Emergency Response: A Multi-Agent System

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Contents

1 Introduction

This report presents the final implementation and results of our multi-agent system (MAS) for emergency response coordination. Building upon our previous designs from Tasks 1 and 2, we have developed a complete, functional system that demonstrates the effectiveness of agent-based approaches in managing complex emergency scenarios.

The system is implemented using CrewAI, a framework that enables the creation and coordination of specialized agent crews. Each crew is designed with specific responsibilities and operates through well-defined processes, ensuring efficient handling of emergency situations. The implementation includes:

- **Emergency Services Crew:** Handles initial emergency assessment and coordination
- **Firefighter Agent Crew:** Manages firefighting resources and operations
- **Medical Services Crew:** Coordinates medical response and hospital resources
- **Public Communication Crew:** Manages public information and communication

Report Structure:

- Section **??** details the design and implementation of each crew, including their process definitions and data models
- Section **??** explains the interaction mechanisms between crews and the overall system flow
- Section **??** presents the results of system testing and validation
- Section **??** concludes with insights and potential future improvements

The implementation builds upon our previous design while introducing several refinements based on practical considerations and testing results. These modifications are documented and justified throughout the report. The complete source code, along with setup instructions and required input files, is provided in the accompanying project repository.

2 Crew Design and Implementation

2.1 General Design Principles

For each crew in our system, a corresponding Python file is used to instantiate the configuration. These configurations are structured based on CrewAI's YAML schema recommendations for crews[1], tasks[2], and agents[3].

These files were generated using CrewAI CLI, a universal tool for creating configurations. The following command demonstrates how to initialize a new crew configuration:
`crewai create crew my_new_crew`[4].

The Python file is structured to include the following key elements:

- **Imports**: Required modules, including CrewAI components such as 'Agent', 'Task', 'Crew', and 'Process'.
- **Tool Instantiation**: Creation of tools for task-specific functionalities.
- **Agent Configuration**: Agents are defined with specific properties, including their roles, goals, delegation capabilities, verbosity, and parameters for interacting with the language model (e.g., temperature settings).
- **Task Configuration**: Tasks are defined with descriptions, expected outputs, dependencies, and execution modes. These configurations ensure tasks are properly structured and validated. Last task of each crew includes `output_pydantic` to ensure that the dictionaries returned to the crew are consistent.
- **Schema Augmentation**: Pydantic schemas can be added to the expected output of tasks using utility functions such as `add_schema_to_task_config`. This function modifies the task configuration by appending the schema JSON to the expected output property, ensuring that the LLM can take it into account.
- **Crew Composition**: The crew integrates agents and tasks into a defined process, executed sequentially, to accomplish its objectives.

The YAML configurations for agents and tasks specify several general properties:

[1]https://docs.crewai.com/concepts/crews#yaml-configuration-recommended
[2]https://docs.crewai.com/concepts/tasks#yaml-configuration-recommended
[3]https://docs.crewai.com/concepts/agents#yaml-configuration-recommended
[4]https://docs.crewai.com/concepts/cli#1-create

Agent Configuration: Agents are defined using YAML properties to specify:

- **Role:** The role the agent plays within the crew.
- **Goal:** The overarching objective or mission assigned to the agent.
- **Delegation Capabilities:** Whether the agent is allowed to delegate tasks.
- **Language Model Parameters:** Specific settings such as the model used and the temperature to control the randomness of the output.

Task Configuration: Tasks are defined in YAML with properties that include:

- **Description:** A clear explanation of the purpose and workflow of the task.
- **Expected Output:** The structure and format of the task output, often validated against a schema.
- **Dependencies:** Other tasks that provide context for the task.
- **Execution Mode:** Specifies whether the task is executed synchronously or asynchronously (e.g., 'async_execution: true').

This modular and schema-driven approach ensures flexibility, reusability, and validation throughout the configuration process.

A design overview of the system.

2.2 Tools

In this section, we describe the various tools developed for the Emergency Planner system. These tools are designed to facilitate different aspects of emergency management, including calculating route distances and managing database entries related to hospitals and incidents. Each tool is implemented with specific functionalities to address different requirements in emergency scenarios.

2.2.1 Route Distance Tool

Purpose The Route Distance Tool calculates the driving route distance between an origin and a destination based on their coordinates. This is essential for determining the quickest routes for emergency response teams.

