

# Tuning Learners before Applying: New Reflection in Defect Prediction

A, B, C

## ABSTRACT

Data mining techniques have been widely applied to software defect prediction with various empirical data sets. Those proposed learners are always evaluated against the state of the art predictors by performing statistical analysis. Undoubtedly, given the bias from data sets and accuracy indicators, the newer predictors outperform counterparts in selected experimental settings. However, most of data mining algorithm based predictors (e.g. CART, random forest, neural networks, SVM) have built-in *magic* parameters, like the number of trees in random forest algorithm. the impact of internal parameters in those methods have been neglected during evaluation. In this paper, we investigate this impact by tuning parameters in defect predictors with search-based software engineering algorithm. Specifically, we used differential evolution to tune the CART and a new predictor based on WHERE algorithm with local data, and then predictors with optimal parameters obtained from tuning process will be applied to predict defects. By comparing the performance of predictors with and without tuning process, we observe that tuning improves the predictors' performance and predictors working with different data sets need different parameters. Our results also suggest that we should not use the predictors of the shelf with their default parameters and tuning should be a processor combined with any predictor with built-in parameters.

## Categories and Subject Descriptors

D.2.9 [Software Engineering]: Management—*Cost estimation*

## General Terms

Experimentation, Algorithm

## Keywords

Defect prediction, Data Mining, Tuning Parameters, CART, WHERE

## 1. INTRODUCTION

Software has becoming a large and complex system and delivering reliable and quality software is imperative for development teams. Empirical study shows that the longer the defects exist in software systems, the more the cost of time and money it will take to fix it [need a ref]. Therefore, project managers and software programmers strive to find defects in their system as early as possible. Defect prediction has been investigated extensively in industrial and academia during the past two decades. As an important research field, building data miners [1, 2, 3, 4, 5, 7, 6] over static code features of software system has been demonstrated to be a way to predict which models are more likely to contain defects.

Classification is an important approach to predict whether some modules in the projects are defective or non-defective. The general idea is to train the learners by using parts of data sets(e.g. ant 1.3, 1.4 in PROMISE<sup>1</sup>) and predict with remaining ones(ant 1.5, 1.6 and 1.7). Many types of defect predictors have been proposed based on different data mining classifiers, including CART, Random Forest [7], Naive Bayes[3],Logistic Regression [8]. During the past years, authors claimed that their new defective learner outperformed others according to their experiment and statistical analysis. To evaluate those learners objectively in terms of accuracy, Lessmann et al [1] carried out a study to compare 22 classifiers over 10 public domain data sets from the NASA Metrics Data repository. By using Nemenyi's post hoc test with  $\alpha = 0.05$ , they concluded that the predictive accuracy of most learners didn't differ significantly in terms of the area under the receiver operating characteristics curve(AUC). Furthermore, according to the fig.2 in [1], Random Forest is significantly better than CART. Lessmann's paper motivates us to investigate whether tuning those CART's parameters by search-based software engineering method can improve the performance. Even though Lessmann considered unpruned tree and pruned tree, They didn't consider other possible parameters in CART which would have impact on the structure of trees, like the depth of the tree, the maximum and minimum number of leafs of the tree.

Software metrics are the core of all the defective prediction model. Many types of metrics are used to build models, like process metrics, McCabe and Halsted metrics and CK metrics. By building prediction models across 85 releases of 12 open source projects, Rahman et al [9] concluded that code

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<sup>1</sup><http://openscience.us/repo/>

metrics are generally less useful than process metrics for prediction. And also the code metrics don't change much from release to release and lead to stagnation in the prediction model. In [10], Radjenović et al [10] reviewed 106 papers regarding software prediction metrics. They found that CK objected-oriented and process metrics have been reported to be more successful in finding defects compared to traditional size and complexity metrics. Moreover, not all the CK metrics perform well equally. The best metrics from CK are CBO, WMC and RFC based on their observation. It seems that the relationship between software metrics and defective prediction is still an open question and need to be addressed. This motivates us to see : whether the impact rankings of those metrics will change after tuning parameters is applied to model learners.

What's the problem in those result?

RQ:

briefly describe our study and our result; observation

structure of this paper.

