Multiagent System for Campus Virtual Tour

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This project implements a sophisticated campus tour simulation using ROS2 (Robot Operating System 2) and Python. The simulation models a campus environment with multiple buildings, hosts, and visitors, managed by different types of agents.The system encompasses a network of intelligent agents capable of dynamic interaction, ensuring efficient and smooth navigation.

1 System Architecture

The system architecture in Fig 1 represents a comprehensive campus simulation environment, driven by various agents and modules to facilitate interaction, pathfinding, and real-time performance monitoring. The architecture is built upon ROS 2 (Robot Operating System) communication for efficient interaction between components. Below is a detailed explanation of each block in the system and their relationships.

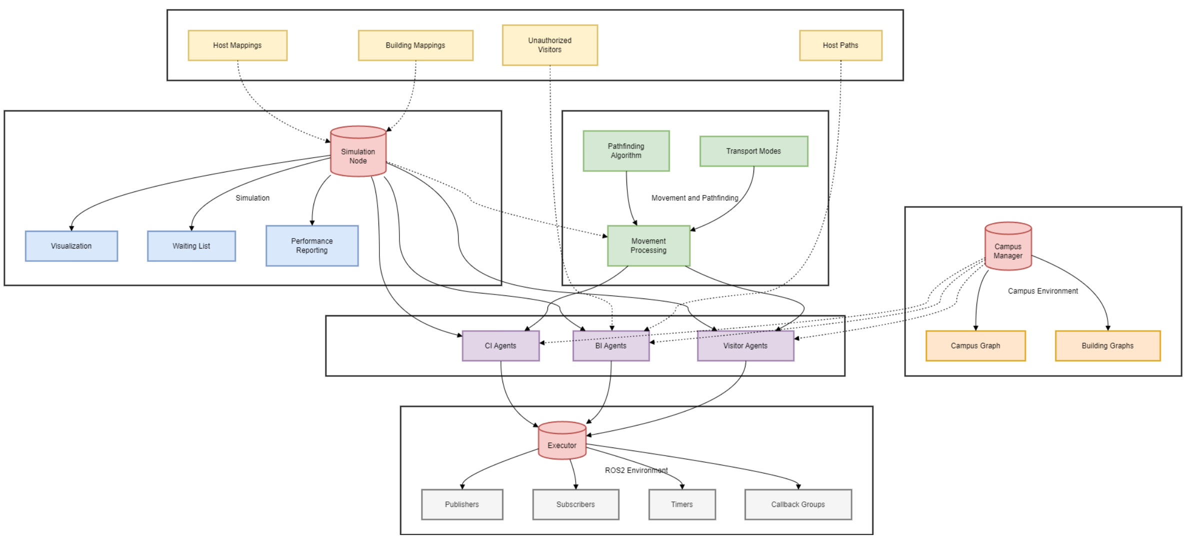

Figure 1: System Architecture

1.1 Campus Manager

The Campus Manager is responsible for overseeing the overall campus environment. It manages both the Campus Graph and the Building Graphs. The manager uses host paths to map predefined routes for hosts. These graphs and paths are used to control and coordinate agents movements within the campus environment.

1.1.1 Campus Graph & Building Graphs

The Campus Graph represents the overall campus layout, with buildings as nodes and the paths between them as edges. It works alongside Building Graphs, which detail the internal structure of individual buildings (rooms and corridors). These graphs are central to the system, feeding data to components like Movement Processing and the Pathfinding Algorithm to help agents navigate the campus.

1.2 Simulation Node

The Simulation Node serves as the core engine of the system. It coordinates key activities like visualization, performance reporting, and the management of agent interactions. It receives data inputs such as Host Mappings (relationships between hosts and buildings), Building Mappings (mapping hosts to building spaces), and updates about Unauthorized Visitors. Outputs include real-time Visualization of agent movements, Performance Reporting, and a Waiting List for managing agents or visitors awaiting permission to proceed.

1.3 Pathfinding Algorithm

The Pathfinding Algorithm is responsible for calculating optimal paths for agents to travel across the campus. It uses the data from the Campus Graph and Building Graphs to compute efficient routes for agents, depending on their Transport Modes (e.g., walking, cycling, or driving). The results are passed to the Movement Processing module, where actual agent movements are simulated.

