# CONCEPTS OF MODEL DRIVEN SOFTWARE DEVELOPMENT IN PRACTICE

## *Generic Model Representation and DSL Interpretation*

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Abstract: This paper discusses possibilities to realize constructs of a domain specific model (DSL) on the concrete development and runtime platform Ibykus AP. Here software engineering takes advantage of a combination of generative techniques and stable so-called DSL interpreters. These techniques to implement model driven software development (MDSD) concepts can improve the flexibility, the quality and the performance of the development of large application systems. Presenting the DSL interpreter approach underlying techniques of generic repository structures to hold the software model as well as runtime configuration information are discussed. The importance of an associated clear and well structured interface and tuning alternatives for the repository are pointed out. Finally the paper concludes with an outlook to future research work.

# 1 INTRODUCTION

In the area of generative software development different approaches have been arisen (Czarnecki, 2004). Starting from the state of the art we will look at practical implementation. Some challenges occurring in practice are picked up and discussed, like e. g. model data storage.

## 1.1 State of the Art of Generative Development

In software development generative techniques are an efficient way to produce software product artifacts. Depending on the development methodology the usage of generators is very different. On the one hand there are generators which work with abstract models e. g. domain specific models. With these generators the level of abstraction can be reduced stepwise by transforming abstract input into less abstract output. On the other hand generators are used to complete implementation details such as standard class methods or documentation. Independent from the concrete purpose a software company aims to speed-up software development, to strengthen quality, and to achieve higher software reuse by applying generative techniques.

In recent years different approaches for an improvement of software development processes and of software quality have been defined. For a successful application of these approaches an automation of steps is essential at least in parts. In doing so, implementation mistakes of well-understood issues can be avoided. Furthermore it enables system developer to model complex systems in an adequate way focusing rather on application level domain objects and their processing than on technical implementation aspects. The implementation of thereby used model elements is carried out by generators on basis of mapping rules. The role of code generation is a fundamental one: Model transformation, software reuse, development and usage of domain specific languages, etc. are application domains. For the state of the art common approaches will be discussed in brief.

### 1.1.1 Domain Specific Languages

Domain Specific Languages (DSLs) (Fowler, 2005; Mernik et al., 2005) are expressive languages which are used in special domains to outline a problem space. Requirements are described formally using



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conventional words of the client and with client's semantics. With DSLs domain experts are able to describe the problem space in their language. So the necessary formalization can be done in cooperation with IT-consultants using a suitable DSL. The model of the software product contains apparently the concepts of the client.

#### 1.1.2 Model Driven Software Development

The fundamental idea of Model Driven Software Development (MDSD) (Mellor et al., 2003; Stahl and Völter, 2006) is to separate the model of an software product from technical details. Two aspects play a key role: The first technological one is to support interoperability and portability in software systems to be developed. Usually application software models are more durable than the technologies used to implement the system. While knowledge is formalized within the model technical implementations can be exchanged. DSLs are used in the formalization process. Once the model is presenting the desired system it can be transformed stepwise to an implementation system using generative techniques. The second conceptual aspect is to strengthen the use of abstraction in the process of software engineering. The domain expert and the application engineer are able to focus on the domain logic while the developer of the modeling and generation environment can focus on details of the technical implementation.

The concepts of MDSD are applied successfully in the area of software architectures e. g. in the EJB sector. A software architect describes the system using platform independent terms like component, interface, etc. The meaning of these terms has to be specified with a mapping to concepts of the target platform. The specification of mapping can be integrated into code generators or interpreters. So the meaning of a term like component is known to a generator and can be transformed in concepts of the platform. The generator produces the skeleton of the application. Only those parts of the application have to be hand coded which are hard to formalize platform independently. A change of the platform results in a change of the mapping rules. The application logic within the model is not affected.

A special form of MDSD is the Model Driven Architecture (MDA) which is a standard defined by OMG (OMG, 2006). It focuses on interoperability and portability. MDA requires an MOF-conform description language, e. g. UML, in contrast to MDSD which does not postulate a certain language. The standard proposes different models (CIM - Computational Independent Model, PIM - Platform Independent Model, PSM - Platform Specific Model) which can be annotated for transformation steps.

