Linear Support Vector Machines Explained

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Mazen Ahmed · Follow

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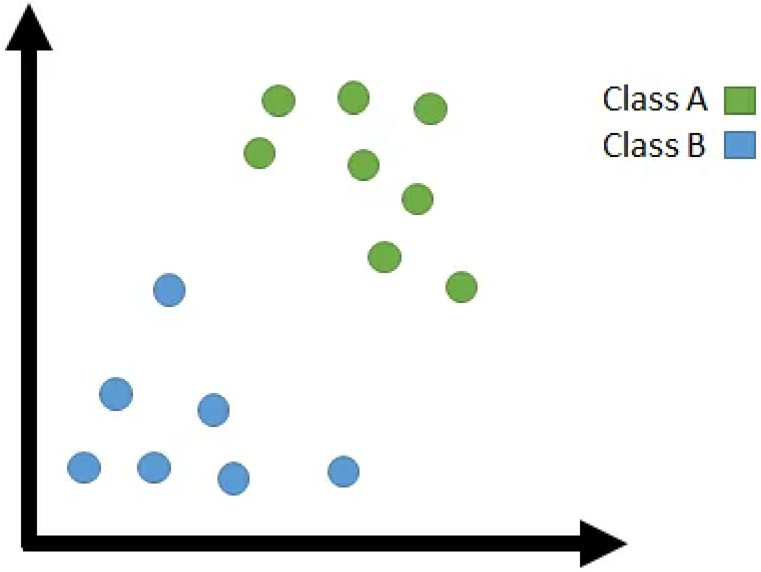
What are Support Vector Machines?

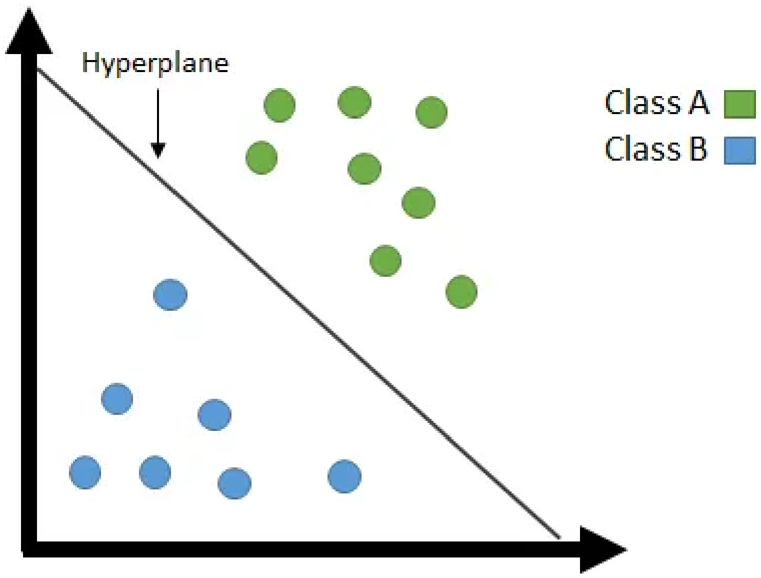
Support Vector machines are a common **supervised** machine learning algorithm used in both **classification** and **regression** problems, however are most commonly used for classification which will be the focus for this article.

Overview

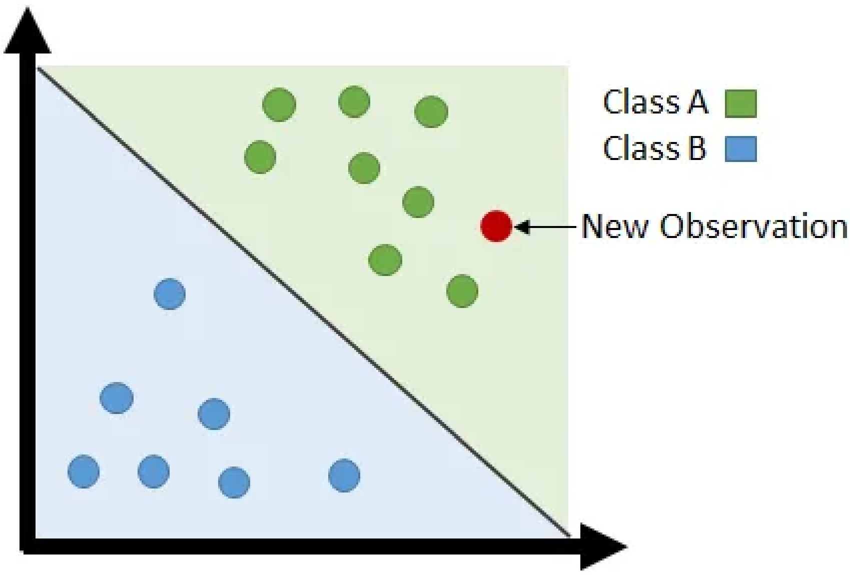
The job of a support vector machine for classification problems is take **labelled data** such as the following:



and determine a **hyperplane** that separates the data:

