Scientific report

1. **Project information**

   Project title:
   Romanian: Abordări noi bazate pe soft computing pentru evoluția software-ului: modificări si gestionarea defectelor

   English: nOvel appRoaCHEs based on Soft compuTing for softwaRe evolution: change and defect management

   Code: PN-III-P1-1.1-TE2021-0892
   Contract no.: 138/2022
   Acronym: ORCHESTRA
   https://www.cs.ubbcluj.ro/~avescan/orchestra

2. **Project objectives**

2.1. Objective 1. Automatic bug priority classification based on the information from the bug reports.

Activities
A 1.1. Synthesizing the most current knowledge in the field of bug priority classification;
A 1.2. Development of an algorithm using soft computing approaches for automatic bug report prioritization
A 1.3. Validation of the proposed algorithm on a set of existing bug reports

Context. Bug tracking systems receive a large number of bugs daily. The process of maintaining the integrity of the software and producing high-quality software is challenging. The bug-sorting process is usually a manual task that can lead to human errors and be time-consuming.

Research investigation. The purpose of this investigation is first to conduct a literature review on the bug report priority classification approaches and, secondly, to replicate existing approaches with various classifiers to extract new insights about the priority classification approaches. To synthesize the most actual research for bug report classification and priority prediction, a Systematic Literature Review (SLR) has been conducted. The second aim of the investigation was to conduct experiments on CNN based approach classification model and SVM to perform a multiclass prioritization (p1-p5) of bug reports. We operated a Naive Bayes classifier approach to automatically prioritize bug reports using the report information retrieved from the summary. Factors extracted from bug reports were further tokenized using Natural Language Processing [NLTK] and served as training and testing data for a Naive Bayes classifier.

Results. Given the bug reports, the performance of the proposed approach is evaluated by calculating the priority-specific precision P, the recall R, and the F1 score F1. The same evaluation metrics were used to determine the performance of our implemented algorithms: CNN and Naive Bayes. Based on these evaluation metrics, we performed an analysis of the data obtained for the 4 projects from Eclipse, but also on 3 different algorithms: SVM, CNN, and NB where we also implemented an NB and CNN algorithm using NLTK and Python libraries.

2.2. Objective 2. Code Smell investigation and software bugs.

Activities
A 2.1. Synthesizing the most current knowledge in the field of code smells, testing code smells, and the impact on errors
A 2.2. Development of code smell detector for SQL queries;
A 2.3. Validation of the proposed algorithm for a real software system

Databases are widely used today in almost all projects. The code source is not always perfect, with no errors. But the main difference between code smells and bugs is the impact that they have on the project: bugs can determine that the app does not function properly, while code smells mean not respecting the basic concepts of the programming language.
The purpose of SQL code smells research is two-fold: firstly, to propose a tool for the automatic detection of three SQL smells, and secondly, to validate the results obtained both through human evaluators and through tool comparison. In this research, the three SQL code smells being investigated are missing primary key, missing table columns, and implicit columns, which can be identified in three SQL statements, CREATE TABLE, INSERT INTO, and SELECT. These SQL code smells are supported by CoolPackSmell, our proposed SQL code smell detector.
To synthesize the most actual research studies for code smells, a Systematic Literature Review (SLR) has been conducted. CoolPackSmell is a tool inspired by *DbDeo* [Sha2018] - SQL code smell detection by syntax analysis using *sqlparser*, which supports the detection of *missing primary key*, *missing columns table,* and *implicit columns* SQL code smells. Note that these SQL code smells are not bugs but indicate a possible problem in the source code. To validate the proposed approach, two empirical studies are used: empirical validation through human evaluators and empirical validation through tool comparison.

2.3. Objective 3. Quality attributes and bug prediction

Activities
A 3.1. Synthetization of the most actual knowledge in the domain of bug prediction and
quality attributes; ((partially in 2022, partially in 2023))
A 3.2. Development of a code smell detector for sql queries;
A 3.3. Validate the proposed models using open-source software systems.

