



INSTITUTO SUPERIOR DE ENGENHARIA DE LISBOA

Área Departamental de Engenharia de Electrónica e Telecomunicações e de Computadores

From asynchronous IO to reactive stream pipelines

Diogo Paulo de Oliveira Rodrigues

Licenciado em Engenharia Informática e de Computadores

Dissertação para obtenção do Grau de Mestre
em Engenharia Informática e de Computadores

Orientador : Doutor Fernando Miguel Gamboa de Carvalho

Júri:

Presidente: [Grau e Nome do presidente do juri]

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Aos meus ...

Acknowledgments

Os agradecimentos. Apesar de haver total liberdade no conteúdo e forma desta secção, normalmente inicia-se com os agradecimentos institucionais (orientador, instituição, bolsas, colegas de trabalho, ...) e só depois os pessoais (amigos, família, ...)

Abstract

The dissertation must contain two versions of the abstract, one in the same language as the main text, another in a different language. The package assumes the two languages under consideration are always Portuguese and English.

The package will sort the abstracts in the proper order. This means the first abstract will be in the same language as the main text, followed by the abstract in the other language, and then followed by the main text.

The abstract is critical because many researchers will read only that part. Your abstract should provide an accurate and sufficiently detailed summary of your work so that readers will understand what you did, why you did it, what your findings are, and why your findings are useful and important.

The abstract should not contain bibliography citations, tables, charts or diagrams. Abbreviations should be limited. Abbreviations that are defined in the abstract will need to be defined again at first use in the main text.

Finally, you must avoid the use of expressions such as "The present work deals with ... ", "In this thesis are discussed ", "The document concludes that ", "apparently and " etc.

The word limit should be observed, 300 words is the limit.

Abstracts are usually followed by a list of keywords selected by the author. Choosing appropriate keywords is important, because these are used for indexing purposes. Well-chosen keywords enable your manuscript to be more easily identified and cited.

Keywords: Keywords (in English) ...

Resumo

Independentemente da língua em que está escrita a dissertação, é necessário um resumo na língua do texto principal e um resumo noutra língua. Assume-se que as duas línguas em questão serão sempre o Português e o Inglês.

O template colocará automaticamente em primeiro lugar o resumo na língua do texto principal e depois o resumo na outra língua.

Resumo é a versão precisa, sintética e selectiva do texto do documento, destacando os elementos de maior importância. O resumo possibilita a maior divulgação da tese e sua indexação em bases de dados.

A redação deve ser feita com frases curtas e objectivas, organizadas de acordo com a estrutura do trabalho, dando destaque a cada uma das partes abordadas, assim apresentadas: Introdução; Objectivo; Métodos ; Resultados e Conclusões

O resumo não deve conter citações bibliográficas, tabelas, quadros, esquemas.

E, deve-se evitar o uso de expressões como "O presente trabalho trata ...", "Nesta tese são discutidos....", "O documento conclui que....", "aparentemente é...."etc.

Existe um limite de palavras, 300 palavras é o limite.

Para indexação da tese nas bases de dados e catálogos de bibliotecas devem ser apontados pelo autor as palavras-chave que identifiquem os assuntos nela tratados. Estes permitirão a recuperação da tese quando da busca da literatura publicada.

Palavras-chave: Palavras-chave (em português) ...

Contents



Introduction

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A
margin-
par
note!

A a note in a line by itself.

Please note that

this package and template are not official for ISEL/IPL.

2

State of the Art

Firstly, on section ??, will be made an overview on previously developed work made on this subject, then, on section ??, will be made a characterization of the key concepts related to it. By last, on section ??, are presented and explained several technologies representative of the state of the Art on asynchronous data flow in different programming realities, e.g. on Kotlin, JAVA and C#.

2.1 Background

From the end of 80's to the beginning of the 2000's, with the acceleration of Moores's Law in hardware and network bandwidth development, the creation of the web as we know today through the wide spread of use of the HTTP protocol and the support from new operative systems to multithreading support, the necessity of high responsiveness servers started to grow. This increase in demand of new ways to handle data through parallelism, caused the necessity of design new programming models compatible with concurrent work.

Taking the wave initiated by the Gang of Four in [gof], where 23 patterns were compiled to deal with object-oriented problems, a group of researchers published the *Proactor Pattern* in the paper [proactor] to deal with asynchronous IO. In the document, are identified four properties that high-performance web server must have:

- Concurrency - The server must process multiple client requests simultaneously.
- Efficiency - The software design must be built aiming the use of least hardware resources as possible.
- Simplicity - The code of the solution must be easy to understand, modular and avoid own built design patterns as possible.
- Adaptability - The system must be totally decoupled from client implementations, allowing it to be easily used by any client independently of the underlying technologic realities. To achieve this, may be used standards e.g. [REST] or SOAP.

The authors propose the *Proactor Pattern*, because in their opinion, conventional concurrency models fail to fully achieve the enumerated properties. In the paper, before presenting the *Proactor Pattern*, are identified two major concurrency models, namely: *multithreading* and *reactive event dispatching*.

The paper refers that one of the most direct implementations of the multithreading approach, is the handling of multiple requests by creating a new thread every request. Each request will then be fully processed and the recently created thread is then be disposed after the work is finished.