1.4 Transport Modes

Transport Modes define the possible movement options for agents, such as `VEHICLE`, `CYCLE`, or `WALK`. This allows for realistic simulation of movement across the campus. These modes are used by both the Pathfinding Algorithm and Movement Processing to differentiate between agent speeds and route availability based on the type of transportation being simulated.

1.5 Movement Processing

The Movement Processing module controls the real-time movement of agents on campus. It takes the routes calculated by the Pathfinding Algorithm and processes the agent's movements accordingly. Depending on the transportation type (walking, cycling, etc.), the module updates the simulation with the agent's movement status, ensuring smooth navigation across the environment.

1.6 CI Agents (Campus Incharge Agents)

The Campus Incharge (CI) Agents are responsible for monitoring the general campus activities. They receive inputs from the Campus Manager (campus layout and host data) and the Pathfinding Algorithm (routes for movement). These agents work collaboratively with Building Incharge Agents (BI) and Visitor Agents to manage activities across the campus.

1.7 BI Agents (Building Incharge Agents)

The Building Incharge (BI) Agents oversee the activities and operations within individual buildings. Like the CI Agents, they receive building layout and pathfinding data, which allows them to monitor and control the internal movement of hosts and visitors in their assigned buildings.

1.8 Visitor Agents

Visitor Agents represent entities moving through the campus, these agents utilize the Pathfinding Algorithm to navigate between buildings and through indoor spaces based on Building Graphs. They also interact with CI Agents and BI Agents to follow campus protocols and gain access to different areas. All the agents logical flow diagrams are shown in Fig 2.

