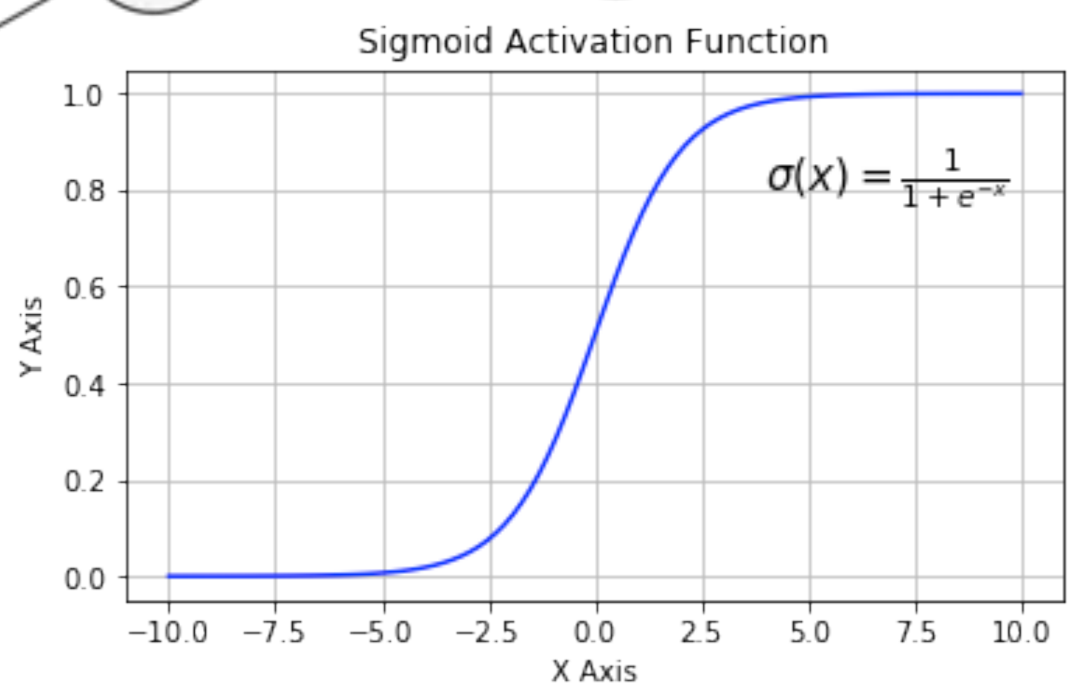


"one-hot" representation of words
(all binary features)

Part V: Perceptron vs. Logistic Regression

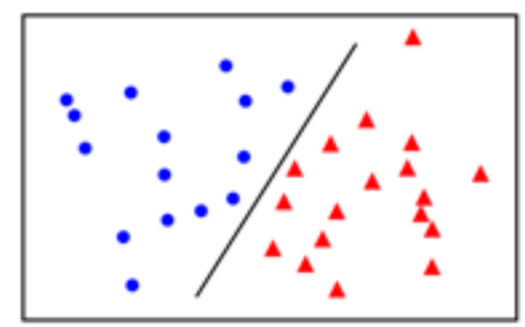
- logistic regression is another popular linear classifier
  - can be viewed as "soft" or "probabilistic" perceptron
  - same decision rule (sign of dot-product), but prob. output





