

# Programming Language Interoperability

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## ABSTRACT

Interoperability of programming languages is the ability for two or more languages to interact as part of the same system. Frequently, this means passing messages and data between potentially very different languages. The differences in these languages poses a serious basic barrier to creating an interoperative system.

However, interoperation is important to many existing systems today, as programming languages have evolved to target particular problem domains at the expense of performance in others or in ease of use. In particular, the domains of client/server architecture and many distributed computing systems utilize multiple languages for network communication and actual processing.

Because the problems inherent to cross language communication are myriad enough that no single approach could address all the issues, several such tools have emerged which approach the problems from different directions. Two broad categories of these tools are virtual machines and markup languages. These two tools are used concurrently in many systems today, reflecting their different strengths.

## Keywords

interoperability, language interoperability, programming languages, virtual machines, markup languages

## 1. INTRODUCTION

Interoperability, colloquially shortened to *interop*, is the ability for two or more systems to work together. This definition is very broad, covering anything from groups of people to businesses or bureaucratic systems to pieces of hardware. This paper will discuss interoperability between programming languages. While this narrows the field significantly, programming language *interop* is still a very broad topic.

For instance, all browsers perform some kind of *interop*. Information to be displayed on a web page is handled by HTML, and while formatting computation handled by PHP or JavaScript; if there is more computation to be done, or if

a database needs to be consulted, these client-side languages will communicate with a server, often written in languages like Java or C.

Likewise, these servers may be written in several languages themselves. A blog hosting service, Kidblog<sup>1</sup>, uses a backend written in both Java and Clojure, using Java to handle translation between the client and server ends, and Clojure to handle the actual server load.

The challenges that arise when dealing with interoperability can be many, and sometimes surprising [3]. The tools and approaches used to overcome these challenges are likewise many. In the interest of brevity, we will look at a small subset of these challenges, along with several tools used to deal with them.

In Section 2 I explore further why interoperability is desirable, what advantages it can confer, and where it can be useful. This will touch on differing language capabilities, ease of use, hardware independence, and implications for distributed computing.

Next, in Sections 3 and 4, I describe two particular tools that are commonly used to achieve interoperability. These tools will be virtual machines, paying particular attention to the Java Virtual Machine (JVM) and .NET's Common Language Runtime (CLR), and markup languages, with focus on two particular systems that make use of markup languages, Starlink and FML.

Section 5 will detail particular challenges involved with interoperability and approaches to handling them. Following a general description of the approach, I will describe how each tool can be used to implement that approach, along with strengths and weaknesses of each setting.

Section 6 will look at a few of the performance implications of the tools discussed.

## 2. INTEROPERABILITY

The primary importance of interoperability lies in the varying capabilities of different languages. Programming languages perform best in particular circumstances, and different languages perform better in different situations.

Some languages are constructed to tackle specific problems, but provide almost no support for others. Erlang, for instance, is one of the primary languages used in distributed computing. It was built around remote procedure calls (RPCs), and handles them simply and powerfully. However, manipulating strings in Erlang is very difficult, because Erlang was never intended to deal with strings. As a result,

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<sup>1</sup>[kidblog.org](http://kidblog.org)

it has no library for string interaction, and treats them as arrays of characters. A system using Erlang for handling distributed communications which also needed to manipulate strings would have use for interop: another language could be used to handle the strings, while leaving the RPCs to Erlang.

Still others allow access in ways that are hidden in other languages. The memory access model in C, for instance, differs from many other high-level languages presently in use. C enables very fine-grained memory access and control, and places all of this control in the programmer's hands. Likewise, assembly languages allow direct access to hardware and the underlying storage mechanisms. The higher level of control offered allows developers to make very specific, fine-tuned adjustments to their systems, enabling performance improvements in ways specific to the program or the hardware platform. However, these languages have high learning curves, and programs using them may have security concerns if not done correctly.

The difficulty involved in learning a language is not a minor concern, either. Developer time and energy are important considerations when designing a system. For example, Java was initially intended to be the go-to language for web development. In practice, most web development now is done with scripting languages like Ruby or JavaScript<sup>2</sup>. Java has, in turn, become more of a server back end language. The reasons for this shift had nothing to do with what Java was capable of, and much more to do with what programmers were willing to deal with. The learning curve for Java is higher than many scripting languages, and is generally much more verbose.

Apart from the capabilities of the languages involved, interoperability is often tied to hardware independence. The problems faced in achieving language independence and hardware independence are frequently similar, or have similar solutions. As noted above in the case of Java, designing for hardware independence allowed the JVM to act as a tool for language independence as well.