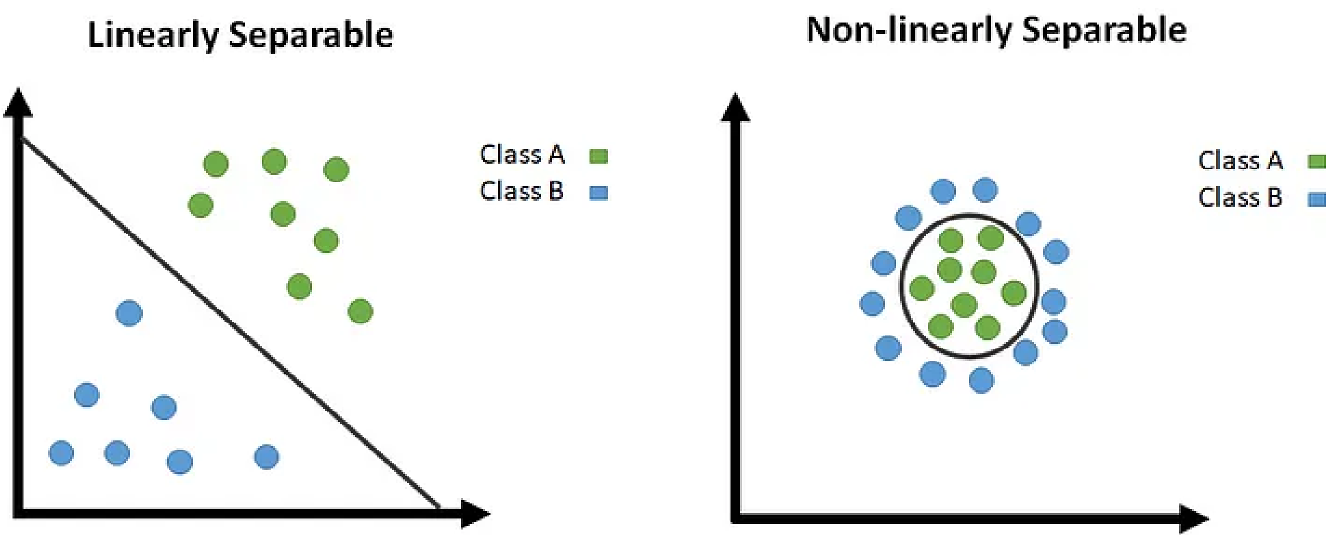


We can then use this hyperplane to make **predictions** for which class a **new data point** belong to:



Since our new observation lies **above the hyperplane** we predict this observation belongs to **Class A.**

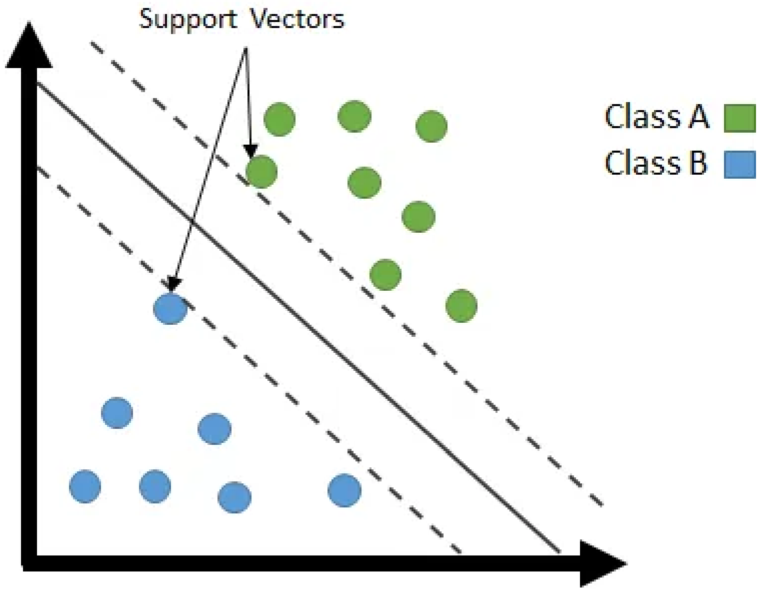
Here, we will be focussing on **linearly separable** support vector machines. The difference between linearly separable and non-linearly separable data is illustrated below:



