Frameworks for Distributed Interoperability

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INTRODUCTION

Interoperability (between two or more systems) is a word formed by the juxtaposition of a prefix (*inter*) and the agglutination of two other words (*operate* and *ability*) and means *the ability* (of two or more systems) *to operate together*.

What these two last words really mean depends largely on the domain which the systems belong to, although there is a pervasive, underlying notion that these systems are active, reacting upon stimuli sent by others and cooperating to accomplish higher level goals than those achievable by each single system.

Interoperability has been studied in domains such as enterprise cooperation (Jardim-Goncalves, Agostinho, & Steiger-Garcao, 2012), e-government services (Gottschalk & Solli-Sæther, 2008), military operations (Wyatt, Griendling, & Mavris, 2012), cloud computing (Loutas, Kamateri, Bosi, & Tarabanis, 2011), healthcare applications (Weber-Jahnke, Peyton, & Topaloglou, 2012), digital libraries (El Raheb et al., 2011) and metadata (Haslhofer & Klas, 2010).

In this article, we adopt a more general perspective, exploring interoperability in the context of distributed systems, independently of what they are or which domain is the most relevant to them. *Distributed* is used here as a synonym of *lifecycle independence*, not necessarily implying geographical dispersion. In other words, two systems are distributed if one can evolve (to a new version) without having to change, to suspend or to stop the behavior or interface of the other.

The main goals are:

- To contribute to a better understanding of what distributed interoperability is and what is really involved;
- To propose an *interoperability framework*, which can be defined as a set of principles, assumptions, rules and guidelines to analyze, to structure and to classify the concepts and concerns of interoperability;
- To exploit partial interoperability through the concepts of compliance and conformance.

This article is structured as follows. The next section describes some of the most relevant existing interoperability frameworks. The following section introduces the basic concepts that establish a foundation for interoperability in distributed contexts. Next, a multidimensional interoperability framework is proposed and its advantages discussed. Finally, future research directions are hinted and conclusions drawn.

BACKGROUND

One of the first systematizations of distributed interoperability was accomplished by the Open Systems Interconnection (OSI) reference model, a standard since 1984 (ISO, 1994), which considers seven layers (Table 1). This standard deals mostly with communication issues, with the objective of sending data and reproducing it at the receiver. How those data are interpreted by the receiver and how it reacts to the data is left unspecified, encompassed by the topmost layer, Application. Since interoperability must ensure not only data exchange but also meaningful use of information (ISO/IEC/IEEE, 2010), we need to detail the Application layer.

Table 1 depicts the basic structure of several interoperability frameworks that use this layered approach, establishing a rough horizontal correspondence between layers.

The C4IF framework, proposed by Peristeras and Tarabanis (2006), is based on four layers: Connection (basic use of a channel), Communication (data formats), Consolidation (meaning through semantics) and Col-

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Table 1. Comparison between several layered interoperability frameworks (referred to by acronym or first author)

<table>
<tr><th>OSI
(1994)</th><th>C4IF
(2006)</th><th>Lewis
(2008)</th><th>Stamper
(1996)</th><th>LCIM
(2009)</th><th>EIF
(2010)</th><th>Monfelt
(2011)</th></tr>
<tr><td rowspan="6">Application</td><td rowspan="5">Collaboration</td><td rowspan="5">Organizational</td><td rowspan="3">Social world</td><td rowspan="3">Conceptual</td><td rowspan="3">Political</td><td>SWOT</td></tr>
<tr><td>Cultural</td></tr>
<tr><td>Ethical</td></tr>
<tr><td rowspan="2">Pragmatic</td><td>Legal</td><td>Legal</td></tr>
<tr><td>Dynamic</td><td rowspan="2">Organizational</td><td>Managerial</td></tr>
<tr><td>Pragmatic</td><td>Organizational</td></tr>
<tr><td rowspan="2">Consolidation</td><td rowspan="2">Semantic</td><td rowspan="2">Semantic</td><td rowspan="2">Semantic</td><td rowspan="4">Semantic (includes syntactic)</td><td>Adaptation</td></tr>
<tr><td>Application</td></tr>
<tr><td>Presentation</td><td rowspan="3">Communication</td><td rowspan="3">Syntactic</td><td rowspan="3">Syntactic</td><td rowspan="3">Syntactic</td><td>Presentation</td></tr>
<tr><td>Session</td><td>Session</td></tr>
<tr><td>Transport</td><td rowspan="4">Machine</td><td rowspan="3">Empirics</td><td rowspan="4">Technical</td><td rowspan="4">Technical</td><td>Transport</td></tr>
<tr><td>Network</td><td rowspan="3">Connection</td><td>Network</td></tr>
<tr><td>Link</td><td>Link</td></tr>
<tr><td>Physical Medium</td><td>Physical world</td><td>Physical Medium</td></tr>
</table>

laboration (through compatible processes). It simplifies the lower levels (distinguishing only connectivity and communication) and refines the application layer, distinguishing information semantics from behavior.

Lewis, Morris, Simanta and Wrage (2008) propose a similar framework, with slight differences but with basically the same structure.

Stamper (1996) applied *semiotics* (the study of signs, stemming from linguistics) to the field of information systems and proposed a semiotic ladder, a layered structure in which each layer builds on the previous one (just like a ladder) in an increasing level of abstraction and complexity. Besides the usual syntax and semantics, pragmatics was used to refer to the effect caused by the reception of a message by a receiver. Empirics refer to the lower levels using the physical world, which details are well established and become less relevant to the understanding of interoperability as a whole. The social world tackles the higher levels, in which people become more involved.

Wang, Tolk, &and Wang (2009) described the LCIM framework, which follows the semiotic ladder in essence, with the interesting addition of a dynamic layer that considers evolution along the system's lifecycle.

The European Interoperability Framework (EIF, 2010) was conceived as a broad framework for the interoperability of public services and establishes four main interoperability levels (legal, organizational, semantic and technical), with an upper political context that should ensure compatible visions and aligned priorities.

Monfelt, Pilemalm, Hallberg, and Yngström (2011) further refined the social layer of the semiotic ladder and extended the basic OSI reference model with another seven layers, to take care of higher level issues, such as risk (SWOT analysis) and "dependencies on social and organizational aspects concerning cultural, ethical and legal values and existing administrative and managerial issues" (p. 126). The organizational layer pertains to the effect a message will have (pragmatic meaning of the message) and the adaptation layer pertains to the semantics of the message, adapting the new layers to the technical layers provided by the OSI model. Although shown above the Application layer, the new ones actually refine it by considering the issues it leaves unspecified (ISO, 1994, p. 33).

Other interoperability frameworks, particularly those conceived for complex systems, such as enterprises, try to complete the scenario by considering more than one dimension of interoperability, so that aspects of a different nature can be tackled in an orthogonal way. For example, the lower layers in Table 1 have a