Automated Smart Parking System - Project Report

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Project Title: Automated Smart Parking System

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2. Introduction

The Automated Smart Parking System is a Java-based console application designed to manage vehicle allocation and generate dynamic parking fees for a multi-level parking facility. The system provides a command-line interface (CLI) for users to perform parking operations while maintaining security and efficiency through automated slot allocation and polymorphic fee calculation.

The project showcases practical application of core Java concepts including inheritance, polymorphism, abstract classes, custom exceptions, and array-based data structures. It simulates a real-world parking management environment where operators can park vehicles, checkout parked vehicles, view occupancy status, and manage parking capacity constraints.

3. Problem Statement

Urban parking management presents significant operational challenges in modern cities and commercial complexes. The challenges addressed by this project include:

- Manual slot allocation leads to inefficiency and human error in busy parking facilities
- Inconsistent billing due to lack of automated fee calculation mechanisms
- Difficulty tracking vehicle occupancy across multiple slots in real-time
- No capacity management to prevent overbooking and overcrowding scenarios
- Time-consuming checkout process resulting in customer dissatisfaction
- Lack of systematic recording of parking transactions

4. Functional Requirements

- **Vehicle Parking:** Users can park three types of vehicles (Car, Bike, PremiumCar) with unique identification
- **Slot Allocation:** Automated assignment of parking slots based on availability
- **Capacity Management:** System maintains hard limit of 10 parking slots with overflow prevention
- **Dynamic Fee Calculation:** Fees calculated based on vehicle type and parking duration
- **Checkout Functionality:** Users can retrieve vehicles and generate parking receipts
- **Occupancy Status:** Real-time display of all currently parked vehicles with details
- **Fee Rates:** Different hourly rates for different vehicle types (Bike: Rs.15, Car: Rs.20, PremiumCar: Rs.40)
- **Error Handling:** Graceful handling of invalid operations with meaningful error messages
- **Vehicle Search:** Quick retrieval of vehicles by ID for checkout operations

5. Non-Functional Requirements

Requirement	Description
Usability	Intuitive command-line interface with clear menu options
Performance	Efficient slot allocation and search operations with constant time response
Maintainability	Clean, well-documented code following OOP principles
Scalability	Architecture supports addition of new vehicle types
Reliability	Robust error handling and exception management
Portability	Platform-independent Java code (JDK 8+)

6. System Architecture

6.1 Architectural Overview

The Smart Parking System follows a modular architecture pattern:

1. **Presentation Tier:** Command-line interface (Main.java)
2. **Business Logic Tier:** Vehicle management and parking operations (Vehicle, Car, Bike, PremiumCar)
3. **Data Management Tier:** Array-based storage and slot allocation (Vehicle[] array)
4. **Exception Handling Tier:** Custom exception management (ParkingException)

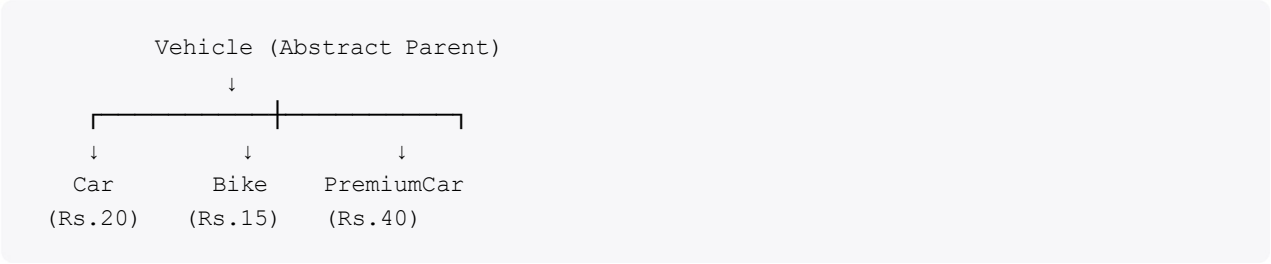
6.2 Component Architecture

The system comprises the following key components:

- **Vehicle (Abstract Base Class):** Defines common vehicle attributes and behaviors
- **Car:** Specialized vehicle type with Rs.20/hour rate
- **Bike:** Specialized vehicle type with Rs.15/hour rate
- **PremiumCar:** Specialized vehicle type with Rs.40/hour rate
- **ParkingException:** Custom exception for parking capacity errors
- **Main:** Application controller and user interface

