

Machine learning

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Introduction

- This presentation focuses on classification problems.
- We will consider decision trees and two machine learning algorithms based on them: random forests and adaBoost.
- The 2014 paper, "Do we need hundreds of classifiers to solve real world classification problems?" (2014), Fernandez-Delgado et al, Journal of Machine Learning, compares the effectiveness of 179 different machine learning approaches on 121 different data sets and rank the classifiers.
- Random forests and adaBoost perform extremely well:

Classifier	Average Accuracy	Rank (out of 179)
Random Forest	81.9%	5 / 179
AdaBoost	79.1%	20 / 179
Decision Tree	73.5%	108 / 179

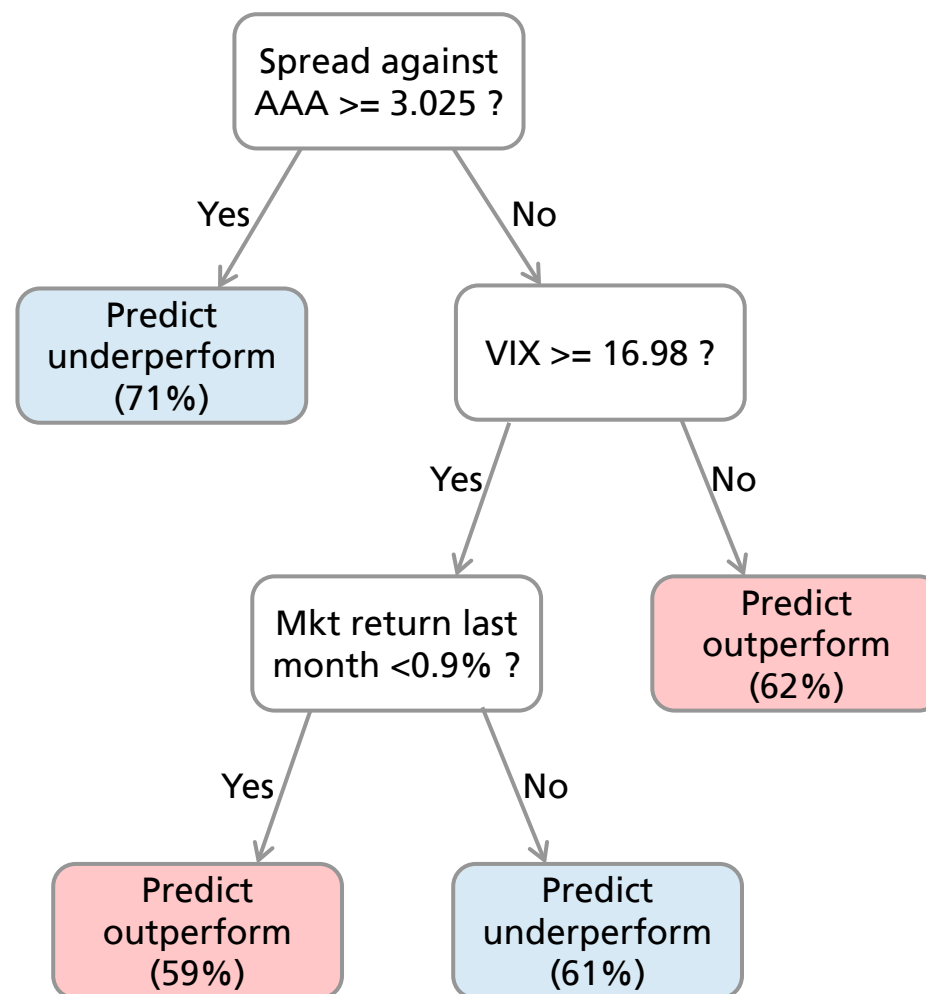
Source: "Do we need hundreds of classifiers to solve real world classification problems?" (2014), Fernandez-Delgado et al, Journal of Machine Learning, Extract from Tables 2 & 3

Section 1

Decision Trees

How to use a tree

- The output looks like a flow chart.
- To make a prediction for today, you work your way down the tree until you reach a "leaf".
- The leaf gives you a forecast class and an attached probability e.g. underperform with a probability of 71%.



