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TÍTULO DO TRBALHO

Por

NOME COMPLETO DO AUTOR

Trabalho de Graduação

BRASÍLIA/2017

Nome completo do Autor

TÍTULO DO TRBALHO

Trabalho apresentado ao Programa de Bacharelado em Ciência da Computação do Departamento de Computação da Instituto Federal de Brasília como requisito parcial para obtenção do grau de Bacharel em Ciência da Computação.

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I dedicate this thesis to all my family, friends and professors who gave me the necessary support to get here.

Agradecimentos

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When one finds a hard problem, the more complicated it is, the more one ought to work towards enlightening it's solution.

—MÁRCIO DE DEUS

Resumo

O gerenciamento eficiente de solicitações de mudança (SM) é fundamental para o sucesso das atividades de manutenção e evolução de software. Entretanto, a atribuição de SMs a desenvolvedores de software é um aspecto custoso desse gerenciamento, pois demanda tempo e requer conhecimento apropriado do projeto de software. Com o propósito de diminuir esse custo, várias pesquisas já propuseram métodos de atribuição automática de SMs. Embora representem avanços na área, existem vários fatores inerentes a atribuição de SMs que não são considerados nessas pesquisas e são essenciais para a automação.

Como demonstrado nesse trabalho, a atribuição automática deve, por exemplo, considerar a carga de trabalho, a experiência e o conhecimento dos desenvolvedores, a prioridade e a severidade das SMs, a afinidade dos desenvolvedores com os problemas descritos nas SMs, e até mesmo os relacionamentos interpessoais. Para tornar esse cenário ainda mais complexo, esses fatos podem variar de acordo com o projeto de software que está sendo desenvolvido. Assim, uma solução para o problema de atribuição de SMs depende de informações contextuais.

Assim, esse trabalho propõe, implementa e valida uma solução arquitetural sensível ao contexto para atribuição automática de SMs. Dado o aspecto contextual da solução, a arquitetura enfatiza a necessidade de considerar as diversas fontes de informações presentes na organização, assim como a necessidade de se desenvolver algorítimos que implementem diferentes estratégias de atribuição. A proposta e implementação dessa solução é embasada em resultados de duas pesquisas quantitativas: um estudo de mapeamento sistemático da literatura, e uma pesquisa de questionário com desenvolvedores de software. Esse último forneceu um conjunto de requisitos que a solução automatizada deve satisfazer para que as estratégias de atribuição sejam atendidas, enquanto o mapeamento da literatura identificou técnicas, algoritmos, e outros requisitos necessários a automação.

A implementação da arquitetura segue uma estratégia de automação, também elaborada nesse trabalho, que possui dois componentes principais: um sistema especialista baseado em regras (SEBR); e um modelo de recuperação de informação (MRI) com técnicas de aprendizagem. Em nossa estratégia, esses dois componentes são executados alternadamente em momentos diferentes a fim de atribuir uma SM automaticamente. O SEBR processa regras simples e complexas, considerando informações contextuais do projeto de software e da organização que o desenvolve. O MRI é utilizado para fazer o casamento entre SMs e desenvolvedores de acordo com o histórico de atribuições.

Palavras-chave: Engenharia de Software, Manutenção e Evolução de Software, Gerenciamento de Solicitações de Mudança, Atribuição Automática de Solicitações de Mudança

Abstract

The efficient management of Change Requests (CRs) is fundamental for successful software maintenance; however the assignment of CRs to developers is an expensive aspects in this regard, due to the time and expertise demanded. To overcome this, researchers have proposed automated approaches for CR assignment. Although these proposals present advances to this topic, they do not consider many factors inherent to the assignments. Indeed, different complex factors may have influence on CR assignment, and most of them vary from one organization to another. For instance, developers' workload, CRs severity, interpersonal relationships, or developers know-how must be considered in the assignments. Actually, as we demonstrate in this work, CR assignment is a complex activity and automated approaches cannot rely on simplistic solutions. Ideally, it is necessary to consider and reason over contextual information in order to provide an effective automation.