perceptron

$$f(\mathbf{x}) = \mathbf{sign}(\mathbf{w} \cdot \mathbf{x})$$



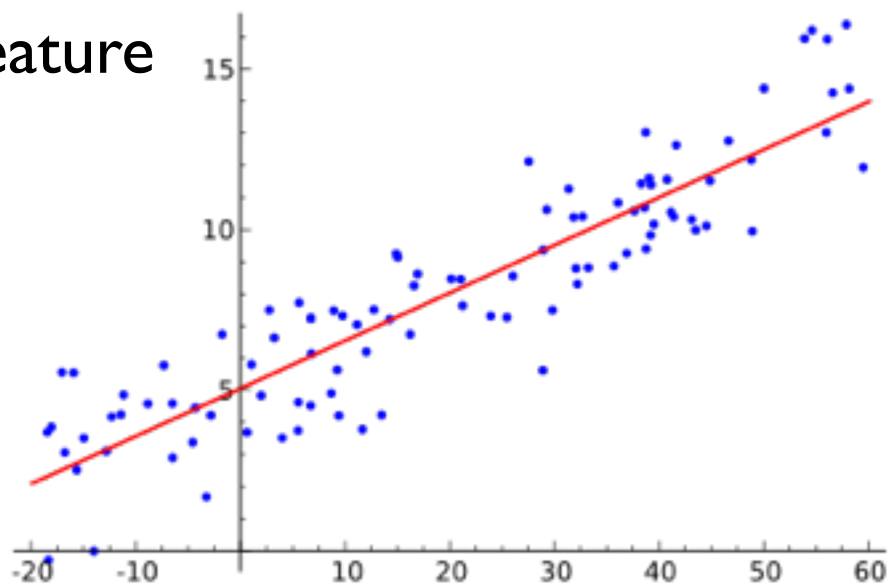
logistic regression

$$f(\mathbf{x}) = \sigma(\mathbf{w} \cdot \mathbf{x}) = \frac{1}{1 + e^{-\mathbf{w} \cdot \mathbf{x}}}$$

Logistic vs. Linear Regression

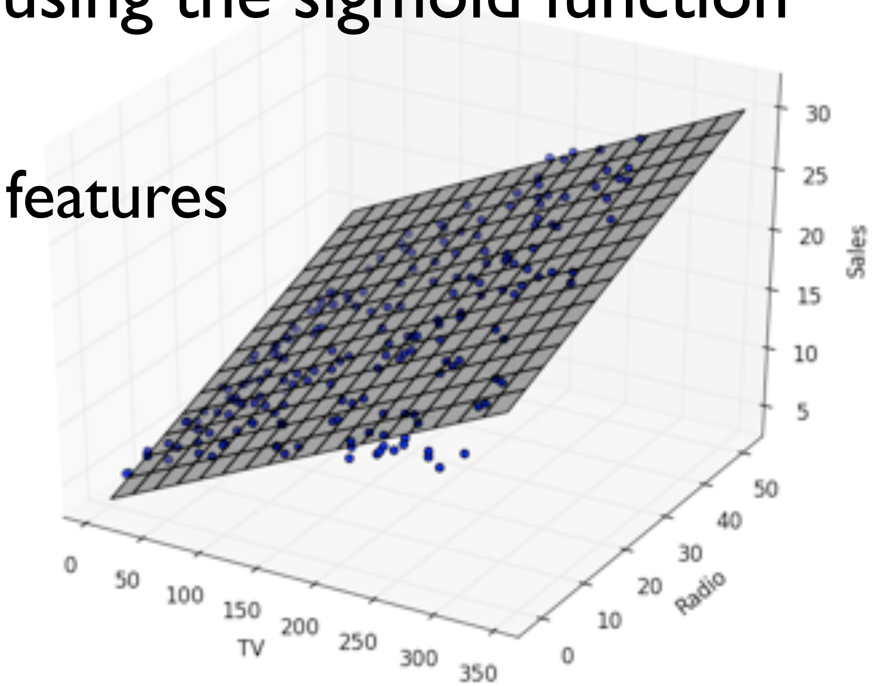
- linear regression is regression applied to real-valued output using linear function
- logistic regression is regression applied to 0-1 output using the sigmoid function

