

Outline of the Course

1. The Learning Problem (April 3)
2. Is Learning Feasible? (April 5)
3. The Linear Model I (April 10)
4. Error and Noise (April 12)
5. Training versus Testing (April 17)
6. Theory of Generalization (April 19)
7. The VC Dimension (April 24)
8. Bias-Variance Tradeoff (April 26)
9. The Linear Model II (May 1)
10. Neural Networks (May 3)

11. Overfitting (May 8)
12. Regularization (May 10)
13. Validation (May 15)
14. Support Vector Machines (May 17)
15. Kernel Methods (May 22)
16. Radial Basis Functions (May 24)
17. Three Learning Principles (May 29)
18. Epilogue (May 31)

- theory; mathematical
- technique; practical
- analysis; conceptual

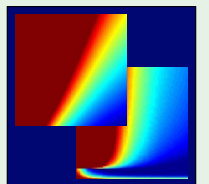
Learning From Data

Yaser S. Abu-Mostafa
California Institute of Technology

Lecture 1: The Learning Problem



Sponsored by Caltech's Provost Office, E&AS Division, and IST • Tuesday, April 3, 2012



The learning problem - Outline

- Example of machine learning
- Components of Learning
- A simple model
- Types of learning
- Puzzle

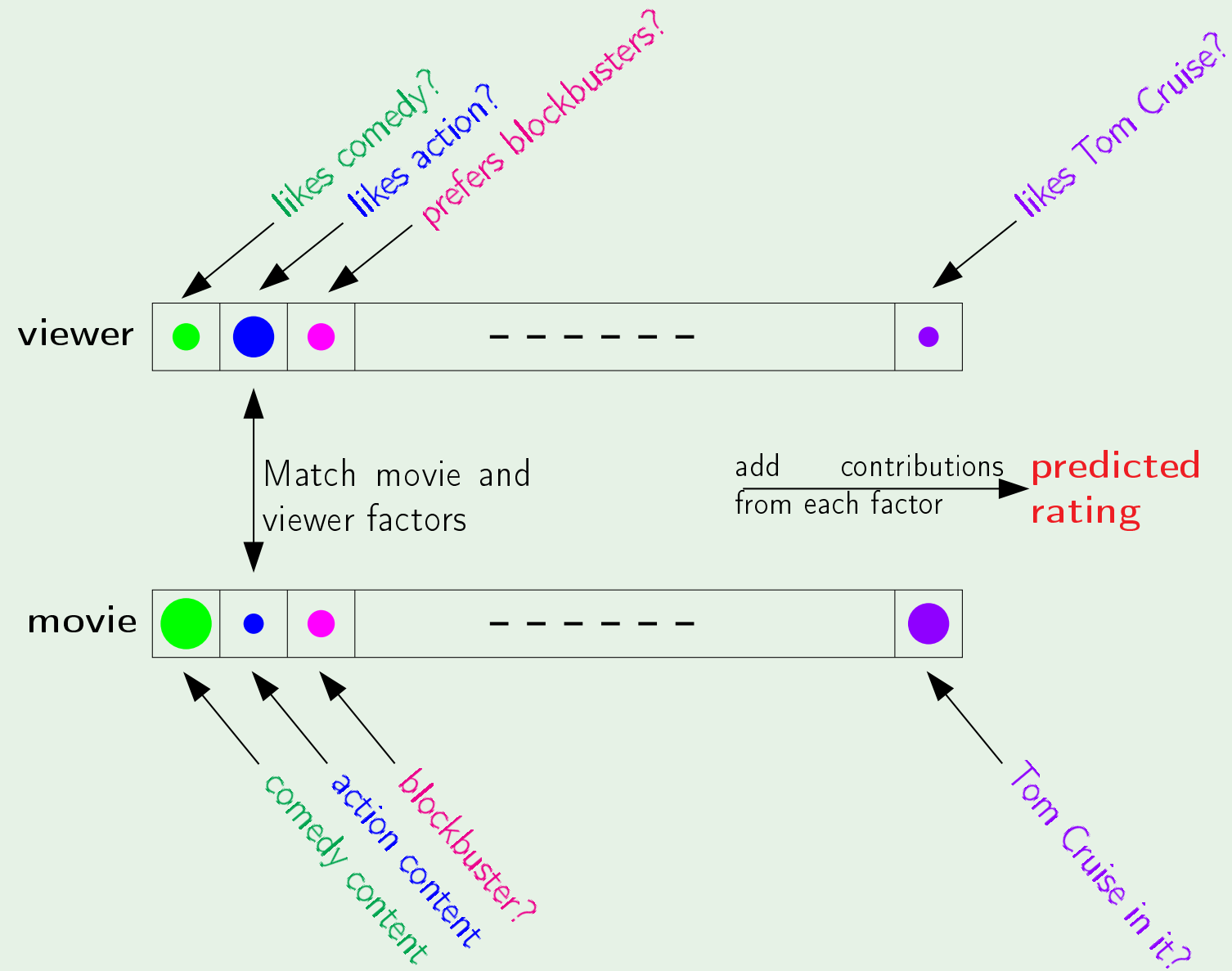
Example: Predicting how a viewer will rate a movie

