Automatic pipeline distribution for monolithic web applications : Toward a better compromise between development scalability and performance scalability not definitive

Etienne Brodu

May 16, 2015

Abstract

TODO

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2.1 Javascript

2.1.1 Explosion of Javascript popularity

2.1.1.1 In the beginning

Javascript was created by Brendan Eich at Netscape around May 1995, and released to the public in September. The initial name of the project was Mocha, then LiveScript, the name Javascript was finally adopted to leverage the trend around Java. The latter was considered the hot new web programming language at this time. It was quickly adopted as the main language for web servers, and everybody was betting on pushing Java to the client as well. The history proved them wrong.

In 1995, when Javascript was released, the world wide web started its wide adoption.[1] Browsers were emerging, and started a battle to show off the best features and user experience to attract the wider public.[2] Microsoft released their browser Internet Explorer 3 in June 1996 with a concurrent implementation of Javascript. They changed the name to JScript, to avoid trademark conflict with Oracle Corporation, who owns the name Javascript. The differences between the two implementations made difficult for a script to be compatible to both. At the time, signs started to appear on web pages to warn the user about the ideal web browser to use for the best experience on this page. This competition was fragmenting the web.

[1] `http://www.internetlivestats.com/internet-users/`

[2] to get an idea of the web in 1997 : `http://1x-upon.com/`

To stop this fragmentation, Netscape submitted Javascript to Ecma International for standardization in November 1996. In June 1997, ECMA International released ECMA-262, the first specification of ECMAScript, the standard for Javascript. A standard to which all browser should refer for their implementations.

The base for this specification was designed in a rush. The version released in 1995 was finished within 10 days. Because of this precipitation, the language has often been considered poorly designed and unattractive. Moreover, Javascript was intended to be simple enough to attract unexperienced developers, by opposition to Java or C++, which targeted professional developers. For these reasons, Javascript started with a poor reputation among the developer community.

But things evolved drastically since. When a language is released, available freely at a world wide scale, and simple enough to be handled by a generation of teenager inspired by the technology hype, it produce an effervescent community around what is now one of the most popular and widely used programming language.

2.1.1.2 Rising of the unpopular language

Javascript started as a programming language to implement short interactions on web pages. The best usage example was to validate some forms on the client before sending the request to the server. This situation hugely improved since the beginning of the language. So much that web-based, Javascript applications are currently now favored instead of rich, native desktop applications.

ECMA International released several version in the few years following the creation of Javascript. The first and second version, released in 1997 and 1998, brought minor revisions to the initial draft. However, the third version, released in the late 1999, contributed to give Javascript a more complete and solid foundation as a programming language. From this point on, the consideration for Javascript keep improving.

An important reason for this reconsideration started in 2005. James Jesse Garrett released *Ajax: A New Approach to Web Applications*, a white paper coining the term Ajax [**Garrett2005**]. This paper point the trend in using this technique, and explain the consequences on user experience. Ajax stands for Asynchronous Javascript And XML. It consists of using Javascript to dynamically request and refresh the content of a web page. The advantage

is that it avoids to request a full page from the server. Javascript is not anymore confined to the realm of small user interactions on a terminal, it can be proactive and responsible for a bigger part in the system spanning from the server to the client. Indeed, this ability to react instantly to the user started to narrow the gap between web and native applications. At the time, the first web applications to use Ajax were Gmail, and Google maps[3].

Around this time, the Javascript community started to emerge. The third version of ECMAScript had been released, and the support for Javascript was somewhat homogeneous on the browsers but far from perfect. Moreover, Javascript is only a small piece in the architecture of a web-based client application. The DOM, and the `XMLHttpRequest` method, two components on which AJAX relies, still present heterogeneous interfaces among browsers. To leverage the latent capabilities of Ajax, and more generally of the web, Javascript framework were released with the goal to straighten the differences between browsers implementations. Prototype[4] and DOJO[5] are early famous examples, and later jQuery[6] and underscore[7]. These frameworks are responsible in great part to the wide success of Javascript and of the web technologies.

In the meantime, in 2004, the Web Hypertext Application Technology Working Group[8] formed to work on the fifth version of the HTML standard. This new version provide new capabilities to web browsers, and a better integration with the native environment. It features geolocation, file API, web storage, canvas drawing element, audio and video capabilities, drag and drop, browser history manipulation, and many mores It gave Javascript the missing pieces to become a true language for developing rich application. The first public draft of HTML 5 was released in 2008, and the fifth version of ECMAScript was released in 2009. With these two releases, ECMAScript 5 and HTML5, it is a next step toward the consideration of Web-based technologies as equally capable, if not more, than native rich applications on the desktop. Javascript became the programming language of this rising application platform.

[3] A more in-depth analysis of the history of Ajax, given by late Aaron Swartz `http://www.aaronsw.com/weblog/ajaxhistory`

[4] `http://prototypejs.org/`

[5] `https://dojotoolkit.org/`

[6] `https://jquery.com/`

[7] `http://underscorejs.org/`

[8] `https://whatwg.org/`

However, if web applications are overwhelmingly adopted for the desktop, HTML5 is not yet widely accepted as ready to build complete application on mobile, where performance and design are crucial. Indeed web-technologies are often not as capable, and well integrated as native technologies. But even for native development, Javascript seems to be a language of choice. An example is the React Native Framework[9] from Facebook, which allow to use Javascript to develop native mobile applications. They prone the philosophy *"learn once, write anywhere"*, in opposition to the usual slogan *"write once, run everywhere"*.[10]

2.1.1.3 Current situation

"When JavaScript was first introduced, I dismissed it as being not worth my attention. Much later, I took another look at it and discovered that hidden in the browser was an excellent programming language."

