Interoperability Frameworks for Distributed Systems

José Carlos Martins Delgado
Universidade de Lisboa, Portugal

INTRODUCTION

A system is *distributed* with respect to another if their lifecycles are not dependent, i.e., if one can evolve (to a new version) without having to change, to suspend or to stop the behavior or interface of the other.

Different systems usually need to interact, raising the concept of *interoperability* (ISO/IEC/IEEE, 2010), which literally means the *ability* (of two or more systems) to *operate together*. An *interoperability framework* is a set of principles, assumptions, rules and guidelines to analyze, to structure and to classify the concepts and concerns of interoperability.

What these words really mean largely depends 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 (Popplewell, 2014; Rezaei, Chiew, & Lee, 2014), e-government services (Sharma & Panigrahi, 2015), military operations (Hussain, Mehmood, Haq, Alnafjan, & Alghamdi, 2014), cloud computing (Zhang, Wu, & Cheung, 2013), healthcare applications (Robkin, Weininger, Preciado, & Goldman, 2015), digital libraries (Agosti, Ferro, & Silvello, 2016) and metadata (Chen, 2015).

In this article, we adopt a more general perspective, exploring interoperability in the generic context of distributed systems, independently of what they are or which domain is the most relevant to them. The following section describes some of the most relevant existing interoperability frameworks. The section after that one 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

The Open Systems Interconnection (OSI) reference model (ISO/IEC, 1994), constitutes one of the first systematizations of distributed interoperability, considering 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. However, interoperability must ensure not only the exchange of data but also the meaningful use of information (ISO/IEC/IEEE, 2010), which means that this layer must be detailed.

Table 1 depicts the basic structure of several interoperability frameworks (referred to by acronym or first author) that use this layered approach, establishing a rough horizontal correspondence between layers.

The C4IF framework (Peristeras & Tarabanis, 2006), is based on four layers: Connection (basic use of a channel), Communication (data formats), Consolidation (meaning through semantics) and Collaboration (through compatible processes). It

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Table 1. Comparison between several layered interoperability frameworks

<table>
<tr><th>OSI
(1994)</th><th>C4IF
(2006)</th><th>Lewis
(2008)</th><th>Stamper
(2000)</th><th>LCIM
(2009)</th><th>EIF
(2010)</th><th>Monfelt
(2011)</th></tr>
<tr><td rowspan="8">Application</td><td rowspan="6">Collaboration</td><td rowspan="6">Organizational</td><td rowspan="4">Social world</td><td rowspan="4">Conceptual</td><td rowspan="3">Political</td><td>SWOT</td></tr>
<tr><td>Cultural</td></tr>
<tr><td>Ethical</td></tr>
<tr><td>Legal</td><td>Legal</td></tr>
<tr><td rowspan="2">Pragmatic</td><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="2">Syntactic</td><td rowspan="2">Syntactic</td><td rowspan="2">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>

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) proposed a similar framework, with slight differences but with basically the same structure.

Stamper, Liu, Hafkamp, and Ades (2000) 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 interaction context and 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, as well as existing administrative and managerial issues. The organizational layer pertains to the pragmatics of the message (its effects in the interaction context) and the adaptation layer pertains to the semantics of the message, adapting the new layers to the technical layers provided by the OSI model.

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