Chapter 1

Introduction

This chapter starts with the aims and motivations for the thesis and associated research. It includes an account of the methodological challenges the subject of the thesis presents for research, challenges that had to be met by the author and that the reader should be aware of to fully appreciate the work. The source of the illustrative material used in the thesis is indicated. The chapter finishes with an outline of the thesis and abbreviations.

1.1 Preliminaries

A reader unfamiliar with the approach to modelling, known as Empirical Modelling, is recommended to see Appendix A which gives an account of the author's first experiences of Empirical Modelling when he modelled a sailboat as part of the M.Sc. module *Definitive Methods for Concurrent Systems Modelling* in December 1992 at the Department of Computer Science, University of Warwick. The account should give anybody who is unfamiliar with the modelling approach useful insight into the main concepts, principles, heuristics, techniques, notations and tools which constitute Empirical Modelling. For a more objective analysis of the modelling of the sailboat the reader is invited to read the paper [NBY94] which is an elaboration of the personal account for publication.

1.2 Aims and motivations

The motivation for this thesis stems from the interest expressed by the now disbanded IBM Warwick Software Development Laboratory (WSDL) in the potential of Empirical Modelling as a software development method. At about the same time they expressed an interest in Empirical Modelling the laboratory was changing its approach to software development from a traditional one, based on workbooks, to the established Shlaer-Mellor object-oriented analysis and design method [DSWW93, SM88, SM92]. Appendix B is a report prepared after an interview, by the author in November 1993, with those who were considering the prospect of giving up the old approach and adopting the techniques of the new method. This report helps to clarify the context in which the ideas developed in this thesis originated.

The primary aim of this thesis is to investigate the suitability of Empirical Modelling as a framework for a new approach to software development [BRS+89] that has creative as well as analytical components.[1] It was found inappropriate, during the investigation of Empirical Modelling, to think of Empirical Modelling in terms of conventional software development. Empirical Modelling provides general concepts and principles which apply to creative as well as analytical activities and artefacts. Showing Empirical Modelling as an appropriate framework for software development has meant finding ways of being explicit about how it combines creative and analytical components and the role that creativity has in the development of software.

In addition to the primary aim, a number of important issues in Empirical Modelling and software development were identified for the research to address:

Empirical Modelling as product design To investigate how Empirical Modelling relates to an essentially creative discipline, such as conceptual design. This investigation serves two purposes. First, to validate the assumption that Empirical Modelling is an appropriate vehicle for creativity. Second, to avoid

[1] The term *components* of Empirical Modelling and software development is used in a specific sense to mean the artefacts and the actions used by modellers and software developers in order to construct artefacts. The terms *creative* and *analytical* qualify the nature of the components: creative components are novel artefacts and the actions of creating novel artefacts; analytical components are familiar artefacts and the actions of forming familiar artefacts. Further clarification of these terms is left for subsequent chapters.

the framework for creativity becoming biased towards analysis; there is a danger that the general concepts and principles of Empirical Modelling may acquire analytical connotations if they are related to software development only.

Integrity of Empirical Modelling To investigate creativity in the Empirical Modelling framework in a way that has scientific integrity. Creativity has always been considered unresearchable because it lacks the rigour thought necessary for science [FWS92]. It tends to depend on introspective and descriptive accounts of creative processes. However, an approach is needed in order to relate Empirical Modelling, product design and software development that has a degree of scientific integrity appropriate to a thesis written for the scientific community. This methodological issue seldom arises when investigating analytical components of the traditional software development framework where the activities of software developers and the necessary properties of formal artefacts are well-established.

A paradigm for creative software development To propose a paradigm for creative software development and assess the likelihood of it being adopted by those currently involved in software development. This proposal is based on the Empirical Modelling framework and borrows from the concepts and principles of Empirical Modelling, product design and conventional software development. Suggestions for alternative paradigms of software development tend to be conservative. A paradigm based on a framework that includes creative and analytical components would be radically different from the paradigm of conventional software development and could potentially change the way software development is thought about and done in the future.

Resolving the software crisis To challenge the assumption that the software crisis will be resolved with the emergence of a software engineering discipline that takes an analytical approach to software development. Gibbs [Gib94] cites the view of many in software development who are confident they are on course for the end of the software crisis believing it is essentially a matter of time before software development and computer science merge to provide a foundation for software engineering. This raises a question: will software development and computer science merge in the future and if they do merge will software engineering provide a total solution to the software crisis?

1.3 Methodological challenges

The subject of this thesis has been regarded as largely unresearchable by scientists and engineers [FWS92]. Although creativity in product design and software development has long been a topic of interest it has not been considered a serious subject for study. Finke *et al* [FWS92] identify two primary reasons for this attitude. One is that the subject of creativity has had unscientific connotations, perhaps resulting from the reliance on anecdotal and introspective accounts to describe the creative process. Textbooks, if they mention creativity at all, tend to do so in an informal, descriptive way compared with the rigour given to processes in science and engineering. The other reason is the difficulties of studying creativity under controlled conditions. It is generally accepted that the creative process depends on the situation in which it occurs and cannot therefore be isolated for the purposes of description and rationalization without losing some of its essential qualities.

