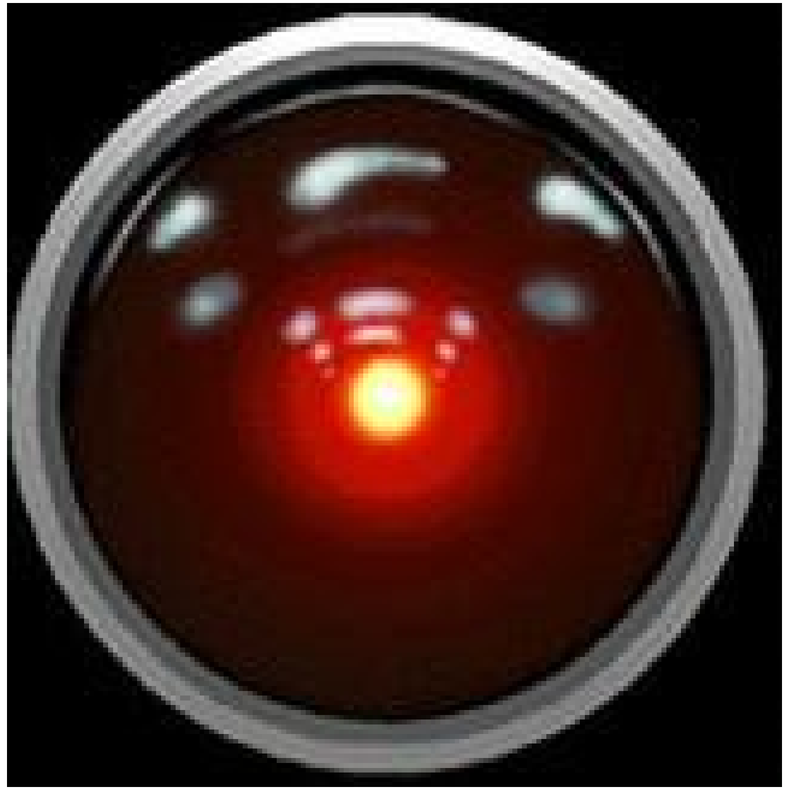
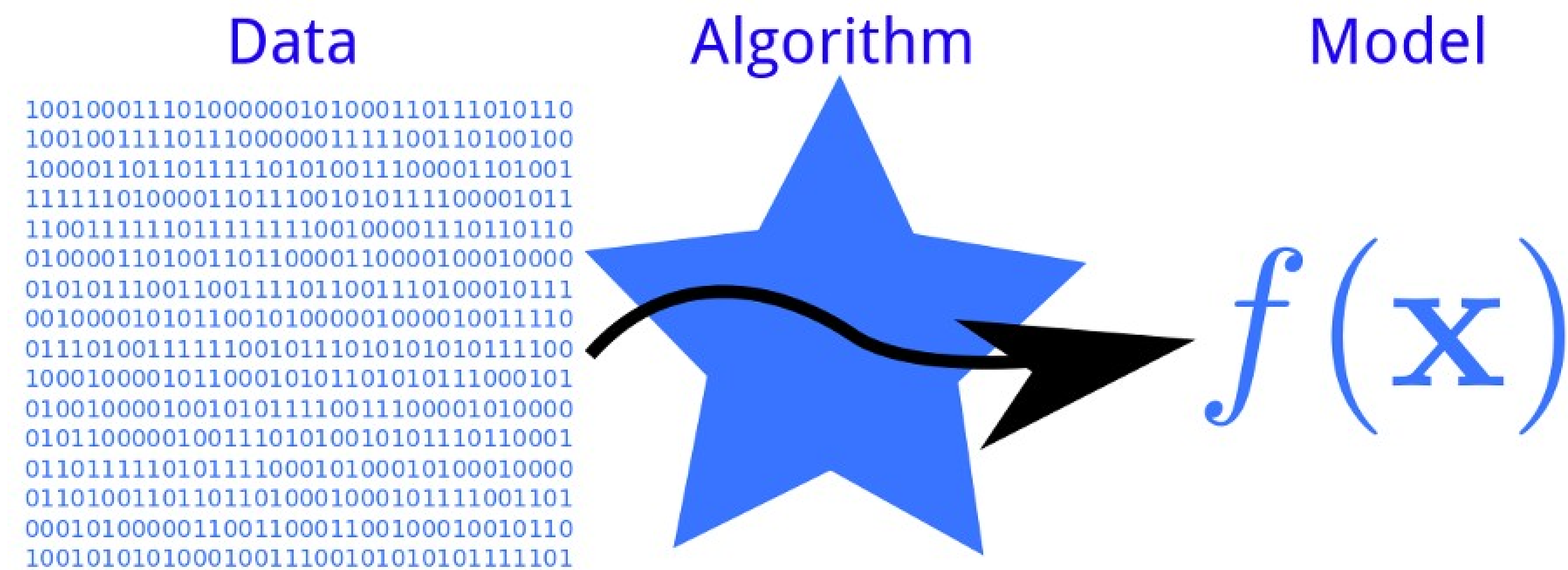


CS 309: Autonomous Intelligent Robotics

Instructor: Jivko Sinapov

http://www.cs.utexas.edu/~jsinapov/teaching/cs309_spring2017/

Machine Learning



Announcements

Final Project Presentations

Saturday, May 13, 7:00-10:00 pm

https://registrar.utexas.edu/schedules/172/finals

Location TBD

Project Deliverables

- Final Report (6+ pages in PDF)
- Code and Documentation (posted on github)
- Presentation including video and/or demo

Project Report Structure / Outline

- Abstract
- Introduction
- Background and/or Related Work
- Technical Approach
- Experiments and/or Evaluation and/or Example Demonstration
- Conclusion and Future Work

Machine Learning

Main Reference

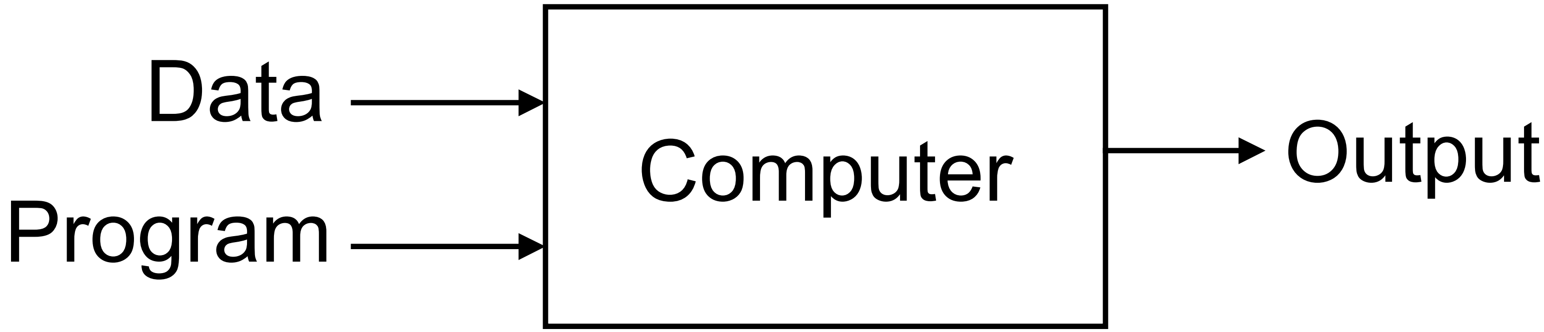
Alex Smola and S.V.N. Vishwanathan,

Introduction to Machine Learning,

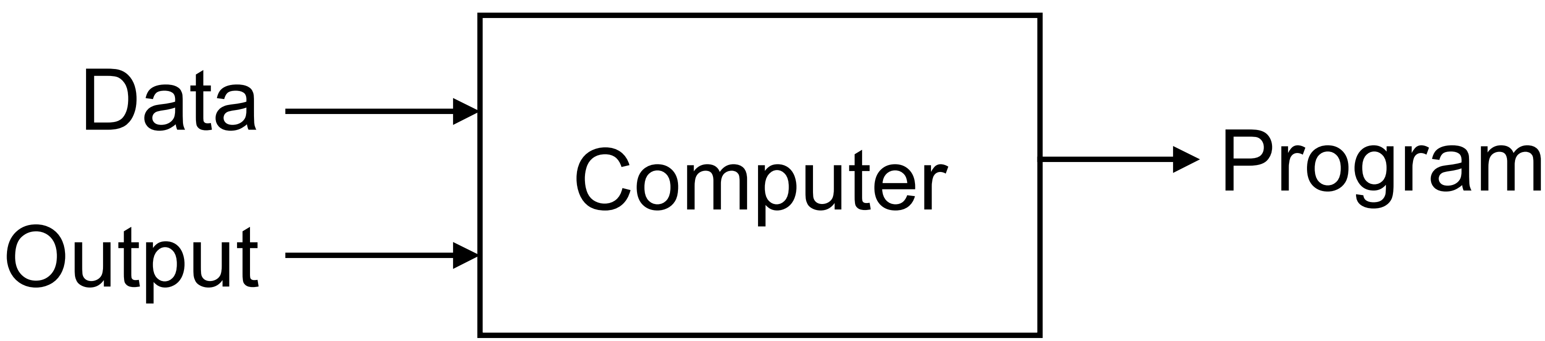
Chapter 1, Cambridge University Press, 2008

What is Machine Learning?

Traditional Programming



Machine Learning



[credit: Pedro Domingos]

What do we mean by program?

What do we mean by program?

- A robot's controller
- A decision function (i.e., classification function)
- A neural network
- A recommendation system
- etc.

KDnuggets Cartoon

"The machine learning algorithm wants to know if we'd like a dozen wireless mice to feed the Python book we just bought."

Machine Learning Frameworks

	supervised	unsupervised
discrete	classification or categorization	clustering
continuous	regression	dimensionality reduction and manifold learning

Classification

Classification

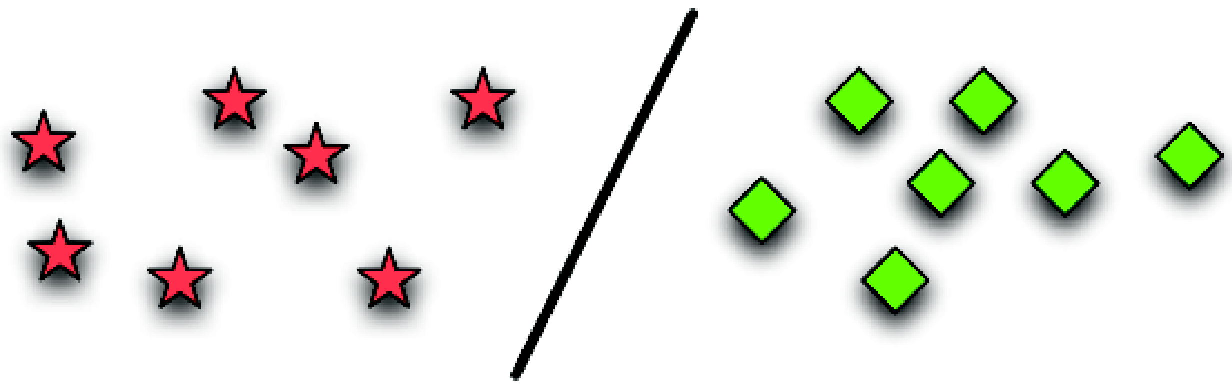


Fig. 1.5. Binary classification; separate stars from diamonds. In this example we are able to do so by drawing a straight line which separates both sets. We will see later that this is an important example of what is called a *linear classifier*.

Classification

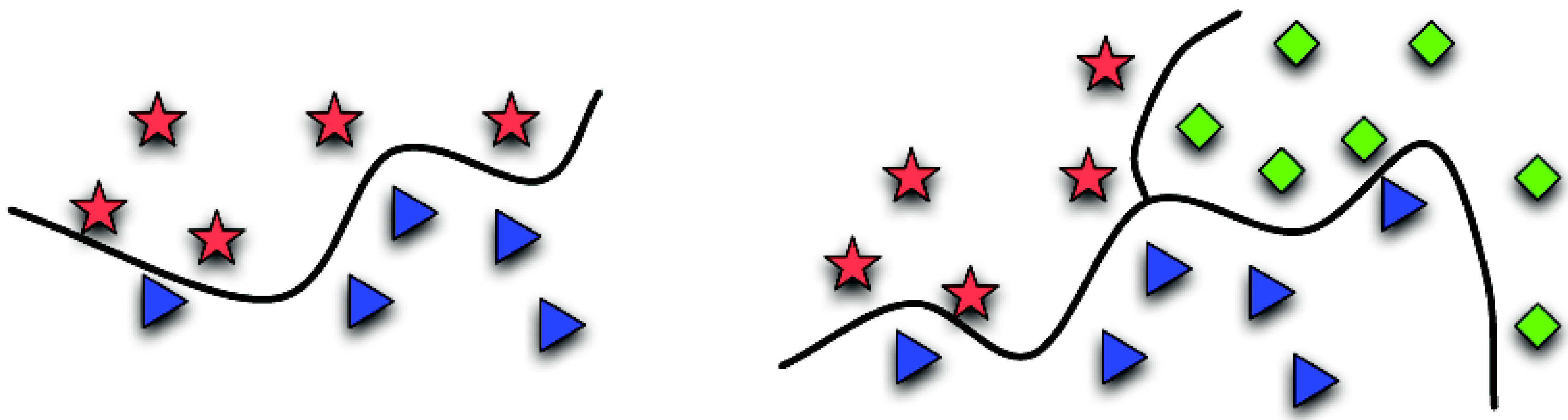


Fig. 1.6. Left: binary classification. Right: 3-class classification. Note that in the latter case we have much more degree for ambiguity. For instance, being able to distinguish stars from diamonds may not suffice to identify either of them correctly, since we also need to distinguish both of them from triangles.