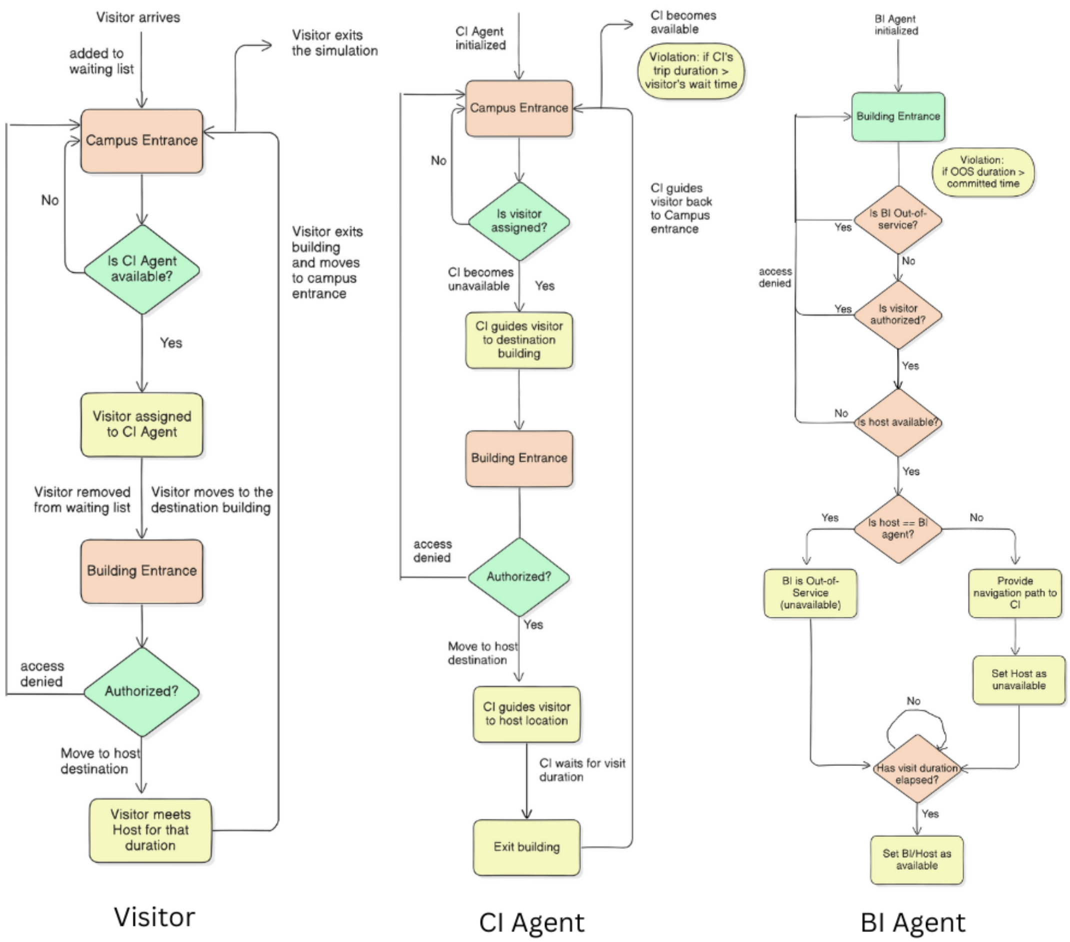

Figure 2: Agents in Campus Virtual Tour

1.9 Executor

The Executor manages the ROS 2 communication environment, processing multiple callbacks and coordinating the execution of tasks in a multi-threaded manner. It ensures that agent movements, pathfinding updates, and interaction between modules occur seamlessly. It works closely with the ROS 2 Environment, which consists of publishers, subscribers, timers, and callback groups to facilitate asynchronous communication.

1.10 ROS 2 Environment

The ROS 2 Environment underpins the system's communication infrastructure, enabling modules to communicate via Publishers, Subscribers, Timers, and Callback Groups. These entities allow the simulation to receive updates on agent movements, broadcast important system updates, and manage timed events in real-time.

1.11 Host Mappings & Building Mappings

Host Mappings and Building Mappings form a critical part of the system by linking hosts to their respective buildings and internal spaces. This information is utilized by the Simulation Node to accurately simulate the placement and movement of agents across the campus. It also helps in determining where visitors or agents are permitted to go.

1.12 Unauthorized Visitors

If a visitor lacks permission, the system sends them back to the campus entrance. This information is shared with the Pathfinding Algorithm and Simulation Node, ensuring security protocols are enforced within the campus.

2 Agent Communication Protocols

The agent communication protocol 3 consists of multiple agents, including the Visitor Agent, Campus Incharge (CI) Agent, Building Incharge (BI) Agent, and the Simulation Node. These agents interact asynchronously to manage visitor navigation, access control, and violation reporting within the campus. The protocol ensures smooth visitor movement, building access, and error management in case of disruptions.

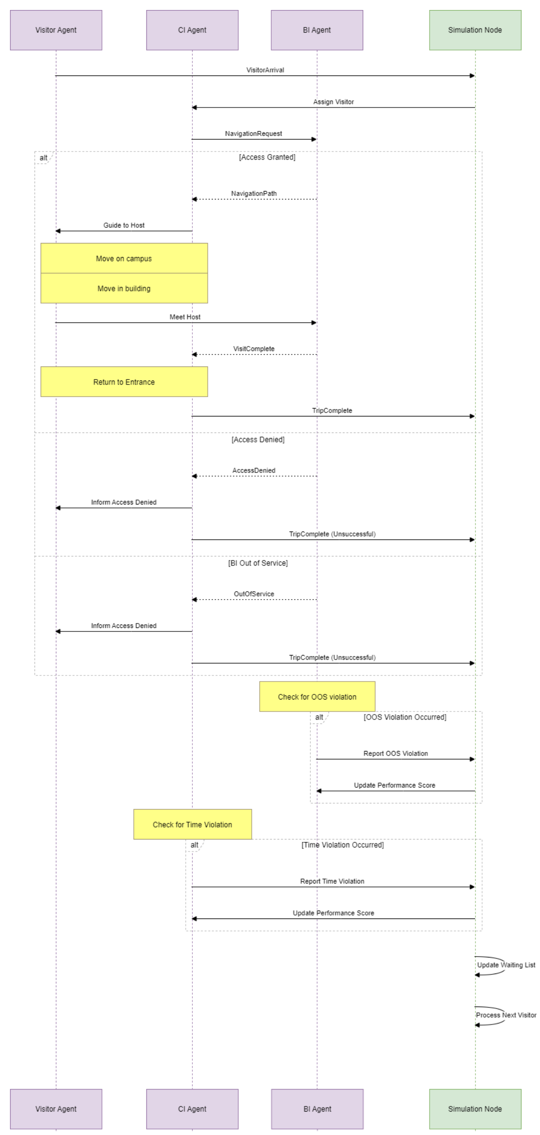

Figure 3: Agent Communication Protocols

2.1 Visitor Arrival

The process begins with the Visitor Agent signaling its arrival by sending a `VisitorArrival` message to the CI Agent. The CI Agent responds by assigning the visitor to the appropriate BI Agent responsible for the building the visitor wishes to enter.

