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Using ADO.NET Entity Framework in Domain-Driven Design: A Pattern Approach

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IT University of Göteborg
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ABSTRACT

In the object community *domain-driven design* philosophy has recently gained prominence. The application of domain-driven design practices in iterative software development projects promises to conquer complexity inherent in building software. And with the reduced complexity comes more intimate understanding of a problem domain, which results in better software, capable of effectively addressing user needs and concerns. The ADO.NET Entity Framework with its emphasis on modeling conceptual business entities and handling persistence can potentially facilitate domain-driven design. However, it is not clear exactly how the framework should be used in the context of domain-driven development. This exploratory case study was commissioned by Volvo Information Technology (Volvo IT) and it sought to provide guidance on using the Entity Framework in domain-driven design at the company. The study produced a number of important results. Firstly, a total of 15 guidelines were proposed for adopting the framework at Volvo IT. These guidelines address such issues as domain modeling during requirements engineering, efficient mapping among various models, reverse-engineering of legacy databases, and a number of others. Secondly, six critical factors (performance, abstraction, competence, features, simplicity and support for multiple data sources) were identified that must be considered in adopting the Entity Framework in domain-driven design at the company. Finally, based on one of these factors, performance evaluation of the framework's querying mechanisms was performed, which further strengthened the guidelines.

Keywords

Domain-driven design, ADO.NET Entity Framework, persistence, domain model, patterns, object-relational impedance mismatch.

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Andrey Yemelyanov

May 17, 2008

Gothenburg, Sweden.

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ABSTRACT

In the object community *domain-driven design* philosophy has recently gained prominence. The application of domain-driven design practices in iterative software development projects promises to conquer complexity inherent in building software. And with the reduced complexity comes more intimate understanding of a problem domain, which results in better software, capable of effectively addressing user needs and concerns. The ADO.NET Entity Framework with its emphasis on modeling conceptual business entities and handling persistence can potentially facilitate domain-driven design. However, it is not clear exactly how the framework should be used in the context of domain-driven development. This exploratory case study was commissioned by Volvo Information Technology (Volvo IT) and it sought to provide guidance on using the Entity Framework in domain-driven design at the company. The study produced a number of important results. Firstly, a total of 15 guidelines were proposed for adopting the framework at Volvo IT. These guidelines address such issues as domain modeling during requirements engineering, efficient mapping among various models, reverse-engineering of legacy databases, and a number of others. Secondly, six critical factors (performance, abstraction, competence, features, simplicity and support for multiple data sources) were identified that must be considered in adopting the Entity Framework in domain-driven design at the company. Finally, based on one of these factors, performance evaluation of the framework's querying mechanisms was performed, which further strengthened the guidelines.

Keywords

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1. INTRODUCTION

In a use-case driven software development process [3, 8, 14, 39] use cases serve as a primary artifact for establishing system requirements, validating system architecture, testing and communicating with domain experts and other project stakeholders [13]. Such a process is often used alongside with the Unified Modeling Language (UML) [8]. After the use case specification is fed into further development stages, two major artifacts are conceived: *analysis model* and *design model*. There is an interesting dichotomy between the two models in that they address two distinct dimensions (problem and solution) of the same given domain. The analysis model represents the product of analyzing a problem domain to organize its concepts. What role these concepts will play in software is not important in that context [22]. It specifies *what* problem needs to be solved. The major content of the analysis model includes collaborations in the UML and analysis classes [19]. The design model, on the other hand, specifies *how* the given problem is to be solved. Crain [19] refers to this model as a platform-specific model because it captures "a mixture of behavior and technology". For example, the design model may include a JDBC [1]class to specify how the lifecycle of persistent business objects is handled.

Such a seeming redundancy in models is necessary in order to ensure a smooth transition from a problem space (use case specifications and analysis model) to a solution space (design and implementation models), which is not trivial. Evans [22] argues that once the implementation begins, analysis and design models grow increasingly disjoint. This happens because the analysis model is created with no design issues in mind. Mixing implementation concerns into analysis models is considered bad practice and is, therefore, highly discouraged. As a result, the pure analysis model proves impractical for design purposes and is abandoned as soon as programming begins [22]. There is a danger to such practice, Evans [22] continues. While analysis models may accurately capture business needs and incorporate valuable knowledge about the problem domain, there is no guarantee that the design model will successfully rediscover the insights gained during analysis. Eventually, as the gap between the models widens, it becomes progressively difficult to feed insights from analysis into design.

Domain-driven design (DDD) [22] vision seeks to bridge the chasm between analysis and design by introducing a single model (*domain model*) that addresses both concerns. A domain model not only represents an important analysis artifact that captures essential business concepts and constraints but also offers a concrete design in the form of object-oriented design classes. Constituting an essential part of application design and architecture, domain models in DDD are expressed in terms of object-oriented constructs such as classes, attributes, operations and relationships and are drawn with the UML class diagram notation (see for example [22, 31] and Appendix C). These models may be referred to as domain object models or conceptual models [25, 31]. We will henceforth refer to such models as just domain models[2]. The basic premise behind DDD is the maximization of knowledge about the domain. This is achieved by a close cooperation between a project team and domain experts with the goal of creating an explicit model of the problem domain. As a result, it is possible to reduce complexity inherent in most

[1] Java Database Connectivity (JDBC) is a technology for connecting to relational databases from Java applications.

[2] Note that in this thesis we address domain-driven design in the context of *business information systems*. We do not consider DDD as applied in embedded systems design or any other domain.

businesses. This, in turn, should lead to better software that effectively supports business operations.

There is a challenge in using domain models in applications. On the one hand, to effectively model a complex business domain with all its valuable operation logic, domain models would necessarily have to use a number of object-oriented constructs, such as inheritance, aggregation/composition and design patterns. These are so-called 'rich' or 'deep' domain models [22, 25]. On the other hand, to provide persistent storage of the domain model state, relational databases are widely used. The fact that these databases use a relational data model to organize data places a practical limit on the 'richness' of domain models [25]. This is caused by a paradigm difference between object-oriented and relational models, which in literature is referred to as *object-relational impedance mismatch* [7, 16, 18, 33, 38]. The basic premise behind it is that objects and relations are fundamentally different and their interplay is not trivial [38]. Fowler [25] discusses structural and behavioral aspects of the impedance mismatch. In a structural sense, the author identifies two major distinctions between objects and relations: identity and relationships handling. From the behavioral perspective, a problem arises when it comes to maintaining data in objects and their corresponding database tables in a consistent state. Issues that need to be considered, for example, are loading objects, ensuring no object for the same row is read more than once and handling database updates. Due to impedance mismatch efficient mapping of 'rich' domain models to relational models presents a problem.

1.1 Problem definition

While Evans [22] stresses that DDD is a set of principles focusing on modeling a business domain and needs no technological and methodological support other than object orientation, we believe that effective adoption of DDD practices is contingent on the availability of tools. Essentially, such a tool would need to directly support domain modeling activity and offer concrete solutions to overcoming object-relational mismatch. In the late 2007, Microsoft Corporation announced the Beta 3 release of the ADO.NET Entity Framework (further abbreviated to EF or just referred to as Entity Framework) [34]. The EF is .NET-based middleware that represents an abstraction layer that promises to alleviate impedance mismatch by decoupling application domain models from underlying relational storage models. A distinguishing characteristic of the EF is the built-in support for development based on an explicit model. It introduces the Entity Data Model (EDM), which captures essential business (domain) entities and their relationships in an explicit conceptual model.

The EF can potentially facilitate DDD as it not only largely overcomes object-relational mismatch but also promotes model-based development of business applications. The resulting adoption of DDD in software development promises to raise the quality of delivered software. However, it is not clear how the feature set offered by the EF can support the DDD practices. To our best knowledge, no guidance has been published on how the EF should be effectively integrated into a software development process with a particular emphasis on DDD. To date, one credible source on the EF is the documentation released by Microsoft [35]. However, it is limited to programming scenarios and walkthroughs. There exists no formal advice on mapping between models should be performed, how and when domain modeling should occur, how models can be validated with the EF, or how DDD with the EF will affect requirements engineering stage. These, we believe, are important issues that must be considered.

1.2 Thesis objective

This exploratory study was commissioned by Volvo Information Technology (Volvo IT) – a subsidiary of the Volvo Corporation based in Gothenburg, Sweden. The impetus for Volvo IT to move toward DDD practices with the EF is the potential reduction in code complexity and further improvement of maintainability of its enterprise applications. Accordingly, the objective of this study is to formulate guidance on applying the Entity Framework in DDD in the context of an iterative software development process at Volvo IT. It addresses the following main research question:

> *How should software development projects that emphasize domain-driven design incorporate the Entity Framework for domain modeling and domain object persistence?*

The main research question can be broken down into the following sub-questions:

RQ1: *What are the main goals behind the company's move to further develop domain-driven design practices with the Entity Framework?*

RQ2: *What are the most important factors that must be taken into account when adopting the Entity Framework in domain-driven design in the company?*

RQ3: *What are the most important guidelines for adopting the Entity Framework in domain-driven software development in the company*?

The thesis achieved a number of important results. Firstly, a set of 15 guidelines were proposed for adopting the EF at Volvo IT. These guidelines address such issues as domain modeling during requirements engineering, efficient mapping between domain models and the EDM, reverse-engineering of legacy databases, and a number of others. Secondly, a number of critical factors were identified that must be considered in using the EF with DDD. Based on one of these factors, performance evaluation of EF querying mechanisms was performed, which further strengthened the guidelines.

1.3 Disposition

The remainder of the report is structured as follows. Section 2 discusses the research methodology used in the study. Section 3 presents a brief overview of the related work. Section 4 delves into the theoretical framework which served as the knowledge foundation for the study. Section 5 addresses RQ1 by presenting main goals of moving to DDD practices with the Entity Framework at Volvo IT. This section also discusses important requirements that the guidelines have to fulfill. Section 6 addresses RQ2 and presents critical factors that must be taken into consideration when adopting the Entity Framework for DDD at Volvo IT. Section 7 builds upon the preceding section and presents the evaluation of the most important factor– query performance. Section 8 presents the overview of the Entity Framework Guidelines (RQ3). Section 9 offers some further reflections on the guidelines. Finally, Section 10 ends the report by presenting important conclusions and outlining recommended future research.

2. CASE STUDY DESIGN

The main purpose of this study was to design a set of guidelines for incorporating the EF into a domain-driven software development process at Volvo IT. We used a qualitative exploratory case study as the methodology behind the study design [48]. Exploratory case studies are suitable for performing preliminary studies where it is not clear which phenomena are significant to look into, or how to quantitatively assess these phenomena [21]. Moreover, to our best knowledge, research concerning the adoption of Entity Framework in domain-driven development is non-existent and current literature provides no conceptual framework for theorizing. This circumstance makes the formulation of a proper hypothesis or theory prior to commencing the study difficult. Another justifiable rationale for choosing an exploratory case study is the descriptive nature of research questions. Rather than asking to provide causative links (*why?*), research objectives in this study mainly focus on so-called *what?*-questions where the major goal is to develop hypotheses for further scientific inquiry.

The research paradigm of this case study can be characterized as interpretive. Unlike positivist approach where reality can be objectively described with measurable properties, interpretive paradigm seeks to gain knowledge through less precise constructions such as language and shared meanings [9, 41]. It is particularly applicable in cases where a degree of uncertainty surrounds the problem (i.e. very little prior research exists). Essentially, we tried to understand the phenomena of domain modeling and object persistence at Volvo IT through the meanings that people assign to them. The aim was to interpret how software architects and system analysts understand domain driven design and object persistence, what they view as best practices and why. This was achieved through a series of semi-structured interviews (see later in the section). Our interpretations were then used in formulating the Entity Framework guidelines, which can be understood as the tentative theory behind applying the EF in DDD. The guidelines represent an initial theory – a theory that must be tested repeatedly to be corroborated or disproved.

2.1 Context and Subjects

The studied company in this research project was Volvo Information Technology (referred to as Volvo IT henceforth). The company is a wholly-owned subsidiary of AB Volvo (Volvo Group), one of the largest industrial groups in the Nordic region. Volvo IT is the information technology competence center for Volvo Group. It provides software solutions to support industrial processes with competencies in Product Lifecycle Management, SAP solutions, and IT operations. This case study was commissioned by Software Process Improvement (SPI) group within Volvo IT, which is responsible for developing and maintaining processes and methods for application development. The group was exploring a possibility of adopting the Entity Framework as a persistence mechanism in software development projects that emphasize domain-driven design. Accordingly, the development of guidance on adopting the framework is a unit of analysis (case) in this study. To our best knowledge, no previous studies have been performed in this area. Thus, the conclusions drawn in this case study could potentially inform critical decisions about incorporating the framework into domain-driven development in a number of similar enterprises. Due to the confidentiality agreement with Volvo IT, the guidelines developed in the thesis are a proprietary asset of the company and, therefore, only their outline will be presented in this report.

2.2 Study Subjects

The subjects in the case study were 1 senior .NET architect, 3 software architects and 2 system analysts. The senior .NET architect provided much-needed guidance on identifying real industrial problems with regards to domain-driven development and object-relational mismatch. He outlined important benchmarks and requirements that the guidelines had to satisfy. The rationale for selecting other software architects as primary subjects was their first-hand exposure to object modeling and persistence. These architects provided critical data that allowed us to identify common object modeling and persistence mechanisms, their characteristics, and also factors affecting the adoption of Entity Framework at Volvo IT. In involving system analysts in the study we sought to identify common methods and techniques used for requirements modeling in the company. In this way, we could see whether system analysis (in which domain modeling should play an important part) placed any limitations on using pure domain-driven design approaches in building business applications.

2.3 Data Collection and Analysis

To increase overall reliability of the study a method of data triangulation was used. That is, a number of data collection methods were used to collect evidence. The primary method for data collection was interviewing. Five semi-structured interviews were conducted with software architects and system analysts to gain knowledge about object persistence approaches and domain modeling in general. Each interview lasted about one hour. Due to time limitations, interview questions tended to be very focused and concrete (see Appendix A). Still, an interviewee was allowed maximum reasonable latitude in elaborating. Interview questions were refined after each interview to account for new information. Each interview was recorded. Subsequently, all interviews were transcribed and the transcripts were analyzed on the subject of any recurring words or phrases. The transcripts were explicitly analyzed according to expected outcomes of the thesis work. No statistical analysis was performed on data extracted from interviews.

In addition to interviews, extensive body of software documentation was reviewed from the software portfolio at Volvo IT. Important information from the documentation was noted and later revisited for analysis. This initial study made further interview questions more focused and relevant. Moreover, an experiment aimed at evaluating the performance of the Entity Framework query execution provided important input to thesis result. Finally, a number of informal discussions with the senior .NET architect also complemented evidence gathered during the study.

2.4 Study Execution

The case study was performed on Volvo IT premises in Gothenburg (Sweden) during the 20-week spring semester period. The study was executed in the following stages:

Stage 1: Several initiation interviews were conducted with the senior .NET architect to identify main goals for transitioning to DDD with the Entity Framework at Volvo IT. The interviews also sought to elicit important requirements that the Entity Framework guidelines would need to fulfill. The data collected during the interviews addressed RQ1 and served as the basis for further guidelines verification.

Stage 2: Five interviews with software architects and system analysts were performed. The goal of these interviews was to identify the most common pattern of working with object modeling and persistence during software development at the company. Furthermore, this stage sought to elicit specific concerns that needed to be addressed in adopting the EF. The data obtained from the interviews was augmented by observing one software architect working with a persistence layer in an actual system. Besides, considerable amount of data was collected through studying documentation for the Entity Framework and some internal Volvo IT production systems as well as during informal discussions with the senior .NET architect. In this way, not only RQ2 was addressed, but also enough information was gathered to begin creating the EF guidelines.

Stage 3: Based on the evidence collected during stages 1 and 2 a set of guidelines for adopting Entity Framework in domain-driven design were created. RQ3 was thus partially addressed.

Stage 4: The purpose of this final stage was to perform initial evaluation of the guidelines proposed in Stage 3. The objective was the verification of understandability and readability of the guidelines. This was achieved through a joint Entity Framework workshop where the researcher and all study subjects discussed the guidelines. Thus, RQ3 was completely addressed.

