The essence of component-based design and coordination

Raphael 'kena' Poss
University of Amsterdam, The Netherlands

June 17, 2013

Abstract

Is there a characteristic of coordination languages that makes them qualitatively different from general programming languages and deserves special academic attention? This report proposes a nuanced answer in three parts. The first part highlights that coordination languages are the means by which composite software applications can be specified using components that are only available separately, or later in time, via standard interfacing mechanisms. The second part highlights that most currently used languages provide mechanisms to use externally provided components, and thus exhibit some elements of coordination. However not all do, and the availability of an external interface thus forms an objective and qualitative criterion that distinguishes coordination. The third part argues that despite the qualitative difference, the segregation of academic attention away from general language design and implementation has non-obvious cost trade-offs.

Contents

1 Motivation

During the period 2012-2013 the author was spectator to the evolution of S-Net [4, 3, 2], a programming language for streaming networks. To this author, a characteristic feature of the research activities around S-Net is the insistence that "S-Net is a coordination language," which pitches S-Net implicitly against "regular programming languages" and suggests that programming for coordination is somehow different from programming for computation.

Meanwhile, the EU-funded project ADVANCE has been supporting effort to optimize the execution of S-Net programs on multi-core computers. During this effort, it has become apparent that S-Net suffers from similar technical issues as the "regular programming languages" it is usually pitched against, namely in two areas: time and space scheduling, and memory allocation. In particular, ADVANCE has revealed a striking overlap of issues and their potential solutions between S-Net and Single-Assignment C, a functional language developed by the same researchers.

This author estimates that this convergence of research issues has caused an *identity crisis* of sorts around S-Net. The crisis was especially visible during a technical meeting in early June 2013, where Alex Shafarenko, designer of S-Net, was failing to convince Kath Knobe, designer of Intel's Concurrent Collections, about what makes coordination fundamentally special.

The crux of the argument was to determine whether the existence of a mechanism to define "black boxes" in a language is a clear criterion that separates coordination languages from other languages. The counter argument was that most languages, including C, Single-Assignment C, Haskell and all those mentioned during the discussion, also enable a programmer to define black boxes at any level of abstraction. By this counter argument, all these language are also coordination languages as well.

The reason why this discussion matters is that the existence of a criterion to identify coordination is a prerequisite to motivate research specialized in "coordination languages and systems" and justify a specialized branch of research and expertise, separate from general programming language design and implementation. Without this conceptual frontier, there would be little remaining justification to continue further effort in developing S-Net and its derived technologies, or requesting funding to that effect.

In this particular discussion, the participating individuals eventually agreed that they have observed *perceived merit* in their work from their community. From then, they were able to conclude that their work must be worthy of further effort, even though they could not clearly *express* why at the time.

This situation was uncomfortable to this author from a conceptual perspective, and this discomfort motivated the production of the present technical report. In the following sections, we propose a formulation of the essence of component-based design (section 2), including the distinction between component specification and instantiation (section 3), and the essence of coordination (section 4). We then discuss the trade-offs of specializing research towards coordination systems in section 5.

Abstraction	How interfaces are defined	How implementations are defined
Classes (OOP)	Method interface	Method code and attributes
Functions (FP)	Function signature	Function code
Unix commands	Manual page (list of command-line arguments and program description)	Executable file
Network service	Protocol	Service implementation
Hardware	Signalling specification	Logic design

Table 1: How components are defined in different paradigms

2 Component-based design

The word "component" is both versatile and usually well-understood. A simple definition can be found in [1]: components are defined by their *interface*, which specifies how they can be used in applications, and one or more *implementations* which define their actual behavior.

