# Chapter 9

# Full Interoperability: Challenges and Opportunities for Future Information Systems

Rita Suzana P. Maciel, José Maria N. David, Daniela Barreiro Claro, Regina Braga

**Abstract**

*This chapter describes full interoperability concept for Information Systems. Some important issues to achieve full interoperability are discussed to better understand the main differences among other levels of interoperability. Although we concentrate on discussing interoperability in three major contexts: cloud computing, the Internet of Things (IoT), and Software Ecosystems, full interoperability is an important non-functional requirement for several other domains. Finally, we discuss some ideas and present our future directions for the full interoperability approach.*

## 9.1. Introduction

Information Systems (IS) are becoming increasingly complex, and this complexity relates mainly to the number of elements comprising the systems, including the amount and diversity of interactions that usually occur, either statically or dynamically, between these elements. IS not only provides business support to a single company, but it also meets the goals of geographically dispersed organizations. Several IS models can be viewed in the current globalized world, for example, an information system that interacts with the Internet of Things (IoT) [IEEE 2015] devices, as a part of an ecosystem platform [Jansen and Cusumano 2012] or sharing published cloud services.

Interoperability is considered as the ability of heterogeneous applications and data sharing procedures to communicate despite being on different pieces of equipment and platforms. Interoperability is usually described as having five main levels: syntactic, semantic, pragmatic, dynamic and organizational (or conceptual) [Asuncion, 2010]. Pragmatic interoperability extends aspects not covered by the syntactic and semantic. It is related to the ability of systems that collaborate to capture the desires of collaboration among those who request and send the results. While several studies have attempted to solve syntactic, semantic and pragmatic interoperability issues, few aim to tackle complex levels, such as the pragmatic, the dynamic, and the organizational. Supporting all interoperability levels for specific domain application can be considered as Full Interoperability support. In a dynamic level, systems are able to understand the changes that occur in both the constraints and the business rules, for example, and treat them properly. In addition, the involved parties expect that the effects caused by the message exchanges are those previously defined. In the organizational level, all previously described treatments are supposed to have been carried out, i.e. assumptions, constraints, and business rules are aligned [Tolk and Muguira 2003].

Considering the needs of interoperating IS, investigating full interoperability support across these systems is a challenge. Specifically, in this new IS usage scenario, we consider interoperability as a major challenge for research in the context of IoT, Software Ecosystem and Cloud Computing. IoT presents interoperability challenges, especially those regarding communication among IS and physical devices whereas cloud computing presents a scenario in which IS must deal with different and heterogeneous platforms. While IoT and cloud computing may host IS from distinct domains (e.g. finance, health, insurance, etc.)

A software ecosystem can be considered as a set of actors who collaborate and interact with a common market by focusing on software and services, along with the relationships between these actors. These relationships are often underpinned by a common technological platform which operates through the exchange of information, resources, and artifacts [Jansen et al. 2009]. In a software ecosystem, in addition to the support of the systems platform, there is a need to consider relationships and interactions between IS providers, organizations that use these systems, research institutes, funding organizations and other stakeholders who are interested in the research results, among other elements. Handling interoperability properly is a key issue in this scenario because different IS will have different requirements for interoperability support. Ecosystems offer a scenario of interoperating different IS however, with similar objectives or properties such as business process, and business rules. Nevertheless, future work must be carried out to explore interoperability issues in other areas, such as systems of systems, smart cities, among others.

This chapter is organized as follows. Section 9.2 presents the state of the art on interoperability, describing work underway on interoperability issues. Some challenges and opportunities on Full Interoperability are described in Section 9.3. Section 9.4 presents Interoperability concerning Cloud environments and its relationship with IS. Section 9.5 describes Ecosystems and Section 9.6 presents IoT both dealing with IS and finally Section 9.7 presents our conclusions.

## 9.2. State-of-the-Art on Interoperability

Interoperability can be defined as the capacity of heterogeneous and distinct applications to share procedures and data on distinct platforms. It is related to application collaboration regardless of the technologies used (methods, programming languages and, environments) [Bernstein 1996]. In the context of information systems, information exchange and interaction between users frequently occurs across heterogeneous environments. Interoperability is therefore a key requirement to support activities in heterogeneous environments efficiently and effectively. Different interoperability types may be necessary for communication between distributed and heterogeneous applications, for example, (i) syntactic (or technical), (ii) semantic (iii) pragmatic and (iv) organizational [Tolk, Diallo, Turnitsa 2007]. These different types of interoperability are usually related in hierarchy levels where syntactic is the most basic and organizational is the highest.

