

# Data, Environment and Society: Lecture 20: Support Vector Machines

Instructor: Duncan Callaway  
GSI: Salma Elmallah

**November 7, 2019**

# IN THE AGE OF A.I., IS SEEING STILL BELIEVING?

*Advances in digital imagery could deepen the fake-news crisis—or help us get out of it.*



By Joshua Rothman

f t m



*As synthetic media spreads, even real images will invite skepticism.*

Illustration by Javier Jaén; photograph by Svetlik / Getty

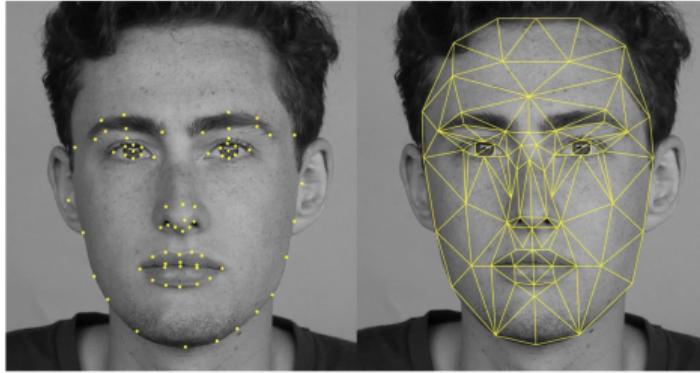
## Announcements

- I'll be teaching from ISLR Ch 9 today.
- HW9 due next Tuesday!
- Next week: Vet's day, no lab:
- Tuesday: Guest lectures by Elinor Benami, co-author on environmental monitoring prediction paper
  - ▶ Re-read the paper – it's in github reading for lecture 21.

# Objectives for today

- Some examples
- Introduce the idea of a **hyperplane** (it's really simple)
- Figure out what a **maximal margin hyperplane** (MMH) is and why we use it
  - ▶ Note, these only work for *separable data*
- Understand how **support vector classifiers** extend the MMH to cases when the data are not separable.
  - ▶ SVCs are *linear* separations of the feature space
- Open your horizons to the **support vector machine**
  - ▶ This provides nonlinear separations of the feature space!

## Motivating examples: Society face recognition



character recognition,



# Motivating examples – environment



## Science of The Total Environment

Volume 395, Issues 2–3, 1 June 2008, Pages 109-116



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Ground-level ozone prediction by support vector machine approach with a cost-sensitive classification scheme

Wei-Zhen Lu , Dong Wang

## Forecasting Power Output of Photovoltaic Systems Based on Weather Classification and Support Vector Machines

Jie Shi, Wei-Jen Lee, *Fellow, IEEE*, Yongqian Liu, Yongping Yang, and Peng Wang

**Abstract**—Due to the growing demand on renewable energy, photovoltaic (PV) generation systems have increased considerably in recent years. However, the power output of PV systems is affected by different weather conditions. Accurate forecasting of PV power output is important for system reliability and promoting large-scale PV deployment. This paper proposes algorithms to forecast power output of PV systems based upon weather classification and support vector machines (SVM). In the process, the weather conditions are divided into four types which are clear sky, cloudy day, foggy day, and rainy day. In this paper, a one-day-ahead PV power output forecasting model for a single station is derived based on the weather forecasting data, actual historical power output data, and the principle of SVM. After applying it into a PV station in China (the capability is 20 kW), results show the proposed forecasting model for grid-connected PV systems is effective and promising.



Fig. 1. Annual installation capacity of PV in China (2000–2010E, CAGR: Capacity Annual Growth Rate).

# Motivating examples – environment

Conferences > 2011 IEEE/PES Power Systems C... 

## Support vector machine based data classification for detection of electricity theft

3 Author(s)

Soma Shekara Sreenadh Reddy Depuru ; Lingfeng Wang ; Vijay Devabhaktuni [View All Authors](#)

57  
Paper  
Citations

1565  
Full  
Text Views



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- What is the term used in this article to describe the condition that must be met to trigger federal protection in discrimination cases? How does it relate to overt intent to discriminate?

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- Why is this conversation relevant to environmental justice?

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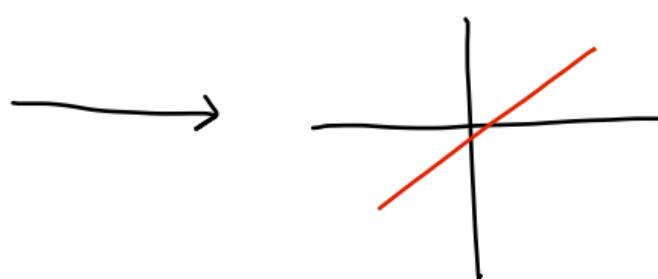
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- Why is this conversation relevant to environmental justice?
  - ▶ One of the origins of environmental racism is housing segregation. To the extent algorithms force people to live in specific areas, they can reinforce these problems.

# The hyperplane

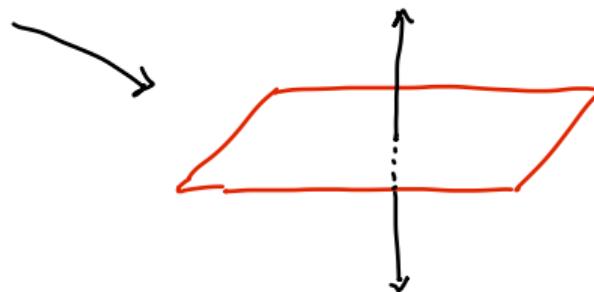
- A point splits a 1-dimensional space in two



- A line splits a 2-dimensional space in two



- A plane splits a 3-dimensional space in two



- A hyperplane splits a  $p$ -dimensional space in two.