This solution has several serious issues. Firstly, creating a new thread per request is highly costly in terms of computational resources, because are involved context switches between user and kernel modes; secondly, must be taken in account synchronization to maintain data integrity. Then, the authors warn about the fact that the IO retrieved data is mainly memory-mapped, wich rises the question: What happens when the data obtained through IO becomes greater than the system memory can hold? The system stalls until more memory becomes available! On last, if the server receives a high demand of requests, the server easily blocks in the process of creating and disposing threads.

To avoid this issue, the authors, recommended the use of dynamic threadpools to process requests, where each request will be linked to a pre-existing thread,

avoiding all the overhead of creating and disposing a thread per request; however, issues related with memory-mapping and overhead due to the switching of data between different threads maintains.

Another traditional concurrency model identified by the authors of the paper, is the *Reactive Synchronous Event Dispatching* or more commonly known as *Reactor Pattern*. In this model, a *Dispatcher*, with a single thread in a loop, is constantly listening requests from clients and sending work requests to an entity named *Handler*. The *Handler*, will then process the IO work Synchronously and request a connection to the client in the *Dispatcher*. When the requested connection is ready to be used, the *Dispatcher* notifies the *Handler*. After the notification, the *Handler* asynchronously sends the data, that is being or has been obtained through IO, to the client.

Although the authors identifying that this approach is positive, because decouples the application logic from the dispatching mechanisms besides with the low overhead due the use of a single thread, the authors identify several drawbacks with this approach. Firstly, since IO operation are synchronous, the code for this approach is complex because must be set in place mechanisms to avoid IO blocking through hand off mechanisms. Then, if a request processing blocks, the processing of another requests may be impacted.

To keep the positive points but mitigating the identified issues of previous approaches, is suggested the *Proactor Pattern*. This pattern is very similar to the *Reactive Synchronous Event Dispatching*, however, after the requests processed by a single threaded *Completion dispatcher*, the IO work is then dispatched asynchronously to the underlying OS IO subsystems, where multiple requests can be processed simultaneously. For the result to be retrieved, is previously registered a callback in the *Completion Dispatcher* and the OS has the responsibility to queue the finished result in a well known place.

Finally, the *Completion Dispatcher* has the responsibility to dequeue the result placed by the OS and call the correct previously registered callback. With this, this model creates a platform that provides: decoupling between application and processing mechanisms, offers concurrent work without the issues inherent with the use of threading mechanisms and since IO is managed by the OS subsystems, is avoided code complexity in handling possible blocking and scheduling issues.

The *Proactor Pattern*, creates the ground for several models used by modern platforms that use a single/few threads to process client requests and parallel mechanisms to do the heavy work in the background; namely, for example: *Javascript*

NODE.JS, Spring Webflux, vertx and others.

From what was explained until now, is evident the tendency followed by software architects in terms of asynchronous processing from non-reactive to event driven approaches. Initially the systems were non-reactive, where each request had to be processed in a specific thread and that thread blocked until something got ready to go further. Then, with the asynchronous systems based on events with the introduction of callback systems inspired in patterns like the *Reactor* or *Proactor*; the software design started to become more event driven, allowing the servers to be more efficient in responsiveness, flexibility and resources optimization.

However, are some limitations in these asynchronous models. For example, if the data to be processed is bigger than the memory available or if the data to be calculated is from a source that produces data at a constant rate that must be processed in real time, these models work badly. The traditional models fail to comply these objectives because are mostly eager by design or not comply with the notion of a continuous source of information that requires to be processed in real time. Taken this in account, projects like project Reactor, Asynchronous Enumerable provided by Microsoft or papers like [LAZYVSEAGER], try to deal with these issues, by providing API's that merge the concepts of Fluent API's, functional programming and code syntax that tries to resemble synchronous code, being the complexity inherent with asynchronous models implementations hidden from the programmer.

2.2 Asynchronous flow key concepts and design alternatives

With the development of several approaches and implementations related to asynchronous data flow in several programming platforms; a dictionary of properties, concepts and design alternatives started to grow by itself. In the following, are discussed several of the concepts related with asynchronous data flow, namely:

2.2.1 Synchronous versus Asynchronous

Before explaining more terms related with asynchronous data flow, it's important to clarify what is synchronous and asynchronous in programming.

Asynchronous in programming, is a call to a function or routine that returns immediately, not blocking the caller until the operation is finished. The operation processing, will be completely independent from the caller execution process and can even be done in another machine. This way, the caller is freed to do more work, even to start N more operations in parallel.

Meanwhile, a call to a synchronous function or routine, blocks the caller until the operation finishes. In this case, the caller has to wait for the completion of the synchronous operation before going forward, which limits the program efficiency if parallelism is applicable.

To better visualize what was explained, we have the following examples:

```
1 // create a client
2 HttpClient client = HttpClient.newHttpClient();
3 // create a request
4 HttpRequest request = HttpRequest.newBuilder(
5     URI.create("https://api.nasa.gov/planetary/apod?api_key=DEMO_KEY"))
6     .header("accept", "application/json")
7     .build();
8
9 //not blocking http asynchronous request
10 var futureResponse = client
11     .sendAsync(request, new JsonBodyHandler<>(DTO.class))
12     .thenAccept(res -> System.out.println(res.body().get().title)); //
    consumer callback for when the operation finishes
13
14 futureResponse.get(); //blocks until the response is received
```

Listing (2.1) Asynchronous call example

(a)

```
1 // create a client
2 HttpClient client = HttpClient.newHttpClient();
3
4 // create a request
5 HttpRequest request = HttpRequest.newBuilder(
6
7     URI.create("https://api.nasa.gov/planetary/apod?api_key=DEMO_KEY"))
8     .header("accept", "application/json")
9     .build();
10
11 // blocking http synchronous request
12 var response = client.send(request, new JsonBodyHandler<>(DTO.class));
13
14 // the response:
15 System.out.println(response.body().get().title);
```

Listing (2.2) Synchronous call example

(b)

Figure 2.1: Example of Synchronous and Asynchronous calls in JAVA

As we can see, in the synchronous call example, the operation return only happens after the whole subsequent remote operation is finished, consequently, the caller operation is dependent from several variables to go forward e.g. : HTTP messaging latency, remote server operation speed or bandwidth issues.