## 2. ALGORITHM: PREDICTOR AND TUNER

In order to conduct the experiment of this paper, we need one tool that can predict defects from the empirical data sets and a second tool to tune the built-in parameters associated with predictor. To compare the effects of the tuning process, we have three different predictors: WHERE-based Predictor, CART and Random Forest. Different Evolution(DE) as an optimizer is used as a tuner in this paper.

We choose CART and Random Forest as a predictor in this paper is motivated by [1], where the performance of both tools as predictors are significantly different based on authors' experiment as mentioned before. We'd like to investigate whether tuning can change such conclusion. WHERE-based Predictor is a new defect predictor based on WHERE[11] algorithm. A comparison with standard predictor like CART and Random Forest will better evaluate and judge the performance such new predictor. As for the tuner, there're many heuristic optimization algorithms in wild. However, DE is a good but maybe not the best candidate for the tuning process considering different performance measurements. To determine which optimizer is fitable and results in better performance is beyond this work scope. We leave it to future works. The rest of this section will describe each tool applied in this work.

### 2.1 WHERE-based Learner

**WHERE-based Learner** is composed of WHERE clustering algorithm and CART decision tree algorithm. The key idea of WHERE-based learner is that instead of training the CART decision tree based on the class labels associated with each training sample, it's using CART to build decision trees based on the cluster labels, which are generated by the WHERE clustering algorithm.

WHERE is a fast clustering algorithm designed by *menzies* for finding software artifacts with similar attributes. It clusters data on dimensions synthesized along the axis of greatest variability in the data. The way WHERE used to find

such dimension is a linear-time heuristic called "FASTMAP" proposed by Faloutsos & Lin[12]. "FASTMAP" randomly picks one instance Z; find the instance *east* X that's furthest away from Z; find the instance *west* Y that's furthest away from *east* X. Next, project all the remaining points onto the line drawn between X and Y. The line  $\overline{XY}$  is an approximation of the first component found by PCA. Then choose the median point as the split and recursively divide all the instances into *west* and *east* clusters until the number of instances within each cluster is less than specific minimum size. The representation of the clustering result is a tree, we call it Where-clustering tree. Such tree will be pruned if applicable in some cases. Finally, cluster labels will be assigned to instances in each of those clusters(leaves).

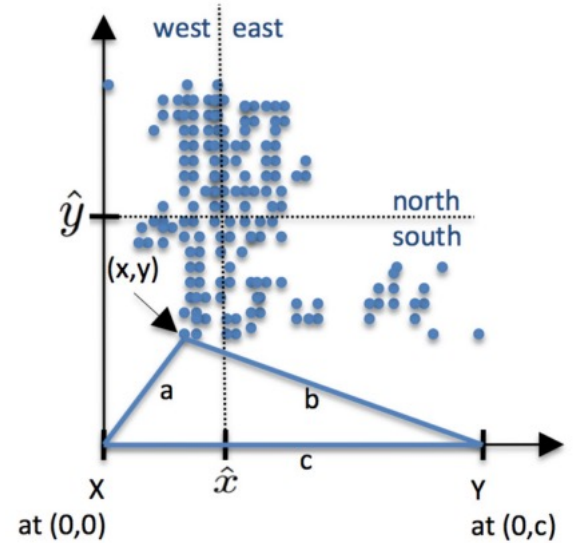


Figure 1: FASTMAP

Then based on the attributes and the cluster labels in each instances, we build a decision tree based on CART algorithm. In each leaf of the tree, there're several instances falling in. This will be the model trained for defect prediction. During testing process, a new instance comes in and traverses the tree according to values of the its attributes. If the instance could reach one leaf of the tree, the predicted value of this instance will be the mean of all the training data values associated with this leaf. Otherwise if stops at intermediate nodes of tree, the predicted value will be the mean of the all the training data value below this node. After estimating all the number of defectives in the test data, whether each instance contains defectives will be determined by comparing with a threshold value. If the predicted value is greater than threshold, the Where-based learner will predict this instance as defective otherwise non-defective.

### 2.2 CART

**CART** is an *iterative dichotomization* algorithm that finds the attribute that most divides the data such that the variance of the goal variable in each division is minimized[13]. The algorithm then recurses on each division. Finally, the cost data in the leaf divisions is averaged to generate the

estimate.

