MBVC – Model Based Version Control: An Application of Configuration Management on Graphical Models

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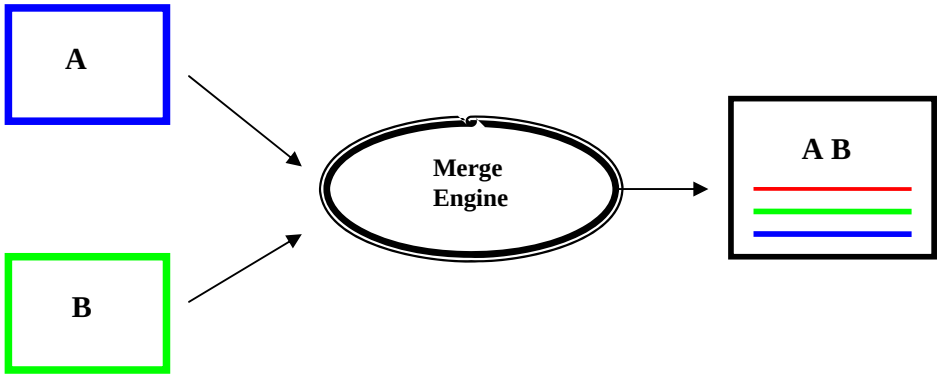

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Abstract

File-based version control consists of tools in the software engineering industry, with many available commercial products that allow multiple developers to work simultaneously on a single project. However these tools are most commonly used on plain textual documents such as source code.

There exist few tools today for versioning fine-grained data such as graphical Simulink models. Since Simulink is widely used as a modeling tool in numerous engineering fields, nonetheless in the mechatronics field, it will be interesting to study the possibility of developing a tool for version control of graphical models.

Two textual software configuration management (SCM) products, CVS and Rational Clear Case, were studied and their functionalities were analyzed, along with a different number of research topics on document versioning. The existing algorithms of '*diff*' and '*merge*' functions were also studied to give an understanding of how these functions work for text based documents. The knowledge gained from the tools, existing algorithms and literature on the subject were used to write MATLAB programs that perform *diff* and *merge* on Simulink models.

The resulted programs perform 2-way diff and merge on Simulink models and display the differences graphically using color codes. Although the tool did have some limitations and did not perform all the expected SCM functions, it still displayed differences between Simulink models. Displaying of results occurred both graphically and textually. A third tool called Rhapsody was studied which is used in model driven development and its interaction with Simulink was also studied, showing that is possible but rather complex and requires knowledge in both programs.

The study shows thus that it is possible to build and develop configuration management tools for graphical models in Simulink, possibly also the 3-way merges, but certain difficulties such as connecting blocks correctly must firstly be solved.

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MBVC – Versionshantering av Grafiska Modeller

En Applikation av CM

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Sammanfattning

Filbaserad versionshantering är ett verktyg inom mjukvaruutvecklingen, och det existerar ett stort utbud av kommersiella produkter. Problemet är dock att de flesta verktygen fungerar endast för textbaserade filer, och saknar någon motsvarighet till hantering av ’fine grained’ filer som exemplevis grafiska Simulink modeller. Eftersom Simulink är ett utspritt modelleringsvertyg och används inom flera utvecklingsarbeten och särskillt inom mekatronik, så är det intressant att studera möjligheten att utveckla ett sådant verktyg.

Genom analys av två tillgängliga konfigurationsverktyg: CVS och Rational Clear Case, samt studie av diverse publikationer och rapporter av versionshantering och algoritmer angående ’*diff*’ och ’*merge*’ funktioner, så utvecklades ett enkelt sådant verktyg.

Programmet utför enkel skillnads- och föreneingsfunktioner (2-way merge) på grafiska Simulink modeller. Verktyget fungerade inte som det var uttänkt i början men det lyckades ändå visa skillnader mellan Simulink modellerna både grafiskt och textmässigt. Ett tredje verktyg, Rhapsody, som används inom MDD studerades, samt dess samarbete med Simulnik testades. Resultatet visar att programmens samverkan är möjlig men något komplex och kräver erfarenheter från båda programmen.

Studien visar att det går att bygga ett mer avancerat konfigurations-hanteringsprogram för Simulink modeller, såsom ett 3-way merge, men vissa svårigheter som en korretk koppling av blocken måste först lösas.

.

Keywords

Model based version control, MBVC
Software Configuration Management
Configuration Management
CVS / Clear Case
Difference, diff
Merge, 2-way merge, 3-way merge

Abbreviations

The following is a list of all the abbreviations used in this report.

API: Application Programming Interface
CC: Clear Case
CM: Configuration Management
CVS: Concurrent Versions Systems
MDD: Model Driven Development
MDA: Model Driven Architecture
RCS: Revision Control Systems
RG: Rhapsody Gateway
SCM: Software Configuration Management
SE: Software Engineering
STEP: STandard for the Exchange of Product model data
PDM: Product Data Management
UBCC: Usefulness Based Control Code
UML: Unified Modeling Language
VCS: Version Control System
VOB: Version Object Base
XML: eXtensible Markup Language

Contents

1 Introduction 1
1.1 Background and Introduction 1
1.2 Problem 2
1.3 Goal 2
1.4 Approach 2
1.5 Assumptions and Limitations 3
1.6 Thesis Outline 3
2 SCM and Model Based Development 5
2.1 Basics of SCM 6
2.1.1 SCM Workflow 7
2.1.2 The Repository 7
2.2 Model Driven Development 7
2.3 Summary of Chapter 2: 8
3 Existing Software Configuration Management Tools 9
3.1 CVS 9
3.1.1 The CVS Repository 10
3.1.2 Viewing Differences 11
3.1.3 Revisions 11
3.1.4 Branching and Merging 12
3.1.5 Multiple Developers 13
3.2 Rational Clear Case 13
3.2.1 ClearCase Views 13
3.2.2 Versions, Elements and VOBs 14
3.2.3 Checking Out Files 14
3.2.4 Checking In Files 15
3.3 Rhapsody and the Telelogic Family 16
3.3.1 Short about UML 2.0 16
3.3.2 The Rhapsody GUI 17
3.3.3 Rhapsody in C++ 17
3.3.4 More Telelogic Programs 19
3.3.5 Conclusions Regarding Rhapsody 20
3.4 Summary of the SCM Tools 21
3.4.1 Concurrent Development 21
3.4.2 The Diff 22
3.4.3 The Merge 22
3.4.4 Locking-Unlocking the Model 23
4 The Analysis of Existing Algorithms: Flat vs. Hierarchic 25
4.1 Diff Algorithm for Flat Data 25
4.1.1 Longest Common Subsequence 26
4.1.2 Representing the Differences 28
4.1.3 2-way vs. 3-way Difference: Presenting the Differences 28
4.2 Merge Algorithm for Flat Data 29
4.2.1 Definition of Merge 29
4.2.2 The 3-way Merge 30
4.2.3 Merge: Relationship to the Difference 34
4.3 Diff Algorithm for Hierarchical Data 34
4.3.1 The XML Language 34
4.3.2 The Theory of XML Document Versioning 36
4.3.3 Edit operations 38
4.3.4 Edit Scripts: Cost Models 40
4.4 Merge Algorithm for Hierarchical Data 40

4.5 Summary of Chapter 4 ..... *41*

5 The Desired Tool Specifications **42**

5.1 Considerations for the Model Based Approach *42*

5.1.1 The Input and Output Types 43

5.1.2 Colour Scheme 43

5.1.3 Limitation 43

5.2 Desired Use Case of the 'Difference' Program *43*

5.3 Desired Use Case of the Merge Program *44*

5.4 Summary of Chapter 5 ..... *44*

6 Implementation of Model Based Tool **45**

6.1 The Input and Output Models *45*

6.2 Actual 'Diff' Program *45*

6.2.1 Modules 45

6.2.2 'Difference' Algorithm 46

6.2.3 Displaying the Differences 48

6.2.4 Actual Results: Difference 49

6.2.5 What Did Not Work: Diff 51

6.3 Actual Merge Program *51*

6.3.1 Merge Modules 52

6.3.2 Merge Algorithm 52

6.3.3 Displaying the Differences: Merge 54

6.3.4 Actual Results: Merge 55

6.3.5 What Did Not Work: Merge 55

6.4 Summary of Chapter 6 ..... *55*

7 Simulink and Rhapsody **57**

7.1 Simulink and Rhapsody *57*

7.2 Vertical Integration Using Rhapsody Gateway and Traceability *57*

7.3 Horizontal Integration Workflow *59*

7.3.1 Other Workflow Methods 60

7.4 Summary of Chapter 7 ..... *61*

8 Conclusions and Discussions **62**

8.1 Conclusions *62*

8.2 Discussions *63*

8.3 Future Work *64*

References: **65**

Appendix: **70**

1 Introduction

1.1 Background and Introduction

This thesis was performed at the Mechatronics Department at the Royal Institute of Technology in Stockholm, Sweden 2005-2006.

The implementation of version control in software engineering has been a contributing factor to the evolution and rapid development of new and advanced software products. The most obvious advantage of such system lies in its ability of allowing multiple users to work simultaneously on the same data, to finally allow merging the finished result in a clever fashion that otherwise, without version control, would lead to confusion and loss of efficiency.

Traditional software configuration management (SCM) tools are used for managing code source and text files also known as *plain* files. This paper will discuss and show the possibility of applying the configuration management (CM) on graphical models known as *hierarchical* or *fine grained* data such as Simulink models. This type of file differs from the plain files in the sense that the structure of the data has semantics.

The initial stages of a version control system (VCS) for models have been established by Jad El-Khoury[1]. To make the system more similar to an SCM tool for graphical models, it has to be supplemented with features common in standard SCM tools, such as the *diff* and *merge* functions.

The most common functionalities that are applied in SCM tools today are merging, branching, checking out files (two options available: either reserved or unreserved checkouts), updating and differencing (viewing differences between two versions of the same file). The functionalities will be described in more detail in the sections that follow.

MDD (Model Driven Development) is an approach that refers to the usage of models as the main engineering artifacts and is considered as the primary class entities in an engineering lifecycle. The term MDD is considered generic, and MDA (Model Driven Architecture) is a specific term belonging to the Object Management Group (OMG). MDA consists of a platform independent base model along with one or more platform specific models, including sets of interface definitions each describing how to implement the base model on different middleware platforms. [OMG]

Traditional development of software involved coding at an early stage by software engineers, where they had to continuously debug, test and run code throughout the development stage. If any changes were to be made at a later stage in the program life cycle, then huge efforts had to be put on even more testing and debugging.

Rhapsody, which is the tool tested in this paper, is based on the MDD technology. Systems are modeled in MDD using UML 2.0 models. The effort is put on the system at

[1] Jad El-Khoury, PhD at mechatronics Department, KTH

an abstract level, while less effort is put on the coding, since one of Rhapsody's functions is to generate embedded code.

1.2 Problem

The problem is how to use the knowledge from existing algorithms and tools that apply SCM on text files, to transform it and apply it on Simulink models. The first problem encountered was that the structure of text documents differs from graphical models. How does one relate a sentence in a page to a Simulink block in a model? Does MATLAB support functions that allow building of such programs?

1.3 Goal

There are two goals concerning this thesis. The first goal of is to develop '*diff*' and *merge* functions to be applied on Simulink models. The user will enter two Simulink models and the program will produce an output model that will contain the differences of the two input models. The results will be shown both graphically and textually. A merge will also ask the user when conflicts occur: which block coming from each revision to be merged.

The second goal is to test how Rhapsody interacts with Simulink models and try to understand the possibilities and capabilities supported by them and sum up the experience.

1.4 Approach

To achieve the first objective of this thesis, topics on plain and fine-grained data were studied, which gave an understanding of the plain and fine-grained structure. Then the existing diff and merge functions were studied to give a basic understanding on how they work. This included white papers and theoretical studies on the *diff*. Thereafter two SCM tools, CVS and Clear Case, were studied and their functionalities were analyzed. This gave a broader understanding on the capabilities of the tools, and showed what was possible to perform using them. It also gave an understanding on how the tools are activated, specifically CVS because it uses a textual user command interface.

Then more research was performed on the *diff* and *merge* functions of the SCM tools by studying white papers on the algorithms of these two functionalities. Thereafter the programming methodology of MATLAB was studied and specifically the functions used with Simulink models. This gave a picture of what functions were useful, and also a better understanding of the layout and structure of Simulink models. The property of Simulink was then studied, and this showed the properties which blocks were made up of.

The information gained was then used to derive a method for performing *diff* and *merge* on Simulink models, by using the information gained from the block properties and by applying algorithms developed from existing tools and other theoretical information of the current *diff* applied to textual documents.

The second objective: to study how well Rhapsody and Simulink interact together, and look on the MDD approach. Rhapsody was installed and tested to understand its capabilities. Moreover, white papers covering Rhapsody were studied, webinars, which are seminars via the web, were attended and different instructional videos were watched. Built-in tutorials of Rhapsody were also used to gain deeper insight of the capability of the software, and UML 2.0 was also revised. MDD and MDA were also studied.

1.5 Assumptions and Limitations

Some assumptions have been made regarding the size and complexity of the models. In the textual approach, files containing thousands of lines are common when the algorithms are applied for the difference and merge programs. This results in different algorithms having different levels of time complexities and efficiencies. In this thesis however the complexity of the algorithms has not been taken into account, since that was not the main aim of the project.

Secondly the Simulink models are regarded as multi-nodes and quite complex with the respect to the sub-system blocks. The structure of the models will be more thoroughly explained in the API of MATLAB section. A complete MBVC or Model Based Version Control system consists of two main parts: the system for checking in and out files, plus the ability to perform different changes to the files such as finding differences and merging them. It is the latter part that will be developed in this thesis.

The algorithms of the two functions that were studied, the difference and merge functions will not be exactly translated into the model based approach. The textual system will thus rather act as a base for understanding the logic and theory behind the algorithms that will be applied to the fine grained graphical models.

The systems that were developed have been tested for the most commonly used toolbox, and was not tested with other more complex toolboxes, but the logic of the program was written to be independent of the type of blocks being used.

The student version of MATLAB being used handles models with a maximum of 1000 blocks, so although models of these sizes are used in real engineering projects, they were not tested in this thesis, since the complexity of the algorithms was not taken into account.

The mathematical approach of the algorithms chapter will not be implemented when developing the actual programs. These approaches were studied to get a broader understanding on how complex and real algorithms in the market work, and what degree of complexity they implement.

1.6 Thesis Outline

Chapter 2 talks about the two major engineering development approaches: SCM and MDD, and about their major characteristics. The history of how the diff began is introduced.

In chapter 3 existing SCM and MDD tools are discussed and the general functions provided along with their capability. The tools are CVS, Clear Case and Rhapsody.

Thereafter current algorithms behind the merge and diff functions are summed up using a mathematical approach in chapter 4. Both the plain and fine grained algorithms are discussed.

Chapter 5 discusses the desired algorithms for the diff and merge and discusses both the requirements on the input and output formats and coloring system as well as the desired use cases.

In the next chapter, chapter 6, the actual diff and merge programs, that was developed as a result of the previous chapters, are described and discussed. They also contain the actual algorithms and pictures from the resulting programs.

Chapter 7 consists of a study on Rhapsody which is a MDD modeling program. There are also two different ways of combining it with Simulink models: horizontal and vertical merging. The final chapter 8 is the conclusions and discussion that are reflected upon the entire project and some possible future work.

2 SCM and Model Based Development

A large number of SCM systems and concepts are available today. There are two main types of data structures: the plain and fine grained. The main difference between them being that the latter involves semantics of the documents and thus introduces logic into the document.

However most SCM tools only work with plain files, which are files containing lines of printed text. There are few configuration management systems that manage hierarchical data structures and tree data systems, such as those present in the XML language. Thus it is important to understand that most SCM tools treat text files as pages with printed text, without taking the logic of the files' structure and content into consideration. This introduces a problem in working with graphical models because they contain important semantics that are not included in plain text files. [CON]

This thesis will consider the development of a model based development tool since it will handle performing diff and merge operations on Simulink models. These models take the semantics into consideration and are thus of fine grained or hierarchical nature.

The classical method in developing technical systems has been to use paper and pen to sketch the initial layout of the system. The requirements were then taken into account and these would be the basis for the development engineers whose work would involve coding by hand. This was a long and challenging process and required an early and accurate definition of the problem to be able to formulate a solution. Thus each coded function would have multiple arguments and would produce different outputs, a process that was interconnected, and where a change in any requirement at a later stage would imply huge loss in efficiency because all the code had to be reviewed and updated manually.

Newer development solutions employ a new approach known as MDD. One such program is Rhapsody and it uses the UML 2.0 modelling language. Rhapsody allows the user to model the project in the UML language and keep track using traceability of the components and requirements using add-ons. The user can then generate code to be directly implemented into embedded systems. One advantage is that Rhapsody can interact with other programs such as Simulink in different ways.

The problem is then to connect Rhapsody and Simulink so that data exchange can occur between them. This is done by one of two methods: either using an external program or using built-in functions of both programs to achieve the communication. An example of an external program is Rhapsody Gateway which is used to create traceability links across the models and requirements. The second major method is to use the internal functions that allow the import of generated code from the program. More about this is discussed in chapter 7 about relating Simulink and Rhapsody.

A number of different studies and research topics covering version management, fine grained version control, XML version management, and the basic principles of SCM such as [CHIEN], [HAU], [CON], [CHAW] were studied. Algorithms proposed for the difference and merge methods were also studied and analyzed.

Version control systems cover a large topic in modern configuration management tools, and in this thesis it will be known as the model based version control or MBVC, since it is about managing revisions of graphical models. A MBVC tool consists of two main scopes:

- Repository: a server/client approach for storing and retrieving the data, to make it available for others, either located in the same office room or in another continent
- Functionalities: different functionalities that are applied to the data, such as merging and differencing the data.

2.1 Basics of SCM

SCM is a management tool that applies an engineering discipline to manage and control the evolution of complex software systems or more practically expressed, it is the discipline that enables one to keep evolving software products under control, and thus contributes to satisfying quality and delaying constraints [EST]. The primary focus of this discipline is to ensure repeatability, traceability and integrity of the system being developed and produced. Today, SCM is a well established and common practice in the later phases of software development, more notably during programming and integration. [OHST], [BOB]

The *diff* was originally developed in the early 1970's for the UNIX systems which was developed at the AT&T Bell Labs. An initial but rather unreliable program known as *proof* was written by Steve Johnson. It was considered as unreliable because it produced line by line changes and used angle brackets (< and >) for presenting line deletions and line insertions. A final and more reliable program that is still in use today, the *diff,* was written by Douglas McIlroy for the early UNIX systems. His research study was published in 1976. This program is still considered as the mother of the modern configuration management differencing tool, although there has been significant improvements on the algorithms and speed of the processes for handling larger text documents.

SCM emerged as a discipline soon after the software crisis during the late 70's and early 80's, when it was understood that programming is not the sole factor for success in Software Engineering (SE), as other factors such as architectural development and evolution play a vital role for achieving advances in SE. At the time it was developed, SCM was considered more of as a version management and rebuilding tool, while nowadays the typical configuration management system aims to provide a wider perspective, covering important topics such as process support, concurrent engineering and distributed development.

There are many tools available on the market today, and they all tend to provide the following basic features: (1) place to store the source code; (2) provide a historical record over what has been done over time; (3) provide a method for different developers to work on the same project simultaneously and merge their work; (4) the developers can cooperate without getting in the way of each other. [SINK]

2.1.1 SCM Workflow

SCM tools generally employ the following workflow:

1- The user copies the file *from the repository into a working directory*: this is done so that there will always exist original documents that can be reviewed later on in the future.
2- The user applies the changes to the file in the working directory: so that no two users can overwrite each others work, and this allows place for individual creativity and concurrency.
3- The updated files are returned into the repository with a new version number: so that each document has its own identity of who created it and when it was created. This step may require a merge to be applied.
4- The above steps are repeated for the entire project.

Each different program applies a different syntax, and uses different nomenclature for the different steps, but the idea is basically the same.

2.1.2 The Repository

A repository is the place where all data files are stored, available for all users in a certain project. The directories and files are arranged in a tree file system, but the special about this configuration is that it involves a third dimension, namely time.

The repository keeps a track record of every change that has ever been made to all files and directories, as well as who did what and when. The system does not store all new revised files as it would require huge amounts of disk space. Thus the system stores the changes that are made, known as deltas, or differences between the latest checked in model and the model that is currently being checked in.

2.2 Model Driven Development

The expression MDD stands for a concept where the development of projects is initiated from the model and allows engineers to overview the model in an abstract and objective way, compared to viewing the project entirely as code. In Rhapsody this gives developers a UML model in the early development stage, and as work proceeds, the model, the functions and events can be monitored and tested throughout the development process. Tools such as Rhapsody allow for production of code for the embedded target system.

By comparing this approach to the classical approach it is evident that changes can be easily made and monitored, and any new project requirements are integrated and traced into the project. Otherwise it would be necessary to manually check for changes after project initiation and make sure that no errors will be made, making it difficult to trace the new changes, and perform more testing and debugging throughout the development life cycle.