Meanwhile, in the asynchronous operation call, the return happens immediately after the call, however, the processing inherent with that operation will start just when the subsystem that handles the asynchronous function is ready to process that work, for example, when the OS is ready to process the received responses from a remote server that handled the operation.

2.2.2 Push vs Pull

Another concept important to understand how asynchronous data flow is handled in programming, is the *Pull* and *Push* processing patterns. In *Pull* pattern, usually, exists a source of data and the program iterates over that source to operate over each item.

On the other hand, in the *Push* pattern, the items of the data source are "Pushed" to a routine that will operate over that item. To help to assimilate what was just explained, we have the following example:

```
1 Integer [] arr = new Integer[] {1,2,3,4,5,6};
2
3 Flowable<Integer> flow = Flowable
4     .fromArray(arr);
5
6 Iterator<Integer> iterator = flow.blockingIterable().iterator();
7
8 while(iterator.hasNext()) {
9     System.out.println(iterator.next());
10 }
11
12 //Output:
13 //1
14 //2
15 //3
16 //4
17 //5
```

Listing (2.3) Pull pattern example

(a)

```
1 Integer [] arr = new Integer[] {1,2,3,4,5,6};
2
3 Flowable<Integer> flow = Flowable
4     .fromArray(arr);
5
6 flow.forEach(System.out::println);
7
8 //Output:
9 //1
10 //2
11 //3
12 //4
13 //5
```

Listing (2.4) Push pattern example

(b)

Figure 2.2: Example of Pull and Push data handling patterns

As we can see, in the pull pattern, the items are "pulled" from a data source through an iteration mechanism.

In contrast with that, in the *Push* pattern, items are pushed to a consumer through a supplier.

2.2.3 Reactive Streams

Reactive Streams is term used to describe several programming initiatives, that aim to enable to provide standardization to asynchronous data processing with non-blocking back pressure.

2.2.4 Hot versus Cold

Another property that must be took in account when handling with *Reactive Streams* or asynchronous data processing in general, is the nature of the data flow. There are two main adjectives to name a data flow, `Hot` or `Cold`.

A `Cold` data flow, is a flow of information that is produced just when the stream pipeline is subscribed by an observer. In this case, the producer only starts sending/producing data when someone is interested in the data from that source. For example, when program uses a IO mechanism to lazily retrieve a sequence of words from a database, the IO mechanism will only start sending information just when a consumer subscribes that data flow. Usually, the data is sent to the consumer in unicast.

On the other hand, in a `Hot` data flow, the data is produced independently of existing any observer to that information. This mechanism usually work in broadcast and the data is continuously produced and sent to possible observers. In this case, when an observer subscribes to a publisher, exists the possibility of data items being already lost to that publisher while in the `Cold` flow, the consumer usually receives all items that were produced by the source. In the following examples, a number is produced each 100 milliseconds:

```

1 Flowable<Long> cold = Flowable.interval(100, TimeUnit.MILLISECONDS);
2 Thread.sleep(1000);
3 cold.blockingSubscribe(System.out::println); //prints: 0,1,2,3,4 .... no
    items lost

```

Listing (2.5) Cold Example

(a)

```

1 ConnectableFlowable<Long> hot = Flowable
2     .intervalRange(0, 100, 0, 100, TimeUnit.MILLISECONDS)
3     .publish();
4 flux.connect(); // Start emission
5 Thread.sleep(1000);
6 flux.blockingSubscribe(System.out::println); // 10,12,13,14,15,16 ...

```

Listing (2.6) Hot Example

(b)

Figure 2.3: Example of Hot and Cold data streams

As we can see, in the `Hot` data flow example, the items are emitted from the moment the producer is created, independently of existing any subscriber or observer attached to that publisher. Notice that when a consumer is subscribed to the publisher, 1 seconds after the emission started, the numbers from 0 to 10 were not printed.

In the `Cold` example, the producer only emits data when a subscription is done, and because of that, all the produced numbers were printed, in contrast with what happen in `Hot` stream, where data loss are almost certain.

2.2.5 Cancelables

As already stated above, Asynchronous operations run outside the main program sequence of operations. Because of that, many times, exists the need to configure a behavior for when the operation is cancelled or finishes, for, e.g. to dispose resources, write logging in a file, etc...

To better understand what a cancelable is, we will pick the example of RxJava and its representation of an asynchronous source of events, the `Observable`.

In RXJava, a `Cancelable`, is a functional interface with the method `cancel()`. Then, the `Cancelable` can be associated to a `Observable` through the call to

the method `Observable.setCancellable()`. When the `Observable` closes for any reason, the method `Cancellable.cancel()` will be called. This way, its defined a behavior for when an asynchronous data source ends, and proper measures can be set.

