Towards an Integrated Service-Oriented Reference Enterprise Architecture

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ABSTRACT
New business information systems are integrating emerging cloud infrastructures with service-oriented platforms and intelligent user-centered mobile systems. Both architecture engineering and management of service-oriented enterprise architectures is complex and has to integrate synergistic disciplines like EAM - Enterprise Architecture and Management for Services & Cloud Computing, Semantic-based Decision Support through Ontologies and Knowledge-based Systems, Big Data Management, as well as Mobility and Collaboration Systems. It is necessary to identify affected decisions by runtime changes of a service-oriented runtime environment and architecture. We have to make transparent the impact of these changes over the integral landscape of affected EAM-capabilities, like directly and transitively impacted business categories, processes, applications, services, platforms and infrastructures. The paper describes a new Metamodel-based integration approach for Service-oriented Reference Enterprise Architectures.

Categories and Subject Descriptors
C.0 [**Computer Systems Organization**]: System Architectures
D.2.11 [**Software Engineering**]: Software Architectures
H.1 [**Information Systems**]: Models and Principles

General Terms
Management, Measurement, Design, Standardization, Theory.

Keywords
Service-oriented Reference Enterprise Architecture, Architecture Metamodel Integration Method, Metamodel and Ontology.

WEA'13, August 19, 2013, Saint Petersburg, Russia
Copyright 2013 ACM 978-1-4503-2314-7/13/08...$15.00
http://dx.doi.org/10.1145/2501585.2501591

1. INTRODUCTION
In recent years innovation oriented companies have introduced service-oriented computing [24] paradigms and combined them with traditional information systems. Information and data are central components of our everyday activities. Social networks, smart portable devices, and intelligent cars, represent a few instances of a pervasive, information-driven vision of current enterprise systems with service-oriented enterprise architectures. Social graph analysis and management, big data, and cloud data management, ontological modeling, smart devices, personal information systems, hard non-functional requirements, such as location-independent response times and privacy are challenging essentials of the above scenario.

Service-oriented systems close the business - IT gap by delivering appropriate business functionality efficiently and integrating new service types coming from the cloud [2-3]. As the architecture of service-oriented enterprise systems becomes more and more complex, and we are going rapidly into cloud computing settings, we need a new and improved set of methodological well-supported instruments and tools for managing, decision support, diagnostics and for optimization of complex service-oriented enterprise architectures and related information systems.

The current state of art research in service-oriented enterprise architecture for services and cloud computing [2-3] and [23] lack an integral understanding of enterprise architecture and management [19-21] and shows an abundant set of low-level integrated standards, methods and tools. The aim of our research is to close this gap and enhance analytical instruments for cyclic evaluations of business and system architectures in real business enterprise system environments. In this paper we introduce our extended service-oriented enterprise architecture reference model in the context of our new architecture metamodel integration approach and ontology for integral enterprise architectures of services and cloud computing systems.

Our research aims to develop a metamodel-based model extraction and integration approach for enterprise architecture viewpoints, models, standards, frameworks [4] and tools for EAM towards consistent semantic-supported service-oriented reference enterprise architectures in cloud environments. The goal is to be able to support architecture development, assessments, architecture diagnostics, monitoring with decision support, and optimization of the business, information systems, and technologies. We intend to provide a unified and consistent ontology-based EAM-methodology for the architecture management models of relevant information resources, especially for service-oriented and cloud computing systems. Our research results are currently validated and extended in research and practical scenarios [24-25] by industrial and academic partners of the SOA Innovation Lab and Germany and Switzerland.

In our current research we are extending our first version of ESARC–Enterprise Services Architecture Reference Cube [24-25]. ESARC is an integral service-oriented enterprise architecture classification framework, which sets a standard of comparison for analyzed enterprise architecture descriptions as a guiding instrument for concrete architecture engineering scenarios. ESARC makes it possible to verify, define and track the improvement path of different business and IT changes considering alternative business operating models, business functions and business processes, enterprise services and systems, their architectures and related cloud-enabled technologies, like infrastructures and platforms as a service. We are interested in a discussion about our approach towards integrated service-oriented reference enterprise architectures for current and new information resources and systems. The novelty in our current research paper comprises new aspects for Enterprise Architecture Management (EAM) and Architectures of Services & Cloud Computing (SCC).

