

# Dirt Spot Sweeping Random Strategy: an upgraded version of Random+ Testing

Mian Asbat Ahmad  
Department of Computer Science  
University of York  
York, United Kingdom  
Email: mian.ahmad@york.ac.uk

Manuel Oriol  
ABB Corporate Research  
Industrial Software Systems  
Baden-Dattwil, Switzerland  
Email: manuel.oriol@ch.abb.com

Department of Computer Science  
University of York  
York, United Kingdom  
manuel.oriol@york.ac.uk

**Abstract**—The paper presents a new and improved automated random testing technique named as Dirt Spot Sweeping Random (DSSR) strategy based on the rationale that, “when failures lies in the contiguous locations across the input domain, the effectiveness of random testing can be further improved through diversity of test cases”. The DSSR strategy selects neighbouring values for the subsequent tests on identification of failure. Resultantly, selected values sweep around the failure leading to the discovery of new failures in the vicinity. To evaluate the effectiveness of DSSR strategy a total of 60 classes (35,785 lines of code), each class with  $30 \times 10^5$  calls, were tested by Random (R), Random+ (R+) and DSSR strategies. T-Test analysis showed significantly better performance of DSSR compared to R strategy in 17 classes and R+ strategy in 9 classes. In the remaining classes all the three strategies performed equally well. Numerically, the DSSR strategy found 43 and 12 more unique failures than R and R+ strategies respectively. This study comprehends that DSSR strategy will have a profound positive impact on the failure-finding ability of R and R+ testing.

## I. INTRODUCTION

The success of a software testing technique is mainly dependent on the number of failures it discovers in the SUT. An effective and efficient testing process discovers the maximum number of failures in minimum possible test cases and time. Exhaustive testing is not always feasible, therefore, strategies in automated testing tools are developed with the aim to select more failure-finding test cases from the whole input domain.

Chan et al. [1] discovered that there are patterns of failure-causing inputs across the input domain. They divided these into point, block and strip patterns on the basis of their occurrence. Chen [2] found that the performance of random testing can be increased by altering the technique of test case selection. Moreover, he also found that the performance increased up to 50% when test input was selected evenly across the whole input domain. This was mainly attributed to the better distribution of input, which increased the chances of selecting inputs from failure patterns.

Based on the assumption that in a significant number of classes, failure domains are contiguous, the Dirt Spot Sweeping<sup>1</sup> is devised to give higher priority to the failure domains for identification of new failures efficiently. The DSSR strategy

is implemented in the York Extensible Testing Infrastructure (YETI)<sup>2</sup>, a random testing tool. To evaluate the effectiveness of DSSR strategy a total of 60 classes (35,785 lines of code) of 32 different projects from the Qualitas Corpus<sup>3</sup>, each class with  $30 \times 10^5$  calls, were tested by R, R+ and DSSR strategies.

This paper is organized as follows: Section II describes the DSSR strategy. Section III presents implementation of the DSSR strategy. Section IV explains the experimental setup. Section V reveals results of the experiments. Section VI discusses the results. Section VII presents related work and Section VIII concludes the study.

## II. DIRT SPOT SWEEPING RANDOM STRATEGY

Dirt Spot Sweeping Random strategy combines the R+ strategy with a Dirt Spot Sweeping (DSS) functionality. It is based on two intuitions. First, boundaries have interesting values and using these values in isolation can provide high impact on test results. Second, failures reside in contiguous patterns. If this is true, DSS increases the performance of the test strategy. Before presenting the details of the DSSR strategy, it is pertinent to review briefly the R and the R+ strategy.

### A. Random Strategy (R)

The random strategy is a black-box testing technique in which the SUT is executed using randomly selected test data. Test results obtained are compared to the defined oracle, using SUT specifications in the form of contracts or assertions. In the absence of contracts and assertions, the exceptions defined by the programming language are used as test oracles. Because of its black-box testing nature, this strategy is particularly effective in testing softwares where the developers want to keep the source code secret [3]. The generation of random test data is comparatively cheap and does not require too much intellectual and computational effort [4], [5]. It is mainly for this reason that various researchers have recommended R strategy in automated testing tools [5]. YETI [6], AutoTest [7], [8], QuickCheck [9], Randoop [10] and JArtege [11] are some of the most common automated testing tools based on R strategy.

<sup>1</sup>The name refers to the cleaning robots strategy, which insists on places where dirt has been found in large amount.

<sup>2</sup><http://www.yetitest.org>

<sup>3</sup><http://www.qualitascorpus.com>

Efficiency of random testing was made suspicious with the intuitive statement of Myer and Sandler [12] who termed random testing as one of the poorest methods for software testing. However, experiments performed by various researchers [8], [13], [14], [15], [16] have proved experimentally that random testing is simple to implement, cost effective, efficient and free from human bias as compared to its rival techniques.