Eventually, by answering all three research sub-questions we were able to address the main research question of the case study.

2.5 Threats to Validity

According to Yin [48], a case study design needs to satisfy the following important quality conditions: construct validity, internal validity, external validity, and reliability. Due to its exploratory nature this case study's design is not exposed to internal validity threat. That is, the current case study does not seek to identify causal links in phenomena, which makes internal validity not a concern.

To achieve sufficient reliability the case study design adhered to the two basic principles specified by Yin [48]. First, data triangulation was applied to minimize the risk of bias in data collected from a single source. Accordingly, we augmented interview data with data from software documentation reviews and informal discussions with stakeholders. Second, the study design maintained a chain of evidence [48] by following a well-defined multi-stage process (see previous subsection) spanning from initial positing of research questions to deriving ultimate case study conclusions.

Admittedly, there exists an external validity threat in that only one company was investigated. This could largely undermine the potential for making generalizations beyond the immediate case. However, this threat cannot be minimized to any significant extent at the present stage as more research is needed to corroborate or disprove the case study findings in a wider industrial context.

There is also a construct validity threat in this case study. The danger to construct validity comes from the fact that data collection methods and resulting evidence may be biased due to investigator subjectivity [45, 48]. To counteract this we used multiple sources of information: interviews, documents and informal conversations. Moreover, the findings from data collection were evaluated by interviewees during a joint Entity Framework workshop.

However, the construct validity threat to this study still remains because we cannot guarantee that during the one-hour workshop the understandability and the readability of the guidelines could be verified with absolute certainty. During the presentation some of the interviewees deemed the guidelines too abstract in their pattern form, while others considered the level of abstraction appropriate. Ultimately, we believe the most reliable way to verify the guidelines in this regard would be to test them in a real development project. However, we did not have this opportunity. Still, we believe we managed to curtail this threat to some extent by including concrete examples within each guideline.

Another threat to construct validity relates to the fact that only the Beta 3 version of the ADO.NET Entity Framework was used in the performance experiment (see Section 7). Thus, the results from an experiment with the release-to-manufacturing version of the framework could diverge from our results, which were obtained with the Beta 3 version.

3. RELATED WORK

The primary source for domain-driven design principles is Evans [22]. The author introduces a number of important fundamental concepts and guidelines for adopting DDD practices within a software development project. However, he does not provide the guidelines in the context of any specific tool. Fowler [25] also offers a relevant discussion of object-oriented domain models and other alternatives to modeling domain logic. Besides, the author presents a detailed discussion of object-relational mapping approaches. Nilsson [36] offers an interesting discussion of implementing domain object models in C# programming language. He considers such issues as building a domain object factory, creating a repository for object aggregates and mapping domain objects to relational tables with the NHibernate mapping tool.

Still, after an extensive literature review we found no studies of how the Entity Framework, based on a conceptual data model, can be incorporated into domain-driven software development. To our best knowledge, there is no research into how rich domain models should be mapped and persisted to a relational database via an Entity Data Model (EDM) supplied by the EF. As the reader may recall, by rich domain models we understand models that describe a complex business domain by using a number of advanced object-oriented techniques, such as inheritance and design patterns [25]. However, several studies of domain-driven design, handling persistence and applying object/relational mapping tools in industrial projects exist.

Landre et al.[30], presenting their experiences from building an oil trading application with an object-based domain model in its core, describe how Java Data Objects (JDO) - based mapping approach was used to persist domain entities. The authors argue that domain-driven design along with a proper object-relational mapping tool generally improved system performance and reduced the code size relative to some of their existing legacy applications. An important improvement came from incorporating a Repository domain pattern [22]. According to this pattern all persistence-related code was encapsulated inside a repository and the resulting business logic code, oblivious of persistence infrastructure, operated only on pure business entities. This in turn resulted in cleaner code, which facilitated communication within the team. However, it was difficult at first, as authors noted, to change the mindset of database-oriented developers to an object-oriented way of formulating JDO queries. The JDO mapping approach did eventually pay off as developers no longer had to concern themselves with the minute details of the relational database schema and instead focus on core business entities. Still, while the authors presented important drivers behind migrating to a mapping layer, no meaningful guidelines were offered on how mapping tools should be integrated into domain-driven development or what role domain modeling should play in the process.

Wu [47] presents an enterprise system intended to assess human performance. The system domain model was generated by the Entity Object framework[3]. This framework closely resembles Repository pattern [22]: it encapsulates all persistence-related issues through object-relational mapping and thus enables a developer to work with a pure object-based domain model. The author claims that the architecture based on the Entity Object framework effectively decoupled the database from the rest of the application and improved the overall design since developers no longer had to be aware of the intricacies in the relational database schema. Still, the author fails to examine the framework in the wider context of domain-driven design and domain modeling.

A promising approach to domain-driven design is proposed by Philippi [38]. The author discusses experiences from developing a model-driven tool that allows visually modeling an object domain model and then automatically generating persistence-related code and data definition language (DDL) SQL queries. The mapping between domain objects and relational tables is specified with a wizard tool. Essentially, an application developer specifies different trade-off criteria, such as maintainability, understandability, which in return generates mappings for a chosen object-relational tool vendor. The system currently supports TopLink. The author also discusses how mappings of attributes, associations and inheritance hierarchies can be performed. He also makes a seminal analysis of different mappings in terms of understandability, maintainability, storage space and performance. We actively used the results from this analysis in formulating mapping patterns which are a part of the Entity Framework guidelines. Finally, the author argues that the starting point for the automatic generation of object-relational mappings is an application object model – a domain model.

Generally, the problem of a paradigm schism between object and relational models has been a longstanding one [18] and has been widely studied [4, 7, 11, 15, 25, 29, 33, 46]. Several pattern languages have been created, which catalogue best practices in mapping objects to relations [15, 29]. We used a number of these patterns to complement our own mapping patterns, especially when it came to mapping the EDM to a relational model. Moreover, to define the pattern language we consulted [29].

Cook and Ibrahim [18] review numerous issues affecting the language/database integration and develop these issues into criteria against which different solutions to impedance mismatch can be evaluated. The authors also present the results from a qualitative evaluation of existing solutions. Their study included such tools as object/relational mapping tools, object-oriented database systems and orthogonal persistence systems.

Researchers and practitioners have developed a number of solutions helping to mitigate or altogether eliminate the object-relational impedance mismatch. Some of the proposed solutions are discussed below.

One solution that completely prevents the mismatch is to use object-oriented database systems (OODBS). OODBS enable a so-called *transparent persistence* [36], whereby both persistent objects and in-memory objects are accessed in the same way. This is achieved through storing objects directly rather than transforming them to relational constructs before persisting [49]. As a result only one object-based domain model needs to exist in the application, resulting in overall design improvements [49]. However, predictions of a wide adoption of OODBS did not materialize as they have achieved only a 2% share of the international database market [32]. Relational databases remain the dominant persistence mechanism [15].

Another interesting approach to persistence is orthogonal persistence [5, 40]. Orthogonality in this sense considers persistence as merely an aspect of an application. The basic tenet behind orthogonal persistence is the obliviousness of the persistence concern. Once persistence has been “aspectisized”, the rest of the application can be built as if no data needs to be persisted. The persistence mechanism can be plugged in at a later time. There have also been some attempts to embed persistence capabilities directly into a programming language [12].

4. THEORETICAL FRAMEWORK

This section seeks to define important terms actively used throughout the thesis report. It contrasts two approaches to addressing domain logic in enterprise applications. The section then introduces the basic concepts of domain-driven design. Finally, the section delves into the Entity Framework: its architecture and its basic premise of conceptual data programming.

4.1 Structuring domain logic

Oldfield [37] discusses three types of requirements that any application software has to fulfill. First, there are requirements originating from users, which determine system’s purpose and how the system is used. These requirements are usually captured in *Use Cases* [10]. Second, there are *non-functional requirements* that capture quality attributes of a system: reliability, performance, security and many others. Finally, there are *domain requirements*. A *domain* of a software product is the subject area in which the user applies this product [22]. Domain requirements capture essential domain concepts, their relationships and important rules. Business rules, for example, constrain and control the way a business operates. In this report, we use the term *business rules* interchangeably with terms like *domain logic*, *business logic* or *application logic*. We also use the terms *business object*, *domain object* and *business entity* interchangeably in this report.

Historically, in the object community there have been several approaches to organizing and implementing business logic in applications. Fowler [25] identified three patterns of organizing domain logic in enterprise applications: table-based record set

[3] .NET-based enterprise framework for domain-driven design. Available at http://neo.sourceforge.net/

(Table Module), procedural (Transaction Script) and domain model-based (Domain Model). Table Module and Transaction Script patterns are largely *database-driven* in a sense that the relational model determines the structuring of domain objects and their relationships. Subsequently, all logic is concentrated in a set of heavyweight application services operating on database table-like objects (data containers), instead of actual business entities where they naturally belong. Domain Model (DM) pattern, on the other hand, stresses the importance of decoupling the object model from the database model and structuring the whole application around the object-based domain model[4] – a *domain-driven* approach [22]. According to this pattern, encapsulating all domain logic in a set of interconnected business objects (domain model) is a way to manage complexity inherent in most businesses. In the following subsections we contrast Transaction Script and Domain Model patterns for illustrating two distinct approaches to structuring domain logic.

4.1.1 Procedural style (Transaction Script)

The basic premise behind this style is that all application logic is organized into a set of procedure-like scripts ("fat services"), each of which handles a single request from the presentation layer. Normally, a single script is responsible for one business transaction, such as book a hotel room, transfer money from one account to another, etc [25]. Figure 1 illustrates a part of a banking application[5] built with the Transaction Script pattern.

The most salient characteristic of this design approach is that domain objects/entities (Account, Customer and BankingTransaction) do not encapsulate any business logic per se. Domain objects in this model represent bare data containers (with getter/setter fields), which is in a fundamental conflict with the object-oriented paradigm of encapsulating both data and behavior [23]. In fact, the structure of the database schema largely determines the design of these objects. Fowler [23] refers to such a model as *anemic domain model* – database-driven with no domain logic. While there is nothing wrong with a domain model structure closely resembling that of a relational model (one-to-one mapping), a mechanic derivation of a domain object model from a database with no regard to the principle of encapsulation could cause problems in later stages of development. Most importantly, this could lead to broken abstractions in the application. For example, a real-world entity Order could be split into several Order-related tables in the database due to normalization requirements. Following the procedural pattern, these tables would be one-to-one mapped to domain objects in the data tier. As a result, the Order entity will be fragmented over a number of related objects in the object model and the mental model of the application will be disrupted. It is necessary to remember that a relational model with its mathematical underpinnings may not be suited for modeling real world domains at a high level of abstraction. It is a *logical* representation of how data is stored in the database [4, 11]. In fact, recognizing this limitation in relational modeling, Peter Chen in 1976 devised the entity-relationship model approach [17] to *conceptual* data modeling. Domain object models, unlike their relational counterparts, model *conceptual* real-world business entities and operate at a higher abstraction level.

All business logic in the procedural style resides in the business tier within MoneyTransferService. This service performs a transfer of money assets from one account to another. The service definition executes all business rules (such as overdrafting policy) before crediting and debiting accounts.

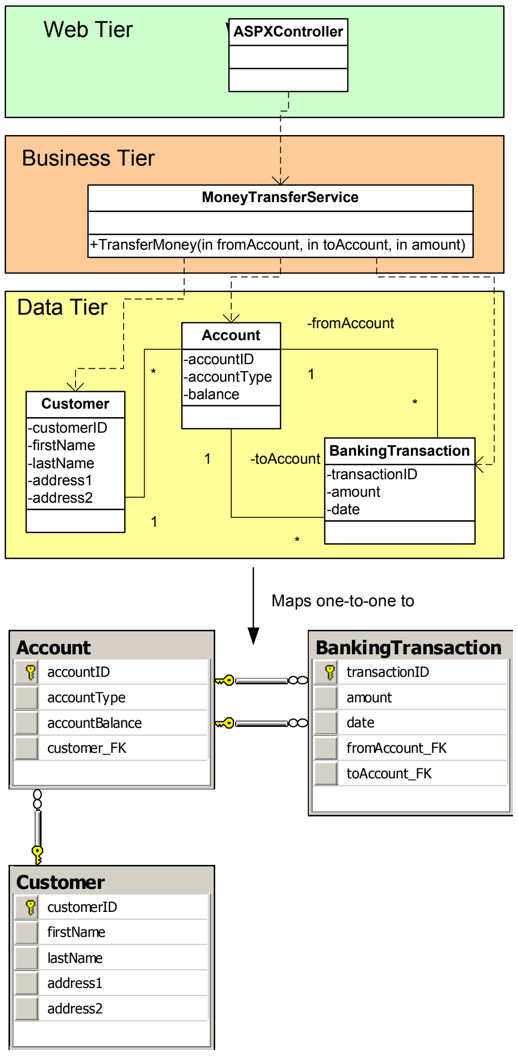


Figure 1: Part of a banking application built in a procedural style

This design style has some properties that make it attractive for building non-sophisticated enterprise applications [25]. First, it is easy to add new functionality by implementing a new transaction script. Second, it does not require significant object modeling skills. In fact, some enterprise application frameworks (e.g. J2EE

[4] Essentially, a domain model is a way to express domain requirements by explicitly capturing essential business concepts, their relationships and rules in a concrete model.

[5] This example was inspired by the presentation made by Chris Richardson on "*Improving Application Design with a Rich Domain Model*". Available at http://www.parleys.com/display/PARLEYS/Improving+Application+Design+with+a+Rich+Domain+Model?showComments=true

EJB[6]) even encourage this style. However, a significant disadvantage of this approach is that it does not scale well to complex business domains. As more and more functionality is added, transaction scripts tend to multiply and swell in size. As a result, the potential for the same business logic to be repeated in several places becomes more pronounced, which seriously undermines application maintainability. Another problem with the style, as we mentioned, is that the resulting object model is largely database-driven – hence, some adverse implications for application abstractions.

4.1.2 Domain Model style

The Domain Model pattern prescribes offloading all the domain logic from services (transaction scripts) and encapsulating it inside a *domain layer* – a layer of objects that model the business area. Essentially, the business logic is modeled as operations on classes and spread among a collection of domain objects. See Figure 2 for the comparison of the two design approaches.

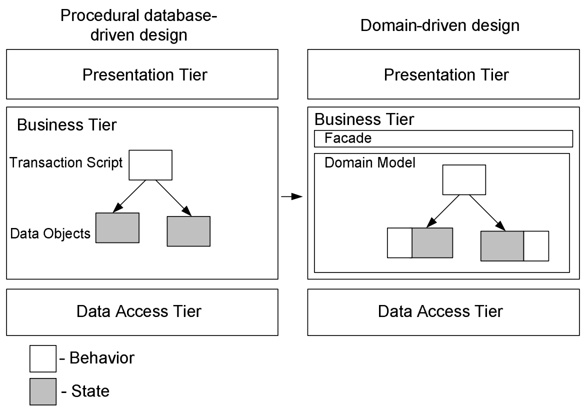


Figure 2: Transitioning from procedural database-driven design to domain-driven design (adapted from Richardson[7])

Most importantly, a domain model is intended to be purely conceptual: classes in this model directly correspond to real-world objects. It is, therefore, likely that the domain model will often diverge from its relational counterpart. To ensure that data can be transparently passed between the two potentially diverging models (due to object-relational impedance mismatch), Fowler [25] suggests that a Data Mapper be used. The sole purpose of the Data Mapper is to move "data between objects and a database while keeping them independent of each other and the mapper itself" [25]. It could be understood as a translator that performs data transformations as it crosses object-relational boundary. *Object-relational mapping tools* emerged as a result of the need for automatic data translation and mapping of object models to database models. To date, a number of commercial (LLBLGen Pro, Apple WebObjects) as well as open source (Hibernate/NHibernate as the most popular) solutions exist. In fact, a whole new discipline appeared as a result of pursuing application design with the domain model at the core – *domain-driven design*. Next sub-section addresses this approach at length.

