The Journal of Systems and Software 86 (2013) 970–984

Contents lists available at SciVerse ScienceDirect

The Journal of Systems and Software

journal homepage: www.elsevier.com/locate/jss

Controversy Corner

Search Based Software Engineering: Review and analysis of the field in Brazil

Thelma Elita Colanzi[a,b], Silvia Regina Vergilio[a,*], Wesley Klewerton Guez Assunção[a], Aurora Pozo[a]

[a] Computer Science Department, Federal University of Paraná (UFPR), CP 19.081, CEP: 81531-970, Curitiba, Brazil
[b] DIN, State University of Maringá (UEM), CEP: 87.020-900, Maringá, Brazil

ARTICLE INFO

Article history:
Received 20 January 2012
Received in revised form 10 April 2012
Accepted 14 July 2012
Available online 4 August 2012

Keywords:
Search based algorithms
Metaheuristics
Software engineering

ABSTRACT

Search Based Software Engineering (SBSE) is the field of software engineering research and practice that applies search based techniques to solve different optimization problems from diverse software engineering areas. SBSE approaches allow software engineers to automatically obtain solutions for complex and labor-intensive tasks, contributing to reduce efforts and costs associated to the software development. The SBSE field is growing rapidly in Brazil. The number of published works and research groups has significantly increased in the last three years and a Brazilian SBSE community is emerging. This is mainly due to the Brazilian Workshop on Search Based Software Engineering (WOES), co-located with the Brazilian Symposium on Software Engineering (SBES). Considering these facts, this paper presents results of a mapping we have performed in order to provide an overview of the SBSE field in Brazil. The main goal is to map the Brazilian SBSE community on SBES by identifying the main researchers, focus of the published works, fora and frequency of publications. The paper also introduces SBSE concerns and discusses trends, challenges, and open research problems to this emergent area. We hope the work serves as a reference to this novel field, contributing to disseminate SBSE and to its consolidation in Brazil.

1. Introduction

Software engineering (SE) problems usually involve competing constraints, ambiguous and imprecise information, and large sets of choices/decisions. Solving such problems is, in general, a complex task that has no exact analytical solutions. Consider the undecidable problem of finding a test data set to satisfy a given test criterion. The input domain can be infinite and different test sets can be good solutions. Furthermore, the solutions (test sets) need to satisfy competing constraints related to the test activity such as execution time, efficacy in terms of revealed faults, and so on. In such case, to recognize a good solution can be very easy for the tester, but very hard to obtain. The problems associated to the SE tasks are in many cases like this. For example: to find the best refactoring sequence for a program, to allocate tasks and resource in the best way, to structure the architecture of a system to satisfy different factors, etc.

The solution of such hard problems has been attacked by a novel research field, named Search Based Software Engineering (SBSE). In SBSE, the SE problems are formulated as optimization problems to be solved by search based techniques, which are derived from the fields of operations research, such as linear programming, and metaheuristics, such as Genetic Algorithms.

The term "Search Based Software Engineering" was first used by Harman and Jones (2001). Such paper has been considered a manifesto for SBSE. Since then the number of related publications has increased rapidly, and keeps growing with the creation and establishment of specialized events. We find successful SBSE approaches that show the applicability of search based techniques in a wide variety of problems from diverse SE areas in many different ways, using different search algorithms. As mentioned by Harman (2007), the problems to be attacked by the SBSE are usually related to labor-intensive human tasks, cases where the solution is highly complex, and the software engineer is prepared to wait for an answer. The search approach provides a lower human cost solution, freeing the software engineer to work in other problems that require imagination and creativity.

The SBSE field is growing rapidly in Brazil. The recently formed Brazilian SBSE community has promoted two editions of an event on the area, the Workshop on Search Based Software Engineering (WOES), co-located with the Brazilian Symposium on Software Engineering (SBES). SBES/WOES is an important instrument to bring together the Brazilian SBSE researchers and contribute to consolidate the area in Brazil. In both editions of the workshop, we have observed a great interest in the SBSE field. Their promising results serve as motivation to this paper that presents results of a mapping study of the SBSE field and its community on SBES. The main goal of a mapping study is to provide an overview of a research area and identify the quantity and type of research and results available within it (Petersen et al., 2008). Therefore, the paper introduces SBSE concerns and provides an overview of the works produced by the Brazilian SBSE community, discussing

* Corresponding author. Tel.: +55 41 33613681; fax: +55 41 33613205.
E-mail addresses: thelmae@inf.ufpr.br (T.E. Colanzi), silvia@inf.ufpr.br (S.R. Vergilio), wesleyk@inf.ufpr.br (W.K. Guez Assunção), aurora@inf.ufpr.br (A. Pozo).

0164-1212/$ – see front matter
http://dx.doi.org/10.1016/j.jss.2012.07.041

trends, challenges, and open research problems to this emergent area.

This paper is in fact an extension of our previous work (Vergilio et al., 2011). A new and updated search was conducted, so, new data were collected and added to our body of knowledge. A validation step in the methodology was conducted, and now the results are presented and analyzed in a deeper way.

Following the guidelines described in Petersen et al. (2008), we map the Brazilian SBSE community on SBES by identifying the main researchers, focus of the published works, fora and frequency of publications. We hope this work can disseminate the SBSE area an contributes for researchers and practitioners to better understand this novel field. We expect to stimulate greater interest on students and non SBSE researchers in the application of search based techniques in SE research and practice. Nowadays, Brazil is becoming one of the world's fastest growing major economies. This aroused interest in the Brazilian research. This work presents the most recent innovations produced by Brazilian research groups, and serves as a reference for SBSE in Brazil. This contributes to consolidate the SBSE Brazilian community and to allow a greater cooperation among its members and international researchers.

We hope this work can serve as a reference for researchers and practitioners to better understand this novel field, which contributes to ease SE tasks integrating knowledge of different SE areas.

The paper is organized as follows. Section 2 reviews the SBSE field, providing background in the area of Intelligent Systems, introducing search based techniques and presenting related work. Section 3 details how the mapping was conducted, presenting research questions and describing the steps of our mapping process. Section 4 presents the outcomes produced, results with respect to our research questions. Section 5 discusses trends, challenges, and perspectives of future research works in this area. Section 6 concludes the paper.

2. The SBSE field

In this section we introduce the SBSE field: definition, search based algorithms, benefits, and we also present related works.

2.1. SBSE definition

We find in the literature approaches for solving SE problems that are derived from basically three research sub-fields of the Intelligent Systems area: (a) knowledge representation, reasoning and decision systems (KR&D); (b) machine learning (ML); and (c) optimization.

Approaches from the sub-field of KR&D belong to an active research field named Knowledge Based Software Engineering (KBSE) (Green et al., 1986). KBSE uses techniques from Artificial Intelligence such as rule-based systems, multi-agent systems and fuzzy systems to solve diverse problems and making more knowledge available to individual programmers, teams, and managers facilitate the timely production of high quality software. Fuzzy systems support a diversity of mechanisms of knowledge representation focusing on approximate reasoning in the face of uncertain information. Moreover, fuzzy sets provide the basis for aggregation operators in multi-criteria decision-making and have found application in software cost estimation models.

The ML field is concerned with the design and development of algorithms that allow computers to evolve behaviors based on empirical data. In other words, machine learning algorithms learn to recognize complex patterns and make intelligent decisions based on them. The process to learn from data usually implies that the algorithm must generalize and build a model that will be used in the future to produce a useful output with new data. Many approaches for SE applying ML have been published in the past two decades (Zhang and Tsai, 2003). In general, ML methods are used to predict or estimate: software quality, software size, software development cost, software effort, fault proneness and localization, etc. Another application of ML is for cluster analysis or clustering. Clustering is the assignment of a set of observations into groups called clusters. The observations in the same cluster are similar in some sense. In SE this method can be useful, for example, to group together components (Paixão et al., 2011). K-means and expectation-maximization algorithms for mixtures of Gaussians are the most used algorithms for this task. However, more sophisticate algorithms have been proposed as self-organizing maps, neural networks and evolutionary algorithms (Hruschka et al., 2009).

The optimization field refers to the selection of a best element from some set of available alternatives. The selection of a best element is made based on some performance criteria (objective functions) and a search method. The application of a search method to solve the SE problem is the subject of the SBSE field. An example of SE task to be optimized is to find an architecture of modules that maximizes cohesion and minimizes coupling.

The search algorithms to be used are from two main groups. The first group includes classical techniques from the operations research field like branch and bound algorithm, and linear programming. The classical algorithms are deterministic, i.e., they generally determine only one solution. The other group includes the metaheuristics, such as Evolutionary Algorithms, Particle Swarm Optimization, Ant Colony Optimization, and many others. The metaheuristics are the most preferred in the SBSE field (Harman, 2007). A reason for this is the nature of the SE problems: they are real world problems, and generally are related to objectives that cannot be characterized by a set of linear equations, and they are not tractable by deterministic methods.

As mentioned above, by definition, the field of SBSE is devoted to the application of search based algorithms to support different SE activities. Hence, the use of KR&D and ML approaches are not generally included in the SBSE field. In the SBSE field the SE problem is formulated as an optimization problem to be solved by a search based algorithm. However, it is important to remark that approaches in the ML field also perform optimization tasks in their core, but the optimized problem is the own learning task (clustering, prediction, classification, etc.). In our work, only approaches that directly optimize the SE problem (optimization ones) are considered SBSE approaches.

Some characteristics that make a problem suitable for being attacked using a search algorithm are found in Clarke et al. (2003) and Harman (2006): a large solution space; no known (optimal) efficient and complete solution; existence of acceptable metrics to evaluate the solutions; cheap automatic generation of solutions, with low computational complexity.

Harman (2007) argues that only two key ingredients are necessary: (1) a representation to the problem: that allows symbolic manipulation; and (2) an objective function: defined in terms of the representation to evaluate the quality of the solutions. The SE problems usually have a lot of related metrics that are good candidate for being objective function, and in many cases the software engineer readily has the representation.

Some advantages that SBSE offers for the software engineers are (Harman, 2007, 2010; Harman and Mansouri, 2010): (a) scalability: the search based algorithms have potential for scalability through parallel execution of objective function evaluations; (b) robustness: due to the ability of search based optimization to cope with noise, partial data and inaccurate objective functions; (c) generality: due to the wide prevalence of suitable representations and objective functions, right across the SE spectrum; (d) source of insights: due to the way in which the search process itself can shed light on the problems faced by decision makers; (e) realism: due to the way in which SBSE caters naturally for multiple competing and conflicting engineering objectives; (f) creation of links between apparently unconnected SE areas: some SE areas have their own separate events and journals, however, they can share common formulations as optimization problems. This fact can approximate the research SE communities. The works mention other advantages and characteristics of the SE problems that make it more attractive than the traditional problems in other engineering disciplines (Harman, 2010). This is due to the nature of the SE artifacts that are abstract, and can be directly optimized, by using a set of collected metrics.

2.2. Search based algorithms

In the sequence we review some search based techniques commonly used in SBSE and that have been applied by Brazilian researchers (see Section 4).

The operations research field includes a wide range of problem-solving techniques and methods (Jensen and Bard, 2003) (here called classical techniques) such as linear programming and branch and bound. Linear programming solves problems in which both the objective function and restrictions are linear. Branch and bound can find optimal solutions of optimization problems, such as discrete and combinatorial optimization. It consists of a systematic enumeration of all candidate solutions, where large subsets of fruitless candidates are discarded en masse, by using upper and lower estimated bounds of the quantity being optimized.