Example of a classification tree
Source: UBS Quants

Pros and cons of decision trees

Pros

- Completely transparent
- Easy to interpret and communicate
- Robust to outliers / non-normal inputs and works with categorical and continuous data inputs
- Does not rely on linear relationships

Cons

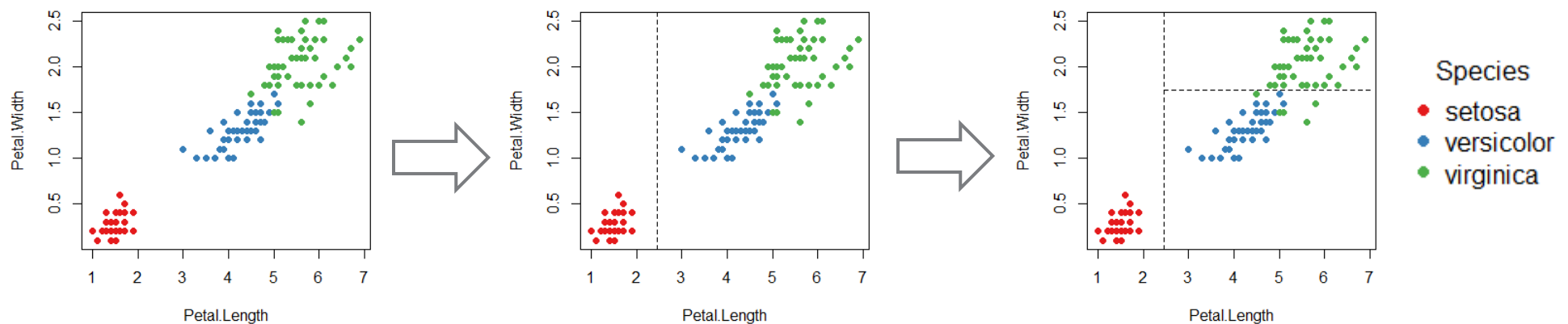
- Decision trees are often unstable i.e. the tree can change completely with the addition of an extra data-point
- Doesn't cope well with severe class imbalances
- Doesn't forecast well for inputs outside the range of its training set
- Sometimes over-fit

How do we grow a tree?

- We start with all of our data.
- If your data-set is finite then for each feature there are a finite number of possible thresholds, so we can test every possible combination of feature and threshold and choose the one which divides the data "most cleanly" into two homogenous sub-groups.
- Then we repeat the process with each of those two sub-groups separately and so on recursively.

Simple example: Two features, three classes

Which feature and which threshold should you choose to divide the data "most cleanly"?



Source: UBS Quants

Data is the iris dataset, showing petal width and petal length for three species of iris

How do we choose the feature and threshold at each node?

- Start by defining the impurity of the data with the Gini coefficient:

$$\text{Impurity} = 1 - \sum_{i=1}^{\# \text{ of classes}} p_i^2$$

where p_i is the proportion of the data from class i . In this example, we have three classes for each of the three species of iris.

- This will be zero if all the group is from a single class and bigger if the data is more mixed.
 - The worst case scenario is if the group has equal numbers of points from each class.
- If we cut the data into two sub-groups then the overall impurity is a weighted sum of the impurity in each sub-group:

$$\text{Overall impurity} = \% \text{ of data in 1}^{\text{st}} \text{ subgroup} \times \text{impurity in 1}^{\text{st}} \text{ subgroup} + \\ \% \text{ of data in 2}^{\text{nd}} \text{ subgroup} \times \text{impurity in 2}^{\text{nd}} \text{ subgroup}$$

- We want to choose the cut which minimises the overall impurity i.e. creates two sub-groups which are almost exclusively a single class.

Over-fitting

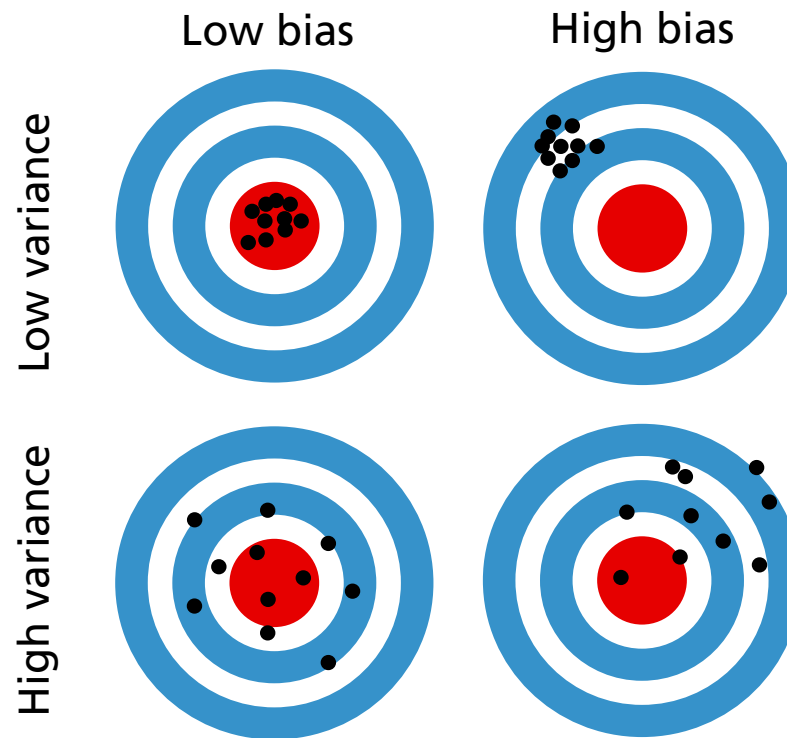
- The rules we have seen so far will make the tree grow until every node is completely homogenous.
- This will typically lead to a massive, complicated tree which over-fits the data.
- R (and other similar stats programs) have two stages to prevent over-fitting:
 1. It does not allow the tree to grow out completely. It stops the tree when:
 - The node is very small
 - The best available split leads to a very small leaf
 - The best available split does not improve the fit by a certain amount
 2. It returns some statistics to show what a "sensible size" is. Then you can prune the tree back so that it doesn't overfit.

