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Semantic SOA - IT Catalyst for Business Transformation

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Abstract

In today's competitive world, a key to success in business is "continuous-innovation". Apart from introducing new products and services, business is forced to continuously innovate and adopt new business models to survive, compete and get leading edge over others. From IT perspective, in rapidly changing world of technology, it becomes a great challenge to facilitate these innovations economically, efficiently and effectively, overcoming "time-to-market" and "technology-shelf-life" constraints. Service-Oriented Architecture (SOA) is considered as the key technology enabler to address these challenges and achieve improved business – IT alignment. However, in many of the B2B, B2C, EAI and BPM scenarios, improving efficiency [xxii, xxx] and effectiveness through dynamic integration and runtime process automation remains a key bottleneck in SOA implementation. Semantic SOA is about applying ontology to the SOA, which empowers enterprises with automatic service discovery, dynamic integration, and runtime process automation capabilities and acts as an IT catalyst for business transformation. In this paper, we will cover the key shortcomings of SOA, business value of Semantic SOA and how standards and technology can help to realize Semantic SOA.

Introduction

In the recent survey report[vi] published by a leading analyst firm, it has been reported that large numbers of small, medium and large enterprises have started adopting Service Oriented Architecture (SOA) strategically or tactically to address various internal and external integration problems. With wider acceptance and adoption of SOA within enterprises and across businesses, there is a strong potential and opportunity to realize the additional business value by adopting dynamic business integration models. Also, as the system go mature; bringing capabilities for extracting "knowledge" from multiple systems and processing it at runtime becomes crucial. It will become inherent expectations from the IT systems to extract and consume "knowledge" across multiple systems, across domains to bring intelligence and autonomics capabilities and thereby increasing the business value of the IT system significantly.

To facilitate the above, in the recent past, there has been a lot of work being done to develop standards for web services and business process modeling to achieve the above goals. The web services standards[ii, iii] include standards for discovery (UDDI, WSDL), standards for Transactions (Web Services Coordination, Web Services Atomic Transactions, and Web Services Business Activity), standards for business processes (WS-BPEL) and standards for management (WSDM) and many others for security, addressing etc.

The business process modeling standards[i] include Business Process Execution Language for Web Services (BPEL4WS), OASIS Business Transaction Protocol (BTP), Web Services Choreography Interface (WSCI), Web Services Conversation Language (WSCL), Workflow Management Coalition (WfMC), Web Services for Business Process Design (XLANG). However, these efforts towards developing standards are falling short of achieving dynamic integration, runtime process automation and system autonomics[iv] (self-optimizing, self-configuring, self-healing, self-protecting) capabilities.

In our point of view, the standard SOA implementation is challenged [xxxiii] to meet these capabilities to realize the additional business value associated with futuristic dynamic business models. The current practice of SOA implementation using the available standards will be unable to provide dynamic integration, runtime process automation and system autonomics capabilities due to following shortcomings.

Key Shortcomings of SOA

SOA enables enterprises to develop standards-based integration solutions. SOA goals (Visible, Accessible, Understandable, and Interoperable) facilitate service discovery, information exchange and process mediation using UDDI Discovery and XML based data integration. To a large extent, the current SOA implementations extensively depend on XML based standards and XML based data integration techniques. The XML based approach for interoperability and integration has many challenges[xxxiii]:

a) **Point-to-Point Integration Schemes are brittle and has higher maintenance overhead:** The XML and XSL-T approach for data transformation forces point-to-point mappings between single source and single target. If the enterprise has N data formats, it results into N^2 - N XSL-T mappings. Any changes in the data formats will force changes in multiple mapping files. The point-to-point integration schemes are brittle; it limits the flexibility and increases the maintenance overhead.

b) **The tight coupling nature of XML, XSL-T violates loose-coupling principle of SOA:** Due to one is to one mapping between XML and XSL-T for data transformation, it creates a tight coupling. In many-to-many information exchange scenarios, it becomes very complex to process these mappings at runtime - it restricts dynamic data transformation capabilities in SOA implementation. The tight coupling nature of static and syntactic XSL-T scripts and mappings violate loose-coupling: the basic principle of SOA.

