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# Interpreting random forest models using a feature contribution method

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## Abstract

*Model interpretation is one of the key aspects of the model evaluation process. The explanation of the relationship between model variables and outputs is easy for statistical models, such as linear regressions, thanks to the availability of model parameters and their statistical significance. For “black box” models, such as random forest, this information is hidden inside the model structure. This work presents an approach for computing feature contributions for random forest classification models. It allows for the determination of the influence of each variable on the model prediction for an individual instance. Interpretation of feature contributions for two UCI benchmark datasets shows the potential of the proposed methodology. The robustness of results is demonstrated through an extensive analysis of feature contributions calculated for a large number of generated random forest models.*

## 1. Introduction

Models are used to discover interesting patterns in data or to predict a specific outcome, such as drug toxicity, client shopping purchases, or car insurance premium. They are often used to support human decisions in various business strategies. This is why it is important to ensure model quality and to understand its outcomes. Good practice of model development involves: 1) data analysis 2) feature selection, 3) model building and 4) model evaluation. Implementing these steps together with capturing information on how the data was harvested, how the model was built and how the model was validated, allows us to trust that the model gives reliable predictions. But, how to interpret an existing model? How to analyse the relation between predicted values and the training dataset? Or which features contribute the most to classify a specific instance? Answers to these

questions are considered particularly valuable in such domains as chemoinformatics and predictive toxicology [11]. Linear models, which assign instance-independent coefficients to all features, are the most easily interpreted. However, in the recent literature, there has been considerable focus on interpreting predictions made by non-linear models [4, 8] which do not render themselves to straightforward methods for the determination of variable/feature influence.

Of interest to this paper is a popular “black-box model” – the Random Forest model [5]. Its author suggests two measures of the significance of a particular variable [6]: the variable importance and the Gini importance. The variable importance is derived from the loss of accuracy of model predictions when values of one variable are permuted between instances. Gini importance is calculated from the Gini impurity criterion used in the growing of trees in the random forest. However, in [9], the authors argue that the above importance measures do not allow for a thorough analysis of a model. Their general representation of variable importance is often insufficient for the complete understanding of the relationship between input variables and the predicted value.

Kuzmin et al. propose in [9] a new technique to calculate the feature contribution, i.e., the contribution of a variable to the prediction, in a random forest model with numerical observed values (the observed value is a real number). Unlike in the variable importance measures [6], feature contributions are computed separately for each instance/record and provide detailed information about relationships between variables and the predicted value: the extent and the kind of influence (positive/negative) of a given variable. This new approach was positively tested in [9] on a Quantitative Structure-Activity (QSAR) model for chemical compounds. The results were not only informative about the structure of the model but also provided valuable information for the design of new compounds.

The procedure from [9] for the computation of feature

contributions applies to random forest models predicting numerical observed values. This paper aims to extend it to random forest models with categorical predictions, i.e., where the observed value determines one from a finite set of classes. The difficulty of achieving this aim lies in the fact that a discrete set of classes does not have the algebraic structure of real numbers which the approach presented in [9] relies on.

The paper is organised as follows. Section 2 provides a brief description of random forest models. Section 3 presents our approach for calculating feature contributions for binary classifiers, whilst Section 4 describes its extension to multi-class classification problems. Section 5 contains applications of the proposed methodology to two real world datasets from the UCI Machine Learning repository. Section 6 concludes the work presented in this paper.

## 2. Random forest

A random forest (RF) of [5] is a collection of tree predictors grown as follows [6]:

1. the bootstrap phase: select randomly a subset of the learning dataset – a training set for growing the tree. The remaining samples in the learning dataset form a so-called out-of-bag (OOB) set and are used to estimate the RF’s goodness-of-fit.
2. the growing phase: grow the tree by splitting the training dataset at each node according to the value of one from a randomly selected subset of variables (the best split) using classification and regression tree (CART) method [7].
3. each tree is grown to the largest extent possible. There is no pruning.

The bootstrap and the growing phases require an input of random quantities. It is assumed that these quantities are independent between trees and identically distributed. Consequently, each tree can be viewed as sampled independently from the ensemble of all tree predictors for a given learning set.

For prediction, an instance is run through each tree in a forest down to a terminal node which assigns it a class. Predictions supplied by the trees undergo a voting process: the forest returns a class with the maximum number of votes. Draws are resolved through a random selection.

