Evolution in Model-Driven Engineering

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Abstract

To be completed.

For my Nanna Spence

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Author Declaration

Except where stated, all of the work contained in this thesis represents the original contribution of the author. Section 6.3 includes work conducted in collaboration with others and the contributions of the thesis author are made clear in that section.

Parts of the work described in this thesis have been previously published by the author in:

- **The Epsilon Generation Language**, Louis M. Rose and Richard F. Paige and Dimitrios S. Kolovos and Fiona A.C. Polack in *Proc. European Conference on Model Driven Architecture – Foundations and Applications (ECMDA-FA)*, volume 5095 of LNCS, pages 116. Springer, 2008.
- **Constructing Models with the Human-Usable Textual Notation**, Louis M. Rose and Richard F. Paige and Dimitrios S. Kolovos and Fiona A.C. Polack in *Proc. International Conference on Model Driven Engineering Languages and Systems (MoDELS)*, volume 5301 of LNCS, pages 249263. Springer, 2008.
- **An Analysis of Approaches to Model Migration**, Louis M. Rose and Richard F. Paige and Dimitrios S. Kolovos and Fiona A.C. Polack in *Proc. Joint Model-Driven Software Evolution and Model Co-evolution and Consistency Management (MoDSE-MCCM) Workshop*, co-located with MoDELS 2009.
- **Enhanced Automation for Managing Model and Metamodel Inconsistency**, Louis M. Rose and Dimitrios S. Kolovos and Richard F. Paige and Fiona A.C. Polack in *Proc. International Conference on Automated Software Engineering (ASE)*, pages 545-549, ACM Press, 2009.
- **Concordance: An Efficient Framework for Managing Model Integrity**, Louis M. Rose, Dimitrios S. Kolovos, Nicholas Drivalos, James. R. Williams, Richard F. Paige, Fiona A.C. Polack, and Kiran J. Fernandes in *Proc. European Conference on Modelling Foundations and Applications (ECMFA)*, volume 6138 of LNCS, pages 62-73. Springer, 2010.
- **Model Migration with Epsilon Flock**, Louis M. Rose, Dimitrios S. Kolovos, Richard F. Paige, and Fiona A.C. Polack in *Proc. International Conference on the Theory and Practice of*

Model Transformations (ICMT), volume 6142 of LNCS, pages 184198. Springer, 2010.

- **Model Migration Case**, Louis M. Rose, Dimitrios S. Kolovos, Richard F. Paige, and Fiona A.C. Polack in *Proc. Transformation Tools Contest (TTC)*, co-located with TOOLS 2010.
- **Migrating Activity Diagrams with Epsilon Flock**, Louis M. Rose, Dimitrios S. Kolovos, Richard F. Paige, and Fiona A.C. Polack in *Proc. Transformation Tools Contest (TTC)*, co-located with TOOLS 2010.

In addition, the author has contributed to [Kolovos *et al.* 2007a], [Kolovos *et al.* 2007b] and [Paige *et al.* 2009].

Chapter 1

Introduction

There is a demand for increasingly complicated software, the construction of which is currently beyond our ability. [Selic 2003] observes that a similar situation occurred when steam and electrical power were introduced during the Industrial Revolution [Pool 1997].

Hardware development seems to advance more quickly than software development. For example, processors become faster and provide greater functionality each year, while software seems to improve more gradually. [Kleppe *et al.* 2003] indicates that software development is perceived to lag behind hardware development because of rising complexity in software systems. Software developers now build distributed and interoperating applications with sophisticated graphical interfaces rather than insular, monolithic mainframe applications with no user interface.

[Brooks 1986] observes that engineering increasingly complicated systems with traditional development approaches presents many challenges, including:

1. *Increasing size of development teams*: large teams may experience communication difficulties, detracting from productivity.

2. *Difficulties providing system overviews*: incomplete system knowledge can impede maintenance activities.

3. *Poor understandability*: new developers suffer a complex learning curve.

4. *Resistance to change*: development reacts slowly when (1) requirements change, (2) new underlying technologies are to be adopted, and (3) unintended behaviour must be corrected.

