

# Automatic pipeline parallelism for Javascript : Abstract scalability constraints from the developer

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## ABSTRACT

The audience's growth of a web application is highly uncertain, it can increase and decrease in a matter of hours if not minutes. This uncertainty often leads the development team to quickly adopt disruptive and continuity-threatening shifts of technology to deal with the higher connections spikes. To avoid these shifts, we propose to abstract web applications into a high-level language, allowing a high-level code reasoning. This reasoning may allow later to provide code mobility to dynamically cope with audience growth and decrease.

We propose a compiler to transform a Javascript, monolithic, web application into a network of small independent parts communicating by message streams. We named these parts *fluxions*, by contraction between a flux and a function. We expect dynamic reorganization of these parts in a cluster of machine can help an application to deal with its load in the same way network routers do with IP traffic.

## Categories and Subject Descriptors

Software and its engineering [Software notations and tools]: Compilers—Runtime environments

## General Terms

Compilation

## Keywords

Flow programming, Web, Javascript

## 1. INTRODUCTION

The growth of web platforms is partially due to Internet's capacity to allow very quick releases of a minimal viable products (MVP). In a matter of hours, it is possible to upload a

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first product and start gathering a user community around. “Release early, release often”, and “Fail fast”. It is imperative to test the viability of a solution by quickly requesting feedbacks from the community. The development often starts with a feature-driven, monolithic, approach, with imperative languages such as Java or Ruby, to quickly concretize a MVP.

If the service complies successfully with users requirements, its community might grow with its popularity. An application is said scalable, if it can quickly respond to this growth. It is difficult to develop scalable applications with this feature-driven approach. Eventually this growth requires to discard the initial monolithic approach to adopt a more efficient processing model instead. Many of the most efficient models distribute the system on a cluster of commodity machines[9]. MapReduce [5] and the Staged Event-driven Architecture (SEDA) [21] are famous examples of that trend, using a pipeline architecture. Once split, the service parts are connected by an asynchronous messaging system. Many tools have been developed to express and manage these service parts and their communications. We can cite Spark [23], MillWheel [1], Timestream [20] and Storm [17], and many, many others. cite Nayad, and more recent papers However, these tools impose specific interfaces and languages, different from the initial monolithic approach. It requires the development team either to be trained or to hire experts, and to start over the initial code base. This shift cause the development team to spend development resources in background without adding visible value for the users. It is a risk for the economic evolution of the team

To lift the risks described above, we propose a tool to compile the initial code base into a high-level language compatible with a more efficient processing model. We focus on web applications driven by users requests, developed in Javascript using the *Node.js* execution environment. Javascript is increasingly used to develop web applications. We think that it is possible to analyze this type of application as a stream of requests, passing through a pipeline of stages. Indeed, the event-loop used in this execution environment is very similar to the pipeline architecture. We propose a compiler to transform a monolithic Javascript application into a network of autonomous parts communicating by message streams. We named these parts *fluxions*, by contraction between a flux and a function.

This short paper presents an early version of this tool as a

proof of concept for this compilation approach. We start by describing in section 2 the execution environment targeted by this compiler. Then, we present the compiler in section 3, and its evaluation in section ???. We compare our work with related works in section 4. And finally, we conclude this paper.

## 2. FLUXIONAL EXECUTION MODEL

Many frameworks for distributed systems are renowned for their performances[21, 14, 22, 23, 1, 17]. However, we focus on a compilation approach to replace the shift in programming model rather than the performance of the runtime. We present in this section an extremely simplified but generic execution model inspired by the literature, only to support the confirmation of feasibility for the compilation process detailed in section 3. The execution model is not distributed, however it isolates the execution of fluxions to reproduce the execution conditions of a distributed execution model.

TODO explain the fluxionnal high-level language

### 2.1 Fluxions

The fluxional execution model manages and invokes autonomous execution units named fluxion. A fluxion is a function consuming an input stream and generating one or more outputs streams. It listens for, and sends back continuous sequence of messages. It is composed of a unique name, a processing function, and a persisted memory called a *context*. The *context* of a fluxion persists the state on which a fluxion rely between two message receptions. At a message reception, the fluxion modifies its *context*, and sends back messages to downstream fluxions. A message is composed of the recipient fluxions' names and a body.