GRASP (Greedy Randomized Adaptive Search Procedure) is a metaheuristic algorithm originally proposed for Combinatorial Optimization Problems (Feo and Resende, 1995). It is a multi-start search procedure that repeatedly applies local search from different starting solutions of a search space. The construction phase builds a feasible solution using a greedy randomized strategy. A feasible solution is initially constructed, element by element. A candidate element is a piece that can be incorporated into the partial solution without destroying its feasibility. The candidate elements are ordered using a function that measures their benefit for the solution. The best n-candidate elements are selected to be at the Restricted Candidate List (RCL), where n is a parameter. One element is randomly chosen in the RCL to be incorporated into the solution. Then, candidate elements are re-evaluated and the RCL is updated. Due to randomness, different starting solutions are obtained in each GRASP iteration. Then, local search is applied in order to improve each solution constructed in the first phase.

Evolutionary algorithms are a unify term for several search methods inspired by the natural evolutionary process and integrate the techniques of Genetic Algorithms (GAs), Genetic Programming (GP), evolution strategies and evolutionary programming. In general, the evolutionary algorithms evolve a population of encoded solutions (individuals) manipulated by a set of operators and evaluated by some fitness function. The operators include: reproduction, mutation, recombination, and selection. The fitness function and the selection operators determine which individuals will survive into the next generation. Therefore, the fitness function is associated to the objective function of the problem being solved. These different techniques manipulate different type of individuals and this lead to determine which evolutionary algorithm is most suitable to solve a specific problem. Hence, GP manipulates individuals that are program structures and evolutionary programming manipulates finite state machines. GA-based algorithms are the most popular because their individuals (or chromosomes) are structures able to encode different kind of solutions (reals, binary and others). Another GA based metaheuristic used by Brazilian authors is Generalized Extremal Optimization (GEO) (Sousa et al., 2003). It is like GA but with the advantage of having only one free parameter to adjust.

Evolutionary algorithms have been increasingly investigated for solving multi-objective optimization problems. The main difference between multi-objective and single-objective optimization is the number of final solutions. In multi-objective optimization, a unique solution that simultaneously optimizes all the criteria does not exist, because, usually the objectives are in conflict and to optimize one the others are compromised. Hence, the solutions form a set called the Pareto front, which represents the solutions with better trade off between the objectives. Evolutionary algorithms are particularly suitable for this task because they evolve simultaneously a population of potential solutions to the problem obtaining a set of solutions to approximate the Pareto front in a single run of the algorithm. Some variants of traditional GA adapted to multi-objective problems exist, called MOEAs (Multi-objective Evolutionary Algorithms). To adapt an evolutionary algorithm to a multi-objective problem usually the selection operator takes into account the non-dominance relation, i.e., one solution is better than another if it is better in one objective and it is not worse in any other one.

The most representative MOEA is NSGA-II (Non-dominated Sorting Genetic Algorithm) (Deb et al., 2002) that sorts individuals considering non-dominance relation. SPEA2 (Coello et al., 2006) is similar to NSGA-II, although, it maintains an external archive that stores non-dominated solutions in addition to its regular population. Some of them are selected for the evolutionary process. For each solution in the archive and in the population, a strength value is calculated, which is used as fitness of the individuals. MOCell algorithm (Andrade et al., 2010) is a recent MOEA based on cellular genetic algorithm, a genetic algorithm in which the population is structured in a specified topology. The MOCell uses an external archive to store non-dominated solutions and a mechanism in which solutions from this archive randomly replace existing individuals in the population after each iteration.

The metaheuristic Ant Colony Optimization (ACO) is an example of an artificial swarm intelligence which is inspired by the collective behavior of social insects (Dorigo, 1992). The ACO algorithm aims to search for an optimal path in a graph, based on the behavior of ants seeking a path between their colony and a source of food. In each interaction, each ant adds information in the pheromone trail following the behavior of real ants to find the shortest route between a food source and their nest.

2.3. Related work

The search based algorithms are applicable to novel and different areas of SE with relative easiness and some authors mention this is the reason for the fast growing of the SBSE field, and the explosion of SBSE works (Harman et al., 2009). Therefore, in the last years a great number of SBSE surveys has been published (Harman, 2007; Mantere and Alander, 2005; Clarke et al., 2000). The works report applications on software bug fixing, project management, planning and cost estimation, refactoring, software slicing, software comprehension, service-oriented software engineering, compiler optimization, quality assessment, and so on. There are some specific SE areas that have their own surveys: software test (McMinn, 2004; Ali et al., 2010; Afzal et al., 2009), software design (Räihä, 2010), requirements (Zhang et al., 2008), and maintenance (O'Keeffe and Cinnéide, 2006).

The most related work, with similar objectives to ours, is the work of Harman et al. (2009). The authors conducted a mapping of the SBSE field and some of the presented outcomes were used to evaluate the field in Brazil. The work shows a considerable increase in the number of SBSE papers in the past five years. The number of papers found in 2008 was over 100, more than twice the number of 40 papers found in 2004. Software testing is the most covered area, 59% of the overall SBSE literature are concerned with Search Based

Software Test (SBST). Other areas that reach expressive coverage are: maintenance, distribution and enhancement (11%), design tools and techniques (10%), and management (9%). The SBSE works make use of a wide range of optimization techniques. Considering the survey again (Harman et al., 2009), over 500 papers were analyzed, and the most used metaheuristic is GA (around 350 papers), followed by GP, Simulated Annealing and Hill Climbing. Evolutionary computation has been used in 71% of all papers on SBSE, and it is the only optimization technique to have been applied to every software engineering application area.

We can also find works of Brazilian authors that introduce the SBSE area describing some works found in the literature (Freitas et al., 2009, 2010), and that present an analysis of the field (Freitas and Souza, 2011). However, these works do not specifically address the Brazilian SBSE community.

3. Mapping process

A systematic mapping study was carried out to provide an overview of the SBSE area on SBES. We adopt the mapping process defined by Petersen et al. (2008). The process include the following activities: (a) definition of research questions; (b) conducting the search for relevant papers; (c) screening of papers; (d) keywording of abstracts (classification schema); and (e) data extraction and mapping. In this section we describe how these activities were conducted.

3.1. Research questions

Our main research goal is to capture the SBSE field in Brazil considering the SBSE community on SBES. In order to reach such goal we formulated a set of research questions described as follows.

- *RQ1: How many SBES papers are on SBSE and has the frequency of SBSE works changed over time?* This question investigates the role that SBES plays for the Brazilian SBSE field. It helps to known how is the SBES production on SBSE considering the other Intelligent Systems fields and all the production of the Brazilian SBSE community. It aims at checking how this production is evolving over the years, mainly considering the last two WOES editions.
- *RQ2: What are the addressed software engineering areas and how many papers cover the different areas? How has this been evolving?* Historically the area of software testing is the most investigated area. But this has been changed last years in the international scenario. Has the same phenomenal been occurring in Brazil?
- *RQ3: What are the preferred optimization techniques and has this changed over time?* Over time Genetic Algorithms and other evolutionary ones have been the most used algorithms, but nowadays other ones have been also investigated. What are they?
- *RQ4: Who are the main researchers on SBSE according to the number of papers and how are the collaborations?* Since the SBSE community on SBES has been just formed, this question helps in the identification of the most prominent authors and the collaboration level among them.
- *RQ5: In which fora have the papers been published and what are the impacts of these publications?* There are few events and workshops devoted to SBSE. Besides them, there are other fora where research may be published. What are they? What kinds of vehicles are preferred?

3.2. Conducting search and screening of papers

The search for relevant publications was finished at December 23rd 2011 and it was conducted in three steps, see Fig. 1. In a first step we searched for papers published in SBES from 1992 to 2011.

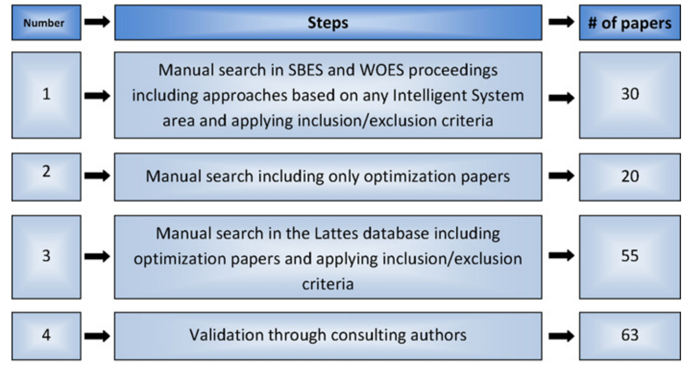


Fig. 1. Main steps of the search for relevant papers.

We also included in this search both editions of WOES (2010 and 2011), the Brazilian Workshop on SBSE. Some proceedings were available only as hard copies and other as soft copies from digital libraries, so the performed search was manually conducted by two authors, without using a search engine string. The authors first examined the title and abstract of the papers, and if necessary the introduction and some parts of the paper. We consider the following inclusion/exclusion criteria in this step.

- inclusion criteria: the paper presents an approach for solving a software engineering problem or survey based on any area of the Intelligent Systems (KR&D, ML and SBSE (optimization)).
- exclusion criteria: papers related to keynotes, communications, posters, tutorials, panels, and Tools Session were not included.

The application of the abovementioned criteria resulted in 30 papers. This give us an idea of the Intelligent Systems areas which are most used for solving SE problems in papers of SBES.

In a second step, papers that are not related to optimization (SSBSE) area were excluded, resulting in 20 papers.

In a third step we created a list of authors that published papers in SBES and WOES in order to identify the researchers that are involved with SBSE in Brazil. We also added to this list Brazilian authors (affiliated to a Brazilian institution) that appear in section Who's Who in SBSE.[1] From this complete list, we searched the Lattes database[2] and applied the following criteria:

- inclusion criteria: the paper presents an approach for solving a software engineering problem or survey based on the SBSE/optimization area.
- exclusion criteria: keynotes, communications, posters, tutorials, panels, short papers and technical reports were not included. The kind of event was not distinguished. The number of pages was not compared.

In this step we found 35 additional papers, resulting in a total of 55. The last step was the validation of the first three by consulting authors related in the created list. In this step the same inclusion/exclusion criteria of the third step was adopted, resulting in 8 additional papers. At the end a set of 63 papers were analyzed and classified.[3]

[1] http://crestweb.cs.ucl.ac.uk/resources/sbse_repository/whoswho/.
[2] A Curriculum and institutions database of Science and Technology areas in Brazil; http://lattes.cnpq.br/english.
[3] The raw data can be found at www.inf.ufpr.br/gres/apoio_en.html.

Table 1
Classification scheme.

Dimension	Categories
SE area	Surveys (D.2.0.e – Surveys of a particular area); Management (D.2.9 – Management); Requirements (D.2.1 – Requirements/Specifications); Testing and Debugging (D.2.5 – Testing and Debugging); Other Subjects (D.2.0.i – Validation, D.2.2 – Design Tools and Techniques)
Search technique	Classical Algorithms; GRASP; GA; GP; ACO; MOEA; Other evolutionary algorithms
Publication fora	National events; National Journals; International events; International Journals

3.3. Classification scheme

According to our research questions, the papers were classified into categories in three dimensions: addressed software engineering area, used search technique and publication forum. For the first dimension, software engineering areas, we decided to use the same classification adopted in the related work (Harman et al., 2009): the ACM Computing Classification System.[4] With respect to the second dimension, two main categories exist: classical and metaheuristic techniques. And for the third dimension, we consider national and international fora, and separated events from journals. The schema evolved in the process mainly during the data extraction, by grouping and splitting some categories. The final schema adopted is presented in Table 1. Some categories with lower number of papers were grouped. We decided to divide the metaheuristics to specify the kind of evolutionary algorithm used. We also considered the number of objectives, and whether a multi-objective treatment to the problem is applied.

