Semantically-enabled Service-oriented Architectures: A Catalyst for Smart Business Networks

Hannes Werthner[1], Martin Hepp[2], Dieter Fensel[2,3] and Jürgen Dorn[1]

[1] Institute for Software Technology and Interactive Systems, Technical University of Vienna, Austria

[2] DERI Innsbruck, Leopold-Franzens Universität Innsbruck, Austria

[3] DERI Galway, National University of Ireland, Galway, Ireland

Abstract

Smart Business Networks are two things: Firstly, an emerging concept for the agile composition of e-business value chains, and secondly a new stream of research. While there exists a coherent vision of Smart Business Networks and the associated functionality, there is insufficient understanding of why creating and maintaining such infrastructure and networks is as difficult as being experienced in real-world scenarios. In this paper, we (1) trace back the complexity of partner selection, process composition, and execution monitoring to the lack of semantics in the description of system elements in SBN environment, (2) propose a semantically-enabled service-oriented architecture (SESA) as a the foundational layer for future Smart Business Networks, and (3) show how our approach significantly reduces the complexity of the core network management tasks by lifting them to a higher level of abstraction.

Keywords: Service-oriented Architecture, Semantics, Layered architecture

1 Introduction

The trend in e-commerce and e-business is characterized by a fragmentation of value chains and flexible outsourcing based on the ad-hoc integration of services, which in combination leads to blurry boundaries of an enterprise. These phenomena may eventually lead to Smart Business Networks (SBN) [1]. In this context it is interesting to note the parallel emergence of two innovative but currently unconnected developments:

First, SBN research, having its roots in Management Science and Information Systems, and second Semantic Web Services frameworks currently driven mainly by research communities in Computer Science. For an overview of the impact of semantics on Computer Science in general, see [2].

Following the SBN research manifesto and the related research questions, we concentrate on the first one: What is the role and impact of new technologies on the creation and operation of value chains?

Tourism, which is one of the liveliest domains in e-commerce, may serve as an example of how SBN will be influenced by this new approach ([3], [4]). Structurally, the supply and the demand side form a worldwide network, where both production and distribution are based on cooperation. In this area, two things can be observed. Firstly, the fact that wide diffusion of e-commerce led to an “informatization” of the entire value chain, in the sense that the flow of information determined the value chains, instead of more stabile organizational arrangements. Secondly, consumer behavior has changed regarding information needs, booking and travel patterns, which in combination has increased the importance of process agility for all market participants. As a consequence, one can observe the Internet-based integration of processes, with a focus rather on value-chain engineering than inter-enterprise process reengineering. In the future, one can expect flexible network configurations (cooperation) and the further integration of consumers into (internal) business processes. Processes go beyond company borders and thus lead to distributed “b2b2c” applications which will require cooperation between enterprises at an unprecedented level of complexity, specificity, and agility, and also the integration of interaction with the consumer based on mobile devices. This is based on the assumption that technology – based on a common pervasive infrastructure – will become transparent, invisible for the consumer; who will be having access to information whenever and wherever desired. This requires scalable and flexible IT solutions, providing seamless integration and interoperability (between all stakeholders), and access to a plethora of legacy systems.

Now, one may ask why the establishment of SBNs is still more burdensome, more costly, and not as agile as the initial optimism had suggested. In reality, one can observe that composing and managing value chains is still widely dependent on human labor for the discovery of partners, resolution of heterogeneity conflicts between systems, the monitoring of process performance and compliant partner behavior, etc. The amount of human involvement in the process lifecycle is in sharp contrast to the initial expectations of “on-the-fly” composition of new value chains, and it leads to high costs, conceptual inconsistencies, and the inability to exploit small or volatile business opportunities.

In this paper, we argue that the major bottleneck in SBN engineering is an insufficient conceptual model for the various layers that make up a value chain. In particular, we show that a lack of formal semantics on the various layers prevents automated partner discovery, systems integration, and process monitoring, even for known patterns of problems; on top of that, the insufficient level of abstraction limits the reuse of existing process models in new contexts. We propose to use the layering described by the Semantic Web services community under the term “SESA” (semantically-enabled service-oriented architectures) as the conceptual foundation for a new generation of SBNs.