1 feature

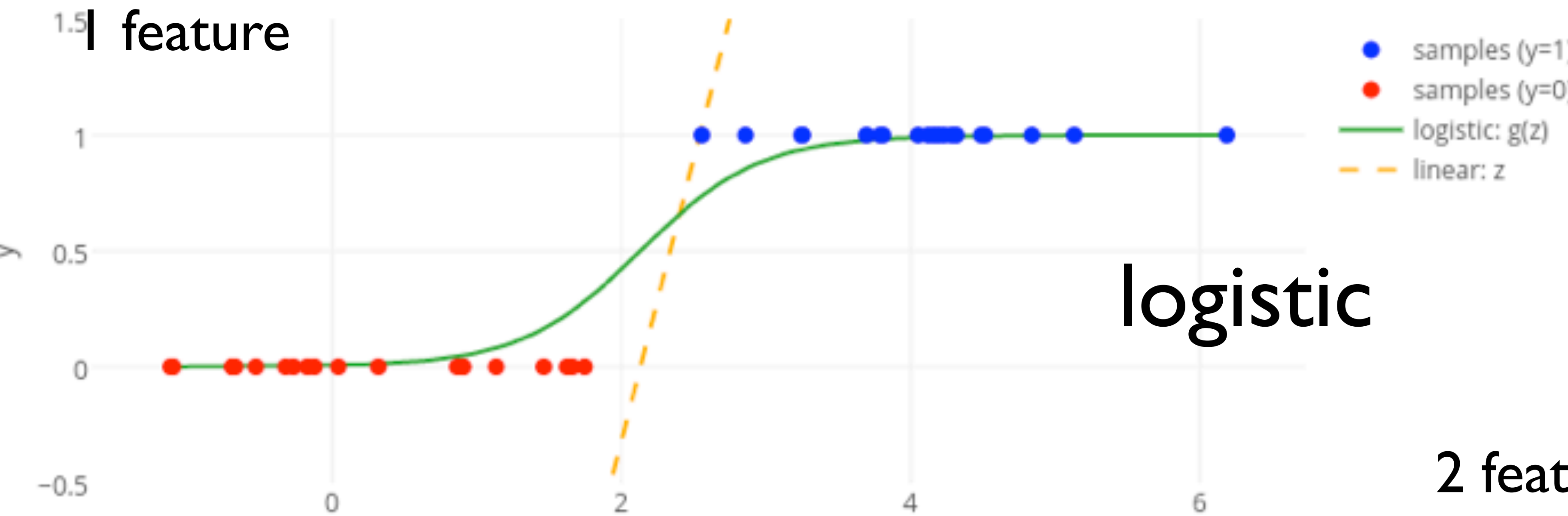


linear

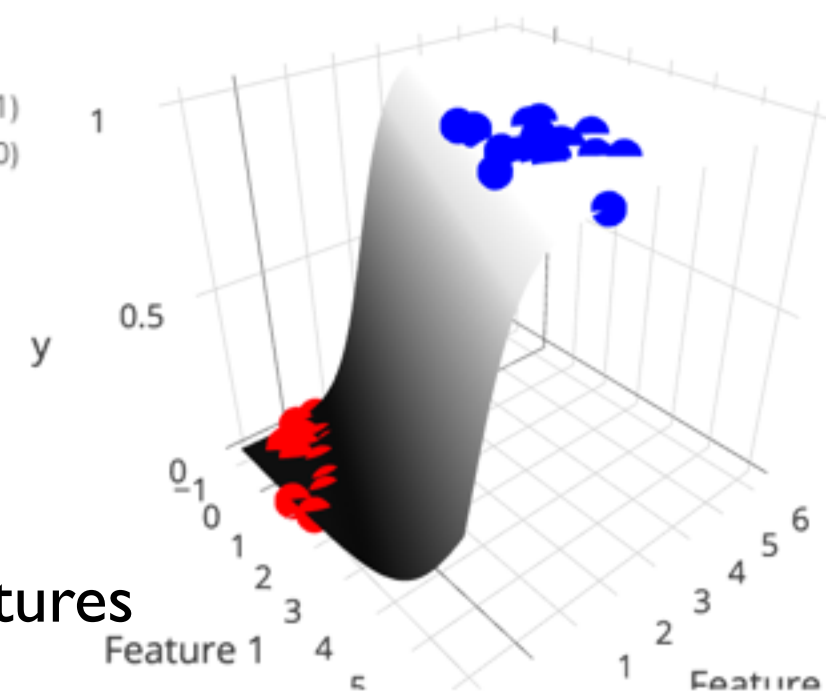
2 features



1 feature



logistic

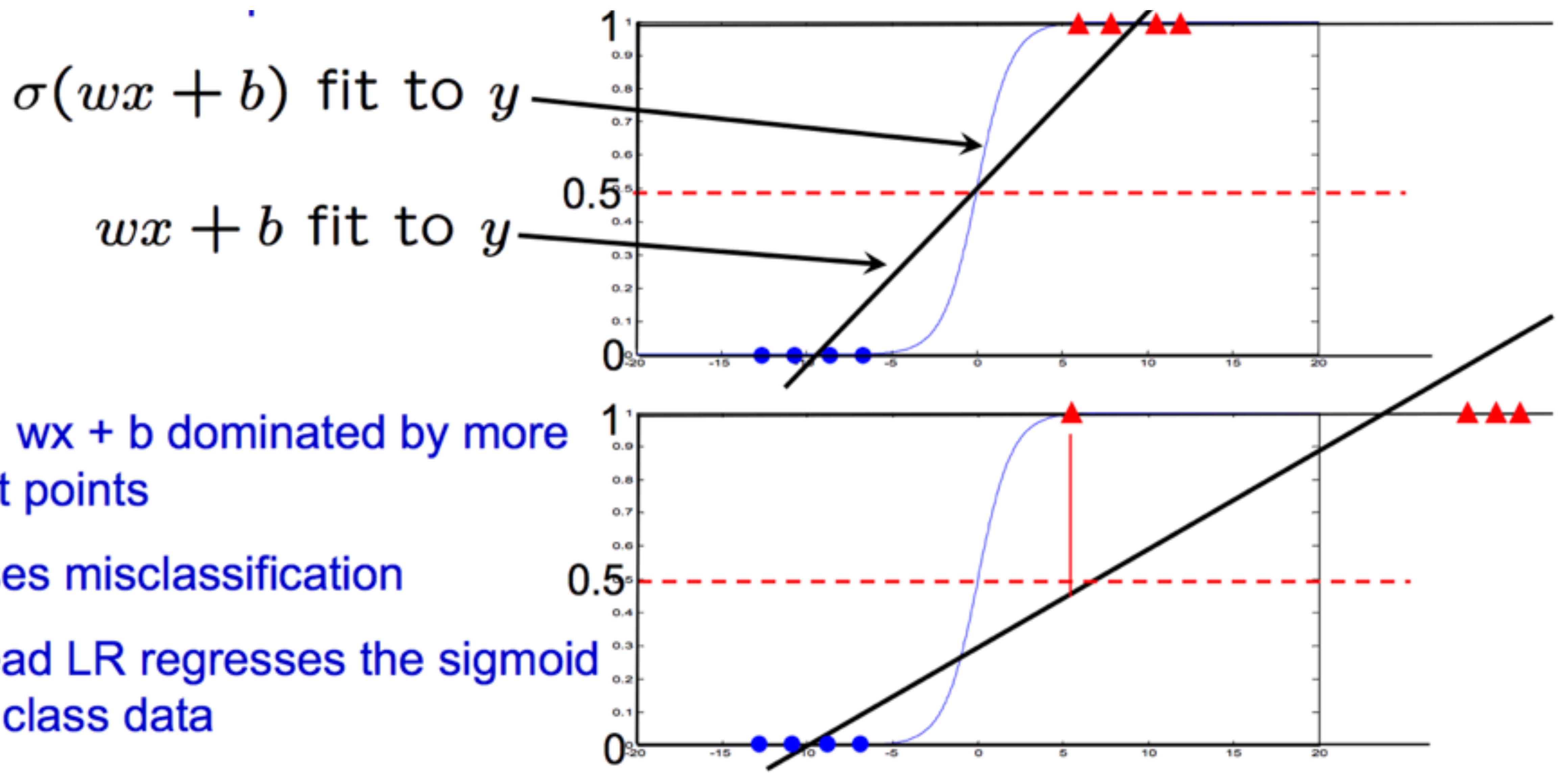


2 features

https://florianhartl.com/logistic-regression-geometric-intuition.html

Why Logistic instead of Linear

- linear regression easily dominated by distant points
  - causing misclassification