Section 2

Machine Learning Theory

Bias vs Variance (1)

- The **bias** is the difference between the expected prediction of the model and the correct value we are trying to predict.
e.g. if you predict election outcomes from a survey of homeowners, the model will have high bias.
- The **variance** is how much the predictions for a given point vary between different realisations of the model.
e.g. if you predict election outcomes from a survey of 20 people the model will have high variance.



Source: UBS Quants

Bias vs Variance (2)

- There is typically a **trade-off between bias and variance** as you increase the model's complexity.
e.g. suppose you fit a polynomial relationship between x and y with 100 data-points. As you increase the degree of the polynomial, you will decrease the bias, but increase the variance.
- If you over-fit a model you can expect to see low bias, but high variance.
- If you under-fit a model you can expect to see high bias but low variance.
- Analysts often obsess over reducing bias, but variance is an equally important a source of error.
- Finding the best model amounts to finding the sweet spot between variance and bias.

Ensemble learning

- Ensemble learning means combining a large number of simple models to create an overall model, typically by taking the average or majority forecast from each simple model.

Why should ensembles work?

- **Statistical**

When you have limited data, there are many different models which give similar accuracy on the training set. Using an ensemble allows you to reduce the risk of choosing the wrong model.

- **Computational**

Many learning algorithms work by a local search, which can lead to them getting stuck in local optima. An ensemble approach allows you to try out multiple different start points which reduces this risk.

- **Representational**

Sometimes by combining models you can produce hypotheses which are not available from individual models

See "Ensemble Methods in Machine Learning",
Dietterich, for much greater detail about this

Section 3

Random Forests

Overview of random forests (1)

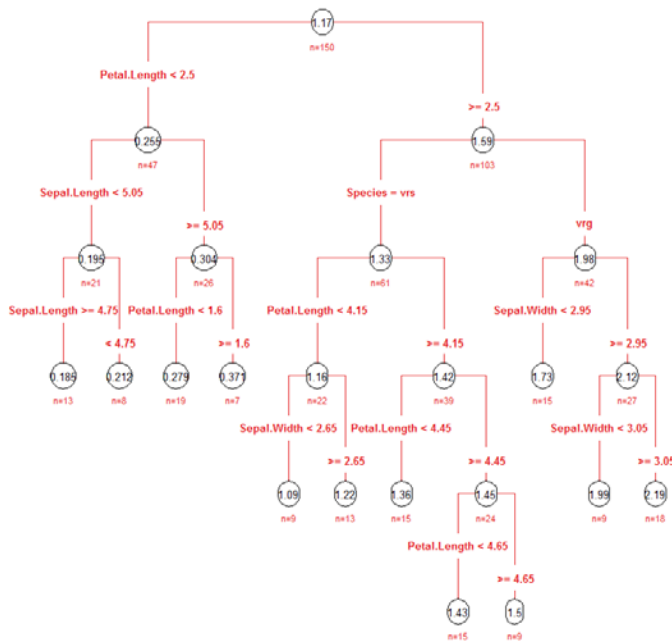
- Random forests (Breiman, 1999) is an algorithm which uses decision trees.
- In brief, a random forest is a large collection of trees, each grown independently, with two additional sources of randomness.
- For each tree in the forest:
 1. Start with a **bootstrap sample** of the data.
 2. At each node, **select M of the available features at random**. Find the best feature and threshold to use at this node.
 - In R, the default value for M is set to $\sqrt{(\text{\# of variables})}$.
 3. Continue this process with each of the two sub-groups until you have completely grown the tree out and each node is homogenous.

Repeat until you have a large number of completely grown out trees.