To present our feature contribution procedure in the following section, we need a probabilistic interpretation of the forest prediction process. Denote by  $C = \{C_1, C_2, \dots, C_K\}$  the set of classes and by  $\Delta_K$  the set

$$\Delta_K = \{(p_1, \dots, p_K) : \sum_{k=1}^K p_k = 1 \text{ and } p_k \geq 0\}.$$

An element of  $\Delta_K$  can be interpreted as a probability distribution over  $C$ . Let  $e_k$  be an element of  $\Delta_K$  with 1 at position  $k$  – a probability distribution concentrated at class  $C_k$ . If a tree  $t$  predicts that an instance  $i$  belongs to a class  $C_k$  then we write  $\hat{Y}_{i,t} = e_k$ . This provides a mapping from predictions of a tree to the set  $\Delta_K$  of probability measures on  $C$ . Let

$$\hat{Y}_i = \frac{1}{T} \sum_{t=1}^T \hat{Y}_{i,t},$$

where  $T$  is the overall number of trees in the forest. Then  $\hat{Y}_i \in \Delta_K$  and the prediction of the random forest for the instance  $i$  coincides with a class  $C_k$  for which the  $k$ -th coordinate of  $\hat{Y}_i$  is maximal.<sup>1</sup>

## 3. Feature contributions for binary classifiers

The set  $\Delta_K$  simplifies considerably when there are two classes,  $K = 2$ . An element  $p \in \Delta_K$  is uniquely represented by its first coordinate  $p_1$  ( $p_2 = 1 - p_1$ ). Consequently, the set of probability distributions on  $C$  is equivalent to the probability weight assigned to class  $C_1$ .

Before we can present our method for computing feature contributions, we have to examine the tree growing process. After selecting a training set, it is positioned in the root node. A splitting variable (feature) and a splitting value are selected and the set of instances is split between the left and the right child of the root node. The procedure is repeated until all instances in a node are in the same class or further splitting does not improve prediction. The class that a tree assigns to a terminal node is determined through majority voting between instances in that node.

We will refer to instances of the training dataset that pass through a given node as the training instances in this node. The fraction of the training instances in a node  $n$  belonging to class  $C_1$  will be denoted by  $Y_{mean}^n$ . It is the probability that a randomly selected element from the training instances in this node is in the first class. In particular, a terminal node is assigned to class  $C_1$  if  $Y_{mean}^n > 0.5$  or  $Y_{mean}^n = 0.5$  and the draw is resolved in favor of class  $C_1$ .

The feature contribution procedure for a given instance involves two steps: 1) the calculation of local increments of feature contributions for each tree and 2) the aggregation of feature contributions over the forest. For a child node ( $c$ ) and a parent node ( $p$ ) the local increment corresponding to a feature  $f$  is defined as follows:

$$LI_f^c = \begin{cases} Y_{mean}^c - Y_{mean}^p, & \text{if the split in the parent is} \\ & \text{performed over the feature } f, \\ 0, & \text{otherwise.} \end{cases}$$

<sup>1</sup>The distribution  $\hat{Y}_i$  is calculated by the function `predict` in the R package `randomForest` [10] when the type of prediction is set to `prob`.

A local increment for a feature  $f$  represents the change of the probability of being in class  $C_1$  between the child node and its parent node provided that  $f$  is the splitting feature in the parent node. It is easy to show that the sum of these changes, over all features, along the path followed by an instance from the root node to the terminal node in a tree is equal to the difference between  $Y_{mean}$  in the terminal and the root node.

The contribution  $FC_{i,t}^f$  of a feature  $f$  in a tree  $t$  for an instance  $i$  is equal to the sum of  $LI_f$  over all nodes on the path of instance  $i$  from the root node to a terminal node. The contribution of a feature  $f$  for an instance  $i$  in the forest is then given by

$$FC_i^f = \frac{1}{T} \sum_{t=1}^T FC_{i,t}^f. \quad (1)$$

The feature contributions vector for an instance  $i$  consists of contributions  $FC_i^f$  of all features  $f$ .

Notice that if the following condition is satisfied:

- (U) training instances in each terminal node are of the same class

then

$$\hat{Y}_i = Y^r + \sum_f FC_i^f, \quad (2)$$

where  $Y^r$  is the coordinate-wise average of  $Y_{mean}$  over all root nodes in the forest. If this unanimity condition (U) holds, feature contributions can be used to retrieve predictions of the forest. Otherwise, they only allow for the interpretation of the model.