c) **It is difficult to harmonize and converge multiple XML Standards for data interoperability:** In order to overcome the issue of multiple data formats and mappings, many of the approaches advocate standardization of XML schemas by using domain specific information exchange standards(v). There exist a bunch of standards for almost every major industry vertical, for e.g. RosettaNet standard for supply-chain, ACORD standard for insurance, ARTS standard for retail sales, HL7 standard for health care, UIG standard for utilities, XBRL standard for accounting and UBL standard for business documents (purchase order, invoice) etc. There are multiple standards in existence for specific industry domain and there is an overlap between standards also; it becomes another problem to harmonize and get convergence among these standards.

d) **Acceptance and adoption of XML Standards globally has many practical challenges:** It is difficult to create a robust standard for a specific industry domain supporting all the variants of business models. The standard schemas are difficult to implement globally across all the enterprises. Besides agreeing on which standards to use, significant effort is required to agree on "how-to use standards" - enterprises have to agree on specifics of message contents, message structures, message sequencing and service execution constraints. Thus, the interoperability and dynamic data transformation issue remains a critical challenge for the external integration scenarios such as B2B Partner Collaboration.

e) **XML based data interoperability is "syntactic" that limits the "knowledge" capabilities:** In another perspective, XML and XSLT based integration technique is syntactic and not "semantic"; it is unaware of the meaning of the data, which limits the "knowledge-processing" capabilities. It fails to provide runtime process automation and optimization capabilities in SOA.

While designing the solution to integration problem, we need to understand that the complexity of solution for integration increases from single information domain to multiple information domain integration. Also, the solution has to deal with multiple technologies, data formats and application connections. Today's SOA based integration solution impose following limitations from dynamic integration and interoperability perspective:

- unable to handle loosely coupled information
- unable to process unstructured information
- unable to handle unplanned data sources and services
- unable to harmonize the vocabulary of data in communication
- unable to provide proactive alerts (knowledge) on data based on the context of operation

Also, the SOA approach supports only the static process orchestration model, which enforces fixed rules and fixed services for a given business process at runtime. The evolving and futuristic business model requires dynamic service selection and dynamic process orchestration capabilities. From runtime process optimization and autonomics (self-configuring, self-optimizing, self-healing, self-protecting) perspective, the today's SOA systems impose following limitations:

- unable to dynamically discover and select services
- unable to process the data based on the context of operation
- unable to negotiate constraints and agreements at runtime
- unable to reconfigure and optimize the flow of execution based on the constraints of the operations
- unable to recover and restart at runtime from the unexpected fault scenario

The above stated shortcomings jeopardize the SOA implementation to provide dynamic integration, runtime process automation and system autonomics capabilities. The Integration problem in an enterprise remains as the key challenge and they are struggling to find a simple, reusable and cost effective solution. Futuristic business models will demand more semantic capabilities in SOA to overcome these limitations.

Semantic SOA is about applying ontology on SOA to improve efficiency and effectiveness in integration, process automation, and mediation business scenarios. Semantic SOA brings the following capabilities:

- automatic service discovery
- dynamic data transformation
- dynamic information exchange for structured and unstructured data
- dynamic integration
- automatic (or semi-automatic) service constraints validations and agreement negotiations
- automatic (or semi-automatic) service selection
- runtime process orchestration, optimization & adjustment
- process: self-configuring, self-optimizing, self-healing, self-protecting

Business Case for Semantic SOA: Dynamic Business Integration

To understand the value of Semantic SOA a from a business perspective, let us take an example of B2B and B2C integration for Partner Collaboration and e-Commerce scenario. Consider a hypothetical scenario for Comparison Shopping Portal, **see Figure 1**.

