DEPARTMENT OF COMPUTER & SOFTWARE ENGINEERING

COLLEGE OF E&ME, NUST, RAWALPINDI

Hospital Emergency Department System Simulation

Project Report

SUBMITTED TO:
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Course Name:
Object-Oriented Programming (OOP)

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Table of Contents

Introduction

Overview of the Project

The Hospital Emergency Department (ED) Simulation Project aims to create a comprehensive simulation model to enhance the efficiency and resource management of an Emergency Department. The project accurately models the patient journey through critical ED stages, including arrival, triage, treatment, and discharge. It considers key operational factors such as the number of available beds, patient arrival rates, severity of conditions (acuity levels), and staff availability. Using priority queues, lists, and arrays, the simulation effectively manages data flow and integrates multiple interconnected modules to replicate the dynamic workflows of a real-world ED. The primary objective is to analyze ED performance through essential metrics like waiting times, bed utilization rates, and resource availability, offering valuable insights for improving operational efficiency and patient care outcomes.

What is a Hospital ED System

A Hospital Emergency Department (ED) is a critical unit within a hospital dedicated to providing immediate medical care to patients with urgent or life-threatening conditions. It serves as the first point of contact for individuals requiring emergency treatment, whether due to accidents, sudden illnesses, or severe health complications. Operating 24/7, the ED is staffed by trained medical professionals, including doctors, nurses, and paramedics, who are equipped to handle a wide range of emergencies. Patients are typically assessed through a triage system, ensuring that those with the most critical needs are treated first. Additionally, the ED often acts as a gateway to other hospital departments, facilitating transfers to specialized care units when necessary.

Why is a Hospital ED System Important?

A well-functioning ED system not only saves lives but also ensures optimal utilization of resources, reducing delays and improving patient satisfaction. Its importance can be highlighted through the following:

1. **Immediate Medical Attention:** Provides life-saving treatment to critical patients.
2. **Triage System:** Prioritizes patients based on the severity of their condition to ensure timely intervention.
3. **Resource Management:** Balances the availability of doctors, nurses, and beds to prevent overcrowding.
4. **Healthcare Gateway:** Acts as a bridge between outpatient care, inpatient wards, and specialized departments.
5. **Efficiency Metrics:** Directly impacts hospital performance through metrics like waiting times and treatment outcomes.

Role of Simulations in Healthcare Systems

Simulations play a crucial role in analyzing and improving healthcare systems, especially in environments as dynamic and complex as hospital Emergency Departments.

1. **Scenario Testing:** Allows hospitals to test "what-if" scenarios, such as increased patient inflow during crises or reduced staffing levels.
2. **Resource Optimization:** Helps identify bottlenecks in the system and suggests improvements in staff allocation**,** bed management**,** and equipment utilization.
3. **Performance Metrics:** Measures critical indicators like patient waiting times**,** bed occupancy rates**,** and resource utilization efficiency.
4. **Cost Efficiency:** Reduces operational costs by identifying waste and improving resource deployment.
5. **Training and Preparedness:** Provides virtual environments for training healthcare staff

to handle emergencies without risking patient safety.

6. **Data-Driven Decisions:** Enables healthcare administrators to make informed decisions based on simulation results.

In this project, simulation serves as a powerful tool to model real-world ED workflows, test various operational strategies, and ultimately improve the quality of care provided to patients.

Problem Statement

The Hospital Emergency Department (ED) Simulation Project addresses challenges like overcrowding, resource allocation inefficiencies, and variable patient flow in emergency healthcare systems. It focuses on simulating disease assignment based on triage categories, ensuring patients are prioritized and treated effectively.

The project uses probability distribution functions (PDFs) to model key processes:

- Weibull Distribution: Patient arrival times.
- Pearson Type VI Distribution: Treatment durations.
- Exponential Distribution: Post-discharge decision times.

These statistical models help replicate the dynamic ED environment, enabling better insights into resource optimization, waiting time reduction, and workflow efficiency. The project aims to deliver data-driven recommendations for improving ED performance and enhancing patient care quality.