In this regarding, this work proposes, implements, and validates a context-aware architecture to automate CR assignment. The architecture emphasizes the need for considering the different information available at the organization to provide a more context-aware solution to automated CR assignment. The development of such architecture is supported by evidence synthesized from two empirical studies: a survey with practitioners and a systematic mapping study. The survey provided us with a set of requirements that automated approaches should satisfy. In the mapping study, in turn, we figured out how state-of-the-art approaches are implemented in regarding to these requirements, concluding that many of them are not satisfied. In addition, new requirements were identified in this mapping study.

For the implementation of the proposed architecture, we developed a strategy to automate CR assignments which is based on two main components: a Rule-Based Expert System (RBES) and an Information Retrieval (IR) model. The strategy coordinately applies these two components in different steps to find the potential developer to a CR. The RBES takes care of the simple and complex rules necessary to consider contextual information in the assignments, e.g., to prevent assigning a CR to a busy or unavailable developer. Since these rules vary from one organization/project to another, the RBES facilitates their modification for different contexts. On the other hand, the IR model is useful to make use of the historical information of CR assignments to match CRs and developers.

Keywords: Software Engineering, Software Maintenance and Evolution, Change Request Management, Automatic Change Request Assignment

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Sumário

1

Introduction

Software maintenance starts as early as the first software artifacts are delivered, and is characterized by its high cost and slow speed of implementation (IEEE Computer Society, 2014). It has been stated that it is the most expensive activity of software development, taking up to 90% of the total costs (EASTWOOD, 1993; ERLIKH, 2000). However, despite of the high cost, it is mandatory to ensure the success of the software project. LEHMAN (1980) argues, in his *Continuing Change* law of software evolution, that the modification of software is a fact of life for software systems if they are intended to remain useful. BENNETT; RAJLICH (2000) reinforced such an argument for the specific case of useful and successful software, where almost all of them have a common practice of stimulating user-generated Change Request (CR). Actually, software maintenance is driven by CRs reported by many stakeholders, such as developers, testers, team leaders, managers, and clients.

In this context, the CR repositories play an important role in the maintenance and evolution process, being actually a focal point of communication and coordination for software projects (BERTRAM et al., 2010). Through a CR repository, the developers manage and coordinate the corrections and new features to be implemented in the software under development or maintenance. Moreover, the data stored in such repositories are a valuable source of information about the project, which can be used to assist in cost estimation, impact analysis, traceability, planning, expertise discovery, and software understanding (CAVALCANTI et al., 2013). Examples of these repositories are Mantis (Mantis Bug Tracker, 2013), Bugzilla (BUGZILLA, 2013), and Trac (The Trac Project, 2013).

