



# **Distributed Programming in Cloud Computing Platforms**

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**Information Systems and Computer Engineering**

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## Abstract

In Cloud environment, programming distributed solutions, covering interoperability between heterogeneous systems, They are essentially based on SOA or REST technology, based on HTTP, XML and JSON. The problem is that these technologies were developed in the Web context where the main objective is the integration of existing systems and not programming distributed with efficiency and performance as top concerns. How to reconcile these two views in the global environment, on cloud computing?

SOA and Web services are heavy and complex technologies. The popularity of REST is due more to its simplicity than to its mapping the paradigm of services. However, any of them is not very efficient, based on HTTP and languages text-based data description (XML and JSON). The result is that the description of Web Services (WSDL) and languages high-level programming, are inefficient and complex. The binary version of XML is no more than a compression data only for transmission effect (compressed and decompressed on the issue at the reception). A solution used in this work uses binary data format natively, does not require schema and the runtime environment uses Web Sockets, much more efficient than HTTP, while maintaining some compatibility.

Our solution developed for distributed programming in cloud computing environment to develop distributed applications, comparing this solution with the more classical solutions based on SOA and REST. The aim of this work explain this solution and its environment execution. Comparison with the corresponding solutions with technologies based on SOA (Web Services) and REST.

**Keywords:** SOA, WSDL, REST, XML, JSON, HTTP, Web Sockets



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# Chapter 1

## Introduction

Distributed applications are a necessity in most central application sectors of the modern information society, including e-commerce, e-bank, e-learn, e-health, telecommunication and transportation. This results from a huge growth of the role that the Internet plays in business, administration and our every-day activities. The fundamental problem is the programming of distributed applications with all the basic interoperability problems involving distributed platforms and heterogeneous components.

On the other way, Clouds create a new challenge for distribution. They bring new opportunities such as scalability, dynamic instantiation, location independence, application management and multi-tenancy (several users using the same application independently). However, they also create distributed platforms and that's why they need to be able to support distributed applications as easily as possible.

Taking as an example the your Android mobile phone, let's say you have an application in your phone that informs you with current weathercast of your city. That application is most probably written in Java since your phone is using Android system and gets current weathercast over Internet, so basically that application asks query to weathercast provider over Internet and gets response data then parse that data and display to you. During this request and response both your mobile phone and weathercast provider must understand each other even they don't use the same language because the provider could be working in a Cloud provider and written in C# language. This interoperability (how to interconnect different programs written in different languages, running in different platforms) issue can be solved with current integration technologies such as SOA or REST and both platforms can communicate between each other. You can get last weathercast information from your Android phone or your iPhone using same weathercast provider.

The traditional integration technologies, based on either SOA or REST, is that they use the document concept as the foundation, with a data description language as the representation format and schema sharing as the interoperability mechanism (both sides use the same schema such XML Schema). Other factors, such as a connectionless protocol (HTTP) and the lack of native support for binary data because

the solutions were also based on text (XML) and contextual information, are limiting for many applications.

As a solution to the problems mentioned above, in our solution we use binary directly, instead of text and compliance and conformance instead of sharing the same schema. The main task of this solution is to show that there can be an alternative solution to XML-based technologies, for document sharing or service invocation between two completely different systems.

The objective of dissertation is aimed to show an alternative solution to Web Services and REST. Implementing a distributed application with a client programmed in one language and a remote service programmed in possibly another language.

The main goal of this dissertation is more than just an implementation and the value of this dissertation lie in the demonstration of conclusions, with respect to Web Services and REST. Showing results that if it is a better solution for application interoperability and also if it is easier to implement. We also assess performance, with comparison current solutions.

This remainder of this dissertation is organized as follows:

- State of Art - Chapter 2 details some aspects of existing solutions for distributed systems for cloud environment, namely SOA and REST. it also details about new tools that we will use, namely Web Sockets.
- Interoperability - Chapter 3 starts describing interoperability and explaining different perspective from classical solutions to our new solution to overcome interoperability problem.
- Architecture of the solution - Chapter 4 provides some insight on how our system can be used and gives a general overview of how and why it works.
- Implementation - Chapter 5 goes more in depth on the inner workings of our system than the previous chapter and presents one implementation for our system.
- Comparison with existing technologies - Chapter 6 presents the benchmarks used to evaluate our system with current solutions and the results obtained.
- Conclusions - Chapter 7 summarizes the work described in this dissertation, the results achieved, and what are its main contributions. It also presents some possible future improvements to our proposed solution.

## Chapter 2

# State-of-the-art

### 2.1 Overview

A detailed description is provided in this section concerning the state of the art technologies existing nowadays in the market. Current Integration technologies available today are based on the SOA and REST architectural styles, with Web Services and REST on HTTP as the most used implementations. This section also gives information about tools that we will use in our solution.

### 2.2 Web Services

Web services allow you to use two different machines or two different pieces of code that talk each other. Two different applications can talk to each other over the network. They can call methods of each other over the network by using web service technology. The other advantage of using web services is actually it is a standard technology because it is not really specific to java or any other language. You can write web services all other technologies. For example you can write web service with Java, .Net, Python, C++ or others. The best part of web service standard what is called as Interoperability that is a property of a product or system, whose interfaces are completely understood, to work with other products or systems, present or future, without any restricted access or implementation[1].

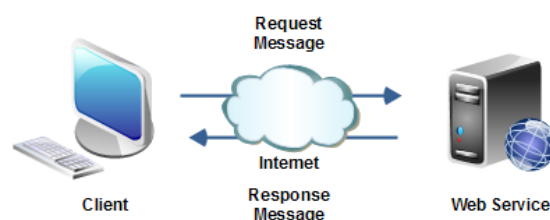


Figure 2.1: Simple Web Service Architecture.