Classification

Inputs:

$$\mathbf{X} := \{x_1, \ldots x_m\}$$

where $x_i \in \mathbb{R}^k$

Outputs:

$$\mathbf{Y} := \{y_1, \ldots y_m\}$$

set of classes:

$$y_i \in \{1, \ldots, n\}$$

Machine Learning Framework

$$y = f(\mathbf{x})$$

output classification function data point

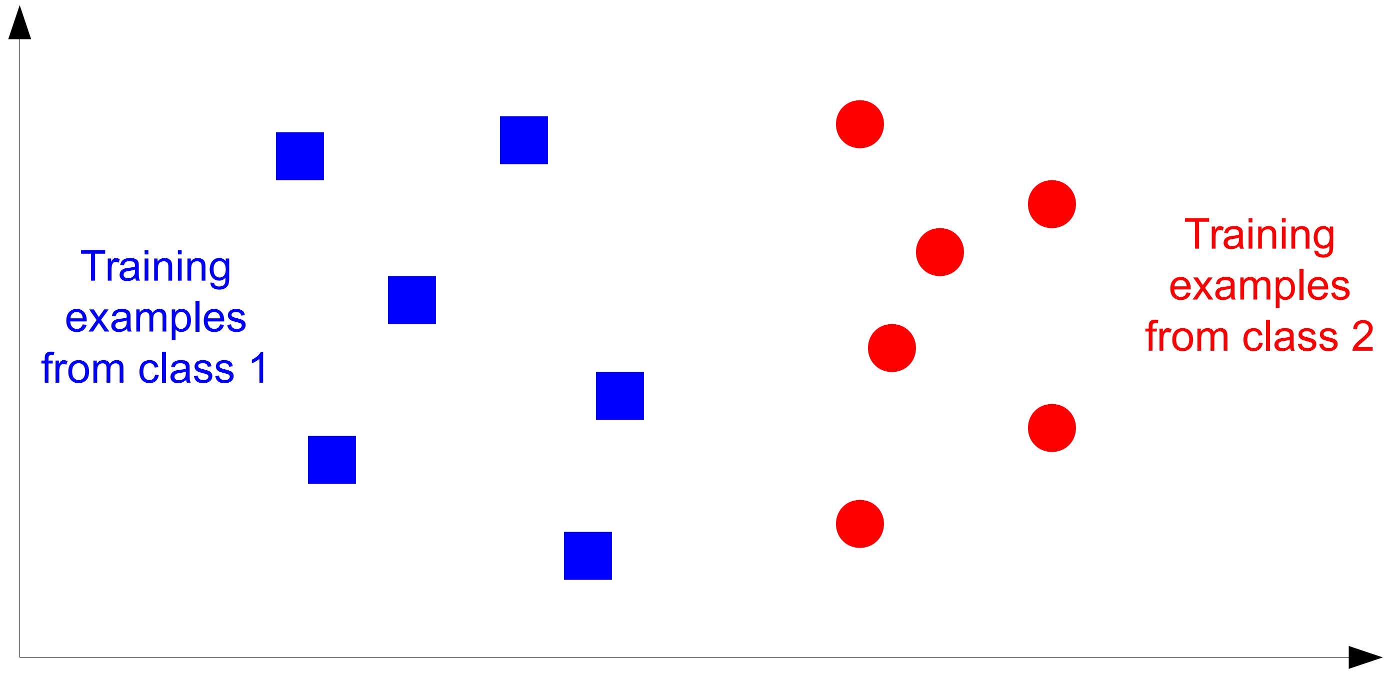
- **Training:** given a *training set* of labeled examples $\{(\mathbf{x}_1, y_1), \ldots, (\mathbf{x}_N, y_N)\}$, estimate the function f by minimizing the error on the training set
- **Testing:** apply f to a never before seen *test example* $\mathbf{x}$ and output the predicted value $y = f(\mathbf{x})$

Slide credit: L. Lazebnik

Example Problem

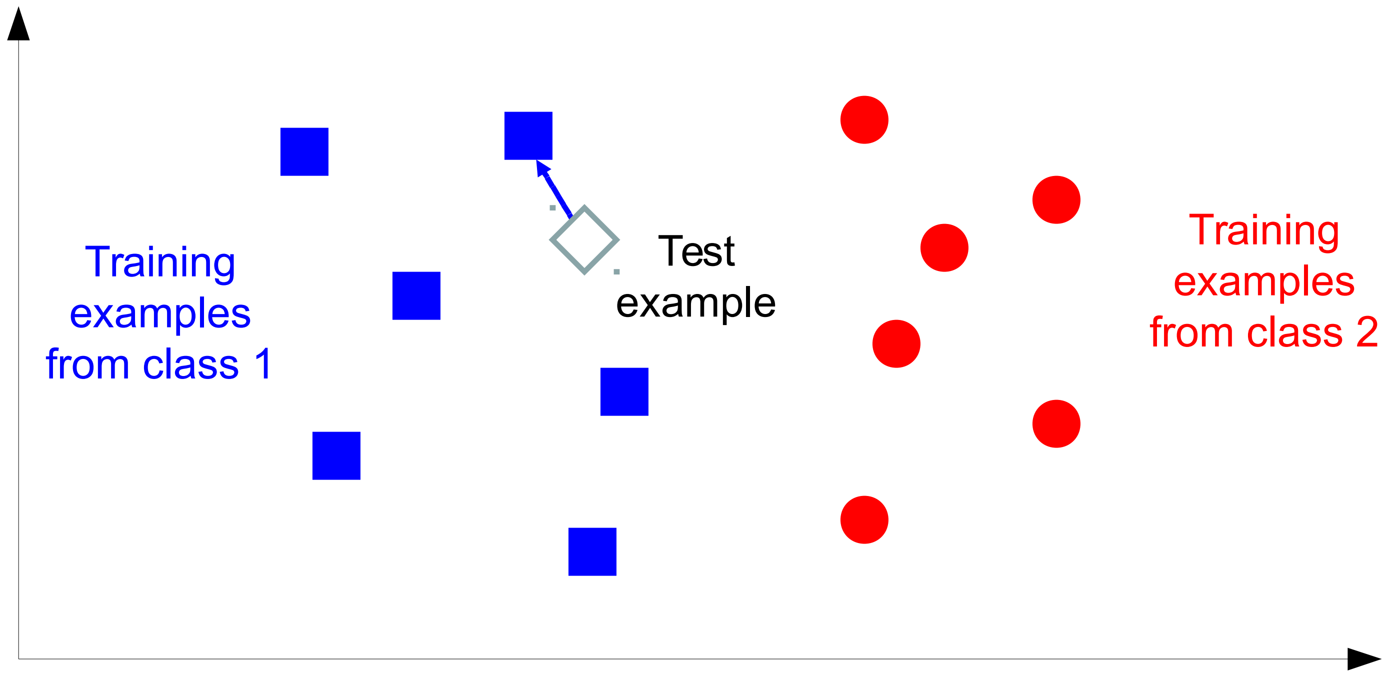
Input data:	Class Labels:
[1 0 0 1 1 1 0 1 0]	+1
[0 1 0 1 1 1 0 0 1]	-1
…	…
[1 0 1 1 0 0 1 0 1]	+1
[0 1 0 1 0 0 0 1 1]	-1

Classification using K-Nearest Neighbors



Slide credit: L. Lazebnik

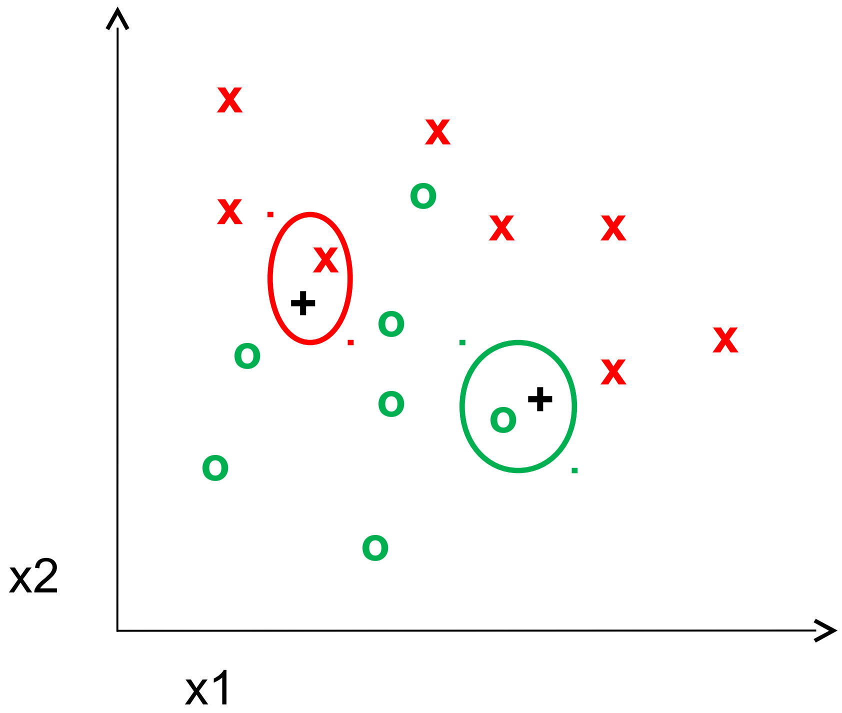
Classification using K-Nearest Neighbors



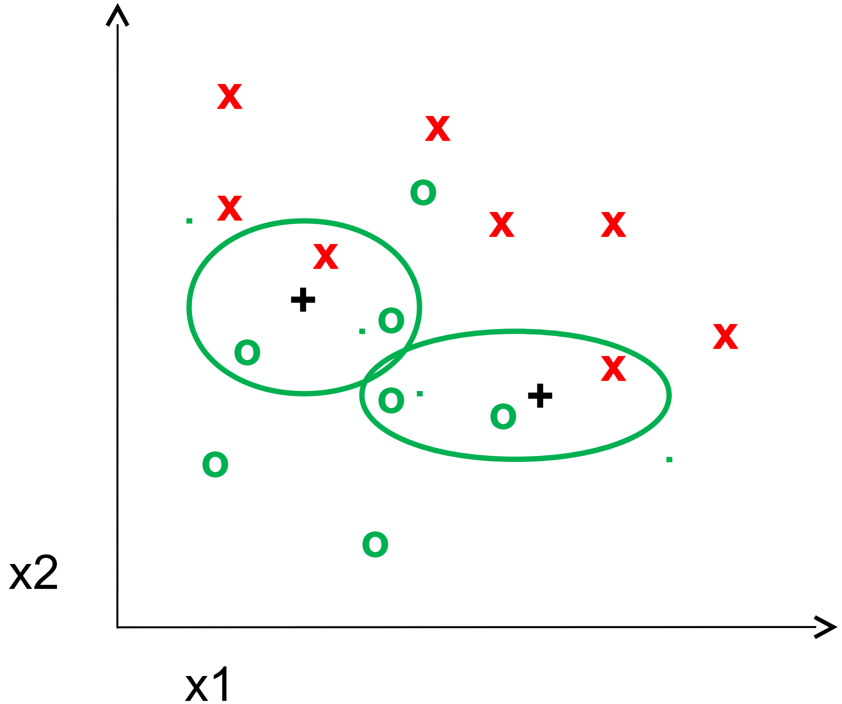
f(**x**) = label of the training example nearest to **x**

Slide credit: L. Lazebnik

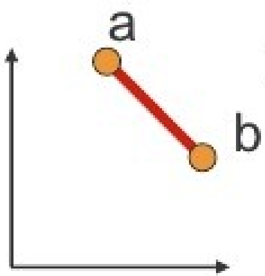
1-Nearest Neighbor



3-Nearest Neighbor

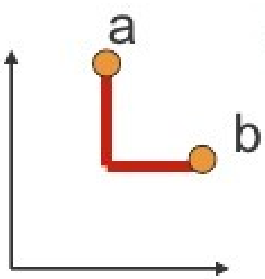


Examples of distances



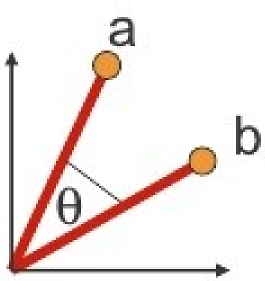
Euclidean distance

$$\text{dist}(a,b) = \|a-b\|_2 = \sqrt{\sum_i (a_i - b_i)^2}$$



Manhattan distance

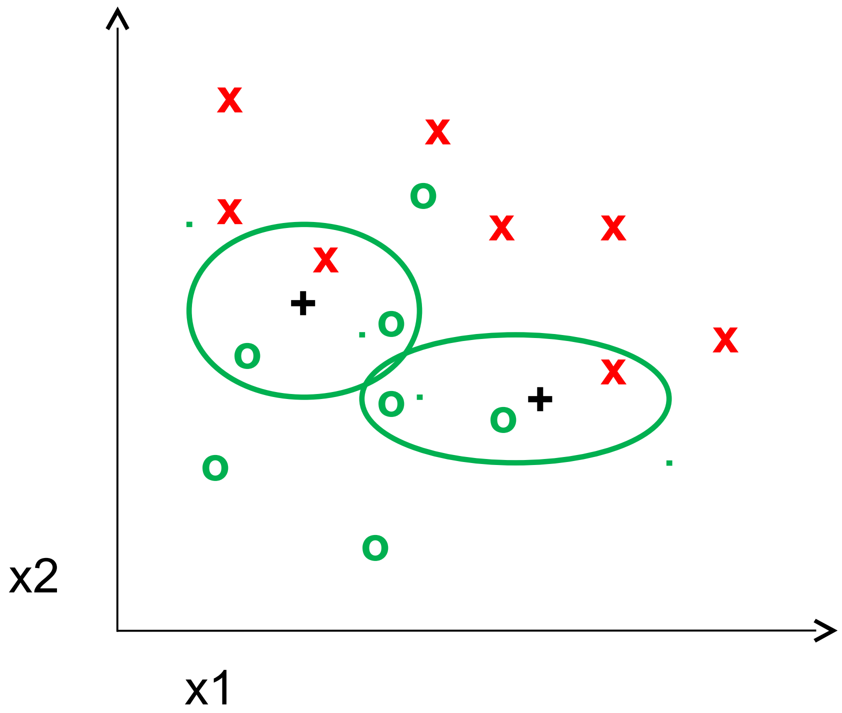
$$\text{dist}(a,b) = \|a-b\|_1 = \sum_i |a_i - b_i|$$