2 SESA-SBN: A Layered Conceptual Model for Smart Business Networks

In the domain of Web services, there is now growing consensus on the fact that Services-oriented Architectures (SOA) have not yet delivered their promise of “on-the-fly” services discovery, substitution, and composition because a semantic level, i.e. one that formalizes the meaning of services and their pre- and post-conditions as well as non-functional properties, was missing. As a consequence, Semantic Web Services frameworks, namely the Web Service Modeling Ontology (WSMO), OWL-S, and WSDL-S are gaining ground. We argue that the lack of a semantic layer is a similar bottleneck on the road to Smart Business Networks. Our vision implies the separation of business / process logics (expressed as a workflow or other form of process description) from the Web Services used (as well as the respective mappings), and where the created set of Web Services correspond to the implemented (business) solution.

One should note, that this approach implies a transformation of meanings, from services as they are understood in management science to web services as defined in computer science. In management science a service is defined as a business economic activity (mostly intangible in nature), offered by one party to another to achieve a certain benefit ([5], [6]), and "generated" by (internal) business processes. In IS a service is a complex (or simple) task executed (within) an organization on behalf of a customer ([7]).

Figure 1. Three Layers of Semantically-enabled Service-oriented Architecture (SESA).

And one should also note that service bundling – using a business term – differs from service composition ([8]): composition assumes a process description, whereas bundling do not make explicit assumptions about time order, but about service connectivity or puts constraints on service configuration, e.g., bundle of services with overall minimum price. This puts emphasis on non-functional aspects of service descriptions.

A Service-Oriented Architecture (SOA) is essentially a collection of services. These services communicate with each other. Such collections can be large - a service-oriented world will likely have billions of services. Computation will involve services searching for services based on functional and non-functional requirements and interoperating with those that they select. However, services will not be able to interact automatically and SOAs will not scale without signification mechanization of service discovery, negotiation, adaptation, composition, invocation, and monitoring as well as service interaction which will require further data, protocol, and process mediation. Hence, machine-processable *semantics* are critical for the next generation of computing - SOAs - to reach its full potential. The goal of *Semantically Enabled Service-Oriented Architectures (SESA)* is to place semantics at the core of computer science. In the following, we describe the layers of such architectures as

1. the problem-solving layer,
2. the common service layer, and

3. the resource layer (see Figure 2),

and propose to use a similar layering for SBNs.

Figure 2. Three Layers of Semantically-enabled Service-oriented Architecture (SESA).

2.1 Problem Solving Layer

The objective of the **problem-solving layer** is to turn a service-oriented architecture into a domain specific problem-solving environment. Following the "layered" approach of our vision the problem solving layer represents the transparent interface to the user(s), where we assume that all computing resources are turned into or expressed as services. In order to provide solutions for distinct business problems – from an Information Systems point of view – the problem solving layer has to support the entire e-commerce framework – information, negotiation and settlement phases [9]. The objective is efficient and effective "resource allocation" for an enterprise or a set of cooperating enterprises.

It has to support transactions, with different negotiation and contracting possibilities. In this sense it also implements a domain specific economic model, where services would be accompanied by specific functional and non-functional "parameters". The architecture should support the implementation and operation of so-called smart business networks, on the level of flexible e-business cooperation. The described flexibility (meeting the changing needs of a business / set of businesses) can be achieved by providing a clear separation between the business / process logic and the Web Services used.

The approach should support the modeling and implementation of a (collaborative) business model. In addition, since no network of businesses operates in an open environment, the vision needs to enable trust domains in which all services are defined in terms of their trust levels and capabilities. This must be based not only on functional requirements but also on non-functional requirements covering business and trust aspects (covering issues such a price of a service, type of payment, performance, reliability; or also security levels, authorization, and past history).