## 2.3 Random Forests

Breiman’s website describes **Random Forests** as follows[14]. “Random Forests grows many classification trees. To classify a new object from an input vector, put the input vector down each of the trees in the forest. Each tree gives a classification, and we say the tree “votes” for that class. The forest chooses the classification having the most votes (over all the trees in the forest). Each tree is grown as follows. If the number of cases in the training set is  $N$ , sample  $N$  cases at random - but with replacement, from the original data. This sample will be the training set for growing the tree. Also, if there are  $M$  input variables, a number  $m \ll M$  is specified such that at each node,  $m$  variables are selected at random out of the  $M$  and the best split on these  $m$  is used to split the node. The value of  $m$  is held constant during the forest growing. Finally, each tree is grown to the largest extent possible (there is no pruning).”

## 2.4 Differential Evolution Algorithm

Differential Evolution (DE)[15] is a stochastic search algorithm that optimizes a problem by iteratively trying to improve a population of candidate solutions with regard to a given quality measurement. Such method makes no assumptions about the problem being optimized and has already been used as a parameter tuner [16, 17].

DE starts with creating a population of candidate solutions and then generates new candidates based on  $New = X + f * (Y - Z)$ , where  $X$ ,  $Y$  and  $Z$  are randomly selected solutions from the current frontier and  $f$  is a crossover factor. The newly generated solution will be added into the next generation of solutions if dominating previous old points in the frontier. To avoid meaning less iteration, early termination strategy is applied that is at the beginning, assign a value to the *life* parameter, it would be reduced by one each time when the new generation of candidate solutions does not improve in terms of quality measurement. The DE will stop when the *life* equals to 0.

Algorithm 1 is a list of pseudocode of DE with early termination for maximizing a score function, where  $np$  is the number of population in each generation,  $f$  is the crossover factor as mentioned,  $cf$  is the probability for crossover operation to generate new candidate, *life* is to control termination.

## 3. EXPERIMENT

### 3.1 Data Set

The data used in this study is from PROMISE repository. Ten software defect prediction data sets are analyzed. They’re *ant*, *camel*, *ivy*, *jedit*, *log4j*, *lucene*, *synapse*, *velocity*, *xalan* and *xerces*. Each of these data sets is composed of several software modules with number of defects and code attributes. For more detailed description of code attributes and the original data sets, please refer to <http://openscience.us/repo/>

### 3.2 Experiment Design

The experiment aims at investigate whether tuning helps learners improve performance in terms of accuracy measurement. We choose compare WHERE-based learner with and

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#### Algorithm 1 Pseudocode for DE with Early Termination

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**Input:**  $np, f, cf, life$

**Output:**  $S_{best}$

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1:  $Population \leftarrow \text{InitializePopulation}(np)$ 
2:  $S_{best} \leftarrow \text{GetBestSolution}(Population)$ 
3: while  $life > 0$  do
4:    $NewGeneration \leftarrow \emptyset$ 
5:   for  $i = 0 \rightarrow n - 1$  do
6:      $S_i \leftarrow \text{GenNew}(Population[i], Population, cf, f)$ 
7:     if  $\text{Score}(S_i) > \text{Score}(Population[i])$  then
8:        $NewGeneration \leftarrow S_i$ 
9:     else
10:       $NewGeneration \leftarrow Population[i]$ 
11:     end if
12:   end for
13:    $Population \leftarrow NewGeneration$ 
14:   if  $\neg \text{Improve}(Population)$  then
15:      $life = 1$ 
16:   end if
17:    $S_{best} \leftarrow \text{GetBestSolution}(Population)$ 
18: end while
19: return  $S_{best}$ 

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without tuning parameters and two *significantly different* learners Random Forest and CART according to [1]. As mentioned above, we’d like to see whether tuning will help change the rank of CART and make it comparable with Random Forest.

To evaluate accuracy performance of learners, several measurements are proposed, like probability of detection ( $pd$ ) and probability of false alarm ( $pf$ )[3], the area under the receiver operating characteristics curve ( $AUC$ ) [1], and precision[18]. In this work, we expect learners should identify as many defective modules as possible while avoiding false alarm. Therefore, learners are evaluated by both of  $pd$  and  $pf$  simultaneously. A single measure, G-measure, defined as the harmonic mean of  $pd$  and  $1 - pf$  is used. The G-measure value is between 0 and 1. The higher, the better.

$$G = \frac{2 * (1 - pf) * pd}{1 - pf + pd} \quad (1)$$

In this experiment, we use three different portions of one project data set for training, tuning and testing process. In contrast to hold out way used in [1, 3], we separate the data sets in order. Since learners are designed to predict defects in future projects, any randomly data set selection without taking into the time series will not sufficient to evaluate the performance of predicting future. To the most, that is good to evaluate the accuracy of classification but not predicting future. Since we have 10 different project data, each of which contains least 3 evolutionary versions. We use the following policy to select the data: in each project, we only use the last three data files for experiment. Specifically, the  $n$ th,  $(n - 1)$ th,  $(n - 2)$ th versions of project data are selected for testing, tuning and training learners, respectively. This will make sure that we don’t use the future project data to train learners and predict previous project.