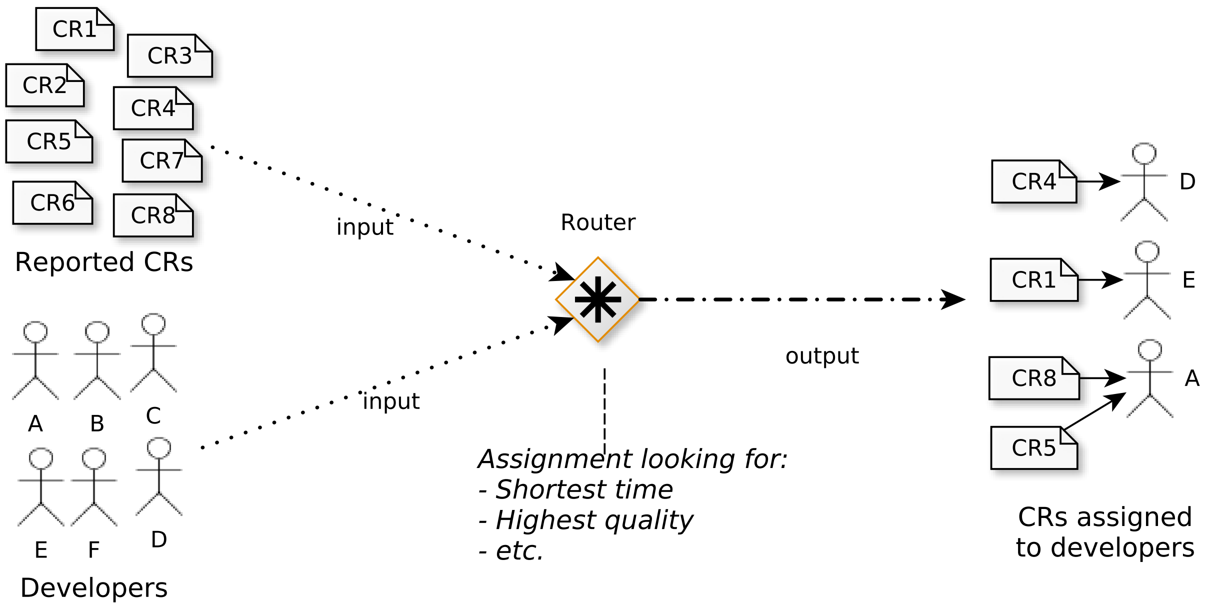
Briefly, a CR describes a defect to be fixed, an adaptive or perfective change, or a new functionality to be implemented in a software system (CAVALCANTI et al., 2013). Each CR stores a variety of fields of free text and custom fields defined according to the necessity of each project. In Trac, for example, it has fields for summary and detailed description of a CR. In the same CR, it can be also recorded information about software version, dependencies with other CRs (such as CRs that are blocked, similar, or duplicate), the person who will be assigned to the CR, among other relevant information. Moreover, during the life cycle of a CR, different kinds of discussion take place through the comments that are inserted in it, such as fixing alternatives, workarounds, and architectural decisions (BERTRAM et al., 2010).

1.1 Motivation (Why to Automate CR Assignment?)

Despite CR repositories claimed benefits to software maintenance and evolution, handling CRs is not cost-free. For example, when new CRs are reported they must be assigned to developers which have adequate expertise to address the request (ALJARAH et al., 2011; HOSSEINI; NGUYEN; GODFREY, 2012; KAGDI et al., 2012). Finding the appropriate developer is crucial for obtaining the lowest, economically feasible, fixing time (LUCCA; PENTA; GRADARA, 2002). Nevertheless, assigning CRs to developers is a labor-intensive and time consuming task (ANVIK, 2006; JEONG; KIM; ZIMMERMANN, 2009). Indeed, depending on the project being developed, the amount of CRs that are reported and need to be assigned can vary from dozens to hundreds per day (CAVALCANTI et al., 2013).

Figura 1.1 shows the activity of assigning CRs. At the top-left corner of the figure, there are the CRs which have been reported to the software project. At the bottom-left corner, there is a set of developers which could be assigned to those CRs. Then, at the center, the assignment of CRs is performed; the CRs and developers must be matched, and each developer should fix one or more CRs. Commonly, the matching is performed aiming at the shortest time and the highest quality for the CR fixing activities.

Figura 1.1: CR assignment. The router, which may be the CCB, project leaders, or managers, must match CRs and developers in order to obtain the shortest fixing and highest quality.



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Nevertheless, by increasing the amount of reported CRs or the size of the development team, it is visible that the router becomes overloaded and the CR assignment becomes an intensive, error prone activity. It was confirmed by JEONG; KIM; ZIMMERMANN (2009), which identified that 37%-44% of the CRs in Mozilla and Eclipse projects did not reach the right developer in the first assignment. These CRs, in turn, had their fixing time delayed because they needed to be reassigned one or more times. Furthermore, if the CRs are not fixed by the appropriate developers, there is also the chance of introducing new defects during the CRs fixing.

In this context, we believe that it is necessary to develop methods and tools to automate the assignment of CRs and ensure that the CRs are being assigned to the appropriate developers. With these methods and tools, we could reduce the time needed to perform the assignments and, given that the appropriate developers are actually being selected, the quality and time for the CR fixing are also improved.

1.2 Problem Statement

As previously mentioned, software maintenance has been considered as the most costly aspect of software development (IEEE Computer Society, 2014). There is a myriad of reasons for this situation. One of them is the many changes that are required after software delivery due to poor documented and misunderstood requirements, or simply because *"the clients do not know what they want"* (BROOKS, 1995).

