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Ingénierie / Systèmes Informatiques

École doctorale  
Informatique, Télécommunication et Électronique Paris (ED130)

**CALOCK : Topological Multi-Granularity Locking for  
Hierarchical data**

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Ayush Pandey

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Devant un jury composé de :

**Jean-Michel DUPONT**, Professeur, Sorbonne Université

**Alice DUPONT**, Directrice de Recherche, CNRS

**Jean-Michel DUPONT**, Professeur, Sorbonne Université

**Pierre AAA**, Maître de conférences, UPMC

**Mesaac MAKPANGOU**, Chargé de Recherche [HDR], INRIA

**Marc SHAPIRO**, Directeur de Recherche Émérite, INRIA, Sorbonne Université, LIP6

**Julien SOPENA**, Maître de Conférences, Sorbonne Université, LIP6

**Swan DUBOIS**, Maître de Conférences, Sorbonne Université, LIP6

*Rapporteur*

*Examinatrice*

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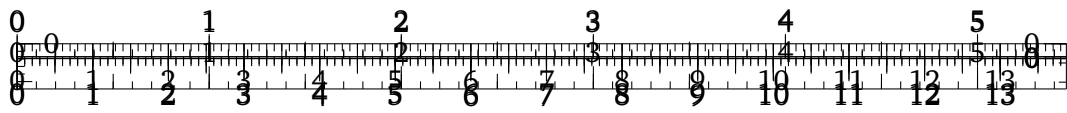
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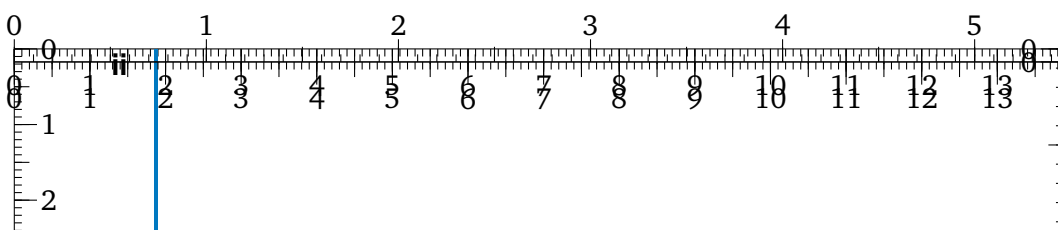


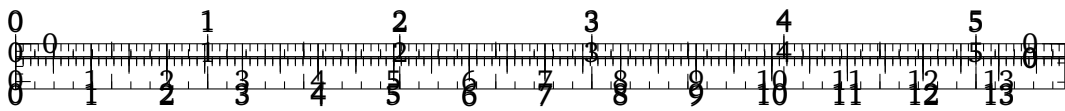
*À Alice et Bob*



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# Remerciements

A PhD is a long journey. For me, it took 3 years, 3 supervisors and education in 3 countries to finally reach here. Throughout this time, I have been supported by many people, without whom I would not have been able to reach here. I would like to take this opportunity to thank them.

First and foremost, I would like to thank the rapporteurs of this thesis, . I am grateful for their time and effort in reviewing my work and providing valuable feedback. I would also like to thank the members of the jury, for taking the time to read, evaluate and provide feedback on this body of work.

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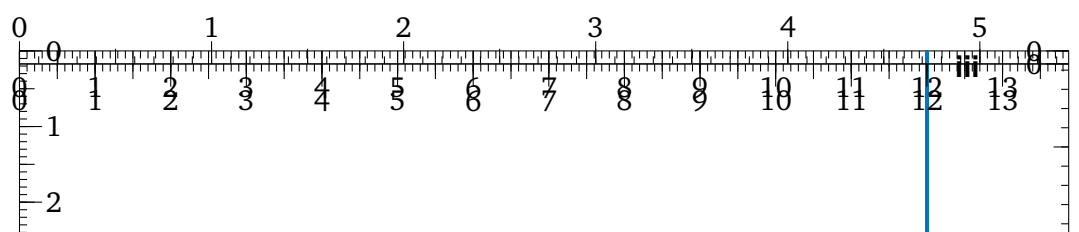
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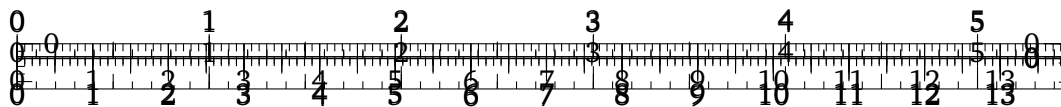
The people without whom this thesis would not have been possible are my supervisors, Marc Shapiro, Julien Sopena and Swan Dubois. From asking me if i would like to do a PhD back in 2021 while i was in Germany to the day I defended my thesis, I cannot thank Marc enough for his constant support, guidance and well placed reality checks. Julien, you have been a great inspiration, not only in the rigor of research but also in correcting my French which, even after several corrections, is still awful. Swan, you have been a great mentor and helped me navigate the finer details of theoretical computer science. I am grateful for the opportunity to have worked with you all.

To the seniors in the lab with whom i have shared numerous lunches, coffee breaks and discussions, thank you for making my time in the lab enjoyable. Thank you Pierre, Jonathan and Alessio for taking care of DELYS and your help in my research.

I have had the pleasure of working with some amazing people during my time in the lab. Saalik, Benoît and Laurent have been great friends and colleagues, helping me navigate the French bureaucracy, teaching me bits of french culture and also helping me with my research direction. I am grateful for your friendship and support. To my fellow PhDs Étienne, Aymeric, Célia, Baptiste and Daniel; Thank you for your discussions and support. I wish you well for your future.

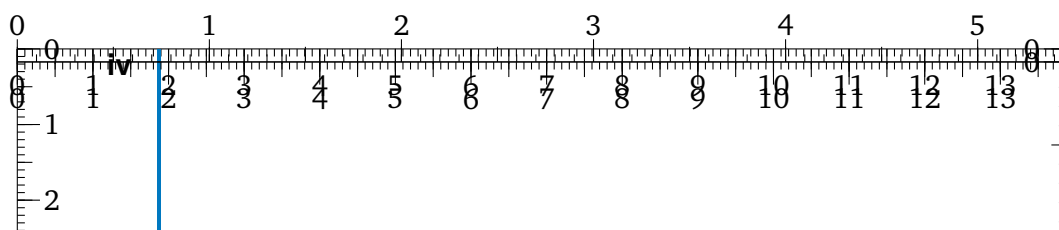
To the lehrstuhl softwaretechnik of RPTU, i extend my thanks, for introducing me to the wonderful world of parallel and distributed systems. I am grateful for the opportunity to have worked with Prof. Dr. Annette Bieniusa without whom I would not have been able to start my PhD.

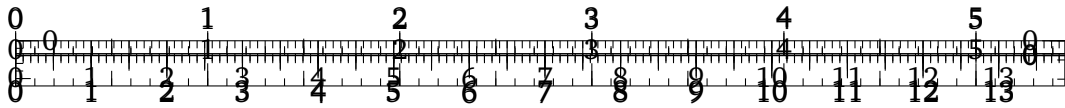




Finally, the people without whom this thesis would not have been imaginable. My family, who dealt with years of daily phone and video calls, the fear of the COVID-19 pandemic, the uncertainty of being abroad and the stresses of a PhD, i am eternally grateful for your support. I dedicate this thesis to you Papa, Mummy and my brother. To my friends from Germany, India and France, thank you for your support, your love and your friendship.

Thankyou everyone.





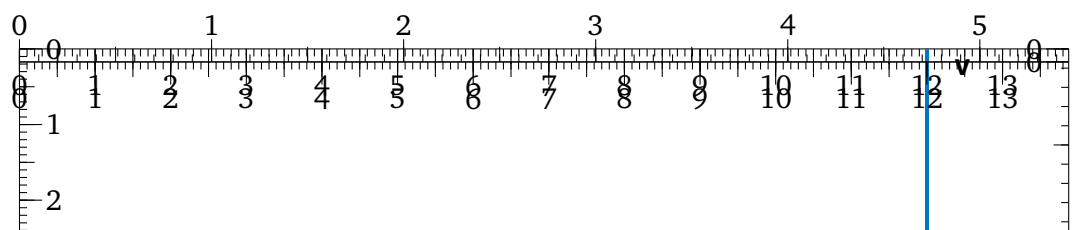
# Abstract

Hierarchies serve as fundamental structures across various disciplines, modeling hierarchical relationships in computer science, biology, social networks, and logistics. However, the dynamic and concurrent updates in real-world systems necessitate synchronization techniques for maintaining data consistency despite concurrent access. This paper explores a novel approach called CALock to synchronize operations on hierarchies by utilizing a labeling scheme that facilitates multi-granularity locking.

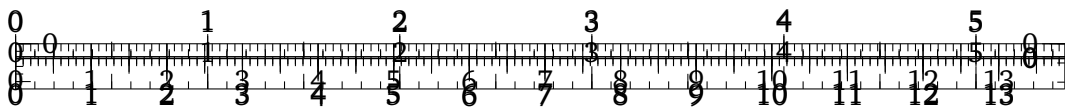
Our approach addresses both concurrent data reads and writes as well as structural modifications. CALock exploits the hierarchical topology via a new labeling scheme to identify the common ancestors of vertices. This enables a thread to identify an appropriate lock granule for its lock request. Leveraging variable lock granularities optimizes operations across the hierarchy while ensuring consistency and performance.