For example let's say you have written web service in Java, let's say you have another web service that written in .Net so what the web service technology allows you to do is Java can call .Net web service and .Net web service can also call Java web service and it just doesn't have to be web service let's say you have another application written in C++, so you can actually have C++ app that call java web service or .Net web service. You can actually have different applications written in different technologies that communicate with each other during execution time and they can call each other. This actually let us do is you can actually pick and choose technologies that you want to use let's say you have set of business web services that are implemented in .Net and your java application can use them.

Web Services are exposed to the Internet for programmatic access. They are online APIs that you can call from your code. When you want to call any API that written by someone else to your java code, you basically add jar or classes to your class path and executions are done inside of machine or single environment. In the case of web services however you have different pieces of code deployed over different machines and they call methods of each other over the network. For example, you must have seen that different apps or games, which can post to your Facebook wall even these games, not designed by Facebook. So you ask that how they can do that or how they can post to a wall of completely different system or application. Basically they do this by calling online APIs. Companies like Facebook or Twitter publish web services that let other developers call them from their code, so other application developers can actually write code to consume these services and they can post things on Facebook or Twitter. They can read or access data from Facebook or Twitter using the APIs of the web services that Facebook or Twitter has provided.

Web services are similar to web pages. For example Twitter has web side URL as "www.twitter.com" when you access this URL on your browser you get an HTML response that let you read and write tweets. They have HTML elements for data and also CSS files for styling, this is because web pages that you see are made human conception. They know that there is actually human is behind of browser on a laptop or devices who was reading these tweets, so they want to make sure about its format properly, so it is easy to access and read. Twitter has also other URL as "api.twitter.com" that does a lot of same things as "www.twitter.com" does, but it behaves a bit differently for instance this API gives you response which doesn't have HTML or CSS code. It contains data but it is xml or json format and there are specific URLs for different operations this is what the developers can use from their code to read or write to twitter, so this data is actually very easy for parsing and converting then using in their objects and their code for developers. In this case there is no need HTML and CSS files.

There are primarily two different types of web services. One of these types called as Simple Object Access Protocol (SOAP) web service and another type called as REpresentational State Transfer(REST) web service. SOAP is older of these two and REST is newer entry to web services world, but both of them are used popular. Next chapter will be focusing on SOAP and REST web services.

## 2.3 SOAP Web Services

Simple Object Access Protocol, or SOAP as it was the first attempt to standardize a web service interface. It is based on sending an XML message to a service, in a specific format, and receiving an XML response in another specific format. The message can be sent across different transports, including HTTP, FTP, SMTP, and more. The specification does not dictate the transport over which the message should be sent, but most implementations send the XML message over HTTP.

I will try to explain shortly SOAP web service by an example. Let's start an example with java application. Let's say we have implementation class and I want to share this implementation class with other developer projects. How I would share this with a consumer class. The best way to share this implementation class would be to contract it with an interface and other consumers would consume this class through this interface. They would call implementation through interface so they get contract and they get the methods, arguments, written types through interface. They actually call the methods of implementation class, so how this works in case of web service, let's say I have web service implementation and I want to share details of this web service to consumers. Is it works with an interface? Probably it will not work because as we discussed before you don't know what technology is consuming it. It might be .Net application or C++ application, so if you have a java web service you might want to give some kind of information that its consumer respects to that technology and that can actually consume. Let's say consumer is .Net and if I give this .Net application a java interface then most probably it will not work because they are different technologies, so the technology that we are going to share with web service consumer has to be technology independent. It should be something that any application or any technology can understand so creators of SOAP web service talked about that problem and what to give format understandable by all technology with all consumers and decided with XML. So what we do is in case of web service, we actually share that contract as an XML document. This XML document is actually called as WSDL.

WSDL document contains the contract to web service and so that's are the things you have to do when you create the web service and you share WSDL document of that web service to the consumers, so this is not something you would have to do it manually. You would do it manually but there are tools which generate WSDL for the web service but it is something that you need to share this WSDL to consumers and it is a XML document, so it respective whatever application because applications such as .Net, C++ or Java can all parse this XML and get to know about service information and typically the content of this WSDL is kind of similar to an interface content. It has operations, arguments and types to return that consumer applications will have idea what to call and how to call.

The new question is that how this exchange happens, how you actually send this information, let's say you have a method in your java application and input argument is a string so you have a java string with you and you need to send to web service and let's say output return type is a list, so how you get

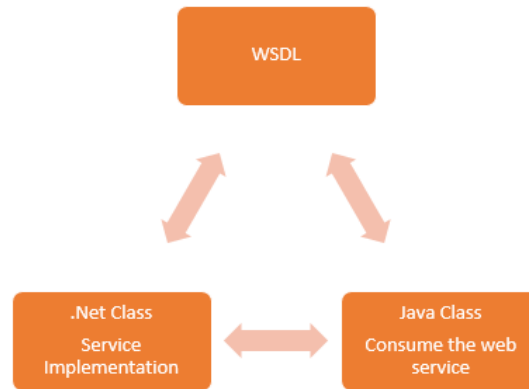


Figure 2.2: WSDL file.

this information because that could be .Net application and string in java obviously different from string in .Net. How do you exchange this between client app and web service? When you exchange information input argument or return type you need to exchange it in the format that all different technologies can understand what you are passing and it should be able to send return type back in language that all these technologies can understand. Again this format is XML. When you are sending any information across the network from a client to the web services and return type back to the client, the data has to be in XML format. You are not really sending java string or a list. So it has to be language natural format which is XML. There is specification about how you need to send all these different input type and output argument basically any type needs to be send specific XML format.