2.2 Common Service Layer

As computer science moves to the next period of abstraction, the practice of developing software applications evolves to the modeling of semantically annotated services that can be composed, i.e., can co-operate, to achieve specific tasks. This leads to a flexible, decoupled world of independent services that can be dynamically discovered, combined, and invoked. The *common services layer (CSL)* provides an adaptive execution environment and supporting infrastructure that maps the problem descriptions generated at the Problem Solving Layer to the services that can solve the problems.

The Execution Environment at the heart of the CSL requires components to map problem descriptions at the problem-solving layer to available services at the CSL. Existing architectures (e.g. Open Grid Service Architecture (OGSA) in the Grid area) already support such mappings for components and prototypical interactions, however they operate over purely syntactic descriptions, hence domain specific problem solutions must be coded manually. Besides providing the interpretation of semantic description the CSL needs also be able to execute descriptions and therefore needs to interoperate with standards defined at this lower level. The Web Service Description Language (WSDL) is used to syntactically define the interface of a component using standard web technologies to define means to invoke operations but it does not define notification mechanisms or a standard way of interacting with stateful resources. The Web Service Resource Framework (WSRF) is a standard that extends WSDL in this direction. Initiatives that define syntactic descriptions of resource are orthogonal to the semantically empowered common service layer. The CSL will make use of the former to facilitate the execution of service requests.

The core of our approach is the semantic enrichment of SOAs that implement the Common Service Layer capabilities. This enrichment helps to automate (1) service discovery, service adaptation, negotiation, service composition, service invocation, and service monitoring; as well as (2) data, protocol, and process mediation. This automation is a prerequisite for SOA scalability. To achieve this, we are developing the W<Triple> technology that combines four major building blocks.[1]

- The *Web Service Modeling Ontology (WSMO)*: a conceptual model for structuring semantic annotation of services [10],
- The *Web Service Modeling Language (WSML)*: a family of languages providing formal semantics for WSMO models [4] Werthner, H. and Ricci, F. (2004) Electronic Commerce and Tourism. *Comm. of the ACM, 47/12*.

[5] Zeithaml, V., Bitner, M. J. Services Marketing. McGraw-Hill, New York, NY, 1996.

[6] Kotler, P. Marketing Management: Analysis, Planning, Implementation and Control, 6th edition. Prentice Hall, Englewood Clis, NJ, 1988.

[7] O'Sullivan, J., Edmond, D., ter Hofstede, A. H. M. Service description: A survey of the general nature of services, report FIT-TR-2003-02. 2002.

[8] Akkermans, H., Baida, Z., Gordijn, J., Pena, N., Altuna, A., Laresgoiti, I. Value Webs: Using Ontologies to Bundle Real-World Service. IEEE Intelligent Systems 19/4, 2004.

[9] Schmid, B. Elektronische Märkte. Wirtschaftsinformatik 35/5, 465-480, 1993.

[10] Dumitru Roman, Uwe Keller, Holger Lausen, Jos de Bruijn, Rubén Lara, Michael Stollberg, Axel Polleres, Cristina Feier, Christoph Bussler, and Dieter Fensel: Web Service Modeling Ontology , Applied Ontology, 1(1): 77 - 106, 2005.

- [11],
- The *Web Service Execution Environment (WSMX)*: an execution environment for the dynamic discovery, selection, mediation, invocation and inter-operation of the semantically described Services [4] Werthner, H. and Ricci, F. (2004) Electronic Commerce and Tourism. *Comm. of the ACM, 47/12*.

[5] Zeithaml, V., Bitner, M. J. Services Marketing. McGraw-Hill, New York, NY, 1996.

[6] Kotler, P. Marketing Management: Analysis, Planning, Implementation and Control, 6th edition. Prentice Hall, Englewood Clis, NJ, 1988.

[7] O'Sullivan, J., Edmond, D., ter Hofstede, A. H. M. Service description: A survey of the general nature of services, report FIT-TR-2003-02. 2002.