Another reason is the fact that a set of development activities must be inevitably performed in order to implement a change. For instance, for each change to be implemented it is necessary to comprehend the existing software artifacts, modify the software's source code to implement the change, perform tests and verification, and deliver the new version of the software.

Additionally, very often, the implementation of the change ends up by introducing new defects in the software.

A third reason is the management aspects of software maintenance. It is necessary to keep track of all these changes that are performed, generally considering different versions of the software and customers.

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1. Firstly, the approaches available in the literature were designed to perform autonomously. That is, the software analysts do not have the control of the approach; they cannot modify the approach's behavior. Without such control, in turn, the approach cannot be properly calibrated. As a consequence, if the approach's performance is not satisfactory, it is simply discarded.

2. Secondly, the reported values for accuracy of these approaches are still low. With low accuracy, the previous reason takes place. That is, as the approaches perform with low accuracy, and the software analysts do not have control over them, the approaches are simply discarded.

3. Finally, the third reason concerns the lack of contextual information in those approaches. As is well known, software development companies are dynamic: developers

move from projects; developers are hired/fired; developers enter in vacation or take a day off; and developers have different experiences. This dynamic influences the assignment of CRs. Thus, contextual information is a necessity in automated approaches.

Based on this context, the main research question investigated by this thesis is:

Research question *Is it possible to develop a new approach for automated CR assignment with satisfactory accuracy, leveraging contextual information, and designed in order to put the software analysts in control of such approach?*

With the objective to answer this question, it is necessary to understand current approaches available in the literature, choose the correct technologies that could support dynamic environments and, mainly, understand the necessities of software analysts regarding a new approach for automated CR assignment. Thus, the goal of the work described in this thesis can be stated as:

Research objective *This work proposes an automated approach for CR assignment which uses Information Retrieval (IR) models, expert systems, and context-aware information in order to select the appropriate developers. The approach is supported by the state-of-the-art in the management of CRs as well as by the understanding of the aspects concerning the CR assignment activity itself.*

1.3 Overview of the Proposal

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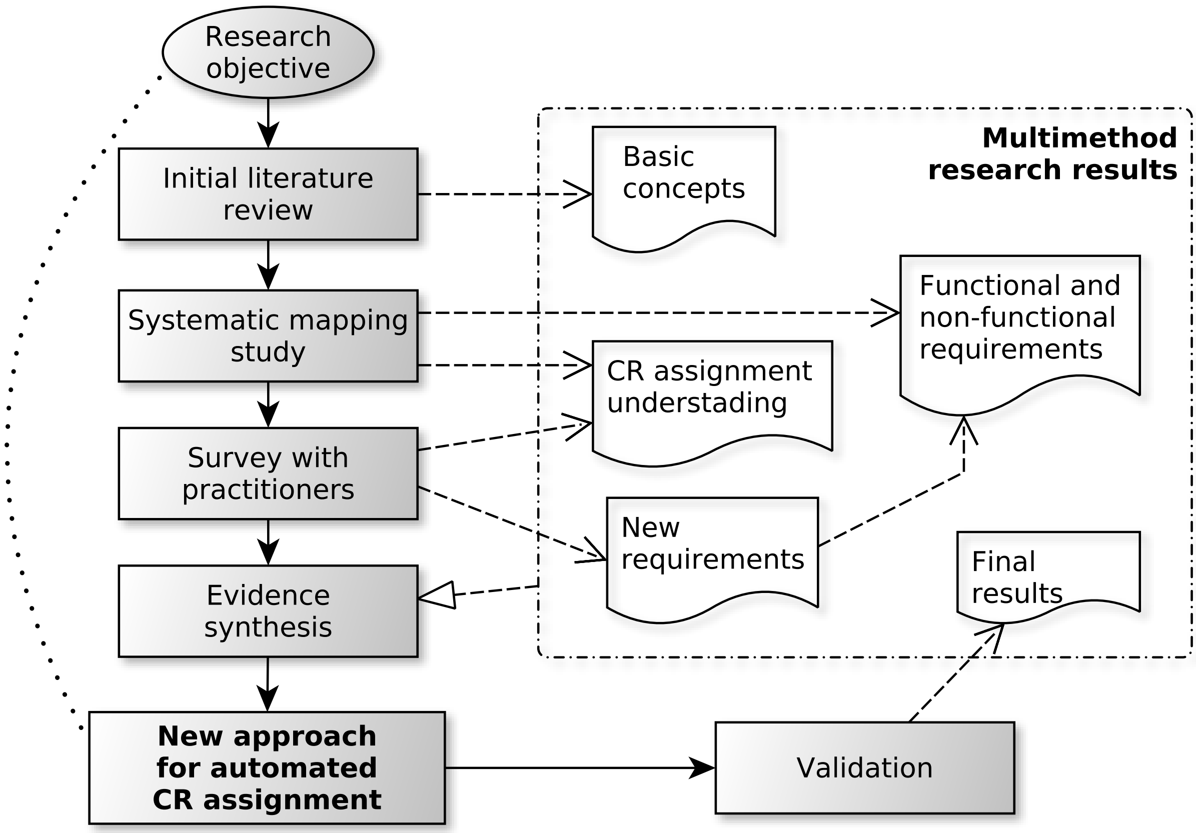
1.4 Research Methodology