Finke *et al* address both these problems by adopting an experimental approach to the study of creativity. They present their approach in a book entitled "Creative Cognition: Theory, Research, and Application" reviewed in Appendix D. Experiments address the problem of scientific integrity by lending objectivity to anecdotal and introspective accounts of creative processes. Experiments, when properly executed, involve the rigorous testing of hypotheses by a community of scientists [Kap64, And68, CM81]. In addition, experiments address the problem of situatedness by allowing creativity to be investigated *in situ* rather than bringing it into the domain of mathematics and logic that is typical of theoretical approaches.

The author of this thesis addresses the problems of scientific integrity and situatedness in a similar way to Finke *et al* [FWS92] by taking an experimental approach. Although such an approach is unusual in computer science it was found to be an appropriate way of researching creativity with respect to the development of software. This thesis can be viewed as the result of an experimental approach to the research of creativity that began with hypotheses stated as aims earlier in this chapter. Research continued by observing Empirical Modelling, product design and software development in order to test the hypotheses. The results of observing the activities and the conclusions drawn from the results are given in subsequent chapters.

Taking an experimental approach to researching creativity causes problems when it comes to representing the results. There is not necessarily an established conceptual framework in which the scientist can work as there is in, for example, computer science. Finke *et al* addressed this problem by using accounts of experiments, drawings of structures, illustrative examples, case studies and descriptions of situations. In this thesis the author has made similar use, as for example in describing Empirical Modelling, of accounts of modelling, pictures of models, illustrative examples, case studies and descriptions of modelling situations in order to support the claims made in the main text. A similar approach to presentation is taken in other literature on Empirical Modelling [BNR+89, BBY92, BFY93, NBY94, BJ94, BSY95, BC97].

1.4 Sources of illustrative material

The main source of illustrative material for this thesis was an extensive project on lift systems. The lift project involved Empirical Modelling, product design and software development for conventional lift systems as well as an unconventional hydraulic system called a Hydrolift. It also involved the discovery of similar work going on at Stanford University under the name of the Sisyphus project [RGE+94, Yos92, Yos94] to do with research in ontologies for knowledge representation for engineering lift systems. Most of the work has been done by the author with some notable exceptions: Suker and Sidebotham [SS94] were funded by the University of Warwick to work during the summer on the lift project, and Yung and Joy worked on relating the Sisyphus models to the Empirical Modelling framework.

The lift project began with the author creating models using Empirical Modelling and object-oriented analysis to represent a conventional lift system from the viewpoint of an individual using the lift. The models based on this personal viewpoint were given the name of single-user-lift or SUL models. A public-domain CASE tool called OOTher [Zie94], based on similar commercially available tools, such as Teamwork used at the IBM WSDL (Appendix B), was used to create the SUL object-oriented models. The object-oriented models were implemented according to conventional object-oriented design and coding approaches using a generic architecture supporting graphical user interfaces and translator, both developed by the author.

The next important stage of the lift project came when the author worked with Suker and Sidebotham on extending the empirical models. First, the group used Empirical Modelling to represent a conventional lift system from the combined viewpoints of many individuals using a lift. The models based on this multiple viewpoint were given the name of multi-user-lift (MUL) models. Second, the group used Empirical Modelling to represent an innovative concept for a lift system, called a Hydrolift, from the viewpoint of an engineering designer. The models based on this engineering viewpoint were given the name of Hydrolift models.

Working in a group meant that communication between members emerged as an important issue. The group members used their LSD specifications, visualizations and animations to communicate their ideas to one another. Occasionally, these conventional artefacts of Empirical Modelling were supplemented by sketches such as a product designer might create during conceptual design. These sketches are reproduced in this thesis to illustrate the artefacts of product design. Sketches were particularly useful in communicating ideas about the Hydrolift.

The object-oriented MUL and Hydrolift models were created by the author after the group project. The author created the structure, behavioural and process models by following a method that was a generalization of the standard object-oriented methods. This began by describing the MUL and Hydrolift as a statement of requirements and then transforming the statement into the appropriate models. Although the author did not use the CASE tool OOTher for this exercise he did use the general principles that the tool shares with other commercially available, and typically more powerful, tools.

Other sources of material used in this thesis include a number of significant

Empirical Modelling projects:

- a sailboat resulting in a sailboat simulator (SBS) [NBY94] (Appendix A);
- a vehicle cruise controller (VCCS) [BBY92];
- the interaction between pupils and teacher in a classroom [Dav96];
- construction of a suite of OXO-like games [BJ94] (Chapter 2);
- a railway system [ABCY94c];
- the construction of a jigsaw puzzle [BSY95];
- the behaviour of a digital watch [BC95].

