

# Final Project v1.0

## Programming Scalable Systems

Universidad Politécnica de Madrid

2023-2024

### Reminder

No exams

personal work every two weeks: mandatory exercises  
just some of them will be reviewed (20%)

1 final project  
team of two or three  
(50% git review + 30% presentation)

This document describes in detail a proposal for a concrete final project which you may work on, *The Betting Exchange Platform*, and provides some limited information on interesting alternative projects.

Of course, you are allowed, to choose yourselves a theme for the course project. Please email us your own project ideas for approval – make sure that the difficulty of realising them is at least as hard as realising *The Betting Exchange Platform* detailed below.

## Contents

### 1 The Betting Exchange Platform Proposal

A betting exchange platform is a marketplace where users can place bets against each other, rather than against a bookmaker. Betfair Exchange and Smarkets<sup>1</sup> are popular examples of such a platform. In a betting exchange, users can either *back* a certain outcome (betting that an event will happen) or *lay* the same outcome (betting that the event will not happen). This allows users to trade positions and manage risk, leading to a more engaging and dynamic betting experience.

#### 1.1 Users and Wallets

Users sign up for an account on the exchange and can deposit and withdraw funds.<sup>2</sup>

<sup>1</sup><https://www.betfair.es> and <https://smarkets.com>, respectively.

<sup>2</sup>Obviously you will simulate it in your implementation!

## 1.2 Events

Users can browse the available *events* (also known as markets) that people can place bets on. These events might be sports events as well as other activities such as political elections. Events or markets are typically registered and managed by the platform's operators or administrators. After the event has concluded, the market is *settled* by determining the winning bets based on the actual outcomes of the event. The platform then updates the users' account balances accordingly and closes the market.

## 1.3 Betting

Users can either back or lay an event, resulting in a backing bet, or a lay bet. For a backing bet to be "accepted, it must be *matched* with an acceptable lay bet. Vice versa, a lay bet must be matched with a backing bet. Here's an explanation of how it works:

### Backing an Event:

When you *back* an event, you are betting that the event will happen. For example, you might back the event "Real Madrid to win the *clásico* against Barcelona". A backing bet specifies a *stake* and an *odds*. The *stake* is the amount of money you are willing to risk (the backing stake). The *odds* offered for backing an event represent the potential winnings if your bet is successful, which is calculated as  $stake \times odds$ .<sup>3</sup>

For example, suppose that you are willing to risk 20€ to back "Real Madrid to win the *clásico* against Barcelona", and you specify an odds of 1.5. Suppose moreover that some other person *lays* a *matching* bet against Real Madrid winning, then first your 20€ (the stake) is removed from your account. After the *clásico* finishes the market is *settled*. If Real Madrid does win your account will receive  $20 \times 1.5 = 30€$  (a gain of 10€). But if Real Madrid draws or loses, you will have lost your original stake of 20€.

### Laying an Event:

When you *lay* an event, you are betting that the event will *not* happen, i.e., in our example, laying "Real Madrid to win the *clásico* against Barcelona", is betting that F. C. Barcelona draws or wins the *clásico*. In other words, you are acting as the bookmaker and taking on the risk of paying out the winnings if the event occurs.

A lay bet specifies a *stake* (lay stake) and an *odds* too. The *stake* is the amount of money you are willing to risk, exactly as in a backing bet.

If the event does not occur, you win the bet and keep the stake of the backer. If the event does happen, you must pay the backer their winnings, calculated as their stake multiplied by the odds, minus the stake itself.

Continuing with the example above, i.e., a backing bet with stake 20€ and odds 1.5, can be matched with a lay bet with a stake at least 10€ and an odds that is 1.5 or greater.

If Real Madrid wins the *clásico* the lay better needs to pay out  $20 \times 1.5 - 20 = 10€$  (the gain of the backing better minus his stake). If Real Madrid does not win then the lay better gains the stake of the backing better, i.e., 20€.

As can be seen, it is advantageous for the lay better to specify as low odds as possible. On the other hand, maybe no backing better will accept such a low odds.

Matches can be partial too. For example, if backing and lay better agrees on an odds of 3.0, with both stakes 20€, then the lay better has to pay out  $20 \times 3.0 - 20 = 40$  euros. But the lay stake is only 20€ – impossible! The maximum betting stake  $x$  consistent with a lay stake of 20€ can be derived from the equation  $x \times 3.0 - x = 20$ , which results in  $x = 10$ . After matching these bets then the backing bet still has a remaining stake of  $20 - 10 = 10€$ , which can be matched against other lay bets.