There are a number of benefits to having a domain model at the core of the application design. Firstly, because the domain model is decoupled from the relational model, such design reflects the reality of business better. Clients to a domain model are able to operate in terms of real business concepts. Secondly, a domain model represents a model of business and its core concepts. These concepts rarely change and are quite stable. Therefore, by encapsulating all business-related functionality in a domain model, it becomes possible to reuse the model in a new context (new applications, for example). Finally, as Evans [22] stresses, a domain model represents a *ubiquitous language* – a common language shared by domain experts, developers, managers and other stakeholders. Ubiquitous language facilitates shared understanding of the domain, and, ultimately, leads to better software that is more in line with the user concerns and needs.

4.2 Domain-driven design

Evans [22] sees domain-driven design (DDD) as the "undercurrent of the object community". The principles of DDD have been known for a long time, yet only recently has the DDD gained increased attention and interest from software developers [22]. The fundamental premise behind the DDD is that most software projects should primarily focus on the problem domain and domain logic. Application design should be based on a domain model. This is achieved by closely mapping domain concepts to software artifacts. DDD should not be viewed as a software development process in its own right. Rather, it is a set of guiding principles, practices and techniques aimed at facilitating software projects dealing with complicated domains. DDD should be applied in the context of an iterative development process, where developers and domain experts have a close relationship.

The centerpiece of the DDD philosophy is a domain model [22]. A domain model represents essential knowledge about the problem area. It is a tool for overcoming information overload and overall complexity when a development team attempts to extract domain knowledge from system users. A domain model "*is not just the knowledge in a domain expert's head; it is a rigorously organized and selective abstraction of that knowledge*" [22] (p. 3).

Fowler [25] offers a relevant discussion of domain models. A domain model captures the business area in which an application operates. It models essential business entities (domain objects) and their intrinsic qualities such as attributes or constraints from a conceptual perspective. But above all, a domain model encapsulates all domain logic, which might include business rules, constraints and other important components.

Importantly, a domain model is not necessarily a diagram or some other illustration, rather, it is the notion that a diagram seeks to convey. A diagram can communicate a model, as can more textual representation. However, considering that object-orientation is largely based on modeling real-life objects, object-oriented models (namely, a class diagram) have become a de-facto standard for capturing domain knowledge (see Appendix C).

In a sense that DDD espouses a model as the primary artifact in software development, it is closely related to model-driven

[6] It is notable how its reference architecture encourages Transaction Script thinking: Enterprise Java Beans (EJB) implement procedures by operating on an anemic Entity Bean-based model.

[7] See http://www.parleys.com/display/PARLEYS/Improving+Application+Design+with+a+Rich+Domain+Model?showComments=true

development (MDD) philosophy. Both methodologies strive to reduce complexity inherent in application domains by raising the level of abstraction in software construction to a level that is closer to a problem domain [42]. However, unlike DDD, MDD stresses automatic generation of programs based on corresponding models [43]. In this context, DDD does not see the domain model as a platform for code generation. Rather, the domain model in DDD is considered to be a facilitator of a common language shared by all stakeholders [22]. Moreover, instead of having just one central model (e.g. a domain model in DDD), MDD prescribes producing a number of models targeted at different abstraction levels [1]. Such models may include computation-independent models (domain models), platform-independent and platform-specific models [1, 26].

4.2.1 The building blocks of domain-driven design

A domain model seeks to bridge the gap between analysis and design by addressing concerns belonging to both of the activities. One can find not only familiar business objects/entities in the model (business analysis model), but also objects representing services, repositories and factories (design model). Figure 3 presents a navigation map of the DDD concepts.

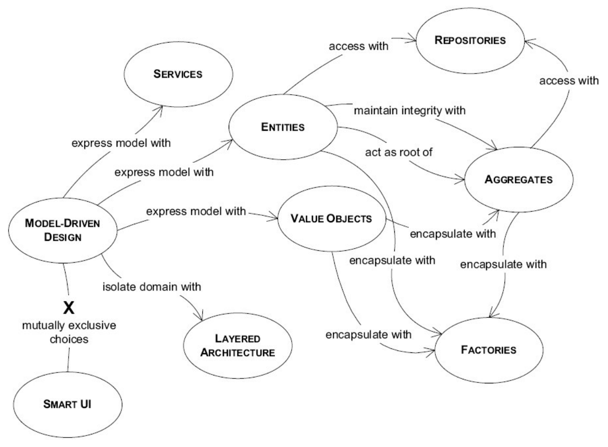


Figure 3: A navigation map of the language of domain-driven design

(source: Evans [22])

In the paragraphs to follow, we briefly discuss each of the building blocks. For a more detailed text the reader is referred to Evans' book on domain-driven design [22].

4.2.1.1 Layered architecture

From an architectural viewpoint, a domain model comprises a distinct layer in an application that encapsulates a set of stable business object types [44]. In DDD a domain layer constitutes the core of the application design and architecture. It is responsible for all fundamental business rules. It is in the domain layer that the model of the problem area resides. This appears in sharp contrast with the procedural approach in Transaction Script where all domain logic is concentrated in the application (service) layer. Figure 4 illustrates the layered architecture to which most DDD applications adhere:

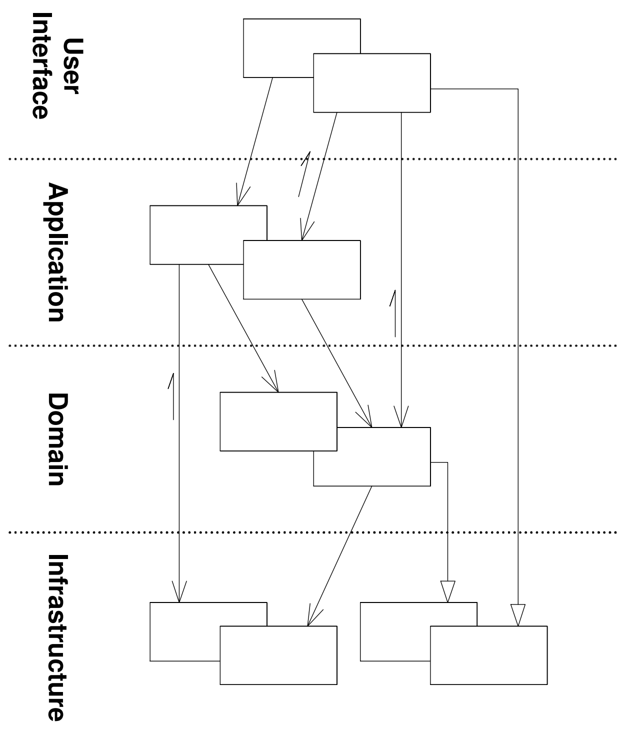


Figure 4: Layered architecture according to DDD

(source: Evans [22])

Infrastructure layer provides technical support for all application services. Such technical capabilities can include message sending, persistence for the domain model, etc. *Domain* layer is the place where the domain model 'lives'. It is responsible for representing business concepts (state) and business rules. *Application* layer is supposed to be thin: it only orchestrates use case flows (task coordination) and then delegates to behavior-rich domain objects for most domain logic. Finally, the *User Interface* layer is a regular front-end of the application. It is either a graphical user interface (GUI) through, which users feed commands to a system, or a system interface to which external applications can connect (e.g. a Web service).

4.2.1.2 Entities

An *entity* represents a domain object that is defined not by its attributes, but rather by continuity and identity [22]. Entities usually directly correspond to essential business objects, such as account or customer. Thus, entities are usually persistent: they are stored in the database. From database storage comes one of the defining characteristics of an entity: continuity. Continuity means that an entity has to be able to outlive an application run cycle. However, once an application is re-started, it should be possible to reconstitute this entity. To differentiate one entity from another a concept of identity is introduced. Every entity possesses an identity that uniquely identifies it in a set. Accordingly, even if two entities have the same attribute values, they are considered distinct so long as their identities differ.

4.2.1.3 Services

Services represent concepts that are not natural to model as entities [22]. Services are responsible for pieces of domain logic that cannot be encapsulated in an entity. A service can be considered as an interface or an entry point into the domain model for external clients. A proper service possesses three important characteristics[22]: 1. the operation a service implements directly relates to a business concept; 2. the service interface is defined in terms of the elements of a domain model (intention-revealing interface); 3. a service operation is stateless.

As an example of a 'good' domain service, consider the case when an application implements a transfer of funds between two bank accounts. The transfer operation directly relates to the banking domain term "funds transfer". Modeling the transfer operation on one of the entities (e.g. account) would be somewhat undesirable because the operation involves two accounts. Thus, a funds transfer operation is best factored into a separate domain service operating on domain entities (see Appendix C). A service can be directly accessible from the application or a presentation layer.

4.2.1.4 Aggregates

An *aggregate* is a set of related entities that can be treated as a unit for the purpose of data changes [22]. In a system with persistent data storage there must be a scope for a transaction to change data. Consider a case when a certain number of related entities are loaded from the database into the main memory. After modifying the state of some of the objects a user attempts to save their work. A database transaction is spun to maintain data consistency during the save operation. However, should the transaction apply only to the saved object or should it also apply to its related object(s)? Another issue arises when a deletion of a domain object occurs. Should the related objects also be deleted from the persistent storage? Essentially, an aggregate addresses these issues by identifying a *graph* of objects that are treated as a unit. Any operation performed on an object within the graph automatically applies to all other graph members (e.g. a transaction). Figure 5 illustrates an aggregate.

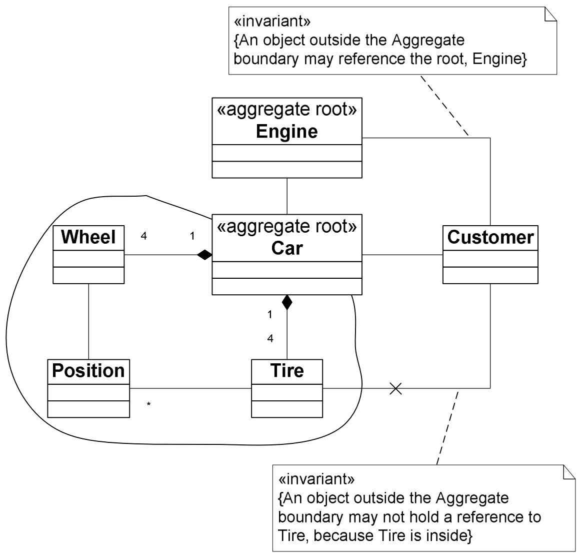

«invariant»
{An object outside the Aggregate boundary may reference the root, Engine}
«aggregate root»
Engine
«aggregate root»
Car
Wheel
4
1
Customer
1
4
Position
Tire
«invariant»
{An object outside the Aggregate boundary may not hold a reference to Tire, because Tire is inside}

Figure 5: Aggregate (adapted from Evans [22])

Each aggregate has a root object (**Car**) and a boundary. The root is a single specific entity which is considered primary. All other objects (**Wheel**, **Position** and **Tire**) within an aggregate are subjected to the root. The boundary defines what is inside the aggregate and what is outside. The defining characteristic of a root is that outside objects are allowed to hold references only to the root of an aggregate.

Aggregates play an important role in a domain model. They provide an abstraction for encapsulating references within the model. For an outsider, a domain model consists only of aggregates and their roots. Clients of a domain model can only hold direct references to aggregate roots. Other non-root objects should be accessed via traversal. Importantly, should an aggregate root be deleted from persistent storage, all aggregate members will also be removed. Also, when a root is saved, the ensuing transaction spans the whole aggregate.

4.2.1.5 Factories

A *factory* is a mechanism for creating complex aggregates [22]. An aggregate, as a rule, has to maintain invariants (constraints). A factory ensures that an aggregate is produced in a consistent state. It makes certain that all entities are initialized and assigned an identity. So instead of directly creating an object from an aggregate via a constructor, a client requests a specific factory to construct an entire aggregate and return a reference to the aggregate root.

4.2.1.6 Repository

A *repository* represents all domain objects of a certain type as a collection [22, 25]. Main responsibilities of a repository are: query databases and return (reconstitute) a collection of objects to the client, delete domain objects from persistence storage and also add new objects to persistent storage. It acts as an object-oriented application programming interface (API) for data, entirely encapsulating database access infrastructure. A repository contains all database-related queries and object-relational mapping specifications. It acts as an additional layer of abstraction over the domain layer. Accordingly, through a repository only aggregate roots can be reached. Other objects internal to an aggregate are prohibited from access except by traversal from the root.

4.3 The ADO.NET Entity Framework

Microsoft Corporation released the beta 3 version of the Entity Framework (EF) in the late 2007 [2]. The fundamental principle behind the EF is that the logical database schema is not always the right view of the data for a given application. Accordingly, the main goal of the framework is to build a level of abstraction over a relational model. This abstraction is realized with the conceptual data model which is composed of entities representing real-world objects. In this way, a database application can view data as conceptual entities rather than as logical database relations. By introducing a conceptual abstraction over a relational store, the EF attempts to isolate the object-oriented application from the underlying database schema changes. In doing so it is very similar to traditional object-relational mapping tools. However, the EF also introduces a distinctive feature – the Entity Data Model – which we discuss in the following subsection. Section 4.3.2 presents the comparison of traditional data access with the SQL Client and new data access with the Entity Framework.

4.3.1 The building blocks of the Entity Framework

Figure 6 illustrates the basic elements of the Entity Framework.

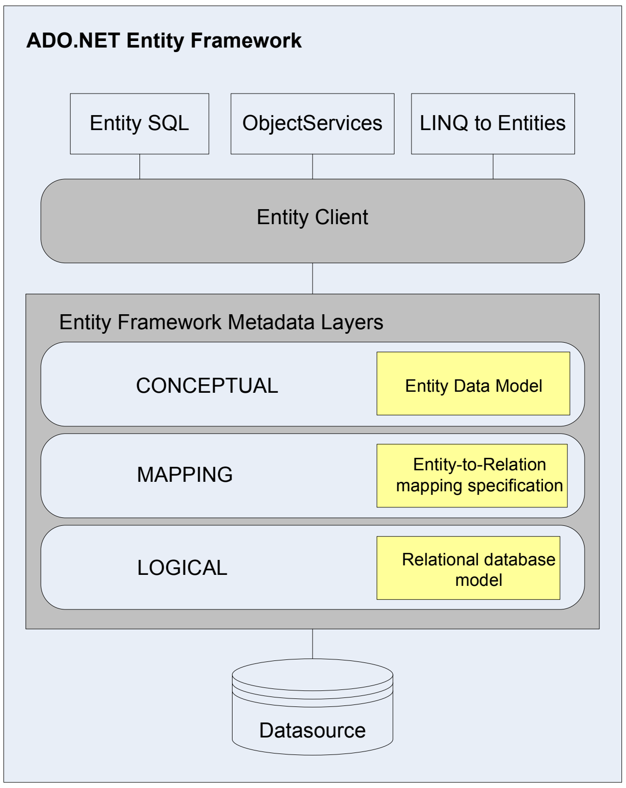


Figure 6: Entity Framework architecture (adapted from [4])

EF is claimed to largely overcome impedance mismatch problem by elevating the level of abstraction in data programming from logical (relational schema) to conceptual [4, 11]. This implies that the application can be oblivious of the relational schema by accessing persistent data through an explicit conceptual model called Entity Data Model (EDM). EDM abstracts away logical (relational schema) design from the rest of the application by exposing high-level business entities as data containers. In this way, persistence layer is decoupled from the application layer, which mitigates impedance mismatch problem.

4.3.1.1 The Entity Data Model

The Entity Data Model (EDM) follows the notation of the Entity-Relationship model [17]. The key concepts introduced by the EDM are [4]:

- *Entity:* entities directly correspond to the same concept in the domain-driven design. They are characterized by continuity (persistent) and have a unique identity. Entities in the EDM represent conceptual abstractions over the relational model and, therefore, model exclusively real-life objects. Each entity is an instance of *Entity Type* (e.g. Employee, Order). At runtime entities are grouped into *Entity Sets*.
- *Relationship*: relationships associate entities to one another. Currently, the EDM supports three types of relationships: association, containment (entities contained are dependent on the parent entity – similar to object composition) and inheritance.