[8] Akkermans, H., Baida, Z., Gordijn, J., Pena, N., Altuna, A., Laresgoiti, I. Value Webs:

[1] This work is being conducted in DERI International, which includes institutes in Galway, Innsbruck, Seoul, and Stanford, and in cooperation with large project consortia (e.g. ASG, dip, Knowledge Web, and SEKT) that include many other university groups, small and medium sized companies, government organizations, and large companies such as British Telecom, HP, IBM, and SAP AG.

Using Ontologies to Bundle Real-World Service. IEEE Intelligent Systems 19/4, 2004.

[9] Schmid, B. Elektronische Märkte. Wirtschaftsinformatik 35/5, 465-480, 1993.

[10] Dumitru Roman, Uwe Keller, Holger Lausen, Jos de Bruijn, Rubén Lara, Michael Stollberg, Axel Polleres, Cristina Feier, Christoph Bussler, and Dieter Fensel: Web Service Modeling Ontology , Applied Ontology, 1(1): 77 - 106, 2005.

[11] Jos de Bruijn, editor. The Web Service Modeling Language WSML. 2005. WSMO Deliverable D16, WSMO Final Draft v0.2, 2005, http://www.wsmo.org/TR/d16/d16.1/v0.2/.

- [12], and
- Triple Space: [13] and [3] Werthner, H. Intelligent Systems in Travel and Tourism. In Proceedings of International Joint Conference on Artificial Intelligence (IJCAI 2003), Acapulco, Mexico, 2003.
- : a protocol for the communication of services based on persistent publication of information following the web paradigm.

2.3 Resource Layer

Resources are used to solve problems or more conventionally to execute applications. The resource layer [13] D. Fensel: Triple-space computing: Semantic Web Services based on persistent publication of information. In *Proceedings of the IFIP International Conference. on Intelligence in Communication Systems November 2004*, Bangkok, Thailand, Lecture Notes in Computer Science (LNCS), Springer-Verlag, Berlin, 2004.

[14] C. Bussler: A Minimal Triple Space Computing Architecture. In *Proceedings of the 2nd WSMO Implementation Workshop*, Innsbruck, Austria, June 2005.

[15] deals with resource discovery, selection and negotiation for advanced or “on-the-fly” consumption of resources. The resource layer also covers the deployment and provisioning of physical and logical resources. Resources in the context of an SOA can be subdivided into multiple classes covering, among others, both physical and logical resources. *Physical resources* (e.g. computers, data servers, and networks), which are commonly connected to form a grid of computing and storage platforms; at this level automatic resource management will be facilitated from the perspective of both resource provisioning as well as its lifecycle management. *Logical resources*, such as application components or common services, enabling

more advanced composition of applications.

Two of the most prominent and widely discussed areas that deal with distributed resources in the context of Service-Oriented Computing are Ubiquitous Computing and Grid Computing. They can be seen as two endpoints in a continuum where their characteristics are somewhat complementary. Grids rely on a relatively large number of hardware devices ranging from small computers to very powerful devices interconnected with mostly conventional networks (Internet). Ubiquitous Computing environments, on the other hand, are suffering from weak and unreliable connections (due to partial autonomy) in very dynamic constellations of a high number of mobile devices with limited memory and processing power.

We assume that using the three layers presented as the conceptual model for SBNs and representing aspects of actual SBN elements using formal semantics (e.g. in WSML) will dramatically increase the degree of automation in the lifecycle of value chains. This is in particular since a library of problem solving methods can then be automatically matched against actual tasks in the SBN environment. For instance, known conflicts between two data representations or process choreographies can be bridged using a reusable mediation component for this particular task. Also, even if resolving all conflicts in a given scenario cannot be fully automated, it will be still beneficial to deduce conflicts by machine reasoning.

3 Preliminary Evaluation of SESA-based Smart Business Networks

In this section, we show how our approach – using all three layers – could reduce the complexity of the aforementioned core network management tasks by lifting them to a higher level of abstraction.

