Assignment: asynchronous messaging with RabbitMQ

This assignment introduces the concepts of asynchronous messaging often used in building distributed systems. The goal is to become familiar with RabbitMQ, a popular open source message broker, through a hands-on programming exercise.

Getting started

Follow the tutorial on MyCourses, which provides the necessary instructions to set up RabbitMQ and links to standard tutorials that describe the core concepts required for this assignment. This assignment is coded in Python (**version 3.6** or greater) and you must use the Pika client library (**version 1.2.0**) for RabbitMQ.

Task

The assignment is to build a smart shopping application. The scenario comprises a **Shopping Sensor** that detects when customer picks and purchases a product out of shopping mall. The application logic resides in the **Shopping Worker** (backend) where pick up and purchase event messages generated by the shopping sensor are processed to calculate a shopping cost and to generate billing events. Customers that pick and purchase products receive alerts on their **Customer App** when they do so; they also receive billing information for shopping when exiting the shopping mall.

Your task is to create the necessary RabbitMQ messaging exchanges and queues for such a scenario as specified in the Requirements below.

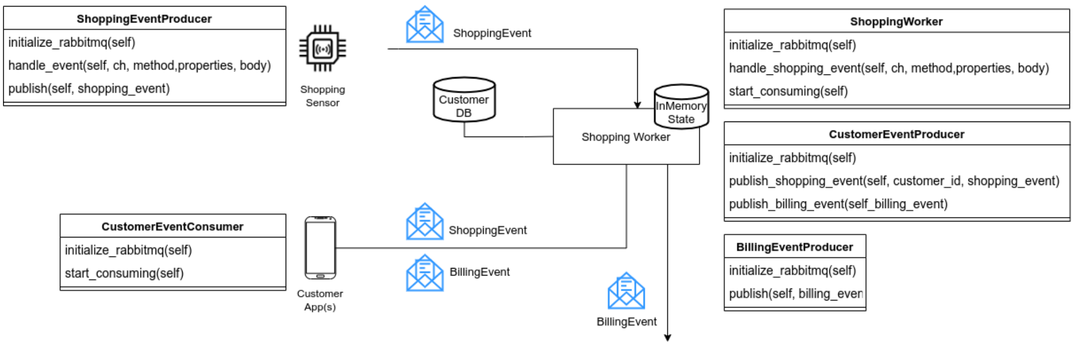
Code structure

> **Note**
>
> To get started you can download a scaffolding application **`here`**. The content of the archive provides the basic structure of the Python application on top of which the messaging can be added.

The files in the scaffolding are as follows:

- `requirements.txt` contains the required Python packages. You can add more libraries / packages to the requirements.txt file if needed.
- `db_end_event_definitions.py` defines the `customers_database`, `cost_per_unit` , `number_of_units` of shopping, and the format of `ShoppingEvent` and `BillingEvent`
- `shopping_sensor.py` defines a class `ShoppingEventProducer` which produces ShoppingEvent(s)
- `shopping_worker.py` defines three classes
  - `ShoppingWorker`: The main class that consumes ShoppingEvent(s) and processes them
  - `BillingEventProducer`: The class that produces BillingEvent(s)
  - `CustomerEventProducer`: The class that produces both ShoppingEvent(s) and BillingEvent(s) to customers
- `customer_app.py` defines a class `CustomerEventConsumer` that consumes both ShoppingEvent(s) and BillingEvent(s) for a given customer
- `xprint.py` provides `xprint()` function that can be used to display your logs, even when executed on the grader.

You must add the logic for initializing RabbitMQ connections, creating message exchanges and queues to the functions therein. Specifically, the diagram shows the methods that you should implement.



You must use Pika's Blocking Connection adapter , like so, `self.connection = pika.BlockingConnection(pika.ConnectionParameters('localhost'))` , assuming that RabbitMQ is running already on the same machine.

> **Attention**
>
> DO NOT change existing method names OR signatures, OR the variables declared in the constructors of any class (__init__() method).
>
> More variables and methods can be added to the classes, but keep the existing ones.
>
> The variables declared in __init__() must be appropriately initialized later in the class.
>
> DO NOT alter the method names / signatures for the provided scaffolding as these interfaces are used to test your submission.
>
> DO NOT alter the close() methods in the classes.
>
> DO NOT alter the `db_and_event_definitions.py` as this file will be overwritten with a new database in the grading system.