—Douglas Crockford

The success of Javascript is due to many factors ; I mentioned previously the standardization, Ajax libraries and HTML5. Another factor, maybe the most important, is the View Source menu that reveals the complete source code of any web application. *The view source menu is the ultimate form of open source*[11]. It is the vector of the quick dissemination of source code to the community, which picks, emphasizes and reproduces the best techniques. This brought open source and collaborative development before github. TODO neither open source nor collaborative development are the correct terms Moreover, all modern web browsers now include a Javascript interpreter, making Javascript the most ubiquitous runtime in history [**Flanagan2006**].

When a language like Javascript is distributed freely with the tools to reproduce and experiment on every piece of code. When this distribution is carried during the expansion of the largest communication network in history. Then an entire generation seizes this opportunity to incrementally build and share the best tools they can. This collaboration is the reason for the popularity of Javascript on the Web.

[9] `https://facebook.github.io/react-native/`

[10] Used firstly by Sun for Java, but then stolen by many others

[11] `http://blog.codinghorror.com/the-power-of-view-source/`

It seems to also infiltrate many other fields of IT, but it is hard to give an accurate picture of the situation. There is no right metrics to measure programming language popularity. In the following paragraphs, I report some popular metrics and indexes available on the net. More detailed informations are available section A.

Search engines The TIOBE Programming Community index is a monthly indicator of the popularity of programming languages. It uses the number of results on many search engines as a measure of the activity of a programming language. Javascript ranks 6th on this index, as of April 2015, and it was the most rising language in 2014. However, the measure used by the TIOBE is controversial. Some says that the measure is not representative. It is a lagging indicator, and the number of pages doesn't represent the number of readers.

On the other hand, the PYPL index is based on Google trends to measure the activity of a programming language. Javascript ranks 7th on this index, as of May 2015.

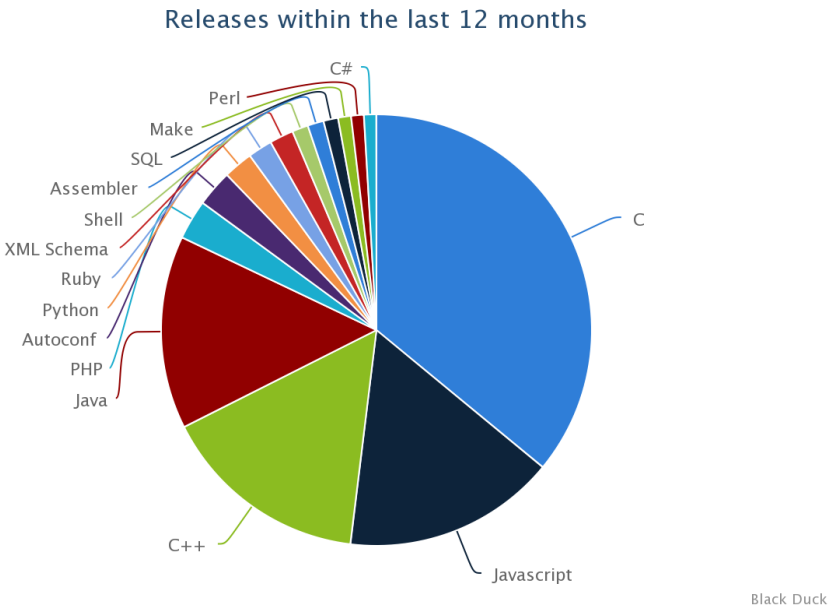
From these indexes, the major programming languages are Java, C/C++ and C#. The three languages are still the most widely taught, and used to write softwares. But Javascript is rising to become one of these important languages.

Developers collaboration platforms Github is the most important collaborative development platform, with around 9 millions users. Javascript is the most used language on github since mid-2011, with more than 320 000 repositories. The second language is Java with more than 220 000 repositories.

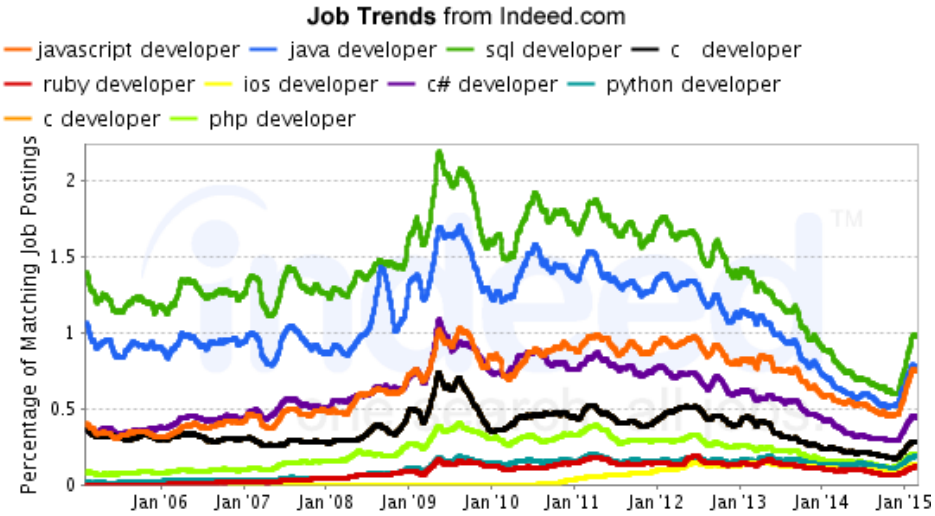
TODO : graph of Github repositories by languages

StackOverflow, is the most important Q&A platform for developers. It is a good representation of the activity around a language. Javascript is the second language showing the most activity on StackOverflow, with more than 840 000 questions. The first one is Java with more than 850 000 questions.