<sup>3</sup>Typically minus some small percentage of money which goes to the operators of the exchange platform itself.

In summary, backing an event means you bet on the event happening, while laying an event means you bet against the event happening. In a betting exchange platform, users can choose either option, allowing them to act as both bettors and bookmakers.

## Matching

The matching algorithm is responsible for pairing back and lay bets from different users, ensuring that they have compatible odds and stake amounts. The main goal of the algorithm is to maximize the total matched amount of money while maintaining fairness and efficiency. Here's an overview of how a typical matching algorithm works:

1. The algorithm starts by collecting all pending back and lay bets for a specific market. These bets are usually stored in separate order books or queues, sorted by the odds and the time they were placed.
2. The algorithm compares the best available back and lay bets (i.e., the bets with the lowest back odds and the highest lay odds). If the back odds is lower than or equal to the lay odds, there is a potential match.
3. If a potential match is found, the algorithm calculates the matched amount by consuming either all of the backing bet stake, or all of the lay bet stake. That is, if the  $\text{backing stake} * \text{odds} - \text{backing stake} \geq \text{lay stake}$  then all of the *lay stake* is consumed. Otherwise all of the *backing stake* is consumed.
4. After the matched amount is calculated, the algorithm updates the stake amounts of the back and lay bets. If either bet is fully matched, it's removed from the order book. If the bet is only partially matched, its stake is reduced by the matched amount, and the bet remains in the order book for future matching.
5. The matched bets, along with their odds and matched amounts, are recorded in the system. This information is used for tracking purposes and to update users' account balances after the market is settled.
6. The algorithm iterates through steps 2-5 until there are no more matches.

The matching algorithm typically operates in real-time or near-real-time, continuously processing new bets and updating the order books as users place, modify, or cancel their bets. This ensures that the platform remains responsive and up-to-date, providing users with an efficient and fair betting experience.

## 1.4 Example

Let's assume an event with the following unmatched bets:

	Back			Lay	
User	<i>a</i>	<i>b</i>	<i>c</i>	<i>d</i>	<i>e</i>
Odds	3	2	1.53	1.5	1.1
Stake	20€	14€	5€	21€	400€

The back and lay bets easiest to match are the bets from users *c* and *d*. User *c* risks 5€ expecting to win  $2.65€ = 7.65 - 5$  ( $7.65 = 5 \times 1.53$ ). User *d* is willing to risk 21€ expecting to win 42€ (solving the equation  $x \times 1.5 - x = 21 \implies x \times 0.5 = 21 \implies x = \frac{21}{0.5} \implies x = 42$ ). The bets are close but do not match since the maximum odds that user *d* permits (1.5) is lower than the odds of user *c* (1.53).

If a user wants to make a new backing bet, its best option is the odds 1.5 offered by lay better *d*. If a user wants to make a new lay bet, its best option is the odds 1.53 by backing better *c*.

1. Let us assume that  $f$  backs the event with the odds 1.5 with a stake of 50€. The new state will be:

	Back				Lay
User	$a$	$b$	$c$	$f$	$e$
Odds	3	2	1.53	1.5	1.1
Stake	20€	14€	5€	8€	400€

and

- 42€ of the stake of  $f$  have been matched with the odds 1.5 against the user  $d$  ( $21 = 42 \times 1.5 - 42$ ).

2. Next let us assume that  $g$  lays the event with a stake of 5€ with a (maximum) odds 1.53. The new state will be:

	Back			Lay
User	$a$	$b$	$c$	$e$
Odds	3	2	1.53	1.1
Stake	20€	14€	3.11€	400€

and

- 4€ of the stake of  $g$  have been matched with the odds 1.5 against the user  $f$  ( $4 = 8 \times 1.5 - 8$ ), and
- 1€ of the stake of  $g$  has been matched with the odds 1.53 against the user  $c$  ( $1 = 1.89 \times 1.53 - 1.89$ ).

**Note:** In most betting exchange platforms, the lay stake represents the amount of money that the lay better is willing to cover from the perspective of a backing better. For example, the starting state in our example would be represented as:

	Back			Lay	
User	$a$	$b$	$c$	$d$	$e$
Odds	3	2	1.53	1.5	1.1
Stake	20€	14€	5€	42€	4000€

## 2 Project Objectives

The objective of this final project is to implement a scalable betting exchange system using Elixir, leveraging its fault-tolerant and concurrent features. The core functionality of the platform should be encapsulated in an Elixir module, which must include the basic functions required to place back and lay bets, manage user accounts, and match opposing bets.