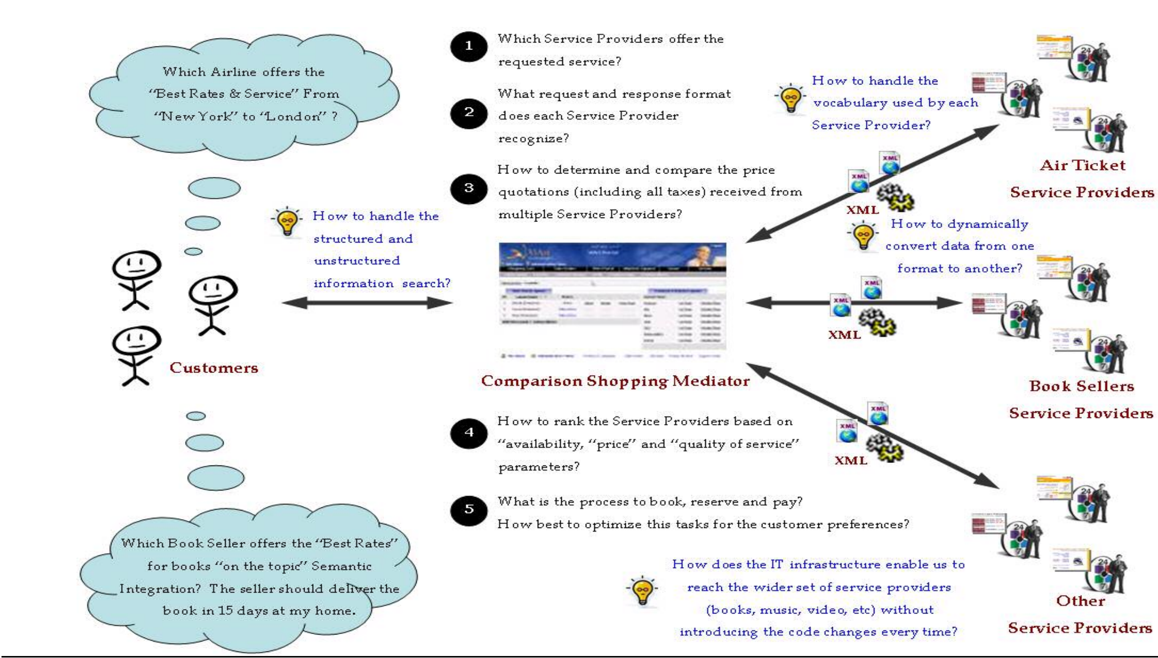

Figure 1 Business Case for Semantic SOA

The scenario and the process depicted here are simplified for better understanding of the principles; the actual process can be much more complex than shown here. The following are the key business use-cases in our scenario:

- Customer wants to **Search** specific product on a Comparison Shopping Mediator Site
- Customer wants to **Compare** the price of the product across different Sellers
- Customer also wants to see other **Context Sensitive Value Added Information** on the product, such as shipping location constraints, shipment duration and product / vendor reviews etc.
- Comparison Shopping Mediator Site has to handle multiple types of product **Search Vocabularies**
- Comparison Shopping Mediator has to **Search the Sellers** for the requested product
- Comparison Shopping Mediator has to **Query** the **Product Availability** from different Sellers
- Comparison Shopping Mediator has to **Query** the **Price** from different Sellers
- Comparison Shopping Mediator has to **Query** the **Shipping Constraints** from different Sellers
- Comparison Shopping Mediator has to **Query** the **Vendor Reviews** from different Sellers
- Comparison Shopping Mediator has to **Handle Responses** from multiple Sellers dynamically
- Comparison Shopping Mediator has to **Rank Sellers** and provide value added information
- Comparison Shopping Mediator has to **Choreograph** the **interactions with Sellers** and automatically come-out in the fault situations
- Comparison Shopping Mediator has to **Perform** runtime adjustments and optimization in the interactions with Sellers based on constraints validations, policy verifications and agreement negotiations.

There exist a multiple such portals today, for e.g. bestfares.com, makemytrip.com and travelguru.com facilitates comparison shopping of air tickets of different airlines. The addall.com and bookhq.com facilitates comparison shopping of books. Both of these examples deal with single information domain – air tickets or books. In a more complex multiple information domain scenario, bestwebbuys.com, pricescan.com and pricegrabber.com etc portals facilitate comparison shopping of multiple items including books, music, video, electronic goods, etc. Also, apart from providing basic price comparison capabilities, some of these portals provide more value added information services such as vendor ratings, product reviews and shipping constraints (location, duration).

There are multiple challenges in implementing a solution for the above business scenario:

a) **How does Comparison Shopping Mediator locate appropriate Sellers?** The SOA solutions use UDDI discovery which is more-or-less keyword (syntactical) search on UDDI registry. Semantic SOA brings ontology-enabled vocabularies, which facilitates meaning and reasoning over the data and syntax, which helps harmonizing the vocabulary for wider search. Semantic Service Discovery can enable Comparison Shopping Mediator to reach-out a wide array of Sellers and offer more options then conventional discovery. The Semantic SOA offers automation of the discovery process and provides automatic seller discovery & selection.

b) **How do the Comparison Shopping Mediator and Sellers recognize and respond to the product specific Queries?** The traditional solutions use predefined (syntactical) agreed-upon data fields as a protocol for communication. We have identified the issues with this XML based and Standards based point-to-point data integration techniques earlier. The ontology information model definition and ontology mappings are capable of determining how to convert one data format into another at runtime. The Semantic SOA facilitate dynamic data transformation and information exchange between Comparison Shopping Mediator and Sellers.