Black Duck knowledgebase analyzes 1 million repositories over various forges, and collaborative platforms to produce an index of the usage of programming language in open source communities. Javascript ranks second. C is first, and C++ third. Along with Java, the four first languages represent about 80% of all programming language usage.



Jobs All these metrics are representing the visible activity about programming language. But not the entire software industry is open source, and the activity is rather opaque. To get a hint on the popularity of programming languages used in the software industry, let's look at the job offerings. Indeed provide some insightful trends. Javascript developers ranked at the third position, right after SQL developers and Java developers. Then come C# and C developers.



All these metrics represent different faces of the current situation of Javascript adoption. We can safely say that Javascript is one of most important language of this decade, along with Java, C/C++. It is widely used in open source projects, and everywhere on the web. But it is also trending, and maybe slowly replacing languages like Java.

Future trends TODO

Code reuse. Why it never worked ?

em-scripten

https://github.com/kripken/emscripten Javascript is a target language for LLVM, therefor everything can compile to Javascript : JS is the assembler of the web.

Isomorphic Javascript

Server-side Javascript

https://www.meteor.com/ https://facebook.github.io/flux/ Javascript can be executed both on the client and the server. That allow use-cases never possible before (server pre-rendering, same team ...)

Reactive

http://facebook.github.io/react/ Javascript is used to model the flow of propagation of state in a web application

—

Some facts to include : https://www.destroyallsoftware.com/talks/the-birth-and-death-of-javascript The Atom editor is written in Javascript node.js. Now, major PaaS (which one) support node.js by default. Heroku support

Python, Java, Ruby, Node.js, PHP, Clojure and Scala Amazon Lambda Web service support node.js in priority. npm raises 8m. http://techcrunch.com/2015/04/14/popular-javascript-package-manager-npm-raises-8m-launches-private-modules/

2.1.2 Overview of the language

Javascript was released in a hurry, without a strong and directive philosophy. During its evolution, it snowballed with different features to accommodate the community, and the usage it was made on the web. As a result Javascript contains various, and sometimes conflicting, programming paradigms. It borrow its syntax from a procedural language, like C, and the object notation from an object-oriented language, like Java, but it provides a different inheritance mechanism, based on prototypes. Most of the implementation adopt an event-based paradigm, like the DOM[12] and node.js[13]. And finally, event though it is not purely functional like Haskel, Javascript borrows some concepts from functional programming.

In this section, we focus on the last two programming paradigm, functional programming and event-based programming. Javascript exposes two features from functional programming that are particularly adapted for event-based programming. Namely, it treats functions as first-class citizen, and allows them to close on their defining context, to become closures.

2.1.2.1 Functions as First-Class citizens

"All problems in computer science can be solved by another level of indirection"

—Butler Lampson

Javascript treats function as first-class citizens. One can manipulate functions like any other type (number, string ...). She can store functions in variables or object properties, pass functions as arguments to other functions, and write functions that return functions.

The most common usage examples of these features, are the methods `Map`, `Reduce` and `filter`. In the example below, the method `map` expect a function to apply on all the element of an array to modify its content, and

[12] `http://www.w3.org/DOM/`
[13] `https://nodejs.org/`

output a modified array. A function expecting a function as a parameter is considered to be a higher-order function. `Map`, `Reduce` and `Filter` are higher-order functions.

```
[4, 8, 15, 16, 23, 42].map(function firstClassFunction(element) {
  return element + 1;
});
// -> [5, 9, 16, 16, 24, 43]
```

Higher-order functions provide a new level of indirection, allowing abstractions over functions. To understand this new level of abstraction, let's briefly summarize the different abstractions on the execution flow offered by programming paradigms. In imperative programming, the control structures allow to modify the control flow. That is, for example, to execute different instructions depending on the state of the program. Procedural programming introduces procedures, or functions. That is the possibility to group instructions together to form functions. They can be applied in different contexts, thus allowing a new abstraction over the execution flow.

So, higher-order functions add another level of abstraction. It allows to dynamically modify the control of the execution flow. The ability to manipulate functions like any other value allows to abstract over functions, and behavior.

Higher-order functions replace the needs for some Object oriented programming design patterns.[14] Though object oriented programming doesn't exclude higher-order functions.

They are particularly interesting when the behavior of the program implies to react to inputs provided during the runtime, as we will see later. Web servers, or graphical user interfaces, for examples, interact with external events of various types.

2.1.2.2 Lexical Scoping

Closures are indissociable from the concept of lexical environment. To understand the former, it is important to understand the latter first.

Lexical environment A variable is the very first level of indirection provided by programming languages and mathematics. It is is a binding between a name and a value. Mutable like in imperative programming to represent the reality of memory cells, or immutable like in mathematics and functional

[14] `http://stackoverflow.com/a/5797892/933670`

programming. These bindings are created and modified during the execution. They form a context in which the execution takes place. To compartmentalize the execution, a context is also compartmentalized. A certain context can be accessed only by a precise portion of code. Most languages defines the scope of this context using code blocks as boundaries. That is known as lexical scoping, or static scoping. The variables declared inside a block represent the lexical environment of this block. These lexical environments are organized following the textual hierarchy of code blocks. The context available from a certain block of code, that is set of accessible variable, is formed as a cascade of the current lexical environment and all the parent lexical environment, up to the global lexical environment.