#### 1.1.3 Software Factories

The idea of Software Factories (Greenfield et al., 2004) or Generative Programming (Czarnecki and Eisenecker, 2000) can be compared with automated industrial production processes such as the assembly process of a car: A software product is no longer programmed but is assembled using standard components. Therefore reuse is essential. The tool to assemble the software is programmed - the assembly line. Software developer's work is reduced to configuration mainly. Programming mistakes are nearly impossible. Configuration and reuse boost generative techniques to create standard components.

### 1.2 State of the Art in Practice

Different approaches to improve the software development process are in the focus of research and are already used in practice in some areas. But the entire potential is not used yet. For different abstraction levels different models are used. This causes consistency problems: client and software developer work on different models. One model with different views can avoid such problems.

Generators play an important role in MDSD. Through generative techniques large parts of software artifacts are produced automatically. Changes are mapped to application code by transforming models and applying generators. But up to now interpreters are not in the focus of MDSD although the benefit can be high and especially the flexibility can be pushed.

Applications of a larger size may demand a certain level of stability and flexibility. Stable data structures for (changing) application data and a fixed infrastructure which allows flexible changes on application level could be essential for successful usage at customer's site. A combination of generative techniques and stable interpreters are used by Ibykus AP as described in the next section. Concepts of MDSD can be found in the software of this company. Furthermore the following section of the paper describes concepts of MDSD which are already used in practice.

# 2 APPLYING MDSD IN PRACTICE

## 2.1 Ibykus AP Platform

One example for such a practical approach is the generative development and interpretative runtime environment *Ibykus AP* (Ibykus, 2007). It is focused to build large application systems in the domain of business, administration and governmental processes. Ibykus AP has been used to successfully develop a number of complex software systems during the last 7 years e. g.

- systems for the management of agricultural promotion fonds of the European Union, the controlling of financial resources and other e-governmental administration processes in several German federal states,
- applications to support business processes like claims and contract handling, project and innovation management as well as other industrial projects.

The generative development process of Ibykus AP is based on a repository to hold a comprehensive model of the software application to be built. The modeling is based on concepts like domain specific application classes like Process, Process Participant, Data Object and others. These domain classes can be interrelated and be equipped with data attributes, processing algorithms, workflows and more domain specific modeling features. Practical experiences in modeling application logic prove the inadequateness of UML based DSLs, at least in the domain of administrative and business process management. Professionals in this area regularly do not accept and comprehend UML based DSLs as means of expression for analysis and design of application logic: misunderstandings and mistakes did occur. Therefore at Ibykus an informal notation with a fixed set of simple graphical elements to represent the mentioned conceptual items is used. It has to be emphasized, that the modeling can be completely focused on to the application domain level. No technical aspects like data storage, transaction and error handling, user interface events, recording of histories need to be modeled explicitly then. These are all addressed by the software generation process and the interpretative runtime component of Ibykus AP as shown in figure 1.

Based on the software model on the one hand the application specific processing logic and the surrounding technical support code are generated. On the other hand runtime configuration structures are populated to implement the structural aspects of the target application. This configuration is interpreted by the Ibykus AP runtime system to establish the infrastructure needed to run the built application. A stable storage structure is dynamically configured to keep the needed application data and likewise the GUI is configured.

## 2.2 Combining Code Generation and DSL Interpretation

DSLs are an expressive way to formally describe stakeholder's requirements and the resulting application-level software design in domain specific terms. The process of transforming these DSL models into platform specific models is often done with help of generative techniques. A stepwise transformation (model-model-transformation) can also be applied as proposed by MDA. Code generation is only one possibility to extract (parts of) the final application.

A different option to DSL-based code generators would be DSL interpreters. Such interpreters work on the runtime level of a system. DSL terms will be read by an interpreter and translated into operations on the targeted platform. At runtime a DSL interpreter decides how to map a specific DSL term onto the platform. For instance the DSL term *booking* has a field *amount*. If a user creates a new booking the field (text control) *amount* is displayed as a part of the form on the screen by the DSL interpreter. After submitting this form the interpreter inserts a corresponding entry into the database.