In our pursuit of approaching defect prediction methodologies that can be used to enhance software quality attributes, our primary objective is a comprehensive exploration of innovative approaches. We aim to systematically synthesize the latest knowledge in the domain, particularly focusing on soft computing methods for defect prediction and quality attribute analysis. Spanning 2022 and 2023, our research efforts are dedicated to achieving a thorough understanding and application of these methodologies to elevate software system quality.
To starting points of our investigation, we embarked on a meticulous replication study of a seminal paper from the Springer journal, Frontiers of Computer Science, focusing on software defect prediction. Our journey began with a Systematic Literature Review (SLR) involving three project members, each tasked with evaluating papers from distinct databases. Through stringent inclusion/exclusion criteria, we meticulously assessed proposed approaches, and dataset availability, and achieved results. This rigorous process led to the selection of nine papers, with final decisions reached through consensus among the team members. Subsequently, we delved into experiments aimed at reproducing and enhancing the results

presented in the selected paper, employing consistent tools and datasets to ensure fidelity. Our initial findings indicate successful replication alongside notable improvements in certain instances, warranting further investigation into the broader applicability and statistical significance of these enhancements.

2.4. Objective 4. Regression testing (TCP) considering bug prediction information

Activities
A 4.1. Synthetization of the most actual knowledge in the domain of regression testing (Test Case Prioritization)
A 4.2. Development of methods for optimally testing the software considering the changes performed on the source code and bug prediction information
A 4.3. Validate the proposed models using open-source software systems.

In this objective, our aim is to improve regression testing by integrating bug prediction into Test Case Prioritization (TCP). The innovative aspect of this research objective is the use of bug prediction models (in TCP), which identify likely defect areas, enabling focused testing efforts. We have started this objective by investigating the most recent papers published in the field of regression testing, focusing on the test case prioritization approaches. We have continued by developing our own methods for TCP and software bug prediction. We have published and sent for review several papers in this context.

2.5. Objective 5. Regression testing (TCP) considering requirements-tests-faults traceability

Activities
A 5.1.Synthetization of the most actual knowledge in the domain of regression testing (Test Case Prioritization) (2023)
A 5.2. Development of methods for optimally testing the software considering the changes and requirements-tests-faults traceability matrix (in 2024)
A 5.3. Validate the proposed models using open-source software systems. (in 2024)

In ensuring the reliability of software systems regression testing plays an important role. Nowadays, maintaining a test suite in continuous integration environments is challenging considering various aspects related to available resources, time, and best-selected test cases. In this respect, Test Case Prioritization is a solution that reorders the test suite for better and sooner fault detection. Yet, current methods use manual detection of artifact dependencies (requirement, code, test cases, faults, cycles).

We have explored artifact traceability in the context of Behavior-Driven Development (BDD) by developing an automatic detection system for dependencies among various artifacts. The primary contribution of this investigation involves designing and implementing an automatic traceability component capable of retrieving dependencies based on BDD artifacts such as requirements, source code, test cases, and faults. Additionally, we integrate the discovered traces as features in a neural network classification model for test cases, aiming to further prioritize them. Various architectures were employed for the neural network classification model. Validation of the models was conducted using a dataset comprising two real-world

BDD projects. A dataset consisting of two real-world BDD projects were used for the validation of the models

To bridge the existing gap in Test Case Prioritization (TCP), we proposed a novel approach that utilizes clustering techniques to categorize test cases based on their coverage of requirements, source code, and fault detection history. By synthesizing this information, our method aims to construct a more informed prioritization scheme that not only targets early fault detection but also ensures a thorough validation of the software's functional and non-functional requirements. This paper introduces a clustering-based TCP approach, integrating requirements coverage, source code coverage, and fault information to enhance the prioritization process. Additionally, we conducted an empirical evaluation of our approach on two widely-used open-source projects, trivial-graph and springmvc-router, demonstrating its effectiveness in improving the quality and efficiency of regression testing.

The research investigations related to this objective were finalized in several research manuscripts, and submitted to international conferences and journals.

3. Research visits and collaborations

3.1. Collaboration with the research group from the Netherlands

Between September 22-29, 2022, 4 members of the team (Andreea Vescan, Andreea Gabin, Alexandra Pasca, and Radu Gaceanu) visited the collaborator, prof. Alexander Serebrenik at the Eindhoven University of Technology. There were meetings in which TU/e members presented to grant members their research topics and the results obtained during the studies, but also meetings in which the grant members presented the objectives.
In the first meeting, Hamid Mohayeji Nasrabadi presented his research on Dependabot security. During another session, Nan Yang talked about log use in software engineering [Nan2022]. On 26th September, Andreea Galbin presented her work on Bug Priority classification models. Alexandra Pasca, on 28th September, presented a tool that she is working on for identifying SQL code smells. Prof. Andreea Vescan gave an invited talk on Test Case Prioritization in Regression Testing at Eindhoven University of Technology on 27th September 2022.
Between November 7-14, 2022, the visit of Prof. Alexander Serebrenik from the Eindhoven University of Technology took place. During his visit to our faculty, there were meetings and discussions both with members of the ORCHESTRA group and in a workshop organized during this period with members of the computer science department. Prof. Dr. Serebrenik Alexander had a presentation during the organized workshop within the ORCHESTRA research grant on the 3rd Nov 2022.