Javascript lexical environment [15]

Javascript implement lexical scoping with function definitions as boundaries, instead of code blocks. The code below show a simple example of lexical scoping in Javascript.

```
1  var a = 4;
2  var c = 6;
3  function f() {
4    var b = 5;
5    var c = 0;
6    // a and b are accessible here.
7    return a + b + c;
8  }
9
10 f(); // -> 9
11
12 // b is not accessible here :
13 a + b + c; // -> ReferenceError: b is not defined
```

Lexical scoping, or statical scoping, implies that the lexical environment are known statically, at compile time for example. But Javascript is a dynamic language, it doesn't truly provide lexical scoping. In Javascript, the lexical environments can be dynamically modified using two statements : `with` and `eval`. We explain in details the Javascript lexical scope in section **??**

2.1.2.3 Closure

"An object is data with functions. A closure is a function with data."

[15] `http://www.ecma-international.org/ecma-262/5.1/#sec-10.2`

—John D. Cook

A closure is the association of a first-class function with its context. When a function is passed as an argument to an higher-order function, she closes over its context to become a closure. When a closure is called, it still has access to the context in which it was defined. The code below show a simple example of a closure in Javascript. The function `g` is defined inside the scope of `f`, so it has access to the variable `b`. When `f` return `g` to be assigned in `h`, it becomes a closure. The variable `h` holds a closure referencing the function `g`, as well as its context, containing the variable `b`. The closure `h` has access to the variable `b` even outside the scope of the function `f`.

```
function f() {
  var b = 4;
  return function g(a) {
    return a + b;
  }
}

var h = f();
// b is not accessible here :
b; // -> ReferenceError: b is not defined

// h is the function g with a closure over b :
h(5) // -> 9
```

2.2 Concurrency

Concurrency is time slicing or multi-threading)

2.2.1 Two concurrency model

2.2.1.1 Time-slicing

Task management

Stack management

2.2.1.2 Multi-Threading

Eventual Consistency

Event-based multi-threading

2.2.2 Event-loop

2.2.2.1 Turn-based programming

2.2.2.2 Promises

TODO

2.2.2.3 Generators

Generators are a way to implement synchronous programming on top of an event-loop (asynchronous programming), like fibers

Javascript, like most programming languages, is synchronous and non-concurrent. The specification doesn't provide any mechanism to write asynchronous nor concurrent execution of Javascript. There is no reference to `setTimeout` nor `setInterval`. These two well-known instructions to asynchronously post-pone execution are provided by the DOM. Indeed, like for many languages, concurrency is supported and provided by the execution engine. For example the JVM in the case of Java, or the operating system in the case of C/C++. These last two languages were mostly used to design CPU intensive applications. The concurrency model for such application is driven by the need for computing power. A concurrency model well adapted for such applications is the threading model. It allows to run multiple executions simultaneously to leverage the potential of parallel architectures, and execute faster. Execution engine provide thread libraries to allow concurrency, like pthreads[16] for POSIX operating systems, and the `Thread`[17] class for Java. But, as we will see in a next chapter, threads are known to be very difficult to manipulate. It is lucky that Javascript was not seen as a language to build CPU intensive applications, so it remained free of this concurrency model, and can adopt a different concurrency model.

Indeed, Javascript was used from the beginning to build graphical user interfaces. Since user interfaces evolved from a simple and sequential user prompt to a full interactive graphical space, the user interacts in a non-sequential way. The interface needs to display and react to multiple streams of interaction. It needs to keep one thread of execution for each stream of interaction. A GUI is only a particular case of a more general class of

[16] `https://computing.llnl.gov/tutorials/pthreads/`

[17] `https://docs.oracle.com/javase/7/docs/api/java/lang/Thread.html`

application : I/O bound application. Web servers also belong to this class of application.

The concurrency need is different for CPU bound applications and for I/O bound applications, and so are their concurrency model. CPU bound applications need several threads to span over several cores of executions, they use multi-threading, while I/O bound applications, need multiple threads to keep track of concurrent control flows in multiple contexts. The difference between the two needs is thin enough for one to be mistaken with the other.

Graphical user interfaces often use an event-loop, which

When an event-loop is used as the concurrency model for a partially functional language like Javascript, it creates what Douglas Crockford called turn-based programming[18].

As said above, most implementations of Javascript feature an event-based programming paradigm. The DOM[19] and node.js[20] are the most famous examples.

Now the browser has a thread-like concurrency model as well, on the form of web workers[21].

An event-loop answer a particular need of concurrency. It is designed to use a thread of execution, to several

The event-loop concurrency model is based around a queue of message, named the event-queue, and a thread of execution to process these messages, named the event-loop. The event-loop process the messages queued on the event-queue one after the other, each during a turn. A turn consists of the event-loop pulling a message from the event-queue, and executing the callback associated with this message until it yield the execution when finished. The execution of the callback is never preempted.

An event-loop is single-threaded, callbacks are executed one after the other on the same CPU. The concurrency is time-sliced. During the execution of a callback, there is no other simultaneous execution. Therefor, each callback has an exclusive access to the memory.