We will demonstrate the calculation of feature contributions on a toy example using a subset of the UCI Iris Dataset [3]. From the original dataset, ten records were selected – five for each of two types of the iris plant: versicolor (class 0) and virginica (class 1) (see Table 1). A plant is represented by four attributes: Sepal.Length (f1), Sepal.Width (f2), Petal.Length (f3) and Petal.Width (f4). This dataset was used to generate a random forest model with two trees, see Figure 1. In each tree, the set LD in the root node collects those records which were chosen by the random forest algorithm to build that tree. The LD sets in the child nodes correspond to the split of the above set according to the value of a selected feature (it is written between branches). This process is repeated until reaching terminal nodes of the tree. Notice that the condition (U) for each tree in this forest is satisfied – each terminal node contains instances of the same class:  $Y_{mean}$  is either 0 or 1.

The process of calculating feature contributions runs in 2 steps: the determination of local increments for each node in the forest (a preprocessing step) and the calculation of feature contributions for a particular instance. Figure 1 shows  $Y_{mean}^n$  and the local increment  $LI_f^c$  for a splitting feature  $f$  in each node. Having computed these values, we can

	iris.row	f1	f2	f3	f4	class
$x_1$	52	6.4	3.2	4.5	1.5	0
$x_2$	73	6.3	2.5	4.9	1.5	0
$x_3$	75	6.4	2.9	4.3	1.3	0
$x_4$	90	5.5	2.5	4.0	1.3	0
$x_5$	91	5.5	2.6	4.4	1.2	0
$x_6$	136	7.7	3.0	6.1	2.3	1
$x_7$	138	6.4	3.1	5.5	1.8	1
$x_8$	139	6.0	3.0	4.8	1.8	1
$x_9$	145	6.7	3.3	5.7	2.5	1
$x_{10}$	148	6.5	3.0	5.2	2.0	1

Table 1: Selected records from the UCI Iris Dataset. Each record corresponds to a plant. Features f1, f2, f3, f4 represent the following attributes: Sepal.Length, Sepal.Width, Petal.Length and Petal.Width. The plants were classified as iris versicolor (class 0) and virginica (class 1).

calculate feature contributions for an instance by running it through both trees and summing local increments of each of the four features. For example, the contribution of a given feature for the instance  $x_1$  is calculated by summing local increments for that feature along the path  $p_1 = n_0 \rightarrow n_1$  in tree  $T_1$  and the path  $p_2 = n_0 \rightarrow n_1 \rightarrow n_4 \rightarrow n_5$  in tree  $T_2$ . According to Formula (1) the contribution of feature f2 is calculated as

$$FC_{x_1}^{f2} = \frac{1}{2} \left( 0 + \frac{1}{4} \right) = 0.125$$

and the contribution of feature f3 is

$$FC_{x_1}^{f3} = \frac{1}{2} \left( -\frac{3}{7} - \frac{9}{28} - \frac{1}{2} \right) = -0.625.$$

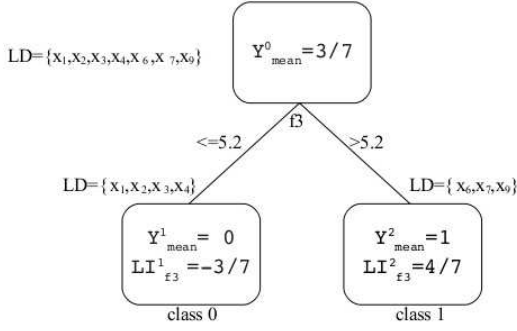
The contributions of features f1 and f4 are equal to 0 because these attributes are not used in any decision made by the forest. The predicted probability  $\hat{Y}_{x_1}$  that  $x_1$  belongs to class 1 (see Formula (2)) is

$$\hat{Y}_{x_1} = \underbrace{\frac{1}{2} \left( \frac{3}{7} + \frac{4}{7} \right)}_{\hat{Y}^r} + \underbrace{(0 + 0.125 - 0.625 + 0)}_{\sum_f FC_{x_1}^f} = 0.0$$

Table 2 collects feature contributions for all 10 records in the example dataset. These results can be interpreted as follows:

- for instances  $x_1, x_3$ , the contribution of f2 is positive, i.e., the value of this feature increases the probability of being in class 1 by 0.125. However, the large negative contribution of the feature f3 implies that the value of this feature for instances  $x_1$  and  $x_3$  was decisive in assigning the class 0 by the forest.
- for instances  $x_6, x_7, x_9$ , the decision is based only on the feature f3.