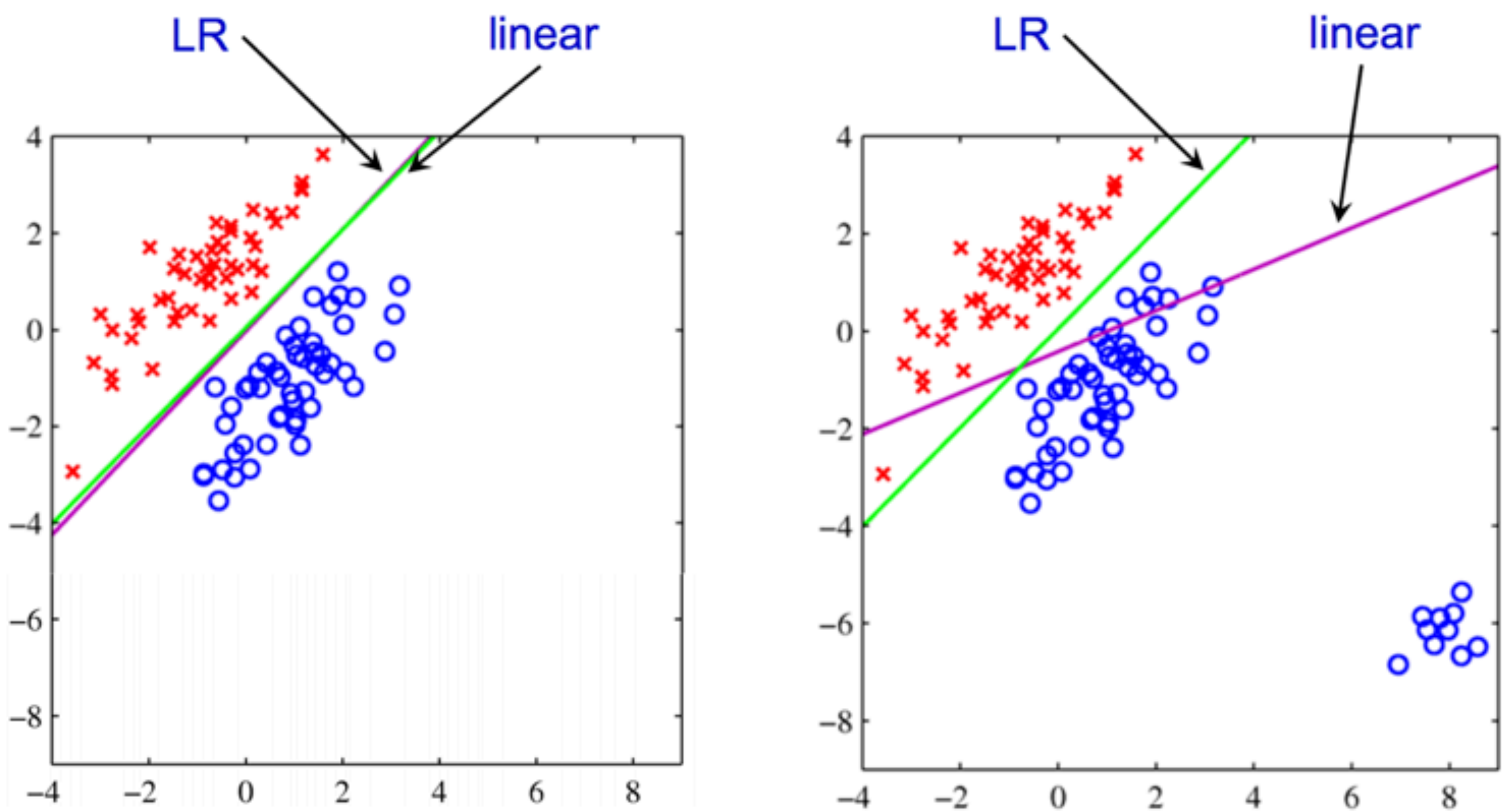


- fit of wx + b dominated by more distant points
- causes misclassification
- instead LR regresses the sigmoid to the class data