c) **How does the Comparison Shopping Mediator reason over the data and formats to facilitate the Price Comparison, Seller Ranking etc?** The traditional solution forces to use hard code this logic based on the pre-defined data formats. Any new capability to "extract knowledge" will require tedious code changes. The reasoning capabilities on ontology information models facilitate model based implementation of such algorithms for product price comparison or seller ranking in Semantic SOA solution.

d) **Do Sellers support Comparison Shopping Mediator's Policies, Constraints and Agreements?** In the current scenario, the Comparison Shopping Mediator interacts with different Sellers. In the practical situations, there are multiple constraints, policies and agreements between these two entities. The traditional solutions require manual interventions for such negotiation and constraint validation steps. The Semantic SOA offers modeling of constraints validation and agreement negotiation through functional and QoS semantics characteristics. In the later sections, we will describe the standards which bring these characteristics in Semantic SOA solution.

e) **How do Comparison Shopping Mediator and Seller Business Process Optimize itself, Self-Manage or Self-Configure itself at runtime to deal with the fault situations?** The SOA solutions will force a hard-coded or somewhat manually configurable solution to facilitate the runtime process orchestrations and execution. It does not offer model based process automation or runtime optimization. The Semantic SOA approach, with the use of functional semantics, execution semantics and QoS semantics characteristics can facilitate runtime process orchestration, optimization & adjustment and system autonomics capabilities.

The key concept to understand is the possibility of creating "new dynamic business models & services" using semantic technologies and how it influences the traditional e-commerce business models. Applying the above scenario for online air-ticket shopping, where-in "comparative pricing of airline tickets" and "searching of suitable airline service providers at runtime" are the catalytic elements which change the traditional business services, business models and business-to-business relations. The concept, benefits and business models can be applied in any e-commerce business scenarios e.g. online book shopping.

Let us take another business scenario, where Semantic SOA can act as a change agent. In the B2B supply chain scenario, the key business processes include the supplier discovery, item search and item procurement. The Semantic SOA capabilities of automatic service (supplier) discovery and harmonization of vocabularies (items) can eliminate the deficiencies supplier discovery and item search (match) business processes and enables automation of end-to-end item procurement process.

In many of the B2B and B2C scenarios, the transaction framework[(xxx, xxiii)] between transacting parties require matchmaking, negotiation, contract formation and contract fulfillment. The matchmaking process addresses the need of identifying (who can fulfill the request) and locating the provider whereas the negotiation process validates the constraints (policies) in context of transaction. The Semantic SOA offers seamless automation of the above steps. It helps to discover the business partnership dynamically through automatic service discovery capability. It also helps to create spontaneous and temporarily interactions between trading parties through dynamic integration and runtime process optimization capabilities.

Semantic SOA acts as an IT change agent that influences the way e-business[(xxii)] and e-commerce[(xxviii)] is done today – it brings new dynamic business models; new business services and facilitates spontaneous B2B relations. It helps to automate the business processes and brings more efficiency and effectiveness in the organizations. These translates to multiple benefits to the business

- new business services helps organizations to increase customer base and there-by increase in revenue
- new business models helps organizations to innovate their selling process
- improved business process efficiency helps organizations to reduce operational cost

We will understand "how" Semantic SOA brings the capabilities for automatic service discovery, dynamic integration and runtime process optimization in the "Technology Realization of Semantic SOA" section of this document.

Other Enterprise IT Situations

There are multiple other enterprise scenarios other then B2B and B2C integration, where Semantic SOA can help to improve IT efficiency and effectiveness for business benefits. The below are few instances:

a) **Discrete Data Sources Integration Scenario:** The traditional development practice to develop separate applications for each business function has resulted in a number of discrete data sources within an enterprise. An integrated view of these data across multiple sources is absolutely a critical requirement to get the valuable information for decision making. The point-to-point integration at database level or at application level is brittle and inflexible to changes, which results in higher total cost of ownership.

b) **Legacy Modernization Scenario:** Enterprises have number of legacy systems to serve different business processes. It is always expected to leverage the investment in legacy systems and at the same time, get right information at right time from these discrete data sources. The plain vanilla SOA based integration at system level or at service level is brittle and inflexible to changes in data formats, which results in higher total cost of ownership.