$T_1$



$T_2$

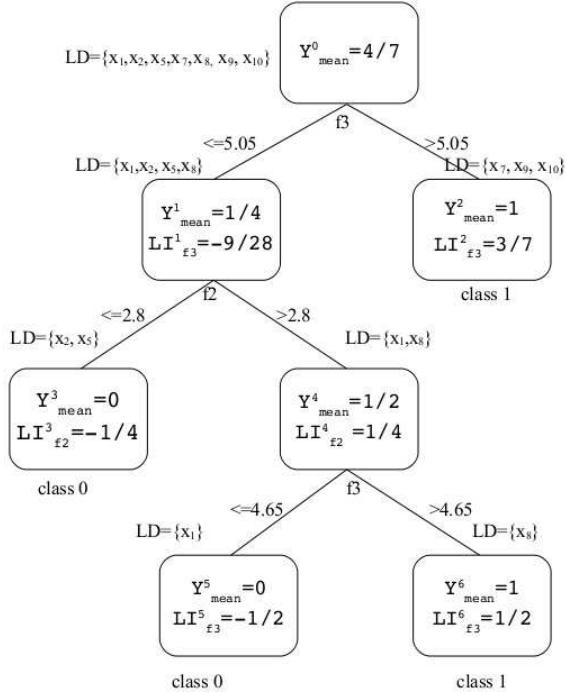


Figure 1: A random forest model for the dataset from Table 1. The set LD in the root node contains a local training dataset for the tree. The sets LD in the child nodes correspond to the split of the above set according to the value of selected feature. In each node,  $Y^n_{mean}$  denotes the fraction of instances in the LD set in this node belonging to class 1, whilst  $LI^n_f$  shows non-zero local increments.

- for instances  $x_2, x_4, x_5$ , the contribution of both features leads the forest decision towards class 0.
- for instances  $x_8, x_{10}$ ,  $\hat{Y}$  is 0.5. This corresponds to the case where one of the trees points to class 0 and the other to class 1. In practical applications, such situations are resolved through a random selection of the class. Since  $\hat{Y}^r = 0.5$ , the lack of decision of the forest has a clear interpretation in terms of feature contri-

	$\hat{Y}$	f1	f2	f3	f4	prediction
$x_1$	0.0	0	0.125	-0.625	0	<b>0</b>
$x_2$	0.0	0	-0.125	-0.375	0	<b>0</b>
$x_3$	0.0	0	0.125	-0.625	0	<b>0</b>
$x_4$	0.0	0	-0.125	-0.375	0	<b>0</b>
$x_5$	0.0	0	-0.125	-0.375	0	<b>0</b>
$x_6$	1.0	0	0	0.5	0	<b>1</b>
$x_7$	1.0	0	0	0.5	0	<b>1</b>
$x_8$	0.5	0	0.125	-0.125	0	<b>?</b>
$x_9$	1.0	0	0	0.5	0	<b>1</b>
$x_{10}$	0.5	0	0	0	0	<b>?</b>

Table 2: Feature contributions for the random forest model from Figure 1.

butions: the amount of evidence in favour of one class is counterbalanced by the evidence pointing towards the other.

#### 4. Feature contributions for general classifiers

When  $K > 2$ , the set  $\Delta_K$  cannot be described by a one-dimensional value as above. We, therefore, generalize the quantities introduced in the previous section to a multi-dimensional case.  $Y^n_{mean}$  in a node  $n$  is an element of  $\Delta_K$ , whose  $k$ -th coordinate,  $k = 1, 2, \dots, K$ , is defined as

$$Y^n_{mean,k} = \frac{|\{i \in TS(n) : i \in C_k\}|}{|TS(n)|}, \quad (3)$$

where  $TS(n)$  is the training set in the node  $n$  and  $|\cdot|$  denotes the number of elements of a set. Hence, if an instance is selected randomly from a training set in a node  $n$ , the probability that this instance is in class  $C_k$  is given by the  $k$ -th coordinate of the vector  $Y^n_{mean}$ . Local increment  $LI^n_f$  is analogously generalized to a multidimensional case:

$$LI^n_f = \begin{cases} Y^n_{mean} - Y^p_{mean}, & \text{if the split in the parent is performed over the feature } f, \\ \underbrace{(0, \dots, 0)}_{K \text{ times}}, & \text{otherwise,} \end{cases}$$

where the difference is computed coordinate-wise. Similarly,  $FC^f_{i,t}$  and  $FC^f_i$  are extended to vector-valued quantities. Notice that if the condition (U) is satisfied, Equation (2) holds with  $Y^r$  being a coordinate-wise average of vectors  $Y^n_{mean}$  over all root nodes in the forest.