This research design of this thesis is based on a multimethod approach (HESSE-BIBER, 2010). Such approach combines two or more quantitative (or qualitative) methods in a single study, such as a survey and an experiment (HESSE-BIBER, 2010). Multimethod must not be confused with mixed method. In this last, methods for both qualitative and quantitative types of research are applied in a single study. On the other hand, multimethod studies combine different methods for a single research type.

When applying a multimethod approach, the triangulation is used to consolidate the results from the different methods, considering, however, that the same research question(s) was/were investigated in these methods. As a consequence, the triangulation of methods enhances the conclusions and completeness of the study, bringing more credibility to the research findings (HESSE-BIBER, 2010). Figura 1.2 shows the multimethod research design applied in this thesis.

The design started by stating the research objective, which we defined in Seção 1.2, and performing the initial literature review. This last provided the basic concepts and understanding

Figura 1.2: The research methodology applied for this thesis.



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of the area. Then, a systematic mapping study and a questionnaire-based survey were conducted. These two gathered detailed information on our research topic. Indeed, both of them were used to understand the key aspects of CR assignment and identify the set of requirements to automate the assignments. In the evidence synthesis step, these results were detailed and organized in order to formulate the approach to automate CR assignments, which was constructed in the next step. Finally, the research design states the validation of the proposed approach.

1.5 Out of Scope

As the proposed approach is part of a broader context, a set of related aspects will be left out of its scope. Thus, the following topics are not directly addressed in this thesis:

1. **Tools for CR management.** We are addressing a specific aspect of CR management, which is the CR assignment activity. Thus, it is out of scope of this thesis to provide a complete solution for CR management. Instead, we are planning to implement standalone software which will be able to integrate with the most well known tools for CR management, such as Mantis, Bugzilla, and Trac, providing a service to leverage the automation of CR assignments.

2. **Software maintenance process.** Software maintenance involves a set of activities aiming at implementing modifications in some software project. These activities must be coordinated through a process so that the maintenance can be successful. In Chapter 2, we discuss some of these processes. However, in this thesis, we are not concerned with the maintenance process itself. Actually, it should be transparent in our approach to automate CR assignment. Thus, it is out of scope of this thesis to provide any process assessment for software maintenance beyond the activity of CR assignment.

3. **IR models.** Many models for IR have been proposed for different objectives, including the CR assignment itself. However, due to the broad availability of these models, it is out of scope of this thesis to develop a new one. Instead, the IR models with better performance, identified through the systematic mapping study, were chose to be integrated in our approach;

4. **Rule-based expert systems.** Similar to IR models, rule-based expert systems have a long history of development. Thus, our approach does not intend to develop a whole new system with this purpose. Actually, we integrated in our approach the Drools[1] expert system, which is a mature tool that can be easily manipulated;

5. **Mathematical formulations on NP-Complete problems.** We understand that the problem of assigning CRs to software developers is in the broad category of *assignment problems*, which is well known to be NP-Complete. Thus, could be formulated as such. However, the mathematical formulations of the CR assignment problem is out of scope of this thesis. As well as finding an optimal solution on the context of NP-Complete problems is also out of scope. The main reason for this is the human factors and context variables that are involved in the assignment of CRs, which make this problem hard to be computable. A mathematical formulation of the CR assignment problem is provided by RAHMAN; RUHE; ZIMMERMANN (2009).