Consisting of conceptual entities and corresponding relationships the EDM hides the relational model of the database from the rest of the application. It corresponds to a conceptual layer in the EF. The EF performs mapping of a conceptual layer to a logical layer (relational model) by introducing two additional layers below the EDM: mapping specification and storage schema definition. Storage schema definition is essentially a specification of a relational database model. Mapping specification reconciles the object-relational impedance mismatch by mapping conceptual entities in the EDM to relations (tables) in the storage schema.

4.3.1.2 Entity client

While the concepts of the EDM and mapping may seem abstract at first, during program execution they are made concrete with a special ADO.NET[8] interface – *EntityClient*. Entity client is a data-access provider for the EF, which is also called *mapping provider*. It encapsulates and handles database and EDM connections. It is very similar to a regular SQL Client in ADO.NET, which allows applications to connect to relational data sources. However, unlike SQL Client, Entity Client provides access to data in the EDM terms. In this case, the EDM acts as a conceptual database similar to Repository concept from DDD.

4.3.1.3 Entity SQL

When an application uses the Entity Framework and its mapping provider to access data, it no longer connects directly to the database. Rather, the whole application operates in terms of the EDM entities. Therefore, it is no longer possible to use the native database query language for retrieving data. The EF enables querying against the EDM by introducing a query language – *Entity SQL* (eSQL) [4]. The overall structure and syntax of Entity SQL is very similar to those of the standard SQL (usual SELECT-FROM-WHERE sequence). Unlike the SQL, eSQL introduces additional features such as support for navigational properties (it is possible to traverse entities instead of using JOIN) and support for inheritance.

4.3.1.4 Object Services

Considering that most applications are written in object-oriented languages and thus operate on objects, the EF introduces *Object Services* feature [4]. The EF includes a tool that, given the EDM definition, will generate a domain object layer for use in the application. By using Object Services it is possible to query the EDM with eSQL and retrieve strongly-typed objects from the store. In the same manner, once the application has finished working with objects in memory, it only has to invoke the SaveChanges operation. Subsequently, the mapping provider will persist these objects by transforming them into corresponding SQL statements to relational database.

4.3.1.5 LINQ to Entities

When it comes to querying databases for data, application programmers have to use two languages for this purpose: the query language and the programming language for manipulating the retrieved data. This not only implies that programmers have to master two distinct languages, but also that queries specified as

[8] ADO.NET is a set of software components that can be used by application developers to access data and data services in .NET environment.

string literals are usually ignored by a compiler and, therefore, can be validated only during the runtime [16]. To address these issues, Microsoft introduced the *Language-Integrated Query* (LINQ) into its programming languages (C#, Visual Basic). Essentially, LINQ became a part of the language definition and its syntax. Therefore, it became possible to perform compile-time validation of queries. The Entity Framework directly supports LINQ and refers to it as *LINQ to Entities* query language. LINQ to Entities is an alternative to eSQL as a query mechanism[9]. Like eSQL, LINQ to Entities supports complex queries to the EDM which return strongly-typed domain objects.

4.3.2 Accessing data via the Entity Framework and SQL Client

In this example we demonstrate how the emphasis on conceptual modeling changes the way data is accessed through the EF. We will show that a higher-level data model can help express the application semantics more explicitly. Consider a hypothetical application that manages orders in an enterprise. The application works with the database schema shown in Figure 7.

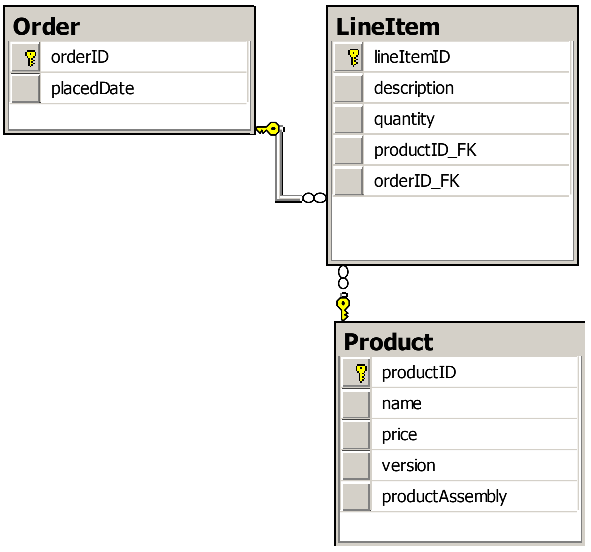


Figure 7: Order application relational schema

The order application can handle orders for two kinds of products: software products and hardware products. A traditional way of discriminating the products stored in a relational table is to have a convention: if **version** column is null (or **productAssembly** is not null) then the table row represents the hardware product; if **productAssembly** column is null (or **version** is not null) then the table row represents the software product.

Note that if the application object model (domain model) maps one-to-one to such a schema (one domain object for each database table), then violations of conceptual abstractions will occur in the domain layer. An application would like to reason about order data in terms of concepts: a software product concept and a distinct hardware product concept, rather than a single relation - Product. As the reader recalls, inappropriate abstractions were one of the drawbacks of a database-driven procedural style of organizing domain logic.

```
1.  void PrintSoftwareProducts(){
2.   using (SqlConnection connection = new
3.  SqlConnection
4.   (@"Data Source=itl3df788\sqlexpress;
5.   Initial Catalog=EFandSQLClient;Integrated
6.  Security=True"))
7.   {
8.      connection.Open();
9.      SqlCommand cmd =
10. connection.CreateCommand();
11.     string cmdText =
12.         @"SELECT name, price, version
13.         FROM Product
14.         WHERE version IS NOT NULL
15.               AND price<100;
16.         ";
17.
18.         cmd.CommandText = cmdText;
19.         SqlDataReader dr =
20. cmd.ExecuteReader();
21.         while (dr.Read())
22.         {
23.         Console.WriteLine("{0}\t{1}\t{2}",
24.               dr["name"],
25.         dr["price"],dr["version"]);
26.         }
27.  }
28. }
```

Figure 8: Data access with SQL Client

Suppose the application is given a command to build a report on all software products with a price under 100 units. Figure 8 illustrates what the SQL client provider code for retrieving information about software products would look like. The SQL query (lines 12-15) shown in Figure 8 is relatively simple. However, its semantics is not obvious. That is, unless a person reviewing the code is familiar with the database model and the requirements for the operation, it is difficult to relate this code to a specific use case requirement. More specifically, the expression "`version IS NOT NULL`" (line 14) actually means "a software product"; however, its meaning will need to be documented separately as it cannot be derived from the query without the appropriate context (a person familiar with the system or detailed documentation).

The basic premise behind the Entity Framework is to hide these storage-specific details from the application programmer and instead expose only first-class business-oriented concepts, such as Software product or Hardware product. Figure 9 illustrates the Entity Data Model that was built on top of the relational schema (in Figure 7) with the goal of abstracting all storage-specific details and presenting only high-level conceptual entities for an application programmer to interact with.

[9] In fact, one goal of our performance study discussed further in the report was to investigate these querying mechanisms in terms of verbosity and simplicity.

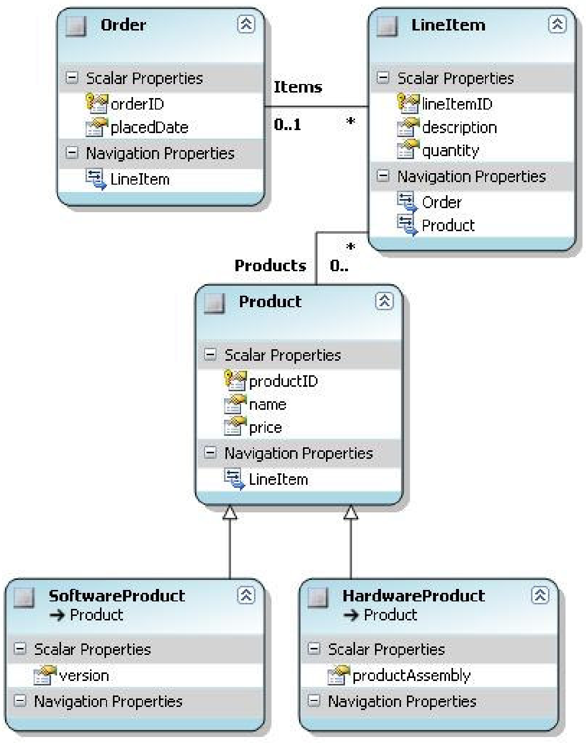


Figure 9: Conceptual Entity Data Model built on top of the relational database schema in order application

In the EDM the rule that "if product version is null then the row is a hardware product" has now been made explicit and new conceptual domain entities have been extracted from the database schema: SoftwareProduct and HardwareProduct. With the EF it is possible to query the EDM instead of the relational database. Therefore, queries become more expressive and intention-revealing as they can operate on real-life business entities. Figure 10 illustrates how the same query can be executed with the LINQ to Entities from the EF.

```
1.  public void PrintSoftwareProducts()
2.  {
3.    using (EFandSQLClientEntities objModel =
4.          new EFandSQLClientEntities())
5.    {
6.
7.   var software = from sw in objModel.Product
8.                  where sw is SoftwareProduct
9.                         && sw.price<100
10.                 select sw;
11.
12.     foreach (SoftwareProduct sw in software)
13.     {
14.          Console.WriteLine(sw.name+"\t"+sw.p
15. rice+"\t"+sw.version);
16.     }
17.   }
```

Figure 10: Data access with LINQ in the Entity Framework

Note how, by querying the Entity Data Model instead of the relational data store, the query has changed. It is no longer necessary to compare a column with null to determine whether a certain row contains a software product. Rather, the query operates in purely conceptual terms and directly requests the EDM for all software products (line 7-10). This improves the overall semantic understanding of the code. In some sense, programming code becomes more self-documenting. Also note that the query returns strongly-typed domain objects as a result of execution. There is no need to manually iterate through a dataset and instantiate domain objects. In lines 12-15 the foreach loop iterates through a collection of SoftwareProduct domain objects and prints them on a screen.

4.3.3 Concluding remarks

As the preceding example has shown, the Entity Framework stresses conceptual modeling prior to any database-related modeling. It ensures that a client application can interact with data in terms of business objects rather than database-like constructs (tables, joins through foreign and primary keys). It should also be noted that although the EF has a number of features similar to those of most object-relational mapping tools, it should not be considered such. Object-relational mapping capabilities in the EF account for a significant part of the product. However, it is the EDM that constitutes the true core of the framework and places it in stark contrast with analogous products where by convention an object model is directly mapped to database tables.

5. ADOPTING THE ENTITY FRAMEWORK IN DOMAIN-DRIVEN DESIGN: MAIN REQUIREMENTS

This section addresses RQ1. Upon the inception of the study we performed a set of initial interviews with the senior .NET architect (referred to as *the architect* in this section) with the goal of eliciting important requirements that would apply to the Entity Framework guidelines. The initial interview was subsequently complemented by a number of informal discussions with the architect about his expectations about the guidelines. Thus, in the first part of the initial study we sought to identify the main goals of further adopting the domain-driven design practices at Volvo IT. In the second part of the initial study the goal was to identify the main requirements which the guidelines would have to fulfill.

5.1 Main goals

The main goal was identified as follows:

Reduce the overall complexity in applications.

Application complexity in this particular case is related to how abstractions are handled in code. As indicated by the architect, it was important to ensure with the DDD practices that the overall complexity could be reduced by making the code operate on more business-oriented abstractions, such as an Order or Spare Part. Having abstractions that are closer to the problem domain would largely reduce the gap between a problem part and a solution part. Closely related to the application complexity is the issue of code understandability. Hence, the second major goal of embracing DDD practices is:

Further increase code understandability.

By *code understandability* we mean the extent to which a code reviewer can relate a certain portion of application code to corresponding system requirements. This might be necessary, for example, during a system maintenance cycle. *Self-documentation* property of application code was identified as the main factor in ensuring acceptable understandability. Self-documentation is one of the pillars of agile development and it relates to the ability of source code to reveal intention behind itself with expressive function names or abstractions that are more in line with the problem domain. Essentially, source code represents the system documentation. Thus, considering that the Entity Framework emphasizes programming at a conceptual level of abstraction (which is more in line with the real-world objects), Volvo IT was interested in how this framework could facilitate the DDD practices from the perspective of reduced complexity and enhanced code understandability.

5.2 Main requirements

During an initial interview and a number of subsequent discussions with the architect we identified a set of main requirements or pre-conditions that the Entity Framework guidelines would have to fulfill. The following requirements were elicited:

*The guidelines must be explicit in providing guidance in **effective** usage of the Entity Framework.*

The architect stressed that the effectiveness of using the EF must be the primary issue addressed by the guidelines. By *effectiveness* in this context he implied the extent to which the EF enabled conceptual abstractions in the application layer and the decoupling of a domain model from the database relational model. In this context, the architect also identified the anti-pattern of using the EF (ineffective use): the framework is used to mechanically derive the domain model from the database schema (database-driven approach). Therefore, the main topic of the guidelines should be the domain-driven development with the EF and the primary focus should be on how to build a conceptual model over a relational model and expose it to application programmers.

All subsequent requirements concerned domain models as such. The architect stated that the guidelines must be premised on the following expectations:

Domain models are object-oriented.

This requirement was stated early in the study by the architect. The reason that the requirement was stated explicitly is that the Entity Data Model in the EF, although it is a conceptual model of a domain, is a data model based on the Entity-Relationship (ER) model. The EDM does not support such object-oriented constructs as operations on entities, aggregation or composition, and others. Therefore, the guidelines would have to reconcile the differences between the two models (object-oriented and the ER model) and offer solutions to bridging the gap between them.

Inheritance is allowed in domain models

The guidelines would have to be such that it would be possible to use inheritance hierarchies during initial domain modeling as well as in subsequent software representations of a domain model.

Domain models encapsulate both state and behavior

The guidelines would have to show how to enable *rich* domain models with the Entity Framework. These domain models would encapsulate not only data but also contain all domain logic.

5.3 The role of the guidelines requirements

The requirements identified in the preceding section played an important role in formulating the guidelines. Together with the input from other interviewees, these requirements could be considered as the primary determinants of the guidelines. Moreover, these requirements were actively used in designing interview questions during Stage 2 of the study.

6. ENTITY FRAMEWORK IN DOMAIN-DRIVEN DESIGN: CRUCIAL FACTORS

This section presents important results from interviews with software architects and system analysts. More specifically, the section discusses critical factors affecting the adoption of the Entity Framework in domain-driven design from the perspective of interviewees.

6.1 Interviews

During a series of interviews conducted at Volvo IT with system analysts and architects we sought to gain knowledge about domain modeling and object persistence handling at the company. For confidentiality reasons we cannot directly report on these activities. Rather, we present the results from our aggregation and subsequent interpretation of the collected information. In this section, specifically, we discuss critical factors that must be considered when adopting the Entity Framework in DDD. These factors were derived from knowledge gained during the interviews. The discussions of the factors are interspersed with actual quotes from the interviews which are there to support some parts of a logical reasoning. As mentioned earlier, in total 6 interviewees were involved in the process: 1 senior .NET architect, 2 system analysts and 3 software architects. To differentiate among quotation authors, these individuals are henceforth coded as: [NETARCH], [SYSAN1], [SYSAN2], [SOFTARCH1], [SOFTARCH2], [SOFTARCH3], respectively.

6.2 Factors

We identified six major factors for consideration. The overview is presented below. Note that the factors are listed in the order of decreasing importance - as deemed by the interviewees.

1. **Data retrieval performance** – the Entity Framework should provide effective mechanisms for retrieving deep object graphs (aggregates).
2. **Support for higher-level abstractions** – the framework should provide intrinsic support for modeling higher-level business-oriented abstractions in the domain object layer.
3. **In-house competence level in object-relational mapping** – effective use of the Entity Framework will largely depend on the skill set possessed by project members in the organization. The required skill set spans object-oriented modeling, relational database modeling and object-relational mapping strategies.
4. **Rich feature set** – the framework should offer flexible querying mechanisms and provide the ability to customize generated database queries.
5. **Simplicity –** the framework should be easy to master and use. Mostly, this applies to how comprehensible mapping specification is in the framework.

