On Sufficiency of Mutants

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It is about the cost

Motivation

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- Motivation
- Needs for experimental study

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- Current testing techniques are still expensive
- We need more effective and less expensive testing techniques
- How to assess the efficiency and effectiveness of the new techniques?
  - Efficiency: relatively easy to assess by defining some metrics (e.g., time, cost, used resources, etc.)
  - Effectiveness: Not easy to address!!!

Needs for experimental study

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Needs for experimental study

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- Experimental study is a tool to assess and compare the effectiveness of different techniques
- Experimental study needs prepared subjects
- Preparing subjects in software testing needs:
  1. A program
  2. Some known faulty versions
  3. A relatively large number of test cases

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Software and Experiments

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- Problem: In software testing research there are only a few well prepared subjects
  - Finding programs with known real faults is difficult
- Not enough data: making the experiments and statistical analysis less significant
- Is there any solution?

Mutating the source code

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- Using mutation to generate faulty versions.
- What is mutation and mutation operators:

Fault - An incorrect part of a code.

- Faulty Code: *while* $(a > b)$ *do* $\{...\}$
- Correct Code: *while* $(a < b)$ *do* $\{...\}$

Mutant - Small modification of a code by mutation operator.

- Correct Code: *while* $(a > b)$ *do* $\{...\}$
- Mutated Code: *while* $(a < b)$ *do* $\{...\}$

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So, what is the problem?

The Problem

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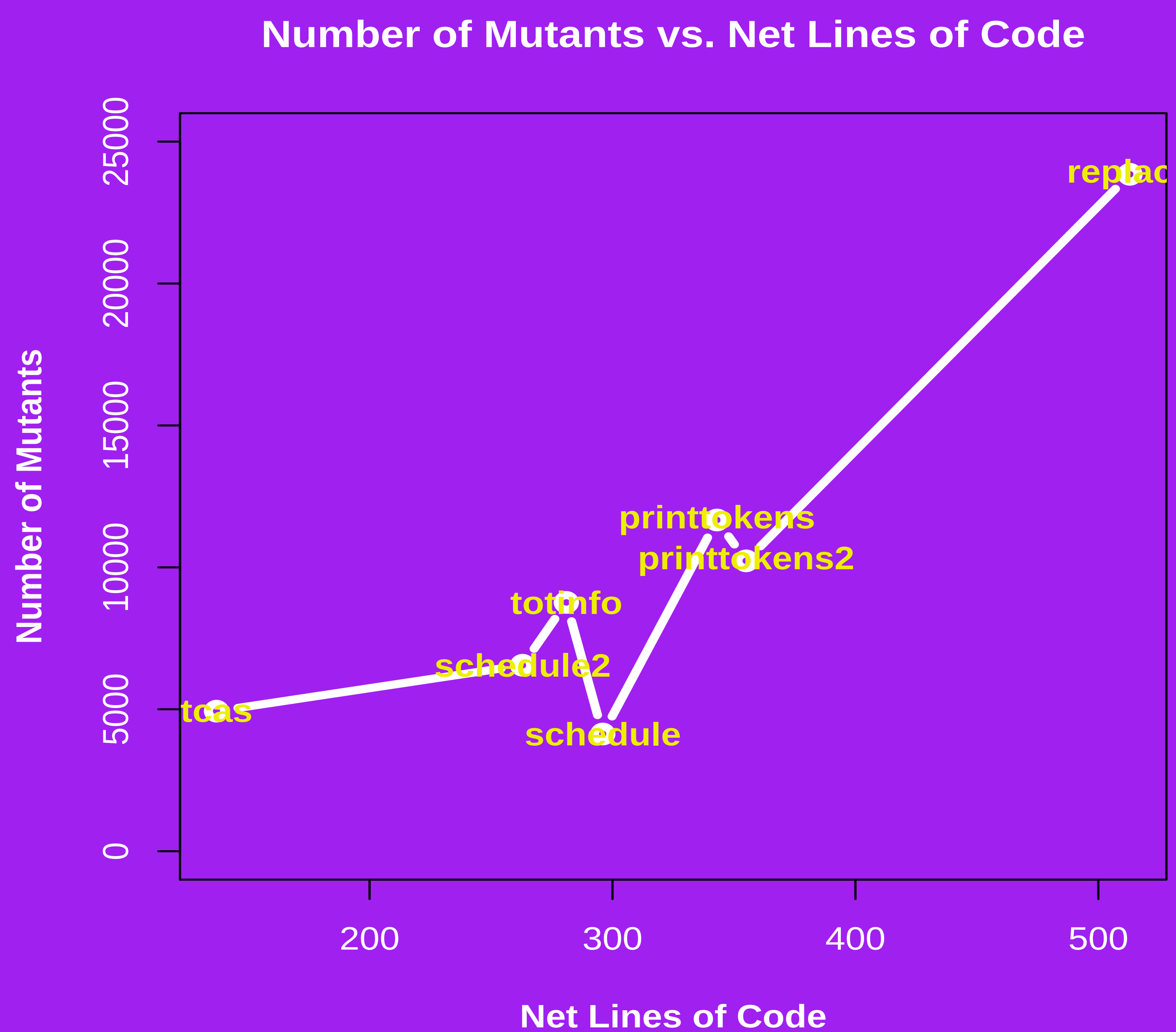
- Many mutation operators (Good or Bad?)
  - Proteum, A mutant generator for C, implements 108 operators
- Good: Simulating defects more closely
- Bad: Enormous number of mutants
  - E.g., A simple program with 137 lines of code can have 4935 mutants
- Infeasible Computation!!!