Cosine distance

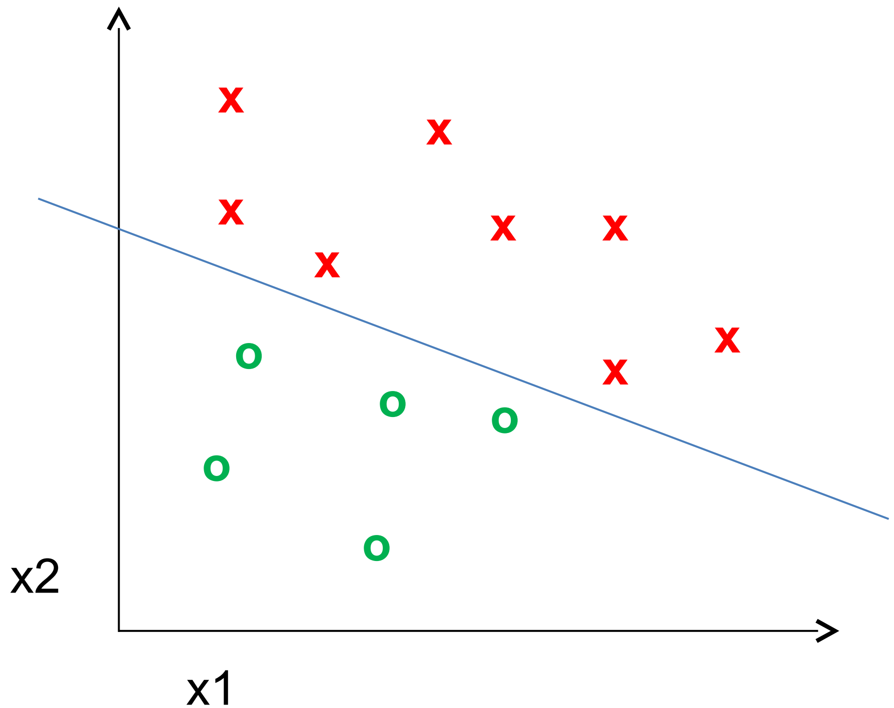
$$\text{dist}(a,b) = cos^{-1} \frac{\langle a, b \rangle}{\|a\| \|b\|}$$

3-Nearest Neighbor



What are some of the limitations of k-NN?

Linear Classifier



- Finds a *linear function* to separate the classes:

$$f(\mathbf{x}) = \text{sgn}(\mathbf{w} \cdot \mathbf{x} + b)$$

Linear Classifier

Algorithm 1.3 The Perceptron

Perceptron($\mathbf{X}, \mathbf{Y}$) {reads stream of observations (x_i, y_i)}

  Initialize $w = 0$ and $b = 0$

  while There exists some (x_i, y_i) with $y_i(\langle w, x_i \rangle + b) \leq 0$ **do**

    $w \leftarrow w + y_i x_i$ and $b \leftarrow b + y_i$

  end while

Dot product

$\mathbf{a} = (1,\ 4,\ -2)$

$\mathbf{b} = (-2,\ 1,\ 7)$

$$\mathbf{a} \cdot \mathbf{b} = 1 \cdot (-2) + 4 \cdot 1 + (-2) \cdot 7$$

$$= -2 + 4 - 14 = -12$$

Linear Classifier

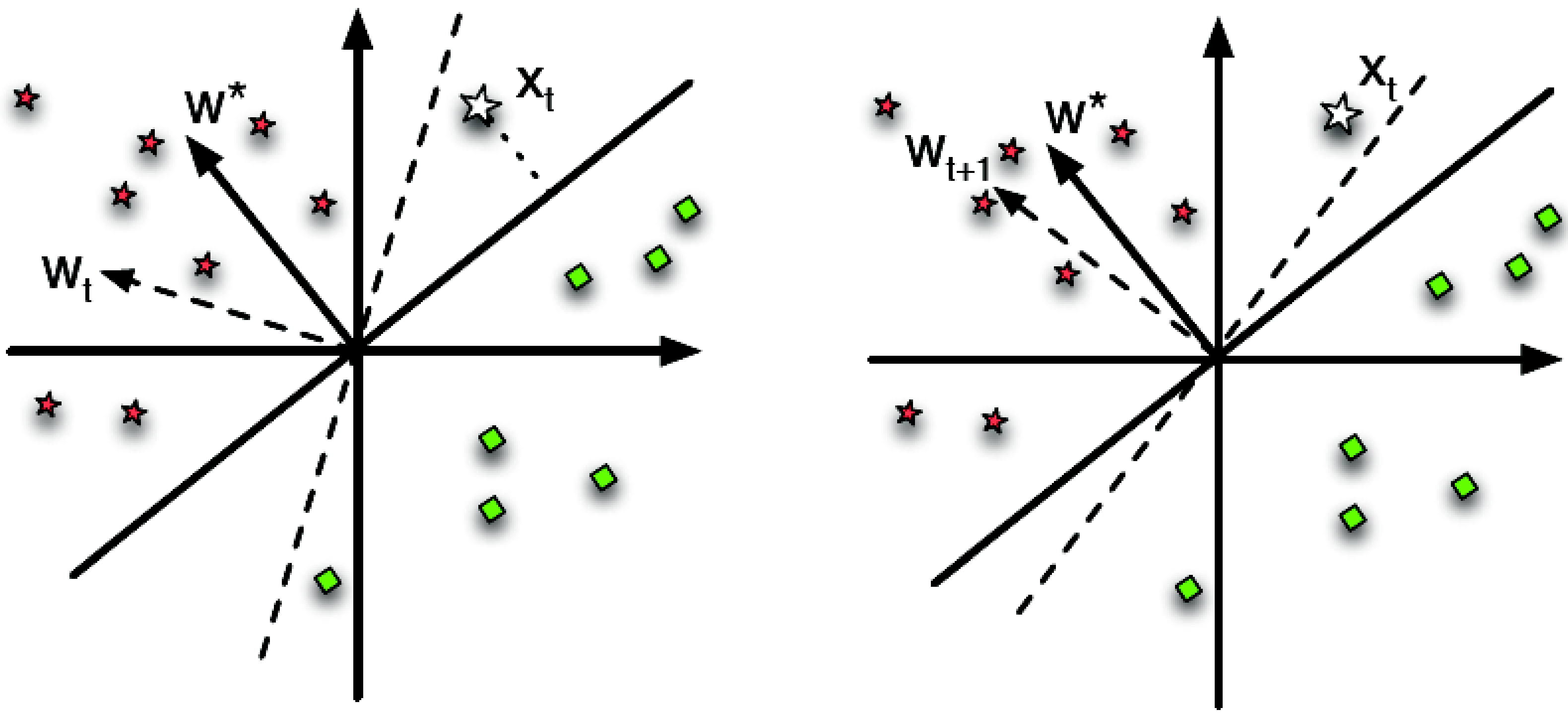
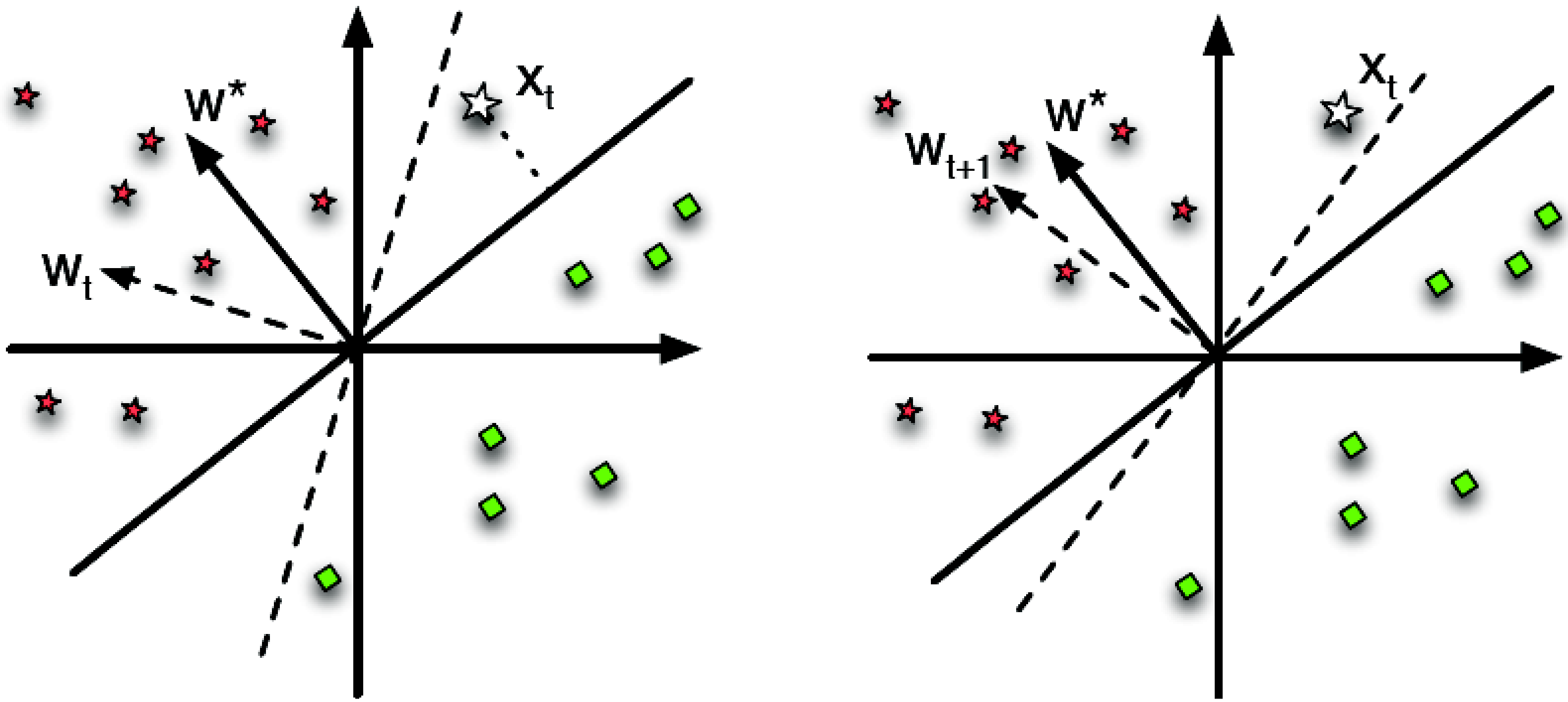


Fig. 1.22. The Perceptron without bias. Left: at time t we have a weight vector w_t denoted by the dashed arrow with corresponding separating plane (also dashed). For reference we include the linear separator w^* and its separating plane (both denoted by a solid line). As a new observation x_t arrives which happens to be mis-classified by the current weight vector w_t we perform an update. Also note the margin between the point x_t and the separating hyperplane defined by w^*. Right: This leads to the weight vector w_{t+1} which is more aligned with w^*.



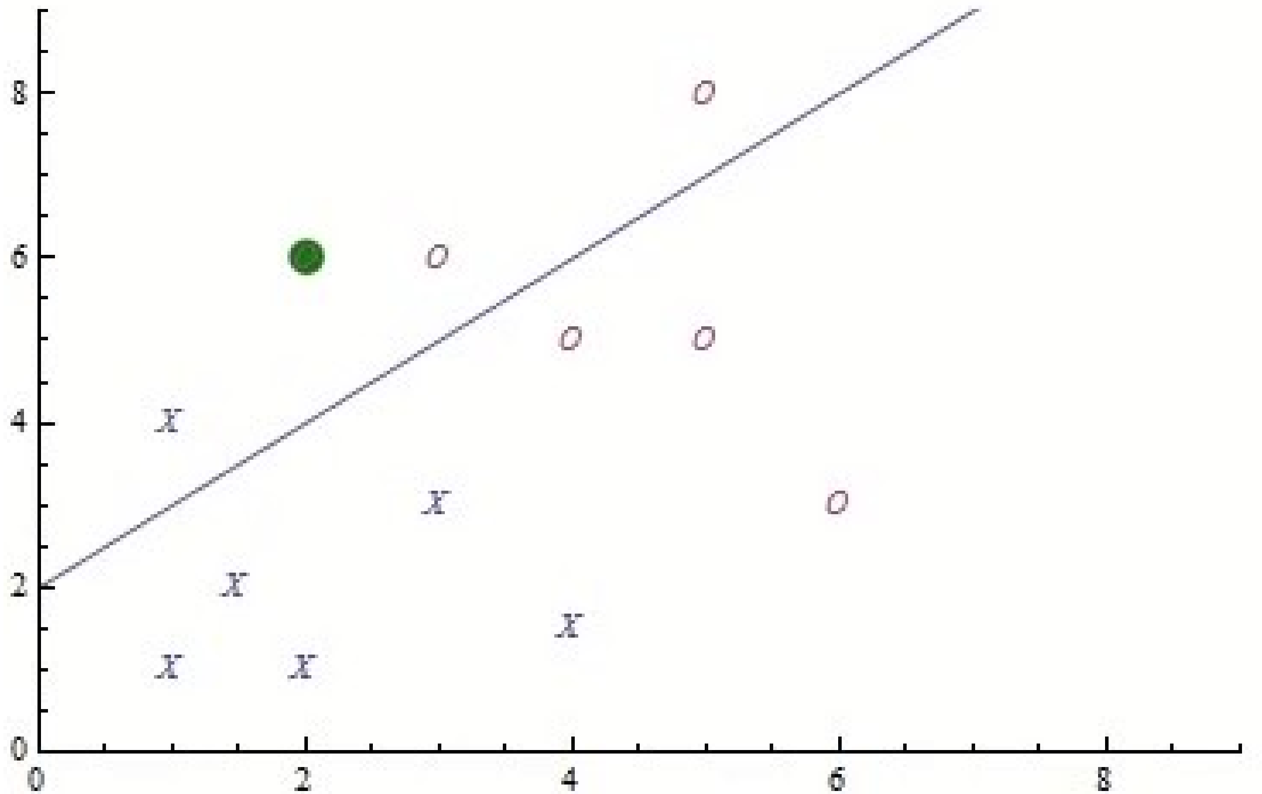
Wt = [-6,1]