http://www.robots.ox.ac.uk/~az/lectures/ml/2011/lect4.pdf

Why Logistic instead of Linear

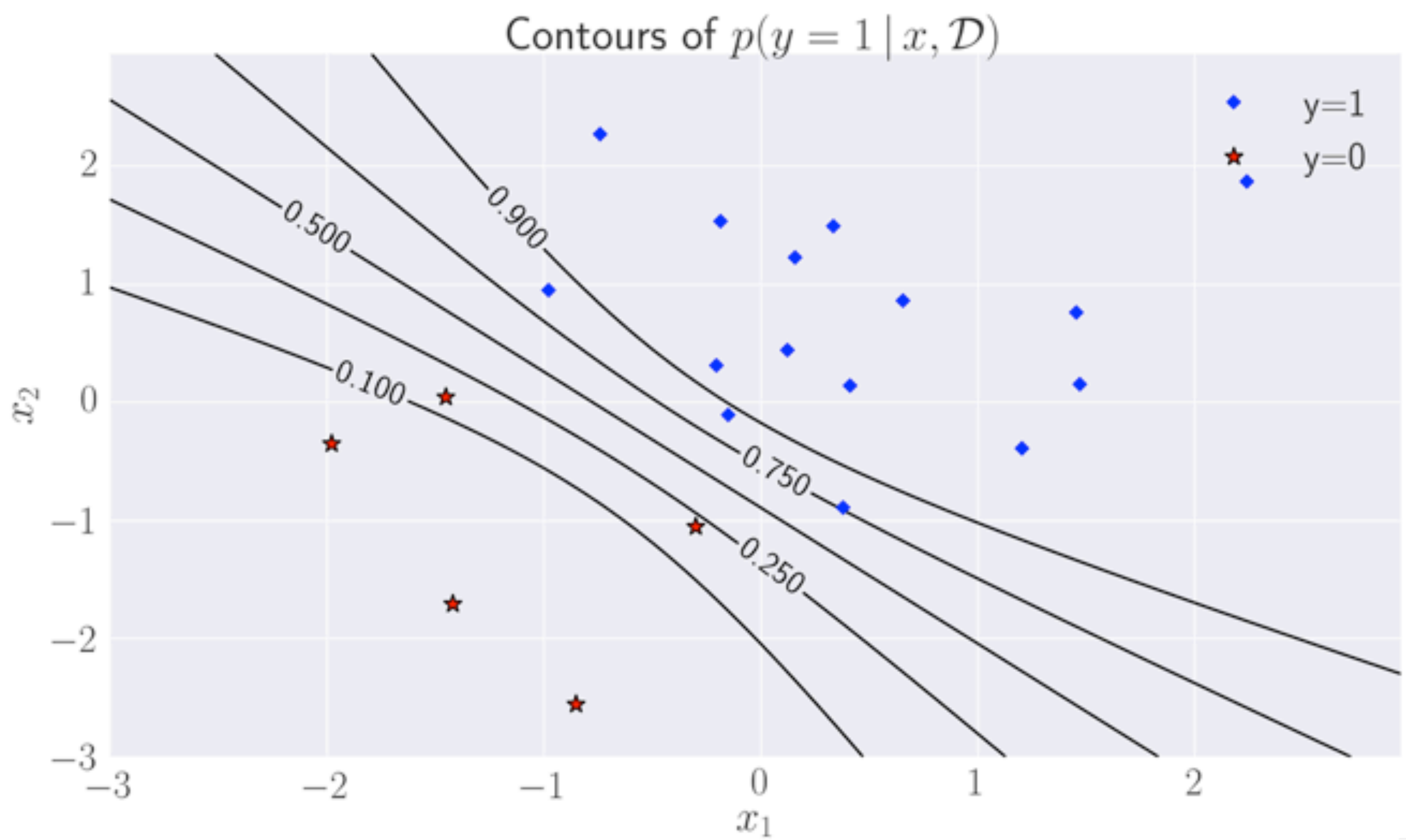
- linear regression easily dominated by distant points
  - causing misclassification