Another important advantage behind this system architecture lies in the fact that the final product is binary executable. This means it can be run on an embedded target with a real time operating system, without the need of re-testing or modifying the model. [NIE]

The disadvantages that can bee seen are the time and money needed to learn and invest into a new software package along with the UML language. Another would be the sole dependency on one product that performs a wide and important task such as developing an entire project. And finally it is important to understand the nature of the embedded system in terms of its storage capacity and processing speed

2.3 Summary of Chapter 2:

SCM is a wide and interesting topic which is considered important in the development of new software. The advantage of it lies in the fact that it introduces powerful functions that allow multiple users to work on the same project at the same time. It started of with the development of the diff function by Douglas McIlroy back in the 1970's. All SCM tools have a repository that contains all the data which allows users to check out the data, edit it and check it back in. The user has the option to perform diff and merge operations on the files to keep track of what changes that have been made and support concurrent development.

The data consists of two main types: plain and fine grained data. There is an important difference between them: their semantics. Plain data consists of printed lines of characters and text. When looking for differences between two plain data file only the actual letters or lines that have been edited, added or deleted will be considered. The data *content* is not considered only its layout.

For example by moving a function in C code to a different place in the document, the program will behave exactly the same, but by performing a diff the user will get huge differences: the addition of the entire function at its new location and the presence of its old location in the previous version. So the SCM tool will display differences and any developer wanting to work on the file must perform a merge, while in reality there should be no need for it since the two C files perform exactly the same function. This occurs because source code documents do not contain semantics.

In the fine grained data, such as XML and UML, the semantics are of importance. That means the data content and its syntax is taken into consideration when searching for differences. For example: representing a library structure in XML with book tags, and where each book contains attributes such as author and title. Changing the location of a book and its content on XML would change its physical layout, but its *contents* are the same.

The advantage of using fine grained data lies in its ability to represent more information than can be presented by plain data files making it more powerful. It allows for faster development since only the data content is of importance and not the layout, thus allowing for facilitated change management.

3 Existing Software Configuration Management Tools

The goal of the first two subchapters is to introduce and describe two common SCM tools that are widely used today in development projects. This will give an overview of the general structure of the programs, and show the possibilities that exist for common SCM tools. By showing sample sessions and examples of common functions one can better understand the general structure of the programs and their syntaxes. In the third subchapter Rhapsody is introduced which is a tool used in the MDD approach.

3.1 CVS

The following chapter is a taken from the manual of the CVS software, [CED], and describes the usage and syntax of CVS, a common and popular version control system.

Concurrent Versions Systems or CVS is a version control system used to record the history of source files. With CVS the user can easily retrieve old versions of documents to (for example) see exactly which change in a certain document caused a bug. CVS stores all the versions of a file in a single file in a way that only stores the difference between versions, known as deltas, instead of storing all the versions which would otherwise waste disk space.

CVS becomes also helpful when multiple users work on the same project, thus the name Concurrent in CVS, and share the same data resources. As the size of the group grows, it becomes easier to overwrite each others' changes, resulting in loss of project data and efficiency. CVS avoids this common problem by insulating the different developers from each other. Every developer works in his own directory and CVS merges the work when each developer is done with his or her work. This is achieved by checking out the files, performing changes and then checking them back into a common repository.

- **What CVS does not represent**

The following is a list of six points that CVS does not represent. This will explain what CVS is capable of doing for its user, and what it is not capable of doing:

1. CVS is not a build system: CVS does not dictate how to build anything, it merely stores files for retrieval in a tree structure which the user devises.
2. CVS is not a substitute for management: the project leaders will still have to keep frequent meetings with the engineers and make them aware of the projects' current status and progress.
3. CVS is not a substitute for developer communication: when a developer comes across a conflict which is too difficult to solve on his own, he will have to solve it by communicating with other developers.
4. CVS does not have change control: the program does not keep track of all the bugs and status of each of them.
5. CVS is not an automated testing program: the software will not perform continuous tests on the written code; it is up to the user to keep track of such activities.

6. CVS does not have a built-in process model: the system does not provide ways to ensure that changes or releases go through various steps, with various approvals as needed.

3.1.1 The CVS Repository

The CVS repository stores a complete copy of all the files and directories which are under version control. The files in the repository are never directly accessed, instead one uses CVS commands to get a copy of the files into a personal working directory (sandbox), and then work on that directory. When finished modifying the files the user checks or commits them back into the repository. The repository will now contain the changes made, when they were made and by whom.

- **A Sample Session**

The following is an example of a sample session which describes basic commands that are often used when initially applying CVS to a file. Suppose one is working on a compiler and the source consists of a handful of C files and a '**`Makefile`**'. The compiler is called '**`tc`**' (Trivial Compiler), and the repository is set up so that there is a module called '**`tc`**'.

CVS stores all files in a centralized repository, also known as the vault. First the user must get a working copy of the source for '**`tc`**', achieved by using the '**`checkout`**' command:

```
$ CVS checkout tc
```

This will create a new directory called '**`tc`**' and populate it with the source files. Suppose one of the files is '**`backend.c'`** and that the user performs some changes to that file and want to save the new version in the repository, making it available to anyone else who is using that same repository:

```
$ CVS commit backend.c
```

CVS will start an editor to allow one to enter a log message (for example: "**`Added an optimization pass`**"). The launch of the editor can be avoided by using the '**`-m`**' flag:

```
$ CVS commit –m "Added an optimization pass" backend.c
```

- **Cleaning Up**

Before exiting the session, the user will remove the working copy of '**`tc`**'. This is achieved by:

```
$ CVS release –d tc
```

The '**`-d'`** flag removes ones' own working copy.

3.1.2 Viewing Differences

If a user does not remember having modified a certain file, the changes can be viewed by using the '**diff**' command. For checking on the file '**driver.c**':

```
$ CVS diff driver.c
```

The '**diff**' command will compare the version of the working copy with the one that was checked out, and print the changes that have been made.

- **Starting a Project with CVS**

For a new project, the easiest method is to start by creating an empty directory structure. In the following: one main directory, '**tc**', with the two subdirectories '**man**' and '**testing**' are created

```
$ mkdir tc
$ mkdir tc/man
$ mkdir tc/testing
```

After using the '**import**' command to create the corresponding empty directory structure inside the repository:

```
$ cd tc
$ cvs import –m "Created directory structure" yoyodyne/dir yoyo start
```

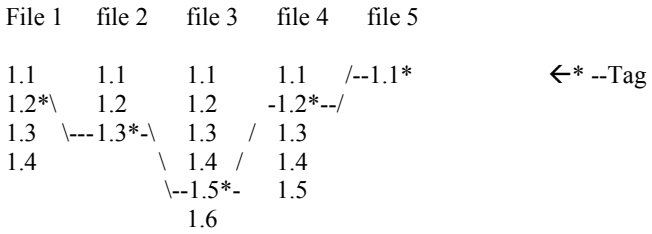
This will add yoyodyne/*dir* as a directory under **$CVSROOT.** Then use **'add'** to add new files and new directories as they appear.

3.1.3 Revisions

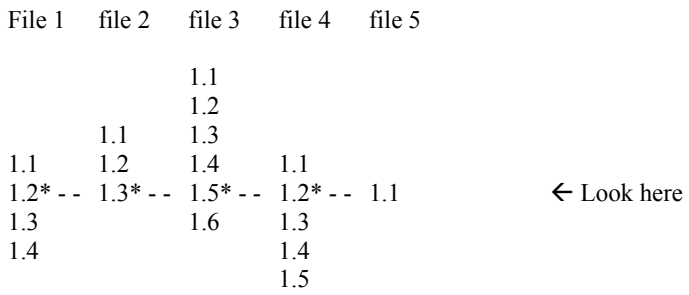
If one wants to keep track of a set of revisions, also known as versions, involving more than one file, such as which revisions went into a particular release, one easily employs a tag. A tag is a symbolic revision which can be assigned to a numeric revision in each file.

The '**checkout**' command has a '**-r**' flag that lets the user check out a certain revision of a module. Deleting and moving tags is a dangerous act, which permanently discards historical information and makes it difficult or impossible to recover from errors. Thus care must be taken when moving or deleting the tags.

The following figure illustrates the usage of tags:



Above: The use of flags can be thought of as a curve drawn through a matrix of filenames vs. revision numbers. The * versions above indicate that the revisions have been tagged. A tag can be thought of as a handle attached to the curve drawn through the tagged revisions. When the handle is pulled, all the tagged revisions are aligned which easily shown by the following illustration:



3.1.4 Branching and Merging

CVS allows the user to isolate changes onto a separate line of development, known as a *branch*. When files on a branch are modified, those changes do not appear on the main trunk or other branches. Later on, the user can move changes from one branch to another branch or to the main trunk by *merging*.

An example of using branches would be when a release (say 1.0) later on proves to involve a fatal bug. Instead of making a bug fix based on the newest sources (1.1), the software designer instead creates a branch on the revision trees for all the files that make up revision (1.0); thereafter modifications can be made to the branch without disturbing the main trunk. When the modifications are finished the programmer can elect to either incorporate them onto the main trunk, or leave them on the branch. It is important to note that branches get created in the repository and not in the working copy.

- **Adding, Removing and Renaming Files and Directories**

To add new files the user must have a working copy of the directory, and then create the new file inside this working copy of the directory. The command '**`CVS add`** *`filename`*' is used to inform CVS to perform a version control on the file. To actually check the file into the repository so that other users can see the file, use the '**`CVS commit`** *`filename`*' command. To add a new directory, use the **`add`** command.

To remove files, but still be able to retrieve exact copies of old releases, one must first remove the file from the working copy of the directory. The next step is to use the '**`CVS remove`** *`filename`*' command. Finally use the '**`CVS commit`** *`filename`*' to actually perform the removal of the file from the repository. To remove a directory, first all files in that must be removed in a similar fashion as described previously. The directory itself can not be removed as there exists no way of doing that. Instead specify the '**`-P`**' option to **`CVS update`** which will cause CVS to remove empty directories from working directories. Doing so will leave the users with the ability of retrieving old releases in which the directory existed.

A simple and safe method of moving files is to copy *old* to *new*, and then issue the normal CVS commands to remove *old* from the repository, and add *new* to it.

```
$ mv old new
$ CVS remove old
$ CVS add new
$ CVS commit –m "Rename old to new" old new
```

3.1.5 Multiple Developers

CVS supports concurrent development which implies that more than one developer can work concurrently or simultaneously on the same project. The default model in CVS is an *unreserved* checkout: the developers can edit their own working copy of a file simultaneously. The first person that commits the edited version will do so without any problems. The persons that commit after him or her will receive an error message, they will have to merge their work with the checked in version of the first person. This is usually performed automatically with no problems using the **`update`** command. The modifications to a file are never lost when using the **`update`** command. If any changes between two files are made too close, CVS will notify the user that an overlap has occurred, and the file will include both versions of the lines that overlap, delimited by special markers.

3.2 Rational Clear Case

The following is a summary of the user manual of Clear Case [CLEARCASE]. Clear Case is another commonly used SCM tool, but is easier to use than CVS, mainly due to its friendlier graphic user interface (GUI).

Rational Clear Case is a configuration management (CM) system that manages multiple variants of evolving software systems. Clear Case maintains the complete version history of the software development artifacts, including code, requirements, models, scripts, test assets, and directory structures. It performs audited system builds and offers multiple developer workspaces.

A major difference between Clear Case and CVS is that the former uses a graphical user interface (GUI); the user picks and clicks with the mouse to perform the operations required. The latter uses a command-line interface (CLI); the user issues the commands by typing them into CVS using its language syntax. This implies that the CVS user must be used to the syntax and nomenclature of the language, while on the other hand, the Clear Case user can more easily click his or her way into the menus and commands. Clear Case also uses a graphical representation of what changes have been made, and who has checked out which files.

3.2.1 ClearCase Views

Files and directories are called *elements*, and the data repositories containing the elements are called *VOB*s (Versioned Object Bases).
Accessing files is achieved by setting up a *view,* which shows a directory tree of specific versions of source files. Clear Case includes two kinds of views: *Snapshot* views, which copy files from data repositories (VOBs), and *Dynamic* views, which uses the Clear

Case multi-version file system (MVFS) to provide immediate, transparent access to the data in the VOBs using a directory tree.

The snapshot view is best used when the computer does not support dynamic views, and the user wants to work with source files support when disconnected from the network hosting the VOBs.

The dynamic view should be used when the user wants to access elements in VOBs without copying them into the computer, and when it is important that the view reflects changes made by team other members at all times without having to update the data.

3.2.2 Versions, Elements and VOBs

Each time a file or directory is revised and checked in, Clear Case creates a new *version* of it. The files and directories are called *elements* and are stored in the *VOBs.* Figure 1 illustrates a VOB that contains the file elements **prog.c**, **util.h** and **lib.c.** Depending on the size and complexity of the software development environment, Clear Case *elements* may be distributed across more than one VOB. For example elements used by the documentation group are stored in one VOB, while elements contributing to software builds are stored in a different VOB.

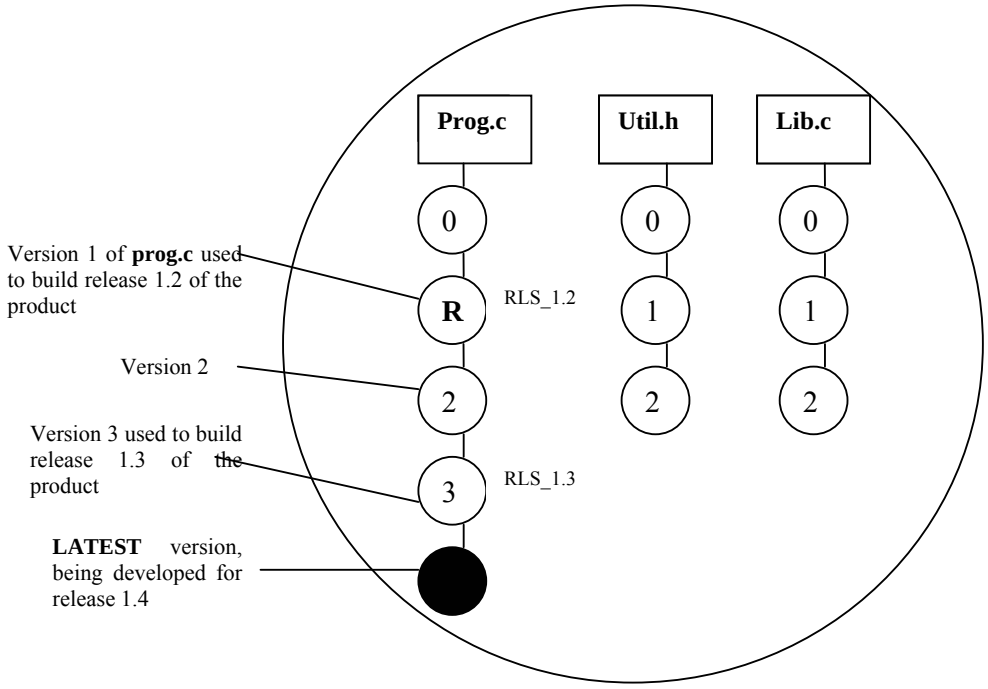


Figure 1: A VOB contains all versions of an element

3.2.3 Checking Out Files

Files that are under Clear Case control must be checked before any modification can take place. That is achieved by first navigating to the directory where the file is located, then right-clicking on the file and then choosing the **Check Out** selection. This opens the check out dialog box, where comments can be provided describing what changes are

planned for the checked out file. Another option is to choose whether a *reserved* or *unreserved checkout* shall be performed. Both reserved and unreserved checkouts are supported. The reserved checkout has the exclusive right to check in a new version for a given development project. In the unreserved checkout, the first view to check in the element creates the successor; other developers working in other views must merge the checked in changes into their own work before they can check in.

3.2.4 Checking In Files

Checking in a file or directory element creates a new version in the VOB, which becomes a permanent part of the element's history, thus the element should be checked in only when the user wants a record of its state.

If the checked in version is not the latest version in the VOB, the program will require the user to merge the changes in the latest version into the version checked out in the view. ClearCase will attempt to merge automatically by starting the Diff Merge tool.

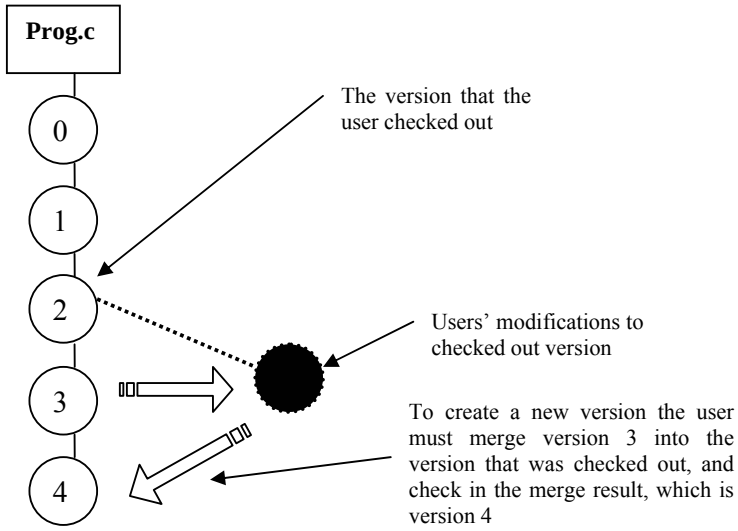


Figure 1: Version 2 of prog.c was checked out and edited. Before checking it back in, someone else checked-in version 3 of prog.c. When the user wants to check-in the new version, Clear Case informs that it has to be merged with version 3 before becoming version 4.

3.3 Rhapsody and the Telelogic Family

Rhapsody is a visual programming development (VPE) tool developed by Telelogic for real-time embedded software developers, and works by implementing solutions built in UML 2.0 design diagrams that generate C++ code. To summarize, Rhapsody allows the user to accomplish the following general tasks:

-*Analysis*: to define the system requirements in the UML language using a MDD approach
-*Design*: perform edits and changes on the model
-*Implementation*: automatically generate code from the analysis model
-*Testing*: debug the model/code

Rhapsody uses the MDD architecture to allow the users, whether system or software engineers, to achieve productivity gains over traditional document driven approaches. This is achieved by allowing the user to simultaneously specify the system design graphically (in the UML language) and to simulate and automatically validate it, while it is being built. All of this will lead to the production of the code form the model of the embedded system. [ILOGIX]

The Rhapsody software contains sample projects such as cars, an elevator, a CD player, a dish washer, a ping pong game, Tetris and many other examples. A couple of these projects were studied in order to try to understand the program more specifically. More information is available in the tutorial section, and specifically the Rhapsody Tutorial in C++.

3.3.1 Short about UML 2.0

To understand Rhapsody well one must have a thorough understanding of the UML 2.0 language. A short introduction to the UML language will be given here, but for more detailed specifications please refer to [UML], [WIKI].

The Unified Modelling Language (UML) is an open source language for object modelling using graphical blocks that are related to each other with the help of different relationships. There are 13 different types of diagrams divided into 2 main categories with one subdirectory, and they are:

1- *Structure diagrams* define what things must be in the model:
Class, component, composite structure, deployment, object and package diagrams

2- *Behaviour diagrams* emphasize what must happen/occur in the model:
Use case, activity and state machine diagrams

3- *Interaction diagrams* are a subset of behaviour diagrams that emphasizes the flow of control and data among the things in the model:
Sequence, timing, communication and overview diagrams

3.3.2 The Rhapsody GUI

The Rhapsody GUI is made up of three key windows and different toolbars for each of the UML diagram types. The 3 main windows are: *browser window, drawing area and output window*, while the 2 main toolbar windows are the *modelling toolbar* and the *standard toolbar* functions.

1-The browser window: contains the directories and sub-directories of the entire model in an expandable tree-structure
2- Drawing area: a sketching area where all UML models can be drawn
3- Output window: window at the bottom which displays messages
4- Modelling toolbar: contains the different tools necessary for drawing each UML model
5- Standard toolbar contains common utilities such as windows toolbar, layout toolbar, zoom toolbar and format toolbar.

Whenever a type of UML diagram is chosen the modelling bar automatically changes to display the connectors and relationships that are used in that specific diagram. For example when creating the use case diagram, the *modelling toolbar* displays buttons to create a new use case, new actor, create association, and create generalization, flow and dependency. When creating a sequence diagram the modelling toolbar will change to display activities that are relevant to it.

3.3.3 Rhapsody in C++

The Rhapsody tutorial on building a mobile handset will now be completed and studied to get more experience and create a wider discussion regarding file based and model based control. The tutorial will not be described in detail because it can be accessed from the program's help menu -> List of Books, but rather only the main functions will be highlighted and covered below.

The following will be treated in this thesis: system boundary box, actors, use cases, association lines, dependencies, generalizations and requirements, creating a structure diagram, drawing block diagrams.

The type of UML diagrams supported by Rhapsody:
Use case, structure, object model, sequence, activity, state charts, collaboration, component and deployment diagrams.

A new empty project was created and named Handset. The first thing to do is to create what is called 'Packages' which basically are folders that allows the user to organize models using subsystem modules consisting of objects, object types, functions, variables and other logical modules. These subsystems or packages are created by the user in the browser window by right clicking the Package file and choosing 'Add New Package', and then renaming each package in accordance. Here the importance of having a solid UML knowledge is seen; since one must know what packages should be created. It is also important to have a good theoretical and practical understanding of the system being modelled.