3.4. Data extraction and mapping

In order to answer the research questions, we analyzed the extracted data quantitatively. Regarding data collection, the abstract, introduction and conclusion paper sections were read and the following information were extracted: Authors; Universities and Companies; Publication Year; City/State; and information needed to categorize the work using the previously defined scheme.

3.5. Threats to validity

In this section threats to the validity of our mapping study are analyzed. The construct validity is concerned to the research questions and mapping process. To minimize this kind of threat, we had several discussions about the questions and goals of our search. We think the research questions reflect the goals of our work, i.e., mapping the Brazilian SBSE community on SBES by identifying the main researchers, focus of the main published works, fora and frequency of publications. In fact the results obtained might not have covered all the Brazilian SBSE researchers and works. The mapping process is oriented to the SBES community, however, it might exist other researchers that publish in other fora (such as Brazilian Symposiums on Artificial Intelligence and Operations Research). To minimize the effects of such threat, we performed a search for authors in the section of Who's Who is SBSE.

Other source of threats is the websites searched that cannot be updated. We mitigated those threats by adding a validation step in our process with participation of the researchers. In such step, around 90% of the authors answered our messages, improving our confidence.

Considering reliability of our research, we can find some threats. Since many SBES proceedings are not in a digital format, the data collection was conducted manually. As a consequence some errors could be introduced in this phase, and the replication of our search can be very difficult. Other source of threats is the classification schema. Other researchers may possible obtain another schema. The works were classified based on our judgment. To mitigate such threats, two authors conducted the search and the classification, reading some parts of the work if necessary, and the other two validated the work. The researchers were consulted reducing mistakes.

Internal validity is concerned to analysis of the data. Since our analysis uses only descriptive statistics the threats can be considered minimal.

4. Outcomes

In this section, every research question is answered as an outcome of the data extraction and mapping. The classification schema is used and different pictures are presented to analyze the obtained results.

4.1. SBSE and SBES

As mentioned before, in the first step of our search we considered all the Intelligent Systems sub-fields (Section 2). Fig. 2(a) and (b) shows the distribution of found papers by each sub-field, considering, respectively, only SBES papers and SBES-WOES papers.

Among SBES papers, we can observe that 50% (6 papers) are on optimization. This shows the great interest of the Brazilian community in SBSE. In SBES, the field of KR&D is also well established, representing 50% of the papers. When WOES (the Brazilian SBSE Workshop) papers are counted together with SBES, 64% are on optimization. Furthermore, papers on ML approaches appear and there is one paper about SBSE evaluation.

Considering the papers obtained at the end of all steps, i.e. only SBSE (optimization) papers, we analyzed the frequency of SBSE publications along the years. In Fig. 3 such frequency is presented considering SBES papers, WOES papers and other fora. We can observe that the frequency of published SBSE papers has been increasing recently, mainly after 2009. But in SBES, this frequency is stable since 1999, when the first paper was published. However, despite of low frequency of SBSE papers in SBES, the frequency of national papers published has increased in the last two years due to WOES. Hence, since WOES is co-located with SBES, we can say that SBES plays an important rule for the SBSE field development in Brazil.

So, aiming at answering **RQ1**, we can state that, unfortunately, the number of SBSE papers published in SBES is low considering all of the SBSE papers published by Brazilians in other fora. And, the frequency of SBSE papers in SBES has improved in the last two years due to WOES, but in the main track of SBES this frequency had not changed.

4.2. Software engineering areas

In order to answer **RQ2** the papers were grouped by SE areas according to our classification schema and considering SBES and SBES-WOES papers. Information about the main areas addressed is illustrated in Fig. 4(a)–(c).

We can observe that in Brazil, like reported in related work and mentioned in Section 2.3, software testing is the area that receives significant attention from the researchers: 60% (and 67% considering only SBES papers) are dedicated to testing. Testing was the first

[4] www.computer.org/portal/web/publications/acmsoftware.

(a) SBES papers (b) SBES and WOES papers

Fig. 2. Intelligent Systems sub-fields.

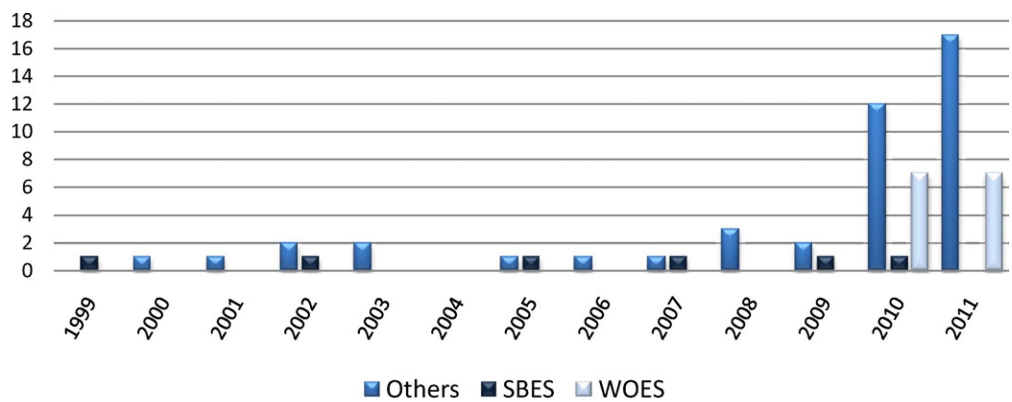
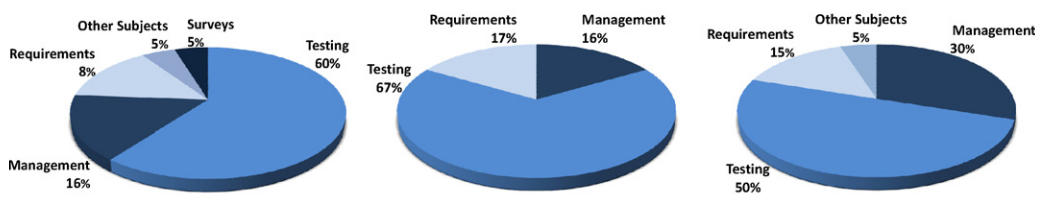


Fig. 3. SBSE papers.



(a) All papers (b) SBES papers (c) SBES and WOES papers

Fig. 4. Software Engineering areas.

area to be tackled by the SBSE researchers, with a large number of publications associated in the international scenario. A possible explanation is based on the nature of the test activity, i.e., test is an expensive and labor-intensive activity. The automation of hard test tasks can benefit a lot from the application of metaheuristics. It is interesting to observe that all the papers published on SBSE from 1999 until 2007 were about search-based software testing.

If we analyze the SE areas addressed along the years (see Fig. 5), we can observe that the first works focused only testing. This context changed in 2008, when management appeared in the scenario, and since then other SE areas. However, we can also observe that the interest in testing is not decreasing. Therefore, this change only indicates that other new application areas of SE are emerging.

Testing is followed by management and requirements. However, differently of what happens in the international scenario and in the WOES, management and requirements receive the same attention in SBES. Other areas are not addressed by SBES papers.

Considering all papers, 5% of them are about other subjects, such as SBSE evaluation and web services composition. Table 2 contains the list of the found papers grouped by area and task addressed. The papers, except the surveys, are briefly described next.

4.2.1. Management

Management is an area where a large variety of search based approaches were applied, with the goal of optimizing both the process of software production as well as the generated product. The analyzed works address different activities mainly related to project planning: scheduling, and tasks and resource allocation. The works are presented next, grouped by each focused task.

In Magdaleno et al. (2010) the software process adaptation is modeled as an optimization problem considering collaboration and discipline as restrictions to be balanced to reduce effort and improving the software process.

The work of Netto et al. (2010) describes a GA method for scheduling error-correction tasks. The goal is to find a schedule that minimizes the time to finish the tasks considering some priority constraints. A similar work (Andrade et al., 2010) based on the multi-objective optimization algorithms, NSGA-II and MOCell, generates a list of defects to be first fixed according to different factors related to views of the software team and client. In Andrade et al. (2011) the same problem was solved by using NSGA-II and MOCell algorithms aiming at selecting the best way to distribute resources, efforts and next releases to perform the error-correction tasks.

The allocation of teams is addressed in Ferreira et al. (2010), Coutinho et al. (2010), Santos et al. (2010), Ribeiro and Elias (2011) and Rocha et al. (2011). In Ferreira et al. (2010) a GA is applied to establish development teams considering the task needs, ability and preferences of each team member. In Coutinho et al. (2010) multi-objective GA-based algorithms are explored. With the same goal, team allocation, the work of Barreto et al. (2008) also

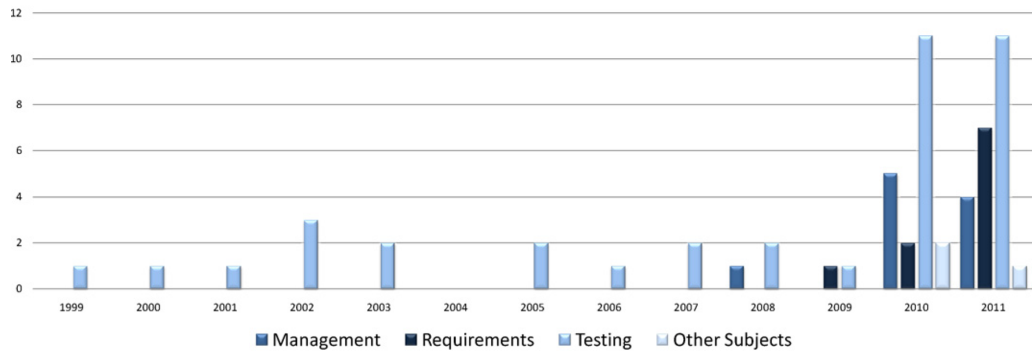


Fig. 5. Software Engineering areas addressed along the years.

Table 2
SBSE papers and Software Engineering areas.

SE area	Task	Works
Survey	SBSE and SBST	Freitas et al. (2009, 2010) and Freitas and Souza (2011)
Management	process optimization	Magdaleno et al. (2010)
	task allocation	Netto et al. (2010) and Andrade et al. (2010, 2011)
	team allocation	Ferreira et al. (2010), Coutinho et al. (2010), Barreto et al. (2008), Santos et al. (2010), Ribeiro and Elias (2011) and Rocha et al. (2011)
	software technologies selection	Neto and Rodrigues (2011)
	selection of project portfolio	Figueiredo and Barros (2011)
Requirements	Next Release Problem	Brasil et al. (2010, 2011a,b), Linhares et al. (2010), Colares et al. (2009), Silva et al. (2011), Freitas et al. (2011a,b) and Souza et al. (2011)
Software testing	test case prioritization	Maia et al. (2008, 2009, 2010a,b) and Farzat and Barros (2010)
	test-data generation	Jino and Bueno (1999), Bueno and Jino (2000, 2001, 2002), Bueno et al. (2007, 2008, 2011), Ferreira and Vergilio (2003, 2005), Abreu et al. (2005, 2007), Yano et al. (2010, 2011), Araki and Vergilio (2010) and Pinto and Vergilio (2010a,b)
	test case selection and evaluation	Emer and Vergilio (2002a,b, 2003), Vergilio and Pozo (2006) and Banzi and Pinheiro (2011)
	integration testing	Cabral et al. (2010), Galvan et al. (2010), Assunção et al. (2011a,b,c,d), Colanzi et al. (2011a,b)
	selection of strategies	Dias Neto et al. (2011) and Neto and Rodrigues (2010)
Other subjects	web services composition	Campos Junior et al. (2010)
	sbse evaluation	Souza et al. (2010) and Barros and Neto (2011)

considers human resources, and other organization constraints to allocate teams, but differently solves the problem with a precise and deterministic method. The problem is modeled as a constraint satisfaction problem. The work describes a decision support tool that allows the manager to select a function to be maximized (or minimized), according to the project needs. In Rocha et al. (2011), NSGA-II is compared with the expert solution for two problems simultaneously solved: (i) team allocation and (ii) task scheduling. As a result, some NSGA-II solutions dominate the expert solutions.