These projects did not involve the author in any direct way, except the SBS that was done almost entirely by the author. It is always made clear when material from these projects is used in the thesis.

1.5 Thesis outline

This thesis draws extensively on the concepts and principles of Empirical Modelling, product design and software development. The principal aim of this thesis is to investigate the suitability of Empirical Modelling as a framework for software development. Product design provides a context to this investigation to ensure that both the creative and analytical aspects of Empirical modelling are considered.

Chapter 2 introduces Empirical Modelling, product design and software development. It presents the basic concepts and principles used throughout the thesis. Empirical Modelling is introduced as a situated computer-based approach to modelling developed at the University of Warwick by the Empirical Modelling Group; the account of product design is based on Pugh's concept of total design [Pug91], with emphasis on the conceptual design phase; a mainstream view of software development is adopted, focusing on object-oriented analysis.

An insight into how Empirical Modelling, product design and software development differ in character is achieved by comparing them. However, it is important to find an appropriate framework for comparison because the three activities are very different in nature. Consideration of artefacts forms a suitable basis for such a framework. The various aspects of Empirical Modelling, product design and software development are then compared with respect to their use of artefacts.

Chapter 3 compares Empirical Modelling, product design and software development. The comparison focuses on the artefacts: the LSD specification, visualization and animation in Empirical Modelling, the sketch in product design, and the structure, behaviour and process models in software development. In addition to artefacts, the actions, subjects, constraints, environments and knowledge of the activities are compared: knowledge informs actions on an artefact within an environment to represent a subject under certain constraints.

Chapter 3 highlights the importance of artefacts in determining the nature of Empirical Modelling, product design and software development. Further investigation of the nature of these artefacts requires an understanding of what makes them essentially different. This investigation demands a framework for identifying and contrasting the properties of artefacts.

Chapter 4 compares the artefacts of Empirical Modelling, product design and software development to identify how they are essentially different. A framework is provided by a set of creative properties, characterized in the theory of creative cognition [FWS92], and their complementary analytical counterparts. The results of examining the artefacts of the lift project with respect to each of the properties are given. The characterization of artefacts is extended to construals for representing novel phenomena [Goo90] and engineering drawings [Fer92].

The activities of Empirical Modelling, product design and software development are essentially sequences of situated actions performed on artefacts by modellers, designers and software developers. Chapter 3 argued that the character of actions and other aspects of activities is determined by artefacts. It follows that the nature of the artefacts identified in Chapter 4 can be expected to determine the nature of actions.

Chapter 5 compares the actions of Empirical Modelling, product design and software development to identify how they are essentially different. A suitable framework for comparison is provided by the theory of creative cognition [FWS92] that characterizes processes as generative and exploratory. The results of examining the processes of the lift project with respect to each kind of action are given. The characterization of processes is extended to observation and experimentation in scientific inquiry [Kap64].

Chapters 3, 4 and 5 show that the artefacts and actions of Empirical Modelling and product design are different from those of software development. This suggests that Empirical Modelling and product design cannot be used as an approach to developing software in the conventional sense. Empirical Modelling and product design are more appropriately applied to the creative development of innovative systems than the methodical transformation of requirements into software that characterizes software development. One way that Empirical Modelling and product design could be construed as approaches to developing software is if software development could be viewed as systems development.

Chapter 6 considers how Empirical Modelling and product design might be used as an approach to developing software based on a generalization of the notions of computer, program and programming. The conventional view of the computer as an electronic device, or embodiment of a Turing machine, is generalized to *computer as artefact*, program as stored program is generalized to *program as system configuration*, and programming as software development is generalized to *programming as configuring systems* that is essentially the activity of Empirical Modelling and product design. The usefulness of this alternative view is assessed by considering how it addresses the topical issues in software development and requirements engineering.

Chapter 7 draws conclusions from the discussions and results in Chapters 3,4,5 and 6 and addresses the aims given in Chapter 1 and finishes with suggestions for further research in the area of creative software development.

1.6 Abbreviations

Abbreviations have been used throughout the thesis to improve readability:

ADM Abstract Definitive Machine and associated definitive programming language;

CDS Component Design Specification;

DoNaLD Definitive Notation for Line Drawing.

EDEN General purpose definitive programming language (abbreviation of "Evaluator of DEfinitive Notations");

EM Empirical Modelling;

Hydrolift The Hydrolift system from the viewpoint of a lift engineer;

LSD Specification language used in Empirical Modelling;

MUL Multi-user-lift system or, in other words, a conventional lift system from the combined viewpoints of multiple users;

PD Product design;

PDS Product Design Specification;

SD Software development;

SUL Single-user-lift system or, in other words, a conventional lift system from the viewpoint of a single user.