2.2 Navigation Request

After a BI Agent is assigned, the Visitor Agent sends a `NavigationRequest` to the CI Agent to request access and obtain a campus navigation path. The CI Agent verifies the visitor's access permissions,providing the necessary navigation path via the `NavigationPath` message. If access is denied, the system follows the Access Denied procedure, which is described later.

2.3 Visitor Movement

Once access is granted and the navigation path is provided, the Visitor Agent begins movement across the campus. The Visitor Agent traverses the campus and navigates through the assigned building to meet their host, completing the visit as directed by the CI Agent.

2.4 Access Denied Procedure

If access is denied during the initial navigation request, the CI Agent sends an `AccessDenied` message to the Visitor Agent and then take the visitor back to campus entrance.

2.5 Building Incharge (BI) Out of Service

If the assigned BI Agent is out of service, the Visitor Agent receives an `OutOfService` message when attempting to interact with the BI Agent. CI Agent sends an `AccessDenied` message to the Visitor Agent and then take the visitor back to campus entrance.

2.6 Violations Monitoring and Reporting

The system is designed to monitor and report two types of violations: OOS (Out of Service) violations and time violations:

- **OOS Violation**: If a BI Agent goes out of service while a visit is in progress, the CI Agent detects this condition. If an OOS violation is found, Simulation Node is notified, which updates the performance score for the affected agents and system components.
- **Time Violation**: The CI Agent also monitors whether the visitor completes their trip within the allotted time. If the CI Agent exceeds the permitted time, a notification is sent to the Simulation Node, updating the performance score and prompting the system to handle the next visitor in the queue.

2.7 Performance Reporting and Queue Management

After detecting and reporting any violations, the Simulation Node updates the corresponding performance scores for the agents involved. Once performance is recorded, the Simulation Node processes the next visitor from the waiting list. This ensures continuous flow and efficiency, preventing delays in visitor interactions and maintaining the overall system's functionality.

3 Simulation Setup

The simulation setup represents a multi-agent system (MAS) facilitating campus navigation for visitors. The agents involved include Campus Incharge (CI), Building Incharge (BI), and Visitor agents.The block diagram of the entire simulation setup is shown in Fig. 4.

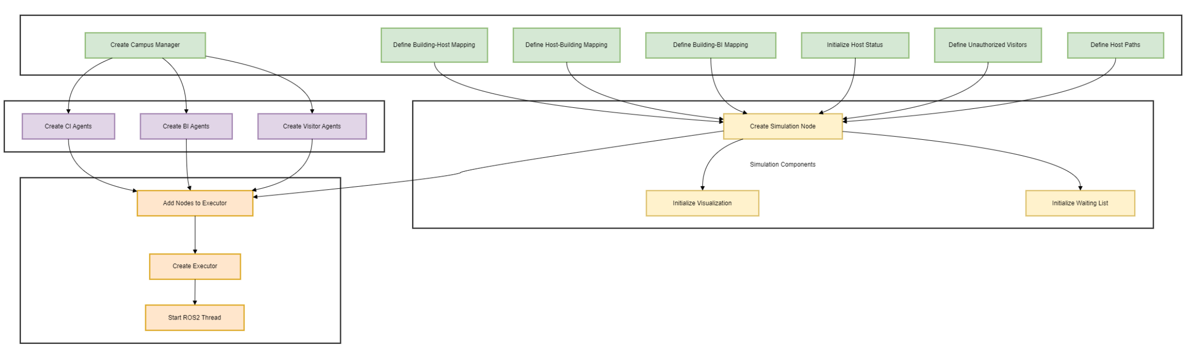

Figure 4: Simulation Setup

3.1 Key system components

- Campus Manager: Responsible for creating and managing the entire simulation environment, including agents and building-host mappings. Create Agents:
- Create Agents
  - CI Agents: Responsible for campus-wide navigation and managing visitors.
  - BI Agents: Manage specific buildings and assist visitors within the building.
  - Visitor Agents: Represent visitors requesting navigation and meeting hosts.
- Mappings and Paths

  - Building-Host mapping defines the allocation of hosts to buildings.
  - Host-Building mapping ensures that each host is associated with specific rooms inside the buildings.
  - Building-BI Mapping assigns BI agents to buildings for managing internal navigation.
  - Unauthorized Visitors simulates scenarios where unauthorized visitors attempt to access restricted areas.
  - Host Paths defines paths for hosts that visitors will be guided to.