Communication problems can occur when there are allocations of implementation tasks among globally distributed teams. In order to mitigate such communication issues, Ribeiro and Elias (2011) proposed a GA-based approach for allocating distributed development teams to implementation tasks of software modules, taking into account both non-technical features of teams and dependences among software modules. In Santos et al. (2010) a fuzzy logic based approach is proposed in order to select technically skilled teams to implement software modules of distributed software product line projects. In this work, the fuzzy logic is applied to select the skilled teams and a GA is used to team allocation.

In Figueiredo and Barros (2011) a GA-based approach to allow a software project portfolio selection technique was proposed to be used in scenarios with a large number of candidate projects to compose the portfolio. Such approach was compared with a local search technique (Hill Climbing) and a non-systematic search technique (Random Search), and it achieved better results than the other algorithms.

The work of Neto and Rodrigues (2011) presents a proposal to model the software technologies selection problem as a combinatorial optimization problem (minimum dominating set) aiming attending different real scenarios in software engineering. The proposed framework aids to select the more appropriated software technologies to be used in a project.

4.2.2. *Requirements*

A problem, known in the literature as *Next Release Problem* (Zhang et al., 2007), has been addressed by some Brazilian researchers. The goal is to find an ideal set of requirements for a software release that balance different objectives such as customer's requests, resources constraints, and requirement characteristics. Multi-objective algorithms are generally applied. In Brasil et al. (2010, 2011a,b) the problem is addressed by using NSGA-II and MOCell considering customer satisfaction and risk management. Also using NSGA-II, other constraints are addressed in Colares et al. (2009), such as: stakeholders' satisfaction, costs, deadlines, available resources, efforts needed, risks management and requirements interdependencies. NSGA-II was also compared with branch and bound in Silva et al. (2011). In Freitas et al. (2011a,b) the same problem is solved by using classical techniques (branch and bound) in the presence of dependent requirements.

In Souza et al. (2011) the ACO algorithm was adapted to solve the software next release problem in the presence of dependent requirements. In comparison with GA and Simulated Annealing, the ACO algorithm generated more accurate solutions for this problem.

Finally, the use of the metaheuristic GRASP to the same problem is described in Linhares et al. (2010).

4.2.3. Software testing

As mentioned before, the area of software testing is the most important SE area of Brazilian SBSE. Search based techniques have been applied to different test tasks and related activities, however we can observe in Table 2 that most works on SBST focuses test data generation. In general, optimization techniques are used to search in a large space (input domain) for solutions (test data sets) that satisfy some test goals which can be, for instance, to improve a test criterion coverage and to cover a given path or statement of the program. Significant percentage of them address structural and program based test.

The first work on SBST (Jino and Bueno, 1999), reported in SBES-1999, generates test data to execute complete paths in program. The work uses a GA to search an initial population based on past input data obtained by using dynamic execution and Case-base Reasoning. The fitness function uses data flow information and a heuristic is introduced that analyses the evolution process to determine infeasible paths. Experiments are conducted comparing with a random strategy (Bueno and Jino, 2000, 2001, 2002). In Bueno et al. (2007) Bueno and Jino introduce a measure used to compute the diversity of a test data. This measure is used by metaheuristics to generate test data with more diversity considering the input domain. Improvements are presented by the authors in Bueno et al. (2008, 2011) a simulated repulsion algorithm is used to improve variability among the test input values and fault detection capacity.

In Ferreira and Vergilio (2003) a GA-based framework, named TDSGen, is described. It works integrated with two test tools to test data generation for structural and fault-based criteria. The fitness function is oriented to the coverage of the criteria implemented by the tools. After this, the framework was extended with tabu search techniques and other hybridization mechanisms, and results showing improvement in the performance are reported in Ferreira and Vergilio (2005). Improvements in the GA performance are also proposed in the work of Abreu et al. (2005), which uses the GEO algorithm to test data generation to cover required paths. In another work (Abreu et al., 2007) the authors successfully use the same algorithm to deal with paths that have loops.

Some recent works address structural criteria for Object Oriented (OO) programs considering Java bytecode (Araki and Vergilio, 2010; Pinto and Vergilio, 2010a,b) and explored multi-objective optimization algorithms. The works (Pinto and Vergilio, 2010a,b) use different objectives to be satisfied by the test data. Besides test coverage, memory consumption, efficacy and execution time are also evaluated to evolve a population of test sets.

In the context of model-based test, we can mention the works of Yano et al. (2010, 2011), on test data generation of test sequences from Extended Finite State Machines. The works introduce an executable model to generate only feasible sequences to cover a test purpose (generally a state transition). The generation involves two objectives beside the coverage; the algorithm also minimizes the size of the generated sequences.

A common characteristic of the mentioned works on test data generation is that they usually used the random strategy to evaluate the proposed ideas. Some of them (Abreu et al., 2005, 2007; Ferreira and Vergilio, 2005; Pinto and Vergilio, 2010b) use a traditional GA-approach to show performance improvements and benefits.

In addition to test data generation, other test tasks were also addressed: selection and evaluation of test sets, integration test, prioritization of test sets and test management.

The work of Emer and Vergilio (2002a) introduces a GP-approach to generate alternative programs to be used as mutants to the program under test. The approach works as a test criterion; the alternatives are used to selection and evaluation of test data sets. A supporting tool based on the framework named Chameleon (Vergilio and Pozo, 2006), is described in Emer and Vergilio (2002b) and experimental results comparing with traditional mutation test are presented in Emer and Vergilio (2003). In the same context, in Banzi and Pinheiro (2011) an multi-objective strategy was proposed to select mutation operators by using Tabu Search.

The integration test has been addressed considering OO and AO (Aspect Oriented) programs, in this problem, it is necessary to establish a test order to integrate modules that minimizes the stubbing costs. A stub is required when dependencies cycles between class (or aspects) exist, and the problem of establishing such orders are related to many factors that are generally in conflict. For example: number of attributes, number of methods, number of return and parameters types, contractual and development aspects, etc. For such cases there is no a single solution, and all these factors can be used as objective functions for the metaheuristics. In the AO context, a GA approach was introduced and presented better results when compared with traditional strategies (Galvan et al., 2010). The approach considers as fitness function the number of attributes and methods. In the OO context, multi-objective algorithms were explored. In Cabral et al. (2010) the multi-objective algorithm based on Ant Colony Optimization (PACO) presented better results than a traditional GA-approach, considering number of attributes and methods. Recently other objectives have been explored in OO programs (Assunção et al., 2011a,b,c), comparing different evolutionary algorithms: NSGA-II, SPEA2 and PAES. Multi-objective algorithms were also explored in the AO-context by using NSGA-II and SPEA2 and different measures (Colanzi et al., 2011a,b; Assunção et al., 2011d).

Other test task that benefits of the search based techniques application is regression test. When changes occur in a software, ideally all the available test sets should be re-executed, however, to reduce costs, only a sub-set should be selected, or the existing test sets should be ordered according to some test priorities. For example, the works (Maia et al., 2008, 2010a) use GRASP metaheuristic to test set prioritization considering the coverage and execution time factors. The algorithm presented better results compared with other ones, such as: GA, Simulated Annealing and Greedy. A more complete formulation of the problem is introduced by the authors in Maia et al. (2009, 2010b) considering other factors related to the test cases such as risk, execution time, and requirements-based metrics (volatility and importance). In such works the multi-objective and evolutionary algorithm NSGA-II is used. The work of Farzat and Barros (2010) selects test cases to maximize coverage and diversity, considering execution time and altered functionalities.

To reduce test efforts and to help in the selection and combination of techniques for model based testing, Dias Neto et al. (2011) and Neto and Rodrigues (2010) introduce a multi-objective approach, named Porantim-Opt. The approach is based on greedy algorithm (local search).

4.2.4. Other subjects

To help in the development phase, the composition of Web Services was addressed as a multi-objective problem in Campos Junior et al. (2010). The services are associated with different quality indicators: runtime, price, availability, reliability and reputation given by opinions of the users. The solutions are obtained with the NSGA-II algorithm and analyzed by using preference relations between the indicators.

Most recent works address an important topic that is the validation of SBSE with respect to its human competitiveness. In Souza et al. (2010) some typical problems addressed by search algorithms were solved by metaheuristics and software engineers and the performance of both were compared. The problems addressed are: the

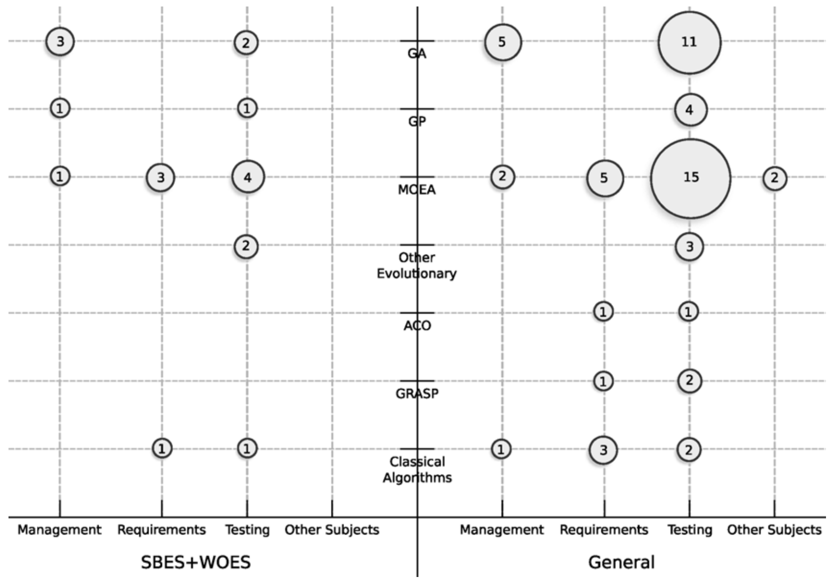


Fig. 6. Bubble plot of the Brazilian SBSE papers.

Next Release Problem, workgroup formation, and test case selection. The work shows that the results obtained by SBSE approaches are human competitive. Another paper address points to be considered aiming at reducing the threats in SBSE works (Barros and Neto, 2011).

4.3. Search based techniques

In this section, the SBSE papers are analyzed aiming at finding what are the preferred optimization techniques (**RQ3**). In this analysis the surveys were excluded, as well as two papers that present a generic optimization approach or validation without mentioning any technique.

