MODEL DRIVEN ARCHITECTURE BASED REAL-TIME ENTERPRISE INFORMATION INTEGRATION
An approach and impact on businesses

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Abstract: The rapid advancements of enterprise applications urge organizations to access and process information in multiple incompatible systems accumulated as massive complex data in diversified formats due to lack of an accepted common base in the development community. EII solutions must provide interoperability across various software platforms with an ability to react and adapt enterprise operations in favor of continues internal and external environmental alterations dealing with time sensitive information. Concept of RTE is based upon the premise of getting the right information to the right people at the right time in “real time”. MDA specifications lead the industry towards interoperable, reusable, and portable software components as well as information models based on standard models. Recently, MDA is considered as another evolutionary step introducing an engineering discipline to practice pattern-based software development. In this paper, we present an innovative approach to achieve the notion of intelligent EII through combining respective strengths of MDA and RTE along with implications over existing business models.

1 INTRODUCTION

EII has steadily gained momentum as a must-have solution in the arsenal of enterprise architects. Collecting information from an array of disparate sources and fusing it together in a unified view is just the ticket for a range of applications. EII fills the gap between application and information integration. It makes possible to insert intelligence to integration process for the information obtained and arranged in common context. On-demand intelligence to deliver information in real-time offers immediate measurable business benefits through faster and better decisions as well as enhanced agility and adaptability.

The distinguishing feature of RTE is to share the information in real-time reducing cycle-time1 (ENOSYS, 2004) and improving operational efficiencies. RTE ensures that the information is current and consistent across all systems, minimizing batch and manual processes related to information. RTE solutions must be adaptable to change and accept change as the process to achieve their specified goals. Successful RTE focuses primarily on the function of the enterprise model that guides the choice of the infrastructure form for accelerating strategic execution. Since the technology is relatively novel, there are still some skeptics related to RTE architectural consistencies.

The Object Management Group’s recent effort to standardize MDA (OMG MDA, 2003) supported by number of models, methodologies to prepare models, and relationships of the different types of models focusing to produce an enterprise architecture modeling capabilities that analyst and developers may utilize to describe EI.

1.1 Our Contribution

We started with the well-known and long established scheme of separating system operations specification from details of techniques to utilize platform capabilities. Our analysis indicates that MDA presents an approach and enables tools to be provided for: specifying a system independently of the platform that supports it, specifying platforms, choosing a particular platform for the system, and

[1] “cycle-time” is relative term and varies depending on the system’s infrastructure. Generally, it is measured from operational and transactional activities.

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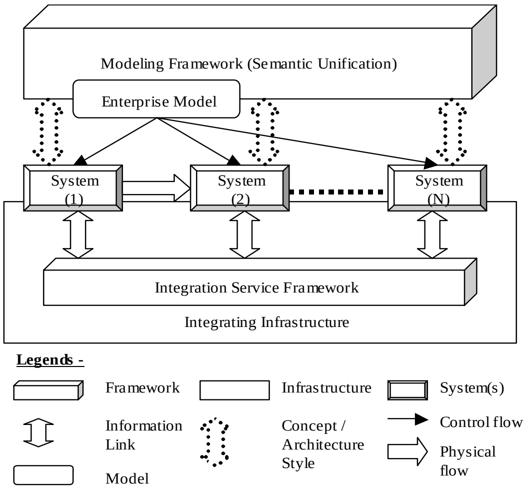


Figure 1: Concept of model driven REI.

transforming the system specification into one for a particular platform.

In order to speed the integration and maximize the success, there are key capabilities that an organization must address - access, integrate, manage, secure, and transact respectively. The framework and specification method developed during our research deals with all the capabilities to deliver single interoperable approach for integrating all types of information, processes, and functionalities across applications and architectures. The MDA approach to achieve real-time enterprise information integration (REI) enables flexible EII architecture, spanning major computing platforms and data stores hiding complexities. We are presenting consistent REI architecture framework and transformation specification process with various case study based on our classification, and impact of REI solution on business models.

2 ISSUES IN DEVOLOPING REI SOLUTIONS

Vision of REI solution is an adaptive technology providing dynamic access to disparate information in the enterprise, leveraging a metadata and heterogeneous query infrastructure to dynamically access information from underlying systems including ERP, CRM, data warehouses, legacy systems, and other sources. The true challenges of integration span far across business and technical issues. Successful REI (OAGi, 2002) not only need to establish communication between multiple computer systems but also between business units and IT departments supporting day-to-day decision making across enterprise operations.