10% improvement = 1 million dollar prize

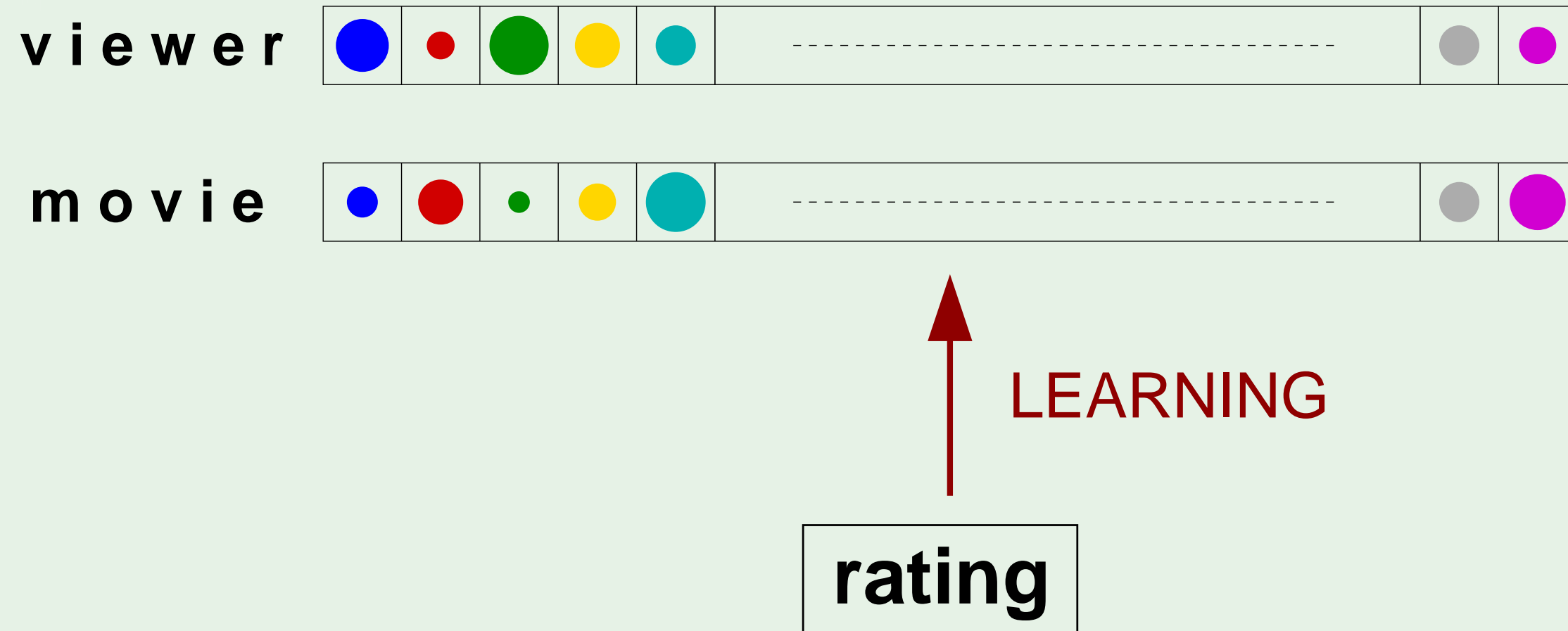
The essence of machine learning:

- A pattern exists.
- We cannot pin it down mathematically.
- We have data on it.

Movie rating - a solution



The learning approach



Components of learning

Metaphor: Credit approval

Applicant information:

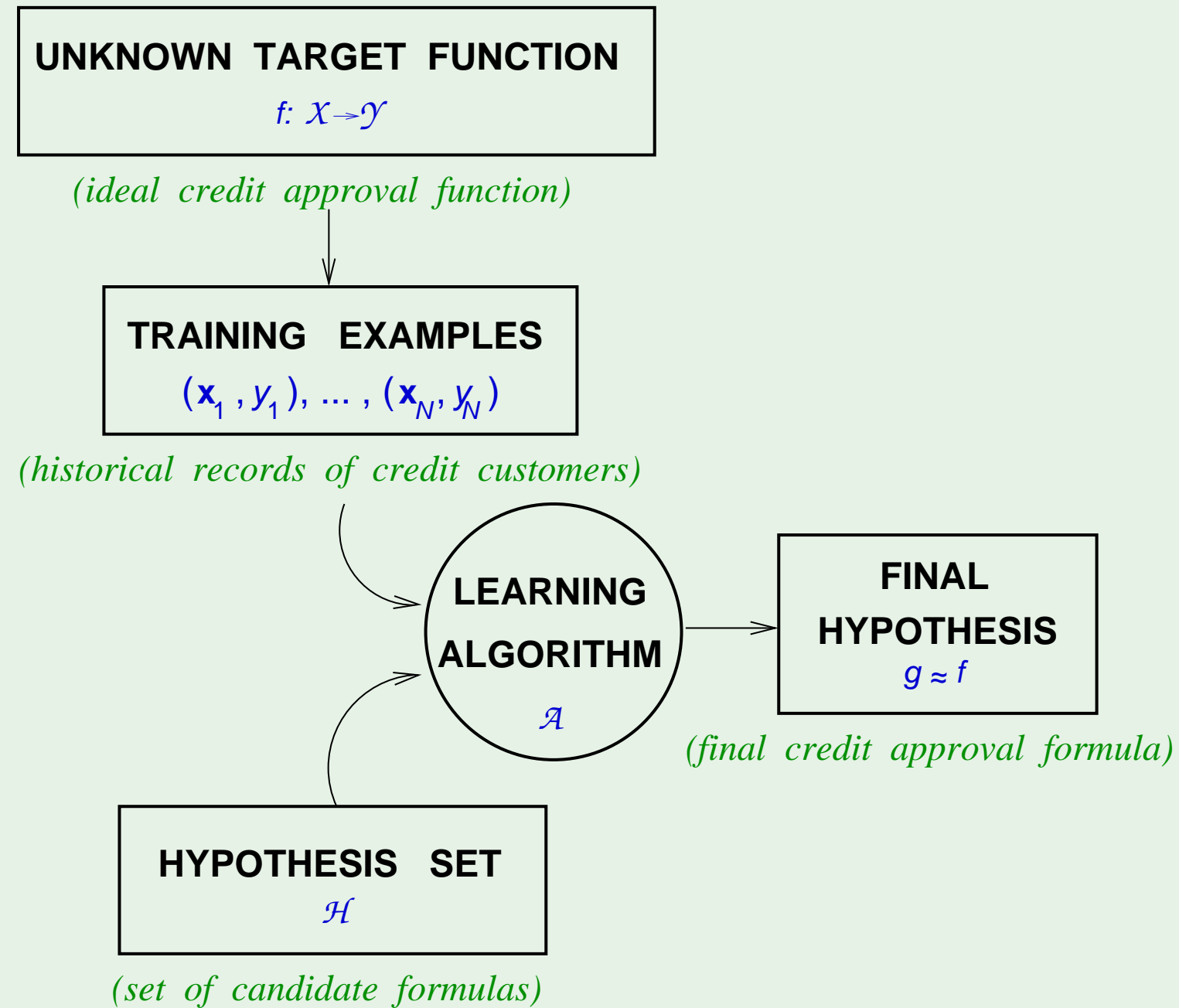
age	23 years
gender	male
annual salary	\$30,000
years in residence	1 year
years in job	1 year
current debt	\$15,000
...	...

Approve credit?

Components of learning

Formalization:

- Input: \mathbf{x} (*customer application*)
 - Output: y (*good/bad customer?*)
 - Target function: $f : \mathcal{X} \rightarrow \mathcal{Y}$ (*ideal credit approval formula*)
 - Data: $(\mathbf{x}_1, y_1), (\mathbf{x}_2, y_2), \dots, (\mathbf{x}_N, y_N)$ (*historical records*)
- ↓ ↓ ↓
- Hypothesis: $g : \mathcal{X} \rightarrow \mathcal{Y}$ (*formula to be used*)



