View metadata, citation and similar papers at core.ac.uk

brought to you by CORE

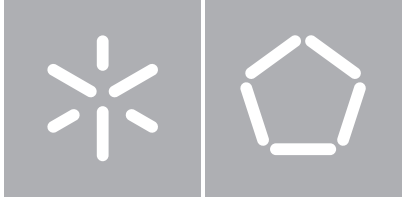
provided by Universidade do Minho: RepositoriUM

Universidade do Minho
Escola de Engenharia

Paulo Filipe de Jesus Cruz

Development of an environment for the generation, mutation and execution of test cases

Outubro de 2013



Universidade do Minho
Escola de Engenharia
Departamento de Informática

Paulo Filipe de Jesus Cruz

Development of an environment for the generation, mutation and execution of test cases

Dissertação de Mestrado
Mestrado em Engenharia Informática

Trabalho realizado sob orientação de
Professor José Creissac Campos

Outubro de 2013

A special thanks to my family that supported me, to my friends who helped me when I needed it, especially those who did not understand anything I said, but listened anyway, and to my supervisor for the opportunity and for being always available to clarify doubts and help me developing this project.

This work was funded by FEDER funds through the Programa Operacional Factores de Competitividade- COMPETE and National Funds through FCT – Fundação para a Ciência e Tecnologia under the project FCOMP-01-0124-FEDER-020554. The work of the author was also supported by a grant with reference PTDC/EIAEIA/119479/2010_UMINHO.

ABSTRACT

Development of an environment for the generation, mutation and execution of test cases

Testing graphic user interfaces (GUI) involves, mainly, lengthy and expensive processes involving user testing. Finding simpler and easier alternatives to use than these processes becomes an exciting proposal. This project presents an alternative to existing processes through the use of Model-based Testing - MBT.

The MBT technique takes advantage of models that describe the correct operation of the system (for this project task models). The use of MBT may thus become a new approach to testing GUI's, since the implemented GUI is tested against the model that specifies it the correct behavior. All inconsistencies found during the tests will be treated as potential errors that must be corrected.

This report describes the development of a prototype for an environment able to generate and execute test cases applying MBT to GUI's.

Key words: Model-based testing, Graphic User Interfaces, Task Models,

Application areas: Web interfaces

RESUMO

Desenvolvimento de um ambiente para a geração, mutação e execução de casos de teste

A realização de testes a interfaces gráficas (GUI) envolve, maioritariamente, processos morosos e dispendiosos. Encontrar alternativas mais simples e fáceis de utilizar do que estes processos torna-se uma proposta aliciante. Este projeto apresenta uma solução alternativa aos processos já existentes através da utilização de casos de teste baseados em modelos (*Model-based Testing* - MBT).

Esta técnica tira partido de modelos que descrevem o correto funcionamento do sistema (no caso particular do projecto modelos de tarefas). A utilização do MBT pode assim transformar-se numa nova abordagem aos testes realizados sobre GUI's, uma vez que a GUI implementada será testada contra o modelo especificado que contém o funcionamento correto desta. As incoerências encontradas nos testes apontam para potenciais erros que deverão ser corrigidos.

Este relatório descreve o desenvolvimento de um protótipo para um ambiente capaz de gerar, mutar e executar casos de teste para GUI's aplicando o MBT.

Palavras-chave: Testes baseados em modelos, interfaces gráficas, modelos de tarefas

Área de Aplicação: interfaces gráficas Web

CONTENTS

ABSTRACT III

RESUMO IV

CONTENTS V

LIST OF FIGURES IX

LIST OF TABLES XI

GLOSSARY AND ACRONYMS XII

1. INTRODUCTION 1

1.1 BACKGROUND 1
1.2 PROJECT DESCRIPTION 3
1.3 REPORT STRUCTURE 4

2. SOFTWARE TESTING 5

2.1 SOFTWARE TESTING LIFE CYCLE 6
2.2 TESTING LEVELS 7
2.2.1 TESTING TARGET 7
2.2.2 TESTING OBJECTIVES 8
2.3 TESTING METHODS 11
2.4 MODEL-BASED TESTING 12
2.5 CONCLUSION 14

3. GUI MODEL-BASED TESTING 15

3.1 APPLYING MBT TO GUI'S 16
3.1.1 TASK MODELING TOOLS 16
3.1.2 TEST CASES AUTOMATION TOOLS 17
3.2 CONCLUSION 19

4. IMPLEMENTATION AND DEVELOPMENT 20

4.1 PROPOSED APPROACH 20
4.2 TASK MODELS WITH CTT (CONCURRTASKTREE) 22
4.3 TEST CASES 25
4.3.1 TEST CASES CONFIGURATION 25
4.3.2 TEST CASES GENERATION 29
4.4 TEST CASES MUTATION 32
4.5 TEST CASES EXECUTION 33
4.6 CONCLUSION 37

5. TESTING USER INTERFACES 38

5.1 TAP PORTUGAL – SEARCH FLIGHTS AND HOTELS 38
5.1.1 TASK MODEL 38
5.1.2 CONFIGURATION FILES 40
5.1.3 TEST CASES 41
5.1.4 TEST CASES EXECUTION 43
5.1.5 MUTATED TEST CASES 45
5.1.6 MUTATED TEST CASES EXECUTION 46
5.2 MICROSOFT OUTLOOK (ONLINE) 48
5.2.1 TASK MODEL 48
5.2.2 CONFIGURATION FILES 50

5.2.3 TEST CASES 51
5.2.4 TEST CASES EXECUTION 53
5.2.5 MUTATED TEST CASES 54
5.2.6 MUTATED TEST CASES EXECUTION 55
5.3 CONCLUSION 57

6. CONCLUSIONS 58

6.1 OBJECTIVES ACHIEVED AND LIMITATIONS 58
6.2 FUTURE WORK 59

REFERENCES 60

APPENDIXES 62

I. TAP CASE STUDY 62

Task Model 62
Generated Code Example 63

II. MICROSOFT OUTLOOK CASE STUDY 73

Task Model 73
Generated Code Example 74

III. UNUSED TERESA OPERATORS 84

Operator: Optional Task 84
Operator: Iterative task 87
Operator: Order Independence 88
Operator: Concurrent with Info Exchange 91
Operator: Disabling 93

Operator: Suspend/Resume 95

LIST OF FIGURES

FIGURE 1 - STLC STAGES AND PERFORMED ORDER (ADAPTED FROM [9]) 6
FIGURE 2 - V-MODEL (ADAPTED FROM [12]) 10
FIGURE 3 - MODEL-BASED TESTING PROCESS (ADAPTED FROM [12]) 14
FIGURE 4 - PROCESS OF GENERATING AND EXECUTING TEST CASES 21
FIGURE 5 - SEARCHING ALPHA AND INTERCITY TRAINS IN CP WEB PAGE 21
FIGURE 6 – ALFA AND INTERCITY TRAINS SEARCH IN CP 25
FIGURE 7 - MAPPING FILE STRUCTURE 26
FIGURE 8 - TEST CASES CONFIGURATION FILE STRUCTURE 26
FIGURE 9 - EXAMPLE OF FILLING THE CONFIGURATION FILES 27
FIGURE 10 - PATH FOUND FOR THE CP EXAMPLE 30
FIGURE 11 - SUCESSFULL TEST CASE EXECUTION 34
FIGURE 12 - TEST RESULTS PRESENTED IN VISUAL STUDIO 2010 35
FIGURE 13 - GENERATED LOG FILE FOR THE EXECUTED TEST CASE 36
FIGURE 14 - GENERATED GRPAH FOR THE TEST CASE 36
FIGURE 15 - SEARCH FOR FLIGHTS (ONE WAY ONLY) IN TAP WEB PAGE 39
FIGURE 16 - TAP TASK MODEL SAMPLE 39
FIGURE 17 - MAPPING THE INTERFACE INTO THE TASK MODEL 40
FIGURE 18 - CONFIGURATION FILES FOR THE ONLY ONE WAY FLIGHTS 41
FIGURE 19 - PATHS FOUND FOR TAP TASK MODEL 42
FIGURE 20 - TAP TEST CASE EXECUTION EXAMPLE 44
FIGURE 21 - TEST RESULTS PRESENTED IN VISUAL STUDIO 2010 45
FIGURE 22 - GENERATED LOG FILE 45
FIGURE 23 - EXEMPLE OF AN EXECUTION OF A MUTATED TEST CASE 47
FIGURE 24 - TEST RESULTS SHOWN IN THE VISUAL STUDIO FOR A MUTATED TEST 47
FIGURE 25 - LOG FILE GENERATED FOR THE MUTATED TEST CASE EXECUTED 48
FIGURE 26 - OUTLOOK TASK MODEL SAMPLE (SEND AN EMAIL) 49
FIGURE 27 - SENDING AN EMAIL IN OUTLOOK 49
FIGURE 28 - MAPPING BETWEEN THE INTERFACE AND THE OUTLOOK TASK MODEL 50
FIGURE 29 - CONFIGURATION FILES FOR SEND EMAIL OPTION 50
FIGURE 30 - EXAMPLE OF PATHS FOUND FOR OUTLOOK TASK MODEL 51
FIGURE 31 - OUTLOOK SEND EMAIL TEST CASE EXECUTION 53

FIGURE 32 - TEST RESULTS PRESENTED IN VISUAL STUDIO 2010 54
FIGURE 33 - GENERATED LOG FILE 54
FIGURE 34 - EXAMPLE OF AN EXECUTION OF A MUTATED TEST CASE 56
FIGURE 35 - TEST RESULTS SHOWN IN THE VISUAL STUDIO FOR A MUTATED TEST 56
FIGURE 36 - LOG FILE GENERATED FOR THE MUTATED TEST CASE EXECUTED 57

LIST 1 - CODE SNIPPET FOR TRAINS SEARCH IN CP 31
LIST 2 - MUTATED TEST CASES GENERATED FOR EACH TYPE OF MUTATION IDENTIFIED 33
LIST 3 - GENERATED TEST CASES FOR TAP TASK MODEL 43
LIST 4 - EXAMPLES OF MUTATED TEST CASES FOR TAP TASK MODEL 46
LIST 5 - EXAMPLE OF TEST CASES GENERATED 53
LIST 6 - EXAMPLE OF MUTATED TEST CASES FOR THE OUTLOOK EXAMPLE 55

LIST OF TABLES

TABLE 1 - SOFTWARE TESTING LIFE CYCLE PHASES (ADAPTED FROM [10]) 7
TABLE 2 - TYPE OF TASKS 22
TABLE 3 - CTT OPERATORS 23
TABLE 4 – KEYORDS DEFINED 24
TABLE 5 - CORRESPONDENCES BETWEEN THE HTML ELEMENTS AND WATIN CLASSES 28
TABLE 6 - CORRESPONDENCES BETWEEN THE HTML ELEMENTS AND WATIN CLASSES (CONTINUATION) 29

GLOSSARY AND ACRONYMS

AGILE	Methodology that promote the planning, development and delivery of a software product.
CTT	ConcurrTaskTrees
GUI	Graphic User Interface
MBT	Model-based Testing
ORACLE	Model from a software system
STLC	Software Testing Life Cycle
SUT	System Unter Test
TASK NOTATION	Hierarchical decomposition into sub-tasks that must be done to achieve an objective.
HTML	HyperText Markup Language. A language for creating web pages and other information that can be displayed in a web browser

1. INTRODUCTION

This report and the project to which it refers were carried out for the Dissertation of the 2nd year of the Master's Degree in Informatics Engineering of the Department of Informatics, School of Engineering, University of Minho. The project is also associated with HasLab (High-Assurance Software Laboratory), INESC TEC.

1.1 Background

What is software quality? The definition of software quality is not that simple since a software product has a lot of characteristics that can be considered crucial. The quality of a software artifact can be understood as the totality of characteristics of the system, component or process that affect its ability to satisfy stated or implied needs (requirements or customer/user needs) [1].

The quality of user interfaces (from the point of view of the user) can be seen as its usability. The principles of usability are described in ISO 9241-11 [2]. A graphical user interface that respects the principles of usability will allow users to achieve their goals with effectiveness (accuracy and completeness with which these goals can be achieved), efficiency (level of effort required) and satisfaction, in a particular context of use (subjective rating on criteria such as discomfort experienced, liking for the product, satisfaction with product use, or acceptability of the workload when carrying out different tasks).

These days, Graphical User Interface (GUI) are a key point for communication between user and system and this means that tests must be performed on the interface layer to guarantee its proper functioning. Software testing is very important to ensure the quality of the developed system. When we put a system under test the main goal is to find software bugs,

errors or inconsistencies in the functionalities that were implemented. Normally, the test effort is performed after the requirements (of the system) are fully defined and the coding process almost or completely finished. However with the adoption of AGILE [1] software development methodologies the testing effort tends to follow the development of the system [3]. It is also important to note that software testing involves considerable costs in terms of time and money. Fortunately, there are several techniques to perform tests on a software system that help to minimize these costs. The chosen one for this project in particular was Model-based Testing.

Model-based testing (MBT) techniques offer the possibility of automating the testing process by making a comparison between the model of a software system (the oracle) and the implemented version of the same system. Techniques such as MBT, by making use of models to analyse the running system, are concrete examples that "modeling is a simple way of capturing knowledge about the system and then reutilizing this knowledge as the system grows" [4]. In the context of this project a model of a software system can be seen as a description of its behavior. The inputs accepted by the interface, the outputs it generates, and the control logic behind them.

Several authors have explored the use of models, trying to find a simple and economic way for testing the interface layer of a software system [5, 6]. The possibility of exploring task models for the generation of oracles has also been studied [7]. These techniques were developed in order to improve the quality of generated test cases, but since a task model only considers the expected behavior of the user, the latter study explores modifications to the oracle to be able to detect problems that may occur due usage errors in the interface layer. That work, however, is still preliminary.

[1] An AGILE methodology promote the planning, development and delivery of a software product in a time-boxed iterative approach and encourages easy and rapid response to changes in the project scope.

The current project arises from the need to create a tool capable of generating and executing test cases in order to test the behavior of web applications. To simulate a scenario in which the user makes mistakes, the possibility of creating mutations on the generated test cases will also be explored.

1.2 Project Description

The work was developed under a research grant from the "PBGT – Pattern Based GUI Testing" project. This project aims to carry out research on the development and validation of test strategies based on models applied to interfaces. It is important to develop an environment for the generation, mutation and execution of test cases able to fulfill this objective. The developed environment must automate the testing process applied to graphical interfaces.

This project aims to develop a tool capable of generating and executing test cases, as well as mutating these test cases in order to test the behavior of the application in case of operating errors. Thus we can improve the ability to detect errors of this kind of technique and increase the quality assurance that the technique allows.

Given that graphical user interfaces are the key point of computer systems these days and that the use of the Web had a tremendous growth, the creation of applications that can generate test cases starting from the specification of the graphic interface (task models, in the case of this project) makes a time consuming process, as the generation of different test cases, a simple task with little effort by the software tester. This work brings a new use to already existing tools and frameworks with the objective to create a standard in the test case automation for the web.

1.3 Report Structure

This report is constituted by six chapters as described:

- Chapter 1 – **Introduction:** This chapter has presented the background of the project as well as the problem to solve.
- Chapter 2 – **Software Testing:** This chapter presents the background needed to understand the concepts used during the project.
- Chapter 3 – **GUI Model-based Testing:** This chapter justifies the use of Model-based testing as well as presenting tools that can help in the application of MBT.
- Chapter 4 – **Implementation and Devepment:** This chapter presents the proposed approach to resolve the problem presented in Chapter 1 as well as the implemented solution.
- Chapter 5 – **Case Studies:** This chapter presents the examples created using the developed tool.
- Chapter 6 – **Conclusions:** This chapter describes all the work done by referencing the objectives achieved and how they can be improved in the future.

2. SOFTWARE TESTING

Computers are nowadays a key player in business, education or recreational activities, responsible for the creation of millions of jobs around the world. This makes it necessary to ensure that the applications they run actually perform the tasks for which they were designed. The "software should be predictable and consistent, offering no surprises to users" [8]. To guarantee that these software applications carry out their functions properly and do not perform actions that should not occur it is necessary to perform tests.

Software testing can be seen as an investigation that provides objective information on the quality of the product. It can also be understood as an independent view of the software, or as a process of validating a software product, in which it must be verified if the implemented software meets the requirements that guided its design and development. If it works as expected and if satisfies the needs of stakeholders.

With the adoption of AGILE software development methodologies the testing effort tends to follow the development of the system, because testing is not a simple activity and must be included in the development and maintenance of the software product. Developing a software system always implies risks and a problem if identified too late may involve too many costs in its resolution. One of the objectives of testing software is to identify errors, software bugs or faults, and the sooner the better. But even a tested software product is not 100% free of errors. Because testing is an expensive process, it is not always possible to test every aspect of the product. The problems not found will increase the software maintenance costs.

2.1 Software Testing Life Cycle

Considering software testing as an iterative process several phases can be identified in which different tasks are performed. These different phases together form the Software Testing Life Cycle – STLC (see Figure 1). These phases cover the whole process of testing a system, from identifying requirements and planning the tests, through to executing them and reporting the results.

Figure 1 - STLC stages and performed order (adapted from [9])

Different techniques are associated to each phase of the STLC, these activities and the associated phase can be viewed in the Table 1. The left column lists the phases identified in Figure 1, and the right column the relevant activities for each phase.

Software engineers must be aware that there are also many methods for testing a software system (described in section 2.3). Even a simple program can generate, theoretically, an infinite set of tests. This means that selecting tests can be a difficult task. Testing a software product will require the identification of which values are acceptable as input and output, which sometimes is not possible. The software engineer must also be able to identify if the observed behavior is consistent with the expected performance.

PHASE	ACTIVITIES
Requirements Analysis/ Design Review	• Review the software requirements/design (if they already exists) • Interaction with stakeholders • Understand the requirements in detail
Test Planning	• Plan the test once gathered the general idea of what need to be tested • Determine cost estimated for tests
Test Designing	• Creation, verification, validation and rework of test cases and test scripts
Test Environment Setup	• Decide the software and hardware conditions under which the product will be tested (replicate the end-users' environment)
Test Execution	• Execute the test scripts in the test environment and verify if they pass
Test Reporting	• Analyze testing artifacts and present them to the stakeholders

Table 1 - Software Testing Life Cycle phases (adapted from [10])

2.2 Testing Levels

2.2.1 Testing Target

"Software testing is usually performed at different levels along the development and maintenance process" [1] this means that the test target can vary. Test can be executed in a single module, a group of modules (related to each other) or the entire system.

The levels defined in the Software Engineering Body of Knowledge [1] are Unit-, Integration-, and System Testing. They are distinguished by the target that they are associated with.

- **Unit testing** refers to tests that verify the functionality of a specific software piece, which is tested separately from the rest of the system. Depending of the context unit tests can be performed in a single module or in a specific program function. Usually, unit testing needs access to the code that will be tested and support of debugging tools.

- **Integration testing** is used to verify the interfaces between software components. Usually it is tested if the different components are properly integrated with each other. Integration testing is an ongoing activity. In each phase of development of the product the software engineers should only focusing on the level they are integrating and disregard the lower-levels (which already have been integrated) [1].