To investigate the impacts of parameters on learners, we use DE as the tuner and compare the G-measure values of

Where-based learner with and without tuning, CART with and without tuning and Random Forests. Since the tuning time for Random Forests is very long, hopefully other researchers design new heuristics to speed up the tuning process for Random Forests. For the time being, even though we don't tune Random Forests, if tuning help CART outperform Random Forests or improve itself performance, we still could conclude that tuning is helpful and necessary when comparing learners.

Besides the Where-based learner implemented by ourself, we use the CART and Random Forest modules from scikit-learn [19] for this experiment. The parameters associated with different learners are listed in Fig.3. **(NEED to elaborate that there're different versions of CART, what's the point to do this experiment)**. For each data set, run CART, naive Where-based learner and Random Forests with corresponding default values. Then using DE to tune corresponding parameters for CART and Where-based Learner, and run them again with the optimal parameters from tuning process to test the performance. This study ranks learners using the Scott-Knott procedure recommended by Mittas & Angelis in their 2013 IEEE TSE paper [20]. This method sorts a list of  $l$  treatments with  $ls$  measurements by their median score. It then splits  $l$  into sub-lists  $m, n$  in order to maximize the expected value of differences in the observed performances before and after divisions.

## 4. RESULT

## 5. DISCUSSION

## 6. RELATED WORK

Tuning in efforts estimation, software engineering.

Defect Prediction

## 7. THREATS TO VALIDITY

Internal and external threats

## 8. CONCLUSION

## 9. ACKNOWLEDGMENTS

## 10. REFERENCES

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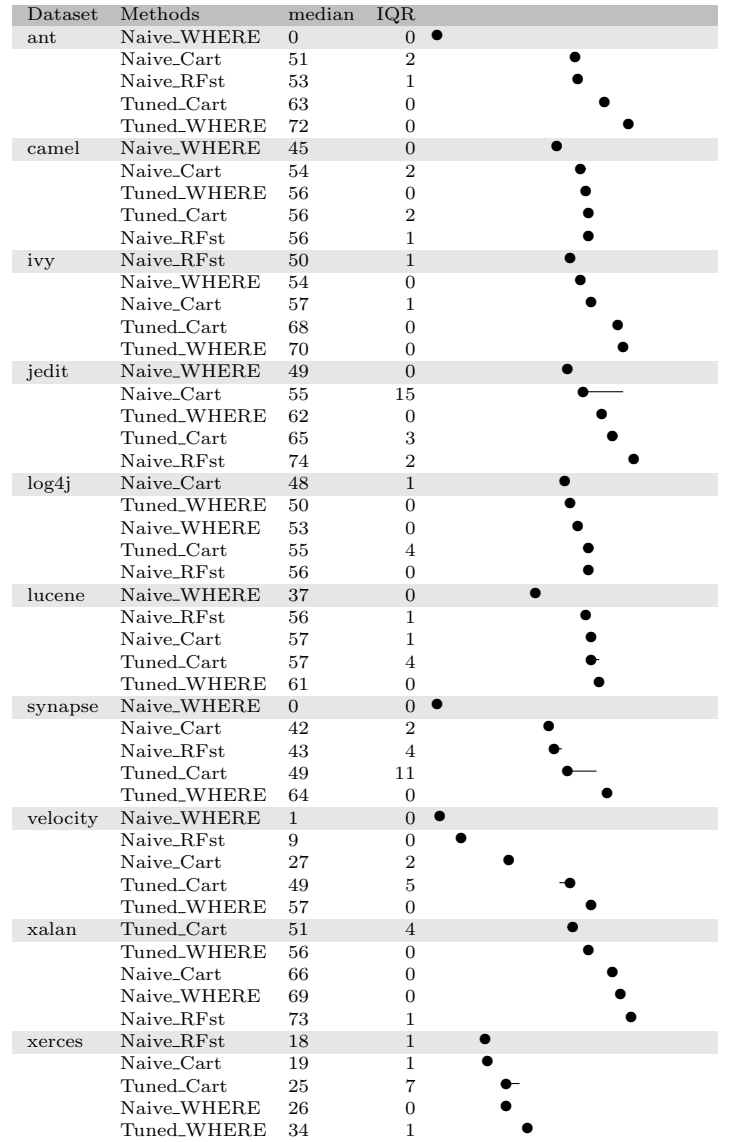