TODO an example of a Fluxion in the fluxionnal language

Fluxions are the stages in a pipeline architecture. The communications between fluxions are carried by the messaging system.

### 2.2 Messaging system

In a distributed approach, the messages between fluxions would be carried over a distributed message broker. But because this execution model is not distributed, we simplify a distributed message broker with a centralised approach. The messaging system loops over a message queue to process messages one after the other by invocation of the destination fluxion. The life cycle of a fluxional application is illustrated in figure 1.

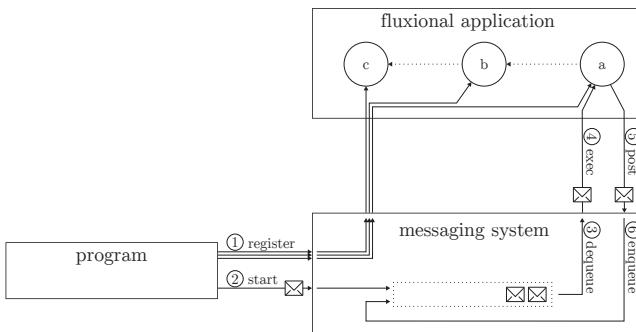


Figure 1: Messaging system details

The messaging system carries messages based on the names of the recipient fluxions. If two fluxions share the same name, it would lead to a conflicting situation for the messaging system. Every fluxion needs to be registered with a unique name. This registration associates a processing function with a unique name and an initial *context*. The registration is done using the `register(<nom>, <fn>, <context>)` function, ①.

To trigger a chain of fluxions, a message is sent using the function `start(<msg>)`, ②. This function pushes a first message in the queue. Immediately, the system dequeues this message and invokes the recipient processing function, ③ and ④. The recipient function sends back messages using the function `post(<msg>)`, ⑤, to be enqueued in the system, ⑥. The system loops through steps ③ and ④ until the queue is empty. This cycle starts again for each new incoming request causing a `start` message.

Algorithms 1 and 2 describe the behavior of the messaging system after the `start` function invocation.

---

#### Algorithm 1 Message queue walking algorithm

---

```

function LOOPMESSAGE()
  while msg presents in msgQueue do
    msg ← DEQUEUE()                                ▷ ③
    PROCESSMSG(msg)
  end while
end function

```

---



---

#### Algorithm 2 Message processing algorithm

---

```

function PROCESSMSG(msg)
  for dest in msg.dest do
    fluxion ← lookup(dest)
    message ← EXEC(fluxion, msg.body) ▷ ④ & ⑤
    ENQUEUE(message)                                ▷ ⑥
  end for
end function

```

---

### 2.3 Service example

To illustrate the fluxional execution model, we present an example of a simple web application. This application reads the file containing its own source code, and sends it back along with a request counter.

The original source code of this application is available on github[3], and in listing 1. In this source code, some points are worth noticing.

- The `handler` function, line 5 to 11, contains the logic we want to split into the fluxional processing chain. It receives the user request in the variable `res` which is used by the last function of the chain, `reply`.
- The `count` object at line 3 is a persistent memory that increments the request counter. This object needs to be mapped to a fluxion *execution context* in the fluxional execution model.
- The `get` and `send` functions, respectively line 5 and 9, interface the application with the clients. The processing chain of functions occurs between these two functions : `get` → `handler` → `readFile` → `reply` → `send`.

```

1 var app = require('express')(),
2   fs = require('fs'),
3   count = 0;
4

```

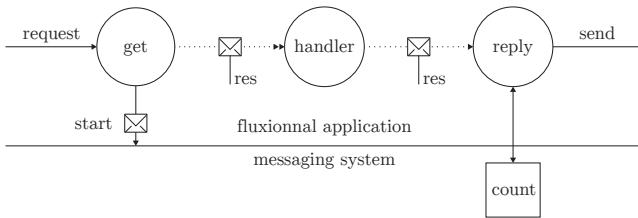
```

5 app.get('/', function handler(req, res){
6   fs.readFile(__filename, function reply(err, data) {
7     count += 1;
8     var code = ('' + data).replace(/\n/g, '<br>').replace
9       (/ /g, '&nbsp');
10    res.send(err || 'downloaded ' + count + ' times<br><br><code>' + code + '</code>');
11  });
12}
13 app.listen(8080);
14 console.log('=> listening 8080');