6. **Support for heterogeneous data sources for the domain model** – the framework should support a number of data sources for domain objects. These could include services, data in XML format, databases from several vendors, and others.

The following sub-sections address each of the factors in detail.

6.3 Data retrieval performance

This factor was identified by software architects to be the most important in determining the success of adopting the EF in domain driven design. Performance requirements represent the cornerstone of enterprise applications, as indicated by interviewees:

"…lately relational database work is not so much about entities and domain models; it is more about the technical optimizations: performance issues and deadlock issues…" [SOFTARCH2], or:

"*…the performance requirements are so data-centric…On a scale, object-relational impedance mismatch gets 1 point and performance gets 10 points …so if I have a problem with object-relational impedance mismatch and I would rate that: performance versus coding for three weeks to go around the mismatch - there is no comparison …*" [SOFTARCH3]

It was a surprising finding that object-relational mismatch was not identified as a special concern by interviewees. Mostly, as they noted, it was a concern for vendors of object-relational mapping software. In their experience, however, impedance mismatch was handled effectively so long as object models did not diverge too far from relational models. Although, one of the architects indicated that he experienced difficulties in mapping inheritance hierarchies once, most interviewees concurred that impedance mismatch was not considered as a 'blocker' in their database work. Read performance, on the other hand, represented an important issue to consider.

Read performance is related to loading persistent object graphs from relational storage. Persistent domain objects outlive the runtime of the application. Commonly, this is achieved by storing object state in a relational database. When an application is started again, persistent objects need to be re-constituted or materialized into the main memory from the relational store [22, 25]. By following object-relational mapping strategies we can restore the whole domain model from data in relational tables. The process of transforming relational data into domain objects (re-constitution) spans a number of activities which include querying the database for data, parsing and iterating through the resulting dataset, instantiating and populating proper objects, constructing object graphs and others. The web of activities in this process may potentially inhibit object retrieval and adversely affect overall application performance.

Re-constituting domain objects in the form of aggregates is one of the services provided by the Entity Framework. An important consideration that needs to be made in adopting the framework is the time it takes to re-constitute a deep graph of domain objects from the relational store. As the reader recalls, DDD philosophy refers to these graphs as aggregates. One of the software architects indicated the importance of aggregate read performance during the interview:

"*…reading aggregates… is highly important… From my perspective, this is something very important to take into selecting the new framework…because those structures are present and they are very frequently accessed…It would be really interesting to see how it [Entity Framework] executes this query [reading aggregates]…It can be very inefficient and this is usually very inefficient…*" [SOFTARCH3]

As this interviewee stated, the issue of how efficient the EF is in retrieving aggregates should be considered carefully before adopting the EF in company's applications. His concern about performance of the EF is not surprising: the framework introduces a number of layers which perform object-relational transformation and this can lead to significant performance penalties when it comes to retrieving aggregates. Ponder the following quote:

"*…my big concern with the new Entity Framework is that it introduces too many layers in regards with metadata, abstractions and other performance reducing layers. The more layers you have, the slower you get …*" [SOFTARCH3]

Thus, how well the framework addresses this issue represents the major deciding factor in its adoption for DDD. In Section 7, we present a short comparison of aggregate read performance with the Entity Framework, NHibernate and a traditional SQLClient DataReader.

6.4 Support for higher-level abstractions

It is essential that the Entity Framework enforce the conceptual abstraction layer of indirection on top of the relational storage. It is important that the framework effectively decouple the two distinct models from each other.

One of the software architects during an interview mentioned an interesting example of a broken abstraction:

"*…you have an Order entity but in reality it consists of ten tables. That is a more interesting problem [assembling a conceptual entity in a domain layer from several tables] than an object-relational mismatch…this is something I am looking forward to in the new framework…*" [SOFTARCH3]

The interviewee indicated that better abstractions in the application layer would go a long way towards reducing overall complexity and, by extension, improving maintainability in the long run. Our view that the Entity Framework should encourage designing applications in terms that are closer to the problem domain was reinforced by a testimony from other two software architects.

"*… I need higher abstractions to be able to be efficient in my software development…*" [SOFTARCH1], or:

"*…I want that layer of freedom [abstraction layer] to be introduced. It would mean a lot. I want to have a full 100% of the schema and mapping: how it works and affects performance, and so on. For the general public [application developers] using the API*[10]*, this [relational model] could be transparent…*" [SOFTARCH3]

As can be seen from the quotes above, extent to which the EF allows for relational and domain models to diverge is an important factor. Support for powerful abstractions represents an important factor in adopting the Entity Framework in DDD. Essentially, what practitioners expect from the EF is that it will effectively abstract away the relational model and expose data

[10] Application Programming Interface – in this specific case, an abstraction layer over the database exposed to application programmers.

storage with a simple object-oriented interface to application programmers. This factor played an important role in creating Entity Framework guidelines discussed in Section 8.

6.5 In-house competence level in objects, databases and object-relational mismatch

This factor largely concerns a wide set of skills: domain modeling with an object-oriented paradigm, relational modeling, and object-relational mapping strategies. The effective use of the Entity Framework in domain-driven software development projects is contingent upon the availability of these skills within an organization.

The interviewees stressed an important mismatch between communities of object modelers and database designers. In fact, Ambler [6] terms this phenomenon as *the cultural impedance mismatch*. This term refers to the difficulties encountered by object-oriented and database-oriented developers when working together [6]. Cultural mismatch creates an interesting dichotomy: application developers tend to ignore proper modeling of relational databases by excessively relying on persistence frameworks to generate a data model from the domain model; data professionals, on the other hand, advocate for domain models being driven by relational data models. Interviewees indicated that in which direction the balance shifts depends largely on what generation a certain developer belongs to.

It appears that the adoption of the Entity Framework will be determined by whether the issue of cultural mismatch between object and data professionals is solved. This can be achieved by maintaining or raising the level of competence in object-relational mismatch. Object-oriented application developers will need to understand the implications of having rich domain models for relational data models. By the same token, database designers will need to realize the importance of abstracting object models from relational models.

6.6 Rich feature set

"*…It [adoption of the Entity Framework] is also a feature thing. You get a lot of features with this [OR mappers]. You should not underestimate that either. If you ignore the abstraction level, the ability to do queries and custom things without hand-coding yourself a lot of infrastructure is a big benefit...* " [SOFTARCH3]

As the interviewee above indicated, in adopting the Entity Framework querying features would represent an important factor. It should be possible to create flexible queries to interrogate the data store about specific domain objects based on a number of criteria. It is best to be able to create declarative queries for data and have them retrieve the data in corresponding object graphs (aggregates). Moreover, an important factor is to have a full control over the generated SQL code as it can potentially prove very inefficient.

6.7 Simplicity

No matter how efficient the framework is in generating code and generous in its feature offerings, these merits will be largely debased if it requires prolonged training sessions to master. The fundamental premise behind this idea – simplicity – is that the Entity Framework is expected to provide sensible mechanisms to declare mappings between a domain model and its relational counterpart. For example, the availability of visual modeling tools for creating domain objects and specifying their mappings could be an important factor, as indicated by the following architect.

"…[on the Entity Framework] as few layers as possible, as fast as possible, with a comprehensible metadata approach…" [SOFTARCH3]

The key word here is *comprehensible metadata approach*. Indeed, specifying mapping declarations in XML format with Hibernate can be rather difficult and confusing. This implies that mapping specification should be as simple as possible for the framework to be actively used. But ultimately it is all about simplicity and understandability:

"*…In my opinion the more I stay in this business is that you have to keep it simple because people do not understand it [any tool] if it is too fancy…*" [SOFTARCH1]

6.8 Support for heterogeneous data sources for the domain model

This factor concerns how various data sources can underlie entities in the Entity Data Model. Interviewees indicated that being able to have multiple data sources for their domain models would be a welcoming development:

"…[We need] a layer of indirection. Let's say that we have two databases, let's say we have a service. From my perspective…resource access layer is not only a database, it could be whatever – it is a resource! In a prolonged term, that could be another system…You might not need to do that, but the possibility must be there…" [SOFTARCH3]

Even though this factor appears to be of the least importance, it would be desirable for the Entity Framework to enable several data sources for the domain model. This abstraction could make possible, for example, retrieving domain objects from an XML store, a number of databases from different vendors and services into a single domain model. This, in turn, would provide a more unified view of data for all applications using the given domain model. A unified view of data would be beneficial in integrating a number of disparate corporate applications into a new application or a service.

6.9 Concluding remarks

These were the major factors that the practitioners view as critical in adopting the Entity Framework for domain-driven design. We actively used these valuable insights in designing the Entity Framework guidelines[11]. For example, the guidelines, by offering a number of mapping patterns, explain how to effectively build business abstractions in the domain layer. Also the guidelines provide recommendations on resolving the cultural impedance mismatch by showing how to proceed with the domain-driven development using the Entity Framework. As the reader might notice, the majority of the factors are technical in their nature with the main input from software architects. Software analysts also provided essential input into the guidelines that concern domain modeling in large.

[11] See Section 8

7. QUERY PERFORMANCE EVALUATION

To address the concern of aggregate read performance in the EF, which was identified as the most important factor in adopting the EF for DDD, we designed and executed an experiment to measure the time it takes to retrieve an object graph (aggregate) from a relational database. Dawson [20] already performed the evaluation of Entity Framework performance. However, the author failed to consider a case of retrieving an object graph instead of a single entity, which we believe is a very important aspect. Moreover, no studies have been performed contrasting the EF with NHibernate - another potential tool for DDD. Figure 11 illustrates the aggregate that was used in the experiment.

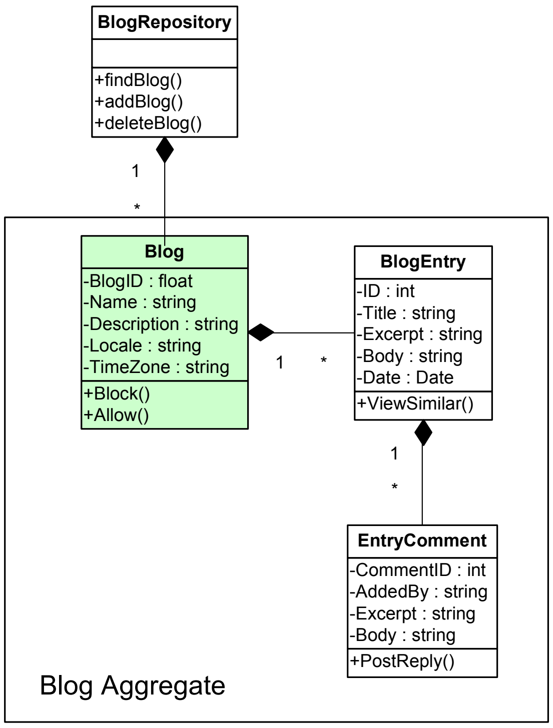


Figure 11: Domain aggregate retrieved from the relational database

Domain object Blog is an aggregate root. A reference to it is returned from a repository. The other domain objects (BlogEntry and EntryComment) can be accessed only by traversing the graph from the root. Note that a Blog contains a number of BlogEntries, each of which is composed of several EntryComments. Figure 12 illustrates the relational model to which the Blog Aggregate maps.

To measure the time it takes to perform the query we used the .NET standard library class – **Environment**. It has a property **TickCount** which returns a number of milliseconds elapsed since the system started. See the code below:

```
int start = Environment.TickCount;
//run the query
int end = Environment.TickCount-start;
```

Before the query was executed, the time was registered as Start. Once the query has finished execution and the program moved to the next line we recorded the End time.

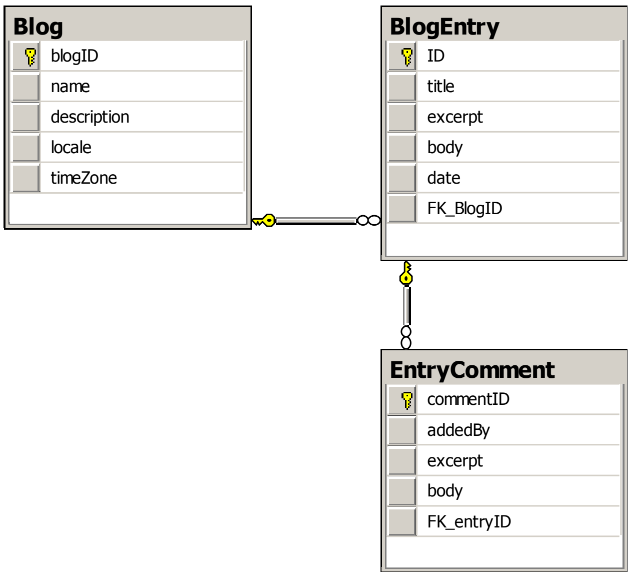


Figure 12: Relational model underlying the Blog Aggregate

Essentially, to retrieve the entire aggregate from the database, a sequence of operations has to occur, which has the following rough structure: Firstly, a SQL query is submitted to the database. To retrieve the data necessary for building the aggregate, the three relations are joined via LEFT OUTER JOIN and a Cartesian product is returned (see Figure 13).

```
select
       b.blogID,
       b.name,
       b.description,
       b.locale,
       b.timeZone,
       a.entryID,
       a.entryTitle,
       entryExcerpt,
       a.entryBody,
       a.entryDate,
       a.commentAddedBy,
       a.commentID,
       a.commentExcerpt,
       a.commentBody
from   Blog b left outer join
              (select
              ID as entryID,
              title as entryTitle,
              BE.excerpt as entryExcerpt,
              FK_BlogID,
              BE.body as entryBody,
              date as entryDate,
              addedBy as commentAddedBy,
              EC.commentID as commentID,
              EC.excerpt as commentExcerpt,
              EC.body as commentBody
       from BlogEntry BE left outer join
       EntryComment EC on ID=FK_entryID) as a
              on b.blogID=a.FK_BlogID;
```

Figure 13: SQL query to retrieve the Blog aggregate

Secondly, the resulting dataset is iterated over and, depending on the algorithm, objects are instantiated and populated with data. Thirdly, an entire object graph is constructed by initializing inter-object references. Finally, a reference to the aggregate root is returned to the caller.

Under the current experiment settings, the Cartesian product returned from joining the three tables was composed of total 4536 tuples. The resulting object graph consisted of 5 Blog objects, 175 BlogEntries and 4534 EntryComments. For example, one of the Blog objects was associated with 35 BlogEntries and each of the entries was associated with 30-40 EntryComments. The experiment measured the time it would take to retrieve the entire graph.

A total of five distinct variables were measured in this experiment. The main variable represents the time it takes to retrieve the aggregate by using a conventional SQLClient SqlDataReader. With this approach, a native .NET SqlDataReader is used to iterate over the dataset returned from the query and from it re-construct the object graph. In this case, no persistence frameworks were used to perform the translation. SqlDataReader approach represents the benchmark against which the remaining four variables were judged. The second measured variable was the time it takes to load the object graph with NHibernate object-relational mapping tool. The third, fourth and fifth variables measure the time for loading the object graph with EntitySQL, LINQ to Entities and compiled LINQ to Entities queries in the Entity Framework, respectively.

The following configuration was used to run the tests:

- Microsoft Visual Studio 2008;
- SQL Express (installed with Visual Studio);
- ADO.NET Entity Framework Beta 3[12];
- NHibernate 2.0;
- Entity Framework Tools December 2007 CTP;
- A C# console application built under the release mode configuration;
- A laptop with a dual core 1.66 GHz processor and 1 GB of RAM.

7.1 SqlDataReader

This test represented the benchmark for evaluating the performance of NHibernate and the Entity Framework. Figure 14 illustrates a portion of the C# source code that was used in running the test (see Appendix B for the full source code).

Essentially, a batch query is submitted to the database (lines 10-16), which returns three distinct datasets corresponding to Blog, BlogEntry and EntryComments. The DataReader then iterates through each of the datasets (line 18) and proper domain objects are instantiated and initialized. In this way the entire object graph is constructed and the reference to the aggregate root is returned.

