Group report - stage 2

Team Member Contributions

Erzhizhi Hu	Implemented the online order processing functionality, designed the customer generation and queue management workflow, and tested the overall simulation runtime behavior.
Haotian Jiang	Developed the control panel functionality, implemented the EventLogger for event logging, exported the project as a JAR executable, and contributed to the writing of the final report.
Jiawen Zhang	Developed the data loading and report generation modules, documented the agile development process, and contributed to the writing of the project report and user guide.
Xiangjin Kong	Implemented the server and barista threads, designed inter-thread communication mechanisms, solved synchronization issues, and was responsible for code integration across the project.
Yusheng He	Designed and implemented the GUI interface, extended the MenuItem and Order classes, created the UML class diagrams for the project, and contributed to the writing of the report.

1. Overview and Implementation of System Functions

This project implements a multi-threaded system that simulates the operation of a coffee shop, successfully fulfilling all core requirements outlined in Stage 2, along with several extended features. The system is capable of simulating customer generation, queuing, order processing by servers, beverage preparation by baristas, and real-time status updates through a graphical user interface (GUI), forming a complete simulation process.

Core Functionality:

The system supports multiple server threads working concurrently, all drawing customers from a shared queue. Customers (along with their orders) are retrieved by a dedicated thread and added to the end of the waiting queue. When a customer reaches the front of the queue and a server becomes available, the customer is assigned to that server for processing. Upon startup, the system loads pre-existing order data from the *orders.csv* file generated in Stage 1 and enqueues these orders in bulk for processing by the servers in sequence. Once all queues are empty and all server and barista threads are idle, the simulation terminates automatically, generates a sales report, and exits the program safely.

Throughout the simulation, the GUI displays the list of waiting customers and their order details, as well as the current status of each server and barista (e.g., idle, busy, processing an order). Users can adjust the simulation speed via the GUI to clearly observe changes in

system states. Additionally, the system features an event logging mechanism: all significant events—such as customer queuing, order assignment, and order completion—are logged and output to a file upon the conclusion of the simulation.

Extended Features:

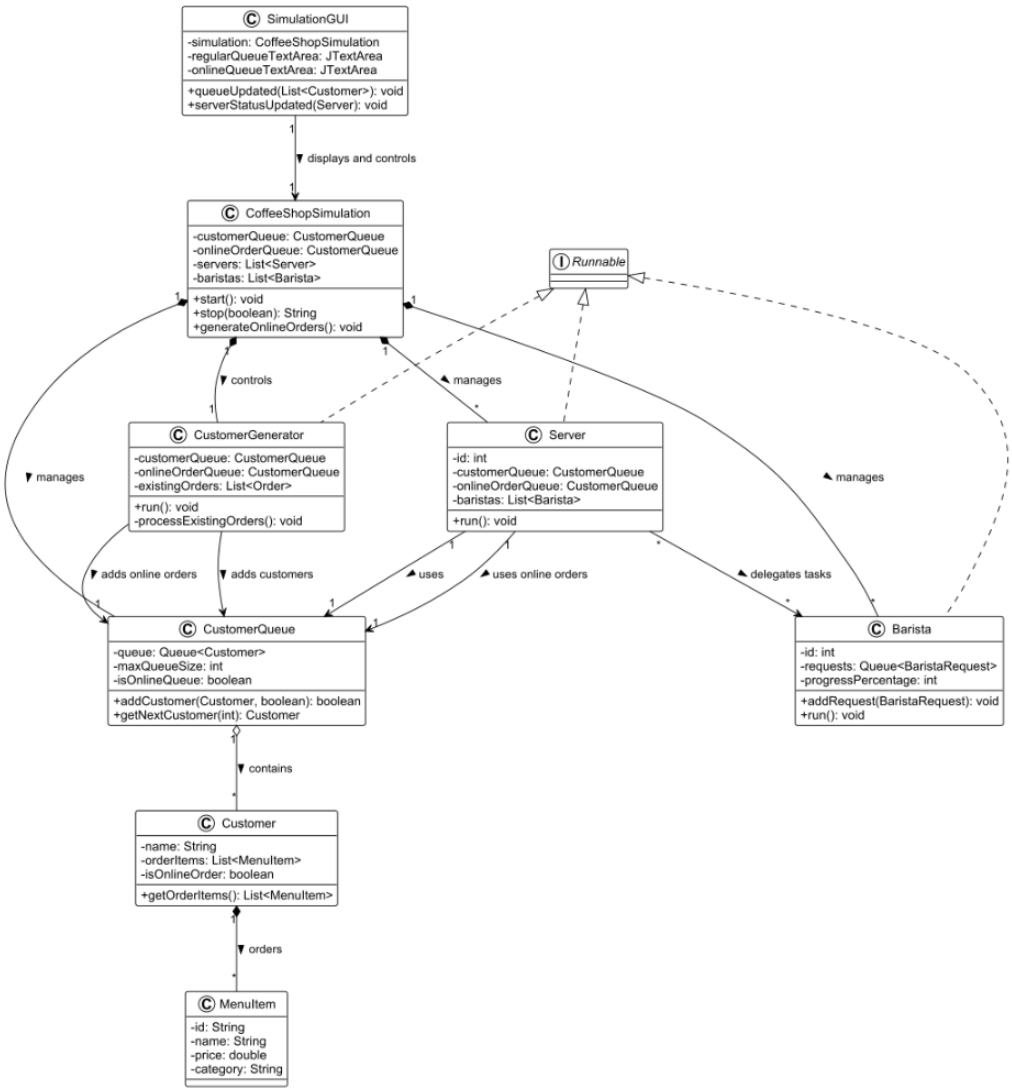
Beyond the fundamental requirements, the system includes a series of enhanced features to improve realism and flexibility. For instance, a simulation speed control slider allows users to dynamically accelerate or decelerate the simulation during runtime. The system also supports the dynamic addition and removal of server and barista threads: users can click GUI buttons to add new threads or remove existing ones, simulating varying staffing configurations.