## Mathematical representation

If we have a line defined by

$$x_2 = -2 + \frac{1}{2}x_1$$

Then the equality defining the hyperplane is:

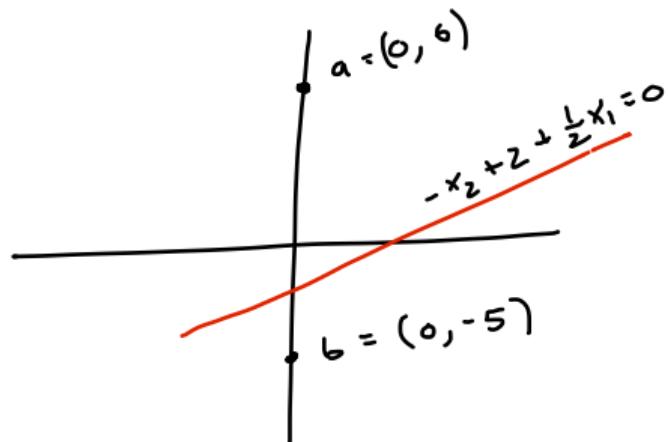
$$x_2 + 2 - \frac{1}{2}x_1 = 0$$

or

$$-2 + \frac{1}{2}x_1 - x_2 = 0$$

## How we'll think about the hyperplane

- In a data set with  $p$  features...
- We'll conceive of it as a  $p - 1$  dimensional object
- ...and we'll identify the location of observations in relation to the hyperplane



$$f(x_1, x_2) = \frac{1}{2}x_1 - 2 - \frac{1}{2}x_2 = 0$$

On the hyperplane:  $f(x_1, x_2) = 0$

Above the hyperplane:  $f(0, 6) = -2 - 6 = -8$   
 $f(x) < 0$

Below the hyperplane:  $f(0, -5) = -2 + 5 = 3$   
 $f(x) > 0$

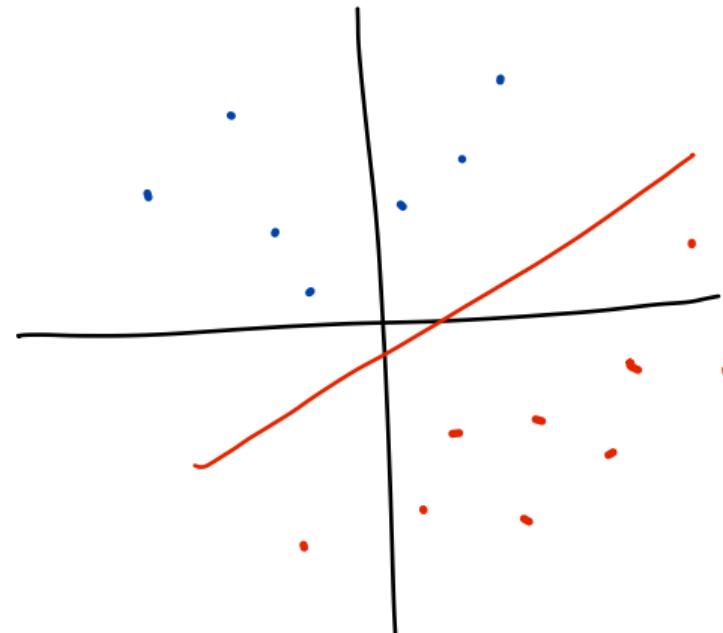
## Theoretical example: Classification with hyperplanes

Suppose we have

- blue points
- red points

A “separating hyperplane” has the property that:

$$f(x) < 0 \text{ if } x$$



## Using the plane for predictions

This part is simple. If we have a test observation, we simply evaluate  $f(x_{\text{test}})$  and assign it to a class on the basis of the sign of the result.

## How to choose the location of the plane?

Let's pose this as a learning problem. We have data and we'd like to place the hyperplane in between the two classes.

- First: What does large  $|f(x_i)|$  imply?

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- First: What does large  $|f(x_i)|$  imply? → A point is far from the hyperplane.

Now, how should we choose which plane to draw?

The rest of this lecture focuses on how to draw these separating geometries

## Maximal margin hyperplane (MMH)

- MMH defined: The MMH is the hyperplane that *maximizes* the *smallest distance* between the plane and all data.
  - ▶ In other words: it is the plane that is farthest from the data.
- Important: This requires that the data are *linearly separable*.

## How many points define the hyperplane?

In two dimensions...

- What is the smallest number of points that could define the hyperplane?
- What is the largest number of points that could define the hyperplane?

...We call these points “support vectors” because each of the 2-3 observations is a “vector” of information that supports the plane.

## Variance alert

In two dimensions, three observations determine the parameters of the model. Or more generally  $p + 1$  parameters. *If*  $p$  is small, this leads to high variance across training data sets.