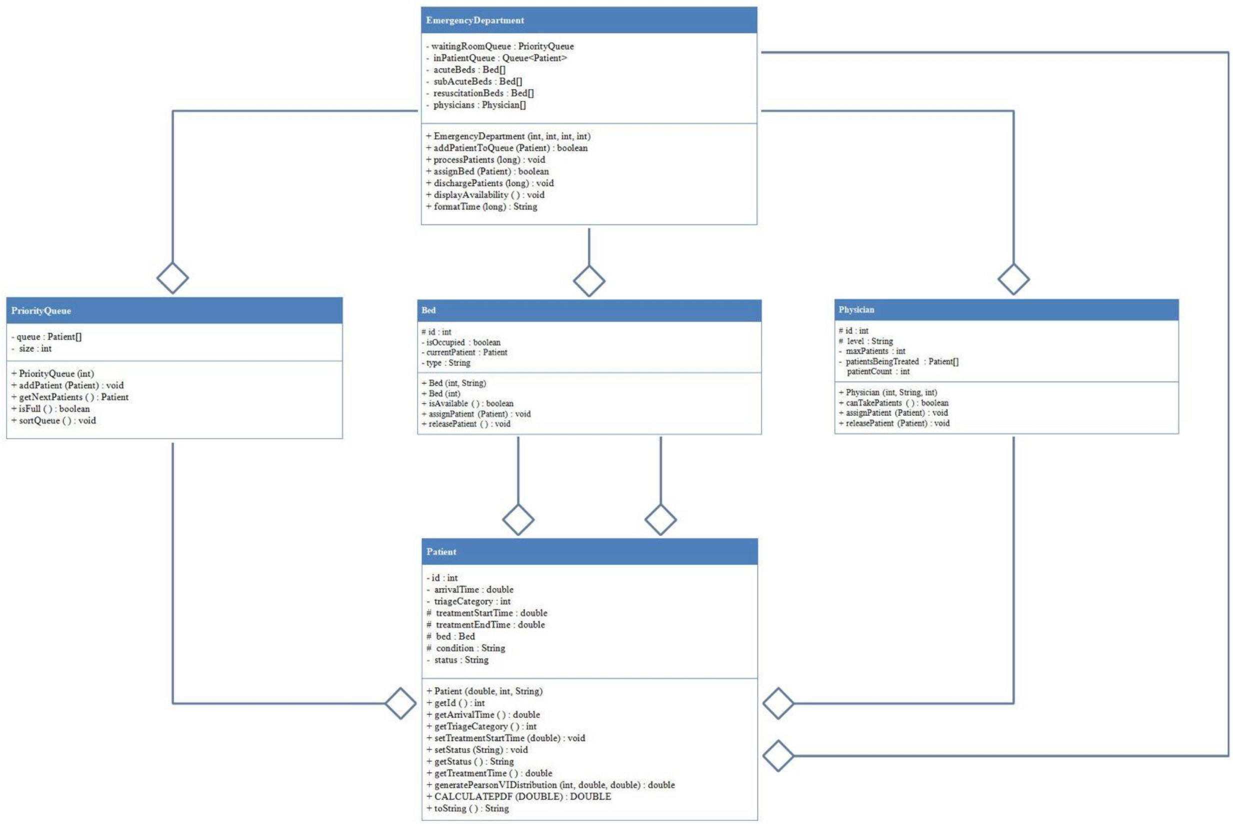
Objectives

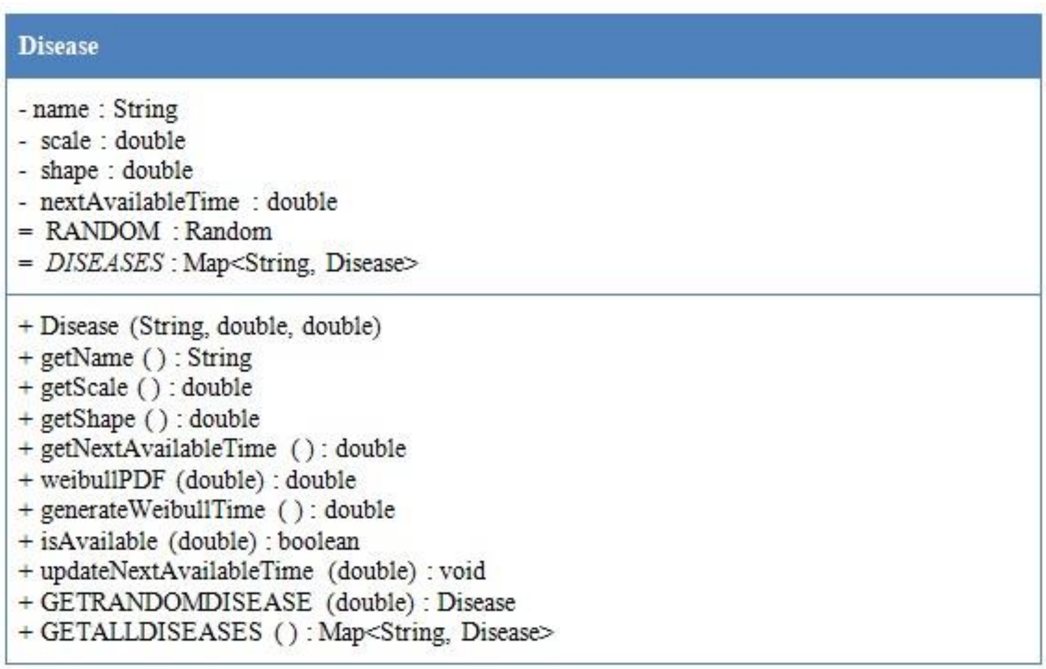
The Hospital Emergency Department (ED) Simulation Project aims to address critical challenges in managing patient flow and resource allocation in emergency healthcare systems. The key objectives are:

- **To simulate disease assignment in an Emergency Department**, ensuring accurate representation of patient conditions based on triage categories.
- **To implement an Object-Oriented Programming (OOP)-based approach** for building a **modular, scalable, and maintainable simulation system**.
- **To use different probability distributions (Weibull, Pearson Type VI, Exponential)** for assigning disease severity, treatment durations, and post-discharge decision times.
- **To optimize resource utilization** (e.g., beds, staff) and minimize patient waiting times through data-driven insights.
- **To provide detailed statistical outputs and performance metrics**, aiding decision-makers in improving ED operations.