Because each callback has exclusive access to the memory, and is never preempted, it can consider the invariant. The event-loop provide concurrency without the need for synchronization on the form of mutual exclusions, and

[18] https://youtu.be/dkZFtimgAcM?t=1852

[19] http://www.w3.org/DOM/

[20] https://nodejs.org/

[21] http://www.w3.org/TR/workers/

locks. It is often said that the event-loop provide atomic execution / de facto exclusion ... whatever, because of this pattern.

However, there is a limitation to this concurrency model. Because all callback are executed on the same core, if one takes two much time to complete, the other can't executes, and the program seems to freeze. Therefore, each turn needs to be executed fast, so as to avoid the event-queue to congest on events waiting for their turn.

GUIs hardly ever congest the event-loop, because if the programmer is not so bad, event are fast, and there is usually not so much event : the graphical space is often limited to the attention of a single user. However, in the case of web applications, there is a lot much more events to process. When there is too many concurrent events to process, the event-loop become congested, and the latency of the application increase.

HOF allows Continuation Passing Style, which is particularly useful in a turn-based programming language such as node.js javascript.

This demonstration focus on application depending on long waiting operations like I/O operations. Particularly, this demonstration focus on real-time web services. It is irrelevant for application heavily relying on CPU operations, like scientific applications.

Threads-based system and event-based system evolved significantly over the last half century. These evolutions were fueled by the long-running debate about which design is better. We try to succinctly and roughly retrace theses evolutions to understand the positions of each community. This demonstration show that thread and events are two faces of the same reality.

Lauer and Needham [**Lauer1979**] presented an equivalence between Procedure-oriented Systems and a Message-oriented Systems.

Adya *et. al.* analyzed this debate and presented fives categories through which to present the problem [**Adya2002**]. These two categories were often associated with thread-based systems and event-based systems. Their advantages and drawbacks were mistaken with those of thread and events. Adya *et. al.* explain in details two of these categories that are most representative, Task management and Stack management. We paraphrase these explanations.

Consider a task as an encapsulation of part of the logic of a complete application. All the task access the same shared state. The Task management is the strategy chosen to arrange the task executions in available space and time.

Preemptive task management executes each task concurrently. Their ex-

ecutions interleave on a single core, or overlap on multiple cores. It allows to leverage the parallelism of modern architectures. This parallelism has a cost however, developers are responsible for the synchronization of the shared memory. While accessing a memory cell, it must be locked so that no other task can modify it. Synchronization mechanism impose the developer to be especially aware of race condition, and deadlocks. These synchronization problems make concurrency hard to program with preemptive task management.

The opposite approach, Serial task management, executes each task to completion before starting the next. The exclusivity of execution assures an exclusive access on the memory. Therefore, it removes the need for synchronization mechanism. However, this approach is ill-fitted for modern applications, where concurrency is needed.

A compromise approach, Cooperative task management, allows tasks to yield voluntarily. A task may yield to avoid monopolizing the core for too long. Typically, it yields to avoid waiting on long I/O operations. It merges the concurrency of the preemptive task management, and the exclusive memory access. Thus, it relieves the developer from synchronization problems. But at the cost of dropping parallel execution.

Threads are associated with preemptive task management, and events with Cooperative task management. For this reason, it is commonly believed that synchronization mechanisms make threads hard to program [**Ousterhout1996**]. While it is really Preemptive task management that is responsible for these synchronization problems [**Adya2002**].

Consider a task is composed of several subtasks interleaved with I/O operations. Each I/O operation signal its completion with an event. The task stops at each I/O operation, and must wait the event to continue the execution. The stack management is the strategy chosen to express the sequentiality of the subtasks.

The automatic stack management is what is mostly used in imperative programming. The execution seems to wait the end of the operations to continue with the next instruction. The call stack is kept intact. This is what is commonly called synchronous programming.

In the manual stack management, developers need to manually register the handlers to continue the execution after the operation. The execution immediately continues with the next instruction, without waiting the completion of the operation. It implies to rip the call stack in two functions; one to initiate the operation, and another to retrieve the result. This is what is

commonly called asynchronously programming.

What we argue is that synchronous is good because it is linear, it avoids stack ripping. But asynchronous is good because it allows parallelism by default.

Threads are associated with the automatic stack management, and events with manual stack management. For this reason, it is commonly believed that threads are easier to program. [**Thread systems allow programmers to express control flow**] [**Behren2003**]. However, the automatic stack management is not exclusive to threads. Fibers, presented by Adya *et. al.* is an example of cooperative task management with automatic stack management [**Adya2002**] . Fibers present the advantage of cooperative task management, without the disadvantage of stack ripping. That is the ease of programming because of the absence of synchronization, without the difficulty of stack ripping.

We argue that the advantages of manual stack management outweigh its drawbacks for web services. Because of the numerous I/O operations, parallelism is

But what is actually highlighted is the automatic state management provided by threads. And with lighter context change, threads are a good choice which provide parallelism.

Historically, events-based system are associated with manual state management, while threads-based systems are associated with automatic state management. Manual state management imposed stack ripping [**Adya2002**]. With closure, it is not the case anymore. Events now have automatic state management as well [**Krohn2007**].