We provide a detailed discussion of the CALock labeling and the locking algorithm, prove its properties, and evaluate it experimentally. On static hierarchies CALock remains competitive with previous labeling schemes and has better concurrency and throughput when structural modifications change the hierarchy. In particular, CALock improves throughput by  $4.5\times$ , and response time by  $1.5\times$  for workloads that contain structural modifications.

**Keywords:** Multi-granularity locking, Hierarchical data, Graphs, Locking, Synchronization, Graph topology, Ancestors.







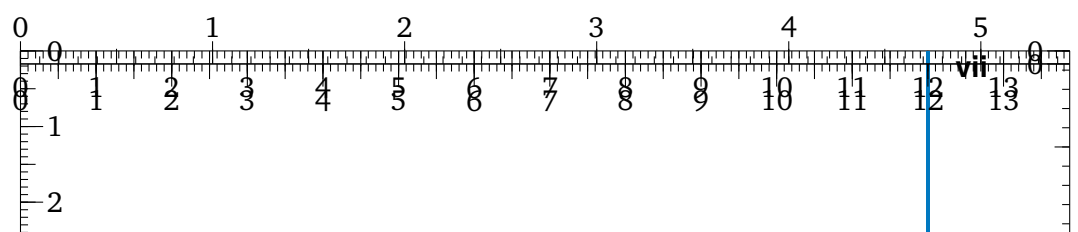
## Résumé

Les hiérarchies servent de structures fondamentales dans diverses disciplines, modélisant les relations hiérarchiques en informatique, en biologie, dans les réseaux sociaux et en logistique. Cependant, les mises à jour dynamiques et simultanées dans les systèmes du monde réel nécessitent des techniques de synchronisation pour maintenir la cohérence des données malgré l'accès simultané. Cet article explore une nouvelle approche appelée CALock pour synchroniser les opérations sur les hiérarchies en utilisant un schéma d'étiquetage qui facilite le verrouillage multi-granularité.

Notre approche concerne à la fois les lectures et écritures concurrentes de données et les modifications structurelles. CALock exploite la topologie hiérarchique par le biais d'un nouveau schéma d'étiquetage permettant d'identifier les ancêtres communs des sommets. Cela permet à un thread d'identifier un granule de verrouillage approprié pour sa demande de verrouillage. L'utilisation de granularités de verrouillage variables optimise les opérations à travers la hiérarchie tout en garantissant la cohérence et les performances.

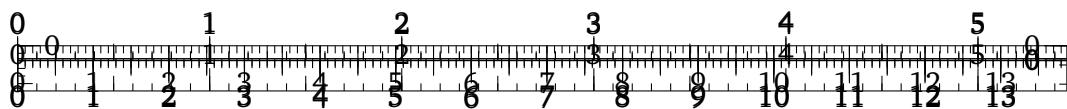
Nous présentons une discussion détaillée de l'étiquetage CALock et de l'algorithme de verrouillage, nous prouvons ses propriétés et nous l'évaluons de manière expérimentale. Sur des hiérarchies statiques, CALock reste compétitif par rapport aux schémas d'étiquetage précédents et offre une meilleure simultanée et un meilleur débit lorsque des modifications structurelles changent la hiérarchie. En particulier, CALock améliore le débit de  $4,5\times$  et le temps de réponse de  $1,5\times$  pour les charges de travail qui contiennent des modifications structurelles.

**Mots-clés:** Verrouillage multi-granularité, Données hiérarchiques, Graphes, Verrouillage, Synchronisation, Topologie des graphes, Ancêtres.



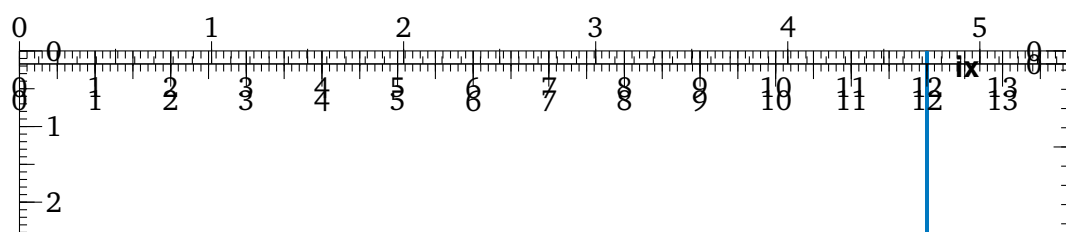


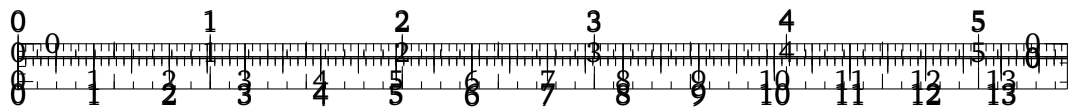




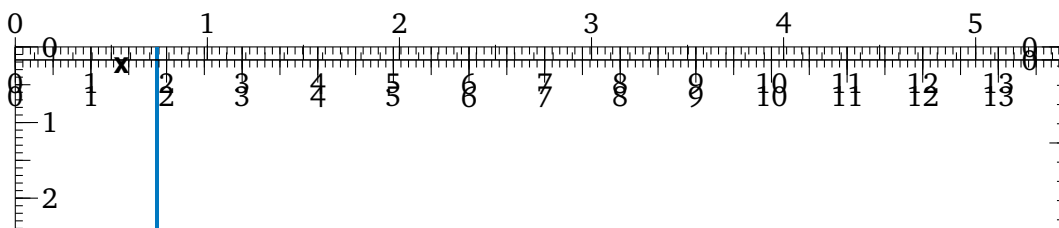
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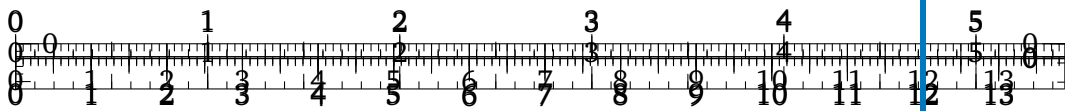
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# 1

## Introduction

main intro part, in general it should contain at least 4 paragraphs each answers one of the following questions.

*P1: What's the thesis main problem?*

*P2: Why the problem is a problem?*

*P3: what's the solution?*

*P4: Why the solution is better than the state of the art?*

### 1.1 Overview

In the first part of this thesis, we explore ...

In the second part of the thesis, we present CALOCK, a ... To answer this challenge, CALOCK takes a hybrid approach, and ...

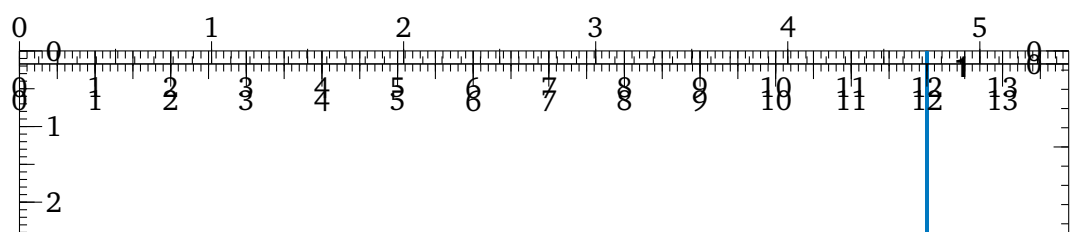
To address the requirements of ..., CALOCK enables ...

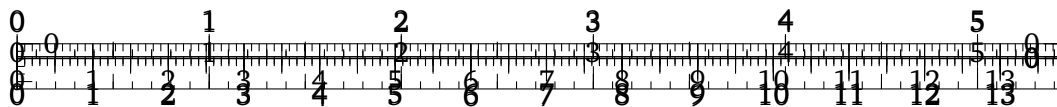
Finally, this thesis addresses a number of design and implementation challenges, including ...

### 1.2 Contributions

The main results of this dissertation are as follows:

- R1
- R2
- R3
- R4





- R5

Our experimental evaluation shows that:...