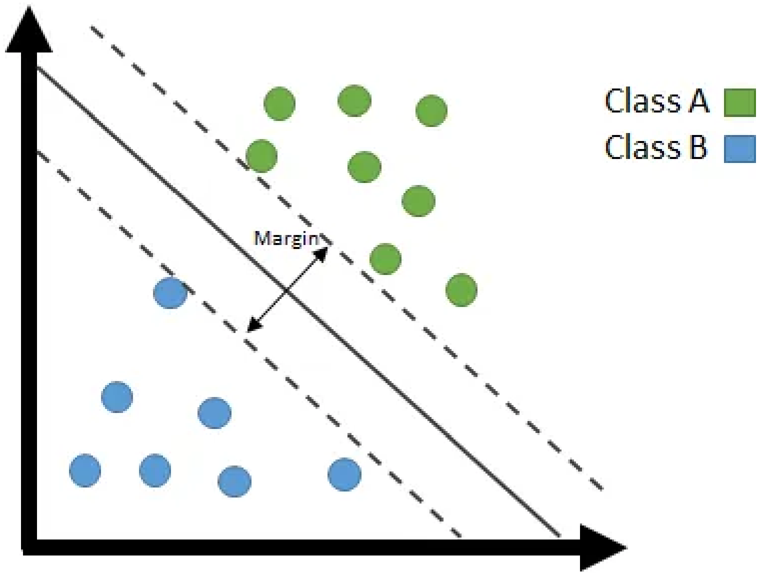
Terminology

Before we go on to see the general method of calculating the hyperplane we must first be aware of some support vector machine terminology.

Support Vectors: Vectors or points that are closest to our hyperplane from each class, if these vectors were to be removed the position of our hyperplane may change.



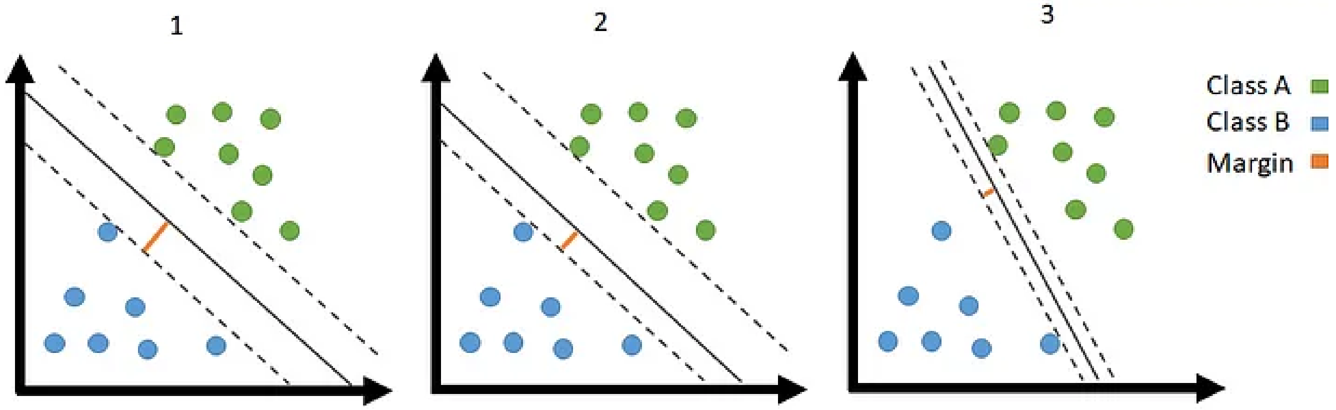
Margin: The distance our hyperplane is away to the **closest** vector. In this case the hyperplane is at the mid-point of the two support vectors so the margin values are the same.



Hyperplane (SVM): A decision boundary used to separate and classify data. In 2-dimensional space (2 features) a hyperplane is 1 dimensional which is a line (the case we have above). In 3-dimensional space (3 features) a hyperplane is 2 dimensions, a plane. In general a Hyperplane is n-1 dimensions where n is our number of features.

