Evolution in Model-Driven Engineering

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Abstract

We present a structure for a proposed thesis, which will focus on software evolution and its impact on the maintainability of systems, particularly in the context of model-driven engineering. In addition, we restate our research aims, discuss the progress made since submission of a report in January 2009, and provide a revised timetable for the next six months.

This report comprises 4,485 words, as counted by detex | wc -w.

Contents

1 Introduction

Software evolution is a development activity in which a software system is updated in response to some external pressure (such as changing requirements). [Brooks 1986] observes that engineering increasingly complicated systems with traditional development approaches presents many challenges including a resistance to evolution. Software evolution is discussed in Section 1.1.

Model-Driven Architecture (MDA) is a software engineering framework defined by the Object Management Group (OMG) [OMG 2008]. MDA provides a set of standards for developing computer systems in a model-centric, or *model-driven*, fashion. In *model-driven engineering* (MDE), models are utilised as the primary software development artefact.

A model is a description of a phenomenon of interest [Jackson 1996], and may have either a textual or graphical representation. A model provides an abstraction over an object, which enables engineers of differing disciplines to reason about that object [Kolovos *et al.* 2006].

Several approaches to MDE are prevalent today, such as [Stahl *et al.* 2006], [Kelly & Tolvanen 2008] and [Greenfield *et al.* 2004]. The approaches vary in the extent to which they follow the standards set out by MDA. [Watson 2008] claims that employing the MDA guidelines significantly improves both developer productivity and the correctness of software.

1.1 Software Evolution in Model-Driven Engineering

In the past, studies [Erlikh 2000, Moad 1990] have found that the evolution of software can account for as much as 90% of a development budget; there is no reason to believe that the situation is different now. [Sjøberg 1993] identifies reasons for software evolution, which include addressing changing requirements, adapting to new technologies, and architectural restructuring. Evolution is key to incremental and iterative software engineering techniques, such as Test-Driven Development (TDD) [Beck 2002].

Software development often involves constructing a system by combining numerous types of artefact (such as source and object code, build scripts, documentation and configuration settings). Artefacts depend on each other. Some examples of these dependencies from traditional development include: compiling object code from source code, generating documentation from source code, and deploying object code using a build script. When one artefact is changed, the development team updates the other artefacts accordingly. Here, this activity is termed *migration*.

MDE introduces additional challenges for controlling and managing evolution [Mens & Demeyer 2007]. For example, MDE prescribes automated transformation from models to code. Transformation may be partial or complete; and may take a model direct to code or use intermediate models [Kleppe *et al.* 2003]. Any code or intermediate models generated by these transformations are interdependent with other development artefacts – e.g. a change to a model may have an impact on other models [Deursen *et al.* 2007]. The process of maintaining consistency between interdependent models is termed *model synchronisation*.

To specify a transformation for a model, the model must have a well-defined set of structural elements and rules that it must obey. This information can be specified in a structured artefact termed a *metamodel*. A model is dependent on its metamodel. When a metamodel is changed, its models may require migration. The process of maintaining consistency between a model and its metamodel is termed *(model and metamodel) co-evolution.*

1.2 Research Aim

In traditional software development, some migration activities can be automated (e.g. background incremental compilation of source code to object code), while some must be performed manually (e.g. updating design documents after adding a new feature). MDA seeks to reduce the amount of manual migration required to develop software, but presently no tools for MDE fully support automated evolution; managing evolution in the context of MDE remains an open research problem.

The aim of our research is to develop structures and processes for managing evolutionary changes in the context of Model-Driven Engineering. In our progress report, we presented and discussed data from existing MDE projects. No data was available for studying model synchronisation, and we decided to focus on developing structures and processes for managing (model and metamodel) co-evolutionary changes.

2 Proposed Thesis Structure

We now describe the anticipated structure for the proposed thesis. Chapter-by-chapter, we describe content and briefly explain how much progress has been made since the progress report. (Section 3 contains a more detailed discussion of progress).

2.1 Introduction

The introduction will motivate the proposed thesis, introducing model-driven engineering and software evolution.