7. Design Diagrams

7.1 Class Hierarchy



7.2 Data Structure

Fixed Array: ParkingSlot[^10]

Feature	Description	Data Type
Array Type	Vehicle reference storage	Vehicle[]
Size	Total parking capacity	10 slots
Storage Method	Null-based empty slot detection	Stack-based
Search Algorithm	Linear sequential search	O(n)
Time Complexity	Worst case slot finding	O(n) where n=10
Space Complexity	Memory allocation	O(1)

7.3 Use Case Diagram

Primary Use Cases:

- **UC1: Park Vehicle** - User parks a vehicle in available slot
- **UC2: View Parked Vehicles** - User views all currently parked vehicles
- **UC3: Checkout Vehicle** - User retrieves a vehicle and generates receipt
- **UC4: Check Capacity** - User views parking facility occupancy status

7.4 Workflow Diagram

Parking Workflow Steps:

1. User selects vehicle type from menu (Car/Bike/PremiumCar)
2. Enters unique vehicle ID
3. Enters parking duration in hours
4. System creates corresponding vehicle object
5. System searches for first available (null) slot in array
6. If slot available: Vehicle stored at that position, confirmation displayed
7. If no slots available: ParkingException thrown, error message displayed
8. System returns to main menu

Checkout Workflow Steps:

1. User enters vehicle ID to checkout
2. System searches entire array for matching vehicle ID
3. If found: Vehicle retrieved, fee calculated based on type and duration
4. Receipt generated with vehicle details and parking charges
5. Slot cleared (set to null) for future use
6. System returns to main menu

8. Technical Architecture

8.1 Core Data Structure

The parking system utilizes a fixed-size array to store vehicle references:

```
Vehicle[] parkingSlot = new Vehicle[^10]
```

Key Characteristics:

- **Size:** 10 parking slots (indices 0-9, displayed as slots 1-10 to users)
- **Search Algorithm:** Linear sequential search from index 0
- **Empty Detection:** Null-based (empty slots = null references)
- **Memory Type:** Stack-based allocation
- **Time Complexity (Search):** O(n) in worst case where n=10
- **Space Complexity:** O(1) excluding vehicle storage

8.2 Object-Oriented Design

Abstract Parent Class: Vehicle

The Vehicle class serves as blueprint for all vehicle types:

Attribute	Type	Purpose
id	int	Unique vehicle identifier for tracking
hours	int	Duration of parking in hours

Key Methods:

- `abstract double calculateFee()`- Polymorphic fee calculation (overridden by children)
- `int getId()`- Returns unique vehicle identifier
- `void display()`- Displays vehicle information on console

Concrete Child Classes:

Car Class - Standard Passenger Vehicles

```
public double calculateFee() {
    return hours * 20.0;  // Rs. 20 per hour
}
```

Rate: Rs. 20/hour | Example (3 hrs): Rs. 60

Bike Class - Two-wheelers and Motorcycles

```
public double calculateFee() {
    return hours * 15.0;  // Rs. 15 per hour
}
```

Rate: Rs. 15/hour | Example (3 hrs): Rs. 45

PremiumCar Class - Luxury and VIP Vehicles

```
public double calculateFee() {
    return hours * 40.0;  // Rs. 40 per hour
}
```

Rate: Rs. 40/hour | Example (3 hrs): Rs. 120

8.3 Exception Handling

Custom Exception: ParkingException

This custom exception is thrown when attempting to park a vehicle in a full parking facility, preventing invalid state transitions and providing clear error messaging.

Exception Specifications:

- **Trigger Condition:** Number of vehicles equals 10 (array capacity reached)
- **Error Message:** "Error: Parking Full! Cannot park more vehicles."
- **Recovery Strategy:** User must checkout an existing vehicle before parking new one
- **Exception Hierarchy:** Extends java.lang.Exception
- **Handling:** Try-catch block with user-friendly error display

9. Implementation Details

9.1 Parking Slot Allocation Algorithm

Algorithm Steps:

1. Initialize Vehicle[] parkingSlot = new Vehicle[^10] (all null initially)
2. Receive vehicle details: type, unique ID, parking duration in hours
3. Create corresponding vehicle object (Car, Bike, or PremiumCar)
4. Iterate through array from index 0 to 9
5. Find first null slot at index i
6. Insert vehicle object at parkingSlot[i]
7. Return success: "Vehicle parked successfully at Slot: (i+1)"
8. If no null slot found → throw ParkingException

Complexity Analysis:

- **Time Complexity:** O(n) where n = 10 (array size) – linear search in worst case
- **Space Complexity:** O(1) for allocation logic (excluding vehicle storage)

9.2 Fee Calculation Strategy

The system implements dynamic billing based on vehicle type and parking duration:

Vehicle Type	Rate/Hour	1 Hour	2 Hours	3 Hours
Bike	Rs. 15	Rs. 15	Rs. 30	Rs. 45
Car	Rs. 20	Rs. 20	Rs. 40	Rs. 60
Premium Car	Rs. 40	Rs. 40	Rs. 80	Rs. 120

Calculation Formula:

```
Parking Fee = Vehicle_Type_Rate × Duration_in_Hours
```

9.3 Checkout System

Checkout Process:

1. User provides vehicle ID to checkout
2. System performs linear search through entire parking array
3. Upon finding matching vehicle ID:
    - Calculate total parking fee using polymorphic calculateFee() method
    - Generate comprehensive parking receipt
    - Display vehicle details and charges
    - Clear slot (set to null) for future use
4. If vehicle not found: Display appropriate error message

10. Project Structure

```
Automated-Smart-Parking-System/
├── Main.java                      # Entry point &amp;amp; user interface
├── README.md                      # Project documentation
├── parking/                       # Core package (src/parking)
│   ├── vehicle.java              # Abstract parent class
│   ├── car.java                  # Car implementation
│   ├── bike.java                 # Bike implementation
│   ├── premiumCar.java           # Premium car implementation
│   └── parkingException.java      # Custom exception class
```

11. Key Features & Functionalities

11.1 Dynamic Slot Allocation

- Automatically finds the first available (null) slot in array
- Assigns vehicle object to that slot instantly
- Returns confirmation with actual slot number (1-indexed for user display)
- Prevents duplicate slot allocation through null checking
- Handles edge cases: first slot, last slot, full parking scenarios

11.2 Polymorphic Fee Calculation

- Different hourly rates for different vehicle types (Bike: Rs.15, Car: Rs.20, PremiumCar: Rs.40)
- Calls overridden calculateFee() method at runtime based on vehicle type
- Supports extensibility for new vehicle types without code modification
- Demonstrates runtime polymorphism principles effectively

- Enables flexible pricing strategy implementation

11.3 Capacity Management

- Maintains hard limit of 10 parking slots
- Throws ParkingException when capacity exceeded
- Prevents overbooking scenarios through exception mechanism
- Includes robust error handling with try-catch blocks
- Allows slot reuse after checkout operations

11.4 Vehicle Viewing

- Displays all currently parked vehicles with their details
- Shows vehicle type, ID, parking duration, and slot number
- Provides real-time occupancy status
- Helps operators track parking facility status

11.5 Occupancy Display

- Shows total number of currently parked vehicles
- Displays available slots remaining
- Lists details of each parked vehicle in organized format
- Updates in real-time after each operation

12. OOP Concepts Demonstrated

Concept	Implementation	Benefit
Abstraction	Vehicle abstract class with abstract method	Hides complex implementation details
Inheritance	Car, Bike, PremiumCar extend Vehicle	Promotes code reusability and DRY principle
Polymorphism	Overridden calculateFee() methods	Runtime method binding based on object type
Encapsulation	Protected attributes and methods	Data protection and access control
Exception Handling	ParkingException custom exception	Robust error management and recovery
Packages	parking/ package organization	Logical code organization and namespacing
Constructors	Parameterized constructors for initialization	Flexible object creation
Access Modifiers	public, protected, private usage	Controlled access to class members

13. System Workflow

13.1 Use Case: Park a Vehicle

1. User selects vehicle type from menu (Car/Bike/PremiumCar)
2. Enters unique vehicle ID (e.g., DL-01-AB-1234)
3. Enters parking duration in hours
4. System validates inputs and creates appropriate vehicle object
5. System searches array for first null slot
6. If slot available: Stores vehicle, displays confirmation with slot number
7. If no slots available: Displays ParkingException error message
8. Returns to main menu