```

**Listing 1: Simple web application.** this application replies to every user request with its own source code and the value of a request counter

This application is transformed manually into the fluxions chain depicted in Figure 2. We expect a similar result with the compiler described in section 3. Circles represent registered fluxions. Envelope symbols represent messages streams between fluxions with the variables transmitted from one fluxion to the other. The square in the messaging system holds the *context* of the reply fluxion. When a new REST request GET is received, a start message triggers the flow. The handler fluxion receives this start message, reads the source file and forwards it to the reply fluxion which increments the counter, and sends the result back. Each fluxion propagates the necessary values from one fluxion to the other exclusively by messages. Horizontal dashed lines show virtual transmission of messages between fluxions although they all go through the messaging system.



**Figure 2: Fluxions chain manually extracted from the example application**

Listing 2 describes this counting application in our high-level fluxional language. There are two types of fluxion depending on their input streams. A fluxion with no input stream is a *root* fluxion, while the others are *following* fluxions. The *root* fluxion initializes the application.

There are two types of stream based on the two functions to send messages, *start* and *post*. A stream is defined with an operator indicating its type, a list of recipient fluxions separated by commas, and a description of its message body. The operator to represent a *start* stream is a double arrow,  $\Rightarrow$  or  $\gg$ , while for a *post* stream it is a single arrow,  $\rightarrow$  or  $\rightarrow$ . The description of the message body is a comma separated list of variables identifiers enclosed in square brackets. It is optional and only gives indications about the message content. A stream is defined with this syntax :

$\langle\text{operator}\rangle \langle\text{recipients list}\rangle [\langle\text{body description}\rangle]$

For the last fluxion of the chain, the output stream is a special stream called *null*.

A fluxion is defined with a header followed by a body with an indentation of two spaces. The header starts with the keyword **flx**, followed by its name and a description of

its memory *context*. After this first line, there is a list of output streams as defined above, and finally the body of the fluxion containing the processing function. The processing function is defined with the Javascript syntax, augmented with the stream syntax to allow it to send output streams. It can access and manipulate only two objects : *msg*, the received message and *this*, the persisted *context*. The *root* fluxion is an exception, as it doesn't have input streams its body isn't a processing function but initialization code. A fluxion is defined with this syntax :

```

flx <name> <context>
<output streams>
<processing function>

```

```

1 flx get
2 >> handler [res]
3   var app = require('express')(),
4     fs = require('fs'),
5     count = 0;
6
7   app.get('/', >> handler);
8   app.listen(8080);
9   console.log('=> listening 8080');
10
11 flx handler
12 -> reply [res]
13   function handler(req, res) {
14     fs.readFile(__filename, -> reply);
15   }
16
17 flx reply {count}
18 -> null
19   function reply(error, data) {
20     count += 1;
21     var code = ('' + data).replace(/\n/g, '<br>').replace
22       (/ /g, '&nbsp');
23     res.send('downloaded ' + count + ' times<br><br><code
24     >' + code + '</code>');
25   }

```

**Listing 2: Manual transformation of the example application in our high-level fluxional language**

The application is organized as follow :

- The *get* fluxion is the *root* fluxion. It initializes the application to listen for user requests by calling `app.get`. Every request is forwarded on the stream to the *handler* fluxion, line 7.
- The *handler* fluxion reads the file containing the source code of the application, and forwards the result to the *reply* fluxion, line 14.
- The *reply* fluxion increments the counter, line 20, formats the reply, and sends it back to the user using the function `res.send`, line 22.

Our goal, as described in the introduction, is not to propose a new programming paradigm with this high-level language but to automate the architecture shift with a compiler.

### 3. DESIGNING A COMPILER FOR FLUXIONAL COMPLIANTY

Current Web applications are mostly written in Java. The language proposes both data encapsulation and a threading model that allow the development of parallel applications. But, this approach is error-prone, and leads to deadlocks and other synchronization problems. TODO citation needed : threads are a bad idea, or something like this. Since 2009, *Node.js*[4] provides a Javascript execution environment for real-time web applications.