Fix an instance  $i$  and let  $C_k$  be the class to which the forest assigns this instance. Our aim is to understand which variables/features drove the forest to make that prediction. We argue that the crucial information is that which explains the value of the  $k$ -th coordinate of  $\hat{Y}_i$ . Hence, we want to study the  $k$ -th coordinate of  $FC^f_i$  for all features  $f$ .

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**Algorithm 1**  $FC(RF, s)$ 

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```
1:  $k \leftarrow forest\_predict(RF, s)$ 
2:  $FC \leftarrow vector(features)$ 
3: for each tree  $T$  in forest  $F$  do
4:    $parent \leftarrow root(T)$ 
5:   while  $parent \neq \text{TERMINAL}$  do
6:      $f \leftarrow SplitFeature(parent)$ 
7:     if  $S[f] \leq SplitValue(parent)$  then
8:        $child \leftarrow leftChild(parent)$ 
9:     else
10:       $child \leftarrow rightChild(parent)$ 
11:    end if
12:     $FC[f] \leftarrow FC[f] + Y_{mean,k}^{child} - Y_{mean,k}^{parent}$ 
13:     $parent \leftarrow child$ 
14:  end while
15: end for
16:  $FC \leftarrow FC / nTrees(F)$ 
17: return  $FC$ 
```

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**Algorithm 2**  $Y_{mean}(RF, D)$ 

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```
1: for each tree  $T$  in forest  $F$  do
2:    $TS \leftarrow \text{training set for tree } T$ 
3:   use DFS algorithm to compute training sets in all
     other nodes  $n$  of tree  $T$  and compute the vector
      $Y_{mean}^n$  according to formula (3).
4: end for
```

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Pseudo-code to calculate feature contributions is presented in Algorithm 1. Its inputs consist of a random forest model  $RF$  and an instance  $s$  which is represented as a vector of feature values. In line 1,  $k$  is assigned a prediction of the random forest  $RF$  for the instance  $s$ . The following line creates a vector of real numbers indexed by features and initialized to 0. Then for each tree in the forest  $RF$  the instance  $s$  is run down the tree and feature contributions are calculated. The quantity  $SplitFeature(parent)$  identifies a feature  $f$  on which a split is performed in the node  $parent$ . If the value of that feature  $f$  is lower or equal to the threshold  $SplitValue(parent)$ , the route continues to the left child of the node  $parent$ . Otherwise, it goes to the right child (each node in the tree has either two children or is a terminal node). A position corresponding to the feature  $f$  in the vector  $FC$  is updated according to the change of values of  $Y_{mean,k}$  between the parent and the child.

Algorithm 2 provides a sketch of the preprocessing step to compute  $Y_{mean}^n$  for all nodes  $n$  in the forest. The parameter  $D$  denotes the set of instances used for training of the forest  $RF$ . In line 2,  $TS$  is assigned the set used for growing tree  $T$ . This set is further split in nodes according to values of splitting variables. We propose to use DFS (depth first search) to traverse the tree and compute the vec-

tor  $Y_{mean}^n$  once a training set for a node  $n$  is determined. There is no need to store a training set for a node  $n$  once  $Y_{mean}^n$  has been calculated.

## 5. Applications

In this section, we demonstrate how feature contributions can be applied to improve understanding of a random forest model. An extensive comparative study of feature contributions is beyond the capacity of a short conference paper. Therefore, we consider one example of a binary classifier using the UCI Breast Cancer Wisconsin Dataset [1] (BCW Dataset) and one example of a general classifier for the UCI Iris Dataset [3]. We complement our studies with a robustness analysis.