2.1.1 Model-Driven Engineering

The proposed thesis will begin by discussing the challenges that MDE addresses. Terminology relevant to MDE will be introduced (including terms such as *model*, *metamodel* and *model transformation*). The benefits of MDE will be discussed along with the main threats to its adoption, which include challenges for controlling and managing software evolution with MDE [Mens & Demeyer 2007].

2.1.2 Software Evolution

The introduction will then discuss software evolution, and its causes. The challenges presented by software evolution will be highlighted, particularly in the context of MDE, and used to motivate the proposed thesis.

2.1.3 Research Aim

The high-level aim of the research will be stated, providing a context for the background and literature review chapters.

2.1.4 Research Method

This section will discuss the way in which the research was conducted, including a description of the evaluation strategy.

2.1.5 Status of the chapter

The introduction will be based on the introduction and literature review chapters of the qualifying dissertation, and introductory material from our publications (discussed in Section 2.6.2). However, as MDE is an emerging discipline, any content taken from previous reports and publications will need to be updated.

2.2 Background

The background chapter will serve two purposes: firstly, to introduce areas of computer science that are related to our research, and secondly to introduce two categories of evolution observed in model-driven engineering. These two categories were described in the progress report.

2.2.1 Related Areas

Several subsections will be used, one per related area. Topics are likely to include domain-specific languages and language-oriented programming; refactoring and design patterns; and iterative and incremental approaches to software engineering. We will discuss the applicability and relationship of each area to software evolution in the context of model-driven engineering.

2.2.2 Categories of Evolution in MDE

This section will discuss model and metamodel co-evolution and model synchronisation, two categories of evolution observed in MDE. These categories were introduced in Section 1 of this thesis outline.

2.2.3 Status of the chapter

The background chapter will be based partly on the literature review section of the qualifying dissertation, and partly on a section from the progress report. Again, any content from previous reports will likely need to be updated.

2.3 Literature Review

The literature review chapter will provide a thorough review and critical analysis of software evolution research. We will compare and contrast existing techniques for managing and automating activities relating to software evolution. As well as reviewing techniques that apply to the specific challenges caused by software evolution in the context of MDE, we will also critique literature from related areas, such as database and XML schema evolution; and program and modelling language evolution. This chapter will conclude by providing high-level research objectives in the context of the reviewed literature.

Status: The literature review section of the qualifying dissertation will provide a framework and some content for this chapter. However, there are areas that will need a more thorough and critical analysis than provided in the qualifying dissertation, such as model synchronisation and incremental model-to-model transformation.

2.4 Analysis

The literature review will motivate a deeper analysis of existing techniques for managing evolution in the context of MDE. The benefits and drawbacks of existing techniques will be highlighted by applying them to data from projects using MDE. The analysis will be used to identify requirements for our research.

2.4.1 Locating Data

The first section of the analysis chapter will be based on a section of the progress report, which discusses the data (existing MDE projects) used to analysis existing techniques for managing evolution in the context of MDE. We will introduce and explain the requirements on the data to be used for analysis, identify candidate MDE projects, describe the selection process, and provide reasons for our choices.

Status: Completed. Discussed in the progress report. Some further data may be located before submission of the proposed thesis.

2.4.2 Analysing Existing Techniques

Having described the selection of suitable data for the analysis, we will then outline the way in which we have applied existing techniques to the data, and introduce criteria against which the effectiveness of existing techniques will be measured.

Status: Completed. Discussed in Section 3.

2.4.3 Requirements Identification

The analysis of existing techniques will lead to requirements for our research. We will conclude the chapter by enumerating these requirements, refining the high-level research objectives from the literature review chapter into lower-level research objectives.

Status: Completed. Discussed in Section 3.

2.5 Implementation

The implementation chapter will describe the way in which we have approached the requirements presented in the analysis chapter. The requirements will be fulfilled by implementing several related solutions. The solutions will take different forms, including domain-specific languages, automation, and extensions to existing modelling technologies.

