

PBGT - Pattern Based GUI Testing

Final Report

TR_08_PBGT_10-2015



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1. Goals of the project

The main goal of this project is to improve the current model-based GUI testing methods and tools, contributing to construct an effectively applicable testing approach in industry and to contribute to the construction of higher quality graphical user interfaces (GUI) and software systems.

One of the problems to overcome when implementing a model-based GUI testing approach is the time required to construct the model and the test case explosion problem. This project aims to:

- identify the right abstraction level of the model by defining a specification language that focuses on common recurrent behavior and that allows describing testing goals
- extract part of that model by a reverse engineering process
- develop a testing environment for modelling, test case generation, and test case execution over a GUI.

The PBGT project is divided in 5 tasks:

- Task 1) Development of a domain specific visual GUI modelling language to describe the testing goals in a high level of abstraction. Those testing goals can be configured in order to be possible to test different web application.
- Task 2) Development of a GUI reverse engineering process and tool to extract part of the testing model of an existing web application
- Task 3) Development of a test case generation and execution environment which is integrated with the modelling environment and from which it is possible to perform all the testing activities including coverage analysis and view final test reports.
- Task 4) Development of an algorithm, and associated tool support, to produce test case mutations enabling the GUI to be tested against erroneous or unexpected user behavior.
- Task 5) Industrial validation and enhancement in which the testing tools developed are used in real case scenarios and the feedback obtained is used to improve such tools and adapt them to the real needs of the industry world.

2. Achieved Goals

We have achieved all the goals expected for the project and sometimes we have surpassed the initially established goals. We developed a web page with a public area to publish the research papers written along the project and a private area to work as a way to promote communication among all the elements of the team project. The web page is available on <https://paginas.fe.up.pt/~apaiva/pbgtwiki/doku.php>

We surpassed the initially planned MSc thesis. There were 6 MSc thesis and 1 (one) PhD thesis developed along the project. The corresponding thesis can be found on the web page of the project (inside tab PUBLICATIONS).

As expected there were 2 paper published in international journals. There were additionally two papers submitted to two international journals that unfortunately we don't know yet the final decision. However we are confident that they will be accepted. One was submitted to STRV (Software Testing Verification and Reliability) and another to CLUS (Cluster Computing). We send the submitted versions (not final versions) in attachment with this report. One document is called "stvr.pdf" and the other is called "clus.pdf".

Regarding the tools, we have developed six tools (instead of four initially planned), four of which integrated with PBGT modeling and testing environment and two additional tools that were developed separately but modular so easily integrated with other environments (not only PBGT tools):

- Modelling environment where it is possible to model testing goals, and configure such models with testing input data
- A test coverage analysis tool that allows to perform coverage analysis over the code, over the model and over a test suite.
- A reverse engineering tool that allows to extract part of the model of an existing software application
- A test case generation tools that allows to generate test cases from models according to different strategies
- A framework implementing an approach to the mutation of test cases
- A Toolset for Conformance Testing against UML Sequence Diagrams (<https://blogs.fe.up.pt/sdbt/>)

With regard to publications in conference, we exceeded by far the initially planned number of publications. Initially we planned to publish 8 papers but we surpassed that number. We have published 18 papers (just two of them in Portuguese conferences). All the publications can be found on the web page of the project.

As a final remark, we can say that the observations and comments received from external consultants and the company participating in the project were very helpful in guiding the research carried out and to improve the tools developed during the project.

Besides all this, the PI of the project organized an international workshop (TESTBEDS 2014 - <http://testbeds14.unl.edu/>). During this fifth International Workshop on “TESTing Techniques & Experimentation Benchmarks for Event-Driven Software” we performed a presentation about PBGT project and discussed research directions.

3. Brief description of the activities developed along the project

3.1. TASK 1 – Development of a domain specific visual GUI modelling language

The main goal of this task was to develop a Domain Specific Language for modelling testing goals in a high level of abstraction. During this task we were able to perform collect a set of patterns for interaction design and the relations among those patterns defined through connectors. Based on the interaction design patterns and connectors identified, we have defined a domain specific language called PARADIGM-DSL for modelling GUIs testing goals. After that we have developed a modeling environment called PBGT tools on which it is possible to build testing models graphically by dragging patterns and linking them through connectors. We can say that all goals for this task were achieved and surpassed.