Evolutionary techniques are preferred (81%). Among them the GA-based are predominant, and we can also mention GP and GEO. Classical techniques are applied by 8% of the works: in this category Greedy and branch and bound are the most used techniques. Despite over time GAs and other evolutionary ones have been the most used algorithms, other ones have also been investigated, for instance, GRASP is used by 5% of the works and ACO is used by two works.

Other important concern is that 48% of the papers apply multi-objective approaches. The majority uses multi-objective evolutionary techniques (among the evolutionary algorithms, almost 53% are multi-objective). NSGA-II is the most used MOEA, but we can cite other evolutionary ones: SPEA2 and MOCell.

Fig. 6 presents the number of SBSE papers that use some kind of optimization technique per SE area. The left side of the bubble plot depicts only SBES and WOES papers and the right side depicts all papers. MOEAs and GAs are the most used algorithms. However, GAs were not used to solve requirements problems. On the other hand, MOEAs were applied in papers of all SE areas. Considering all works, all kinds of optimization algorithms were used to solve problems related to testing. In the context of SBES, besides classical algorithms, only evolutionary algorithms were used (GA, GP, MOEAs).

4.4. Brazilian researchers and collaborations

In order to identify the main researchers and to answer **RQ4**, we have compiled a ranking considering Brazilian authors that have published at least four papers on SBSE. The main authors receive the same score as co-authors. If the author belongs to more than one institution, both were counted. Table 3 presents a list ordered according to the total number of publications, including event and journal works. The three most prolific authors have participated in more than 20% of the SBSE publications. There are a large gap among these three authors and the others from the ranking.

Considering the 63 analyzed papers, there are 56 authors. However, authors who published only one paper represent the largest group, formed by 26 researchers. The authors are from different universities distributed around different regions of the country: UECE, UFPR, UNICAMP, UNIRIO and UFAM. This distribution shows potential for dissemination over all the country, which contributes to consolidate the research field in Brazil. Fig. 7 shows the number of publications and the number of authors over the Brazilian map. In cases in which the papers have more than one author from different regions, the publication was counted for all the regions. The size of the circles represents the number of authors in that place. The greater number of authors is in UECE (Fortaleza/Ceará) and in UFPR (Curitiba/Paraná), the same universities that have the greater number of publications.

The number of researchers from UNICAMP (Campinas/São Paulo) is lower than UFPR and UECE's numbers, but the authors

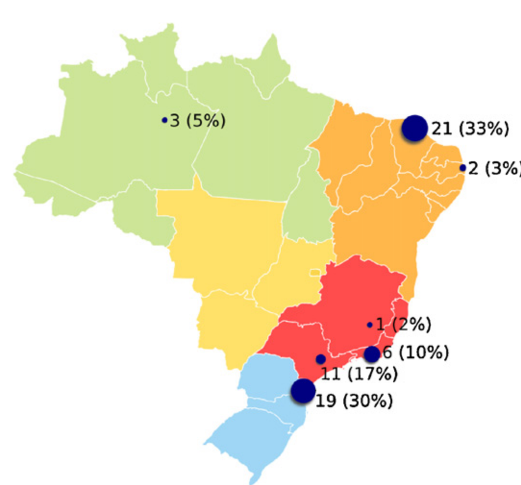


Fig. 7. Map of SBSE researchers and publications.

Table 3
Ranking of Brazilian authors with more than 3 papers.

Author	University	Events		Journals		Total	%
		I	N	I	N		
Jerffeson T. Souza	UECE	5	16	2	1	24	28.92
Silvia R. Vergilio	UFPR	7	10	2		19	22.89
Fabricio G. Freitas	UECE	4	12	2	1	19	22.89
Aurora T. R. Pozo	UFPR	3	7	1		11	13.25
Camila L. B. Maia	UECE	2	7	1	1	11	13.25
Rafael A. Carmo	UECE	1	6	1		8	9.64
Mario Jino	Unicamp	4	1	2		7	8.43
Paulo M. S. Bueno	Unicamp	4	1	2		7	8.43
Daniel P. Coutinho	UECE	1	5	1		7	8.43
Thiago G. N. Silva	UECE	2	5			7	8.43
Gustavo A. L. Campos	UECE		4	1	1	6	7.23
Marcio O. Barros	UNIRIO		5	1		6	7.23
Marcia M. A. Brasil	UECE	3	3			6	7.23
Thelma E. Colanzi	UFPR/UEM	2	4			6	7.23
Wesley K. G. Assunção	UFPR	2	4			6	7.23
Eliane Martins	Unicamp	2	2			4	4.82
Fabiano L. Sousa	Unicamp	2	2			4	4.82
Mariela I. Cortés	UECE	2	2			4	4.82
Arilo C. Dias Neto	UFAM	1	3			4	4.82

Table 4
Published papers by university along the years.

Year	Universities							
	Unicamp	UFPR	UECE	Unirio	UFRJ	UFAM	UFPB	UFMG
2011	2	7	9	2	1	3	1	–
2010	1	6	9	3	1	1	1	–
2009	–	–	3	–	–	–	–	1
2008	1	–	1	1	1	–	–	–
2007	2	–	–	–	–	–	–	–
2006	–	1	–	–	–	–	–	–
2005	1	1	–	–	–	–	–	–
2004	–	–	–	–	–	–	–	–
2003	–	2	–	–	–	–	–	–
2002	1	2	–	–	–	–	–	–
2001	1	–	–	–	–	–	–	–
2000	1	–	–	–	–	–	–	–
1999	1	–	–	–	–	–	–	–

from UNICAMP published the first SBSE paper in SBES (1999) and they have published SBSE papers with regularity along the years (1999–2011). The same happens with the group from UFPR. This can be observed in Table 4. Both pioneer groups of researchers, as it was expected, have been working on software testing. The other groups are recently formed and address other SE areas.

Considering the optimization technique, only three universities have used MOEAs: UECE, UFPR and UNICAMP. ACO was used only in papers from UECE's and UFPR's authors. Branch and bound was applied in papers published by authors from UECE and UNIRIO. Authors from all mentioned universities published papers using GA, the most used technique, except from UFAM. Other techniques, such as Greedy, GP, GRASP and GEO were applied in works from only one university: UFAM, UFPR, UECE, UNICAMP, respectively. We can say that researchers have their preferred search technique.

The Brazilian SBSE community has been just composed, and then there are few papers written collaboratively. The first collaboration was between UNIRIO and COPPE/UFRJ in 2008, and they published two papers together (Magdaleno et al., 2010; Barreto et al., 2008). More recently collaborations were established between UECE and UFMG (Colares et al., 2009), UFAM and COPPE/UFRJ (Dias Neto et al., 2011), UNIRIO and UFAM (Barros and Neto, 2011), UFPR and UEPG (Campos Junior et al., 2010) and UFPR and UEM (Assunção et al., 2011a,b,c,d; Colanzi et al., 2011a,b). Most of them obtained from the cooperation between advisors and advisees.

4.5. Main fora and research impacts

In this section the SBSE papers are analyzed in terms of impact and publication forum (**RQ5**). As mentioned before and shown in Fig. 3, the number of SBSE published papers has increased since 2008. 60% of the papers are national publications and 40% are international. Since 2009 the number of national publications has increased (see Fig. 8). The high number of published papers in 2010 and 2011 (in fact, an explosion of works) is due to WOES, which counts with the greatest number of published papers.

Most of the publications are on events (86%, out 63). There are few events and workshops devoted to SBSE. Besides them, there are other fora where research may be published. In the Brazilian context, we can mention SBES and other ones from the area of Computational Intelligence (SBRN), software testing (WTF) and operations research (SBPO). Table 5 contains the ranking of the events that published more than one of Brazilian papers. The majority of the works are published in national events (WESB, SBPO and SBES), but there are publications in well-qualified international events too (GECCO, SSBSE, ICST, etc.). It is interesting to note that all publications on SBPO came from the same university (UECE).

Journal papers are only 14%. Table 6 presents all the journals that published SBSE Brazilian papers with their respective number of publications and percentage.

Regarding to the impact of these publications we have compiled a ranking with the most cited works in Scopus and Google Scholar (GS). Table 7 shows the works that have at least 5 citations

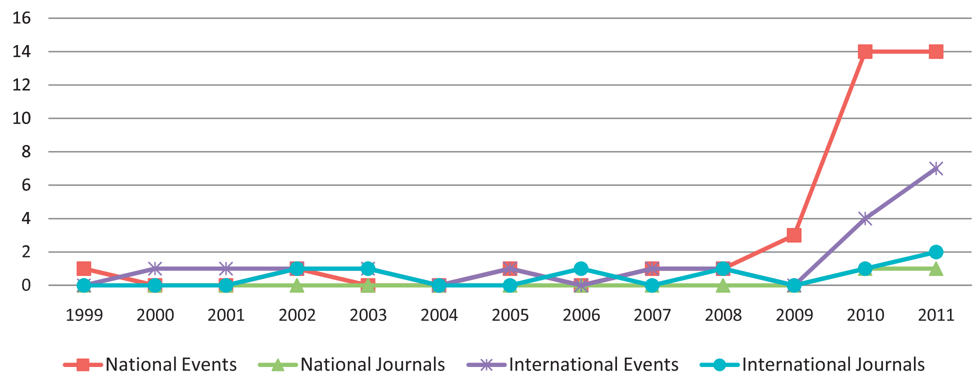


Fig. 8. Evolution of the published works along the years.

Table 5
Ranking of events with more than one paper.

Event	Scope	#	%
Brazilian Workshop on Search Based Software Engineering (WOES)	N	14	25.45
Brazilian Symposium on Operational Research (SBPO)	N	7	12.73
Brazilian Symposium on Software Engineering (SBES)	N	6	10.91
Symposium on Search-Based Software Engineering (SSBSE)	I	4	7.27
Genetic and Evolutionary Computation Conference (GECCO)	I	2	3.64
IEEE International Conference on Testing, Verification and Validation (ICST)	I	2	3.64
International Conference on Software Engineering and Knowledge Engineering (SEKE)	I	2	3.64
Latin-American Workshop on Aspect-Oriented Software Development (LA-WASP)	N	2	3.64
InfoBrasil	N	2	3.64
Workshop on Test and Fault Tolerance (WTF)	N	2	3.64

on Scopus. Considering that most SBSE papers were published in the last two years, they have not a great number of citations in Scopus and GS yet. Another important observation is that the majority of the most cited works were published in international journals or events. This fact points out that the Brazilian events and journals have not so great impact in the international context.

Table 8 contains the number of citations on GS for each work related in Table 7. Thus, it is possible to analyze the citations of a particular work in each year. In this table we also present the minimum, average and maximum numbers of citations per year considering all SBSE papers. Some papers have being cited through the years even though they are not recent papers. In the other hand, papers published in 2010 (7 and 10) were highly cited in 2011.

Despite the Brazilian SBSE papers not having so high number of citations in Scopus when compared with the papers published by international authors, some of our works have achieved important results. For instance, the branch predicate fitness function using similarity reasoning and Hamming distance proposed by Bueno and Jino (2002) appears to be especially well suited to generate data for path testing, outperforming all other methods in seven of the eight experiments performed by Watkins and Hufnagel (2006). The work of Buzzo (2011) corroborates this fact, since in the Buzzo's work the fitness function proposed in Bueno and Jino (2002) was also considered the best.

Table 6
Ranking of journals.