2.5.1 Metamodel-Independent Syntax

XMI, an OMG standard for metamodel interchange, and EMF, arguably the most widely used modelling framework, serialise models in a metamodel-specific manner. Consequently, information from the metamodel is required during deserialisation. If the metamodel has evolved since the model was last serialised, deserialisation may fail. This limitation has a major impact on existing techniques for performing co-evolution, forcing them to store original and evolved copies of metamodels.

In a submission to ASE 2009, we have highlighted the problems that a metamodel-specific syntax poses for managing and automating co-evolution, and described our solutions. We prescribe the use of a metamodel-independent syntax for storing models. We also show other ways in which a metamodel-independent representation can be useful for managing and automating co-evolution: Specifically, checking consistency with any metamodel, and performing automatic consistency checking when a new metamodel version is encountered.

Status: Completed. Discussed in Section 3. The work has been submitted to ASE 2009.

2.5.2 Human-Usable Textual Notation

The Human-Usable Textual Notation is an OMG standard textual concrete syntax for the MOF metamodelling architecture. The notation is metamodel-independent – it can be used with any model that conforms to any MOF-based metamodel. HUTN provides a human-usable means for visualising and specifying models, even when those models are inconsistent with their metamodel.

Status: Completed. As discussed in the progress report, we have developed the only implementation of OMG HUTN, publishing our work at MoDELS 2008 ([Rose *et al.* 2008a]). We have discussed the way in which HUTN may be used during semi-automated migration of inconsistent models in our submission to ASE 2009.

2.5.3 DSL for Migration Strategies

Some of the requirements presented in the analysis chapter can be addressed by a domain-specific language for specifying migration strategies. Migration strategies will be specified as a model transformation on inconsistent models expressed in a metamodel-independent representation. Transforming a metamodel-independent representation affords us some advantages (such as being able to store partially consistent models) over existing techniques (which transform metamodel-specific representations). As discussed in the progress report, a domain-specific language, rather than an existing model-to-model transformation language, is required to address the specific requirements of model migration.

Status: Ongoing. A plan for completion is discussed in Section 3.2.

2.5.4 Further solutions

Further solutions will be required to meet all of the requirements outlined in the analysis chapter. These solutions are likely to include approximately two of the following:

- Extending the DSL for migration strategies: [Herrmannsdoerfer *et al.* 2008a] identify the need for re-usable migration strategies, encoded independently of the evolving metamodel. Supporting re-usable migration strategies will likely involve extending the DSL discussed above.

- Inference of migration strategies: [Lerner 2000] motivates an alternative to a migration strategy language in which migration strategies are inferred by comparing old and new metamodels. Cicchetti has explored this idea, providing a prototypical implementation in [Cicchetti *et al.* 2008]. We will investigate the benefits and drawbacks of inferring migration strategies compared to using a migration strategy language. We may choose to develop a new (or extend an existing) inference algorithm, and analyse to what extent it complements a migration strategy language for managing co-evolutionary change in the context of MDE.

- A metamodel refactoring browser for EMF: inspired by the Smalltalk refactoring browser [Roberts *et al.* 1997], this tool will provide descriptions and allow execution of refactorings for improving the design of existing metamodels. Refactorings will preserve model and metamodel consistency. A refactoring browser for EMF would increase developer productivity by automating common metamodel evolutions.

- Model-driven migration: As discussed in our ASE 2009 submission, a metamodel-independent syntax enables new approaches to co-evolution. For instance, co-evolution can be driven from models, rather than their metamodel:

  1. Discover a new concept to be modelled.
  2. Represent an existing model that lacks this concept using a metamodel-independent syntax, and generate corresponding HUTN.
  3. Evolve the model in HUTN to express the new concept.
  4. Check consistency with the existing metamodel. Reconcile any inconsistencies by evolving the metamodel.
  5. Use the model evolution from step 3 to guide migration of other models.

  We will explore and implement a new approach for automated management of co-evolution, such as the one outlined above.

Status: Ongoing. A plan for deciding between these options, and for their completion, is discussed in Section 3.2.