Solution components

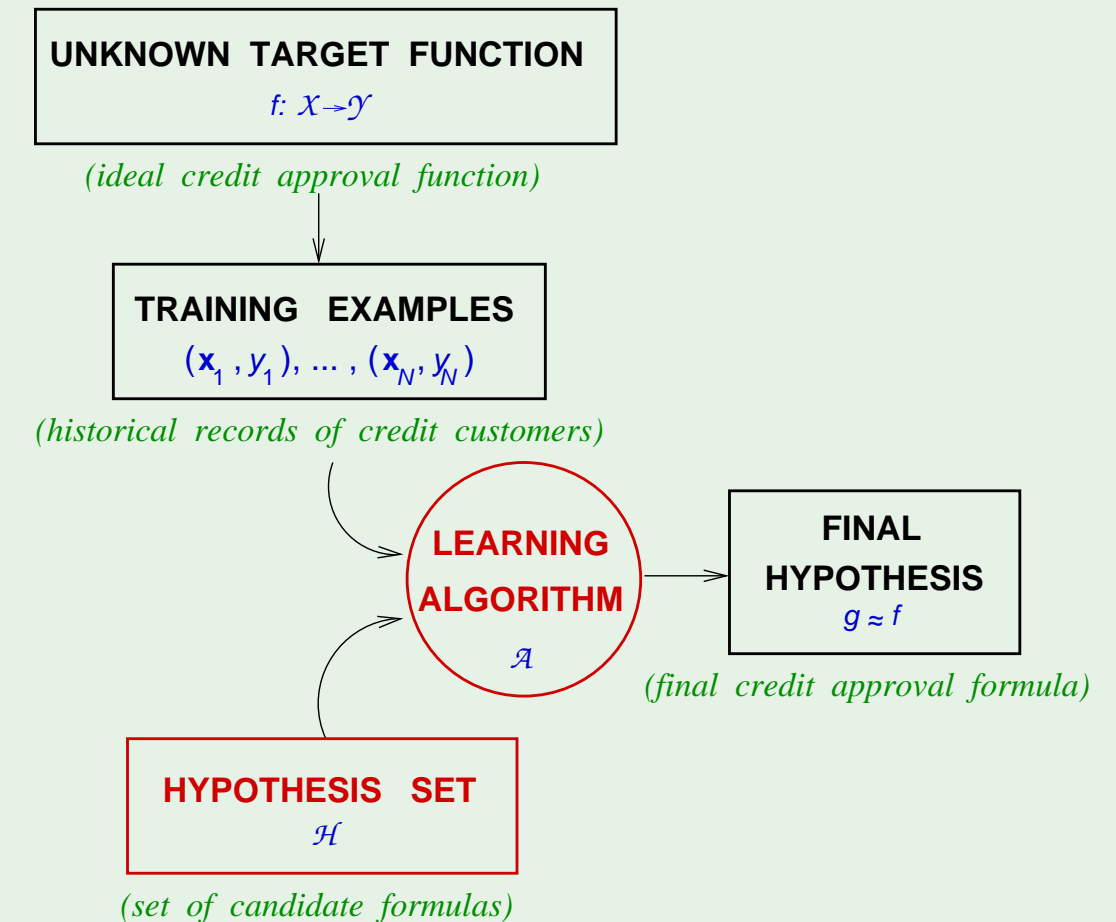
The 2 solution components of the learning problem:

- The Hypothesis Set

$$\mathcal{H} = \{h\} \quad g \in \mathcal{H}$$

- The Learning Algorithm

Together, they are referred to as the *learning model*.



A simple hypothesis set - the 'perceptron'

For input $\mathbf{x} = (x_1, \dots, x_d)$ 'attributes of a customer'

Approve credit if $\sum_{i=1}^d w_i x_i > \text{threshold},$

Deny credit if $\sum_{i=1}^d w_i x_i < \text{threshold}.$

This linear formula $h \in \mathcal{H}$ can be written as

$$h(\mathbf{x}) = \text{sign} \left(\left(\sum_{i=1}^d w_i x_i \right) - \text{threshold} \right)$$

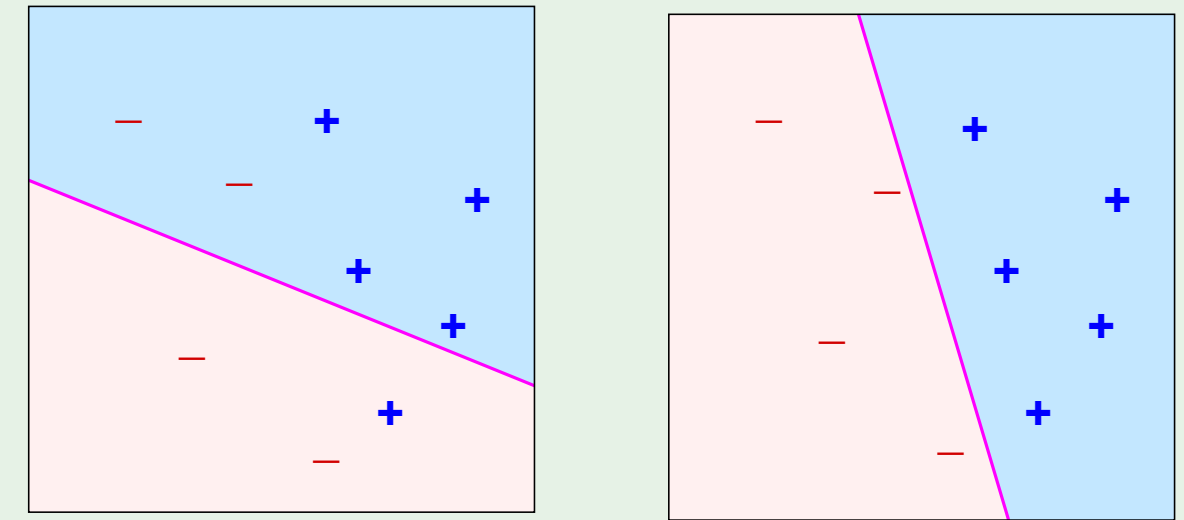
$$h(\mathbf{x}) = \text{sign} \left(\left(\sum_{i=1}^d \mathbf{w}_i x_i \right) + \mathbf{w}_0 \right)$$