Instructions

Overview

A shopping sensor (ShoppingEventProducer) generates shopping events containing the entry_type (`pick up` or `purchase`), product number (identity of the product) and time stamp of the pick up and purchase event. These events are consumed by ShoppingWorkers.

ShoppingWorkers process these events by looking up customer information (i.e., a customer ID) from a product (product number), maintaining state of which products are currently in the customer basket, and finally calculating the amount the customer is to be charged when the purchase event is received. Shopping Workers also generate messages to the customer application. The customer application (CustomerEventConsumer) consumes messages that are relevant only for that customer.

To achieve this, you must implement the following:

1. The ShoppingEventProducer produces shopping events to an exchange named `shopping_events_exchange`. You must ensure that the pick up and purchase events for a particular product are consumed by the same worker.

   This is because a worker only saves memory in-state, and cannot communicate with other workers. You can accomplish this through a **consistent hash exchange type** by assigning **equal weight values** to both workers. This means that both workers will process roughly the same number of ShoppingEvents.

2. The ShoppingWorkers consume messages from a queue bound to the `shopping_events_exchange` (consistent hash exchange). On receiving a pick up or purchase shopping event, the worker looks up the customer associated with the product number. The workers produce shopping events for every `pick up` and `purchase` to a `customer_app_events` exchange.

   Additionally, when a product is purchased, the worker handling that particular customer produces a billing event to a queue called `billing_events` through a default (nameless) exchange. The billing event message must contain the following:

   - Customer ID
   - Product number
   - Pick up time
   - Purchase time
   - Shopping cost

   Note that there is a **20% discount** going on in the shopping center so the shopping cost must be calculated based on `cost_per_unit` * `number_of_units` - 20% from `db_and_event_definitions.py`.

3. The ShoppingWorker maintains a dictionary called `shopping_state` and a list of all received ShoppingEvents called `shopping_events`. The dictionary `shopping_state` is used to maintain state of the products that are currently in the customer basket.

   When a products is picked up by a customer, an entry should be added to the dictionary, where the key is the `product number` and the value is the `timestamp` of the event: `self.shopping_state[shopping_event.product_number] = shopping_event.timestamp`.

   When a product is being purchased, the state should be removed from the dictionary. This can be done with `self.shopping_state.pop(shopping_event.product_number)`.

   When an purchase event is received for a product currently in the shopping_state dictionary, the product is removed from the dictionary, i.e., the product is no longer in the state.

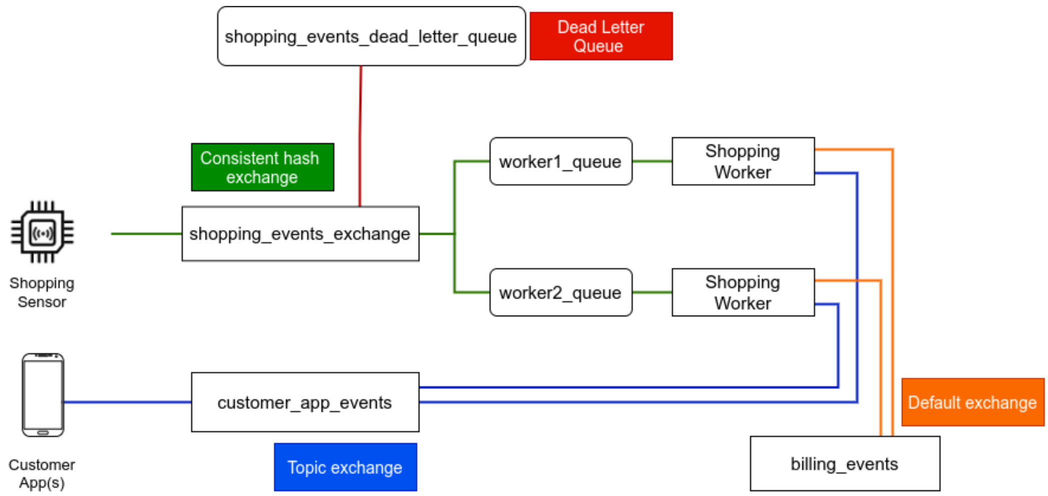
   The list `shopping_events` contains all the ShoppingEvent objects received by the ShoppingWorker. The messages should be appended to the lists appropriately. The first message received should be saved at index 0, the second to index 1 and so on. In Python this can be achieved by using the append() method (e.g. `self.shopping_events.append(shopping_event)`)

4. If a `pick up` or `purchase` ShoppingEvent is received for an unknown product number (i.e., the product number does not exist in the `customers_database`), it **MUST NOT** be added to the `shopping_state` dictionary. Instead, the ShoppingWorker must negatively acknowledge such a message. The exchange should be set up in such a way that a negatively acknowledged message should be republished by the RabbitMQ Broker to a dead letter queue called `shopping_events_dead_letter_queue`.