UCD – Use Case Diagrams: display the main features of the system in an easy to understand fashion, and also display the actors outside the system. This is done by right-clicking on the Analysis Package and choosing to add a new UCD and naming it (in this

example it was named 'Functional Overview'). Then a new Boundary Box is created and named 'Handset Protocol Stack' along with two actors the 'Network' and 'MMI' that will interact with the system.

This UCD has four use cases, and they are: place a call, receive a call, supplementary services (messaging, forwarding, conference etc) and provide status (network status, signal strength etc). Thus a use case is created for each of the four use cases and named in accordance to their function.

The next step is to associate each of the actors with the use cases. For example the MMI actor places and receives calls, while the Network actor notifies the system of incoming calls and provides status. Thus, an association represents a connection between objects or users. Another feature that can be represented is the Generalization in use case diagrams, which is the relationship between a general and a more specific element, with the specific element inheriting the properties of the general one. Thus Supplementary Services will be a specific type of placing a call.

Now a new UCD called 'Place Call Overview' will be drawn and will contain 3 new use cases: Place Call, Data Call and Voice Call. The difference this time being that the Place Call will not be created; instead it will be chosen from the browser window and dragged into the new UCD.

The next step is to create and name *Requirements* to show how they trace to the use cases. For example a requirement called *Req 1.1* stating that: 'The mobile shall be fully registered before a place call sequence can begin' is associated with the Place Call use case. Now dependencies can be created between the respective requirements and use cases, using the *Dependency tool*. First the requirements are dragged from the Browser Window into the UCD. Now the dependencies are drawn from the individual requirements to the use cases. For example a dependency is drawn from *Req 1.1* to the Place Call use case. Dependencies can also be drawn between the requirements.

Stereotype is a function that can relate requirements to each other or to other model elements, by extending the semantics of the UML model by typing UML entities. Two types of stereotypes included are *Derive* and *Trace*:
-Derive: a requirement is a consequence of another requirement.
-Trace: a requirement traces to an element that realizes it.

Notes:
-Each time a new requirement was added into a model, even if the requirement exists in the Browser window, one had to manually change its options to display its name.
- Right clicking a component and choosing '*Remove from Model*' will delete it totally, and it must be created again. To remove components from the view choose instead '*Remove from View*'.

The first moment will be to create *Structure Diagrams* that define the components of a system and the flow of information between the components in a black-box perspective. Structure diagrams consist of the following parts:
Objects, blocks, composite classes, ports, files, links, flows and dependencies

Start by right-clicking on the Architecture package and add a new Structure Diagram and name it 'Block Diagram'. The toolbar changes also and displays the following tools:
Composite class, object, block, create port, link, dependency and flow

In the handset model there will be three blocks and they are: *Connection Management*, *Mobility Management* and *Data Link*. These are created with the *Block* tool. Next step is to add *Objects* that are the components of a system that form a cohesive unit of data and behaviour.

Ports are another important feature in Rhapsody and they represent interaction points between any class, object or block with its surrounding environment. They are represented as small squares on the boundary of the class, object or block. The ports have another distinctive feature; they allow the user to understand the architecture of the system by specifying the interfaces between the system components and the relationships between the sub-systems. *Data Flows* specify the information exchange between the system elements at an early stage before committing to any specific design. The data flow can be created between the ports of the objects and the blocks, and also between the elements themselves. The direction of the data can also be chosen to be bi-directional form the features options.

For more information regarding Rhapsody please refer to the manual located in the help menu. The following are the remaining types of diagrams that are supported in Rhapsody but not covered in this chapter:

Structure diagrams—Show the system structure and identify the organizational pieces of the system.
Object model diagrams—Show the structure of the system in terms of classes, objects, and blocks, and the relationships between these structural elements.
Sequence diagrams—Show sequences of steps and messages passed between structural elements when executing a particular instance of a use case.
Activity diagrams—Specify the overall control flow for classifiers (classes, actors, use cases), objects, blocks, and operations.
Statecharts—Show the behaviour of a particular classifier (class, actor, use case), object, or block over its entire life cycle.
Collaboration diagrams—Provide the same information as sequence diagrams, emphasizing structure rather than time.
Component diagrams—Describe the organization of the software units and the dependencies among units.
Deployment diagrams—Show the nodes in the final system architecture and the connections between them.

3.3.4 More Telelogic Programs

The following section describes other interesting programs of the Rhapsody family:

SYNERGY Active CM
There has been some difficulties in attaining data regarding the following tools, and to compensate for this many power-point presentations and video presentations were

attended to try and get as much data as possible regarding the usage and functionality of the software.

To perform simple configuration management, the **Active CM** tool can be applied. This tool integrates with the Windows Explorer by adding an Active CM tool bar along with a to-do list when the documents are managed in SYNERGY. When a user wants to perform a task, the system automatically updates the file version number by one, and it allows the user to add a note on what was performed. The performed task is then removed from the to-do list.

In the video example that was demonstrated in [VIDEO], a user opens the to-do list and finds two different tasks. The first was "To add a company logo to a specification", where the document had the version number 4. He then adds a logo to the file and saves it. The software automatically updates the CM Synergy repository to version 5 and he adds a tag stating "Added company logo". The to-do list is then re-opened and now contains only 1 to-do action.

This is basic SCM and is developed for all users that do not have any previous experience in using other SCM tools. Clearly the software does not handle more complex functions and was not intended for software engineers, but rather for everyday configuration tasks.

DOORS
This is a management tool that allows control and configuration management of any project, by connecting the entire project team members, and allowing them to share resources. In the demo [PRES] a team encompassing a product manager, project manager, requirement analyst, software and test engineers, quality assurance and the end user all interact using the tools available in DOORS/ERS (Enterprise Requirement Suite). This software allows linking and tracing of documents across platforms and users, so that for example a software engineer can link the coding statements to the original requirement given from the sales department. The system allows also for tracking document history. It also allows customers to connect to the database and ask question or monitor the project progress, and allows electronic signing of documents.

Rhapsody Gateway (RG)
The RG is an add-on that allows traceability between different software to be shown in Rhapsody. RG consists of configuration editors, converters and filters that take in a large number of different files, such as Doors, Word, Excel etc and links between them and produces an image of requirements traceability in relation to the project to be shown in the Rhapsody interface [GATE]. This tool is studied further in chapter 7.

TAU
The TAU software is a tool that is similar to Rhapsody but with the difference lying in its support for Model Driven Architecture (MDA) in comparison with MDD as well as offering support for UML 2.0, UML testing, model simulation and code generation.

3.3.5 Conclusions Regarding Rhapsody

After having interacted with Rhapsody and studied its capabilities the following can be said:

Rhapsody is a tool when considering the MDD technique: modelling a project in UML diagrams and debugging and testing it while it is being built and have the ability to generate code for embedded systems, in this case C++ code. The problem is that one must understand UML 2.0 well.

It was advantageous to be able to generate the code in four languages (Java, C, C++ and Ada) because it gives the user a free choice of programming language, depending on the character of the targeted embedded system. It also simplifies changes made to a project while the project is being modelled, allowing adding or removing of: actors, events, or functions during any time of the project stages.

The Telelogic software constitutes a large family of tools and when mastered offers a development environment for all the project members, and allows them to track and trace all the work.

There are many white papers about Rhapsody that are available for free; one only needs to register for a Telelogic Passport on the homepage. There are many free webinars too that can be attended. The problem was that the papers were not of technical character, but instead described the advantages in using Rhapsody, and the webinars were presented by respective companies that displayed the interaction between their product and Rhapsody.

There is no support for SCM as it was thought of in the beginning. To perform simpler types of configuration management the Synergy Active CM add-on is required but is not available for download.

Other interesting add-ons are the Reporter Plus and the Test Conductor. The add-ons are programmed to generate reports and perform tests according to user defined settings which can be done across the DOORS platform.

3.4 Summary of the SCM Tools

A general quality among all SCM tools is their support for concurrent development: that is allowing more than one person to work on the same document at a time. This development style has some advantages and disadvantages that are discussed briefly below. This chapter summarizes the general functionalities of SCM tools CVS and Clear Case, described in this chapter.

3.4.1 Concurrent Development

There are two main concurrent development styles. The first is called the "*checkout-edit-check in*" method, where only one person at a time can checkout a file, edit it and then check it back into the repository. During the checkout no other person can edit the file as other users must wait until the file gets checked back in. This method is considered safe and traditional since only one developer can work on any file at any given moment. The other method is called "*edit-merge-commit*" (available for example in CVS) and allows multiple users to edit the same file simultaneously or concurrently, as long as they work on the latest checked out version. After editing, the software will merge all the changes and then commit the file back into the repository. [SINK]

Eric Sink, Software developer at Source Gear, and builder of the original version of the "Internet Explorer" browser describes concurrent engineering as follows:

> *"Think of your team as a multithreaded piece of software, each developer running in its own thread. The key to high performance in a multithreaded system is to maximize concurrency. Our goal is to never have a thread which is blocked on some other thread."*

Thus to keep a high efficiency in the development process, support for concurrent development is vital, whether the development regards textual files or graphical ones.

3.4.2 The Diff

In text files, the Diff function will open up the current working version and the latest checked in version as two separate windows next to each other. A certain color code will highlight the differences, indicating what has been deleted, what has been moved to other parts of the file and what new lines have been added. This makes it easier to spot the differences between any two versions. There are many different algorithms and tools for the difference tool, which will be discussed in the next coming chapters.

3.4.3 The Merge

Merging two text files is a basic part of everyday concurrent development as it enhances productivity and allows developers to improve and update their work constantly. Otherwise developers would have to spend endless time waiting for others to finish their work and check it in. The problem of conflict arises when the users check in their work back to the repository, due to the fact that the files were of the same base version when checked out, but were checked in with different versions.

When user A checks in his work, the software updates the version number by one with respect to the check out version. When user B now checks in his work, which was checked out according to the same version as user A initially had, there might be some conflict. In this case the software will complain that there are differences. There are three common solutions to the problem: (1) is to attempt using auto merge; (2) to use a visual merge tool; (3) perform changes by hand.

- Auto Merge: is most often effective and rarely complains, but it may refuse to produce a merged version if both users' changes are in conflict with each other. That occurs when both users modify the same line.

- Visual Merge: using a visual merge tool can be of great help when auto merge refuses to perform any merge. The visual merge tool will highlight the differences using a certain predefined color code. This simplifies the merge as the user can easily recognize the differences, and overcome the conflict.

- Rewrite the File: the third option can be used when changes are too complex to be made by hand, the user can restart editing the base version completely. This is useful when, for example, a function has been completely removed from a user's version, and it would thus be easier to rewrite the entire version.

Examples of software tools that can be used for visual merge are Guiffy and Araxis Merge. [ARA], [GUI]

3.4.4 Locking-Unlocking the Model

Most engineering tools allow the users to work concurrently on the same files, so that work can be merged in some way when committed back into the repository. There is a method known as locking and unlocking a model. In this way only one user can check out a file and edit it, while all other users must wait until the file is checked back and unlocked. The advantage of doing so is that it is guaranteed that only one person can perform a change at a time, and no conflicts can occur when checking back the files into the repository, but on the other hand there are the following serious disadvantages with locking and unlocking models or files [TOR]:

- *Locking may cause administrative problems*: A user that has checked out a file may happen to forget about it, and leave it locked for a long time. This forces other users to wait until they can perform their changes, thus loosing valuable time. If the user that has locked the file is not present for a longer time due to sickness or vacation, the other users must get an administrator to release the lock. This only causes unnecessary delays, wasted energy and frustration for the other users.

- *Locking may cause unnecessary serialization*: If a user wants to edit the beginning of a file, while another wants to edit the end of the same file, he or she must still wait until the file has been returned and unlocked. This is also a problem involving great waste of time. In this specific case, both users might have worked concurrently on the same file without causing any loss to each others work.

- *Locking may cause a false sense of security*: Suppose that a user locks and edits file A, while another user locks and edits file B, and that both file A and B are dependent upon each other. In this case the changes that were made to the files may cause them to become incompatible with each other. In this case the locking system failed completely to prevent the problem of overwriting, and created a false sense of security for both users. In this case the individual users thought that by locking the file it would be safe to edit it, without causing incompatibility to any other files. This problem would be solved by both users discussing and solving the problem together, forcing them to find suitable common time to discuss and solve the issue.

Another major problem would be if the users are located in different geographic regions, making all of the three above disadvantages even harder to cope with. This would add costs to the communication process such as national or international telephones calls and regular meetings.

This chapter also described and discussed Clear Case and CVS, two major tools used in SCM and the third tool: Rhapsody, used for MDD. The SCM tools functionality was described and their major strengths explained, as well as how they primarily function. The major functions presented are: the support for concurrent development, diff and merge functions and locking and unlocking of models. Rhapsody on the other hand supports MDD of UML models in order to produce code for embedded systems.

The following is a summary of the pros and cons of CVS and Clear Case.

CVS:

Pros:

- Saves disk storage space: CVS stores only the differences between the versions and uses these deltas to build the previous version
- Supports concurrent development: advantageous when multiple users work on the same project
- Has few functions: relatively easy to learn
- It is freeware

Cons:

- CVS is not a system for writing the data files, only for keeping track of the concurrent development
- Difficult to view the deltas and understand the previous versions by just viewing the deltas, thus the program must construct the version from the deltas
- Not a substitute for developer communication: when a developer comes across a conflict which is too difficult to solve on his own, he will have to solve it by communicating with other developers
- CVS does not have change control: the program does not keep track of all the bugs and status of each of them
- Used only for source file and does not support other document types

Clear Case

Pros:

- Uses a graphical interface: simple to view and understand
- Offers a view of the actual file history in a tree structure
- Works for a wide variety of document types: word, excel, PDF

Cons:

- Complex and has many built-in features that requires more time to learn
- Stores the entire file and uses large amount of memory
- When installed Clear Case integrates into the window explorer bar
- Expensive software that mist be bought and licensed

4 The Analysis of Existing Algorithms: Flat vs. Hierarchic

In this chapter, the difference and merge algorithms will be studied and analyzed since these functionalities will be developed later on to be applied onto the graphical models used in Simulink. There are two main different data models that exist: (1): *simple*, *plain* or *flat* text files and (2): *fine grained* or *hierarchically* structured data. At first the difference between these two types may not seem important as both types consist of printed lines. The main difference lies in how the *semantic* of the data is defined and how the algorithms are built when treating the data. Examples of simple, flat or non-structured data are printed text documents and source code. Hierarchically structured data on the other hand is XML and UML data in which the structure of the data is semantic. Simulink models which will be presented later in this document are examples of the latter type of data.

The first part of this chapter will cover the *plain textual difference* algorithm and the second part will cover the *plain textual merge* algorithm. The two last chapters will cover the fine grained or hierarchical data in which the details of the syntactical structure of the document are considered.

It is important to state that this chapter describes the purely mathematical approach of the algorithms. Thus it gives a deeper understanding of how the algorithms work on a detailed technical level.

4.1 Diff Algorithm for Flat Data

The main idea behind the difference, or *diff* as it sometimes is referred to, is to feed two revisions or versions of a textual file such as program code or any other text document and output the differences between these documents in a neat fashion using a color code in one single document. Thus the process of identifying the differences between two objects involves two main steps: firstly identifying the differences in an efficient way, and secondly displaying the differences correctly in a useful way, most often using colors. This means that the parts or differences coming from revision one (v1) are colored in a certain color, and the differences coming from the other revision (v2) relative to the first are colored in another different one. Different colors are used because it becomes easier for the user to view the differences than indicating it by adding more text.

The main function of the program was to solve the LCS or *Longest Common Subsequence* problem to find the lines that do not change between files in plain or linear text files. At that time the output was shown textually using angle brackets (< and >) for presenting line deletions and line insertions.

Today applications for *diff* algorithms include comparison of amino acid sequences in the DNA research filed (and the answer to the question of 'how far apart are we?'), storage reduction in a version control system, historical analysis of different copies of old texts, and by the "patch" command to update source files without needing to replace

the whole file, using advanced and fast algorithms that operate in linear time and space complexity.

4.1.1 Longest Common Subsequence

By definition a *subsequence* of some sequence is a new sequence which is formed from the original sequence by deleting some of the elements without disturbing the relative positions of the remaining elements. Take the following example:
< ***B,C,D,B*** > is a subsequence of **< *A,C,B,D,E,G,C,E,D,B,G*** >, with corresponding index sequence <**3,7,9,10**>.
Now given two sequences *X* and *Y*, a sequence *G* is said to be a *common subsequence* of *X* and *Y*, if *G* is a subsequence of both *X* and *Y*. For example, if
X = < ***A,C,B,D,E,G,C,E,D,B,G*** > and *Y* = < ***B,E,G,C,F,E,U,B,K*** > then a common subsequence of *X* and *Y* could be *G* = < ***B,E,E*** >. This would not be the *longest common subsequence* (LCS), since *G* only has length 3, and the common subsequence < **B,E,E,B** > has length 4. The longest common subsequence of *X* and *Y* is < **B,E,G,C,E,B** >
Back to the original problem of finding the LCS or longest common subsequence involves the application of computer algorithms, and there are many topics available on that such as [BER], [LIB].
A straightforward method to compute the *LCS*(*X*,*Y*) consists in considering all the subsequences of *X*, checking if they are subsequences of *Y* and keeping the longest of them. [CHA]. One method, which uses a dynamic programming strategy, is *the polynomial time edition* of the LCS which can be summarized in the following four steps [ANSWERS]:

- Analyze the LCS properties

There exist a large number of research topics on the LCS properties such as [GOE] and [MAS]. One popular such is the LCS having an *optimal-substructure* property.

The ***Optimal-Substructure of an LCS Theorem*** is:

Let **X** = < $x_1,...,x_m$ > and **Y** = < $y_1,...,y_n$ > be sequences, and let **Z** = < $z_1,...,z_k$ > be any LCS of **X** and **Y**.

1. If $x_m = y_n$, then $z_k = x_m = y_n$ and Z_{k-1} is an LCS of X_{m-1} and Y_{n-1}.
2. If $x_m \neq y_n$, then $z_k \neq x_m$, implies that Z is an LCS of X_{m-1} and Y.
3. If $x_m \neq y_n$, then $z_k \neq y_n$ implies that Z is an LCS of X and Y_{n-1}.

- Devise a recursive solution compute the LCS

The second step involves finding a recursive solution to compute the LCS. There is a common standard recursive formula for the LCS which has been agreed upon among a vast number of computer scientists which relies on the Optimal Substructure Theorem above, and is defined as the following:

$$c[i,j] = \begin{cases} 0, & \text{if i} = 0 \text{ or j} = 0 \\ c[i-1,j-1]+1, & \text{if i,j} > 0 \text{ and } x_i = y_j \\ max(c[i,j-1], c[i-1,j]) & \text{if i,j} > 0 \text{ and } x_i \neq y_j \end{cases}$$

For two sequences X_i and Y_j of lengths m and n respectively, *c[i,j]* is the length of the longest common subsequence in the sequences. The first part of the formula says if either one of the sequences has length 0, then there can be no proper subsequence of a null sequence. The other two parts breaks the LCS apart into smaller sub problems until we reach the null sequence in a recursive fashion. [ANS]

- Compute the LCS, using for example the Generic LCS Delta method

Computing the LCS can be done with many existing methods such as [HIR], [EPP], and one common is using the Generic LCS Delta method which is in polynomial time.
LCS Delta algorithm takes the two sequences **X** and **Y** as inputs and creates a table ***c*** with the lengths of X and Y. The algorithm also has a table ***b***, which is a copy of ***c***, which is used to store the optimal solution of the LCS. The rest of the algorithm uses the formula defined above to compute the LCS, and populate the table. The algorithm runs in *O(mn)* time, where m and n are the length of **X** and **Y** respectively. There are more efficient algorithms, namely LCS Alpha and LCS Beta, but this algorithm, the LCS Delta is the most intuitive.

```
LCS-Delta(X,Y)
m <- LENGTH[X];
n <- LENGTH[Y];
for i <- 1 to m, do c[i,0] <-0;
for j <- 0 to n, do c[0,j] <-0;
b <- c;
for i <- 1 to m, do {
    for j <- 1 to n do {
         if (x_i = y_j) {
             c[i,j] <- c[i-1,j-1]+1;
             b[i,j] <- "UP-LEFT";
         }
         else if (c[i-1,j] >= c[i,j-1]) {
             c[i,j] <- c[i-1,j];
             b[i,j] <- "UP";
         }
         else
             c[i,j] <- c[i,j-1];
             b[i,j] <- "LEFT";
         }
    }
 return c and b
```

The entire LCS algorithm given above runs in *O(mn)* in time and space.