2.6 Evaluation

The evaluation chapter will outline our evaluation method and results, including the impact and limitations of our research; and discuss the extent to which the requirements identified in the analysis chapter have been fulfilled. Evaluation will be conducted in three ways: application of our structures and processes in a case study; publication of our research in academic journals, international conferences and workshops; and assessing the contribution made when delivering our work through an Eclipse research incubation project.

2.6.1 Case Study

We will apply our structures and processes to the Eclipse Generative Modelling Framework (GMF) project [Gronback 2006]. GMF allows the definition of graphical concrete syntax for metamodels. GMF prescribes a model-driven approach: Users of GMF define concrete syntax as a model, which is used to generate a graphical editor. In fact, five models are used together to define a single editor using GMF.

GMF defines the metamodels for graphical, tooling and mapping definition models; and for generator models. The metamodels have changed considerably during the development of GMF. Some changes have caused inconsistency with GMF models. Presently, migration is encoded in Java. Gronback has stated[1] that the migration code is being ported to QVT (a model-to-model transformation language) as the Java code is difficult to maintain.

We identified GMF as the most appropriate candidate for the analysis phase of our research. Consequently, we decided to reserve GMF for the evaluation of our work.

Status: Scheduled to begin in February 2010, as discussed in Section 3.2.

2.6.2 Publications

Publication in academic journals, and at international conferences and workshops ensure that our work is reviewed by experts, and is well-established and communicated in our field of research. So far, I have been the primary author for publications at one international conference ([Rose *et al.* 2008a]), one European conference ([Rose *et al.* 2008b]), and one workshop ([Rose *et al.* 2009]). The first was published at MoDELS/UML, the leading international conference on model-driven engineering, in a year when it had a record number of submissions (274, 20% acceptance), and has been nominated by HISE for the annual departmental award for best paper by a research student.

We will submit our work to software evolution conferences, as well as at model-driven engineering conferences. Doing so will allow us to assess the impact of our research for a broader audience.

Status: Ongoing. We plan to submit to at least ECMDA 2010 and MoDELS/UML 2010, as discussed in Section 3.2.

2.6.3 Delivery through Eclipse

The tools produced as part of our research have been and will continue to be released as part of the Epsilon project, a member of the research incubator for the Eclipse Modeling Project (EMP), arguably the most active MDE community at present. EMP's research incubator hosts a limited number of participants, selected through a rigorous process. Contributions made to the incubator undergo regular technical review.

Contributing to Epsilon allows us to deliver our research to the growing community [Kolovos 2008] of Epsilon users.

Status: Ongoing. Bugs and requests for feature enhancements are being tracked via Epsilon's newsgroup and bug tracking software.

[1] Private communication, 2008.

2.6.4 Limitations

We will discuss the limitations of our work, using for context the feedback of users, reviews of publications and scenarios from the case study discussed in Section 2.6.1.

Status: Not yet started.

2.7 Conclusion

The conclusion will provide a summary of the challenges addressed by, and the objectives of, our research. We will summarise the way in which we have approached the challenges and met the objectives, concluding with a summary of the evaluation and discussion of future work.

Status of the chapter: Not yet started.

3 Progress

3.1 Achievements

We now reproduce the goals described in the progress report, and discuss the achievements made since submission of that report.

Plan stake-holder survey No existing co-evolution research identifies requirements from developers working on MDE projects. By surveying developers working on existing MDE projects, we planned to ascertain data which would be used to derive requirements for our research. The survey would find answers to the following types of questions: Which tools are developers using for editing and versioning their models and metamodels? Are developers regularly introducing inconsistencies between their models and metamodels? Are developers performing co-evolution manually or using a tool? Which tools are being used for co-evolution?

Goals: Devise and conduct a survey of developers working on existing MDE projects. Identify a process for devising an effective survey. Determine suitable questions, and use the answers to derive requirements for the proposed thesis.

Progress: To discuss conducting a survey of developers, I met with Chris Power and Paul Cairns (members of the York Human Computer Interaction group, who both have experience in developing surveys). Power and Cairns advised against conducting a survey, because producing a concise survey containing clear, unambiguous language would be very difficult. Instead, Power and Cairns suggested we interview experts in the field to ascertain the most widely used and unambiguous terms, and then conduct a survey.

