Predicting aging-related bugs using software complexity metrics

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Aging-Related Bugs

Mandelbug

If

- A time lag between the fault activation and the failure occurence.
- Bug influenced by timing of operations or order of operations or environment interactions.

Then $\Longrightarrow$ *Mandelbug* :-(
Else $\Longrightarrow$ *Bohrbugs* :-) , can thus be easily isolated

Aging-Related Bugs

Aging-related mandelbug

If Mandelbug and

The bug causes the accumulation of internal error states

Or

The running time increase the risk of the bug activation/propagation

Then $\Longrightarrow$ *Aging-related Mandelbug* :'(
Also called *Aging-related bug* or ARB.

Aging-Related Bugs

Examples

What can causes an ARB ?

- Numerical error due to rounding or imprecision accrue over time
- A malloc() without free()
- A queue continuously increased
- Size of ressource exceeded
- ...

How can we detect them ?

short answer: Select metrics then use a classifier !
But, there are remaining questions about that solution:

Questions

- Which metrics to use ?
- New metrics ?
- Which classifier to use ?
- will be the classifier effective for all projects ?

Project used as training set

3 complex projects will be used.

- Linux
- MySQL
- CARDAMOM, a middleware for air traffic control systems

ARBs are found manually.

Which metrics to use ?

46 metrics correlated with bug density:

- Program size. 26 metrics
  (lines of codes, comments, blank, semicolons, functions, preprocessor)
- Cyclomatic complexity. 11 metrics
- Halstead metrics. 9 metrics

Halstead metrics

Halstead metrics: set of metrics based on the number of operands and number of operators.
Based on

$$\begin{aligned} \eta_1 &= \text{The number of distinct operators} \\ \eta_2 &= \text{The number of distinct operands} \\ N_1 &= \text{The total number of operators} \\ N_2 &= \text{The total number of operands} \end{aligned}$$

Some halstead metrics

- Program vocabulary $= \eta = \eta_1 + \eta_2$
- Program length $= N = N_1 + N_2$
- Volume $= N \times \log_2 \eta$
- Difficulty $= \frac{\eta_1}{2} \times \frac{N_2}{\eta_2}$

Tried classifiers

- Naive Bayes (NB)
- Bayesian networks (BayesNet)
- Decision trees (DecTree)
- Logistic regression (Logistic)

Results without new metrics

Terminology

$$PD = \text{Probability of detection} = \frac{\text{true positives}}{\text{true positives} + \text{false negatives}}.100\%$$

$$PF = \text{Probability of false alarms} = \frac{\text{false positives}}{\text{true negatives} + \text{false positives}}.100\%$$

$$Bal = Balance = 100 - \frac{\sqrt{(0 - PF)^2 + (100 - PD)^2}}{\sqrt{2}}$$

log : metrics at a logarithmic scale

note: the difference between the highest and the second highest value can be statistically not significant. See numbers in bold.

Results without new metrics

Linux

Classifier	PD	PF	Bal
NB	60.13	12.46	**69.24**
NB + log	**92.33**	**37.09**	**72.28**
BayesNet	3.72	1.85	31.91
BayesNet + log	5.34	1.95	33.06
DectTree	0.00	0.03	29.30
DectTree + log	0.00	0.00	29.30
Logistic	1.00	0.63	30.01
Logistic + log	3.84	0.62	32.01

Results without new metrics

MySQL

Classifier	PD	PF	Bal
NB	49.14	10.46	63.02
NB + log	**88.30**	**34.67**	**73.53**
BayesNet	44.57	8.65	60.26
BayesNet + log	44.50	8.65	60.21
DectTree	11.21	2.64	37.17
DectTree + log	11.28	2.65	37.22
Logistic	22.93	4.46	45.40
Logistic + log	25.07	5.13	46.88

Results without new metrics

CARDAMOM

Classifier	PD	PF	Bal
NB	0.00	7.18	29.08
NB + log	**54.50**	**25.15**	**53.25**
BayesNet	0.00	0.00	29.30
BayesNet + log	0.00	0.00	29.30
DectTree	0.00	0.00	29.30
DectTree + log	0.00	0.00	29.30
Logistic	0.00	1.21	29.30
Logistic + log	0.00	0.65	29.30

Results without new metrics

$\Longrightarrow$ Select the Naive Bayes classifier with metrics at a logarithmic scale.