Xt = [2,4]   Yt = +1

< Wt , Xt > + b = (-6)*(2) + 1*4 + 0 = -8

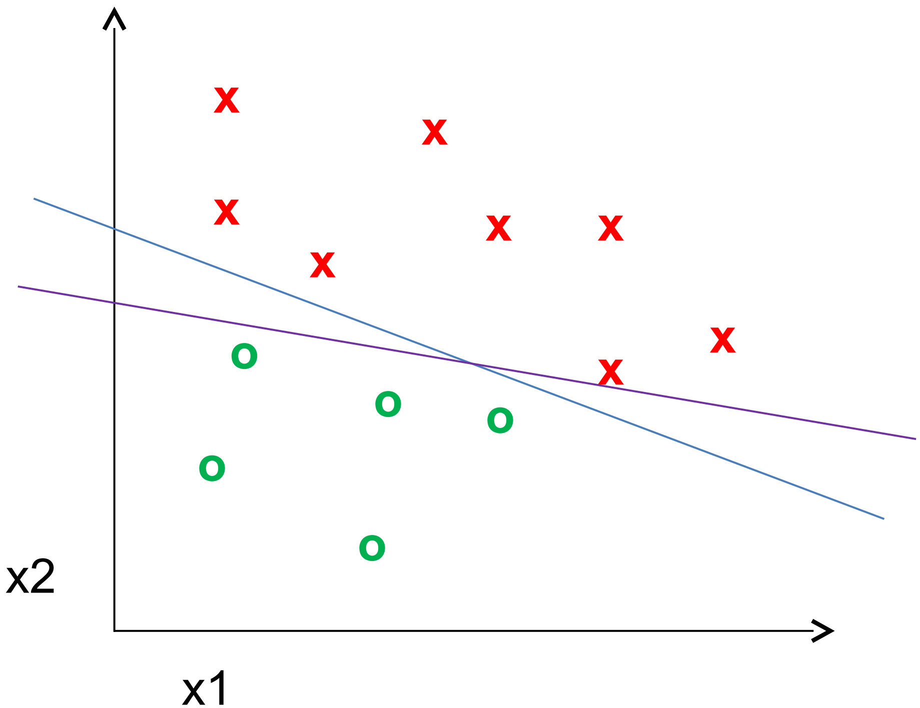
Wt[0] = Wt[0] + Yt * Xt[0] = -6 + 1 * 2 = -4

Wt[1] = Wt[1] + Yt * Xt[1] = 1 + 1 * 4 = 5



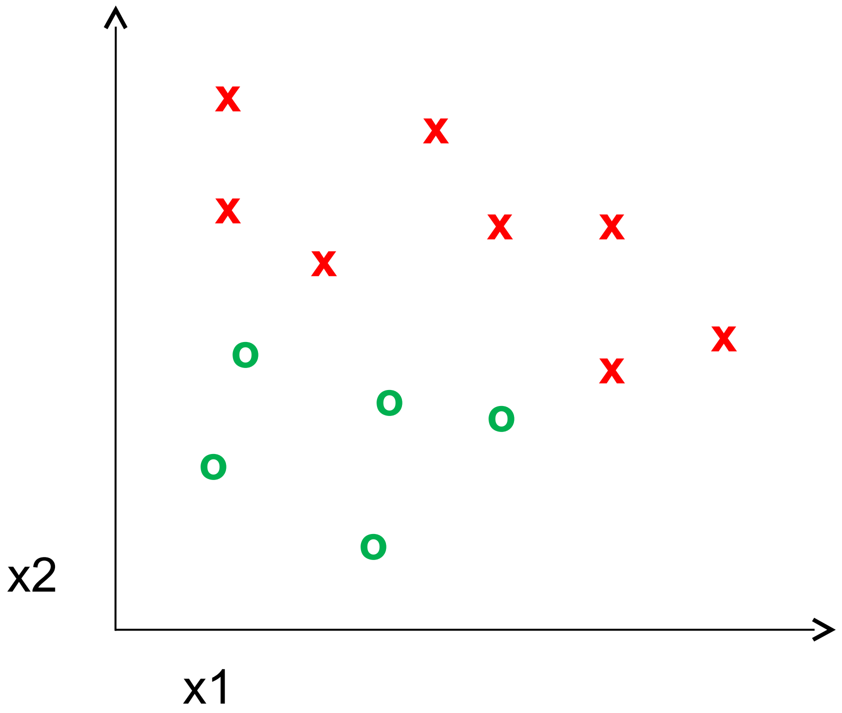
8
6
4
2
0
0
2
4
6
8
O
O
O
O
O
X
X
X
X
X
X

Linear Classifier

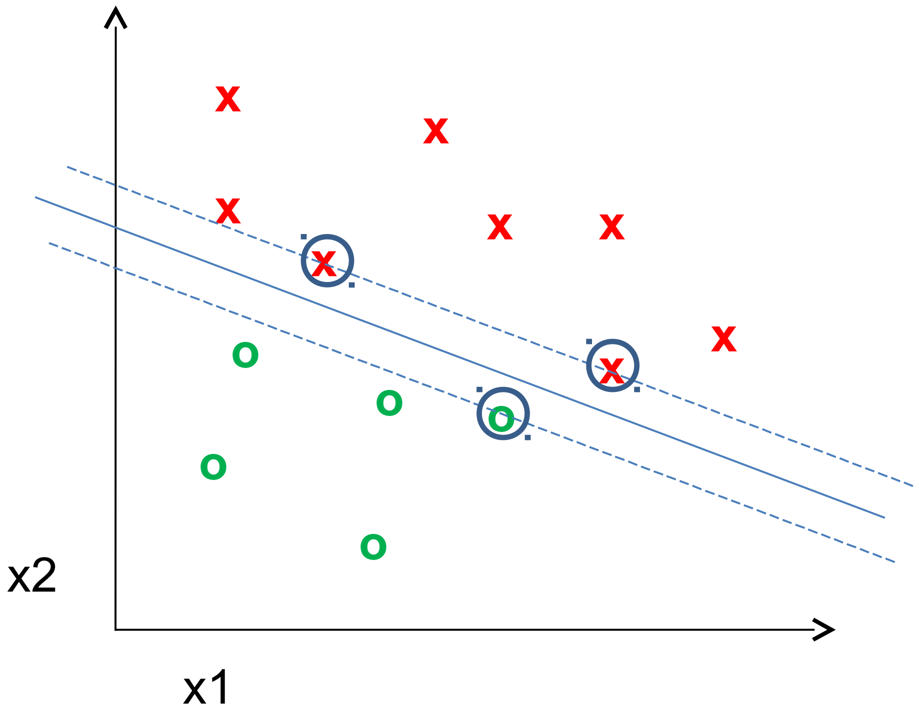


- How do we decide which line is the best?

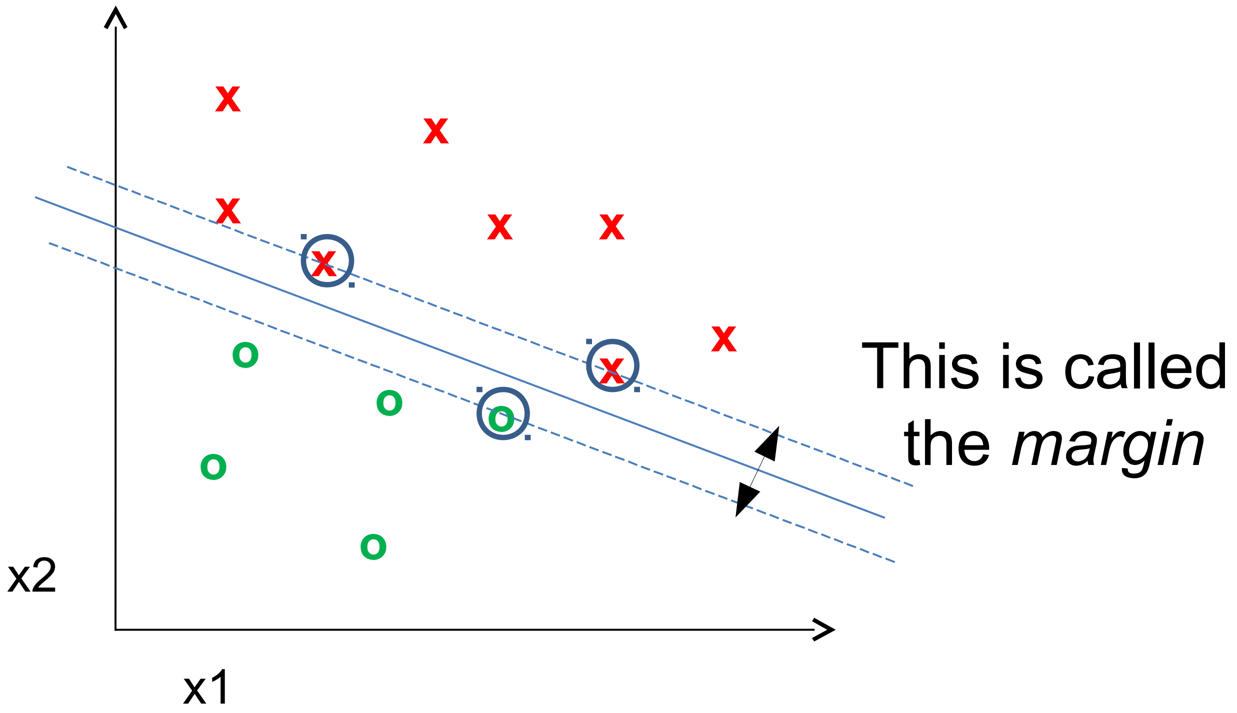
Linear Support Vector Machine



Linear Support Vector Machine

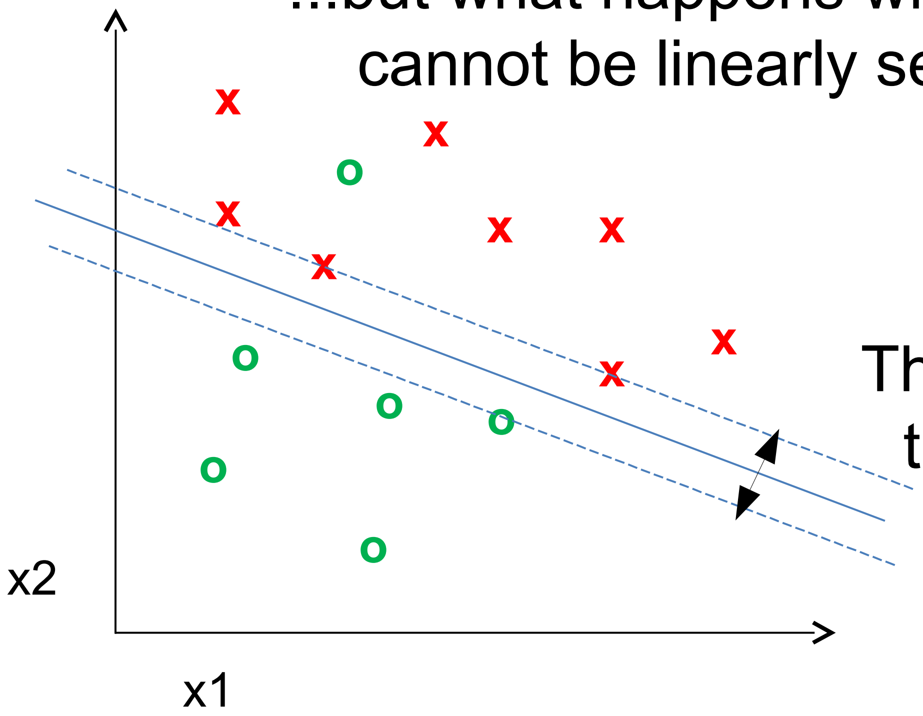


Linear Support Vector Machine



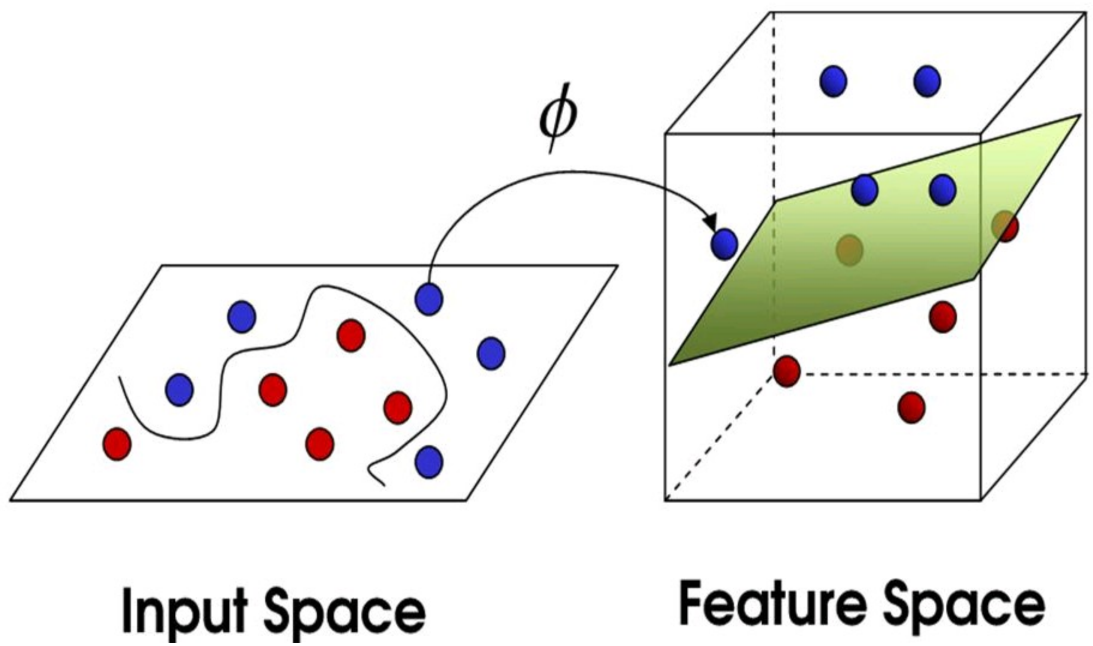
Linear Support Vector Machine

...but what happens when the data cannot be linearly separated?