13.2 Use Case: Checkout a Vehicle

1. User selects checkout option from menu
2. Enters vehicle ID to checkout
3. System searches entire array for matching vehicle
4. If found:
    - Calculates parking fee using vehicle's calculateFee() method
    - Displays receipt with vehicle details and charges
    - Clears slot (sets to null)
5. If not found: Displays appropriate error message
6. Returns to main menu

13.3 Use Case: View Parked Vehicles

1. User selects view vehicles option
2. System iterates through entire parking array
3. For each non-null slot, displays:
    - Slot number
    - Vehicle type
    - Vehicle ID
    - Parking duration
4. Displays total occupancy status (X/10 slots occupied)
5. Returns to main menu

14. Installation & Compilation

14.1 Prerequisites

- Java Development Kit (JDK) 8 or higher
- Command-line terminal or IDE (IntelliJ, Eclipse, Visual Studio Code)

14.2 Compilation Steps

```
1. Navigate to project directory
2. Create folder structure: src/parking
3. Place all .java files in src/parking folder
4. Open terminal in project root directory
5. Execute command: javac -d . src/parking/*.java
```

14.3 Execution Steps

```
1. Run command: java parking.Main
2. Follow menu prompts for parking operations
3. Enter vehicle details as requested
4. View confirmations and receipts
5. Continue with next operation or exit
```

15. Usage Instructions

15.1 Main Menu Options

```
===== SMART PARKING SYSTEM =====
1. Park a Vehicle
2. Checkout a Vehicle
3. View Parked Vehicles
4. Exit

Enter your choice: _
```

15.2 Parking a Vehicle

- Select option 1 from main menu
- Choose vehicle type (1=Car, 2=Bike, 3=PremiumCar)
- Enter vehicle ID (unique identifier)
- Enter parking duration (in hours)
- System confirms successful parking with slot number

15.3 Checking Out a Vehicle

- Select option 2 from main menu
- Enter vehicle ID to checkout
- System displays fee calculation and receipt
- Slot becomes available for new parking

15.4 Viewing Occupancy

- Select option 3 from main menu
- System displays all currently parked vehicles with details
- Shows occupancy status (X/10 slots)

16. Error Handling & Edge Cases

16.1 Handled Scenarios

- **Parking Full:** Exception thrown when all 10 slots occupied
- **Invalid Vehicle ID:** Error message when vehicle not found during checkout
- **Invalid Input:** System re-prompts for correct input format
- **Empty Parking Lot:** Gracefully handles display when no vehicles parked
- **Duplicate Parking:** Each vehicle ID can be parked independently

16.2 Exception Types

Exception	Trigger	Message	Recovery
ParkingException	Parking lot full (10/10)	"Error: Parking Full!"	Checkout a vehicle first
InputMismatchException	Invalid input format	Handled by try-catch	Re-prompt user
NullPointerException	Vehicle not found	Caught and displayed	Return to main menu

17. Algorithm Analysis

17.1 Slot Allocation Analysis

Operation	Best Case	Average Case	Worst Case	Space
Park Vehicle	O(1)	O(5)	O(10)	O(1)
Checkout	O(n)	O(n/2)	O(n)	O(1)
View All	O(n)	O(n)	O(n)	O(1)

Where n = 10 (parking slots)

17.2 Memory Analysis

Memory Allocation:

- Vehicle[] array: 10 × reference size ≈ 80 bytes (on 64-bit JVM)
- Each vehicle object: id (4 bytes) + hours (4 bytes) + object header ≈ 24 bytes
- Maximum total: 10 vehicles × 24 bytes ≈ 240 bytes
- Total system memory: < 1 KB