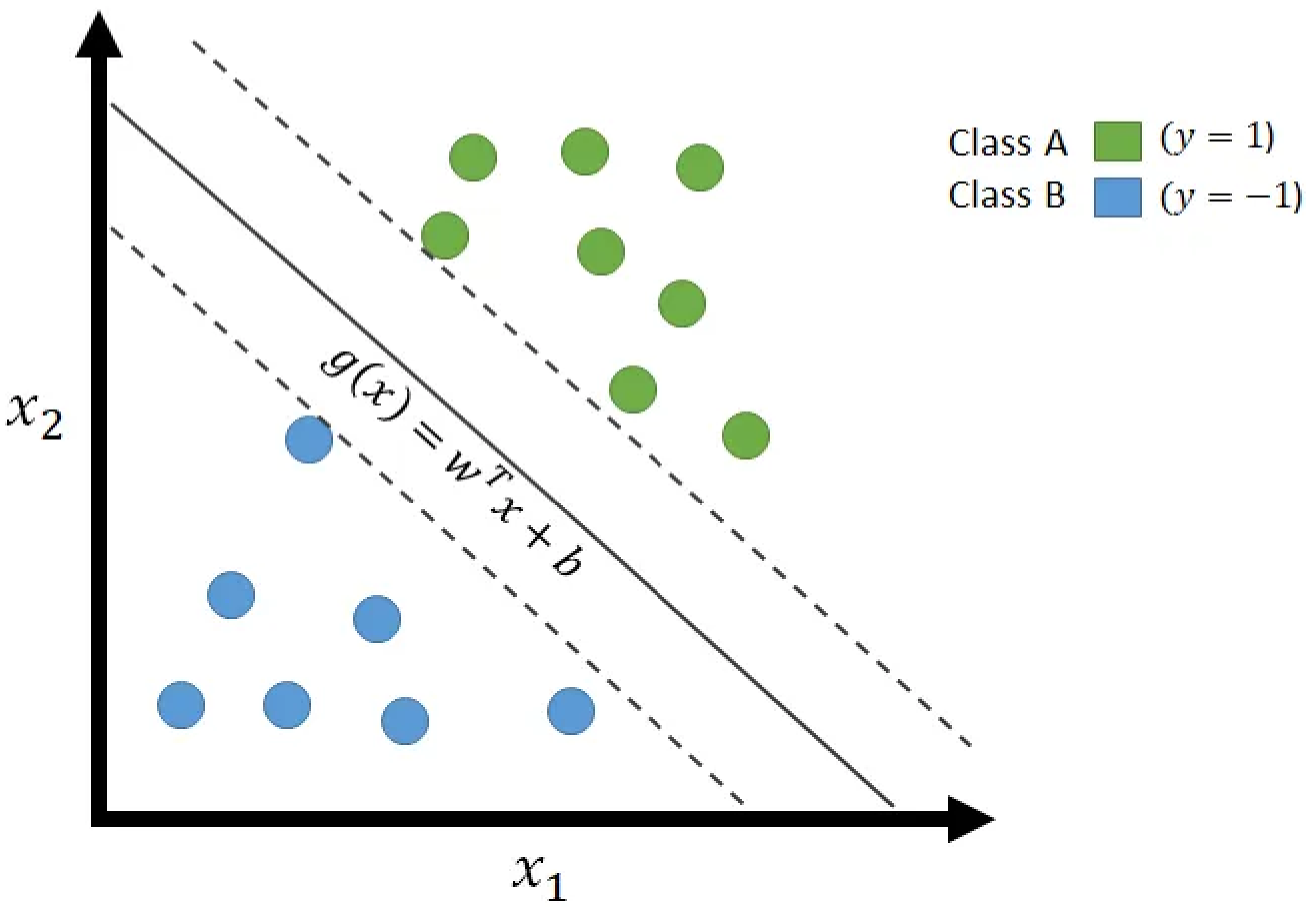
Calculating the Hyperplane

Take a look at the following three hyperplane separating our data:



Our optimal hyperplane is given by the hyperplane with the **largest margin** which in this case is shown in **graph 1** above.

Our **Hyperplane** takes the following formula:



$$g(x) = w^T x + b = w_1 x_1 + w_2 x_2 + b$$

where

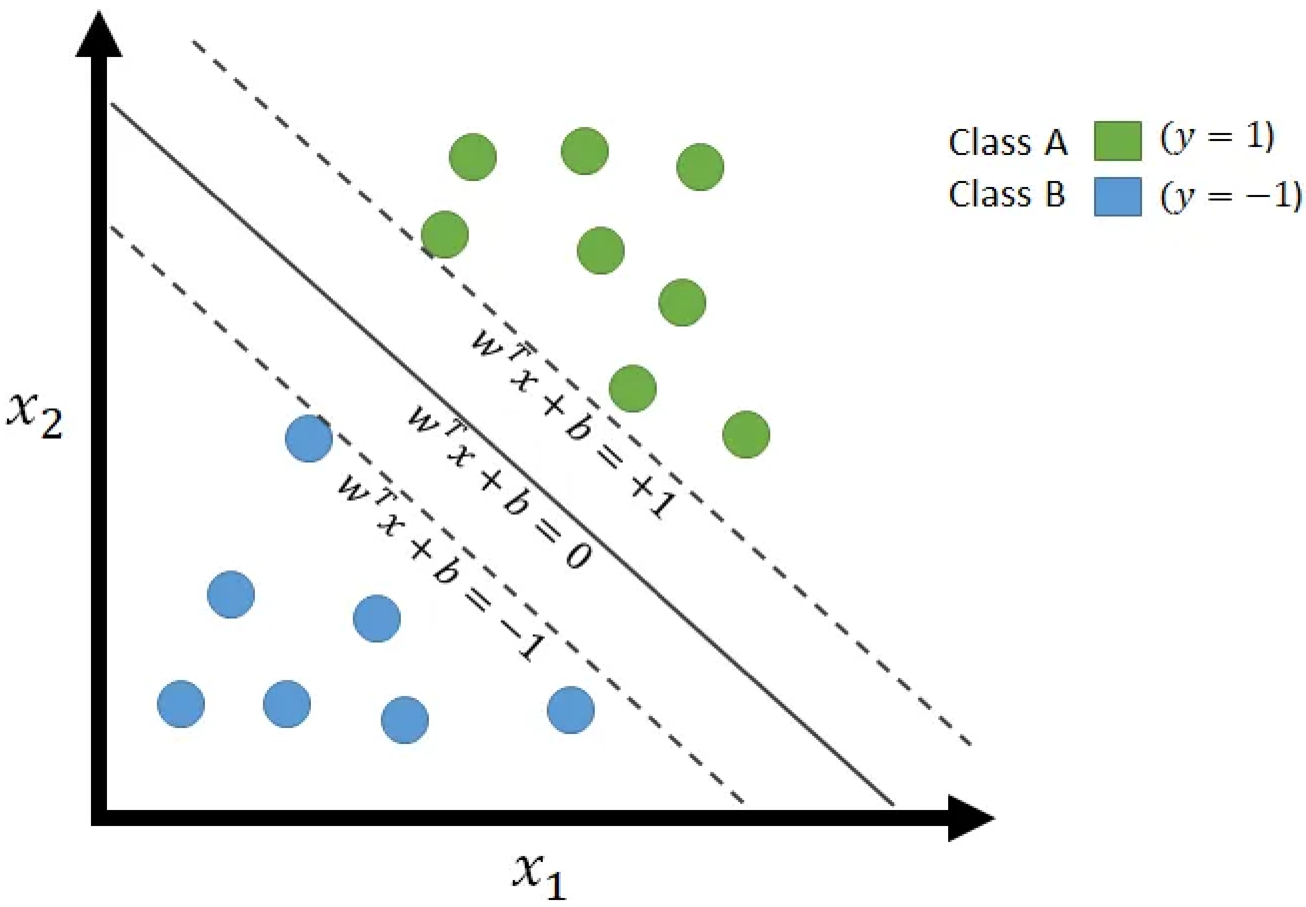
- w is a vector of weights of parameters

