

# Programming Models and Languages for Distributed Computation

Christopher S. Meiklejohn  
Université catholique de Louvain  
Louvain-la-Neuve, Belgium  
`christopher.meiklejohn@gmail.com`

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# 1 Promises

## 1.1 Relevant Reading

- *Promises: linguistic support for efficient asynchronous procedure calls in distributed systems*, Liskov and Shriram, PLDI 1988 [8].
- *Multilisp: A language for concurrent symbolic computation*, Halstead, TOPLAS 1985 [5].

## 1.2 Commentary

Outside of early mentions from Friedman and Wise on a *cons* cell with placeholder values [4] and Baker and Hewitt’s work on incremental garbage collection [1], *futures* originally appeared as one of the two principal constructs for parallel operations in MultiLisp. MultiLisp attempted to solve a main challenge of designing a language for parallel computation: how can parallel computation be introduced into a language in a way that fits with the existing programming paradigm. This problem is motivated by the fact that computer programmers will need to introduce concurrency into applications because automated analysis may not be able to identify all of the points for parallelism. Halstead decides there is quite a natural fit with a Lisp/Scheme: expression evaluation can be done in parallel. MultiLisp introduces two main concepts: *pcall*, to evaluate the expressions being passed to a function in parallel and introduce concurrency into evaluation of arguments to a function, and *futures*, to introduce concurrency between the computation of a value and the use of that value. Halstead also notes that futures closely resemble the “eventual values” in Hibbard’s Algol 68, however were typed distinctly from the values they produced and later represented. [5]

In 1988, Liskov and Shriram introduce the concept of a *promise*: an efficient way to perform asynchronous remote procedure calls in a type-safe way [8]. Simply put, a promise is a placeholder for a value that will be available in the future. When the initial call is made, a promise is created and the asynchronous call to compute the value of the promise runs in parallel with the rest of the program. When the call completes, the value can be “claimed” by the caller.

An excerpt motivation from *Promises: linguistic support for efficient asynchronous procedure calls in distributed systems* (Liskov and Shriram, PLDI 1988):

“Remote procedure calls have come to be the preferred method of communication in a distributed system because programs that use procedures are easier to understand and reason about than those that explicitly send and receive messages. However, remote calls require the caller to wait for a reply before continuing, and

therefore can lead to lower performance than explicit message exchange.”

The general motivation behind the work by Liskov and Shriram can be thought as the following critiques of two models of distributed programming.

- The Remote Procedure Call (RPC) paradigm is preferable by programmers because it is a familiar programming model. However, because of the synchronous nature of RPC, this model does not scale in terms of performance.
- The message passing paradigm is harder for programmers to reason about, but provides the benefit of decoupling of request and response, allowing for asynchronous programming and the subsequent performance benefits.

*Promises* attempts to bridge this gap by combining the remote procedure call style of building applications, with the asynchronous execution model seen in systems that primarily use message passing.

The first challenge in combining these two programming paradigms for distributed programming is that of order. Synchronous RPC imposes a total order across all of the calls in an application: one call will fully complete, from request to response, before moving to the next call, given a single thread of execution. If we move to an asynchronous model of RPC, we must have a way to block for a given value, or result, of an asynchronous RPC if required for further processing.

*Promises* does this by imagining the concept of a *call-stream*. A *call-stream* is nothing more than a stream of placeholder values for each asynchronous RPC issued by a client. Once a RPC is issued, the *promise* is considered *blocked* as asynchronous execution is performed, and once the value has been computed, the *promise* is considered *ready* and the value can be *claimed* by the caller. If an attempt to *claim* the value is issued before the value is computed, execution blocks until the value is available. The stream of placeholder values serves as an implicit ordering of the requests that are issued; in the Argus system that served as the implementation platform for this work, multiple streams were used and related operations sequenced together in the same stream<sup>1</sup>.

### 1.3 Impact and Implementations

While promises originated as a technique for decoupling values from the computations that produced them, promises, as proposed by Liskov and

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<sup>1</sup>Promises also provide a way for stream composition, where processes read values from one or more streams once they are *ready*, fulfilling placeholder *blocked* promises in other streams. One classic implementation of stream composition using *promises* is the Sieve of Eratosthenes.

Shrira mainly focused on reducing latency and improving performance of distributed computations. The majority of programming languages in use today by practitioners contain some notion of *futures* or *promises*. Below, we highlight a few examples.

