The Bridge problem

Multithreading synchronised programming visualisation in Java and React

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1. Project assumptions

On a two-way north-south road, there is a narrow bridge that allows cars to pass in only one direction at a time. Synchronize the passage of cars from the south and north to avoid collisions and ensure that a car from each direction can eventually cross the bridge.

2. Installation and running

2.1. Using Docker

1. Navigate to main directory of a project (the one with docker-compose.yml file) using **Terminal** in Linux or **CMD** in Windows.
2. Pull frontend and backend images from Dockerhub by typing command:

   docker pull marcinbator/bridgeproblem_frontend

   docker pull marcinbator/bridgeproblem_backend

3. Run containers with settings from docker-compose.yml:

   docker-compose up

   By default, the backend of the project will listen on port 8080, and the frontend will listen on port 3000. If you want to change those values, you can do it by editing them in docker-compose.yml file. Make sure that the ports are not occupied by other processes.

4. To see the OPENAPI documentation of the backend endpoints, open **http://*localhost:8080/api/docs.html*** in web browser.
5. To open the application, open **http://*localhost:3000*** in web browser. If no cars appear after adding them, you have to refresh cache of your browser (Ctrl+F5 in Chrome).

2.2. Using IDE

2.2.1. Backend

You will need IntelliJ IDEA or other IDE that can run Spring Boot project from Maven. Open the *bridgeproblem_backend* folder in IDE and run the *BridgeProblemBackendApplication* class. The service will listen on port 8080.

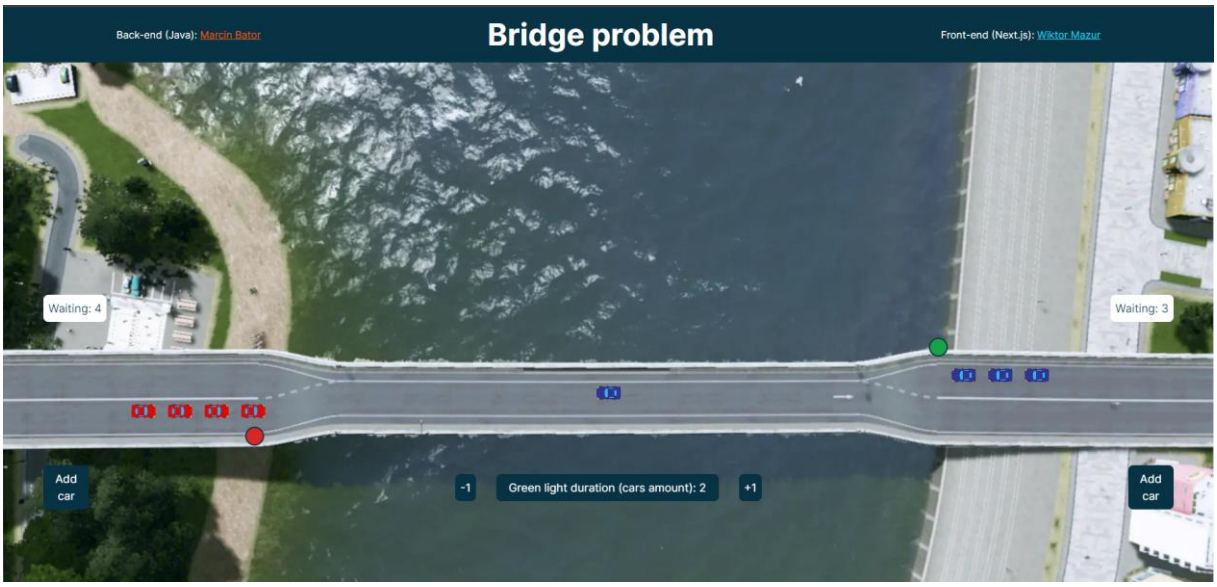
2.2.2. Frontend

You need to have installed Node 20 on your machine or environment. Navigate to *bridgeproblem_frontend* directory and run the command:

npm run dev

The service will listen on port 3000.

3. Usage



Picture 1 – GUI of an application

1. To add the car, press the blue *Add Car* button below the road on selected side of the bridge.
2. To see the bridge passing time of any car, hover selected car with the mouse.
3. To modify the number of vehicles passing on one side before the light changes, press *-1* or *+1* button under the bridge. The default amount is 2. Current amount is shown in blue field between the buttons.

4. Implementation agenda

Solution comes as web application that can be opened in a web browser. It uses both server- and user-side code, and multithreading is implemented on the back-end server.

User can spawn a new car on the road and select whether it's coming from north or south. Time needed for passing the bridge is random in range 5-10 seconds for every car. Car then places itself at the end of selected queue and waits for the bridge to be empty, because bridge can only have one car at time. Once the bridge is empty and green light appears on the right side, car passes the bridge and drives further down the road. User can also select how many cars will be let into the bridge from one side until the green light appears on the other one.