3.2. Collaboration with the research group from Austria

Between October 22-29, 2023, 2 members of the team (Andreea Vescan and Radu Gaceanu) visited the collaborator, prof. Alexander Egyed at the Johannes Kepler University (JKU), Linz, Austria. During this visit to Johannes Kepler University, there were meetings and discussions both with members of the ORCHESTRA group and PhD students and professors from the Software-Intensive Systems department of Johannes Kepler University.
The first presentation was from Prof. Paul Grünbacher, who presented ECCO, an alternate version control system. Other presentations included quality constraints checks in safety critical systems from Christoph Mayr-Dorn, applications of large language models in software

in the software development life-cycle from Anamaria Roberta Preda, transitioning from monolithic systems to microservices from Saad Shafiq and Design Space which is a shared environment that allows several platforms to integrate and collaborate.

On October 23, 2023, Andreea Vescan and Radu Gaceanu prepared and presented *Test Case Prioritization approaches in Regression Testing* detailing several contributions as well as research directions that are currently being pursued in this field.

The seminar "Regression testing using soft computing approaches" (*23 October 2023*) is at its second session, the first one being held in Romania on the 20th of June. Researchers from both universities discussed open issues in regression testing and the advantages of incorporating machine learning methods as well as soft computing approaches in order to enhance the TCP process.

The seminar "Quality attributes and bug prediction" (*26 October 2023*) is at its second edition, the first one taking place in Romania on the 19th of June, 2023. Researchers from both universities approached the topic of quality attributes and bug prediction and discussed possible applications in other contexts, like test case prioritization.

Prof. Dr. Alexander Egyed, Full Professor and Chair for Software-Intensive Systems at Johannes Kepler University, Austria (JKU), was invited to deliver a workshop as part of the ORCHESTRA grant. The workshop, titled "Evolving Product Lines – One Product at a Time," took place on June 21, 2023, at the FSEGA Building in Cluj-Napoca, Romania.

4. Events

4.1. Research Seminars

Several **Research Seminars** took place in 2022 and 2023, both during the visit to the research groups of our collaborators in the Netherlands and Austria and during their visits to Romania.

- two meetings during the research visit of the team in the Netherlands, Eindhoven (September 26 and 28, 2022)
- two meetings regarding Objectives 1 and 2 in Romania (November 10, 2022), during the visit of Prof. Alexander Serebrenik at Babes-Bolyai University.
- two sessions (one in Cluj-Napoca at Babeș-Bolyai University on Monday, 19 June 2023, 11:00 – 12:00 and one in Linz at the Institute of Software Systems Engineering (ISSE), Johannes Kepler University on Friday, 26 October 2023, 11:00 – 12:00) with discussions on quality attributes and bug prediction.
- two sessions (one in Cluj-Napoca at Babes-Bolyai University on Tuesday, 20 June 2023, 9:00 – 10:00 and one in Linz at the Institute of Software Systems Engineering (ISSE), Johannes Kepler University on Tuesday, 23 October 2023, 12:30 – 13:30) with discussions on regression testing using soft computing approaches.

4.2. Research Workshops

Research Workshop in 2022
Gender and Community Smells. **by Prof. Dr. Serebrenik Alexander.** Alexander Serebrenik delivered an invited talk on gender and community smells at the FSEGA Building, Room C335, Teodor Mihali Street, No. 58-60, 400591, Cluj-Napoca, Romania, on Wednesday, November 9, 2022, from 12:30 to 13:30. His presentation explored the correlation between community smells—patterns indicating suboptimal organization and communication within software development teams—and gender diversity. *Learning and Applying Best Practices for Code*

Evolution, **by Assoc. dr. Dig Danny.** Danny Dig delivered an invited talk on adapting best practices for code evolution and learning, held online on Thursday, November 10, 2022, from 17:30 to 18:30 (EET). In his presentation, he addressed the gap between the rapid growth of Python-based ML systems and the lagging advancements in software evolution, underscoring the need to bridge this disparity.