## 1.3 Publications

Some of the results presented in this thesis have been published as follows:

- myFirstPublication
- mySecondPublication

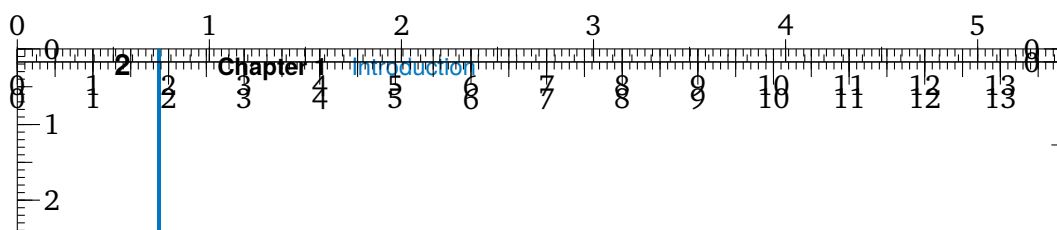
During my thesis, I explored other directions and collaborated in several projects that have helped me to get insights on the challenges of ... These efforts have led me to contribute to the following publications and deliverables:

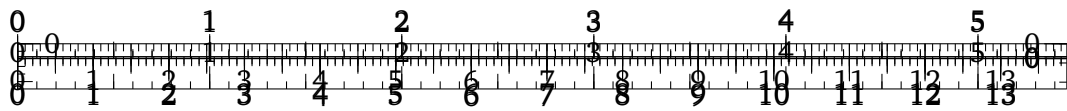
- TechReport
- ANRProjectDeliverable
- EUProjectDeliverable

## 1.4 Organization

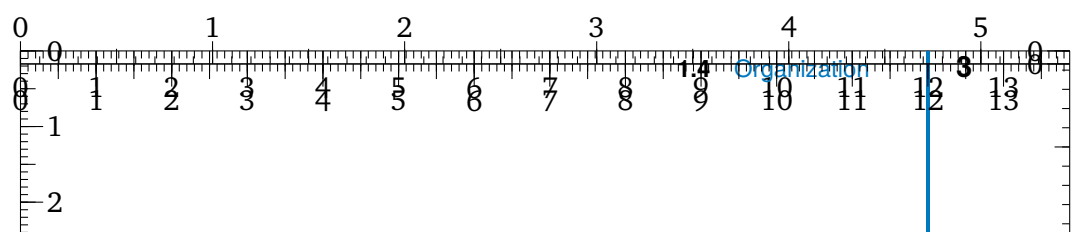
This thesis is divided into three parts. The rest of this document is organized as follows:

- Part I introduces the common background of our work, formulate the problem, presents the existing solutions and discusses the use-case requirements, this part is divided into three chapters:
  - Chapter 2 provides a complete and up-to-date review of the MyDomain.
  - Chapter 3 presents a use-case point of view of the ...
  - Chapter 4 studies and compares the solutions that have been designed in the state of the art of ...
- Part II, in light of what we saw in the existing work, we will here justify some protocol choices used in our approach...





- Part III provides an experimental evaluation demonstrating the benefits of our approach, compared to other solutions from the state of the art.
- the last part IV we summarize our contribution, and present our vision for the future requirements towards more ...





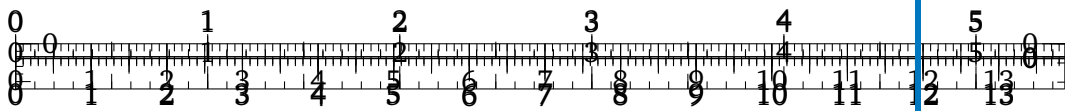
# Part I

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Background







# 2

## My Domain Paradigms

let me remind the rules at Sorbonne Univ. (french version below).

### 2.1 The detailed steps of the defence

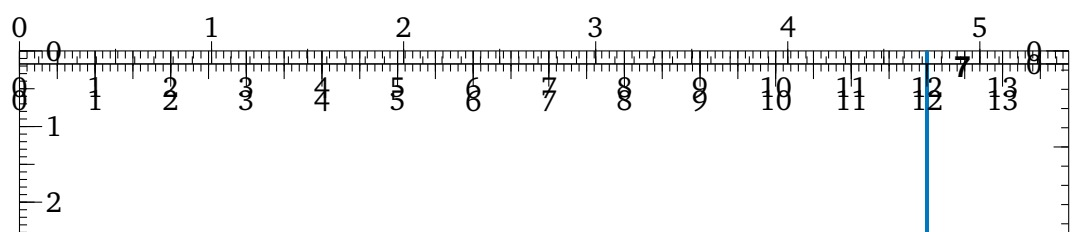
### 2.2 The manuscript

**Language of the manuscript** As the thesis leads to the award of a French national degree, it should generally be written and defended in French. However, it may be the case that, for scientific reasons, the subject matter requires the use of a language other than French. By decision of the Scientific Council of 4 March 2013, this is now decided by the directors of doctoral schools, who are competent to judge matters of scientific priority. As recommended by the Ministry, a lengthy written summary of the thesis in French will be required.

**Writing the manuscript** To help you write your manuscript, Sorbonne University provides you with a guide for writing and presenting theses, as well as two style sheets, one of which concerns international co-supervision theses.

- Guide to writing and presenting theses
- Classic style sheet
- *Style sheets*: theses in international co-supervision

Communication courses are organised for the preparation of your manuscript but also for the defence. Find these courses in the training catalogue for doctoral candidates at Sorbonne University.



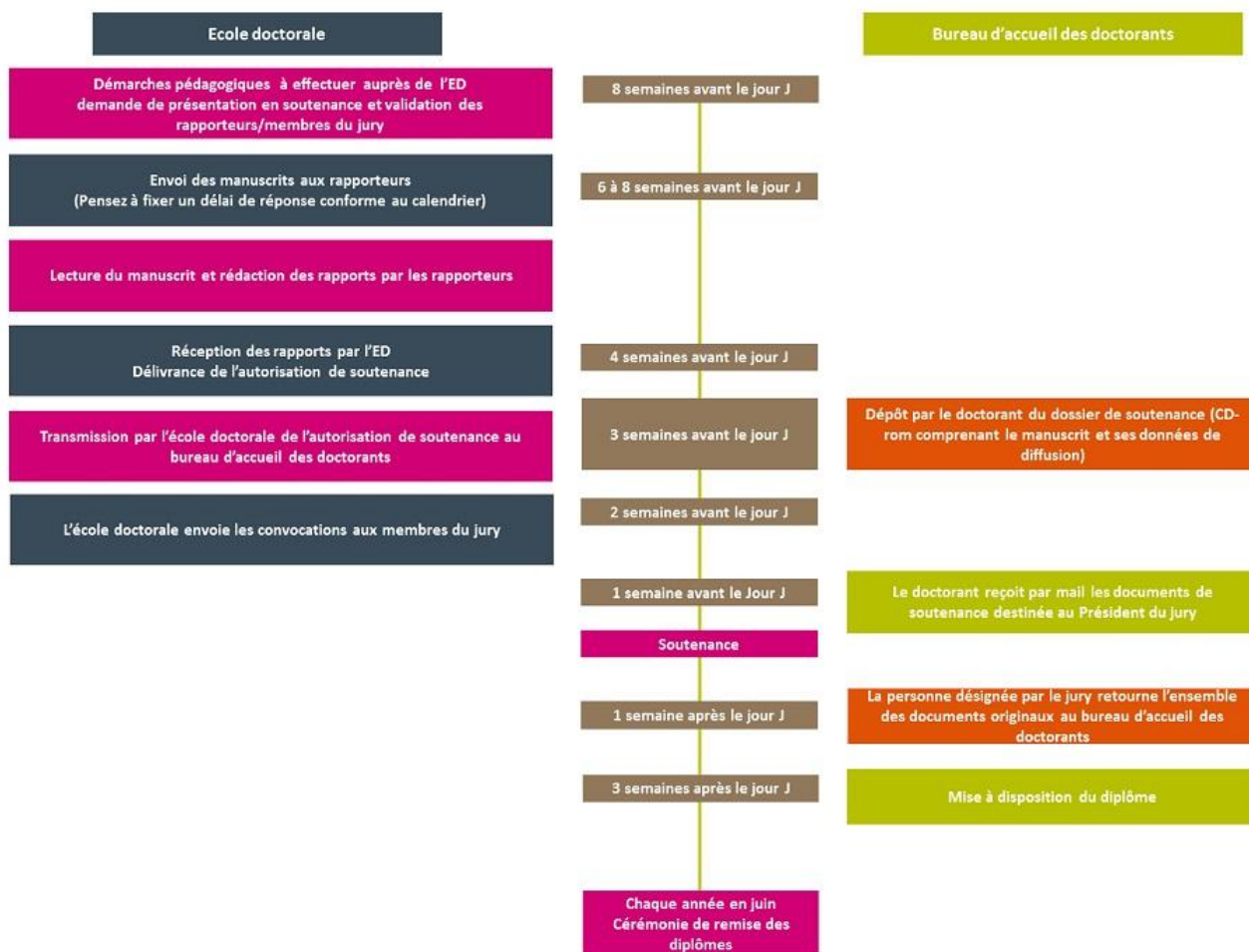
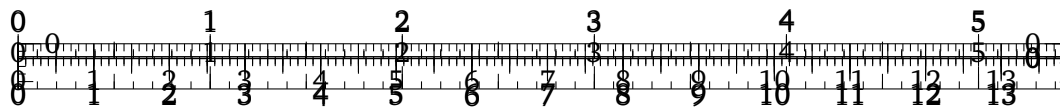
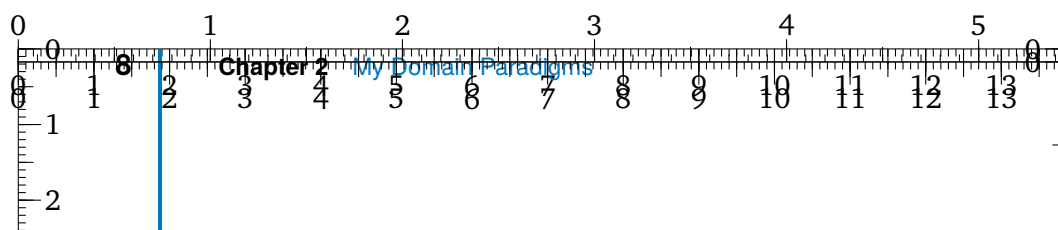
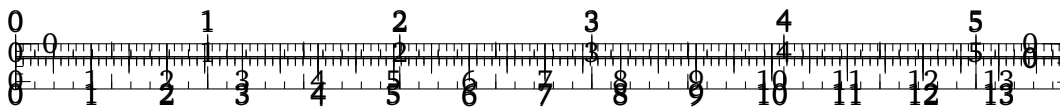


Fig. 2.1.: Admin steps of the defence.