### B. Random Plus Strategy (R+)

The random+ strategy [7] is an extension of the R strategy. It uses some special pre-defined values which can be simple boundary values or values that have high tendency of finding failures in the SUT. Boundary values are the values in the start and end of a particular type [17]. For instance, such values for `int` could be `MAX_INT`, `MAX_INT-1`, `MAX_INT-2`, `MAX_INT-3`, `0`, `MIN_INT`, `MIN_INT+1`, `MIN_INT+2`, and `MIN_INT+3`. The tester might also add some other special values that are considered effective in finding failures in the SUT. For example, if a program under test has a loop from `-50 to 50` then the tester can add `-55 to -45`, `-5 to 5` and `45 to 55` to the pre-defined list of special values. This static list of interesting values is manually updated before the start of the test and has a high priority (10%) than selection of random values because of more relevance and better chances of finding failures.

### C. Dirt Spot Sweeping (DSS)

Chan et al. [1] found that there are patterns of failure-causing inputs across the input domain. They divided these patterns into three types called point, block and strip patterns (figure 1) and argued that a strategy has more chances of hitting the failure patterns if test cases are selected farther from each other. Other researchers [18], [19], [20], also tried to generate test cases further away from one another targeting these patterns and achieved better performance. Such increase in performance indicates that failures more often occur contiguous across the input domain. In DSS, if a value reveals

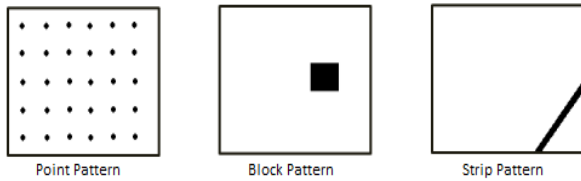


Fig. 1. Failure patterns across input domain [2]

failure from the block or strip pattern then for the selection of the next test value, DSS may not look farthest from the known value but picks the closest value to find another failure from the same region. DSSR strategy relies on DSS that comes into action when a failure is found in the system. On finding a failure, it immediately adds the value causing the failure and its neighbouring values to the existing list of interesting values. For example, in a program when the `int` type value of 50 causes a failure in the system then DSS will add values from 47 to 53 to the list of interesting values. The addition

of neighbouring values will explore other failures present in the block or strip domain of the SUT. The list of interesting values in DSSR strategy is dynamic and changes during the test execution of each program as against R+ where the list remains static.

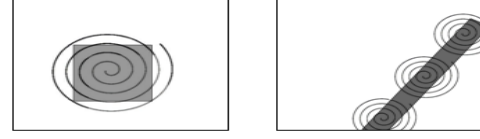


Fig. 2. DSSR strategy covering block and strip pattern

Figure 2, shows how DSS explores the failures residing in the block and strip patterns of a program. The coverage of block and strip pattern is shown in spiral form because first failure leads to second, second to third and so on till the end. In case the failure is positioned on the point pattern then the added values may not be effective because point pattern is only an arbitrary failure point in the whole input domain.

### D. Structure of the Dirt Spot Sweeping Random Strategy

The DSSR strategy continuously tracks the number of failures during the execution of the test. This tracking is done in a very effective way with zero or minimum overhead [21]. The test execution is started by R+ strategy and continues till a failure is found in the SUT after which the program copies the values leading to the failure as well as the surrounding values to the variable list of interesting values.

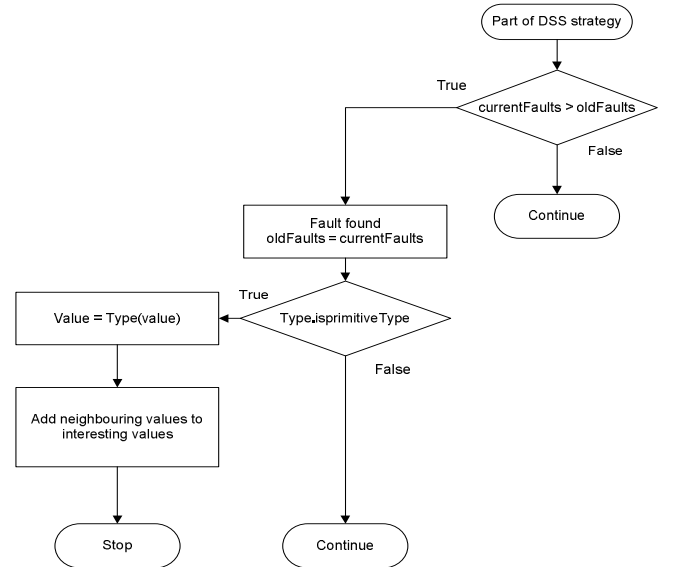


Fig. 3. Working mechanism of DSSR strategy

Both the variables `currentFaults` and `oldFaults` are initialised to 0 at the start of the test, when a fault is found the `currentFaults` value is incremented which make the condition true. The flowchart presented in Figure 3 depicts

the case when fault is caused by a primitive type value. The DSSR strategy identifies its type and adds values only of that particular type to the list of interesting values. The resultant list of interesting values provides relevant test data for the remaining test session and the generated test cases are more targeted towards finding new faults around the existing fault in the given SUT.

| Data Type   | Values to be added  |
|---|---|
| X is int, double, float, long, byte, short & char | X, X+1, X+2, X+3, X-1, X-2, X-3   |
| X is String                                       | X<br>X + " "<br>" " + X<br>X.toUpperCase()<br>X.toLowerCase()<br>X.trim()<br>X.substring(2)<br>X.substring(1, X.length()-1) |
| X is object of user defined class                 | Call its constructor recursively until empty or primitive values  |

TABLE I: Data types and Corresponding values to be added

Table I presents the data types with the corresponding neighbouring values to be added to the list of interesting values. In the table the test value is represented by X where X can be int, double, float, long, byte, short, char and String. All values are converted to their respective types before adding them to the list of interesting values.