Introduce an artificial coordinate $x_0 = 1$:

$$h(\mathbf{x}) = \text{sign} \left(\sum_{i=0}^d \mathbf{w}_i x_i \right)$$

In vector form, the perceptron implements

$$h(\mathbf{x}) = \text{sign}(\mathbf{w}^T \mathbf{x})$$



'linearly separable' data

A simple learning algorithm - PLA

The perceptron implements

$$h(\mathbf{x}) = \text{sign}(\mathbf{w}^T \mathbf{x})$$

Given the training set:

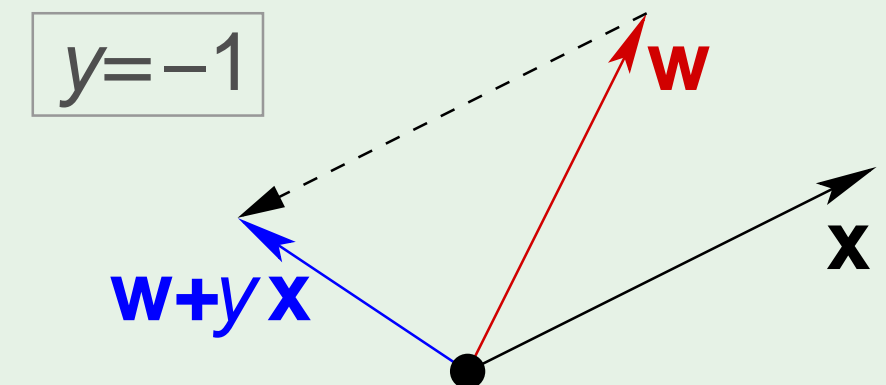
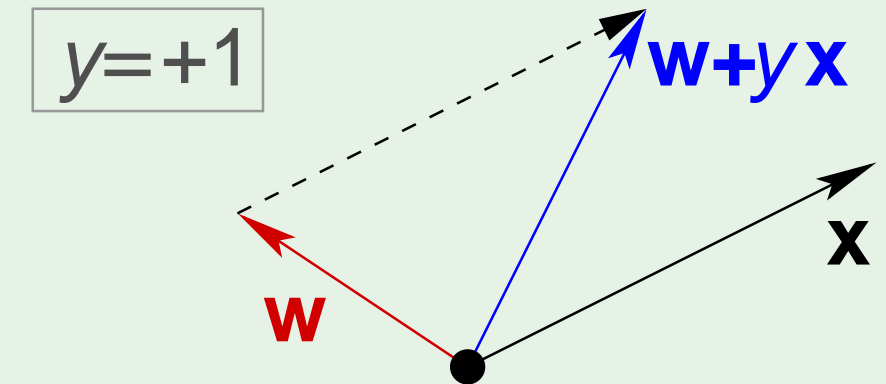
$$(\mathbf{x}_1, y_1), (\mathbf{x}_2, y_2), \dots, (\mathbf{x}_N, y_N)$$

pick a **misclassified** point:

$$\text{sign}(\mathbf{w}^T \mathbf{x}_n) \neq y_n$$

and update the weight vector:

$$\mathbf{w} \leftarrow \mathbf{w} + y_n \mathbf{x}_n$$



Iterations of PLA

- One iteration of the PLA:

$$\mathbf{w} \leftarrow \mathbf{w} + y\mathbf{x}$$

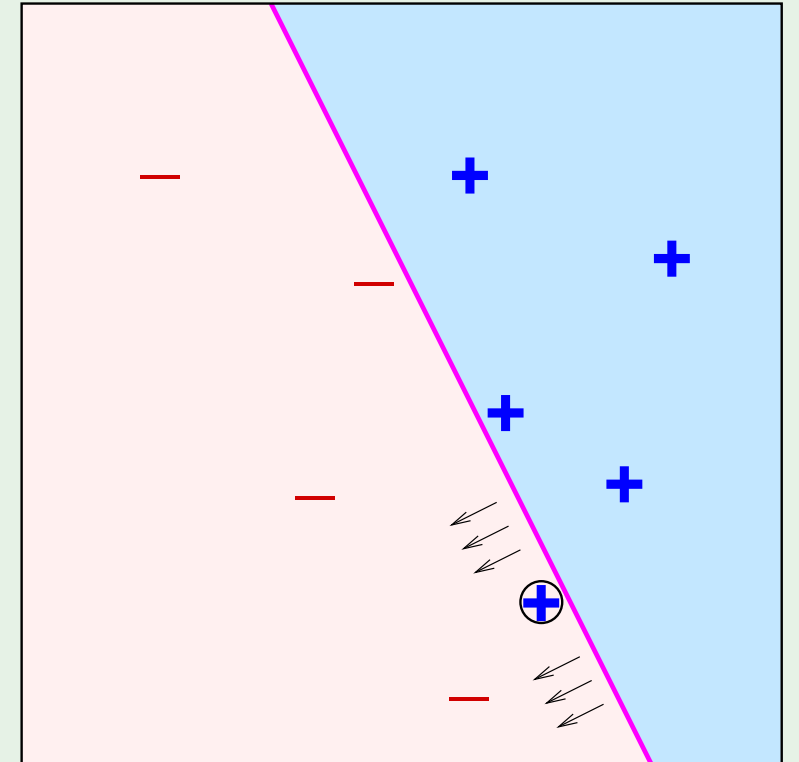
where (\mathbf{x}, y) is a misclassified training point.