It is a protocol that is a way in which both sender and receiver and this XML is called SOAP. It is a way in which these different technologies can access objects can access data it supposedly simple so that a part of the name is called simple object access protocol. So with this protocol all different technologies written in different languages can kind of understand what they all taking about.

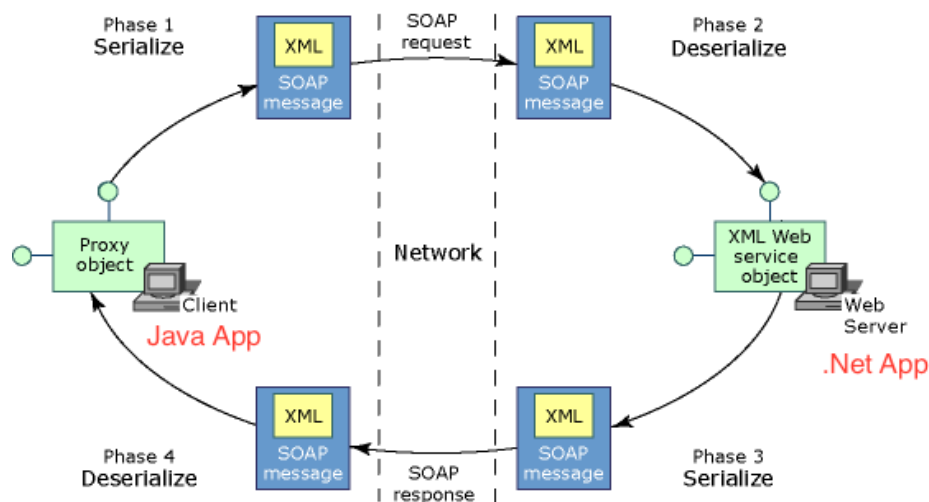


Figure 2.3: SOAP.



Now we know what is the mechanism we know what need to be send and we know how to send which is using SOAP protocol but who does conversion? So for example you have your string object or complex object, so how do you convert it from java object to a soap message? The conversion is actually done with intermedia class so this class takes care of converting all your objects into a SOAP message. The whole method calls itself is actually done by SEI(Service Endpoint Interface). The SEI access interface to your web service endpoint so you have an interface at your client app to the service endpoint which translate all web service call to a SOAP message and then it makes sure that the other things is able to understand this message. So we don't have to write this class and all the conversion ourselves. We can have it automatically generated for us. When you are making a web service call you don't worry about where the web service is. When you need to call, all you need to do is have this endpoint interface and good thing about this service endpoint that you can actually have an interface that specific to what you are developing. When you have a java application you will have a specific SEI for java application and it knows to convert java objects to SOAP message. Let's say your .Net application calling the same web service so you will have SEI for .NET that know to convert .Net objects to SOAP message.

## 2.4 REST Web Services

REST (Representational State Transfer) was created in 2000 by Roy Fielding[2]. Developed in an academic environment, this protocol embraces the philosophy of the open Web. Instead of using XML to make a request, REST relies on a simple URL in many cases. In some situations you must provide additional information in special ways, but most Web services using REST rely exclusively on obtaining the needed information using the URL approach. REST can use four different HTTP 1.1 verbs (GET, POST, PUT, and DELETE) to perform tasks.

Resources are the fundamental building blocks of web-based systems. A resource is anything we expose to the Web, from a document or video clip to a business processor device. A URI uniquely identifies a web resource, and at the same time makes it addressable, or capable of being manipulated using an application protocol such as HTTP. The relationship between URIs and resources is many-to-one. A URI identifies only one resource, but a resource can have more than one URI. That is, a resource can be identified in more than one way, much as humans can have multiple email addresses or telephone numbers. This fits with our need to identify real-world resources in more than one way. Everything in REST web services has URI is unique and standard. for example Facebook, when you open an account on Facebook, you will get a profile page that obviously dynamically generated pages, so whenever there is a new profile, it basically the same page which does same processing but render different content depending on profile that you are watching. In REST web services we need to think of resources and create unique urls for them. For example you are creating weathercast application and you want to get weather for different cities of Portugal, so your URI needs to be unique for each city as examples below.

- <http://weatherapp.com/city/Lisbon> (Unique URI for Lisbon city)
- <http://weatherapp.com/city/Porto> (Unique URI for Porto city)
- <http://weatherapp.com/city/Algarve> (Unique URI for Algarve city)

In REST web services, with same unique URI we can do different actions, for example if you are administrator of weathercast application and you want to get data of Lisbon or if you want to update data of Lisbon or deleting data of Lisbon you can use the same unique url for all these methods using HTTP methods. Only a single concrete URI, a single URI template, and four HTTP verbs. In fact, it's so compact that we can provide an overview in just a few lines, as shown in Table 2.1.

Verb	URI or template	Use
POST	/city	Create a new city
GET	/city/cityName	Request the data of city specified by the URI.
PUT	/city/cityName	Update an city data at the given URI with new information.
DELETE	/city/cityName	Logically remove the city identified by the given URI.

Table 2.1: HTTP Methods.

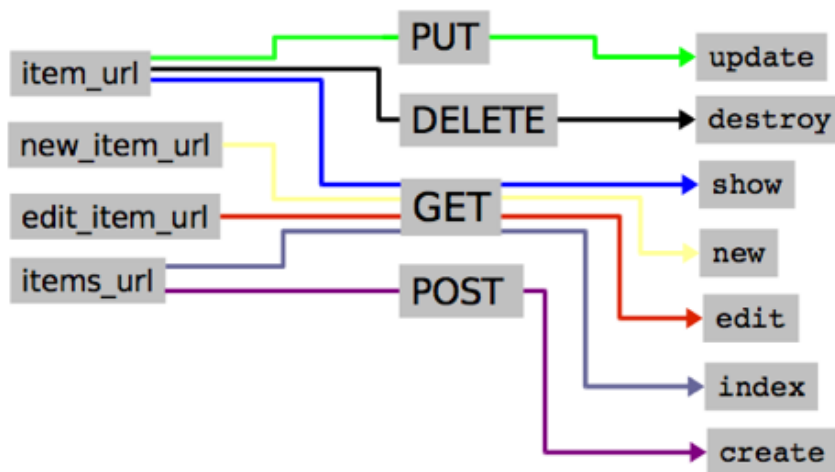


Figure 2.4: REST.