- Construct the LCS

The fourth and final step involves construction of the LCS. This is achieved by the result of the above step which returns the table **b** (below) and is used to construct the LCS. The b table could look something like this:

$$\begin{bmatrix} ! & 0 & 0 & 0 & 0 & 0 \\ 0 & UP-LEFT & LEFT & 0 & 0 & 0 \\ 0 & 0 & 0 & UP-LEFT & 0 & 0 \\ 0 & 0 & 0 & 0 & UP-LEFT & 0 \\ 0 & 0 & 0 & 0 & UP & LEFT \end{bmatrix}$$

In this case the table initiates from the (*m,n*) position and continues following the directions until it reaches the end of the LCS denoted by the ! mark. This computation method is *O(m+n)* in time and space complexity. [CHA]

4.1.2 Representing the Differences

For plain textual difference approach two documents are fed into the algorithm. These are called the *base documents* and it is between those that the differences should be displayed. The document that will contain both the common and the specific parts of both the base documents will be known as the *unified document*. This nomenclature applies to both the simple and hierarchical data models.

In the plain textual approach both base documents are placed next to each other and the common parts are arranged in a side-by-side fashion in two adjacent columns. The differences are highlighted to indicate which changes lay within each base document relative the other.

Thus for example one color is defined for each version of the document and a third color is chosen to indicate that there is a difference between the data. For example one can allocate the green and blue color respectively to each of the two documents and red to indicate existence of a difference between them.

4.1.3 2-way vs. 3-way Difference: Presenting the Differences

It is apparent that the common parts in both base documents should be represented only once in the unified document. Thus the final unified document will consist of both the common parts and the specific parts of each base document. Different colors are used for displaying the differences. An interesting aspect discussed in [OHST] is the following: If the colors are removed from the unified document, does it result in a type of "merged" document? This is false since a merged document is associated with removing conflicts in a logical method. In that sense the unified document is not a merged document. This topic will be covered in the chapter of the merge algorithm.

This thesis will cover the 2-way diff which as its name indicates finds the difference between two base documents. There is another type of diff known as the 3-way diff in which three base documents are implemented. In this latter method two documents are direct children versions of the third, thus the three base documents lie in parallel branches of a version tree.

The way to present differences is by using different colors to show which changes came from which respective revision or base document. For the 2-way difference an optimal number of colors are three: one color for each revision such as green and blue, and one for the different parameters (usually red).

For the 3-way difference five different colors are needed: one for the common parts, also a standard such as black, two colors for presenting insertions and deletions in the first branch and two for changes in the second branch. This may become rather too colorful and becomes a debated issue if the user can maintain an overview of the bulk of information presented in the unified document.

4.2 Merge Algorithm for Flat Data

This subchapter will define the term *merge*, and also introduce the 3-way merge function, in which three documents are needed to complete a merge. Again the word *flat* is used since the data has no hierarchy and a document is simply regarded as printed lines of text.

Merging is used today in many everyday applications such as in PDAs (Personal Digital Assistant) or handheld computer synchronization. This occurs whenever the user performs synchronization between a computer and a PDA; a memo added on the PDA should also be visible on the computer. Another usage is in computer patches, where a patch represents a textual difference between two text files, and is merged with an older version to produce a newer one.

4.2.1 Definition of Merge

A formal definition of the technical term "merge" taken from the National Institute of Standards and Technology [NIST] is:
"The input is two sequences, A=$\{a_1, ..., a_n\}$ and B=$\{b_1, ..., b_m\}$, each sorted according to some total order, ≤. The output is a single sequence, merge(A,B), which is a sorted permutation of $\{a_1, ..., a_n, b_1, ..., b_m\}$.

merge(A, B) is

1. A, if B is empty,
2. B, if A is empty,
3. $\{a_1\}$**.**merge($\{a_2, ..., a_n\}$, B) if $a_1 <= b_1$, and
4. $\{b_1\}$**.**merge(A, $\{b_2, ..., b_m\}$) otherwise.

The symbol "**.**" stands for concatenation, for example, $\{a_1, ..., a_n\}$**.**$\{b_1, ..., b_m\} = \{a_1, ..., a_n, b_1, ..., b_m\}$."

It is to be noted that this formal definition of the technical term of merge is applied for integers since the total order is less than or equal i.e. it involves the use of numbers.

So simply put, a merge, or more precisely a two-way merge in this case, is a combination of two different objects, such as vectors containing letters or digits that are combined in a certain fashion to form one object which will contain both common parts of the objects and some or all of their differences. It is then up to the user to decide which changes are to be merged, the ones coming either from the first or second version. This method is similar to and based on the difference algorithm defined in the previous chapter to define the differences, and with the only difference being on deciding how to resolve conflicts. Finally, the output will be composed of the file and the changes incorporated by the user.

The figure below describes the general layout of the 2-way merge. This figure shows that the input data must be of the same type, and that the output will include both common and shared data. The merge engine is left empty and could host different algorithms using different processing methods with different levels of efficiency and complexity.

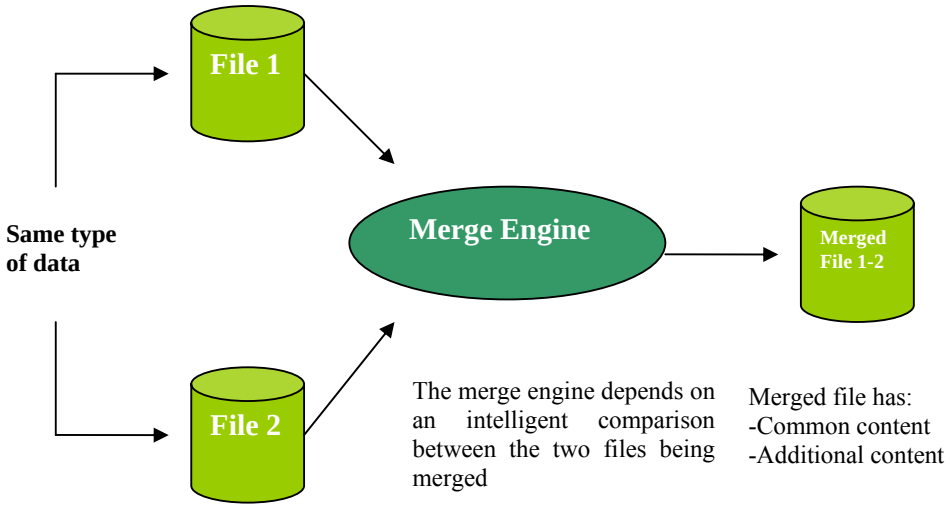


Figure 2: A two-way merge. This can be applied to any types of files as long as the algorithm handles reading them and the input data are of the same type that is flat or otherwise.

4.2.2 The 3-way Merge

The 3-way merge is more complex but also more powerful than the 2-way merge as it provides a way to also synchronize data [DXML], and involves as its name indicates three different documents to initiate. The 3-way merge is widely used in concurrent development, for example when two different users check out a copy of the latest version *v*, and want to check it back in after editing it. The first user will not face a problem and will check in the file successfully, with a version number exceeding the last checked out version number by one that is *v+1*. The second user on the other hand will have to perform a 3-way merge, between his current document, the first users' document (*v+1*) and the original checked out version *v*.

A 3-way merge takes place between three versions of a document. First there is the user's version known as the ***selected*** version, and it is with this version that one wants to reconcile the changes with. Second there is the ***current*** version which is the working version that has been modified, and should be merged into the selected version. The current version is called so because it is the last or newest available version of the model. A common reference known as the ***common*** version is also chosen in order to determine what changes that have taken place in reference to the original version.

An interesting and illustrative example on the three way merge is available in [TIG]. It illustrates a picture of a tiger with whiskers and white eyes (*common* version). Along with this original picture are also two modified copies, in which the first is a tiger with no whiskers (*current* version) and in the second a tiger with yellow eyes and whiskers (*selected* version). After performing a 3-way merge, the final picture will show the tiger with yellow eyes and no whiskers.

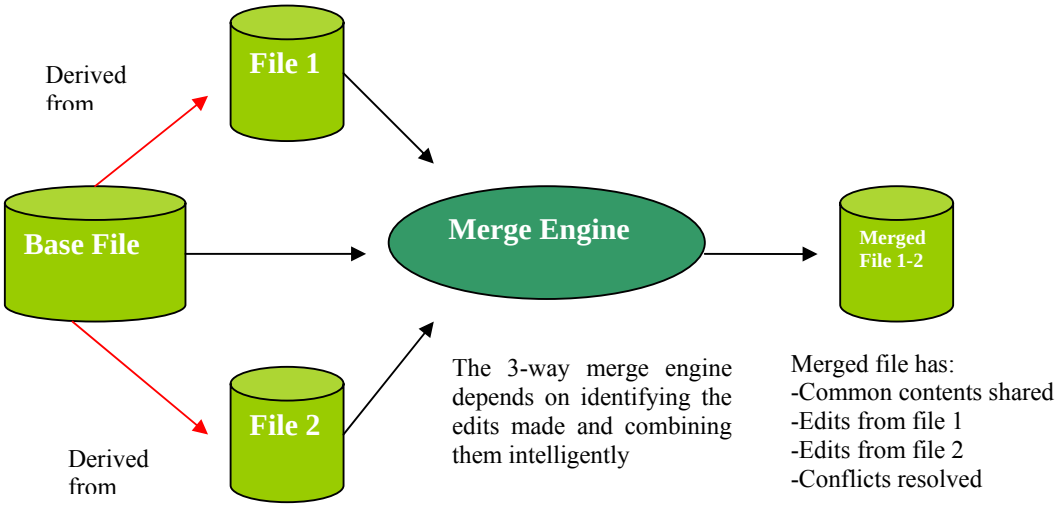


Figure 3: The 3-way merge overview. This can be applied to any types of files as long as the algorithm handles reading them.

Figure 3 above shows the general layout of the 3-way merge, and indicates that file 1 and 2 are derived from the base document. All three documents are fed into the merge engine and results in the final merged result. Regarding the merge engine, one may use different algorithms with different efficiencies and complexities.

Applying the 3-way merge may result in a total of 14 different cases presented below covering all possible outcomes, where files may differ or not. For the case where *all three files exist*

- all 3 may be identical (**1 case**)
- each of the 3 pairs may be identical (**3 cases**)
- all 3 may differ (**1 case**),

thus resulting in a total number of **five** (**5**) different cases.
Now, for the three cases where only *two files exist*: either they differ or do not differ, giving a total of **six** (**6**) cases. Along with the **three** (**3**) cases where *one file exists* in only one version gives a total of 14 cases (**5**+**6**+**3**). [RCS]

Thus the following table can be regarded as an algorithm for the 3-way merge, where any of the **14** cases can exist. It is made up of four columns representing the case number and type, the action that will be taken by the program, and an explanation of that specific action.

By implementing a program that starts be applying a difference between the files, one can write a program that uses the results of the differences to go further on. Take the following as an example: If a difference is run between the files with a zero result, which means no change has been detected between the files; then the program will use

case 1 and prompt nothing. This is applied to cover all the five cases and construct a useful 3-way merge tool.

First, the 5 cases where all *three files exist*:

Case No	**Case**	**Action**	**Explanation**
1	All files equal	No prompt	Since no changes have been made to any of the data.
2	All files differ	Prompt *merge*	There are no equivalent files among the three files in each version. It is assumed that the user is interested in merging the selected version's changes with the current version. Therefore, the default action is to merge.
3	Selected file differs	Prompt *replace*	The version of the file is unchanged from the common version, yet the selected version has been modified. It is assumed then, that the selected version of the file is more up to date, and the default action is to replace the users file with the file from the selected version.
4	Working file differs	No *prompt*	The selected version has no changes to incorporate
5	Common file differs	No *prompt*	The working and selected version have both changed, but the changes are identical, so there are no changes to incorporate into the working version.

Secondly, the 3 cases where only one pair of files exist but are *equal*:

Case No	Case	Action	Explanation
6	Common and Selected.	Prompt *nothing*.	The user deleted a file and the selected version didn't. The selected version has not been modified, so it is assumed that the file is obsolete.
7	Common and Working	Prompt *delete*.	The selected version deleted a file that the user has not

			modified, so it's assumed that the file should be deleted.
8	Working and Selected.	No action.	Both versions have added an identical file, there are no changes to incorporate

Thirdly, the 3 cases where only **one** pair of file exists but are *different*:

Case No	Case	Action	Explanation
9	Common and Selected.	Prompt *nothing*.	The user deleted a file and the selected version didn't. The selected version has been modified. This type of conflict cannot be merged, the user must decide what to do. The default action assumes the deletion is correct.
10	Common and Working.	Prompt *delete*.	The selected version deleted a file that the user has modified, so it's assumed that the file should be deleted, even though he/she modified the file.
11	Working and Selected.	Prompt *merge*.	Both versions added a file and the files differ. The merge will take place with an *empty* common file, and is likely to produce serious changes.

Finally, the 3 cases where only a *single file exists*:

Case No	Case	Action	Explanation
12	Common.	No action.	Both versions deleted the file, so there are no changes to incorporate.
13	Working.	No action.	Working version added a file; selected version has no change to incorporate.
14	Selected.	Prompt *add*.	The file exists only in the selected version and is assumed to have been added.

4.2.3 Merge: Relationship to the Difference

The merge was explained in the previous section as the function that will find differences between two documents and 'bake' the differences into a new document that will contain both the common parts and the specific ones coming from each revision of the document, while leaving any conflicts for the user to decide on. Thus the first stage of a merge is detecting the differences between the documents, if any such exist. So if a difference program already exists, and works properly, then it can be easily modified for usage in the merge program.

4.3 Diff Algorithm for Hierarchical Data

This subchapter will describe an algorithm for finding differences between fine grained or hierarchical data. The main types of data considered are XML and UML structures, and the program developed in this thesis is of this type too.

4.3.1 The XML Language

Many research topics have been conducted on the use of the differencing and merging on higher hierarchical languages such as the XML or eXtensible Markup Language that it stands for. The XML language provides a non-proprietary universal format for sharing hierarchical data among different software systems. XML is a verbose plaintext format, making it robust, platform-independent and legible1 to humans without additional tools. XML was designed to be a deployable subset of the Standardized Generalized Markup Language (SGML), which is widely used by government agencies and major corporations to ensure interoperability and persistent data accessibility. XML is currently being heavily pushed by the industry and community as the *lingua franca* for data exchange on the Internet. XML is supported by the World Wide Web Consortium or W3C as well as major corporations such as Microsoft, Sun Microsystems and IBM. For more information about XML please refer to [XML], [W3] and [LIN].

XML provides a way to *mark up* content that adds information about its purpose. With the information stored using XML, an application known as a parser can extract the relevant information and process it accordingly for multiple situations resulting in a hierarchical data structure. Examples of the situations include usage in databases, servers and in editors. [IBM]

The most suitable structure for representing XML data is trees, since all XML elements are strictly nested. All the trees are described using three main qualities: roots, labels and orders. This means that data has exactly one root node, all the roots are associated with a value and the order of the siblings is essential. Thus referring to a tree now only requires a rooted, labelled and ordered reference. For more on the topic of labelling terms please refer to the interesting topic [KYR].

The following is an example of an XML fragment which consists of the tree node: **`library`** which has children nodes: **`books.`** Each child node has a **`title`** attribute and a **`content`** child node. Each of the **`content`** nodes has a **`chapter`** attribute and a **`keyword`** child node. The tree can be expanded by adding new book nodes and filling in the new relevant information.

```
<library>
       <book>
       <title> Intro to XML</title>
          <content>
              <chapter title=”An XML fragment”>
                     <keyword> XML </keyword>
              </chapter>
          </content>
       </book>
       <book>
       <title> UML Modelling</title>
          <content>
              <chapter title=”UML”>
                     <keyword> UML </keyword>
              </chapter>
          </content>
       </book>
       etc...
</library>
```

Figure 4: An XML fragment of a book library system

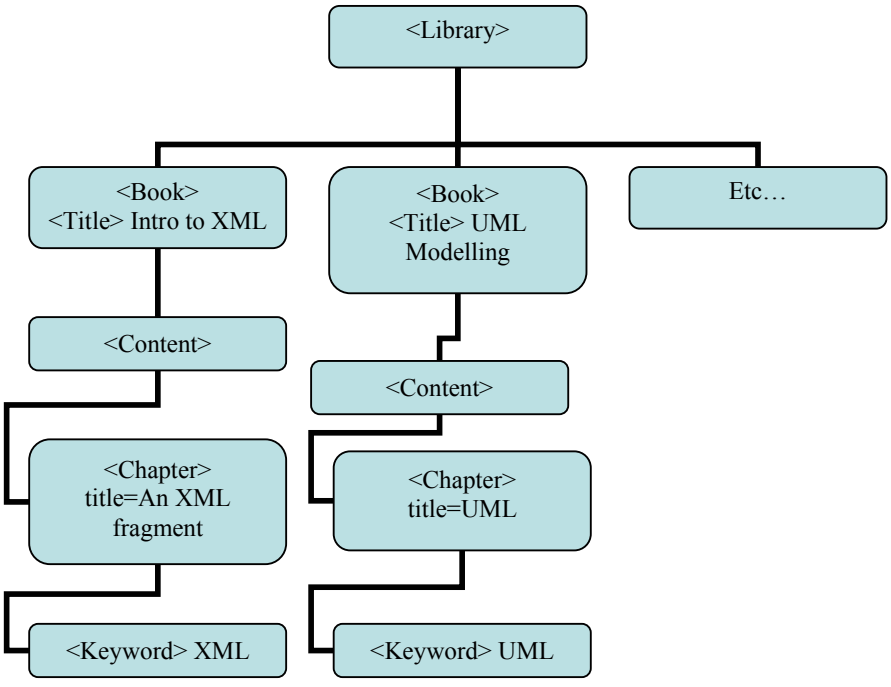


Figure 5: A tree structure system depicting the XML fragment code shown in the previous figure above

4.3.2 The Theory of XML Document Versioning

This section introduces the theory behind documents versioning of XML and will describe the edit scripts that are used for representing document changes.
The traditional document versioning systems are *edit-based*, edit scripts are used for representing changes in documents, also known as deltas, and also for reconstructing the versions incrementally. The edit scripts are introduced in more detail in section 4.3.4 Edit Scripts: Cost Models. There are two types of edit scripts: reverse editing and forward editing scripts. The difference between these is that the reverse editing script, like the one used in RCS, [TIC], stores the most current version of the document entirely while previous versions are stored as reverse editing scripts. The scripts describe how to go back from one version to another in the document's development history. These deltas or differences are used in building in what is known as a *minimum cost edit script*. The minimum cost edit script for two trees is defined using node insert, node delete, node update and sub-tree move as the basic editing operations.

The problem of finding what data is similar in two objects can be complex and time consuming, but since Simulink models have identifiers they will simplify this task.

As an example, consider the two trees T_1 and T_2 shown in Figure 6 and Figure 7. The number inside each node is the *node's identifier* and the letter inside each node is its *label*. All of the interior nodes have null values not shown here for simplicity. Leaf nodes have the values indicated in parentheses. Thus these trees could represent two structured documents where the labels **`D`**, **`P`** and **`S`** denote **`Document`**, **`Paragraph`** and **`Sentence`** respectively. The values of the sentence nodes are the sentences themselves. This is one of the advantages of XML: the trees can be used for representing an infinite amount of systems as long as they are defined correctly for that specific system [CHAW].

T_1 represents the older or initial version while T_2 represents the newer or later version. When one wants to determine an appropriate transformation from T_1 to T_2, the primary task is to find the two nodes in the two trees that remain unchanged. In our models these two nodes are assumed to be the unchanged.