Figure 5: Results over Different Data Sets

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Learner Name	Parameters	Default	Tuning Range	Description
Where-based Learner	threshold	0.5	[0,1]	The value to determine defective or not .
	infogain	0.33	[0,1]	The percentage of features to consider for the best split to build CART tree <sup>2</sup> .
	min_sample_size	4	[1,10]	The minimum number of samples required to be a leaf for CART tree.
	min_Size	0.5	[0,1]	The value to determine the minimum number of samples to be a Where-clustering tree based on $n_{samples}^{min\_Size}$ .
	depthMin	2	[1,6]	The minimum depth of the tree below which no pruning for Where-clustering tree.
	depthMax	10	[1,20]	The maximum depth of the Where-clustering tree.
	wherePrune	False	T/F	Whether or not to prune the Where-clustering tree.
CART	treePrune	True	T/F	Whether or not to prune the classification tree built by CART.
	threshold	0.5	[0,1]	The value to determine defective or not.
	max_feature	None	[0,01,1]	The number of features to consider when looking for the best split.
	max_depth	None	[1,50]	The maximum depth of the tree.
	min_sample_split	2	[2,20]	The minimum number of samples required to split an internal node.
Random Forests	min_smamples_leaf	1	[1,20]	The minimum number of samples required to be at a leaf node.
	threshold	0.5	-	The value to determine defective or not.
	max_feature	None	-	The number of features to consider when looking for the best split.
	max_depth	None	-	The maximum depth of the tree.
	min_sample_split	2	-	The minimum number of samples required to split an internal node.
	min_smamples_leaf	1	-	The minimum number of samples required to be at a leaf node.
	n_estimators	100	-	The number of trees in the forest.

Figure 2: List of parameters to be tuned in Where-based learner and CART in scikit-learn.

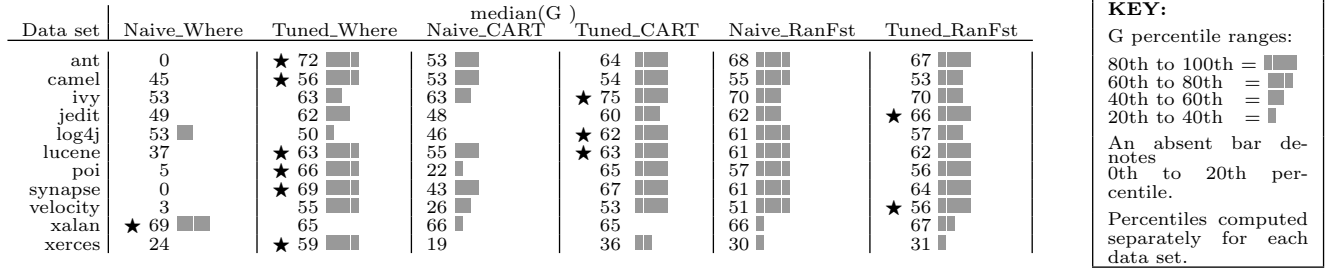
Learner Name	Parameters	Default	ant	camel	ivy	jedit	log4j	lucene	poi	synapse	velocity	xalan	xerces
Where-based Learner	threshold	0.5	0.16	0.87	0.89	0.68	0.58	0.62	0.06	0.09	1	0.64	0.02
	infogain	0.33	0.33	0.49	1	0.82	0.12	0.54	0.38	0.01	1	0.36	0.25
	min_sample_size	4	8	1	1	5	8	1	5	9	1	5	5
	min_Size	0.5	1	0.67	0.99	1	0.63	1	0.95	0.59	1	0.88	0.64
	depthMin	2	3	4	1	1	2	1	1	5	1	1	3
	depthMax	10	8	14	16	18	1	16	13	5	9	18	20
	wherePrune	False	True	True	False	False	False	True	True	False	True	False	True
CART	treePrune	True	False	True	True	True	False	False	True	False	False	False	False
	threshold	0.5	0.01	0.98	0.94	0.67	0.47	1	0.01	0.12	0.9	0.57	0.01
	max_feature	None	0.01	1	0.29	0.28	0.53	0.13	0.01	0.01	0.87	0.47	0.01
	max_depth	None	27	46	33	21	42	36	39	17	29	11	31
	min_sample_split	2	6	2	13	17	12	2	14	12	7	16	13
Random Forests	min_smamples_leaf	1	6	3	18	12	3	10	4	20	8	11	1
	threshold	0.5	0.06	0.88	1	0.73	0.41	0.81	0.11	0.16	1	0.63	0.29
	max_feature	None	0.21	0.98	0.78	0.73	0.36	0.35	0.01	0.01	0.01	0.65	0.89
	max_leaf_nodes	None	31	35	41	40	23	12	26	41	46	49	35
	min_sample_split	2	12	14	2	5	8	11	1	16	1	9	20
	min_smamples_leaf	1	6	15	2	17	3	9	19	8	2	14	9
	n_estimators	100	111	120	89	68	64	84	107	100	79	113	50