Because we have only a limited amount of time to dedicate to requirements analysis, we have decided not to pursue surveying developers. Instead, we will focus on analysing existing techniques and collaborating with colleagues working with evolving metamodels to derive requirements. Furthermore, feedback from users will be used to further guide development of our structures and processes.

Analyse COPE and Cicchetti's work Both [Herrmannsdoerfer *et al.* 2008b] and [Cicchetti *et al.* 2008] describe tools for performing co-evolution. By analysing both tools with data located from existing MDE projects, we have continued to identify areas in which these tools are effective, and ways in which they may be improved. The analysis has provided requirements for our research.

Goals: Use the example data discussed in the progress report to determine the effectiveness and shortcomings of existing tools for performing automated co-evolution. Use the findings to derive requirements for our research.

Progress: We have devised six experiments for the co-evolution tools identified above. Each experiment explored different capabilities of the tools. We have used the findings to identify and motivate requirements. For example, one of the experiments assessed the effectiveness of the tools when managing the migration of a small number of inconsistent models. Considerable effort was required to use either of the tools for any amount of automated migration. Consequently, we felt that the tools provided diminishing returns when used to manage co-evolution in the face of a small number of inconsistent models. In our submission to ASE 2009, we discuss this situation in more detail, describe a semi-automated solution, and provide a concrete example.

Collaborate with Barber and with Sampson We have continued to collaborate with Barber (University of York) and with Sampson (University of Kent) to iteratively and incrementally produce metamodels as discussed in the progress report. Initially, we wished to collect a record of evolutionary changes made during the development of metamodels. Were we to encounter any evolutionary changes that inhibited development, we would use them to derive further requirements for our research.

Goals: Determine the extent to which the development of Barber's and Sampson's metamodels will aid our research. Observe and record any evolutionary changes made during the development. Obtain requirements from the data, and from Barber's and Sampson's experiences with MDE.

Progress: Collaboration with Sampson and Barber has allowed us to observe several evolutionary changes, three of which we had not previously observed for any other metamodel. Work with Sampson is ongoing. One of Sampson's colleagues, Jon Simpson, a research student at the University of Kent, will be further developing Sampson's metamodel, and developing model management operations for that metamodel. I am optimistic that Simpson's work will produce data for an initial study of model synchronisation, a category of evolutionary change in MDE for which we presently have no data.

Plan model migration language We have consolidated the results of previous activities to produce requirements for a language for specifying and executing model migration strategies. In addition, we have begun to prototype the language. The primary aim of the prototype was for me to gain experience with unfamiliar technologies.

Goals: Produce a list of requirements for a co-evolution language. Investigate any unfamiliar technologies that may aid in the development of the language.

Progress: We have produced a list of requirements for the language. Briefly, the requirements are the need for: concise and expressive language constructs for manipulating metamodel-independent representations of a model, constructs that provide re-use between migration strategies, a homogenous transformation engine[2], and development tools that provide assistance in formulating and executing migration strategies.

Presently, we are investigating implementation strategies. We will likely implement the language as an internal extension to an existing language, such as Ruby or Scala. Another option is to contribute a new language to Epsilon, a model management framework providing a re-usable architecture for specifying DSLs that manipulate EMF-based models.

Write paper for MoDELS / SLE / MCCM 2009 The research conducted before July 2009 has yielded publishable results. The progress report stated that the collaboration with Barber would be used to generate a report describing our experiences with current MDE tools. We would be able to highlight the need for automated co-evolution tools and discuss why this need is not yet being fulfilled.

Goals: Publish a paper at MoDELS 2009 (or co-located conferences).

Progress: The work with Barber (and with Sampson) highlighted deficiencies with existing modelling technologies. In particular, we found several issues that inhibited our ability to develop a metamodel iteratively and incrementally in a collaborative environment. These issues motivated requirements for our research. We have submitted a paper to ASE 2009 that discusses this issues and describes our solutions. We chose ASE rather than MoDELS to assess the contribution in the context of a wider audience (ASE is a software engineering conference, rather than a model-driven software engineering conference), and because the deadline for ASE was later than for MoDELS. If the submission is not accepted at ASE, we will revise and send it to another conference.

