



## CHAPTER 1

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# Bagging and Random Forests

Bagging (Bootstrap Aggregating) and Random Forests are ensemble machine learning methods that are primarily used to improve the stability and accuracy of prediction models.

## 1.1 Bagging

Bagging, an abbreviation for Bootstrap Aggregating, is a method for generating multiple versions of a predictor and using these to get an aggregated predictor. The aggregation averages the output (for regression) or performs a vote (for classification).

Given a standard training set  $D$  of size  $n$ , bagging generates  $m$  new training sets  $D_i$ , each of size  $n'$ , by sampling from  $D$  uniformly and with replacement. By sampling with replacement, some observations may be repeated in each  $D_i$ . If  $n' = n$ , then for large  $n$  the set  $D_i$  is expected to have the fraction  $(1 - 1/e) \approx 63.2\%$  of the unique examples of  $D$ , the rest being duplicates.

## 1.2 Random Forests

Random Forests is a substantial modification of Bagging that builds a large collection of de-correlated trees, and then averages them. When building these decision trees, each time a split in a tree is considered, a random sample of  $k$  features is chosen as split candidates from the full set of features. The split is allowed to use only one of those  $k$  features. A fresh sample of  $k$  features is taken at each node, and the best feature/split-point among the  $k$  is chosen.

For classification problems,  $k = \sqrt{p}$  is typically taken, where  $p$  is the number of features in the model. For regression problems, the inventors recommend  $k = p/3$ , with a minimum node size of 5 as the default.

In Random Forests, there is no need for cross-validation or a separate test set to get an unbiased estimate of the test set error. It is estimated internally, during the run, as follows:

1. Each tree is constructed using a different bootstrap sample from the original data.
2. About one-third of the cases are left out of the bootstrap sample and not used in the construction of the  $k$ -th tree.
3. Let  $y_{\text{tree } k}(x)$  be the class prediction of the  $k$ -th Random Forest tree for  $x$ . Then the Random Forest classifier does a majority vote over all trees:

$$y_{\text{RF}}(x) = \text{majority}\{y_{\text{tree } k}(x), k = 1, \dots\}$$

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*This is a draft chapter from the Kontinua Project. Please see our website (<https://kontinua.org/>) for more details.*



## APPENDIX A

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# Answers to Exercises





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# INDEX

Bagging, [1](#)

Random Forest, [2](#)