Implementation

- **Input:** The tool requires the x and y coordinates of both the origin and destination locations.
- **Execution:** The city map graph is loaded from a GraphML file, and the shortest path is calculated using the travel time as the weight. The total distance is then computed.
- **Output:** The tool returns the total driving distance in kilometers.

The Route Distance Tool is a critical component to bring the Emergency Planner system closer to the real world. It gives the agents access to accurate geographical information, enabling them to make informed decisions about resource allocation and response times.

2.2.2 Database Management Tools

Purpose The Database Management Tools include the Hospital Reader, Hospital Updater, and Incident Retrieval tools. These tools manage and update the database entries related to hospitals and incidents, ensuring that the information is current and accurate.

Implementation

- **Hospital Reader Tool:**
  - **Input:** No input parameters are required for this tool.
  - **Execution:** The tool connects to the SQLite database and executes a query to fetch all hospital records.
  - **Output:** The tool returns a list of hospitals, including their IDs, locations, and available resources.
- **Hospital Updater Tool:**

  - **Input:** The tool requires the hospital ID, number of beds reserved, number of ambulances dispatched, and number of paramedics deployed.
  - **Execution:** The tool connects to the SQLite database and executes an update query to modify the hospital's available resources.
  - **Output:** The tool returns a confirmation of the update operation.

- **Incident Retrieval Tool:**
  - **Input:** The tool requires the x and y coordinates of the location, fire severity, fire type, and a summary of the new incident.
  - **Execution:** The tool connects to the SQLite database, retrieves related incidents based on proximity, fire severity, and fire type, and inserts the new incident into the database.
  - **Output:** The tool returns a list of related incidents.

The Database Management Tools are essential for maintaining up-to-date and accurate information on hospitals and incidents. By efficiently managing and updating the database, these tools ensure that the data is consistent throughout crews and runs, thus helping mitigate the hallucinative nature of the LLM-based agents.

2.3 Emergency Services Crew

2.3.1 Design

Purpose The Emergency Services Crew is tasked with the critical responsibility of assessing emergency situations and ensuring the appropriate response teams are dispatched effectively. This foundational role involves processing incoming emergency calls, structure the received information and decide which crews should be notified.

Changes In the initial design, the Emergency Services Crew was intended to utilize two specialized tools:

- *Database Management:* A system for systematically entering and recording emergency details.
- *GPS Mapping:* Software for locating and verifying the caller's position, assessing the scene, and prioritizing the severity of the incident if necessary.

However, after evaluation, it was determined that the core purpose of the crew was receiving the already transcribed incoming calls and deciding which team should receive the information, so both task could be accomplished without these tools. Removing them simplified the workflow, reduced overhead, and maintained focus on the essential tasks of the crew.

Structure and Components The Emergency Services Crew leverages the `CrewBase` framework to orchestrate its agents and tasks in a sequential process, ensuring efficient and orderly operations. The key components of the design are:

- **Agents:**
  - `emergency_call_agent`: Processes incoming emergency calls using a predefined configuration, ensuring the accurate extraction of relevant details.
  - `notification_agent`: Decides which crews need to be notified about the emergency, based on the nature and severity of the situation. This ensures the appropriate response teams are activated in a timely manner.
- **Tasks:**
  - `receive_call`: Captures and processes the details of emergency calls using schemas derived from the `EmergencyDetails` model, ensuring structured and consistent data handling.
  - `notify_other_crews`: Evaluates the information detailed in the `EmergencyDetails` and decides if other crews are needed, utilizing the `CallAssessment` schema to ensure clarity and comprehensiveness in the communication.
- **Crew:** The crew is constructed using the `Crew` class, integrating the agents and tasks into a seamless workflow. This design ensures the efficient progression from receiving an emergency call to notifying the relevant response teams.

The modular design of the Emergency Services Crew enables it to integrate seamlessly with other components of the multi-agent system while maintaining flexibility for updates or extensions.