### 2.1 Scalability Requirements

As the platform is expected to handle a large number of concurrent users and transactions, the implementation must be scalable. To achieve this, you should carefully consider the data structures (or databases) used, the algorithms for e.g. matching and so on. Moreover, it is advantageous to employ Elixir's OTP patterns, which will help in creating a robust, fault-tolerant, and scalable system. Proper use of OTP patterns, such as supervisors, GenServers, and Agents, is essential for meeting the project's scalability requirements.

Please be aware that your system might undergo abrupt terminations and subsequent restarts. After these service outages, everything should be functioning properly.

## Optional Tasks

If you desire there are a number of additional functionalities that your betting platform may provide. These are, for example, (i) a Telegram bot for betting,<sup>4</sup> (ii) a REST API for betting, and a (iii) Web application for betting.<sup>5</sup>

Note that such application normally authenticate users when betting. For this exercise, however, you are not required to implement user authentication (but you are allowed to do so should you so desire).

## 2.2 Project Deliverables

The following deliverables are expected for the successful completion of this final project:

1. A well-documented Elixir module implementing the core functionality of the betting exchange platform, relaying on OTP patterns for scalability. **IMPORTANT: please document clearly the exact steps to build your application, and to run the tests provided. For example, if you use *Ecto* how is the database created and which keys and username are used.**
2. A series of unit tests to validate the correctness of the implemented functions.
3. (Optional) A user-friendly Telegram bot interface, implemented using the ExGram library, for interacting with the betting exchange platform.
4. (Optional) A REST API for betting.
5. (Optional) A web interface for betting.
6. (Optional) Think and make a proposal to create a trading bot: an application that analyses the markets and try to find a bet that makes a user to always win (e.g, if the user backed an event 5 to 1 and now there is an unmatched back bet 3 to 1).

## 2.3 Required API

In this section we will describe the basic API that all solutions should implement. We will provide some basic tests that check that your API provides some basic level of functionality. The API should be implemented in a module named *Betunfair*.

### 2.3.1 Odds and Stakes in API calls and return values

When stakes are used as arguments to API calls, or returned from API calls the amount of money represented as integers multiplied by 100, i.e. cents. Similarly returned account balances, and money deposits and withdrawals, are represented in cents. For example, the stake 2.25 is represented as 225, and the stake 11.333333 is represented as 1133 (use *truncation to convert the decimal number to an integer*). Similarly odds are represented as multiplied by 100 in API calls and values returned by the API (including as values in maps). For example, the odds 1.5 is represented in API calls as 150.

**Note** that internal calculations in the exchange which divides an amount by another amount should be done using integer division (i.e., truncation).

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<sup>4</sup>The ExGram library ([https://github.com/rockneurotiko/ex\\_gram](https://github.com/rockneurotiko/ex_gram)) can be utilized, which provides an Elixir wrapper for the Telegram Bot API. This would allow users to interact with the platform through a familiar messaging interface.

<sup>5</sup>For implementing a REST API or a Web application the Phoenix framework (<https://www.phoenixframework.org/>) can be utilized to craft an API or an interactive Web app.

### 2.3.2 Persistence

Your exchange should be persistent. That is, a library for storing information persistently (on disk) such as *dets*, *CubDB* (<https://github.com/lucaong/cubdb>), or a normal database behind *Ecto* (<https://github.com/elixir-ecto/ecto>) (e.g., PostgreSQL/MySQL), can be used to store exchange data. Note however that neither *dets* nor *CubDB* by themselves offer good APIs to handle “transactions”, i.e., when multiple accounts have to be updated “atomically” (without other updates taking place inbetween). You should at least analyze the negative consequences if, e.g., there is a power failure in the middle of settling a market. Will the market have a consistent state when the application is restarted using the persistent information?

### 2.3.3 Function specification

The expected type of function arguments, and the value returned by a function, will be indicated using the normal Elixir function specification style, documented in <https://hexdocs.pm/elixir/main/typespecs.html#defining-a-specification>. For example,

```
@spec user_withdraw(id :: user_id(), amount :: integer()) :: :ok | :error
```

specifies that first argument of the `user_withdraw` function is expected to be a string, and the second argument an integer, and it returns either the atom `:ok` or the atom `:error`.