Syntax deals with the abstract study of signs and their formal relationship to each another without regard to their meaning and use. Syntactic interoperability is associated with the formatting of messages to exchange among different applications that collaborate to accomplish an activity. Syntactic interoperability is concerned with ensuring that data from the exchanged messages are in compatible formats. The message sender encodes data in a message using syntactic rules, specified in some grammar. The message receiver decodes the received message using syntactic rules defined in the same or some other grammar. Syntactic interoperability problems arise when the sender's encoding rules are incompatible with the receiver's decoding rules, which leads to (the construction of) mismatching message parse trees. Web Services standards address syntactic interoperability by providing XML-based standards.

Semantic interoperability concerns the capacity of distinct entities (transmitter and receiver) to comprehend message content meaning. Some problems arise when the message sender and receiver have a different conceptualization or use a different representation of the entity types, properties, and values from their subject domains. Some examples of these semantic differences include: (i) *nomenclature* where there are synonymous and antonyms between data, (ii) *scales and units* when different scales are used to quantify or to evaluate same data, (iii) *divergence of similar concepts*, but of different definitions are exchanged, (iv) *domain* when it involves culture differences and specific knowledge about the domain, and (v) *integrity* when there is disparity between the data integrity of the applications. It is worth noting that to provide semantic interoperability the exchanged information should ensure the same meaning for both the message sender and receiver. Data in both messages have meaning only when interpreted regarding respective subject domain models. However, the message sender does not always know the subject domain model of the message receiver. Depending on their knowledge, the message sender makes assumptions about the subject domain model of the receiver and uses them to construct a message.

Pragmatic interoperability ensures that the message sender and receiver share the same expectation about the effect of the exchanged messages. When a system receives messages, it changes its state, sends a message back to the environment, or both [Asuncion 2010]. In most cases, messages sent to the system change or request the system state, and messages sent from the system change or request the state of the environment. That is, messages are always sent with the intention of achieving some desired effect. In most cases, the effect is realized not only by a single message but also by various messages sent in some order. Pragmatic interoperability problems arise when the intended effect differs from the actual effect. Therefore, this interoperability type is usually associated with the context in which the information is transmitted.

However, we observe that the definition of pragmatic interoperability remains largely unsettled. Unlike syntactic and semantic interoperability definitions, some variations in the definition of pragmatic interoperability are currently used, and there seems to be a lack of canonical understanding.

Other definitions of interoperability can be found in the literature. For example, the definitions are usually grouped into two categories: system and business levels. By system level, we mean that the interaction is mostly between applications through the exchange of messages. By business level, we mean that the collaboration is mostly between organizations, business units, business processes, or even human actors [Legner and Wende 2006].

In this document, we named Organizational Interoperability what some authors call pragmatic interoperability at the business level. Only organizational interoperability deals with compatibility between the business requirements of collaborating parties expressed through their business intentions, business rules, and organizational policies. Collaborating parties should also have a shared understanding of the services they offer and the context in which these services are to be used. Beyond these, they should also establish beforehand and maintain during collaboration trust and reputation-related issues. Some even argue that pragmatic interoperability cannot exist if the willingness of the collaborating parties is not established at the outset [Asuncion 2010]. For smart cities, SOS ubiquitous and autonomous computing, Organizational Interoperability is a desired requirement.

Full Interoperability could be initially defined when a piece of software achieves all desired interoperability levels from the most basic to the highest. Full interoperability means the interoperability support required by a system, a system of system and platforms such as Cloud or IoT. Some scenarios will require syntactic and semantic interoperability, meanwhile others pragmatic and organizational ones. It is the developer's responsibility to define the levels of interoperability requirements to be fulfilled.

The absence of adequate support for full interoperability is a problem for system developers and users as there is a need to use a single environment or the non-automated treatment when distinct tools are adopted. Aspects related to a specific interoperability level are usually implicitly treated in their own application, generating tightly coupled systems hampering application evolution, for example.