$\sigma(w_1x_1 + w_2x_2 + b)$ fit, vs $w_1x_1 + w_2x_2 + b$

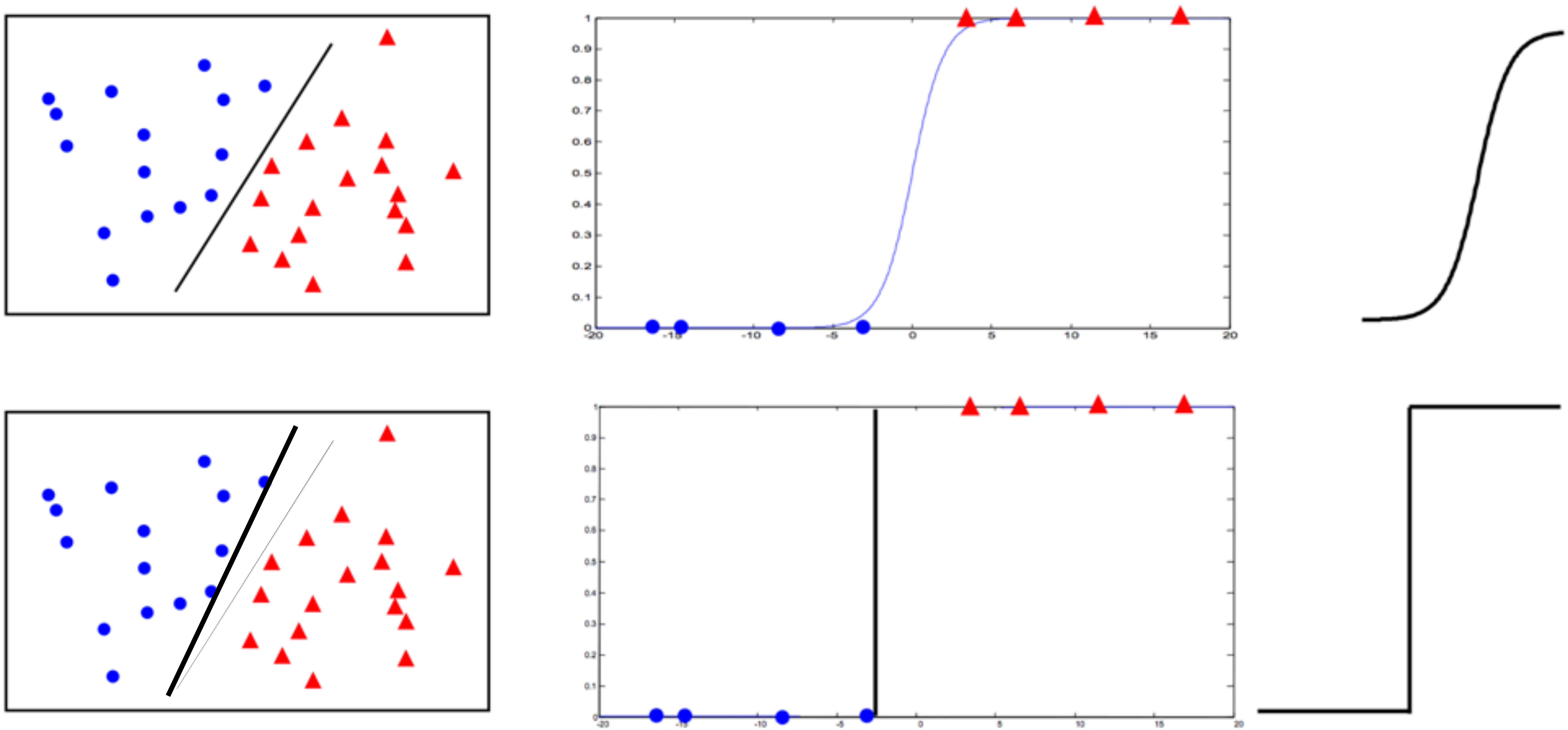
Why 0/1 instead of +/-1

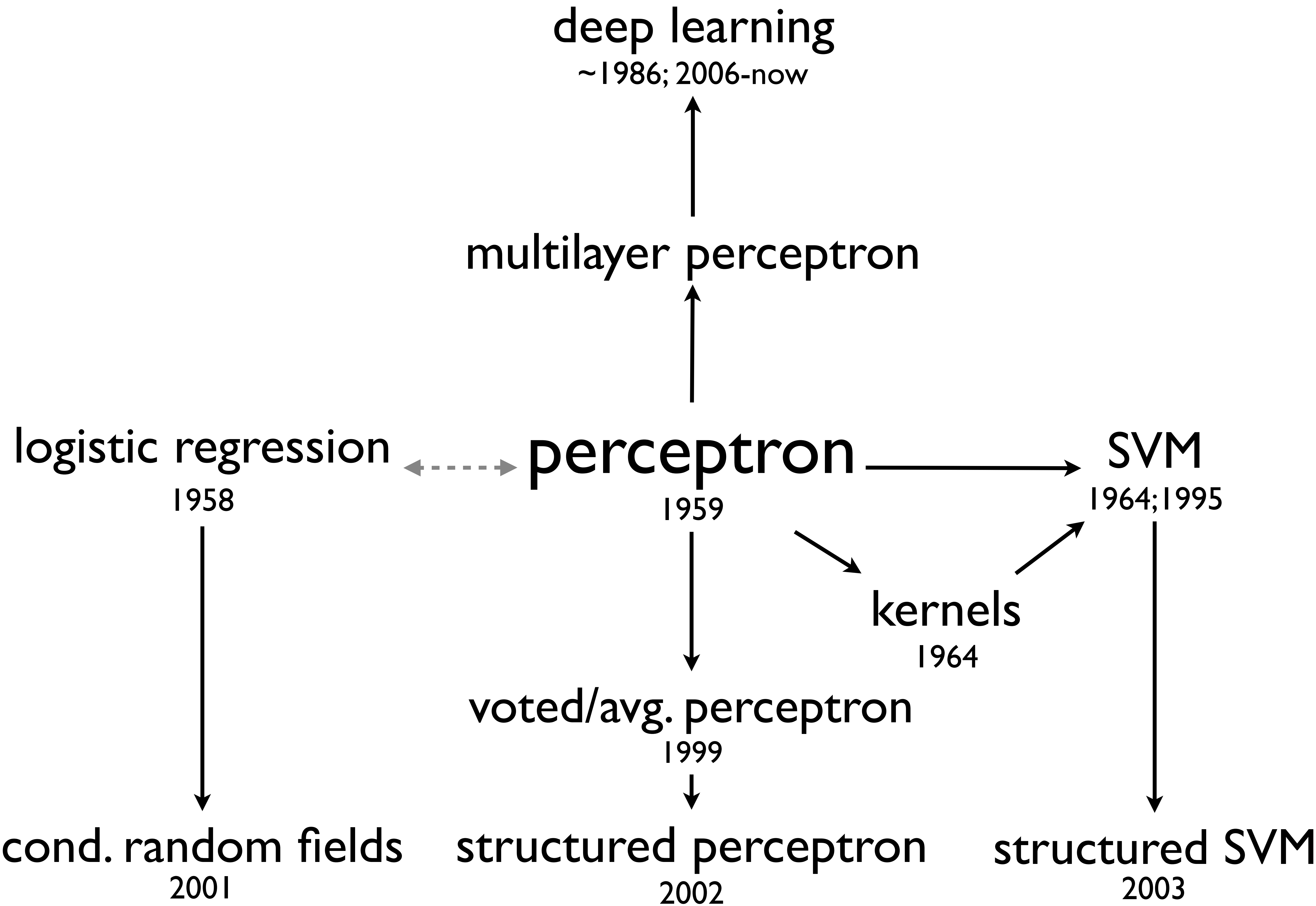
- perc: y=+1 or -1; logistic regression: y=1 or 0
- reason: want the output to be a probability
- decision boundary is still linear: p(y=1 | **x**) = 0.5



Logistic Regression: Large Margin

- perceptron can be viewed roughly as "step" regression
- logistic regression favors large margin; SVM: max margin
- in practice: perc. << avg. perc. ≈ logistic regression ≈ SVM




deep learning
~1986; 2006-now
multilayer perceptron
logistic regression
1958
perceptron
1959
SVM
1964;1995
kernels
1964
voted/avg. perceptron
1999
cond. random fields
2001
structured perceptron
2002
structured SVM
2003