We've looked at requests so far, and understood what resource URIs and HTTP methods. We make request to resource URIs with using HTTP methods. Let's switch to responses now. After making request, RESTful web service will be responded. It is important format of response because client needs to write code to handle that response. if that were a web application, the response would be html page with styling formatting. When it comes RESTful Web service you don't need all this styling because it can be basically XML or Json.

Json is much more populer than XML because it is more compact especially you have large amount of data and also when client is browser which is pice of javascript code running on browser so sending respinse data in json

## 2.5 Web Sockets

WebSockets[3] are a relatively new technology which promises to make websites more reactive by allowing lower latency interaction between users and the server.

WebSocket is a protocol which allows for communication between the client and the server/endpoint using a single TCP connection. It sounds a bit like http. The advantage WebSocket has over HTTP is that the protocol is full-duplex (allows for simultaneous two-way communication) and its header is much smaller than that of a HTTP header, allowing for more efficient communication even over small packets of data.

Web Sockets are also fundamental in the efficient support for binary data and increases performance.

Example of WebSocket life cycle: 1. Client sends the Server a handshake request in the form of a HTTP upgrade header with data about the WebSocket it's attempting to connect to. 2. The Server responds to the request with another HTTP header, this is the last time a HTTP header gets used in the WebSocket connection. If the handshake was successful, the server sends a HTTP header telling the client it's switching to the WebSocket protocol. 3. When connection is opened and the client and server can send any number of messages to each other until the connection is closed. These messages have very low bytes of overhead.



## Chapter 3

# Interoperability

### 3.1 Overview

Resources need to interact to accomplish collaboration, either designed or emergent. This necessarily entails some form of mutual knowledge and understanding, but this creates dependencies on other resources that may hamper resource evolution and that's why Interoperability, a necessary condition to achieve integration between different systems. Another important factor for integration between systems is decoupling which says that resources need to be independent to evolve freely and dynamically. Unfortunately, independent resources do not understand each other and are not able to interact. Therefore, the fundamental problem of resource integration is to provide the maximum decoupling possible while ensuring the minimum interoperability requirements.

### 3.2 Interoperability in SOA and REST

Currently, enterprise integration is based on SOA and/or REST; the two most used architectural styles for distributed interoperability. These styles use symmetric arrangement in which a sender produces a message according to some schema and the receiver uses the same schema to validate and to get the contents of the message. The message is sent over a channel between sender and receiver. In SOA web services, schema is usual in XML Schema and WSDL. In the REST world, schemas are known as media types but perform the same role. The difference is that, instead of being declared in a separate document referenced by messages, they need to be previously known to the interaction resources, either by being standard or by having been previously agreed. In any case, the schema or media type must be the same at both sender and receiver and therefore imposes coupling between the resources for all its possible values, even if only a few are actually used. In either case, data types need to be fully known by both interacting resources.

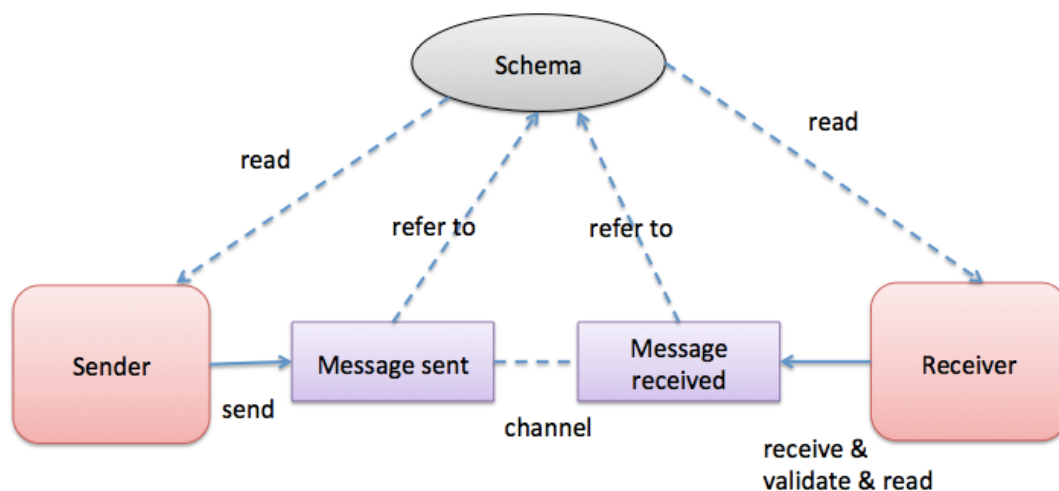


Figure 3.1: Interoperability in SOA and REST.

### 3.3 Asymmetric interoperability

In our solution, we show how interaction is still possible with only a partial knowledge of types, as long as the characteristics actually used are included (partial interoperability). This is a way of getting closer to solving the fundamental integration problem, by reducing coupling to what is actually required.

Coupling is thus a necessary bad, without which no interaction is possible. Our goal is to minimize it as much as possible, down to the minimum level that ensures the level of interaction required by the resources to integrate.

In this solution we will show different approach, based on compliance. Messages do not obey some external schema. Each message has one specific value which are structured or primitive with its own exclusive schema that is nothing more than a self-description, without the value variability that a type exhibits. This value and its description can be validated against an infinite number of schemas, those that have this particular value included in the set of their instances.