This is called the *margin*

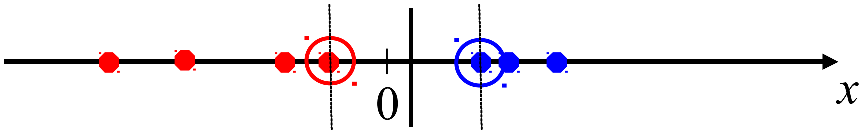
Nonlinear Support Vector Machine



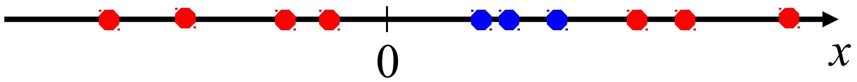
[http://www.imtech.res.in/raghava/rbpred/svm.jpg]

Nonlinear Support Vector Machine

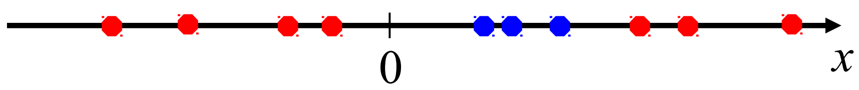
Linearly separable:



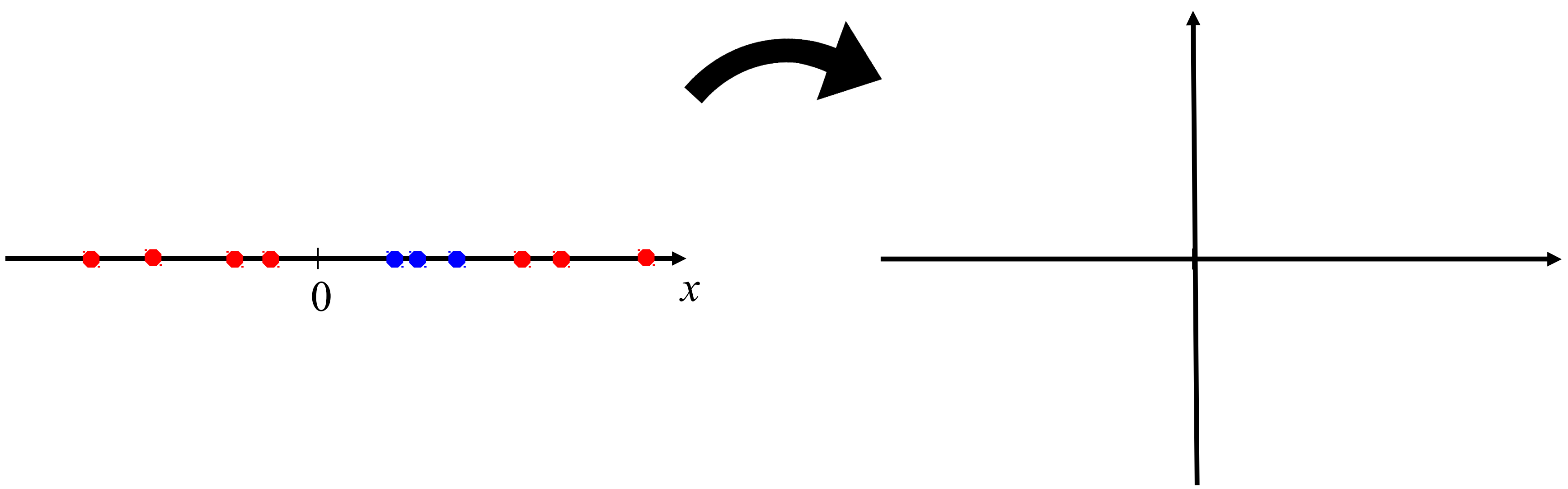
Not linearly separable:



Can we construct a mapping function from 1D to 2D such that the data in the 2D space is linearly separable?



Can we construct a mapping function from 1D to 2D such that the data in the 2D space is linearly separable?

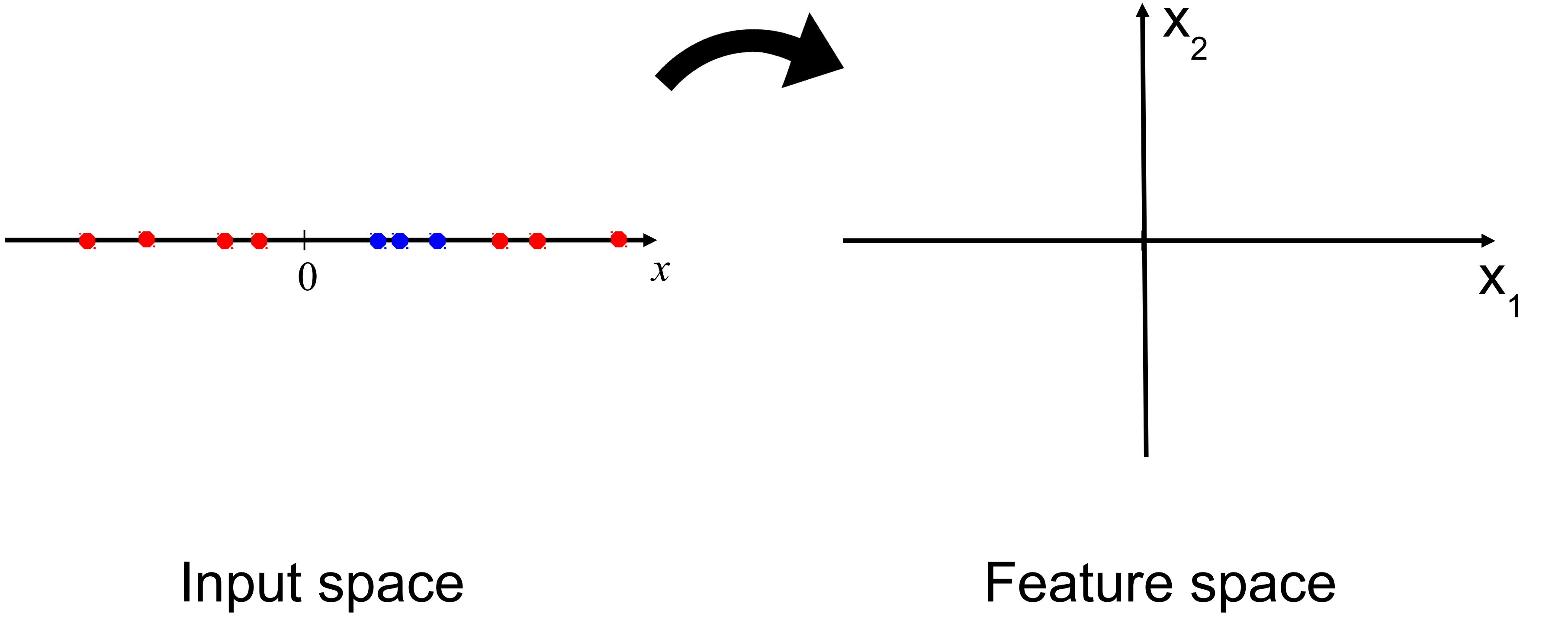


Input space

Feature space

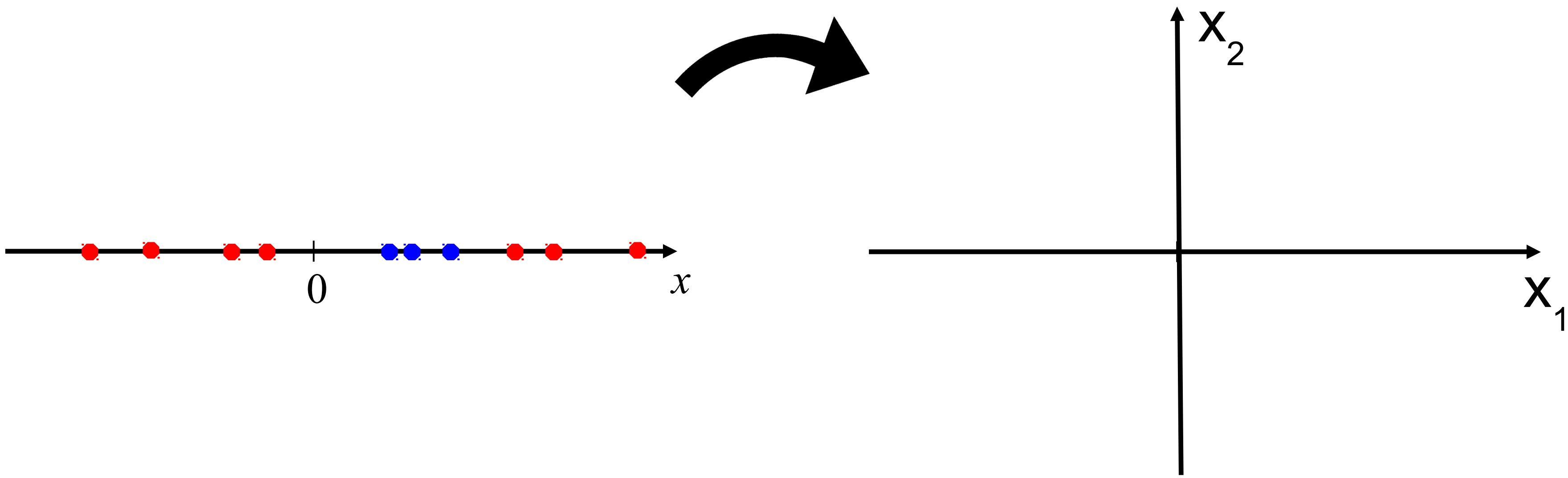
Can we construct a mapping function from 1D to 2D such that the data in the 2D space is linearly separable?

$\varphi(x) \rightarrow \langle x_1, x_2 \rangle$



Can we construct a mapping function from 1D to 2D such that the data in the 2D space is linearly separable?

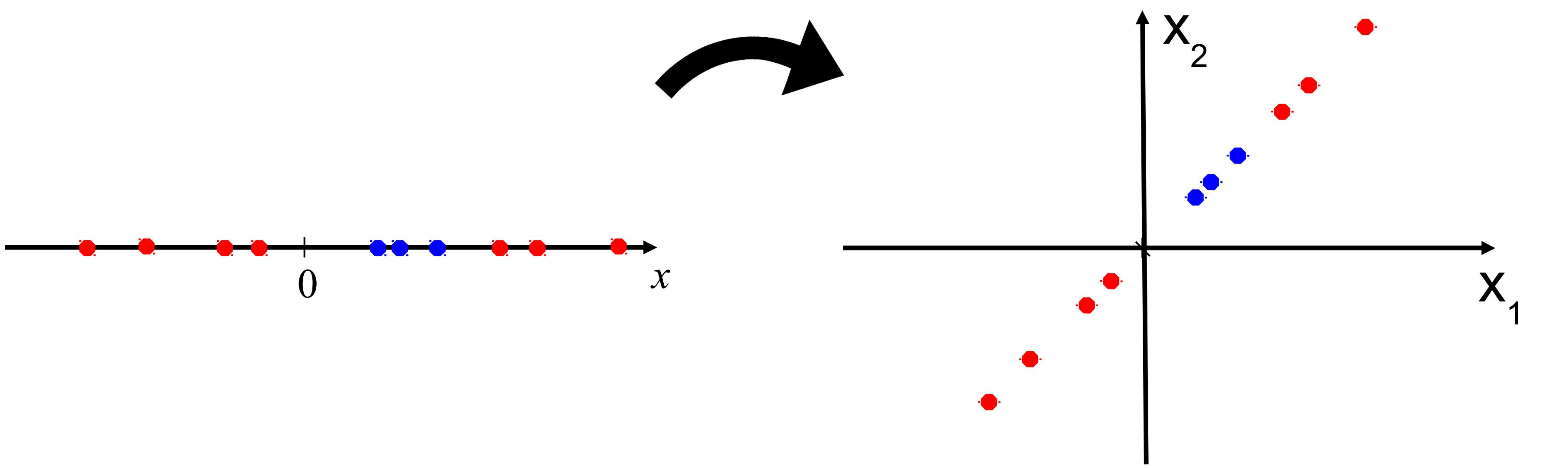
$$\varphi(x) \rightarrow \langle x_1, x_2 \rangle$$



In other words, both x_1 and x_2 need to be function of x

Can we construct a mapping function from 1D to 2D such that the data in the 2D space is linearly separable?

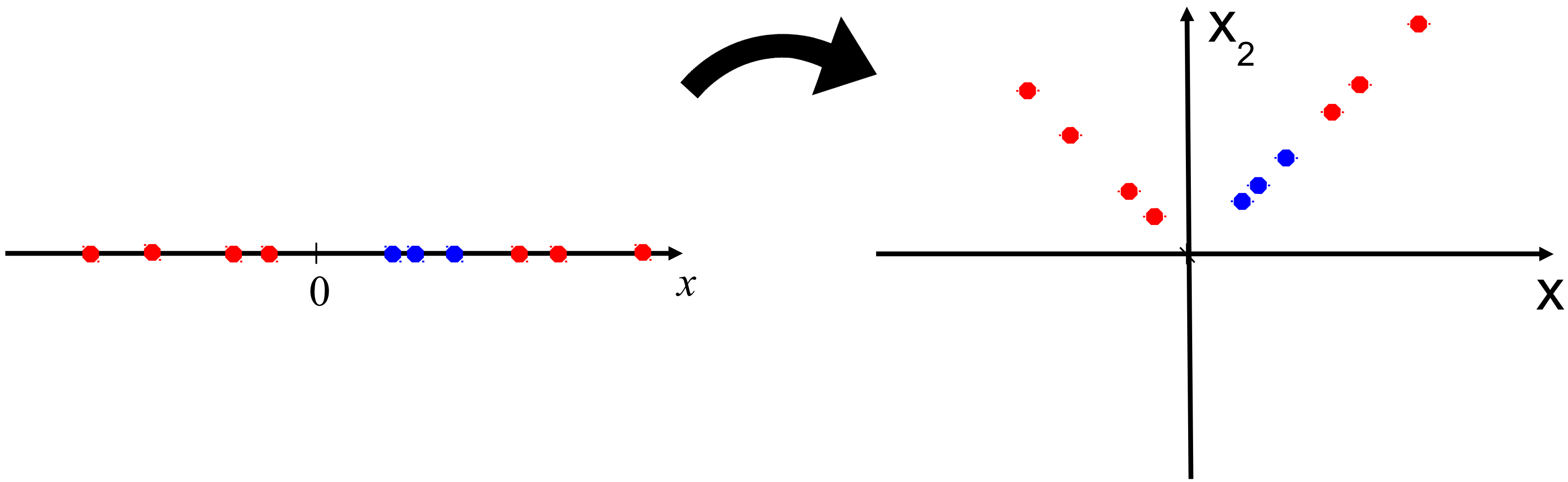
$\varphi(x) \rightarrow \langle x,x \rangle$



Example: both x_1 and x_2 are set to x

Can we construct a mapping function from 1D to 2D such that the data in the 2D space is linearly separable?