Research Workshop in 2023
Focus on mind. Mindfulness science and practice. From mind overload to presence, stillness & focus in research team. by **Nicoleta PFEFFER-BARBELA,** MSc., founder citySTILLE Mindfulness Center Vienna. The workshop, organized as part of the ORCHESTRA grant, took place at the Faculty of Mathematics and Computer Science. The event occurred on Wednesday, June 21, 2023, from 11:00 AM to 12:00 PM, within the FSEGA Building, specifically in Room C404, located at Teodor Mihali Street, No. 58-60, 400591, Cluj-Napoca, Romania. **Evolving Product Lines – One Product at a Time, by prof. dr. Alexander Egyed.** The workshop, held on Wednesday, June 21, 2023, from 12:30 PM to 1:30 PM in Room C335 of the FSEGA Building on Teodor Mihali Street, No. 58-60, 400591, Cluj-Napoca, Romania, drew participants both in-person and online. The online participation option was facilitated through a Teams Meeting Link, along with the relevant Meeting ID and passcode.

Research Workshop in 2024 The third organized workshop was in 2024, the F-TRANSFER workshop within the SANER conference (Facilitating continuous educaTion and tRaining through AI iN SoFtware EngineeRing, F-TRANSFER). The workshop was co-financed by the SANER conference and the ORCHESTRA project. The link to the workshop page is: https://www.cs.ubbcluj.ro/~avescan/f-transfer/

4.3. Training sessions

Training sessions. Training sessions, conducted both online and in person, covered crucial topics including communication, time management, and team dynamics essential for fostering cohesive teamwork. Attending two sessions, the first online on September 15, focused on public speaking, assertive communication, time management, and problem-solving facilitated by professional psychologists, employing interactive methods such as games and practical examples alongside slide presentations. The second session, held face-to-face on November 8, delved deeper into group dynamics, offering theoretical insights supplemented with real-life examples and practical exercises. Topics from both sessions proved highly beneficial, equipping the team with insights into common causes of team failure, stages of team development, and effective communication strategies, including identifying and transitioning towards assertive communication, empowering both the team as a whole and individual members.

5. Project progress summary and dissemination of results

5.1. Publications. Conferences and Journals.

2022 – Conferences and Journals
- Andreea Galbin-Nasui, Andreea Vescan, Bug reports priority classification models. Replication study, Automated Software Engineering Journal, 2024, 31:35

- Alexandra-Maria Pasca, Andreea Vescan, *CoolPackSmell* for detecting SQL code smells: an empirical study, ISI journal, submitted in 2022/2023, under review

2023 – Conferences and Journals
- *A. Vescan, R. Găceanu, C. Serban, Exploring the Impact of Data Preprocessing Techniques on Composite Classifier Algorithms in Cross-Project Defect Prediction, Automated Software Engineering Journal, 2023/2024 (under review, revision April 2024)*
- A. Vescan and R. Găceanu, "Cross-Project Defect Prediction using Supervised and Unsupervised Learning: a Replication Study," *2023 27th International Conference on System Theory, Control and Computing (ICSTCC)*, Timisoara, Romania, 2023, pp. 440-447, doi: 10.1109/ICSTCC59206.2023.10308464.
- *A. Vescan, R. Găceanu, A. Szederjesi-Dragomir, "Neural Network-Based Test Case Prioritization in Continuous Integration," 2023 38th IEEE/ACM International Conference on Automated Software Engineering Workshops (ASEW), Luxembourg, Luxembourg, 2023, pp. 68-77, doi: 10.1109/ASEW60602.2023.00014.*
- I. -C. Rotaru and A. Vescan, "Test Case Prioritization Based on Neural Network Classification with Artifacts Traceability," *2023 38th IEEE/ACM International Conference on Automated Software Engineering Workshops (ASEW)*, Luxembourg, Luxembourg, 2023, pp. 78-87, doi: 10.1109/ASEW60602.2023.00015.

2024 – Conferences and Journals
- R. Gaceanu, A. Szederjesi-Dragomir, A. Vescan, *"Leveraging Rough Sets for Enhanced Test Case Prioritization in a Continuous Integration Context", Workshop on Validation, Analysis and Evolution of Software Tests Co-located with the International Conference on Software Analysis, Evolution and Reengineering (SANER), 2024*
- A. Szederjesi-Dragomir, R. Gaceanu, A. Vescan, *"Industrial Validation of a Neural Network Model Using the Novel MixTCP Tool", 19th International Conference on Evaluation of Novel Approaches to Software Engineering (ENASE), 2024*
- A. Vescan, R. Gaceanu, A. Szederjesi-Dragomir, *"Embracing Unification: a Comprehensive Approach to Modern Test Case Prioritization", 19th International Conference on Evaluation of Novel Approaches to Software Engineering (ENASE), 2024*
- A. Moldovan, A. Vescan, *Outlier Detection through Connectivity-based Outlier Factor for Software Defect Prediction, 19th International Conference on Evaluation of Novel Approaches to Software Engineering (ENASE), 2024*
- A. Vescan, R. Gaceanu, A. Szederjesi-Dragomir, *Rough Sets for Test Case Prioritization with Artifacts Traceability*, ISI journal manuscript, submitted in 2024
- A. Vescan, R. Gaceanu, C. Serban, Clustering-based TCP with *Artifacts Traceability*, ISI journal manuscript, submitted in 2024

5.2. Dissemination of results

Objective 7 of the project regarding *Dissemination and exploitation* was operationalized by several activities that are outlined in what follows.