### 5.1. Breast Cancer Wisconsin Dataset

The UCI Breast Cancer Wisconsin Dataset contains characteristics of cell nuclei for 569 breast tissue samples; 357 are diagnosed as benign and 212 as malignant. The characteristics were captured from a digitized image of a fine needle aspirate (FNA) of a breast mass. There are 30 features, three (the mean, the standard error and the average of the three largest values) for each of the following 10 characteristics: radius, texture, perimeter, area, smoothness, compactness, concavity, concave points, symmetry and fractal dimension.

To reduce correlation between features, the min-max (minimal-redundancy-maximal-relevance) method was applied and the following features were removed from the dataset: 1, 3, 8, 10, 11, 13, 12, 15, 19, 10, 21, 24, 26. A random forest model was generated on 2/3 randomly selected instances using 500 trees. The other 1/3 of instances was used for testing. The test set validation showed that the model accuracy was 0.9682 (only 6 instances out of 189 were classified incorrectly); similar accuracy was achieved when the model was generated using all the features.

We applied our feature contribution algorithm to the above random forest binary classifier. To align notation with the rest of the paper, we denote the class “malignant” by 1 and the class “benign” by 0. Aggregate results for the feature contributions for all 569 instances and both classes are presented in Figure 2. Light-grey bars show medians<sup>2</sup> of contributions for instances of class 1 (malignant), whereas black bars show medians of contributions for instances of class 0. Notice that there are only a few significant features in the graph: F7 – the mean of the cell concavity, F14 – the standard deviation of the cell area, F23 – the mean of the cell perimeter and F28 – the average of three largest measurements of concave points. This selection of significant

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<sup>2</sup>The median is a robust estimator for the expectation of a distribution.

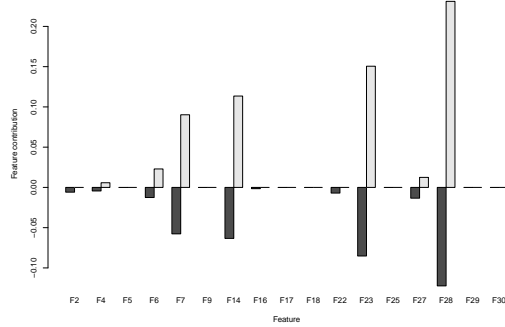


Figure 2: Medians of feature contributions for each class for the BCW Dataset. The light grey bars represent contributions toward class 1 and the black bars show contributions towards class 0.

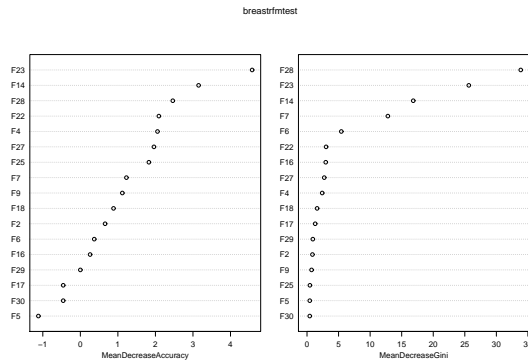


Figure 3: The left panel shows permutation based variable importance and the right panel displays Gini importance for a RF binary classification model developed for the BCW Dataset. Graphs generated using randomForest package in R.

features is in agreement with the results of the permutation based variable importance (the left panel of Figure 3) and the Gini importance (the right panel of Figure 3). Interpreting the size of bars as the level of importance of a feature, our results are more in line with those provided by the Gini index. However, the main advantage of the approach presented in this paper lies in the fact that one can study the reasons for the forest’s decision for a *particular instance*.

Comparison of feature contributions for a particular instance with medians of feature contributions for all instances of one class provides valuable information about the forest’s prediction. In a typical case when most of the trees vote for class 1 the feature contributions for that instance are very close to the median values (see Figure 4). This happens in around 80% of all instances predicted to be in class 1. However, when the decision is less unanimous, the analysis of feature contributions may reveal interesting information. As an example, we have chosen instances 194 and

Instance Id	benign (class 0)	malignant (class 1)
3	0	1
194	0.298	0.702
537	0.234	0.766

Table 3: Percentage of trees that vote for each class in RF model for a selection of instances from the BCW Dataset.