3.2. TASK 2 – development of a GUI reverse engineering process

This task had major challenges. During this task we had the opportunity to try different approaches and to choose the best option. We've explored an approach where we have applied ILP (inductive logic programming). We found out that we had some scalability problems. Then we've tried another approach using a "parser" over the execution traces automatically extracted from an existing web application in order to identify interaction patterns and build the test model automatically. The reverse engineering tool developed following this process was integrated within the PBGT modeling and testing environment and is available for download on the web page of the project.

3.3. TASK 3 - Development of a test case generation and execution environment

The goal of this task was to develop a tool capable of generating test cases from models and executing those tests over software applications through their GUI.

We could surpass our initial goals in the sense that it was possible to build a tool that is capable of executing the test cases over a web application and over Android software applications.

Additionally, we have also developed a toolset for Conformance Testing against UML Sequence diagrams which may be used to define interactions with software applications.

We have performed some experiments with the tool developed and the information about such experiments are described in the web page of the project (inside the tab CASE STUDIES).

So we can say that we have achieved all the goals of this task.

3.4. TASK 4 - Development of an algorithm, and associated tool support, to produce test case mutations enabling the GUI to be tested against erroneous or unexpected user behavior.

The main output of this task was the development of a framework implementing an approach to the mutation of test cases. Through the mutation process the framework enables testing Web application against possible user error. The framework covers both the generation of test cases, and the automated testing of Web applications against them. It was developed using a modular approach in order to support its integration into PBGT tools and, possibly, other tools. This modular approach made it possible to explore the use of reverse engineering techniques and task modelling tools for the generation of test oracles.

We also developed and explored the idea of usability 'smells'. The goal here was to define a catalogue of user interface features that might impact usability negatively so that later tests that address them might be defined.

3.5. TASK 5 - Industrial validation and enhancement

Throughout this task, the Wintrust Company had the opportunity to try the tools that were being developed throughout the project and provide comments and give insights to improve them.

During these experiments, Wintrust followed in the footsteps of the installation provided on the web site of the project and had the opportunity to identify potential problems during this activity. Wintrust also reviewed the videos available on the project web page. These videos aim to help users and newer developers to understand how the tool works and how you can extend it because the code is freely available and anyone can improve and add functionality to environment developed test.

Besides all these, Wintrust was also able to use PBGT tools to test the software HP Tours. Tours HP is a web application that simulates an airline reservation system in which users can select cities of origin and destination, dates of flights, and complete the booking of features throughout the various screens that allow to complete the booking of one or more flights. In addition, they used some reference sites such as Gmail, Outlook to recreate some examples to test the tool in learning the same.

All objectives of this task were achieved.

4. Detailed description about the activities performed along the project

This report describes the activities performed along the tasks of the PBGT project.

4.1. TASK 1 – Development of a domain specific visual GUI modelling language

The main goal of this task was to develop a Domain Specific Language for modelling testing goals in a high level of abstraction. During this task we were able to perform the following steps:

- We have collected a set of patterns for interaction design, have identified relations between those patterns and have defined connectors between interaction design patterns
- Based on the interaction design patterns and connectors identified, we have defined a domain specific language called PARADIGM-DSL for modelling GUIs testing goals.
- We have developed a modeling environment called PBGT tools on which it is possible to build testing models graphically by dragging patterns and linking them through connectors. This environment is developed on top of Eclipse Modelling Framework. Besides being possible to build test models, it is possible to configure the model and perform coverage analysis over the model, the test cases and over the code (if written in PHP)

We can say that all goals for this task were achieved and surpassed.

Besides the tools developed, and as expected, there was a PhD student that finished his research work related to this task and two master thesis.

Besides papers published on international conferences, there were also two paper published on international journals and two papers submitted to STVR journal and CLUS journal that unfortunately we do not know yet the result of the submission but we are confident that they will be accepted.

4.1.1. RESULTS

PhD Thesis:

- Rodrigo Moreira, PhD Dissertation: “Pattern-Based GUI Testing”, Faculty of Engineering of the University of Porto, July 2015

MSc Thesis:

- Tiago Monteiro, MSc Dissertation: “Ambiente gráfico de modelação para DSL”, Faculdade de Engenharia da Universidade do Porto, julho de 2012
- Liliana Vilela, MSc Dissertation : “Implementation of a Coverage Tool”, Faculty of Engineering of the University of Porto, July 2013

Journal:

- Rodrigo M. L. M. Moreira, Ana C. R. Paiva, Miguel Nabuco, Atif Memon, “Pattern-based GUI testing: Bridging the gap between design and quality assurance”, in Software Testing, Verification and Reliability Journal (STVR), John Wiley & Sons, Ltd, 2017, DOI: 10.1002/stvr.1629

Papers:

- Inês Coimbra Morgado, Ana C. R. Paiva, “UI Test Patterns for Mobile Applications”, Proceedings of the 20th European Conference on Pattern Languages of Programs (EuroPLOP 2015), Kloster Irsee in Bavaria, Germany, July, 2015
- Rodrigo Moreira , Ana C. R. Paiva, “A Novel Approach using Alloy in Domain-Specific Language Engineering”, in (MODELSWARD) - 3th International Conference on Model-Driven Engineering and Software Development, 2015.