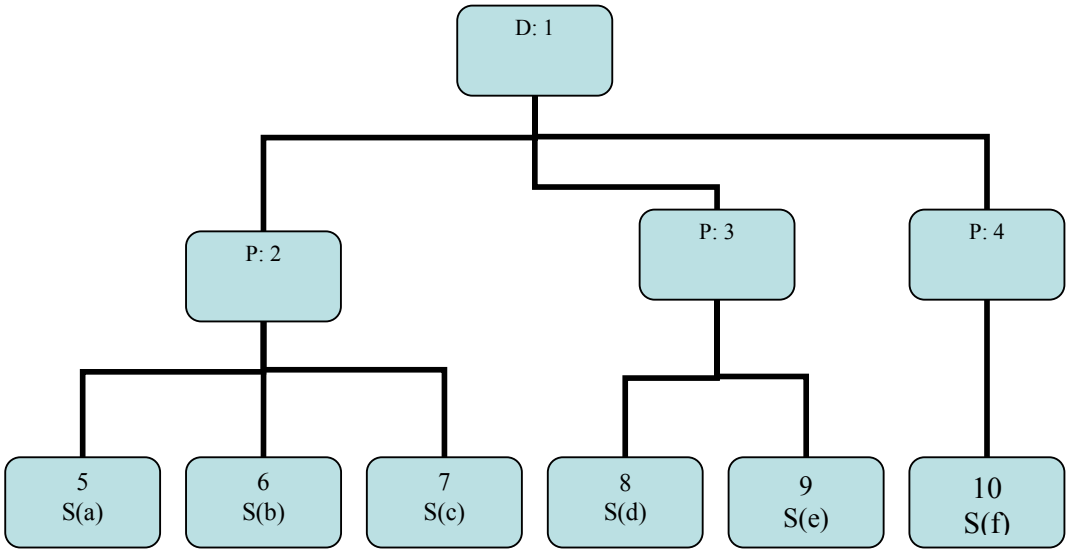


Figure 6: Tree T1 consisting of 3 paragraphs (P) and a total of 6 sentences (S)

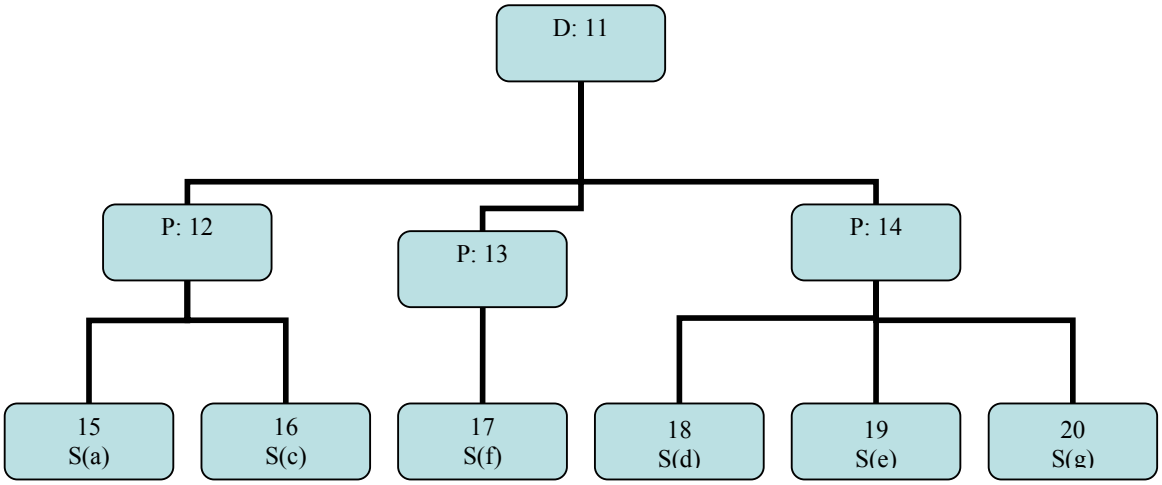


Figure 7: Tree T2 also consisting of 3 paragraphs and 6 sentences

By looking carefully and comparing the two trees one understands their structure and notices the following differences: the numbering of the nodes starts at the root and continues incrementing as one move to the right throughout the tree (breadth first labelling).

Moreover the following can be noticed: node 5 in T_1 has the same value S(a) as node 15 in T_2 thus nodes 5 and 15 should probably be the same. Similarly nodes 4 and 13 have one child each with the same value S(f) and thus should probably correspond.

An interesting discussion is: how detailed should the match be? To simplify the matching two terms are introduced: *partial* and *total* matching between the trees. Partial matching is when some of the nodes in the two trees participate, while the matching is total if all the nodes participate. Most often the matches are partial, but it depends of course on the number and size of changes that have been made to a tree. It is thus less likely that the matches are total matches, but one would like to match nodes that are approximately equal. For instance node 3 in T_1 should match node 14 in T_2 even though node 3 is missing the child S(g) .

The term *isomorphic* is introduced in [CHAW] to indicate that two trees are identical except for the node identifiers. For trees T_1 and T_2 once a *partial matching, M*, is found the next step would be to find a sequence of operations that would transform tree T_1 into another tree T'_1 that is isomorphic to tree T_2. The changes that are involved in the tree T_1, may include deleting nodes, inserting nodes, updating the values of the nodes and moving entire nodes along with their sub-trees. The next step would be take the partial matching M and extend it into a total matching M´ between the trees T'_1 and T_2. This new total matching M´ now defines the isomorphism between the trees T'_1 and T_2.

The sequence of change operations between the two trees is called edit script, and the goal is to find one such that uses a minimum number of changes. To fulfill this goal each edit change is given a cost, and now one must find a *minimum cost edit script*, also referred to as the Minimum Conforming Edit Script (MCES).

4.3.3 Edit operations

This section will describe each of the edit operations that are used for transforming one tree into another. In an ordered tree let the nodes $\boldsymbol{v_1}\ldots\ \boldsymbol{v_m}$ be children nodes of u, then naturally $\boldsymbol{v_i}$ is the ***i:th*** child of ***u***. For a node ***x*** let ***l(x)*** denote the label, ***v(x)*** denote the value and ***p(x)*** denote the parent of ***x***, if ***x*** is not the root. Now T_1 will refer to the tree on which the operations are to be performed on and T_2 refers to the resulting tree. The four edit operations will then be:

- **Insert**: The insertion of a new leaf node ***x*** into the tree T_1 is denoted by **INS*((x,l,v),y,k)***. This stands for a node ***x*** with label ***l*** and value ***v*** is inserted as the ***k***:th child of node ***y*** of T_1 .

- **Delete**: The deletion of a leaf node ***x*** into the tree T_1 is denoted by **DEL**(***x***). This operation will result in a tree T_2 which is similar to tree T_1 except that it does not contain the node ***x***. This operation does not change the relative ordering of the remaining children of ***p(x)***.

- **Update**: The update operation updates the value of a node in a tree ***x*** in T_1 achieved by **UPD**(***x,val***). T_2 is the same as T_1 except that in T_2 ***v(x) = val***.

- **Move**: The move operation moves an entire sub-tree from one parent node to another in T_1 denoted by **MOV*(x,y,k).*** T_2 will be the same as T_1 except for that ***x*** becomes the ***k:th*** child of ***y***.

The following is an illustrative example of how the insert and delete operations can be implemented.

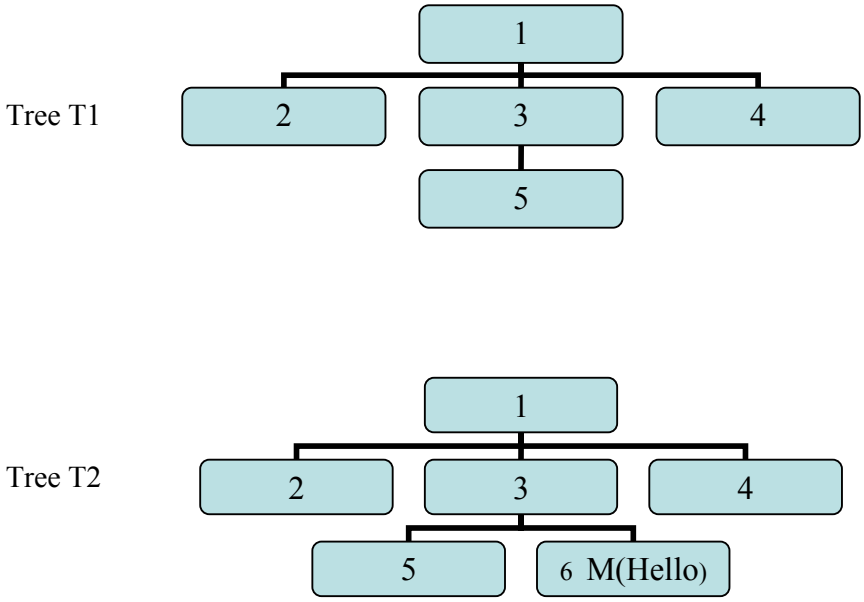


Figure 8: Illustration of the insert operation. By applying the operation **INS**((6,M,Hello),3,2) to tree T1 (the upper one) results in the lower tree T2. This is explained by adding a node 6 with label M and value ´Hello´ as the second child of the third node of tree T1. The remaining labels and values are not shown.

By applying the delete operation **DEL**(6) on the second tree T_2 above one obtains the initial tree T_1.
To illustrate the move operation, consider the second tree T_2 and apply **MOV**(3,1,1). This will result in a new tree T_3 (below) by moving the third node and its entire children to being the first child of node 1 as shown in figure

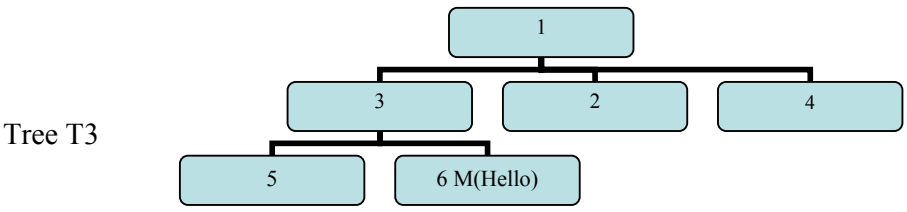


Figure 9: The new tree T3 after applying a move **MOV**(3,1,1). That is moving the node **3** and all of its children to the new location as first (**1**) child of node **1**.

4.3.4 Edit Scripts: Cost Models

Now the four different edit operations have been introduced it is time to introduce the edit scripts. By definition an edit script is a time ordered sequence of edit operations that transform a tree T_1 into a tree T_2. A general method for representing an edit script is using arrows (→) between two trees to indicate the application of an edit operation. Thus, the edit operation e_1 that is applied to a tree T_1 to transform it into a tree T_2 is represented by: $T_1 \rightarrow e_1 T_2$. This representation is used for any number of edit operations for the total transformation from the initial tree into the final tree.

There are many different ways to realize a tree from its initial tree model. For example instead of applying a move operation on tree T_1 or a sub-child of it, one can delete the entire node (**DEL**) and its children, and then add them one by one (leaf by leaf) using the insert operation (**INS)**. This latter method is clearly more time consuming; so to apply a measure of how time effective any given script is, the term *cost of an edit operation* is introduced. The cost of an edit operation depends on the type of operation and the nodes involved in the operation.

A general model is letting $C_D(\boldsymbol{x})$, $C_I(\boldsymbol{x})$ and $C_U(\boldsymbol{x})$ denote the cost of deleting, inserting and updating a node $\boldsymbol{x}$, and let $C_M(\boldsymbol{x})$ be the cost of moving a sub-tree with its root in node $\boldsymbol{x}$. The costs generally depend on the position of node x in the tree and on the label and value of it. For simplicity the costs of deleting, inserting and moving a node $\boldsymbol{x}$ is assumed to be unit cost, that is $C_D(\boldsymbol{x}) = C_I(\boldsymbol{x}) = C_M(\boldsymbol{x}) = 1$.

For the cost of updating, a new function is introduced: *compare*. This function inputs two nodes as arguments and returns a value between zero and two [0,2]. The idea behind the compare function is to decide whether the two inputs are close to each other or different in value. So supposing that $\boldsymbol{x}$ is moved and its value $\boldsymbol{v}$ is updated to $\boldsymbol{v}'$ close to the initial value, then running the *compare* will result in a value less than 1 since the cost of moving and updating $\boldsymbol{x}$ must be less than the cost of deleting and replacing it with a new one with value $\boldsymbol{v}'$. In a similar manner, if the inputs $\boldsymbol{v}$ and $\boldsymbol{v}'$ are different then it would be more cost efficient to implement an edit script containing a delete and insert operation pair [CHAW].

The final cost result of the edit script is the sum of the cost of the individual operations. This result is proportional to the number of changes and the size of the trees. Smaller trees have lesser nodes and require a relatively smaller number of edit operations than larger trees, taking a proportional number of changes.

4.4 Merge Algorithm for Hierarchical Data

The merge algorithm for hierarchic data relies on the 'diff' algorithm for hierarchical data discussed in the sections above.

Thus, the same table introduced above in section *4.2.2 The 3-way Merge* and involves the first five cases. It consists of five possible outcomes: (1) all files are equal; (2) no files are equal and three cases (3), (4), (5) where each case consists of one of the three files differing from the other two.

This section will not be developed more as it consists of a combination of the hierarchical diff algorithm along with the logical table in the flat merge section.

4.5 Summary of Chapter 4

Chapter 4 introduced defined the theoretical approach behind the diff and merge algorithms that are used in the various tools in SCM applications. The diff algorithm for flat data introduced the Longest Common Sequence, in which a new sequence is formed by removing data from the old sequence without altering the relative order of the data, using a strict logical scheme.

Then the colors for visually presenting the differences were discussed, and three colors were needed to display a complete 2-way diff. For the 3-way diff five colors were needed. The merge algorithm for flat data also uses a logical scheme presented in a tabular form. Then the diff for hierarchical data was presented and it consists of tree structures and 'edit scripts'. The goal of the edit script was to find the optimal cost models. The merge algorithm uses the same procedure but complements it with the tabular form.

5 The Desired Tool Specifications

This chapter describes the desired algorithms of the programs for the Simulink models. This is partly done using the API of MATLAB presented in the chapter above along with the other useful functions that are developed here. It must be clear that the algorithms of the textual algorithms can not be immediately implemented without making certain assumptions or simplifications. This is mainly due to the difference in structure of the two types of objects: text files and Simulink graphical models. For example an assumption is made regarding the size of the files. In textual files, documents containing literally thousands of lines, say 10'000 lines, are considered extremely large and the complexity of the algorithm, whether linear or otherwise has an important effect on the accuracy and time complexity. The graphical models employed in this thesis are multi-levelled and contain multiple nodes; they are still relatively smaller than the large text files. So no models containing thousands of blocks and hundreds of levels were ever employed for the sake of simplicity.

It must be pointed out that this chapter describes the **desired** properties of the diff and merge programs, but it does not mean that all the properties were developed successfully. For more about what was developed please refer to the next chapter. Secondly the complex diff and merge algorithms that were introduced and discussed in chapter 4 are not implemented in the development of the desired specifications.

5.1 Considerations for the Model Based Approach

For version control of text based files, the CM software does not take the logic of the file content into consideration. When performing a version control between two files, the system only compares the files line by line and lists the differences using a certain predefined color code. The different colors indicate the different changes such as what lines have been moved, deleted or changed etc. depending on the software. Diagrams can not be reasonably displayed in this manner, because one has to distinguish between differences in the layout and differences in the conceptual diagram elements [OHST].

A graphical model has two important features of data, known as the *layout data* and the *model data*. These two data are different with respect to their definition and content. The layout data are defined as the positions and the sizes of the nodes in a diagram or the position of corner points in edges; that is everything that would essentially be considered as irrelevant in the textual representation of the diagrams content. The model data on the other hand express the semantics of the document.

After having tested and edited models in Simulink the following can be concluded:
Blocks in models can be edited and changed in several ways. Parts of the model can be created, deleted or shifted. The individual differences between two versions of one diagram can be classified as intra-block differences and structural differences, by dividing up all the object parameters into the following two differences:

- **Intra-block differences** are differences within a certain block in the model. Examples of such intra-block differences are parameters such as priority and tag. Some of these properties are not directly visible in the model, since the block properties editor must be opened before such differences can be seen.

- **Structural differences** cover changes when blocks are shifted, created or removed. Other structural differences are changes made to the size, position, and color of the blocks. These changes are also defined as visual ones; they can be seen immediately in the models.

Thus all changes in our models come from the object parameters of the blocks, but in this case they have been divided into the two different categories just mentioned.

5.1.1 The Input and Output Types

The input files will consist of two Simulink models supplied by the user. The output model will bear the name supplied by the user, and is composed of a Simulink model that displays for the user the similarities and differences between the input models. The goal of the output file is not to contain too many colours since it will confuse the user.

5.1.2 Colour Scheme

In the theory section of the thesis it was discussed that three (3) colours are optimal for displaying the differences between two (2) versions. Black is the colour for displaying no difference between blocks. According to the theory in this thesis two colours, one for each model version should be used to indicate insertions and deletions such as blue and green. A third color, red, will be used to indicate a property difference in a block.

5.1.3 Limitation

A limitation is that the upper most subsystem that contains the entire model cannot be altered in any matter. This means no position changes, no property changes and no addition nor deletion of blocks at that level. This is so because it will be used in naming the models and the names of the models must remain unchanged to avoid confusion when running the program.

5.2 Desired Use Case of the 'Difference' Program

The following is the use case of the 'difference' program and will define its working process, the type of inputs, and the type of output that the program will generate.

- It shall be based on modules meaning that it will be made of smaller programs that work together to achieve the goal.
- The goal of the 'difference' program is that the user will input two Simulink models and the result is to show the differences between them graphically using colours. The comparison will be performed by finding similar pair of blocks in the two models, thereafter their block properties will be compared to find any differences.
- The differences between the two blocks will be displayed in two ways: graphically using colours in a new model and in written form in the MATLAB script window. If a block does not have a similar counterpart it will be shown in a different colour implying that the block exists in only one model and not the other.

- The algorithm will be recursive, thus it will result in a compact and easy to follow program code.
- The result of the program will be a new graphical model that bears the output name defined by the user and will include or display the common and different blocks by using colours and texts to indicate those.

All of the above points of the use case are discussed in more detail in the next chapter.

5.3 Desired Use Case of the Merge Program

The following is the use case of the 'merge' program and will define its working process, the type of inputs, and the type of output that the program will generate.

- It shall be based on modules meaning that it will be made of smaller programs that work together to achieve the goal and have a recursive algorithm.
- The goal of the 'merge' program is that the user will input two Simulink models and the result is to show one final model including common parts and the differences chosen by the user. The comparison will be performed by finding similar pair of blocks in the two models, thereafter their block properties will be compared to find any differences.
- When differences are discovered the user shall be informed by a message and will decide on which version to implement. The differences between the blocks will be displayed in two ways: visually using colours and in written form in the MATLAB script window.
- The algorithm will be recursive, thus it will result in a compact and easy to follow program code.
- The result of the program will be a new graphical model that bears the output name defined by the user and will include or display the common blocks and the ones chosen by the user.

All of the above points of the use case are discussed in more detail in the next chapter.

The goal of the merge program is to allow the user to input 2 graphical models and let the program find the differences, to finally produce a third model containing the common blocks, and allow the user to decide on which blocks to add when conflicts arise. A main difference between this merge program and the 'difference' is that this program will interact with the user when conflicts are discovered. This is done when a change has been performed to the same variable in two different models. The user will be prompted to choose from which model to incorporate the changes from.

5.4 Summary of Chapter 5

Chapter 5 described the specification of the desired programs that will be developed. It described the different colour scheme that should be used in displaying the differences between the models and also defined the desired use cases of both the diff and merge, which is how the programs should work when completed. Thus the programs shall be composed of modules and be recursive. For the actual programs that were developed and how well they worked please refer to the next chapter.

6 Implementation of Model Based Tool

This chapter will describe the actual developed programs and describe what worked and what did not relative to the use case. It will cover all of the use case specifications that were defined in chapter 5.

6.1 The Input and Output Models

The program inputs are Simulink models, built of the basic and common types of blocks. These can be either simple or multileveled models by using the subsystem blocks. One important case is that whatever graphical model used it must always be contained in a top-level subsystem block. This was chosen so that one can indicate if any changes have been done inside the subsystem by colouring that subsystem.

The user will name the input by indicating the model name followed by the subsystem name, separated by the slash character. Supposing that a model name is `'wing'` and the top-level subsystem name is `'motor'` then the input name to the program would be `'wing/motor'`.

The output model will be made up of a new model, named after any desired name allocated by the user. This name should be chosen so that it will indicate some information about what two versions were compared.

Rerunning the programs with the same name of the output model as an existing open one will not cause any problem. The program will close the previous output model without saving it and open a new one with the same name.

6.2 Actual 'Diff' Program

The following sections will cover the actual difference program: a modularised and recursive approach.

6.2.1 Modules

The main module was the '**`findDifference`**' because it contained the algorithm that checked for the differences and requested the displaying of the block in different colours. The remaining modules were composed of small programs that performed different tests to check if models exist or not. Here are the modules that were developed:

1- **`checkDifference(model1, model2, output)`**: this program checks if the **output** model exists and is open. If so it will close it without saving it and call on **`startDifference`**. Otherwise it will directly call on **`startDifference`**.
2- **`startDifference(model1, model2, output)`**: this module will create the empty model with the requested **output** name. It then proceeds to call on two main programs: **`findDifference`** and **`findDifference_Reverse`**.
3- **`findDifference(model1, model2, output)`**: this is the main program responsible for finding the differences between the models and displaying the output in the output model. The main algorithm is located within this module. It contains the following modules:
    a. **`entity_directChildren ('model', 'block'):`** this module returns all the direct child of 'block' type for 'model'

b. **`block_uniqueIdentifier('block'):`** This module defines a unique identifier for each 'block'
c. **`entities_entityMatchingUniqueIdentifier(entitiesToCompare, identifier)`** this module returns a matching unique block with a defined 'identifier' by comparing it with the set of blocks in 'entitiesToCompare'
d. **`block_differentProperties(block1,block2)`** returns the different property between 'block1' and 'block2'

4- **`findDifference_Reverse(model1, model2, output)`** is the second logic part of the overall program that loops through the blocks in model2 and adds the blocks that only exist in model2 as green.

6.2.2 'Difference' Algorithm

The second part of the use case was to have two models as input and get one model as output. The algorithm is described below:

The syntax for running the 'difference' program is:

```
checkDifference ('model_1', 'model_2', 'Output_Name')
```

Here `'checkDifference'` is the program name, while the first two variables are the names of the input models `'model_1'`, `'model_2'`. The third and last variable `'Output_ Name'` is the name of the output model which is freely chosen by the user.

The program will check whether the output name requested is open or not. If it is open the program will close it and start by creating a new empty model with the requested output name. It then adds the upper most subsystem block into the newly created output model.

The program will then find the first child block of the upper most subsystem in the first model and find its equivalent in the second model. This is achieved by finding a unique identifier. A unique identifier is as its name indicates: an identifier that makes each block unique. This is achieved by combining the name and block type for each block, thus no two same blocks in the same model should have the same name and be of the same type.