Application is fully *dockerized*, which means that it can be fast runned anywhere using docker-compose.yml file in main directory of the project. Both front-end and back-end layers are stored in separate images.

5. Technologies

5.1. Front-end (client side):

- React 18
- Next.js 14.0.4
- TypeScript 5
- Tailwind CSS 3.3.0

5.2. Back-end (server side):

- Java 17.09
- Spring Boot 3.2
- Apache Maven

6. Front-end implementation details

6.1. Overview

Application comes with pleasant and straightforward UI. User can add cars from both sides and increase or decrease amount of passing cars before switching side. Moreover, there is visualisation of cars and their state, red and green lights from every side and amount of cars in each queue. After hovering the car, its time of passing the bridge is shown. Time of passing the bridge is being generated as a random integer from range 5000 to 10000 milliseconds as soon as the car is being added to queue by user.

6.2. API communication

Front-end layer is being exposed on port 3000 and communicates with back-end API located on port 8080. As workflow is quite straightforward, the standard JS *fetch* and *await* is being used. To get the current state of every car, application calls an API every 10 milliseconds.

7. Back-end implementation details

7.1. Overview

The web layer of backend application is provided by modern Java web framework: Spring Boot in latest stable version 3.2. REST controller is pretty simple and consists of 6 endpoints, which deliver following features: adding a car, getting all cars in list, getting current direction with green light, getting current amount of cars being let from each side, changing mentioned amount and the last one, which is being called every 100 milliseconds, looks for the cars that have been crossed the bridge for at least 5 seconds and removes them from the list.

The service layer provides whole workflow for processing cars in the queues. Car added by user is being put into desired queue, ‘SOUTH’ or ‘NORTH’, which means the direction the car is coming from. Every 100 milliseconds program checks the queues and if necessary, starts a new thread.

Simulation of time needed for crossing the bridge is done by sleeping the thread for desired amount of milliseconds. During the car begins to cross the bridge, its status is changed from 'WAITING' to 'PROCESSING'. After successful passing the river, status is updated to 'PROCESSED'.

There are 2 thread types used in program: one for each queue. New thread is run if the queue is not empty and there is no thread that currently processes the queue from the direction.

To make sure that only one car is currently crossing the bridge, the method for that uses *synchronized* keyword, which creates semaphore and unlocks it at the end of the method. Moreover, to avoid *races* between threads, program uses concurrent-safe data structures.

7.2. Endpoints (web layer)

As mentioned before, the backend web layer of the application consists of 6 endpoints:

- *GET('/api/cars'):* returns the list of all cars added to the program in JSON format;
- *POST('/api/add-car'):* allows to add a new car into the program; JSON body is required (CarAddRequest class) and should contain following fields:
  - *String name (text),*
  - *Source source (enum; NORTH, SOUTH),*
  - *Int processingTime (number);*
- *GET('/api/direction):* returns the direction from which cars are currently passing the bridge;
- *GET('/api/max-cars):* returns the current amount of cars that will be let to pass from one side;
- *POST('/api/max-cars):* allows to set new max-cars. Requires a number in body;
- *SCHEDULED: performs checks if running new threads is necessary and deletes all cars that have passed the bridge for at least 10 seconds;*

All endpoints doesn't require any authentication or headers to be accessed and are also doesn't have any specified allowed domains, which mean they can work with any front-end code from all domains.

7.3. Service (server layer)

The most important class of the program is *BridgeService*. It has 7 private fields:

- *Queue<Car> cars*: queue of all cars added to the program,
- *Queue<Car> northQueue*: queue of cars coming to the bridge from the north,
- *Queue<Car> southQueue*: queue of cars coming to the bridge from the south,
- *int maxCarsAmount*: stores the amount of cars that can pass from one side – default value is 2,
- *Source currentDrivingSource*: stores the direction which currently has green light,
- *Thread southThread*: thread for the south queue,
- *Thread northThread*: thread for the north queue.

It has also 3 public methods: *addToQueue(Car car)* which allows to add a new car to queue, *runThreads()* that makes and starts new threads if necessary and *deleteProcessed()* which is called to remove all processed cars from list.

Private method *processQueue(Queue<Car> queue)* mentioned before is method that comes through the queue passed as an argument and if they are present, allows them to pass the bridge.

Private method *CrossBridge(Car currentCar)* is method that simulates the passing the bridge by the car.

8. Summary

The implemented multithreading solution in Java addresses the bridge problem in a two-way road scenario. The web application, using React on the front-end and Spring Boot on the back-end, allows users to spawn cars from the north or south, each with a customizable crossing time.

The backend employs a simple REST controller with endpoints for adding cars to queues and retrieving their states. Program manages the workflow, employing synchronized threading to ensure only one car crosses the bridge at a time.

Overall, the system provides a visual representation of the classic synchronization problem in a web-based environment, enhancing understanding of multithreading concepts.