18. Results

```
PS D:\Java\VITYARTHI Project\Automated-Smart-Parking-Simulation> java main
--- Automated Smart Parking System ---

1. Park Car (Rs.20/hr)
2. Park Bike (Rs.15/hr)
3. Park Premium Car (Rs.40/hr)
4. Checkout Vehicle
5. View All Parked
6. Exit
Select Option: 1
Enter Vehicle ID: 101
Enter Duration (Hours): 3
Success: Vehicle parked at Slot 1

1. Park Car (Rs.20/hr)
2. Park Bike (Rs.15/hr)
3. Park Premium Car (Rs.40/hr)
4. Checkout Vehicle
5. View All Parked
6. Exit
Select Option: 2
Enter Vehicle ID: 102
Enter Duration (Hours): 6
Success: Vehicle parked at Slot 2

1. Park Car (Rs.20/hr)
2. Park Bike (Rs.15/hr)
3. Park Premium Car (Rs.40/hr)
4. Checkout Vehicle
5. View All Parked
6. Exit
Select Option: 5

--- Current Parking Status ---
Slot 1: ID: 101 | Hours: 3
Slot 2: ID: 102 | Hours: 6
```

```
1. Park Car (Rs.20/hr)
2. Park Bike (Rs.15/hr)
3. Park Premium Car (Rs.40/hr)
4. Checkout Vehicle
5. View All Parked
6. Exit
Select Option: 4
Enter Vehicle ID to Checkout: 101

--- Receipt ---
ID: 101 | Hours: 3
Total Fee: Rs. 60.0
Status: Paid & Checked Out

1. Park Car (Rs.20/hr)
2. Park Bike (Rs.15/hr)
3. Park Premium Car (Rs.40/hr)
4. Checkout Vehicle
5. View All Parked
6. Exit
Select Option: 6
System Shutting Down...
```

19. Future Enhancements

19.1 System Expansion

- Implement multi-level parking (Ground, Level 1, Level 2, etc.)
- Add vehicle size categories (Small, Medium, Large)
- Support seasonal and hourly rate variations
- Implement advance reservations system
- Add membership/VIP card support

19.2 Data Management

- Implement database integration (MySQL, PostgreSQL)
- File-based transaction logging and reporting
- Audit trail for all parking operations
- Monthly and annual revenue reports
- Vehicle occupancy analytics

19.3 Security Features

- PIN-based operator authentication
- Transaction encryption and security
- Automated backup and recovery mechanisms
-

Real-time monitoring and alerts

- Suspicious activity detection

19.4 User Interface Improvements

- Graphical User Interface (GUI) using Swing/JavaFX
- Web-based interface (Spring Boot + React/Vue.js)
- Mobile application support (Android/iOS)
- QR code generation for digital receipts
- Real-time SMS/Email notifications

19.5 Business Intelligence

- Demand forecasting and peak hour analysis
- Revenue optimization through dynamic pricing
- Customer behavior analytics
- Parking utilization heat maps
- Predictive maintenance alerts

20. Learning Outcomes

Upon successful implementation of this project, students will demonstrate competency in:

1. **Array Operations:** Searching, insertion, null detection, boundary checking
2. **OOP Principles:** Inheritance, polymorphism, abstraction, encapsulation concepts
3. **Exception Handling:** Creating, throwing, and catching custom exceptions
4. **Package Architecture:** Organizing code into logical, maintainable modules
5. **Algorithm Design:** Linear search, allocation strategies, complexity analysis
6. **System Design:** Real-world problem modeling and solution implementation
7. **Java Fundamentals:** Classes, methods, constructors, access modifiers, packages
8. **Software Engineering:** Code documentation, version control, project management
9. **Object Relationships:** Composition, inheritance hierarchies, method overriding
10. **Real-world Application:** Practical problem solving using computer science concepts

21. Conclusion

The Automated Smart Parking System effectively demonstrates how core computer science concepts can solve real-world problems in urban infrastructure management. By leveraging simple data structures (arrays), OOP principles, and exception handling, this project creates a functional parking management solution suitable for practical deployment.

The project is well-suited for students at Units 1–3 level, providing hands-on experience with essential programming concepts while maintaining code simplicity and clarity. The modular design allows for

easy expansion and enhancement, making it an excellent foundation for more complex parking management systems in future iterations.

This project successfully bridges the gap between theoretical programming concepts and practical application, preparing students for real-world software development challenges. The implementation demonstrates industry-standard practices in code organization, error handling, and system architecture design.

Key achievements of this project include:

- **Practical Implementation:** Real-world parking system simulation
- **OOP Mastery:** Comprehensive use of inheritance, polymorphism, and encapsulation
- **Problem Solving:** Effective algorithm design and optimization
- **Error Management:** Robust exception handling and edge case management
- **Code Quality:** Clean, well-documented, maintainable codebase
- **Scalability:** Extensible architecture supporting future enhancements

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