The test was executed 100 times and the average execution time was 45 milliseconds. Note that the first execution took 187 milliseconds and was disregarded due to one-time costs of establishing a database connection and generating an execution plan.

```
1.  List<Blog> blogs = new List<Blog>();
2.  SqlConnection connection = new
3.  SqlConnection
4.  (@"Data
5.  Source=itl3df788\sqlexpress;Initial
6.  Catalog=BlogDatabase;Integrated
7.  Security=True");
8.  connection.Open();
9.  SqlCommand cmd =
10. connection.CreateCommand();
11. string cmdText =
12.        @"select * from Blog; select *
13. from BlogEntry; select * from
14. EntryComment";
15. cmd.CommandText = cmdText;
16. SqlDataReader dr = cmd.ExecuteReader();
17.
18. if(dr.HasRows)
19. {
20.   while (dr.Read())
21.   {
22.     //starting with first data set - Blog
23.     Blog b = new Blog();
24.         if (!dr.IsDBNull(0))
25.                 b.BlogID =dr.GetInt32(0);
26.         if (!dr.IsDBNull(1))
27.                 b.Name = dr.GetString(1);
28.         if (!dr.IsDBNull(2))
29.                 b.Description =
30.         dr.GetString(2);
31.         if (!dr.IsDBNull(3))
32.                 b.Locale =
33.         dr.GetString(3);
34.         if (!dr.IsDBNull(4))
35.                 b.TimeZone =
36.         dr.GetString(4);
37.
38.     blogs.Add(b);
39.   }
    }
    ...
```

Figure 14: SQL Client

7.2 NHibernate

The same object graph was retrieved with NHibernate 2.0. The following query was executed (Figure 15):

```
ISession session =
HibernateSessionFactory.OpenSession();
ICriteria criteria;

criteria =
session.CreateCriteria(typeof(Blog)).
        SetFetchMode("Entries",FetchMode.E
ager).
        SetFetchMode("BlogEntry.Comments",
FetchMode.Eager);
IList<Blog> blogs=criteria.List<Blog>();
```

Figure 15: hSQL in NHibernate

The test was executed 100 times and the average execution time was 385 milliseconds. The first execution took 625 milliseconds.

7.3 Entity Framework

In the Entity Framework three querying mechanisms were tested: Entity SQL, LINQ to Entities and compiled LINQ to Entities. The following Entity Data Model was queried in the experiment (Figure 16).

[12] The framework and its tools are available from http://www.microsoft.com/downloads/details.aspx?FamilyId=15DB9989-1621-444D-9B18-D1A04A21B519&displaylang=en

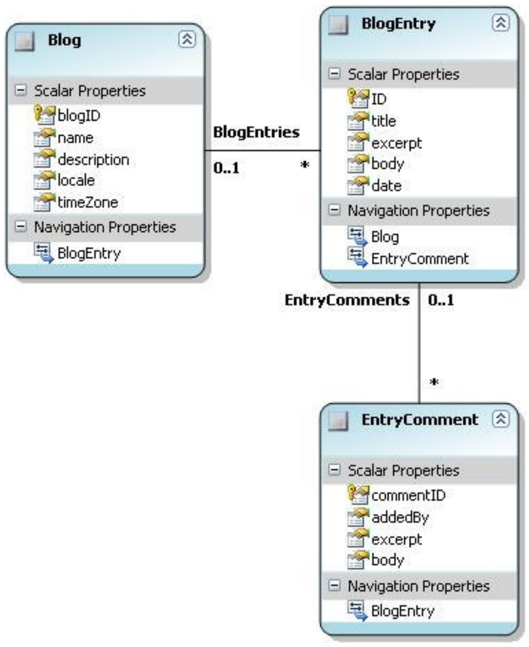


Figure 16: The Entity Data Model generated from the Blog relational model

7.3.1 Entity SQL

Entity SQL represents one of the main querying mechanisms in the Entity Framework. The following query was executed to retrieve the object graph:

```
using (BlogDatabaseEntities objModel = new
BlogDatabaseEntities())
{
   ObjectQuery<Blog> blogs = objModel.Blog.Include
               ("BlogEntry.EntryComment");
   blogs.Execute(MergeOption.OverwriteChanges);
}
```

The query was executed 100 times and the average execution time was 350 milliseconds. The first execution took some 828 seconds. This was due to a number of operations that the Entity Framework performed, such as view generation, metadata initialization and others. See Dawson [20] for a detailed explanation of the initialization process.

7.3.2 LINQ to Entities

LINQ to Entities represents a strongly-typed LINQ-based query language integrated into C# programming language. The following query was executed:

```
var blogsQuery = from blog in objModel.Blog
 select new { Blog=blog,  Entry=blog.BlogEntry,
        Comment=(from entry in blog.BlogEntry
        select new {Comment=entry.EntryComment})};
```

Note how the LINQ query differs from the SQL query. Instead of operating on relations and joins based on foreign keys, the query operates on domain objects and their associations. Moreover, the query is more expressive and far less verbose. The test was executed 100 times and the average execution time was 360 milliseconds. The first execution took 1062 milliseconds.

7.3.3 Compiled LINQ to Entities

A compiled LINQ query differs from its non-compiled counterpart in that on its first run the query execution tree is built and cached. On subsequent executions the execution tree is reused, which in theory should improve performance. The following compiled query was executed (figure 17).

```
var compiledQuery = CompiledQuery.Compile(
(BlogDatabaseEntities context) => from blog
in context.Blog
select new
{
        Blog = blog,
        Entry = blog.BlogEntry,
        Comment = (from entry in
        blog.BlogEntry
        select new { Comment =
        entry.EntryComment })
});

using (BlogDatabaseEntities objModel = new
BlogDatabaseEntities())
{
        var blogsQuery =
        compiledQuery.Invoke(objModel);
}
```

Figure 17: Compiled LINQ to Entities query

Like all previous tests, this query was executed 100 times and the average execution time was 336 milliseconds. The first execution took 1032 milliseconds.

7.4 Analysis

Interestingly, the read performance of the two persistence frameworks does not even remotely match the performance of the regular SqlDataReader. SqlDataReader may thus seem as a viable option to create the data access layer. However, for large systems, writing custom mapping infrastructure could represent an intimidating task. According to Keene [28], building and configuring object/relational data access could account for some 30-40% of total project effort.

At the same time, the Entity Framework appears to perform well compared to NHibernate. In fact, the performance of its three querying mechanisms is slightly better than that of NHibernate. This could be explained by different caching strategies employed by the EF. However, on the average, the costs associated with the first-time initialization in the EF appear to be higher than those of NHibernate. In the EF the first execution took from 828 to upwards 3045 milliseconds. The first execution time in NHibernate was relatively stable at 625 milliseconds. Yet, during subsequent query executions, the EF performed better than NHibernate (see Figure 18). Dawson [20] argues that high initialization costs in the EF are mainly caused by the run-time view generation – creating SQL views based on the specified mappings. According to him, some 56% of the first-time execution time is expended on generating entity-relation views. This step can be avoided by generating views at compile-time. As a result, Dawson continues, the first-time execution can be decreased by 28%.

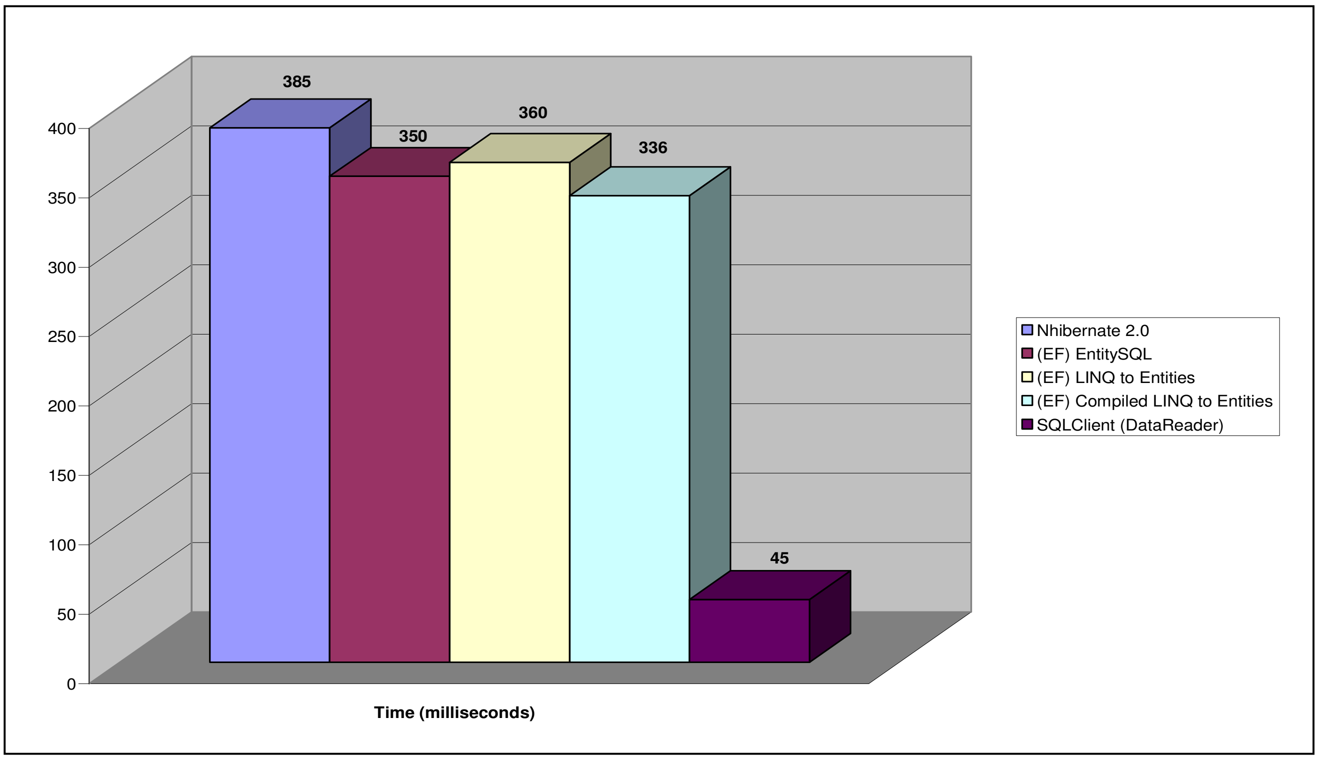


Figure 18: A comparative evaluation of query performance with DataReader, NHibernate and the Entity Framework

Even though the Entity Framework performs poorly compared to the SqlDataReader, its feature set needs to be taken into account. It not only performs automatic object state tracking and management but also offers a number of querying options. These, in turn, could dramatically improve developers' productivity. Accordingly, we believe that the Entity Framework will need to be further tested in real project settings to determine if the posed tradeoff is acceptable.

Eventually, the results from this performance evaluation served as an important input to the Entity Framework guidelines. For example, based on this experiment we could give informed recommendations on using querying mechanisms in repositories.

8. ENTITY FRAMEWORK GUIDELINES

The Entity Framework Guidelines contain a number of recommended activities that need to be performed when using the EF in DDD. In many ways, we view them as best practices. The guidelines cover a wide range of issues: domain modeling, model-driven development in the EF, applying domain patterns and mapping domain objects to relations. In designing the structure of the guidelines we sought to ensure that they could be easily catalogued and accessed. With this goal in mind, we opted for a *pattern language* [27] approach. According to Jessop [27], a pattern language is a collection of patterns, "each of which is a simple description of a problem and a suggestion for its solution and contains links to other patterns in the language". To our best knowledge, no pattern languages addressing the use of the EF in DDD exist in literature. Figure 19 illustrates the taxonomy of the Entity Framework guidelines.

After cataloguing our best practices of using the EF in DDD, we created a *repository* consisting of a total 15 patterns. The repository has two main parts: core guidelines (8 patterns) and mapping patterns (7 patterns). The partitioning of the guidelines into two distinct compartments was motivated by the structuring requirements. More specifically, it was necessary to organize the guidelines around domain modeling and design on one side (core guidelines), and resolving object-relational impedance mismatch on the other (mapping patterns). Accordingly, core guidelines address the most basic principles that need to be followed for effectively using the EF in DDD. Mapping patterns concern the issues of mapping a domain model to the Entity Data Model and database tables. Note that mapping patterns play an auxiliary role in relation to the core guidelines. They present detailed instructions on how to perform certain activities within the core guidelines. Each pattern follows a well-defined structure, which is presented below:

- **Applicability** – in what cases the given pattern should be used;
- **Goal of the pattern** – what expected results the pattern produces;
- **Problem description** – a description of a problematic situation, which the given pattern tries to solve;
- **Solution** – how should the posed problem be solved;
- **Example** – shows a concrete example of applying the pattern.

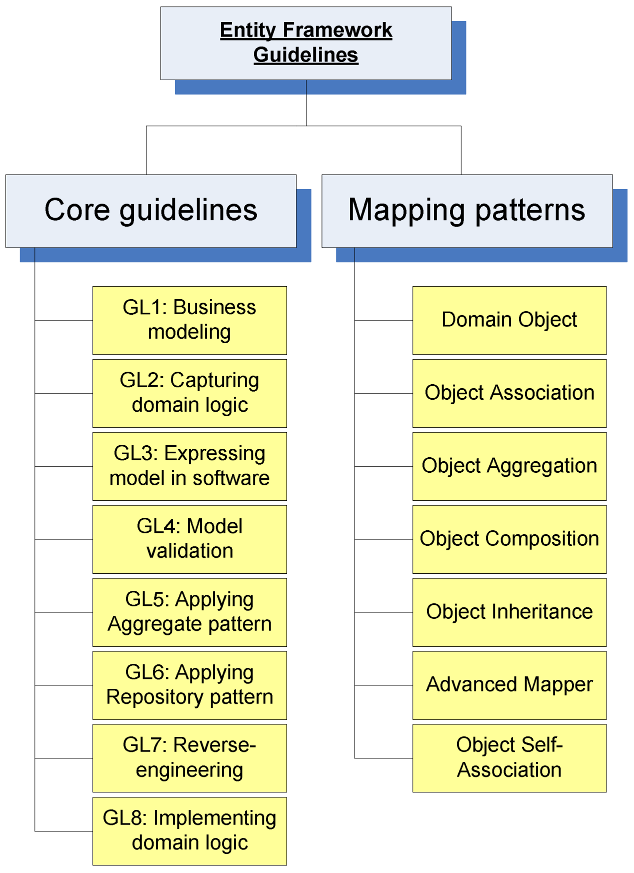


Figure 19: Taxonomy of the Entity Framework Guidelines

Essentially, we see this structure as the *language of a pattern*. It serves as a common language for defining a pattern, which could potentially allow a broader range of people within Volvo IT to consume patterns and contribute new ones, thus increasing the overall knowledge base in the domain-driven design. Eventually, this language was used to develop all the Entity Framework guidelines, which were then presented to the Software Process Improvement Group at Volvo IT. The guidelines were presented in the context of a real-world sample domain-driven application: the guidelines show how to proceed with the DDD, beginning from initial domain modeling and ending with the implementation of a portion of a DDD application supported by the EF. The following sub-sections discuss the pattern discovery process and present an overview of the guidelines, which are the main result of this Master thesis. The details of the guidelines are a proprietary asset of Volvo IT and cannot be published according to our confidentiality agreements.

8.1 Pattern discovery process

The main goal of the discovery process was to capture 'hidden' organizational knowledge about domain modeling and design, and document it in the form of a structured description of a solution to a recurring problem. In this way, we sought to make implicit (tacit) knowledge within Volvo IT explicit and universally accessible to all employees within the organization. To achieve this and catalogue a collection of patterns, we interviewed software architects and systems analysts on such topics as domain modeling, object-relational mismatch and object persistence. For example, an architect was interviewed about domain-driven design in his projects. Then, his suggestions for incorporating DDD into a software development process or domain modeling in general were used in formulating guidelines 1 and 2. In the same manner, systems analysts contributed to these two guidelines. Some other guidelines (GL3, 5 and 6, for example) were elicited from studying available literature on the topic and then validated with the senior .NET architect. Also, jointly with this architect all mapping patterns were identified.