If this mechanism did not exist, would exist the risk of asynchronous operation not being properly closed, which could have serious consequences for the system running.

2.2.6 Error Handling

In synchronous enviroments, usually, when something goes wrong, the way to handle an error in the majority of cases its by throwing an exception and propagate it until the proper code handles it. However, in cases when exists an asynchronous operation where a continuous stream data items are being received, this way of dealing with an error, can imply several issues, e.g: computational resources overhead that can impact the processing smotness, log losing or data stream processing blockage.

Since blocking an whole operation because of a badly handled error in a single item in unacceptable, the best way to deal with errors in asynchronous stream processing its to isolate the error to allow the operation to continue even if a error occurs. To mitigate these issues, the best way to handle errors in asynchronous processing is to have proper callbacks that are called when an error occurs on the stream. This way, the function can handle the error properly, without the nescesity to blocking any data stream processing, if avoidable.

2.2.7 Asynchronous Enumerables

To better understand what a asynchronous enumerable is, firstly, we must define what Enumerables are.

An enumerable, is the logical representation of a collection that can be iterated. In synchronous programming, this is usually made by creating a `Collection` class, that implements a method that enables iteration over its items.

On the other side, in the asynchronous world, many times exists situations where a stream of data items are constantly arriving from a remote source, the commonly named *asynchronous Flows* or *asynchronous streams*.

The software designers saw, that didnt existed many logical differences between a collection and real time data sources; the only difference was that a collection could be iterated at once while the data flows are iterated over time when items are received.

Taking all this in account, borned the idea of creating the notion of the asynchronous enumerable, where the asynchronous enumerable is the representation of a constant source of readable items. With the use of this concept, were implemented several mechanisms, e.g. AsyncEnumerables in CS, that simplify the iteration over asynchronous data sources. Making the code similar to synchronous statments, easier to mantain, and, once again, abstracting the programmer from many complex details inherent with asynchronous processing.

To better visualize what was explained, we have next an asynchronous enumerables example written in CS, where we can observe an asynchronous iteration over a continous data source in real time without any blockage.

```
1 static async Task Main(string[] args)
2 {
3     Console.WriteLine($"{DateTime.Now.ToLongTimeString(): Start");
4     await foreach (var item in FetchItems())
5     {
6         Console.WriteLine($"{DateTime.Now.ToLongTimeString(): {item}");
7     }
8     Console.WriteLine($"{DateTime.Now.ToLongTimeString(): End");
9 }
10
11 static async IEnumerable<int> FetchItems()
12 {
13     for (int i = 1; i <= 10; i++)
14     {
15         await Task.Delay(1000);
16         yield return i;
17     }
18 }
19
20 //Output:
21 //01:00:01: Start
22 //01:00:02: 1
23 //01:00:03: 2
24 //01:00:04: 3
25 //01:00:05: 4
26 //.....
27 //01:00:05: 9
28 //01:00:05: End
29
30
```

Listing (2.7) Asynchronous Enumerables example

(a)

2.2.8 Intrinsic Keywords

Asynchronous code is tendentiously harder to understand because, in opposition with what happens in synchronous code, the sequence of programming statements may not happen chronologically ordered with the operations started by these . Because of that, many times it's difficult to debug and sustain asynchronous code.

For that reason, many languages started to add syntax techniques that allow the programmer to build asynchronous code that resembles the synchronous syntax. Under the hoods, the virtual machines that sustain this syntax mechanisms, handle the code bounded with that 'intrinsic words' and builds asynchronous routines that the programmer will not be aware of; being this a way to abstract the programmer from the complexity of handling and sustaining complex asynchronous code.

One example of this 'intrinsic words' mechanisms, is the `for await...of` mechanism provided by *Javascript*. `//todo exampl example`

2.2.9 Backpressure

When asynchronous flows produce items faster than the consumer can process, exists several strategies to mitigate this issue. These strategies are commonly referred as Backpressure.

Some of these strategies are:

1. **DROP:** Drops items after the buffer gets full
2. **Buffer everything:** Buffers all items that are received without any threshold.
3. **Error:** An error is thrown when the buffer threshold is reached
- 4.
5. **Buffer disable:** No backpressure strategy its in place, all excedent items are discarded.

2.3 State of the Art

In this section, will be presenting and explaining the different frameworks that are the *State of the Art* in asynchronous data processing in several programming languages.

First of all, in the section 2.3.1, will be presented the multi-language `reactivex.io` project, and how the `Observer Pattern` is used in this project to implement real time asynchronous processing with and without *back-pressure*.

Secondly, in the section 2.3.2, will be presented the *.NET Async Enumerables* and how this approach diverges from approaches made in *reactivex.io*, *Javascript*, and in Kotlin with *Kotlin Flow*. In the sections 2.3.3 and 2.3.4, will be respectively presented the Javascript and the Kotlin Flow strategies for asynchronous data processing.

Finally, in the section 2.3.5, will be made an overview and taken conclusions about the different technologies presented, and how each approach can be used for different problems and objectives. Then, will be made a theoretical prediction on how each technology behaves in several know circumstances.

2.3.1 ReactiveX.io Project

After the historical context explained in the chapter 2.1, many groups of developers started to implement several solutions to handle asynchronous data flows. One of the most ambitious results of this proactivity is the *reactiveX* project.