- **System testing** like the name implies tests a completely integrated system to verify that it meets its requirements. At this stage of testing the majority of functional malfunctions should been already identified and resolved in unit and integration testing levels.

2.2.2 Testing Objectives

Tests can be conducted taking into account different objectives. Testing efforts can be aimed at verifying if functional specifications are properly implemented, but several nonfunctional properties of the system can be tested as well.

Depending on the objectives to be achieved with the tests, different levels of testing were identified by A. Abran et al [1].

- **Acceptance/Qualification testing:** Acceptance testing verifies the system behavior against the customer's requirements.
- **Installation testing:** After accomplishment of system and acceptance testing, the software can be verified upon installation in the target environment.
- **Alpha and beta testing:** Before the software is released, it is given to a small representative set of potential users for trial use, either in-house (alpha testing) or external (beta testing), which report problems with the product.
- **Conformance testing/ Functional testing/ Correctness testing:** Validating whether or not the observed behavior of the tested software conforms to its specifications.
- **Reliability achievement and evaluation:** In helping to identify faults, testing is a means to improve reliability. By contrast, by randomly generating test cases according to the operational profile, statistical measures of reliability can be derived.
- **Regression testing:** According to IEEE610.12-90 [11], regression testing is the "selective retesting of a system or component to verify that modifications have not caused unintended effects".
- **Performance testing:** Verify that the software meets the specified performance requirements, for instance, capacity and response time.
- **Stress testing:** Stress testing exercises software at the maximum design load, as well as beyond it.
- **Back-to-back testing:** A single test set is performed on two implemented versions of a software product, and the results are compared.
- **Recovery testing:** Recovery testing is aimed at verifying software restart capabilities after a "disaster."
- **Configuration testing:** In cases where software is built to serve different users, configuration testing analyzes the software under the various specified configurations.

- **Usability testing:** This process evaluates how easy it is for end-users to use and learn the software, including user documentation.
- **Test-driven development:** Test-driven development is not a test technique per se, promoting the use of tests as a surrogate for a requirements specification document rather than as an independent check that the software has correctly implemented the requirements.

In practical terms tests are typically conducted at four main levels Unit-, Integration-, System- and Acceptance Testing. An example of use of these four levels of testing is the V-Model.

The V-Model (Figure 2) is a modified version of Waterfall method (Development Software Model). The V-Model process associates to each development stage of the software development process one software testing level.

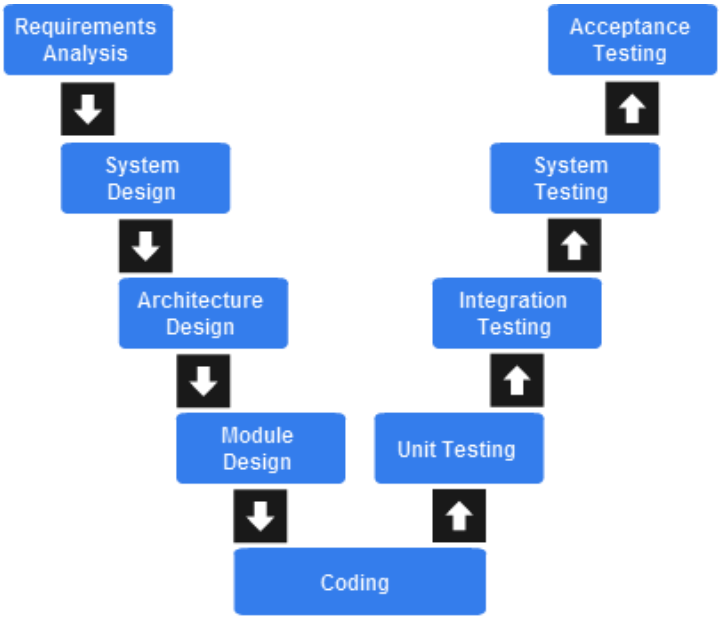


Figure 2 - V-Model (adapted from [12])

2.3 Testing Methods

Different methods can be applied to test a given software system. **Static testing** techniques' main goal is to improve the quality of the software under test finding errors and bugs in the initial stages of software development. To do this these techniques don't need to run the code, only need to examine it.

Unlike static testing **dynamic testing** techniques execute the code under inspection. The main purpose of this testing is to confirm if the implemented software system operates in conformance with the business requirements established. It involves giving input values and checking if the output is as expected by executing specific test cases that can be executed manually or with the use of automated processes. Dynamic testing techniques are usually divided into two different classes: white-box and black-box.

White-box testing techniques are used to test internal structures or components of the software under survey. Executing this type of technique requires knowledge of the internal code structure of the software but also good programming skills so that it is possible to design test cases. The tester must choose which inputs allow certain paths to be executed. For example, inputs that will allow that both if and else statements of a method will be executed. The software tester should also determine the appropriate outputs.

Black-box techniques are used to test functional and non-functional features of the software without any knowledge of its internal implementation. The tester uses external descriptions of the software like Requirements Specifications or Design Documents of the system to develop the test cases, this means that the tester only knows what the software is supposed to do and not know how it does it. Black-box testing techniques include Mode-based Testing (which will be described next).

2.4 Model-based Testing

For the purpose of the project being carried out the technique chosen to test user interfaces was model-based testing (MBT), which as previously mentioned fits the techniques of Black-box testing. This technique makes use, as its names implies, of a model of the **System Under Test** (SUT), which describes how the software is supposed to behave. The developed model is then used to "generate tests cases and can also be used as the oracle that checks whether the implementation under test passes the test" [4]. MBT can be executed during the Unit-testing phase, but for this project will be applied for the entire system (System Testing). In terms of testing objectives MBT can be used in Regression testing comparing the model of a previous version of a system with its new implementation, and also in Acceptance or Conformance testing. If appropriate, MBT should be incorporated in all of STLC phases.

Modeling is an efficient approach of capturing knowledge about a system and makes it possible to reuse this knowledge as the system develops [13]. This way "the test designer writes an abstract model of the SUT and then the model-based testing tool generates a set of tests cases from that model, instead of manually writing hundreds of test cases (sequences of operations)" [14].

The generation of test cases can be accomplished in two distinguished ways *offline* or *online* where, in both techniques, test cases are generated by exploring a model of the SUT. In the *offline* approach the test case is generated before it is executed while in the *online* approach the test case is generated as the test executes.

The use of a tool that generates test cases means that different tests cases can be generated simply by changing the selection criteria. This process (Figure 3) can be divided, according to [14], into five main steps:

1. Model the SUT and/or its environment
2. Generate abstract tests from the model
3. Concretize the abstract test to make them executable
4. Execute the tests on the SUT and assign verdicts
5. Analyze the test results

In the first step an abstract model of the SUT must be written, this model must be smaller and simpler than the SUT. The created model needs to be checked to verify if it's consistent with the requirements and if it has the expected behavior. For the second step abstract tests are generated from the model. This step involves an interaction with the tests generation tool being utilized, in which the user chose the test criteria to generate tests from the model. The third step consists in transforming the abstract tests into executable ones. The generated tests are expressed in terms of the model (abstract). It is necessary to transform them into tests to be executed on the system (concrete). For example, choosing an option (in the model) can be realized by pressing a button or selecting an option in a menu (in the interface).

An executable test communicates directly with the SUT. In the fourth step the test results must be registered and it should be verified if the results are consistent with the expected output from the system as dictated by the model. An important note is that in online testing steps 2, 3 and 4 are usually merged into one single step. In the fifth and final step the results from the tests are analyzed (comparing the test results with the model) to understand what went right or wrong [14].

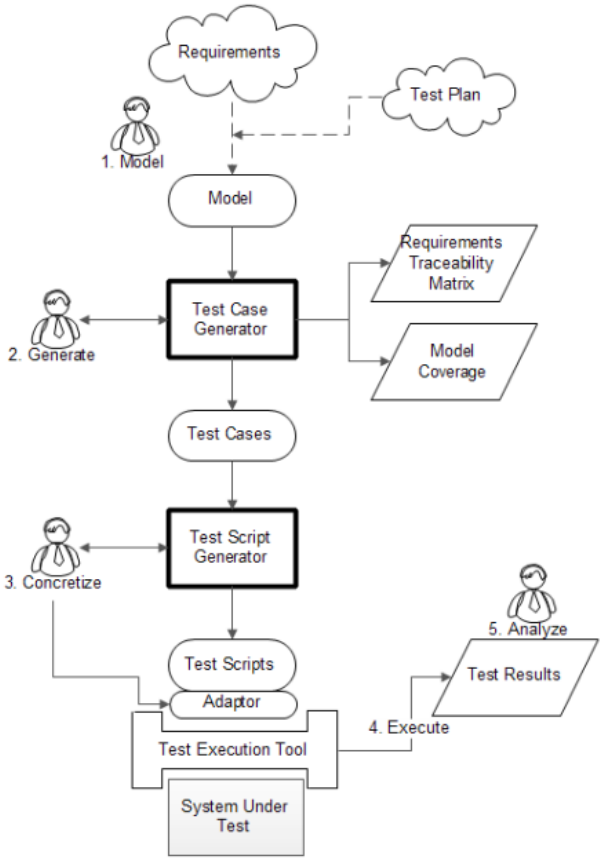


Figure 3 - Model-based testing process (Adapted from [12])

2.5 Conclusion

This chapter has presented the background in Software Testing needed to understand the project. The testing technique to be used – Model-based Testing was also introduced.

3. GUI MODEL-BASED TESTING

A GUI must allow their users to be able to achieve their goals efficiently and effectively. This concept has the name of Usability [2]. To ensure that a GUI fulfills the premise of usability is necessary that it be subject to tests. The main techniques for user interface testing are based on the observation of the behavior and actions of users when they interact with the system interface. The testers while observing the users must detect errors in the interface usage, as well as determinate if the interface serves its objectives. It should be noted that the users in the tests may be interacting with a version of the system or only a prototype [15]. To speed this process there are tools that enable, in an automatic way, to capture the actions of the users of the system, however the tester still must check and validate the logs created by the tool.

Usability tests based on observation of the users are very expensive and there are not always users available for carrying them out. On the other hand, techniques based on observing the user are not focused on systematically finding implementation errors. They are more focused on interface design errors. To find the maximum implementation errors possible the use of testing techniques that test the system exhaustively and preferably in an automatic way is required. This is where MBT can be helpful.

We can have a model that predicts all possible uses (obtained by modeling the behavior of the interface) and this will enable us to test all possible user behaviors at the user interface. The issue is that it is typically unfeasible to generate all possible tests. If we model the expected behavior of the user, the number of tests will be less, but we will be missing error behaviors. Hence, the idea of the project is to start with the expected behavior and add the more likely errors that might happen.

The greatest difficulty to apply MBT to interfaces is the mapping between the abstract model and the concrete interface since is necessary to interact with the interface to obtain the required information to create the model.

3.1 Applying MBT to GUI's

A research was carried out on tools that support the testing process to be developed for GUI's, i.e., tools capable to support the development of models and the generation of test cases from the same models, as well as the execution of the test cases in the running application.

3.1.1 Task Modeling Tools

A simple approach for the representation of user interaction with a system is the use of task models. Task models enable us to express how the user should interact with the system to achieve a certain objective. The more common type of task model is a hierarchical decomposition of tasks into the sub-tasks that must be performed to achieve a particular goal [7]. Different tools that support the creation of task models can be used such as TERESA, MARIAE or HAMSTERS, which are described next.

CTT belongs to the family of hierarchical task analysis notations. Task analysis is the analysis of how a task is accomplished, including description of both manual and mental activities and other assumptions that can be important like duration or frequency.

TERESA is an environment for designing interactive applications for multiple platforms, from desktop, mobile, vocal or multimodal to digital TV, which uses task models written in the ConcurTaskTrees (CTT) notation. From logical descriptions of user interfaces TERESA is capable of generating implementations that adapt to the interaction resources available, in several implementation languages [16]. The CTT notation allows the creation of task models that can be

used as oracles in model-based testing context. Although TERESA has been discontinued MARIAE was presented as its successor. Other option is the **CTT Environment** (CTTE) which is an environment for editing and analysis of task models very similar to TERESA, but with less features.

MARIA Environment (MARIAE) offers a solution capable of taking advantage of task models (in CTT notation) and user interface models (represented in the MARIA language) for the design and development of interactive applications based on Web services for numerous types of platforms (desktop, smartphones, vocal, multimodal, ...). This tool is able to import, in an automatic way, service and annotation descriptions and supports interactive association of basic system tasks with Web services operations. Next, a series of semi-automatic transformations are applied, which explore the information in such service and annotation descriptions to derive usable multi-device service front ends [17].

HAMSTERS (which stands for Human-centered Assessment and Modeling to Support Task Engineering for Resilient Systems) is a task modeling language that provides a supporting tool. Its creation was inspired by existing tools and notations (CTT, for example) and tries to gather the best of each [18]. Note that the development of the tool is not yet finished.

The chosen tool was TERESA because their successors MARIAE and CTTEnvironment, when the study was conducted, presented limitations that preclude their use as expected. HAMSTERS was not chosen because it was in an early stage of its development.

3.1.2 Test Cases automation tools

There are also tools that interact with the GUI and from a model created by them or by the test engineer automatically generate and/or execute test cases.

Selenium is a portable software testing framework used for web applications. Selenium provides an Integrated Development Environment (Selenium IDE). Selenium IDE is a Firefox

extension and is able to create Selenium test cases. The Selenium IDE can be used to record, edit and debug test scripts. The test scripts are written in *Selenese*, the test scripting language used by Selenium. This language provides commands for actions performed in browsers (like click in a link or select an option) and also for retrieving data from the resulting pages. Selenium is able to write tests in a number of popular programming languages, including C#, Java, Groovy, Perl, PHP, Python and Ruby.

MISTA (Model-based Integration and System Test Automation) is a model-based test generation and execution tool. MISTA uses lightweight high-level Petri nets as a visual modeling notation. This tool supports several programming languages such as Java, C, C++, C#, HTML, and VB and different testing frameworks like JUnit, NUnit, Selenium IDE or Robot Framework. MISTA can be used for offline test execution but also supports on-the-fly testing and online execution of generated tests through Selenium WebDriver or a RPC protocol (JSON-RPC or XML-RPC).

WatiN stands for Web Application Testing in .NET. WatiN is a framework that allows the execution of tests in web applications through Internet Explorer (6 and above) and Firefox (2 and 3). WatiN is inspired by Watir (Web Application Testing in Ruby) which is an open source family of Ruby libraries for automating web browsers. Watir unlike WatiN is available for Internet Explorer, Firefox, Chrome, Opera and Safari. WatiN is developed in C# and its main goal is to automate tests with Internet Explorer and Firefox using .Net. WatiN can open IE or Firefox instances and then find the page elements by multiple attributes in order to carry out tests.

The possibility of using MISTA involved a change of task models to models based on Petri nets. The hypothesis was studied but due to limitations of the version available for free to the public this idea was dropped. Because it is based in C#, one of the more popular programming languages currently, WatiN use becomes easy and simple to understand. For this, WatiN was picked instead of Selenium IDE. Using C# also makes it possible to use Microsoft Visual Studio

as development environment and integrate WatiN frameworks with already existing Visual Studio test configurations.

3.2 Conclusion

In this chapter was presented how MBT can be used to create an automated testing process for web applications. Was also presented the decision on which tools and frameworks to be used to build a prototype capable of generating, mutating and executing test cases from task models.

4. IMPLEMENTATION AND DEVELOPMENT

4.1 Proposed Approach

Following the approach in [7] the process consists in using a state machine generated through a task model as an oracle of the model-based testing process. Initially it is necessary to create the task model. Then, using TERESA a file is generated that represents a finite state machine. This representation is called Presentation Task Sets (PTS). Additionally it is necessary to define the mapping between the task model and the interface, as well as the input values to be used for the generation of the test cases. For each of these two needs a configuration file is created. The Variables configuration file defines the mapping, while the Parameters configuration file defines the input values.

With the three files above (PTS, Variables and Parameters) created the application to be developed should create a graph. With this graph, test cases are generated according to the model. If desired, test cases corresponding to mistaken operations executed in the interface can also be designed. The test cases are generated in C#. Once the code with the test cases is generated, they can be performed using the WatiN framework.

As previously mentioned, by being based on a task model, test cases capture how designers and developers expect that the user will use the interface. These are, however, the most predictable interactions, so can potentially be tested even manually. Moreover, often problems occur because users deviate from the expected behavior. To test this possibility the introduction of errors in the test cases must be considered. Unlike previous studies where errors were introduced directly in the model [19], it was decided to introduce errors in the test cases. Introducing errors in test cases and not in the model makes it possible to maintain a history of versions of the models used and for each model the set of test cases (with and without errors).

Figure 4 shows the testing process developed, which will be explained in detail in the following chapters. As an illustrative example the search service of the Alpha and Intercity trains (Figure 5) from CP - *Comboios de Portugal*[2] - will be used. More complex examples will be presented in Section 5. This example is only used due to its simplicity, which facilitates the understanding of the testing process developed.

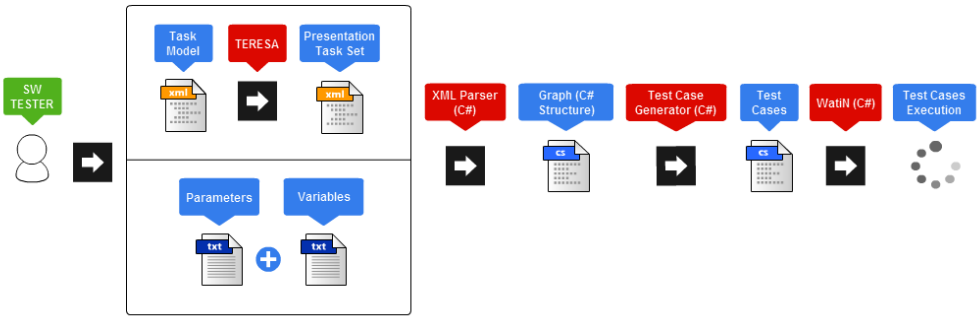


Figure 4 - Process of generating and executing test cases

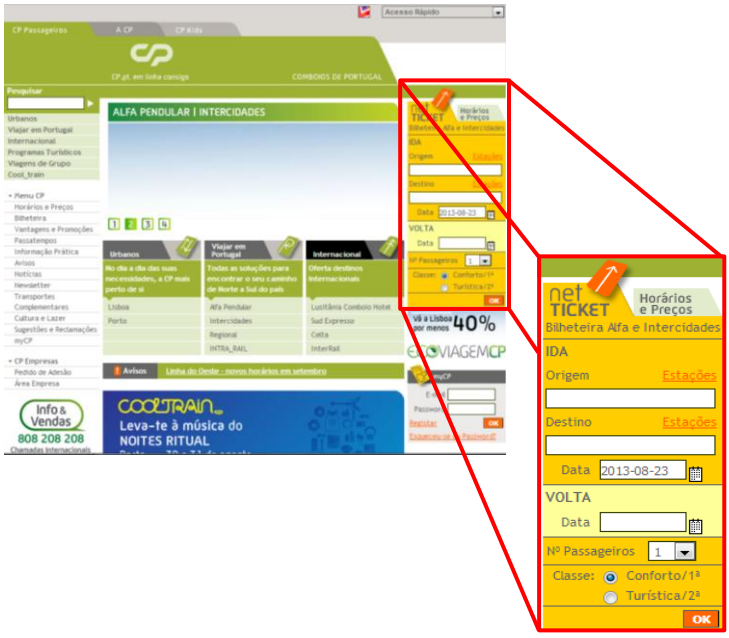


Figure 5 - Searching Alpha and Intercity trains in CP web page

[2] Available at: http://cp.pt/

4.2 Task Models with CTT (ConcurrTaskTree)

A simple approach to represent user interaction with a system is as said before, the use of task models. A task model allows the representation of activities to be performed to achieve a certain goal. The support tool of choice for the design of task models is TERESA. This tool supports the CTT notation (ConcurTaskTrees) [20] and provides, in addition to the creation of a task model, the generation of a finite state machine (in form of Presentation Task Sets - PTS) that represents the behavior of the model.