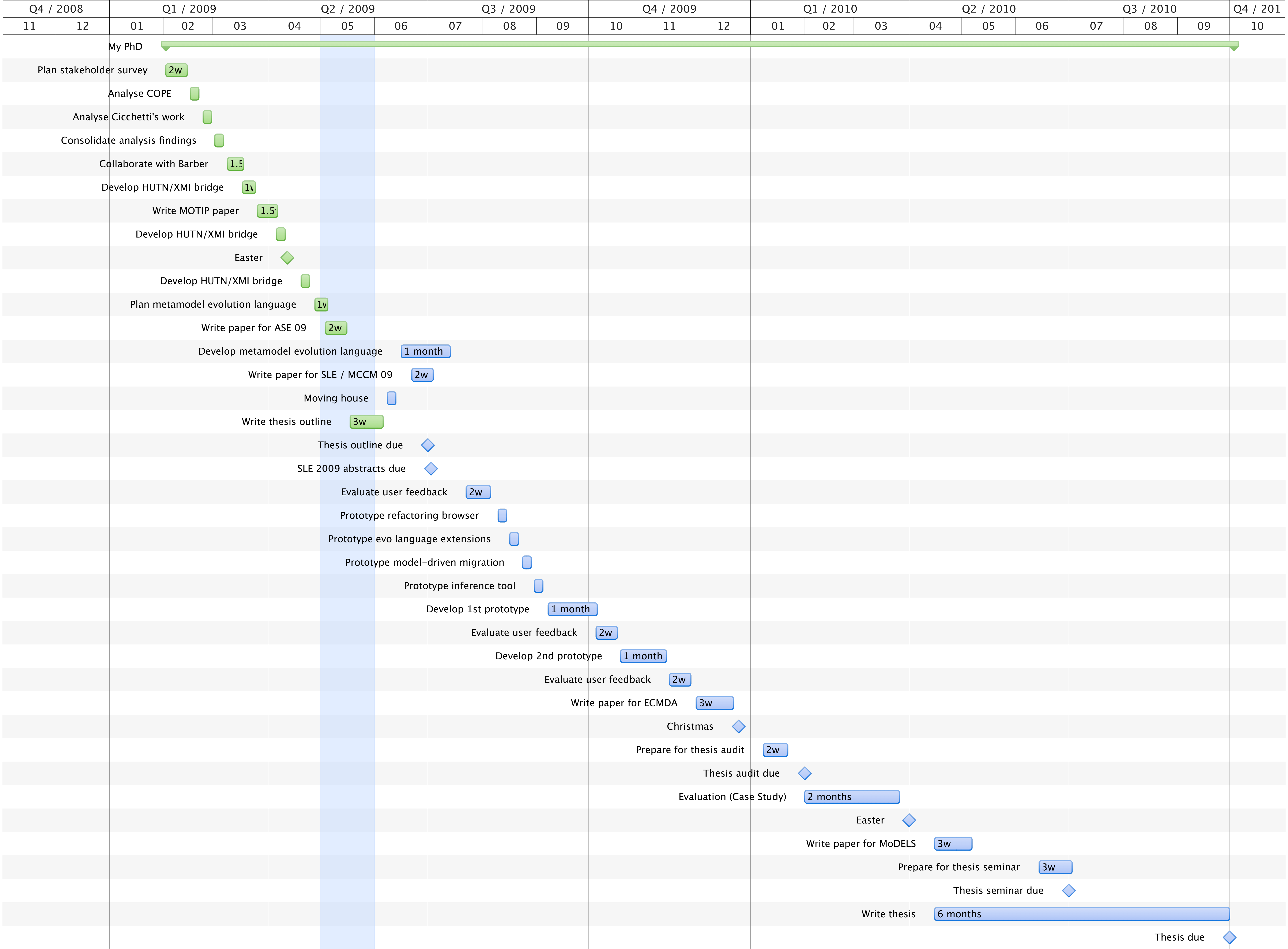
Other achievements Deciding not to conduct the developer survey permitted us some time for other research activities. In [Rose *et al.* 2009], we have documented our experiences in testing model management languages and tools, providing a small catalogue of emerging patterns for specifying automated unit tests. Automated unit tests can increase the maintainability of a system by decreasing its resistance to evolution [Fowler 1999].