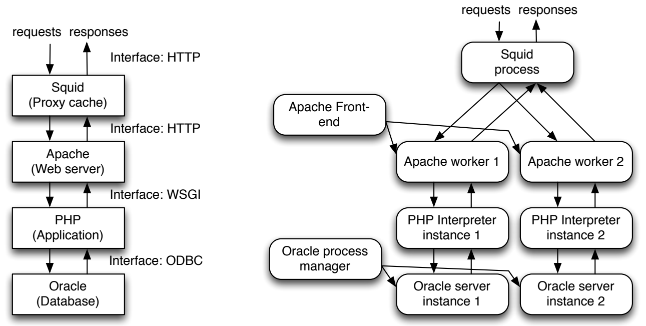
The two general principles of *component-based design* are then phrased as follows. The first is *interface-based integration*: when a designer uses a component for an application, he agrees to only assume what is guaranteed from the interface, so that another implementation can be substituted if needed without changing the rest of the application. The second is *reusability*: once a component is implemented, a designer can reuse the component in multiple applications without changing the component itself.

Component-based design is embedded in different programming paradigms using different abstractions. For example, in object-oriented languages, classes define components: the set of methods defines the component interface, and the set of attributes and method implementations define the component implementation. In functional languages, individual functions can be seen as components: the function signature (list of argument and return types) define its interface, whereas the function definition ("right-hand side") defines its implementation. Other examples are given in table 1.

3 Component specifications and instances

We also need to acknowledge a further distinction which is less commonly found discussed: the difference between *component specification* and *component instance.*

To illustrate our distinction, we can consider the perspective of a software engineer tasked with designing a web CRM, who decides to realize the work by combining a proxy cache, a web server, PHP and a database server. From this engineer's perspective, the "advertised" structure of the application is likely to conform to fig. 1a, which highlights the logical relationship between the 4 components the engineer has reused. In contrast, the system administrator who observes the application at run-time may instead observe the situation described in fig. 1b. Here, contrary to the "abstract" specification in fig. 1a, the Squid proxy process does not communicate with the Apache server directly; instead it communicates with two worker instances spawned by the Apache server. Each



(a) Specification of a web CRM.

(b) A particular instance of the web CRM.

Figure 1: Specification and instance of a web CRM.

Conceptual domain	Word for blueprint	Word for real-world reification
Object-oriented programming	“class”	“object”
Functional programming	“function”	“activation record”
Operating systems	“program”	“process”
Software builds	“source code”	“object code”
Instruction execution	“executable code”	“instruction stream”
Computer architecture	“design”	“implementation”
Simulation	“model”	“simulator”
Parsers	“grammar”	“parse tree”
Component-based design	**“specification”**	**“instance”**

Table 2: Vocabulary for models and instances

worker instance has in turn spawned its own PHP process to process its incoming requests. On the database side, a duplication has also occurred: each time a PHP process requests an ODBC connection, Oracle creates a new server process specific to that connection. In this run-time scenario, 9 components are involved instead of 4.

In the rest of this discussion we name *component specification* the result of the design work by the programmer, and *component instance* the real-world representation of a specification at run-time. As the previous example shows, each instance is indirectly “caused by” one specification, but a single specification may “cause” multiple instances. Again, the distinction between specification and instance is found in many shapes across computing domains; related terms are given in table 2.

A reason why this distinction is often not needed or used is that most systems traditionally have a one-to-one mapping between specifications and instances. In the example above, in the early age of the Internet the specification would be reified using exactly one Squid process, one Apache process, one PHP interpreter and one Oracle process. Both the application programmer and the system administrator could then use the same words “the Apache server” to designate either the specification or the instance, using context to disambiguate meaning.

4 Coordination vs. computation

Beyond the basic definitions of components, component-based design relies on *compositionality*: defining new aggregate or *composite* components built out of sub-components. To achieve this, an application designer works in a *coordination environment* which provides both facilities to specify composites, i.e. a *coordination language*, and to run these composite specifications, i.e. a *coordinating run-time system.*

The characteristic of coordination environments is that they can be fully defined and implemented before the library of actual primitive components is known. This can be illustrated with the example of Unix. With Unix, an operating system kernel can be implemented to run commands from disk before the commands themselves are implemented. Moreover, both Unix "shell" interpreters and scripts can be implemented and validated, also independently from the commands they will invoke at run-time.