Integration has also to be seen as a never ending process. Over time both the internal and the external environment changes. The enterprise must react to these changes in real-time and adapt its operation accordingly. Present does not yet provide a complete solution for enterprise modeling (J. Schekkerman, 2004). Existing EII solutions seem to compete with each other, focus on particular issues and use conflicting terminology. There are three major groups of issues (J. Vesterager et al., 2001) that need to be addressed and resolved during EII.

- Lack of an accepted common base in the research community
- Limited awareness in the user community
- Insufficient information technology support

Despite the wide-spread need for integration solutions, only few standards (David C., 2001) have established themselves in this domain. While developing an REI solution is challenging in itself, operating and maintaining such a solution are even more daunting. The mix of technologies and the distributed nature of REI solutions make deployment, monitoring, and trouble-shooting complex.

Patterns are a constructive approach to convey experiences and accepted solutions to recurring problems within a known context. Enterprise integration patterns assist architects to design and implement integration solutions more rapidly and reliably. Primary integration styles are file transfer, shared database, remote procedure invocation, and messaging. Asynchronous messaging is fundamentally a pragmatic reaction to the problems of distributed systems encouraging design of components with high cohesion and low adhesion. The integration patterns are classified as channel, message construction, transformation, endpoint, and system management patterns in (Gregor H. et al, 2003) depending on the integration style and implications of respective EII application.

3 CHARACTERISTICS OF RTE

RTE presents real-time information to employees, customers, suppliers, and partners and implement processes to ensure validity as well as consistency of information across all systems, minimizing batch and manual processes related to information. Following are the typical RTE characteristics recognized during our research from (ENOSYS, 2004), (MetaMatrix, 2001), and (Taylor et al., 2004).

- Produce reusable views to frequently access information by various groups within company.
- Universal access to real-time applications both within and across corporate firewalls.

- Accessible information integration strategy for applications to gather the retrieved information and efficiently delineate application and mission-critical information from variety of sources.
- Mask the complexity of underlying real-time information sources from applications and users.
- Maintain and coordinate access security rules for full variety of accessible real-time information sources since today's corporations often require information from partners, suppliers, and customers in an extended network.
- Rapid information access capabilities to reduce the risk due to outdated information that can be useless or even damaging.

4 MDA – AN APPROACH

In this section, we have categorized MDA (OMG MDA, 2003) and MOF (OMG MOF, 2002) specifications in conceptual, logical, and execution views to illustrate the MDA approach and its implications during development of REI solution.

4.1 Conceptual View

At the heart of MDA, there are three models CIM, PIM, and PSM that may also be perceived as viewpoints to reduce the logical complexities.

Computation Independent Model - CIM provides environment of system, and respective requirements. CIM describes situation in which the system is used. Such a model is sometimes called a domain or business model. It may hide much or all details concerning the use of automated information processing system. CIM requirements should be traceable to corresponding PIM and PSM constructs that implements them and vice-versa.

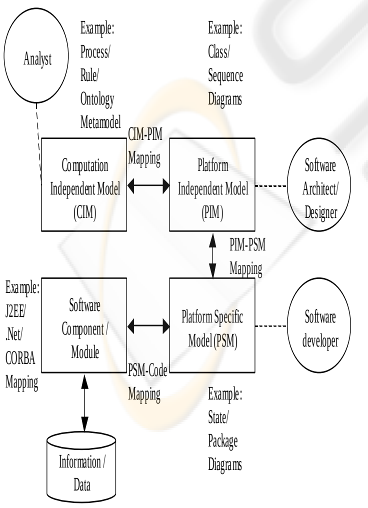
Platform Independent Model - PIM focuses on operation of system while hiding details necessary for particular platform. PI view illustrates part of the complete specification that may not change from one platform to another. PI view may use a general purpose modeling language. PIM might consist of enterprise, information, and computational specifications suited for several architectural styles.

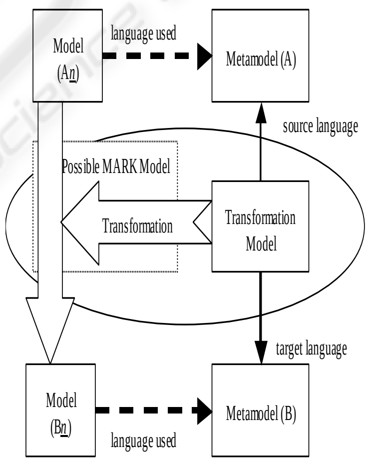
Platform Specific Model - PSM combines the platform independent viewpoint with an additional focus on detail of platform specific use by system.

4.2 Logical View

Model transformation is the process of converting one model to another model of the same system. An MDA mapping provides specifications for transformation of a PIM into a PSM for a particular platform. The platform model determines the nature of mapping.