## TODO talk about the ascension of Javascript

We focus on this promising environment for its initial simplicity and efficiency. We develop a compiler that transforms a *Node.js* application into a fluxional system compliant with the architecture described in section 2.

We do not target all Javascript Web-based application as this work is only a proof of concept for the compilation. If we are able to transform a consequent subset of currently running applications without external developer help, we expect a real execution gain in a cloud environment.

TODO remove the next few lines, and talk about turn-based programming instead, and follow with what is a rupture point

As javascript forbids user-space thread API, a javascript application is developed as a mono-threaded application. Moreover, in Javascript the memory is hierarchical and the root scope may be accessed by any function, which leads to bad component isolation. Our compiler uses a new approach to find rupture points marking out independent parts into most of *Node.js* applications. It assures isolation and memory consistency for the application parts.

The rest of this section describes the two parts of the compiler responsible to isolate application parts. Section 3.1 explains how the *analyzer* detects rupture points in the web application to mark out the independent parts. Section 3.2 explains how the *linker* resolves the missing dependencies due to the distribution of the central memory.

### 3.1 Analyzer : execution parallelism

The Sun programming guide<sup>1</sup> defines **parallelism** as a condition that arises when at least two threads are executing simultaneously, and **concurrency** as a condition that exists when at least two threads are making progress. A more generalized form of parallelism that can include time-slicing as a form of virtual parallelism. **Asynchronism** is a condition that arises when a client continues its execution while waiting for the result to its request.

In the *Node.js* environment, all of the application execution take place in a single thread : the main thread. When the application calls an asynchronous function, the requested operation takes place in a thread in parallel : the I/O thread. At the end of this operation, the I/O thread pushes the result and a function to process it in a queue to be executed by the main thread. This function is named a callback and is provided by the application purposely to process the result of the asynchronous operation. The *Node.js* environment confine the application to run in a single thread to avoid concurrency and the memory synchronizations problems associated with it. Without these memory concerns, the callback and the associated result could be deported on a different thread, provided that the needed memory be accessible.

#### 3.1.1 Rupture points

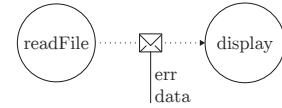
A rupture point is the discontinuity between the asynchronous operation and the callback execution. It marks out the separation between two independent application parts, each with a different execution path. In the *Node.js* environment, these two application parts are executed one after the other on the same execution thread. But the rupture point split the two application parts and reveal a pipeline

1. <http://docs.oracle.com/cd/E19455-01/806-5257/6je9h032b/index.html>

parallelism, as defined in[11]. Listing 3 is an example of a rupture point in a simple application. The division of this application into two application parts is illustrated figure 3. The asynchronous function call `fs.readFile` and the callback function `display` represent the rupture point between the first execution path, line ?? and the second, line ???. The first application part is the whole program minus the function `display`, the second application part contains only the function `display`, lines ?? to ???.

```
1 var fs = require('fs');
2
3 @\label{lst:callback_begin}@fs.readFile(__filename,
4   @\label{lst:second_ep}@  function display(err, data) {
5     @\label{lst:second_ep}@  console.log('>> second
6       concurrent execution path');
7     console.log(err || data.toString());
8   @\label{lst:callback_end}@)
9
10 @\label{lst:first_ep}@console.log('>> first concurrent
11   execution path');
```

**Listing 3: Example of a rupture point : an asynchronous function call, `fs.readFile()`, with a callback parameter, function `display`**



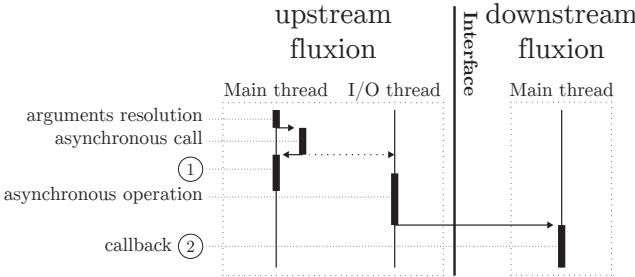
**Figure 3: Division of the listing 3 into two application parts, the asynchronous call to `readFile` and the callback function `display`**

There are two types of rupture points : *start* and *post*. Figure 4 and 5 illustrate the different interfaces implied by rupture points between two application parts. In these figures, the two concurrent execution paths are indicated by ① and ②, the applications parts are encapsulated in upstream and downstream fluxions.