The following Section 2 describes our research platform for Service-oriented Reference Enterprise Architecture. Section 3 presents our new Enterprise Architecture Metamodel Integration approach for Service-oriented Enterprise Architectures and presents exemplar ontological representations for the Business & Information Reference Architecture in the context of major standards. Section 4 presents conclusions and outlines our ongoing research.

2. SERVICE-ORIENTED REFERENCE ENTERPRISE ARCHITECTURE

The ESARC – Enterprise Services Architecture Reference Cube [24] (see Figure 1) is more specific and completes existing architectural standards in the context of EAM – Enterprise Architecture Management [22], [21], and [19] and extends these architecture standards for services and cloud computing. ESARC is an original architecture reference model, which provides a holistic classification model with eight integral architectural domains. ESARC abstracts from a concrete business scenario or technologies, but is applicable for concrete architectural instantiations.

The OASIS Reference Model for Service Oriented Architecture [12] defines an abstract framework, which guides our concept of reference architectures, as in [1], [7], and [18]. Reference models are conceptual models of a functional decomposition of model elements together with the data flows between them. The Reference Model for Service Oriented Architecture of OASIS [12] defines basic generic elements and their relationships of a service-oriented architecture. This reference model is not a standard, but provides a common semantics for the more specific reference architectures. Reference architectures, in [7] and [18], are specialized models of a reference model. Reference architectures provide a composition of architectural elements, which are built from typed building blocks as the result of a pattern-based mapping of reference models to software concepts.

The Open Group Architecture Framework [19] provides the basic blueprint and structure for our extended service-oriented enterprise architecture domains (Figure 1) of ESARC [24], [25] like: Architecture Governance, Architecture Management, Business and Information Architecture, Information Systems Architecture, Technology Architecture, Operation Architecture, and Cloud Services Architecture. ESARC provides a coherent aid for examination, comparison, classification, quality evaluation and optimization of architectures.

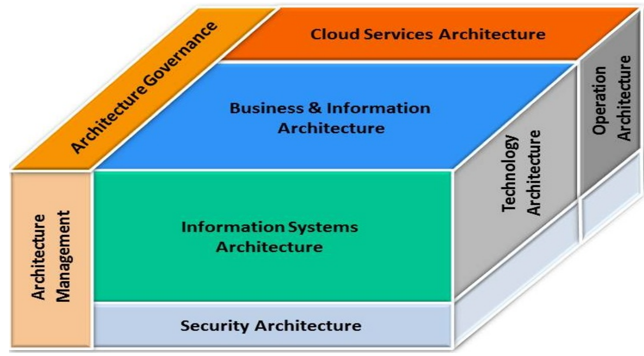

Figure 1. Enterprise Services Architecture Reference Cube.

Architecture Governance, as in [24], defines and maintains the Architecture Governance Cycle [22]. It sets the abstract governance frame for concrete architecture activities within the enterprise or a product line development and specifies the following management activities: plan, define, enable, measure, and control. The second aim of Architecture Governance is to set rules for architecture compliance to internal and external standards. Enterprise and software architects are acting on a sophisticated connection path emanating from business and IT strategy to the architecture landscape realization for interrelated business domains, applications and technologies. Architecture Governance has to set rules for the empowerment of people, defining the structures and procedures of an Architecture Governance Board, and setting rules for communication. We specify architecture governance models for concepts such as: service strategy and life cycle management of software and system architecture artifact's state, service security, service testing and monitoring, service contracts, registries, service reuse, service ownership, definition and versioning.

The Business and Information Reference Architecture - BIRA [24-25] provides, for instance, a single source and comprehensive repository of knowledge from which concrete corporate initiatives will evolve and link. This knowledge is model-based and defines an integrated enterprise business model, which includes organization models and business processes. The BIRA opens a connection to IT infrastructures, IT systems, and software as well as security architectures. The BIRA confers the basis for business-IT alignment and therefore models the business and information strategy, the organization, and main business demands as well as requirements for information systems, such as key business processes, business rules, business products, services, and related business control information.