- Pedro Costa, Ana C. R. Paiva, and Miguel Nabuco, “Pattern Based GUI Testing for Mobile Applications”, in 9th International Conference on the Quality of Information and Communications Technology (QUATIC’14), 23 to 26 September, Guimarães, Portugal, 2014.
- Inês Coimbra Morgado, Ana C. R. Paiva, João Pascoal Faria, “Automated Pattern-Based Testing of Mobile Applications”, 5th Portuguese Software Engineering Doctoral Symposium (SEDES 2014) hosted by QUATIC’2014 – 9th International Conference on the Quality of Information and Communications Technology (QUATIC), September 23rd, 2014 – Guimarães, Portugal.
- Rodrigo M. L. M. Moreira and Ana C. R. Paiva, “Towards a Pattern Language for Model-Based GUI Testing, Proceedings of the 19th European Conference on Pattern Languages of Programs (EuroPLOP 2014), Kloster Irsee in Bavaria, Germany, 9-13 July, 2014.
- Rodrigo M. L. M. Moreira, Ana C. R. Paiva, “A GUI Modeling DSL for Pattern-Based GUI Testing - PARADIGM”, 9th International Conference on Evaluation of Novel Approaches to Software Engineering (ENASE 2014), 28-30 April, Lisbon, Portugal.
- Rodrigo Moreira, Ana Paiva and Atif Memon, “A Pattern-Based Approach for GUI Modeling and Testing”, in ISSRE’13 - The 24th IEEE International Symposium on Software Reliability Engineering, Pasadena, CA, 2013.

Tools:

- A modelling environment where it is possible to build test models by dragging and dropping elements and connectors belonging to the DSL developed

Reports:

- A technical report explaining how to install the modelling environment – “Installation Manual of PARADIGM-ME” (available on the web page of the project – Tab Publications)
- A technical report about the modelling environment (“Ambiente gráfico de modelação DSL” – available in the web page of the project – tab publications)

Journals:

- Paper submitted to STRV (Software Testing Verification and Reliability). The version submitted is in attachment with this report. The file is called “strv.pdf”.

4.2. TASK 2 – development of a GUI reverse engineering process

This task had major challenges. During this task we had the opportunity to try different approaches and to choose the best option. We explored an approach where we have applied ILP (inductive logic programming). We found out that we had some scalability problems. Then we’ve tried another approach using a “parser” over the execution traces automatically extracted from an existing web application in order to identify interaction patterns and build the test model automatically. The reverse engineering tool developed following this process was integrated within the PBGT modeling and testing environment and is available for download on the web page of the project.

4.2.1. RESULTS

Master thesis:

- Clara Sacramento, MSc Dissertation: “Reverse Engineering of Interaction Patterns”, Faculty of Engineering of the University of Porto, July 2014

Papers:

Regarding research papers published we surpassed the number expected. Initially we anticipated the publication of two papers but we published four papers on international conferences and one paper on an international journal.

- Clara Sacramento and Ana C. R. Paiva, “Web Application Model Generation through Reverse Engineering and UI Pattern Inferring”, in 9th International Conference on the Quality of Information and Communications Technology (QUATIC'14), 23 to 26 September, Guimarães, Portugal, 2014.
- Miguel Nabuco, Ana C. R. Paiva, “Inferring User Interface Patterns from Execution Traces of Web Applications”, Software Quality workshop of the 14th International Conference on Computational Science and Applications (ICCSA 2014), June 30 - July 3, 2014, Guimarães, Portugal.
- Inês Coimbra, Ana C. R. Paiva, João P. Faria, Rui Camacho, “GUI Reverse Engineering With Machine Learning”, in RAISE'12 - Workshop on Realizing Artificial Intelligence Synergies in Software Engineering, June 5, Zurich, Switzerland, 2012
- Miguel Nabuco and Ana C. R. Paiva, “Inferring UI Patterns with Inductive Logic Programming”, CISTI'2013 (8ª Conferência Ibérica de Sistemas e Tecnologias de Informação), 19 e 22 de Junho de 2013, em Lisboa, Portugal

