Abstract

In order to achieve Separation of Concerns in the domain of remote method invocation, a small functional adapter is added atop Java RMI, eliminating the need for every remote object to implement `java.rmi.Remote` and making it possible to remotely access existing code, unchanged. The `Remote` monad is introduced, and its implementation and usage are detailed. Reusing the existing, proven technology of RMI allows not to re-invent the underlying network protocol. As a result, orthogonal remote invocation is achieved with little or no implementation effort.

Categories and Subject Descriptors D.3.2 [Programming Languages]: Language Classifications—Concurrent, distributed, and parallel languages; D.3.3 [Programming Languages]: Language Constructs and Features—Procedures, functions, and subroutines

Keywords Functional programming, distributed programming, closures, RMI, Scala

1. Introduction

Enterprise application development can be viewed as a struggle to maximize useful payload code (often referred to as business logic) with respect to an ever growing, dark mass of boilerplate/generated supporting code, for all the features expected in the enterprise context (remote access, transactions, persistence, logging, security, failure recovery, monitoring, etc.) The big Java enterprise frameworks are devised to automate as much as possible the handling of these features, making it as transparent as possible. Needless to say that they only partially succeed in this endeavor, just considering the enormous complexity of the tools themselves.

One way out of this quagmire might be through Separation of Concerns (SoC) [Wikipedia 2016]: if one could address one or more of the aforementioned features separately, it would suddenly become more tractable. This paper is specifically focused on the topic of remote invocation, which has usually many adhesions to other concerns.

2. Outline

The paper is organized as follows. Section 3 gives a historical perspective on RMI. Section 4 introduces the `Remote` monad and its implementation. Section 5 explains its usage. Section 6 details a modification to RMI’s generated code that is necessary in the most common 2-tiered case with non-serializable data. Section 7 compares our setting with existing work and Section 8 concludes.

3. State of the art

Since its inception, not late after Java itself, RMI (Wollrath et al. 1996) has been plagued by a several problems, not so hard individually speaking, but which as a whole resulted in the technology never really being adopted by the industry. Among these problems are the following:

1. RMI is Java-only and cannot interact with e.g. Microsoft technologies, contrary to its former incarnation, CORBA, which could do so, but at the expense of increased complexity
2. It is not web-friendly and cannot easily cross proxies and firewalls, due to not using HTTP
3. An emphasis was made on the code downloading feature, which incurred security concerns (the same as with applets)
4. For the programmer, it is not completely transparent: the way an object is made remotely accessible is by extending RMI’s `UnicastRemoteObject`, which complicates inheritance hierarchies and hinders SoC.

Due to points 1 to 5 above, the industry favored web services, which are secure, inter-operable with non-Java technology, and can travel the web (obviously). Meanwhile, JDBC came with its own means of communication for database access, independent of RMI. As a result, 3-tiered architectures (JDBC + web front-end) today are still the most prominent model of enterprise Java applications. The
Table 1. JDBC Driver Categories

| DRIVER CATEGORY | ALL JAVA | NETWORK CONNECTION |
|-----------------|----------|--------------------|
| 1 - JDBC-ODBC Bridge | No | Direct |
| 2 - Native API as basis | No | Direct |
| 3 - JDBC-Net client | Yes | Indirect |
| 4 - Native protocol as basis | Yes | Direct |

outcome of point 4 is that remoting code cannot be separated from other concerns in a RMI application, making the model uncompetitive compared to more straightforward technology like JDBC, which finally took over.

JDBC however does not achieve SoC either, as is clearly visible looking at the table of driver types (Table 1), with remote access and SQL operation always intertwined. One could even argue, that if SQL is still in use today in the Java world, is because JDBC is so convenient as a network bridge. Thus, a purely remoting middleware is called for. On the server side, SQL could be replaced by native/integrated queries, whose implementation would be simplified, being purely local.

This paper introduces a simple RMI adapter for Scala that follows the Monad pattern, the Remote monad, aimed at making remote invocations truly orthogonal, independent from other concerns.