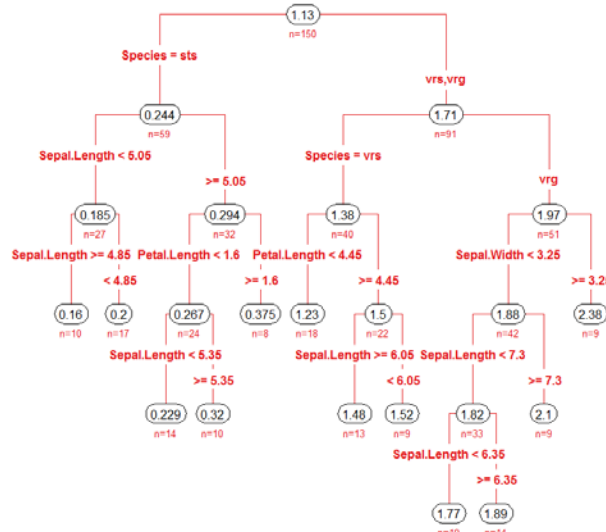
Overview of random forests (2)

- To use the forest for prediction, you take the prediction from each of the individual trees and combine them with a majority vote.

Tree 1,

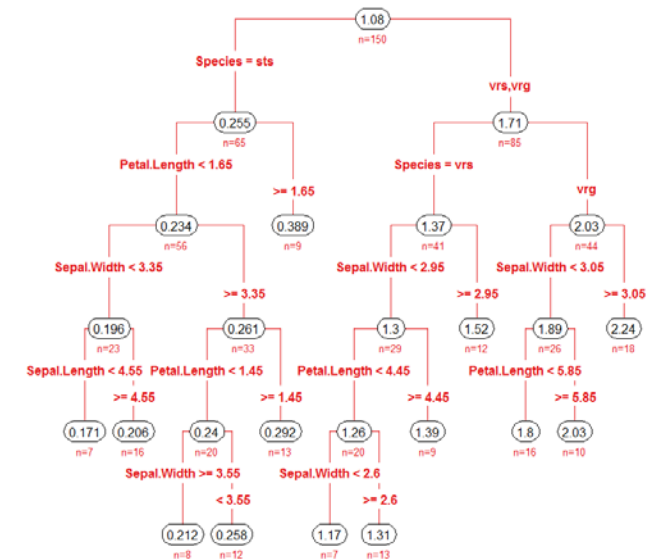


Tree 2,



....,

Tree 500



Source: UBS Quants

Why should a forest be better than a tree?

Intuitive argument:

- If you have multiple (somewhat independent) models with different pieces of useful information, then choosing just one of them, even if it is the best, means throwing away some of that information.
- If you instead combine models, you can keep the insights from all the models, which should produce a stronger, more robust overall model.

Bias vs Variance argument:

- In a random forest, the bias of the forest is equal to the bias of an individual (overgrown) tree, but the variance of the forest is much smaller than the variance of an individual tree, so the overall error is much lower.
- We ensure that each individual tree has low correlation to its peers by allowing them to grow all the way out, using bootstrap sampling and using random feature selection, so that the variance decreases more rapidly.

Importance

- A random forest can also tell us which of our features is most important:
 - For each feature, we look across all the trees and find every node which uses that feature.
 - Then we compute how much each node which uses that feature decreases the Gini impurity.
 - We take the average.
- A higher value indicates the feature is very effective at distinguishing between classes and a lower value indicates the feature is less effective.
- It can be helpful to use random forests to order a list of features to understand your data better, even if you then go on to use a different model.
 - Be careful though; this statistic does not take into account the correlation between features. Two very highly correlated features will have similar importance, but there is little to be gained from including both in your model.

Pros and cons of the random forests

Pros

- Much more effective than an single decision tree.
- Very little pre-processing of your signals is required. Random forests can handle outliers, non-normal inputs and both categorical and continuous inputs.
- Easy to parallelise which allows for faster runtimes.
- Identifies important signals, which is helpful when you build other models.

Cons

- Random forests are (to some extent) a black box. They are far harder to interpret and communicate than a simple decision tree.
- Can still struggle with severe class imbalances.
- Random forests can struggle to generalise to new data if it lies outside the range of data it was trained on.
- Random forests tend to be biased towards continuous variables or categorical variables with lots of splits.

Random Forests: forecasting dividend cuts (1)

The problem:

- Forecast **which stocks in the Russell 1000 will cut their dividend** by more than 5% in the next 12 months
 - 5% requirement reduces "noise"
 - We only use ordinary dividends per share (no special dividends or stock dividends etc.)
 - We exclude firms which have had large corporate actions in the 12m before the ex-div date.