2.3.2 Implementation

Emergency Call Agent The emergency_call_agent uses the configuration specified in self.agents_config["emergency_call_agent"] to ensure proper handling of call data. It acts as the first step in the emergency response workflow, extracting and structuring information from the calls.

```python
@agent
def emergency_call_agent(self) -> Agent:
    return Agent(config=self.agents_config["emergency_call_agent"])
```

Notification Agent The notification_agent uses the configuration provided in self.agents_config["notification_agent"]. This agent ensures that only the relevant teams are alerted, streamlining the response process and avoiding unnecessary notifications.

```python
@agent
def notification_agent(self) -> Agent:
    return Agent(config=self.agents_config["notification_agent"])
```

Receive Call Task This task processes the incoming call details and structures them according to the schema provided by the EmergencyDetails model. This ensures data consistency and validity.

```python
@task
def receive_call(self) -> Task:
    config = add_schema_to_task_config(
        self.tasks_config["receive_call"], EmergencyDetails.model_json_schema()
    )
    return Task(config=config)
```

Notify Other Crews Task This task uses the processed emergency details to notify other relevant crews. It structures its output using the CallAssessment schema, ensuring clarity in communication.

```python
@task
def notify_other_crews(self) -> Task:
    config = add_schema_to_task_config(
        self.tasks_config["notify_other_crews"], CallAssessment.model_json_schema()
    )
    return Task(config=config, output_pydantic=CallAssessment)
```

Crew Construction The agents and tasks are combined into a sequential process using the Crew class. This design ensures an orderly workflow from receiving calls to notifying the appropriate teams, where the Emergency Services Crew acts as a critical component for initial emergency assessment and coordination across multiple teams within the system.

```python
@crew
def crew(self) -> Crew:
    """Creates the Emergency Services Crew"""
    return Crew(agents=self.agents, tasks=self.tasks, process=Process.sequential)
```

2.4 Firefighter Agent Crew

2.4.1 Design

2.4.2 Implementation

2.5 Medical Services Crew

2.5.1 Design

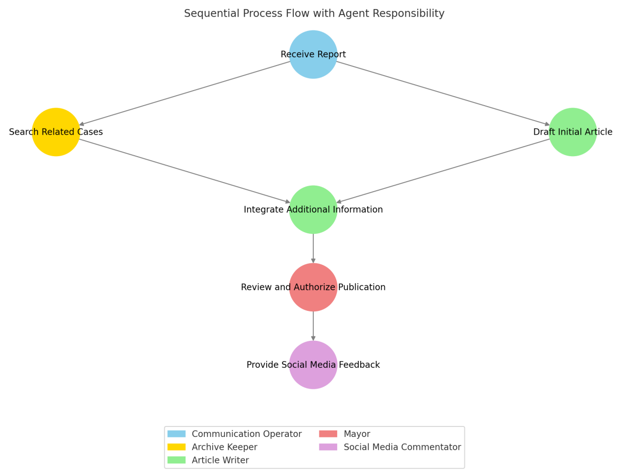
2.5.2 Implementation

2.6 Public Communication Crew

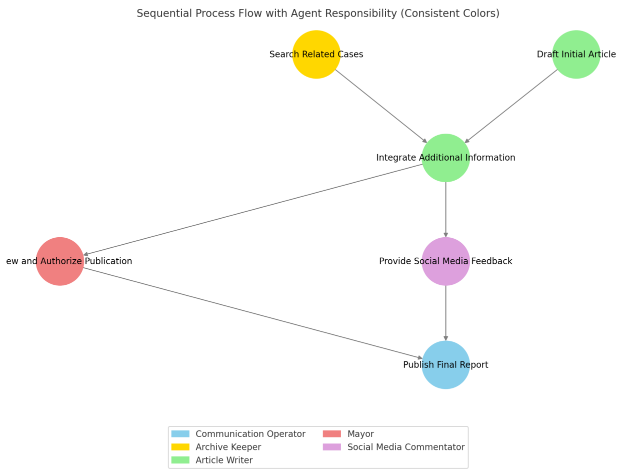
2.6.1 Design

Purpose The Public Communication Crew is tasked with the essential responsibility of ensuring clear, accurate, and timely information dissemination during emergency situations. This includes relaying updates between emergency teams and the public, maintaining historical records for decision-making, and crafting engaging and informative public communications.

Changes Initially, the tasks of the Public Communication Crew (PCC) were planned in a different order and with a distinct execution flow. A comparison of the initial and updated workflows is presented in **Figure ??**. In the updated process, the first task has been removed, and a new task has been added to consolidate all the information into the desired format. Additionally, the steps involving the Mayor's approval and social media commentary are now performed asynchronously.