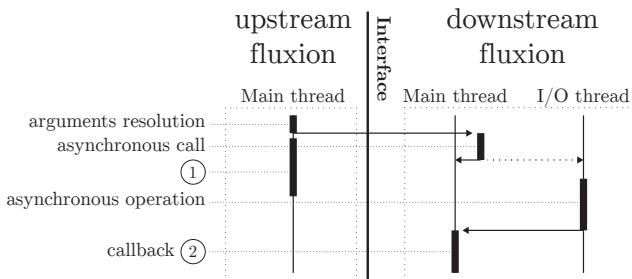
**Start rupture points** are on the border between the application and the outside, continuously receiving incoming user requests, like `app.get()` in listing 4. These functions indicate the input of a data stream in the program, and the beginning of a chain of application parts following this stream. The asynchronous function is called only once, while the callback is triggered for each new request. The interface of this rupture point is placed between the two, as illustrated in figure 4, because it implies the least modifications on the program structure.

**Post rupture points** represent a continuity in the execution flow after a finite asynchronous operation, such as reading a file in listing 3. As the result of this read operation probably is a voluminous object between two application parts, this interface is specially placed before the call to the asynchronous function, but after the resolution of the arguments. This placement allow the asynchronous function call to occur in the same application parts as the callback, avoiding the transfer of this voluminous result, as illustrated in figure 5. For a write operation, the data transfer is the opposite so the interface is placed between the asynchronous operation and the callback, like for a *start rupture point*, as illustrated in figure 4

The impact of these rupture points on the application structure during the compilation is illustrated in listing 7 and explained in section 3.3.



**Figure 4: Basic rupture point interface.** The rupture point interface is placed between the asynchronous operation and the callback to reduce the impact on the application structure.



**Figure 5: Special rupture point interface.** The rupture point interface is placed before the asynchronous operation, to avoid moving the result across the interface from one application part to the other. However, the resolution of the arguments for this asynchronous call is kept upstream to reduce the impact on the application structure

The application in listing 4 presents the two types of rupture points. The division of this application is illustrated figure 6.

```

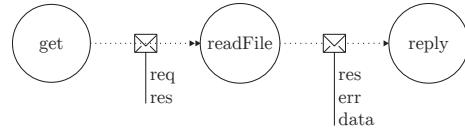
1 var app = require('express')(),
2   fs = require('fs');
3
4 app.get('/', function handleRequest(req, res) {
5   fs.readFile(__filename, function reply(err, data) {
6     res.send(err || data.toString());
7   })
8 });
9
10 app.listen(8080);
11 console.log('server listening to 8080');

```

**Listing 4: Example of an application presenting the two types of rupture points.** A start with the call to `app.get()`, and a post with the call to `fs.readFile()`

### 3.1.2 Detection

Detecting a rupture point requires detecting its two components : the asynchronous function and the callback function.



**Figure 6: Division of the listing 4 into three application parts**

### Asynchronous functions

The compiler is prebuilt knowing some module names exposing asynchronous functions, like the `express` and the `fs` module in listing 4. To detect asynchronous calls, the compiler keeps a list of variables holding these modules. In listing 4, the compiler adds both variables `app` and `fs` in this list. When the compiler encounters a call expression, it compares its callee name with this list to spot asynchronous functions.

### Callback function

For each asynchronous call detected, the compiler test if one of the arguments is of type function to spot the callback. Some callback functions are declared *in situ*, and are trivially detected. For every other variable identifier, we track the declaration up to the initialization value to detect its type.

### Variable tracking

To detect both the asynchronous function and the callback function, the compiler needs to statically track the types of variables. Missing rupture points by false negatives in the detection is sub-optimal, but false positives are more critical, as they eventually produce a runtime execution. Therefore, the detection needs to be as accurate as possible to screen out false positives. We use a technique similar to a Program Dependency Graph (PDG)[8] to track changes in the value of variables. This method walks an intermediate representation of the source code to spot the statements modifying a certain variable. From this intermediate representation, the variable tracker builds a dependency graph which helps the analyzer to detect the type of a variable at a certain point in the execution. The variable tracker is still in early development and is limited to only a few cases.