### 9.2.1. Proposals for Interoperability

Interoperability has been a subject of interest in many research works. Semantic interoperability solutions are usually addressed by using ontologies and thesaurus. Pragmatic interoperability is still in its early stages, and the actual solutions are based on discovery, selection and composition of interoperable services in a specific domain and implemented at design time [Neiva et al. 2016], [Tamani and Evripidou 2006]. These solutions are based on human judgment of interoperable pragmatic services, so after human intervention, interoperable pragmatic services can be automatically selected. Currently, with dynamic problems, these solutions are not always feasible, context changes occur at runtime and a pragmatic approach between services implemented at design time does not promote effective collaboration of them.

Information Systems infrastructures are becoming more geographically distributed. This has brought new challenges and increased the need to address interoperability requirements in general. Tamani and Evripidou (2006) propose a method based on search services and user context; however, they do not advance on interoperability issues.

According to Liu et al. (2014), a large number of heterogeneous data sources and their technical factors make interoperability solutions complex. A framework is proposed to assist these complex solutions, but the authors do not explore higher levels of interoperability. Neiva et al. (2016) discuss the pragmatic interoperability solutions in Collaborative Systems domain and in general concluded that there is still a need to conduct further research to support this level of interoperability. Given these results, and what was presented earlier, it is difficult to find straightforward solutions to interoperability.

## 9.3. Full Interoperable Information Systems: Challenges and Opportunities

The adoption of standards has been used to address aspects of the different levels of interoperability. At the syntactic level patterns have been proposed by organizations (e.g. IEEE, OMG) to ensure the evolution of their systems. At the upper levels (semantic and pragmatic), solutions have been investigated considering specific domains. The evolution of solutions and the integration between the different levels are key issues to the establishment of full interoperability. Setting standards is necessary, but recent research has shown that upper interoperability levels require solutions that go beyond the technical aspects. While some areas opt for open standards, not proprietary, others have adopted specific solutions often based on proprietary standards.

In general, the advance in technology has led to IoT being a paradigm with challenges and opportunities. In the IoT world, multiple devices interact with multiple environments in people's daily lives expanding the possibilities of solutions that can improve their quality of life. Smart devices collect data on the network, process information, make decisions and act considering the interactions carried out. However, the connections between different geographically dispersed devices require advances in research not only regarding the support for different types of interoperability, but also on specific aspects of each domain in the world of things.

Considering the huge use of cloud applications and solutions, interoperability in Cloud Computing might enable solutions or data to move from one provider (public or private) to another cloud. One of the greatest challenges in cloud computing is "lock-in", that is, when consumers of a cloud become dependent on provider services (data or applications) and cannot change or migrate to different providers (horizontal heterogeneity), or in the same cloud (vertical heterogeneity). Establishing interoperability standards[1] has been a feature of certain proposals. The absence of broader support in interoperability can result in the following: (i) restricting the movement of organizations in relation to facilities that cloud computing can offer (ii) reduction in size of the markets of the organizations that develop and use information systems (iii) isolation of organizations in relation to technological advances.

Interoperability in Software Ecosystem (ECOS) is related to the ability of different Information Systems to connect and share services dynamically. The relationships of these systems occur to generate aggregated value for ECOS, which require the opening of its borders where third-party applications can connect and benefit from ecosystem services, creating value for the parties involved. In this scenario, it is crucial that Information Systems and their services are interoperable. Therefore, supporting full interoperability is a key issue.

## 9.4. Cloud Computing and Information Systems

Enterprise Information Systems users have begun to use a large number of heterogeneous applications to support their business rules. Currently, it is common to find a single company using hundreds of applications designed from different technologies, and running them on different operating systems and databases [Pokraev 2009].

Cloud computing is a paradigm in Information Systems field where computing resources such as hardware, software, development environment and other infrastructure are provided to users as services over the Internet [Shawish and Salama 2014]. The advantages of this paradigm are on-demand self-service, broad network access, resource pooling, rapid elasticity and measured service [NIST 2011].

The National Institute of Standards and US Technology (NIST) classifies cloud computing in three service level models and three deployment models. The three service level models are Software as a Service (SaaS), Platform as a Service (PaaS) and Infrastructure as a Service (IaaS). SaaS involves all applications needed to access the resources of the cloud, PaaS corresponds to operating systems, the development environment such as programming languages and libraries, and IaaS represents all the infrastructure such as servers and storage devices [NIST 2011]. These services are organized in three deployment models according to their type and access policies: private, public and hybrid cloud [Shawish and Salama 2014].