The program will start by taking a block from Model_1 and find its counterpart in Model_2 by comparing their unique identifiers. If there is a match the next step would be to check if they have the same object parameter values, and if they do then the block is drawn in **black** in the output model. While if there is a unique model counterpart but with different object properties it will be displayed in **red**. A text is also added in Matlab describing the different property of the block.

Next step is to perform the same check for the remaining child blocks of the subsystem. If a block does not have a child block it will return an empty child block list. The program then takes on another block and performs the same comparison of unique identifiers.

The next step is to add all blocks in Model_1 that did not have any counterpart (no matching unique identifier) in **blue**. To achieve a recursive algorithm, the next step is to call on the program again for the remaining child blocks.

Then the same procedure is performed but this time by looping through Model_2 and finding all blocks that do not have a matching unique identifier and adding those blocks in **green** in the output model.

Below is a generic graphical illustration of how the program will display the differences between two models. Here the blocks are shown as basic geometric figures, while in reality they are blocks in the Simulink block directory.

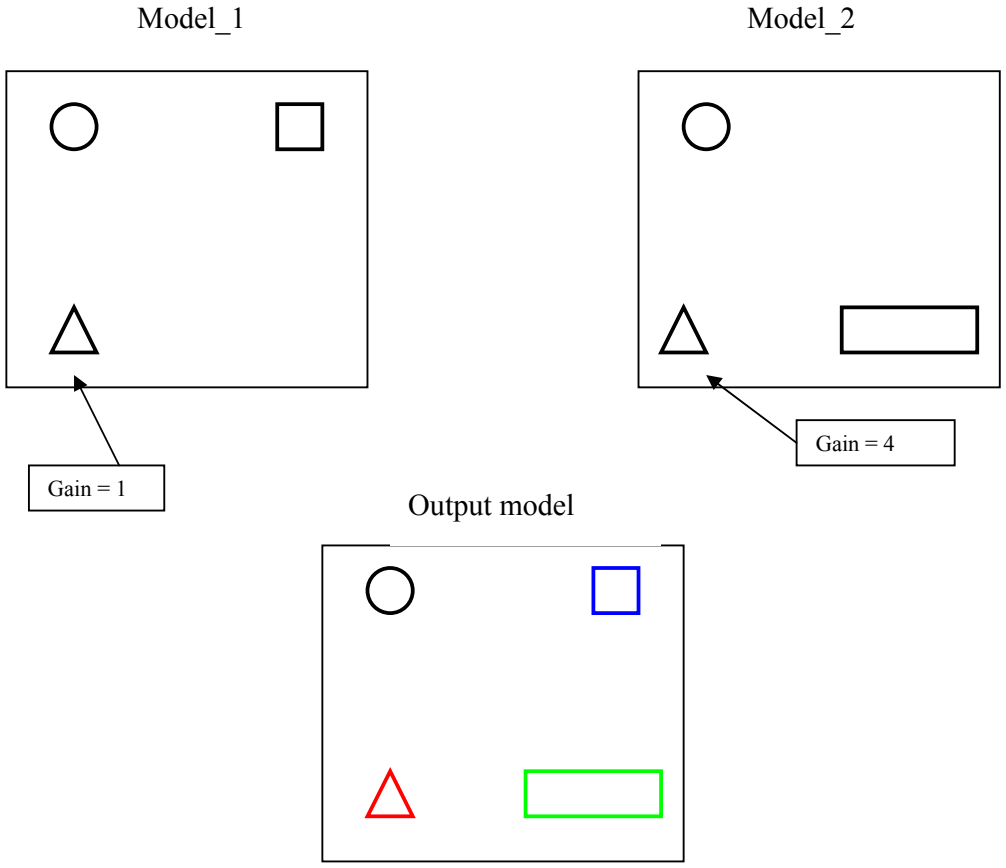


Figure 10: A graphical illustration of the 'difference' program

The above figure illustrates how the difference program works. If the input models are Model_1 and Model_2 each consisting of three blocks, where Model_1 has a circle, a square and a triangle with a Gain parameter = 1, while Model_2 has the same circle, a rectangle and a triangle with Gain parameter = 4.

Then the output model will contain the following blocks:

The same common circle, since it has the same internal block properties in both models.

A **blue** square since that block exists in Model_1 but not in Model_2.

A **green** rectangle since that block exists in Model_2 but not in Model_1.

A **red** triangle since it has a different object parameter "Gain" in both models. This is a conflict indicating that the same parameter in both models has a different value. The different values are printed in the MATLAB program.

Applying the 'difference' algorithm to Figure 11:

The algorithm would start by taking the first block in Model_1 and finding its counterpart using its unique identifier, which in this case is the circle block. Then the properties of these pair of blocks will be compared, and if they match (have no differences) the circle is displayed in **black** in the output model.

Next block would be the square, and it will not have a counterpart therefore it will be directly displayed in **blue**. Then the triangle is compared with its counterpart. Here the program will find a difference in the Gain parameter and will therefore display the triangle in **red**, and print in the MATLAB script what the differences are.

The final step is to go through all blocks in Model_2 and for all blocks with no unique identifiers in Model_1 will be displayed in **green**. In this case it is the rectangle block.

Below is figure 15, which is also used to display how the program works. In the output model the **blue** blocks indicate what blocks came from Model_1 while the **green** blocks display the ones coming from Model_2.

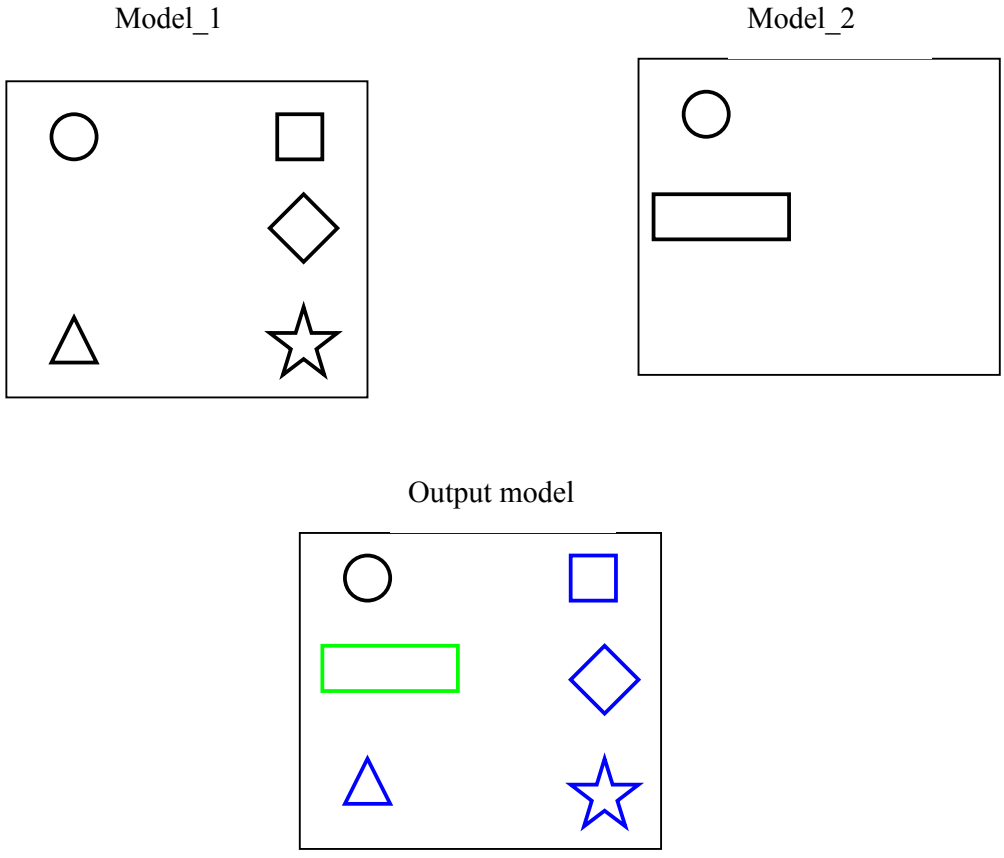


Figure 11: Another illustration of the 'difference' program

6.2.3 Displaying the Differences

The following are the colours of the blocks that will be shown in the output model that are used to indicate the differences between common pair blocks in `'model_1'` and `'model_2'`:

- **Black** blocks mean no differences between the block properties.
- **Red** indicates there is a property difference between the two blocks.
- **Blue** blocks mean the block exists in `'model_1'` but not in `'model_2'`
- **Green** blocks mean the block exists in `'model_2'` but not in `'model_1'`

There are two main categories of differences that will be shown between the two models: internal and external differences. The **internal** differences cover a large number of object parameters that describe any given block. These block properties can be called upon in Matlab by:

```
get_param ('block_Name', 'ObjectParameters')
```

Example of object parameters that describe any block are: name, tag, description, type, parent and handle. There are a total of 144 object parameters for any given block.

The program will compare all the parameters for each pair of blocks coming from `'model_1'` and `'model_2'`. Any differences in values for any given pair of blocks will result in a **red** output block.

The other type of difference will be called **external** and these include blocks that exist in one model but not the other. These differences will be shown in the **blue** and **green** depending on which model the came from. So for example a **green** block in the output model indicates that the block exists in `'model_2'` but not in `'model_1'`.

Another function that was implemented was to colour the subsystem which had a change made within it to **orange**. This is helpful because when the user spots an orange subsystem, then it automatically indicates that there is a change within it.

6.2.4 Actual Results: Difference

The following two models (figures 12 and 13) were baked into the actual 'difference' program. The result is shown in figure 14

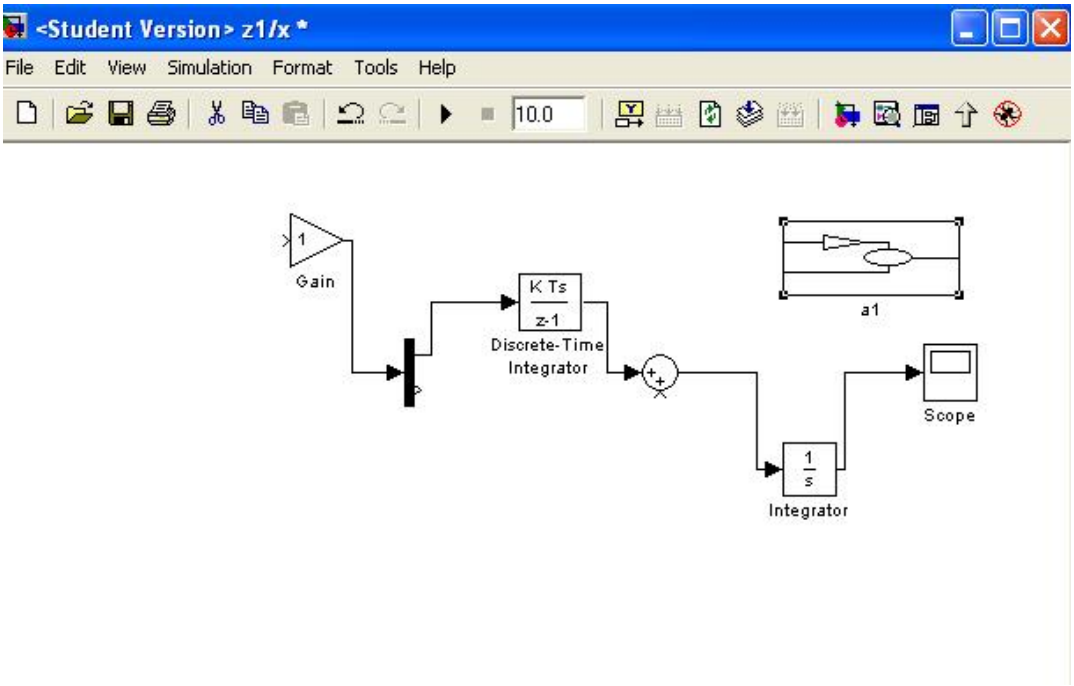


Figure 12: The model z1/x: The upper subsystem level name is z1 and this is x.

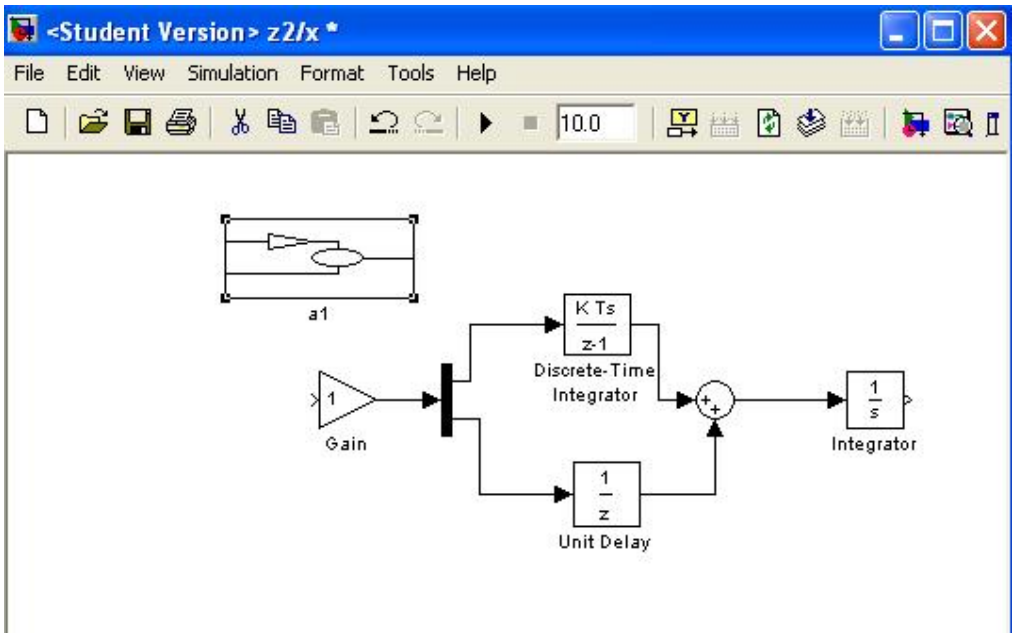


Figure 13: The model z2/x: The upper subsystem level name is z2 and this is x

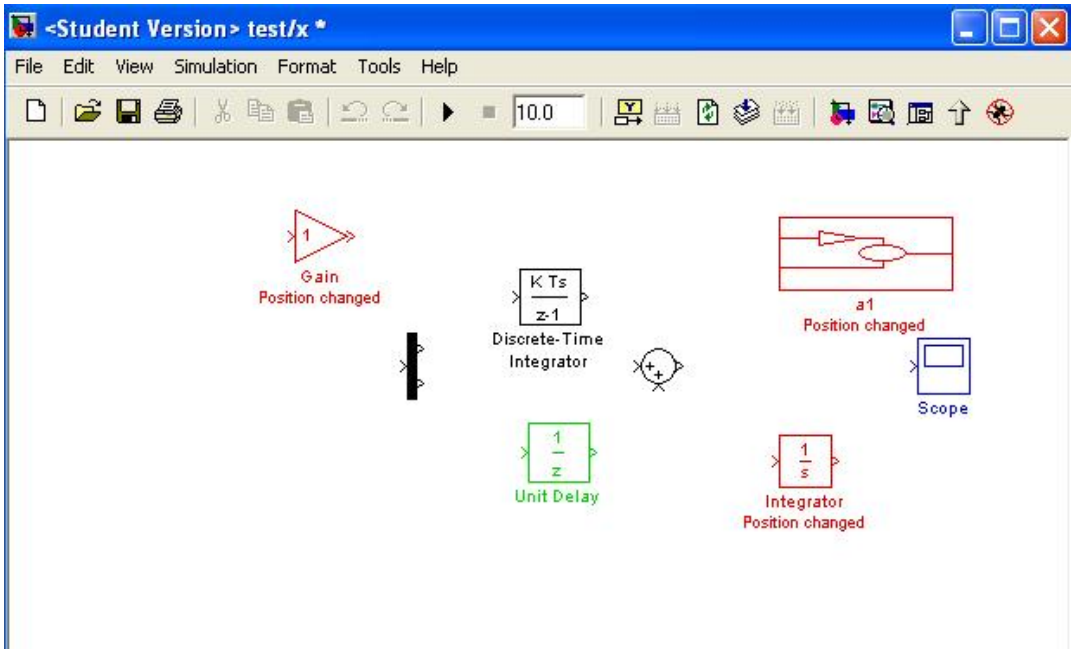


Figure 14: The 'difference' program run on the two above models

The red blocks indicate that there exists a parameter change, but that both blocks exist in the both models. The rule is that the actual changes are taken from the first model. The blue block indicates that it exists in model 1 only, while the green block indicates that it exists in model 2 only.

6.2.5 What Did Not Work: Diff

The initial idea was to include lines into the models, but it showed that lines were complex to handle because they are connected to blocks via block handles. When a block is deleted the handle will also be deleted, and there will be a problem in connecting the lines. Therefore the lines were ignored during this program, and so were the input and output ports.

Another point that not tested was the efficiency and speed of the algorithm. There was no special care taken for achieving a fast algorithm.

Another problem was when the edits to the files were too complex, that is when many new blocks and subsystems were added and deleted, the program was not capable of displaying the correct changes, and sometimes crashed. This is thought because there is a bug in the code which does not correctly use the name of subsystem blocks and causes the program to compare blocks of different subsystem levels.

6.3 Actual Merge Program

This section will summarize the actual merge program including the algorithm as it was used in this thesis. This was achieved by studying how the methods are implemented in the text file approach of the CM tools and their algorithms, to be further expanded for implementation into the Simulink graphical models, while taking consideration for the information presented until now throughout this report. Of course the structure of

MATLAB and the possibility of retrieving block data has been a contributing factor for solving the problem and writing the programs.

Moreover the merge function is closely related and is actually based on the difference function. This is explained by the fact that to merge any two documents or objects, firstly the differences between them must be found and defined if any such exist. Thereafter the merge algorithm may take place.

The following merge program shares many similar modules with the difference program.

6.3.1 Merge Modules

The main module was the '**`checkMerge2`**' because it contained the algorithm that checked for the differences and requested the displaying of the block in different colours. The remaining modules were composed of small programs that performed different tests to check if models exist or not. Here are the modules that were developed:

1- **`checkMerge2(model1, model2, output)`**: this program checks if the **output** model exists and is open. If so it will close it without saving it and call on **`startMerge2`**. Otherwise it will directly call on **`startMerge2`**.
2- **`startMerge2(model1, model2, output)`**: this module will create the empty model with the requested **output** name. It then proceeds to call on two main programs: **`merge2`** and **`merge2_Reverse`**.
3- **`merge2(model1, model2, output)`**: this is the main program responsible for merging the differences between the models and displaying the output in the output model. It contains the following modules:
    a. **`entity_directChildren ('model', 'block'):`** this module returns all the direct child of 'block' type for 'model'
    b. **`block_uniqueIdentifier('block')`**: This module defines a unique identifier for each 'block'
    c. **`entities_entityMatchingUniqueIdentifier(entitiesToCompare, identifier)`** this module returns a matching unique block with a defined 'identifier' by comparing it with the set of blocks in 'entitiesToCompare'
    d. **`block_differentProperties(block1,block2)`** returns the different property between 'block1' and 'block2'
4- **`merge2_Reverse(model1, model2, output)`** is the second logic part of the overall program that loops through the blocks in model2 and adds the blocks that only exist in model2 as green.
5- **`callMerge(block, match, difference)`**: **`merge2`** and **`merge2_Reverse`** call upon this function. This function will inform the user on which differences exist in each model, and prompt the user which block, the one from the first or second model that he wishes to merge when conflicts arise. It then returns the choice back to **`merge2`** and **`merge2_Reverse`**.

6.3.2 Merge Algorithm

The second part of the use case was to have two models as input and get one model as output. The merge algorithm is described below:

The syntax for running the 'merge' program is:

```
checkMerge2('model_1', 'model_2', 'Output_Model_Name')
```

Here `'checkMerge2'` is the program name, while the first two variables are the names of the input models `'model_1'`, `'model_2'`. The third and last variable `'Output_Model_Name'` is the name of the output model which is freely chosen by the user.

The program will check whether the output name requested is open or not. If it is open the program will close it and start by creating a new empty model with the requested output name. It then adds the upper most subsystem block into the newly created output model.

The program will then find the first child block of the upper most subsystem in the first model and find its equivalent in the second model. This is achieved by finding a unique identifier. A unique identifier is as its name indicates: an identifier that makes each block unique. This is achieved by combining the name and block type for each block, thus no two same blocks in the same model should have the same name and be of the same type.

The program will start by taking a block from Model_1 and find its counterpart in Model_2 by comparing their unique identifiers. If there is a match the next step would be to check if they have the same object parameter values, and if they do then the block is drawn in **black** in the output model. While if there is a unique block counterpart but with different object properties, then the program will prompt the user if he wishes to merge the block coming the first or second version. In accordance the block will be added with its respective colour depending on which model/version it came from.
Next step is to perform the same check for the remaining child blocks of the subsystem. If a block does not have a child block it will return an empty child block list. The program then takes on another block and performs the same comparison of unique identifiers.