And now for the math

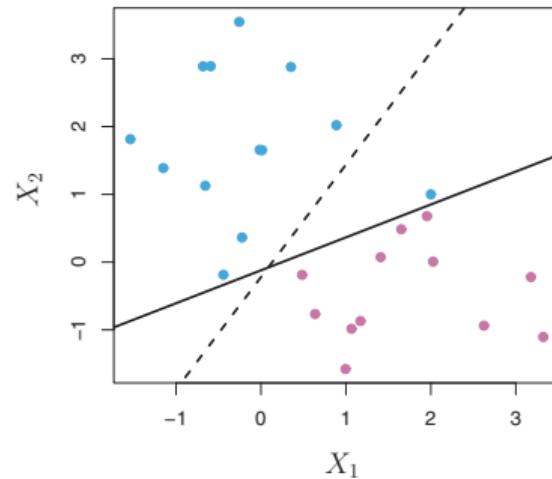
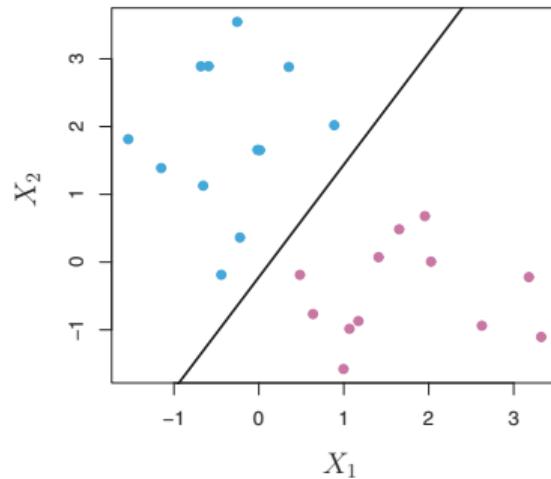
We'll solve for the location of the MMH using...

And now for the math

We'll solve for the location of the MMH using...you guessed it, optimization.

Pause for a moment...

The location of the MMH is very sensitive to the support vectors:



Furthermore:

- Though the  $M$  objective in the MMH formulation *can* in principle be negative (which allows for non-separable data)...
- ...the problems of variance get worse as data become non-separable.

## Support vector *classifiers*

Can we get

- ...less sensitivity to individual observations, and
- ...better classification for most training data (at expense of some poor classifications)

The answer is yes – but we will

- Allow some training data to enter the “margin”
- ...and perhaps even be on the wrong side of the hyperplane.

Now we call the margin a “soft margin”

## Support vector classifier details

The optimization problem is:

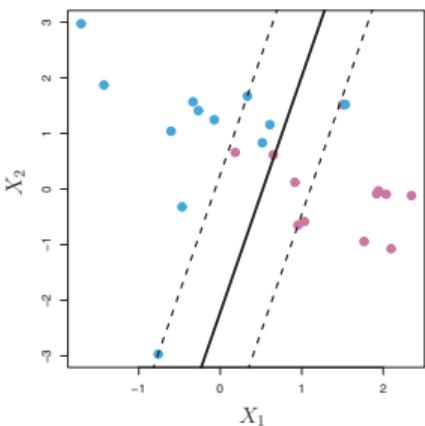
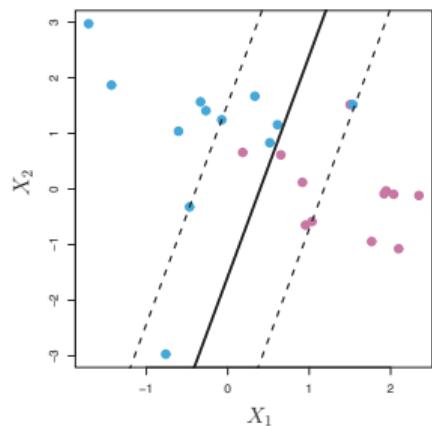
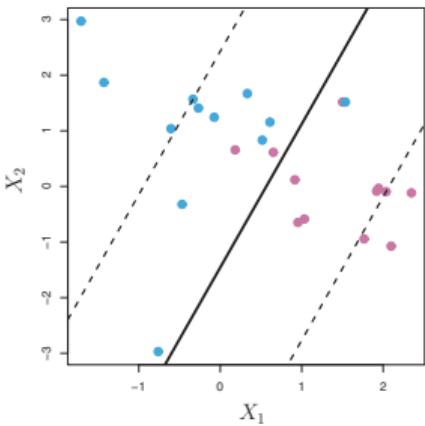
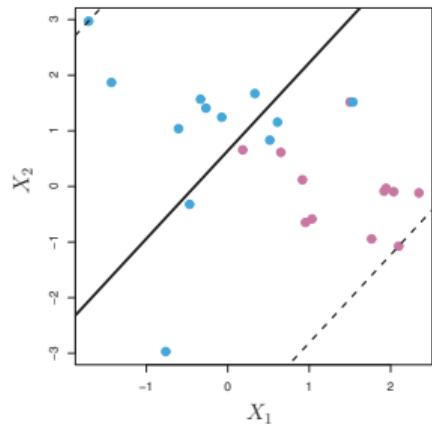
We'll solve a slightly different optimization problem.

- Still classifies observations on the basis of what side of the hyperplane they're on
- But a few observations can be mis-classified.

## What are the $\epsilon_i$ ?

- Each *observation* gets its own  $\epsilon_i$ .
- The  $\epsilon$  are decision variables – the optimization problem will solve for them.
- Without  $C$ , we'd just give everyone an  $\epsilon$  and go on a misclassification binge.
- But with  $C$ , the  $\epsilon$  values are chosen within a budget.
  - ▶  $\epsilon_i = 0$ , no margin violation
  - ▶  $0 < \epsilon_i < 1$ , in the margin but on the correct side of the plane
  - ▶  $\epsilon_i > 1$ , on the wrong side of the plane.