## 2.3 Appointment of rapporteurs and the thesis jury

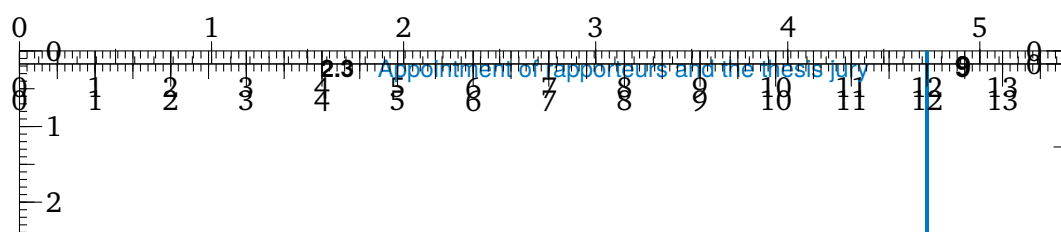
The President of Sorbonne University delegates the appointment of rapporteurs, the composition of the jury and the authorisation of the defence to the director of the doctoral school.

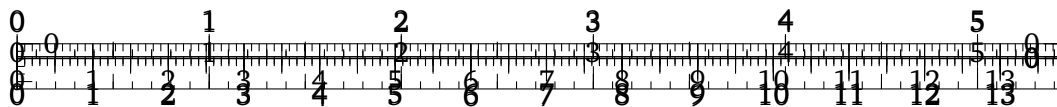
**Appointment of rapporteurs** The President appoints two rapporteurs, authorised to direct research or belonging to one of the categories referred to in Article 17 of the Order of 25 May 2016 at the proposal of the director of the doctoral school and after consulting the thesis director.

- Rapporteurs must come from outside the doctoral school and the doctoral candidate's institution of enrolment.
- They have no involvement in the work of the doctoral candidate.
- They may come from foreign higher education or research institutions or other foreign bodies.
- The rapporteurs shall make their opinion known by means of written reports on the basis of which the President shall authorise the defence. These reports shall be made known to the jury and the candidate before the defence.
- In the event of disagreement between the two rapporteurs, the President shall appoint a third rapporteur.

**Appointment of the thesis jury** The thesis jury is appointed by the president after consulting the director of the doctoral school and the thesis director. There are between 4 and 8 jury members.

At least half of its members are French or foreign people, from outside the doctoral school and the candidate's enrolment establishment, chosen for their scientific competence, subject to provisions relating to the international co-supervision of the thesis. At least half of the jury must be made up of professors or similar personnel, or teachers of equivalent rank who do not report to the Ministry in charge of higher education. Its composition must allow a balanced representation of women and men. The thesis director is a member of the jury, but does not take part in the decision. The thesis jury must include, apart from the thesis director, a lecturer or researcher from Sorbonne University - i.e. attached to a research structure associated with Sorbonne University - holding accreditation to direct research or similar.





## 2.4 Request for defence

Two steps are necessary with two different structures: one with the doctoral school, the other with the reception office.

**At the doctoral school at least 8 weeks before the defence** Candidates must contact the director of the doctoral school they belong to, following the procedures indicated on the doctoral school's website, and must submit the "Application for authorisation to present a defence" and "Authorisation to defend" forms, duly completed and signed by the thesis director.

**When the jury is accepted by the doctoral school** Candidates send the documents called "Letters accompanying the manuscript" and "Thesis reports" to their referees, with their manuscript specifying the name, e-mail address and physical address of the head of the doctoral school to which they should be returned. The reports and the defence authorisation form must be sent by the doctoral school to the reception office at least three weeks before the date scheduled for the defence. It is the candidate's responsibility to find out whether the reception office has received their documents.

**At the doctoral candidates' reception office at least 4 weeks before the defence** Candidates must submit their defence file including their manuscript on CD-Rom and the documents necessary for the dissemination of their thesis.

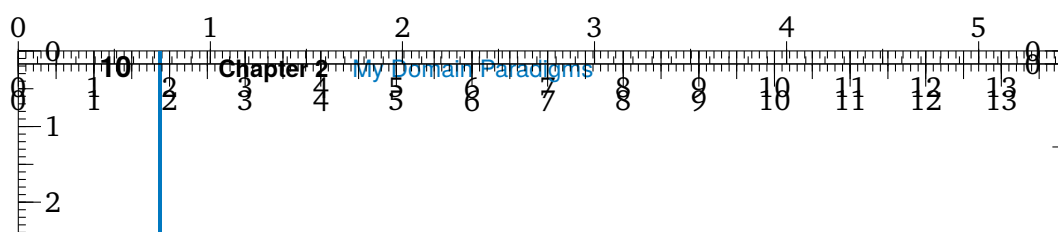
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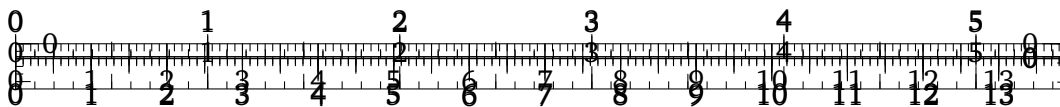
## 2.5 Defence File

The defence file includes

- The CD-ROM
- The Documents

It must be submitted to the doctoral candidates' reception office at least 4 weeks before the defence: make an appointment with the doctoral candidates' reception office. The thesis subject must have the same wording on all documents and copies.





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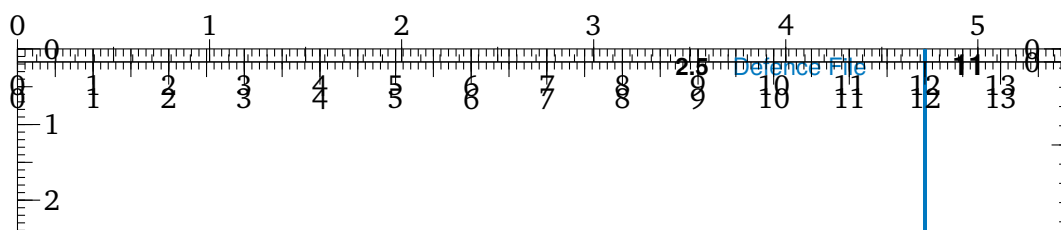
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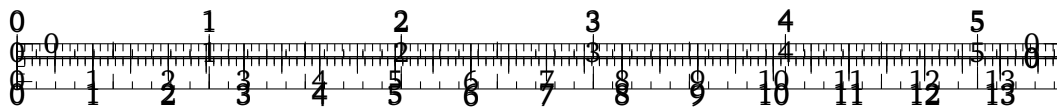
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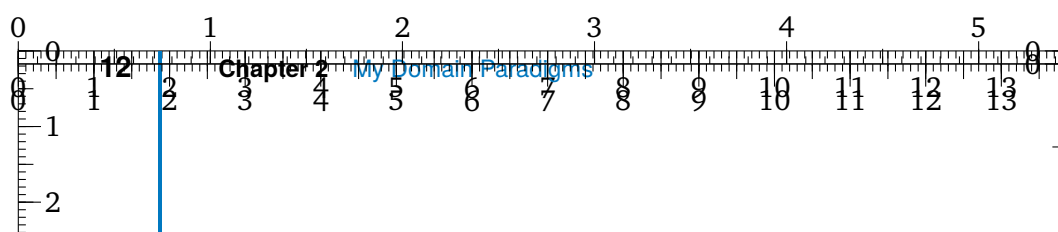
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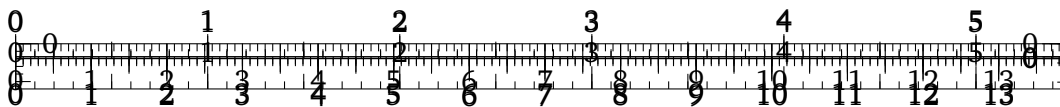
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If necessary, complete and print the authorisation form for an off-site defence.

## 2.6 Submission and dissemination of the thesis

**Submission of the thesis** Final manuscripts must be submitted in digital format (CD-Rom) to the doctoral candidates' reception office 4 weeks before the date of the defence without waiting for the corrections requested by the rapporteurs. This CD-Rom is accompanied by the Defence File. The defence is subject to the submission to the president of the selection board of certification of the submission of the thesis and the completed electronic form. If the jury or the rapporteurs have requested corrections, the new doctor has three months after the defence to submit his corrected thesis in electronic format, accompanied by a certificate from the jury member stating that the corrections have been made.





**Dissemination of the thesis** Sorbonne University files the validated version of the thesis in its dissemination and archiving formats, as well as the electronic docket, in the national STAR application managed by the Agence bibliographique de l'enseignement supérieur - ABES. The college of doctoral schools offers you a course cycle called "Biblio@doctorate". You can sign up for it.