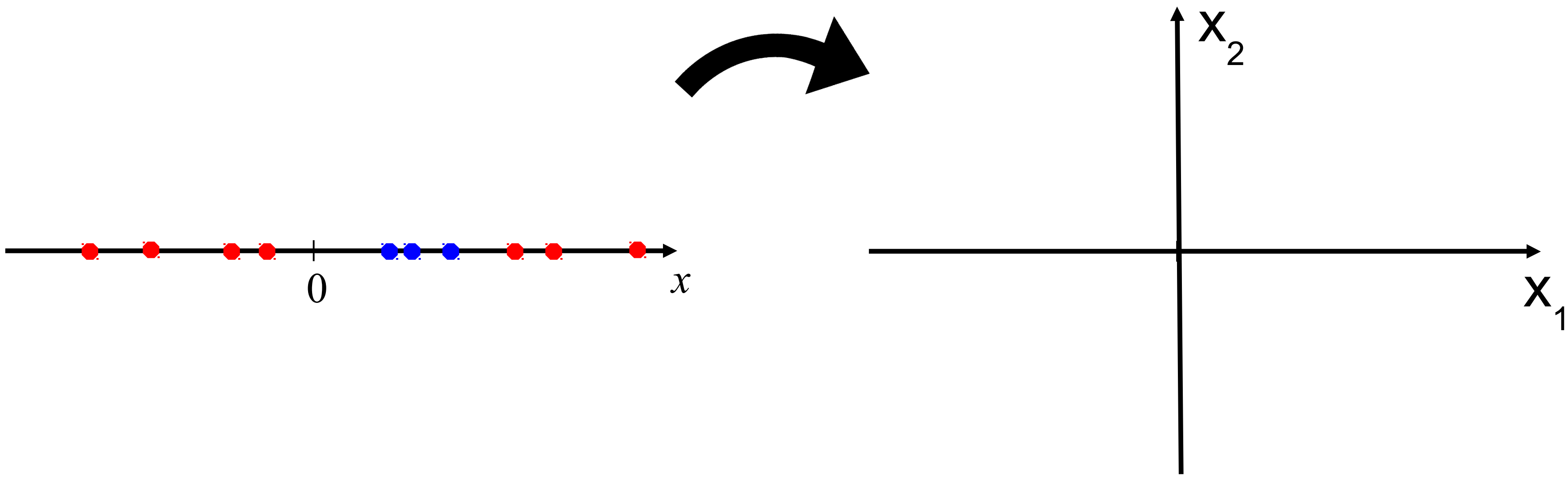
$\varphi(x) \rightarrow \langle x, |x| \rangle$



Example: $x_1 = x$ and $x_2 = |x|$

Can we construct a mapping function from 1D to 2D such that the data in the 2D space is linearly separable?

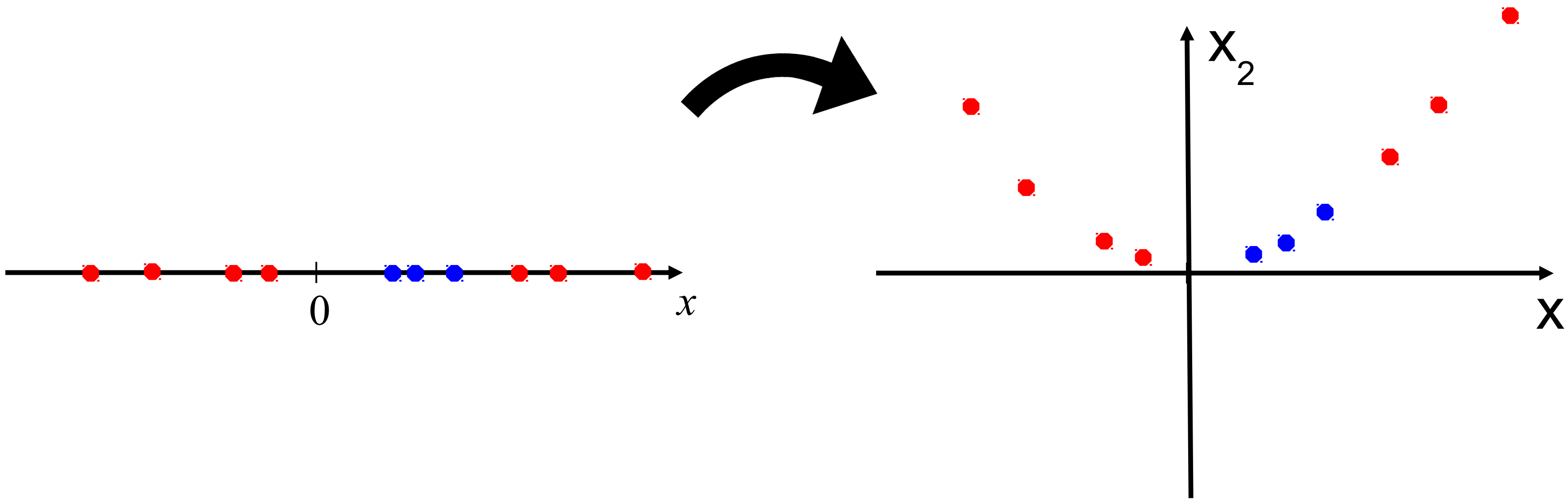
$\varphi(x) \rightarrow <x_1,x_2>$



In other words, both x_1 and x_2 need to be function of x

Can we construct a mapping function from 1D to 2D such that the data in the 2D space is linearly separable?

$$\varphi(x) \rightarrow \langle x, x^2 \rangle$$

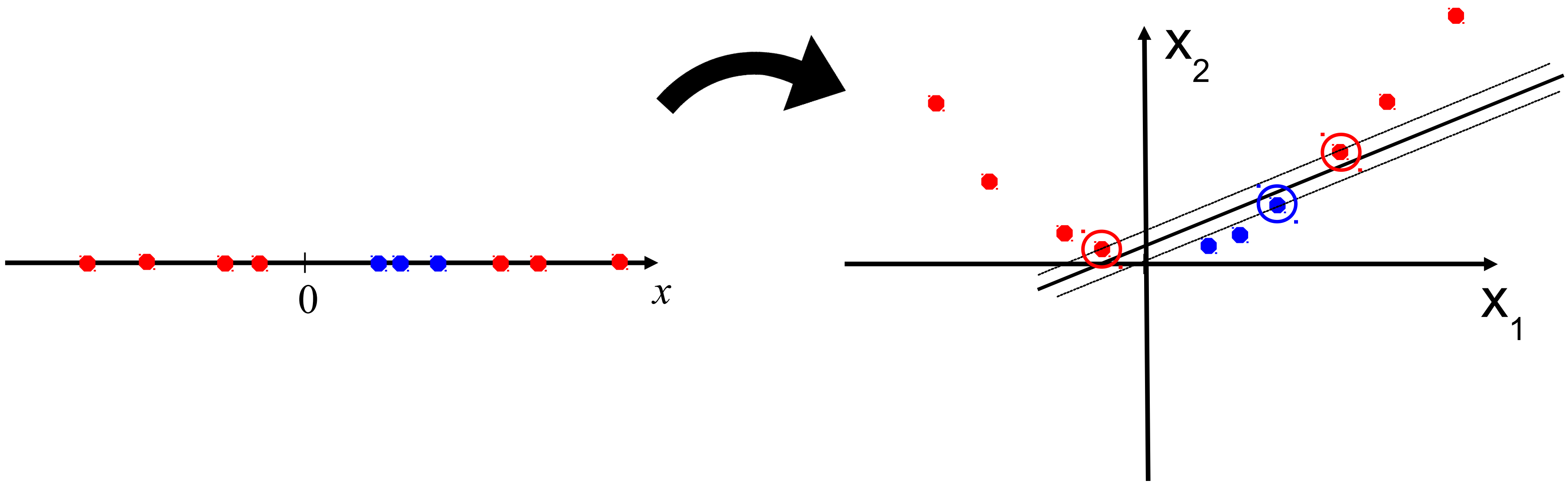


Input space

Feature space

Can we construct a mapping function from 1D to 2D such that the data in the 2D space is linearly separable?

$\varphi(x) \rightarrow \langle x, x^2 \rangle$



Input space

Feature space

Nonlinear Support Vector Machine

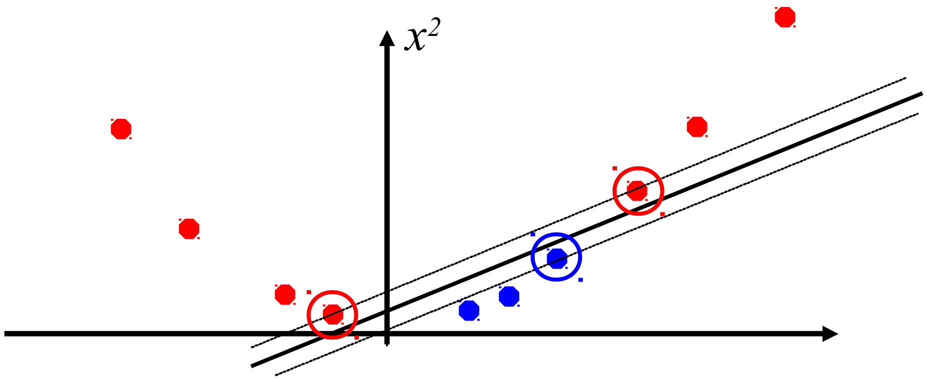
- *The kernel trick*: instead of explicitly computing the lifting transformation $\boldsymbol{\varphi}(\mathbf{x})$, define a kernel function K such that

$$K(\mathbf{x}_i, \mathbf{x}_j) = \boldsymbol{\varphi}(\mathbf{x}_i) \cdot \boldsymbol{\varphi}(\mathbf{x}_j)$$

  (to be valid, the kernel function must satisfy *Mercer's condition*)
- Intuitively, the kernel function should encode a measure of similarity between $\mathbf{x}_i$ and $\mathbf{x}_j$

Nonlinear Support Vector Machine

Consider the mapping $\varphi(x) = (x, x^2)$



$$\varphi(x) \cdot \varphi(y) = (x, x^2) \cdot (y, y^2) = xy + x^2 y^2$$

$$K(x, y) = xy + x^2 y^2$$

Nonlinear Support Vector Machine

- Polynomial Kernel:

$$K_{poly}(\mathbf{x}_i, \mathbf{x}_j) = (\mathbf{x}_i^{\mathbf{T}} \mathbf{x}_j + 1.0)^p$$

- Histogram kernel function:

$$K_{hist}(\mathbf{x}_i, \mathbf{x}_j) = e^{-\rho d_{a,b}(\mathbf{x}_i, \mathbf{x}_j)}$$

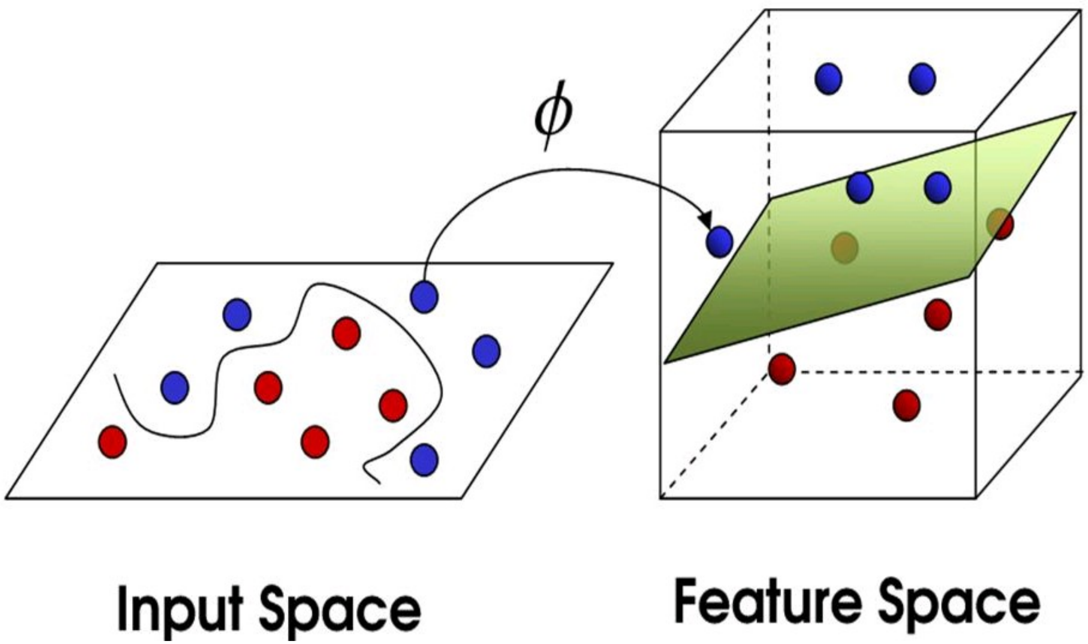
$$d_{a,b}(\mathbf{x}_i, \mathbf{x}_j) = \sum_k |x_{ik}^a - x_{jk}^a|^b$$

Nonlinear Support Vector Machine

- linear: $K(\mathbf{x}_i, \mathbf{x}_j) = \mathbf{x}_i^T \mathbf{x}_j$.
- polynomial: $K(\mathbf{x}_i, \mathbf{x}_j) = (\gamma \mathbf{x}_i{}^T \mathbf{x}_j + r)^d$, $\gamma > 0$.
- radial basis function (RBF): $K(\mathbf{x}_i, \mathbf{x}_j) = \exp(-\gamma \|\mathbf{x}_i - \mathbf{x}_j\|^2)$, $\gamma > 0$.
- sigmoid: $K(\mathbf{x}_i, \mathbf{x}_j) = \tanh(\gamma \mathbf{x}_i{}^T \mathbf{x}_j + r)$.