CTT is a language that supports Hierarchical Task Analysis. Thus, a CTT model is a tree in which the hierarchical decomposition of tasks into subtasks that must be performed to achieve a specific goal (the tree root) is carried out. Different interactions may be represented by one of the four possibilities provided by the language, as illustrated in Table 2.

TYPE	DESCRIPTION
Interaction Task	Represents user interaction with the system.
Application Task	Represents tasks that must be performed by the system.
User Task	Represents user decision points.
Abstraction Task	Represents abstract tasks (i.e. the combination of subtasks into a higher level task)

Table 2 - Type of tasks

All types mentioned above, except abstract tasks, should appear as leaves of the tasks models that are to be built. An abstract task should be used to structure the model and must appear only as an internal node of the tree.

In addition to different types of tasks the language also provides operators to model tree traversal (i.e. how to combine different sub-tasks at the same level in the tree). The available operators and their purpose can be found in Table 3.

OPERATOR	DESCRIPTION
[Task]	**Optional task operador:** The task is optional so it might not be executed
Task *	**Iterative operator:** The task is repeated.
Task1* [ ] *Task2	**Choice operator:** Choose which of two tasks will be performed.
Task1* |=| *Task2	**Order Independence operator:** The two tasks have to be performed, but when one starts the other has to wait for the first to finish its execution.
Task1* ||| *Task2	**Independent current operator:** Two tasks can be executed concurrently
Task1* |[ ]| *Task2	**Concurrent with Information Exchange operator:** Two tasks can be performed concurrently, but need to be synchronized as they will exchange information with each other.
Task*1 [> *Task2	**Deactivation operator:** When the task on the right is activated the one on the left is deactivated.
Task1* |> *Task2	**Suspende/Resume operator:** The task of the right can stop the task on the left. Once the task on the right finishes its execution, the task of the left continues its execution from the point where it was interrupted.
Task1* >> *Task2	**Enabling operator:** The task on the right is executed when the task on its left finishes its execution.
Task1* [ ]>> *Task2	**Enabling with Information Passing operator:** The task of the right begins to run once the task on its left finish its execution. The task on the left transmits information to the task on the right.

Table 3 - CTT Operators

As it can be seen in the table, most operators are applied to pairs of tasks. There is no limit to the number of children a node can have. The only requirement is that all nodes must be related to their adjoining nodes by one of the operators. Operators in the table are presented in decreasing order of priority.

In order to facilitate the automatic generation of test cases, a set of rules to name the sub-tasks in the model were defined (adapted from [7]). All tasks are obliged to have a name (the tool allows tasks not to have a name). The name of the tasks must then be composed of a keyword and a variable. Keywords are used to define the type of action the user or system will perform. Table 4 lists the defined keywords and their respective function.

KEYWORD	DESCRIPTION
Start variable	Initialize a new task.
Enter variable	Introduce a value into a textbox in the current web page.
Press variable	Press a button/link, select a radio button option or check a checkbox option in the current web page.
Show variable	Show a specific web page.
Display variable	Verify a value in the current web page.

Table 4 – Keyords defined

The task model in Figure 6 represents the search for Alfa and intercity trains in CP's webpage. In this example only the search from origin to destination was modeled and not both origin-destination and destination-origin. To simplify the testing process (to only have a path navigating the tree) only the enabling operator (>>) was used. Other operators are used in the cases studies presented in Section 5.

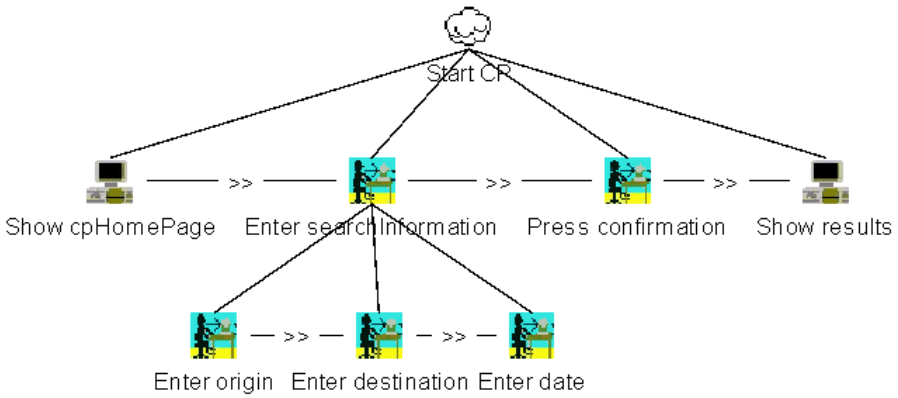


Figure 6 – Alfa and intercity trains search in CP

For a valid train search is necessary to fill the origin (Enter origin) and destination (Enter destination) fields with valid train station names, and also select a valid date (Enter date). Once these are filled it is then necessary to press the OK button (Press confirmation). With correct values in the fields a new page will be shown with the trains options (Show results). In case of error a notification is displayed in the browser but the element is not represented in HTML (an alert window is used) and cannot be mapped to the model, hence we have decided not to model it here.

4.3 Test Cases

4.3.1 Test Cases Configuration

As stated above, from the task model it is possible, using TERESA, to generate a finite state machine called a PTS representing the behavior of the model. Together with the PTS is also necessary to define two configuration files. A file mapping variables in the model to elements in the interface (see Figure 7) contains, for each variable in the model what kind of HTML element to find on the web page, how to find it (which attribute), etc.. This file must contain the definition of all the variables in the task model. An additional variable must also be included in this file –

urlStart. This variable is important to define the Web Page where we want to find the HTML elements.

```
urlStart?URL
Variable?KeyWord=ElementType=FindBy!ValueToFind[=parameter]
...
```

Figure 7 - Mapping file structure

For each variable in the model there is a line in the file (see syntax in Figure 7):

- **Variable**: name of the task in the task model.
- **Keyword**: one of the keywords: Press, Enter, Show, Display.
- **ElementType**: Class WatiN that mapps the HTML element (to be explain later).
- **FindBy**: the attribute through which we want to find the HTML element on the web page.
- **ValueToFind**: the value of the attribute.
- **Parameter**: the parameter is only available and required for Label, Textbox and Textarea elements, and is used to indicate which values to use for input (Textbox and Textarea)/ expected in the output (Label). Instead of concrete values, in this file the name of a parameter is indicated. The value of the parameter must be defined in the test cases configuration file.

The input values to be used during testing are stored in another configuration file (see Figure 8). Thus, the software tester can define different test cases from the same behavior (by changing the input values).

```
NumberOfTestCases
parameter?value
...
```

Figure 8 - Test Cases configuration file structure

The file contains a sequence of test cases. Each test case is a sequence of assignments of values to the parameter used in the mapping file. The content of the file is as follow:

- **NumberOfTestCases**: the number of tests that are defined.
- **Parameter**: the parameter used in the mapping file.
- **Value**: the value that we want to see in the HTML element.

For the example of Figure 6, the configuration files being created would have the contents shown in Figure 9. In the example, the variable **confirmation** is a button and the HTML element is found in the Web page through the attribute Value with the value "OK" (`<input type="submit" value="OK"/>`). In the same example it is also possible to observe that the variable **origin** is a textbox, which should be found on the Web page by the attribute Name and the value "departStationName". As indicated the value to be filled in the text box is set in the **setOrigin** parameter.

Observing the parameters configuration file, we can see that two test cases are defined. Each assigns different values to the **setOrigin**, **setDestination** and **setDate** parameters.

```
                    Variables Configuration File:

urlStart?http://cp.pt
cpHomePage?http://cp.pt
origin?Enter=TextFieldExtended=Name!departStationName=setOrigin
destination?Enter=TextFieldExtended=Name!arrivalStationName=setDestination
date?Enter=TextFieldExtended=Name!departDate=setDate
confirmation?Press=Button=Value!OK
results?http://venda.cp.pt


                    Parameters Configuration File:

2
setOrigin?porto - campanha
setDestination?braga
setDate?2013-10-08
setOrigin?braga
setDestination?Lisboa - Oriente
setDate?2013-10-09
```

Figure 9 - Example of filling the configuration files

The identification of the type of HTML element to be used in the configuration file of the variables is important. The developed tool generates code to automatically test the user interface. WatiN is used because it provides the functionality to interact programmatically with the interface, allowing the simulation of user events in order to execute the test cases without requiring human intervention. The correspondences between the HTML elements and proper class in WatiN can be found in Tables 5 and 6 [3]

It is important to note that the inclusion of the keyword in the configuration file is due to the fact that it is extremely important to determine how the code will be generated. Depending on the keyword, generated code will vary. For example, for the Enter keyword code will be generated for the setting the value of the corresponding HTML element. If the keyword is Press the code will be generated for clicking the HTML element.

HTML ELEMENT	WATIN CLASS
<a/>	Link
<area/>	Area
<button/> **<input type=button/>** **<input type=reset/>** **<input type=submit/>**	Button
** **	Div
<form/>	Form
<frame/> **<iframe/>**	Frame
<frameset/>	FrameCollection

Table 5 - Correspondences between the HTML elements and WatiN Classes

[3] Adapted from: http://watin.org/documentation/element-class-mapping-table/ (last visited in 13/07/2013)

HTML ELEMENT	WATIN CLASS
<img/> **<input type=image/>**	Image
<input type=checkbox/>	CheckBox
<input type=file/>	FileUpload
<input type=hidden/> **<input type=password/>** **<input type=text/>** **<textarea/>**	TextField
<input type=radio/>	RadioButton
<label/>	Label
<option/>	Option
<p/>	Para
<select/>	Select
****	Span
<table/>	Table
<tbody/>	TableBody
<td/>	TableCell
<tr/>	TableRow

Table 6 - Correspondences between the HTML elements and WatiN Classes (continuation)

4.3.2 Test Cases Generation

The developed tool used an internal structure in the form of a graph, which stores all the information contained in the files. With this graph the tool is able to find paths between various nodes (derived from the PTS states) and with that information create test cases. Each node represents a method with one or more actions to be performed on the website (for which the model was designed). Each path found (Figure 10) defines the correct order of calling each

method generated (List 1). Note that one method will be generated for each task in the task model with the keywords Show, Enter, Press and Display (the latter was not used in this example).

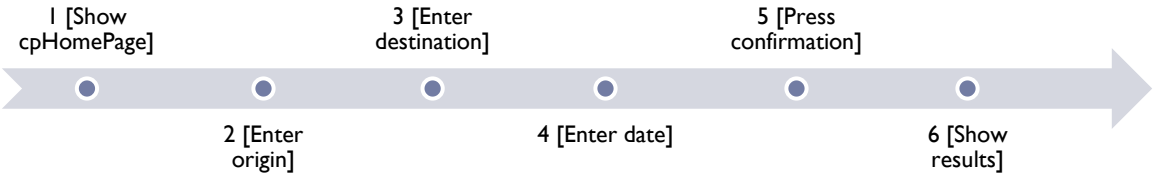


Figure 10 - Path found for the CP example

```
public void cpHomePage(string url)
{
        try
        {
                if (!browserInstance.Url.Contains(url))
                {
                        using (System.IO.StreamWriter file = new
                        System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                        {
                                file.WriteLine("Method cpHomePage: The page was not found: " +
                                url);
                        }
                        Environment.Exit(0);
                }
        }
        catch(Exception e)
        {
                using (System.IO.StreamWriter file = new
                System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                        file.WriteLine("An error was found while exectuing cpHomePage(): " +
                        e.Message);
                }
                Environment.Exit(0);
        }
}

public void origin(string setOrigin)
{
        try
        {
                TextField departStationName = browserInstance.TextField(Find.ByName
                ("departStationName"));

                departStationName.Value = setOrigin;
        }
        //...
}
```

```
//...

public void confirmation()
{
        try
        {
                Button OK = browserInstance.Button(Find.ByValue("OK"));
                OK.Click();
        }
        //...
}

public void results(string url)
{
        try
        {
                if (!browserInstance.Url.Contains(url))
                {
                        using (System.IO.StreamWriter file = new
                        System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                        {
                                file.WriteLine("Method results: The page was not found: " +
                                url);
                        }
                        Environment.Exit(0);
                }
        }
        //...
}

[TestMethod]
public void testMethod1()
{
        cpHomePage("http://cp.pt");
        origin("porto - campanha");
        destination("braga");
        date("2013-10-08");
        confirmation();
        results("http://venda.cp.pt");
}


[TestMethod]
public void testMethod2()
{
        cpHomePage("http://cp.pt");
        origin ("braga");
        destination ("Lisboa - Oriente");
        date("2013-10-09");
        confirmation ();
        results("http://venda.cp.pt");
}
```

List 1 - Code snippet for trains search in CP

4.4 Test Cases Mutation

In order to test the system under user error conditions, the possibility of changing (mutating) the test cases to represent user error was studied. There are three main types of user errors [21]:

- **Slips** – a change in the order of execution of two actions.
- **Lapses** – the omission of an action.
- **Mistakes** - performing an action with a wrong value.

Following these types of errors, three different methods were developed to perform mutations in the test cases. The introduction of errors is performed with the information found in the paths in the graph. **Slip** type errors are generated swapping the order of execution of two methods of the path found. The choice of which position to be swapped is made randomly.

The generation of **Lapse** errors appeals also to the random choice of a method. However unlike Slip errors, in this type of error the method chosen is eliminated from the path.

Finally, **Mistake** errors are generated only in methods that take input parameters. In this case, a character is inserted in one of the input parameters of the method (both randomly chosen). Examples of generating mutated test cases can be seen in List 2 (compare with the first test cases in List 1).

```
//Slip Mutation
[TestMethod]
public void mutatedTestMethod1()
{
    cpHomePage("http://cp.pt");
    confirmation();
    destination("braga");
    date("2013-10-08");
    origin("porto - campanha");
    results("http://venda.cp.pt");
}
```

```
//Lapse Mutation
[TestMethod]
public void mutatedTestMethod2()
{
    cpHomePage("http://cp.pt");
    origin ("porto - campanha");
    date("2013-10-08");
    confirmation();
    results("http://venda.cp.pt");
}

//Mistake Mutation
[TestMethod]
public void mutatedTestMethod3()
{
    cpHomePage("http://cp.pt");
    origin("por#o - campanha");
    destination ("braga");
    date("2013-10-08");
    confirmation();
    results("http://venda.cp.pt");
}
```

List 2 - Mutated test cases generated for each type of mutation identified

In the first mutated test case the order between filling the origin station and pressing the button (confirmation method) has been changed. The second case tests forgetting to fill the destination station (which was deleted from the test case). Finally, the third case simulates an error filling the origin station.

4.5 Test Cases Execution

WatiN (Web Application Testing in. NET) is a framework that, as previously mentioned, can open instances of a Web browser (Internet Explorer 6 or higher and Firefox 2 and 3) and then find page elements by multiple attributes. Using this framework it is then possible to run the test cases (Figure 11). In case of success an entry is written to a log file to mention that the method was performed without any problem. In cases where an abnormality is detected, test execution is completed and an entry is written to the log file where it is possible to visualize what happened wrong during test execution. Among the anomalies may be, for example, a failure when trying to find the HTML elements on the Web page under test.

It must be noted that these abnormalities do not necessarily mean an error from the implementation. This will have to be determined by analysis of the case. For example, due to the introduction of errors in the test cases, it is possible that if the test fails because the interface does not allow execution of the case as defined (for example, when there is no password or the user name is wrong if we are conducting a test to a login system). Unless the task model provides these possibilities, the aim is for the test to fail. For the case described, when the values defined in the test were correct the tests cases were successfully performed.

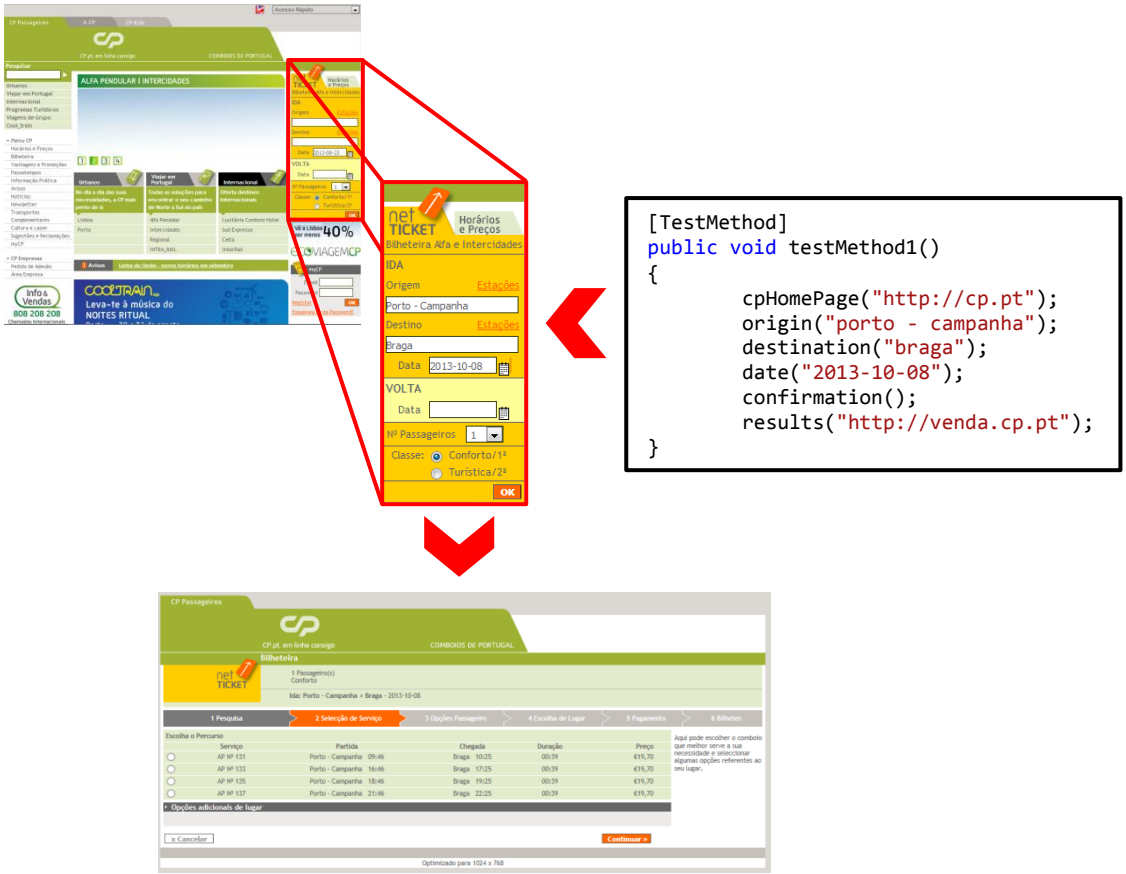


Figure 11 - Sucessfull test case execution

A software tester needs to analyze the results of the tests. For that he can visualize the results presented in Visual Studio (Figure 12) and the generated log file (Figure 13). Using Visual Studio (VS) brings the possibility of making use of testing options integrated in it. For this project the WatiN framework was used in a VS Test Project. The log file generated for each entry states the method that was executed and the result of its execution.