## 3.2 Linker : memory distribution

As each fluxion is a unique thread accessing a dedicated memory, there is no concurrency, therefor, no synchronization needs, and no possibility of memory corruption. But we need to prove that the transformation to message passing is not altering the memory consistency, given the correct isolation.

Pipeline parallelism is not enough for an application to be distributed. The compiler also needs to distribute the memory into the application parts for the application to be compliant with the fluxional execution model. In Javascript, scopes are nested one in the other up to the all-enclosing global scope. Each function creates a new scope containing variables local to itself, and chained to the scope of the parent function. Rupture points always take place in between scopes. A rupture point placed between a child scope and its parent breaks a chain of scopes, and makes the child unable to access its parent as expected, eventually leading the application to a runtime error. The linker analyzes how scopes are distributed among the application parts to detect and resolve their unmet dependencies. Depending on how a shared variable is used in the scopes, there are different si-

tuations to resolve. In this section, we explain the different cases of unmet dependencies emerging from the partitioning of a central memory.

### 3.2.1 Signature

The signature is the part of a message containing all the variables to send downstream. If a variable is needed for read-only access by at least one downstream application part, like the variable `res` in figure 3, it is added to the signature of the rupture point. As fluxions are chained one after another, a fluxion must provide every dependency for the next one, even if some of these dependencies are not needed by the current application part. These dependencies must be passed fluxion after fluxion from the producing fluxion to the consuming fluxion. The compiler modifies those variable identifiers inside the application part to make them point to the signature instead of the function scope.

### 3.2.2 Scope

The scope of an application part consists of all the variables declared outside, but needed for modification in only this application part. An example of such a variable is the counter in listing 5. Initialized to 0 in the global scope, it is incremented for each request by the `reply` function. This counter is in the scope of the application part containing the `reply` function. The scope of an application part is stored in the *context* of the encapsulating fluxion. If one of these variables needs to be read by another application part, this variable also becomes part of the signature sent downstream.

### 3.2.3 Sync

If a variable is needed for modification by more than one application parts, this variable needs to be synchronized between the fluxions. The synchronization of a distributed memory is a well-known subject, with Brewer's theorem[10][12], and the ACID (Atomicity, Consistency, Isolation, Durability) versus BASE (Basically Available, Soft state, Eventual consistency) opposition[9]. We choose to stay out of this topic, the objective for this compiler is to be able to transform only a subset of web applications with a satisfying result. The compiler merges the parts too tightly coupled by modification accesses on a shared variable.

## 3.3 Compilation example

To illustrate the compiler features, we compiled the application used as an example for the execution model in section 2. The source and compiled results of this application are available on github[3]. The compiler source code is the property of Worldline, and is not publicly available, but we are planning of releasing it as an open source project in the future.

To test the source or the result of the compilation, one would launch respectively `source.js` or `result.js` with node and check the service available at `localhost:8080`. Both executable needs their dependencies to be resolved with `npm` before execution.

```
git clone https://github.com/etnbrd/flx-example
cd flx-example
npm install
node result.js
open http://localhost:8080
```

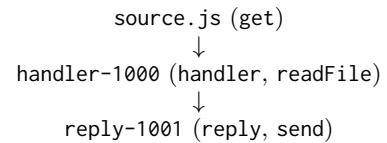
The file `source.js`, in listing 5, is the source of this compilation example. This application sends back its own source

along with a download counter. The processing chain of function is : `get` → `handler` → `readFile` → `reply` → `send`. It uses two asynchronous function call with *in situ* callback, one to listen for user requests and one to read its own source, respectively `app.get` line 5 and `fs.readFile` line 6. It uses a global variable to increment the download counter defined line 3. This global variable is used only in the `reply` function, line 7 and 9.

```
1 var app = require('express')(),
2   fs = require('fs'),
3   count = 0;
4
5 app.get('/', function handler(req, res){
6   fs.readFile(__filename, function reply(err, data) {
7     count += 1;
8     var code = ('' + data).replace(/\n/g, '<br>').replace
9       (/ /g, '&nbsp');
9     res.send(err || 'downloaded ' + count + ' times<br><br><code>' + code + '</code>');
10   });
11 });
12
13 app.listen(8080);
14 console.log('>> listening 8080');
```