#### E. Explanation of DSSR strategy on a concrete example

The DSSR strategy is explained through a simple program seeded with three faults. The first fault is a division by zero exception denoted by 1 while the second and third faults are failing assertion denoted by 2 and 3 respectively in the given program. It is followed by the description of how the strategy performs execution.

```
/**
 * Calculate square of given number
 * and verify result.
 * @author (Mian and Manuel)
 */
public class Math1 {
    public void calc (int num1) {
        // Square num1 and store result.
        int result1 = num1 * num1;
        int result2 = result1 / num1; // 1
        assert result1 >= num1; // 2
        assert Math.sqrt(result1) == num1; // 3
    }
}
```

In the above code, one primitive variable of type int is used; therefore, the input domain for DSSR strategy is

from -2,147,483,648 to 2,147,483,647. The strategy further select values (0, Integer.MIN\_VALUE & Integer.MAX\_VALUE) as interesting values that are prioritized for selection as test inputs. As the test starts, three faults are quickly discovered by DSSR strategy in the following order:

**fault 1:** The strategy selects value 0 for variable num1 in the first test case because 0 is available in the list of interesting values and its priority is higher than other values. This will cause Java to generate division by zero exception (1). After discovering the fault, the strategy adds its surrounding values to the list of interesting values i.e. 1, 2, 3, -1, -2, -3.

**fault 2:** After a few tests the DSSR strategy may select Integer.MAX\_VALUE for variable num1 from the list of interesting values leading to the discovery of the 2nd fault because int variable result1 will not be able to store the square of Integer.MAX\_VALUE. Instead of the actual square value Java assigns 1 (Java language rule) to variable result1 that will lead to the violation of the next assertion (2).

**fault 3:** In the third test case the strategy may pick -3 as a test value, which is added to the list of interesting values after the discovery of first fault. This may lead to the third fault where assertion (3) fails because the square root of 9 is 3 against the input value of -3.

The above process explains that including the border, fault-finding and surrounding values to the list of interesting values in DSSR strategy leads to the discovery of faults quickly and in fewer tests as compared to R and R+ strategies. The R and R+ strategies takes more time and number of tests to discover the second and third faults because the search for new unique faults starts again randomly in spite of the fact that the remaining faults are very close to the first fault.

### III. IMPLEMENTATION OF THE DSSR STRATEGY

Implementation of the DSSR strategy is made in the YETI, an open-source automated random testing tool. YETI, coded in Java, is capable of testing systems developed in procedural, functional and object-oriented languages. Its language-agnostic meta model enables it to test programs written in multiple languages including Java, C#, JML and .NET. The core features of YETI include easy extensibility for future growth, capability to test programs using multiple strategies, high speed tests execution, real time logging, GUI support and auto generation of test report at the end of test session [22], [23].

YETI can be divided into three loosely coupled main parts: the core infrastructure, the language-specific bindings and the strategies. The core infrastructure contains representation for routines, a group of types and a pool of specific type objects. The language-specific bindings contain the code to make the calls and process the results. The strategies define the procedure of selecting the modules (classes), the routines (methods) and generation of values for instances involved

in the routines. By default, YETI uses the R strategy, if no particular strategy is defined during test initialization. It also enables the user to control the probability of using null values and the percentage of newly created objects for each test session. In addition to GUI, YETI also provides extensive logs of the test session for more in-depth analysis.

#### IV. EVALUATION

The DSSR strategy is experimentally evaluated by comparing its performance with that of R and R+ strategy [7]. General factors such as system software and hardware, YETI specific factors like percentage of null values, percentage of newly created objects and interesting value injection probability have been kept constant in the experiments.

##### A. Research questions

For evaluating the DSSR strategy, the following research questions were formulated and addressed in this study:

- 1) Is there an absolute better strategy among R, R+ and DSSR strategies?
- 2) Are there specific classes for which any of the three strategies provide better results?
- 3) Can we pick the best default strategy among R, R+ and DSSR strategies?

##### B. Experiments

To evaluate the performance of DSSR we performed extensive testing of programs from the Qualitas Corpus [24]. The Qualitas Corpus is a curated collection of open source Java projects designed with the aim of helping empirical research in software engineering. These projects have been collected in an organised form containing both the source and binary forms. Version 20101126 containing 106 open source Java projects was used in our experiments. From 32 randomly selected projects, 60 classes were selected at random with the help of automated pseudo-random generator. The selected classes produced at least one failure and timed out within the testing session of not more than 10 minutes. Every class was tested thirty times by each strategy (R, R+, DSSR). Test details of the classes are presented in Table II. Programs tested at random typically fail most of the times as a result of large number of calls. Therefore, it is necessary to cluster failures that likely represent the same failure. The traditional way is to compare the full stack traces and error types and use this as an equivalence class [8], [22] called a unique failure. The same concept of unique failure has been adapted in the present study.