But, do we need to decide between an interpretative or generative approach? Generators and interpreters do not rule out each other. Far from it! The construction of software could benefit of a mixture of these approaches much more. En route from *High-Level* DSL terms to computer platforms a first generative step results in intermediate language constructs. These constructs are interpreted at run time by a generic interpreter. Thereby, the intermediate language could be a script-based programming language or a *Low-Level* DSL or even entries in some control structures.

In both approaches modeling is done application-domain- and customer-oriented. Fundamental concepts of MDSD/MDA have to be kept in mind. In the end DSL interpreters and DSL generators are a different technical implementation of the same concept. A DSL interpreter works on the logical level of a DSL. The main functionality is part of the runtime level while in case of generative programming the knowledge of the architecture is within generators.

One example for a concrete usage of the concept

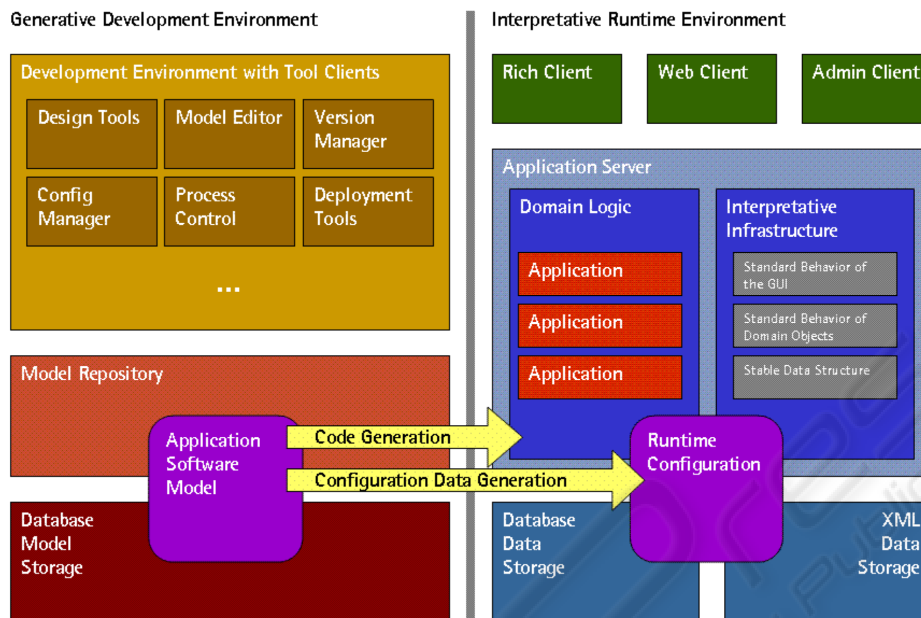



Figure 1: Architecture and main components of Ibykus AP.

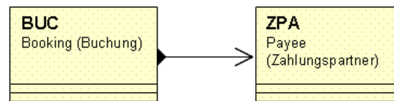
of the combination of generative and interpretative techniques is Ibykus AP. As figure 1 shows, the Application Software Model as a *High-Level* DSL is built up in the Generative Development Environment. Besides the generation of code parts the model elements are automatically transformed into runtime control information to build up the executable software system. This control information in turn is interpreted by the Runtime Environment to display, process and store application level objects like *booking*.

The approach of Ibykus AP is to improve the flexibility of application software and its engineering by using MDSD. This is illustrated in figures 2 and 3. Figure 2 presents the model of a reference between two application domain classes: as a booking has got an associated payee a reference form BUC to ZPA is defined. And figure 3 shows the resulting GUI interpretation of the runtime configuration generated from the model: in the booking form the reference is represented by two data fields with some identifying and describing information for the referenced payee and by one button to navigate to the payee form and to alter the associated payee. In fact the display of these GUI elements is an interpretation of runtime configuration entries, that can be altered at runtime. In addition to the modeling and generation of the runtime configuration it is possible to create, alter and remove GUI elements in an already running application. Of course this can be guarded by an appropriate user, role and permission management.

### 2.2.1 Generic Concept

A model representation is needed in both cases: For interpreters as well as for generators. Changes in the model have no effect on the runtime level i. e. an interpreter remains unchanged and has to be generic therefore. Furthermore a generic repository is necessary which is able to store various models. The meta model of such a repository is in a schema-instance-relation with the concrete model. But how can we determine this meta model? One way is to store the meta model and the model within the same repository. With this generalization, different DSLs can be stored within the generic repository. The meta model is common for the repository and the models of the interpreter and generator. An interpreter is also able to acquire information on used modeling language. So a DSL becomes flexible and can be extended without changing the interpreter. The generic structure of the data model used for the (run-time) repository can be fixed. This is an advantage for interpreters which normally may not change over lifetime.