# Tuning $C$



## Questions

- ➊ Which plot has large  $C$ ? Which is small?
- ➋ What's going to have the highest variance? Large or small  $C$ ?

But decision boundaries aren't always so simple...

What if the boundary looked like this?

We might get better performance if we replaced the constraint in the optimization problem:

## Setup for SVM “Kernels”: Linear boundary

Let  $\langle x_i, x_k \rangle = \sum_{j=1}^p x_{ij}x_{kj}$

One can show that:

$$\beta_0 + \sum_{j=1}^p \beta_j x_{ij} \Leftrightarrow \beta_0 + \sum_{k=1}^n \alpha_k \langle x_i, x_k \rangle$$

## Setup for SVM “Kernels”: Linear boundary

What's the relationship between  $\alpha$  and  $\beta$ ?

Let  $\langle x_i, x_k \rangle = \sum_{j=1}^p x_{ij}x_{kj}$

One can show that:

$$\beta_0 + \sum_{j=1}^p \beta_j x_{ij} \Leftrightarrow \beta_0 + \sum_{k=1}^n \alpha_k \langle x_i, x_k \rangle$$

## SVM Kernels

$$K_{\text{linear}}(x_i, x_k) = \langle x_i, x_k \rangle = \sum_{j=1}^p x_{ij} x_{kj}$$

$$K_{\text{polynomial}}(x_i, x_k) = (1 + \sum_{j=1}^p x_{ij} x_{kj})^d$$

$$K_{\text{radial}}(x_i, x_k) = \exp(-\gamma \sum_{j=1}^p (x_{ij} - x_{kj})^2)$$

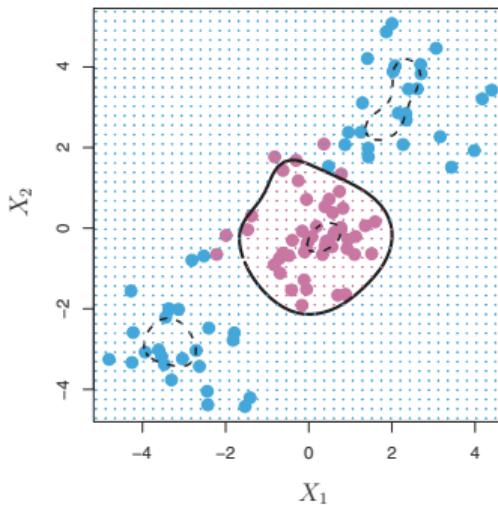
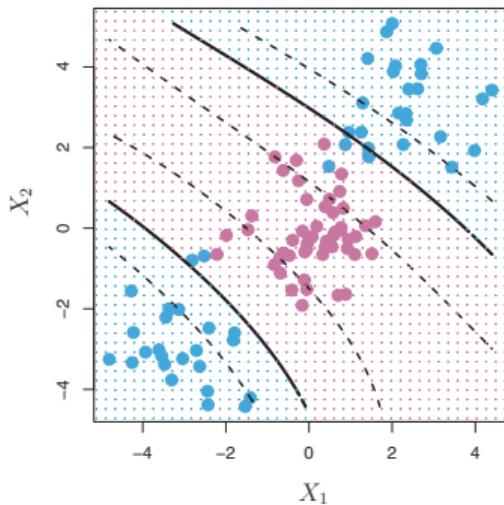
The radial kernel serves to give training observations far from a test point less weight (due to negative exponential).

For the radial kernel, all the data comprise the model – analogous to KNN.

Then we can apply these kernels:

$$f(x_i) = \beta_0 + \sum_{k=1}^p \alpha_k K(x_i, x_k)$$

## What do the kernels look like?



Left: Polynomial,  $d = 3$ .  
Right: Radial.

Note that  $d$  and  $\gamma$  are parameters to tune (via cross validation!)

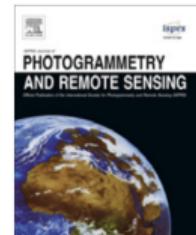
# SVM Example



Contents lists available at SciVerse ScienceDirect

## ISPRS Journal of Photogrammetry and Remote Sensing

journal homepage: [www.elsevier.com/locate/isprsjprs](http://www.elsevier.com/locate/isprsjprs)



Comparison of support vector machine, neural network, and CART algorithms  
for the land-cover classification using limited training data points

Yang Shao<sup>a,\*</sup>, Ross S. Lunetta<sup>b</sup>

<sup>a</sup> US Environmental Protection Agency, National Research Council, National Exposure Research Laboratory, 109 T.W. Alexander Drive, Research Triangle Park, NC 27711, USA

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## Shao and Lunetta setup

Loads of remote sensing data (MODIS):

- 46 input features for each 250 m<sup>2</sup> pixel
  - ▶ 23 short wave infrared (SWIR) surface reflectance
  - ▶ 23 Enhanced Vegetation Index metrics – basically a summary of the wavelengths
- Training data from National Land Cover Dataset (NLCD), classifying land as
  - ▶ urban,
  - ▶ deciduous forest,
  - ▶ evergreen forest,
  - ▶ agricultural land, and
  - ▶ wetland
- Question: How do SVM, Neural networks (coming soon!), and regression trees perform relative to one another?