Journals:

- Inês Coimbra Morgado, Ana C. R. Paiva, João Pascoal Faria, “Dynamic Reverse Engineering of Graphical User Interfaces”, International Journal on Advances in Software, Vol.5 nº 3&4, pp.-, 2012

Tools:

- A GUI reverse engineering tool that is integrated with the modelling environment and is capable of explore an interactive application through its GUI and identify the existing UI patterns and afterwards build the test model that can test those patterns

Reports:

- Clara Sacramento, State of the art report: “Engenharia Reversa de Padrões de Interação”, Porto, Portugal, fevereiro 2014 (available on the web page of the project – tab Publications).

4.3. TASK 3 - Development of a test case generation and execution environment

The goal of this task was to develop a tool capable of generating test cases from models written in the specification language defined in task 1 and executing those tests over software applications through their GUI.

We could surpass our initial goals in the sense that it was possible to build a tool that is capable of executing the test cases over a web application and over an Android software applications. The tool is developed based on Selenium (for the web) and based on Selendroid (to execute the tests over mobile applications).

It is possible to configure the test case generation algorithm in order to generate test cases according to different test strategies. In addition, the way all PBGT tools are developed (within a framework) allows to extend the tools and in this particular case it is possible to add more test case generation algorithms as needed.

Additionally, we have developed a toolset for Conformance Testing against UML Sequence diagrams which may be used to define interactions with software applications (<https://blogs.fe.up.pt/sdbt/>).

We have performed some experiments with the tool developed and the information about such experiments are described in the web page of the project (inside the tab CASE STUDIES).

So we can say that we have achieved all the goals of this task. The tools are freely available through the website of the project with installation manuals and helps for developers that may want to extend the tool and testers that may want to use the tool to test web and mobile applications.

4.3.1. RESULTS

Journals:

- João Pascoal Faria , Ana C. R. Paiva, “A Toolset for Conformance Testing against UML Sequence Diagrams based on Event-Driven Colored Petri Nets”, International Journal on Software Tools for Technology Transfer (JSTTT), pp.1-20, 2014.

Papers:

- Inês Coimbra Morgado, Ana C. R. Paiva, “Mobile GUI testing”, in Software Quality Journal, 2 September 2017.
- Ana C. R. Paiva, Liliana Vilela, “Multidimensional test coverage analysis: PARADIGM-COV tool”, in Cluster Computing Journal, March 2017, Volume 20, Issue 1, pp 633–649, DOI: 10.1007/s10586-017-0728-4
- Pedro Costa, Ana C. R. Paiva, and Miguel Nabuco, “Pattern Based GUI Testing for Mobile Applications”, in 9th International Conference on the Quality of Information and Communications Technology (QUATIC'14), 23 to 26 September, Guimarães, Portugal, 2014.
- Miguel Nabuco, Ana C. R. Paiva, “Model-based test case generation for Web Applications”, 14th International Conference on Computational Science and Applications (ICCSA 2014), June 30 - July 3, 2014, Guimarães, Portugal.
- Liliana Vilela, Ana C. R. Paiva, “PARADIGM-COV - A Multidimensional Test Coverage Analysis Tool”, in CISTI 2014 - 9ª Conferencia Ibérica de Sistemas y Tecnologías de Información, Barcelona, 18-21 Junio, 2014.
- Tiago Monteiro and Ana C. R. Paiva, “Pattern Based GUI Testing Modeling Environment”, March 18, Fourth International Workshop on TESTING Techniques & Experimentation Benchmarks for Event-Driven Software - TESTBEDS, Co-located with The Sixth IEEE International Conference on Software Testing Verification and Validation, 2013.

Tools:

- Test case generation tool integrated within the modelling and testing environment capable of executing tests over the web and over mobile
- A Toolset for Conformance Testing against UML Sequence Diagrams (<https://blogs.fe.up.pt/sdbt/>)

Reports:

- Case studies within web page of the project inside tab CASE STUDIES
- Model-based test case generation for web applications – available on the web page of the project under publications tab

4.4. TASK 4 - Development of an algorithm, and associated tool support, to produce test case mutations enabling the GUI to be tested against erroneous or unexpected user behavior.

The main output of this task was the development of a framework implementing an approach to the mutation of test cases. Through the mutation process the framework enables testing Web application against possible user error. The framework covers both the generation of test cases, and the automated testing of Web applications against them. It was developed using a modular approach in order to support its integration into PBGT tools and, possibly, other tools. This modular approach made it possible to explore the use of reverse engineering techniques and task modelling tools for the generation of test oracles.