Every class is evaluated through  $10^5$  calls in each test session.<sup>4</sup> Because of the absence of the contracts and assertions in the code under test, undeclared exceptions were considered as unique failures in accordance with previous studies [22].

All tests were performed with a 64-bit Mac OS X Lion Version 10.7.4 running on 2 x 2.66 GHz 6-Core Intel Xeon processor with 6 GB (1333 MHz DDR3) of RAM. YETI

runs on top of the Java™SE Runtime Environment [version 1.6.0\_35]. The machine took approximately 100 hours to process the experiments.

##### C. Performance measurement criteria

Various measures including the E-measure (expected number of failures detected), P-measure (probability of detecting at least one failure) and F-measure (number of test cases used to find the first failure) have been used by researchers to find the effectiveness of the R strategy. The P-measure has been heavily criticized and is not considered effective measuring technique [2] while the F-measure has been often used by various researchers [25], [26]. In our initial experiments the F-measure was used to evaluate the efficiency. However it was realized that this was not the right choice. In some experiments a strategy found the first failure quickly than the other but on completion of test session that very strategy found lower number of total failures than the rival strategy. The preference given to a strategy by F-measure, because it finds the first failure quickly, without giving due consideration to the total number of failures is not fair [27].

The literature review revealed that the F-measure is used where testing stops after identification of the first failure and the system is given back to the developers to remove the failure. Currently automated testing tools test the whole system and print all discovered failures in one go, therefore, F-measure is not the favourable choice. In our experiments, performance of the strategy was measured by the maximum number of failures detected in the SUT by a particular number of test calls [28], [8]. This measurement, similar to E-measure, is effective because it considers the performance of the strategy when all other factors are kept constant.

#### V. RESULTS

Results of the experiments including class name, Line of Code (LOC), mean value, maximum and minimum number of unique failures and relative standard deviation for each of the 60 classes tested by R, R+ and DSSR strategies are presented in Table II. Each strategy found an equal number of failures in 31 classes while in the remaining 29 classes the three strategies performed differently from one another. The total of mean values of unique failures in DSSR (1075) is higher than for R (1040) or R+ (1061) strategies. DSSR also finds a higher number of maximum unique failures (1118) than both R (1075), and R+ (1106). DSSR strategy finds 43 and 12 more unique failures compared to R and R+ respectively. The minimum number of unique failures found by DSSR (1032) is also higher than R (973) and R+ (1009), which attributes to higher efficiency of DSSR strategy over R and R+ strategies.

##### A. Is there an absolute better strategy among R, R+ and DSSR strategies?

Based on our findings DSSR strategy performs better than R and R+ strategies. Figure 4 presents the average improvement of DSSR strategy over R and R+ strategies for 17 classes showing substantial difference between DSSR and R, DSSR

<sup>4</sup>The total number of tests is thus  $60 \times 30 \times 3 \times 10^5 = 540 \times 10^6$  tests.