The features:

- We selected 116 factors from our daily factor database and supplemented each variable with its 3-month and 12-month changes. In total this gives us **348 explanatory variables**
 - The model does not include information about the companies' dividend policies nor does it attempt to forecast changes in dividend policies
- We use 7-year rolling windows for the analysis
 - There are secular changes in dividend yields, so an expanding window is misleading
 - For long periods of time, almost no stocks cut their dividends so you need a long window.

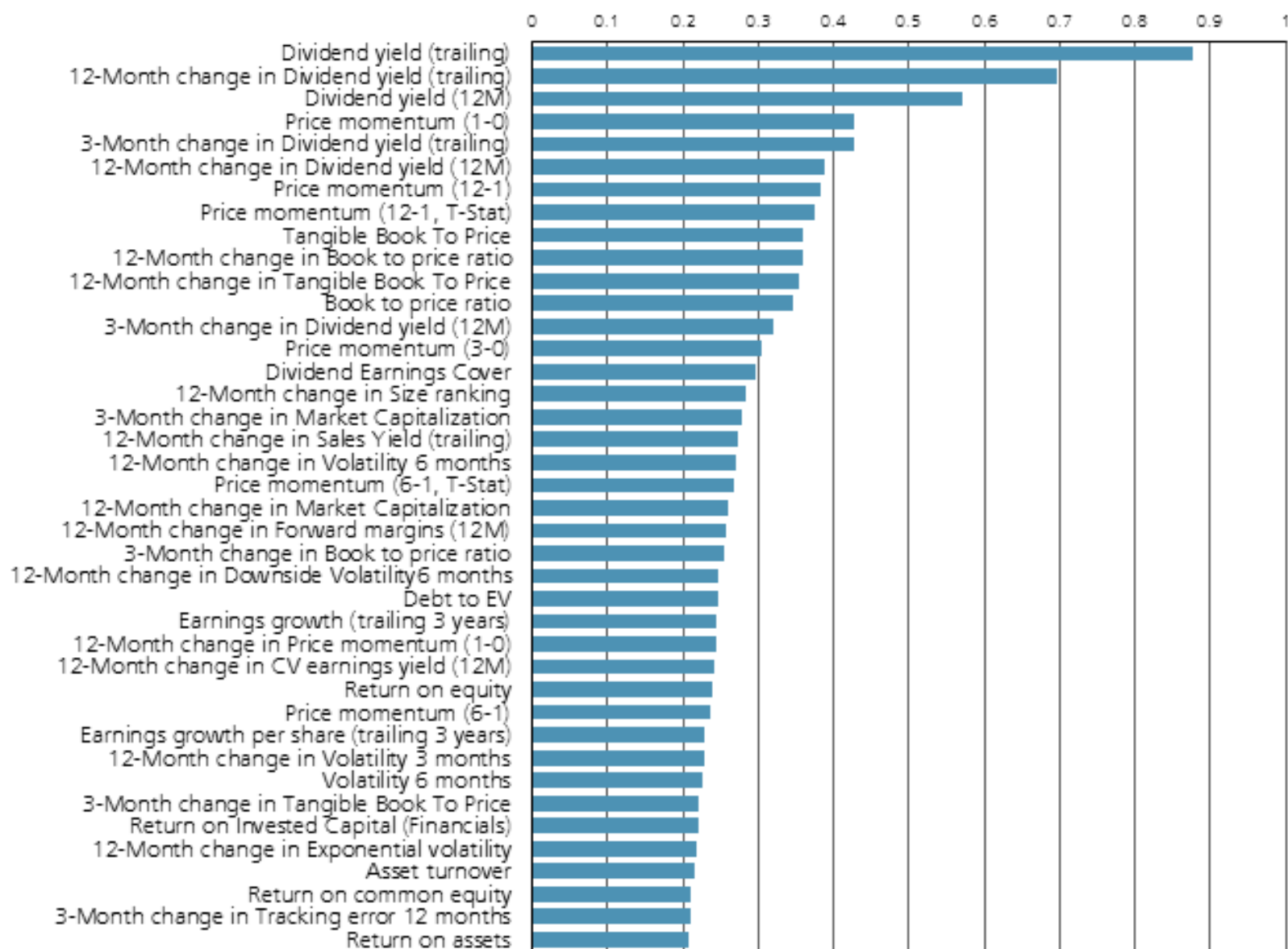
The model:

- Random Forest with 2000 decision trees

Random Forests: forecasting dividend cuts (2)