To complement the use of patterns and mutations to guide the testing process, the idea of usability 'smells' was defined and explored. The goal here was to define a catalogue of user interface features

that might impact usability negatively so that later tests that address them might be defined. This will make it possible to maximizing the coverage of usability related problems while keeping the number of test cases at a reasonable level.

During the last six months of the project the framework was used to test an existing Web application. This made it possible to validate the framework.

4.4.1. RESULTS

MSc Thesis:

- Diogo Francisco de Carvalho Almeida, MSc Dissertation: “Catálogo de Usability Smells”, Outubro 2014
- Paulo Cruz, MSc Dissertation: “Development of an environment for the generation, mutation and execution of test cases”, December 2013
- Raphael Julien Rodrigues. Testes Baseados em Modelos. Dissertação de Mestrado. Escola de Engenharia, Universidade do Minho, 2014.

Papers:

- Towards a Catalog of Usability Smells, D. Almeida, J.C. Campos, J. Saraiva and J.C. Silva, In ACM SAC 2015 proceedings - Volume I: Artificial Intelligence and Agents, Distributed Systems, and Information Systems, pages 175-181. ACM. 2015
- Uma Abordagem para a Geração de Casos de Teste Baseada em Modelos - A Model-based Approach for Test Cases Generation, CISTI'2013 (8ª Conferência Ibérica de Sistemas e Tecnologias de Informação), 19 e 22 de Junho de 2013, em Lisboa, Portugal
- Ambiente de geração, mutação e execução de casos de teste para aplicações Web, P.J. Cruz and J.C. Campos (2013), In Luís Magalhães and Beatriz Santos, editors, Atas da Conferência Interação 2013, pages 45-52. Universidade de Trás-os-Montes e Alto Douro

Reports:

- Report about the case study performed during this task – available on the web page of the project under publications tab.

4.5. TASK 5 - Industrial validation and enhancement

This task had some adversities that could be overcome. Wintrust is a company working in software testing field and was excited to integrate the PBGT project team. Thus, besides the adversities, we could accomplish the tasks originally envisaged.

Throughout this task, the Wintrust Company had the opportunity to experience the tools that were being developed throughout the project and provide comments and give insights to improve them. During these experiments, Wintrust followed in the footsteps of the installation provided on the web site of the project and had the opportunity to identify potential problems during this activity. All information obtained allowed the FEUP elements to improve documentation and to facilitate the installation task.

Wintrust also reviewed the videos available on the project web page. These videos aim to help users and newer developers to understand how the tool works and how you can extend it because the code is freely available and anyone can improve and add functionality to environment developed test. During this analysis, Wintrust gave feedback that was useful to improve such videos. It was decided to provide a video for each testing strategy (UI test patterns) and also videos for developers and testers.

Besides all these, Wintrust was also able to use PBGT tools to test the software HP Tours. Tours HP is a web application that simulates an airline reservation system in which users can select cities of origin and destination, dates of flights, and complete the booking of features throughout the various screens that allow to complete the booking of one or more flights. In addition, they used some

reference sites such as Gmail, Outlook to recreate some examples to test the tool in learning the same.

All information obtained during these experiments are part of a report that was carefully examined by FEUP team members. The last stage of the project within PBGT FEUP was used to improve the tools, its usability and functionality. The final versions of the tool are available on the project web site. After the improvements, Wintrust had the opportunity to experience the final versions of the tool.

Besides two papers already published in international journals (the ones expected to be published during the project), there were additionally two papers submitted to two international journals that we don't know yet the final answer but hope they will be accepted in the near future. One was submitted to STRV (Software Testing Verification and Reliability) and another to CLUS (Cluster Computing).

All objectives of this task were achieved.

4.5.1. RESULTS

Papers:

- Rodrigo M. L. Moreira and Ana C. R. Paiva, "PBGT Tool: An Integrated Modeling and Testing Environment for Pattern-Based GUI Testing", 29th IEEE/ACM International Conference on Automated Software Engineering (ASE 2014). September 15 - 19, Västerås, Sweden, 2014

Reports :

- Results of some experiments performed comparing PBGT with other testing tools are in the tab "Case studies" of the web site of the project
- The report produced by Wintrust is in attachment to this report. The file is called "reportWintrust.pdf".

Tools:

Tools are available for download on the web page of the project accompanied with installation manuals and helpers for developers and testers. We also provide videos that can help tester and developers working with the tools developed along the project.

Ana Paiva

FEUP - 2015