c) **EAI, BPM Integration Scenario:** Enterprises have number of heterogeneous applications for different business processes each serving a specific business function. Each system has its own database model. Also, each system exposes its own set of interface API methods (even web services) for process integration. The interface methods demand a specific data structure for facilitating integration. Again, it forces application and process point-to-point integration at system level, which is inefficient.

d) **Mergers & Acquisitions Scenario:** Application Portfolio Consolidation Scenario: For faster inorganic growth, the enterprises take the route of mergers & acquisitions. There is a humungous work involved in such cases for application consolidation, application alignment, and process integration. Also, there are multiple heterogeneous technology platforms that add to the complexity of the application portfolio realignment.

In all above scenarios, the main focus and challenges are around facilitating dynamic data transformation, dynamic integration, dynamic mediation, runtime process orchestration, optimization & adjustment. Use of ontology in Semantic SOA adds the required "dynamic" flavor on the plain SOA implementation and brings flexible and scalable integration capabilities to an enterprise.

On a broader note, for any business, the key performance indicators consist of these measures: Efficiency i.e cost savings, Effectiveness i.e. return on assets and Growth i.e. return on investment. Semantic SOA helps to improve all the three measures for success: efficiency, effectiveness and growth. The combined power of dynamic integration and runtime process optimization creates enough avenues for business to visualize, adopt, realize and sustain innovative business models and services; and thereby it can act as an IT catalyst to facilitate business transformation.

Academic & Research Work

The research paper on Semantic eBusiness Vision [xxii,xxx, xxxiv] defines Semantic Commence as an approach to managing knowledge for the coordination of e-business processes through the systematic application of semantic web technologies. It provides the examples of innovative, knowledge-rich business models that enhance the vision of Semantic eBusiness. It brings out the fact that competition is forcing organizations to improve the efficiency and effectiveness of their business processes, using emergent technologies that offer seamless availability of knowledge. Semantic eBusiness Vision brings value to the organizations by introducing a mean to design collaborative, integrative, efficient, effective and reusable, inter and intra-organizational business processes using emerging semantic technologies.

Considerable amount of interest has been demonstrated by multiple academic and defense organizations to leverage the full potential of semantic technologies for higher efficiency, effectiveness, intelligence and analytics[xvii,xviii,xix]. The key research projects from Large Scale Distributed Information Systems (LSDIS) include METEOR-S (Semantic Web Services and Processes), SemGrid (Semantic Discovery on Adaptive Services Grid), and Semantic Middleware.

Another piece of work from Digital Enterprise Research Institute (DERI) has cluster[xxi]of research projects around Semantic Web, Semantic Web Services and Semantic Integration in Business. The goal of the

Semantic Web Cluster is to develop the baseline technologies that will make data on the World Wide Web understandable to machines. It will enable the data to be used in a more efficient way and enable the Internet to really interact with people in a useful manner. The goal of the Semantic Web Services cluster is to develop a scaleable Semantic Web Service modeling and execution solution with a combination of Web Service and Semantic Web technology.

Data, Information and Process Integration (DIP) with Semantic Web Services[xx] is another project focused to produce the new technology infrastructure for Semantic Web Services (SWS) - an environment in which different web services can discover and cooperate with each other automatically. DIP's long term vision is to deliver the enormous potential benefits of Semantic Web Services to e-Work and e-Commerce.

Technology Realization of Semantic SOA

The Semantic SOA is a standards-based, ontology-enabled, constraint-driven approach that enables automatic service discovery & selection, dynamic integration and runtime process orchestration, optimization & adjustment. Semantic SOA is about applying ontology to the SOA implementation to bring the dynamic integration and runtime process automation capabilities to SOA. The Semantic SOA architecture goal is to enable enterprise with following additional capabilities:

- automatic service discovery & selection
- dynamic integration, data transformation and information exchange
- runtime service constraints validation & agreement negotiation
- runtime process orchestration, optimization & adjustment
- system autonomics: self-configuring, self-optimizing, self-healing, self-protecting

Semantic SOA brings the characteristics of Data Semantics, Functional Semantics, Execution Semantics and Quality of Service (QoS) Semantics[xxxi, xxxiii] on the top of various SOA standards. In next few paragraphs, we will understand "how" the Semantic SOA characteristics overcome the key shortcomings of SOA and bring the above listed dynamic IT capabilities required for business transformations. The power of semantics simplifies and automates complex process mediation scenarios through ontology-based dynamic integration and runtime process automation. Ontology offers multiple advantages over tradition XML based information exchange to facilitate these capabilities.