# Shao and Lunetta SVM Result

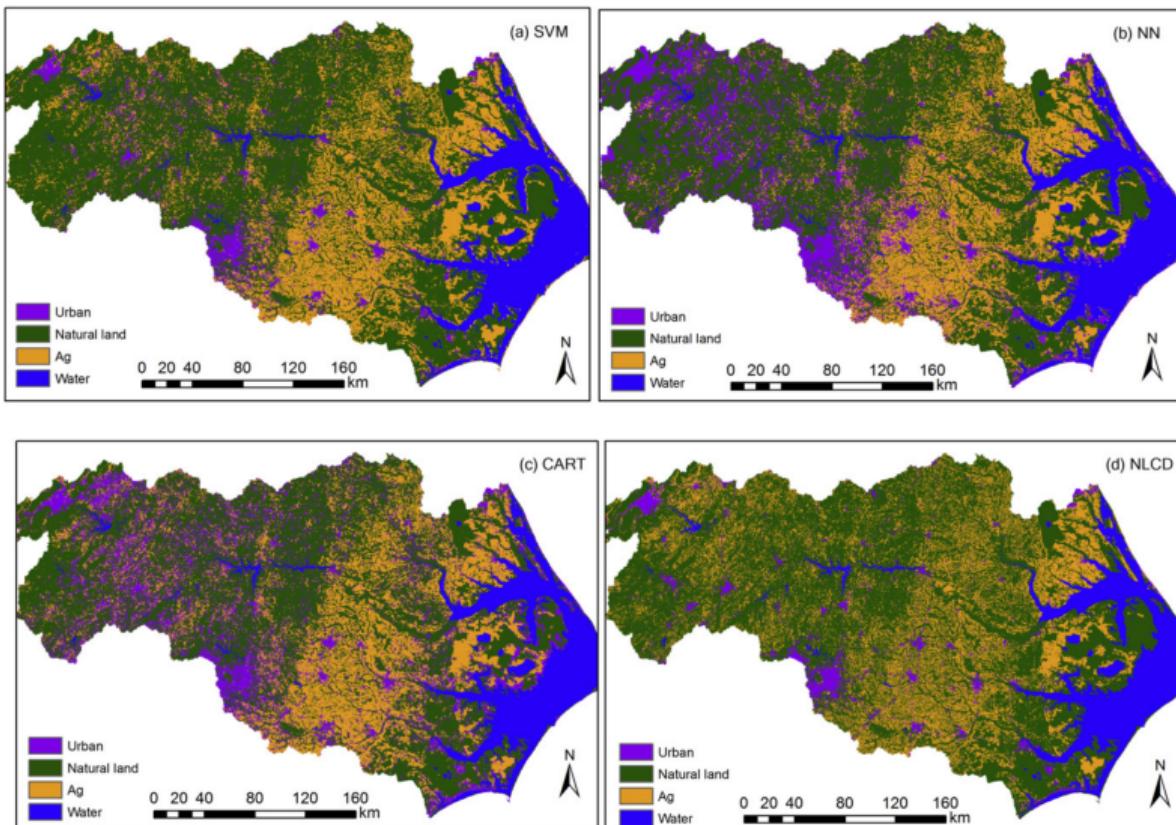
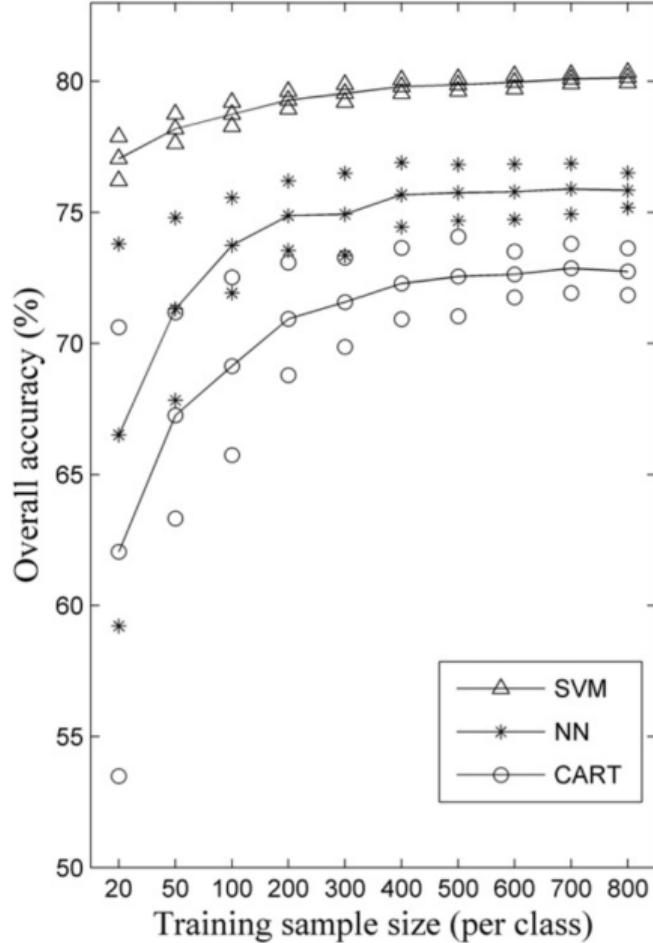


Fig. 3. Comparison of classification results for SVM (a), NN (b), and CART (c) algorithms. The NLCD 2001 (d) is also included as reference.