Uhl[1] notes that software development improves radically only when systems can be defined at a higher level of abstraction. Historically, raising the level of abstraction of software development has led to increased productivity. For example, assembly language provides mnemonics for machine code, allowing developers to disregard superfluous detail (such as the binary representation of instructions). Object-orientation and functional programming permit further abstraction over assembler, enabling developers to express solutions in a manner that is more representative of their problem domain.

[1]Keynote address to the Fourth European Conference on Model Driven Architecture (ECMDA), June 2008, Berlin, Germany.

Improvements to development processes have also facilitated greater abstraction. For example, developers are increasingly employing models of systems to aid design and implementation. During the 1990s, methods that prescribed modelling to aid software development were popular. A common modelling language, the Unified Modelling Language (UML) [OMG 2007a], was standardised by combining the modelling languages from three methods []. By communicating designs and abstracting away from unimportant details, software engineers are using models to address the first three of Brooks's challenges. However, modelling is effective only when the models are an accurate representation of the computer system.

During a system's lifecycle, design documents are often neglected and become out-of-date. Without a well-defined connection to the system's implementation, models are effectively design documents that might be neglected and can become inaccurate representations of the system [Frankel 2002, Kleppe *et al.* 2003]. For models to be used as effective means of communication and education, they must be accurate and, therefore, must be maintained and updated in response to change. Maintaining two unconnected representations of a system (models and implementation) obviously detracts from the productivity of the development team. Instead, an approach to software development that integrates modelling and coding can be used to address this productivity problem, as well as the first three of Brooks's challenges.

1.1 Model-Driven Engineering

1.2 Software Evolution

Studies [Erlikh 2000, Moad 1990] suggest that the evolution of software can account for as much as 90% of a development budget. Such figures are sometimes described as uncertain [Sommerville 2006, ch. 21], mainly because terms such as evolution and maintenance are used ambiguously. However, precise figures are not required to see that the effects of evolution can inhibit the productivity of software development.

Studying software evolution can provide benefits other than improving the maintainability of a system. For instance, by understanding the mistakes made in the engineering of existing software systems, similar mistakes may be avoided in the future. Experts and analysts can devise best practices that guide developers away from problematic practices. For this reason, Kerievsky notes that "studying the evolution of great software designs will be more valuable than studying the great designs themselves" [Kerievsky 2004].

[Lehman 1980, Lehman 1978, Lehman 1969] identify several laws of software evolution for *evolutionary-type systems* (*E-type systems*) – systems that solve problems or implement software in the real world. E-type systems differ from *specification-type systems* (*S-type systems*) where the "sole criterion of acceptability is correctness in the mathematical sense" [Lehman 1985].

The law of *continuing change* states that "E-type systems must be continually adapted else they become progressively less satisfactory" [Lehman 1978]. Later, Lehman et al. [Lehman 1996] introduce another complementary law, the law of *declining quality*: "The quality of E-type systems will appear to be declining unless they are rigorously maintained and adapted to operational environment change". Both laws indicate that the evolution of E-type systems during their effective lifetime is inevitable.

1.3 Software Evolution Challenges in MDE

1.4 Research Hypothesis

The research presented in this thesis explores the following hypothesis:

> *In existing MDE projects, evolution is typically managed in an ad-hoc manner with little regard for re-use. Dedicated structures and processes for identifying and managing evolutionary change can be designed by analysing evolution in existing MDE projects. Furthermore, supporting those dedicated structures and processes in contemporary MDE environments is beneficial in terms of increased **productivity**, **understandability**, and **portability**.*

Some of the terms used in the research hypothesis are ambiguous, and require further definition. Specifically, the terms productivity, understandability and portability are defined as follows:

Productivity is a measure of the amount of work required to complete a development activity. For example, the productivity of data entry might be increased by using an Optical Character Recognition (OCR) system rather than a typist. In this scenario, the extent to which productivity might be increased is affected by at least the following: the accuracy and capabilities of the OCR system, the speed and accuracy of the typist, and the legibility and consistency of the data. In general, productivity is affected by many factors.