The receiver in Figure 3.2 exposes a schema that defines the values it is willing to accept. When a message is received, its internal schema is checked against the receiver's own schema. If it complies which means satisfies all the requirements of the receiver's schema, the message can be accepted and processed. The advantage of this is that a resource can send a message to all the resources with schemas that the message complies with and, conversely, a resource can receive messages from any resource that sends messages compliant with its receiving schema.

In other words, coupling occurs only in the characteristics actually used by messages and not in all the characteristics of the schemas used to generate the message or to describe the service of the receiving resource. Since the schemas of the message and of the receiver are not agreed beforehand, they need to be checked structurally. Resources of primitive types have predefined compliance rules.

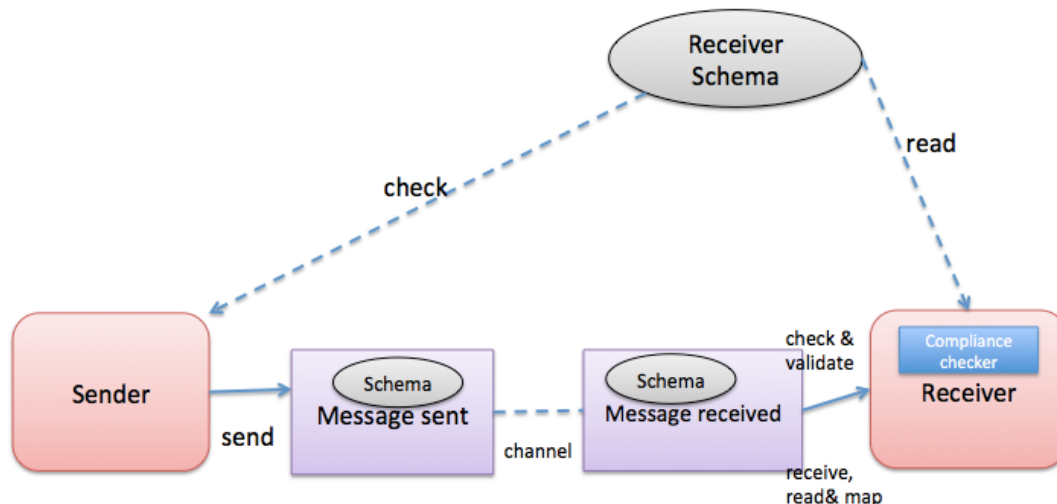


Figure 3.2: Asymmetric interoperability.

Structured resources are compared by the names of components (regardless of order of declaration or appearance) and (recursively) by the compliance between structured resources with matching names. Since the order of appearance of named component resources may differ in the message and in the receiving schema, there is the need to map one onto the other (bottom of Figure 6c). This is a form of polymorphism that increases the range of applicability of both sender and receiver, constituting a means to reduce coupling to only what is actually used. Sender and receiver no longer need to be designed for each other but, as long as compliance is ensured, one resource can replace another (as a result of a new iteration of the lifecycle, for example). In this case, what is involved is conformance between the replacement and the resource replaced, stating that the former supports all the characteristics supported by the latter. When a resource is able to interact with another, although not entirely interoperable with it, we say that have partial interoperability

Figure 7 illustrates these concepts and differentiates compliance from conformance. It also describes complete transactions, with both request and response. The interacting resources now perform the roles of consumer who makes the request and provider, with sender and receiver roles reversed from request to response. Interoperability of a consumer with a provider is possible by satisfying the following properties:

Compliance[4] which means that the consumer must satisfy (comply with) the requirements established by the provider to accept requests sent to it, without which these cannot be honored.

Conformance (Kim Shen, 2007; Adriansyah, van Dongen van der Aalst, 2010): The provider must fulfill the expectations of the consumer regarding the effects of a request (including eventual responses), therefore being able to take the form of (to conform to) whatever the consumer expects it to be.

In full interoperability, the consumer can use all the characteristics that the provider exposes. This is what happens when schemas are shared. In partial interoperability, the consumer uses only a subset of those characteristics, which means that compliance and conformance need only be ensured for that subset. These properties are not commutative (e.g., if P complies with Q, Q does not necessarily

comply with P), since the roles of consumer and provider are different and asymmetric by nature, but are transitive (e.g., if P complies with Q and Q complies with R, then P complies with R)

In Figure 7, a resource A, in the role of consumer, has been designed for full interoperability with resource B, in the role of provider. A uses only the characteristics that B offers and B offers only the characteristics that A uses. Let us assume that we want to change the provider of A to resource X, which has been designed for full interoperability with resource Y, in the role of consumer. The problem is that A was designed to interact with provider B and X was designed to expect consumer Y. This means that, if we use resource X as a provider of A, B is how A views provider X and Y is how X views consumer A. Ensuring that A is interoperable with X requires two conditions such as Compliance and Conformance. For Compliance; B must comply with Y. Since A complies with B and Y complies with X, this means that A complies with X and, therefore, A can use X as if it were B, as it was designed for; For Conformance: Y must conform to B. Since X conforms to Y and B conforms to A, this means that X conforms to A and, therefore, X can replace (take the form of) B without A noticing it. Partial interoperability has been achieved by subsumption, with the set of characteristics that A uses as a subset of the set of characteristics offered by X. This inclusion relationship, without changing characteristics, is similar in nature to the inheritance-based polymorphism supported by many programming languages, but here it applies to a distributed context. It constitutes the basis for transitivity in compliance and conformance, as well as the mechanism to reduce coupling between two resources to the minimum required by the application.