| S. No | Class Name        | LOC    | R    |      |     |       | R+   |      |      |       | DSSR |      |      |       |
|-------|-------------------|--------|------|------|-----|-------|------|------|------|-------|------|------|------|-------|
|       |                   |        | Mean | Max  | Min | R-STD | Mean | Max  | Min  | R-STD | Mean | Max  | Min  | R-STD |
| 1     | ActionTranslator  | 709    | 96   | 96   | 96  | 0     | 96   | 96   | 96   | 0     | 96   | 96   | 96   | 0     |
| 2     | AjTypeImpl        | 1180   | 80   | 83   | 79  | 0.02  | 80   | 83   | 79   | 0.02  | 80   | 83   | 79   | 0.01  |
| 3     | Apriori           | 292    | 3    | 4    | 3   | 0.10  | 3    | 4    | 3    | 0.13  | 3    | 4    | 3    | 0.14  |
| 4     | BitSet            | 575    | 9    | 9    | 9   | 0     | 9    | 9    | 9    | 0     | 9    | 9    | 9    | 0     |
| 5     | CatalogManager    | 538    | 7    | 7    | 7   | 0     | 7    | 7    | 7    | 0     | 7    | 7    | 7    | 0     |
| 6     | CheckAssociator   | 351    | 7    | 8    | 2   | 0.16  | 6    | 9    | 2    | 0.18  | 7    | 9    | 6    | 0.73  |
| 7     | Debug             | 836    | 4    | 6    | 4   | 0.13  | 5    | 6    | 4    | 0.12  | 5    | 8    | 4    | 0.19  |
| 8     | DirectoryScanner  | 1714   | 33   | 39   | 20  | 0.10  | 35   | 38   | 31   | 0.05  | 36   | 39   | 32   | 0.04  |
| 9     | DiskIO            | 220    | 4    | 4    | 4   | 0     | 4    | 4    | 4    | 0     | 4    | 4    | 4    | 0     |
| 10    | DOMParser         | 92     | 7    | 7    | 3   | 0.19  | 7    | 7    | 3    | 0.11  | 7    | 7    | 7    | 0     |
| 11    | Entities          | 328    | 3    | 3    | 3   | 0     | 3    | 3    | 3    | 0     | 3    | 3    | 3    | 0     |
| 12    | EntryDecoder      | 675    | 8    | 9    | 7   | 0.10  | 8    | 9    | 7    | 0.10  | 8    | 9    | 7    | 0.08  |
| 13    | EntryComparator   | 163    | 13   | 13   | 13  | 0     | 13   | 13   | 13   | 0     | 13   | 13   | 13   | 0     |
| 14    | Entry             | 37     | 6    | 6    | 6   | 0     | 6    | 6    | 6    | 0     | 6    | 6    | 6    | 0     |
| 15    | Facade            | 3301   | 3    | 3    | 3   | 0     | 3    | 3    | 3    | 0     | 3    | 3    | 3    | 0     |
| 16    | FileUtil          | 83     | 1    | 1    | 1   | 0     | 1    | 1    | 1    | 0     | 1    | 1    | 1    | 0     |
| 17    | Font              | 184    | 12   | 12   | 11  | 0.03  | 12   | 12   | 11   | 0.03  | 12   | 12   | 11   | 0.02  |
| 18    | FPGrowth          | 435    | 5    | 5    | 5   | 0     | 5    | 5    | 5    | 0     | 5    | 5    | 5    | 0     |
| 19    | Generator         | 218    | 17   | 17   | 17  | 0     | 17   | 17   | 17   | 0     | 17   | 17   | 17   | 0     |
| 20    | Group             | 88     | 11   | 11   | 10  | 0.02  | 10   | 4    | 11   | 0.15  | 11   | 11   | 11   | 0     |
| 21    | HttpAuth          | 221    | 2    | 2    | 2   | 0     | 2    | 2    | 2    | 0     | 2    | 2    | 2    | 0     |
| 22    | Image             | 2146   | 13   | 17   | 7   | 0.15  | 12   | 14   | 4    | 0.15  | 14   | 16   | 11   | 0.07  |
| 23    | InstrumentTask    | 71     | 2    | 2    | 1   | 0.13  | 2    | 2    | 1    | 0.09  | 2    | 2    | 2    | 0     |
| 24    | IntStack          | 313    | 4    | 4    | 4   | 0     | 4    | 4    | 4    | 0     | 4    | 4    | 4    | 0     |
| 25    | ItemSet           | 234    | 4    | 4    | 4   | 0     | 4    | 4    | 4    | 0     | 4    | 4    | 4    | 0     |
| 26    | Itexpdf           | 245    | 8    | 8    | 8   | 0     | 8    | 8    | 8    | 0     | 8    | 8    | 8    | 0     |
| 27    | JavaWrapper       | 513    | 3    | 2    | 2   | 0.23  | 4    | 4    | 3    | 0.06  | 4    | 4    | 3    | 0.05  |
| 28    | JmxUtilities      | 645    | 8    | 8    | 6   | 0.07  | 8    | 8    | 7    | 0.04  | 8    | 8    | 7    | 0.04  |
| 29    | List              | 1718   | 5    | 6    | 4   | 0.11  | 6    | 6    | 4    | 0.10  | 6    | 6    | 5    | 0.09  |