Understandability is a measure of the ease with which the purpose, motivation and workings of a system can be identified from the representation of that system. For example, the function of a circuit is arguably easier to understand when examining a schematic of the circuit rather than a Printed Circuit Board (PCB) that implements the circuit. For example, components are often arranged to save space on a PCB, while components might be arranged to ease understanding of the system on a schematic. Clearly, understandability is somewhat subjective. Due to differences in knowledge and experience, a representation that is easy to understand for one person may be difficult for another.

Portability is a measure of the extent to which a system can be changed to interoperate with other systems. For example, a system implemented directly in machine code can be used with only one family of machines, while an equivalent system implemented in a high-level language (and compiled to machine code) can be used with different families of machine. Hence, the latter is more portable than the former.

1.4.1 Thesis Objectives

The objectives of the thesis are to:

1. Identify and analyse evolutionary change in existing MDE projects.

2. Investigate the extent to which existing structures and processes for identifying and managing evolutionary change can be used in MDE.

3. Develop new structures and processes for identifying and managing evolutionary change in the context of MDE, and integrate those structures and processes with a contemporary MDE development environment.

4. Evaluate and assess new and existing structures and processes for identifying and managing evolutionary change, particularly with respect to productivity, understandability and portability.

1.5 Research Method

To explore the hypothesis outlined above, the thesis research was conducted using the method described in this section and summarised in Figure 1.1. The green boxes represent the three *phases* of research, which are described below. The white boxes represent inputs and outputs to those phases.

Firstly, the *analysis* phase involved identifying the ways in which evolution has occurred and has been identified and managed in existing MDE projects. The type of data obtained from the analysis phase determined the context in which the thesis research was conducted, model-metamodel co-evolution. Examples of evolution taken from existing MDE projects were used to investigate the strengths and weaknesses of existing structures and processes for identifying and managing evolution. Requirements for new structures and processes for identifying and managing evolution were formulated from the results of the analysis phase.

The *implementation* phase involved designing and implementing novel structures and processes for identifying and managing evolution, and integrating the structures and processes with a contemporary MDE environment. The examples of evolution used in the analysis phase were used for testing the implementation of the structures and processes.

The *evaluation* phase involved assessing the novel structures and processes for identifying and managing evolution by comparison to existing structures and processes. Evaluation was performed using examples of evolution from MDE projects. To mitigate a possible threat to the validity of the research, the examples used in the evaluation phase were different to those used in the analysis phase. The strengths and weaknesses of the novel and existing structures and processes were synthesised from the comparisons, particularly with respect to productivity, understandability and portability.

A similar method was used successfully in [Dig 2007] to explore the extent to which component-based applications can be automatically evolved. Initially, [Dig & Johnson 2006b] conducted *analysis* to identify and categorise evolution in five existing component-based applications, with the hypothesis that many of the changes could be classified as behaviour-preserving. By using examples from the survey, [Dig *et al.* 2006] were able to *implement* an algorithm for automatically detecting behaviour-preserving changes. The algorithm was then used to implement tools for (1) migrating code in a distributed and collaborative software development environment [Dig & Johnson 2006a], and (2) analysing the