Nonlinear Support Vector Machine

- Support Vector Machine: a discriminative learning algorithm



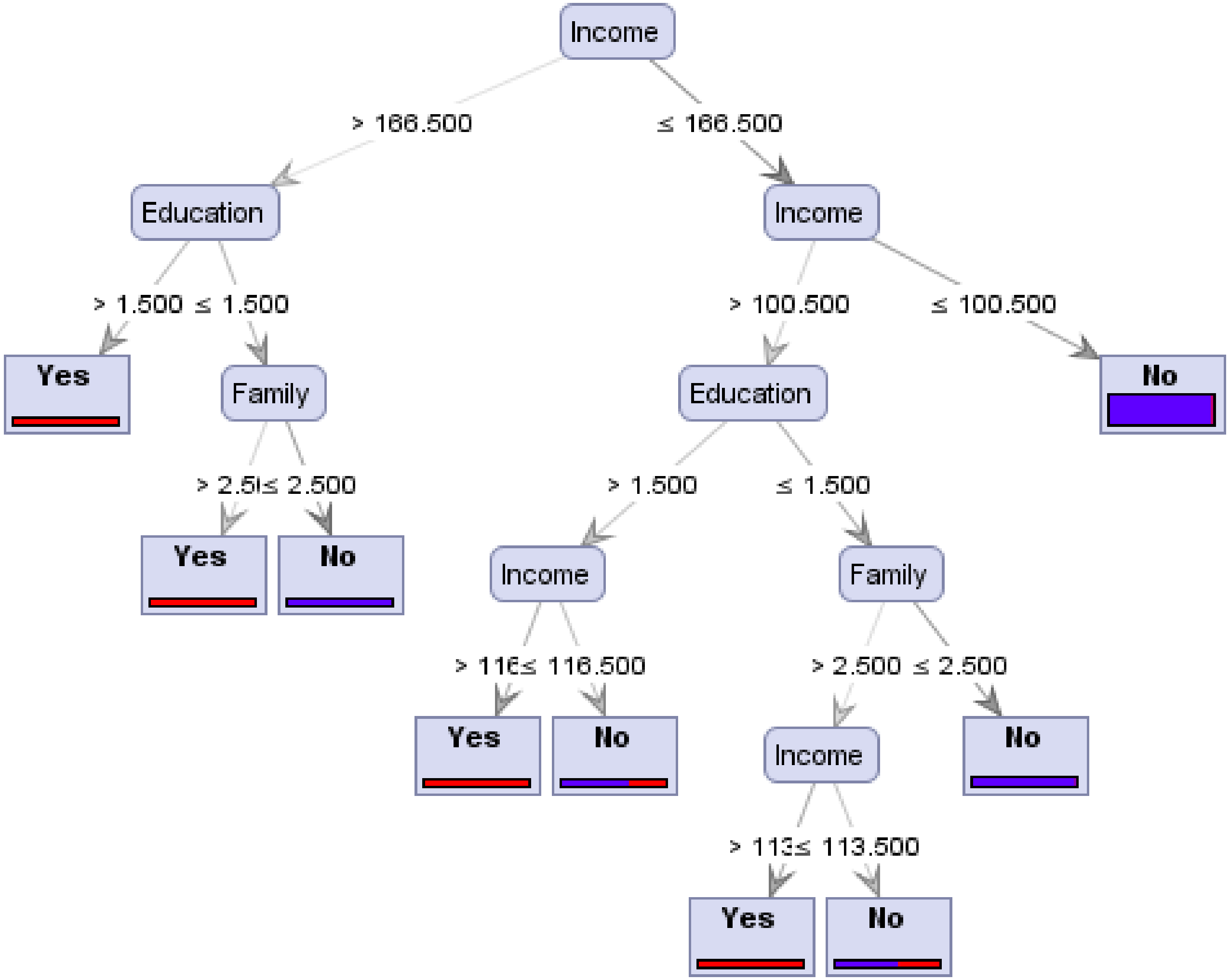
1. Finds maximum margin hyperplane that separates two classes

2. Uses Kernel function to map data points into a feature space in which such a hyperplane exists

[http://www.imtech.res.in/raghava/rbpred/svm.jpg]

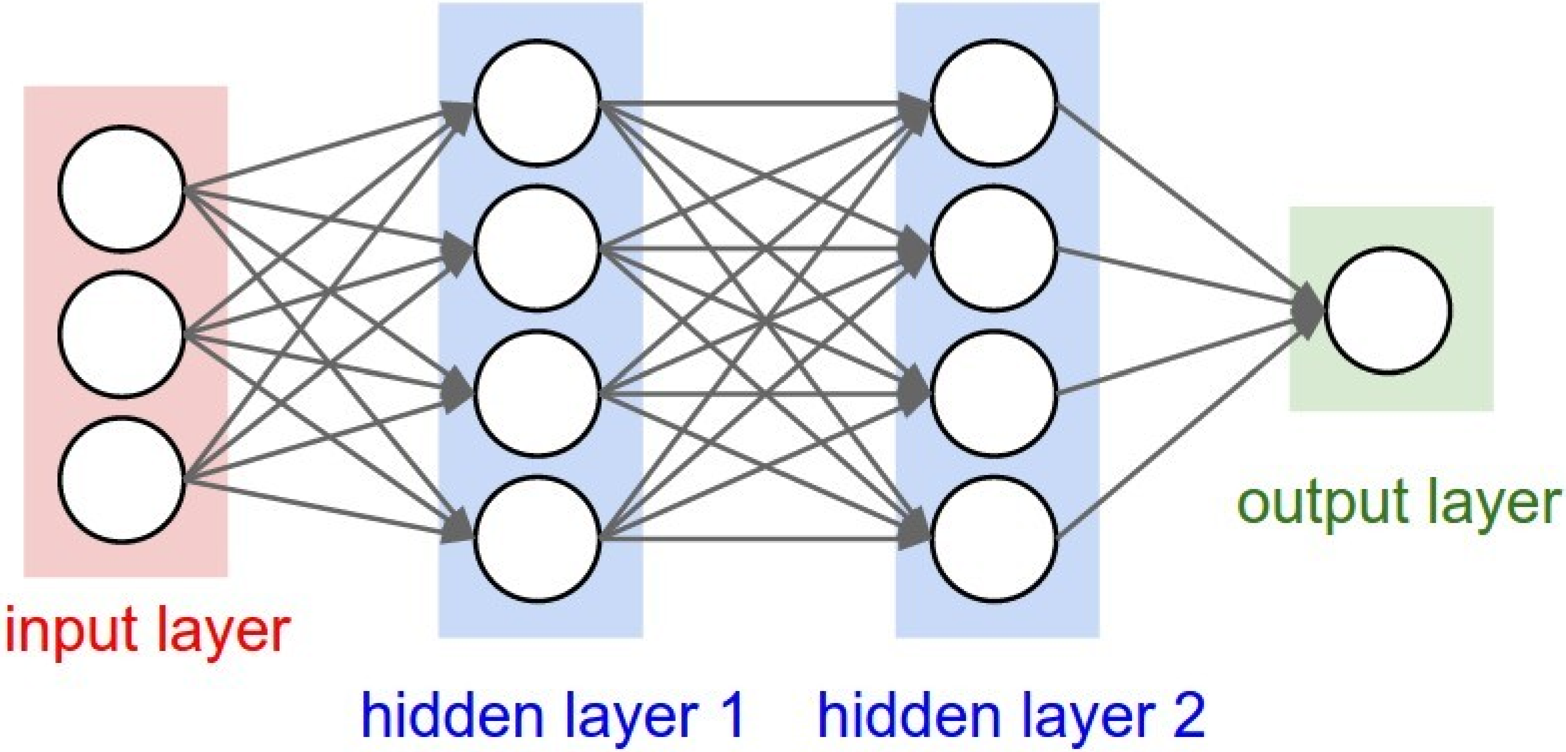
There are many other classifiers out there...

Decision Trees



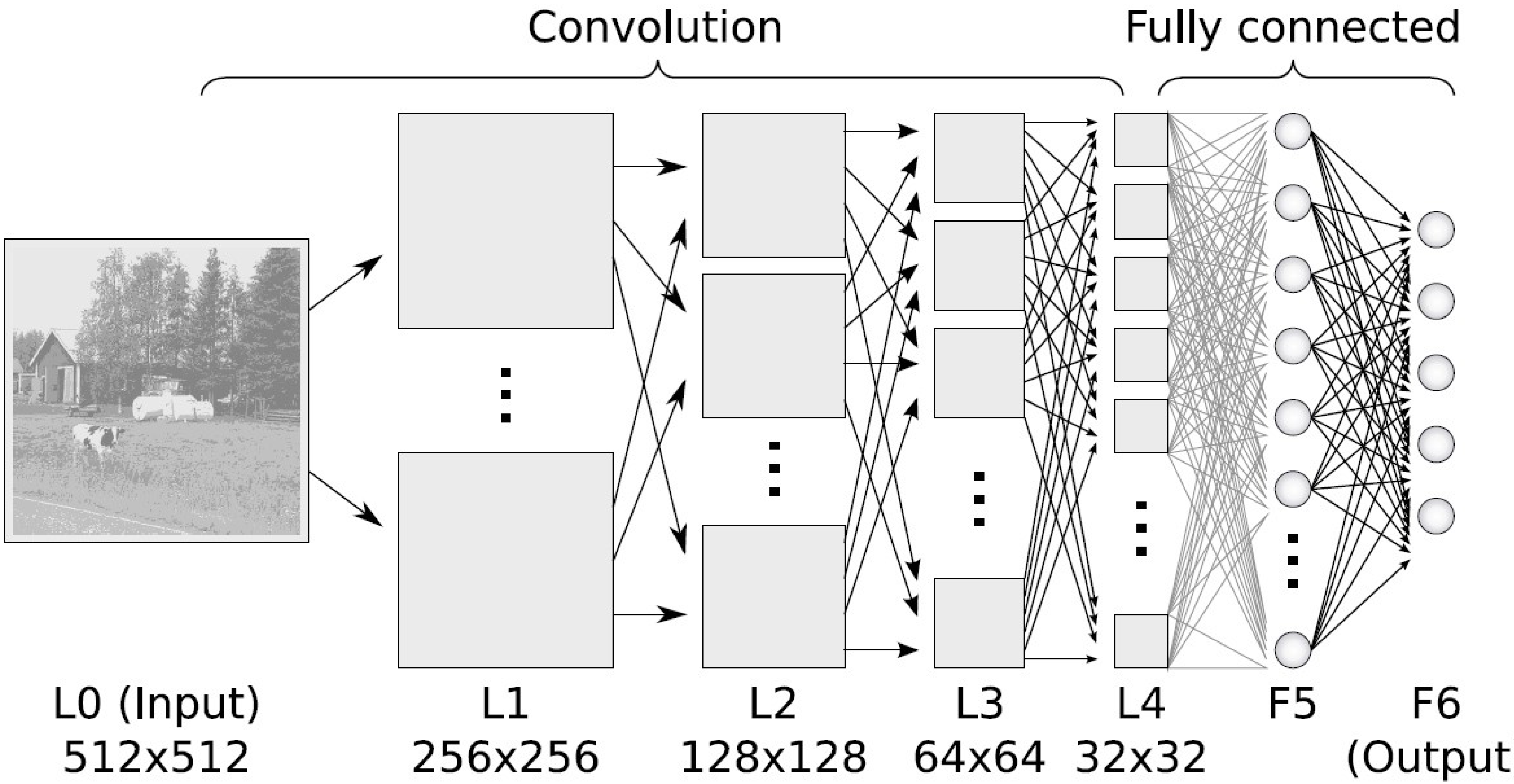
[http://cdn2.hubspot.net/hub/64283/file-15380323-png/images/rapidminer-decision-tree-personal-loan-accept.png]