The Information Systems Reference Architecture – ISRA [24-25] is the application reference architecture and contains main application-specific service types, defining their relationship by a layer model of building services. The core functionality of domain services is linked with application interaction services and with the business processes of the customer organization. In our research we are considering the standard reference models [12] and reference architectures [7] and [21] for services computing. We have differentiated a consistent set of layered service types. The information services for enterprise data can be thought of as data centric components [24], providing access to the persistent entities of the business process. Close to the access of enterprise data are context management services, which are provided by the technology architecture: error compensation or exception handling, seeking for alternative information, transaction processing of both atomic and long running and prevalent distributed transactions.

Process services [24] are long running services, which compose task services and information services into workflows, to implement the procedural logic of business processes. Process services can activate rule services, to swap out a part of the potentially unstable gateway-related causal decision logic. Process services are frontend by interaction services or by specific diagnostic service and process monitoring services. Often process services manage distributed data and application state indirectly, by activating task and information services. When processes services participate in human interaction workflows, they have to support long-running transactions where compensation of possible errors or exceptions happens in the business logic.

Cloud architectures are still under development and have not reached so far their full potential in integrating EAM with Services Computing and Cloud Computing. Integrating and exploring these three architectural dimensions into consistent reference architectures is a central part of our current research. The Cloud Services Reference Architecture provides a reference-model-based synthesis of current standards and reference architectures from [11], [2], and [3]. Today's development of cloud computing technologies and standards are growing very fast and provide a more and more standardized base for cloud products and service offerings. The NIST Cloud Computing Reference Architecture [11] defines the Conceptual Reference Model from the perspectives of the following Actors in Cloud Computing: Cloud Consumer, Cloud Provider, Cloud Auditor, and the Cloud Broker. The NIST standard defines following deployment models: private cloud, community cloud, public cloud, and hybrid cloud. Cloud Computing offers essential characteristics like: on-demand self-services, broad network access, resource pooling, rapid elasticity, and measured services. The fundamental part of the NIST Reference Architecture is defined by following Cloud Service Models: IaaS – Infrastructure as a Service, PaaS – Platform as a Service, and SaaS – Software as a Service. Some Standard extensions like [2] provide practical additions for supporting more directly modern business architectures by BPaaS – Business Process as a Service and giving a direct link to Service-oriented Enterprise Architectures. The IBM Cloud Computing Reference Architecture provides in [2] additionally to the standardization of NIST best-of-industry knowledge and cloud product specifications by integrating the NIST standard with own technology stacks, middleware, as well as service-oriented programming and runtime platforms. The IBM Cloud Computing Reference Architecture [2] has integrated the basic NIST standard of the Cloud Computing Reference Architecture [11] with the SOA Reference Architecture [18] from the Open Group: All cloud services are SOA services, but not all SOA services are also Cloud services. The security additions from the CSA Security Guidelines for Critical Areas of Focus in Cloud Computing [3] defines a Jericho-Security-focused Service-oriented Reference Architecture for Cloud Computing and integrates the management perspectives from standards like ITIL and TOGAF [19].

The Service-Oriented Cloud Computing (SOCCI) Framework [20] is an enabling framework for an integrated set of cloud infrastructure components. Basically it is the synergy of service-oriented and cloud architectures by means of a consistent As-a-Service-Mechanism for all types of cloud services. The basic characteristics of a Service-oriented Infrastructure (SOI) are: business-driven infrastructure on-demand, operational transparency, service measurement, and consumer provider model. The SOCCI-Service-Oriented Cloud Computing Framework is the extension of the Service-oriented Infrastructure (SOI) mapped to the SOA Reference Architecture [18]. The SOI-Framework is the layer on top of the basic infrastructure and provides important elements of SOCCI: Compute, Network, Storage, and Facilities. SOCCI extends these basic elements of SOCCI by Business and Operational SOCCI Management Building Blocks.

3. ENTERPRISE ARCHITECTURE METAMODEL INTEGRATION METHOD

Our originally developed integration model ESAMI – Enterprise Services Architecture Metamodel Integration – [26] serves as an integration method for integrating systematically base models of enterprise architecture standards, like [19], [21], architecture frameworks [5], [8], [6], [4], [13], and [14], metamodels from practice and from tools. ESAMI is based on our approach of correlation analysis and a systematic integration process.