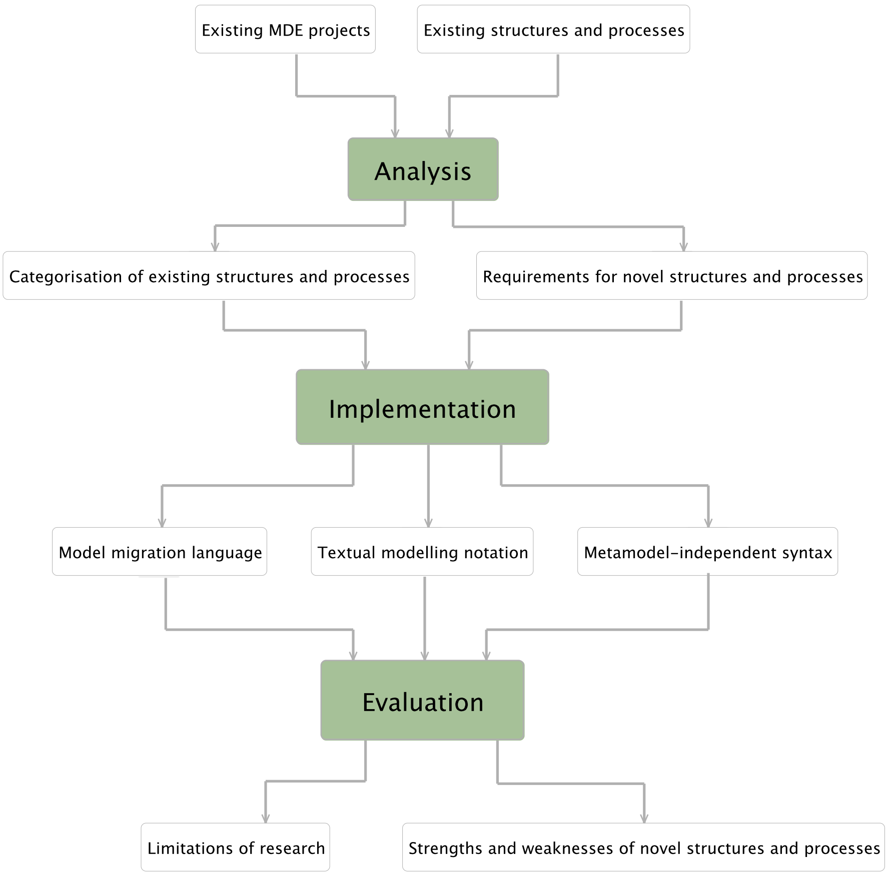

Figure 1.1: Overview of the research method.

history of component-based applications [Dig *et al.* 2007]. The latter facilitated better understanding of program evolution, and refinement of the detection algorithm. Finally, [Dig 2007] *evaluated* the tools and detection algorithm by application to three further component-based applications.

1.6 Thesis Structure

Chapter 2 gives an overview of MDE by defining terminology; describing associated engineering principles, practices and tools; and identifying related areas of computer science. Section 2.5 synthesises some of the benefits of – and challenges to – contemporary MDE.

Chapter 3 reviews theoretical and practical software evolution research. Areas of research that underpin software evolution are described, including refactoring, design patterns, and traceability. The review then discusses work that approaches particular categories of evolution problem, such as programming language, schema and grammar evolution. Section 3.2.4 surveys work that considers the evolution of MDE development artefacts (such as models and transformations). Section 3.3 identifies three types of evolution that occur in MDE projects and highlights challenges for their management.

Chapter 4 surveys existing MDE projects and categories the types of evolution occurring in each project. From this survey, a context for the thesis research is established (a type of evolution termed model-metamodel co-evolution). Examples of evolution taken from the existing MDE projects are used to identify the strengths and weaknesses of existing structures and processes for identifying and managing evolution. From this, Section 4.2.2 identifies a process for identifying and managing evolution which has not been recognised previously in the literature, Section 4.2.3 derives a categorisation of the existing structures and processes, and Section 4.3 synthesis requirements for novel structures and processes for identifying and managing evolution.

Chapter 5 describes three novel structures and process for identifying and managing evolution in the context of MDE. The first, a metamodel-independent syntax, is used to identify – and to facilitate the reconciliation of – problems caused by evolution. The textual modelling notation described in Section 5.2 and the model migration language described in Section 5.4 are used for reconciliation of problems caused by evolution. The latter provides a means for performing reconciliation in a repeatable manner.

Chapter 6 assesses the novel structures and processes developed in Chapter 5 by comparison to existing structures and processes. To explore the research hypothesis, several different types of comparison were performed, including an experiment in which quantitive measurements were derived, a collaborative comparison of model migration tools with three MDE experts, and application to a large, independent example of evolution taken from a real-world MDE project.

Chapter 7 summarises the achievements of the research, and discusses results in the context of the research hypothesis. Limitations of the thesis research and areas of future work are also outlined.

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