- At iteration $t = 1, 2, 3, \dots$, pick a misclassified point from

$$(\mathbf{x}_1, y_1), (\mathbf{x}_2, y_2), \dots, (\mathbf{x}_N, y_N)$$

and run a PLA iteration on it.

- That's it!



The learning problem - Outline

- Example of machine learning
- Components of learning
- A simple model
- Types of learning
- Puzzle

Basic premise of learning

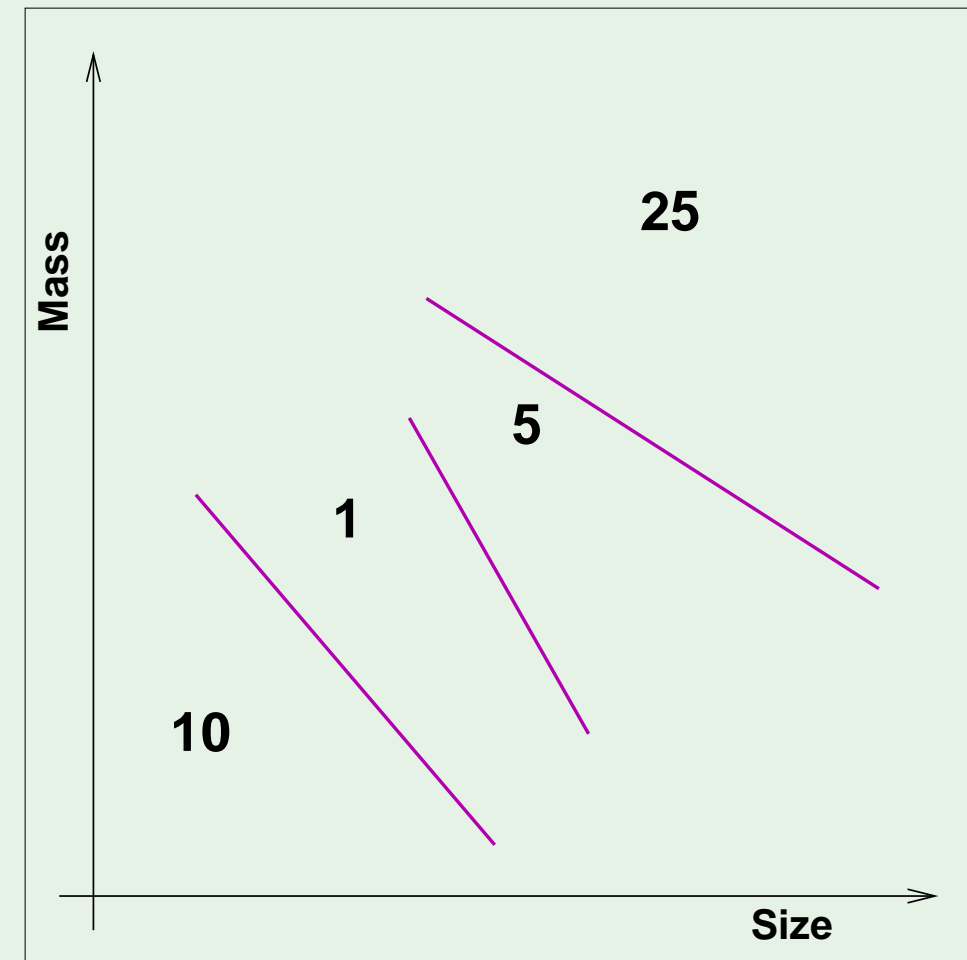
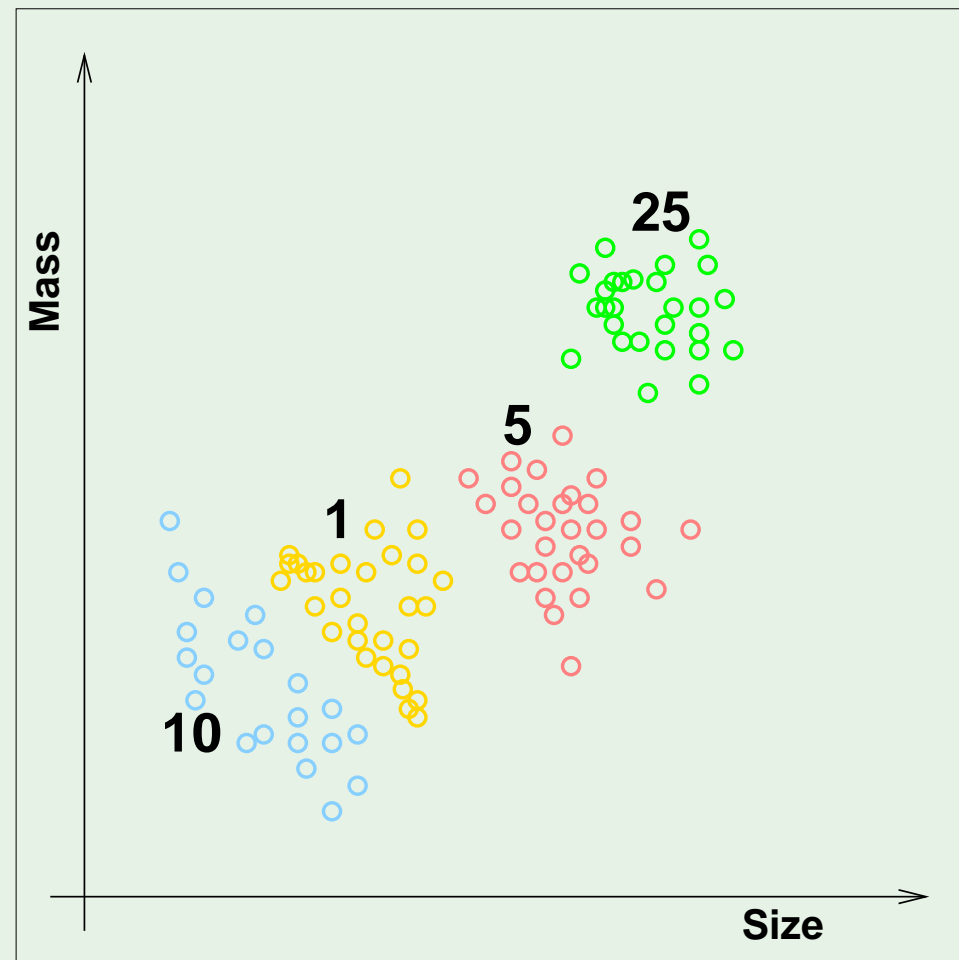
“using a set of observations to uncover an underlying process”