## Chapter 4

# Architecture of the solution

### 4.1 Overview

As we discussed before, The idea is to compare current technologies (Web Services, REST, XML, JSON) with our solution. This solution is a new programming technology alternative current solutions. Basically, this is an alternative to XML-based technologies, for document sharing or service invocation, between two completely different systems. Following sections will explain about how we implemented the interoperability, our primitive data formats and solution of binary level compliance and conformance.

### 4.2 Binary Format

The one of ideas in this technology is using binary format instead of using text or other formats. Because binary is faster to write, communicate and read. When we compare serialization or deserialization performance with binary, XML and JSON. We easily see that binary format gives faster speed than the others especially with large data [5].

On the other hand, Text is far more flexible. Textual representation leads parsing overheads. Messages received are parsed directly in binary, much faster than text parsing. The binary representation provides native support for binary data, has a smaller length and is faster to parse.

We define a binary format to which messages are serialized on send and recovered on reception. For binary format using TLV (Tag, Length and Value) binary markup[6], we use an array of bytes with each resource serialized in a tag (a byte codifying each resource type), size, name (only on structure and resource components) and value (the actual sequence of bytes resulting from serializing the resource).

The binary format used to serialize the resources with TLV (Tag, Length and Value) binary markup. This supports the direct integration of binary information but also facilitates parsing, since each resource, primitive or structured. Binary message format resulting from compilation of the source program and that

uses self-description information and only when needed. This allow us maintaining all the information necessary to communicate in a standard and platform independent way.

Resources can be represented with or without variable names:

Binary, no variable names (components are referred to by their position index in the resource); Variable names, in a dictionary that maps names to position indices;

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As long as we control the serialization format, we can perform the serialization in one language and the deserialization in another. The binary format is always the result of serializing data in each language, with a tag, the number of bytes that follow and the serialized content. Recovering the serialized data is simply testing the tag to find the data type and then using the number of bytes and the serialized content.

We start by serializing several objects to the binary format. Each will have a tag, a size (number of bytes it occupies after the tag). This is implemented as following:

- An integer is always 64 bits, with each byte serialized in sequence. The receiver will recover the integer in the same way.
- Booleans can use just two different tags. There is no size or content, since the tag says it all
- Strings use a UTF-8 encoding, since it is already byte oriented. We decided which byte of each character goes first, if it has more than one byte. Check in both C and Java which is the best way to deal with strings, in terms of serialization. You cannot use predefined serialization, unless you know exactly how it is done. It cannot be language dependent.
- Structures. Sequence of fields, in which, for each field, you should include: name (a string) and the component proper (serialized according to its type of resource)

Objects with variables should be serialized to a compound data (composed of inner data). This means having a compound data type, with its own tag, and inner components serialized according to their own data type (composition can be recursive). This is always recoverable at the receiver, with advantage of the tag.

To define a set of classes implementing each type of resource, including serialization to the binary format and recovery from that format (each resource knows how to produce its bytes and to recover from bytes with its tag). The tag permits to reconstruct completely a given resource that has been serialized.

## 4.3 Compliance and Conformance

The other idea in this technology is using compliance and conformance instead of sharing the same schema. There are no schemas or data types that need to be shared or agreed upon beforehand. This means that two partners will be able to communicate as long as the sender complies with receiver which

follow what the receiver requires and the receiver conforms to what the sender expects (supports all the features that the sender requires), just in the features actually invoked by the sender.

When a resource receives a message, it tries to match it against the type of the input parameter of each of its operations. If one is found, the message received is partially assigned to that argument and the operation invoked. Partial assignment means that the input parameter is created first, then each matching component (by name) of the message is assigned to the parameter. This means that some components of the message can be ignored and some components of the argument may stay unassigned (these are the components that do not match). If all non-optional components in the argument are matched, there is compliance, the matching components of the message are assigned to those of the argument with the same name and those that do not match are ignored. Thus the designation partial assignment.

Using the simple matching that we described above to avoid complexity in the implementation and still achieve interoperability based on compliance and show that two different messages can still match a given operation's argument.

## **4.4 No static data binding**

The other idea is eliminating the need for static data binding (generation of stubs based on a schema). The receiver has always a default value for the message, and only the message components that comply with what the receiver expects are assigned to the matching receiver argument's components. Matching is done by name. This means that the argument is either primitive (int, bool, string) or structured, with named components. Matching is either the same type (primitive types) or name by name (if the argument is a structured type). Only the components that match are assigned to the formal argument of the operation.

## **4.5 Annotations**

To make compliance possible, we should also serialize the formal argument of each operation. These should also support optional components which use the formal argument component if none in the message matches it. Therefore, the serialization methods in the static serialization class should include whether it is optional. The best is for each primitive data type to have two tags, one for mandatory and another for optional. Annotations allow us define tags for primitive data type. Messages sent use only mandatory values. Serialized formal arguments can use both mandatory and optional.



# Chapter 5

## Implementation

### 5.1 Overview

In this section we describe the implementation of the Binary Level Serialization, Central Serializer, Receiver, Message Transportation and Deployment.

### 5.2 Binary Level Serialization

When we try to work with different computer language and their object types we had problem with serialization. We can not use standard Java or .Net(C#) object serialization, because different program languages uses different algorithms for serialization that's why we'll run into the problem. for example in our case Java and .Net does'nt use same serialization algorithm if you serialize an object in Java to binary format and then if you try to deserialize it in .Net language you will have problem because .Net will not recognize that binary format while deserializing.

Figure - . NET and Java String Object Binary

In this case we will use our algorithms instead of using stardard serializer for Java or .Net that both languages could understand and easily serialize or deserialize.

The binary format is always the result of serializing data in each language, with a tag, the number of bytes that follow and the serialized content. Recovering the serialized data is simply testing the tag to find the data type and then using the number of bytes and the serialized content. So instead of using stardard serializer with this algorithm we could serialize object in a language and deserialize with another language.