For a graphical representation of the test cases the software tester also has access to a graph generated by the tool (Figure 14). This graph is merely informative of the sequence that the test case has followed.

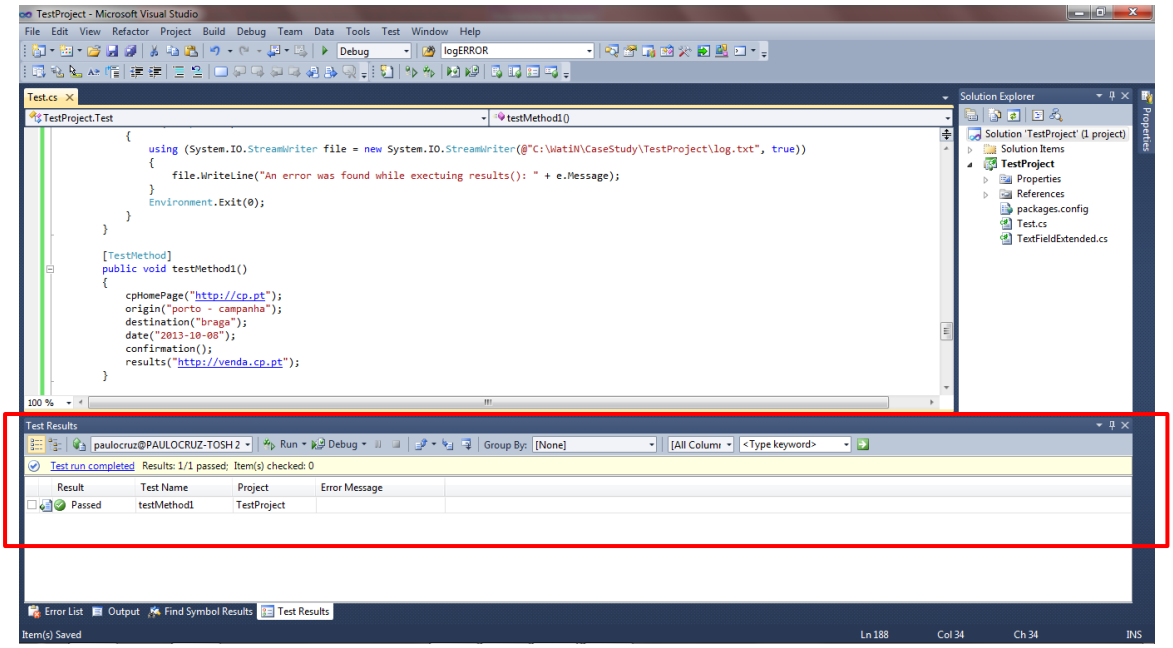


Figure 12 - Test Results presented in Visual Studio 2010

```
Method cpHomePage: The page was found: http://cp.pt
Method origin: The correct value was found in departStationName
Method destination: The correct value was found in arrivalStationName
Method date: The correct value was found in departDate
Method confirmation: The action OK was successfully executed.
Method results: The page was found: http://venda.cp.pt
```

Figure 13 - Generated log file for the executed test case

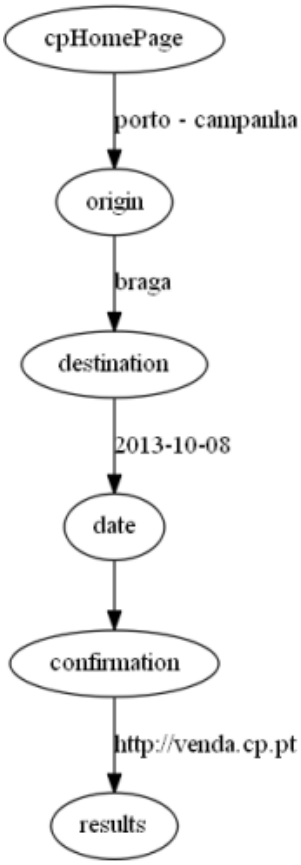


Figure 14 - Generated grpah for the test case

4.6 Conclusion

This chapter has presented the proposed approach to the Model-based Testing of web applications' user interfaces. The modeling language used to describe the oracle, and the configuration files to create the test cases were described, as was the approach used to consider user error in the testing phase. A small example has been used to illustrate the approach. More examples are provided in the next chapter.

5. TESTING USER INTERFACES

This chapter presents two case studies designed to demonstrate the application of the developed tool. The first case study depicts the search of flights and hotels on the TAP website. The second case is about the use of some features of the online version of Microsoft Outlook.

For each case study a task model, configuration files and samples of generated code are presented.

5.1 TAP Portugal – Search flights and hotels

The TAP Portugal example tests the flights and hotels search functionality provided at TAP's web site[4] (see Figure 15).

5.1.1 Task Model

The excerpt from the task model in Figure 16 represents the tasks necessary to conduct to search for flights (only one way) on TAP web page (Figure 15). To perform this type of search it is necessary to select the "Só ida" option and fill, at least, the fields "De", "Para" and "Partida". The complete task model can be found in Appendix I.

[4] Available at: http://www.flytap.com/Portugal/pt/Homepage

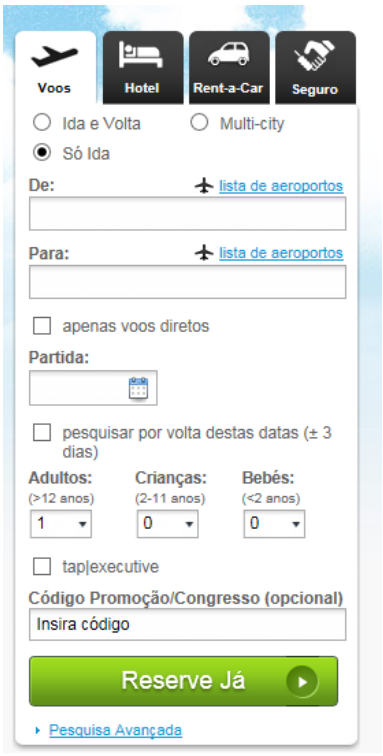


Figure 15 - Search for flights (one way only) in TAP web page

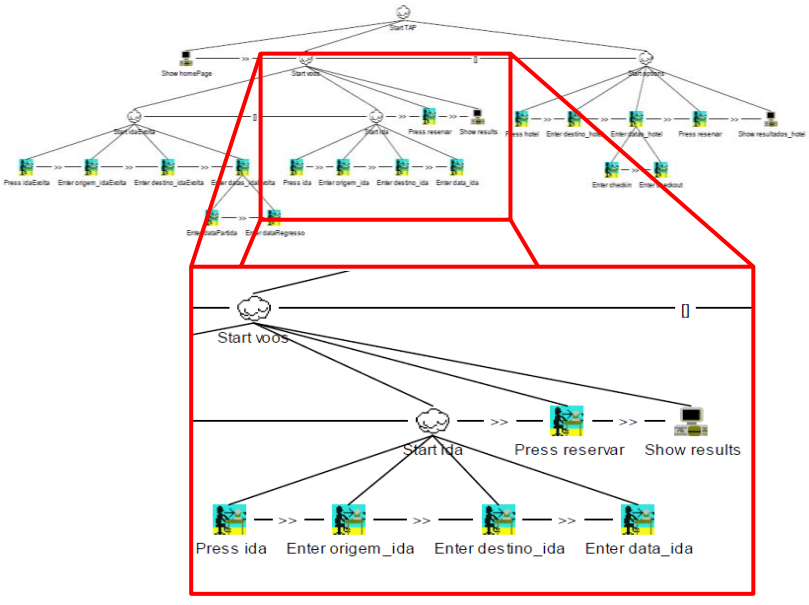


Figure 16 - TAP Task Model sample

5.1.2 Configuration Files

The configuration files are a key point for code generation because it is in them that the mapping between the interface and the task model is specified. Figure 17 illustrates this mapping, showing how each task in the model (on the right) corresponds to some element in the user interface. Boxes with the same color denote related elements. The respective configuration files can be viewed in Figure 18. Only one set of input parameters is being specified. In this case, corresponding to a search for flights from Porto to Barcelona on November 6, 2013.

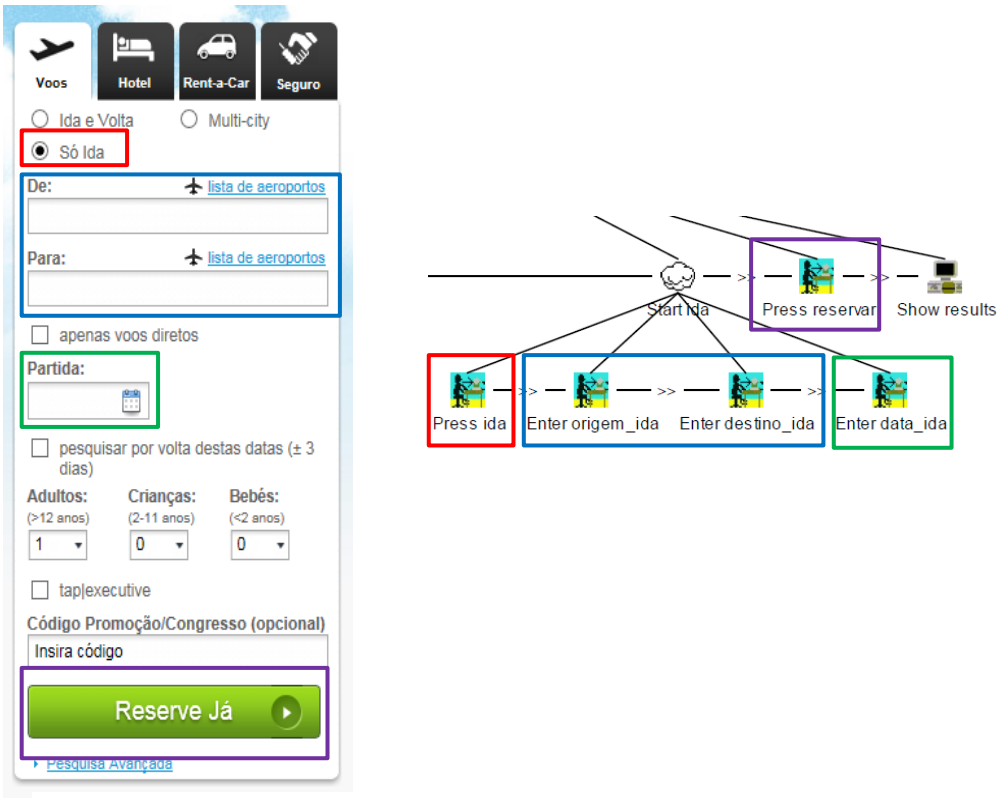


Figure 17 - Mapping the interface into the task model

```
                    Variables Configuration File:

urlStart?http://www.flytap.com/Portugal/pt/Homepage
homePage?http://www.flytap.com/Portugal/pt/Homepage
ida?Press=RadioButton=Id!IDA
origem_ida?Enter=TextField=Name!fromCity=cidadeOrigem
destino_ida?Enter=TextField=Name!toCity=cidadeDestino
data_ida?Enter=TextField=Name!data_partida=dataIda
reservar?Press=Span=Text!Reserve Ja
results? http://book.flytap.com


                    Parameters Configuration File:
1
cidadeOrigem?Porto, Portugal
cidadeDestino?Barcelona, Espanha
dataIda?06/11/2013
```

Figure 18 - Configuration files for the only one way flights

5.1.3 Test Cases

Once the configuration files step is completed, the process of generating code can start. The tool will start by creating a graph structure to be able to find execution paths. The paths found will be our test cases with the correct order of execution of the methods generated. The paths for the TAP example can be seen in Figure 19 (the second path matches the example presented in Figures 15 and 16).

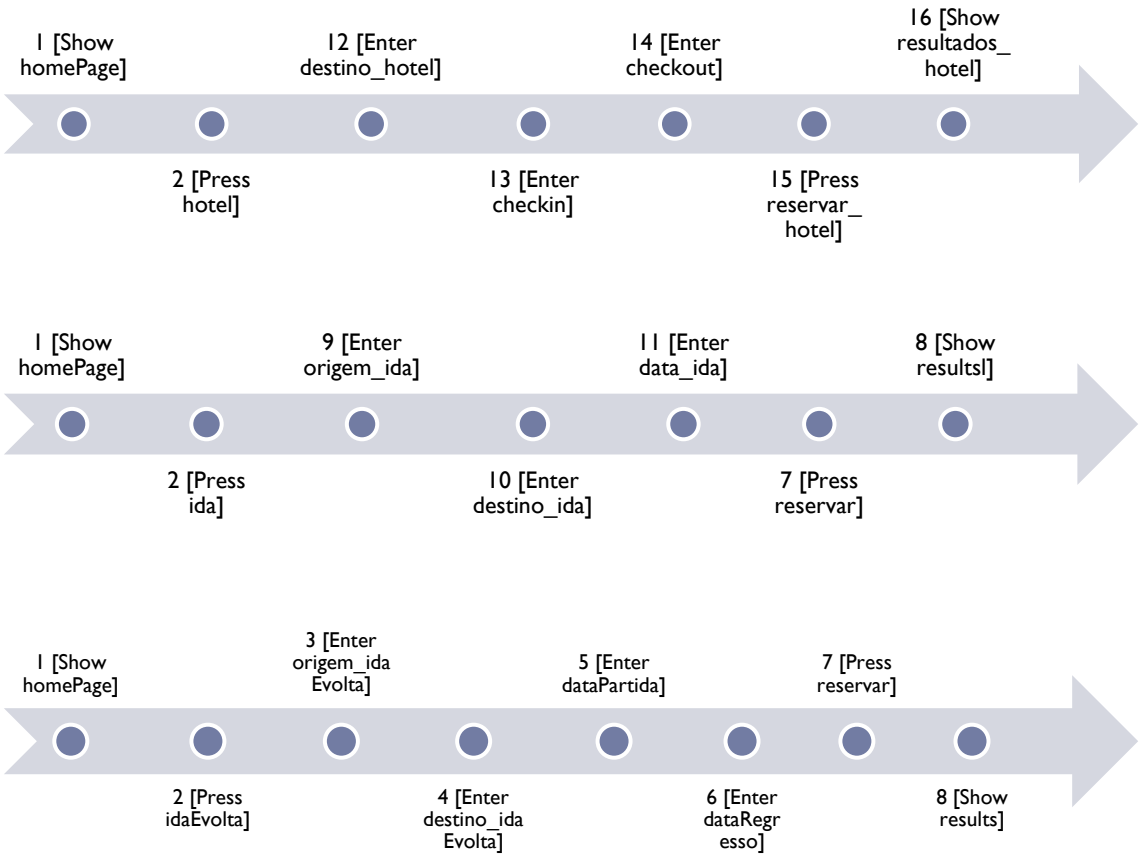


Figure 19 - Paths found for TAP task model

Once the paths are found the test cases can be generated as presented in List 3. The full listing of the generated code can be found in Appendix III.

```
[TestMethod]
public void testMethod1_1()
{
    homepage("http://www.flytap.com/Portugal/pt/Homepage");
    hotel();
    destino_hotel("Barcelona");
    checkin("06/11/2013");
    checkout("13/11/2013");
    reservar_hotel();
    resultados_hotel("http://book.flytap.com");
}

[TestMethod]
public void testMethod2_1()
{
    homepage("http://www.flytap.com/Portugal/pt/Homepage");
    ida();
    origem_ida("Porto, Portugal");
    destino_ida("Barcelona, Espanha");
    data_ida("06/11/2013");
    reservar();
    results("http://book.flytap.com");
}

[TestMethod]
public void testMethod3_1()
{
    homepage("http://www.flytap.com/Portugal/pt/Homepage");
    idaEvolta();
    origem_idaEvolta("Porto, Portugal");
    destino_idaEvolta("Barcelona, Espanha");
    dataPartida("06/11/2013");
    dataRegresso("13/11/2013");
    reservar();
    results("http://book.flytap.com");
}
```

List 3 - Generated test cases for TAP task model

5.1.4 Test Cases Execution

Figure 20 shows the execution of the test case that performs the search of flights for Barcelona from Porto on the specified date.

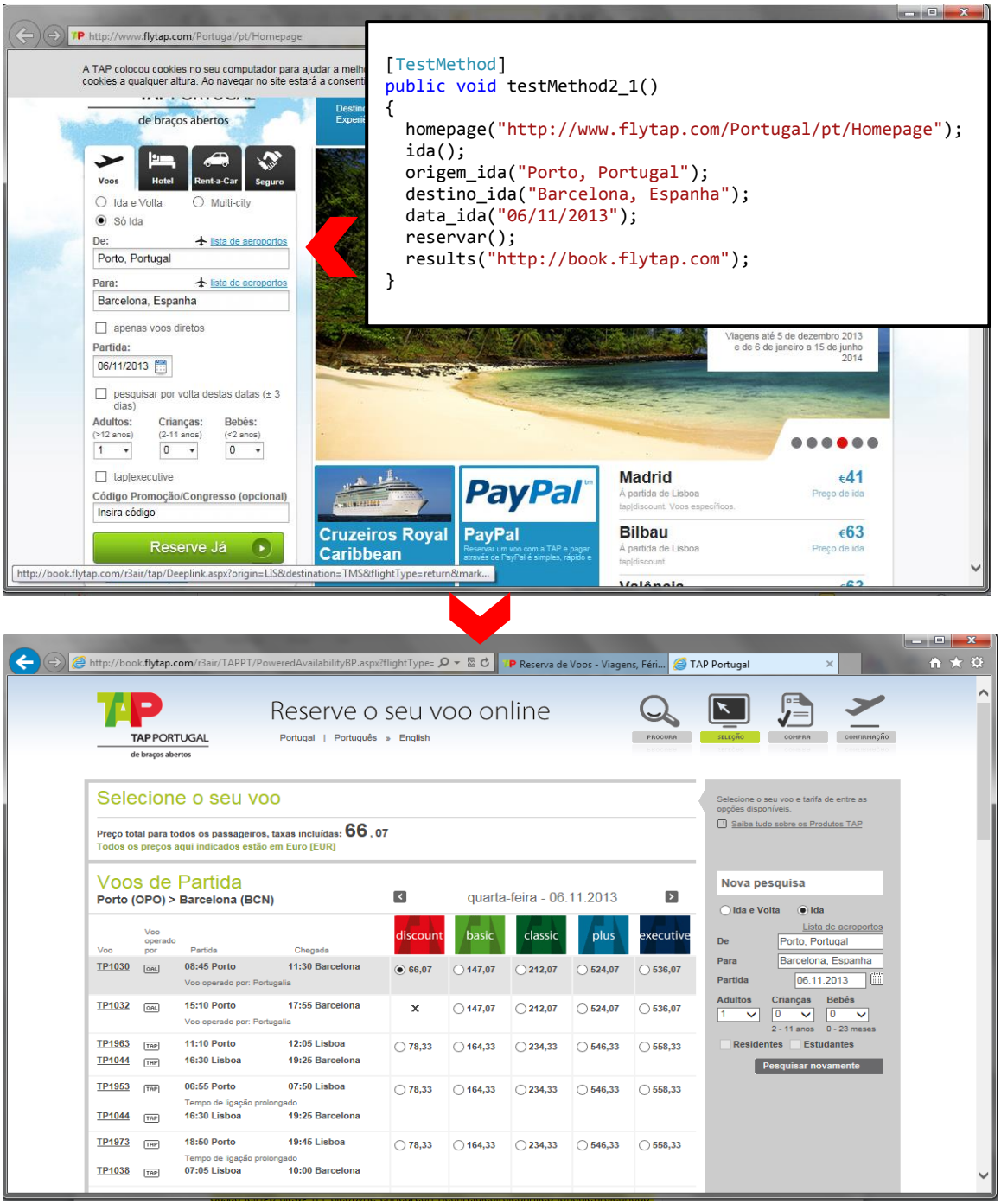


Figure 20 - TAP test case execution example

The results of the test cases executed can be viewed (an entry for each test case) in Visual Studio (Figure 21). If everything goes as plan the Visual Studio shows the test as **Passed**. The log file (Figure 22) can also give information to the software tester.