**Confidentiality or embargo?** You have submitted the final version of your manuscript. It will be forwarded to the university library for flagging and distribution. However, the manuscript's dissemination may be delayed either by the doctor (embargo) or by the university (confidentiality).

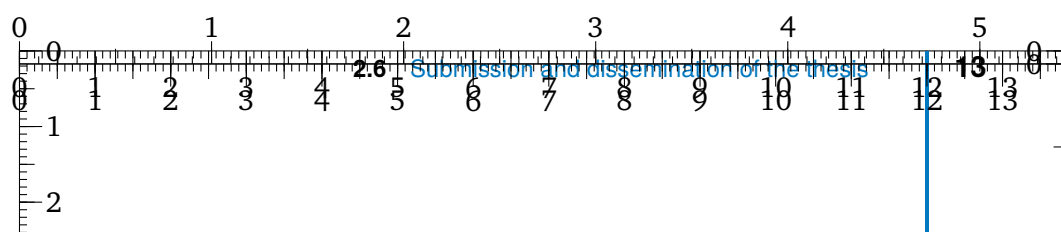
- Embargo

When you submit your manuscript, you can ask to delay its release, for example when results are pending publication. This is known as an embargo request. You will be asked to specify an embargo end date, i.e. the date on which you want your thesis to be disseminated. To request an embargo, just indicate it on the thesis form.

- Non-disclosure

This is a matter of prohibiting the disclosure, reproduction and dissemination of the thesis over a given period of time. This request is generally linked to the existence of a research contract or agreement signed between the partners of the doctoral research project to define the objectives of the research, the contributions of each party and the rules of intellectual property of the results. The request comes from you but from your thesis director, laboratory director or partner institution. Only the President of Sorbonne University can grant it. The thesis is then only reported but cannot be disclosed, reproduced or disseminated before the end of the non-disclosure period granted.

**How do I make a non-disclosure request?** No later than three months before the defence For PhD candidates hosted in a research unit whose promotional activities are managed by Sorbonne University\*, the thesis director completes the non-disclosure request form specific to Sorbonne University For doctoral candidates hosted in a research unit whose promotional activities are not managed by Sorbonne University but by another supervising institution, the thesis director completes the non-disclosure request form specific to the other institutions, has it signed by the promotional structure they belong to and returns it to the Doctoral Candidates Reception Office.





\* : for any question relating to the establishment which manages the promotion of your unit please contact: Lise Tourneux-Ravel at the Directorate of Research and Innovation (DR-I) This document is filed before the defence with the doctoral candidates' reception office.

**For research units whose promotional activities are managed by Sorbonne University :** All "readers" of the manuscript must agree to keep the data confidential and complete the Non-disclosure Form (including the thesis supervisor. It must also be sent to the rapporteurs at the same time as the manuscript. The members of the jury may complete it by the time of the oral presentation at the latest. If confidential results are presented at the hearing, the non-disclosure undertaking will be signed by each of the persons present. A list will be drawn up by the president of the jury from the list prepared for this purpose. If they have not been submitted, the doctor, the thesis director and the chair of the selection board will complete this non-disclosure certificate.

**Request for in camera proceedings** The physical organisation of a closed session is the responsibility of the president of the jury who will complete the list of those present.

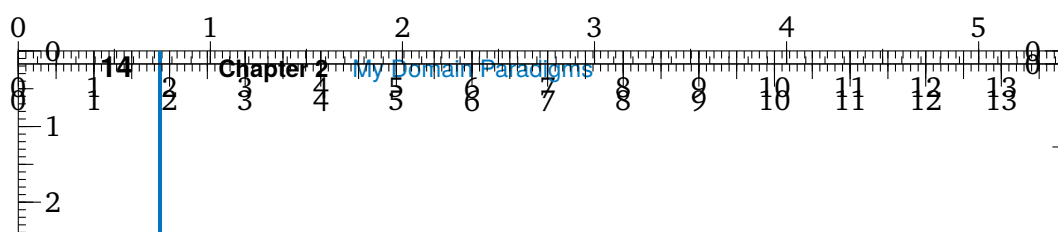
**At the end of the defence** Once the defence has been completed, all documents must be handed over to the doctoral candidates' reception office. The degree certificate will only be handed over in light of the complete non-disclosure file.

*For research units whose promotional activities are not contracts managed by Sorbonne University*

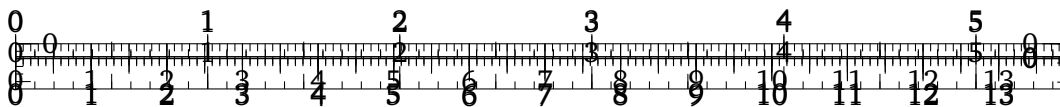
The equivalent of this procedure may be organised by the institution in charge of the promotional activity.

## 2.7 The stages of a defence

The thesis is defended in two stages: a presentation by the doctoral candidate of their research work followed by a question-and-answer session with the members of the jury. At the end of the defence, the jury meets to deliberate and then announces its decision to award the thesis to the doctoral candidate. The defence is public, unless the headmaster exceptionally grants an exemption if the subject of the thesis







is proven to be confidential (cf Thesis filing and dissemination/Non-disclosure) The defence is traditionally followed by a "thesis party" organised at the discretion of the doctoral candidate.

**Appointment of the President of the Jury** During the defence, the members of the jury shall appoint a chairman and, if necessary, a rapporteur for the defence from among themselves. The chairman must be a professor or equivalent or a teacher of equivalent rank. The thesis director cannot be appointed either as rapporteur for the defence or as president of the jury. The thesis director does not take part in the decision.

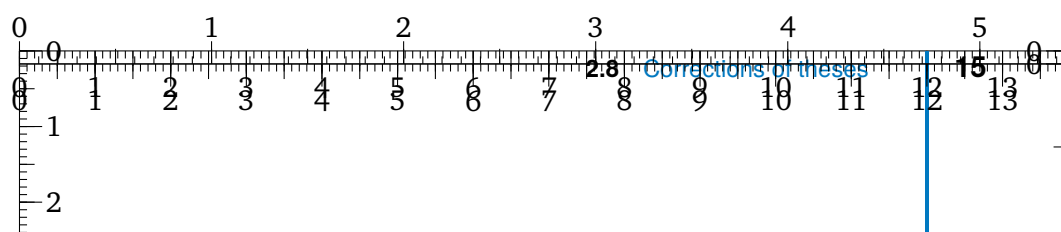
**Awarding the title of doctor** Admission or adjournment will be decided after deliberation by the selection board. The chairman signs the defence report, which is countersigned by all the members of the selection board. The report is sent to the candidate in the month after the defence. In accordance with regulations in force, the doctorate is awarded without any special mention.

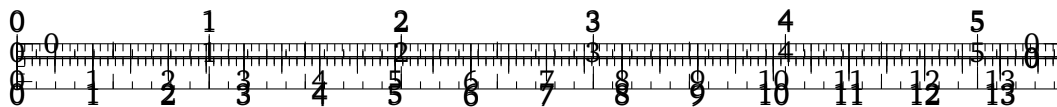
## 2.8 Corrections of theses

Final manuscripts must be submitted in digital format (CD-Rom) to the doctoral candidates' reception office 3 weeks before the date of the defence without waiting for any corrections requested by the rapporteurs. At the end of the defence, they will be sent by the doctoral candidates' reception office at the Sorbonne University library according to the instructions given by the president of the jury in the defence report.

**The thesis can be reproduced as is without any correction.** The CD-Rom that is filed before the defence is considered to be final and sent to the library for distribution, archiving...

However, if the doctor wishes to make minor corrections: You have a period of one month to make minor corrections (typos, formatting, etc.) and submit the corrected version (labelled corrected version) and on CD-ROM to the doctoral candidates' reception office accompanied by a signed declaration from you indicating that the corrections have been made (manuscript modification declaration form) and the report from the Facile application. At the end of this period, even if the corrections





have not been made, the thesis will be sent to the library to be reported, reproduced and disseminated.

**The thesis cannot be reproduced as-is...** The jury wanted major corrections under the responsibility of a designated jury member. You then have 3 months to make these corrections and submit the corrected version of your thesis on CD-Rom accompanied by the form for declaring modifications to the manuscript) and the report from the Facile application to the doctoral candidates' reception office. The CD must be accompanied by a letter from the member of the jury designated during the defence, certifying that the requested corrections have been made. The delivery of the graduation certificate, the reporting, reproduction, distribution and consultation of the manuscript are subject to the delivery of the corrected versions and the certificate.

Emmanuel DESCUBESBSU Electronic Theses Service Snake Library Email: [bibth@upmc.fr](mailto:bibth@upmc.fr) ■

## 2.9 Collection of degrees

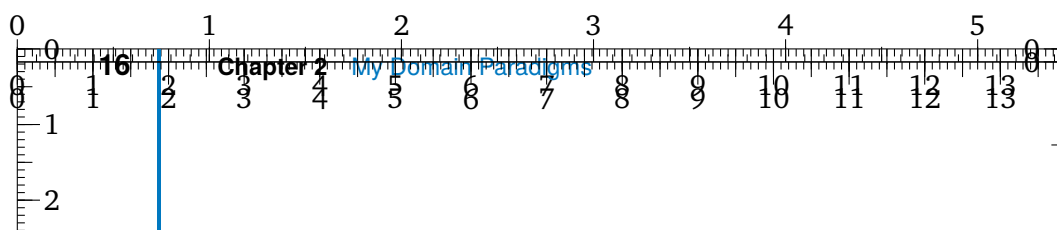
Once the defence is over, don't forget to bring the original of your report to the Doctoral Candidates' Office. Then, you will be able to collect your degree by appointment within a fortnight. Previous degrees are published within a maximum period of 6 months.