To prevent resource issues caused by uncontrolled queue growth, a maximum queue size (e.g., 10 customers) is enforced. The system strictly adheres to the producer-consumer model in managing the queue: when the queue is full, the customer generator thread pauses and waits until a server removes a customer and makes space available. Furthermore, the system introduces an independent channel for online orders, utilizing a separate priority queue. When users click the "Generate Online Orders" button in the GUI, a batch of online orders is created; these are prioritized over regular queued customers and are picked up first by available servers. The system also includes an auto-stop option that determines whether it automatically shuts down once all orders have been processed, and a GeneratorCustomer option that allows random new customers to be generated after the system finishes reading orders from the *orders.csv* file.

Finally, the system introduces barista threads to simulate beverage preparation. While processing an order, a server delegates drink-making tasks to an independent barista thread. Upon completion, the barista notifies the server via a callback mechanism. All these processes are clearly visualized in the GUI, allowing users to observe the entire workflow in real time—from customer arrival and order placement to beverage preparation and order completion.

Overall, the system features comprehensive modules with tightly integrated interactions, fully satisfying the functional requirements for the coffee shop simulation project.

2.UML Diagram



3. Detailed Information on Agile Development Process

In Stage 2 of this project, we fully adopted agile development methods. The team followed an iterative approach to development, setting clear objectives for each iteration and continuously refining the system's functionality. We conducted three major iterations, each resulting in a well-defined, working software product. This methodology enabled the team to effectively manage project progress and quality, and to respond quickly to changing requirements.

(1) First Iteration (Version v0) – Implementation of Basic Functionality

Objectives:

Establish a basic thread framework to verify the producer-consumer relationship between servers and the customer generator.

Implement an initial GUI interface to provide basic status display.

Implementation Process:

In this iteration, we constructed a multi-threaded architecture and completed the initial design and implementation of the customer generator thread and server threads. We implemented a simple, thread-safe customer queue from which server threads could retrieve customers and process their orders. Simultaneously, a basic GUI was developed to display the number of customers in the queue and their basic statuses in real time.

Outcomes:

Completed the initial thread architecture and the implementation of a safe customer queue.

The GUI was able to display the customer queue status initially.

Retrospective and Improvements:

Through daily stand-up meetings and code reviews, we discovered issues such as unclear display of thread states and an unfair task distribution strategy among server threads. Some threads were overloaded while others were underutilized. This prompted us to introduce more comprehensive status monitoring and thread load balancing mechanisms in the next iteration.