Feed-Forward Neural Networks

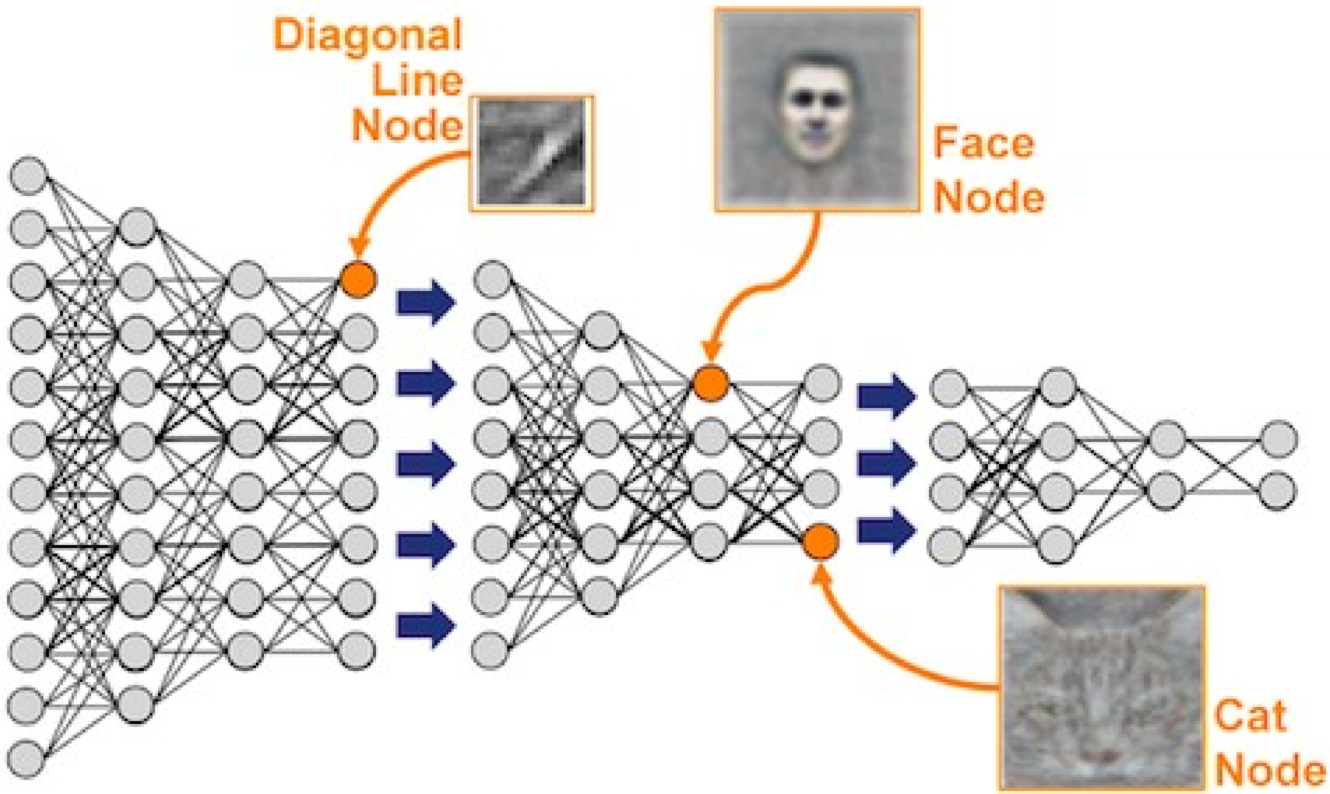


[http://cs231n.github.io/assets/nn1/neural_net2.jpeg]

Deep Learning Methods



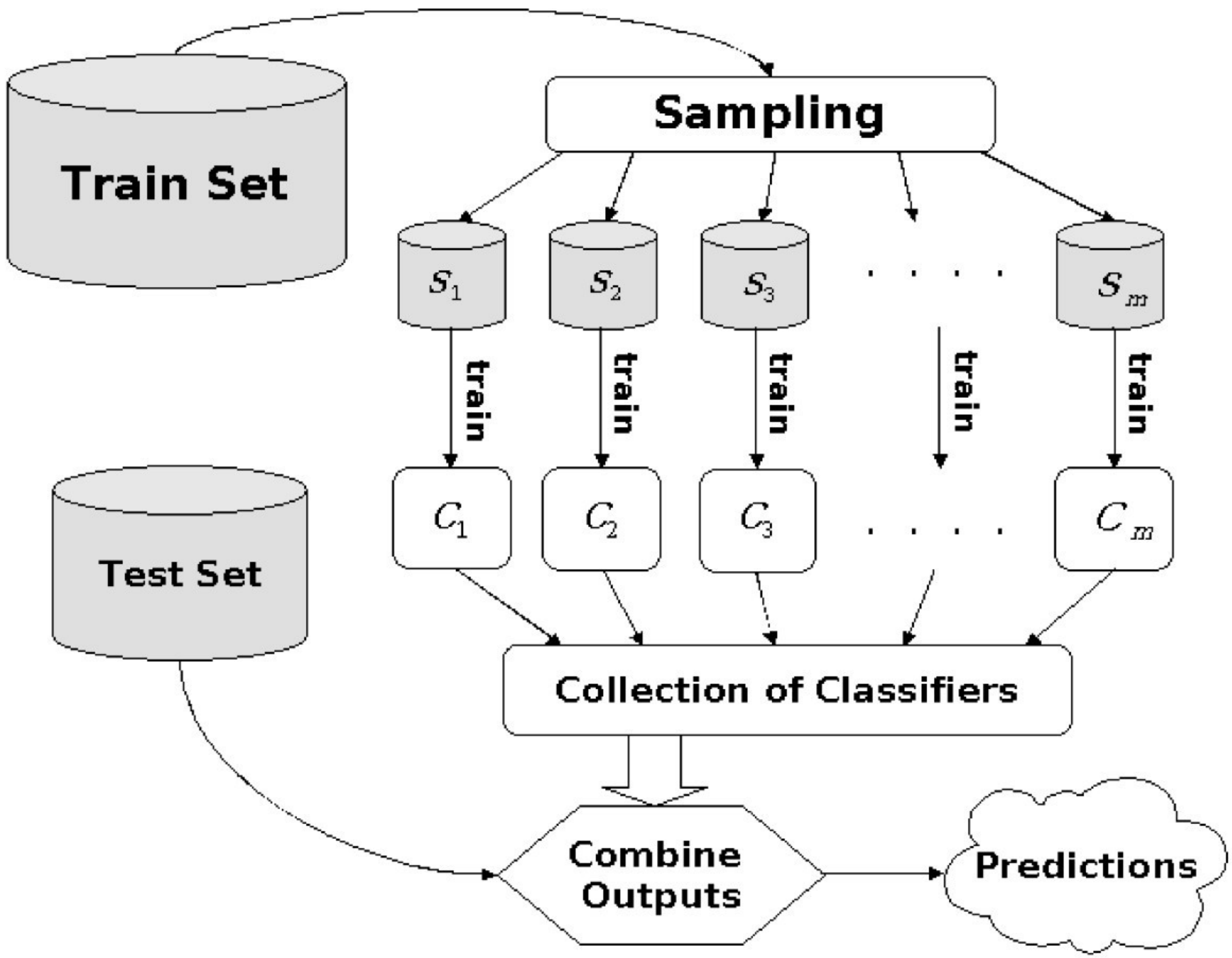
Deep Learning Methods



http://www.kdnuggets.com/wp-content/uploads/deep-learning.png

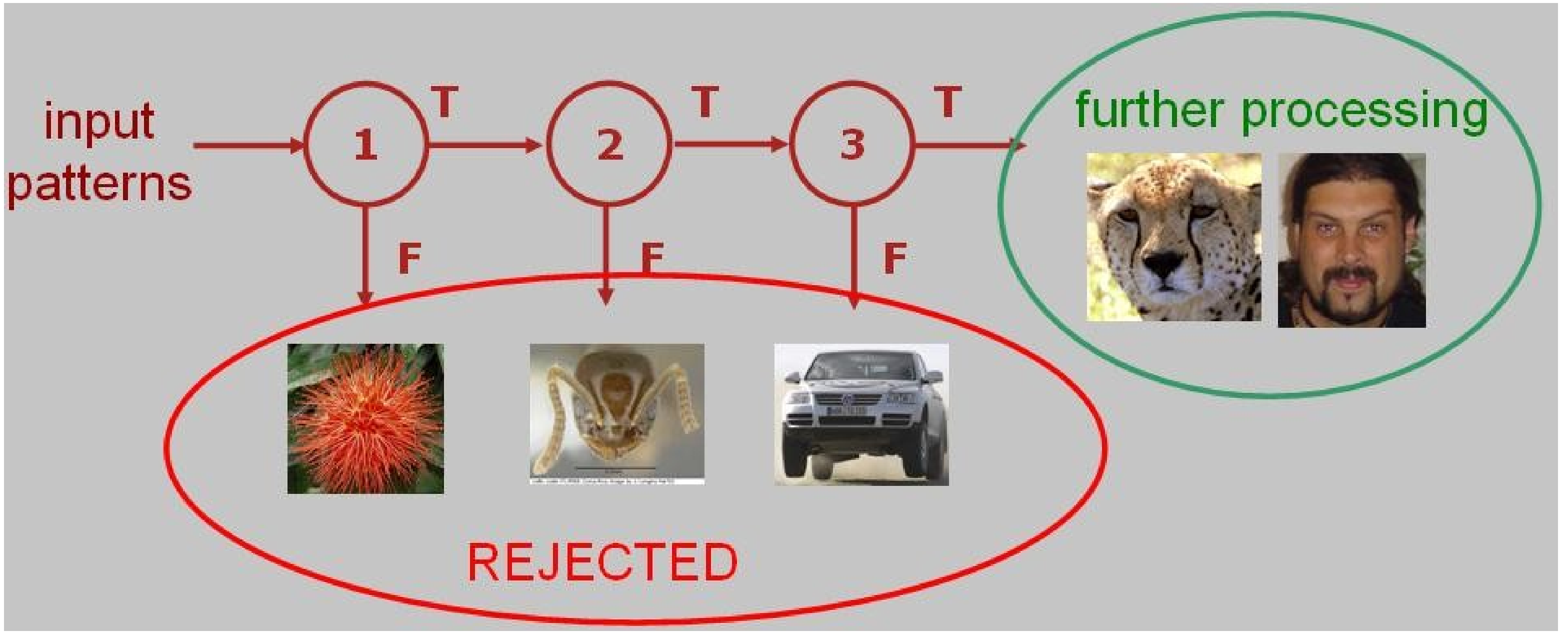
There are many ways to combine classifiers...

Classifier Ensembles



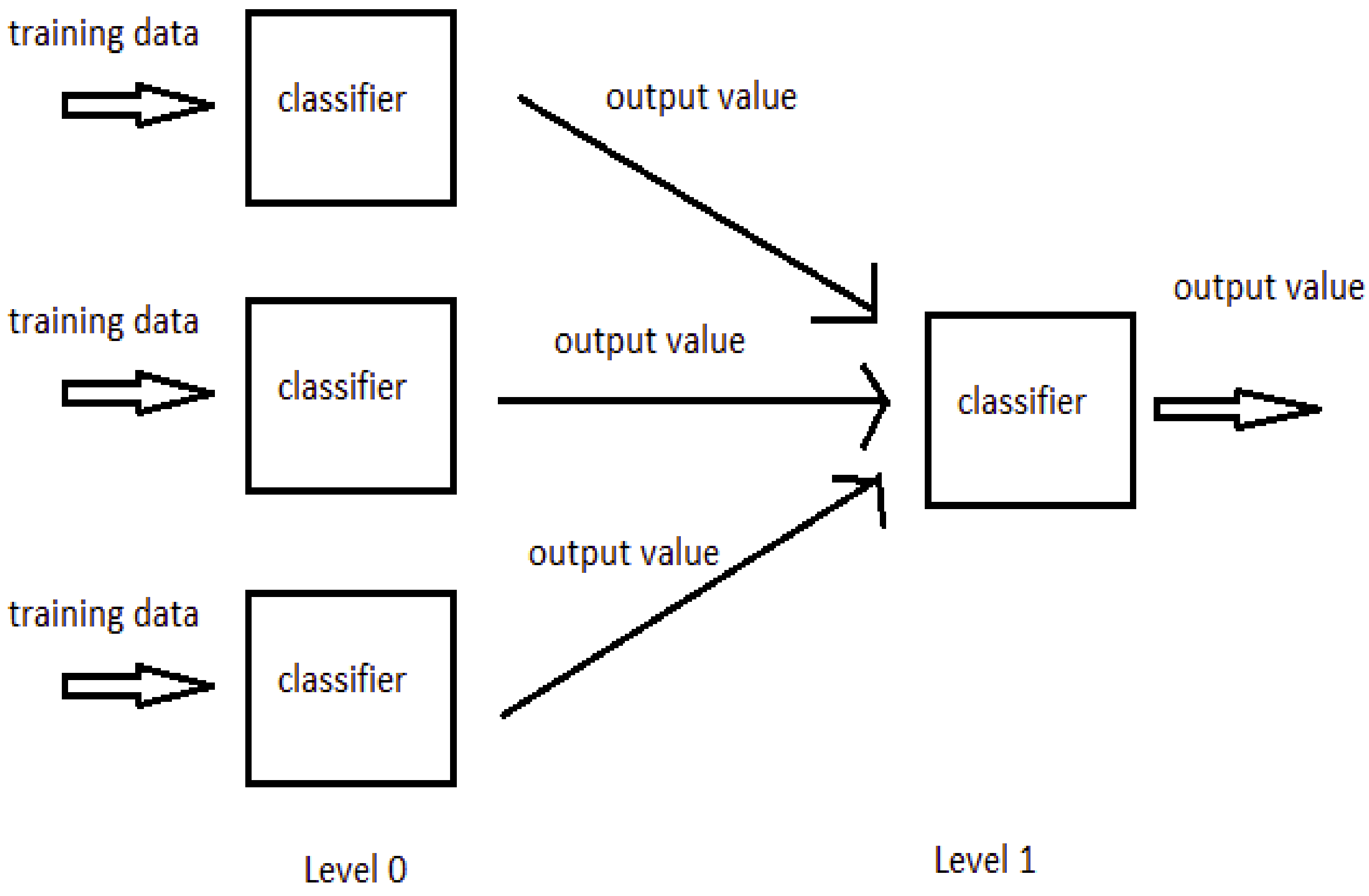
Boosting

Sequences of classifiers that grows in complexity of classifier



http://www.svcl.ucsd.edu/~ehsan/web/Img/cascadeflow.jpg

Concept Diagram of Stacking



http://www.chioka.in/wp-content/uploads/2013/09/stacking.png

Discussion

What are some problems faced by our service robots which could benefit from a machine learning solution?

What are some common things in the environment that the robot could learn to classify?

Can a classifier be used for prediction?

Take-home message

"The decision to *use* machine learning is more important than the choice of a *particular* learning method."

- James Hays, Brown University

Resources

- Introduction to Machine Learning textbook: http://alex.smola.org/drafts/thebook.pdf
- WEKA Machine Learning Library (in Java): http://www.cs.waikato.ac.nz/ml/weka/
- Support Vector Machine example using OpenCV: http://docs.opencv.org/2.4/doc/tutorials/ml/introduction_to_svm/introduction_to_svm.html

THE END