Sequential Process Flow with Agent Responsibility
Receive Report
Search Related Cases
Draft Initial Article
Integrate Additional Information
Review and Authorize Publication
Provide Social Media Feedback
Communication Operator
Archive Keeper
Article Writer
Mayor
Social Media Commentator

(a) Initial process


Sequential Process Flow with Agent Responsibility (Consistent Colors)
Search Related Cases
Draft Initial Article
Integrate Additional Information
ew and Authorize Publication
Provide Social Media Feedback
Publish Final Report
Communication Operator
Archive Keeper
Article Writer
Mayor
Social Media Commentator

(b) Updated process

Figure 1: Comparison of the Public Communication Crew's execution flow. (a) shows the initial process, while (b) illustrates the updated process with task removal, task addition, and asynchronous steps.

Structure and Components The Public Communication Crew leverages the `CrewBase` framework to orchestrate its agents and tasks, ensuring cohesive and efficient operations. The key components of the design are:

- **Agents:**
  - `communication_operator`: Relays information between the flow and the public communication team, acting as the primary joint to ensure clarity, correctness and structured format.
  - `archive_keeper`: Manages and retrieves historical data related to past incidents, supporting informed decision-making and comparative analysis.
  - `article_writer`: Drafts and refines articles for public dissemination, focusing on clear and engaging communication.
  - `mayor`: Reviews and approves public communications to ensure alignment with city policies and standards.
  - `social_media_commentator`: Provides lighthearted, constructive feedback on emergency responses, engaging the public while maintaining morale.
- **Tasks:**
  - `search_related_cases`: Analyzes historical records to identify similar incidents, highlighting trends and providing context for current events.
  - `draft_initial_article`: Crafts clear and concise initial drafts of public articles based on structured incident data.
  - `integrate_additional_information`: Refines drafts by integrating relevant historical or supplementary details, ensuring the article is ready for publication.
  - `review_and_authorize_publication`: Evaluates the refined draft for quality and policy alignment, providing final approval or feedback.
  - `provide_social_media_feedback`: Offers public-facing commentary that combines wit and constructive critique to enhance communication strategies.

  - `publish_final_communication`: Consolidates all elements into a cohesive, structured and definitive public communication ready for dissemination.

- **Crew:** The crew is constructed using the `Crew` class, which integrates the agents and tasks into a seamless workflow. This design ensures effective progression from incident analysis and draft creation to final public dissemination and archival.

The modular design of the Public Communication Crew enables it to adapt to a wide range of scenarios, ensuring accurate, engaging, and timely communication with both internal teams and the public.

2.6.2 Implementation

Communication Operator Agent The `communication_operator` agent uses the configuration specified in `self.agents_config["communication_operator"]`. This agent facilitates communication between emergency crews and public communication teams, ensuring clarity and accuracy in information flow.

```python
@agent
def communication_operator(self) -> Agent:
    return Agent(config=self.agents_config["communication_operator"])
```

Archive Keeper Agent The `archive_keeper` agent leverages the configuration from `self.agents_config["archive_keeper"]` to manage historical data archives, providing quick access to relevant past incident reports and trends.

```python
@agent
def archive_keeper(self) -> Agent:
    return Agent(config=self.agents_config["archive_keeper"])
```

Article Writer Agent The `article_writer` agent is configured through `self.agents_config["article_writer"]` to draft, refine, and integrate informative articles for public dissemination.

```python
@agent
def article_writer(self) -> Agent:
    return Agent(config=self.agents_config["article_writer"])
```

Mayor Agent The `mayor` agent ensures oversight by reviewing and authorizing final communications, as configured in
`self.agents_config["mayor"]`.

```python
@agent
def mayor(self) -> Agent:
    return Agent(config=self.agents_config["mayor"])
```

Social Media Commentator Agent The `social_media_commentator` agent, configured via `self.agents_config["social_media_commentator"]`, provides witty yet constructive commentary for social media engagement.

```python
@agent
def social_media_commentator(self) -> Agent:
    return Agent(config=self.agents_config["social_media_commentator"])
```

Search Related Cases Task This task utilizes the `RelatedCases` model to analyze historical data and identify trends or reoccurring issues. To force the tool output as the result of an agent's task, the `result_as_answer` parameter is set to `True`, ensuring the tool output is captured and returned as the task result without modifications by the agent.

```python
@task
def search_related_cases(self) -> Task:
    config = add_schema_to_task_config(
        self.tasks_config["search_related_cases"], RelatedCases.model_json_schema()
    )
    return Task(config=config, tools=[IncidentAnalysisTool(result_as_answer=True)])
```