(2) Second Iteration (Version v1) – Design Pattern Integration and GUI Enhancements

Objectives:

Introduce the Observer pattern to improve real-time GUI status updates.

Refine the Singleton pattern for the event logger (EventLogger).

Improve fairness in task distribution among server threads.

Implementation Process:

In this iteration, the team applied the Observer pattern to clearly separate state update responsibilities from the model to the view, allowing the GUI to update automatically in response to model changes. We also completed the Singleton implementation of the EventLogger, ensuring unified logging of system events, which facilitated debugging and analysis. Furthermore, we redesigned the task acquisition strategy of server threads, introducing polling and randomized selection to significantly improve load balance across threads.

Outcomes:

GUI state updates became significantly more stable and responsive.

Unified management of event logging simplified error tracing.

Thread workload was more evenly distributed.

Retrospective and Improvements:

In the iteration retrospective, the team recognized two key shortcomings: the lack of a priority mechanism for handling online orders, and the inability to dynamically add or remove servers and baristas during runtime. As a result, we decided to focus on implementing online order priority handling and dynamic thread management in the next iteration, along with further system performance optimization.

(3) Third Iteration (Version v2) – Advanced Feature Extensions and Performance Optimization

Objectives:

Implement a priority handling mechanism for online orders.

Introduce dynamic thread management for servers and baristas.

Add simulation speed adjustment functionality to enhance user experience.

Conduct comprehensive thread synchronization and performance optimization to prevent deadlocks and blocking.

Implementation Process:

In this iteration, the team added a separate priority queue for online orders and implemented a mechanism allowing server threads to prioritize and preemptively handle online orders, significantly improving their processing efficiency. We also implemented dynamic thread management, enabling users to add or remove server and barista threads in real time via the GUI, thereby simulating different staffing configurations. Additionally, a simulation speed control slider was added, allowing users to adjust the simulation speed as needed.

For performance optimization, we reinforced thread synchronization mechanisms using wait/notify, timeout mechanisms, atomic variables, and callback strategies. These improvements significantly enhanced system stability under high concurrency and effectively eliminated potential deadlock risks.

Outcomes:

Online order prioritization significantly improved user responsiveness.

Dynamic thread management enabled flexible runtime control.

Simulation speed adjustment enhanced the interactivity and observability of the system.

Overall system stability and concurrency performance were greatly improved.

Retrospective and Summary:

During the retrospective, the team reviewed the development experience and concluded that agile development through iterative delivery significantly improved our ability to adapt. Daily stand-up meetings enhanced team collaboration in solving complex problems, while continuous integration helped avoid integration conflicts and risks during code merging.

4. Thread Model and Synchronization Mechanism Analysis

(1) Thread Role Allocation

This system adopts a multi-threaded concurrent architecture, where different threads assume distinct responsibilities and collaboratively simulate the concurrent business processes of a coffee shop:

Main Thread (Event Dispatch Thread):
Responsible for starting the simulation, creating the GUI, and maintaining the event loop. It handles user interactions (such as button clicks to adjust parameters) and invokes corresponding control logic. At the same time, it ensures all GUI updates are executed on the event dispatch thread to avoid unsafe direct interactions between background threads and UI components.

Customer Generator Thread:
An independent producer thread that continuously generates new customers and their orders at fixed intervals. At startup, it reads the initial order list provided from Stage 1 and enqueues those customers in bulk. During the simulation, it randomly creates customers at intervals, simulating the real-world arrival of customers at a coffee shop.

Server Threads:
Each instance of Server corresponds to one server thread. Multiple servers concurrently process customer orders from the queue. Each server thread repeatedly retrieves the next customer: it first checks the online order queue and serves online customers with priority; if that queue is empty, it fetches from the regular queue. If both queues are empty, the thread waits briefly and then retries. The order processing procedure includes recording the order, computing price and discounts, delegating drink-making tasks to barista threads, and waiting for beverage preparation to finish. After serving one customer, the server thread loops back to fetch the next one, continuing until a stop signal is received.

Barista Threads:
Each instance of Barista represents a barista thread responsible for asynchronously handling beverage-making tasks assigned by servers. Each barista thread maintains a task queue to which servers submit requests via the addRequest() method. While running, the thread checks the request queue: if there are tasks, it processes them; otherwise, it enters a waiting state until new requests arrive. Upon completing a beverage, the barista triggers the callback function included in the request to notify the corresponding server, enabling it to proceed with further steps.