This project gathers several ideas and known design patterns to implement an asynchronous data flow mechanism. The most positive points about this project implementation is that the mechanism is implemented in several programming languages using an open source approach and the solution design is done in a way, that all the complexity inherent with asynchronous programming is hidden from the programmer, making the code very intuitive and iterative an easily understandable for programmer that are not used to handle with asynchronous environments. In this dissertation, we will analyze the implementation of *reactiveX* made for Java, which is named: *RXJava*

2.3.1.1 RxJava architecture

To implement an asynchronous flow that can handle `Hot` and `Cold` data flows with and without back-pressure, the project adopted the *Observer pattern* allied with the concepts described in the *Publishes/subscriber pattern*. The designers justify this choice by saying that this model allows treating streams of asynchronous events with the same simplicity made in the synchronous counterparts e.g. in `Collection` and `Iterator`. The designer complement the justification by saying that, using this approach, the code complexity inherent with low-level threading, non-blocking IO, thread-safety etc... are completely abstracted from the programmer.

In the implementation, the data source/publisher of an asynchronous stream of events is represented by the classes `Observable` and `Flowable`. In this case, the only difference between `Observable` and `Flowable`, is that the class `Flowable` supports back-pressure through different bufferization strategies.

On the other hand, the observers/subscribers are represented by consumers that are attached to `Observable` through the method `Observable.subscribe()`. The consumers can be either implementations of the functional interface `Consumer<T>` or implementations of the interface `Observer`.

The `Observer` interface is built with the intent to offer an extra control over the stream processing through error handling, which a `Consumer<T>` implementation lacks. The `Observer` can be viewed as the asynchronous representation of the java util interface `Iterator`, the resemblance can be seen by seeing the interface `Observer` methods:

1. `onSubscription()`: Method called right after the subscription is made with an `Observable`
2. `onNext(T item)`: Method called when an item is emitted by the asynchronous data source.
3. `onError()`: In contrast with `Iterator`, the RxJava `Observer` is equipped to support error handling.
4. `onComplete()`: Method called when the data source closes or if the subscription finishes.

H

	Single Item	Multiple Items
Synchronous	T getData()	Observable<T> getData()
Asynchronous	Future<T> getData()	Observable<T> getData()

3

A Short **LaTeX** Tutorial with Examples

This Chapter aims at exemplifying how to do common stuff with `LaTeX`. We also show some stuff which is not that common! ;)

Please, use these examples as a starting point, but you should always consider using the Big Oracle (aka, [Google](#), your best friend) to search for additional information or alternative ways for achieving similar results.

3.1 Document Structure

In engineering and science, a thesis or dissertation is the culmination of a master's or Ph.D. degree. A thesis or dissertation presents the research that the student performed for that degree. From the student's perspective, the primary purpose of a thesis or dissertation is to persuade the student's committee that he or she has performed and communicated research worthy of the degree. In other words, the main purpose of the thesis or dissertation is to help the student secure the degree.

From the perspective of the engineering and scientific community, the primary purpose is to document the student's research. Although much research from theses and dissertations is also communicated in journal articles, theses and dissertations stand as detailed documents that allow others to see what the work was and

how it was performed. For that reason, theses and dissertations are often read by other graduate students, especially those working in the research group of the authoring student [gustavii2016write, glasman2010science, chicago, strunk].

With a thesis or dissertation, the format also encompasses the names of the sections that are expected:

1. Thesis Cover
2. Acknowledgments (if exist)
3. Abstract (Portuguese and English)
4. Index
5. List of Figures
6. List of Tables
7. Nomenclature/List of Abbreviations (if exists)
8. Glossary (if exists)
9. Introduction
10. State-of-the-Art or Related work
11. Proposed method
12. Experiment result
13. Conclusion and Future work
14. References, and
15. Appendix (if exists)

3.1.1 State-of-the-Art

State-of-the-Art (SoTA) is a step to demonstrate the novelty of your research results. The importance of being the first to demonstrate research results is a cornerstone of the research business¹.

Besides demonstrating the novelty of your research results, a SoTA has other important properties:

¹“Why and how to write the state-of-the-art”, by Babak A. Farshchian, May 22, 2007

1. It teaches you a lot about your research problem. By reading literature related to your research problem you will learn from other researchers and it will be easier for you to understand and analyze your problem;
2. It proves that your research problem has relevance;
3. It shows different approaches to a solution;
4. It shows what you can reuse from what others have done.

3.1.2 Related work

In the *Related Works* section, you should discuss briefly about published matter that technically relates to your proposed work²

A short summary of what you can include (but not limited to) in the Related Works section:

1. Work that proposes a different method to solve the same problem;
2. Work that uses the same proposed method to solve a different problem;
3. A method that is similar to your method that solves a relatively similar problem;
4. A discussion of a set of related problems that covers your problem domain.

3.2 Glossary and Nomenclature/List of Symbols

Many technical documents use terms or acronyms unknown to the general population. It is common practice to add a glossary to make such documents more accessible. A *glossary* is a nice thing to have in a report and usually very helpful. As you probably can imagine, it is very easy to create in LaTeX.