| 30    | NameEntry         | 172    | 4    | 4    | 4   | 0     | 4    | 4    | 4    | 0     | 4    | 4    | 4    | 0     |
| 31    | NodeSequence      | 68     | 38   | 46   | 30  | 0.10  | 36   | 45   | 30   | 0.12  | 38   | 45   | 30   | 0.08  |
| 32    | NodeSet           | 208    | 28   | 29   | 26  | 0.03  | 28   | 29   | 26   | 0.04  | 28   | 29   | 26   | 0.03  |
| 33    | PersistentBag     | 571    | 68   | 68   | 68  | 0     | 68   | 68   | 68   | 0     | 68   | 68   | 68   | 0     |
| 34    | PersistentList    | 602    | 65   | 65   | 65  | 0     | 65   | 65   | 65   | 0     | 65   | 65   | 65   | 0     |
| 35    | PersistentSet     | 162    | 36   | 36   | 36  | 0     | 36   | 36   | 36   | 0     | 36   | 36   | 36   | 0     |
| 36    | Project           | 470    | 65   | 71   | 60  | 0.04  | 66   | 78   | 62   | 0.04  | 69   | 78   | 64   | 0.05  |
| 37    | Repository        | 63     | 31   | 31   | 31  | 0     | 40   | 40   | 40   | 0     | 40   | 40   | 40   | 0     |
| 38    | Routine           | 1069   | 7    | 7    | 7   | 0     | 7    | 7    | 7    | 0     | 7    | 7    | 7    | 0     |
| 39    | RubyBigDecimal    | 1564   | 4    | 4    | 4   | 0     | 4    | 4    | 4    | 0     | 4    | 4    | 4    | 0     |
| 40    | Scanner           | 94     | 3    | 5    | 2   | 0.20  | 3    | 5    | 2    | 0.27  | 3    | 5    | 2    | 0.25  |
| 41    | Scene             | 1603   | 26   | 27   | 26  | 0.02  | 26   | 27   | 26   | 0.02  | 27   | 27   | 26   | 0.01  |
| 42    | SelectionManager  | 431    | 3    | 3    | 3   | 0     | 3    | 3    | 3    | 0     | 3    | 3    | 3    | 0     |
| 43    | Server            | 279    | 15   | 21   | 11  | 0.20  | 17   | 21   | 12   | 0.16  | 17   | 21   | 12   | 0.14  |
| 44    | Sorter            | 47     | 2    | 2    | 1   | 0.09  | 3    | 3    | 2    | 0.06  | 3    | 3    | 3    | 0     |
| 45    | Sorting           | 762    | 3    | 3    | 3   | 0     | 3    | 3    | 3    | 0     | 3    | 3    | 3    | 0     |
| 46    | Statistics        | 491    | 16   | 17   | 12  | 0.08  | 23   | 25   | 22   | 0.03  | 24   | 25   | 22   | 0.04  |
| 47    | Status            | 32     | 53   | 53   | 53  | 0     | 53   | 53   | 53   | 0     | 53   | 53   | 53   | 0     |
| 48    | Stopwords         | 332    | 7    | 8    | 7   | 0.03  | 7    | 8    | 6    | 0.08  | 8    | 8    | 7    | 0.06  |
| 49    | StringHelper      | 178    | 43   | 45   | 40  | 0.02  | 44   | 46   | 42   | 0.02  | 44   | 45   | 42   | 0.02  |
| 50    | StringUtils       | 119    | 19   | 19   | 19  | 0     | 19   | 19   | 19   | 0     | 19   | 19   | 19   | 0     |
| 51    | TouchCollector    | 222    | 3    | 3    | 3   | 0     | 3    | 3    | 3    | 0     | 3    | 3    | 3    | 0     |
| 52    | Trie              | 460    | 21   | 22   | 21  | 0.02  | 21   | 22   | 21   | 0.01  | 21   | 22   | 21   | 0.01  |
| 53    | URI               | 3970   | 5    | 5    | 5   | 0     | 5    | 5    | 5    | 0     | 5    | 5    | 5    | 0     |
| 54    | WebMacro          | 311    | 5    | 5    | 5   | 0     | 5    | 6    | 5    | 0.14  | 5    | 7    | 5    | 0.28  |
| 55    | XMLAttributesImpl | 277    | 8    | 8    | 8   | 0     | 8    | 8    | 8    | 0     | 8    | 8    | 8    | 0     |
| 56    | XMLChar           | 1031   | 13   | 13   | 13  | 0     | 13   | 13   | 13   | 0     | 13   | 13   | 13   | 0     |
| 57    | XMLEntityManger   | 763    | 17   | 18   | 17  | 0.01  | 17   | 17   | 16   | 0.01  | 17   | 17   | 17   | 0     |
| 58    | XMLEntityScanner  | 445    | 12   | 12   | 12  | 0     | 12   | 12   | 12   | 0     | 12   | 12   | 12   | 0     |
| 59    | XObject           | 318    | 19   | 19   | 19  | 0     | 19   | 19   | 19   | 0     | 19   | 19   | 19   | 0     |
| 60    | XString           | 546    | 23   | 24   | 21  | 0.04  | 23   | 24   | 23   | 0.02  | 24   | 24   | 23   | 0.02  |
| Total |                   | 35,785 | 1040 | 1075 | 973 | 2.42  | 1061 | 1106 | 1009 | 2.35  | 1075 | 1118 | 1032 | 1.82  |