Number of Mutants vs. Net Lines of Code
Number of Mutants
0
5000
10000
15000
20000
25000
200
300
400
500
Net Lines of Code
tcas
schedule2
totinfo
schedule
printtokens
printtokens2
replac

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Is there any solution?

The Solution

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- Finding a minimal subset of mutation operators (problem?)
    - The minimal subset might not be necessarily the best
- Finding a sufficient subset of mutants called sufficient mutants (How?)
- Offutt et al. worked on selecting one of several fixed subsets of 21 mutation operators
- Wong et al. suggested defining constrained mutation so that the most critical and useful operators will be used in experiments

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Statistical Techniques

Empirical Studies

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1. Finding sufficient subset through statistical techniques
    - Correlation Analysis
    - Cluster Analysis
    - All-Subset Regression Analysis
2. Applying multiple-linear regression on the identified enough subset

Metrics Defined

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- Cost of each operator μ_i:

$$C_i = \sum_j \frac{\#Mutants\ Generated\ By\ \mu_i}{\#All\ Mutants}$$

for $j \in \{Subject\ Programs\}$

- For each test suite:

1. Am_i : Detection ratio of the mutants generated by the operator μ_i
2. AM: Detection ratio of the mutants generated by all operators

Correlation Analysis: A useful technique

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- Correlation between two variables (How?)
  1. Constructing correlation matrix
  2. Comparing each pair of variables
  3. Eliminating one with high cost if there is a high correlation
     - What is high correlation? $cor(X, Y) \geq 0.90$ (Standard Guilford Scalling)
- Calling the remaining variables the sufficient set
- Applying multiple-linear regression on the sufficient set

Cluster Analysis: A similarity technique

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- Clustering variables based on their similarities (How?)
  1. Constructing proximity matrix
     - Computing the nearest neighbor
  2. Generating a dendrogram
  3. Eliminating one with high cost if there is a high correlation
     - What is high correlation? $cor(X, Y) \geq 0.90$
- Calling the remaining variables the sufficient set
- Applying multiple-linear regression on the sufficient set

All-Subset Regression: A search

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- Select a small subset of a large set of variables that model a response variable (How?)
  1. Constructing all regression models exhaustively
     - Number of variables involved in each model chosen by the analyst
  2. The result is already a multiple-linear regression
- Calling the variables involved in the chosen model the sufficient set

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- Applied the techniques to tcas.c program so far
- 300 test suites for each group
- Applied only to random-based test suites