Journal	#	%
International Journal of Software Engineering and Knowledge Engineering	2	25
Advances in Software Engineering	1	12.5
Information Sciences	1	12.5
International Journal of Computer Applications	1	12.5
Computers & Operations Research	1	12.5
Revista de Sistemas de Informação da FSMA	1	12.5
Software Quality Journal	1	12.5

5. Trends on SBSE in Brazil

With respect to the future of the SBSE research and practice in Brazil, we identify some trends, by analyzing the papers published in the last two years and the current state of SBSE in the international scenario (Harman et al., 2009). Next, these trends and potential directions for future works are discussed.

5.1. SE areas

Despite SBSE has a great potential to optimize the most diverse SE problem comprising any software development phase, only three main SE areas are addressed by the Brazilian papers: testing, requirements and management, however, it was observed this has been changing in the last years. Similar phenomenon occurred in the international scenario (Harman et al., 2009). Considering such equivalence, examples of areas that are expected to be addressed in the next years are: maintenance, reuse, and refactoring.

The following SE areas, in our opinion, have challenging problems to be focused. For instance, the distributed software development is associated to different problems that involve to find trade-offs between diverse factors to decrease efforts and costs, as well as, the development of Web applications and embedded systems. There is also great potential for SBSE application in the area of software agents (given their intelligent nature), and test driven development (given the close relationship with the test activity). The area of software architecture can also benefit of SBSE, including optimization concerns related to the modularization, patterns, aspect-oriented programming, cloud based architectures, etc.

In addition to this, the results point out that the interest in the testing area will continue. Some challenges to be addressed in software testing are the test data generation for test criteria in AO context, distributed and parallel software. For this kind of software the execution of a test data is not deterministic, and this can complicate the use of the existing test approaches. Other related areas to be addressed are debugging, security and protection.

Table 7
The most cited SBSE works (ordered by Scopus).

N.	Ref.	Authors	Work	Event/journal	Scopus/GS
1	Bueno and Jino (2002)	P. M. S. Bueno and M. Jino	Automatic Test Data Generation for Program Paths Using Genetic Algorithms	International Journal of Software Engineering and Knowledge Engineering	22/37
2	Barreto et al. (2008)	A. Barreto, M. Barros and C. Werner	Staffing a software project: A constraint satisfaction and optimization-based approach	Computers &Operations Research	15/345
3	Bueno and Jino (2000)	P. M. S. Bueno and M. Jino	Identification of Potentially Infeasible Program Paths by Monitoring the Search for Test Data	International Conference on Automated Software Engineering (ASE)	13/32
4	Bueno et al. (2007)	P. M. S. Bueno and M. Jino	Improving Random Test Sets Using the Diversity Oriented Test Data Generation	International Conference on Automated Software Engineering (ASE)	6/15
5	Emer and Vergilio (2003)	M. C. Emer and S. R. Vergilio	Selection and Evaluation of Test Data Based on Genetic Programming	Software Quality Journal	6/13
6	Emer and Vergilio (2002b)	M. C. Emer and S. R. Vergilio	GPTesT: A Testing Tool Based on Genetic Programming	GECCO	5/11
7	Souza et al. (2010)	J. T. Souza, C. L. Maia, F. G. Freitas and D. P. Coutinho	The Human Competitiveness of Search Based Software Engineering	SSBSE	5/7
8	Abreu et al. (2007)	B. Abreu, E. Martins and F. L. Sousa	Generalized Extremal Optimization: a Competitive Algorithm for Test Data Generation	SBES	5/7
9	Abreu et al. (2005)	B. Abreu, E. Martins and F. L. Sousa	Automatic test data generation for path testing using a new stochastic algorithm	SBES	5/6
10	Yano et al. (2010)	T. Yano, E. Martins and F. L. Sousa	Generating Feasible Test Paths from an Executable Model Using a Multi-Objective Approach	International Conference on Software Testing, Verification, and Validation	5/6

Table 8
The number of citations on Google Scholar per year of the most cited SBSE works.

Year	Min.	Aver.	Max.	Works									
				1	2	3	4	5	6	7	8	9	10
2011	1	2.5	7	6	7	6	2	3	2	6	3	3	6
2010	1	3.5	16	8	16	6	3	2	2	1	–	–	–
2009	1	3.5	7	5	7	2	7	3	1	–	3	–	–
2008	1	2.8	6	6	2	5	2	1	–	–	–	1	–
2007	1	1.5	2	1	2	2	–	2	–	–	1	1	–
2006	1	2.4	5	5	–	1	–	2	3	–	–	1	–
2005	1	1.5	2	2	–	1	–	–	–	–	–	–	–
2004	1	2	3	2	–	3	–	–	1	–	–	–	–
2003	1	1.3	2	1	–	2	–	–	1	–	–	–	–
2002	1	2	3	1	–	3	–	–	–	–	–	–	–
2001	1	1.5	1	–	–	1	–	–	–	–	–	–	–

Another trend that was observed in the analyzed papers is the evaluation of the SBSE. Here and outside there is a special care to make the SBSE approaches applicable to real SE problems. Hence, it is important an interaction and participation of the Brazilian industries, and to perform well-designed evaluation empirical studies.

5.2. Search based techniques

As we mentioned before, evolutionary techniques are the preferred in the analyzed papers, being GA the most used, similar result found in related works (Harman et al., 2009). But this has been changing as we can see in Fig. 9. There is a trend to use other algorithms, including Ant Colony Optimization and Particle Swarm Optimization. These techniques work well in cases where the problem changes fast, and are adequate for SE problems with dynamic nature.

In a recent work, Harman (2011) presents some reasons for this preference. Evolutionary algorithms can cater to single and multiples objectives. They can be parallelized and can incorporate human fitness evaluation. But they present some disadvantages such as the numerous parameters to be explored, performance, etc. Considering this, an important research topic is to investigate ways to help in the selection of the best algorithm for a particular software engineering problem.

The use of multi-objective algorithms (mainly evolutionary ones (MOEAs)) is a trend observed in the most recent works (since 2009). These algorithms are suitable to better deal with complex problems and constitute an indispensable alternative for SBSE. The use of preference relations to deal with the great number of solutions found by these algorithms is also a potential topic to be investigated.

Harman et al point out other trends (Harman, 2007; Harman et al., 2009) that are: (a) co-evolution: captures a predator–prey model of evolution, in which both populations are stimulated to evolve together. For instance the use of a population of programs and other of test data, both evolving together from the specification; (b) hybridization: allows combination of search based techniques. Classical techniques and meta-heuristics are combined to improve performance. SBSE approaches are used with clustering, prediction or knowledge based ones to better solve the SE problems; and (c) interactive optimization: incorporates human judgement in the objective functions to represent subjective constraints.

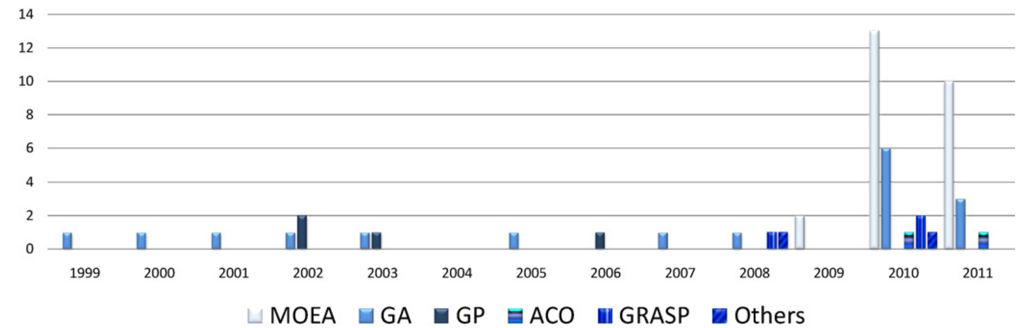


Fig. 9. Main search based techniques used along the years.

5.3. SBSE community

The Brazilian SBSE community has been just formed and it is crescent the number of researchers and works. We observe an explosion since 2008. The organization of both editions of the Brazilian Workshop on SBSE is a starting union point. We can say that the SBST (Search Based Software Testing) area in Brazil is a mature and consolidated research area, presenting a regular production and the greatest number of research groups. The tutorial named "Test Data Generation" co-located with SBES 2011 was a joined effort of the SBST Brazilian community, with the participation of researchers from UFAM, UFPR and UNICAMP. We can also mention another result from an international cooperation: a tutorial containing a step-by-step guide to the application of search based techniques to Software Engineering (Harman et al., 2011). It helps students and non-experts start to get practical results with SBSE.

There are incipient research groups that can be consolidated in next years, such as in UFAM (Manaus/Amazonas) and in UFPB (João Pessoa/Paraíba) with 5% and 3% of publications, respectively. And, then new collaborations may occur leveraging the SBSE Brazilian production. We believe that the SBES-WOES helped to establish some collaboration and that new research partnership can emerge from this workshop. In addition to these new collaborations, as next steps, the Brazilian community should make efforts to increase the number of publications in SBES and international journals, to consolidate the area in Brazil and to reach greater research impacts.

6. Conclusions

This paper presents results of a mapping performed to provide an overview of the SBSE field in Brazil. We mapped the Brazilian SBSE community on SBES by identifying the main researchers, focus of the published works, fora and frequency of publications.

First at all, the novel field of SBSE was introduced. The main concerns associated to the definition of SBSE are discussed in Section 2. We hope this can help the researchers to better understand the scope of their papers in the Intelligent Systems sub-fields, eliminating confusions and inconsistencies on the use of the related terms.

We observed that the frequency of published SBSE papers has been increasing recently, mainly after 2008. 60% of the papers are national publications and 40% are international. Since 2009 the number of national publications has increased. This is due to both editions of WOES, co-located with SBES. We found researchers working on SBSE in diverse regions of Brazil. This represents potential for dissemination over all the country.

In spite of the frequency of SBSE papers in SBES has been stable since 1999, when the first paper was published, WOES in conjunction with SBES contributes to disseminate SBSE works and to the field consolidation. SBES plays an important role for SBSE, providing a space for the development of this embryonic area in Brazil.

The main works published by the Brazilian SBSE community were described according to the addressed SE area. In Brazil, the SBSE works are concentrated in three main areas: software testing, requirements and management. Similarly to the international scenario software testing is the most investigated area, and the evolutionary search techniques are preferred. However, we observed that this has been changing. The results of the existing works are very encouraging and many areas can benefit from SBSE. We think that there are many reasons to adopt search based techniques in SE, learning again from the experiences of the Engineering and Intelligent Systems areas.

As shown in the paper, the potential of SBSE application is huge. Because of this, we expect that in the next years the field keeps growing and becomes strong in Brazil. We hope this paper contributes in this direction.

Acknowledgments

We would like to thank all the authors that kindly answered our emails and contributed with the validation step. This work is supported by CNPq (Productivity grant numbers: 303761/2009-1 and 306608/2009-0 and Universal Project grant numbers: 472510/2010-0 and 481397/2009-4) and by CAPES/Reuni.

References

Abreu, B.T., Martins, E., Sousa, F.L., 2005. Automatic test data generation for path testing using a new stochastic algorithm. In: 18th Brazilian Symposium on Software Engineering (SBES05), pp. 247–262.

Abreu, B.T., Martins, E., Sousa, F.L., 2007. Generalized extremal optimization: a competitive algorithm for test data generation. In: 20th Brazilian Symposium on Software Engineering (SBES07), pp. 342–358.

Afzal, W., Torkar, R., Feldt, R., 2009. A systematic review of search-based testing for non-functional system properties. Information and Software Technology 51, 957–976.

Ali, S., Briand, L.C., Hemmati, H., Panesar-Walawege, R.K., 2010. A systematic review of the application and empirical investigation of search-based test-case generation. IEEE Transactions on Software Engineering 36, 742–762.