1.6 Statement of the Contributions

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[1] `http://www.jboss.org/drools/`

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1. An overview of the software maintenance concepts and processes, with emphasis on the importance of CR management aspects;

2. A survey performed with practitioners from a large organization, in order to understand the aspects of the CR assignment activity. Published in the *17^{th} International Conference on Evaluation and Assessment in Software Engineering (EASE'2013)* (CAVALCANTI et al., 2013);

3. A replication of the previous survey in two more organizations;

4. A systematic mapping study performed to understand the challenges and opportunities of CR management, as well as to identify research gaps and the road ahead. Accepted for publication in the *Journal of Software: Evolution and Process* (CAVALCANTI et al., 2013);

5. The definition of the functional and non-functional requirements that are required to effectively automate CR assignment, which takes as input the systematic mapping study and the survey;

6. The definition of an approach that satisfies the identified requirements to automate the CR assignment activity;

7. The realization of the proposed approach's architecture, in which we described the methods and techniques used for the implementation, as well as the components that have to be built and the third party components that should be assembled together in order to provide a service for automated CR assignment; and

8. The evaluation of the proposed approach, performed as an offline experiment simulating a real context.

1.7 Organization of the Thesis

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2

Background

2.1 Introduction

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3

Development

3.1 Introduction

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Listing 3.1: Python Fribonacci Code

```python
from math import *

# define function
def analytic_fibonacci(n):
  sqrt_5 = sqrt(5);
  p = (1 + sqrt_5) / 2;
  q = 1/p;
  return int( (p**n + q**n) / sqrt_5 + 0.5 )

for i in range(1,31):
  print analytic_fibonacci(i)
```

This is a reference to Code 3.1 . . .

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Listing 3.2: Hello World C Code

```
#include<stdio.h>

main()
    {
        printf("Hello World");
    }
```

This is a reference to Code 3.2 . . .

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Listing 3.3: Hello Java Code

```
public class HelloWorld {

    public static void main(String[] args) {
        System.out.println("Hello, World");
    }
}
```

This is a reference to Code 3.3 . . .

3.2 Section

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4

Conclusion

4.1 Introduction

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Apêndice

A

Mapping Study's Instruments

Tabela A.1: List of conferences on which the searches were performed.

Acronym	Conference
APSEC	Asia Pacific Software Engineering Conference
ASE	IEEE/ACM International Conference on Automated Software Engineering
CSMR	European Conference on Software Maintenance and Reengineering
ESEC	European Software Engineering Conference
ESEM	International Symposium on Empirical Software Management and Measurement
ICSE	International Conference on Software Engineering
ICSM	International Conference on Software Maintenance
ICST	International Conference on Software Testing
InfoVis	IEEE Information Visualization Conference
KDD	ACM SIGKDD International Conference on Knowledge Discovery and Data Mining
MSR	Working Conference on Mining Software Repositories
OOPSLA	Object-Oriented Programming, Systems, Languages and Applications
QSIC	International Conference On Quality Software
SAC	ACM Symposium on Applied Computing
SEAA	EUROMICRO Conference on Software Engineering and Advanced Applications
SEDE	19th International Conference on Software Engineering and Data Engineering
SEKE	International Conference on Software Engineering and Knowledge Engineering

Tabela A.2: List of journals in which the searches were performed.

Journal title
ACM Transactions on Software Engineering and Methodology
Automated Software Engineering
Elsevier Information and Software Technology
Elsevier Journal of Systems and Software
Empirical Software Engineering
IEEE Software
IEEE Computer
IEEE Transactions on Software Engineering
International Journal of Software Engineering and Knowledge Engineering
Journal of Software: Evolution and Process
Software Quality Journal
Journal of Software
Software Practice and Experience Journal

Tabela A.3: Search string per Search Engine.