As discussed in Section 2.5.1, we also worked on providing metamodel-independent representation of EMF models, submitting our work to ASE 2009.

[2]Homogenous transformations were compared to heterogeneous transformations in the progress report. Homogenous transformations are well-suited to model migration, as migration typically requires a small amount of changes to the source model [Sprinkle 2003].

3.2 Revised Plan

A revised research plan is provided overleaf. I have found the plan in the progress report to be more effective than the plan in the qualifying dissertation. Defining clear goals, and decomposing large activities into smaller activities, increased my focus. I have continued to apply these techniques to produce the plan shown overleaf. A final plan for activities starting after January 2010 will be presented at the thesis audit.



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Write paper for SLE / MCCM 09
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Write thesis outline
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SLE 2009 abstracts due
Evaluate user feedback
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Prototype refactoring browser
Prototype evo language extensions
Prototype model-driven migration
Prototype inference tool
Develop 1st prototype
1 month
Evaluate user feedback
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Develop 2nd prototype
1 month
Evaluate user feedback
2w
Write paper for ECMDA
3w
Christmas
Prepare for thesis audit
2w
Thesis audit due
Evaluation (Case Study)
2 months
Easter
Write paper for MoDELS
3w
Prepare for thesis seminar
3w
Thesis seminar due
Write thesis
6 months
Thesis due

3.3 Goals

Over the next six months, our primary goal is to address the requirements we have defined for managing co-evolutionary changes in the context of model-driven engineering. Specifically, we will develop a language for describing and executing migration strategies, and other structures and processes that will automate some of the development activities that occur during model and metamodel co-evolution.

Our research will be evaluated using the Graphical Modelling Framework (GMF) [Gronback 2006] as a case study. We will demonstrate that those problems occurring in GMF caused by co-evolutionary change can be managed using the structures and processes that we develop.

Develop model migration language In the progress report, we motivated the need for a dedicated language for specifying and executing model migration. By analysing existing examples of co-evolution, we have designed a minimal core syntax for the language. Over the next month, we will choose an implementation strategy (internal extension to a general purpose language, or new task-specific language for Epsilon) and a target platform (e.g. Ruby, Scala, Epsilon). We will then implement the model migration language and development tools. The work will produce publishable results, possibly in time for submission to the 2nd International Conference on Software Language Engineering (SLE), or to the 2nd International Workshop on Model Co-Evolution and Consistency Management (MCCM).

Goals: Choose an implementation strategy and target platform. Implement the language. Publish a paper at SLE / MCCM 09.

Evaluate user feedback The model migration language will be released as part of the Epsilon research incubation project. Potentially, users will provide feedback and suggest improvements. Clearly, it is difficult to predict the amount of user feedback we will receive. Regardless, we have planned some time for improving the language in response to user feedback.

Goals: Improve the model migration language based on user feedback.

Prototyping and further development In Section 2.5.4, we identified several further solutions that could be implemented to address the requirements of structures and processes for managing co-evolutionary change in the context of MDE. We have planned time to rapidly prototype each of the solutions. Time has been planned for further development of two of the prototypes. The developed solutions and the prototypes will provide content for the proposed thesis. One or both of the developed prototypes will likely be publishable.

Goals: Prototype the solutions discussed in Section 2.5.4, selecting two of them for further development. Develop the chosen two solutions. Publish a paper at ECMDA 2010.

3.4 Summary

In this outline, we have presented a structure for the proposed thesis, which will focus on software evolution and its impact on the maintainability of systems, particularly in the context of model-driven engineering. We have discussed the progress made since January, and provided a revised timetable for the next six months. The primary aim of our research during that time will be to address the requirements that we have defined for managing co-evolutionary changes in the context of model-driven engineering.

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