(2) Thread Synchronization Mechanism

To ensure safe and efficient collaboration among threads, the system implements various synchronization strategies to coordinate access to shared resources and inter-thread communication:

Monitor Locks (Synchronized Methods):
Critical shared data structures are protected with built-in Java locks to ensure thread safety. For instance, the methods addCustomer() and getNextCustomer() in CustomerQueue are declared public synchronized, ensuring that only one thread can access or modify the internal queue at any given time, thus preventing race conditions.

Conditional Wait and Notify (wait/notify):
Used alongside locks to coordinate producer-consumer behavior. When the customer queue is full, the customer generator thread calls wait() inside addCustomer() to suspend itself. Once a server removes a customer, notify() is called within getNextCustomer() to awaken waiting producers. This guarantees that the queue will not overflow, and producers will resume only when space becomes available. Similarly, for barista threads, if their task queue is empty, they enter a wait() state; when a new task is submitted, notify() is used to awaken any waiting barista. This wait/notify mechanism enables smooth coordination between threads and avoids wasteful busy-waiting.

Atomic Variables (AtomicBoolean):
Each major thread (server, barista, customer generator) uses an AtomicBoolean flag named running to control whether the thread should continue running. When a thread needs to be stopped, its running flag is set to false, and its loop checks this flag to safely exit. The atomic nature ensures visibility and correctness when accessed by multiple threads.

Callbacks and CountDownLatch:
After a server submits a drink-making task to a barista, it must wait for the barista to finish. To avoid long lock-holding or active polling, the system employs callback mechanisms combined with Java's synchronization utilities like CountDownLatch for asynchronous waiting. Specifically, the server includes a callback Runnable or a CountDownLatch in the

BaristaRequest. When the barista finishes the task, the callback is executed or the latch is decremented, allowing the server thread to resume. This approach avoids blocking and polling, ensures the server is properly notified, and maintains logical correctness.

Timeouts and Interrupt Handling:
To enhance robustness, all wait() calls specify timeouts or are checked for interruption. For instance, barista threads use wait(1000) to limit waiting to 1 second and periodically check their running flag, ensuring responsiveness to termination signals. Similarly, server threads use a custom waitFor(500) method to sleep briefly (0.5 seconds) when no customers are available, instead of continuous busy-waiting. These measures effectively prevent deadlocks and indefinite blocking.

GUI Update Synchronization:
Due to Swing's single-thread rule, background threads are not allowed to directly update GUI components. Therefore, all status change notifications from server and barista threads are handled via the Observer pattern in the GUI thread or explicitly passed to the event dispatch thread using SwingUtilities.invokeLater(). For example, when a server starts serving or a barista is making a drink, the GUI is notified to refresh its display. This asynchronous update method ensures thread safety and avoids cross-thread UI manipulation issues.

Through this multi-layered synchronization strategy, the system ensures thread safety while enabling efficient communication and collaboration between concurrent components. It avoids resource contention and deadlocks and maintains high responsiveness across all active modules.

5. Explanation of Design Pattern Usage

To enhance the maintainability and scalability of the system, we consciously adopted several classic software design patterns in our system architecture. The primary patterns used are explained as follows:

1. **Singleton Pattern:**
   The event logger (EventLogger) in this system is implemented using the Singleton pattern. There exists only one instance of EventLogger throughout the application, which is accessed globally via the static factory method getInstance(). This pattern ensures unified management of event logging, avoiding inconsistencies caused by multiple logger objects. Additionally, the Singleton provides a simple global access point, making it convenient for components across the system to record events. The EventLogger is lazily initialized upon first use, thereby conserving system resources.
2. **Observer Pattern:**

The Observer pattern is widely used in the system to enable loosely coupled communication between components. When a model object changes state, it notifies its observers (typically the GUI) to update the interface. For example, the CustomerQueue maintains a list of QueueObserver objects. When a customer joins or leaves the queue, the notifyObservers() method is called, triggering each observer's queueUpdated() method and passing a snapshot of the current queue to the GUI. Similarly, the Server and Barista classes define ServerObserver and BaristaObserver interfaces respectively, which are implemented by the GUI. Whenever a server or barista's status changes, it notifies the GUI to update the display accordingly.