Objects with variables should be serialized to a compound data (composed of inner data). This means having a compound data type, with its own tag, and inner components serialized according to their own data type (composition can be recursive). This is always recoverable at the receiver, thanks to the tag.

In following section CentralSerializer class will help us to seriliaze objects to binary level using primitive type object serialization.

## 5.3 Central Serializer

A message to be sent should be an object (in Java or .Net) that should provide a serialization method, which basically builds a serialized message (an array of bytes) by sucessively adding each of its components, serialized. This is done by invoking the methods of the serialization class for primitive data (ints, bools, etc), or by recursively invoking the serialization method of structured objects that constitute the message.

The idea of centralizing the “object of primitive type to a sequence of bytes” and vice-versa methods in a single class is to avoid the need for every class to have these methods. Since they are static (they receive an object and return bytes, or vice versa), they can simply be concentrated in a static class (no instances) and invoked from anywhere.

The methods to serialize can receive a primitive object (integer, Boolean, etc) and an array of bytes, returning the array of bytes with the serialized object’s bytes appended. Therefore, each serialization method grows the byte array. When the user wants to send a message, that message needs to be an instance of a class that has a method that knows how to serialize it, by invoking the serialization methods of the static class for each of its variables. This needs to be programmed by the use and is similar to the programming language’s serialization methods.

We will show some examples of primitive type serialization.

[Integer] [String] [Boolean]

## 5.4 Message Transportation

Transferring the array of bytes from sender to receiver requires a binary channel like Web Sockets(HTTP2) or more classical way by encoding and decoding the binary array with BASE64 and then use typical HTTP-based solutions (Web Services or REST). The classical solution is of course non-optimal compared to the other ones, but it can easier to implement given existent tools.

Message Transportation in this solution is done with essentially JavaScript and WebSockets [14], to circumvent some of the limitations of HTTP. The most important issue is that finally humans are also becoming direct Web producers and not merely clients of servers.

Web Sockets [44] are fundamental in the efficient support for binary data removes this restriction, increases performance. They use the protocol upgrade feature of HTTP and provide a substantial degree of compatibility with existing systems. Part of the HTML5 world, servers and firewalls are increasingly supporting them and removes this restriction, adds binary support and increases performance.

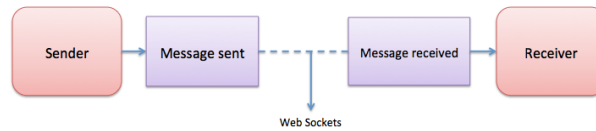


Figure 5.1: Message Transportation.

## 5.5 Receiver

The Receiving platform makes compliance tests in binary because binary format to be able to traverse both the received message and each operation's formal argument, previously serialized. Only the components that match are assigned to the formal argument of the operation.

Two partners will be able to communicate as long as the sender complies with receiver and the receiver conforms to what the sender expects and it supports all the features that the sender requires, again just in the features actually invoked by the sender

When the receiver finds a suitable operation, it builds another array of bytes from both the message and the formal argument then receiver matches components in the formal argument, if it matches it uses the message ones but if not matched by any in the message, use the ones already in the formal argument

The receiver has always a default value for the message, and only the message components that comply with what the receiver expects are assigned to the matching receiver argument's components. Matching in your case is done by name. This means that the argument (just one) is either primitive (int, bool, string) or structured, with named components. Matching is either the same type (primitive types) or name by name (if the argument is a structured type).

Then, the platform invokes the operation after generating the argument's object from array of bytes. This can be done either by reflection or by invoking a constructor defined by the user in the class of the formal argument, which knows how to build itself from an array of bytes that respects its components (the new array of bytes respects this because it was created by copying the original array of bytes of the serialized formal arguments, replacing only the components that matched).

## 5.6 Compliance

Compliance is done at the binary level, with primitive components, as we described in previous section. Only the components that match are assigned to the formal argument of the operation.

We should also serialize the formal argument of each operation to make compliance possible. These should also support optional components which use the formal argument component if none in the message matches it. Therefore, the serialization methods in the static serialization class should include the name of the component, whether it is optional (a boolean), the type (encoded in the tag) and the value. For each (primitive) data type can have mandatory annotation. Messages sent use only mandatory values. Serialized formal arguments can use both mandatory and non-mandatory.

To clarify the compliance, the idea is to serialize the argument (only one, but it can be structured) of each operation of a service (receiving object). This acts like a default value, against which the message received is matched. A service receiving a message matches it against the argument of each operation, until it finds one, assigns the message to that argument (partial assignment, see below) and runs the operation, returning eventually a result.

When checking for compliance, a component in the message with the same name as a component in the operation's argument matches it and can be assigned to it (if the message complies with the argument, as a whole). If not, it is ignored. If a component in the argument is not matched by any of the message's components and is optional, retains the argument's value (which acts as a default value). If all non-optional components in the argument are matched, there is compliance, the matching components of the message are assigned to those of the argument with the same name and those that do not match are ignored. Thus the designation partial assignment.

## 5.7 Deployment

The solution is developed and in two different language. They are .NET and Java and deployed Microsoft Azure Cloud. That's way we can have 2 different provider and .Net client can send message to Java provider over the cloud by using WebSockets and also Java client can send message to .Net provider. Using Microsoft Azure Cloud allowed us to test project in cloud enviroment



## 5.8 Overview

dddd

## Chapter 6

# Comparison with existing technologies

Current integration technologies for distributed systems in Cloud environment are generally supported on textual data description languages (XML and JSON) and HTTP protocol. These technologies especially designed for human-level interaction and that creates integration problems. In this section we will do comparison qualitatively and quantitatively with these current technologies and our new approach.