High probability of detection but high probability of false alarm. Still useful for Verification & Validation process:

avoids to inspect the files classified as non-ARB !

Attribute selection

Which attribute to select ?

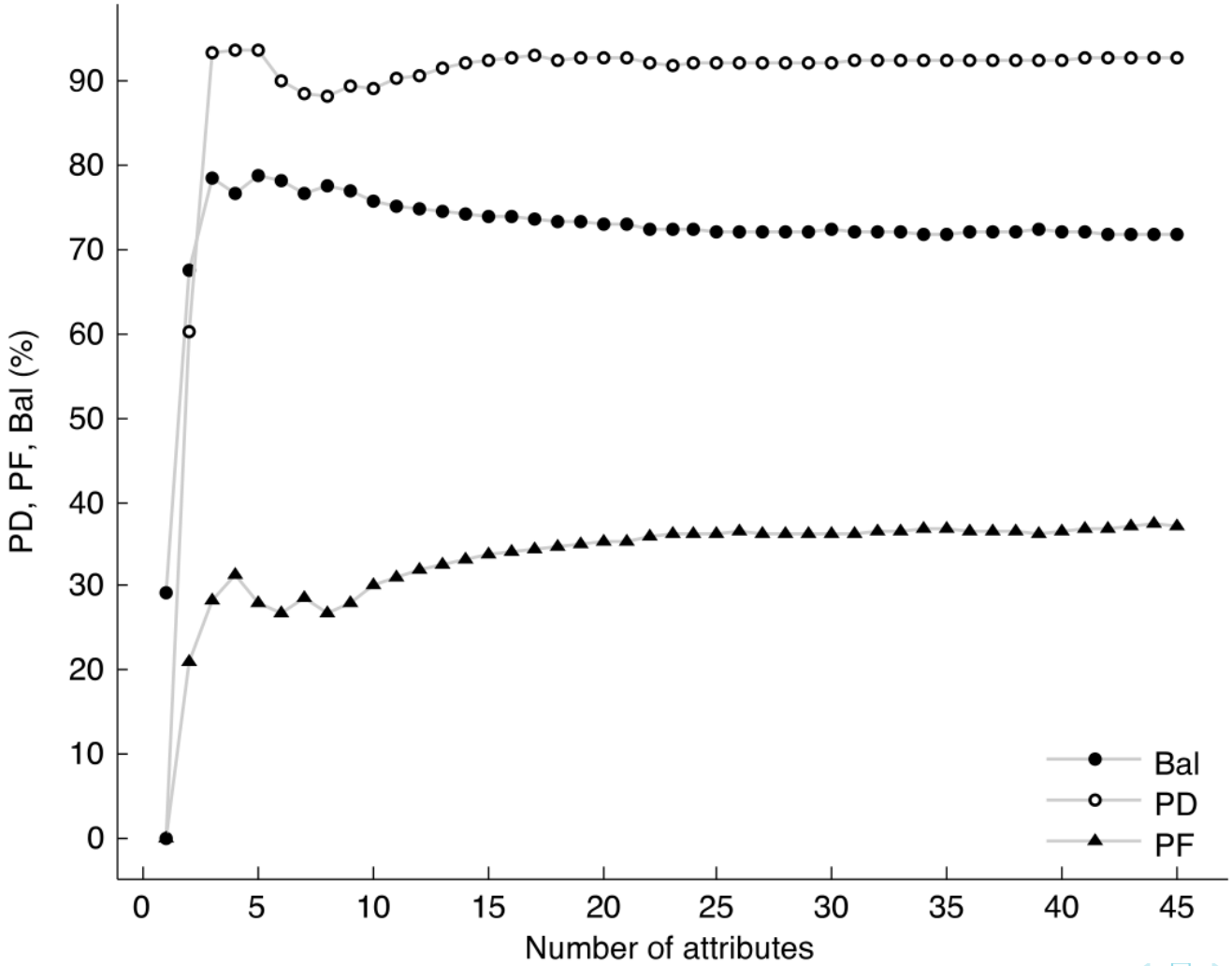
For each project, sort metrics by *Information Gain*:

$InfoGain(A_i) =$ the number of bits of information obtained by knowing the value of attribute A_i

Then, in a decreasing order of $InfoGain(A_i)$, compute PD, PF and Bal with the NB+log classifier.