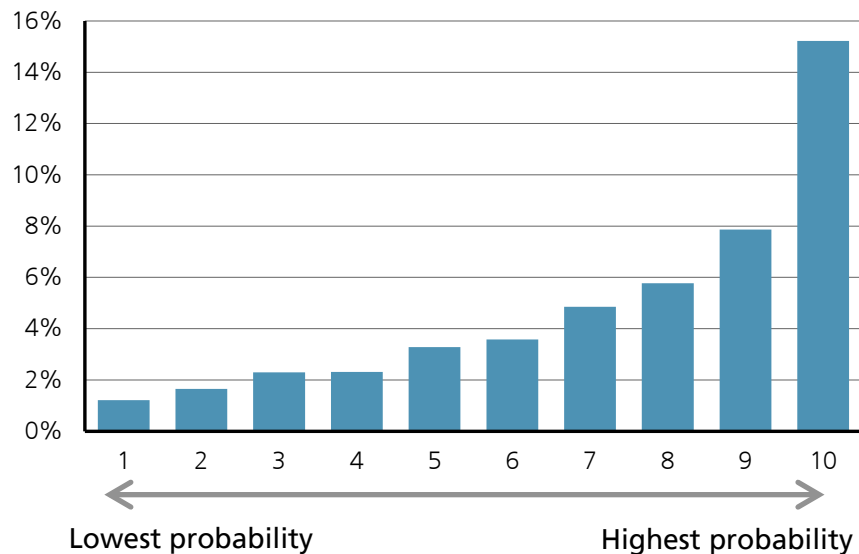
The 40 most important explanatory variables (average importance across the 30 panels, rescaled)

1. Dividend yield
2. Changes in dividend yield
3. Price momentum
4. Book to price
5. Dividend cover
6. Debt to Enterprise Value
7. Historic earnings growth
8. Profitability
9. Volatility



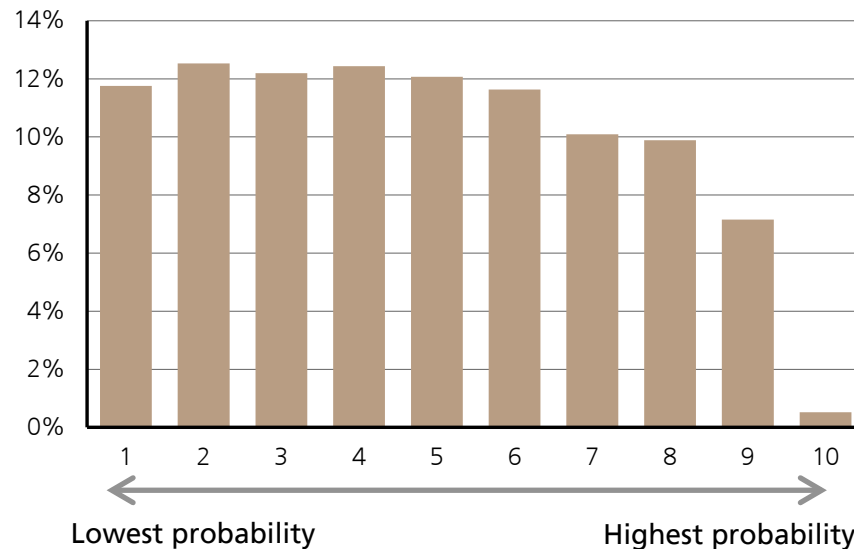
Random Forests: forecasting dividend cuts (3)

Proportion of dividend reduction in each decile



Source: UBS Quantitative Research. US largest 1000 stocks.

Average DPS growth rate in each decile



Source: UBS Quantitative Research. Trimmed average. US largest 1000 stocks.