Draft Initial Article Task The task generates an initial draft for public dissemination based on structured incident data.

```python
@task
def draft_initial_article(self) -> Task:
    config = add_schema_to_task_config(
        self.tasks_config["draft_initial_article"], DraftArticle.model_json_schema()
    )
    return Task(config=config)
```

Integrate Additional Information Task This task integrates supplementary historical data and refines the article for professional publication.

```python
@task
def integrate_additional_information(self) -> Task:
    config = add_schema_to_task_config(
        self.tasks_config["integrate_additional_information"],
        IntegratedArticle.model_json_schema(),
    )
    return Task(config=config)
```

Review and Authorize Publication Task The `review_and_authorize_publication` task ensures that communications adhere to policies and meet quality standards.

```python
@task
def review_and_authorize_publication(self) -> Task:
    config = add_schema_to_task_config(
        self.tasks_config["review_and_authorize_publication"],
        ReviewedArticle.model_json_schema(),
    )
    return Task(config=config)
```

Provide Social Media Feedback Task This task evaluates the public-facing content and adds a lighthearted commentary for engagement.

```python
@task
def provide_social_media_feedback(self) -> Task:
    return Task(config=self.tasks_config["provide_social_media_feedback"])
```

Publish Final Communication Task The final task consolidates and publishes the refined article along with mayoral approval and social media feedback.

```python
@task
def publish_final_communication(self) -> Task:
    config = add_schema_to_task_config(
        self.tasks_config["publish_final_communication"],
        PublicCommunicationReport.model_json_schema(),
    )
    return Task(config=config, output_pydantic=PublicCommunicationReport)
```

Crew Construction The Public Communication Crew is constructed as a sequential process to manage tasks and agents cohesively.

```python
@crew
def crew(self) -> Crew:
    """Creates the Public Communication Crew"""
    return Crew(
        agents=self.agents, tasks=self.tasks, process=Process.sequential, verbose=True
    )
```

3 Crew Interactions and Flow

3.1 Interaction Design

3.2 CrewAI Flow

3.3 Justification of Design Choices

4 Testing

4.1 Unit Tests

The unit testing framework for evaluating different agent crews is structured to be modular and scalable, accommodating diverse agents with varying input requirements. Below, we outline the folder structure, testing script, and execution process to ensure a comprehensive and systematic evaluation.

Folder Structure

The directory structure of the project is designed for clarity and organization:

```
project_root/
\
 crews/

 data_models/

 test/
    inputs/
       test_PC.json              # Input JSON for testing Public Communication Crew
    logs/
       test.log                  # Log file for recording test execution
    results/
        PublicCommunicationCrew_output_1.txt  # Results of the first test

 test.py                           # Main script to load, test, and log results
```

Testing Script

The testing script, `test.py`, is the core of the framework and is responsible for loading test cases, executing the corresponding agents, and logging the results. Key features include:

- **Dynamic Crew Mapping**: The script dynamically maps crew names (e.g., `PublicCommunicationCrew`) to their respective Python classes for instantiation.
- **Logging**: Logs are stored in `test/logs/test.log` and include detailed information about each test case, intermediate results, and final outputs.
- **Input Validation**: Inputs are validated using Pydantic models from the `data_models` package to ensure consistency and type safety.
- **Result Storage**: Results of each test are saved in `test/results/` with a structured format for easy review.

Execution Process

The process for running the tests is as follows:

1. **Prepare Input JSON**: Create or modify test cases in `test/inputs/`. Each JSON file should contain an array of test cases with fields specifying the crew to test and the inputs required.
2. **Run the Script**: Execute `test.py` using Python. For example:

   ```
   python test.py
   ```

3. **Review Logs**: Check the log file in `test/logs/test.log` for detailed execution information.
4. **Review Results**: Inspect output files in `test/results/` for the results of each test case.

Advantages

This framework offers the following advantages:

- **Modular Design**: Each agent crew is implemented and tested independently, ensuring modularity and ease of debugging.
- **Type Safety**: Pydantic models enforce input validation, reducing runtime errors and ensuring consistent data structure.
- **Scalability**: New agent crews can be added by implementing their logic and updating the crew mapping in `test.py`.
- **Traceability**: Detailed logging captures both intermediate and final outputs, enhancing reproducibility.

This structure ensures a clear, efficient, and scientifically rigorous approach to unit testing multi-agent systems.

4.2 Integration Tests

4.3 Results

5 Conclusion

6 References