Impact of attribute selection

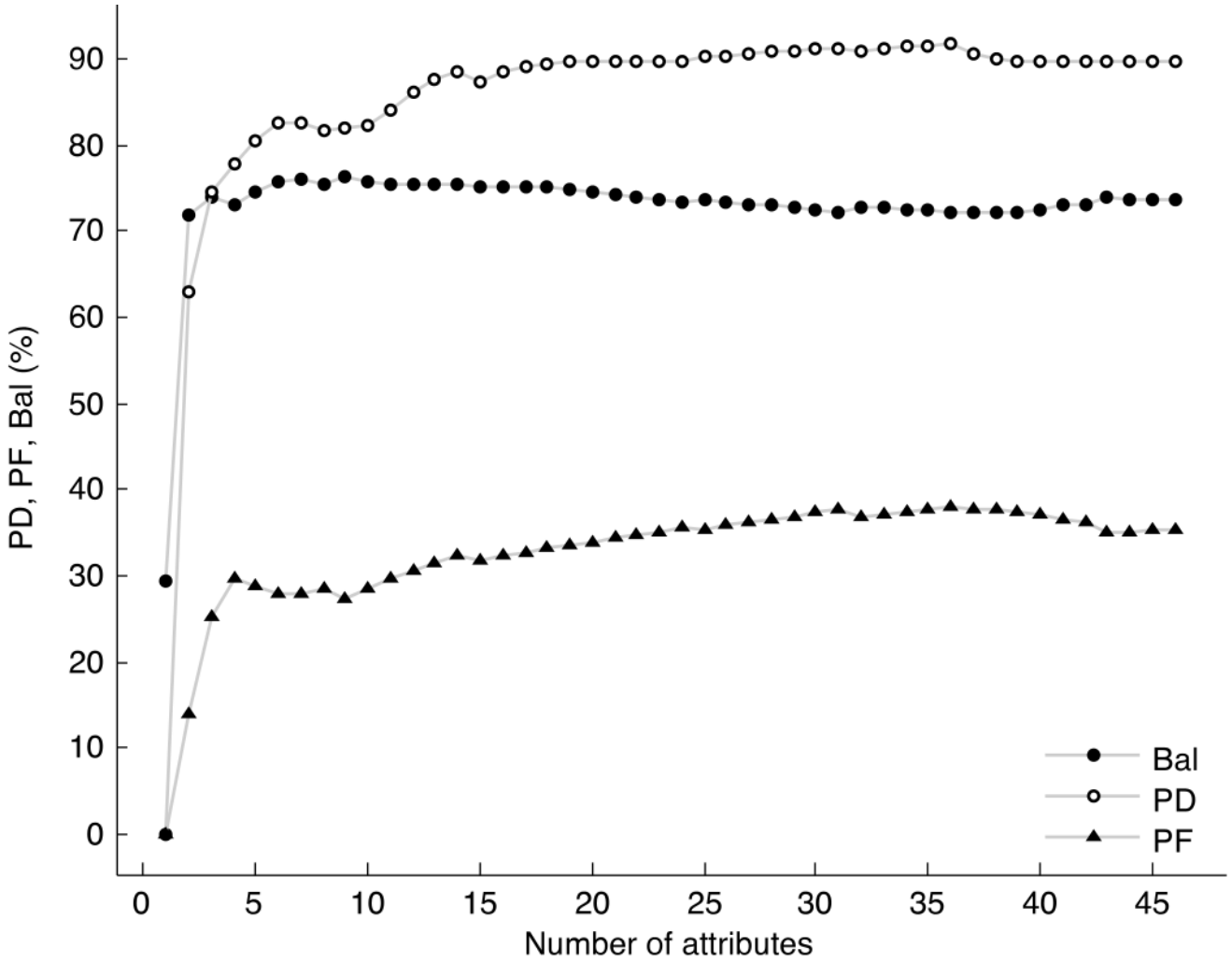
Linux



Top 10 metrics
AvgLineComment
AltAvgLineComment
AvgLine
AvgCyclomaticModified
SumCyclomaticStrict
Dif
CountLineComment
SumEssential
AltCountLineComment
AvgCyclomatic