8.2 Core guidelines

8.2.1 GL 1: Business domain modeling

As opposed to the database-driven design, the designers should already at the domain modeling stage use object-oriented constructs (such as inheritance) rather than database-related constructs (i.e. constructs that can be readily stored in the database). This guideline ensures that an object-oriented domain model captures domain concepts and their relationships in a more precise way than do database-oriented object models. Essentially, it offers guidance on collecting knowledge about a domain from domain experts and distilling it in a model. It shows when in a generic software development process at Volvo IT domain modeling should take place. This guideline is largely based on recommendations made by Evans [22], but it also offers advice based on knowledge gained during interviews with systems analysts. We view this guideline to be one of the focal ones as it addresses primary issues raised by interviewees:

"*…The biggest value of a domain model is that you have a common language and you have a base for…[application] architecture…If you know the domain, how concepts are related to each other, you can reflect this in the architecture of the software. And then you do better software…*" [SOFTARCH1]

8.2.2 GL 2: Capturing domain logic

A central characteristic of a domain model is that it not only captures essential business concepts but also provides a mechanism for structuring domain logic. This guideline addresses the issue of capturing domain logic and illustrates how the process should be organized. It was largely informed by software architects and complemented by the work of some authors [22, 25]. Essentially, the guideline is about what domain logic should be modeled in entities and what logic should be modeled as services, for example. This guideline was largely inspired by a software architect interviewed during the study:

"*…business rules are very important…If you don't think about business rules and just go ahead and specify your use cases, you will have serious problems because business rules are normally quite complex and they are not flows like use cases…When you do use cases, you have to be aware that you have business rules…*"[SOFTARCH1]

8.2.3 GL 3: Expressing domain model in software

Once the domain model has been produced, it is necessary to make it explicit in software: transform it into its software representation. This guideline shows how to express a domain model with the Entity Framework and make the model executable. The guideline addresses a number of issues in performing mappings of different domain model constructs to their software peers.

8.2.4 GL 4: Validating the domain model

Once the first versions of a domain model have been released in the project, it is critical to perform the validation of a model with domain experts. This is explained by the need to ensure that the domain model accurately captures important domain concepts, their relationship and essential business rules. This guideline shows how to effectively perform validation of a domain model with the Entity Framework.

8.2.5 GL 5: Applying the Aggregate pattern

This guideline shows how to apply the Aggregate pattern within the Entity Framework. Such important issues are considered as: the choice of a query language for retrieving aggregates, aggregate boundary definition, implementing aggregates within the EDM and others. The guideline actively uses the results from evaluating performance of the EF querying mechanisms.

8.2.6 GL 6: Applying the Repository pattern

The repository is an abstraction over a domain model. It represents an object-oriented collection of domain objects: an in-memory object database. This guideline discusses how Entity Framework features can be leveraged for creating an effective mechanism for managing domain objects in an application. Such issues are considered as: managing ObjectServices context, defining and building proper transactions and others. Moreover, this guideline addresses the problems of defining Factories for creating domain aggregates with the Entity Framework. Finally, this guideline discusses the creation of services that consume domain objects from the repository. In this context, the guideline provides recommendations in scoping and creating transactions. Also, strategies for preventing optimistic concurrency violations are addressed in this guideline.

8.2.7 GL 7: Reverse engineering

It is likely that a new object-oriented application will need to be built on an existing legacy database. In such a project it may be the case that no documentation will exist short for the legacy data model. Therefore, considering that object-oriented languages are best suited for operating on concepts, it becomes essential to be able to effectively reverse-engineer the legacy database and extract important concepts from its relational model. This guideline shows how the Entity Framework should be used for reverse engineering existing databases and, subsequently, migrating these systems to domain-driven design practices. For example, the guideline shows how to:

- extract inheritance structures from a relational model;
- extract aggregation/composition relationships;
- extract associations of different cardinalities, especially many-to-many associations;

8.2.8 GL 8: Implementing business rules in the Entity Framework

An essential characteristic of a domain model is that business logic is embedded directly into domain objects. However, the EDM is only a data model: it is impossible to specify business rules in this model. We need to find a way of encapsulating business logic in domain objects. This guideline discusses different possibilities of implementing domain logic in domain objects generated by the Entity Framework.

8.3 Mapping patterns

Mapping patterns complement the core guidelines with the detailed guidance on mapping a domain model to the Entity Data Model and then mapping the latter to a relational database model. We identified a set of 7 major patterns. Possibly, many more may exist, but the current seven, we believe, represent the most common cases in domain modeling. The catalogue of patterns was identified and validated by the senior .NET architect. The details of some mapping patterns were also informed by [7, 25, 29]. Some mapping patterns are accompanied by a discussion of implications (consequences) of applying it for maintainability and performance attributes.

8.3.1 Pattern: Object Association

Object association represents the fact that one object is in some way related to another (see Figure 20). This pattern describes the process of mapping object associations to the EDM constructs and database tables. The pattern considers the following multiplicities: one-to-one, one-to-many and many-to – many.

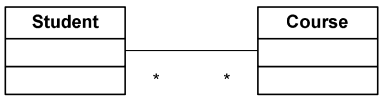


Figure 20: Object association

8.3.2 Pattern: Object Aggregation

Object aggregation shows that one object (aggregate) consists of some other object(s) (see Figure 21). This is a so-called "has-a" relationship. Object Aggregation pattern shows the options for mapping aggregation to the EDM constructs and subsequently to database tables.

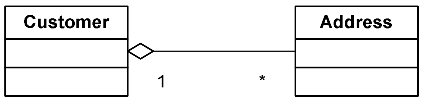


Figure 21: Object aggregation

8.3.3 Pattern: Object Composition

Object composition is stronger than aggregation in that the composite determines the life of its components. That is, should the composite be destroyed, all of its components will also be destroyed (see figure 22). This pattern shows how to ensure composite behavior in both the EDM and the relational model.

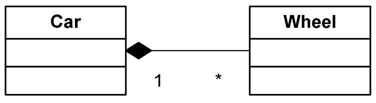


Figure 22: Object composition

8.3.4 Pattern: Object Self-Association

Self-association occurs when a class maintains a reference to itself. More specifically, an object would refer to a subset of objects of the same class. Consider figure 23.

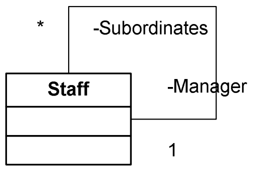


Figure 23: Object self-association

Within the whole staff, there is a subset of managers. Each manager has a set of subordinates. In this case, on the 1 side of the relationship a manager is reached. The **many** side of the relationship accesses a group of subordinates who report to this manager. Accordingly, this pattern shows how to perform the mapping of such an association to the EDM and the relational model.

8.3.5 Pattern: Object Inheritance

While the EDM supports the concept of structural inheritance (only attributes are inherited), the notion of inheritance is absent from a relational model. Instead, it can be emulated by various schema arrangements. To date, three options exist in mapping object inheritance to relational tables: table-per-hierarchy (TPH), table-per-concrete class (TPCC) and table-per-class (TPC) [7, 15, 25, 29].

In TPH, the entire inheritance hierarchy is mapped to a single database table (figure 24).

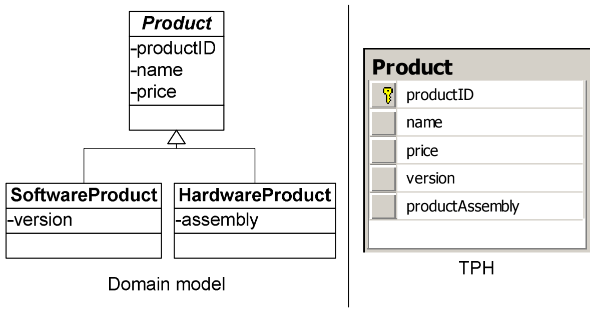


Figure 24: Table-Per-Hierarchy inheritance mapping

In TPCC each concrete class is mapped to its own table. Abstract classes are not mapped (figure 25).

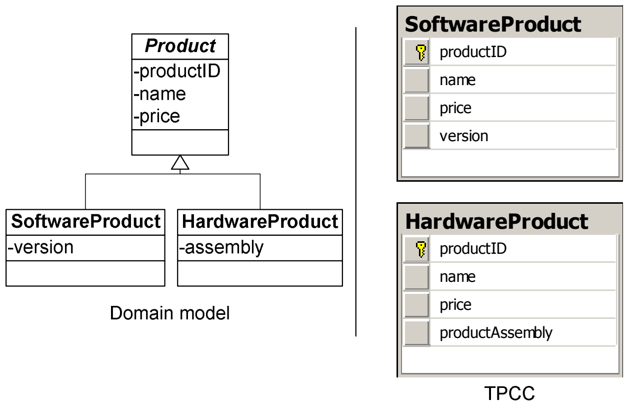


Figure 25: Table-Per-Concrete-Class inheritance mapping

In TPC every single class (concrete or abstract) is mapped to a database table (figure 26).

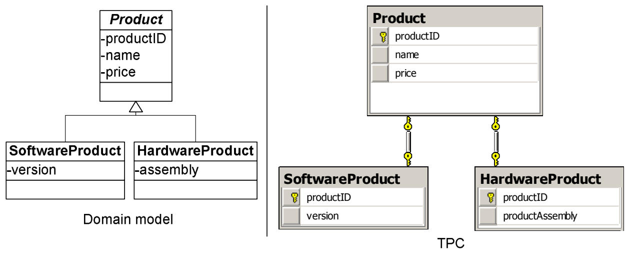


Figure 26: Table-Per-Class inheritance mapping

Thus, Object Inheritance pattern describes how the mapping options presented above can be implemented in the EDM with the Entity Framework.

8.3.6 Pattern: Domain Object

This is a fundamental pattern that discusses mapping a domain entity to the EDM entity and a relational model. It considers the mapping of object attributes to the attributes in the EDM entities. This pattern also discusses how the EDM entity can be split across several tables to ensure proper normalization in the database, and yet, have conceptual abstractions in the domain layer.

8.3.7 Pattern: Advanced Mapper

This pattern considers more advanced cases of mappings (beyond the more common one-to-one mapping) and presents a generic solution to most complex mapping problems. See figure 27 for an example of a domain model calling for advanced mapping.

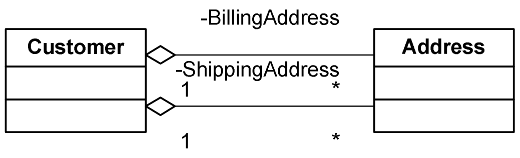


Figure 27: Multiple association

In this case a Customer may possess several Billing and several Shipping Addresses. Both types may overlap: that is, a Customer can have a Shipping address which is at the same time a Billing address. Figure 28 shows a possible relational model to which such a structure could have to be mapped.

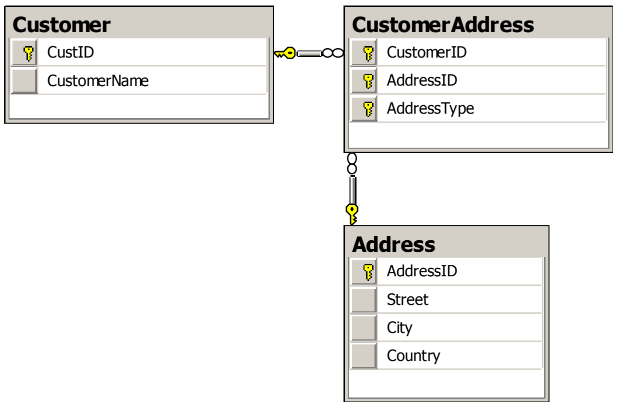


Figure 28: Mapping to relational model

In this model, an association table is created which not only connects customer to addresses but also stores the role a certain connection plays – AddressType (Billing or Shipping). Mapping such models to a domain model presented in figure 27 requires more advanced techniques that go beyond simpler mappings in the Entity Framework designer. Exactly these situations are addressed by the Advanced Mapper pattern.

8.3.8 Mapping pattern example

Pattern: Object Association

Applicability

This pattern applies to mapping associations in a domain model.

Goal of the pattern

The pattern shows how to map different types of object associations to the EDM inter-entity associations and database tables.

Problem description

How should a one-to-many object association be mapped to the EDM entity relationship?

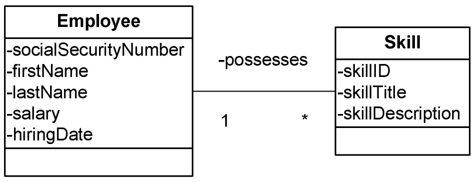
Solution

Map one-to-many association to an entity association with the same multiplicity characteristics. This is possible because EDM associations are inherently weak, which means that the destruction of an object does not necessarily lead to the destruction of a related object.

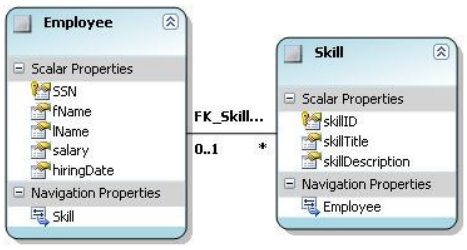
To map the resulting structure to database tables perform the following: Create a table for each EDM entity. The keys and attributes from the EDM remain the same in the database tables. Add a foreign key to the table that represents the EDM entity on the *many* side of the association. The foreign key is the key from the entity on the *one* side of the association.

Example

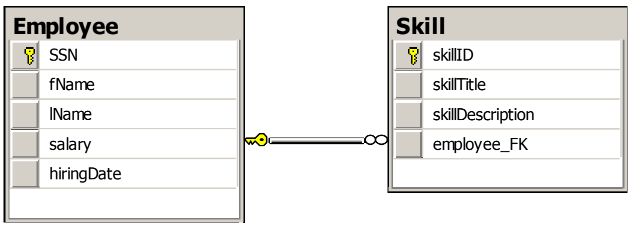
Consider a portion of a domain model below:



This model denotes that an Employee may possess a number of various Skills. How should we approach mapping this model to the EDM and the relational database model? Firstly, this model is mapped to the EDM constructs. By applying one-to-one mapping between the domain model and the EDM and using a weak association we can derive the following model:



Then map the resulting EDM model to the following relational structure:



The entities are mapped one-to-one to database tables. The keys from the entities in the EDM remain the same in the tables. Note the addition of a foreign key to Skill table denoting the one-to-many relationship from Employee table to Skill table.

9. DISCUSSION

9.1 Why patterns?

We decided to present the guidelines with a pattern approach for a number of reasons. First and foremost, an individual pattern is focused on one and only one specific problem/solution pair at a time. A pattern does not attempt to address numerous issues simultaneously; rather, it tackles a single problem in an isolated fashion. Fowler [24] refers to such approach as encapsulating the problem and states that it is instrumental in solving design problems in such a massive topic as software. A pattern is very specific in showing solutions to a concrete problem. Alternatively, we could formulate the guidelines in the form of general principles. However, principles are often too abstract and may not lend themselves well to specific problematic situations in using the Entity Framework. For example, consider a case of mapping an abstract conceptual model to a relational model. Unless mapping is performed by a highly experienced developer (in which case he does not really need any patterns: he knows the solutions already), documented best practice will be required for the less skilled developers to perform effective mapping.

Second, patterns are defined by a language, which imposes a standard structure on them. With a well-defined structure patterns can be catalogued and accessed more easily. Considering that a pattern explicitly states in which context it is applicable, it should be a more straightforward process finding an appropriate solution to the given problem.

Finally, a catalogue of patterns is the knowledge base of an organization. Fowler [24] offers a relevant discussion of the value of 'patternizing' organizational knowledge. The fundamental irony of patterns is that they, by definition, do not offer anything new. Rather, they capture what has already been known (implicitly or explicitly) in a structured description. In fact, they may even seem trivial to experts in the field. One could argue that this debases the value of patterns. However, one should also consider that there are less skilled individuals who are only now beginning to master the field and they need to gain access to experts' knowledge. And here lies the primary benefit of cataloguing patterns: they help disseminate expert knowledge within an organization.