[1] http://cloud-standards.org

Despite the advantages, Zhang, Cheng and Boutaba (2010) claim that cloud computing presents a number of challenges that need to be considered, such as security, autonomy, availability, scalability and standardization. Although a standardization process for cloud providers has been widely analyzed, its actual stage of development is far from what we need for IS. An increasing number of heterogeneous cloud providers (horizontal heterogeneous) and heterogeneous services (vertical heterogeneous) have been emerging as one of the major challenges to provide interoperability support among clouds. All levels of interoperability should be addressed to facilitate exchanges of data and applications. As the device is located on the edge of a cloud, fog computing is also heterogeneous, especially in the scenarios of the IoT, thus increasing the challenge of interoperability levels support [Yi, Li and Li 2015], [Stojmenovic and Wen 2014].

## 9.5. Software Ecosystem and Information System

Business Workflow [WfMC 1999] is a widely used approach in the IS context. However, the specification of business workflows is not a trivial task. It requires specialized knowledge, often interdisciplinary understanding, and some computing skills from project managers. As a result, it creates some barriers as well as difficulties in developing and reusing workflows when designed by other managers, which often leads to rework. The concept of Software Product Line (SPL) has been used in the IS context [Clements and Northrop 2001]. SPL in information system may help managers in the workflow design. However, an IS business process goes beyond this step. Complex workflows involve interactions between users, and aspects such as the use of large amounts of data and the need for this to be supported by distributed computing resources and services. Besides, they require intense relationship support among resources and services as well as among users. Such issues can be explored in an Information System ecosystem platform.

A Business Workflow specification is a collaborative activity. It goes through a life cycle that begins with the definition of the problem followed by modeling and the execution of the workflow, and finally gets to the results. During this business workflow, information can be lost and reuse opportunities for resources and services can be wasted if the supporting platform does not consider these aspects. This is also because nowadays, business workflows encompass distributed services and users. Therefore, they need to interact across geographically distributed sites. Hence, one of the challenges is the lack of an ecosystem platform to support collaborative business workflow modeling, execution, so that users can act as a unit, can consume services from third parties, and the services must relate to complete a given task.

The specification of a Software EcoSystem (SECO) to support modeling and the execution of business workflows could be a solution to this challenge, applying SECO concepts in the Information System domain, more specifically, in order to support the collaborative development of business workflows. This platform should therefore be flexible so that it can be integrated with external business applications that usually evolve in an independent and constant way. These relationships occur to aggregate value in SECO, which requires an open source code, through which external applications can connect and benefit from its services, creating value for all.

Hence, a SECO platform to support IS must be extensible and flexible. SECO must be both a service provider and a consumer of business software services, requiring the platform to be able to carry out new services integrations without substantial changes. Finally, the platform needs to be scalable, since it supports extensibility and may result in a sudden and unexpected increase in requests for services. With the aim of helping IS users during all stages of a business workflow life cycle, also dealing with high volumes of data, SECO must provide an extensible and integrated platform, supported by a peer-to-peer network. The objective is to achieve a shared environment, which allows the simultaneous presence of IS working in the same business workflow. Furthermore, large volumes of data related to the process can be processed.

Therefore, as contributions, we address two points of view: i) the developer's point of view, where non-functional requirements are evaluated with metrics, and ii) the business workflow´s point of view as an actor using the platform, collaboratively composing workflows and using third-party applications in a real context. As specific contributions, we can mention:

- Developer´s point of view
    - Specification of a distributed repository through which interactions are stored, relevant data is persisted, enabling playback of the workflow.
    - Specification and implementation of a peer-to-peer network, integrated into the platform, enabling the sharing of large volumes of data.
- User´s point of view
    - A SECO platform to support users to carry out collaborative business workflows.
    - Support during the stages of the business workflow life cycle,
    - Sharing of workflow execution data and their assets from the Software Product Line between users and application instances, using the SECO platform, and connected by a peer-to-peer network.