In client/server architecture, such as in Kidblog, the client-side and server-side environments are likely written in different languages, and guaranteed to be on different machines. Kidblog handles communication between the two using JSON, a markup language. On the client-side, JavaScript marshals blog posts into JSON objects, which are then sent to the server. There, they are converted to Java objects, which Clojure can then act on. Since Java is more strongly typed than JavaScript, JSON is also used to help translate between the two. We'll take a closer look at this in Section 5.1.

### 3. VIRTUAL MACHINES

The term virtual machine (VM) refers to software that models the operating system of a computer or the underlying physical hardware. Effectively, VMs are indistinguishable from the OS or hardware they are emulating, which allows them to run programs not runnable by the native OS, or with restrictions not enforced by the native OS or hardware. The focus of this paper will be on virtual machines that act as a runtime environment for a single process, sometimes called process VMs. These VMs in particular enforce restrictions on what system resources their hosted process has access to.

<sup>2</sup>Unrelated to Java

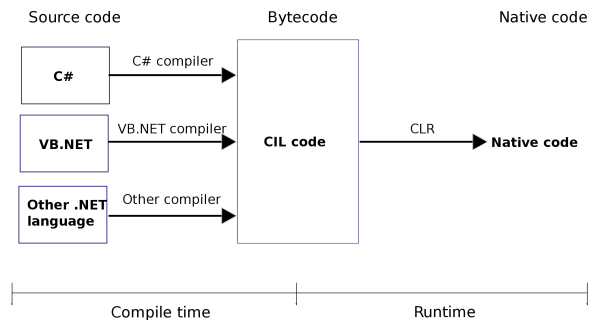


Figure 1: VM architecture in the CLR [8]

Specifically, they typically provide restricted, VM managed memory spaces, ensuring that hosted processes can't access memory beyond what is allocated to it. [12] *is this relevant?*

There are two major advantages to virtual machines. The first of these is a type safety mechanism. Virtual machines such as the Java Virtual Machine (JVM) and .NET's Common Language Runtime (CLR) have a base set of types (in the CLR, this is actually called the Common Type System, or CTS. It is implicit and unnamed in the JVM). The VMs can use these type systems to ensure the correctness of participating languages and gives languages a common ground for their type information.

The second advantage lies in the VM's intermediate language. These are low-level languages, designed to be both compact and efficiently compiled to machine code, and are what is actually run by the virtual machine. As shown in Figure 1, any high-level language can be run on a virtual machine, as long as there is a compiler to translate that language into the VM's intermediate language.

These languages are still an abstraction of machine code, and so they still require an interpreter or a compiler for execution. The VMs also contain interpreters for their intermediate language, but also utilize a run-time optimization method called Just-In-Time (JIT) compilation. Most of the code is still interpreted, but portions of code are monitored for frequent use. High-usage sections of code are compiled to machine language for quicker access. This allows for specific optimizations based on the current input and hardware, which are rarely known before execution. [11]

The JVM and CLR will be our main subjects when discussing virtual machines. While similar in certain ways, these two VMs were designed for different purposes.

The JVM<sup>3</sup> was designed alongside Java for the purpose of hardware independence. Since the intent of Java was to be run off the web, there was no way of knowing what kind of hardware would end up running a piece of code, or even what kind of browser it would be running from. They needed to be able to compile to machine code only when the code was actually run, such that any hardware would be able to compile and run the code correctly. The solution was the JVM. The eventual discovery that other languages could make use of Java's intermediate language and the JVM was completely accidental.

<sup>3</sup>References to "The JVM" refer to the general concept of Java's virtual machine. There are many implementations of JVMs, which follow certain specifications but implement certain concepts in different ways and may support different operating systems. [9, 10]

```

1 <Types>
2   <Method>String</Method>
3   <URI>String</URI>
4   <Version>String</Version>
5   <ST>String</ST>
6   <MX>Integer</MX>
7   ...
8 </Types>
9
10 <Header type=SSDP>
11   <Method>32</Method>
12   <URI>32</URI>
13   <Version>13,10</Version>
14   <Fields>13,10:58</Fields>
15 </Header>
16
17 <Message type=SSDP_M-Search>
18   <Rule>Method=M-SEARCH</Rule>
19 </Message>
20
21 <Message type=SSDP_Resp>
22   <Rule>Method=HTTP/1.1</Rule>
23 </Message>

```

Figure 2: A Starlink MDL specification (taken from [2])

In contrast, the CLR was developed with a host of languages, and was designed in part with the intent of facilitating interoperability between them. The purpose of the virtual machine in this context was to intentionally provide the common ground for languages based on the CLR, giving them access to features promoting interop, such as the Common Type System and metadata engine (discussed further in Section 5.1).