As with all packages, you need to load glossaries with `\usepackage`, but there are certain packages that must be loaded before glossaries, if they are required: `hyperref`, `babel`, `polyglossia`, `inputenc` and `fontenc`.

```
\usepackage{glossaries}
\makenoidxglossaries
```

²<https://academia.stackexchange.com/questions/68164/how-to-write-a-related-work-section-in-computer-science>

Once you have loaded `glossaries`, you need to define your terms in the preamble (or, separated file) and then you can use them throughout the document.

Next you need to define the terms you want to appear in the glossary. Again, this must be done in the preamble. This is done using the command

```
\newglossaryentry{<label>}{<key-val list>}
```

The first argument `<label>` is a unique label to allow you to refer to this entry in your document text. The entry will only appear in the glossary if you have referred to it in the document using one of the commands listed later. The second argument is a comma separated `<key>=<value>` list.

Inside the text you just need to use the command `\gls{name}` or `\glspl{name}` (plural name) to call it. For example, the following defines the term 'set' and assigns a brief description. The term is given the label `set`. This is the minimum amount of information you must give:

```
\newglossaryentry{set} % the label
{ name=set,             % the term
  description={a collection of objects} % a brief description
}
```

Other example, now the glossary associated with a symbol, universal set:

```
\newglossaryentry{U} % the label
{ name={universal set}, % the term
  description={the set of all things} % a brief description
  symbol={\ensuremath{\mathcal{U}}} % the associated symbol
}
```

Here's a simple example:

```
\usepackage{glossaries}
\newglossaryentry{ex}{name={sample},description={an example}}
\newacronym{svm}{SVM}{support vector machine}
\newacronym{beta}{$\beta$}{Second letter of the greek alphabet}
\newacronym{alpha}{$\alpha$}{First letter of the greek alphabet}
```

```

\begin{document}
Here's my \gls{ex} term. First use: \gls{svm}.
Second use: \gls{svm}.

\textit{I want the \gls{beta} to be listed after the \gls{alpha}}.
\end{document}

```

This produces: *Here's my sample term. First use: support vector machine (SVM).
Second use: SVM.
I want the Second letter of the greek alphabet (β) to be listed after the First letter of the
greek alphabet (α).*

Do not use `\gls` in chapter or section headings as it can have some unpleasant side-effects. Instead use `\glsentrytext` for regular entries and one of `\glsentryshort`, `\glsentrylong` or `\glsentryfull` for acronyms. Alternatively use `glossaries-extra` which provides special commands for use in section headings, such as `\glsfmtshort{<label>}`.

The plural of the word “matrix” is “matrices” not “matrixs”, so the term needs the plural form set explicitly:

```

\newglossaryentry{matrix}% the label
{
  name=matrix, % the term
  description={a rectangular table of elements},
  plural=matrices % the plural
}

```

Given a set of numbers, there are elementary methods to compute its Greatest Common Divisor, which is abbreviated GCD. This process is similar to that used for the Least Common Multiple (LCM).

3.3 Importing Images

3.4 Floats Figures and Tables, and Captions

The `tabular` environment can be used to typeset tables with optional horizontal and vertical lines. L^AT_EX determines the width of the columns automatically. The first line of the environment has the form: `\begin{tabular}[pos]{table spec}`

`table spec` tells L^AT_EX the alignment to be used in each column and the vertical lines to insert.

`pos` can be used to specify the vertical position of the table relative to the baseline of the surrounding text.

The number of columns does not need to be specified as it is inferred by looking at the number of arguments provided. It is also possible to add vertical lines between the columns here.

Some notes are important to followed, such as present in Table ??:

- i) Not defined vertical lines;
- ii) The legend must be on top;
- iii) Use `\toprule`, `\midrule` and `\bottomrule` to draw horizontal lines.

Table 3.1: Table's rules.

Item		
Animal	Description	Price (\$)
Gnat	per gram	13.65
	each	0.01
Gnu	stuffed	92.50
Emu	stuffed	33.33
Armadillo	frozen	8.99

There are two ways to incorporate images into your L^AT_EX document, and both use the `graphicx` package by means of putting the command `\usepackage{graphicx}` near the top of the L^AT_EX file, just after the `documentclass` command.

The two methods are

- include only PostScript images (esp. ‘Encapsulated PostScript’) if your goal is a PostScript document using dvips;
- include only PDF, PNG, JPEG and GIF images if your goal is a PDF document using pdf_latex, TeXShop, or other PDF-oriented compiler.

Some PNG images within my L^AT_EX document. The quality of the image files is sufficient and the result using L^AT_EX and viewing the resulting DVI file is quite looks good.

To get the best quality of the images in PDF files I’d recommend using vector-based graphics for images. The best format to save images in is .pdf, see Figure ???. With programs like Inkscape, you can draw as you would in MS Paint (and do much more), and because the images are vector-based instead of pixel-based, their quality should be preserved when converting to PDF in any way.

In all cases, each image must be in an individual 1-image file; no animation files or multipage documents.

There are two different ways to place two figures/tables side-by-side. More complicated figures with multiple images. You can do this using subfigure environments inside a figure environment. Subfigure will alphabetically number your subfigures and you have access to the complete reference as usual through `\ref{fig:figurelabel}`, Figure ??, or Figure ?? using `\ref{fig:subfigurelabel}`.