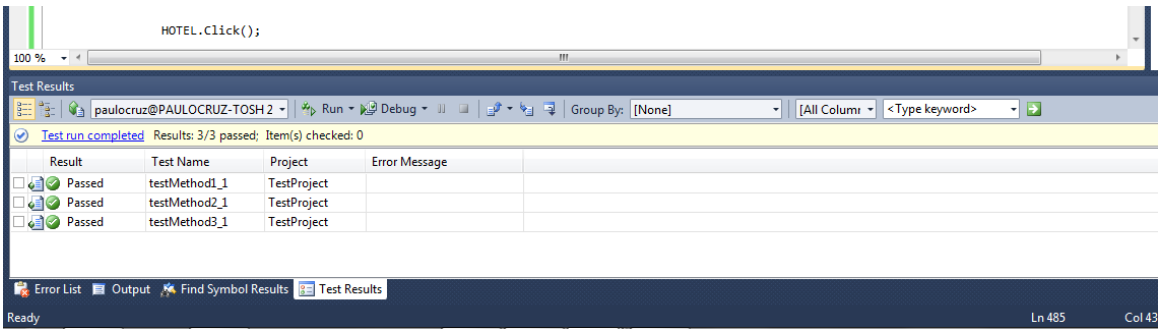


Figure 21 - Test results presented in Visual Studio 2010

```
Method homePage: The page was found:
http://www.flytap.com/Portugal/pt/Homepage
Method ida: The action IDA was successfully executed.
Method origem_ida: The correct value was found in fromCity
Method destino_ida: The correct value was found in toCity
Method data_ida: The correct value was found in data_partida
Method reservar: The action Reserve_Ja was successfully executed.
Method results: The page was found http://book.flytap.com
```

Figure 22 - Generated log file

5.1.5 Mutated Test Cases

If during the code generation the tester chose an option to mutate the test cases, for each test case a mutated test case will be created. Note that for each run only one type of mutation can be chosen. List 4 shows examples of mutated test cases, for each type (Slip, Lapse and Mistake), generated by the tool for the TAP task model.

```
//Slip Mutation
[TestMethod]
public void mutatedtestMethod1_1()
{
    homepage("http://www.flytap.com/Portugal/pt/Homepage");
    reservar_hotel();
    destino_hotel("Barcelona");
    checkin("06/11/2013");
    checkout("13/11/2013");
    hotel();
    resultados_hotel("http://book.flytap.com");
}

//Lapse Mutation
[TestMethod]
public void mutatedtestMethod2_1()
{
    homepage("http://www.flytap.com/Portugal/pt/Homepage");
    ida();
    origem_ida("Porto, Portugal");
    destino_ida("Barcelona, Espanha");
    data_ida("06/11/2013");
    results("http://book.flytap.com");
}

//Mistake Mutation
[TestMethod]
public void mutatedtestMethod3_1()
{
    homepage("http://www.flytap.com/Portugal/pt/Homepage");
    idaEvolta();
    origem_idaEvolta("Porto, Portugal");
    destino_idaEvolta("Barcel#na, Espanha");
    dataPartida("06/11/2013");
    dataRegresso("13/11/2013");
    reservar();
    results("http://book.flytap.com");
}
```

List 4 - Examples of mutated test cases for TAP task model

5.1.6 Mutated Test Cases Execution

In the example shown in Figure 23 the first mutation from List is being tested. We can observe that the results page is not shown because the action of pressing the reservation is executed before the required fields were filled in (“Destino”, “Check-in” and “Check-out”), which causes the test to fail.

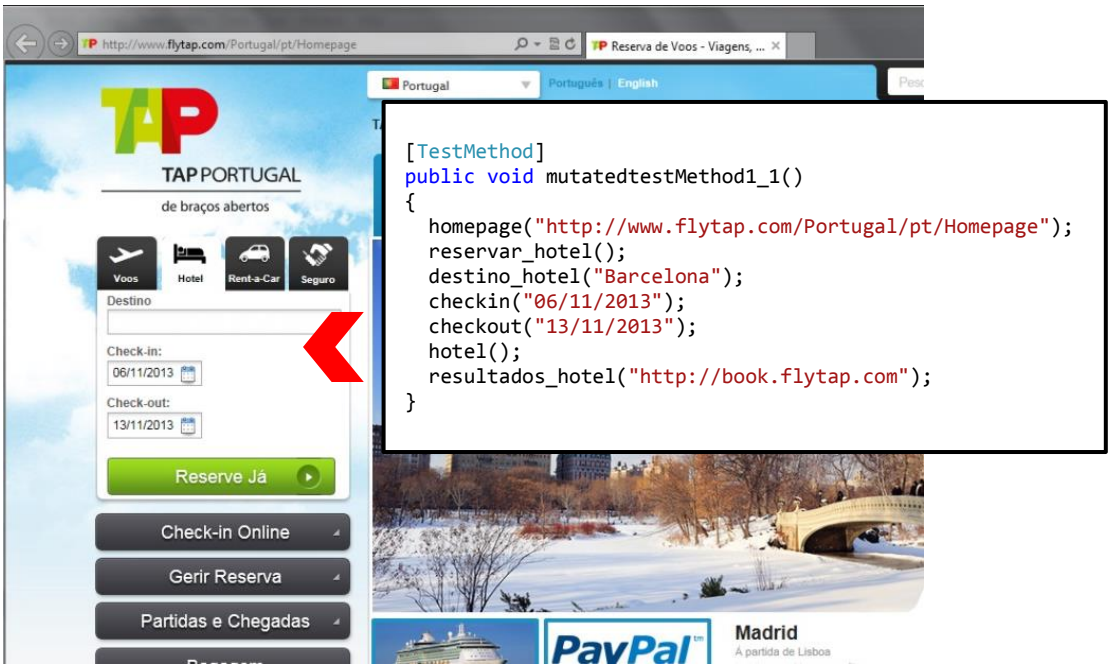


Figure 23 - Exemple of an execution of a mutated test case

Figure 24 shows the result of the execution of the mutated test case in Visual Studio 2010 with the value **Aborted**. This means that the test was not executed with success because the expected result from the method *resultados_hotel* was not found. To better understand why the test fail the log file (Figure 25) should be analyzed. Note that the test is supposed to fail because the results cannot be presented if the *reservar_hotel* is not executed.

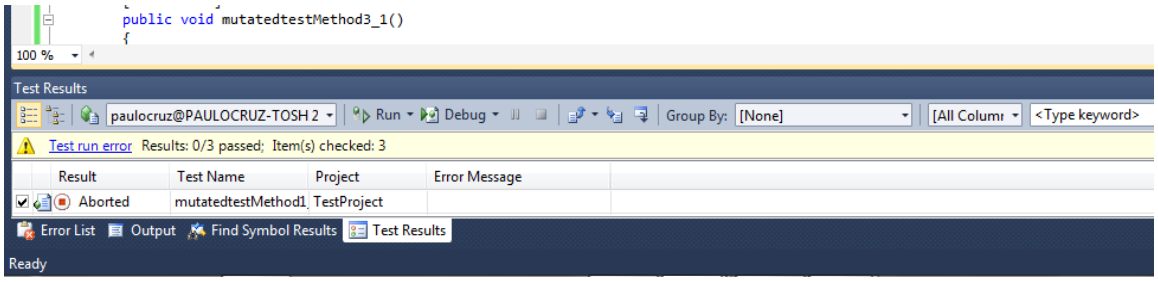


Figure 24 - Test results shown in the Visual Studio for a mutated test

```
Method homePage: The page was found:
http://www.flytap.com/Portugal/pt/Homepage
Method hotel: The action HOTEL was successfully executed.
Method checkin: The correct value was found in checkin_date
Method checkout: The correct value was found in checkout_date
Method resultados_hotel: The page was not found: http://book.flytap.com
```

Figure 25 - Log file generated for the mutated test case executed

5.2 Microsoft Outlook (Online)

As a second example of application of the tool, Microsoft Outlook (online) will be used.

5.2.1 Task Model

The excerpt from the task model in Figure 26 represents the tasks necessary to send an email on Outlook (Figure 27). More specifically, to send an email in Outlook it is necessary to click in "New". After that a new page will be presented to the user. In that page it is required that at least the textbox "to" be filled (in this example the textbox "subject" can also filled) and that the "Send" button be clicked. It should be noted that it is necessary to be logged in Outlook to perform these actions. The complete task model can be found in Appendix II.

One aspect that distinguishes this example from the previous one is that the concurrency and choice operators are being used in this case. See tasks "Edit" and "NewEmail Options" in Figure 26.

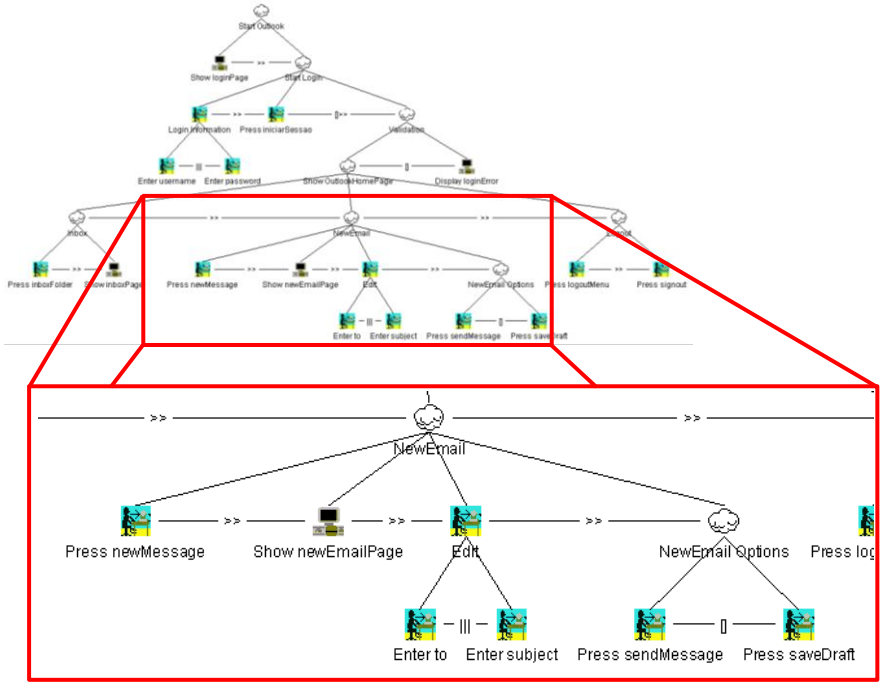


Figure 26 - Outlook task model sample (send an email)

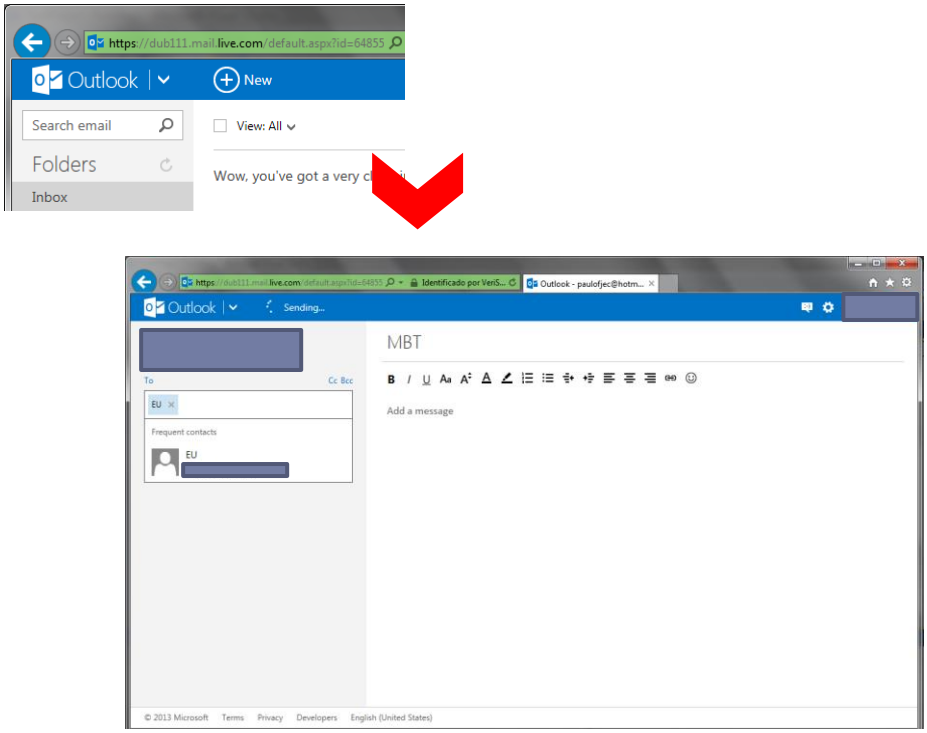


Figure 27 - Sending an email in Outlook

5.2.2 Configuration Files

The mapping between the interface and the task model is presented in Figure 28. The respective configuration files can be viewed in Figure 29.

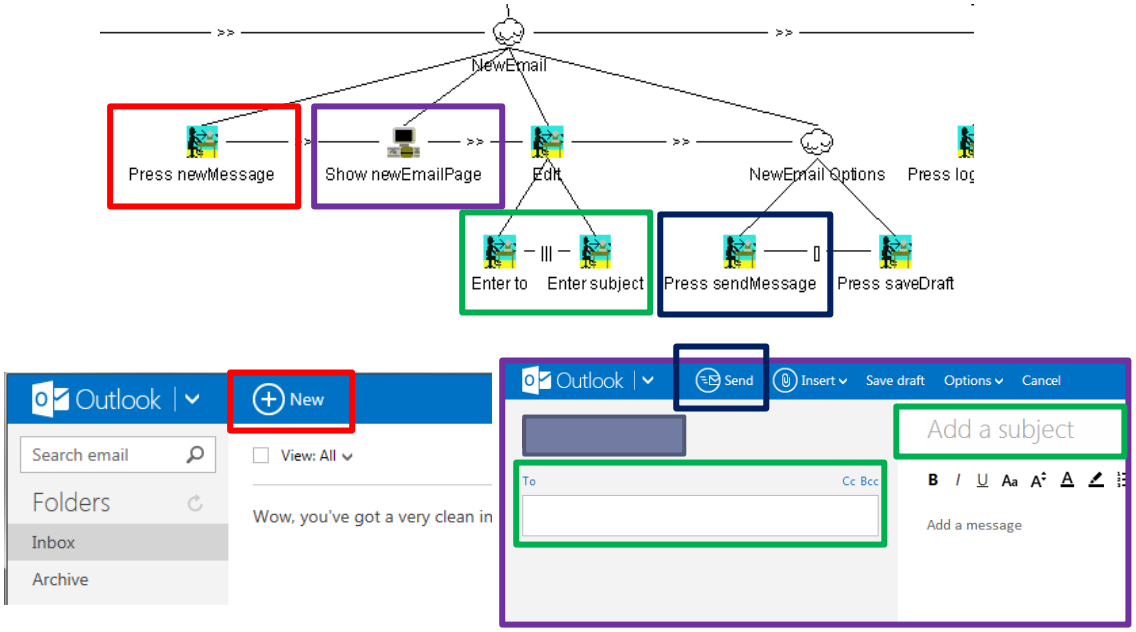


Figure 28 - Mapping between the interface and the outlook task model

```
                    Variables Configuration File:

urlStart?http://www.flytap.com/Portugal/pt/Homepage
newMessage?Press=Link=Id!NewMessage
to?Enter=TextFieldExtended=Class!cp_primaryInput cp_anyInput
t_urtc=mail
subject?Enter=TextField=Name!fSubject=message
sendMessage?Press=Link=Id!SendMessage
newEmailPage?https://dub111.mail.live.com


                    Parameters Configuration File:
1
user?example@hotmail.com
pass?******
message?MBT
mail?example@sapo.pt
```

Figure 29 - Configuration files for send email option

5.2.3 Test Cases

As before, once completed the configuration files step the process of generating code can start. Two of the eight paths found for the Outlook example can be seen in Figure 30 (the colored circles mean the continuation of the path). In this example the operator ||| is used. This means that the two tasks can be executed concurrently. To simulate this two test cases were generated with the order of the tasks changed. Consider, for example, that the tasks A and B are executed concurrently and after task C is executed. Two different test cases will be generated: A > B > C and B > A > C. An example of code generated can be found in Appendix IV.