- Simulation Nodes: These nodes are responsible for executing the agents' behaviors and interactions. Each agent runs as a ROS2 node that communicates with others through topics. These nodes interact and simulate navigation, using ROS2 communication protocols for message passing between agents. Key responsibilities of the simulation node include managing the communication between agents, executing navigation paths, and handling visitor requests.

- Initialize Visualization: Once agents are created and their responsibilities are defined, the visualization of the campus and building structures is initialized. This helps track the movements of agents in real-time, offering insights into how visitors and agents navigate the environment.

- Initialize Waiting List: The waiting list feature is initialized to simulate scenarios where multiple visitors need to be managed by the same CI agent.

- Add Nodes to Executor: The created CI, BI, and Visitor agents are added to the ROS2 Executor, which is responsible for managing node execution. The executor ensures that agents interact asynchronously, simulating real-world communication and navigation delays.

- Create Executor: The Executor is responsible for coordinating all the nodes (agents) in the simulation, handling the timing and execution of different agent tasks. It runs the simulation by processing messages from the ROS2 topics and ensuring the agents behave as intended.

- Start ROS2 Thread: A separate thread is created to manage the ROS2-based communication. This ensures that the simulation runs in parallel with agents processing messages and interacting asynchronously.

4 Simulation scenarios

The simulation scenario 5 focuses on a multi-agent system designed to facilitate campus navigation, enabling visitors to interact with Campus Incharge (CI) and Building Incharge (BI) agents in a systematic and structured manner. This system is primarily built to ensure that visitors can reach their intended destinations efficiently while also maintaining control over building access and agent availability. By utilizing a combination of CI and BI agents, the simulation ensures that every visitor is guided from arrival to departure, with agent interactions controlling their movement and access permissions across the campus.

4.1 Visitor Arrival

The process begins when a visitor arrives at the campus. This is the starting point of the scenario, and it marks the initialization of the agent-based interaction. Upon arrival, the visitor seeks assistance to navigate through the campus, triggering the sequence of checks and interactions with the system.

4.2 Check for CI Agent Availability

Once the visitor arrives, the system checks whether a Campus Incharge (CI) agent is available. CI agents serve as the first point of contact, responsible for guiding visitors to their designated destinations. If a CI agent is available, they are assigned to the visitor. This assignment process initiates the agent's role of assisting the visitor throughout the campus. However, if no CI agent is available at the moment, the visitor is placed on a waiting list. This waiting list acts as a queue, ensuring that visitors are handled in a systematic manner without any being ignored. If placed in the queue, the next visitor in line is processed as soon as an agent becomes available.

4.3 Assign CI Agent and Set Movement Mode

For visitors who have been assigned a CI agent, the next action involves setting the movement mode. Movement mode refers to the method or route through which the visitor will be guided towards their destination (the assigned building). This stage involves communication between the visitor and the CI agent, where the agent determines the most appropriate path or mode of transportation to lead the visitor. The efficiency of this stage depends on the agent's ability to optimize the route and provide smooth movement towards the building.

4.4 Move to Building

Once the movement mode is set, the visitor, under the guidance of the CI agent, proceeds to move toward the assigned building. This step marks the physical movement in the system, where the CI agent navigates the visitor through the campus towards the intended location.

4.5 Building Interaction and Check for BI Agent Availability

Upon reaching the building, the system now checks if a Building Incharge (BI) agent is available. BI agents are responsible for handling visitor entry and permissions within the building. The availability of a BI agent is crucial for the visitor to continue the interaction. If a BI agent is available, they will facilitate the next steps of the visit, such as allowing access to the building. However, if the BI agent is unavailable, the visitor is denied access. This denial event is a critical decision point in the system, as it halts the visitor's progress and redirects the interaction to record the event.

4.6 Access Denied or Granted

At this juncture, the BI agent can either grant or deny access to the building, depending on the rules or restrictions in place. If access is denied, it is immediately logged, and the system records the reason for denial. Access denial is a key part of the system, ensuring that unauthorized or unexpected visits are prevented. On the other hand, if the BI agent grants access, the visitor and CI agent is allowed to enter the building and proceed with their visit.