A model type mapping specifies a mapping from any model built using types specified in PIM language to models expressed using types from PSM language. These mappings may also specify mapping rules in terms of instance values to be found in models expressed in PIM language. A metamodel mapping is a specific example of a model type mapping. In certain cases, mappings may be expressed as transformations of type instances in PIM (or meta-classes) into type instances in PSM as articulated in other languages including natural language. Another approach to mapping models is to





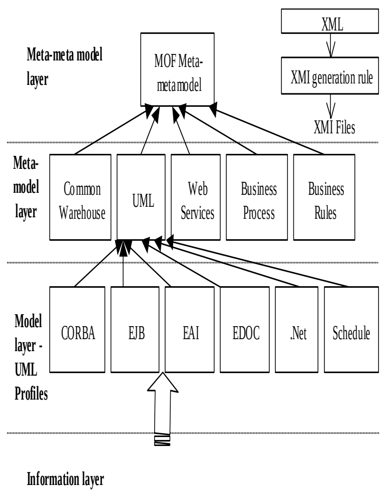


Figure 2a: MDA conceptual overview. Figure 2b: Metamodel mapping transformation. Figure 2c: MOF four layers.

identify model elements in PIM that should be transformed in particular mode giving the choice of a specific platform for PSM. Model instance mappings should define marks. A mark represents a concept in PSM and is applied to an element of PIM to indicate method for transforming element. It is consider as transparent layer placed over model.

Mappings, however, consists of combination of the above approaches. The marks may appear from different sources as identified below.

- Types from a model - specified by classes, associations, or other model elements
- Roles from a model – patterns
- Stereotypes from metamodel (Ascential, 2002)
- Elements from meta-metamodels (David S. et al, 2003)
- Model elements from metamodels (ISIS, 2004)

The consecutive step is to obtain the marked PIM and transform it into PSM. A tool might transform PIM directly to deployable code without producing PSM. Such a tool might also produce a PSM for use in understanding or debugging the code. The results of transforming a PIM using a particular technique are a PSM and a record of transformation. The record of transformation includes a map from the element of PIM. Model transformation approaches are as follows.

- Marking using array of mapping and marking
- Metamodel transformation using transformation specification through PI metamodel and PS metamodel
- Model transformation using transformation specification through PI type and PS type
- Pattern application

Along with PI and PS marks, additional information may be supplied to guide the transformation. Inputs to transformation (TR) are patterns (AP), technical choices (TC), and quality requirements (QR) represented as TR [AP, TC, QR].

4.3 Execution View

Meta-Object Facility (OMG MOF, 2002) technology provides a model repository that may be utilized to specify models encouraging consistency in manipulating models in all phases of the use of MDA. All MDA models are related since they are all based on a very abstract metamodel – MOF. Central theme of the MOF approach to meta-information management is extensibility. The goal is to provide a framework that supports any metadata and allows new types to be added as required. In order to achieve this characteristic, MOF has layered metadata architecture - information, model, metamodel, and meta-metamodel layer.

5 COMBIMNING STRENGTHS OF MDA AND RTE

Meta-information management is a fundamental element of REI: access to information in a seamless and uniform manner. REI depends on sophisticated technologies to collect, manage, and model metadata, metamodels, and meta-metamodels as well as query management and connection technology for available information systems. Various benchmarks identified for information integration are categorized in terms of effort spent in data conversion, lookup transformation, and built-in function transformation.

MDA makes it possible to practice pattern-based software development since model compilers replicates proven patterns more quickly and accurately. The motivating features offered by MDA approach for constructing organization wide REI are multi-platform models, federated systems, multiple applications of pattern, general model to model transformations, reuse of mappings, and enables interoperability.

MDA move up the abstraction ladder caring the development paradigm inexorably away from computing platform and towards REI. A key issue is “how to treat remaining gap?” or the abstraction gap between REI and software specification. Transformation technique resolves and achieves the co-ordination (SOSY, 2004 and iO, 2001).

5.1 Transformation Specification

We have divided transformation specification process to formally specify the intended behavior of model transformer in three distinct specifications. The details of each step are analyzed and identified with Generic Modeling Environment (ISIS, 2004), (Aditya et al, 2003) tool set and discussed below.

The pattern specification – It is at the centre of transformation specification. Purpose of the phase is to represent integration patterns in concise and scalable format and use semantic meaning to enumerate the implementation details. The pattern is represented by PAIR of [<class, attribute>, <association, source<class, attribute>, destination<class, attribute>>] where “<,>” depicts the “set of”. Association is distinguished from the source class to the association class and from association class to the destination class. Cardinality (n) should be specified for each pattern with the semantic meaning that a single pattern (class, attribute) must match “n” host <class, attribute>. Pattern matching algorithms supports single, fixed, and variable cardinality as well as partial matching to reduce the complexity of transformation.