## Textbook example: Heart Data

First: Receiver operating characteristic (ROC)

**Sensitivity** = the fraction of “positives” that are correctly identified as positives

**Specificity** = fraction of negatives that we correctly identify as negatives

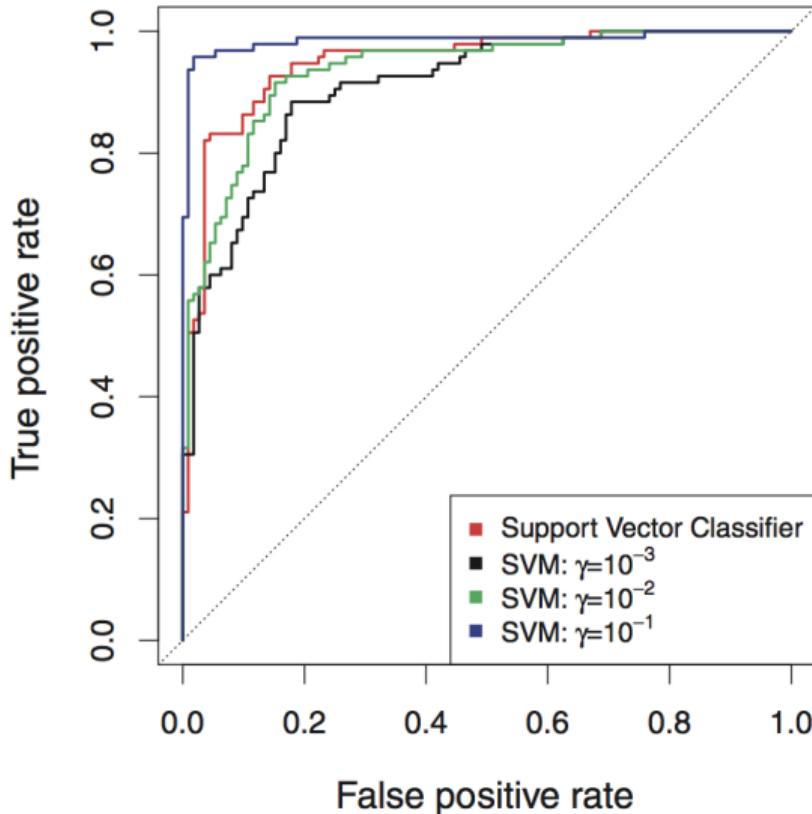
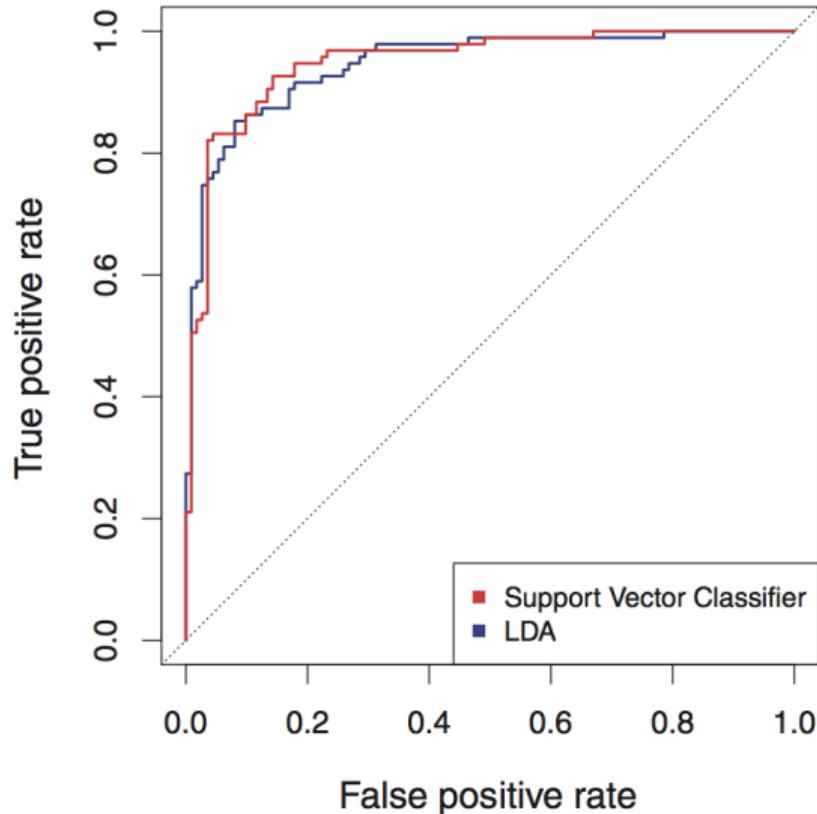
**True positive rate** = sensitivity