Impact of attribute selection

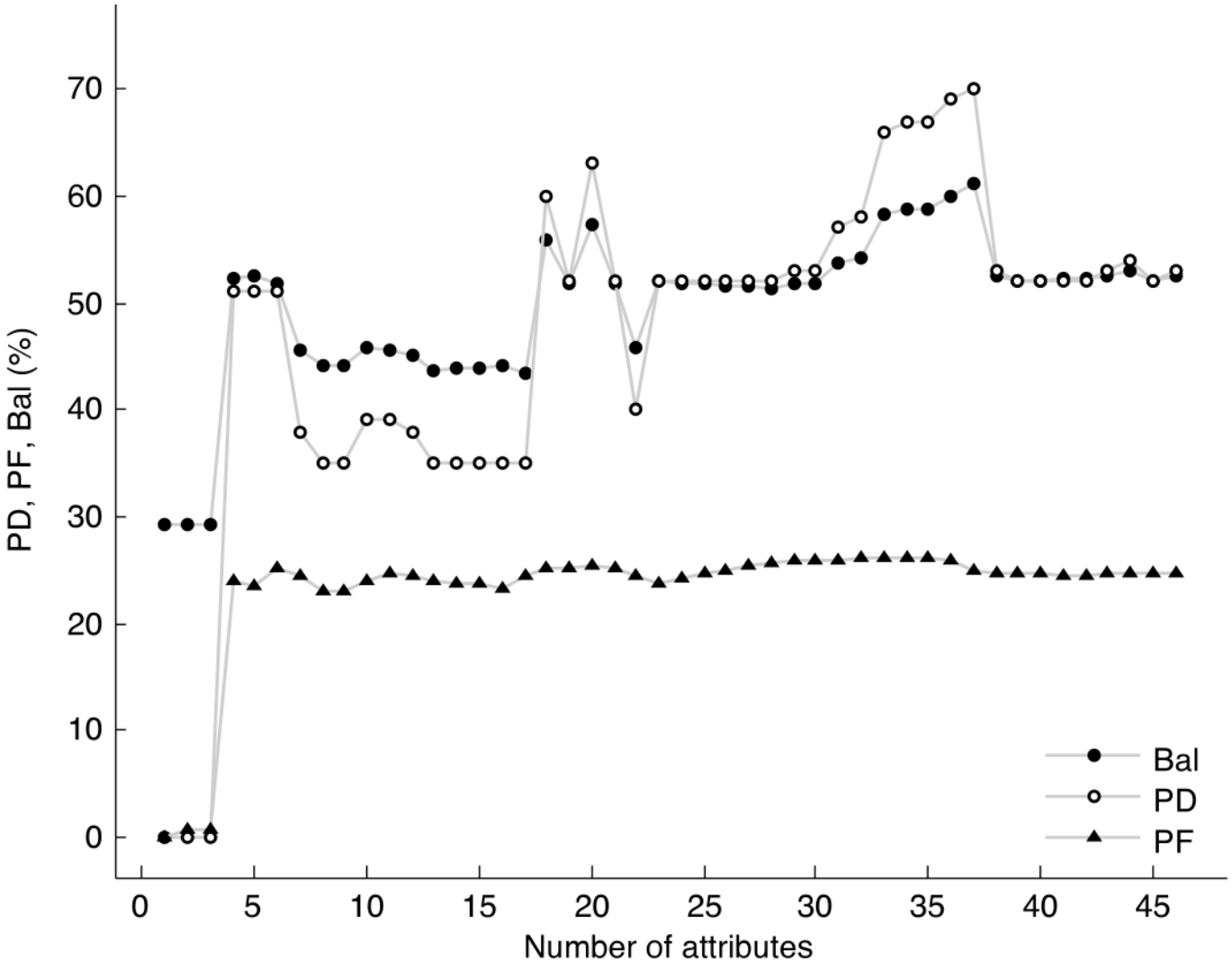
MySQL



Top 10 metrics
CountLineBlank
CountLineCode
CountStmt
AltCountLineBlank
CountSemicolon
MaxCyclomaticModified
AltCountLineCode
CountStmtEmpty
MaxCyclomatic
CountLineComment