broad premise \implies many variations

- Supervised Learning
- Unsupervised Learning
- Reinforcement Learning

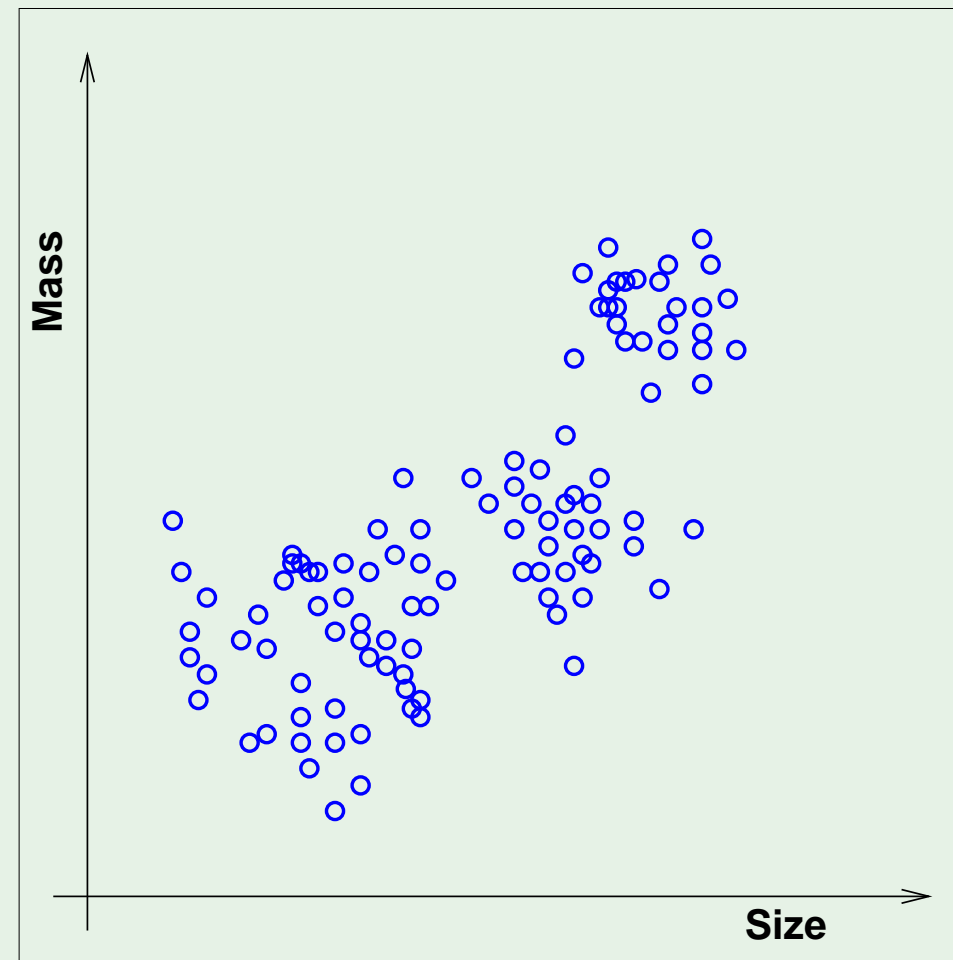
Supervised learning

Example from vending machines – **coin recognition**



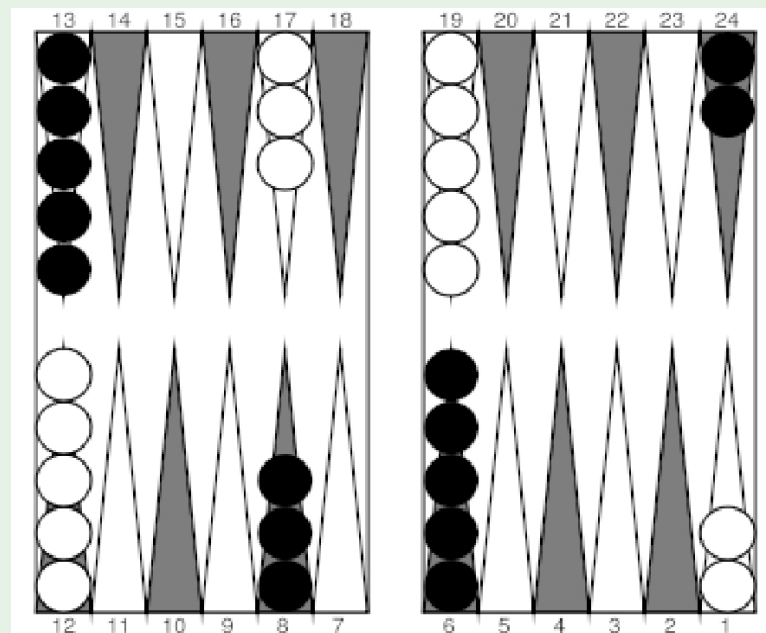
Unsupervised learning

Instead of (input, correct output), we get (input, ?)



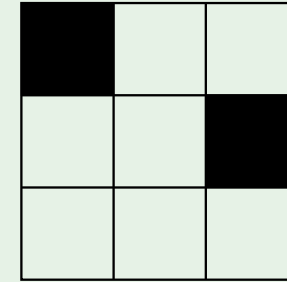
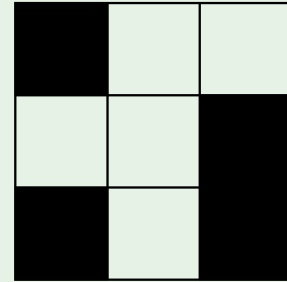