- **b** is our bias term or intercept
- x is our input vector, in the above case we just have two features x_1 and x_2 but we may have hundreds or more.

All data points x that belong in class A have label y = 1.
All data points x that belong in class B have label y =-1.

We give an objective that our hyperplane:

- predicts a value **greater than or equal to 1** for all data points in **Class A (when y = 1).**
- Predict a value **less than or equal to -1** for all data point in **Class B. (when y = -1).**



Mathematically:

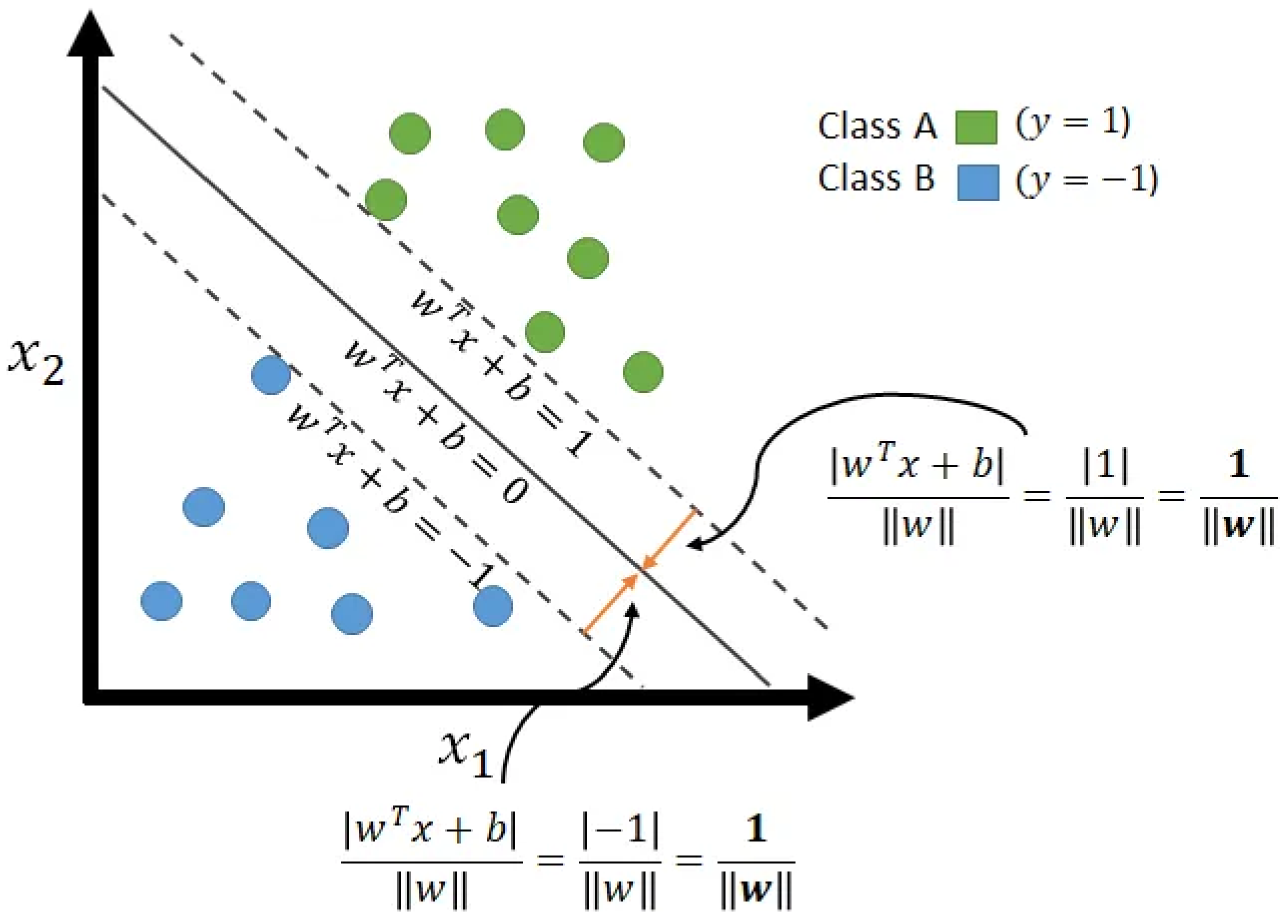
$$w^T x_i + \mathrm{b} \geq 1 \quad \text{for all } (y_i = 1)$$
$$w^T x_i + \mathrm{b} \leq -1 \quad \text{for all } (y_i = -1)$$