9.2 Initial evaluation

To assess whether the pattern approach to presenting guidelines made sense, we conducted a joint evaluation workshop with the software architects and analysts (referred to as *evaluators* in this section) that had been interviewed earlier. During the workshop we presented some of the core guidelines and mapping patterns to the evaluators and then solicited their spontaneous comments. Our primary goal was to see if the method of presenting the guidelines (pattern approach) was viable within Volvo IT, given the culture in its project teams. The workshop was organized in two parts. During the first part we presented the pattern language for defining the guidelines, which was followed by a demonstration of sample guidelines prepared prior to the workshop. During the second part of the workshop we moderated a discussion among the evaluators where they were asked to elaborate on the strengths and weaknesses of our pattern approach. A summary of our deliberations is presented below.

Initially, we had a concern that the pattern approach to the guidelines would adversely affect their usefulness. Developers would have to decide for themselves which patterns to use and when to use. Extracting a proper pattern from a repository and learning to apply it in a specific context could prove to be difficult. We suggested to the evaluators that, possibly, a better option was to present the guidelines in the form of tutorials – step-by-step instructions on performing domain-driven development with the Entity Framework. However, the tutorial method was considered inappropriate by the evaluators for two main reasons. First, step-by-step instructions are usually too detailed and context-dependent and therefore cannot be followed in absolutely all cases. Second, tutorial approach (with numerous activities and instructions) could obscure important principles underlying the guidelines.

Interestingly, as the guidelines were presented, some evaluators appeared to be confused and deemed the guidelines too abstract. However, once we presented the example part of each guideline, they admitted that the guidelines were much more understandable with concrete examples of applying them. Eventually, by the end of the workshop, evaluators endorsed the pattern approach citing that it succeeded in conveying the 'big picture': applications need to be structured around a domain model. But there was a reservation. As of now, it is impossible to be certain about the applicability of the guidelines and the Entity Framework in general until they are applied in a real software development project at Volvo IT. Most importantly, as some of the evaluators noted, performance of the Entity Framework will need to be carefully evaluated before any further commitment to the guidelines can be made.

10. CONCLUSION

The application of the domain-driven design philosophy within an iterative software development process promises to conquer complexity inherent in building software. With complexity at bay comes more intimate understanding of the problem domain. This, in turn, results in better software capable of effectively addressing user concerns. There are two essential aspects to domain-driven design. The first is about *modeling*: capturing and distilling domain knowledge in an abstraction – a domain model. In this context, a domain model represents an analysis artifact – the result of crunching information about a domain from a number of sources. The second aspect concerns, not surprisingly, software *design*. In this regard, domain-driven design seeks to address the issue of implementing a domain model in software. It is about encapsulating a model of business within the overall architectural framework as well as structuring the logic inside the business model at the design level.

The adoption of the domain-driven design practices depends on the availability of appropriate tools that would not only enable software engineers to perform domain modeling but also address practical issues in implementing domain-driven applications. These issues include such cross-cutting concerns as persistence and transaction management. The ADO.NET Entity Framework with its emphasis on modeling conceptual business entities can potentially support domain-driven design.

10.1 Key findings

This exploratory study provided initial knowledge about using the Entity Framework in domain-driven design at Volvo IT. Most importantly, a number of guidelines were conceived which provide guidance in using the Entity Framework for modeling a domain and implementing it in software. The guidelines re-iterated the importance of employing conceptual modeling practices in software development projects as well as following sound design techniques in working with domain object persistence. We used a pattern approach to structuring and presenting the guidelines. Our initial evaluation of the pattern approach showed that generally it was perceived as understandable by the key study interviewees: software architects and systems analysts. However, it is still early to state this with absolute certainty as the guidelines need to be properly evaluated in a real software development project within Volvo IT.

Apart from the guidelines, six key factors affecting the adoption of the Entity Framework in domain-driven design at Volvo IT were identified. These factors (performance, abstraction, competence, features, simplicity and multiple data sources) served as important input to the guidelines. Out of the six factors, the read performance was stated as number-one concern in adopting the Entity Framework. Considering this we conducted an evaluation of aggregate read performance of the Entity Framework. The performance experiment showed that the aggregate read performance of the Entity Framework compares well with that of NHibernate mapping tool. The performance experiment also demonstrated a number of different querying mechanisms in the Entity Framework.

10.2 Future research

It is important to remember that this exploratory case study was conducted at only one company. We believe more similar studies need to be performed at different software organizations to confirm or disprove the guidelines proposed in this study. For example, it is important to conduct a similar study once the Entity Framework is released to manufacturing. It is conceivable that the guidelines based on the release version of the framework might in parts differ from our findings. While the guidelines addressing modeling are unlikely to differ, more implementation-specific guidance may well differ. For example, guidance addressing aggregate and repository patterns might be different. Furthermore, a more comprehensive performance testing should be performed. Future research should focus on testing performance of not only loading objects but also writing data back to the database. Finally, it would be beneficial to research more options in mapping EDM entities to database tables with the Entity Framework and document them in patterns.

11. ACKNOWLEDGMENTS

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Appendix A: Interview questions

Interviews with software architects

1. When building data-centric applications heavily relying on relational databases, do you have reverse-engineering projects (relational database model already exists) and forward engineering projects (development is started from scratch, no models exist yet)? What other project types can you point out?
2. What is the primary method or technique used for requirements modeling?
3. From your experience, do system analysts use any object-oriented techniques for modeling requirements? Say, for example, domain modeling?
4. Use cases are traditionally more well-suited for capturing usage scenarios, rather than for capturing business rules or validations. Do you agree? Do other developers share this notion?
5. How are business rules actually captured and modeled?
6. What do you understand by domain models and domain-driven design?
7. In your view, would a domain model represent an effective mechanism for collecting and distilling requirements?
8. In data-centric applications, there is a data layer with a relational model and an application layer with an object-oriented model. Are object models defined independently of relational data models or usually object models are data-driven?
9. Does the relational data schema place any limitations on the object model? For example, does it prevent developers from using inheritance in object models?
10. How much behavior do object models contain?
11. Do object models contain any of such constructs as inheritance, aggregation/association and association?
12. In your view, do developers which you observed possess skills in conceptual data modeling, such as Entity-Relationship modeling or do they usually start off with defining relational schema?
13. Did projects that you observed use object-relational mapping tools? What kind of tools? How was the mapping specified? Did the tools impose any limitations on the complexity of object models (mapping inheritance, composition/aggregation and associations)?
14. In your view, are object models and data models (relational models) developed independently of each other? Or is either of the models is subjected to the other? For example, object models are primarily driven by relational data models, or vice versa?
15. If the relational schema already exists in the project, how do you derive or build an object model on top of the relational model? Do you simply generate objects from tables with an object-relational mapping tool? Or do you build object models independently regardless of the relational schema?
16. In general, in .NET projects is object persistence challenging? Do you have to expend a lot of effort trying to map the two models: relational and object-oriented?

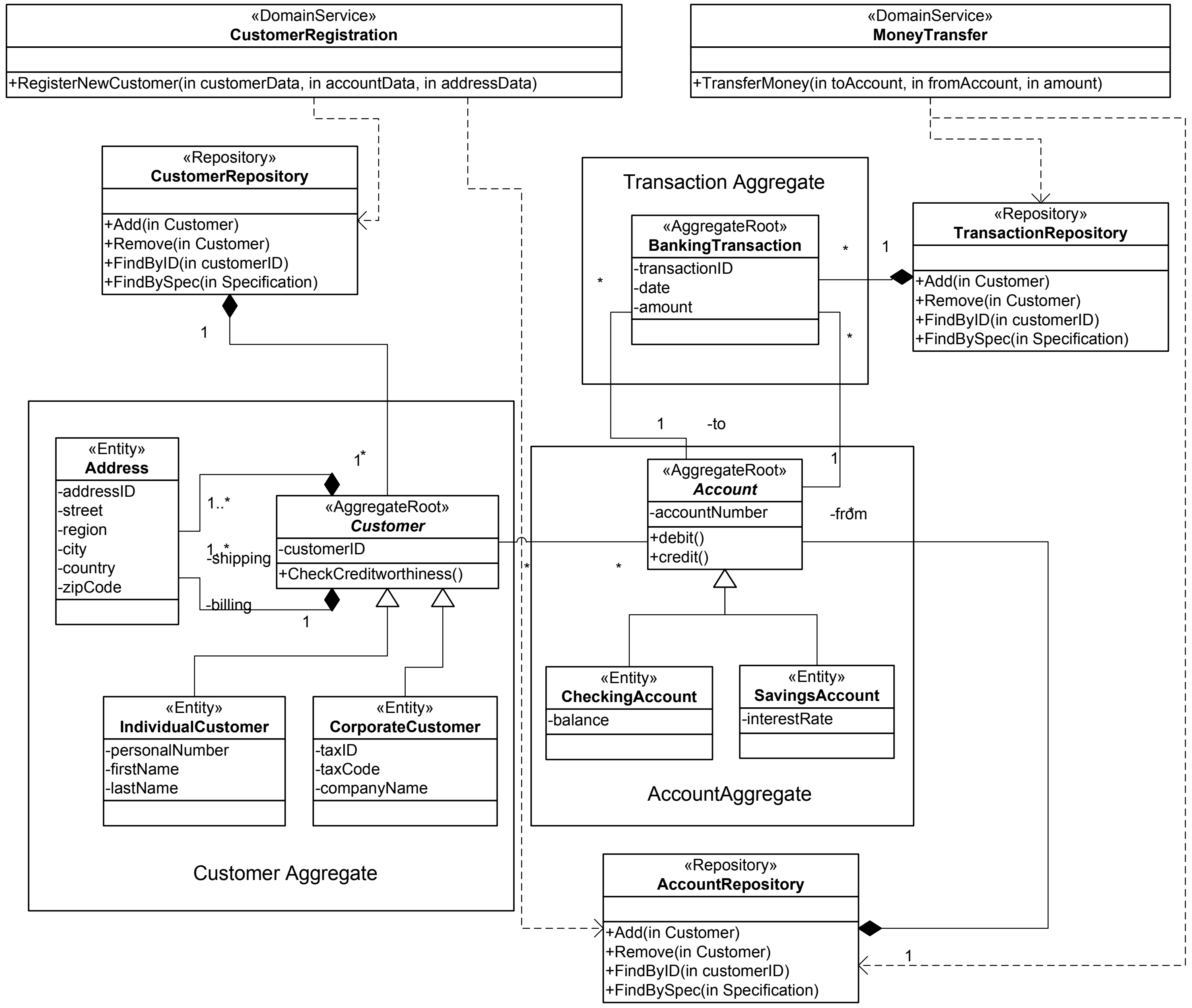
Interviews with systems analysts

1. What is the primary technique used for requirements modeling in software development projects?
2. Do you perform conceptual modeling during requirements engineering stage? If so, what is the method you use?
3. Do you use object-oriented techniques for requirements modeling in your projects? If so, which?
4. Do you perform formal domain modeling to complement use case modeling?
5. How do you capture main business concepts in the problem domain? In other words, how do you learn about the domain? Do you use use-cases for this? How do you build a common vocabulary among developers and business customers?
6. What roles do domain models play in your projects? Are they further refined into object-oriented design or data models?
7. What constructs do your domain models include?
8. How do you capture business rules and validations? Do you incorporate then into use-case documents?
9. In your view, would a domain model represent an effective mechanism for collecting and distilling requirements along with use cases?
10. From your experience, do project members usually use conceptual modeling techniques, such as Entity-Relationship modeling or object-oriented conceptual modeling (class diagrams)?
11. What are the 5 main challenges which occur during requirements modeling in your projects?

Appendix B: C# code to retrieve the blog aggregate with the SQL client

```
public int PerformSQLCLIENTquery()
{
      int start = Environment.TickCount;
      List<Blog> blogs = new List<Blog>();
      SqlConnection connection = new SqlConnection
                  (@"Data Source=itl3df788\sqlexpress;Initial
                  Catalog=BlogDatabase;Integrated Security=True");
      connection.Open();
      SqlCommand cmd = connection.CreateCommand();
      string cmdText =
      @"select * from Blog; select * from BlogEntry; select * from EntryComment";
      cmd.CommandText = cmdText;
      SqlDataReader dr = cmd.ExecuteReader();

      if(dr.HasRows)
      {
            while (dr.Read())
            {
                  //starting with first data set - Blog
                  Blog b = new Blog();
                  if (!dr.IsDBNull(0)) b.BlogID = dr.GetInt32(0);
                  if (!dr.IsDBNull(1)) b.Name = dr.GetString(1);
                  if (!dr.IsDBNull(2)) b.Description = dr.GetString(2);
                  if (!dr.IsDBNull(3)) b.Locale = dr.GetString(3);
                  if (!dr.IsDBNull(4)) b.TimeZone = dr.GetString(4);

                  blogs.Add(b);
            }
      }

      //move to BlogEntry dataset
      dr.NextResult();

      if (dr.HasRows)
      {
            while (dr.Read())
            {
                  //re-constitute BlogEntry object
                  BlogEntry be = new BlogEntry();
                  if (!dr.IsDBNull(0)) be.EntryID = dr.GetInt32(0);
                  if (!dr.IsDBNull(1)) be.Title = dr.GetString(1);
                  if (!dr.IsDBNull(2)) be.Excerpt = dr.GetString(2);
                  if (!dr.IsDBNull(3)) be.Body = dr.GetString(3);
                  if (!dr.IsDBNull(4)) be.Date = dr.GetDateTime(4);

                  int blogID = dr.GetInt32(5);
                  //find the Blog object with the given ID
                  Blog theBlog=blogs.Find(delegate(Blog b) { return b.BlogID ==
                  blogID; });
                  //add the current BlogEntry to the Blog
                  theBlog.Entries.Add(be);
                  be.Blog = theBlog;
            }
      }
//move to EntryComment dataset
      dr.NextResult();

      if (dr.HasRows)
      {
            while (dr.Read())
            {
                  //re-constitute EntryComment object
                  EntryComment ec = new EntryComment();
                  if (!dr.IsDBNull(0)) ec.CommentID = dr.GetInt32(0);
                  if (!dr.IsDBNull(1)) ec.AddedBy = dr.GetString(1);
                  if (!dr.IsDBNull(2)) ec.Excerpt = dr.GetString(2);
                  if (!dr.IsDBNull(0)) ec.Body = dr.GetString(3);

                  int blogEntryID = dr.GetInt32(4);
                  bool entryFound = false;
                  foreach (Blog blog in blogs)
                  {
                        foreach (BlogEntry entry in blog.Entries)
                        {
                              if (entry.EntryID == blogEntryID)
                              {
                                    //add the entry comment to the blog entry
                                    entry.Comments.Add(ec);
                                    ec.BlogEntry = entry;
                                    entryFound = true;
                                    break;
                              }
                        }
                              if (entryFound)
                                    break;
                  }
            }
      }


                  connection.Close();

                  int end = Environment.TickCount - start;

                  return end;
}
```

Appendix C: Example domain model based on domain-driven design principles


«DomainService» CustomerRegistration
+RegisterNewCustomer(in customerData, in accountData, in addressData)
«DomainService» MoneyTransfer
+TransferMoney(in toAccount, in fromAccount, in amount)
«Repository» CustomerRepository
+Add(in Customer)
+Remove(in Customer)
+FindByID(in customerID)
+FindBySpec(in Specification)
Transaction Aggregate
«AggregateRoot» BankingTransaction
-transactionID
-date
-amount
«Repository» TransactionRepository
+Add(in Customer)
+Remove(in Customer)
+FindByID(in customerID)
+FindBySpec(in Specification)
«Entity» Address
-addressID
-street
-region
-city
-country
-zipCode
«AggregateRoot» Customer
-customerID
+CheckCreditworthiness()
1..*
1..*
-shipping
-billing
1
1*
«Entity» IndividualCustomer
-personalNumber
-firstName
-lastName
«Entity» CorporateCustomer
-taxID
-taxCode
-companyName
Customer Aggregate
«AggregateRoot» Account
-accountNumber
+debit()
+credit()
1
-to
1
-from
*
*
*
«Entity» CheckingAccount
-balance
«Entity» SavingsAccount
-interestRate
AccountAggregate
«Repository» AccountRepository
+Add(in Customer)
+Remove(in Customer)
+FindByID(in customerID)
+FindBySpec(in Specification)
1