TABLE II: Complete results for R, R+ and DSSR strategies. Results present Serial Number (S.No), Class Name, Line of Code (LOC), mean, maximum number of unique failures, minimum number of unique failures and relative standard deviation for each Random (R), Random+ (R+) and Dirt Spot Sweeping Random (DSSR) strategies.

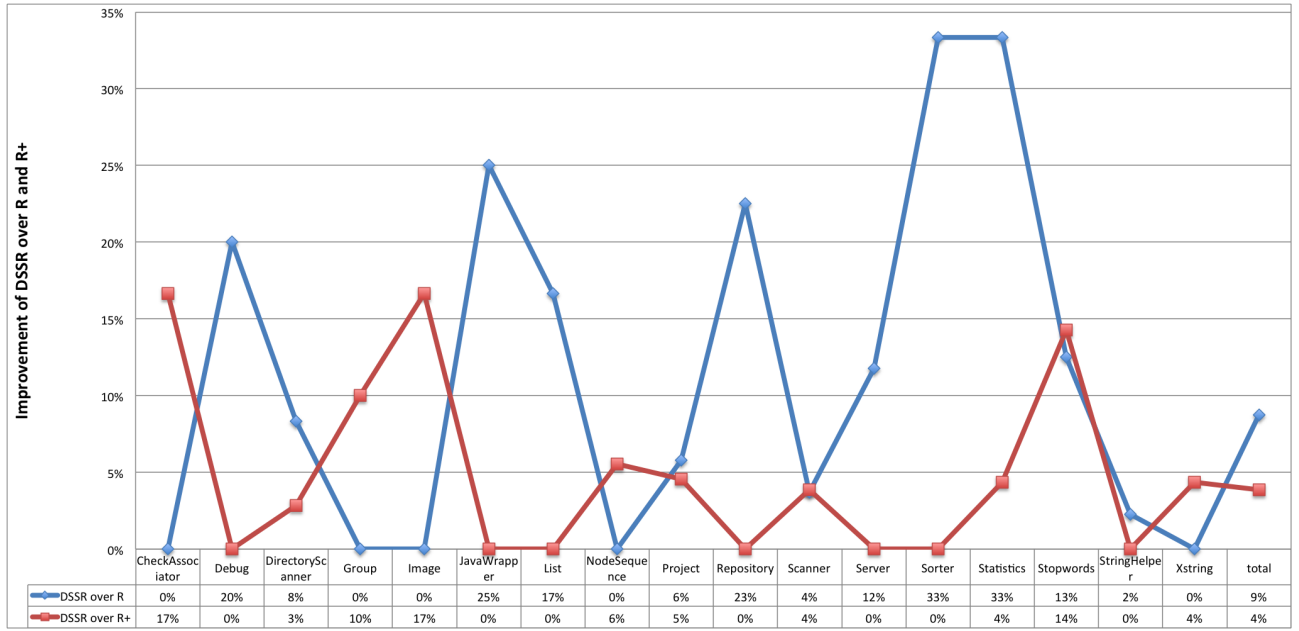


Fig. 4. Improvement of DSSR strategy over R and R+ strategy.

and R+. The blue line with diamond symbol shows the performance of DSSR over R and the red line with square symbols depicts the performance of DSSR over R+ strategy. The findings show that DSSR strategy perform up to 33% better than R and up to 17% better than R+ strategy. In some cases DSSR perform equally well with R and R+ but in no case DSSR performed lower than R and R+. Based on the results it can be stated that DSSR strategy is a better choice than R and R+ strategy. The improvement of DSSR over R and R+ strategy is calculated by applying the formula (1) and (2) respectively.

$$\frac{Averagefailures_{(DSSR)} - Averagefailures_{(R)}}{Averagefailures_{(R)}} * 100 \quad (1)$$

$$\frac{Averagefailures_{(DSSR)} - Averagefailures_{(R+)}}{Averagefailures_{(R+)}} * 100 \quad (2)$$

*B. Are there classes for which any of the three strategies provide better results?*

T-tests applied to the data given in Table III showed significantly better performance of DSSR compared to R strategy in 17 classes and R+ strategy in 9 classes. In the remaining classes all the three strategies performed equally well. It is interesting to note that in no single case R and R+ strategies performed better than DSSR strategy. We attribute this to DSSR possessing the qualities of R and R+ whereas containing the spot sweeping feature.

*C. Can we pick the best default strategy between R, R+ and DSSR strategies?*

Analysis of the experimental data reveals that DSSR strategy has an edge over R and R+. This is mainly because of the additional feature of DSS in DSSR strategy which can identify new faults quickly in the case of different faults or helps in debugging by providing more fault revealing input in the case of single fault. However, further analysis of DSSR strategy in terms of code coverage and overhead is required before picking it as a default strategy.

## VI. DISCUSSION

In the present study, we evaluated DSSR strategy against R and R+ strategies under identical conditions. This is in accordance with the common practice to evaluate performance of an extended strategy by applying it in combination with other existing strategies to the same programs and comparing the results obtained [29], [30]. We used random testing as a baseline for comparison as advocated by Arcuri et al [31].

In our experiments we selected projects from the Qualitas Corpus [24] which is a collection of open source java programs maintained for independent empirical research. These projects are carefully selected and span across the whole set of java applications [22], [24]. The selection of programs in the current study is made through automated random process to avoid any bias and maintain representative selection of classes.

All the three strategies have the potential of finding failures. However, DSSR strategy found more number of unique failures than both R and R+ strategies as reflected in the results. This improved performance of the strategy can be attributed to the additional feature of DSS in the DSSR strategy.

In DSSR strategy no pre-existing test cases are required because it utilises the border values from R+ and regenerate