We can combine the above conditions into one to give:

$$(w^T x_i + b) y_i \geq 1$$

Keeping this condition in mind, we will now calculate algebraically our margin.

Using the formula for the distance between a **line** and a **point**:



giving a total margin of:

$$\frac{1}{\|w\|} + \frac{1}{\|w\|} = \frac{2}{\|w\|}$$

Remember that best hyperplane is that with the **largest margin**. So to maximise the margin above we must **minimise**:

$$||w||$$

We take the square of this value and half it, to ease solving this minimisation problem, and are left with the following minimization problem with the condition identified before:

$$\min \frac{1}{2}||w||^2$$

$$\text{Such that: } (w^T x_i + b)y_i \geq 1$$

$$\text{for } \ \mathrm{i} = 1, \dots, \mathrm{m}$$

This is a non-linear **programming problem**, which can be solved using Karush-Kuhn-Tucker conditions. Applying the aforementioned method, we obtain the conditions:

$$\mathrm{w} = \sum_{i=1}^{m} \lambda_i y_i x_i \qquad \text{and} \qquad \sum_{i=1}^{m} \lambda_i y_i = 0$$

where **m** is our number of training examples and λ is our Lagrangian multiplier.

Read more about how these conditions are obtained here:
https://www.csd.uwo.ca/~xling/cs860/papers/SVM_Explained.pdf

We use the conditions above to obtain optimal values for **w** and **b** given training data *x* and labels **y**, which gives us the equation of the hyperplane with the **largest margin** as required.

Summary

- Support Vector Machines are commonly used in classification problems.
- SVMs work by calculating a hyperplane which separates our data with the largest margin. This is done using and optimization technique called **non-linear programming.**
- We then use this hyperplane as a decision boundary to classify data into groups.

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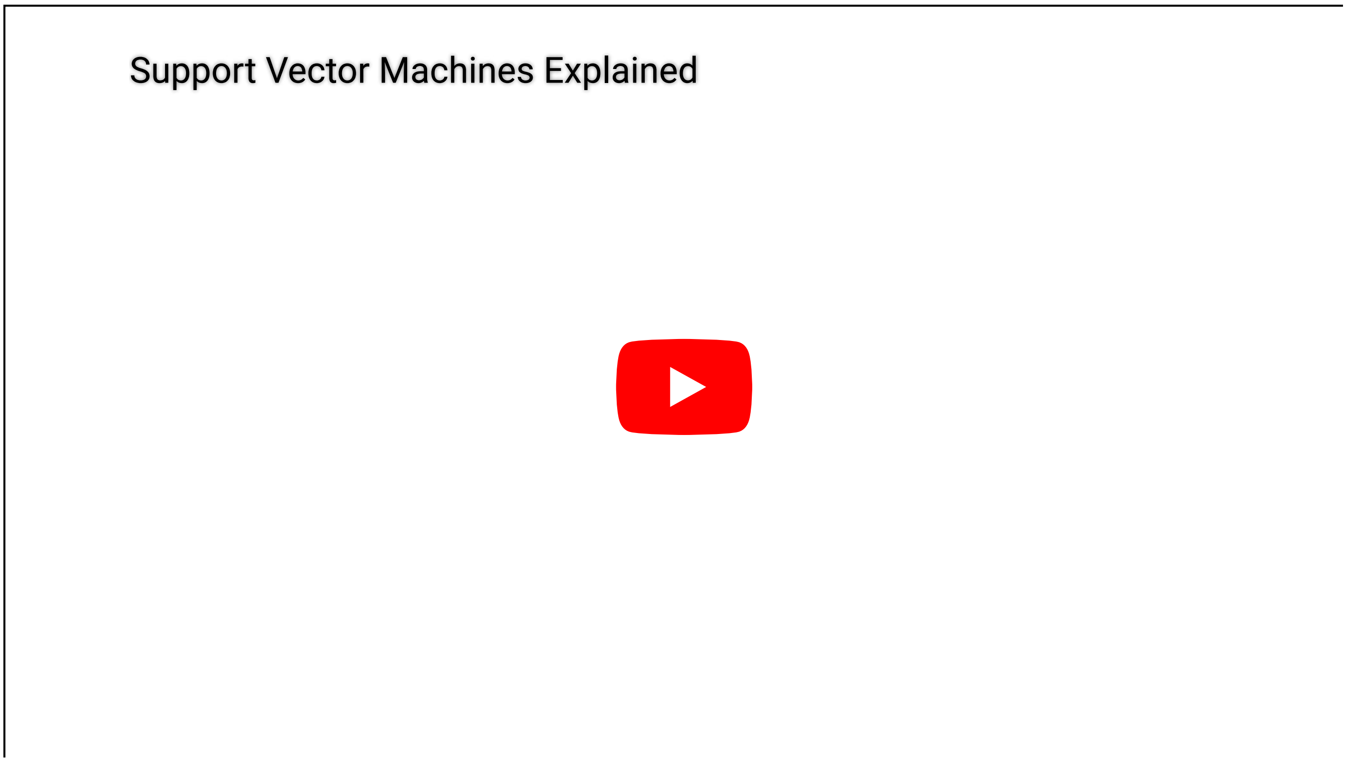

