

# Dependable Distributed Systems- Project 1 - Phase 1

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## 1 Overview

This document discusses the first phase of the first project for the CSD project (2022/23 edition). The project will be presented as three phases, that will focus on specific aspects of the project as a whole. Throughout the execution of the project each group will always be working towards the final goal, which is already discussed in this document (and might be refined in the next specifications of the project).

Overall, the first project of CSD aims at building a replicated system whose goal is to offer an open goods market. The idea of this market is to operate akin to an auction system (think on the lines of <https://ebay.com>) but with some twists. In practice in this system, users are able to register offers of goods, including the type of good, quantity, and price per unit that they are willing to sell, and they can also register their interest in acquiring goods, by indicating the type of good, quantity they want to acquire, and the maximum price they are willing to pay for each unit. The system will match these offers and requests to effectively offer a market system for trading general goods. While the specificities of this system, in particular what features could be provided to end users to make it more attractive, usable, and dependable can be discussed in a future phase of the project, the generic architecture of the system is fixed. Throughout the labs in the Dependable Distributed Systems (Confiabilidade de Sistemas Distribuídos) we will be discussing different aspects and features of the implementation of this project. This will assist groups in building the most effective system and also in devising mechanisms to validate the correctness and the performance of their developed solutions. The project will be implemented in Java, taking advantage of the Babel Framework that was already presented in the first lab.

In the following sections, we present some of the details of the project that should guide your implementation efforts. In particular, this document presents the architecture (and some of their interfaces) that should be constructed for the first project (Section 2). The programming environment for developing the project is briefly discussed next (Section 4). Finally, the document concludes by providing some information on operational aspects and delivery rules for this phase of the project (Section 5). Notice that the document does have literature, which is recommended that students read before starting to implement their solutions.

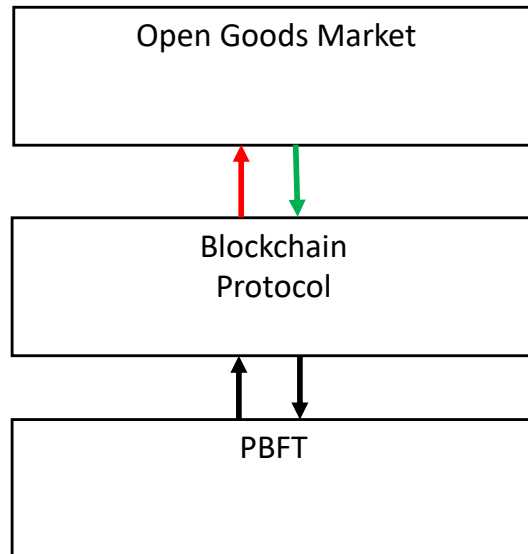


Figure 1: Architecture of a Process.

## 2 Solution Architecture

Figure 2 illustrates the layering of protocols that you will have to develop for the first project<sup>1</sup>. In a nutshell, each replica of our Open Goods Markey system will be composed of three layers (or protocols). From top to bottom, we will have our application logic (which is labelled *Open Goods Market* in the diagram); we will have a *Blockchain Protocol*; and the lowest layer we will have a Byzantine-fault tolerant agreement protocol, in particular we will be using the well known Practical Byzantine Fault Tolerance Protocol (*PBFT*), which was studied in the lectures. We now provide an overview of the main responsibilities of each of these layers that groups will have to implement. Further details in this document are provided on the interface used by the Blockchain protocol and PBFT to interact.

### 2.1 Application Logic (*Open Goods Market*)

The application logic protocol will be responsible for two primary tasks: *i*) interactions with clients, receiving their operations and replying to them to confirm that those operations were received and will be processed; and *ii*) maintaining state about current offers and requests, and matches that might be executed among them, this will also require that the application logic exposes operations to clients that allow them to gather information (asynchronously) about the state of their current made (and confirmed) offers and requests for goods. The application will have to submit operations received by the clients to the blockchain protocol, such that these operations can be registered in the replicated ledger (and potentially be matched). Additional details about this protocol will be provided on future releases of this problem statement.

### 2.2 Blockchain Protocol

The blockchain protocol will maintain a replicated ledger that will register all client operations, and potentially management operations such as adding a new replica or removing a replica from the system. The replicated ledger will be composed of an ordered set of blocks of operations, that include the operations described previously. The blockchain

<sup>1</sup>For evaluation purposes this layering is *mandatory*.