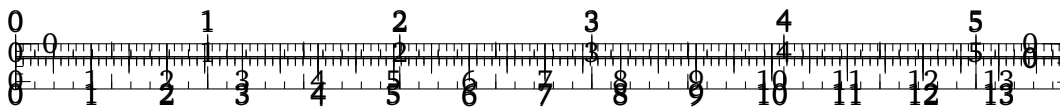
**Collection at the reception office** You can pick it up at the Doctoral Candidate Reception Office. Please bring an identity document (national or European identity card, passport, residence permit). If you can't make it, another person can come in your place. They will need to bring a handwritten power of attorney, a copy of your ID and their own ID.

Doctoral candidates reception office - - 15 rue de l'école de médecine - Escalier G – 2e étage 75006 PARIS (métro Odéon) Opening hours: 9:30 am - 4:30 pm (closed on Wednesdays)

**Collection by mail** You can also have your diploma sent to you. If you wish to receive your degree by post, please send us:

*For a delivery to France*





- €6.82 in postage stamps
- A registered letter with acknowledgement of receipt filled in at the permanent address at which you wish to receive your diploma in the addressee box and "Sorbonne Université - Bureau d'accueil des doctorants - 15 rue de l'école de médecine - 75006 Paris" in the sender box.

*For a delivery abroad*

- €12.10 in postage stamps or the equivalent in international coupons
- An international registered mail shipping slip (CN07)
- A deposit form (517/517 bis) filled in with the permanent address at which you wish to receive your diploma in the recipient box and "Sorbonne Université - Bureau d'accueil des doctorants - 15 rue de l'école de médecine - 75006 Paris" in the sender box.
- You can frank your mail from your home in France or abroad on the website of the Post Office.

*Do you need your degree authenticated?*

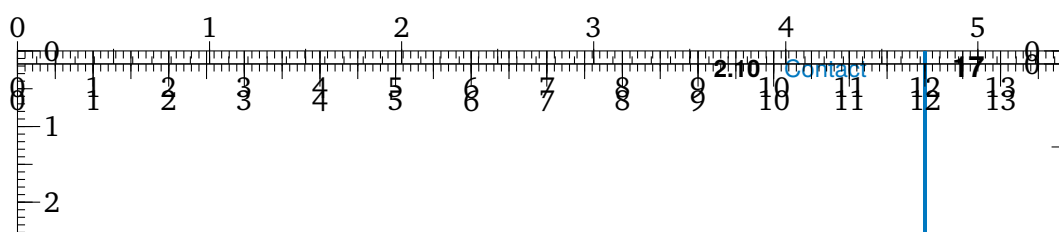
- Find out about legalisations: <https://www.diplomatie.gouv.fr/fr/services-aux-francais/legalisation-et-notariat/faire-legaliser-un-document/>
- Legalisation or apostille: for which country: <https://www.service-public.fr/particuliers/vosdroits/>

## 2.10 Contact

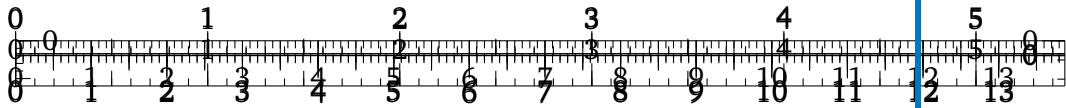
Bureau d'accueil des doctorants - 15 rue de l'école de médecine 75006 Paris [scolarite-doctorat@sorbonne-universite.fr](mailto:scolarite-doctorat@sorbonne-universite.fr)

## 2.11 Conclusion

In this chapter, we made a copy paste from: <https://www.sorbonne-universite.fr/en/research-and-innovation/doctorate/administrative-procedures/defence>







3

## Requirements for my domain

...

### 3.1 XX requirements

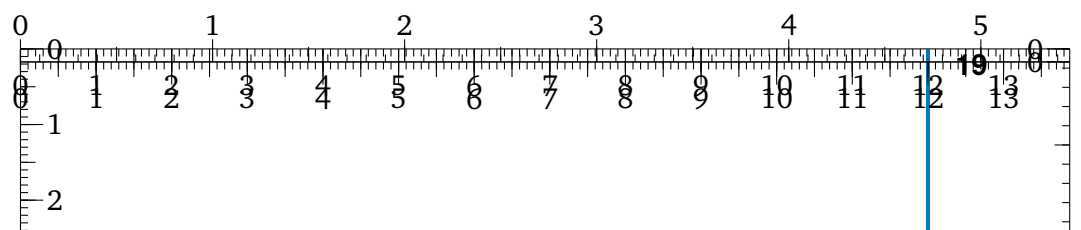
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### 3.2 YY requirements

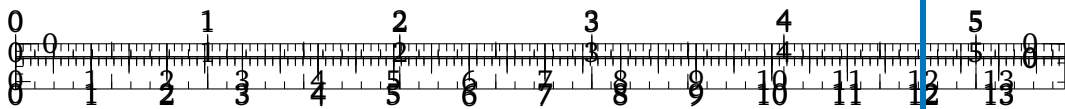
...

### 3.3 Summary

...







4

## Related Work

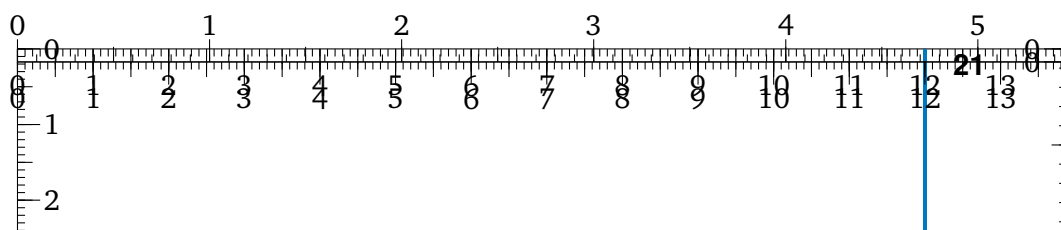
Intro paragraph

### 4.1 Overview

...

#### 4.1.1 Discussion

...





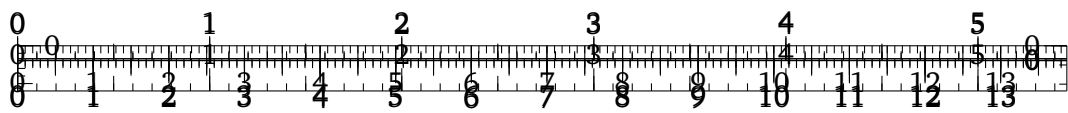


# Part II

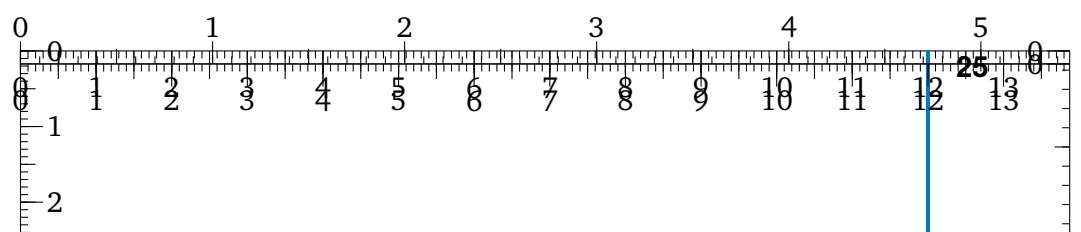
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Contributions

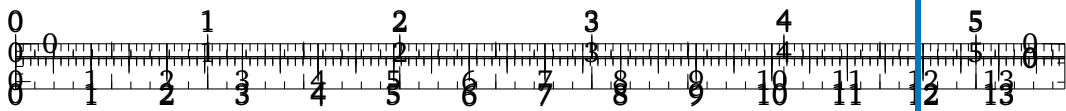




In this chapter, we present the design, algorithms and architecture of ...