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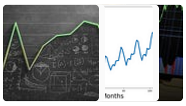

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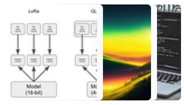

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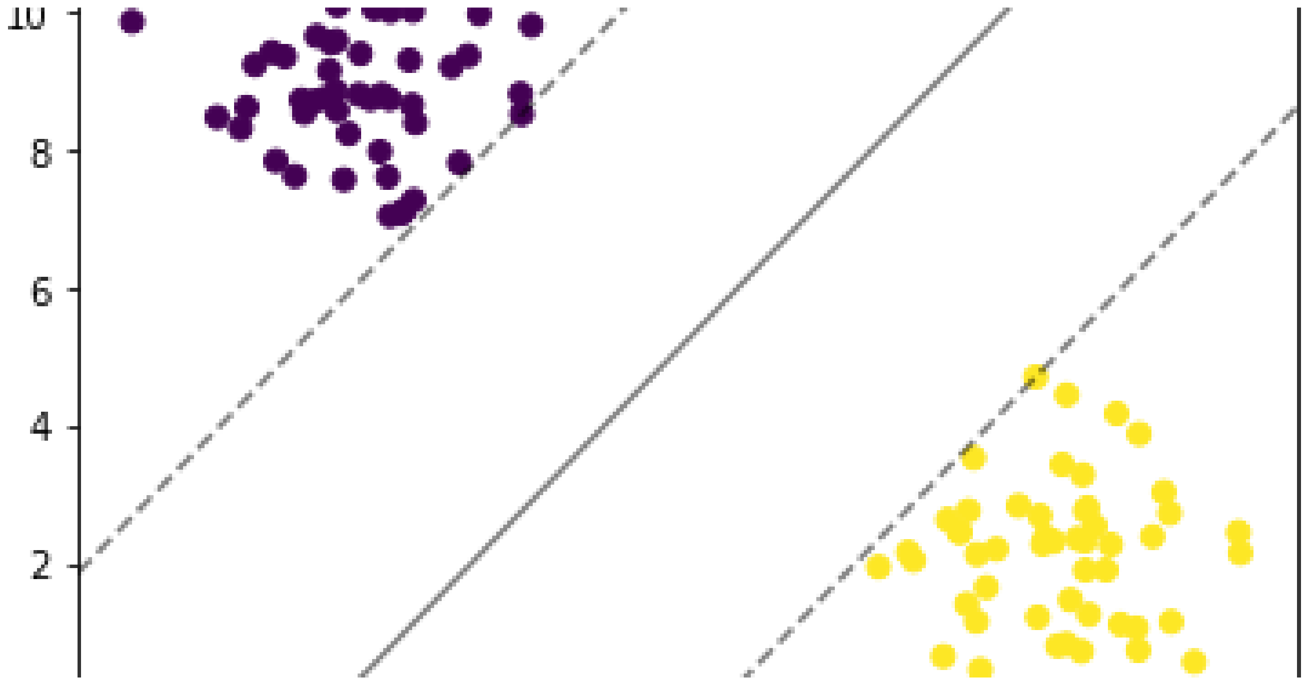