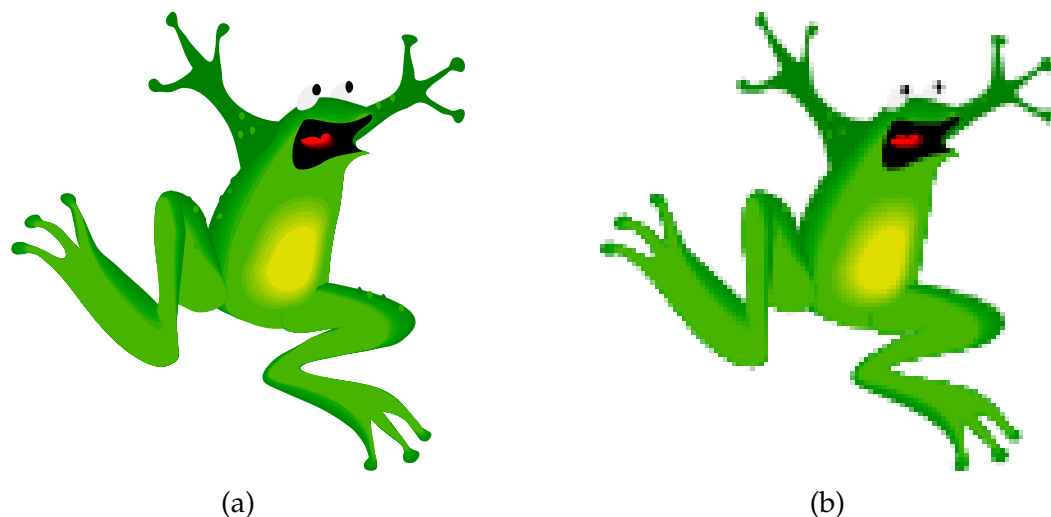


Figure 3.1: Subfigure example with vectorial and no-vectorial images

Using the package listings you can add non-formatted text as you would do with `\begin{verbatim}` but its main aim is to include the source code of any programming language within your document. If you wish to include pseudocode or algorithms see [LaTeX/Algorithms_and_Pseudocode](#), as Listing ??.

```

59     private static void printSet(Set set) { // comment
60         int[] elements = set.getElements();
61         System.out.print('{ ');
62         for (int i = 0; i < elements.length; i++) {
63             System.out.print(elements[i] + (i == elements.length
-1 ? " " : ", "));
64         }

```

Listing 3.1: Static method - SetApp

```

1  # comentário
2  square <- function(x) {
3      x^2
4      % |$x^{2}$|
5  }
6
7  # nerv
8  x <- c(1:100)
9  y <- square(x)

```

Listing 3.2: R-Code (Test).

3.5 Generating PDFs from L^AT_EX

3.5.1 Generating PDFs with pdf_latex

You may create PDF files either by using `latex` to generate a DVI file, and then use one of the many DVI-2-PDF converters, such as `dvipdfm`.

Alternatively, you may use `pdflatex`, which will immediately generate a PDF with no intermediate DVI or PS files. In some systems, such as Apple, PDF is already the default format for L^AT_EX. I strongly recommend you to use this approach, unless you have a very good argument to go for `latex + dvipdfm`.

A typical pass for a document with figures, cross-references and a bibliography would be:

```

$ pdflatex template
$ bibtex template
$ pdflatex template (twice)

```

You will notice that there is a new PDF file in the working directory called `template.pdf`. Simple :)

Please note that, to be sure all table of contents, cross-references and bibliography citations are up-to-date, you must run `latex` once, then `bibtex`, and then `latex` twice.

3.5.2 Dealing with Images

You may process the same source files with both `latex` or `pdflatex`. But, if your text include images, you must be careful. `latex` and `pdflatex` accept images in different (exclusive) formats. For `latex` you may use EPS ou PS figures. For `pdflatex` you may use JPG, PNG or PDF figures. I strongly recommend you to use PDF figures in vectorial format (do not use bitmap images unless you have no other choice).

3.5.3 Creating Source Files Compatible with both `latex` and `pdflatex`

Do not include the extension of the file in the `\includegraphics` command, use: `\includegraphics{evolution_steps}`, and not:

```
\includegraphics{ evolution_steps.png}.
```

In the first form, `latex` or `pdflatex` will add an appropriate file extension.

This means that, if you plan to use only `pdflatex`, you need only to keep (preferably) a PDF version of all the images. If you plan to use also `latex`, then you also need an EPS version of each image.

To be included in the sections above

If you are writing only one or two documents and aren't planning on writing more on the same subject for a long time, maybe you don't want to waste time creating a database of references you are never going to use. In this case you should consider using the basic and simple bibliography support that is embedded within L^AT_EX.

L^AT_EX provides an environment called `thebibliography` that you have to use where you want the bibliography; that usually means at the very end of your

document, just before the `\end{document}` command. Here is a practical example:

```
\begin{thebibliography}{9}
\bibitem{lamport94}
  Leslie Lamport,
  \emph{\LaTeX: A Document Preparation System}.
  Addison Wesley, Massachusetts,
  2nd Edition,
  1994.
\end{thebibliography}
```

In this document, the bibliography is in a separate document: `bibliography.bib` where information is entered from <https://scholar.google.pt/>, as show Figure ??.