| S. No | Class Name       | T-test Results |             |              | Interpretation |
|-------|------------------|----------------|-------------|--------------|----------------|
|       |                  | DSSR, R        | DSSR, R+    | R, R+        |                |
| 1     | AjTypeImpl       | 1              | 1           | 1            |                |
| 2     | Apriori          | <b>0.03</b>    | 0.49        | 0.16         |                |
| 3     | CheckAssociator  | <b>0.04</b>    | <b>0.05</b> | 0.44         | DSSR better    |
| 4     | Debug            | <b>0.03</b>    | 0.14        | 0.56         |                |
| 5     | DirectoryScanner | <b>0.04</b>    | <b>0.01</b> | 0.43         | DSSR better    |
| 6     | DomParser        | <b>0.05</b>    | 0.23        | 0.13         |                |
| 7     | EntityDecoder    | <b>0.04</b>    | 0.28        | 0.3          |                |
| 8     | Font             | 0.18           | 0.18        | 1            |                |
| 9     | Group            | 0.33           | <b>0.03</b> | <b>0.04</b>  | DSSR = R > R+  |
| 10    | Image            | <b>0.03</b>    | <b>0.01</b> | 0.61         | DSSR better    |
| 11    | InstrumentTask   | 0.16           | 0.33        | 0.57         |                |
| 12    | JavaWrapper      | <b>0.001</b>   | 0.57        | 0.004        | DSSR = R+ > R  |
| 13    | JmxUtilities     | 0.13           | 0.71        | 0.08         |                |
| 14    | List             | <b>0.01</b>    | 0.25        | <b>0</b>     | DSSR = R+ > R  |
| 15    | NodeSequence     | 0.97           | <b>0.04</b> | <b>0.06</b>  | DSSR = R > R+  |
| 16    | NodeSet          | <b>0.03</b>    | 0.42        | 0.26         |                |
| 17    | Project          | <b>0.001</b>   | 0.57        | <b>0.004</b> | DSSR better    |
| 18    | Repository       | <b>0</b>       | 1           | <b>0</b>     | DSSR = R+ > R  |
| 19    | Scanner          | 1              | <b>0.03</b> | <b>0.01</b>  | DSSR better    |
| 20    | Scene            | <b>0</b>       | <b>0</b>    | 1            | DSSR better    |
| 21    | Server           | <b>0.03</b>    | 0.88        | <b>0.03</b>  | DSSR = R+ > R  |
| 22    | Sorter           | <b>0</b>       | 0.33        | <b>0</b>     | DSSR = R+ > R  |
| 23    | Statistics       | <b>0</b>       | 0.43        | <b>0</b>     | DSSR = R+ > R  |
| 24    | Stopwords        | <b>0</b>       | 0.23        | <b>0</b>     | DSSR = R+ > R  |
| 25    | StringHelper     | <b>0.03</b>    | 0.44        | 0.44         | DSSR = R+ > R  |
| 26    | Trie             | 0.1            | 0.33        | 0.47         | DSSR better    |
| 27    | WebMacro         | 0.33           | 1           | 0.16         |                |
| 28    | XMLEntityManager | 0.33           | 0.33        | 0.16         |                |
| 29    | XString          | 0.14           | <b>0.03</b> | 0.86         |                |

TABLE III: T-test results of the classes showing different results

the data very cheaply in a dynamic fashion different for each class under test without any prior test data and with comparatively lower overhead.

The DSSR strategy performs comparatively better when the number of failures is higher in the SUT. The logical explanation is that the higher the number of failures in the SUT, the more connected are their failure domains, increasing the chances of finding failures by DSS.

As pointed out earlier, DSSR strategy relies on R+ strategy to identify the first unique failure. We noticed in our experiments that discovery of first unique failure in the early stage of the test triggers the activation of Dirt Spot Sweeping, resulting in quick finding of failures in the SUT. The process is delayed when the identification of the first unique failure is not accomplished in the early stage by R+ strategy. The limitation of the new strategy may be addressed in future studies by avoiding the reliance of DSSR strategy on R+ for the discovery of first failure.

## VII. RELATED WORK

Random testing used in the current study is a popular technique with simple algorithm but a proven method to find subtle failures in complex programs and Java libraries [32], [33]. Its simplicity, ease of implementation and efficiency in generating test cases make it one of the best choices for test automation [15]. Some of the well known automated

tools based on R strategy include Jartege [11], Eclat [32], JCrasher [33], AutoTest [5] and YETI [22].

The R+ strategy is an extension of the R strategy in which interesting values, beside pure random values, are added to the list of test inputs [7]. These interesting values include border values which have high tendency of finding failures in the given SUT [17]. Results obtained with R+ strategy show significant improvement over R strategy [7].

In pursuit of better test results and lower overhead, many variations of R strategy have been proposed. Adaptive random testing (ART) [3], Quasi-random testing (QRT) [20] and Restricted Random testing (RRT) [18] achieved better results by selecting test inputs randomly but evenly spread across the input domain. Mirror Adaptive Random Testing (MART) [19] and Adaptive Random Testing through dynamic partitioning [19] increased the performance by reducing the overhead of ART. The main reason behind better performance is that even spread of test input increases the chance of exploring the failure patterns present in the input domain.

A more recent research study [34] stresses the effectiveness of data regeneration in close vicinity of the existing test data. Their findings showed up to two orders of magnitude more efficient test data generation than the existing techniques. Two major limitations of their study are the requirement of existing test cases to regenerate new test cases and increased overhead due to using “meta heuristics search” based on hill climbing



algorithm to regenerate new data.

## VIII. CONCLUSION

In the present study, we developed a new Dirt Spot Sweeping Random strategy as an upgraded version of the R+ strategy based on the Dirt Spot Sweeping feature, which strengthens the ability of finding more failures in lower number of tests. The DSSR strategy is particularly more effective when the failure domain forms block and strip patterns across the input domain. In addition, the findings of the present study indicated significantly better performance of DSSR in comparison with R and R+ strategies with respect to finding higher number of failures.

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