Current work extends our basic service-oriented enterprise architecture model from ESARC by integrating EA-Models from architecture frameworks, from books and conference papers, and from metamodels of EAM-tools and specifications from our industrial partners. To be able to integrate these resources efficiently and exactly we have developed ESAMI – Enterprise Services Architecture Metamodel Integration, which is a correlation-based model integration approach for service-oriented enterprise architectures with following steps:

1. Analyze from each resource the structure of each Architecture Base Model using Concept Maps,
2. Extract the Base Viewpoint Model from each resource: Viewpoint, Model, Element, Example,
3. Initialize the Architectural Reference Model from Base Viewpoint Models: Viewpoint, Model, Element
4. Analyze Correlations (Concept Mappings) between Base Viewpoint Models and the Architectural Reference Model, and optionally conclude transitive correlations
5. Determine Integration Options for the resulting Viewpoint Integration Model
6. Develop the Synthesis Metamodel from Base Metamodels
7. Consolidate the Architectural Reference Model according the Synthesis Metamodel, and finally readjust Correlations and Integration Options
8. Develop the Viewpoint Map (Capability Map) and Ontology of the Architectural Reference Model
9. Develop Correspondence Rules between Model Elements
10. Develop Patterns for Architecture Diagnostics and Optimization.

First we have to analyze and transform given architecture resources with concept maps and extract their coarse-grained aspects in a standard way [26] by delimiting architecture viewpoints, architecture models, their elements, and illustrating these models by a typical example. Architecture viewpoints are representing and grouping conceptual business and technology functions regardless of their implementation resources like people, processes, information, systems, or technologies. They extend these information by additional aspects like quality criteria, service levels, KPI, costs, risks, compliance criteria a. o. We are using modeling concepts from ISI/IEC 42010 [5] like Architecture Description, Viewpoint, View, and Model. Architecture models are composed of their elements and relationships, and are represented by architectural diagrams.

For each architecture resource we are extracting then a Base Viewpoint Model in a standardized way. Then we develop the model of the initial Architectural Reference Model from each Base Viewpoint Model. This first version of the Architectural Reference Model is the result of a simple union from Base Viewpoint Models and could enclose redundant model information. In the next step we extend the initial Architectural Reference Model (Figure 2) by analyzing model correlations as quantified mappings between analyzed architecture models and by deriving synthesis or integration options for an optimized Architectural Reference Model. A Synthesis Metamodel of the Base Metamodels following the specifications of the Integration Options supports this step.

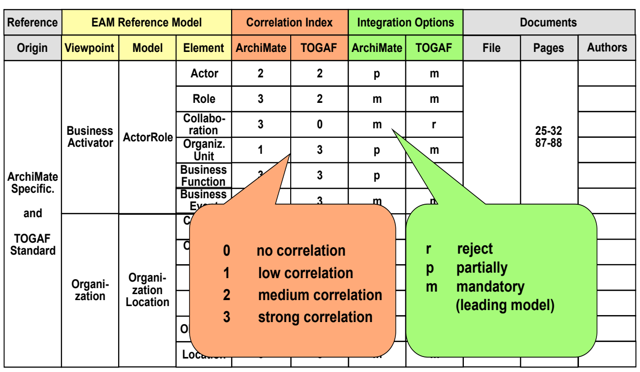

Figure 2. Correlation Analysis and Integration Options.

The Architecture Metamodel (Figure 3) is the base for the synthesized Architectural Reference Model, with its set up based on consolidated correlation and synthesis indicators from (Figure 2). Finally we cluster the resulting Viewpoint Map as a base for the Capability Map with final their Models and Elements.

Ontologies, as in [25], [23], and [17], provide both a fundamental base for a clear understanding of the integrated architectural concepts and for additional knowledge representation and inference mechanisms. We are currently researching about semantic-supported representations for service-oriented enterprise architectures to provide a base for easier navigation and simulation within the complex space of enterprise architectures. The semi-automated navigation between architectural concepts enables new functionalities for impact management as well as for cyclic architecture evaluations and for real-time architecture analytics, diagnostics and decision support.

We are using metamodels [16], [26] to define architecture model elements and their relationships within ESARC. We use metamodels as an abstraction for architectural elements and relate them to architecture ontologies [25], [26]. Architecture ontologies represent a common vocabulary for enterprise architects who need to share their information based on explicitly defined concepts. Ontologies include the ability to automatically infer transitive knowledge. The Metamodel of the Business & Information Reference Architecture – BIRA consists of ESARC-specific concepts, which are derived as specializations from generic concepts such as Element and Composition from the Open Group's SOA Ontology [17].