**False positive rate** =  $1 - \text{specificity}$

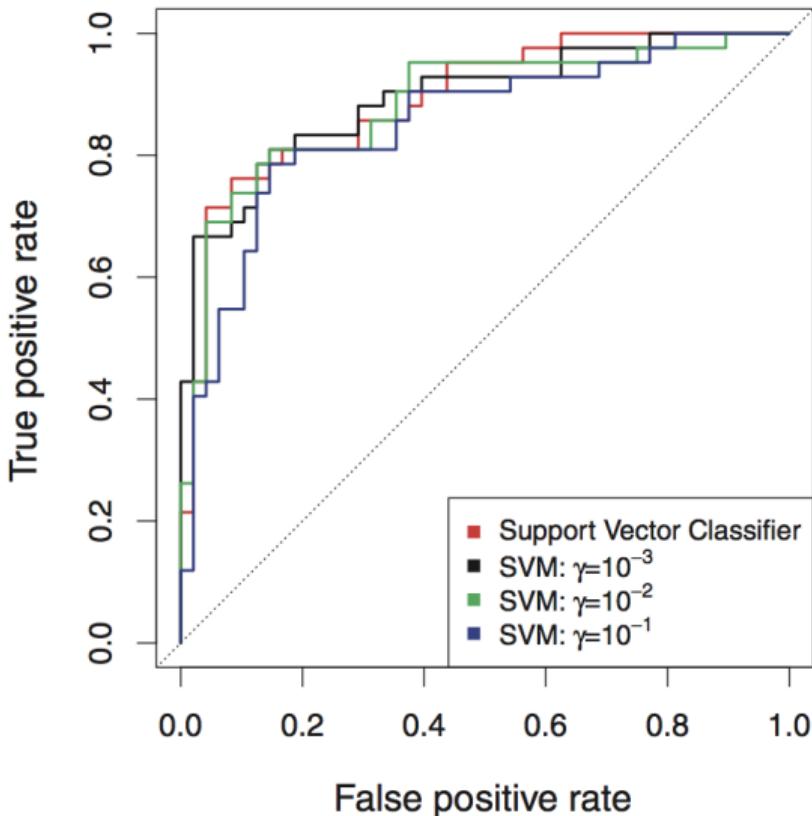
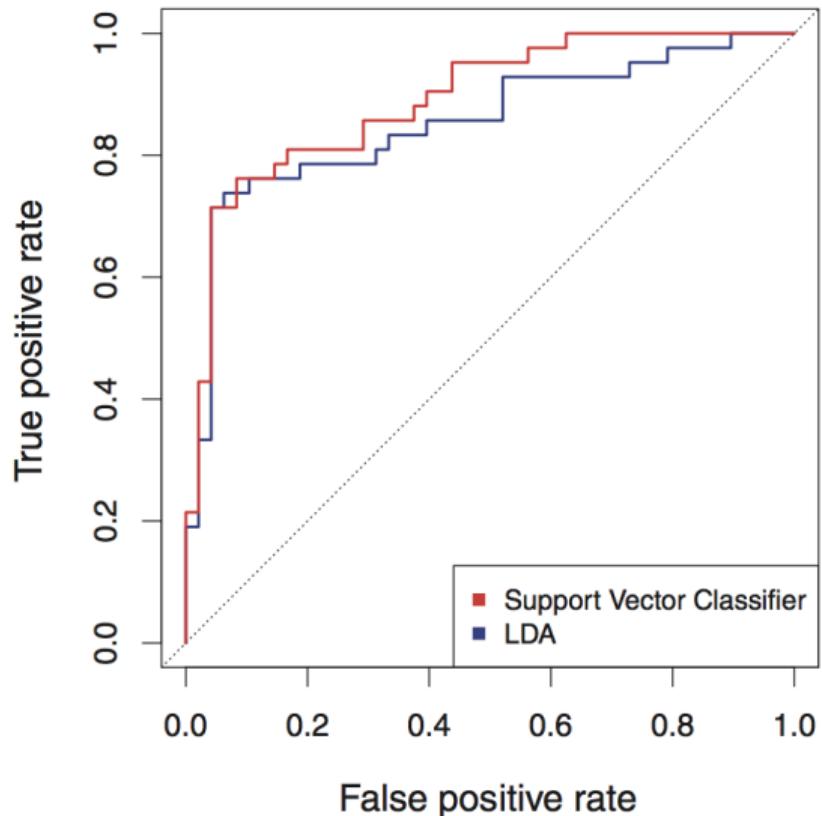
Ideal classifiers have large true positive rate and low false positive.

For a given method, there are usually parameters one can tune to explore the tradeoff between true and false positives.

## Classifying heart disease



## Classifying heart disease – test data



## Interpreting Heart data result

SVC is better than LDA, though surprisingly not by much if one recalls how simple the LDA approach is.

On training data, SVM with radial kernels are exceptional

...But not so much on test data. Why?