3.1 Partner Selection

Partner selection, often also referred to as “Matchmaking” [cf. e.g., 16] or “Discovery” with blurry borders between these terms, involves all task of finding, ranking, and selecting suitable business partners for a given task. This process is extremely complex in real-world business scenarios, for several reasons. Firstly, most available resources are not described using a common conceptual framework, and in particular not described using a single ontology. This makes it hard to impossible to include all suitable matches; in other words, precision and recall remain unsatisfying due to the inability to include implicit knowledge about available resources. A typical example is that *“This service provides data mediation between X12 and proprietary formats”* may mean at least two different things: It can mean that the service can mediate between any X12 variant to any from a finite, consensual set of formats. It may also mean that the service can only mediate between some of them. Also, resource description on such low levels of expressivity often completely ignores actual availability of resources. However, it is a triviality that e.g. the actual pricing will be substantially affected by the amount of available resources.

Secondly, the utility (in the economical sense) of a resource is usually affected by multiple characteristics of a service, and there is a multi-dimensional trade-off between various properties. Thus, the strict separation of discovery into coarse search (“discovery”) and negotiation is flawed in many practical scenarios. The description of resources at a semantic level using ontology languages allows the use of machine reasoning and the use of implicit information in the process of partner selection. The description of services on the Common Service Layer and the Problem Solving Layer allows the reuse of existing functionality in the process of partner selection and will thus expand the search space.

3.2 Contracting

The actual contracting about a service is currently subject to the prior establishment of a framework contract. E.g., a travel service provider may enter into an agreement with either a network of travel resource providers or individual providers, and may then trigger contracting on an instance basis automatically. This works well as long as the amount of transactions per framework contract is high. However, as soon as the number of potential partners increases and the number of transactions per each business partner decreases, the overhead caused by establishing framework contracts prior to contracting individual business transactions may become prohibitively high. The representation of pre-conditions in a SESA architecture and business policies using rule languages will allow for making the contractual dimension accessible to machine reasoning. Even if framework contracts did not become obsolete, their establishment would consume less resources and cause less delay. In a SESA environment, legal ontologies could also be imported that allow matching the bilateral agreements to the general legal environment.

3.3 Technical Integration

The SESA idea includes, as a core design element, mediation [17]. Mediation means computational functionality that can bridge heterogeneities between systems, e.g. data representation mismatches or process incompatibilities. The layered approach of SESA allows for establishing a library of mediation components for various purposes, thus lowering the amount of proprietary software engineering in systems integration. Since the capabilities of mediators in a SESA framework are again described using machine-processable semantics, the discovery of needed mediation components can also be supported by machine reasoning.

3.4 Process Composition

At a business level, process composition is often regarding as the mere ordering of activities by causal or temporal dependencies. However, at a higher level of abstraction, it becomes obvious that process compositions created this way may be inconsistent, since they may violate constraints in the form of pre- or post-conditions. The SESA approach includes expressive formalisms for encoding the pre- and post-conditions of any service. This allows for validating such complex processes that were composed manually, and it will also support the development of tools for the semi-automatic composition of processes. Note that the SESA idea separates the representation from the automation of a task in the lifecycle. Even if fully-automated process composition is computationally too expensive, SESA still allows capturing all relevant aspects of the system. In other words, the SESA conceptual model is guided by the idea of providing a comprehensive capture of all relevant aspects, not by the question whether the respective representation can be used in a fully automated manner.

4 Discussion and Conclusion

The proposed SESA framework represents a vision in Computer Science, which itself is on the edge towards an important new period of abstraction. A generation ago computer science learned to abstract from hardware and currently learns to abstract from software in terms of service-oriented architectures (SOA). SESA brings now machine processable semantics to SOAs in order to leverage its full potential. In the long term, the objective is to provide a new operating system – supporting SBNs – that provides a smooth and transparent integration of millions of resources and services on a world wide scale.