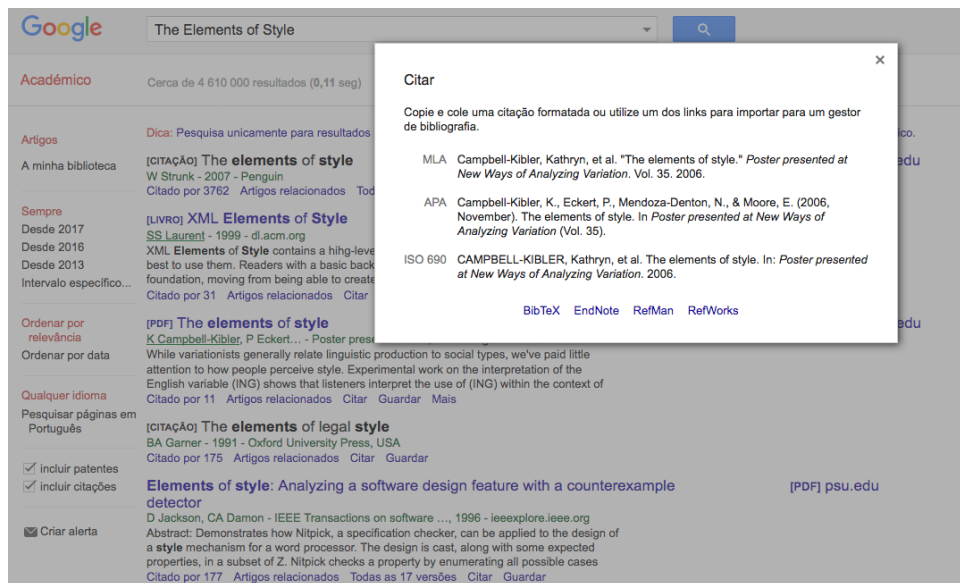


Figure 3.2: Screenshot from Scholar Google

To actually, cite a given document is *very* easy. Go to the point where you want the citation to appear, and use the following: `\cite{citekey}`, where the `citekey` is that of the `bibitem` you wish to cite, e.g. `\cite{lamport94}`. When L^AT_EX processes the document, the citation will be cross-referenced with the `bibitems` and replaced with the appropriate number citation. The advantage here, once again, is that L^AT_EX looks after the numbering for you.

When a sequence of multiple citations are needed, you should use a single `\cite{}` command. The citations are then separated by commas. Note that you must

not use spaces between the citations. Here's an result example [**strunk**, **chicago**, **texbook**].

Footnotes are a very useful way of providing extra information to the reader. Usually, it is non-essential information which can be placed at the bottom of the page. This keeps the main body of text concise.

The footnote facility is easy to use: `\footnote{Simple footnote}`³.

3.6 Equations

Typesetting mathematics is one of L^AT_EX's greatest strengths. It is also a large topic due to the existence of so much mathematical notation. It is recommend to read the following document available in [Short Math Guide for L^AT_EX - AMS - American Mathematical Society](#).

3.7 Page orientation

The default page layout is “portrait”, but sometimes it is still useful/necessary to have the whole document or only single pages changed to “landscape”. The latter might be due to a large table or figure. If you want to make appear the left side up, better readable on screen, the `pdflscape`-package will do it: `\usepackage{pdflscape}`

and again:

```
\begin{landscape}  
...  
\end{landscape}
```

or, `\includepdf[landscape=true,pages={1}]{example.pdf}`

to put the page in “landscape”, while the rest will remain in “portrait” orientation. Nevertheless, the header/footer will also be changed in orientation.

**Written by Matilde Pós-de-Mina Pato with collaboration of Nuno Datia,
2012 October (1st version)**

**Written by Matilde Pós-de-Mina Pato,
January 6, 2022 – version 2.5.3 (last version)**

³Simple footnote



Applied Survival Analysis by Hosmer and Lemeshow

Stata Textbook Examples Applied Survival Analysis by Hosmer and Lemeshow
[newtest]

The data files used for the examples in this text can be downloaded in a zip file
from the Wiley FTP website or the Stata Web site.

```
1 # The R package(s) needed for this chapter is the survival package.
2 # We currently use R 2.0.1 patched version. You may want to make sure
3 # that packages on your local machine are up to date. You can perform
4 # updating in R using update.packages() function.
5
6 # url: http://www.ats.ucla.edu/stat/r/examples/
7 # data set is hmohiv.csv.
8 hmohiv<-read.table("http://www.ats.ucla.edu/stat/r/examples/asa/hmohiv.
9   csv", sep="," , header = TRUE)
10 attach(hmohiv)
11
12 # using the hmohiv data set. To control the type of symbol, a variable
13   called psymbol is created.
14 # It takes value 1 and 2, so the symbol type will be 1 and 2.
15 psymbol<-censor+1
16 table(psymbol)
```

```
17 plot(age, time, pch=(psymbol))
18 legend(40, 60, c("Censor=1", "Censor=0"), pch=(psymbol))
19
20 age1<-1000/age
21 plot(age1, time, pch=(psymbol))
22 legend(40, 30, c("Censor=1", "Censor=0"), pch=(psymbol))
23
24 # Package "survival" is needed for this analysis and for most of the
    analyses in the book.
25 library(survival)
26 test <- survreg( Surv(time, censor) ~ age, dist="exponential")
27 summary(test)
28
29 pred <- predict(test, type="response")
30 ord<-order(age)
31 age_ord<-age[ord]
32 pred_ord<-pred[ord]
33 plot(age, time, pch=(psymbol))
34 lines(age_ord, pred_ord)
35 legend(40, 60, c("Censor=1", "Censor=0"), pch=(psymbol))
```