Now, there is implementation of thread model with cooperative management, with context-switch overhead improved enough to fill the gap with events model. And there is implementation of event model with automatic state management filling the gap with thread model. In this condition, we ask, what really is the difference between thread and events. We argue there is none. Except the isolation, versus sharing of the memory, which, again is not significant of either. In the first case, the different execution threads exchange messages, while in the second, they use synchronization mechanism to assure invariants in their states

For a single thread of execution, both model could avoid synchronization through cooperative task management, which assure invariants. Or avoid procedure slicing (if any) using synchronization. These are the two ends of a design spectrum. One end (cooperative task management) fits better for small processing with heavy use of shared resources. While the other

end (synchronization) fits better for long processing with small use of shared resources. When one end of the design spectrum is used while the other should be used, one might expect unresponsiveness because of too heavy events, or performance fall due to interlocking.

Scalability is achieved through parallelism, which is itself achieved in our case (web servers) through cluster of commodity machines.

With distribution, this design spectrum gets a better contrast.

The synchronization of distributed, shared resources is limited through the CAP theorem [**Gilbert2002a**]. Partition tolerance is a requirement of a distributed system. One needs to choose good latency (availability) or consistency. The CAP theorem is generalized into a broader theroem about[**Gilbert2012**]

The isolation of resources implies to split the architecture in different stages, like Ninja [**Gribble2001**], SEDA [**Welsh2000**], or Flash [**Pai1999**]. This splitting is difficult for the developer. The splitting which is good for the machine, is not the same as the one good for the design in modules.

The two ends of this design spectrum presented map directly onto the two kinds of parallelism advocated for scalability. That is pipeline parallelism, and data parallelism.

Pipeline parallelism is good for data locality, and important throughput. But each stage adds an overhead in latency.

Data parallelism is good for latency, because one request is processed from beginning to the end without waiting in queues. But it implies that the different machines share a common database. Which is a shared resource, and is limited by the CAP theorem.

Both parallelism have advantages and drawbacks, and both could be combined, like in the SEDA architecture. Ultimately, it would be possible to design a design spectrum to choose which kind of parallelism for a set of requirements. But we leave this for future works.

Splitting an architecture in stages is a difficult process, which prevent future code refactoring, and module modifications. We argue that the design for the technical architecture, and the design for the human minds should not be the same. Threads belong to the mental model, the design granularity Events belong to the execution model, the architecture granularity It is a mistake to attempt high concurrency without help from the compiler [**Behren2003**]. Through compilation, we want to transform an event-loop based program (cooperative task management, no synchronization) into a pipeline parallelism distributed system. So, basically, we argue that it is

possible to distribute one loop event onto multiple execution core.

/! WARNING The paper Why events are a bad idea states that : the control flow patterns used by these applications fell into three simple categories: call/return, parallel calls, and pipelines. Indeed, it is no coincidence that common event patterns map cleanly onto the call/return mechanism of threads. Robust systems need acknowledgements for error handling, for storage deallocation, and for cleanup; thus, they need a "return" even in the event model. » Why is it completly false ? It is crucial to find an answer. Moreover, Ayda et. al. state that : For the classes of applications we reference here [file servers and web servers], processing is often partitioned into stages. Other system designers advocated non-threaded programming models because they observe that for a certain class of high-performance systems [...] substantial performance improvements can be optained by reducing context switching and carefully implementing application-specific cache-conscious task scheduling.

The paper Why events are a bad idea states that : One could argue that instead of switching to thread systems, we should build tools or languages that address the problems with event systems (i.e., reply matching, live state management, and shared state management). However, such tools would effectively duplicate the syntax and run-time behavior of threads. » Well, yes ... With the exception of the stack junction. The paper on Duality had it right, their graph is correct, but for threads, it cannot be distributed because of stacks, while for events, it can.

Software evolution substantially magnifies the problem of function ripping: when a function evolves from being compute-only to potentially yielding, all functions, along every path from the function whose concurrency semantics have changed to the root of the call graph may potentially have to be ripped in two. (More precisely, all functions up a branch of the call graph will have to be ripped until a function is encountered that already makes its call in continuation-passing form.) We call this phenomenon "stack ripping" and see it as the primary drawback to manual stack management. Note that, as with all global evolutions, functions on the call graph may be maintained by different parties, making the change difficult. » Stack ripping is what I am talking about. While the stack are joined, it is not possible to distribute. If they say that stack ripping is necessary, that means it is not possible to encapsulate asynchronous function into synchronous function.

2.3 Scalability

2.3.1 Theories

2.3.1.1 Linear Scalability

2.3.1.2 Limited Scalability

2.3.1.3 Negative Scalability

Conclusion : scalability = concurrency + not sharing the resources that grows with the scale

2.3.2 Scalability outside computer science (only if I have time)

If I have time, I would like to try to explain why scalability is at the core of material engagement and information theory, and is at the core of our universe : the propagation of Gravity wave is an example : it is impossible to scale

/EOF

We define a web service as a computer program whose main interface is based on web protocols, such as HTTP. Such a service uses resources allocated on a network of computers. Scalability defines the ability of the service to use a certain quantity of resource to meet a desired performance. We call system the association of the computer program and the available resources. The performance of this system is measured by its latency and throughput.

2.3.3 Latency and throughput

Latency is the time elapsed between the reception of a request, and the sent of the reply. It includes the time waiting for resources to be free to process the request, and the time to process the request.

Throughput is the number of requests processed by the system by unit of time.

Latency and throughput are linked in a certain way. If a modification of the web service reduces its mean latency to a half, then the throughput doubles immediately. It takes half the time to process a request, therefore, the

service can process more requests in the same time. However, if throughput augment, the latency doesn't necessarily decrease.