### 2.3.4 Return Values

All functions signal whether their execution was successful or not. A successful execution is indicated by a tuple `{:ok, result}`. In case no value needs to be returned `result` may be any Elixir value. In case a function is specified to return a tuple where the result is a map, e.g., `{:ok, %{id: user_id(), balance: integer()}}` the tuple returned *must* contain the specified keys (e.g., `id` and `balance`) but *may* contain additional keys.

An unsuccessful result is signaled if the function returns a tuple `{:error, reason}`, where `reason` may be any Elixir value. In the following function specifications **only the successful result type will be specified**.

### 2.3.5 Returning a large number of elements

Some functions potentially return a large number of elements, e.g., `market_bets` should return all bets in a market which, when your exchange becomes a commercial success :-), may be a lot of bets. Such functions will be specified, in a non-standard manner, with the return type `Enumerable.t(bet_id())` (where `bet_id()` is the type of elements returned by `market_bets`; other functions return other types of elements). You are *encouraged* to implement such enumerables as lazy streams (see <https://hexdocs.pm/elixir/1.14/Stream.html>) which can yield a better performance if not all returned bets needs to be inspected. Alternatively, you can for instance use ordinary lists.

### 2.3.6 Required Functions

Your *Betunfair* module *must* implement the following functions:

#### Exchange interaction

- `start_link(name :: string()) :: {:ok, _}` – starts the exchange. If an exchange name does not already exist it is created. If it exists the existing data (markets, bets, users) is recovered.
- `stop() :: :ok` – shuts down a running exchange in an orderly fashion (preserving exchange data).

## User interaction

- `user_create(id :: string(), name :: string()) :: {ok, user_id()}`  
adds a user to the exchange. The id parameter must be unique (e.g., a DNI/passport number, email, username). Fails, for instance, if a user with the same id already exists. Returns a user identifier (you may choose its representation).
- `user_deposit(id :: user_id(), amount :: integer()) :: ok` – adds amount (should be positive) to the user account.
- `user_withdraw(id :: user_id(), amount :: integer()) :: ok` – withdraws amount (should be positive, and the account balance must be at least amount) to the user account.
- `user_get(id :: user_id()) :: {ok, %{name: string(), id: user_id(), balance: integer()}}`  
retrieves information about a user.
- `user_bets(id :: user_id()) :: Enumerable.t(bet_id())` – returns an *enumerable* containing all bets of the user.

## Market interaction

- `market_create(name :: string(), description :: string()) :: {ok, market_id()}`  
creates a market with the unique name, and a potentially longer description.
- `market_list() :: {ok, [market_id()]}` returns all markets.
- `market_list_active() :: {ok, [market_id()]}` returns all active markets.
- `market_cancel(id :: market_id()) :: ok` – cancels a non-terminated market. Returns all stakes in matched or unmatched market bets to users.
- `market_freeze(id :: market_id()) :: ok` – stops all betting in the market; stakes in non-matched bets are returned to users.
- `market_settle(id :: market_id(), result :: boolean()) :: ok`  
the market (event) has been resolved with argument result. Winnings are distributed to winning users according to stakes and odds.
- `market_bets(id :: market_id()) :: {ok, Enumerable.t(bet_id())}`  
all bets (matched or unmatched) for the market are returned.
- `market_pending_backs(id :: market_id()) :: {ok, Enumerable.t({integer(), bet_id()})}`  
all pending (non matched) backing bets for the market are returned. **Note** that the bets are returned as a tuple {odds, bet\_id}, and that the elements should be returned in *ascending* order (i.e., bets with smaller odds first).
- `market_pending_lays(id :: market_id()) :: {ok, Enumerable.t({integer(), bet_id()})}`

all pending lay bets for the market are returned. **Note** that the bets are returned as a tuple {odds,bet\_id}, and that the elements should be returned in *descending* order (i.e., bets with larger odds first).

- `market_get(id :: market_id()) ::`  
`{:ok, %{name: string(),`  
`description: string(),`  
`status: :active |`  
`:frozen |`  
`:cancelled |`  
`:settled, result::bool()}}`
- `market_match(id :: market_id()) :: :ok` – try to match backing and lay bets in the specified market.

### Bet interaction

- `bet_back(user_id :: user_id(),`  
`market_id :: market_id(),`  
`stake :: integer(),`  
`odds :: integer()) :: {:ok, bet_id()}`

creates a backing bet by the specified user and for the market specified.

- `bet_lay(user_id :: user_id(),`  
`market_id :: market_id(),`  
`stake :: integer(),`  
`odds :: integer()) :: {:ok, bet_id()}`

creates a lay bet by the specified user and for the market specified.