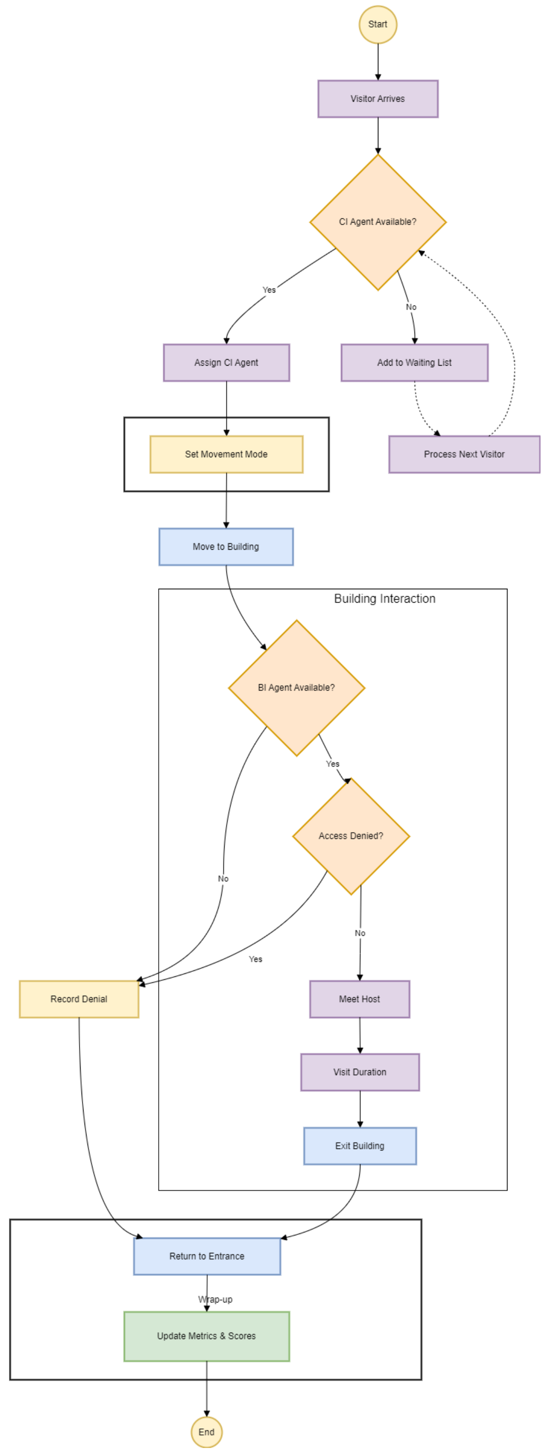

Figure 5: Simulation scenarios

4.7 Meet Host and Track Visit Duration

Once the visitor gains access to the building, they proceed to meet their designated host. The meeting represents the core purpose of the visit. During this period, the visit duration is tracked. Tracking the visit duration is important for logging metrics on how long the visitor spends in the building and with the host.

4.8 Exit Building and Return to Entrance

After the visit concludes, the visitor exits the building. This marks the end of their primary objective. Upon exiting the building, the CI agent guides the visitor back to the campus entrance. Returning to the entrance ensures that the visitor is safely navigated out of the campus, completing the loop of interaction between the CI agent and the visitor.

4.9 Update Metrics and Scores

Once the visitor has exited the building and returned to the entrance, the system updates its metrics and scores. These metrics include data such as visit duration, the performance of CI and BI agents, any access denial events, and the overall time taken for the visitor to complete their journey. The scores can be used for evaluating agent efficiency and ensuring that they are meeting expected performance criteria.

5 Performance Analysis and Interpretation of Results

The campus virtual tour simulation 6 was conducted to analyze the performance of Campus Incharge (CI) Agents, Visitor (VI) Agents, and Building Incharge (BI) Agents under two different transport modes: vehicle and cycle.