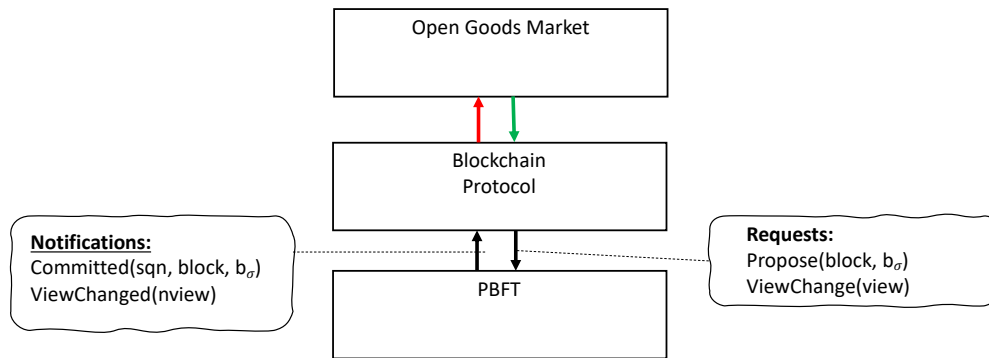


Figure 2: Interface between the Blockchain Protocol and PBFT.

protocol has to aggregate these operations in blocks which are then proposed to the agreement protocol for being ordered. Notice that the blockchain protocol is operating also as a byzantine-tolerant state machine replication, meaning that it is the responsibility of the blockchain protocol to manage operations that allow to change the system membership (commonly denominated by *view*). The blockchain protocol will act as the client for the PBFT agreement protocol. Additional details about this protocol will be provided on future releases of this problem statement, namely some behaviours of the system can be handled by smart contracts registered on and processed by this protocol.

### 2.3 PBFT

This is the agreement protocol used in our system to allow replicas to agree on which set of operations (i.e., block) to be added to the replicated ledger maintained by the Blockchain protocol. This protocol will be an implementation of the classical PBFT protocol [2], potentially using some optimisations to reduce the size of message exchanged by the protocol. The interface of the protocol to the blockchain protocol is based on events that should be processed asynchronously. There are fundamentally two requests that this protocol can receive from the blockchain protocol above: *i*) a PROPOSE request that carries a *block* generated by the blockchain protocol above and the signature of that block ( $b_{\sigma}$ ), that will serve as the value to be proposed by PBFT on the next non-committed instance of the current view of the protocol; and *ii*) a VIEWCHANGE request that carries a *view* (membership of the system) to be installed in the system. Each of these requests will lead to triggering notifications to the Blockchain protocol above to indicate to the above protocol the outcome of previous requests. Namely, the COMMITTED notification indicated that a *block* (with its respective signature  $b_{\sigma}$ ) has been committed on the sequence number *sqn* of the current view; and the VIEWCHANGED notification that carries a new view of the system (*nview*) that is currently employed by PBFT. Notice that the events reported can be changed by students to carry additional information if the groups executing the project consider it necessary.

In terms of messages exchanged by this protocol, the students are free to define their messages as they see fit, following the original specification of the protocol (as discussed in lectures and in [2]), with possible implementation for improving performance. As an additional useful reading for implementing and understanding this protocol, it should be noted that the correctness of PBFT has been discussed in [1].

## 3 Report

This project will require each group to prepare a written report where groups will document the implementation of their solutions, including the presentation of arguments that justify the correctness of their solutions in an asynchronous (more precisely partially synchronous) system under the byzantine fault model as well as an experimental evaluation of the developed system that studies its performance.

### 3.1 Correctness

When justifying the correctness of the solutions you should be considering the operation of this system in a partially synchronous model under the byzantine fault model. You should also document the attacks that you have considered in the development of this solution and how these attacks are handled (or mitigated) by your solution. Be as precise as possible in documenting these aspects in the document, and avoid very generic statements.

### 3.2 Evaluation of Your Solution

You will conduct an experimental evaluation of the developed solutions. To that end groups will have to design a simple client application that generates some workload for replicas of the system. Evaluation is expected to be conducted on the DI and NOVA LINC'S research cluster. The main aspects that should be considered in the evaluation of the developed solutions is:

**Throughput:** Number of client operations that can be handled by the system per time unit. Notice that the throughput should be considered taking into account the number of clients operations registered on the replicated ledger. Naturally, this number might be affected by the number of clients interacting with the system, a factor that should be taken into consideration by students when preparing their experimental evaluation. For instance, it is interesting to study how this performance indicator evolves with increasing numbers of clients interacting with the system (or potentially with the number of replicas or disruptions over the system).

**Latency:** The time required for client operations to be registered in the replicated ledger. Similar to throughput, latency might be affected by the number of clients interacting with the system, a factor that should be taken into consideration by students when preparing their experimental evaluation. Similar to the previous metric, it might be interesting to study how this performance indicator evolves with increasing numbers of clients interacting with the system (or potentially with the number of replicas or disruptions over the system).

## 4 Programming Environment

The students will develop their project using the Java language (1.8 minimum). Development will be conducted using a framework developed in the context of the NOVA LINC'S laboratory<sup>2</sup> written by Pedro Fouto, Pedro Ákos Costa, João Leitão, named **Babel** [3].

The framework resorts to the Netty framework<sup>3</sup> to support inter-process communication through sockets (although it was designed to hide this from the programmer). The framework will be discussed in the labs, and example protocols will be made available to students. Moreover the top layer that is responsible for injecting load in the system (i.e., propagate messages and receive them) is offered.

The javadoc of the framework can be found here: <https://asc.di.fct.unl.pt/~jleitao/babel/>.