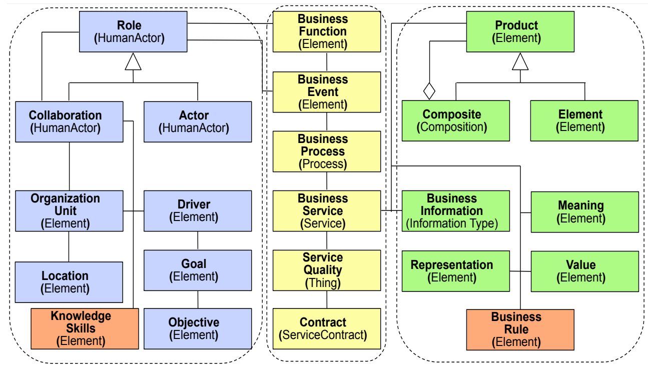

Figure 3. Ontology-supported Architecture Metamodel.

The technical standard of Service-oriented Architecture Ontology from [17] defines core concepts, terminology, and semantics of a service-oriented architecture in order to improve the alignment between the business and IT communities. In our understanding architecture ontologies represent a common vocabulary for enterprise architects who need to share their information based on explicitly defined concepts. Ontologies include the ability to infer automatically transitive knowledge. Our developed ontology for ESARC ([25], [26] and Figure 3) follows [17] has some practical reasons: share the common understanding of the ESARC Architecture domains and their structures, reuse of the architectural knowledge, make architectural requirements, structures, building blocks explicit and promote reusability of architectural artifacts, separate the architectural knowledge according orthogonal architectural domains, classify, analyze, diagnose enterprise systems according to the service-oriented reference architecture od ESARC.

The SOA ontology represents core concepts of a generic service-oriented architecture as classes and properties. The SOA ontology includes in addition natural language descriptions of main concepts and relationships UML diagrams, which show graphically the semantic concepts as classes and the properties as UML associations. The UML diagrams are intended for explanation only, but are helpful constructs for understanding the modeled domain of SOA architecture and more concise than the more spacious formal descriptions in OWL. The SOA ontology defines the relations between semantic concepts, without mentioning the exact usage of these architecture concepts.

We have developed the ESARC Ontology, as in [9], and [10], and defined ontology concepts for ESARC using the ontology editor Protégé [15]. We have merged our specialized ESARC Ontology with the generic SOA Ontology from [17]. The so-called *Asserted View* from Protégé shows the *is-a-relationship* between specific concepts of the Business & Information Reference Architecture and the Open Group's generic SOA Ontology Reference Architecture. The terminal concepts are specific concepts of ESARC. In Figure 3 we point within parentheses to the linked generic concepts of the SOA Ontology. Additionally we have determined knowledge properties for the modeled ontology concepts of ESARC. Using the ESARC ontology we intend further to navigate easier within the complex space of enterprise architecture management structures and to enable semantic-supported decisions and more transparency for stakeholders.

4. CONCLUSION AND FUTURE WORK

The basic approaches within each field are already well known and used. However, those are not directly applicable and properly integrated for decision-support in service-oriented enterprise engineering and architectures. Our ontology approach for Service-oriented Enterprise Architectures for cloud-based information systems extends previous research about semantic support through ontologies for service-oriented reference architectures, reference implementations and reference models for EAM - Enterprise Architecture Management for Services & Cloud Computing, the models of ESARC - Enterprise Services Architecture Reference Cube, as well as associated architecture metamodels, ontologies and architecture patterns. Our approach provides a sound basis for architecture decision support from theory and from practical evaluations of service-oriented platforms in heterogeneous environments with four major global technology providers, like IBM, SAP, ORACLE, and Microsoft, and vendors of Enterprise Architecture Management tools. Future work will include conceptual work on both static and dynamic architecture complexity, and in connecting architecture quality procedures with prognostic processes on architecture maturity with simulations of enterprise and software architectures. Additional improvement opportunities will focus on methods for impact management, decision linking, visualization of architecture artifacts and architecture control information, which has to be operable in an architecture management cockpit.

5. ACKNOWLEDGMENTS

This work was partially supported by the SOA Innovation Lab.

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