This separation is possible because *interfaces in component specifications map to interfacing mechanisms between component instances* at run-time. With Unix, command-component interfaces are specified via their acceptable command-line arguments and how they promise to behave with regards to network, file, signal and IPC operations. At run-time, these specifications are mapped to uses of system calls.

A coordination environment is thus composed of:

- a *run-time system* where execution occurs, which can be extended with new components after the system is implemented;
- a *coordination language*, where a designer can specify external primitive components by interface only, and composites thereof;
- an *interfacing mechanism* in the run-time environment, between the coordination system and component implementations;
- *language semantics that guarantee common run-time properties over composites*, without requiring a full definition of the primitive components (since this definition may not be known at specification time).

Environment	Coordination language	Specification construct for external primitive components	Run-time mechanism for interfacing
POSIX	POSIX API	`fork`/`exec`	File, network, signal and IPC system calls
GHC and run-time	Haskell	`foreign`	Any of C/C++, .NET, JVM, Windows or other system-specific ABI call conventions
.NET	C#, F#, VB# etc.	`DllImport`/`extern`	Dynamic linker and standard call convention
C	C	`extern`	Static linker and ABI call convention
C	C	`asm`	Processor's Instruction Set Artchitecture
C/Unix	C	`dlopen`/`dlsym`	Dynamic linker and ABI call convention
JVM	Java, Scala	`native`	Linker and ABI call convention
Common LISP	LISP	`defctype`, `defcfun`	Linker and ABI call convention
CPython	Python	`import`	Linker and ABI call convention
S-Net and run-time	S-Net	`box`	Linker and ABI call convention

Table 3: How existing programming environments provide interfaces for externally defined primitive components

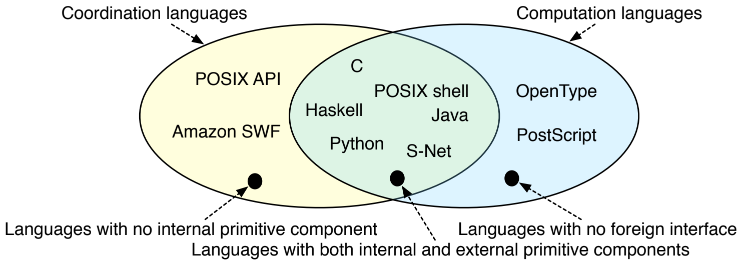


Figure 2: Coordination vs. computation: a Venn diagram

This definition partly contrasts with what we can call "computation" languages. The part of a language dedicated to computation requires that the language semantics fully define how to manipulate *data values* and how to explicitly express them using *literals* within the language. However, most programming languages oriented towards computation are actually implemented using a coordination environment. For example, C programs can use `extern` definitions and the `asm` statement to compose behavior from components only known in the execution environment. Other examples are given in table 3.

In other words, coordination environments are a subset of programming environments, which *also* contain computation environments. This relationship is illustrated in fig. 2.

The availability of a foreign interface depends on the language, and without it a computation language cannot be used for coordination. For example, PostScript lacks the ability to define components externally and is thus "only" a computation language.

Complementarily, a language may offer a foreign interface but no expressivity to express computations "within it". This is the case of Amazon's Software Workflow Framework[1], as of this writing, which only manipulates services defined externally. This type of language can thus be called "purely coordinating." Note that S-Net, which is usually "marketed" as a coordination language, does provide facilities to express literals and compute over them (record tags and filters) and can thus be used for computation without using external primitive components at all.

5 Discussion

Perhaps unsurprisingly, the formulation so far confirms the idea that most programming languages contain some elements of coordination. However, it also confirms that coordination can be recognized using a clear-cut criterion.

This criterion is whether the language designer enables a programmer to *import and use new primitive components not defined by the language itself and which may only be fully known in the run-time environment.* Using this criterion, one can recognize that PostScript, for example, does not support coordination.