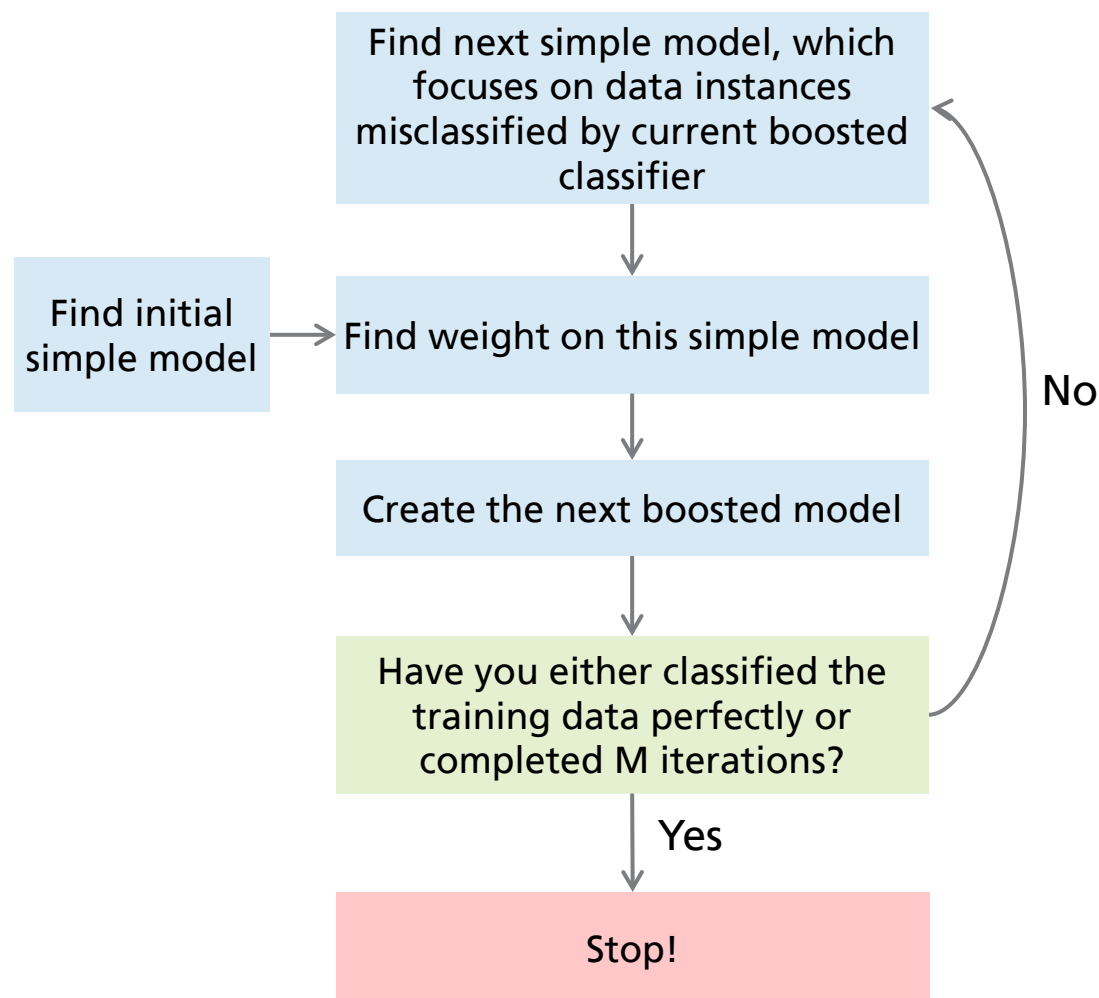
- More than 15% of the companies with the highest estimated likelihood of a dividend cut ended up reducing their dividends compared to just 4.8% across all the deciles.
- The companies with the highest expected probability of a dividend cut grew their dividend per share by an average of less than 2.8% over the following 12 months compared to an average growth rate of more than 10% across all the companies.

Section 4

AdaBoost

AdaBoost: algorithm in words

- AdaBoost is a boosting algorithm which often (but not always) uses decision trees.
- We **iteratively** create a series of simple models (often decision trees which are constrained to have only one node) on the dataset.
- As we go, we create a boosted model made up of **a linear combination of all the simple models** so far.
- Each new simple model is built to be expert at instances handled incorrectly by the current boosted model.



Source: UBS Quants

AdaBoost: algorithm in maths

- Some definitions:
 - w_i is the weight of data instance i .
 - κ_m is the m^{th} simple model. This is often a heavily pruned decision tree.
 - α_m is the weight of the m^{th} simple model in the boosted model
 - C_m is the m^{th} boosted model. This is defined as a linear combination of the simple models so far:
$$C_m(x_i) = \alpha_1 \kappa_1(x_i) + \dots + \alpha_m \kappa_m(x_i)$$

Start with equal weights

Initialise the weights, so that $w_i = 1$ for all i

Each new simple model focuses on data instances with bigger weights - those currently being misclassified

For m in 1 to M :

Find the simple model, κ_m , which minimises the weighted error:

$$error = \sum_{i: \kappa_m(x_i) \neq y_i} w_i / \sum_{i=1}^N w_i$$

Simple models with smaller weighted errors will have a bigger impact on the boosted model

Define $\alpha_m = \frac{1}{2} \ln\left(\frac{1-error}{error}\right)$

Define C_m , the m^{th} boosted model as $C_m(x_i) = \alpha_1 \kappa_1(x_i) + \dots + \alpha_m \kappa_m(x_i)$

Give greater weight to data instances which are misclassified by the boosted model

Update the weights so that $w_i = \exp(-y_i C_m(x_i))$ for all i

End

Source: UBS Quants

Pros and cons of AdaBoost

Pros

- Very robust to data inputs – doesn't need to be normal or continuous
- Unlikely to over-fit
- Can reduce both bias and variance