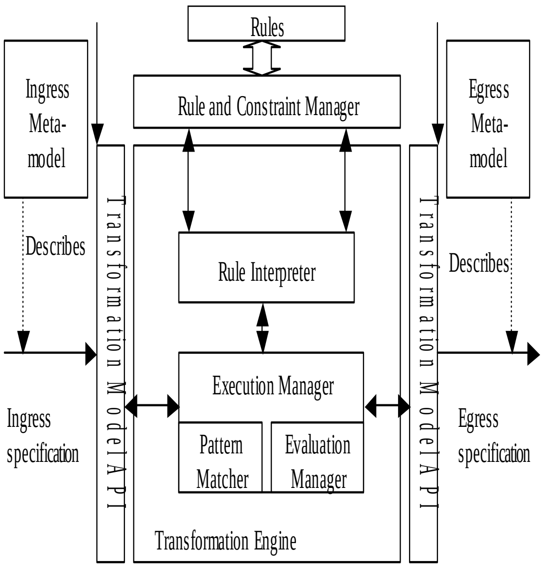


Figure 3: Run-time model transformation.

Static structural constraint specification – Structural integrity is the primary concern in model transformation. The problem to specify, maintain, and reference different models conforming various metamodels is resolved by using source and destination models to explicitly specify the temporary PAIR(s). It requires defining rules for following operations.

- Bind to match objects in the PAIR(s).
- Delete to remove objects after the match.
- New to create objects after the match.

Execution of rule involves matching each pattern object marked either bind or delete. Upon successful pattern match, remove the pattern objects that are marked as delete and create that are marked new.

Control flow specification – The initial bindings and application ordering are necessary to increase efficiency and effectiveness. Control flow specification allows user to manage complexity of transformation and control application. Features of the control flow specifications are rule sequencing, non-determinism for parallel execution of rules, hierarchy for primitive transformation rules, recursion of rules, and test/case to choose between different control flow paths.

Enterprises utilize and combine various transformations to define meta-information. The most frequent transformations during REI are mathematical, decomposition, union, and decision transformations. Mathematical transformation creates a column and computes it from two different information elements. Information element decomposition transformation receives a single value and decomposes it into one or more elements. The enterprise defines group in the meta-information using union transformation and integrates semantically equivalent information from different sources. It presents information as if they are from a single source, eventually results into aggregation of information from different enterprise divisions. An appropriate example of union transformation is the result of demand-supply statistics of retail products. Decision transformations defer the choice of which information element to use until run-time. It supports critical real-time business decisions. Excellent example using decision transformation is return value of daily activities, and data indicating variation in the cost of different stocks.

5.2 REI Solution Selection

REI focuses primarily on the function of model that guides choices of the infrastructure form to accelerate strategic execution. We have recognized following dimensions during selection process.

- Principles to construct REI.
- Capabilities offered by REI.
- Extendibility - abilities to enhance for future harnesses of REI.

The dimensions are subcategorized in Table 1. At present, only approach to measure success (or failure) of REI is to distinguish the business before and after implementation.

Table 1: Selecting REI solution: Dimensions.

Principle	**Capability**	**Extendibility**
Vision	Technology	Operational fit
Channels	Services	Technical fit
Awareness	Pricing	Functional fit
Geographic-coverage	Agility	Vendor-support
Business-drivers	Financials Execution Personnel	Experiences
Industry focus		
Investment		
Volatility		

6 CASE STUDY – MDA BASED REI

In this section, we have analysed and indicated the classification of implementation strategies adapted by various solution providers to resolve domain specific problems for explicit industry segment and their experiences. Typical approaches to introduce MDA and RTE concepts are - profiling, middleware, and information base layer.

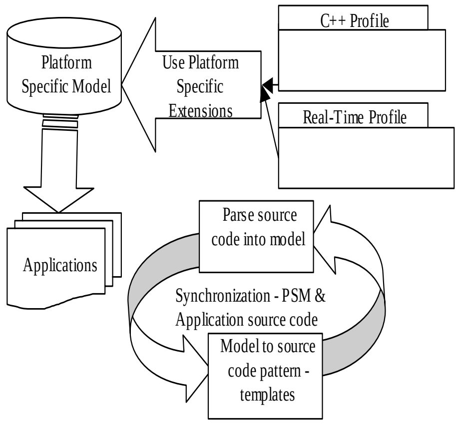


Figure 4: Round-Trip Engineering with UML-Profiling.