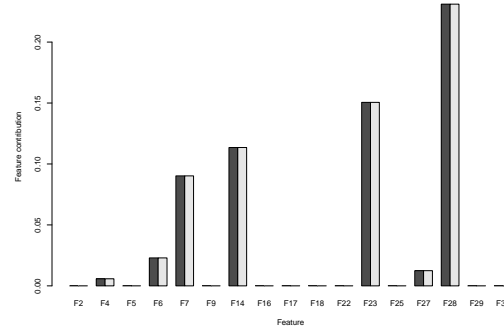


Figure 4: Comparison of the medians of feature contributions over all instances of class 1 (black bars) with feature contributions for instance number 3 (light-grey bars) from the BCW Dataset.

537 (see Table 3) which were classified as malignant (class 1) by a strong majority of trees but with a significant number of trees expressing an opposite view. Figure 5 presents feature contributions for these two instances (grey and light grey bars) against the median values for class 1 (black bars). The largest difference can be seen on the contribution of feature F23: it is highly negative for two instances under consideration compared to a large positive value commonly found in instances of class 1. Recall that a negative value contributes towards the classification in class 0. There are also three new significant attributes (F2, F17 and F22) that contribute towards the correct classification. Feature F22 is judged as moderately important by both of the variable importance methods in Figure 3. However, features F2 and F17 are located towards the bottom of both panels. It is, therefore, surprising to note that the contribution of these three new features was instrumental in correctly classifying instances 195 and 537 as malignant. This highlights the fact that features which may not generally be important for the model may, nonetheless, be important for classifying specific instances. The approach presented in this paper is able to identify such features, whilst the standard variable importance measures for random forest cannot.

## 5.2. Iris Dataset

In this section we use the UCI Iris Dataset [3] to demonstrate interpretability of feature contributions for multi-

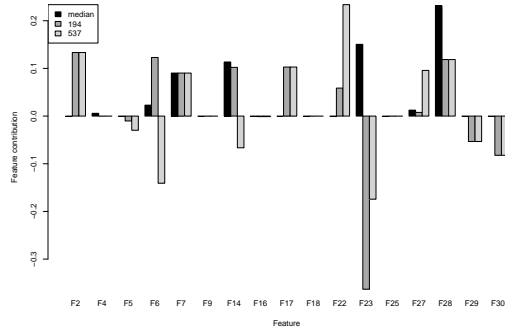


Figure 5: Comparison of the medians of feature contributions over all instances of class 1 (black bars) with feature contributions for instances number 194 (grey bars) and 537 (light-grey bars) from the BCW Dataset.

classification models. We generated a random forest model on 100 randomly selected instances. The remaining 50 instances were used to assess the accuracy of the model: 47 out of 50 instances were correctly classified. Then we applied our approach for determining the feature contributions for the generated model. Figure 6 presents medians of feature contributions for each of the three classes. In contrast to the binary classification case, feature contributions are positive for all classes. A positive feature contribution for a given class means that the value of this feature directs the forest towards assigning this class. A negative value points towards the other classes.

Feature contributions provide valuable information about the reliability of random forest predictions for a particular instance. It is commonly assumed that the more trees voting for a particular class, the higher the chance that the forest decision is correct. We argue that the analysis of feature contributions offers a more refined picture. As an example, take two instances: 120 and 150. The first one was classified in class Versicolour (88% of trees voted for this class). The second one was assigned class Virginica with 86% of trees voting for this class. We are, therefore, tempted to trust both of these predictions to the same extent. Table 4 collects feature contributions for these instances. Recall that the highest contribution to the decision is commonly attributed to features 3 (Petal.Length) and 4 (Petal.Width), see Figure 6. These features also make the highest contributions to the predicted class for instance 150. The indecisiveness of the forest may stem from an unusual value for the feature 1 (Sepal.Length) which suggested a different class. In contrast, the instance 120 shows standard (low) contribution of the first two features and unusual contributions of the last two features: very low for feature 3 and high for feature 4. Recalling that features 3 and 4 tend to contribute most to the forest’s decision (see Figure 6) with values between 0.25 and 0.35, the low value for feature

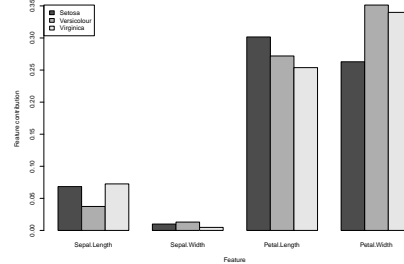


Figure 6: Medians of feature contributions for each class for the UCI Iris Dataset.

Instance	Sepal		Petal	
	Length	Width	Length	Width
120	0.059	0.014	0.053	0.448
150	-0.097	0.035	0.259	0.339

Table 4: Feature contributions for selected instances from the UCI Iris Dataset.