Through the Observer pattern, the model and view are decoupled: the model does not need to know any details of the interface, and it simply notifies observers based on predefined conventions. The view, on the other hand, actively subscribes to the model by implementing observer interfaces and receives updates automatically when the model changes. This pattern supports one-to-many notification, allowing the GUI to listen to the status of multiple servers and baristas simultaneously. Observers can also be added or removed dynamically, enabling the system to register or unregister interface components flexibly at runtime.

3. **Model-View-Controller (MVC) Architecture:**
   The overall design adheres to the MVC architecture, separating business logic, interface rendering, and control flow. The Model layer contains core business logic and data structures, such as the simulation main class CoffeeShopSimulation, the CustomerQueue, and entities like Customer, MenuItem, and Order, as well as the background processing threads Server and Barista. The View layer is represented by SimulationGUI and its subcomponents, which are responsible for rendering the graphical interface and managing user interactions. The Controller layer includes various components working together, such as the CustomerGenerator for generating input (customers), the OnlineOrderQueue and CustomerQueue for dispatching tasks, GUI event handlers for translating user actions into model updates, and DataLoader for loading data during initialization.

The benefit of MVC lies in separation of concerns: the view and model interact through observer interfaces without needing to know each other's internal implementation, allowing GUI layout and business logic to evolve independently. Moreover, MVC facilitates team development, enabling one developer to focus on model logic while another designs the interface without conflict. It also improves testability—for example, core logic in the model can be independently tested without launching the GUI.

4. **Command Pattern:**
   In the beverage preparation process handled by baristas, we used the Command pattern to encapsulate drink-making requests into objects for asynchronous execution.

Specifically, we defined an inner class BaristaRequest, which includes the MenuItem to be prepared and a callback Runnable. When a server needs a drink prepared, it creates a BaristaRequest object, passing in the menu item and callback. The barista thread executes the request and invokes request.complete() upon finishing, which in turn executes the previously provided callback (notifying the server that the drink is ready).

With the Command pattern, the system encapsulates the description of the task (the beverage and the follow-up action) into an object that can be queued and executed parametrically. The server does not need to know the implementation details, only waiting for the callback. This design makes the task handling process more flexible and extensible. For example, it is easy to add support for different types of drink requests in the future. The pattern also facilitates request queuing and logging. The Barista's request queue can hold multiple BaristaRequest objects in sequence, each carrying all necessary information for execution—making debugging and tracking more efficient.

5. **Factory Method Pattern:**
   The Factory Method pattern is used to encapsulate object creation logic and avoid scattered use of new operations throughout the business code. In this project, we applied this pattern in the CustomerGenerator class to create different types of customer objects. For instance, based on the input parameters, the createCustomer() method determines whether to generate a regular customer or an online customer. This centralizes customer object creation and simplifies adding special creation logic in the future (e.g., tagging online customers).

Furthermore, the factory method allows subclasses to override the object creation logic, following the open-closed principle. When introducing new types of customers, developers can simply modify the factory method without changing the calling code, thus enhancing extensibility and flexibility.

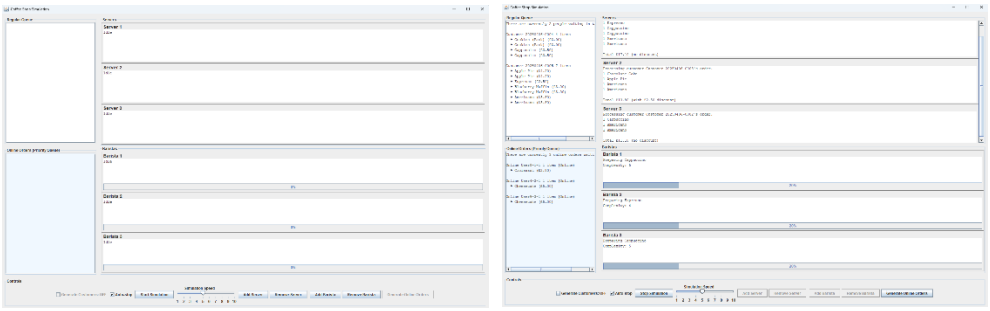
6. **Producer-Consumer Pattern:**
   This pattern is extensively applied in the system's queue management. The CustomerGenerator (producer) and the Server (consumer) form a classic producer-consumer pair: the former continuously produces customers and adds them to a queue, while the latter retrieves them for order processing. They are decoupled through a shared buffer—the CustomerQueue—so the producer does not directly interact with the consumer. If the production rate exceeds the consumption rate, the queue builds up; if the queue is full, the producer waits; if the queue is empty, the consumer waits. Our implementation follows this pattern strictly: CustomerQueue has a fixed capacity, and when addCustomer() detects the queue is full, the producer thread waits. Once a customer is removed, getNextCustomer() calls notify() to wake