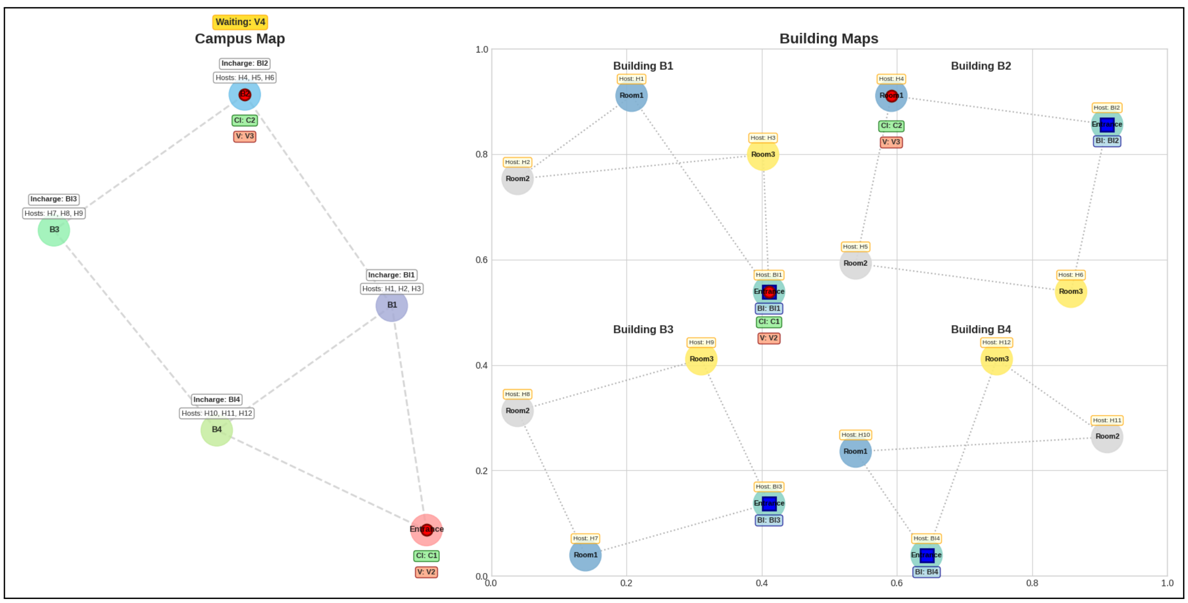

Figure 6: Agent Interaction and Navigation Across Campus and Buildings

5.1 Visitor Movements and Time Efficiency

The time taken by agents and visitors to move between locations is a critical aspect of the simulation. In the vehicle mode, CI Agents and Visitors completed movements between buildings within 2 time units. For example, CI Agent C2 and Visitor V1 moved from the entrance to Building B1 in just 2 time units using a vehicle. This rapid movement led to faster interactions and reduced waiting times for visitors.

In contrast, the cycle mode exhibited slower movements, with time units typically ranging from 4 to 6 for similar distances. This increase in travel time likely led to delays in visitor-agent interactions, prolonging the overall experience for visitors and reducing the efficiency of the system.

5.2 Violations and Adherence to Commitments

A key performance metric is the number of violations logged during the simulation. This is depicted in Fig 7. In the vehicle mode, both CI Agent C1 and C2 exhibited zero violations and incurred no violation time. This means that all visitor-agent interactions adhered to the committed schedules, with no delays. Moreover, the BI Agents responsible for managing building access also showed no Out-of-Service (OOS) violations.

In the cycle mode, the slower movements likely led to an increase in violations. The delays in CI Agents reaching their destinations on time would have impacted their ability to meet visitors within the committed timeframes, resulting in higher violation counts and increased violation time.