## 4. MARKUP LANGUAGES

Markup languages are primarily used for describing data. There are a range of markup languages covering several use cases, from document display or creation to data transfer and storage. For instance, HTML (HyperText Markup Language) is used to convey content information for web pages, while  $\text{\TeX}$  is a language used to describe the layout and formatting of text documents. Others, such as JSON and YAML, were designed for modeling data in ways consistent with object oriented design<sup>4</sup>.

One of the major players in the world of markup languages is XML, the Extensible Markup Language. XML’s method of describing data is to enclose the relevant data with a tag. Tags are easily distinguishable from the data they contain, and are considered separate from the data when the XML is read. Notice in Figure 2 that the fields (**Method**, **URI**, **Version**) are made distinct from the actual data with angled brackets. Also note that tags can be nested: lines 11 through 14 are contained within the **Header** tag. This allows XML to describe full records or objects, which will be important in Section 5.1.

The eponymous extensibility of XML comes in the form of defining new tags. Systems using XML are not constrained to using the tags built in to XML, but can create new ones based on the data they will be handling. This allows for the creation of new markup languages based on XML, but built for a specific purpose. HTML is one example of such a language. Two others, which we’ll take a closer look at, are FML and Starlink.

<sup>4</sup>JSON and YAML in particular are sometimes called Data Description Languages for this reason

Starlink [2] is actually more than just a markup language. It is a software framework designed to achieve distributed interoperability between existing systems with different communications protocols. One of the core features of Starlink is XML-based markup languages called the Message Description Languages (MDLs). MDLs are used to model incoming messages from a protocol as abstract messages: messages separated into their constituent parts and types. A translation logic specification, also written in XML, defines what parts in two MDLs can be related to one another. Once Starlink has performed appropriate transformations based on the message type received, it can then marshal a message for the target protocol using the newly created abstract message.

The Fuzzy Markup Language [1] (FML) was not designed for interoperating systems at all, but for releasing fuzzy controllers from hardware constraints. Fuzzy controllers are used in systems where either input or output cannot be meaningfully modeled as true or false. An example of such a system might be in street lamps, where the decision of when to turn on depends on the ambient light level. One issue with fuzzy controllers is that they are generally written in an intensely low-level way, and therefore particular implementations are tightly bound to the hardware they are designed to run on. As Acampora [1] mentions, this means that in a distributed context, a new controller may have to be designed for every hardware installation regardless of the similarity in purpose.

FML is the solution to this. The specifications for FML allow it to model the full controller, including

## 5. DIFFICULTIES AND APPROACHES

When building a system with interoperating languages, there are several aspects of the system that designers need to account for. Of particular importance is the lowest common denominator (LCD) constraint.

The LCD in this case is the largest subset of concepts that can be translated across the languages in use. These concepts include data types and underlying data structures. For example, if you have a system wherein you want to use a key/value map, but one of the languages only has support for arrays. This restriction is part of the system’s LCD, and limits the functionality of the overall system. Here, this can be dealt with in several ways: Remove the restricting language from the system, remove the use of maps and just use arrays instead, or find ways to model maps as arrays. The first two options are rarely preferable. If a particular language is present in a system, it usually has a contribution not easily matched by any other language. Likewise, maps may be the ideal way to store the particular data being used, while arrays will be insufficient.

Finding a method of translating a concept from one language to the other is preferable, but may not always be possible, or as straightforward as in the above example. In some cases, achieving the translation can mean a loss of information or a loss of precision. C, for instance, has no concept of booleans. Zero is treated as false, while any other number is treated as true. When interoperating with a language that does use booleans, precision of booleans is lost. A number could be just a number, or it could be True. On C’s end, information could be lost if a true/false test is made to determine if a variable contains a number, and act upon that number if it does. If C receives a True from another language,

```

Class Person
  string name = "Cliff"
  date dateOfBirth = 4/16/1978
  int height = 74
  double weight = 212
end

```

Figure 3: A Person class strongly-typed language

```

Class Person
  var name = "Cliff"
  var dateOfBirth = 4/16/1978
  var height = 74
  var weight = 212
end

```

Figure 4: A Person class in an untyped language

it may read it as one.

For issues like these, there are two concepts that help enable this translation with minimal loss: metadata and standards.