- `bet_cancel(id :: bet_id()) :: :ok` – cancels the parts of a bet that has not been matched yet.
- `bet_get(id :: bet_id()) ::`  
`{:ok, %{bet_type: :back | :lay,`  
`market_id: market_id(),`  
`user_id: user_id(),`  
`odds: integer(),`  
`original_stake: integer(), # original stake`  
`remaining_stake: integer(), # non-matched stake`  
`matched_bets: [bet_id()], # list of matched bets`  
`status: :active |`  
`:cancelled |`  
`:market_cancelled |`  
`:market_settled, boolean()}}`

### Bot Command Proposal

In this section you can find inspiration for the Telegram bot commands:<sup>6</sup>

1. `/deposit <amount>`: Deposits funds into the user's account.
2. `/withdraw <amount>`: Withdraws funds from the user's account.

<sup>6</sup>Something that should inspire the screens of a Web app or the URI of resources of a REST API.



3. `/balance`: Retrieves and displays the user's account balance.
4. `/markets`: Lists all available markets for betting.
5. `/market <market_id>`: Retrieves and displays information about a specific market.
6. `/back <market_id> <amount> <odds>`: Back an event.
7. `/lay <market_id> <amount> <odds>`: Lay an event.
8. `/cancel <bet_id>`: Cancels a bet.
9. `/bets`: Lists all bets placed by the user.
10. `/matched`: Lists all matched bets for the user (unsettled, won and lost).
11. `/help`: Displays a help message with a list of available commands.

### 3 Norms and Deadlines

The deadline for completing the project is **May 31st 23:59:59**.

1. Create a git repository at Gitlab or Github. Your repository **must be private**.
2. Include a file `AUTHORS` with your names and UPM emails, one per line, in this form:  
  
"Sofía Huertas Arévalo" <sofia.huertas.arevalo@alumnos.upm.es>  
"Luis Fernández Araujo" <luis.fernandez.araujo@alumnos.upm.es>
3. Include a file `README` that clearly documents the *exact* steps needed to build your application, and to run the tests provided. For example, if you use *Ecto* how is the database created and which keys and username are used. Moreover, please state which e.g. additional software tools must be installed. The more concrete information provided, the better.
4. Work in the project following good practices like *small and single-purpose commits*, and *detailed commit messages*.
5. Include a set of no more than 15 slides in PDF: `presentation.pdf`. The contents of the slides should detail the design, implementation, and testing and benchmarking of the project, including any challenges faced and future improvements related with scalability aims.

#### 3.1 Code Review (50%)

To review your code, after the deadline, we will ask you to give us access to your repository.

#### 3.2 Presentation (30%)

We will make an appointment with you to make a 5 minutes presentation on **June 10th** between 15:00 to 21:00.

#### 3.3 Teams

We want you to work in teams of **two or three**. But, if you have a bigger proposal, two teams can work together.

### 3.4 Alternative projects

We enumerate a few other project ideas: a survey app e.g. game based learning platform<sup>7</sup>, a weather telegram bot, a twitter clone, a marketplace app, an auction system, a task management and collaboration platform, an e-learning platform, a distributed message platform, a distributed database, a processing pipeline library, a chat, etc. If you want to face an alternative project, it should have a **comparable level of difficulty** to the betting exchange system proposal.

### 3.5 The risks of using betting web sites

Finally, do exercise caution when gambling (online and otherwise), as doing so can lead to addiction problems. To quote our friend ChatGPT:

*Using a betting website can be risky, as it can potentially lead to addiction and other negative consequences. Online betting can be a highly addictive activity, and it's important to recognize the signs of problem gambling. If you find that you're spending more time and money on betting than you intended, or if you're neglecting other important aspects of your life in favor of gambling, it may be time to seek help.*

*Another risk of using a betting website is the potential for fraud or scams. Some betting sites may not be reputable or may be outright fraudulent, which can result in financial loss for users. It's important to research any betting site thoroughly before using it and to stick with reputable and well-established companies.*

*It's also important to be mindful of the risks associated with online security when using a betting website. Hackers and other malicious actors may try to gain access to your personal and financial information through the site, so it's important to use strong passwords and to only use reputable sites that prioritize user security.*

*Overall, while using a betting website can be a fun and potentially lucrative activity, it's important to be aware of the risks and to use caution and discretion when participating in online betting.*

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<sup>7</sup>Like Wooclap or Kahoot.