In this paper, we argue that current SBNs – falling short in terms of the agility of value chain composition since they lack a comprehensive conceptual framework – may benefit from such an approach. We trace back the complexity of partner selection, process composition, and execution monitoring to the lack of semantics in the description of system elements in SBN environments. As a consequence, we propose to adopt the layered conceptual model of semantically-enabled service-oriented architectures (SESA) as the foundational layer for future Smart Business Networks. And we discuss how our approach may reduce the complexity of the aforementioned core network management tasks by lifting them to a higher level of abstraction.

Acknowledgements: The work presented in this paper was partly funded by the European Commission under the projects DIP (FP6-507483), Harmonise (IST–2000-29329), Harmo-Ten(eTen C510828), SUPER (FP6-026850), and MUSING (FP6-027097), by Science Foundation Ireland under the DERI-Lion Grant No.SFI/02/CE1/I13, and by the Trans IT Entwicklungs- und Transfercenter at the University of Innsbruck.

References

[1] Vervest, P., van Heck, E., Preiss, K., Pau, L. (eds) Smart Business Networking. Springer Verlag, 2005.

[2] Brodie, M., Bussler, C., de Brujin, J., Fahringer, T., Fensel, D., Hepp, M., Lausen, H., Roman, D., Strang, T., Werthner, H., Zaremba, M. (2005) Semantically Enabled Service-Oriented Architectures: A Manifesto and a Paradigm Shift in Computer Science. DERI-TR-2005-12-25, Dec. 2005.

[3] Werthner, H. Intelligent Systems in Travel and Tourism. In Proceedings of International Joint Conference on Artificial Intelligence (IJCAI 2003), Acapulco, Mexico, 2003.

[4] Werthner, H. and Ricci, F. (2004) Electronic Commerce and Tourism. *Comm. of the ACM, 47/12*.

[5] Zeithaml, V., Bitner, M. J. Services Marketing. McGraw-Hill, New York, NY, 1996.

[6] Kotler, P. Marketing Management: Analysis, Planning, Implementation and Control, 6th edition. Prentice Hall, Englewood Clis, NJ, 1988.

[7] O’Sullivan, J., Edmond, D., ter Hofstede, A. H. M. Service description: A survey of the general nature of services, report FIT-TR-2003-02. 2002.

[8] Akkermans, H., Baida, Z., Gordijn, J., Pena, N., Altuna, A., Laresgoiti, I. Value Webs: Using Ontologies to Bundle Real-World Service. IEEE Intelligent Systems 19/4, 2004.

[9] Schmid, B. Elektronische Märkte. Wirtschaftsinformatik 35/5, 465-480, 1993.

[10] Dumitru Roman, Uwe Keller, Holger Lausen, Jos de Bruijn, Rubén Lara, Michael Stollberg, Axel Polleres, Cristina Feier, Christoph Bussler, and Dieter Fensel: Web Service Modeling Ontology , Applied Ontology, 1(1): 77 - 106, 2005.

[11] Jos de Bruijn, editor. The Web Service Modeling Language WSML. 2005. WSMO Deliverable D16, WSMO Final Draft v0.2, 2005, http://www.wsmo.org/TR/d16/d16.1/v0.2/.

[12] Emilia Cimpian, Tomas Vitvar, Michal Zaremba (editors): Overview and Scope of WSMX. WSMX Deliverable D13.0, WSMX Final Draft v0.2, 2005, http://www.wsmo.org/TR/d13/d13.0/v0.2/.

[13] D. Fensel: Triple-space computing: Semantic Web Services based on persistent publication of information. In *Proceedings of the IFIP International Conference. on Intelligence in Communication Systems November 2004*, Bangkok, Thailand, Lecture Notes in Computer Science (LNCS), Springer-Verlag, Berlin, 2004.

[14] C. Bussler: A Minimal Triple Space Computing Architecture. In *Proceedings of the 2nd WSMO Implementation Workshop*, Innsbruck, Austria, June 2005.