## 5.1 Metadata and Data Type Conversion

When passing data between two languages, a system must have a way of ensuring that the type systems of its component languages are respected. Additionally, it must ensure that type information is not lost when data moves from a strongly typed language to a weakly typed language, so that information is available when the data moves the other way.

Metadata is the method by which this is accomplished [5]. Simply put, metadata is data describing data. This can be almost anything, as long as it conveys information beyond what the data can by itself. In the case of strongly-typed languages, the type information included as part of a variable declaration is a kind of metadata. In Figure 3, for instance, we can tell that there is a difference between the `height` and `weight` fields, despite both fields being a number.

### *VMs and metadata*

There are two primary ways virtual machines handle metadata: language type specifications and metadata files. Both of these are handled by a compiler at compile time. Once the system has been compiled to the intermediate language, there should be no syntactic difference between the different parts, as they are now all the same language.

As mentioned above, the explicit type information in strongly-typed languages, like Java or C# is a kind of metadata. This metadata is entirely for use by their compilers, to assist with translation to the intermediate language. In weakly

```

Class Person
  var name = ["Cliff", "string"]
  var dateOfBirth = [4/16/1978, "date"]
  var height = [74, "int"]
  var weight = [212, "double"]
end

```

Figure 5: An untyped Person class, with type metadata

```

<Person>
  <name> Cliff </name>
  <birthdate> 4/16/1978 </birthdate>
  <height> 74 </height>
  <weight> 212 </weight>
</Person>

```

Figure 6: An XML description of a person

or dynamically typed languages like Ruby and Groovy, this metadata does not exist (Figure 4). Since these languages perform run-time type checks instead of at compilation time, significantly more code is generated by their compilers, and they cannot take advantage of the intermediate language's primitive type system (everything must be assumed to be an Object-type object)<sup>5</sup>. **I need to confirm this is true for Groovy**

Compilers for both the JVM and CLR also generate metadata along side the intermediate code. The JVM stores this metadata in the same file as the code, while the CLR stores it in a separate file in the same location. This metadata is used by the run-time interpreter for type checking and to assist with JIT optimization, but can also be accessed by other tools.

### *MLs and metadata*

Metadata is the strong point of markup languages, as they are designed around the same concept of describing data. Essentially, the fields in a markup language (tags, in the case of XML-based languages) act as metadata for the data they are attached to.

When translating into an object for another programming language,

The real metadata in a markup language can be stored in many ways. In Starlink's MDLs, for example, the type information of fields is stored in a `<type>` tag before the definition of the fields begins, as can be seen in Figure 2 [2]. In other cases, the type information is stored in-line with specifications for correct formatting, as in XML schema (discussed in Section 5.2).

## 5.2 Standards and Interfaces

Metadata is the core of successful interoperability. But if two systems attempting to communicate are expecting differently tagged data, they will still fail to interoperate. Metadata alone is not enough.

There are two aspects to standards. One is agreement on similar data types, the other is the reaction to or approach to handling those types once received. Ide and Pustejovsky [5] refer to this difference as syntactic interoperability (agreement on data type and communication protocols) and semantic interoperability (the ability to act on data received in a way unsurprising to other components of a system).

Shetty and Vadivel [7] demonstrate an example of a failure in semantic interoperability even while retaining some (though not all) syntactic interoperability between Java and .NET (CLR languages) web services. While they found several syntactic mismatches, such as the Java's lack of unsigned numbers, there were issues even where the systems

<sup>5</sup>While this does have performance implications [6], they do not outweigh the gains from utilizing the VM

supported the same types. In particular, Shetty and Vadivel noted that null values were handled in largely incompatible ways. When given an array with a null element, Java interpreted as a null object, and printed `null` when that element was requested. In contrast, .NET interpreted the element as empty, and printed an empty string when the element was requested. Additionally, they found that precision of decimal, double, and float types differed between platforms. When asked to add and display 4.111111 and 8.999999, the Java client returned 12.999999 with full precision, while the .NET client returned 13.

### VMs and Standardization

Although the above study found issues between virtual machines, systems run on homogeneous virtual machines architecture actually have an advantage. Systems on a virtual machine already have a standard implemented in the form of the intermediate language. Because the intermediate language has a full language specification, including both a type system and data interpretation behavior, it can act as a description for required behavior. Moreover, once a system has been compiled into the intermediate language, the behavior of the different components is constrained by that virtual machine's behavior.

This is not a perfect solution however, as it still requires that the high-level languages have conventions for calling the other language. These conventions are tied to compilers at least, so grammar for calling other languages on a particular VM can be included as part of a new compiler specification without affecting other implementations of that language.