The next step is to add all blocks in Model_1 that did not have any counterpart (no matching unique identifier) in **blue**. To achieve a recursive algorithm, the next step is to call on the program again for the remaining child blocks.
Then the same procedure is performed but this time by looping through Model_2 and finding all blocks that do not have a matching unique identifier and adding those blocks in **green** in the output model.

Below is a generic graphical illustration of how the merge program will display the differences between two models. Here the blocks are shown as geometric figures, while in reality they are blocks in the Simulink block directory.

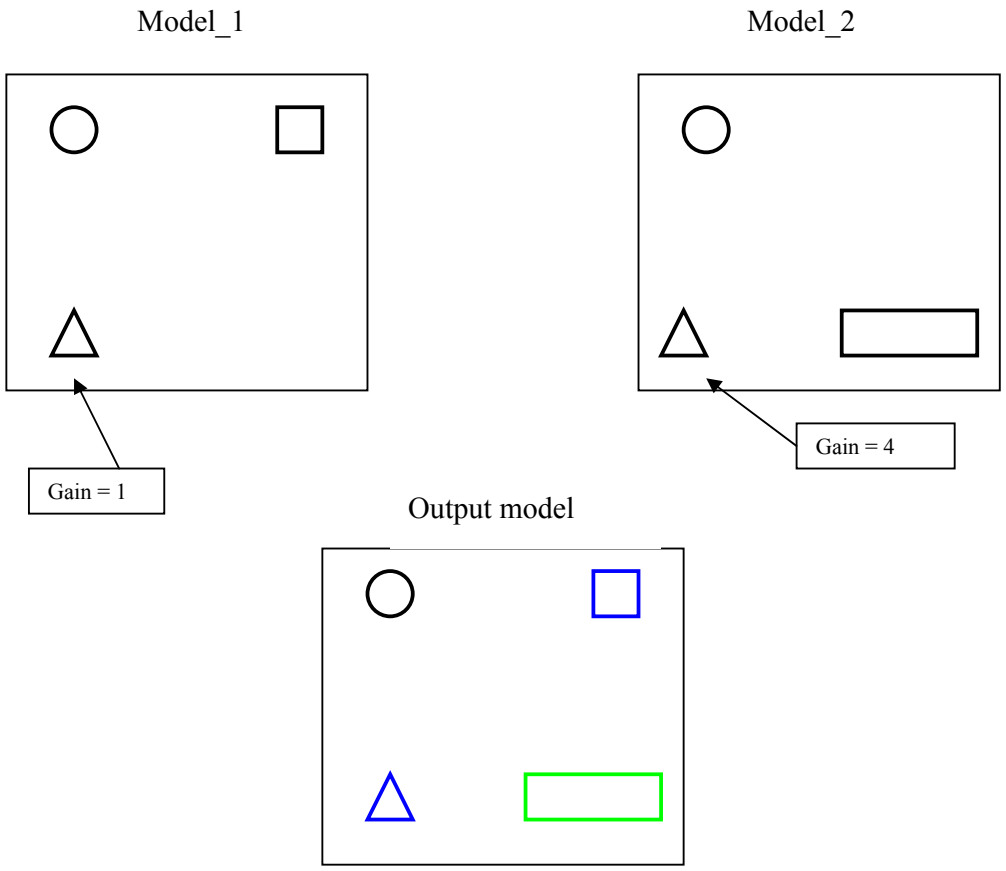


Figure 15: Illustration of the Merge2 program, when the user chose to merge the gain block coming from the first model. Thus it was allocated the blue colour.

The above figure illustrates how the merge2 program works. If the input models are Model_1 and Model_2 each consisting of three blocks, where Model_1 has a circle, a square and a triangle with a Gain parameter = 1, while Model_2 has the same circle, a rectangle and a triangle with Gain parameter = 4.

Then the output model will contain the following blocks:

The same common circle, since it has the same internal block properties in both models.

A **blue** square since that block exists in Model_1 but not in Model_2.

A **green** rectangle since that block exists in Model_2 but not in Model_1.

A **blue** triangle since it has a different object parameter "Gain" in both models. This is because the user chose to merge it when prompted.

6.3.3 Displaying the Differences: Merge

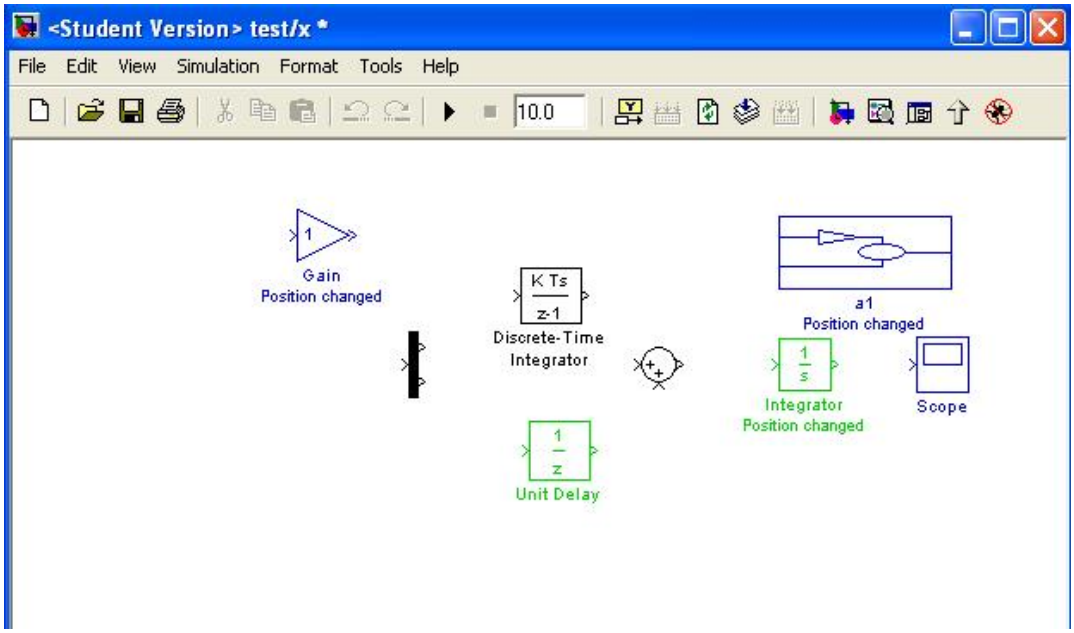
The following are the colours of the blocks that will be shown in the output model that are used to indicate the differences between common pair blocks in `'model_1'` and `'model_2'`:

- **Black** blocks mean no differences between the block properties.
- **Blue** blocks mean the block exists in `'model_1'` but not in `'model_2'`

- **Green** blocks mean the block exists in `'model_2'` but not in `'model_1'`

6.3.4 Actual Results: Merge

Again the same models used in figures 13 and 14 were used in the actual merge program. The result is shown below:



Figur 16: The result of the merge program on models in figures 16 and 17

When the program prompted which versions to merge, the following inputs were given: 1, 2, 1. Thus the program will merge the Gain block from the first model, the Integrator from the second model and the Sub System block from the first model. For the Unit Delay block no text below the block indicates what changes occurred, this is because the block exists in model 2 only. The same is for the Scope; it exists in model 1 only.

6.3.5 What Did Not Work: Merge

The initial goal of this thesis was to develop a 3- way merge. This was changed towards the end of the project due to lack of time. Thus only the 2-way merge and 'difference' were developed.

Another point is that the merging of lines was not taken into consideration due to the same fact presented earlier in the difference section.

6.4 Summary of Chapter 6

This chapter described the actual implementation of the diff and merge programs that were developed and discussed. Both logical and actual diagrams were used to display the results that were obtained.

It must be said that the initial goal at the beginning of the project was to develop fully functional programs that would eventually include lines and ports in the models, but these were removed since they were difficult to handle because of their structure. Secondly it was desired to develop a 3-way merge, but due to more difficulties only the 2-way merge was developed.

The programs did fulfil most of the initial desires and that was: modularised functions and recursive programming style. They also fulfilled the type of input and output, which are two Simulink models as input and another one as output. The output was also displayed both graphically and textually as initially requested.

7 Simulink and Rhapsody

The main goal of this chapter will be to understand the possibilities and capabilities of combining Rhapsody with Simulink, and to try out the different functions which they support.

7.1 Simulink and Rhapsody

There are two main methods of using Simulink and Rhapsody together: vertical or horizontal integration between the software. Both ways are of interest and can be used for different purposes. The words horizontal and vertical do not imply that Rhapsody and Simulink are placed in any certain layout, but merely to distinguish the two different methods of combining the software.

Simulink is advantageous when it comes to developing logical and mathematical algorithms by using analytical blocks that define the dynamic behaviour of physical elements. Rhapsody on the other hand does not have mathematical blocks at all. Instead its environment consists of modelling and designing systems in the UML language, and conduct tests on each function to ensure that they are correct, to produce source code.

The advantage in combining both Simulink and Rhapsody is that one combines two powerful programs in hybrid engineering for developing models and also allows traceability between the models and requirements.

A Rhapsody block can be accessed in Simulink as any other block and enables one to model the behaviour and logic of blocks representing embedded systems using the full Rhapsody UML environment. Moreover Rhapsody designs can be tested against plant models with a true co-simulation [BOL]. An example of this allows the modelling of a physical plant in Simulink and its electronic module in Rhapsody. In the same way, Simulink blocks can be used in Rhapsody. In this case mathematical algorithms can be integrated into the Rhapsody models.

In vertical integration an add-on known as Rhapsody Gateway is used by introducing traceability links, while in the horizontal integration the code generated in Simulink's real-time workshop are implemented as a block in Rhapsody.

7.2 Vertical Integration Using Rhapsody Gateway and Traceability

In vertical integration the software are related using a Rhapsody add-on called Gateway (RG). This program comes with Rhapsody and allows the user to link the requirements of a project to any Simulink or Rhapsody blocks. The textual requirements can come from different formats such as Word, Excel or PDF documents and DOORS.

Rhapsody Gateway consists of 5 main windows: *Management View, Coverage Analysis Mode, Impact Analysis Mode, Graphical Mode and the Requirement Details*.

The Management View presents all coverage ratios, overall project information, rule violations and possible document generations. The *Coverage Analysis Mode* consists of 3 windows: the central column contains all the documents defined in the project configuration. The right column presents the downstream elements: what is covering the selection in the middle column, and the left column presents upstream elements: what files are covered by the selection in the central column. This system allows for an effective navigation in the traceability graph. The *Impact Analysis* View gives a recursive view of all the higher and lower levels. The *Graphical View* gives an overview of traceability elements linked together. The *Requirement Details* presents all the requirements for a given document with all their attributes.

The process starts by defining which element or elements in Simulink are covering the given requirements. Then those requirements are chosen from the RG window and pasted into the *Description* field of the *Block Properties* of the block. This automatically creates a traceability link across the programs.

The requirements across the project are divided into different level requirements. Thus for example the requirements in a Word document describing the general functionality of the model are known as High-Level requirements or HL_Req. The next level is the UML Low-Level requirements denoted as LL_Req.

RG has a built-in basic diff tool that allows the user to see what differences exist between modified requirements. It is accessed by opening the *Snapshot Editor* and clicking on the modified requirement. This will open two windows showing the old and new requirement next to each other.

In Figure 17 RG acts as a link between the entire components and keeps track of all the requirements of the project. Changing or editing any requirement will be seen in all other components of the project. The arrows are drawn as double speared because the traceability can be traced in both views: top-down and down-top view depending on which element is studied.

For a project to be configured in Rhapsody one must define the location of the files, the links between them and the requirements traceability information to be searched for in each file. RG does not contain a hardcore configuration management tool, but instead it can support the setting up of reference versions that can be transmitted when needed to a configuration management for generating analysis documentation in customized formats.

A useful function provided by RG is the *impact analysis capability*. This function allows the user to see what elements or blocks in Simulink that are impacted upon by a requirement change by simply clicking on the requirement in RG.

The disadvantage is that the linking document must contain requirements that are linked in the Simulink documents, and allows for traceability between the blocks. Therefore a full understanding in both programs is crucial for the entire project, and for a person not having sufficient knowledge in both programs will have difficulty in implementing the functions of the Rhapsody Gateway.

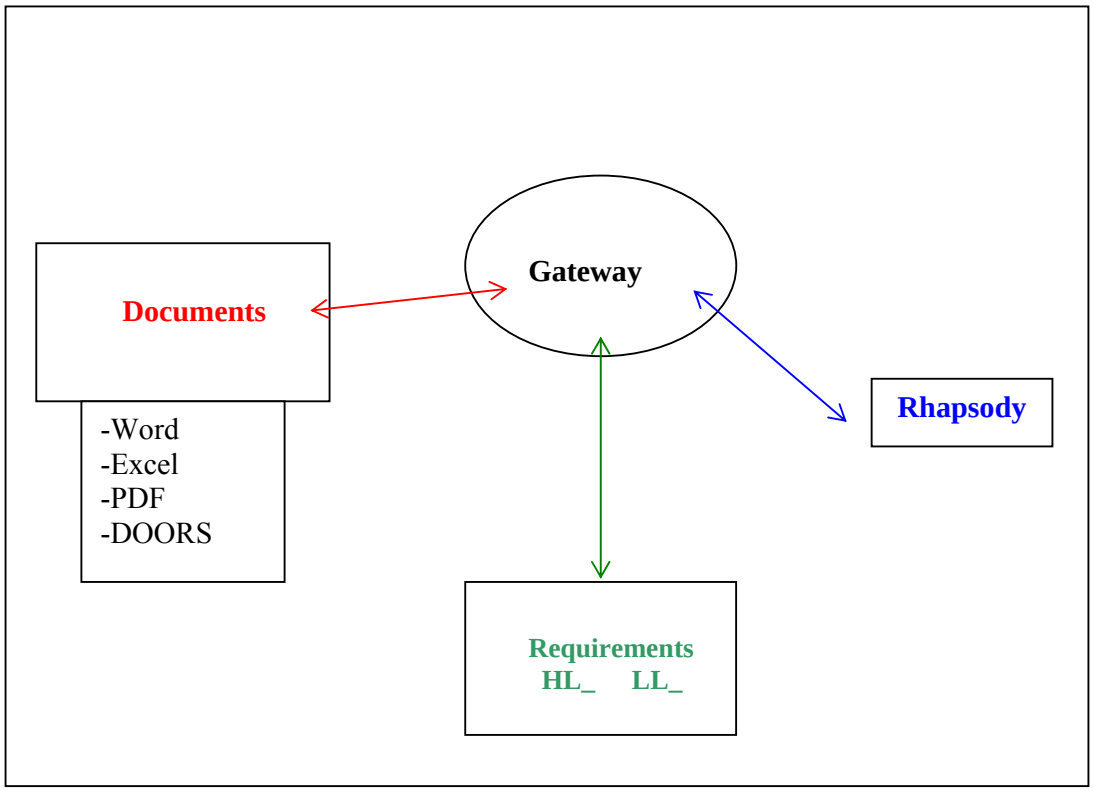


Figure 17: This figure shows Gateway as a central actor coupling the high-level and low-level requirements with Rhapsody. Thus any new requirement will create a traceability link that can be followed (traced) throughout the entire project from the requirement chart to Rhapsody. The requirements can be of the data types shown above (Word, PDF, Simulink etc…)

7.3 Horizontal Integration Workflow

In the horizontal approach the user can implement a Simulink block directly into the Rhapsody model without the need of any add-on. The Simulink block will in this case be a wrapper and not a physical block, consisting of the C code generated from the Simulink real time workshop model and appears in Rhapsody as a block. The generated code will interact with the rest of the Rhapsody model.

This is convenient since the developer only needs to model the dynamics of a system into Rhapsody and also allows the actual production code to be tested as a complete system in the software environment.

An example would be when modelling a power control system of a car window. The controller itself, which is the embedded code, is modelled in Rhapsody, but the general dynamics of the window itself that is the current position, the weight and speed of the window (its behaviour) come from the Simulink model as a wrapper. So the Simulink model depicting the dynamics of the window is shown as one single Rhapsody block, but is actually a wrapper in Rhapsody and interacts with the controller blocks. This is clearly shown in Figure 18.

Performing horizontal integration starts by generating the C code from the Simulink model. This is done by choosing the Real-Time workshop and building the model. Next step is to view the code and use it within Rhapsody: this is done by choosing '*Reverse Engineering*' option from the *Tools* menu. Doing so allows the C code generated from Simulink to be added into the Rhapsody environment. Choose an option called '*Import Code as External*' so that Rhapsody does not generate the code again. To view the data generated from Simulink go to the '*Package*' menu and choose the file with the '*_rtw*' that indicates Real Time Workshop. This file contains many other files such as the data and types of functions. Doing so will automatically list the functions that need to be used in the Rhapsody environment such as the initialize, terminate and step time functions along with the various input and output variables. Rhapsody also generates a view of how the Simulink files are related to each other. This is done by opening the '*Object Model Diagram*'.

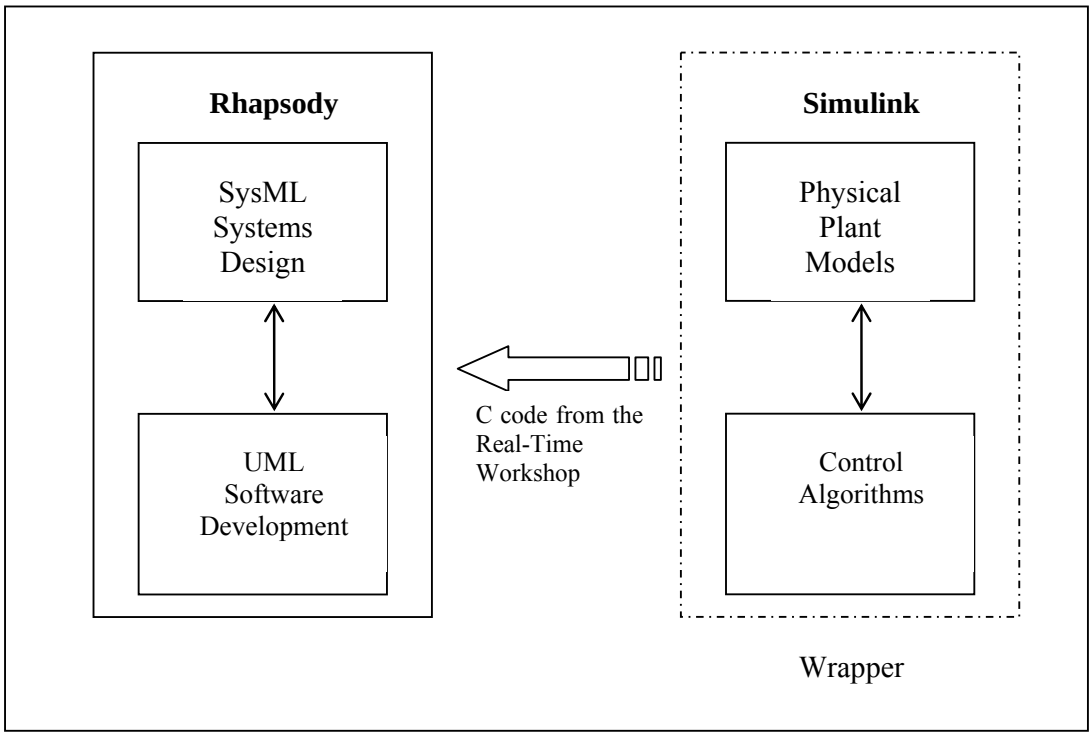


Figure 18: This figure shows the interaction between the Simulink 'wrapper' whose code generated in the real-time workshop will be produced into the Rhapsody model, and shown as a normal Rhapsody block.

7.3.1 Other Workflow Methods

Moreover the opposite of this workflow can be generated: C code can be generated from Rhapsody and sent into the Simulink model. This workflow allows the user to model the behaviour and logic of the blocks using UML.

The third and final workflow is combining the code generated form both platforms and integrated between each other. This approach is possible by using third software. One such is Exite, which will not be covered in this paper, and allows each engineer to use his or her favourite tool and not necessarily both tools.

The Horizontal integration is useful when there is no need immediate need for using the project requirements. It is a faster method to use because there is no need for any other programs. The obvious disadvantage is the lack of traceability which is an important part of most development projects. Traceability allows multiple users to be sure that their work fulfils the requirements of the project at every stage of development and will lower the overall development time for unnecessary and expensive debugging time.

7.4 Summary of Chapter 7

In chapter 7 an interesting topic was discussed regarding the combination of MATLAB's Simulink and Telelogic's Rhapsody, which has resulted in a hybrid-modelling development. There are two main ways of doing this: vertical and horizontal integration. Each method has its advantages and disadvantages.

The vertical integration requires an add-on known as Rhapsody Gateway. All the traceability links are created using this add-on and it allows for faster development time because the user can easily follow the requirements and see which ones are covered and non-covered (fulfilled requirements). The input data can be Simulink models, Word, Excel, PDF and DOORS documents.

The horizontal integration consists of three different workflows: wrapping a Simulink model in the Rhapsody environment and using its C code generated in the real time workshop to interact with the rest of the model. The second way is the opposite of the first, which is a Rhapsody block that is represented in the Simulink environment. The problem is that a user needs to have knowledge in both software. To overcome this there is a third workflow but it requires the use of third program such as Exite that uses a Java interface.