How can we achieve that model, configuration and



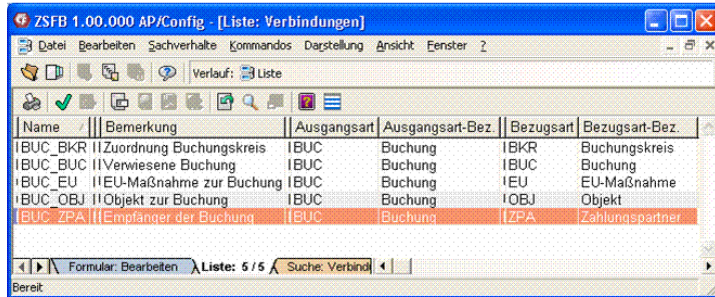




Figure 2: New model entry: Reference from Booking to Payee.

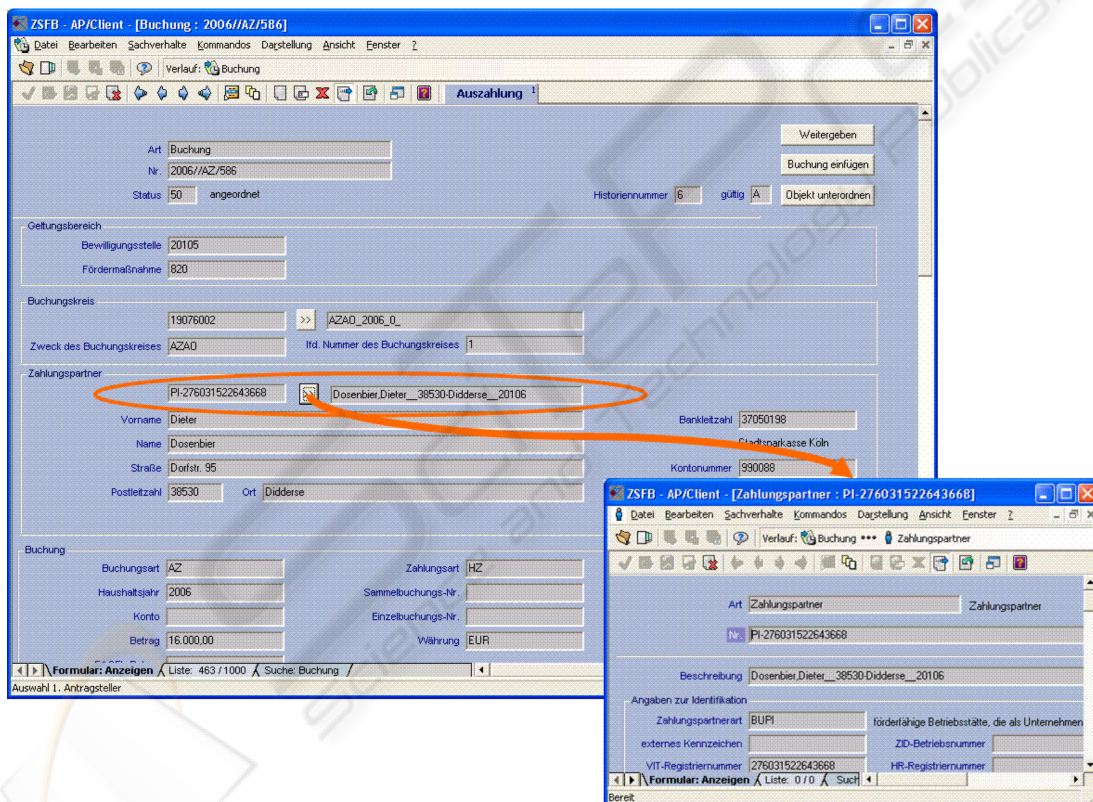



Figure 3: Resulting GUI elements for data and navigation.

application data can be stored generically in the same way without changing repository schemes? Though UML representations like XMI, MOF-based main memory object representations and model transformation as well as code generation techniques are supported by a great variety of utility software and frameworks Ibykus AP uses a model representation in a relational database. The reasons are the following: First, 7-10 years ago when Ibykus AP emerged, none of these concepts and tools existed. Secondly, the model querying and retrieval capabilities of a relational database are superior and faster by far, what is essential especially for the online interpretation.