Andrade, T.C., Freitas, F.G., Coutinho, D.P., Souza, J.T., 2010. Uma abordagem de otimização multiobjetiva para o problema da priorização da correção de defeitos. In: I Workshop on Search Based Software Engineering (WOES'2010), pp. 32–39 (in Portuguese).

Andrade, T.C., Freitas, F.G., Silva, T.G.N., Coutinho, D.P., Souza, J.T., 2011. Uma abordagem multi-objetiva para o problema de seleção de defeitos. In: XLIII Brazilian Symposium of Operational Research (SBPO'2011), pp. 1–12 (in Portuguese).

Araki, L., Vergilio, S.R., 2010. Um framework de geração de dados de teste para critérios estruturais baseados em código objeto Java. In: 11th Workshop on Test and Fault Tolerance (WTF'2010), pp. 91–104 (in Portuguese).

Assunção, W.K.G., Colanzi, T.E., Pozo, A.T.R., Vergilio, S.R., 2011a. Establishing integration test orders of classes with several coupling measures. In: 13th Genetic and Evolutionary Computation Conference (GECCO'2011), pp. 1867–1874.

Assunção, W.K.G., Colanzi, T.E., Vergilio, S.R., Pozo, A.T.R., 2011b. Estabelecendo sequências de teste de integração de classes: Um estudo comparativo da aplicação de três algoritmos evolutivos multiobjetivos. In: 12th Workshop on Test and Fault Tolerance (WTF'2011), (in Portuguese).

Assunção, W.K.G., Colanzi, T.E., Pozo, A.T.R., Vergilio, S.R., 2011c. Reduzindo o custo do teste de integração com algoritmos evolutivos multiobjetivos e diferentes medidas de acoplamento. In: Brazilian Meeting on Artificial Intelligence (ENIA'2011), (in Portuguese).

Assunção, W.K.G., Colanzi, T.E., Pozo, A.T.R., Vergilio, S.R., 2011d. Uma avaliação do uso de diferentes algoritmos evolutivos multiobjetivos para integração de classes e aspectos. In: II Workshop on Search Based Software Engineering (WOES'2011), (in Portuguese).

Banzi, A., Pinheiro, G.B., árias, J.C., Nobre, T., Vergilio, S.R., Pozo, A.T.R., 2011. Seleção de operadores de mutação baseada em algoritmo de otimização multiobjetivo. In: Brazilian Workshop on Systematic and Automated Software Testing (SAST'2011), (in Portuguese).

Barreto, A., Barros, M.O., Werner, C.M.L., 2008. Staffing a software project: a constraint satisfaction and optimization-based approach. Computers & Operations Research 35 (10), 3073–3089 (Special Issue: Search-Based Software Engineering).

Barros, M.O., Neto, A.C.D., 2011. Desenvolvendo uma abordagem sistemática para avaliação dos estudos experimentais em Search-Based Software Engineering. In: II Workshop on Search Based Software Engineering (WOES'2011), (in Portuguese).

Brasil, M.M.A., Freitas, F.G., Silva, T.G.N., Souza, J.T., Cortés, M.I., 2010. Uma nova abordagem de otimização multiobjetiva para o planejamento de releases em desenvolvimento iterativo e incremental de software. In: I Workshop on Search Based Software Engineering (WOES'2010), pp. 40–47 (in Portuguese).

Brasil, M.M.A., Silva, T.G.N., Freitas, F.G., Ferreira, T.N., Cortés, M.I., Souza, J.T., 2011a. Aplicando técnicas de busca multiobjetivas na priorização de requisitos de software. In: XLIII Brazilian Symposium of Operational Research (SBPO'2011), pp. 1–12 (in Portuguese).

Brasil, M.M.A., Silva, T.G.N., Freitas, F.G., Souza, J.T., Cortés, M.I., 2011b. Multiobjective software release planning with dependent requirements and undefined number of releases. In: 13th International Conference on Enterprise Information Systems (ICEIS'2011), pp. 97–107.

Bueno, P.M.S., Jino, M., 2000. Identification of potentially infeasible program paths by monitoring the search for test data. In: IEEE International Conference on Automated Software Engineering (ASE'2000), pp. 209–218.

Bueno, P.M.S., Jino, M., 2001. Automatic test data generation for program paths using genetic algorithms. In: International Conference on Software Engineering and Knowledge Engineering, pp. 2–9.

Bueno, P.M.S., Jino, M., 2002. Automatic test data generation for program paths using genetic algorithms. International Journal of Software Engineering and Knowledge Engineering (IJSEKE) 12 (6), 691–709.

Bueno, P.M.S., Wong, W.E., Jino, M., 2007. Improving random test sets using the diversity oriented test data generation. In: 2nd International Workshop on Random testing, 22nd IEEE/ACM International Conference on Automated Software Engineering (ASE'2007), ACM, pp. 10–17.

Bueno, P.M.S., Wong, W.E., Jino, M., 2008. Automatic test data generation using particle systems. In: ACM Symposium on Applied Computing, pp. 809–814.

Bueno, P.M.S., Jino, M., Wong, W.E., 2011. Diversity Oriented Test Data Generation using Metaheuristic Search Techniques, Information Sciences (online). URL: http://www.sciencedirect.com/science/article/pii/S0020025511000442.

Buzzo, A.V., 2011. Estudo de algoritmo evolutivo com codificação real na geração de dados de teste estrutural e implementação de protótipo de ferramenta de apoio. Master's Thesis. Universidade Estadual de Campinas – Instituto de Computação (in Portuguese).

Cabral, R.V., Pozo, A.T.R., Vergilio, S.R.,2010. A Pareto Ant Colony Algorithm applied to the class integration and test order problem. In: 22nd IFIP International Conference on Testing Software and Systems (ICTSS'10). Springer, Berlin/Heidelberg, pp. 16–29.

Campos Junior, A., Pozo, A., Vergilio, S., Savegnago, T., 2010. Many-objective evolutionary algorithms in the composition of web services. In: 11th Brazilian Symposium on Neural Networks (SBRN'2010), pp. 152–157.

Clarke, J., Harman, M., Hierons, R.M., Jones, B., Lumkin, M., Rees, K., Roper, M., Shepperd, M.J., 2000, August. The application of metaheuristic search techniques to problems in software engineering. Tech. Rep. TR-01-2000, University of York, Brunel University, University of Glamorgan, British Telecom, Strathclyde University, Bournemouth University.

Clarke, J., Dolado, J., Harman, M., Hierons, R., Jones, B., Lumkin, M., Mitchell, B., Mancoridis, S., Rees, K., Roper, M., Shepperd, M., 2003. Reformulating software engineering as a search problem. IEEE Software 150 (3), 161–175.

Coello, C.A.C., Lamont, G.B., Veldhuizen, D.A.V., 2006. Evolutionary Algorithms for Solving Multi-Objective Problems (Genetic and Evolutionary Computation). Springer-Verlag New York, Inc., New York, NY.

Colanzi, T.E., Assunção, W.K.G., Vergilio, S.R., Pozo, A.T.R., 2011a. Generating integration test orders for aspect-oriented software with multi-objective algorithms. In: Latinamerican Workshop on Aspect Oriented Software (LA-WASP'2011), pp. 1–6.

Colanzi, T.E., Assunção, W.K.G., Vergilio, S., Pozo, A.T.R., 2011b. Integration test of classes and aspects with a multi-evolutionary and coupling-based approach. In: Third International Conference on Search Based Software Engineering (SSBSE'2011). Springer-Verlag, Berlin, Heidelberg, pp. 188–203.

Colares, F., Souza, J.T., Carmo, R.A., Padua, C., Mateus, G.R., 2009. A new approach to the software release planning. In: 22nd Brazilian Symposium on Software Engineering (SBES09), pp. 207–215.

Coutinho, D.P., Freitas, F.G., Carmo, R.A.F., Maia, C.L., Souza, J.T., 2010. Uma abordagem multi-objetiva para o problema da alocação de equipes. In: XLII Brazilian Symposium of Operational Research (SBPO'2010), pp. 1–12 (in Portuguese).

Deb, K., Pratap, A., Agarwal, S., Meyarivan, T., 2002. A fast and elitist multiobjective genetic algorithm: NSGA-II. IEEE Transactions on Evolutionary Computation 6 (2), 182–197.

Dias Neto, A.C., Rodrigues, R.F., Travassos, G.H., 2011. Porantim-opt: optimizing the combined selection of model-based testing techniques. In: 4th International Conference on Software Testing, Verification and Validation Workshops (ICSTW'2011), pp. 174–183.

Dorigo, M., 1992. Optimization, learning and natural algorithms. Ph.D. Thesis. Politecnico di Milano.

Emer, M.C.P.F., Vergilio, S.R., 2002a. Selection and evaluation of test sets based on genetic programming. In: 16th Brazilian Symposium (SBES02) on Software Engineering, pp. 82–97.

Emer, M.C.F.P., Vergilio, S.R., 2002b. GPTesT: a testing tool based on genetic programming. In: Genetic and Evolutionary Computation Conference (GECCO'2002), pp. 1343–1350.

Emer, M.C.F.P., Vergilio, S.R., 2003. Selection and evaluation of test data based on genetic programming. Software Quality Journal 11, 167–186.

Farzat, F.A., Barros, M.O., 2010. Método de seleção de casos de teste para alterações emergenciais. In: I Workshop on Search Based Software Engineering (WOES'2010), pp. 9–17 (in Portuguese).

Feo, T., Resende, M., 1995. Greedy Randomized Adaptive Search Procedures. Journal of Global Optimization, 109–133.

Ferreira, L.P., Vergilio, S.R., 2003. A framework for generation of test data sets based on genetic algorithms. In: IEEE Latin-American Test Workshop (LATW'2003).

Ferreira, L.P., Vergilio, S.R., 2005. TDSGen: an environment based on hybrid genetic algorithms for generation of test data. In: 17th International Conference on Software Engineering and Knowledge Engineering (SEKE'2005), pp. 312–317.

Ferreira, F.S., Souza, J.T., Silva, J.S.V., 2010. Formação de grupos de trabalho com algoritmo genético. In: III Congresso Tecnológico da InfoBrasil, pp. 1–5 (in Portuguese).

Figueiredo, F.V., Barros, M.O., 2011. Otimização heurística de uma técnica para seleção e priorização de portfólios balanceados de projetos de software. In: II Workshop on Search Based Software Engineering (WOES'2011), (in Portuguese).

Freitas, F.G., Souza, J.T.,2011. Ten years of Search Based Software Engineering: a bibliometric analysis. In: Third International Conference on Search Based Software Engineering (SSBSE'2011). Springer-Verlag, Berlin, Heidelberg, pp. 18–32.

Freitas, F.G., Maia, C.L.B., Coutinho, D.P., Campos, G.A.L., Souza, J.T., 2009. Aplicação de metaheurísticas em problemas da engenharia de software: Revisão de literatura. In: II Congresso Tecnológico InfoBrasil (InfoBrasil'2009), (in Portuguese).

Freitas, F.G., Maia, C.L.B., Campos, G.A.L., Souza, J.T., 2010. Otimização em teste de software com aplicação de metaheurísticas. Sistemas de Informação 5 (1), 3–13 (in Portuguese).

Freitas, F.G., Silva, T.G.N., Carmo, R.A.F., Brasil, M.M.A., Souza, J.T., 2011a. Branch-and-bound aplicado na seleção multiobjetiva de requisitos de software com dependência. In: XLIII Brazilian Symposium of Operational Research (SBPO'2011), pp. 1–12 (in Portuguese).