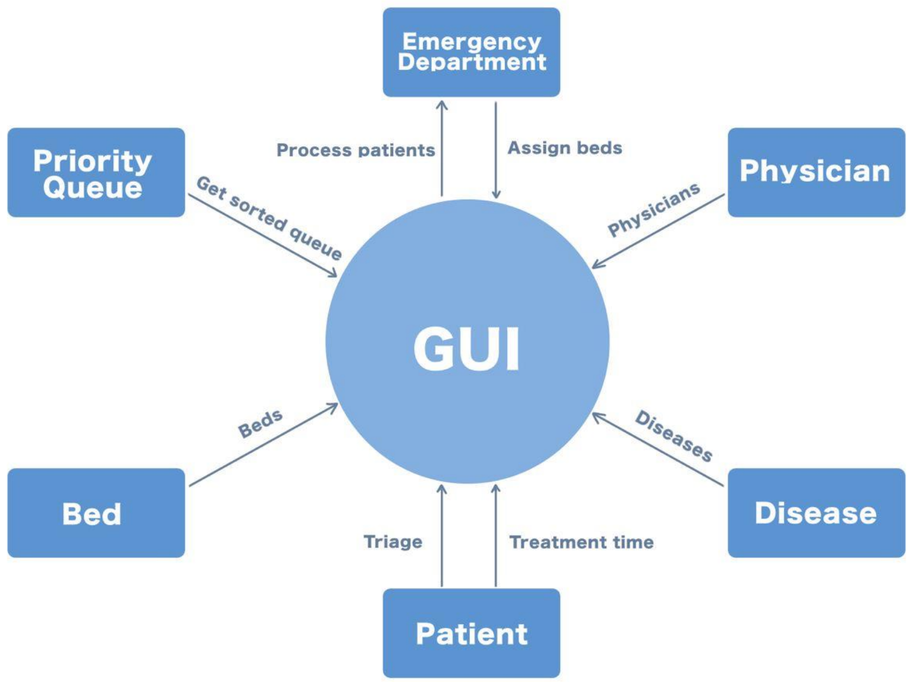
System Design

Class Diagrams





System Level Diagrams



Implementation Details

- **Programming Language Used:** Java
- **OOP Principles Applied:**
    - Encapsulation: Patient and TriageSystem classes encapsulate their attributes and methods.
    - Inheritance: Specialized classes inherit common functionalities from base classes.
    - Polymorphism: Functions like `assignDisease()` adapt behaviour based on disease severity.
- **Key Classes and Methods:**
    - `Patient::getTreatmentTime()`: Assigns scale for the Pierson VI calculation to determine the treatment time.
    - `Patient::generatePearsonVIDistribution()`: Calculates treatment time using the Pearson VI formula.
    - `EmergencyDepartment::processPatients()`: Assigns beds and physicians to patients and start their treatment process until treatment is complete.
    - `Main::scheduler.scheduleAtFixedRate()`: Orchestrates the simulation at a fixed rate and keep it running under the proper conditions.
- **Probability Distribution Integration:**

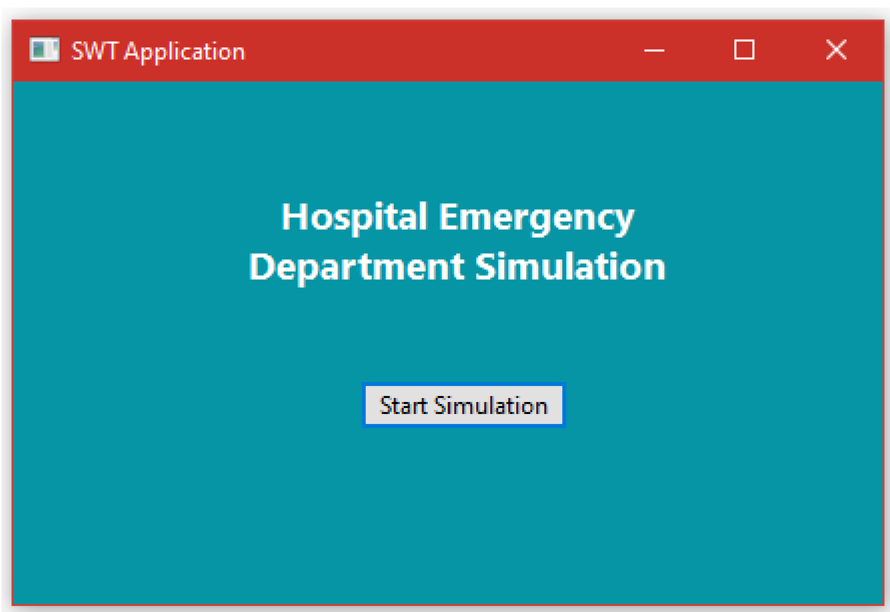
- Weibull Distribution: Used for modelling patient arrival intervals.
- Pearson VI Distribution: Used for determining treatment durations.
- Exponential Distribution: Used for post-discharge decision times.