One important component of a SECO platform is the Interoperability Layer. This layer can help IS user collaboration in business workflow development. It focuses on the modeling phase, referring to the moment when collaboration must be intense in order to maximize service reuse, discovery, selection and composition. Thus, we propose a layer that can enhance interoperability through service discovery, selection and composition process by considering syntactic, semantic and pragmatic services aspects. These services can indicate if two or more services/application may interoperate at a certain interoperability level or not. It is worth mentioning that all communication events that occur in SECO must be sent to the interoperability layer. However, different activities performed on the platform require the support of different interoperability types as already mentioned.

## 9.6. IoT and Information System

The Internet of Things is based on three main pillars, namely, (i) hardware, which includes objects with a unique ID through Radio-Frequency Identification tags (RFID) associated with sensors, (ii) connectivity, which is characterized by the infrastructure that is established between objects and sensors, (iii) services and software that support the intelligence issues so that IoT can operate. The semantic web is one of the technologies that can contribute to this support. Its goal is to process collected data and give meaning to them in specific contexts. In the IoT context, objects can communicate with each other establishing Machine-Machine (M2M) communication. This communication does not necessarily have to have human intervention to be effective [IEEE 2015].

In IoT, devices, such as household appliances, vehicles, cell phones are connected to the Internet. They communicate with each other with a single goal: to improve the quality of life of people. Certainly, this entails other needs and requirements that need to be properly addressed, such as: security, privacy, interoperability and integration, among others. Security and privacy emerge as key requirements because the connected objects manipulate personal and organizational information which is accessed in different application domains. Integration is a key aspect, especially when dealing with data and information associated with geographically distributed organizations. In this chapter, we are mainly interested in interoperability between IoT devices. IoT information can be stored in clouds, thus enabling the use of IoT in any places and at any time. These concepts, associated with a software ecosystem features, contribute to the creation of an IoT ecosystem. Conceptually, IoT can be understood as a set of devices using built-in sensors to gather data. These devices act on that data over a network allowing connectivity of these devices. As a result, they also generate opportunities for users (Song et al. 2010). The use of cloud computing can be integrated into the IoT through the Cloud paradigm of Things (CoT) [Aazam et al. 2015].

Supporting interoperability and establishing standards are key aspects when we talk about the IoT. Therefore, full interoperability should be investigated in depth. There are initiatives in Brazil for research into smart cities and homes, which use IoT concepts, but we still need to advance, especially with regard to supporting different levels of interoperability. Despite the fact that standards have been proposed, adequate interoperability support is necessary due to the risk of non-appliance of standards by organizations. Moreover, the devices involved may have low market acceptance hampering widespread adoption of the IoT. In this context, all devices communicate with each other in different layers. As a result, an IoT ecosystem can be compromised without the support of full interoperability. The adoption of standards is certainly needed, as well as the existence of an Internet infrastructure that supports high quality connections (low cost, high stability and reliability, among other attributes) between objects.

Some market segments in which the IoT can be used are: (i) smart cities (public security, public lighting control, disaster monitoring and traffic) (ii) smart homes (home security, control of home appliances, and control of electricity) (ii) monitoring of diseases and drugs (iii) monitoring of agriculture and farming, and (iii) monitoring and control of vehicles, among others. These are only a few segments that present both opportunities and challenges for research and innovation in Information Systems, particularly regarding interoperability support.

In general, challenges and opportunities for Software Ecosystems (SECO) research are also applied to the IoT ecosystem, such as (i) advance in the SECO monitoring area to ensure their sustainability and longevity (ii) perform knowledge management from the network of SECO actors (iii) analyze ECOS from the perspective of complex networks to enhance strategic decision making involving SI (iii) advance in the studies of the quality of products and services in SECO, considering the advance of the IoT in particular and the importance and market investment in this technology (iv) investigate the management of SECO architecture focusing on its stability, security, among others (v) investigate ways to manage the diversity of licenses (vi) investigate the governance models related to IoT actors, objects, hardware and software.

## 9.7. Discussion and Future Directions

In this work, the major challenge we consider is to study solutions to support full interoperability requirement for Information Systems, focusing on specific solutions for the IoT, Software Ecosystem and Cloud Computing contexts. In addition, we consider specific application domains such as health, e-government and banking systems, among others. In other words, the challenge is to create, evaluate, modify, write, manage and explore interoperability models related to information systems in such contexts.