Preliminary Result

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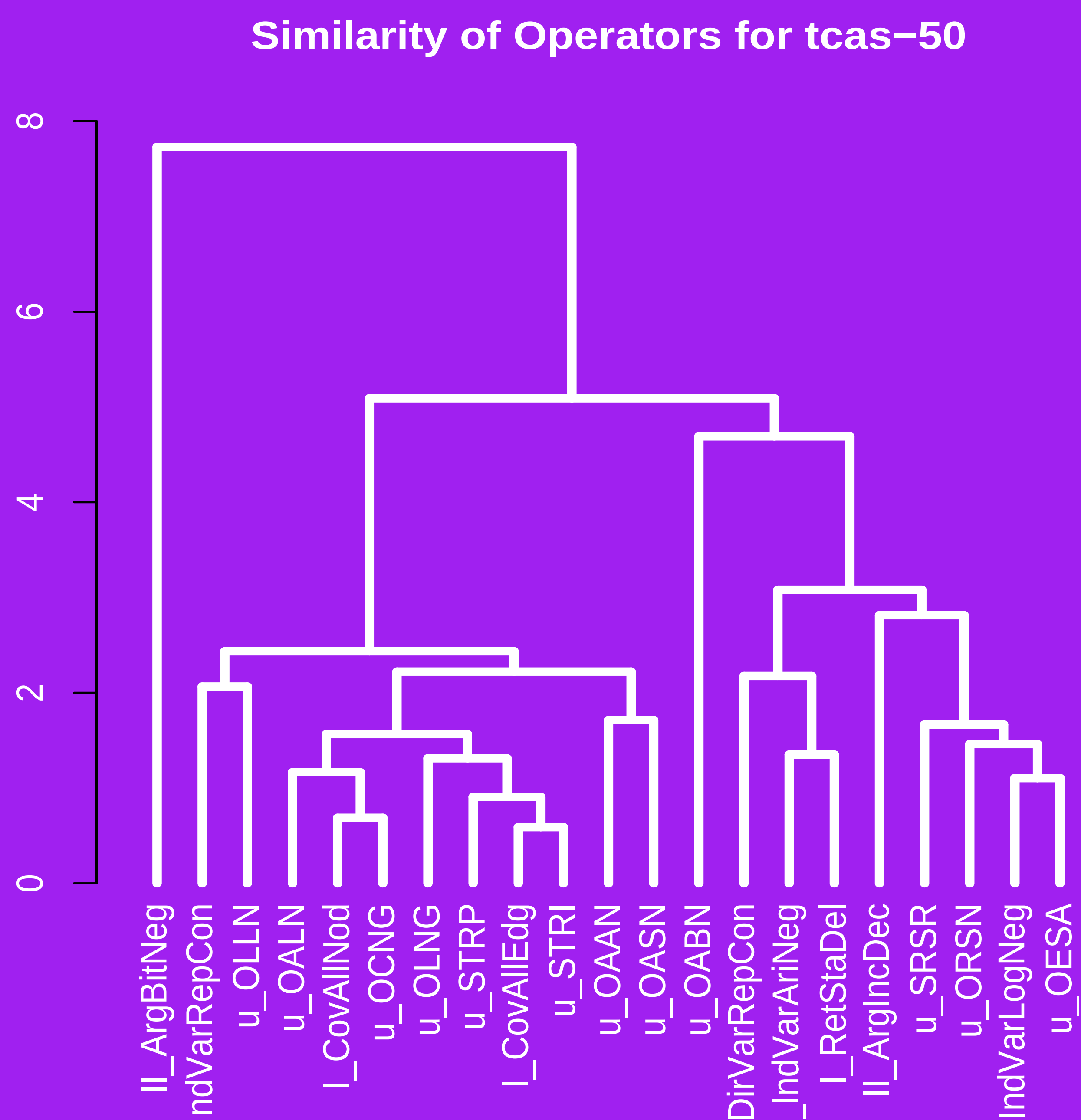
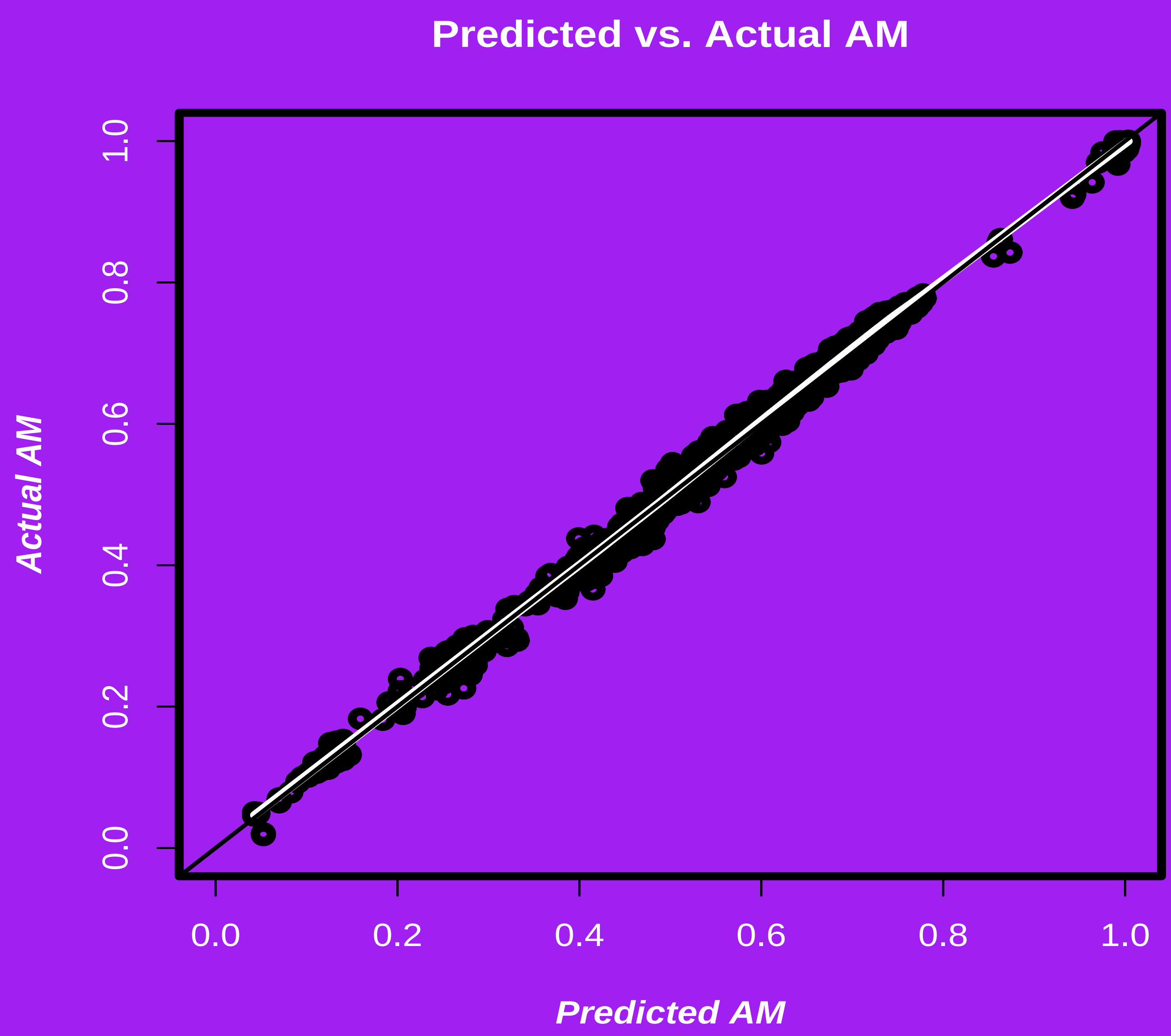
core-SUB	Mutants
I-DirVarAriNeg	44
I-DirVarRepReq	220
I-IndVarLogNeg	19
I-IndVarRepReq	91
u-OABN	3
u-OLSN	34
u-VDTR	111
u-VGSR	794
u-VTWD	74
II-ArgLogNeg	3
Total	1393