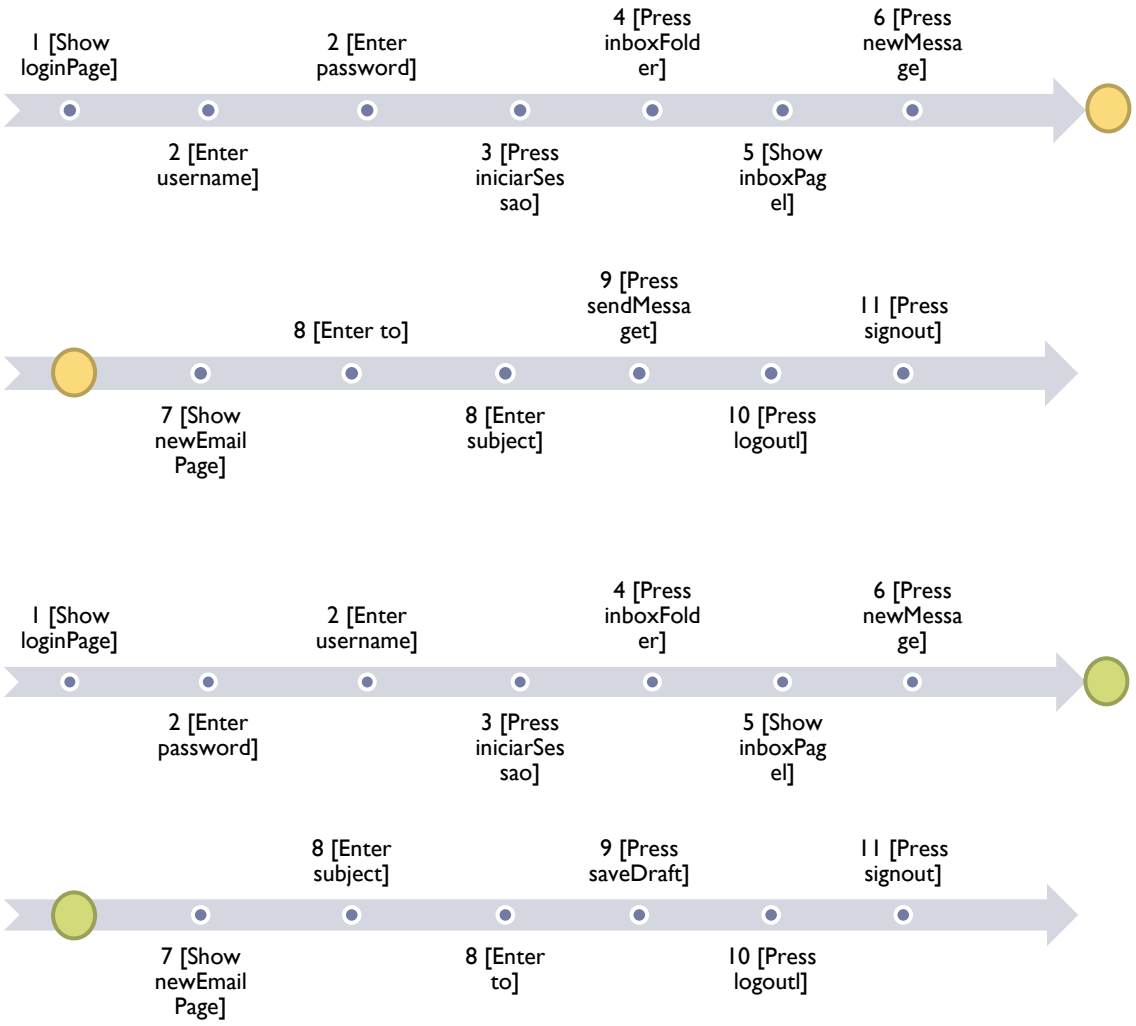


Figure 30 - Example of paths found for Outlook task model

Once the paths are found the test cases can be generated as presented in List 5.

```
[TestMethod]
public void testMethod1_0()
{
    loginPage("https://login.live.com");
    username("example@hotmail.com");
    password("*******");
    iniciarSessao();
    inboxFolder();
    inboxPage("https://dub111.mail.live.com");
    newMessage();
    newEmailPage("https://dub111.mail.live.com");
    to("example@sapo.pt");
    subject("MBT");
    sendMessage();
    logoutMenu();
    signout();
}

[TestMethod]
public void testMethod2_0()
{
    loginPage("https://login.live.com");
    username("example@hotmail.com");
    password("*******");
    iniciarSessao();
    inboxFolder();
    inboxPage("https://dub111.mail.live.com");
    newMessage();
    newEmailPage("https://dub111.mail.live.com");
    to("example@sapo.pt");
    subject("MBT");
    saveDraft();
    logoutMenu();
    signout();
}

[TestMethod]
public void testMethod3_0()
{
    loginPage("http://outlook.com");
    password("*******");
    username("example@hotmail.com");
    iniciarSessao();
    inboxFolder();
    inboxPage("https://dub111.mail.live.com");
    newMessage();
    newEmailPage("https://dub111.mail.live.com");
```

```
    to("example@sapo.pt");
    subject("MBT");
    saveDraft();
    logoutMenu();
    signout();
}
```

List 5 - Example of test cases generated

5.2.4 Test Cases Execution

Figure 31 shows the execution of a test case that sends an email.

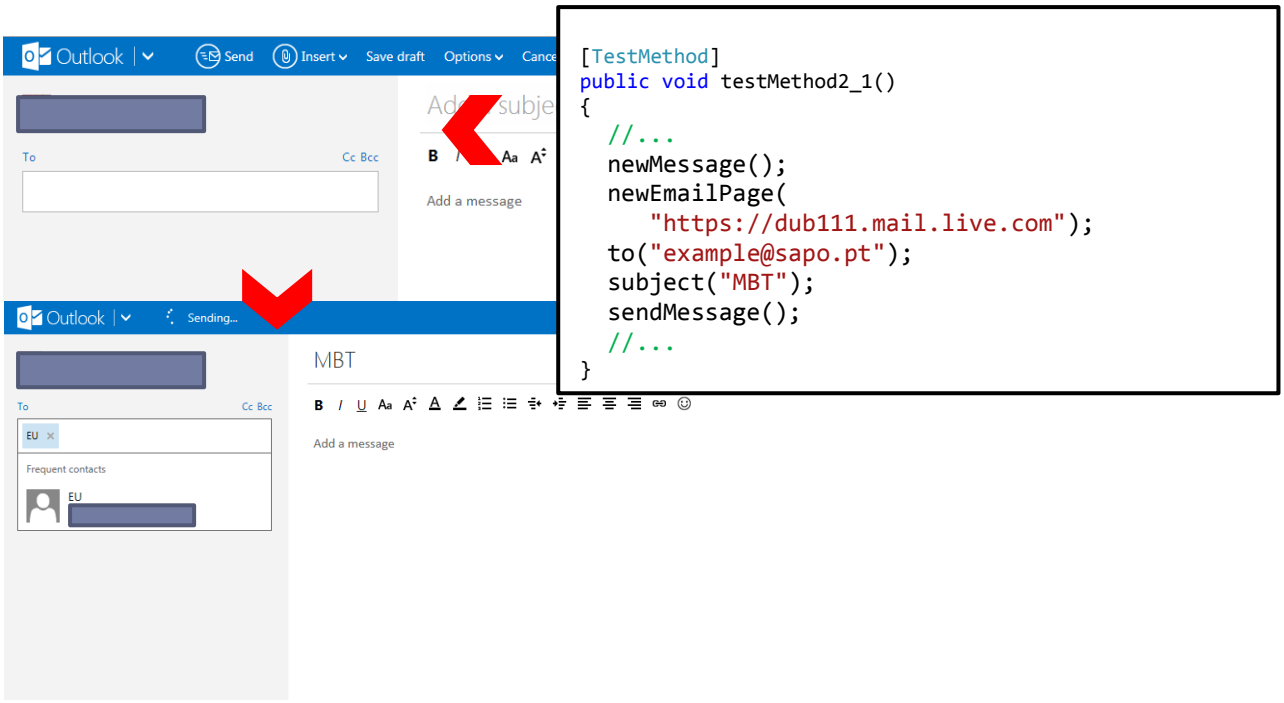


Figure 31 - Outlook send email test case execution

The results of the test cases executed can be viewed in Figure 32. If everything goes as plan Visual Studio shows the test as **Passed**. As before, the log file (Figure 33) can also give information to the software tester.

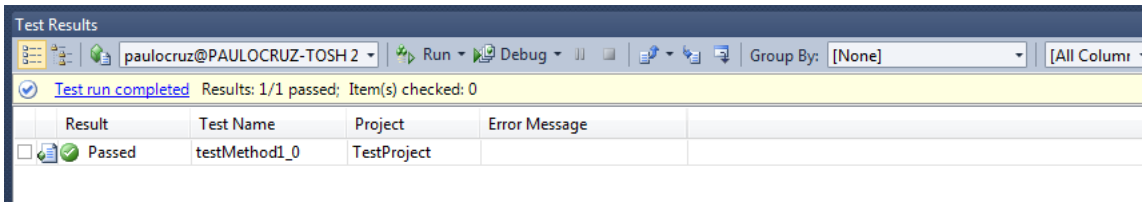


Figure 32 - Test results presented in Visual Studio 2010

```
Method newMessage: The action NewMessage was successfully executed.
Method newEmailPage: The page was found: https://dub111.mail.live.com
Method to: The correct value was found in
cp_primaryInput_cp_anyInput_t_urtc
Method subject: The correct value was found in fSubject
Method sendMessage: The action SendMessage was successfully executed.
```

Figure 33 - Generated log file

5.2.5 Mutated Test Cases

List 6 shows examples of mutated test cases generated by the tool, one for each type of error, for the Outlook task model.

```
//Slip Mutation
[TestMethod]
public void mutatedtestMethod1_1()
{
    loginPage("https://login.live.com");
    username("example@hotmail.com");
    password("*******");
    inboxFolder();
    iniciarSessao();
    inboxPage("https://dub111.mail.live.com");
    newMessage();
    newEmailPage("https://dub111.mail.live.com");
    to("example@sapo.pt");
    subject("MBT");
    sendMessage();
    logoutMenu();
    signout();
}
```

```
//Lapse Mutation
[TestMethod]
public void mutatedtestMethod2_1()
{
    loginPage("https://login.live.com");
    username("example@hotmail.com");
    iniciarSessao();
    inboxFolder();
    inboxPage("https://dub111.mail.live.com");
    newMessage();
    newEmailPage("https://dub111.mail.live.com");
    to("example@sapo.pt");
    subject("MBT");
    saveDraft();
    logoutMenu();
    signout();
}

//Mistake Mutation
[TestMethod]
public void testMethod3_0()
{
    loginPage("http://outlook.com");
    password("*******");
    username("exa#ple@hotmail.com");
    iniciarSessao();
    inboxFolder();
    inboxPage("https://dub111.mail.live.com");
    newMessage();
    newEmailPage("https://dub111.mail.live.com");
    to("example@sapo.pt");
    subject("MBT");
    saveDraft();
    logoutMenu();
    signout();
}
```

List 6 - Example of mutated test cases for the outlook example

5.2.6 Mutated Test Cases Execution

In the example shown in Figure 34, we can observe that the outlook user home page is not shown because the user login is filled incorrectly, which causes the test to fail.

Figure 34 - Example of an execution of a mutated test case

Figure 35 shows the result of the execution of the mutated test case in Visual Studio 2010 with the value **Aborted**. This means that the test was not executed with success. To better comprehend why the test failed the log file (Figure 36) should be analyzed. Note that this was the intended results since the login was filled incorrectly.

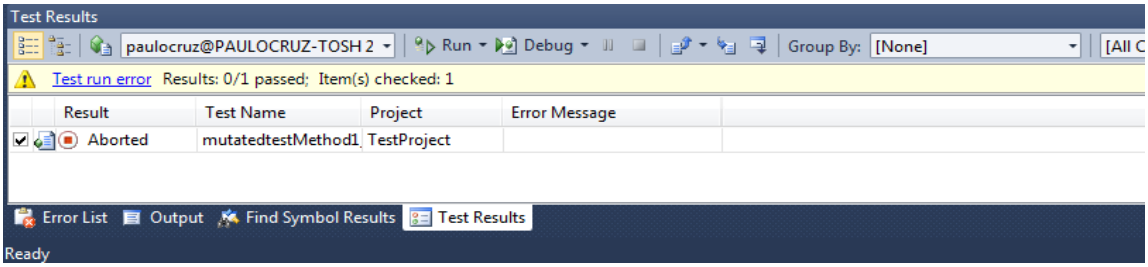


Figure 35 - Test results shown in the Visual Studio for a mutated test

```
Method loginPage: The page was found: https://login.live.com
Method username: The correct value was found in login
Method password: The correct value was found in passwd
Method iniciarSessao: The action Iniciar_sessao was successfully
executed.
An error was found while exectuing inboxFolder(): Could not find SPAN
element tag matching criteria: Attribute 'innertext' matches '^ *Inbox
*$' at
https://login.live.com/ppsecure/post.srf?wa=wsignin1.0&ct=1382894379&rv
er=6.1.6206.0&sa=1&ntprob=-
1&wp=MBI_SSL_SHARED&wreply=https:%2F%2Fmail.live.com%2F%3Fowa%3D1%26owa
suffix%3Dowa%252f&id=64855&snsc=1&cbcxt=mail&bk=1382894380
```

Figure 36 - Log file generated for the mutated test case executed

5.3 Conclusion

This chapter has presented two examples of testing a user interface. The tool worked as expected. Given that this is just a prototype the existing limitations can always be corrected in the future. One of the improvements is to extend the scope of the Display keyword. Currently the generated code for Display only checks if a given text is present in the HTML element, however if the text shown is dynamic, ie, varies depending on the error, it is not possible to test this event. Due to this limitation, it was decided that the keyword Display would not be a part of the test cases, ie, the method is created, but is not used in the test cases.

Being an approach based on method calls nothing limits the software tester to create his own test cases and make use of methods for the keyword Display and the others by entering valid values and/or invalid inputs.

6. CONCLUSIONS

This dissertation described an approach (using Model-based testing) to test web applications. This approach makes use of task models to check the behavior of these applications is in accordance with the behavior in the model. Although the approach does not guarantee a faithful representation of the actions of users, since each user can interpret and perform the same actions in various ways, it is capable of identifying problems in the implementation of the system and of providing information regarding how the GUI responds to actions that were not planned or were performed incorrectly. As result of this work, a paper was accepted for publication at Interacção 2013 [22].

6.1 Objectives achieved and limitations

The current tool allows the software tester to perform a wide range of test cases. There are however a number of ways in which the development should be continued.

A first aspect is related to the processing of task models. In order to simplify the state machine generated, and to bypass some limitations in the generation of PTS, it was decided to treat only the >>, [ ]>>, ||| and [ ] operators. Although these operators are those which comprise most cases and, in our experience, are sufficient to express most models (for example, a cyclic task necessarily has to be reduced to a finite number of iterations) in the future it is intended to extend the approach to eliminate this limitation, in order to be able to recognize and treat all existing operators. The unused operators and the reason why they were not used in the developed models can be found in Appendix V.

Regarding validation of system responses, this is currently done at the level of the window (ie, if the current window has the elements necessary for the continuation of the interaction or

not). In order to make the process even more automated the Display keyword was introduced. The implementation of this reserved word means the possibility of defining in the test cases the expected value of a particular user interface element in response to action user.

6.2 Future work

To overcome the limitations identified above a number of improvements to the tool should be considered. The most relevant include:

- The implementation of different algorithms to search for paths in the graph, allowing the software tester to define different coverage criteria. These could include obvious algorithms such as traversing all nodes or all connections in the graph, but also some more problem oriented ones like all possible user actions or all possible system responses in the task model.
- Generating the graphs from other models in addition to CTT task models, ensuring that the application is not limited only to models written in CTT.
- Supporting the semi-automatic generation of configuration files, which currently must necessarily be created manually. This could be achieved by implementing a tool to interactively map user interface elements to tasks in the CTT model.

REFERENCES

[1] A. Abran, J. W. Moore, P. Bourque, and R. Dupuis, *Software Engineering Body of Knowledge*. 2004.

[2] ISSO 9241-11:1998, "Ergonomic requirements for office work with visual display terminals (VDTs) - Part 11: Guidance on usability," 1998.

[3] K. Beck, M. Beedle, A. van Bennekum, A. Cockburn, W. Cunningham, M. Fowler, J. Grenning, J. Highsmith, A. Hunt, R. Jeffries, J. Kern, B. Marick, R. C. Martin, S. Mellor, K. Schwaber, J. Sutherland, and D. Thomas, "Agile Manifesto." [Online]. Available: http://agilemanifesto.org/.

[4] J. Jacky, V. Margus, C. Colin, and S. Wolfram, *Model-Based Software Testing and Analysis with C#*. Cambridge University Press, 2007.

[5] A. C. R. Paiva, C. P. Faria, N. Tillmann, and R. A. M. Vidal, "A Model-to-implementation Mapping Tool for Automated Model-based GUI Testing," *7th Int. Conf. Form. Eng. Methods, ICFEM 2005, Manchester, UK, Novemb. 1-4, 2005. Proc.*, vol. 3785, pp. 450–464, 2005.

[6] P. a Brooks and A. M. Memon, "Automated gui testing guided by usage profiles," *Proc. twentysecond IEEEACM Int. Conf. Autom. Softw. Eng. ASE 07*, p. 333, 2007.

[7] J. L. Silva, J. C. Campos, and A. C. R. Paiva, "Model-based User Interface Testing With Spec Explorer and ConcurTaskTrees," *Electron. Notes Theor. Comput. Sci.*, vol. 208, pp. 77–93, 2007.

[8] G. J. Myers, C. Sandler, and T. Badgett, *The Art of Software Testing*. Wiley Publishing, 2004, p. 225.

[9] V. Rungta, "Software Testing Life Cycle STLC." [Online]. Available: http://www.guru99.com/software-testing-life-cycle.html.

[10] "Software Testing Life Cycle (STLC) | Software Testing Fundamentals." [Online]. Available: http://softwaretestingfundamentals.com/software-testing-life-cycle/.

[11] "IEEE Std 610.12-1990 (R2002), IEEE Standard Glossary of Software Engineering Terminology, IEEE." 1990.

[12] S. Mathur and S. Malik, "Advancements in the V-Model," *Int. J. Comput. Appl.*, vol. 1, no. 12, pp. 29–34, 2010.

[13] L. Apfelbaum and J. Doyle, "Model Based Testing," *Procedings 10th Int. Softw. Qual. Week*, pp. 1–14, 1997.

[14] M. Utting and B. Legeard, *Practical Model-Based Testing: A Tools Approach*. San Francisco, USA, Morgan Kaufmann, 2007.

[15] M. Y. Ivory and M. a Hearst, "The state of the art in automating usability evaluation of user interfaces," *ACM Comput. Surv.*, vol. 33, no. 4, pp. 470–516, 2001.

[16] "Multimodal TERESA - Tool for Design and Development of Multi-platform Applications." [Online]. Available: http://giove.isti.cnr.it/teresa.html.

[17] "MARIAE." [Online]. Available: http://giove.isti.cnr.it/tools/MARIAE/home.

[18] "Hamsters WEB." [Online]. Available: http://www.irit.fr/recherches/ICS/softwares/hamsters/.

[19] A. Barbosa and A. C. R. Paiva, "Test Case Generation from Mutated Task Models," EICS '11 Proceedings of the 3rd ACM SIGCHI symposium on Engineering interactive computing systems, pp. 175–184, 2011.

[20] F. Paternò, C. Mancini, and S. Meniconi, "ConcurTaskTrees: A Diagrammatic Notation for Specifying Task Models," *Proceeding INTERACT '97 Proc. IFIP TC13 Interantional Conf. Human-Computer Interact. Chapman Hall, Ltd. London, UK, 1997*, p. Pages 362–369.

[21] J. Reason, "Human Error," *Cambridge Univ. Press. 1990. xv, 302 p., 1990.*, 1990.

[22] P. J. Cruz and J. C. Campos, "Ambiente de geração, mutação e execução de casos de teste para aplicações Web," *Interacção*, 2013.

[23] A Hartman and K. Nagin. 2004. "The AGEDIS Tools for Model Based Testing," In Proceedings of the 2004 ACM SIGSOFT international symposium on Software testing and analysis (ISSTA'04), ACM, New York, NY, USA 129-132.