4. The Remote monad

The Remote monad is implemented as a remote object in the RMI sense. It encapsulates a normal Java object, of type T. A Remote interface is defined, with type parameter T, extending java.rmi.Remote, and declaring the two monadic higher-order functions map and flatMap as remote methods. A third method get is also provided to “force” the monad, that is to bring the encapsulated value locally.

```scala
@remote trait Remote[T] extends java.rmi.Remote {
  def map[S](f: T => S): Remote[S]
  def flatMap[S](f: T => Remote[S]): Remote[S]
  def get: T
}
```

The remote implementation RemoteImpl extends RMI’s UnicastRemoteObject and implements the above defined Remote interface.

```scala
class RemoteImpl[T](val get: T) extends UnicastRemoteObject with Remote[T] {
  def map[S](f: T => S) = Remote(f(get))
  def flatMap[S](f: T => Remote[S]) = f(get)
}
```

Remote references of class RemoteImpl.Stub are obtained through the rmic utility. In newer Java versions this step can be omitted, as it is being replaced by the use of a dynamic Proxy.

Remote objects are registered and obtained through factory methods rebind and lookup, respectively. The apply method is the monadic “return” function.

```scala
object Remote {
  def apply[T](value: T) = new RemoteImpl(value)
  def rebind[T](name: String, value: T) = Naming.rebind(name, apply(value))
  def lookup[T](name: String) = Naming.lookup(name).asInstanceOf[Remote[T]]
}
```

5. Usage

The basic usage of the Remote monad is as follows. On the server side, an object is first instantiated and registered through these instructions:

```scala
Remote.rebind("obj", new Object)
println("obj bound in registry")
```

On the client side, a remote reference to the object is then obtained and operated like so:

```scala
val ra = Remote.lookup[Object]("obj")
val str = for (a <- ra) yield a.toString
println(str)
```

Operations involving more than one object are also possible, as shown below:

```scala
val rb = for (a <- ra) yield new Object
val rc = for (a <- ra; b <- rb) yield a.equals(b)
println(rc)
```

The process is summarized in Figure 1: operation op is sent remotely (query shipping) and applied to objects a and b. The result is encapsulated in a new remote object and...
Figure 1. Monadic remote invocation

6. Modification of RMI’s generated code

In order to support the most common case of a 2-tiered application, a small adjustment to RMI’s generated code has to be made. When a remote reference returns to the place where it was first instantiated, and contrary the intuition, it is not replaced by its implementation. This specifically causes a problem when two or more remote objects are operated on, as in the last example, which is desugared to:

```scala
val rc = ra.flatMap(a => rb.map(b => a.op(b)))
```

This corresponds to the following sequence of actions:

- Closure \( a \Rightarrow \ldots \) is sent to remote object \( ra \)’s location, capturing remote object \( rb \).
- From \( ra \)’s location, closure \( b \Rightarrow \ldots \) is addressed to \( rb \) via its method \( \text{map} \), capturing local object \( a \).
- Even if \( rb \) resides on the same location as \( ra \), method \( \text{map} \)’s receiver is a remote reference, not an implementation.
- Consequently, the call to \( \text{map} \) induces the serialization of closure \( b \Rightarrow \ldots \), and henceforth of object \( a \).
- Object \( a \) is deserialized once arrived at \( rb \)’s location.
- Operation \( op \) is performed on \( a \) and \( b \), and the result is encapsulated and returned.

Hence, when \( ra \) and \( rb \) are in the same location, we have an opportunity to prevent serialization of the content of \( ra \), if we replace remote references by their implementation when they come back home. This is done through the addition of method \( \text{readResolve} \) below to \texttt{rmic}’s output \texttt{RemoteImpl}.

```scala
public Object readResolve() throws
    java.io.ObjectStreamException {
    return Remote$.MODULE$.replace(this);
}
```

Method \( \text{replace} \) above is implemented in \texttt{Remote}’s companion object using Java’s \texttt{WeakReference} mechanism, and method \( \text{apply} \) is modified accordingly, storing newly created remote objects in the cache prior to returning them.

```scala
val cache: Map[java.rmi.Remote,
    Reference[Object]] = new WeakHashMap[
    java.rmi.Remote, Reference[Object]]()

def apply[T](value: T) = {
    val obj = new RemoteImpl(value)
    cache.put(obj, new WeakReference(obj))
    obj
}

def replace[T](obj: Remote[T]): Object = {
    val w = cache.get(obj)
    if (w == null) obj else {
        val o = w.get()
        if (o == null) obj else o
    }
}
```

It must be noted that since \texttt{Remote} is the only RMI object that will have to be synthesized in our setting, the manipulation is done once and for all.