5. The CustomerEventConsumer consumes shopping events and billing events **only** relevant to it (based on the customer-ID) from the `customer_app_events` exchange.

   You can accomplish this through a **topic exchange**. The CustomerEventConsumer must also maintain two lists of `shopping_events` and `billing_events` containing the received ShoppingEvents and BillingEvents respectively. These two lists maintain all events received by the customer app, and the messages should be appended to the above lists appropriately. The first message received should be appended to index 0, the second to index 1 and so on. In Python this can be achieved by using the append() method (e.g. `self.shopping_events.append(shopping_event)`)

The diagram below shows an overview of the exchanges and messaging queues to be implemented.



> **Attention**
>
> Update (11/10/2022): The functions to implement with some additional hints are published in this PDF.

How to test your code

We have provided three Python scripts (in the scaffolding code under `scripts/`) that can help you test your code **locally**. With these scripts you can recreate the scenario that will be tested by our automated grading script. Once you have implemented the RabbitMQ exchanges and messaging, you can run the scripts as follows:

1. Start a worker with `python3 run_worker.py --id "<worker-id>" --queue "<worker-id>_queue" -w "1"`
2. Start a customer app with `python3 run_customer_app.py -c "<customer-id>"`
3. Generate ShoppingEvents through `python3 produce_shopping_event.py -e "pick up" -c "<customer-id>" -t 5` and `python3 produce_shopping_event.py -e`

> **Note**
>
> Remember to enable the `x-consistent-hash-exchange` as shown here

With these scripts you can check whether the messages are received as expected. You can start more **ShoppingWorkers** and **CustomerEventConsumers** in different shell windows to recreate the scenario that will be tested in the grader (described next).

Grading

You must submit a **zip archive** containing the full implementation of shopping application. Your ZIP file must have the following structure:

```
./exercise.zip
└── exercise
    ├── __init__.py
    ├── requirements.txt (optional)
    ├── customer_app.py
    ├── db_and_event_definitions.py
    ├── shopping_sensor.py
    ├── worker.py
    ├── xprint.py
```

Our automated grading system relies on Python. The RabbitMQ server will be started on the same server in our test with the `rabbitmq_consistent_hash_exchange` plugin already enabled; thus, you only need to connect to `localhost` when initilizing the Pika Blocking Connection.

> **Hint**
>
> Use the `xprint()` function provided in `xprint.py` to print logs from your code. The grader will display any statements printed by `xprint()` after running the test cases. Other print statements will be ignored.
>
> DO NOT hard-code any customer information in your code, you must always look up the `customers_database` defined in the `db_and_event_definitions.py` file, as we test with a different database in the grading system.

We will use your code to start two ShoppingWorkers and five different CustomerEventConsumers. The assignment will run the following tests, which give points as shown in the table below.

Note

Test	Points
Five pick up events are produced for known product numbers using the submitted ShoppingEventProducer The test checks that two ShoppingWorkers have received the events correctly by reading the `shopping_events` list.	10
Five purchase events are produced for the same product numbers as in step 1. The test checks that the purchase events are received on the same worker that received the pick up event for that product number.	20
The test checks that the five customer apps have each received two shopping events by reading the `shopping_events` list.	10
The test starts consuming from the `billing_events` queue and checks that the five billing events have been correctly produced **Note** This consumer is test code and is only started and closed at this step.	10
The test checks that the five customer apps have each received one billing event by reading the `billing_events` list.	10
One pick up event for an unknown product number (i.e., not present in customers_database) is produced using the submitted ShoppingEventProducer. The test starts consuming from the `shopping_events_dead_letter_queue` queue and checks that the one shopping event is received. **Note** This consumer is test code and is only started and closed at this step.	