The comparison between the two modes as shown in Table 1 demonstrates the direct impact of transport efficiency on violations. The absence of violations in vehicle mode reflects better synchronization and adherence to the planned schedule, a key factor in ensuring a seamless visitor experience.

```
[INFO] [1727710019.736885272] [ci_agentC1]: CI Agent C1 moved from Room1 to Room2 in building B1
[INFO] [1727710021.740004605] [vi_agentV5]: Visitor V5 moved from Room1 to Room2 in building B1
[INFO] [1727710023.747234087] [ci_agentC1]: Visitor V5 meeting host H2 in building B1. Host Unavailable for 29 seconds
[INFO] [1727710025.760241165] [ci_agentC3]: CI Agent C3 moved from Entrance to Room1 in building B2
[INFO] [1727710027.763626236] [vi_agentV4]: Visitor V4 moved from Entrance to Room1 in building B2
[INFO] [1727710029.766898012] [ci_agentC3]: CI Agent C3 moved from Room1 to Room2 in building B2
[INFO] [1727710031.769953813] [vi_agentV4]: Visitor V4 moved from Room1 to Room2 in building B2
[INFO] [1727710033.772887582] [ci_agentC3]: CI Agent C3 moved from Room2 to Room3 in building B2
[INFO] [1727710035.775874558] [vi_agentV4]: Visitor V4 moved from Room2 to Room3 in building B2
[INFO] [1727710037.778783534] [ci_agentC3]: Visitor V4 meeting host H6 in building B2. Host Unavailable for 11 seconds
[INFO] [1727710041.737275354] [bi_agentBI1]: BI Agent BI1 is now back in service
[WARN] [1727710041.737790319] [bi_agentBI1]: BI Agent BI1 violated OOS duration. Expected: 20, Actual: 25.00
[INFO] [1727710045.803858309] [vi_agentV6]: Visitor V6 and CI Agent C2 have left the building
[INFO] [1727710045.808588343] [ci_agentC2]: CI Agent C2 moved from B1 to Entrance using cycle in 10 time units
[INFO] [1727710048.761750578] [bi_agentBI2]: Host H6 is now available again.
[INFO] [1727710048.790909619] [ci_agentC3]: CI Agent C3 moved from Room3 to Room2 in building B2
[INFO] [1727710050.794047147] [vi_agentV4]: Visitor V4 moved from Room3 to Room2 in building B2
[INFO] [1727710052.730370340] [bi_agentBI1]: Host H2 is now available again.
[INFO] [1727710052.776958930] [ci_agentC1]: CI Agent C1 moved from Room2 to Room1 in building B1
[INFO] [1727710053.798139143] [ci_agentC3]: CI Agent C3 moved from Room2 to Room1 in building B2
[INFO] [1727710054.796267632] [vi_agentV5]: Visitor V5 moved from Room2 to Room1 in building B1
[INFO] [1727710055.801056745] [vi_agentV4]: Visitor V4 moved from Room2 to Room1 in building B2
[INFO] [1727710055.816634904] [vi_agentV6]: Visitor V6 moved from B1 to Entrance using cycle in 10 time units
```

Figure 7: Communication Logs between Agents

5.3 CI Agent and BI Agent Performance Scores and Environmental Impact

The performance of CI and BI Agents is strongly influenced by the transport mode—vehicle, cycle, or walk—which impacts both the number of visitors entertained and the overall efficiency of the system.

5.3.1 Environment Variables

The simulation parameters were set to 20 seconds for committed time for out-of-service responses and a visitor wait time to 100 seconds. Vehicle mode allowed agents to stay within these limits, while slower modes like cycle and walk increased violation penalties, reducing performance scores.

$$\text{BI Agent Score} = (\text{CI Agents Guided} \times 10) - (\text{OOS Violations} \times 5)$$

$$\text{CI Agent Score} = (\text{Visitors Entertained} \times 10) - (\text{Violation Count} \times 5)$$

Table 1: Performance Comparison: Cycle vs Vehicle Mode (Actual Data)

Agent	Metric	Cycle Mode			Vehicle Mode		
		Value	Violations	Score	Value	Violations	Score
BI	BI1	3	1	25.00	2	0	20.00
	BI2	2	0	20.00	1	0	10.00
	BI3	1	0	10.00	0	0	0.00
	BI4	0	0	0.00	1	0	10.00
CI	C1	2	0	20.00	2	0	20.00
	C2	2	1	15.00	2	0	20.00
	C3	2	1	15.00	-	-	-

5.3.2 Vehicle Mode Performance

In vehicle mode, CI Agents C1 and C2 achieved perfect scores, each entertaining 2 visitors without any violations, resulting in a score of 20. This reflects their ability to handle visitors efficiently and stay on schedule. BI Agents B1, B2, and B4 also achieved high scores of 10 or 20, depending on the number of CI Agents they guided, with no Out-of-Service (OOS) violations.

5.3.3 Cycle Mode Performance

In cycle mode, the slower movement (5x slower than vehicles) reduced the number of visitors each CI Agent could entertain, leading to lower scores. Higher violation counts and delays further impacted performance negatively.

5.3.4 Walk Mode Impact

The walk mode (10x slower than vehicles) would exacerbate these inefficiencies, significantly reducing the number of visitors handled and increasing the likelihood of violations.