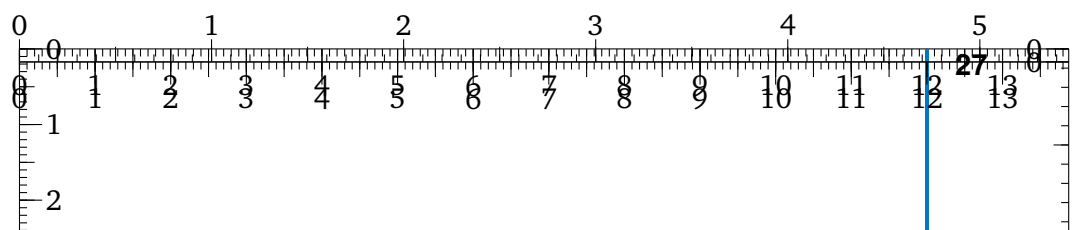


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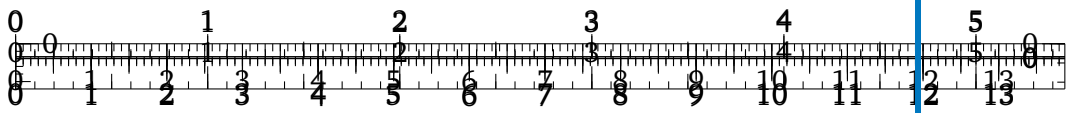
Contrib 1

## 5.1 Contrib 1

TBD



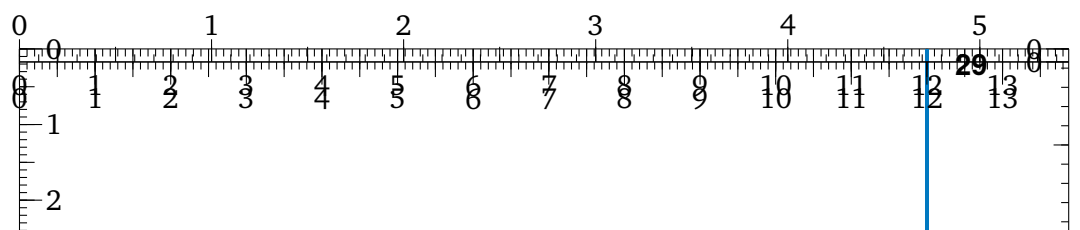




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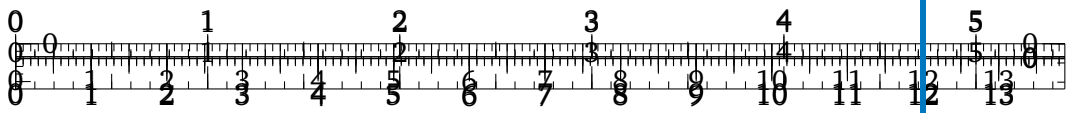
## Contrib 2

TBD





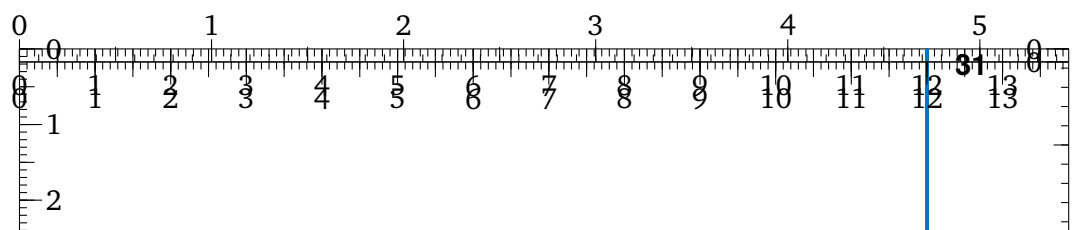




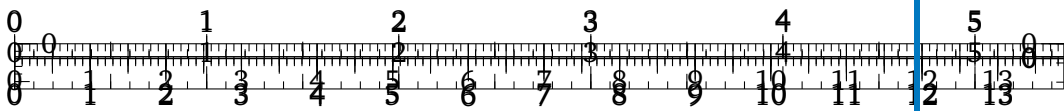
7

Contrib 3

TBD







# 8

## System API and Implementation

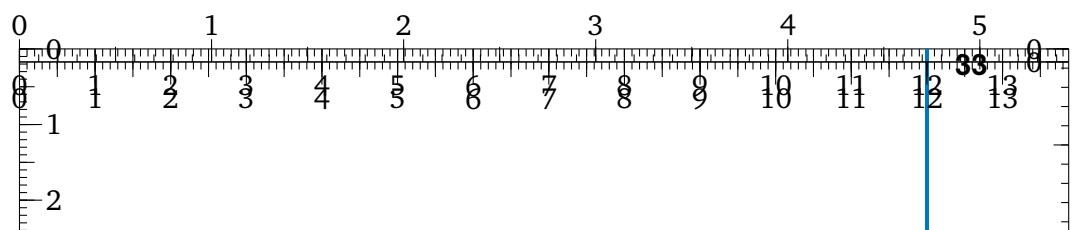
TBD

### 8.1 Example of code input

```
1  let dc_connection = colony_dc.connect(CONFIG.dbURI, CONFIG.credentials);
2  let cnt = dc_connection.counter("myCounter");
3  dc_connection.update(
4    cnt.increment(3)
5  )
6
7  let peer_connection = colony_pop.connect(CONFIG.signalingServers, CONFIG.
   credentials)
8  let tx = await peer_connection.startTransaction()
9  let map = tx.gmap("myMap");
10 tx.update([
11   map.register("a").assign(42),
12   map.set("e").addAll([1, 2, 3, 4])
13 ])
14 tx.commit().then(
15   console.log(
16     await peer_connection.gmap("myMap").set("e").read()
17   )
18 )
```

**Fig. 8.1.:** An example of CALOCK program.

The TypeScript example in Figure 8.1 illustrates the API. This application opens a session (Line 1). Then, it creates and increments a CRDT counter object (Lines 2–5). Then it connects to a peer group (line 7), and updates the grow-only map (gmap) "myMap" in a transaction (lines 8–12). This map contains references to a register object (key "a") and a set object (key "e"). The counter update and the commit are both asynchronous (Lines 9 and 13), returning a promise. At line 13, the client waits for the promise, and displays the content of the set.



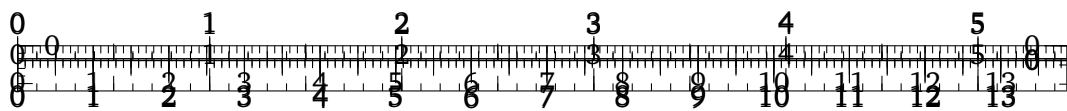


# Part III

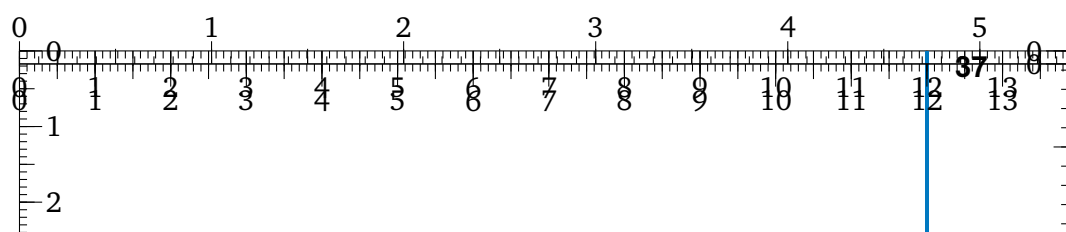
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Experimental Evaluation



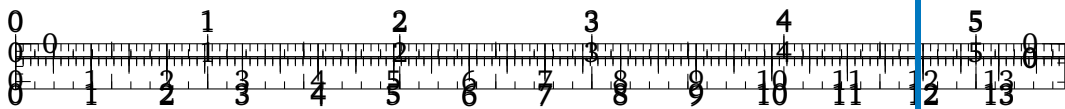


Don't forget to put the source code link ;-)







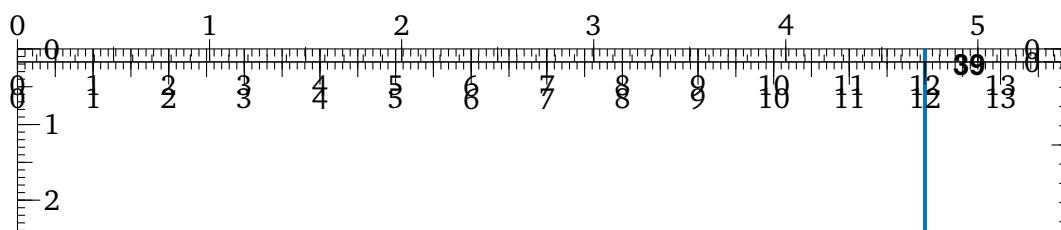


9

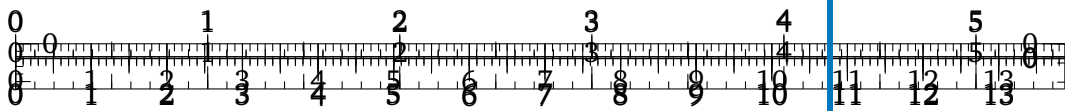
## Benchmark app and setup

Overview ...

Workload ...







10

## Performance Evaluation

The performance evaluation will focus on situations where ...

### 10.1 Setup

...

### 10.2 Metrics A

...

### 10.3 Metrics B

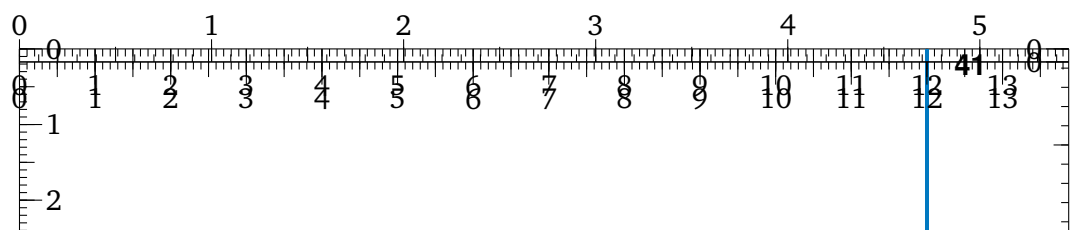
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### 10.4 Metrics C

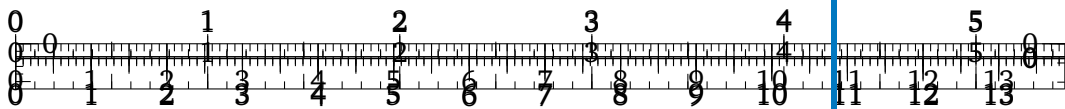
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### 10.5 Metrics 4

...