2.3.4 Scalability granularity

We define a computer program as a set of operations. In the case of a web service, these operations can be directly requested by the user through the interface. An operation can cause any other operation to execute.

Because both the resources used and the operations executed are discrete : not infinitely divisible, scalability is inherently discrete.

Scalability granularity is the increment of resources. How the input data can be split up ? How the program can be deployed on many machines ?

We call system the association of the computer program with the resources

2.3.5 Horizontal and vertical scaling

There is two ways to augment the resources of the system. Enhance the nodes in the computer network - vertical scaling. Or add more nodes to the computer network - horizontal scaling.

There are three theories, from the most restrictive, to the most general.

Scalability is the property of a computer program to occupy available resources to meet a needed performance. EIther in Latency, or in throughput.

2.3.6 Linear scalability

Clements et. al. [**Clements2013a**] prove that a computer program scale linearly if all its operations are commutative. Two operations are said to be commutative if they can be executed in any orders, and the same initial state will result in the same final state. Commutativity implies the two operations to be memory-conflict free, or independent, which is equivalent to say that they can be executed in parallel.

Therefore, to achieve linear scalability, a computer program must be composed of a set of operations that commutes. Thus, all the operations are parallel, they can be executed simultaneously, on any number of machines as required.

The size of the operations sets the scalability granularity.

However, commutativity is not achievable in real applications. Even sv6, the operating system resulting from the work on commutative scalability only has 99% commutativity. For real application, in the best case, the granularity is coarse, in the worst case, there is no possible commutativity because of shared resources (like a product inventory, or a friend graph).

2.3.7 Limited scalability

Amdahl introduced in 1967 a law to predict the limitation of speedup a computer program can achieve if a fraction of its code is sequential. Amdahl worked at increasing the speed of computer clock, while the scientific community was working on improving parallelism of computing machines.

In a set of operations, even if one is non-commutative, it cannot be executed in parallel of any others, the scalability is limited by this operation.

There is a difference if the operation is non-commutative with itself, or only with others. In the first case, it impose a queuing, while in the second case, it only increase the granularity : you can regroup the non-commutative operation with its subsequents, and form a bigger commutative operation.

2.3.8 Negative scalability

Gunther generalized Amdahl's law into the Universal Scalability Law. It includes the parallelization of non-independent operations with the use of synchronization.

It models the negative return on scalability from sharing resources observed in many real world applications.

2.3.9 Eventual Consistency

To overpass the scalability limits set by the previous rules, it is possible to abandon consistency. It simply tolerate incoherences between multiple replicas. The output of an operation can be false while its state is synchronized with the other replicas.

2.4 Objectives

2.4.1 Problem : the pivot

2.4.1.1 Development & Performance Scalability

Where I explain the two (It should be clear from the two previous section), and why it is difficult to switch from one to the other.

2.4.1.2 A difficult compromise

It is impossible to truely merge development and true linear performance scalability : linear performance scalability means perfect parallelism, that is impossible for multiple reasons. It is impossible to reduce the time of an operation infinitely : an instant computation doesn't exist. It is impossible to decompose a set of operation past a certain point : the coupling (sharing / causality) is needed for computation : this composition is the fabric of computation.

2.4.2 Proposal and Hypothesis

2.4.2.1 LiquidIT

TODO liquid IT is roughly about improving the compromise between development and performance scalability (it is more than that, and I need to explain it briefly, but I need to narrow the field to focus on my thesis)

2.4.2.2 Pipeline parallelism for event-loop

The hypothesis is that it is possible for event-looped web applications to be pipeline parallelized, and so to be distributed

2.4.2.3 Parallelization and distribution of web applications

the proposal is to study and develop a solution to parallelize and distribute web applications.

Chapter 3

State of the art

3.1 Framworks for web application distribution

3.1.1 Micro-batch processing

3.1.2 Stream Processing

3.2 Flow programming

3.2.1 Functional reactive programming

3.2.2 Flow-Based programming

3.3 Parallelizing compilers

OpenMP and so on

3.4 Synthesis

There is no compiler focusing on event-loop based applications

Chapter 4

Fluxion

4.1 Fluxionnal Compiler

Some parts of this are already written in the first paper. It needs a lot additional explanations and rewritting

4.1.1 Identification

4.1.1.1 Continuation and listeners

4.1.1.2 Dues

4.1.2 Isolation

4.1.2.1 Scope identification

Scope leaking

4.1.2.2 Execution and variable propagation

4.1.3 distribution

4.2 Fluxionnal execution model

Everything here is already written in the first paper : flx-paper. It only needs to be rewritten

4.2.1 Fluxion encapsulation

4.2.1.1 Execution

4.2.1.2 Name

4.2.1.3 Memory

4.2.2 Messaging system

Chapter 5

Evaluation

5.1 Due compiler

5.2 Fluxionnal compiler

5.3 Fluxionnal execution model

Chapter 6

Conclusion

Appendix A

Language popularity

A.1 PopularitY of Programming Languages (PYPL)

[1] The PYPL index uses Google trends[2] as a leading indicator of the popularity of a programming language. It search for the trend for each programming language by counting the number of searches of this language and the word "tutorial".