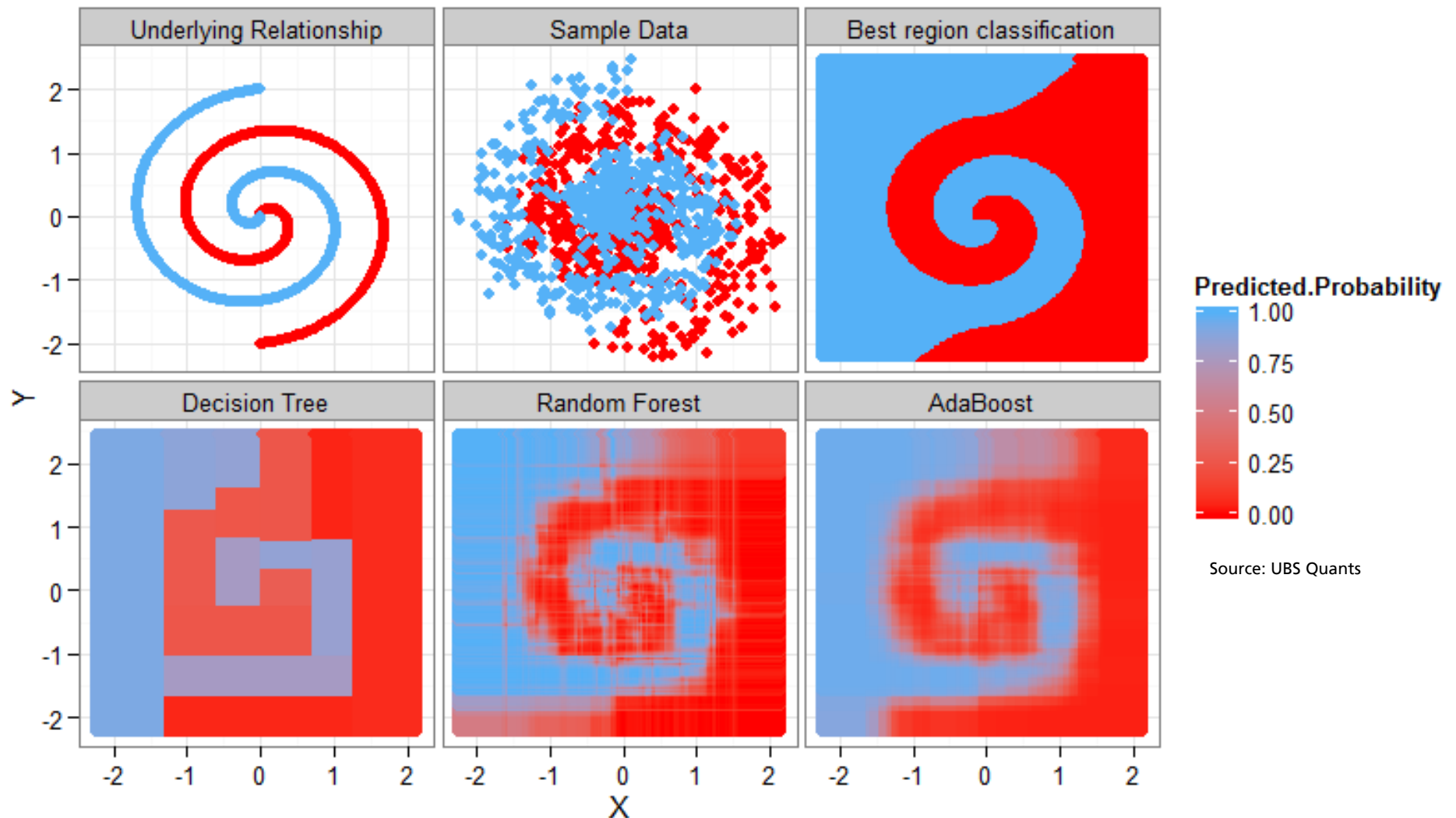
Cons

- Very sensitive to incorrect classification of data in its training set
- Sometimes struggles with very noisy data
- It is iterative so cannot be run in parallel

Section 5

Machine Learning Horse Race

Machine learning horse race



Source: UBS Quants

	Decision Tree	Random forest	AdaBoost
Out of sample accuracy	70%	76%	76%
Time taken	0.05 secs	0.435 secs	0.863 secs

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Neutral	FSR is between -6% and 6% of the MRA.	39%	28%
Sell	FSR is > 6% below the MRA.	12%	22%
Short-Term Rating	Definition	Coverage ³	IB Services ⁴
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Source: UBS. Rating allocations are as of 31 December 2015.

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