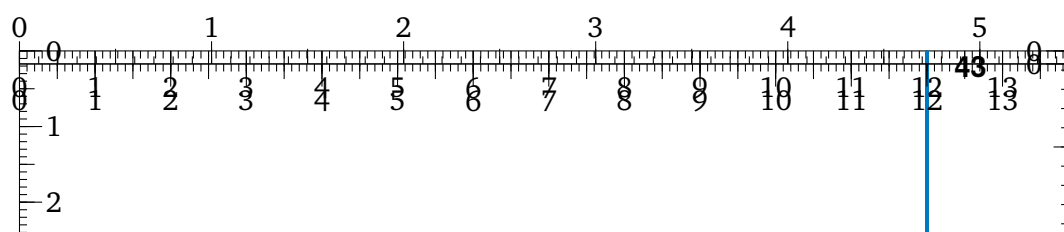




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## Summary and discussion

...





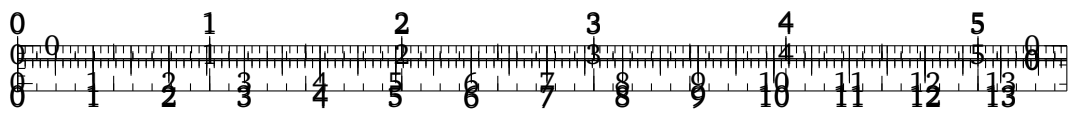
# Part IV

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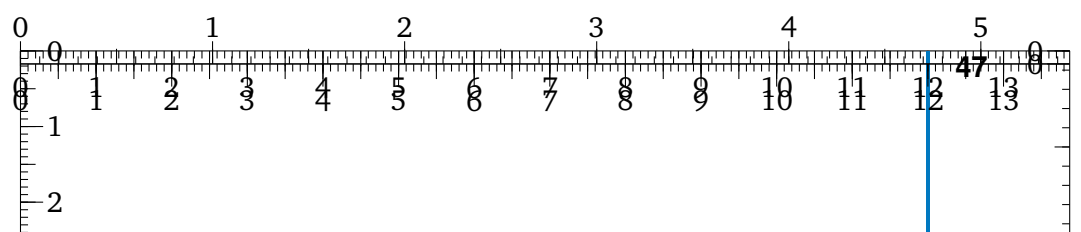
Conclusion



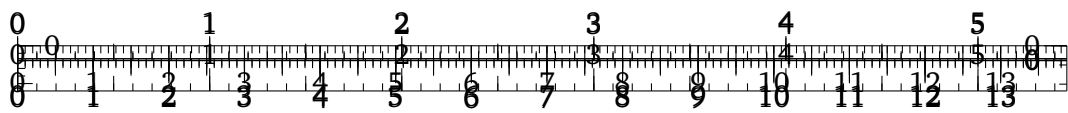




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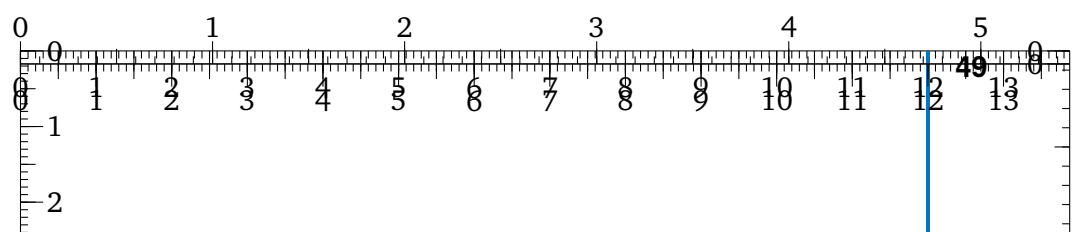




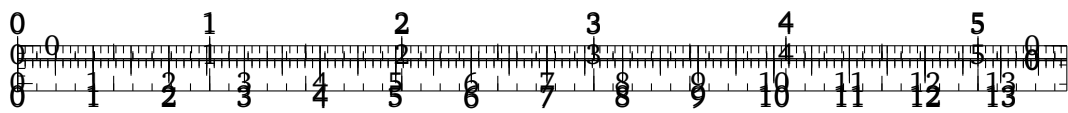


## List of Figures

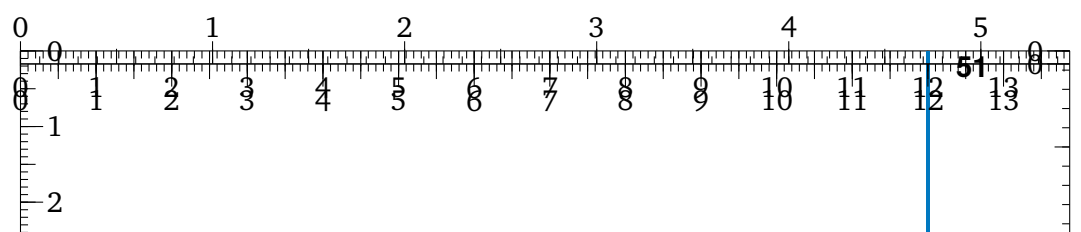
|     |                                       |    |
|-----|---------------------------------------|----|
| 2.1 | Admin steps of the defence. . . . .   | 8  |
| 8.1 | An example of CALOCK program. . . . . | 33 |



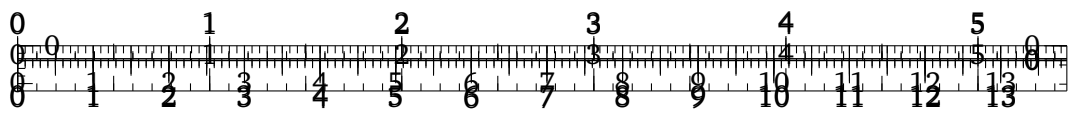




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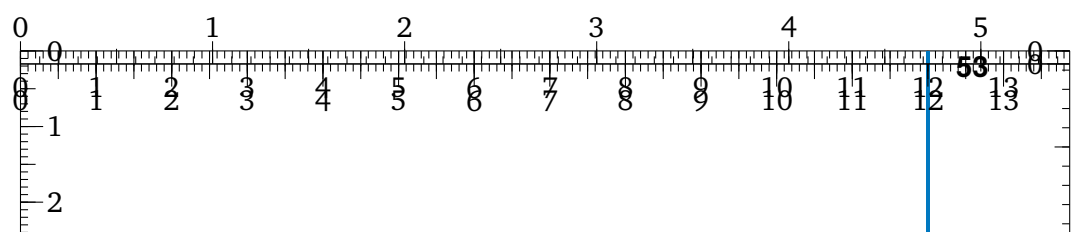






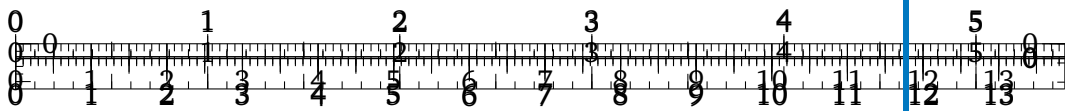
## List of Listings

docs/typescript/src/api.ts . . . . . 33









# A

## Résumé

The doctoral schools of Sorbonne Université require at least one page of summary in French. (Even if the website says that you need to provide more than one page, one is enough, which I did).

Résumons donc en français. Tout bon résumé commence par une description générale du problème de la thèse. Le problème étant que les écoles doctorales de Sorbonne Université exigent au moins une page de résumé en français. Voici donc un résumé garanti non traduit sur un DeepL.

Le deuxième paragraphe du résumé doit répondre à la question *pourquoi le(s) problème(s) présenté(s) est un vrai problème ?*.

Ensuite, le troisième paragraphe doit répondre à la question *quelles sont les solutions apportées par la thèse à ces problèmes ?* Cette thèse explore ces problèmes en profondeur, en étudiant l'état de l'art lié ... et présente la solution *SystèmeCool2Ouf*, conçu pour répondre aux problématiques exposées. L'une des principales exigences est une approche *DurACuir* qui *EstVraimentVraimentDureCar...* Cependant, cela rend difficile la satisfaction des attentes en matière de *Toute solution à des petits défauts et compromis, on va pas se le cacher*.

Paragraphe 4, *En quoi la solution est meilleure que l'état de l'art ?* Pour répondre à ces défis, nous avons fait le choix d'adopter une approche ... en fournissant les plus fortes garanties de .... Un défi connexe est ..., que nous avons limité grâce à ...

Enfin, traditionnellement on liste une référence aux contribution, Les contributions de cette thèse peuvent être résumées comme suit:

- ...;
- ...;
- ...;

Notre évaluation expérimentale montre que ...