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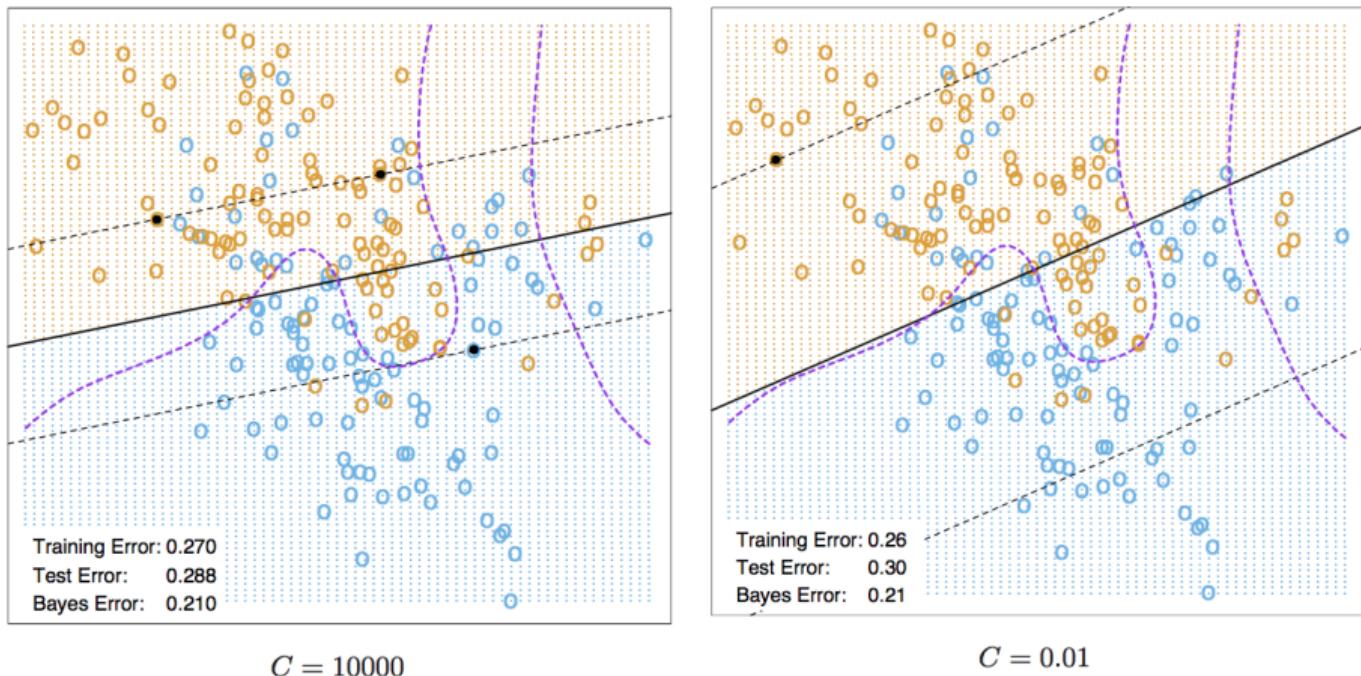
On training data, SVM with radial kernels are exceptional

...But not so much on test data. Why?

The decision boundary is really “wiggly” and prone to overfit.

It appears that SVC would have lower variance / higher bias and they balance perfectly in this particular case.

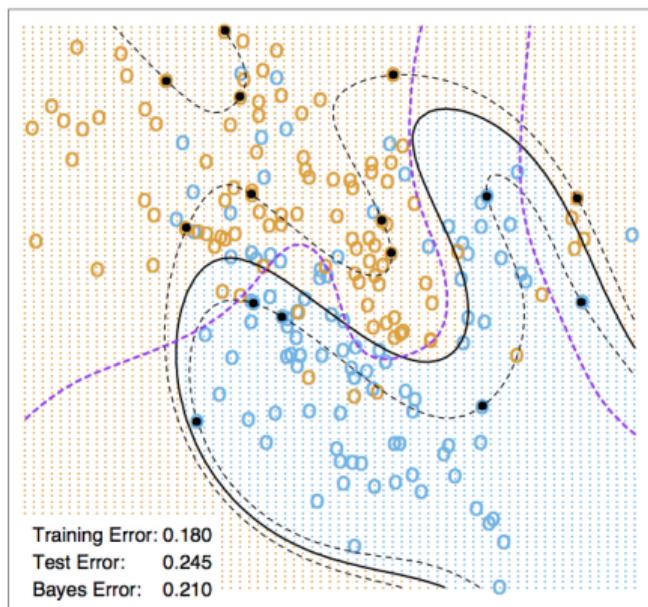
# Speaking of wiggly boundaries: From Elements of Statistical Learning



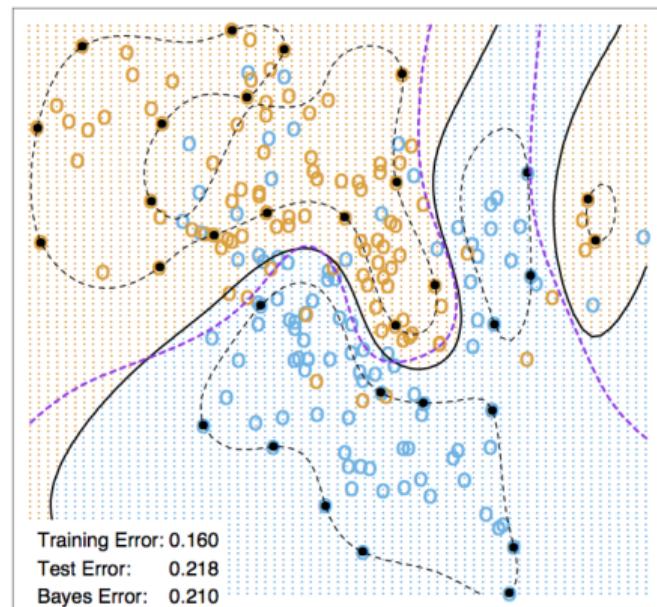
These boundaries constructed with SVC. Purple is “truth” (what they used to generate the data). Note! In ESL  $C$  is the inverse of  $C$  in ISLR. So large  $C$  here corresponds to small  $C$  there, and vice versa.

# One more example: From Elements of Statistical Learning

SVM - Degree-4 Polynomial in Feature Space



SVM - Radial Kernel in Feature Space



These boundaries constructed with SVM. Purple is “truth” (what they used to generate the data).