How generic shall such a database representation

be? Looking at most graphical modeling languages a Node-Arc-Property-Model (NAP model, see figure 4) is sufficient to map any language constructs. All DSL modeling elements are represented as instances of *Node* and their interrelations and dependencies as instances of *Arc*. Both, *Nodes* as well as *Arcs* are attributable by instances of *Property*. This model representation – mathematically denoted by annotated graphs – is suitable for any DSL and modeling constructs. In consequence the NAP model is independent from a specific application which is essential for a generic interpreter. A similar approach is the GOPRR-Model (Graph, Object, Property, Relationship, and Role (Kelly, 1997)) used in MetaEdit+ from MetaCase (MetaCase, 2007)

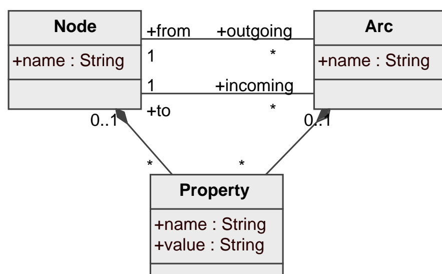



Figure 4: NAP structure.

In Ibykus AP an application data storage model was developed on the basis of such a generic model as shown in figure 5. All domain objects are stored as instances (data records) of *domain class*. It embraces an optional parent reference as well as a number of fixed parameters like the internal numerical *id*, an additional domain level identification called *ident*, a textual object description *desc*, the object's *state* and other parameters that are mandatory for all objects. More freely definable application specific parameters and relations to other domain objects are represented as instances of *parameter* and *reference*. With respect to this data model in practice it turned out that data migration due to new software versions is not necessary. This is a huge benefit in areas with regularly changing application demands like the permanently adapted agricultural promotion programs of the EU and others.

Regarding the structures to hold the software model repository and the runtime configuration it is important to mention that both adhere to the same generic representation concept even though they are usually stored in two different system environments: the first in the generative development environment and the second in the interpretative runtime environment.

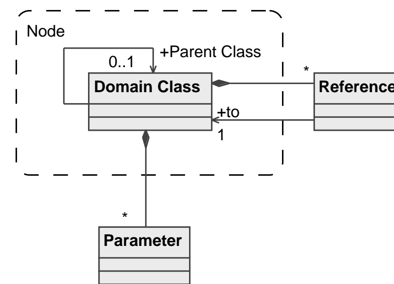



Figure 5: Application data storage model (simplified).

In the model repository of Ibykus AP (figure 6) all domain classes are described as instances of *type*. A *type* can have freely modelable data *parameters* (domain class attributes) and *commands* (domain methods). *Types* can be interrelated with a number of definable *relations*. Additionally each domain *type* is derived from a certain predefined *base type* which provides a set of basic domain specific attributes, processing logic and other properties. Details of all these modeling elements are to be described by associated *attributes*.

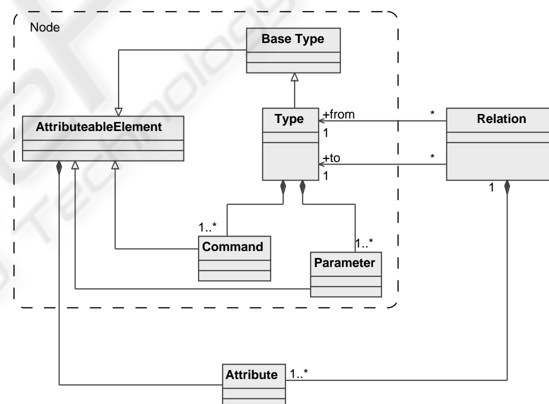



Figure 6: Storage structure of software model repository (simplified).

The AP runtime structure (figure 7) is optimized for fast interpretation as discussed later on. It stores the information in terms of a hierarchy of configuration *components*, configuration *elements* and configuration *parts* which are fleshed out by *attributes* and interconnected by *references*.