PYPL for May 2015

[1] http://pypl.github.io/PYPL.html
[2] https://www.google.com/trends/

Rank	Change	Language	Share	Trend
1		Java	24.1%	-0.9%
2		PHP	11.4%	-1.6%
3		Python	10.9%	+1.3%
4		C#	8.9%	-0.7%
5		C++	8.0%	-0.2%
6		C	7.6%	+0.2%
7		Javascript	7.1%	-0.6%
8		Objective-C	5.7%	-0.2%
9		Matlab	3.1%	+0.1%
10	2× ↑	R	2.8%	+0.7%
11	5× ↑	Swift	2.6%	+2.9%
12	1× ↓	Ruby	2.5%	+0.0%
13	3× ↓	Visual Basic	2.2%	-0.6%
14	1× ↓	VBA	1.5%	-0.1%
15	1× ↓	Perl	1.2%	-0.3%
16	1× ↓	lua	0.5%	-0.1%

A.2 TIOBE

[3]

The TIOBE index uses many search engines as an indicator of the current popularity of programming languages. It count the number of pages each search engine find when queried with the language name and the word "programming". This indicator indicates the number of resources available, and the discussions about a given programming language.

Javascript was the most rising language of 2014 in the TIOBE index.

TIOBE for April 2015

[3] http://www.tiobe.com/index.php/content/paperinfo/tpci/index.html

Apr 2015	Apr 2014	Change	Programming Language	Ratings	Change
1	2	↑	Java	16.041%	-1.31%
2	1	↓	C	15.745%	-1.89%
3	4	↑	C++	6.962%	+0.83%
4	3	↓	Objective-C	5.890%	-6.99%
5	5		C#	4.947%	+0.13%
6	9	↑	JavaScript	3.297%	+1.55%
7	7		PHP	3.009%	+0.24%
8	8		Python	2.690%	+0.70%
9	-	2× ↑	Visual Basic	2.199%	+2.20%

A.3 Programming Language Popularity Chart

[4]

The programming language popularity chart indicates the activity of a given language in the online communities. It uses two indicators to rank languages : the number of line changed in github of, and the number of questions tagged with a certain language.

Javascript is ranked number one in this index. The Javascript community is particularly active online, and in the open source.

indeed.com

A.4 Black Duck Knowledge

[5]

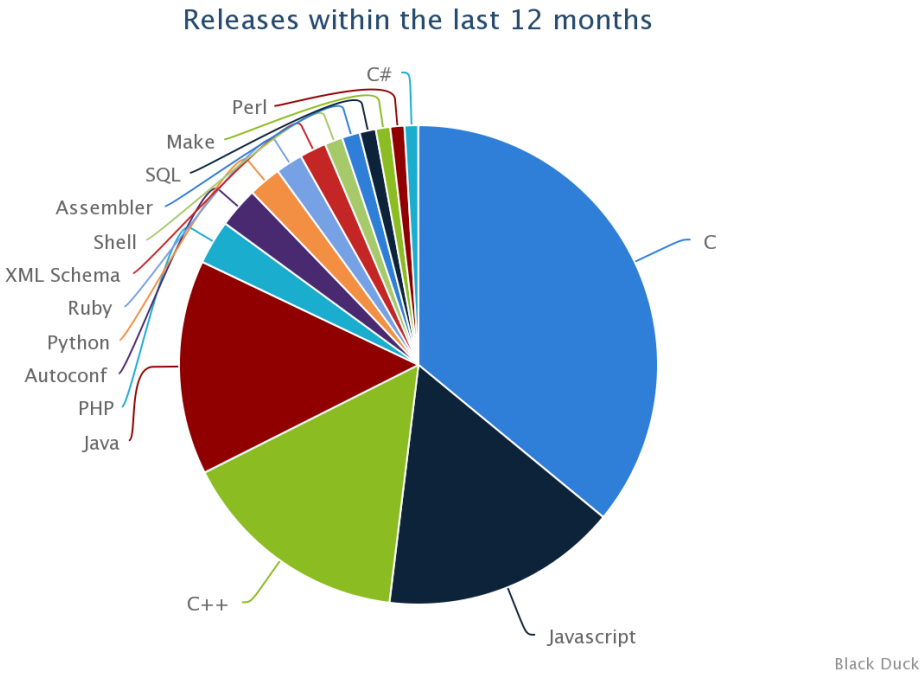
The black-duck, which analyze the usage of language on many forges, and collaborative hosts, rank Javascript number 2, after C, and with about the same usage as C++.

github.com sourceforge.net cpan.org rubyforge7.org planetsourcecode.com ddj.com

[4] http://langpop.corger.nl

[5] https://www.blackducksoftware.com/resources/data/this-years-language-use

Language	%
C	34.80
Javascript	15.45
C++	15.13
Java	14.02
PHP	2.87
Autoconf	2.65
Python	2.15
Ruby	1.77
XML Schema	1.73
Shell	1.18
Assembler	1.16
SQL	1.07
Make	0.94
Perl	0.92
C#	0.90



A.5 Github

http://githut.info/

A.6 HackerNews Poll

https://news.ycombinator.com/item?id=3746692

Language	Count
Python	3335
Ruby	1852
JavaScript	1530
C	1064
C#	907
PHP	719
Java	603
C++	587
Haskell	575
Clojure	480
CoffeeScript	381
Lisp	348
Objective C	341
Perl	341
Scala	255
Scheme	202
Smalltalk	130
Other	195
Erlang	171
Lua	150
Assembly	116
SQL	112
Actionscript	109
OCaml	88
Groovy	83
D	79
Shell	76
ColdFusion	51
Visual Basic	47
Delphi	45
Forth	41
Tcl	34
Ada	29
Pascal	28
Fortran	26
Rexx	13
Cobol	12