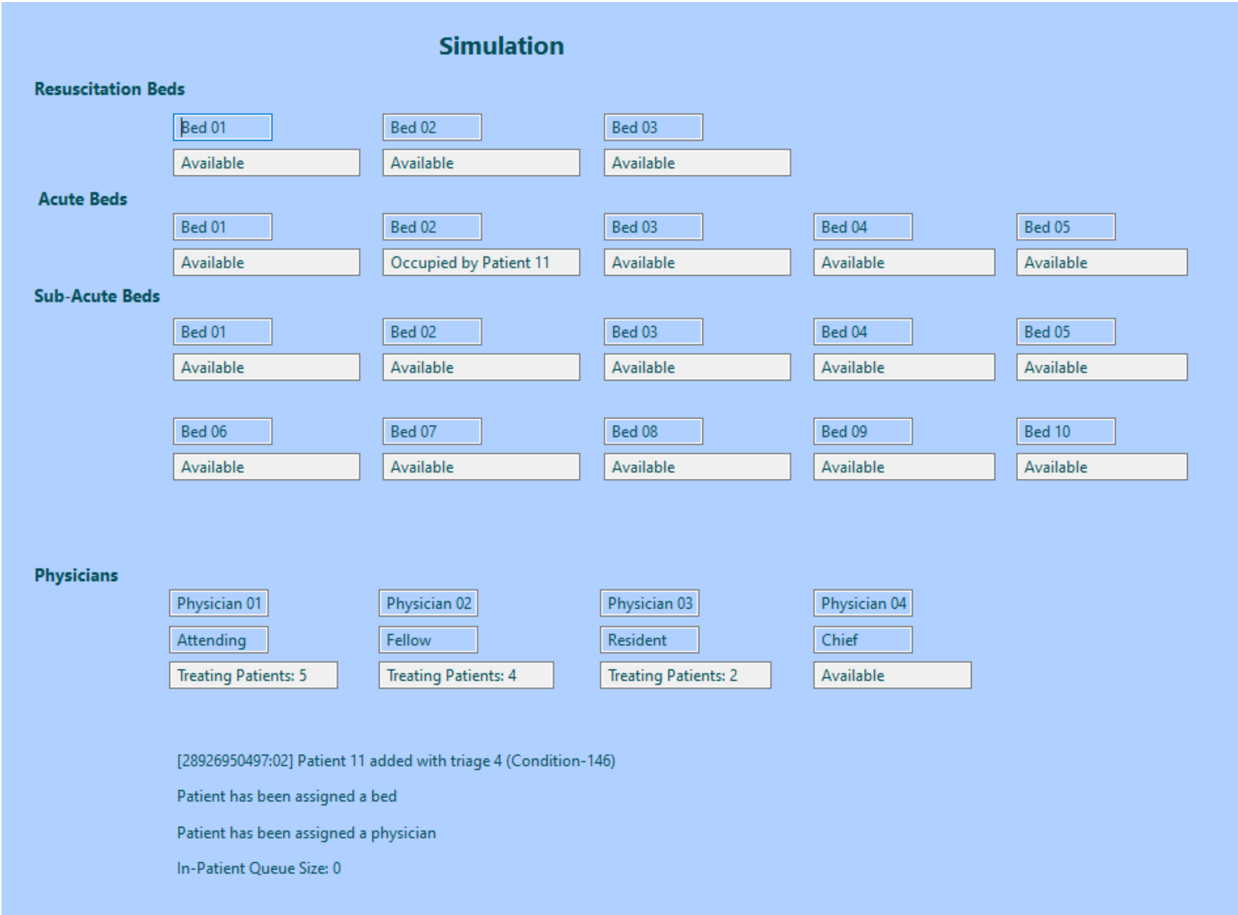
- **Constants and Parameters:**
  - Weibull (λ = 180, k = 0.914)
  - Pearson VI (λ = 355, α = 1.64, β = 5.72)
  - Exponential (Mean = 156, Rate = 0.00641)

Key Features

- **Randomized Disease Assignment:** Patients are assigned diseases based on triage categories using probability distributions.
- **OOP-Based Modular Design:** Ensures scalability and easy maintenance.
- **Extensibility:** New triage categories, diseases, or scenarios can be added seamlessly.
- **Performance Metrics:** Outputs include patient waiting times, resource utilization, and disease distribution.
- **Graphical/Console-Based Results:** Results can be visualized either through terminal outputs or graphical dashboards.

Results and Outputs





Challenges and Solutions

- **Implementing Complex Probability Distributions:**
  - Challenge: Accurate integration of Weibull, Pearson VI, and Exponential distributions.
  - Solution: Used mathematical libraries and rigorous testing to validate distribution outcomes.
- **Synchronization Between Modules:**
  - Challenge: Ensuring seamless data flow between the various classes.
  - Solution: Implemented buffer queues and synchronized access mechanisms.
- **Scalability:**
  - Challenge: Simulating large numbers of patients while maintaining performance.
  - Solution: Optimized data structures and memory management techniques.

Conclusions

The Hospital Emergency Department Simulation Project successfully modelled patient flow, disease assignment, and resource utilization using an OOP-based approach combined with probability distribution functions. Key outcomes include insights into patient waiting times, resource utilization efficiency, and disease treatment patterns.

Future Development Possibilities:

- Integration with real-time patient data from hospital management systems.
- Incorporation of machine learning algorithms for predictive analytics.
- Development of a graphical dashboard for real-time monitoring and control.

This project serves as a valuable tool for improving healthcare system efficiency and resource management in hospital emergency departments.

References

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