7. Discussion

The \texttt{Remote} monad operates synchronously, which means calls to methods \( \text{map} \) and \( \text{flatMap} \) are blocking. To avoid network delays, it is relevant to make it asynchronous. It turns out to be one more feature that can be factored out and implemented separately, namely using the Future monad (Haller et al. 2012). By prepending the \texttt{Async} adapter below to the \texttt{Remote} monad, the resulting model is semantically close to Future, that is, execution is done in parallel on a different thread/processor, just also on a different host.

```scala
class Async[T](val value:
    Future[Remote[T]]) {
    def map[S](f: T => S) = Async(value.map {
        remote => remote.map(f)
    })
    def flatMap[S](f: T => Async[S]) =
        Async(value.map {
            remote => remote.flatMap {
                t => Await.result(f(t).value,
                    Duration.Inf)
            }
        })
    def get = value.map {
        remote => remote.get
    }
}
```

Class \texttt{Async} takes a constructor argument of type \texttt{Future} of \texttt{Remote} and encapsulates it. Its method \( \text{map} \) forwards the
call to the Remote and re-encapsulates the result. So does method flatMap, but with a modified function argument that forces (awaits for) the returned Future. Method get again forwards the call to the Remote, that is, forces it (brings it locally). Its return value has type Future and can be used as is for further asynchronous operation, or forced to get the underlying value. Function apply below is overloaded to allow instantiation from both a Remote and a Future of Remote.

```scala
object Async {
  def apply[T](value: Remote[T]): Async[T] = apply(Future(value))
  def apply[T](value: Future[Remote[T]]) = new Async(value)
}
```

Likewise, the Function Passing model (Miller and Haller 2015) introduces a monadic remoting concept that is similar to ours, but that in addition features deferred application as one of its core principles, in order to save time and space. This feature can also be factored out and separated from purely remoting concerns, which is done through the Deferred adapter below.

```scala
class Deferred[U, T](val remote: Remote[U], val op: U => T) {
  def map[S](f: T => S) = Deferred(remote, f.compose(op))
  def flatMap[S](f: T => Deferred[U, S]) = f(get)
  def get = remote.map(op).get
}
```

Class Deferred takes a Remote and a function as constructor arguments. Value member `op` is used as an accumulator for functions passed to method `map`, which then re-encapsulates it together with the Remote object. Method `flatMap` just forces the monad and applies its function argument `f` to the result. Method `get` applies the accumulated function to the Remote object and forces it (brings it locally). Method `apply` is again overloaded, to allow initial instantiation from a Remote, and re-instantiations from the same Remote and a function accumulator `op`.

```scala
object Deferred {
  def apply[T](remote: Remote[T]): Deferred[T, T] = apply(remote, identity[T])
  def apply[U, T](remote: Remote[U], op: U => T) = new Deferred(remote, op)
}
```

### 8. Conclusion

We have presented a functional programming equivalent to Java’s Remote Method Invocation in the form of a Remote monad, which allows accessing existing business logic remotely without any change. By re-using RMI as the underlying network stack, the implementation was made straightforward and simple. We have shown how our setting can be easily adapted to reproduce the operation of similar models like the Future monad or the Function Passing model.

### References

P. Haller, A. Prokopec, H. Miller, V. Klang, R. Kuhn, and V. Jovanovic. Futures and promises. Technical report, http://docs.scala-lang.org/overviews/core/futures.html, 2012.

H. Miller and P. Haller. Function passing: A model for typed, distributed functional programming. Technical report, https://infoscience.epfl.ch/record/205822/files/f-p.pdf, 2015.

Wikipedia. Separation of concerns. Technical report, https://en.wikipedia.org/wiki/Separation_of_concerns, 2016.

A. Wolthath, R. Riggs, and J. Waldo. A distributed object model for the java system. Technical report, https://pdos.csail.mit.edu/6.824/papers/waldo-rmi.pdf, 1996.