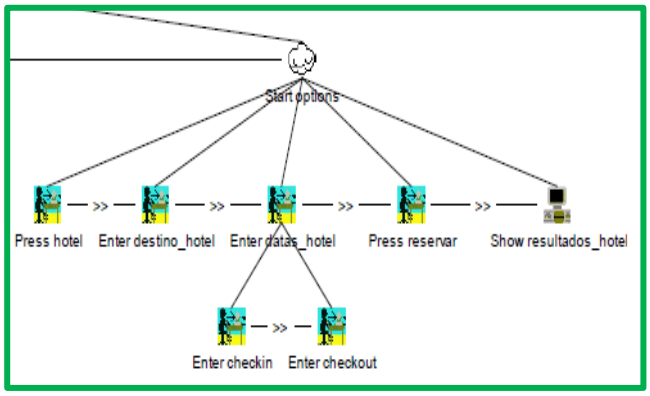
[24] A. Barbosa, A.C.R Paiva. and J.C. Campos, "Test case generation from mutated task models,". *Proceedings of the 3rd ACM SIGCHI symposium on Engineering interactive computing systems (EICS '11)*. ACM, New York, NY, USA, 175-184. DOI=10.1145/1996461.1996516 http://doi.acm.org/10.1145/1996461.1996516, 2011.

APPENDIXES

I. TAP CASE STUDY

This appendix lists the task model as well as an example of generated code for the TAP case study presented in section 5.1.

Task Model



Generated Code Example

```
using System;
using System.Text;
using System.Collections.Generic;
using System.Linq;
using Microsoft.VisualStudio.TestTools.UnitTesting;
using WatiN.Core;
using WatiN.Core.Native;

namespace TestProject
{
    [TestClass]
    public class Test
    {
        Browser browserInstance;
        string url = "http://tap.pt";

        [TestInitialize]
        public void WithAnInstanceOfThebrowserInstance()
        {
            browserInstance = new IE(url);
        }

        [TestCleanup]
        public void ShutdownbrowserInstanceWhenDone()
        {
            browserInstance.Close();
            browserInstance = null;
        }

        public void homePage(string url)
        {
            try
            {
                if (!browserInstance.Url.Contains(url))
                {
                    using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                    {
                        file.WriteLine("Method homePage: The page was not found: " + url);
                    }
                    Environment.Exit(0);
```

```
                }
                else
                {
                    using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                    {
                        file.WriteLine("Method homePage: The page was found: " + url);
                    }
                }
            }
            catch (Exception e)
            {
                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("An error was found while exectuing homePage(): " +
e.Message);
                }
                Environment.Exit(0);
            }
        }

        public void idaEvolta()
        {
            try
            {
                RadioButton flighttype_return =
browserInstance.RadioButton(Find.ById("flighttype_return"));

                flighttype_return.Click();

                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("Method idaEvolta: The action flighttype_return was
successfully executed.");
                }

            }
            catch (Exception e)
            {
                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("An error was found while exectuing idaEvolta(): " +
e.Message);
                }
                Environment.Exit(0);
            }
        }

        public void ida()
        {
            try
            {
                RadioButton IDA = browserInstance.RadioButton(Find.ById("IDA"));

                IDA.Click();

                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("Method ida: The action IDA was successfully executed.");
                }
```

```
            }
            catch (Exception e)
            {
                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("An error was found while exectuing ida(): " + e.Message);
                }
                Environment.Exit(0);
            }
        }


        public void hotel()
        {
            try
            {
                Button HOTEL = browserInstance.Button(Find.ById("HOTEL"));

                HOTEL.Click();

                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("Method hotel: The action HOTEL was successfully executed.");
                }

            }
            catch (Exception e)
            {
                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("An error was found while exectuing hotel(): " + e.Message);
                }
                Environment.Exit(0);
            }
        }

        public void origem_idaEvolta(string cidadeOrigem)
        {
            try
            {
                TextField fromCity =
browserInstance.ElementOfType<TextFieldExtended>(Find.ByName("fromCity"));
                fromCity.Value = cidadeOrigem;

                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("Method origem_idaEvolta: The correct value was found in
fromCity");
                }

            }
            catch (Exception e)
            {
                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("An error was found while exectuing origem_idaEvolta(): " +
e.Message);
```

```
                }
                Environment.Exit(0);
            }
        }

        public void destino_idaEvolta(string cidadeDestino)
        {
            try
            {
                TextField toCity =
browserInstance.ElementOfType<TextFieldExtended>(Find.ByName("toCity"));
                toCity.Value = cidadeDestino;

                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("Method destino_idaEvolta: The correct value was found in
toCity");
                }

            }
            catch (Exception e)
            {
                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("An error was found while exectuing destino_idaEvolta(): " +
e.Message);
                }
                Environment.Exit(0);
            }
        }

        public void dataPartida(string dataIda)
        {
            try
            {
                TextField data_partida =
browserInstance.ElementOfType<TextFieldExtended>(Find.ByName("data_partida"));
                data_partida.Value = dataIda;

                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("Method dataPartida: The correct value was found in
data_partida");
                }

            }
            catch (Exception e)
            {
                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("An error was found while exectuing dataPartida(): " +
e.Message);
                }
                Environment.Exit(0);
            }
        }

        public void dataRegresso(string dataVolta)
        {
            try
```

```
            {
                TextField data_regresso =
browserInstance.ElementOfType<TextFieldExtended>(Find.ByName("data_regresso"));
                data_regresso.Value = dataVolta;

                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("Method dataRegresso: The correct value was found in
data_regresso");
                }

            }
            catch (Exception e)
            {
                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("An error was found while exectuing dataRegresso(): " +
e.Message);
                }
                Environment.Exit(0);
            }
        }

        public void reservar()
        {
            try
            {
                Span Reserve_Ja = browserInstance.Span(Find.ByText("Reserve Ja"));

                Reserve_Ja.Click();

                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("Method reservar: The action Reserve_Ja was successfully
executed.");
                }

            }
            catch (Exception e)
            {
                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("An error was found while exectuing reservar(): " +
e.Message);
                }
                Environment.Exit(0);
            }
        }

        public void results(string url)
        {
            try
            {
                if (!browserInstance.Url.Contains(url))
                {
                    using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                    {
                        file.WriteLine("Method results: The page was not found: " + url);
                    }
```

```
                    Environment.Exit(0);
                }
                else
                {
                    using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                    {
                        file.WriteLine("Method results: The page was found: " + url);
                    }
                }
            }
            catch (Exception e)
            {
                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("An error was found while exectuing results(): " +
e.Message);
                }
                Environment.Exit(0);
            }
        }

        public void origem_ida(string cidadeOrigem)
        {
            try
            {
                TextField fromCity =
browserInstance.ElementOfType<TextFieldExtended>(Find.ByName("fromCity"));
                fromCity.Value = cidadeOrigem;

                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("Method origem_ida: The correct value was found in
fromCity");
                }

            }
            catch (Exception e)
            {
                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("An error was found while exectuing origem_ida(): " +
e.Message);
                }
                Environment.Exit(0);
            }
        }

        public void destino_ida(string cidadeDestino)
        {
            try
            {
                TextField toCity =
browserInstance.ElementOfType<TextFieldExtended>(Find.ByName("toCity"));
                toCity.Value = cidadeDestino;

                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("Method destino_ida: The correct value was found in toCity");
                }
```

```
            }
            catch (Exception e)
            {
                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("An error was found while exectuing destino_ida(): " +
e.Message);
                }
                Environment.Exit(0);
            }
        }


        public void data_ida(string dataIda)
        {
            try
            {
                TextFielExtended data_partida =
browserInstance.TextFielExtended(Find.ByName("data_partida"));
                data_partida.Value = dataIda;

                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("Method data_ida: The correct value was found in
data_partida");
                }

            }
            catch (Exception e)
            {
                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("An error was found while exectuing data_ida(): " +
e.Message);
                }
                Environment.Exit(0);
            }
        }

        public void destino_hotel(string hotel)
        {
            try
            {
                TextField hotel_destination =
browserInstance.TextField(Find.ByName("hotel_destination"));
                hotel_destination.Value = hotel;

                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("Method destino_hotel: The correct value was found in
hotel_destination");
                }

            }
            catch (Exception e)
            {
                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
```

```
                    file.WriteLine("An error was found while exectuing destino_hotel(): " +
e.Message);
                }
                Environment.Exit(0);
            }
        }

        public void checkin(string dataCheckin)
        {
            try
            {
                TextField checkin_date =
browserInstance.ElementOfType<TextFieldExtended>(Find.ByName("checkin_date"));
                checkin_date.Value = dataCheckin;

                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("Method checkin: The correct value was found in
checkin_date");
                }

            }
            catch (Exception e)
            {
                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("An error was found while exectuing checkin(): " +
e.Message);
                }
                Environment.Exit(0);
            }
        }

        public void checkout(string dataCheckout)
        {
            try
            {
                TextField checkout_date =
browserInstance.ElementOfType<TextFieldExtended>(Find.ByName("checkout_date"));
                checkout_date.Value = dataCheckout;

                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("Method checkout: The correct value was found in
checkout_date");
                }

            }
            catch (Exception e)
            {
                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("An error was found while exectuing checkout(): " +
e.Message);
                }
                Environment.Exit(0);
            }
        }

        public void reservar_hotel()
```

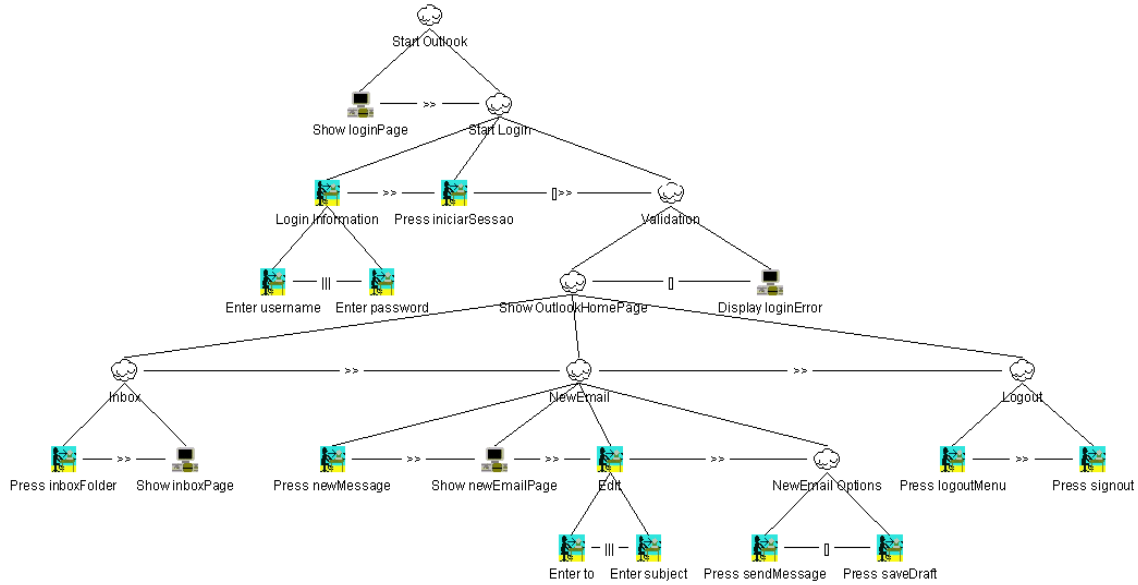
```
        {
            try
            {
                Span Reserve_Ja = browserInstance.Span(Find.ByText("Reserve Ja"));

                Reserve_Ja.Click();

                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("Method reservar_hotel: The action Reserve_Ja was
successfully executed.");
                }

            }
            catch (Exception e)
            {
                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("An error was found while exectuing reservar_hotel(): " +
e.Message);
                }
                Environment.Exit(0);
            }
        }

        public void resultados_hotel(string url)
        {
            try
            {
                if (!browserInstance.Url.Contains(url))
                {
                    using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                    {
                        file.WriteLine("Method resultados_hotel: The page was not found: " +
url);
                    }
                    Environment.Exit(0);
                }
                else
                {
                    using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                    {
                        file.WriteLine("Method resultados_hotel: The page was found: " + url);
                    }
                }
            }
            catch (Exception e)
            {
                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("An error was found while exectuing resultados_hotel(): " +
e.Message);
                }
                Environment.Exit(0);
            }
        }

        [TestMethod]
        public void testMethod1_1()
```

```
        {
            homepage("http://www.flytap.com/Portugal/pt/Homepage");
            hotel();
            destino_hotel("Barcelona");
            checkin("06/11/2013");
            checkout("13/11/2013");
            reservar_hotel();
            resultados_hotel("http://book.flytap.com");
        }

        [TestMethod]
        public void testMethod2_1()
        {
            homepage("http://www.flytap.com/Portugal/pt/Homepage");
            ida();
            origem_ida("Porto, Portugal");
            destino_ida("Barcelona, Espanha");
            data_ida("06/11/2013");
            reservar();
            results("http://book.flytap.com");
        }

        [TestMethod]
        public void testMethod3_1()
        {
            homepage("http://www.flytap.com/Portugal/pt/Homepage");
            idaEvolta();
            origem_idaEvolta("Porto, Portugal");
            destino_idaEvolta("Barcelona, Espanha");
            dataPartida("06/11/2013");
            dataRegresso("13/11/2013");
            reservar();
            results("http://book.flytap.com");
        }
    }
}
```

II. MICROSOFT OUTLOOK CASE STUDY

This appendix lists the task model as well as an example of generated code for the Microsoft Outlook case study presented in section 5.2.

Task Model



Generated Code Example

```
using System;
using System.Text;
using System.Collections.Generic;
using System.Linq;
using Microsoft.VisualStudio.TestTools.UnitTesting;
using WatiN.Core;
using WatiN.Core.Native;

namespace TestProject
{
    [TestClass]
    public class Test
    {
        Browser browserInstance;
        string url = "http://outlook.com";

        [TestInitialize]
        public void WithAnInstanceOfThebrowserInstance()
        {
            browserInstance = new IE(url);
        }

        [TestCleanup]
        public void ShutdownbrowserInstanceWhenDone()
        {
            browserInstance.Close();
            browserInstance = null;
        }

        public void loginPage(string url)
        {
            try
            {
                if (!browserInstance.Url.Contains(url))
                {
                    using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                    {
                        file.WriteLine("Method loginPage: The page was not found: " + url);
                    }
                    Environment.Exit(0);
                }
                else
                {
                    using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                    {
                        file.WriteLine("Method loginPage: The page was found: " + url);
                    }
                }
            }
            catch (Exception e)
            {
                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("An error was found while exectuing loginPage(): " +
e.Message);
```

```
                }
                Environment.Exit(0);
            }
        }

        public void username(string user)
        {
            try
            {
                TextField login =
browserInstance.ElementOfType<TextFieldExtended>(Find.ByName("login"));
                login.Value = user;

                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("Method username: The correct value was found in login");
                }

            }
            catch (Exception e)
            {
                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("An error was found while exectuing username(): " +
e.Message);
                }
                Environment.Exit(0);
            }
        }

        public void password(string pass)
        {
            try
            {
                TextField passwd = browserInstance.TextField(Find.ByName("passwd"));
                passwd.Value = pass;

                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("Method password: The correct value was found in passwd");
                }

            }
            catch (Exception e)
            {
                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("An error was found while exectuing password(): " +
e.Message);
                }
                Environment.Exit(0);
            }
        }

        public void iniciarSessao()
        {
            try
            {
                Button Iniciar_sessao = browserInstance.Button(Find.ByValue("Iniciar sessão"));
```

```
                Iniciar_sessao.Click();

                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("Method iniciarSessao: The action Iniciar_sessao was
successfully executed.");
                }

            }
            catch (Exception e)
            {
                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("An error was found while exectuing iniciarSessao(): " +
e.Message);
                }
                Environment.Exit(0);
            }
        }

        public void inboxFolder()
        {
            try
            {
                Span Inbox = browserInstance.Span(Find.ByText("Inbox"));

                Inbox.Click();

                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("Method inboxFolder: The action Inbox was successfully
executed.");
                }

            }
            catch (Exception e)
            {
                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("An error was found while exectuing inboxFolder(): " +
e.Message);
                }
                Environment.Exit(0);
            }
        }

        public void inboxPage(string url)
        {
            try
            {
                if (!browserInstance.Url.Contains(url))
                {
                    using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                    {
                        file.WriteLine("Method inboxPage: The page was not found: " + url);
                    }
                    Environment.Exit(0);
                }
                else
```

```
                {
                    using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                    {
                        file.WriteLine("Method inboxPage: The page was found: " + url);
                    }
                }
            }
            catch (Exception e)
            {
                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("An error was found while exectuing inboxPage(): " +
e.Message);
                }
                Environment.Exit(0);
            }
        }

        public void newMessage()
        {
            try
            {
                Link NewMessage = browserInstance.Link(Find.ById("NewMessage"));

                NewMessage.Click();

                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("Method newMessage: The action NewMessage was successfully
executed.");
                }

            }
            catch (Exception e)
            {
                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("An error was found while exectuing newMessage(): " +
e.Message);
                }
                Environment.Exit(0);
            }
        }

        public void newEmailPage(string url)
        {
            try
            {
                if (!browserInstance.Url.Contains(url))
                {
                    using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                    {
                        file.WriteLine("Method newEmailPage: The page was not found: " + url);
                    }
                    Environment.Exit(0);
                }
                else
                {
```

```
                    using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                    {
                        file.WriteLine("Method newEmailPage: The page was found: " + url);
                    }
                }
            }
            catch (Exception e)
            {
                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("An error was found while exectuing newEmailPage(): " +
e.Message);
                }
                Environment.Exit(0);
            }
        }

        public void to(string mail)
        {
            try
            {
                TextField cp_primaryInput_cp_anyInput_t_urtc =
browserInstance.ElementOfType<TextFieldExtended>(Find.ByClass("cp_primaryInput cp_anyInput
t_urtc"));
                cp_primaryInput_cp_anyInput_t_urtc.Value = mail;

                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("Method to: The correct value was found in
cp_primaryInput_cp_anyInput_t_urtc");
                }

            }
            catch (Exception e)
            {
                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("An error was found while exectuing to(): " + e.Message);
                }
                Environment.Exit(0);
            }
        }

        public void subject(string message)
        {
            try
            {
                TextField fSubject = browserInstance.TextField(Find.ByName("fSubject"));
                fSubject.Value = message;

                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("Method subject: The correct value was found in fSubject");
                }

            }
            catch (Exception e)
            {
```

```
                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("An error was found while exectuing subject(): " +
e.Message);
                }
                Environment.Exit(0);
            }
        }

        public void sendMessage()
        {
            try
            {
                Link SendMessage = browserInstance.Link(Find.ById("SendMessage"));

                SendMessage.Click();

                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("Method sendMessage: The action SendMessage was successfully
executed.");
                }

            }
            catch (Exception e)
            {
                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("An error was found while exectuing sendMessage(): " +
e.Message);
                }
                Environment.Exit(0);
            }
        }

        public void saveDraft()
        {
            try
            {
                Link SaveDraft = browserInstance.Link(Find.ById("SaveDraft"));

                SaveDraft.Click();

                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("Method saveDraft: The action SaveDraft was successfully
executed.");
                }

            }
            catch (Exception e)
            {
                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("An error was found while exectuing saveDraft(): " +
e.Message);
                }
                Environment.Exit(0);
            }
```

```
        }

        public void logoutMenu()
        {
            try
            {
                Link c_melink = browserInstance.Link(Find.ById("c_melink"));

                c_melink.Click();

                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("Method logoutMenu: The action c_melink was successfully
executed.");
                }

            }
            catch (Exception e)
            {
                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("An error was found while exectuing logoutMenu(): " +
e.Message);
                }
                Environment.Exit(0);
            }
        }

        public void signout()
        {
            try
            {
                Link c_signout = browserInstance.Link(Find.ById("c_signout"));

                c_signout.Click();

                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("Method signout: The action c_signout was successfully
executed.");
                }

            }
            catch (Exception e)
            {
                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("An error was found while exectuing signout(): " +
e.Message);
                }
                Environment.Exit(0);
            }
        }

        public void loginError(string error)
        {
            try
            {
                Div errorDiv_first = browserInstance.Div(Find.ByClass("errorDiv first"));
                try
```

```
                {
                    if (errorDiv_first.Text.Equals(error))
                    {
                        using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                        {
                            file.WriteLine("Method errorDiv_first: The correct value was found
in errorDiv_first");
                        }
                    }
                }
                catch (Exception e)
                {
                    using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                    {
                        file.WriteLine("An error was found while exectuing loginError(): " +
e.Message);
                    }
                    Environment.Exit(0);
                }

            }
            catch (Exception e)
            {
                using (System.IO.StreamWriter file = new
System.IO.StreamWriter(@"C:\WatiN\CaseStudy\TestProject\log.txt", true))
                {
                    file.WriteLine("An error was found while exectuing loginError(): " +
e.Message);
                }
                Environment.Exit(0);
            }
        }


        [TestMethod]
        public void testMethod1_0()
        {
            loginPage("https://login.live.com");
            username("example@hotmail.com");
            password("*******");
            iniciarSessao();
            inboxFolder();
            inboxPage("https://dub111.mail.live.com");
            newMessage();
            newEmailPage("https://dub111.mail.live.com");
            to("example@sapo.pt");
            subject("MBT");
            sendMessage();
            logoutMenu();
            signout();
        }

        [TestMethod]
        public void testMethod2_0()
        {
            loginPage("https://login.live.com");
            username("example@hotmail.com");
            password("*******");
            iniciarSessao();
            inboxFolder();
            inboxPage("https://dub111.mail.live.com");
            newMessage();
```

```
    newEmailPage("https://dub111.mail.live.com");
    to("example@sapo.pt");
    subject("MBT");
    saveDraft();
    logoutMenu();
    signout();
}

[TestMethod]
public void testMethod3_0()
{
    loginPage("http://outlook.com");
    username("example@hotmail.com");
    password("*******");
    iniciarSessao();
    inboxFolder();
    inboxPage("https://dub111.mail.live.com");
    newMessage();
    newEmailPage("https://dub111.mail.live.com");
    subject("MBT");
    to("example@sapo.pt");
    sendMessage();
    logoutMenu();
    signout();
}


[TestMethod]
public void testMethod4_0()
{
    loginPage("http://outlook.com");
    username("example@hotmail.com");
    password("*******");
    iniciarSessao();
    inboxFolder();
    inboxPage("https://dub111.mail.live.com");
    newMessage();
    newEmailPage("https://dub111.mail.live.com");
    subject("MBT");
    to("example@sapo.pt");
    saveDraft();
    logoutMenu();
    signout();
}


[TestMethod]
public void testMethod5_0()
{
    loginPage("http://outlook.com");
    password("*******");
    username("example@hotmail.com");
    iniciarSessao();
    inboxFolder();
    inboxPage("https://dub111.mail.live.com");
    newMessage();
    newEmailPage("https://dub111.mail.live.com");
    to("example@sapo.pt");
    subject("MBT");
    sendMessage();
    logoutMenu();
    signout();
}
```