The adoption of the aforementioned technologies will be evaluated through the progress of researches, such as, (i) advancing the state of the art of semantic interoperability (ii) advancing in relation to supporting pragmatic interoperability in the IS context (iii) advancing the state of the art in organizational interoperability and other levels (iv) defining and coining the term full interoperability, or synonyms, especially in the IS context (v) suggesting ways to achieve full interoperability (vi) promote the adoption of approaches by industry to adopt the various levels of interoperability.

This proposal aligns with the Grand Challenges in Research defined by SBC (2015). Supporting full interoperability issues can bring significant advances in computer science researches as it can encourage the integration of information systems, considering the software ecosystems, the IoT and Cloud Computing. Moreover, it is not restricted to a single research project, but it can be applied in projects in various fields of IS, such as health, e-government, banking systems (SBC, 2015), among others, that may belong to the IS ecosystem. Moreover, there is a growing demand for interoperable solutions for public and private organizations, involving the areas of the IoT, Software Ecosystem and Cloud Computing. Advances in researches these three areas can be broken down and obtained incrementally, as technological changes occur over time.

Considering the current scenario and the increasing demand for interoperable solutions, a multidisciplinary approach emerges as a key element, especially considering the areas of the IoT, Software Ecosystems and Cloud Computing. For example, health systems require interoperation with electronic government systems and banking systems, among others. Therefore, we believe that there is a need to step up research on interoperability, otherwise we risk paralyzing research in IS which requires full interoperability solutions.

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### Rita Suzana P. Maciel

CV: http://lattes.cnpq.br/0290950513716961

Rita Suzana Pitangueira Maciel has a Ph.D. in Computer Science from the Federal University of Pernambuco and Masters in Computer Science from the Federal University of Rio Grande do Sul. She is currently an Associate Professor at the Federal University of Bahia and is a member of the Graduate and Undergraduate Computer Sciences Programs. Her main research interests in Software Engineering area include Model Driven Development, Requirements Engineering, Service-Oriented Architecture and Collaborative Systems. Additionally, she has practiced application software engineering for ten years in industry. Site: http://homes.dcc.ufba.br/~ritasuzana/. e-mail: ritasuzana@gmail.com

### José Maria N. David

http://lattes.cnpq.br/3640497501056163

Bachelor's degree in Electrical Engineer from Military Institute of Engineering (IME-RJ). Received his Master degree (M.Sc.) and Doctoral degree (D. Sc.) at Computer and Systems Engineering from Federal University of Rio de Janeiro. Professor David is currently an associate professor at the Federal University of Juiz de Fora, working on the undergraduate Program in Computer Science and is a member of the Post Graduate Program of Computer Science. Has experience in Computer Science, focusing on Software Engineering, specifically in the following topics: CSCW, Distributed Software Development, Interoperability and Software Ecosystems. e-mail: jose.david@ufjf.edu.br

### Daniela Barreiro Claro

http://lattes.cnpq.br/9217378047217370

Daniela Barreiro Claro is an associate professor in the Computer Science Department at Federal University of Bahia (UFBA). She has a Ph.D. in Computer Science from the University of Angers, France, and Masters in Computer Science from the Federal University of Santa Catarina. She is currently a member of the Graduate and Undergraduate Computer Sciences Programs. Her main research area is Databases including Semantic Analysis in Texts, Clouds, and Devices. Specifically, she has been working on Open Information Extraction, Semantic and Pragmatic Interoperability in Cloud environments. Site: http://www.dcc.ufba.br/~dclaro/ e-mail: dclaro@ufba.br

### Regina Braga

CV: http://lattes.cnpq.br/7690593698223418

Graduated in Computer Science from Federal University de Juiz de Fora (1991). Received her master degree in Computer and Systems Engineering from Federal University of Rio de Janeiro in 1995. She is Ph.D. in Computer Science and Systems Engineering from Federal University of Rio de Janeiro (2000). Professor Braga is currently an associate professor at the Federal University of Juiz de Fora, working on the undergraduate program in Computer Science and is a permanent member of the Master Program of Computer Science. Braga has experience in computer science, with emphasis on software engineering and databases, specifically in the following topics: component based software development, ontologies, data integration and scientific workflows. e-mail: regina.braga@ufjf.rdu.br