However, the fact remains that most languages contain both elements of computation and coordination. Also, the expressive power of a language focused on coordination can be equally well be constructed using abstractions within a

---

[1] `https://aws.amazon.com/swf/`

language focused on computation that also provides a foreign interface. The two fundamental questions that motivated this analysis thus remain:

1. is there room in the technology landscape for languages and run-time systems designed and advertised mainly towards coordination?
2. if so, should they be implemented using their own technology stack, or instead as libraries of constructed abstractions within established languages?

There are two arguments in favor of the first point. One is that industrial software engineering acknowledges, supports and extensively exploits black-box design when designing large applications. This audience may find interest in technology that acknowledges componentization and promotes willful ignorance of component definitions while specifying composites. The other argument is reuse: it is a fact that software components already exist in different languages, and coordination technology that can integrate them together enables more reuse.

There are also two arguments against. One is that different languages create fragmentation of expertise in the population of programmers and subsequently effort duplication: common coordination features end up being implemented both as features of coordination languages and as libraries in computation languages. This translated to redundancy of human effort. The second is that systematic componentization creates an artifical barrier to cross-layer optimizations, for example inter-procedural optimizations in a compiler between the procedures of different components. In other words, componentization is a likely source of run-time inefficiency.

From the implementation perspective (the second point mentioned above), the argument in favor of a separate technology is one of research efficiency. Indeed, in a research environment, time and effort are precious. The luxury of a specialized implementation enables researchers to focus on issues specific to coordination, without requiring them to care about integration in a more general language whose implementation is thus also necessarily more complex.

The argument against is, again, fragmentation of expertise. When embedding coordination in an existing language substrate, research projects can recruit new members from the pool of existing programmers acquainted with that language's implementations. If the substrate language and implementations are different/new, recruiting is more difficult and/or implies more training overhead.

The discussion about the consequence of these trade-offs on the future of S-Net and related work lies outside the scope of this report.

6 Conclusion

This report has confirmed the existence of a view in which coordination languages and programming languages are not two disjoint sets. Programming for coordination can be seen as a mere *style* of programming, which requires a *technical* means by which composite software applications can be specified using components that are only available separately, or later in time. This technical means is the availability of a foreign component interface in the language, and we propose to call "coordination languages" those language who provide this facility.

Meanwhile, most currently used languages provide foreign interfaces, and thus exhibit some elements of coordination. However not all do, and the availability of a foreign interface thus forms an objective and qualitative criterion to identify languages that can be used for coordination.

However, despite the availability of a clear-cut qualitative definition of coordination, the segregation of academic attention away from general language design and implementation has non-obvious cost/benefit trade-offs, mostly related to duplication of effort and skill fragmentation across language boundaries.

Acknowledgements

This document reports on thoughts nurtured during successive discussions with Merijn Verstraaten, Alex Shafarenko, Sven-Bodo Scholz, Kath Knobe, Roy Bakker, Michiel W. van Tol and Sebastian Altmeyer.

References

[1] Don Batory and Sean O'Malley. The design and implementation of hierarchical software systems with reusable components. *ACM Trans. Softw. Eng. Methodol.*, 1(4):355–398, 1992. ISSN 1049-331X. `doi:10.1145/136586.136587`.

[2] Clemens Grelck, Sven-Bodo Scholz, and Alex Shafarenko. Asynchronous stream processing with S-Net. *International Journal of Parallel Programming*, 38(1):38–67, 2010. `doi:10.1007/s10766-009-0121-x`.

[3] Frank Penczek, Jukka Julku, Haoxuan Cai, Philip Kaj Ferdinand Hölzenspies, Clemens Grelck, Sven-Bodo Scholz, and Alex Shafarenko. S-Net language report, version 2.0. Technical Report 499, University of Hertfordshire, School of Computer Science, Hatfield, AL10 9AB, United Kingdom, April 2010.

[4] Alex Shafarenko. Non-deterministic coordination with S-Net. In Wolfgang Gentzsch, Lucio Grandinetti, and Gerhard Joubert, editors, *High Speed and Large Scale Scientific Computing*, number 18 in Advances in Parallel Computing. IOS Press, 2009. ISBN 978-1-60750-073-5. `doi:10.3233/978-1-60750-073-5-74`.