Impact of attribute selection

CARDAMOM



Top 10 metrics
CountDeclFunction
CountLine
AvgLineCode
CountDeclClass
AvgLineComment
CountLineCodeExe
CountLineInactive
CountLineComment
CountLineBlank
CountLineCodeDecl

Impact of attribute selection

- Top metrics not the same
- Need about 5 top metrics
- With all metrics, nearly the same results than with 5

$\Longrightarrow$ We keep the full set of metrics.

New metrics

lot of ARB are about memory leaks.

6 new metrics related to memory usage, the ARMs:

- *AllocOps* : Number of instruction about allocation of memory (malloc)
- *DeallocOps* : Number of instruction about Deallocation of memory (free)

New metrics

- *DerefUse* : Number of times a pointer variable is dereferenced to write

Dereferencing a structure member

```
typedef struct X { int a; int b; } X;
X x;
X* p = &x;
p->a = 3.14159;
```

- *DerefSet* : Number of times a pointer variable is dereferenced to read

Dereferencing p and read

```
printf("%d", p->a);
```

New metrics

- *UniqueDerefSet* : Same as DerefSet but variable counted one time per file
- *UniqueDerefUse* : Same as DerefUse but variable counted one time per file

Results with new metrics

Linux

Classifier	PD	PF	Bal
NB	60.13	12.46	69.24
NB + log	**92.33**	**37.09**	72.28
NB + ARMs	58.13	11.88	68.34
NB + log + ARMs	**93.56**	35.90	**73.25**

It decreases PF.

Results with new metrics

MySQL

Classifier	PD	PF	Bal
NB	49.14	10.46	63.02
NB + log	**88.30**	**34.67**	73.53
NB + ARMs	48.42	10.06	62.61
NB + log + ARMs	**88.37**	32.99	**74.69**

It decreases PF.

Results with new metrics

CARDAMOM

Classifier	PD	PF	Bal
NB	0.00	7.18	29.08
NB + log	54.50	**25.15**	53.25
NB + ARMs	0.00	6.57	29.12
NB + log + ARMs	**68.00**	10.22	**70.32**

It decreases PF and increases PD. $\Longrightarrow$ We keep ARMs.

Cross-component classification

In the same project, Can we predict ARB in a new component ?

Results of classifier when we exclude a component and use it as a test set:

Project	Component	PD	PF	Bal
Linux	Network drivers	88.9	41.7	69.5
	SCSI drivers	75.0	27.6	73.7
	EXT3	100.0	52.2	63.1
	IPv4	100.0	52.2	63.1
MySQL	InnoDB	65.6	16.5	73.0
	Replication	100.0	28.6	79.8
	Optimizer	100.0	69.7	50.7
CARDAMOM	Foundation	0.0	0.0	29.3
	Load Balancing	100.0	9.0	93.7

(0% of ARB detected in Foundation because there is only one ARB.)

Cross-project classification

Can those classifiers predict ARB for another project ?

Results of classifier when the training set comes from another project than the test set:

Train	Linux			MySQL			CARDAMOM		
	PD	PF	Bal	PD	PF	Bal	PD	PF	Bal
Linux	-	-	-	82.9	23.8	79.3	0.0	0.2	29.3
MySQL	100.0	50.7	64.2	-	-	-	33.3	11.8	52.1
CARDA	0.0	0.1	29.3	0.0	0.6	29.3	-	-	-

Low performance with CARDAMOM due to the difference of caracteristics between CARDAMOM and the two others.

(CARDAMOM in pure C++, MySQL in mixed C/C++, Linux in pure C)

Conclusion

Predicting ARBs with software metrics is possible.

High PD: We can avoid inspecting files classified as non ARB-prone.

We have to check if caracteristics are similar before using a classifier for another project.