Search Engine	Search String
Google Scholar	bug report OR track OR triage “change request” issue track OR request OR software OR “modification request” OR “defect track” OR “software issue” repositories maintenance evolution
ACM Portal	Abstract: "bug report"or Abstract:"change request"or Abstract:"bug track"or Abstract:"issue track"or Abstract:"defect track"or Abstract:"bug triage"or Abstract: "software issue"or Abstract: "issue request"or Abstract: "modification request") and (Abstract:software or Abstract:maintenance or Abstract:repositories or Abstract:repository
IEEExplorer (1)	(((((((((("Abstract": "bug report") OR "Abstract":"change request") OR "Abstract":"bug track") OR "Abstract":"software issue") OR "Abstract":"issue request") OR "Abstract":"modification request") OR "Abstract":"issue track") OR "Abstract":"defect track") OR "Abstract":"bug triage") AND "Abstract":software)
IEEExplorer (2)	(((((((((("Abstract": "bug report") OR "Abstract":"change request") OR "Abstract":"bug track") OR "Abstract":"software issue") OR "Abstract":"issue request") OR "Abstract":"modification request") OR "Abstract":"issue track") OR "Abstract":"defect track") OR "Abstract":"bug triage") AND "Abstract":maintenance)
IEEExplorer (3)	(((((((((("Abstract": "bug report") OR "Abstract":"change request") OR "Abstract":"bug track") OR "Abstract":"software issue") OR "Abstract":"issue request") OR "Abstract":"modification request") OR "Abstract":"issue track") OR "Abstract":"defect track") OR "Abstract":"bug triage") AND "Abstract":repositories)
IEEExplorer	(((((((((("Abstract": "bug report") OR "Abstract":"change request") OR "Abstract":"bug track") OR "Abstract":"software issue") OR "Abstract":"issue request") OR "Abstract":"modification request") OR "Abstract":"issue track") OR "Abstract":"defect track") OR "Abstract":"bug triage") AND "Abstract": repository)
Citeseer Library	(abstract: "bug report"OR abstract:"change request"OR abstract:"bug track"OR abstract:"issue track"OR abstract:"defect track"OR abstract:"bug triage"OR abstract: "software issue"OR abstract: "issue request"OR abstract: "modification request") AND (abstract:software OR abstract:maintenance OR abstract:repositories OR abstract:repository)
Elsevier	("bug report"OR "change request"OR "bug track"OR "issue track"OR "defect track"OR "bug triage"OR "software issue"OR "issue request"OR "modification request") AND (software OR maintenance OR repositories OR repository)
Scirus	("bug report"OR "change request"OR "bug track"OR "issue track"OR "defect track"OR "bug triage"OR "software issue"OR "issue request"OR "modification request") AND (software maintenance OR repositories OR repository) ANDNOT (medical OR aerospace)
ScienceDirect	("bug report"OR "change request"OR "bug track"OR "issue track"OR "defect track"OR "bug triage"OR "issue request"OR "modification request") AND LIMIT-TO(topics, "soft ware")
Scopus	("bug report"OR "change request"OR "bug track"OR "issue track"OR "defect track"OR "bug triage"OR "software issue"OR "issue request"OR "modification request") AND (software maintenance OR repositories OR repository)
Wiley	("bug report"OR "change request"OR "bug track"OR "issue track"OR "defect track"OR "bug triage"OR "software issue"OR "issue request"OR "modification request") AND (software maintenance OR repositories OR repository)
ISI Web of Knowledge	("bug report"OR "change request"OR "bug track"OR "issue track"OR "defect track"OR "bug triage"OR "software issue"OR "issue request"OR "modification request") AND (software maintenance OR repositories OR repository) ANDNOT (medical OR aerospace)
SpringerLink	("bug report"OR "change request"OR "bug track"OR "issue track"OR "defect track"OR "bug triage"OR "software issue"OR "issue request"OR "modification request") AND (software maintenance OR repositories OR repository) ANDNOT (medical OR aerospace)