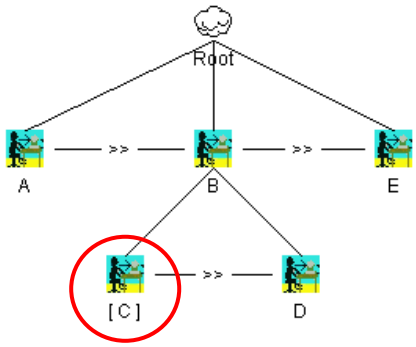
```
        [TestMethod]
        public void testMethod6_0()
        {
            loginPage("http://outlook.com");
            password("*******");
            username("example@hotmail.com");
            iniciarSessao();
            inboxFolder();
            inboxPage("https://dub111.mail.live.com");
            newMessage();
            newEmailPage("https://dub111.mail.live.com");
            to("example@sapo.pt");
            subject("MBT");
            saveDraft();
            logoutMenu();
            signout();
        }


        [TestMethod]
        public void testMethod7_0()
        {
            loginPage("http://outlook.com");
            password("*******");
            username("example@hotmail.com");
            iniciarSessao();
            inboxFolder();
            inboxPage("https://dub111.mail.live.com");
            newMessage();
            newEmailPage("https://dub111.mail.live.com");
            subject("MBT");
            to("example@sapo.pt");
            sendMessage();
            logoutMenu();
            signout();
        }


        [TestMethod]
        public void testMethod8_0()
        {
            loginPage("http://outlook.com");
            password("*******");
            username("example@hotmail.com");
            iniciarSessao();
            inboxFolder();
            inboxPage("https://dub111.mail.live.com");
            newMessage();
            newEmailPage("https://dub111.mail.live.com");
            subject("MBT");
            to("example@sapo.pt");
            saveDraft();
            logoutMenu();
            signout();
        }
    }
}
```

III. UNUSED TERESA OPERATORS

This appendix lists the TERESA operators that were not used due to some inconsistencies found. However it should be noted that the correction of these inconsistencies can make the operators viable to the developed tool.

Operator: Optional Task

Example Model 1



Generated PTS

```
<ETSlist>
  <ETS number="1">
     <task name="A"/>
  </ETS>
  <ETS number="2">
    <task name="C"/>
    <task name="D"/>
  </ETS>
  <ETS number="3">
    <task name="E"/>
  </ETS>
</ETSlist>
```

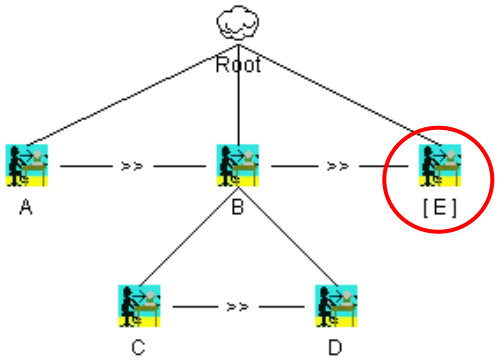
```
<DynamicBehaviour>
  <Rule>
    <TaskSet> TS2 </TaskSet>
      <Transition>
        <Task name ="D"/>
      </Transition>
    <TaskSet> TS3 </TaskSet>
  </Rule>
  <Rule>
    <TaskSet> TS1 </TaskSet>
      <Transition>
        <Task name ="A"/>
      </Transition>
    <TaskSet> TS2 </TaskSet>
  </Rule>
</DynamicBehaviour>
```

Problem

The optional task "C" in the transitions is not shown this creates a problem when constructing the graph because this task will never be used. Although being optional, the PTS generated should give information between what states it should be executed. For this example, should be created two different transitions the states 1(TS1) and 2 (TS2):

- A > C > D > E
- A > D > E

Example Model 2



Generated PTS

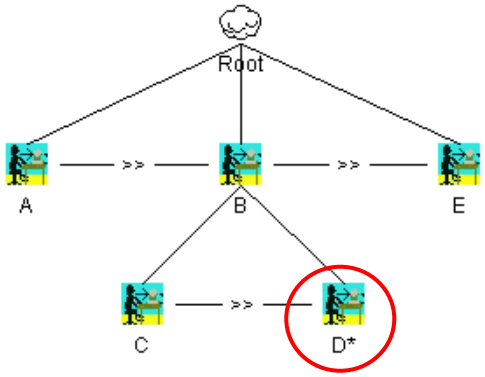
```
<ETSlist>
  <ETS number="1">
    <task name="A"/>
  </ETS>
  <ETS number="2">
    <task name="C"/>
  </ETS>
  <ETS number="3">
    <task name="D"/>
  </ETS>
  <ETS number="4">
    <task name="E"/>
  </ETS>
</ETSlist>

<DynamicBehaviour>
  <Rule>
    <TaskSet> TS3 </TaskSet>
    <Transition>
      <Task name ="D"/>
    </Transition>
    <TaskSet> TS4 </TaskSet>
  </Rule>
  <Rule>
    <TaskSet> TS2 </TaskSet>
    <Transition>
      <Task name ="C"/>
    </Transition>
    <TaskSet> TS3 </TaskSet>
  </Rule>
  <Rule>
    <TaskSet> TS1 </TaskSet>
    <Transition>
      <Task name ="A"/>
    </Transition>
    <TaskSet> TS2 </TaskSet>
  </Rule>
</DynamicBehaviour>
```

Problem

The optional task “E” is not shown on the transitions, but the state that execute that task is (state 4 – TS4). However this creates a problem with the graph because nothing in the PTS generated says that the task “E” is optional, and with this PTS it is always executed.

Operator: Iterative task

Example Model 1



Generated PTS

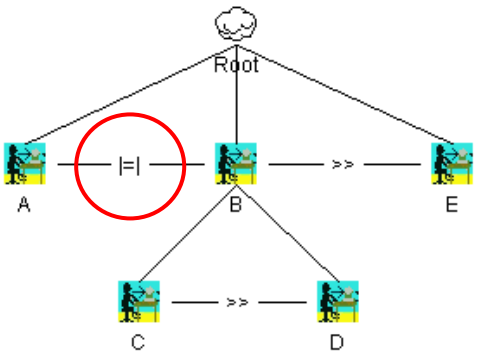
```
<ETSlist>
  <ETS number="1">
    <task name="A"/>
  </ETS>
  <ETS number="2">
    <task name="C"/>
  </ETS>
  <ETS number="3">
    <task name="D"/>
  </ETS>
</ETSlist>

<DynamicBehaviour>
  <Rule>
    <TaskSet> TS2 </TaskSet>
    <Transition>
      <Task name ="C"/>
    </Transition>
    <TaskSet> TS3 </TaskSet>
  </Rule>
  <Rule>
    <TaskSet> TS1 </TaskSet>
    <Transition>
      <Task name ="A"/>
    </Transition>
    <TaskSet> TS2 </TaskSet>
  </Rule>
</DynamicBehaviour>
```

Problem

Although it is said that the task “D” is iterative in PTS nothing is said about it. Being an iterative task all the tasks that are placed on the model to be performed then will not be realized. In this example in the model we can visualize the task “E” but this task is not shown in the PTS.

Operator: Order Independence

Example Model 1



Generated PTS

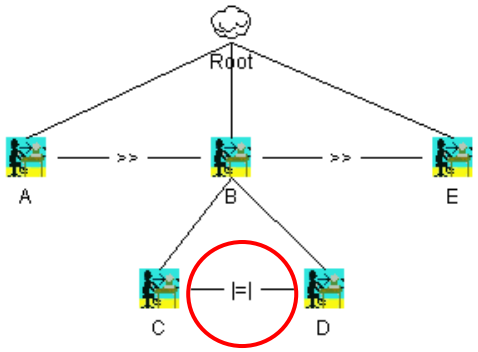
```
<ETSlist>
  <ETS number="1">
    <task name="A"/>
    <task name="C"/>
  </ETS>
  <ETS number="2">
    <task name="D"/>
  </ETS>
  <ETS number="3">
    <task name="E"/>
  </ETS>
</ETSlist>
```

```
<DynamicBehaviour>
  <Rule>
    <TaskSet> TS2 </TaskSet>
    <Transition>
      <Task name ="D"/>
    </Transition>
    <TaskSet> TS3 </TaskSet>
  </Rule>
  <Rule>
    <TaskSet> TS1 </TaskSet>
    <Transition>
      <Task name ="C"/>
    </Transition>
    <TaskSet> TS2 </TaskSet>
  </Rule>
</DynamicBehaviour>
```

Problem

In the transitions he task “A” is not shown. Using this operator the task A can be executed before task “C” and “D” or after, but always before task “E”. This creates a problem when constructing the graph because the task “A” will never be executed.

Example Model 2



Generated PTS

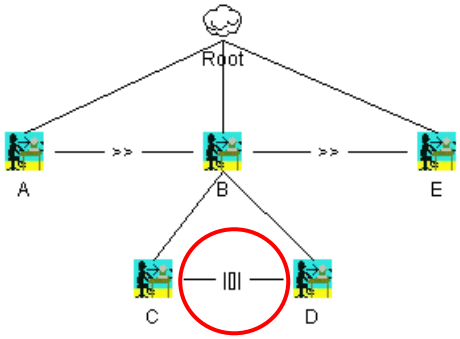
```
<ETSlist>
  <ETS number="1">
    <task name="A"/>
  </ETS>
  <ETS number="2">
    <task name="C"/>
    <task name="D"/>
  </ETS>
  <ETS number="3">
    <task name="E"/>
  </ETS>
</ETSlist>

<DynamicBehaviour>
  <Rule>
    <TaskSet> TS2 </TaskSet>
    <Transition>
      <Task name ="D"/>
    </Transition>
    <TaskSet> TS3 </TaskSet>
  </Rule>
  <Rule>
    <TaskSet> TS1 </TaskSet>
    <Transition>
      <Task name ="A"/>
    </Transition>
    <TaskSet> TS2 </TaskSet>
  </Rule>
</DynamicBehaviour>
```

Problem

The problem is the same from de Example Model 1, only the task that will not be executed is “C” instead of “A”.

Operator: Concurrent with Info Exchange

Example Model 1



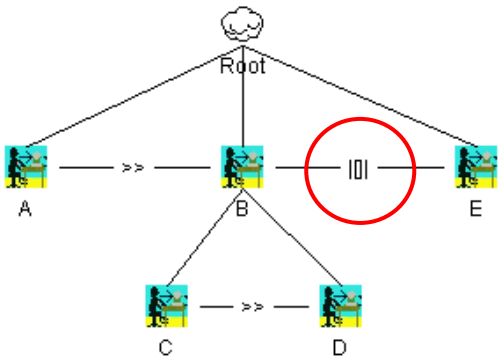
Generated PTS

```
<ETSlist>
  <ETS number="1">
    <task name="A"/>
  </ETS>
  <ETS number="2">
    <task name="C"/>
    <task name="D"/>
  </ETS>
  <ETS number="3">
    <task name="E"/>
  </ETS>
</ETSlist>

<DynamicBehaviour>
  <Rule>
    <TaskSet> TS2 </TaskSet>
    <Transition>
      <Task name ="D"/>
    </Transition>
    <TaskSet> TS3 </TaskSet>
  </Rule>
  <Rule>
    <TaskSet> TS1 </TaskSet>
    <Transition>
      <Task name ="A"/>
    </Transition>
    <TaskSet> TS2 </TaskSet>
  </Rule>
</DynamicBehaviour>
```

Problem

The task “C” is not shown in the transitions, but to task “E” be executed both tasks (“C” and “D”) must be executed. The order could be “C” then “D” or vice-versa.

Example Model 2



Generated PTS

```
<ETSlist>
  <ETS number="1">
    <task name="A"/>
  </ETS>
  <ETS number="2">
    <task name="C"/>
    <task name="E"/>
  </ETS>
  <ETS number="3">
    <task name="D"/>
    <task name="E"/>
  </ETS>
</ETSlist>

<DynamicBehaviour>
  <Rule>
    <TaskSet> TS2 </TaskSet>
    <Transition>
      <Task name ="C"/>
    </Transition>
    <TaskSet> TS3 </TaskSet>
  </Rule>
```

```
    <Rule>
      <TaskSet> TS1 </TaskSet>
      <Transition>
        <Task name ="A"/>
      </Transition>
      <TaskSet> TS2 </TaskSet>
    </Rule>
  </DynamicBehaviour>
```

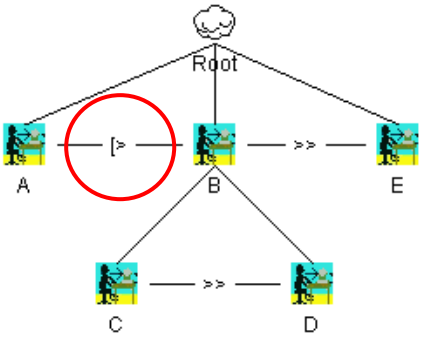
Problem

Task "B" (in the PTS only tasks "C" and "D") and task "E" can are concurrent and exchange information, this means that we can execute different permutation between tasks "C", "D" and "E":

- C > E > D
- C > D > E
- E > C > D
- E > D > C is not valid in this context because "D" must be executed always after "C" (using the operator >>)

Operator: Disabling

Example Model 1



Generated PTS

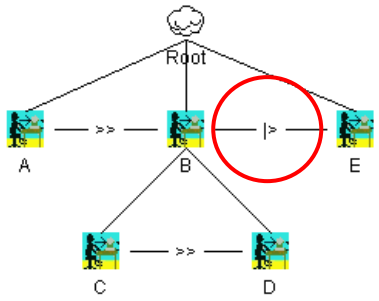
```
<ETSlist>
  <ETS number="1">
    <task name="A"/>
    <task name="C"/>
  </ETS>
  <ETS number="2">
    <task name="D"/>
  </ETS>
  <ETS number="3">
    <task name="E"/>
  </ETS>
</ETSlist>

<DynamicBehaviour>
  <Rule>
    <TaskSet> TS2 </TaskSet>
    <Transition>
      <Task name ="D"/>
    </Transition>
    <TaskSet> TS3 </TaskSet>
  </Rule>
  <Rule>
    <TaskSet> TS1 </TaskSet>
    <Transition>
      <Task name ="C"/>
    </Transition>
    <TaskSet> TS2 </TaskSet>
  </Rule>
</DynamicBehaviour>
```

Problem

Using this operator the task “A” can be or not executed. But in the transitions the only possible scenario is the one where it is not executed.

Operator: Suspend/Resume

Example Model 1



Generated PTS

```
<ETSlist>
  <ETS number="1">
    <task name="A"/>
  </ETS>
  <ETS number="2">
    <task name="C"/>
    <task name="E"/>
  </ETS>
  <ETS number="3">
    <task name="D"/>
    <task name="E"/>
  </ETS>
</ETSlist>

<DynamicBehaviour>
  <Rule>
    <TaskSet> TS2 </TaskSet>
    <Transition>
      <Task name ="C"/>
    </Transition>
    <TaskSet> TS3 </TaskSet>
  </Rule>
  <Rule>
    <TaskSet> TS1 </TaskSet>
    <Transition>
      <Task name ="A"/>
    </Transition>
    <TaskSet> TS2 </TaskSet>
  </Rule>
</DynamicBehaviour>
```

Problem

Although all tasks can be represented the right behavior is not the one in the PTS. The task “E” can stop the execution of the tasks “C” or “D”, but once finished its execution the tasks “C” or “D” continue its execution. For example:

- C > E > C > D
- C > D > E > D