The framework was specifically designed thinking about two complementary goals: *i*) quick design and implementation of efficient distributed protocols; and *ii*) teaching distributed algorithms in advanced courses. A significant effort was made to make it such that the code maps closely to protocols descriptions using (modern) pseudocode. The goal is that you can focus on the key aspects of the protocols, their operation, and their correctness, and that you can easily implement and execute such protocols.

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<sup>2</sup><http://nova-lincs.di.fct.unl.pt>

<sup>3</sup><https://netty.io>

## 5 Operational Aspects and Delivery Rules

### *Group Formation*

Students can form groups of up to three students to conduct the project. Groups composition cannot change across the different phases of the project. While students can do the project alone or in groups of two students this is **highly discouraged**, as the load of the project was designed for three people.

Since you will be given access to the DI and NOVA LINCS research cluster (see below) to conduct your experiments and extract performance numbers, you must pre-register your group as soon as possible such that you can get credentials to use the cluster. This can be done by sending an e-mail to Alex Davidson (a.davidson@fct.unl.pt) with subject *CSD 22/23 GROUP REGISTRATION*. The e-mail should contain for each member of the group: student number, full name, and institutional e-mail. Even students that plan to do the project alone must register following the procedure above. You will get a reply from the professor (eventually) providing your username and password to access the cluster.

### *The DI and NOVA LINCS Research Cluster*

The cluster is used for (mostly) research purposes, although some (advanced) courses also use it. The cluster has a limited amount of machines, and hence people might need to compete over computational resources and time. The cluster features a reservation mechanism where you can reserve a set of machines for exclusive access during a period of time. You should not use the cluster for development purposes and only to extract final numbers. Moreover, each group should only reserve at most five machines at a time. Each machine should be able to execute several processes, although you might want to execute different replicas of the system on different machines (and use another one to execute clients). Docker is available in the cluster, and you can freely use it. Each group will be restricted to a limited amount of computational time (where using more machines accounts for a higher consumption of time). Notice that automation is key for success, not only will it allow you to easily repeat experiments, but it might also allow you to run experiments during the night period (where typically usage of the cluster is much more reduced).

The technical specification of the cluster as well as the documentation on how to use it (including changing your group password and making reservations) is online at: <https://cluster.di.fct.unl.pt>. You should read the documentation carefully. The cluster is accessible from anywhere in the world through ssh. Be careful with password management. Never use a weak password to avoid attacks and intrusions on our infrastructure. Incorrect or irresponsible use of the department resources made available to students will be persecuted through disciplinary actions predicted in the School regulations.

### *Code Management*

At the start of the project, you are given a code repository (available on GitHub) that you can work from at the following link: <https://classroom.github.com/a/-w4hjyDu>. Using this code as a starting point, and using `git` to track your changes and the building of your solutions, you can develop the ultimate end result of your project.

Using `git` and GitHub is not mandatory, but is highly recommended. It will ensure consensus on changes amongst all of the members of your group, and also provides allows you to develop a helpful summary of the execution of your project. If you're new to `git` and GitHub, you can use the following link to learn more about it, and the different operations that you can perform for managing your codebase: <https://classroom.github.com/a/uvxp8U8M>.

### *Evaluation Criteria*

The project delivery includes both the code and a written report that, ideally, should have the format of a short paper. Considering that format, this document refers from this point onward to your final report as simply the *paper*.

This phase of the project will be graded in a scale from 1 to 20 with the following considerations:

- The paper should be at most 10 pages long, including all tables, figures, and references. It should be written with font size no bigger than 10pts and be in two column format. It is highly recommended (for your own sanity) that you use  $\LaTeX$  to do this. If you do not know  $\LaTeX$  it is indeed a great time to learn. Videos from an introductory course on  $\LaTeX$  by João Lourenço shall be provided online at a future date. A  $\LaTeX$  template for writing the paper shall also be provided.
- The project will be evaluated by the correctness of the implemented solutions, their performance, and the quality of the implementations (in terms of code readability).
- The quality and clearness of the paper can impact the final grade: students with a poorly written report might be penalised on the evaluation, even if they ultimately produce a correct solution.

### *Deadline*

Delivery of project 1 (which includes all phases of this project) is due on May 5<sup>th</sup> 2023 at 23:59:59. Further details regarding the delivery rules for the project will be provided at a future date.

## **References**

- [1] Miguel Castro, Barbara Liskov, et al. A correctness proof for a practical byzantine-fault-tolerant replication algorithm. Technical report, Technical Memo MIT/LCS/TM-590, MIT Laboratory for Computer Science, 1999.
- [2] Miguel Castro, Barbara Liskov, et al. Practical byzantine fault tolerance. In *OsDI*, volume 99, pages 173–186, 1999.
- [3] P. Fouto, P. Costa, N. Preguiça, and J. Leitão. Babel: A framework for developing performant and dependable distributed protocols. In *2022 41st International Symposium on Reliable Distributed Systems (SRDS)*, pages 146–155, Los Alamitos, CA, USA, sep 2022. IEEE Computer Society.