As an example of this, Java was not initially intended to run other languages, making calls to non-Java languages is a difficult proposition [3]. However, new JVM languages, like Clojure and JRuby, inherently provide support for accessing at least Java classes, if not other JVM languages directly.

### MLs and Standardization

Standards are not inherent to markup languages, and there is no simple way to use them to enforce anything more than syntactic interop. While this is a shortcoming of markup languages, it is hardly the end of the world: syntactic interoperability can be achieved by explicit standards at the development level, though this requires that developers be particularly aware of their system's LCD.

Semantic interop is much easier to attain with markup languages. Although not built in, many markup languages have a notion of schema, which can be used to regulate correct formatting. Messages sent in the markup language can be checked against these schema to ensure both that they contain the right fields in the right places, as well as that those fields contain the correct type of data. As Figure 7 shows, type metadata can be stored within the schema specifications.

It should be noted that schema and similar mechanisms are themselves simply a standard, and are not expressly enforced or singular. XML has several schema languages associated with it. Figure 7 is an example of the W3C<sup>6</sup> recommended standard.

## 6. PERFORMANCE

<sup>6</sup>World Wide Web Consortium

```
<?xml version="1.0" encoding="utf-8"?>
<xs:schema elementFormDefault="qualified" xmlns:xs="http://www.
  <xs:element name="Person">
    <xs:complexType>
      <xs:sequence>
        <xs:element name="name" type="xs:string" />
        <xs:element name="birthdate" type="xs:date" />
        <xs:element name="height" type="xs:double" />
        <xs:element name="weight" type="xs:double" />
      </xs:sequence>
    </xs:complexType>
  </xs:element>
</xs:schema>
```

**Figure 7: A W3C-style XML schema for the person in Figure 6.**

Regardless of how the system is built or the interop implemented, an interoperating system will always accrue some overhead. The cost of translating from one language to another can have surprising impacts on efficiency.

The main issue faced in virtual machines is the LCD constraint. Because all languages eventually end up running in the same language, care must be taken that higher-level languages can be reasonably translated to the intermediate. Li, White, and Singer [6] show that in the Java Virtual Machine, non-Java languages rely heavily on existing Java code libraries in order to mitigate performance difficulties. Additionally, they found that non-Java languages produced distinctly non-Java sequences of bytecode. For dynamically-typed languages like Ruby, these sequences are significantly longer than bytecode from an equivalent Java class. Additionally, JRuby bytecode contains none of the built-in type operators, which are used to optimize performance. This has some performance and space implications when comparing JRuby and Java, although JRuby does still see benefits from JIT optimization.

While I am not aware of a similar study focusing on languages on the CLR, the CLR was designed both with interoperability in mind and with an awareness that dynamically-typed languages would be running on it. From these two points, it seems reasonable to assume that CIL bytecode and the CLR interpreter are designed to handle dynamic types more efficiently or concisely.

The primary concern for markup languages is in translation time. Because systems involving MLs usually also involve different languages at runtime, they also require translating between two or three languages during execution.

Bromberg et al's report on the Starlink framework, which handles three translations per message, showed a non-negligible time lapse between when the initial message was received by Starlink and when Starlink returned a reply to that protocol.

**Is this still too vague?**

Ultimately, the performance costs of achieving interoperability must be weighed against the potential performance gains. In systems involving several specialized domains, or in systems utilizing diverse hardware, the gains can well outweigh the costs.

## 7. CONCLUSIONS

Virtual machines and markup languages each have strengths

and weaknesses in different use cases.

Virtual machines are much more feasible for systems being built from scratch, where all language decisions are in the hands of the developers. They may also be available to existing programs on a VM which a developer wishes to extend to a larger system; in this case, the extended system merely need be built on the same virtual machine, and it will be able to interoperate with the pre-existing software.

In comparison, markup languages are better suited to dealing with preexisting or legacy systems, where there is too much code to make rewriting a feasible option, or where parts of the source are simply unavailable, potentially due to working with a third-party software. Likewise, if the existing system cannot target a particular virtual machine, perhaps because a compiler from that language to that VM doesn't exist, recompiling the existing program is not feasible.

Additionally, markup languages have an advantage in distributed system environments, where they can be used in sending data over the network. This is particularly important in client/server architecture, where servers have no way of guaranteeing the hardware or sometimes even the software being run by the clients. A markup language can act as an intermediary, providing the data in a language and hardware free way.

These two cases are not mutually exclusive, and can even be complementary. A real-world system is more likely to make use of both virtual machines and markup languages to cover relevant aspects of their system than to rely on just a single approach.

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