8 Conclusions and Discussions

8.1 Conclusions

The topic of version control is a broad and interesting research field, with many improvements to come in the future regarding more efficient and faster algorithms with lower complexity and improved search engines. The *diff* algorithms are purely mathematical and use the longest common sequence recursively to achieve the goal. The merge also showed to be mathematical and uses sort algorithms to perform its objective. In the hierarchical approach the algorithms were also mathematical and use edit scripts to find the lowest cost script in a tree structure.

The existing *diff* uses a 2-color system to display the differences between two revisions. In our results three colors were needed, 2 colors to display the origin of a block, and a third color for showing internal differences between blocks. An important factor that was used in ours solution was the usage of unique identifiers. This approach simplifies the data search and cuts down on algorithm complexity.

The goal of this thesis was to construct a method for merging and differencing graphical models implemented in Simulink. Although the developed programs contained bugs, but they still show the possibility of using '*diff*' and merge on graphical models. The different blocks were detected and shown in different colors as was demanded initially and the program interacts with the user when conflicts are discovered, allowing for merging of programs.

One more aspect was making the programs compatible when interchanging information regarding the existence of differences between two revisions. Since the merge program starts by asking for differences between two revisions, it will receive a true or false statement after which it can continue processing the rest of the algorithm. The result of this must be sent back to the main algorithm, and has to be understood correctly.

There was a clear relationship between the *diff* and the merge algorithms: the merge algorithm is built on the difference algorithm. It was important to keep in mind when writing the *diff* algorithm to make it compatible with the merge algorithm. This had to be planned by defining the sub-system at the same levels in both programs, and employing the same definition to the blocks.

MDD is an approach that refers to the development of platform independent models, to raise the level of abstraction at which software is developed. The models are built using the UML 2.0 language. An example of an MDD tool is Rhapsody which was tested in this work. One of the functions in Rhapsody is that the user can choose a target language to generate code for an embedded system; in this project C++ was chosen.

Rhapsody offers the interaction with Simulink models in three ways: horizontal, vertical and bi-directional. The terms horizontal and vertical do not refer to any structural method, but were chosen to differentiate the types of interactions. In the horizontal method a wrapper was created around the Simulink model, making the model appear as a Rhapsody block that interacts with the rest of the system. In the vertical integration requires an add-on known as Gateway, which creates traceability links between the

different system requirements. In the bi-directional method an external tool is needed, such as Exite, which allows both tools to interact in both directions.

8.2 Discussions

A problem was in detecting changes when moving/deleting the lines that connect different blocks. Since some blocks are deleted from a revision, the ports will not exist, and thus it will not be possible to draw lines correctly between deleted blocks. Therefore a warning message is displayed when lines can not be detected by the program. This is why the lines were omitted from the program. A partial solution to this problem would be to copy all lines automatically from both models. This would create many overlapping lines and certain lines would either be connected to one or no blocks. The problem was that the lines had no logical meaning. One could go through all lines in the resulting model and find all lines that do not have a connected endpoint and remove them.

Another challenge was to identify equivalent blocks in different models. This was achieved by using the unique identifier, in which each block was uniquely defined by its name and type of block. The advantage in using these unique identifiers was that they simplify the models, because the program would only need to compare and check for the name and type of blocks.

The developed program was tested for small sized models, ranging from three blocks to around thirty different blocks. The *diff* program was always able to indicate the differences. The algorithms of both the *diff* and the *merge* did not take into consideration the complexity of the programs. This can be seen as a restricting factor for using these algorithms and programs on larger models. Large models can be considered as consisting of thousands of blocks. It is for these larger models that a programs' complexity and efficiency comes into work.

A test engine was initially built and would be used for creating a random model revision from any given model. The idea behind this was to create a new random revision, while knowing all the changes. Then a *diff* would be performed between the revision and its randomly generated partner. The results from the developed *diff* program would be compared with the actual known changes listed by the test engine. Fortunately the changes were the same indicating that the *diff* worked correctly. The test engine was removed from this study because it did not give more depth into the main problem.

A difficulty was to understand the syntax of the MATLAB commands that were used for manipulating the Simulink models. The programming language itself was not complex but to understand the overall structure and connect it with the already developed MBVC toolbox took some time.

Classical development of software starts with engineers using pen and paper, then they immediately start programming the code. They keep on developing and adding more functions as time goes by, which requires continuous testing and debugging. This method works well, but is time consuming because of all testing and error correcting, and is platform dependant, which means that a program developed in Java cannot be used with applications in C or C++.

The new development techniques use models to develop software. A model is much easier for a user to overview than code is. Models can be built platform independent, so that one model can be transformed to work on different platforms. Rhapsody is a program that is used in MDD, and the user can model a system, and then also generate embedded code for that system. Rhapsody can generate four different source codes, to be used on different platforms.

A discussion is whether the code generated from Rhapsody is more optimized or advantageous in terms of size and efficiency over code developed by hand. This was not part of this thesis and thus no conclusion can be said about which code is "better" than the other. On the other hand it can be said that certain applications are safety critical and need fast and optimal code, while others do not. Therefore it is important to take into consideration what the end product requires in terms of processing speed and memory capacity.

8.3 Future Work

One interesting future study would be to implement other functionalities into the MBVC toolbox, such as branching, that provides the possibility to create branches and revisions, and be able to view the relations between them in an efficient manner.

Another interesting functionality is the locking and unlocking of models which is a type of restriction on how many users can check out the same file and modify it. This function supports concurrent development, and does not seem to involve algorithm planning, but rather a purely programming aspect.

One improvement that might be taken into consideration is introducing more efficient search algorithms and taking into regard the complexity of them. This requires a deeper study in the structure of programming strategy and knowledge in different complexity of algorithms. Algorithms with lower complexity could be used on larger models for studying the performance of the programs, and thus become one step closer to implementation in real life engineering development.

Another possible study would be to use models that do not have unique identifiers in any of their nodes, and see what improvements can be made to the algorithms and how difficulties in relating the blocks to each other can be resolved.

The functionalities can be expanded to work on other modeling languages such as Modelica or Dymola. It would be interesting to see such functionalities being built into the software. One further application is to connect this program with Java since MATLAB supports construction of Java objects. And finally to see the more powerful and complex 3-way merge, which was discussed in this thesis but never implemented.

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Appendix:

Appendix A

Pseudo Code: Difference

The complete 'difference' program is composed of two main programs: one that goes through all the blocks in the first model while the second goes through the blocks in the second model (reverse):

```
-------------------------------------------------------------
Function difference = FindDifference ('model_1','model_2','output')


for children blocks of model_1
    find the equivalent unique identifier if there is any such
    if there is a such identifier
        if the pair of blocks have equal properties
            add the block as black in output model
        else
            add the block as red in output model
            print the value of the different block properties
            if the blocks parent is of type subsystem
                colour that parent orange in the output model
            end
        end
    else  % If blocks do not have equal unique id's
        add the block as blue in output model
        if the blocks parent is of type subsystem
            colour that parent orange in the output model
        end
    end
    if the block is of type subsystem
        update the output to newOuptput
        findDifference(block,match,newOutput)
    end
end: for
end: function
-------------------------------------------------------------
Function diff_2= FindDifference_Reverse ('model_1','model_2','output')


for children blocks of model_2
    find the equivalent unique identifier % if there is any such in
model_1
```

```
    if there exists such an identifier
        do nothing
    else %If blocks do not have equal unique id's
        add the block as green in output model
        if the blocks has parent of type subsystem
            colour that parent orange in the output model
        end
    end
    if the block is of type subsystem
        update the 'output' to 'newOuptput'
        FindDifference_Reverse (block, match, newOutput) % recursive
    end
end: %for loop
end: %function
```

Appendix B: MATLAB's API

This section discusses the application programming interface (API) of MATLAB, the popular programming software. MATLAB is a high-level technical computing language and interactive environment for algorithm development, data visualization, data analysis, and numerical computation. MATLAB was chosen for this project since the models that were initially used for simulations were drawn in Simulink, and above that the model based version control system used for checking in- and out files was also written in MATLAB, thus making it a natural choice. [MAT]

MATLAB comes with a number of toolboxes each specialized for a certain field of engineering such as: optimization, statistics, curve fitting, control systems and other toolboxes. This idea of using specialized toolboxes for each specific field made it interesting to try and create a new toolbox based on the knowledge attained from this thesis.

Simulink models

Simulink is a platform for multi-domain simulation and Model Based Design of dynamic systems. It provides an interactive graphical environment and a customizable set of block libraries that let the user accurately design, simulate, implement, and test control, signal processing, communications, and other time-varying systems.

Models are built from a set of defined block libraries such as: math operations (addition, division, absolute values etc), logic and bit operations, signal routing (demux, bus selectors), discrete and continuous blocks (filters and transfer functions) and the possibility to create user defined functions. For more on toolboxes please refer to Simulink's homepage or the user manual [SIMU].

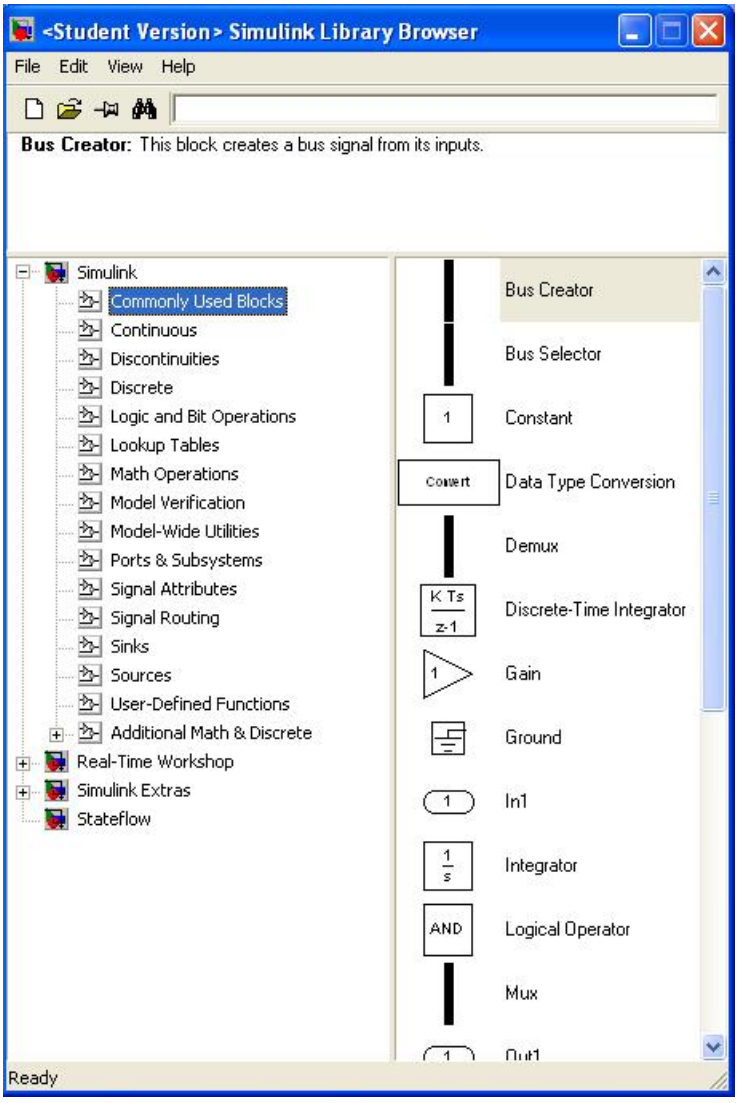

Figure 19: Overview of the Simulink toolboxes. Here is the "Commonly Used Blocks" toolbox shown. The blocks can be easily dragged into a model.

Models are the working area of Simulink and are created by choosing **File>New>Model**. Blocks from the toolboxes can then be dragged into this model and populated to create the specific models that are requested by the user.

Blocks are connected by lines, which are drawn between their ports. Each block has at least two ports, one *in port* and one *out port* with the exception of a few blocks such as in/out ports, constants and ground blocks. Ports belonging to blocks are named *internal ports of that block*. The name of each block can be easily changed by clicking on its existing name and typing in the new name.

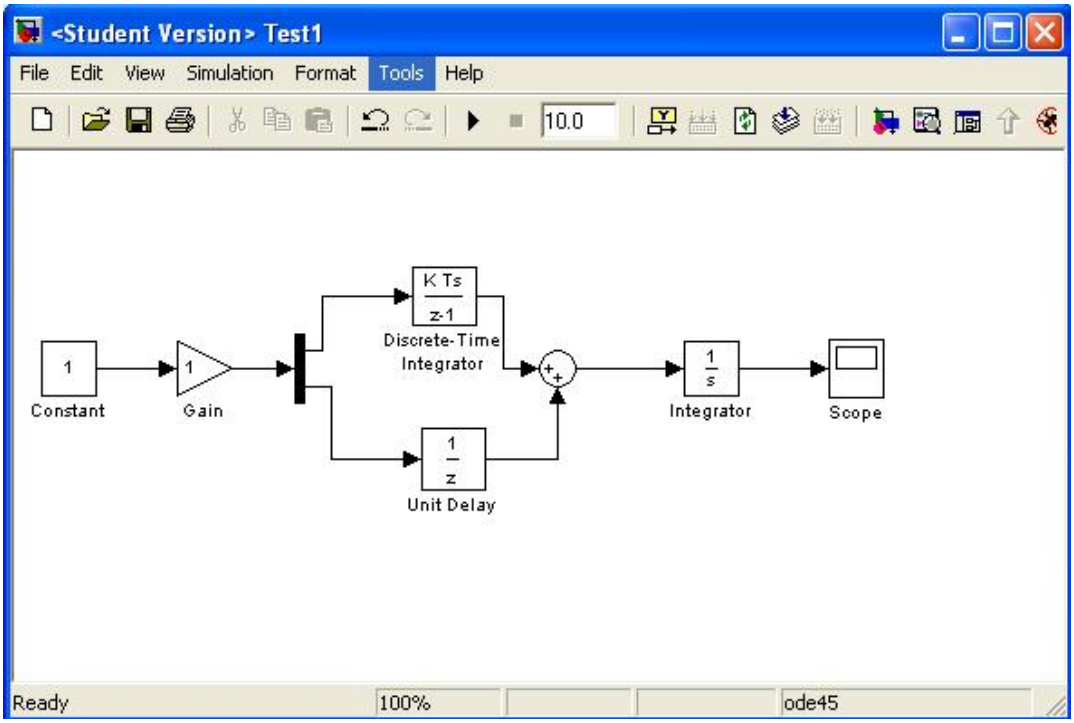

Figure 20: Figure showing a sample model built by blocks from the commonly used blocks toolbox

Subsystems are a clever way of connecting different systems together without having to deal with a large number of blocks in the same model. A subsystem has a specifically defined number of ports connecting it to the rest of the model using ports that are referred to as *external ports* relative to the model. Subsystems can be built into each other, thus connecting a large number of blocks and models into each other, resulting in a multi-level structured model.

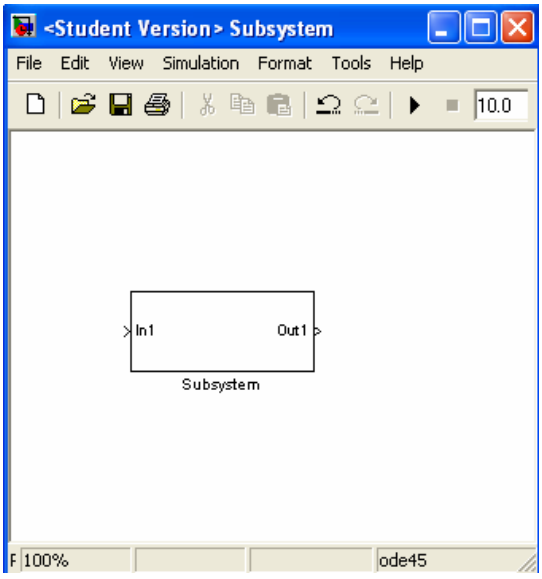

Figure 21: A subsystem block which may contain other blocks and/or sub models

New functions may be added to MATLAB's vocabulary if they are expressed in terms of other existing functions. The commands and functions that comprise the new

function must be put in a file whose name defines the name of the new function, with a filename extension of '**.m**'. At the top of the file must be a line that contains the syntax definition for the new function. For example, the existence of a file on disk called **STAT.M** with:

```
function [mean,stdev] = stat(x)
%STAT Interesting statistics.
n = length(x);
mean = sum(x) / n;
stdev = sqrt(sum((x - mean).^2)/n);
```

defines a new function called STAT that calculates the mean and standard deviation of a vector. The variables within the body of the function are all local variables.

Useful MATLAB Commands

MATLAB has commands that can be called upon that describe the qualities of each component in Simulink and these can be used to set new values for the parameters of the blocks. The following are useful built-in functions that make it easier to manage blocks:

ADD_BLOCK('SRC','DEST') copies the block with full path name '**SRC**' to a new block with full path name '**DEST**'. The block parameters of the new block are identical to those of the original. The name 'built-in' can be used as a source system name for all Simulink built-in blocks. Then, to add a 'Gain' block from the commonly used blocks toolbox, into a model 'test' one applies:

ADD_BLOCK('built-in/Gain','test/Gain') where the destination name, in this case Gain, may be any name of choice.

Another useful function is the **DELETE_BLOCK('BLK')** which is used for deleting a block from a Simulink system and where '**BLK**' is the full block path name.

Another important function is the GET_**PARAM('OBJ','PARAMETER')** which returns the value of the specified parameter, where 'OBJ' is either a system or block path.

GET_PARAM(OBJ,'ObjectParameters') returns a structure that describes **OBJ's** parameters. Each field of the returned structure corresponds to a particular parameter name (e.g., the '**Name**' field corresponds to **OBJ's** name parameter). If **OBJ's** is a block, the command will return a total of 144 object parameters describing the block, such as: name, tag, description, type, ports etc. Each block can be made unique by defining specific values to each of the object parameters.

One more important function is the:

FIND_SYSTEM('PARAMETER_NAME1',VALUE1,'PARAMETER_NAME2',VALUE2,...) that searches all open systems and returns a cell array containing the full path names in hierarchical order of all systems, subsystems, and blocks, whose specified parameters have the specified values. This function can also be modified to constrain certain searches by adding a couple of constraint/value pair followed by the specified

parameter/value pairs. One may also modify the command by adding a filter string, so that it searches only for a specific type of object type, such as lines, blocks or ports.

For a complete list of all constraint/value pairs please refer to the help section by typing **`help find_system.`**

Block Properties

Each block defined in Simulink has a '**`Block Type`**' property which can be prompted using the **`GET_PARAM(OBJ, 'BlockType')`** command, resulting in answers such as: **`'SubSystem'`**, **`'Inport'`**, **`'Constant'`**, **`'Gain'`**, **`'Sum'`**, **`'Outport'`** depending on the specific block type.

Another property of the blocks is the **`'Name'`** property which returns the name of the respective blocks. Another interesting property is changing colours of the blocks. The default colour is black, but one can choose among a large number of available ones such as: red, blue and green. The object is **`'ForegroundColor'`** and the command for doing so is **`set_param('Blk','ForegroundColor','Color')`** where **`'Color'`** is a string containing the desired colour and **`'Blk'`** is the full path name of the block.

Now one can access and change each of the individual property of each block, which gives the user a consistent method of specifying blocks with a few simple commands.

Lines

The lines are another important aspect of the Simulink models as they connect the different blocks through their input and output ports. The lines have the important idea of acting as logical flows for the data between the blocks. Lines are drawn by clicking on the desired port and by holding down the left mouse button, and then moving the pointer to the other port, and then finally releasing the mouse button. Simulink will automatically auto route the lines, that is it will draw the line in such a way to avoid passing through any other block in its path.

The **`add_line`** command adds a line to the specified system and returns a handle to the new line. A line can be defined in two ways: (1) by naming the block ports that are to be connected by the line or (2) by specifying the location of the points that define the line segments. **`add_line('sys','oport','iport')`** adds a straight line to a system from the specified block output port **`'oport'`** to the specified block input port **`'iport'`**. **`'oport'`** and **`'iport'`** are strings consisting of a block name and a port identifier in the form '**block/port**'. Most block ports are identified by numbering the ports from top to bottom or from left to right, such as **`'Gain/1'`** or **`'Sum/2'`**.

If a block is connected to a line, and the block is deleted, then the line will change to a red broken line automatically. The same happens if a line is not connected to two ports through its start and end points. A red line does not have the qualities of a line in MATLAB meaning that MATLAB does not consider it to be a line, although it is visible in the model. Only after connecting both of its ends to valid ports will it turn into a solid black line, and be given the qualities of a line.

Ports

As it was discussed earlier all types of blocks at least one port, while two ore more ports being more common. The ports are used to connect the various blocks with each other.

The ports have a specific port handle that identifies them, and can be called upon using the **`get_param('BLK','PortHandle')`** command, where **`BLK`** is the block path name. The result is a specific 6 digit number used for identifying the various ports.

Ports can be checked if they are empty or full, implying if they have lines connected to them or not using the **`get_param('PORT','line')`** where **`PORT`** is port handle given from the previous command. If the result is **-1**, negative value of one, then the port is empty and does not have a line connected to it, else a new six digit number is returned specific for the non-empty port.