**Listing 5: Source of the compilation example**

The result of the compilation into our high-level language is in the file `result.flx`, presented in listing 6. The analyzer detects both asynchronous calls as rupture points. The first one is a *start* rupture point, associated with the `app.get` asynchronous function call which makes the callback `handler` listen for the stream of user requests. The second one is a *post* rupture point, associated with the `fs.readFile` asynchronous function call which reads the source file and hands it to the callback `reply`. These two rupture points result in three application parts. The first application part is encapsulated in the root fluxion, named after the filename, `source.js`, line 1. It initializes the system to route the user requests to the fluxion `handler-1000`, line 8. This second fluxion reads the file, and sends the result to the next and last fluxion `reply-1001`, line 14. We can identify the processing chain of functions in this chain of fluxion.



The linker detects that the fluxion `reply-1001` needs two variable to send the result back to the user, `res` and `count`. The variable `res` depends on the user connection and is initialized for each new request. It needs to be part of the *signature* of the message transferred to the last fluxion. The variable `count` is global, and the `reply` function in the fluxion `reply-1001` needs to increment it at each new request. This global variable is in the *scope* of only this application part, so the compiler stores it in the *context* of this fluxion. The division by the compiler of this application is illustrated figure 7. This result is very similar to the manual division illustrated figure 2, as expected.

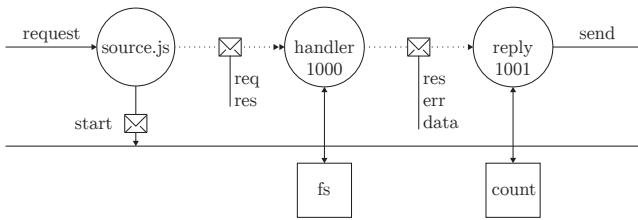
```
1 flx source.js {}
2 >> handler-1000 [res]
3 var app = require('express')(), fs = require('fs'),
4   count = 0;
4 app.get('/', >> handler-1000);
5 app.listen(8080);
```

```

6   console.log('> listening 8080');
7
8 flx handler-1000 {fs}
9 -> reply-1001 [res]
10 function handler(req, res) {
11   fs.readFile(__filename, -> reply-1001);
12 }
13
14 flx reply-1001 {count}
15 -> null
16 function reply(err, data) {
17   count += 1;
18   var code = ('' + data).replace(/\n/g, '<br>').replace
19     (/ /g, '&nbsp;');
20   res.send(err || 'downloaded ' + count + ' times<br><br><code>' + code + '</code>');
21 }

```

**Listing 6:** High level fluxional language result of the compilation example



**Figure 7:** Division of the listing 6 into three application parts. This result is similar to the manual division illustrated in figure 2

The compiler also produces an executable targeting a simple implementation of the fluxional execution model. This result is in the file `result.js`, presented in listing 7. The *root* fluxion is not registered because it doesn't need to receive any message by another fluxion, it only initializes the application. The two following fluxions are registered in the messaging system. This registration encapsulates the processing function in a *capsule* function. The *special rupture points* implies the asynchronous call to be in the downstream fluxion. The *capsule* function encapsulates the asynchronous call from a *special rupture points* or the callback from *basic rupture points* in a unified processing function.

The original callback is replaced with a placeholder function, line 3, sending the *start* message to `handler-1000`. Line 17, `handler-1000` pushes the user request `res` in the message and post it directly to `reply-1001`. Because there is a special rupture point between `handler-1000` and `reply-1001`, the asynchronous call is moved to `reply-1001` and the `post` function doesn't replace the callback, like the placeholder line 3, but is directly called. Finally, `reply-1001` receives the message containing the user request and reads the file. The callback of this asynchronous operation, `reply` function, line 27, increments the variable counter, line 28, and sends the reply, line 30.

```

1 var flx = require('flx');
2 var app = require('express')(), fs = require('fs'), count
3   = 0;
4 app.get('/', function placeholder() {
5   return flx.start(flx.m('handler-1000', {
6     _args: arguments,
7     _sign: {}
8   }));
9 app.listen(8080);