Of course modeling is not done directly with NAP or its derived model representation structure. In the upper part of figure 2 a sample of the GUI used for DSL modeling in Ibykus AP is shown. It allows creating all needed application level object classes and the relations between them, to define the required processing commands and procedures as well as to specify all other domain-level aspects of the resulting application. To build the final application software the

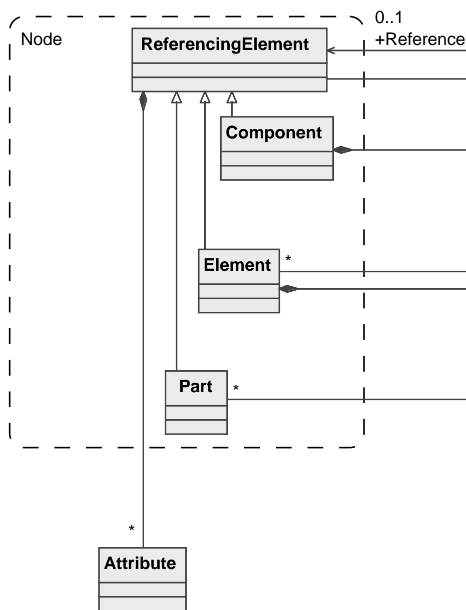



Figure 7: Storage structure of runtime configuration (simplified).

DSL elements are associated with fragments in an overall generation system. In this process each modeled item is transformed into application code or configuration entries in the generic runtime configuration or both.

#### 2.2.2 A Boost of Flexibility

With DSL interpreters modeling and configuration is very flexible and can be done even at runtime. While the technical base (architecture) is fixed, functional changes can be made by developers or even by customers themselves.

Using AP, it is possible to model the application roughly and to install the platform at customer's site. Changes and refinements are made together with stakeholders. Results of non-structural changes like the addition of application class attributes for instance can be made effective directly. Structural changes like the definition of new application classes require a repetition of the automatic generation process. For example, in AP a new relation between two application classes can be added within minutes (GUI, navigation, application logic and database storage – see figure 2) at customer's site. The changed parts of the customized model can be synchronized into the repository at developer's site later if reasonable. Using this kind of prototyping the period of time to understand complex requirements is reduced significantly. These short feedback cycles enable agile software development.

#### 2.2.3 Generative Vs. Interpretative Approach

Independent from the question which approach is applicable, the explicit preparation of domain knowledge is very important. This knowledge can be integrated in generators or interpreters. Especially exception handling and the missing compiler step raise the effort to implement an interpreter. But the additional work amortizes very fast if the gained flexibility is necessary and used.

- Pro generator
  - fast program execution
  - less effort to program than interpreters
  - easier to debug
- Pro interpreter
  - high flexibility
  - deployment of new application versions is easier (e. g. no client update)
  - old and new software version are executable at the same time
  - low probability for data migration
  - migration to new versions affect only functional and no technical level

### 2.3 Runtime Tuning

In practice often special runtime requirements need to comply. Due to the generic nature of the NAP model the real storage model has to be adapted. Thereby it is important to keep concepts of this model in mind. With the following performance optimization the logical model and their interfaces remain unchanged.

Tuning is a technical activity to improve runtime performance. Tuning on repository level does not requires any changes of DSL interpreters. It has also no effect on modeler. One possible tuning activity is a breakdown of data base normalizations.

For instance in the application data store (figure 5) the heavily used relation between child and parent data records are represented directly as a reference. And all other references are aggregated as contained elements of the referring data record. By separating the relations into different storage alternatives the storage structure is optimized below its logical interface in order to speedup storage and retrieval operations.

Another tuning method is applied to the runtime configuration data structure (figure 7): to increase the retrieval speed for interpretation the configuration elements (nodes in NAP) are classified along their nesting hierarchy. *Program components* are master elements without a parent. They contain *elements* as major configuration items which in turn contain *parts* as

minor items. All of them are characterized in detail by attributes and can have references to other configuration items.

So in practice all three structures, the software model repository, the runtime configuration and the application data store, are optimized in their physical storage table layout to support their respective processing demands: modeling and generation on the one side and runtime interpretation and data processing on the other.