[15] T. Fahringer, R. Prodan, R. Duan, F. Nerieri, S. Podlipnig, J. Qin, M. Siddiqui, H.-L. Truong, A. Villazon, and M. Wieczorek: ASKALON A Grid Application Development and Computing Environment. In *Proceedings of the 6th ACM/IEEE International Workshop on Grid Computing (Grid 2005)*, Seattle, November. 2005.

[16] Y. Hoffner and S. Field: Transforming Agreements into Contracts. International Journal of Cooperative Information Systems, vol. 14, 217-244, 2005.

[17] Fodor, O. and Werthner, H. (2005) Harmonise – a Step towards an Interoperable e-Tourism Marketplace. International Journal of Electronic Commerce, 9/2.

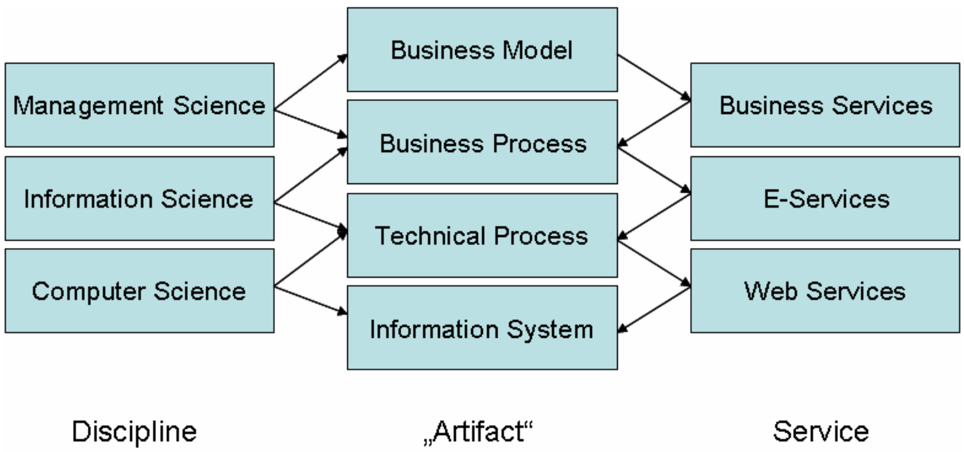

Figure 3. Three Layers of Semantically-enabled Service-oriented Architecture (SESA).

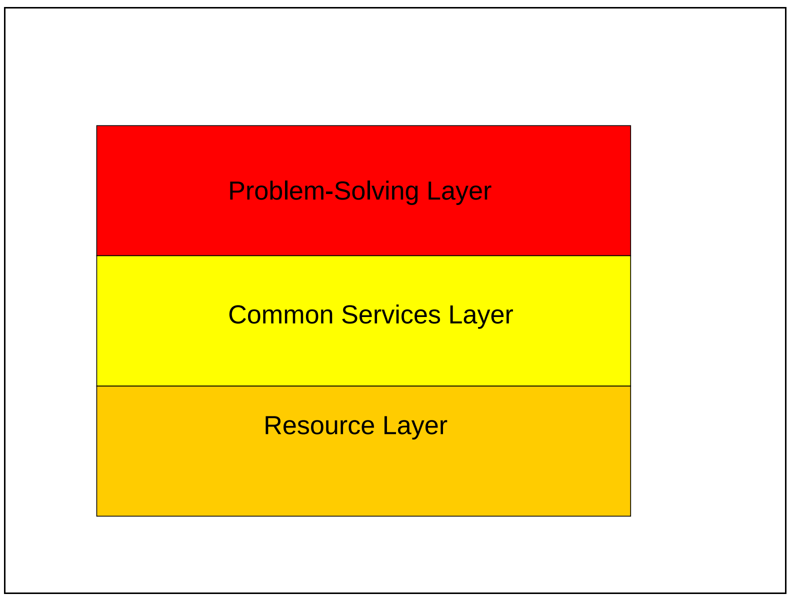

Figure 4. Three Layers of Semantically-enabled Service-oriented Architecture (SESA).