The Oz [7] language, designed for the education of programmers in several different programming paradigms, provides a functional programming model with single assignment variables, streams, and promises. Given every variable in Oz is a dataflow, and therefore every single value in the system is a promise. Both Distributed Oz [6] and Derflow (an implementation of Oz in the Erlang programming language) [3] provide distributed versions of the Oz programming model. The Akka library for Scala also provides Oz-style dataflow concurrency with Futures.

More recently, promises have been repurposed by the JavaScript community to allow for asynchronous programs to be written in direct style instead of continuation-passing style. ECMAScript 6 contains a native Promise object, that can be used to perform asynchronous computation and register callback functions that will fire once the computation either succeeds or fails [9].

## 2 Eden and Emerald

### 2.1 Relevant Reading

- *The development of the Emerald programming language*, Black, Andrew P and Hutchinson, Norman C and Jul, Eric and Levy, Henry M, HOPL 2007 [2].

### 2.2 Commentary

The Eden Programming Language (EPL) was a distributed programming language developed on top of Concurrent Euclid that extended the existing language with support for remote method invocations. However, this support was far from ideal: incoming method invocation requests would have to be received and dispatched by a single thread while the programmer making the request would have to manually inspect error codes to ensure that the remote invocation succeeded.

Eden also provided location-independent mobile objects, but the implementation was extremely costly. In the implementation, each object was a full Unix process that could send and receive messages to each other: these messages would be sent using interprocess communication if located on the same node, resulting on latencies in the milliseconds. Eden additionally implemented a “kernel” object for dispatching messages between processes, resulting in a single message between two objects on the same system taking over 100 milliseconds, the cost of two context switches at the

time. To make applications developed in EPL more efficient, application developers would use a lightweight heap-based object implemented in Concurrent Euclid (that, appeared as a single Eden object consuming a single Unix process) for objects that needed to communicate, but were located on the same machine, that would communicate through shared memory. Obviously, the next problem follows naturally: the single abstraction provided resulted in extremely slow applications, so, a new abstraction was provided to compensate, and the user is now left having to program with two object models.

In a legendary memo entitled “Getting to Oz”, the language designers of Eden and the soon-to-be language designers began discussions to improve the design of Eden. This new language would be entitled “Emerald”<sup>2</sup>.

We enumerate here the list of specific goals the language designers had for Emerald, outside of the general improvements they wanted to make on Eden.

1. Convinced distributed objects were a good idea and the right way to construct distributed programs, they sought to *improve the performance of distributed objects*.
2. Objects should stay relatively cost-free, for instance, if they do not take advantage of distribution: *no-use, no-cost*.
3. *Simplify* and reduce the dual object model, remove explicit dispatching, error handling and other warts in the Eden model.
4. To support *the principle of information hiding* and have a single semantics for both large and small, local or distributed, objects.
5. Distributed programs can fail: the network can be down, a service can be unavailable, and therefore a language for building distributed applications needs to *provide the programmer tools for dealing with these failures*.
6. *Minimization of the language* by removing many of the features seen in other languages and building abstractions that could be used to extend the language.
7. *Object location needs to be explicit* even as much as the authors wanted to follow the *principle of information hiding* as it directly impacts performance. Objects should be able to move, but moving an object should not change the operational semantics of the language<sup>3</sup>.

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<sup>2</sup>As in, the Emerald city from the “Wizard of Oz” referencing the original runtime for the Oz language “Toto”, and the nickname for Seattle

<sup>3</sup>This dichotomy is presented as the *semantics* vs. the *locatics* of the language and the authors soon realized that one aspect of the language influenced both of these: failures.

## 2.3 Impact and Implementations

Emerald made several technical innovations that we will present below.

The authors of Eden and Emerald express an extremely interesting point early on in their paper on the history of Emerald [2]: the reason for the poor abstractions requiring manual dispatch of method invocations to threads, and the explicit error handling from network anomalies, was because as researchers working on a language, *they were not implementing distributed applications themselves*. To quote the authors:

“Eden team had real experience with writing distributed applications, we had not yet learned what support should be provided. For example, it was not clear to us whether or not each incoming call should be run in its own thread (possibly leading to excessive resource contention), whether or not all calls should run in the same thread (possibly leading to deadlock), whether or not there should be a thread pool of a bounded size (and if so, how to choose it), or whether or not there was some other, more elegant solution that we hadn't yet thought of. So we left it to the application programmer to build whatever invocation thread management system seemed appropriate: EPL was partly a language, and partly a kit of components. The result of this approach was that there was no clear separation between the code of the application and the scaffolding necessary to implement remote calls.”

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