core-EBC	Mutants
I-IndVarAriNeg	19
I-IndVarLogNeg	19
II-ArgRepReq	5
u-OALN	2
u-OASN	2
u-OCNG	8
u-OLLN	17
Total	72

core-CA	Mutants
I-CovAllEdg	12
I-DirVarRepCon	38
I-IndVarAriNeg	19
I-RetStaDel	17
II-ArgIncDec	54
u-OABN	3
u-OALN	2
u-OASN	2
u-OCNG	8
u-OLNG	51
u-ORSN	30
u-SRSR	60
u-STRP	70
Total	366


Similarity of Operators for tcas−50
0
2
4
6
8
II_ArgBitNeg
ndVarRepCon
u_OLLN
u_OALN
I_CovAllNod
u_OCNG
u_OLNG
u_STRP
I_CovAllEdg
u_STRI
u_OAAN
u_OASN
u_OABN
DirVarRepCon
IndVarAriNeg
I_RetStaDel
II_ArgIncDec
u_SRSR
u_ORSN
IndVarLogNeg
u_OESA



Predicted vs. Actual AM
Actual AM
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
Predicted AM

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- Addressing the expensive cost of mutation by three statistical analysis
  - Correlation Analysis
  - Cluster Analysis
  - All-Subset Regression Analysis
- Which one is better?
  - In terms of efficiency: Cluster Analysis
  - In terms of accuracy: All-Subset Regression Analysis

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- Applying techniques to all Siemens subject programs
- Verifying the result with other subject programs
- Applying the techniques to different programming languages using different mutant generators