the producer.

This buffering mechanism helps the system automatically balance production and consumption rates, preventing overload. Additionally, the Producer-Consumer pattern decouples customer generation from order processing, allowing them to evolve independently. Apart from the customer queue, the same pattern is applied between server and barista threads: servers produce beverage requests, and baristas consume them. Overall, this pattern is effectively used in the project to ensure coordinated and orderly operation among threads under concurrency.

In summary, the thoughtful application of design patterns significantly improved the modularity, code reusability, and extensibility of the system. By considering these patterns during the design phase, we were able to meet complex requirements at a relatively low cost and maintain code clarity even as functionality expanded.

6. Sample screen shots



7. Comparison of Development Experiences in Stage 1 and Stage 2

Throughout the entire project, our team experienced two distinct development methodologies. Stage 1 adopted a plan-driven development approach, while Stage 2 was conducted using agile development practices. Each approach has its own advantages and disadvantages and brought different experiences and challenges in practice.

(1) Stage 1: Characteristics and Experience of Plan-Driven Development

Stage 1 emphasized complete upfront design and unified planning. Before writing any code, we carried out detailed class structure design, task responsibility allocation, and data structure determination. All functionalities were implemented strictly based on the static requirement specifications provided in the coursework, with minimal adjustments made during development.

Advantages:

A clear architectural blueprint was established early, ensuring unified direction at the beginning of development.

Tasks could be allocated in advance, allowing team members to work relatively independently on their respective modules.

For systems with relatively stable and clearly defined functionality, plan-driven development can lead to higher efficiency.

Issues and Limitations:

It was difficult to respond quickly to changes. Once a design flaw was identified, modifying the system incurred high costs.

There was a lack of iterative feedback. Problems such as incompatible interfaces or poor module integration were often not discovered until the final stages.

Low communication frequency among team members led to incomplete understanding of the overall system architecture for some individuals.

(2) Stage 2: Agile Development Practice and Reflection

In Stage 2, we adopted an agile methodology and proceeded with development in iterations. Each iteration had clearly defined goals and resulted in a functional and testable version of the system. During this phase, we also implemented agile practices such as daily stand-up meetings, pair programming, and continuous integration.

Advantages:

Problems were discovered and resolved more quickly; the system was gradually improved, and directions could be adjusted flexibly.

After each iteration, the system was runnable and testable, which facilitated test-driven development.

Team members developed a better understanding of the overall system structure, and the high communication frequency led to closer collaboration.

Challenges and Responses:

Changes in requirements led to partial redesigns, but we managed to maintain system maintainability through refactoring.

We encountered technical difficulties in thread synchronization and GUI interaction, which were gradually resolved through pair programming and team discussions.

Effective time management was essential. To prevent over-scoping in iterations, we later

adopted time-boxing techniques, setting fixed time limits for each task to improve delivery efficiency.

Summary:

Overall, while plan-driven development is stable and suitable in scenarios where requirements are well-defined and functionality is fixed, agile development proved to be more efficient and adaptable for a project like ours, which involved multithreaded concurrency, graphical interface interactions, and evolving requirements.

We believe that the agile methodology is particularly well-suited for exploratory and frequently changing development tasks, allowing for continuous delivery and ongoing improvement in short cycles. In the future, we intend to continue using agile development methods in similar projects, supplemented by phased planning to achieve a balance between flexibility and stability.