3 is non-standard for its predicted class, which increases the chance of it being wrongly classified. Indeed, both instances belong to class Virginica while the forest classified the instance 120 wrongly as class Versicolour and the instance 150 correctly as class Virginica.

### 5.3 Robustness analysis

For the validity of the study of feature contributions, it is crucial that the results are not artefacts of one particular realization of a random forest model but that they convey actual information held by the data. We therefore propose a method for robustness analysis of feature contributions. We will use the UCI Breast Cancer Wisconsin Dataset studied in Subsection 5.1 as an example.

We removed instance number 3 from the original dataset to allow us to perform tests with an unseen instance. We generated 100 random forest models with 500 trees with each model built using an independent randomly generated training set with  $379 \approx 2/3 \cdot 568$  instances. The rest of the dataset for each model was used for its validation. The average model accuracy was 0.963. For each generated model, we collected medians of feature contributions separately for training and testing datasets and each class. The variation of these quantities over models for class 1 and the training dataset are presented using a box plot in Figure 7a. The top of the box is the 75% quantile, the bottom is the 25% quantile, while the bold line in the middle is the median. Whiskers show the extent of minimal and maximal values for each feature contribution. Notice that the variation between simulations is moderate and conclusions drawn for one realization of the random forest model in Subsection



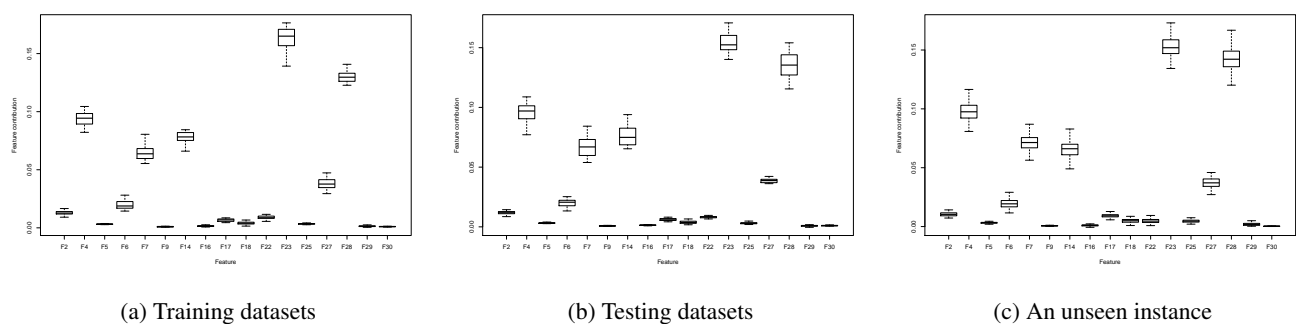


Figure 7: Feature contributions for 100 random forest models.

5.1 would hold for each of the generated 100 random forest models.

A testing dataset contains those instances that do not take part in the model generation. One can, therefore, expect more errors in the classification of the forest, which, in effect, should imply lower stability of the calculated feature contributions. Indeed, the box plot presented in Figure 7b shows a slight tendency towards increased variability of the feature contributions when compared to Figure 7a. However, these results are qualitatively on par with those obtained on the training datasets. We can, therefore, conclude that feature contributions computed for a new (unseen) instance provide reliable information. We further tested this hypothesis by computing feature contributions for instance number 3 that did not take part in the generation of models. The statistics for feature contributions for this instance over 100 random forest models are shown in Figure 7c. Similar results were obtained for other instances.

## 6. Conclusions

Feature contributions provide a novel approach towards black-box model interpretation. They measure the influence of variables/features on the prediction outcome and provide explanations as to why a model makes a particular decision. In this work, we extended the feature contribution method of [9] to random forest classification models and we proposed a framework for the robustness analysis. Using UCI benchmark datasets we showed the robustness of the proposed methodology. We also demonstrated how feature contributions can be applied to understand the dependence between instance characteristics and their predicted classification and to assess the reliability of the prediction. The relation between feature contributions and standard variable importance measures was also investigated. The software used in the empirical analysis was implemented in R as an add-on for the randomForest package and is currently being prepared for submission to CRAN [2]. Application of

feature contributions for model interpretation is particularly valuable for drug discovery or predictive toxicology, which is the topic of our ongoing research.

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