Figure 3: Optimal parameters from tuning process with objective of G measure over different data sets.

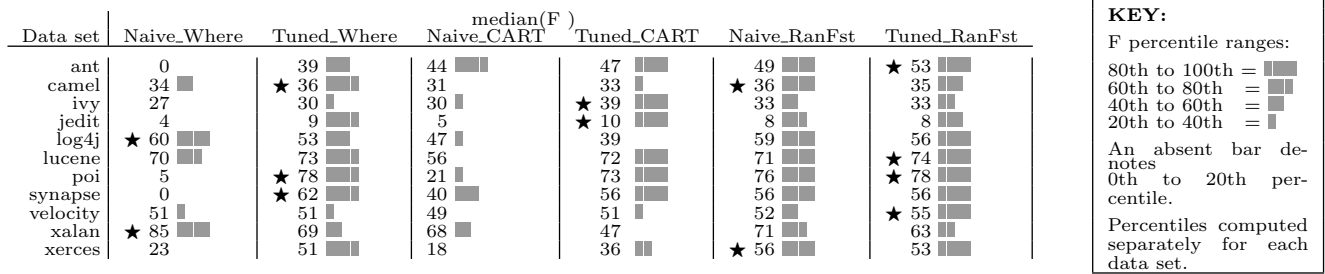
Data Set	Feature Selections with Default Parameters	Feature Selection with Tuning Parameters
ant	mfa, lcom3, cam, ic, dam	wmc, lcom3, cam, dam, npm, rfc
camel	cam, wmc, dit, mfa, rfc, loc	rfc, cam, loc, wmc, dam, dit, mfa, lcom3, npm
ivy	cam, dit, dam, ic, lcom3	cam, dam, mfa
jedit	mfa, dam, cam, dit, cbm, ic	mfa, loc, dit, dam, cam, wmc
log4j	lcom3, mfa, loc, ic, dit	mfa, wmc
lucene	mfa, lcom3, cam, dam, ic	wmc, lcom3, avg_cc, rfc, ce, mfa, dam, npm, cam
poi	mfa, dam, amc, lcom3, cbm, loc	loc, lcom3, cam, amc, dam
synapse	dam, loc, mfa, cam	loc
velocity	dit, dam, lcom3, ic, mfa	mfa, cam, avg_cc, loc, lcom3, cbo, dam, ic, rfc, lcom
xalan	mfa, cam, wmc, lcom3, rfc, dit	mfa, rfc, loc, dam, lcom3, wmc, npm
xerces	cam, wmc, mfa, rfc, amc, loc	mfa, loc, cam, amc, avg_cc

Figure 4: Features selection before and after tuning over objective of G values

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**Figure 6: Median G values in tune once and test ten times experiment. Gray bars show G values discretized into 20th percentile ranges from min to max. All data available from <http://openscience.us/repo/effort>.**



**Figure 7: Median F values in tune once and test ten times experiment. Gray bars show F values discretized into 20th percentile ranges from min to max. All data available from <http://openscience.us/repo/effort>.**

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