8. Problems Encountered During Development and Their Solutions

During the development and integration testing in Stage 2, we encountered several practical issues and challenges. Below is a summary of typical problems and the corresponding solutions we adopted:

Thread Termination and Restart Issues:

When implementing dynamic removal of server and barista threads, we discovered that restarting new threads after stopping old ones could lead to conflicts. Initially, we simply interrupted the threads, but they could become stuck in a wait() state and fail to exit in time. Our solution involved introducing a thread-running flag (AtomicBoolean running) combined with timed waiting: when the user requested to remove a server, we set running = false and called interrupt() to wake up the thread, allowing it to exit the loop and terminate safely. We then started a new server thread either from a thread pool or by instantiating a new object. Additionally, we ensured that all thread addition/removal operations were executed serially on the GUI event thread to avoid concurrent modifications of the server list. These measures enabled smooth thread restarts: terminated threads released resources properly, and new threads joined the system without interference.

Uneven Thread Workload:

In our initial implementation, we observed that some threads were heavily loaded while others remained idle. For example, servers initially assigned drink-making tasks to baristas in a fixed order, causing the barista with the smallest ID to handle nearly all drink preparation tasks, while others were underutilized. To resolve this imbalance, we modified the task

distribution strategy: drink preparation requests were allocated using round-robin or randomized selection, ensuring a more balanced workload among barista threads. As for servers retrieving customers from the queue, our use of a single shared queue with a fair locking mechanism naturally ensured that the longest-waiting server received the next customer, helping balance the server workload. In cases where one server happened to take multiple online orders consecutively, we introduced a short delay (waitFor(500ms)) after each retrieval, giving idle servers a better chance to compete for the next customer. After these adjustments, the workload across server and barista threads became much more balanced, and no individual thread was overloaded.

Queue Capacity and Blocking Issues:

Before we implemented blocking mechanisms, if the customer generation rate exceeded the order processing speed, the queue could grow uncontrollably, consuming excessive memory. To address this, we imposed a maximum queue capacity (e.g., 10 customers). Initially, we considered discarding new customers when the queue was full, but this resulted in order loss, which was unacceptable. Eventually, we adopted a strict producer-consumer model: when the queue was full, the customer generator thread would block and wait in addCustomer(..., wait=true) until a server removed a customer and triggered a notify(), allowing the producer to resume. This approach both prevented queue overflow and ensured that no orders were lost. Additionally, we added a GUI warning when the queue was full, alerting users to the congestion. Through tight capacity control and coordinated blocking/waking mechanisms, the system effectively resolved overflow issues under high concurrency.

Thread Synchronization and Deadlock Risks:

During the development of interactions between servers and baristas, we were initially concerned about potential deadlocks—for instance, servers waiting for baristas while baristas waited for servers to release locks. Upon analysis, we found that a potential deadlock could occur if a server thread held a customer lock while waiting for the barista callback. To avoid this, we introduced additional lock objects specifically for waiting on drink preparation, separate from the main lock, and used counters or CountDownLatch to track the number of unfinished drinks. The server thread would only proceed after all drinks were completed. We also set timeouts during waiting to ensure that unexpected issues (e.g., barista thread failure) would not cause indefinite blocking. Furthermore, we carefully designed the nesting order of synchronized blocks to ensure that no thread would attempt to hold multiple resource locks simultaneously. In the final implementation, collaboration between servers and baristas was deadlock-free, and threads were able to acquire and release locks in an orderly fashion.

GUI Refresh and Thread Concurrency Issues:

Initially, we updated GUI components directly from background threads, which occasionally caused interface lag and runtime exceptions due to violations of Swing's single-thread rule. We promptly corrected this by ensuring that all GUI updates were handled either by observers on the event dispatch thread or wrapped in SwingUtilities.invokeLater(). For example, when a server's status changed, it would no longer directly manipulate UI labels; instead, it would call notifyObservers() to let the GUI thread handle the updates. In some specific cases, we explicitly used SwingUtilities.invokeLater() to encapsulate UI update logic. These measures completely resolved the instability caused by cross-thread UI updates. As a result, both queue changes and thread status updates are now communicated to the GUI in a thread-safe manner, and the interface remains responsive and stable without freezing or flickering.

The process of identifying and solving these problems greatly deepened our understanding of the intricacies of multi-threaded applications. It also reinforced the importance of sound concurrent design—such as the appropriate use of synchronization mechanisms and design patterns—in preventing real-world development pitfalls.