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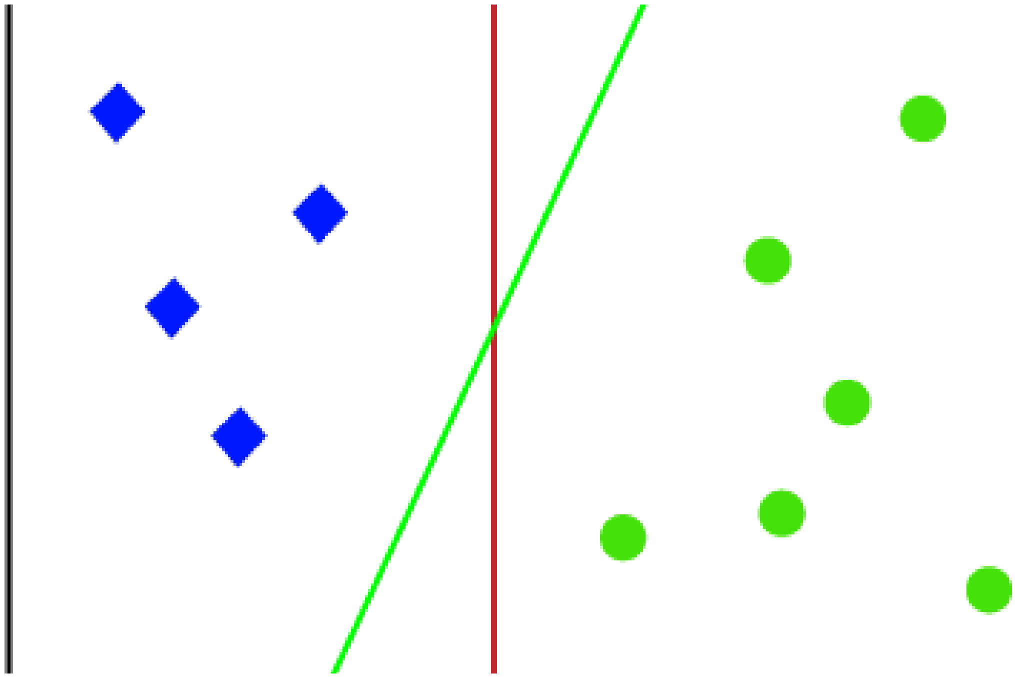

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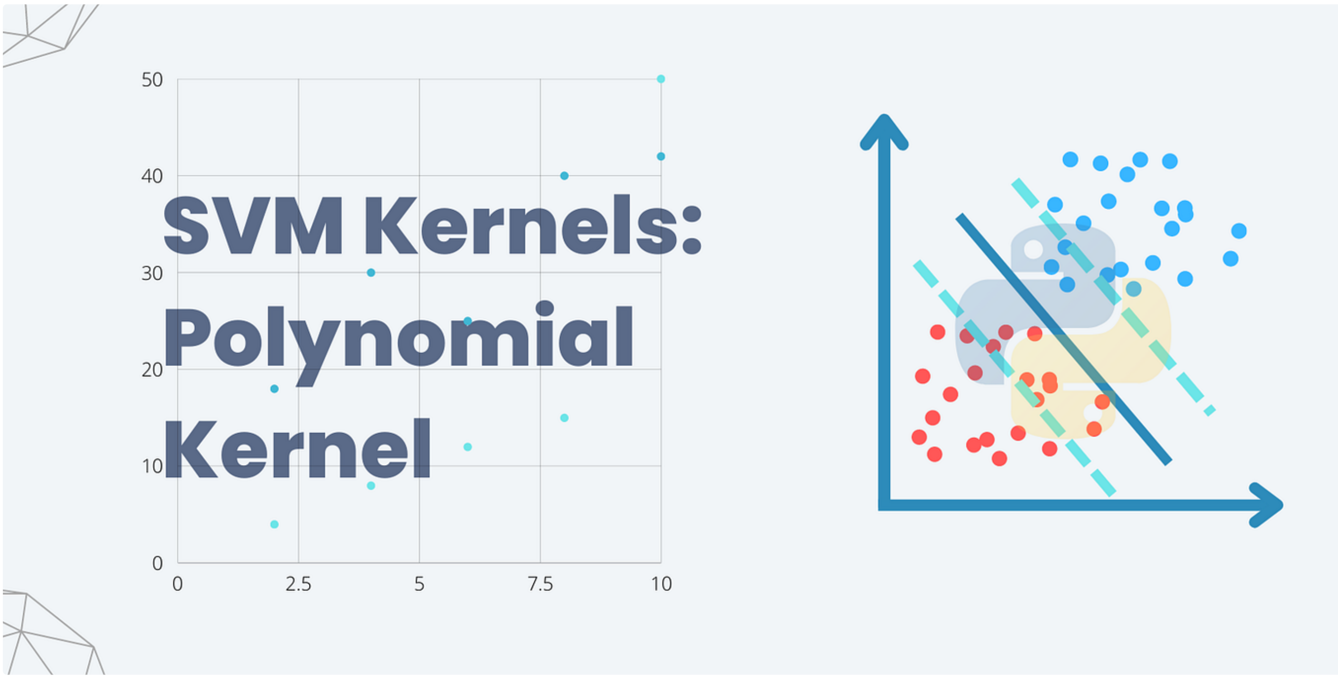

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