ARTiSAN Software's Real-time studio (Matthew, 2002) provides modeling the system in its environment by creating a context diagram defining a high level view of the system without constraining to implementation platforms and configurations in terms of profile. One of the key concepts is the modeling of systems from different viewpoints persistent on particular concerns or an area of functionality or an area of interest to the system. Viewpoints can be reused on different systems. Real-time studio allows packages to be exchanged between models. The profile can be used across many projects.

Component Synthesis with Model Integrated Computing - CoSMIC (K. Balasubramanian, 2003) is MDA tool suite tailored to the requirements of real-time systems. It addresses following unresolved challenges in using middleware to build mission-critical systems with time and space constraints.

- Lack of middleware composability to support multidimensional Quality of Services (QoS).
- Accidental complexities during integration.
- Lack of principled methodologies to support reflective middleware capabilities.
- Accidental complexities during configuration.

The CoSMIC activities involve developing aspect-oriented modeling tools for high-level specification, tool to analyse end-to-end QoS and time/space constraints, mapping constraints specified in the models to target-specific middleware configuration parameters, generators that compose optimized and fine-tuned middleware components to meet the end-to-end constraints, program transformation tools that weaves in application QoS requirements to compose customized middleware from fine-grained QoS enabled components, and additional aspect weavers that instrument synthesized code to collect, organize and present QoS meta-information to the QoS adaptation layer controlling middleware infrastructure.

MetaBase EII (MetaMatrix, 2001) suite integrates information from various sources and systems across the extended enterprise using model driven approach. The enterprise applications gain access to integrated sets of real-time information through the virtual data layer by submitting a single request to server. The identified advantages over other integration approaches are described below.

Data Warehousing, Data Marts, and Data Staging creates new complex data structure that is specific to limited number of applications. Data is updated from native store in batch processes such that real-time information is not available.

Content Integration method is lacking to provide back-end integration to information processing.

Enterprise Application Integration lacks to address the need for enterprise-wide information integration rather it is hard-coded into the process of each specific solution.

7 IMPACT OF REI ON BUSINESS MODELS

The correlation between REI and business decisions can be identified from the impact on businesses due to adaptation and utilization of REI solution by various organizations. (Dr. Y. Malhotra, 2004) briefs the impact of REI on business models. IT analysts have attributed Wal-Mart's success to its investment in REI technologies, classical example of setting the benchmark of doing more with less. Dell has developed and perfected its REI by strong ties with its customer. Dell's early innovations in passionate pursuit for being the low cost 'build on demand' leader for consumer computing products has yielded it the advantage of real-time business performance. GE business model defined for maintaining quality standards has been extended to control costs by minimizing response time to problems affecting products purchased by its customers. The critical variables including sales, daily order rates, and inventory levels can be tracked in real-time.

Cisco prided itself about the REI technologies that offered apparently seamless integration of real-time data within and across its supply-chain and customer ordering system but ignored the consequences that the past may not be accurate predictor of future. Cisco ended up writing off $2.2Billion in inventories and sacking 8500 employees demonstrates that even the best technology offer no protection against appalling business decisions, especially when the assumptions embedded in the dominant logic are taken for granted. Enron had emphasized that efficiency gains made possible by dynamic pricing, the company deployed REI sought out new technology wherever possible. Unfounded and overly optimistic belief in technology as the means for generating profits led to Enron's downfall.

8 CONCLUSION

In this paper, we represented strengths of MDA and RTE to achieve REI architecture framework. One of the major problems analyzing behavior of REI processes is to identify unpredictability of various components or modules within a specified system infrastructure. It is challenging to estimate interactions between different enterprise applications and establish appropriate mapping and transformation techniques as described in MDA specification. Our approach also resolves architectural dependencies in very initial stages of software development life cycle.

Ideally, REI initiative position users and model driven information together not by swapping them but alerting with relevant modifications enabling analysis mode and act to achieve specific objective. Real-time capabilities of EII provide efficient risk management, accurate information, and precise forecast due to various real-time collaboration techniques. Reducing the cycle-time and latency of information flow within an enterprise and its supply-chain is meaningless without the context of terms and conditions that outline permissible actions by supply-chain partners that is provided through the MDA based approach. Implementing real-time analytical capabilities to MDA ensures timeliness, pervasive connectivity, ubiquitous delivery, high availability, and scalability.

OMG's QVT (Queries, Views, and Transformations) (OMG MDA, 2003) proposal utilizes pattern matching as one of the key factor providing single language for relations and mapping that lowers entry barrier to transformation use.

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