a) **Data Semantics for Dynamic Integration:** Data Semantics describes Ontology Definitions and Ontology Mappings for a specific Information Model. Data Semantics describes ontology for the definition of request and response message structures for a given service operation. Use of ontology, by characteristics and by definition, eliminates the need of maintaining multiple mappings for data transformation and information exchange between different ontology models. It is possible to define a single ontology model for a specific information model. Using the ontology mapping files, it is possible to link and transform ontology information models dynamically. The linked ontology mappings are capable of determining how to convert one data format to another at runtime. This eliminates the need of maintaining multiple XML, XSLT mappings and provides dynamic integration capabilities. The semantics nature of ontology also provides "meaning" to the data, which enables "reasoning" at runtime to further improve the efficiency of information exchange. Ontology mappings also eliminate the need of using common domain specific XML standards for information exchange. Enterprises are "free" to use their own data formats. This addresses the issues related to acceptance and adoption of common XML standards between trading parties in traditional SOA.

b) **Functional Semantics for Automatic Service Discovery & Selection:** Functional Semantics describes ontology for the definition of service capabilities and operations offered. Functional Semantics can be used for Service Publication and Discovery. The standards based implementation of functional semantics provides a template based service discovery with matchmaking algorithm, which provides ranked "available service" results. The ontology annotations for the service definition and operations enable Automatic Service Discovery and Automatic Service Selection.

c) **Execution Semantics and QoS Semantics for Runtime Process Negotiation & Optimization:** Execution Semantics describes ontology for the execution flow of services in a business process or operations in a service. The ontology annotations help to determine the flow for service execution and invocation at runtime. The execution semantics help to optimize the business process flow at runtime. Quality-of-Service (QoS) Semantics describes ontology for the qualitative and quantitative constraints for service execution and invocation. The ontology annotations help to dynamically negotiate the constraints and agreements before actually executing the services. Both these characteristics facilitate Runtime Process Orchestration, Optimization and Adjustment capability to the SOA solution.

We visualize the following conceptual architecture view for developing the Semantic SOA based solution:

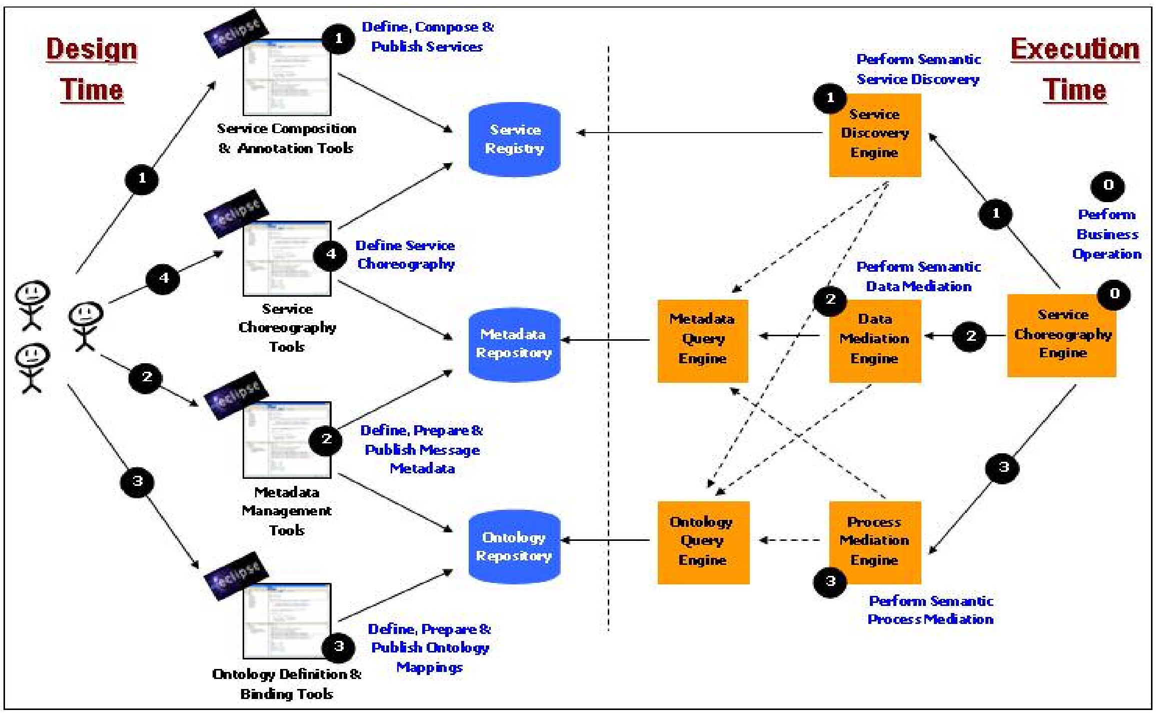

Figure 2 Semantic SOA Architecture View

Our architecture approach is very much similar and derived from WSMX architecture[(xxxii)], reader may refer to it for functional understanding of various architecture components.

The design time architecture components provides capabilities to –

- define, compose and publish services
- define, prepare and publish service and message metadata
- define prepare and publish ontology and ontology mappings
- define service choreography for process orchestration

The runtime architecture components include –

- semantic service discovery engine for automatic service discovery
- data mediation engine for dynamic data transformation using ontology and metadata
- process mediation engine for runtime process orchestrations and service integration
- service choreography engine for runtime process optimization, adjustments and system autonomics

The ontology enabled standards bring the data semantics, functional semantics, execution semantics and QoS semantics characteristics to Semantic SOA architecture. Many ontology based standards have evolved over a period of time which brings the required dynamic characteristics in SOA implementation. OWL-S[(viii)], derived from DAML-S, is a standard which helps software robots to discover, invoke, compose and monitor web services offered from multiple resources using their service descriptions. It uses Web Ontology Language (OWL) to describe its semantics. It consists of three major parts. It exposes Service Profile for advertising and discovering services, process model that gives detailed information about its operations and grounding to facilitate communications between services using messages.

Web Service Semantics (WSDL-S[x]) takes a step further to OWL-S and defines procedures to include semantic annotations to WSDL documents. It uses external ontologies described in different semantic models and maps various WSDL components to it. Data-types, operations and interfaces of WSDL can be directly associated with appropriate concepts in semantic model.

Web Services Modeling Ontology (WSMO[xi]) or provides a conceptual framework and a formal language to describe semantic aspects of web services to improve their discovery, composition and invocation on web. WSMO is richer than WSDL-S and have capability to describe preconditions, post conditions, assumptions and effects on operations as well as orchestration and choreography of interfaces. WSMO contains four basic elements namely ontology, web service description (describes functional and behavioral aspects of service), goals (describes user's interests in services) and mediators (handles interoperability between other three elements). The formal logic language used in WSMO is described using Web Service Modeling Language or WSML[xii].

Semantic Web Services Ontology (SWSO[xv]) describes conceptual model of ontology as well as a first-order-logic axiomatization (called FLOWS) to define semantics of ontology. FLOWS enable reasoning between web services using semantics for interaction between each other and other applications. A similar attempt from METEOR-S also aims at adding semantics BPEL4WS, a standard for orchestration of web services.

Web Service Modeling Execution Environment (WSMX[xvi]) is the reference implementation of WSMO (Web Service Modeling Ontology). It is an execution environment for business application integration; it facilitates dynamic web services integration to increase the business process automation in a flexible and scalable manner. It has the capabilities to consume semantic messages, discover semantically described web services, invoke, compose and choreograph their interactions.

Conclusion

Semantic SOA empowers enterprises with dynamic integration and runtime process automation capabilities. It offers efficient, scalable, agile and future-proof business integration solution. The combined power of dynamic integration and runtime process optimization creates enough avenues for business to visualize, adopt, realize and sustain innovative business models and services. It can act as an IT catalyst to facilitate business transformation.

At the same time, Semantic SOA is comparatively new, innovative and ambitious approach for dynamic integration and runtime process optimization. Many of the standards in the industry are still evolving and not tested enough to handle today's complexity and challenges in business integration. Apart from challenges around senior managements' commitment to implement SOA and Semantics, the visual tools provide very limited development productivity and unavailability of the ontology skills restricts the adoptability of Semantic SOA.

To conclude – even though Semantic SOA looks very ambitious at this stage, the enterprises can not ignore the power and agility that it brings to address today's integration challenges. It is suggested that enterprises adopting SOA must approach "semantics" in a step-by-step manner; keeping balance between innovation and realization. The SOA implementation should be planned and designed for "semantics" to make it future proof.

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