Freitas, F.G., Coutinho, D.P., Souza, J.T., Article, 2011b. Software next release planning approach through exact optimization. International Journal of Computer Applications 22 (8), 1–8 (Published by Foundation of Computer Science).

Galvan, R., Pozo, A.T.R., Vergilio, S.R., 2010. Establishing integration test orders for aspect-oriented programs with an evolutionary strategy. In: Latinamerican Workshop on Aspect Oriented Software (LA-WASP'2010).

Green, C., Luckham, D., Balzer, R., Cheatham, T., Rich, C., 1986. Report on a Knowledge-based Software Assistant. Morgan Kaufmann Publishers Inc., San Francisco, CA, pp. 377–428 (Ch. 23).

Harman, M., Jones, B., 2001. Search Based Software Engineering. Journal of Information and Software Technology 43 (14), 833–839.

Harman, M., Mansouri, A., 2010. Search Based Software Engineering: introduction to the special issue of the IEEE Transactions on Software Engineering. IEEE Transactions on Software Engineering, 737–741.

Harman, M., Mansouri, S.A., Zhang, Y., 2009, April. Search Based Software Engineering: a comprehensive analysis and review of trends techniques and applications. Tech. Rep. TR-09-03. King's College London.

Harman, M., McMinn, P., De Souza, J., Yoo, S., 2011. Search Based Software Engineering: techniques, taxonomy, tutorial. In: Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), pp. 1–59.

Harman, M., 2006. Search Based Software Engineering. In: 6th International Conference on Computer Science (ICCS'2006), pp. 740–747.

Harman, M., 2007. The current state and future of Search Based Software Engineering. In: Future of Software Engineering (FOSE'2007), pp. 342–357.

Harman, M., 2010. Why the virtual nature of software makes it ideal for search based optimization. In: 13th International Conference on Fundamental Approaches to Software Engineering (FASE'2010), vol. 6013, Lecture Notes in Computer Science, pp. 1–12.

Harman, M., 2011. Software engineering meets evolutionary computation. Computer 4 (10), 31–39.

Hruschka, E.R., Campello, R.J.G.B., Freitas, A.A., Carvalho, A.C.P., 2009. A survey of evolutionary algorithms for clustering. IEEE Transactions on System, Man and Cybernetics, Part C 39, 133–155.

Jensen, P., Bard, J., 2003. Operations Research Models and Methods. John Wiley and Sons, Danvers, MA.

Jino, M., Bueno, P.M.S., 1999. Geração automática de dados e tratamento de não executabilidade no teste estrutural de software. In: 13th Brazilian Symposium on Software Engineering (SBES99), (in Portuguese).

Linhares, G.R.M., Freitas, F.G., Carmo, R.A.F., Maia, C.L.B., Souza, J.T., 2010. Aplicação do algoritmo GRASP reativo para o problema do próximo release. In: XLII Brazilian Symposium of Operational Research (SBPO'2010), pp. 1–12 (in Portuguese).
Magdaleno, A., Werner, C., Araujo, R., Barros, M.O., 2010. Formulando a adaptação de processos de desenvolvimento de software como um problema de otimização. In: I Workshop on Search Based Software Engineering (WOES'2010), pp. 56–64 (in Portuguese).
Maia, C.L.B., Carmo, R.A.F., Campos, G.A.L., Souza, J.T., 2008. A reactive GRASP approach for regression test case prioritization. In: XL Brazilian Symposium of Operational Research (SBPO'2008).
Maia, C.L.B., Carmo, R.A.F., Freitas, F.G., Campos, G.A.L., Souza, J.T., 2009. A multi-objective approach for the regression test case selection problem. In: XLI Brazilian Symposium of Operational Research (SBPO'2009).
Maia, C.L.B., Carmo, R.A.F., Campos, G.A.L., Freitas, F.G., Souza, J.T., 2010a. Automated test case prioritization with reactive GRASP. Advances in Software Engineering 2010, 1–19.
Maia, C.L.B., Freitas, F.G., Souza, J.T., 2010b. Applying search-based techniques for requirements-based test case prioritization. In: I Workshop on Search Based Software Engineering (WOES'2010), pp. 24–31.
Mantere, T., Alander, J.T., 2005. Evolutionary software engineering: a review. Applied Software Computing 5 (3), 315–331.
McMinn, P., 2004. Search-based software test data generation: a survey: research articles. Software Testing, Verification & Reliability 14, 105–156.
Neto, A.C.D., Rodrigues, R.F., 2010. Otimizando a seleção combinada de técnicas de teste baseado em modelos através da determinação do menor conjunto dominante multiobjetivo. In: I Workshop on Search Based Software Engineering (WOES'2010), (in Portuguese).
Neto, A.C.D., Rodrigues, R.F., 2011. Uma proposta de framework de apoio á seleção de tecnologias de software aplicando estratégias de busca. In: II Workshop on Search Based Software Engineering (WOES'2011), (in Portuguese).
Netto, F., Barros, M.O., Alvim, A., 2010. Uma abordagem automatizada para geração de cronogramas de tarefas de correção de bugs. In: 23rd Brazilian Symposium on Software Engineering (SBES2010), pp. 81–90 (in Portuguese).
O'Keeffe, M., Cinnéide, M.O., 2006. Search-based software maintenance. In: Conference on Software Maintenance and Reengineering (CSMR'2006), pp. 249–260.
Paixão, M.P., Silva, L., Viana, T.B., Elias, G., 2011. Large software component repositories into small index files. In: International Conference on Advances in Databases, Knowledge, and Data Applications (DBKDA'2011), pp. 122–127.
Petersen, K., Feldt, R., Mujtaba, S., Mattsson, M., 2008. Systematic mapping studies in software engineering. In: 12th International Conference on Evaluation and Assessment in Software Engineering (EASE'2008), pp. 1–10.
Pinto, G.H.L., Vergilio, S.R., 2010a. A multi-objective genetic algorithm to test data generation. In: 22nd IEEE International Conference on Tools with Artificial Intelligence (ICTAI'2010), vol. 1, pp. 129–134.
Pinto, G.H.L., Vergilio, S.R., 2010b. Gerando dados de teste para programas orientados a objeto com um algoritmo genético multi-objetivo. In: I Workshop on Search Based Software Engineering (WOES'2010), pp. 18–23 (in Portuguese).
Räihä, O., 2010. A survey on search-based software design. Computer Science Review 4, 203–249.
Ribeiro, B., Elias, G., 2011. Uma abordagem baseada em algoritmo genético para alocação de equipes distribuídas. In: II Workshop on Search Based Software Engineering (WOES'2011), (in Portuguese).
Rocha, I.M., Viana, G.V.R., Souza, J.T., 2011. Uma abordagem otimizada para o problema de alocação de equipes e escalonamento de tarefas para a obtenção de cronogramas eficientes. In: II Workshop on Search Based Software Engineering (WOES'2011), (in Portuguese).
Santos, V., Pereira, T., Ribeiro, B., Elias, G., 2010. Um framework de recomendação para alocação de equipes de desenvolvimento em projetos distribuídos de linhas de produto de software. In: 4th Workshop on Distributed Software Development (WDDS'2010), pp. 1–8 (in Portuguese).
Silva, T.G.N., Freitas, F., Souza, J., 2011. Abordagem híbrida para o problema multiobjetivo do próximo release. In: II Workshop on Search Based Software Engineering (WOES'2011), (in Portuguese).
Sousa, F., Ramos, F., Paglione, P., Girardi, R., 2003. New stochastic algorithm for design optimization. AIAA Journal 41 (9), 1808–1818.
Souza, J.T., Maia, C.L.B., Freitas, F.G., Coutinho, D.P., 2010. The human competitiveness of Search Based Software Engineering. In: 2nd International Symposium on Search Based Software Engineering (SSBSE), pp. 143–152.
Souza, J.T., Maia, C.L.B., Ferreira, T.N., Carmo, R.A.F., Brasil, M.M.A.,2011. An Ant Colony Optimization approach to the software release planning with dependent requirements. In: Third International Conference on Search Based Software Engineering (SSBSE'2011). Springer-Verlag, Berlin, Heidelberg, pp. 142–157.
Vergilio, S.R., Pozo, A.T.R., 2006. A grammar-guided genetic programming framework for software engineering. International Journal of Software Engineering and Knowledge Engineering (IJSEKE) 16 (2), 245–267.
Vergilio, S., Colanzi, T.E., Pozo, A., Assunção, W.K.G., 2011. Search Based Software Engineering: a review from the Brazilian Symposium on Software Engineering. In: Brazilian Symposium on Software Engineering (SBES'2011) – Track SBES is 25, pp. 50–55.
Watkins, A., Hufnagel, E.M., 2006. Evolutionary test data generation: a comparison of fitness functions: research articles. Software – Practice & Experience 36, 95–116.
Yano, T., Martins, E., Sousa, F.L., 2010. Generating feasible test paths from an executable model using a multi-objective approach. In: Third International Conference on Software Testing, Verification, and Validation Workshops (ICSTW'2010), pp. 236–239.
Yano, T., Martins, E., Sousa, F.L., 2011. MOST: a multi-objective search-based testing from EFSM. In: 4th International Conference on Software Testing, Verification and Validation Workshops (ICSTW'2011) – Workshop on Search-Based Software Testing, pp. 164–173.
Zhang, D., Tsai, J.J.P., 2003. Machine learning and software engineering. Software Quality Control 11, 87–119.
Zhang, Y., Harman, M., Mansouri, S.A., 2007. The multi-objective next release problem. In: 9th Genetic and Evolutionary Computation Conference (GECCO'2007), pp. 1129–1136.
Zhang, Y., Finkelstein, A., Harman, M., 2008. Search based requirements optimisation: existing work & challenges. In: 4th International Conference on Requirements Engineering: Foundation for Software Quality (RE'2008), pp. 88–94.

Thelma Elita Colanzi received the MS degree (1999) from University of São Paulo, USP/São Carlos, Brazil. She is currently a PhD candidate at the Post-graduation Program in Informatics of Federal University of Parana (UFPR). She has been a faculty member in the Computer Science Department at the State University of Maringá, Brazil since 2006. Her research interests are in the area of Software Engineering, such as: software product line, software metrics, search based software engineering and software testing.

Silvia Regina Vergilio received the MS (1991), and DS (1997) degrees from the University of Campinas, UNICAMP, Brazil. She is currently in the Computer Science Department at the Federal University of Paraná, Brazil, where she has been a faculty member since 1993. She has been involved in several projects, and her research interests are in the areas of Software Engineering, such as: software testing, software quality, software metrics and Search Based Software Engineering.

Wesley Klewerton Guez Assunção is a PhD student at Computer Science Department on Federal University of Paraná, Brazil. He receives the MS (2012) degree from Federal University of Paraná and the BS (2006) degree in Information Systems from the Faculty South Brazil, Brazil. His main interest are Software Engineering, Software Testing and Search Based Software Engineering.

Aurora Trinidad Ramirez Pozo is an associate professor at the Computer Science Department, and Numerical Methods for Engineering at Federal University of Paraná, Brazil, since 1997. She received a MS in Electrical Engineering from Federal University of Santa Catarina, Brazil, in 1991. She received a PhD in Electrical Engineering from the Federal University of Santa Catarina, Brazil. Aurora's research interests are in Evolutionary Computation, Data Mining, and Complex Problems.