### 6.1 Qualitatively Comparison

#### 6.1.1 Textual or binary representation

Current integration technologies for distributed systems in Cloud environment are generally supported on textual data description languages (XML and JSON) and HTTP protocol. These technologies especially designed for human-level interaction and that creates integration problems. In this section we will do comparison with these current technologies and our new approach.

SOA is usually implemented by Web Services with WSDL, which is a set of conventions on XML usage to describe services at the interface level and SOAP as a message protocol, which is again based on XML.

Many developers found SOAP cumbersome and hard to use. For example, working with SOAP in JavaScript means writing a ton of code to perform extremely simple tasks because you must create the required XML structure absolutely every time. one perceived disadvantage is the use of XML because of the verbosity of it and the time it takes to parse.

REST also requires that data types, which are usually, called media types and standardized or previously agreed, when they are application specific. REST doesn't have to use XML to provide the

response. You can find REST-based Web services that output the data in Command Separated Value (CSV), JavaScript Object Notation (JSON) and Really Simple Syndication (RSS). The point is that you can obtain the output you need in a form that's easy to parse within the language you need for your application. While this may seem like it adds complexity to REST because you need to handle multiple formats, JSON usually is a better fit for data and parses much faster. REST allows better support for browser clients due to its support for JSON.

SOA and REST use textual representation but textual representation brings parsing expenses and poor support for binary data. Instead of using textual representation, the binary representation provides native support for binary data, has a smaller length and is faster to parse.

Our approach is designed to work with binary representation. The binary representation uses a modified version of the TLV format (Tag, Length and Value) used by ASN.1 [6]. This not only supports the direct integration of binary information but also facilitates parsing, since each resource, primitive or structured.

### **6.1.2 Message protocol**

SOAP is language, platform, and transport independent SOAP can use almost any transport to send the request, using everything from the afore mentioned to SMTP (Simple Mail Transfer Protocol) and even JMS (Java Messaging Service), but REST requires use of HTTP/HTTPS.

Our approach does not depend on any particular transport protocol, relying only on message delivery. Any existing server can be used, based on HTTP, WebSockets or any other protocol. In fact, several servers can be used simultaneously, receiving messages that are handed over to the message handlers that are able to process them.

New protocols, such as WebSockets, reduce some of the problems. Web Sockets, now part of the HTML5 world, removes this restriction, adds binary support and increases performance. XML is verbose and complex, has limited support for binary formats, is inefficient in computer terms due to parsing and exhibits symmetric interoperability, based on both sender and receiver using the same schema, which constitutes a relevant coupling problem.

### **6.1.3 The interoperability problem**

In both SOA and REST, interoperability is achieved by using common data types (usually structured), either by sharing a schema (i.e., WSDL files) or by using a previously agreed data type (typical in RESTful applications). There is usually no support for partial interoperability and polymorphism in distributed systems.

The basis of data interoperability with XML and JSON is schema sharing(at runtime or with previously standardized or agreed upon internet media types). Both the producer and consumer (reader) of a document should use the same schema, to ensure that any document produced (with that schema) can

be read by the consumer. This means that both producer and consumer will be coupled by this schema. Schemas must be shared between interacting Web Services, establishing coupling for all the possible values satisfying each schema, even if they are not actually used. In this case, a reference to a schema acts like its name.

REST also requires that data types (usually called media types) must have been previously agreed, either standardized or application specific.

Searching for an interoperable Web Service is usually done by schema matching with similarity algorithms [7] and ontology matching and mapping [? ]. This does not ensure interoperability and manual adaptations are usually inevitable.

In our solution, we propose to use partial interoperability, based on the concepts of compliance and conformance. It introduces a different perspective, stronger than similarity but weaker than commonality (sharing). The trick is to allow partial interoperability, by considering only the intersection between what the consumer needs and what the provider offers. It allow us for increased interoperability, adaptability and changeability, without the need to have resource types necessarily shared or previously agreed. Building interoperability on compliance and conformance avoids the problem of having to define schemas as separate documents and to agree upon them beforehand. As long as compliance and conformance hold, any two resources can interoperate, even if they were designed unawares to each other.

## Chapter 7

# Conclusions

In this thesis we propose a solution for . This solution extends methodologies already used for . We discussed some methodologies that seem most relevant, . The tool proposed here consists of five components, where the implementation of three of them is part of the scope of this thesis. Section 4 briefly describes the tool architecture, describing its components and the interaction between them. Section 5 describes in more detail the implementation of the three components belonging to this thesis, the SysCFG, Extract Structure and SysSMT. SysCFG aims to extract the CFGs of the source code functions from the SystemC description. To accomplish this it was necessary to convert the SystemC source code to an easily manageable intermediate representation. Thus it was chosen LLVM framework which has a wide acceptance in recent years by the community. At this time there are several front-ends for LLVM built, while others are being developed and improved, as is the case of PinaVM. This is the LLVM front-end for SystemC used in this thesis. This thesis (see Section 6.1) shows that this component presents promissory results not only for small programs but also to real systems like the echo cancellation system. The Extract Structure consists on a source code parser to extract the static structure of the embedded system modeled in SystemC. This component saves the signs, modules and their connections between the two of them. At the same time, it also extracts the define directives. This component arose from the need to create a helper structure at IVG component (outside the scope of this thesis) to create the CFG of the embedded system under analysis. In SystemC, module functions that emulate the module behavior are never called directly from the source code, only in simulation time SystemC decides who and when to call. Thus it is necessary to know beforehand the static structure to help in the organization of CFGs of the source code functions in order to build the embedded system CFG. Finally, we propose a solution to the Thus we had to find a solution from scratch where most components had to be developed.

### 7.1 Future Work

A few ideas for future work...



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