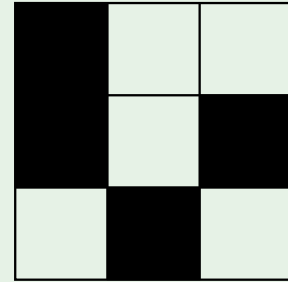
Reinforcement learning

Instead of (input, correct output),
we get (input, *some* output, grade for this output)

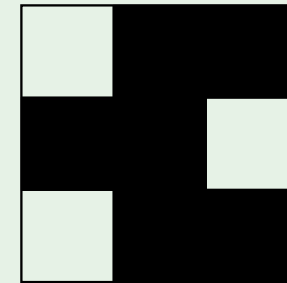
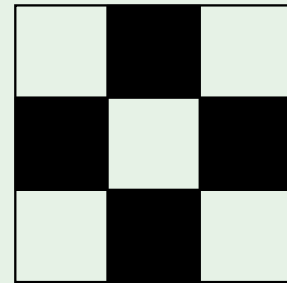
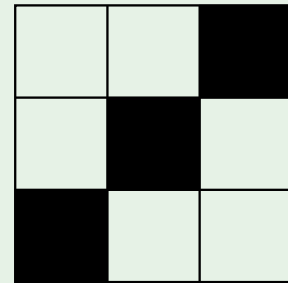


The world champion was
a neural network!

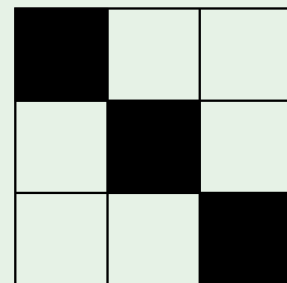
A Learning puzzle



$$f = -1$$



$$f = +1$$



$$f = ?$$