```

```

10 console.log('> listening 8080');
11
12 // handler-1000
13 // -> reply-1001 [res(signature), count(scope)]
14
15 flx.register('handler-1000', function capsule(msg) {
16   (function handler(req, res) {
17     flx.post(flx.m('reply-1001', {
18       _args: arguments,
19       _sign: { res: res }
20     }));
21   }.apply(this, msg._args));
22 }, { fs: fs });
23
24 // reply-1001 -> null
25
26 flx.register('reply-1001', function capsule(msg) {
27   fs.readFile(__filename, function reply(err, data) {
28     this.count += 1;
29     var code = ('' + data).replace(/\n/g, '<br>').replace
30       (/ /g, '&nbsp;');
31     msg._sign.res.send(err || 'downloaded ' + this.count
32     + ' times<br><br><code>' + code + '</code>');
33   }.bind(this));
34 }, { count: count });

```

**Listing 7:** Result of the compilation example targeting the fluxional execution model

### 3.4 Limitations

This compiler aims at transforming a subset of Javascript web applications presenting a specific syntax and design. In this section, we describe briefly the current limitations of our compiler and how we plan to overcome them in future works.

- Variables poorly encapsulated or used too broadly tighten dependencies across the code, and might result in a coarser division of the application.
- The compilation silently fails if a variable holding a callback or a module is overwritten, or not defined in the declaration. The variable tracker is unable to track accurately all the modification of a variable to detect these situations which may lead the compiler either to miss rupture points, or to detect non existing one.
- The compiler is unable to track a dynamically resolved value, even if the value is deducible statically. If this variable is used in a potential rupture point, the compiler screens it out.
- The Javascript language offers rich composition possibilities leading to many corner cases. The compiler is not robust enough to understand all corner cases. For example, the *express* module is only detected if initialized like in listing 4.

There may be other limitations we aren't aware of.

The three last limitations described above are caused by the variable tracker - described in section 3.1 - being in an early stage of development. We are currently in the process of improving the robustness of the compiler to extend the subset of compilable applications.

## 4. RELATED WORKS

The execution model, is inspired by some works on scalability for very large system, like the Staged Event-Driven Architecture (SEDA) of Matt Welsh[21], System S developed in the IBM T. J. Watson research center[14, 22], and later the MapReduce architecture[5]. It also drew its inspiration from more recent work following SEDA. Among the best-known following works, we cited in the introduction

Spark [23, 24], MillWheel [1], Timestream [20] and Storm [17]. The idea to split a task into independent parts goes back to the Actor's model[13] in 1973, and to Functional programming, like Lucid[2] in 1977 and all the following works on DataFlow leading up to Flow-Based programming (FBP)[Morrison1994a] and Functional Reactive Programming (FRP)[6]. Both FBP and FRP, recently got some attention in the Javascript community with, respectively, the projects *NoFlo*[18] and *Bacon.js*[19].

The first part of our work stands upon these thorough studies, however, we are taking a new approach on the second part of our work, to transform the sequential programming paradigm into a network of communicating parts known to have scalability advantages. Promises[16] are related to our work as they are abstractions from a concurrent programming style, to an asynchronous and parallel execution model. However, our approach using Node.js callback asynchronism to automate this abstraction seems unexplored yet.

The compiler uses AST modification, as described in[15], and an approach similar to the Program Dependency Graph (PDG)[8]. Our implementation is based on the work by Ryan Dahl : *Node.js*[4], as well as on one of the best-known web framework available for *Node.js* : *Express*[7].

## 5. CONCLUSION

In this paper, we presented our work on a high-level language allowing a high-level code reasoning. We presented a compiler to transform a *Node.js* web application into a network of independent parts communicating by message streams. To identify these parts, the compiler spots rupture points in the application indicating an independence between two parts, possibly leading to parallelism and memory distribution. We also presented the execution model to operate an application expressed in our high-level language. This distributed approach allows code-mobility which may lead to a better scalability. We believe this high-level approach can enable the scalability required by highly concurrent web applications without discarding the familiar monolithic and asynchronous programming model used in *Node.js*.

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