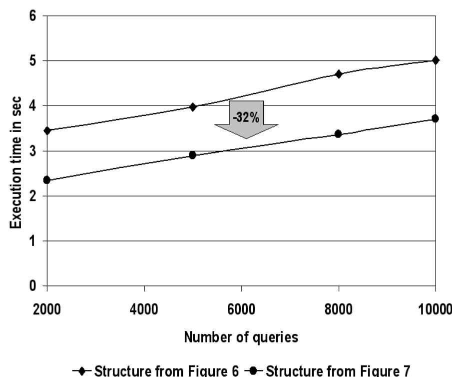



Figure 8: Retrieval performance utilizing different storage structures.

Figure 8 points out the potential of storage structure optimization by comparing the storage structures shown in figure 6 and 7. Slightly exceeding 80,000 model elements in hierarchies of approximately 5 levels and a fan-out of about 4 on each level were stored using both structures. A number of queries were processed retrieving model elements and their parent elements up to the root. The recorded query execution times indicate a significant reduction by 32% using the optimized structure.

Additionally these structures can be partitioned into data sets that are restricted to their respective demand. For instance the GUI interpreter does not need any information about data storage configuration. So a repository partition can be used that is restricted to hold only the GUI configuration. This concept could be extended in a way that a complete physical repository is not existent at all. But nevertheless, this is only a technical optimization issue, the repository interface is not affected at all and logically the repository as a whole is at hand for each component.

Due to historical reasons, tuning possibilities in AP are not covered behind interfaces completely. Developer and modeler have the possibility to use the tuned structures instead of the interface, but practice suggests that the barrier should be very high.

# 3 CONCLUSION AND FUTURE CHALLENGES

This paper discusses selected concepts of MDSD which are applied in practice. Experiences with the Ibykus AP platform show benefits of using such concepts.

Especially, using the model driven generative software development techniques with Ibykus AP, we experienced a boost of overall project performance of 20%-50%. Though it is rather difficult to number the increase in efficiency, the records of more than 20 major projects in the last 7 years show this significant reduction of project duration or team size or increase of accomplishable project size or complexity. One example shows the typical performance boost quite well: A legacy accounting solution of the German federal state of Niedersachsen processing about 1.2 millions booking records per year with about 15 sub-records each and an overall transaction volume of about 800 million Euros was replaced with a new solution. The legacy application had been developed over the last 10 years with 5-10 team members. In contrast the replacement project required 7 team members, 11 months and surpassed the functionality.

Furtheron it was pointed out that a generic data structure is a good technological base to develop a model repository to hold different aspects e. g. the software model and the runtime configuration. On top of that low-level format a domain specific language can be used to model an application. A high-level DSL is independent from technical realizations.

A generic data structure is a good base to develop one model repository to hold different views of the model e. g. the software model and the runtime configuration. On top of that low-level format a domain specific language can be used to model an application. A high-level DSL is independent from further technical realizations.

In an application a generic structure is also useful. For performance reasons the generic structure has to be adapted to special needs. One aspect can be usage frequencies of special entities or relations. Due to such a stable data structure software version updates do not affect customer's data. Compatibility of data is ensured completely.

Mostly MDSD is associated with generative approaches to transform models or to produce software artifacts. But a combination of generative and interpretative techniques leads to much more flexibility. Changes within an application will be done on functional level. "On-line" modifications are possible and can be done very fast while the technical base (inter-

preter) remains unchanged.

Of course there are mismatches between concepts of MDSD and practice. Regarding PSMs defined in the MDA approach no explicit platform specific model is available. But this model is implicit present – in form of platform specific interpreters. The mapping from PIM to PSMs is integrated there.

Through applying MDSD in practice agile software development can be implemented within an enterprise. But there are issues which need to be observed in future. For instance incremental changes in a model should not force a complete generation process of all elements. Such a process consumes a lot of time in large applications. In practice incremental generation of software artifacts are important for the creation and deployment of software updates. Especially in e-governmental areas, changing requirements have to be processed and delivered very fast. A future task will be to find a method to describe dependencies between model elements on platform level.

Another question is how to handle different versions of a model. Often an application is delivered to different customers. Main parts of the model are identical but some parts are customized. It is desirable to have no copies of common parts because it can cause inconsistencies and additional management work.

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