Project web page activity. Creating and maintaining the web page of the project with information regarding various meetings, visits, and events that took place under the ORCHESTRA grant umbrella.

The webpage contains the summary of the project, the objectives, the team members, along with contacts. The web pages were updated with the presentations and workshops that took place during the visits of the researchers to The Netherlands, Austria, and to Romania.

Disseminations of Results through Workshops. The workshop meetings in Romania were disseminated on the webpage of the project, on the Faculty of Mathematics and Computer Science webpage, also by emails to various research collaborators, both from universities and from IT firms. The third workshop organized and co-financed by the project took place in Finland withing the SANER conference.

Disseminations of Results through articles in journals and participations to conferences. As a result, the provided performance criteria were met: one paper accepted to the ASE journal for the first objective, one paper submitted for the second scientific objective for publication in an ISI/WoS journal with high impact factor, for the third scientific objective the submission to an ISI/WoS journal received a revision response in April 2024 and also two papers were presented in international conferences, for the fourth scientific objective a paper was submitted to an ISI/WoS journal and two participations to international conferences took place, and for the fifth scientific objective, two papers were submitted to ISIWoS journals and three participations to international conferences.

Disseminations through Research visits. Several research visits took place in the Netherlands and Austria with the research groups of our collaborators and also visits to Romania that facilitated the organization of several research seminars and workshops, allowing knowledge transfer sessions between group members and external collaborators.

Furthermore, the project objectives have been met, and all associated activities have been completed and carried out in accordance with the project implementation plan.

Executive Summary of Activities

Software maintenance and evolution play an important role in obtaining a qualitative software system, either during the development phase or after release. The changes that occur during software development are one of the important factors that threaten the quality of the software system, therefore, methods and tools to achieve a better state of the system are a must.

The main objective of the project is to explore and develop an innovative set of soft computing techniques for software maintenance and evolution-related activities regarding software changes.

In 2022, two directions were approached entirely (bug priority classification, code smells for SQL queries) and another one (quality attribute prediction) was started with the final activity in 2023. Two research visits were employed during 2022, four researchers from the group visited the research team of Professor Alexander Serebrenik in The Netherlands at the Eindhoven University of Technology and in November we received a visit from the same professor. Workshops were organized during the visit in Romania, with a presentation on *Gender and Community Smells*. Another online presentation was provided by Assos. prof. Danny Dig with the title *Learning and Applying Best Practices for Code Evolution*. During the visits, several other presentations and seminars took place to disseminate the project work, and the respective expertise of the two teams, and help foster potential new collaborations.

In 2023, two directions were approached entirely (test case prioritization in continuous integration and using information from requirements-test-faults) and another one (test case prioritization using traceability matrix) was started with the final activity in 2024. Two research visits were employed during 2023, professor Alexander Egyed from Austria (Institute of Software Systems Engineering (ISSE), Johannes Kepler University (JKU)) visited our research group in Romania in June, and two researchers from the group visited in October the research team of professor Alexander Egyed. Workshops were organized during the visit in Romania, with a presentation on *Evolving Product Lines – One Product at a Time*. Another presentation was provided by Nicoleta Pfeffer-Barbela, MSc., founder cirySTILLE Mindfulness Center Vienna with the title *Focus on mind. Mindfulness science and practice. From mind overload to presence, stillness & focus in research teams*. During the visits, several other presentations and seminars took place to disseminate the project work, and the respective expertise of the two teams, and help foster potential new collaborations.

In 2024 the test case prioritization problem was investigated further, culminating with several participations at international conferences (SANER with workshop VST and ENASE with two approaches) and two manuscripts to ISI journals. The F-TRANSFER (Facilitating continuous educaTion and tRaining through AI iN SoFtware EngineeRing) workshop was co-organized along with the SANER conference, being seen as a tool for researchers, industry experts, and professionals to exchange insights on the latest developments and prospective avenues in software engineering methodologies and tools.

Project Director,
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