Multi-agent Dynamic Interaction in Simulation of Complex Adaptive Systems

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Presenter information

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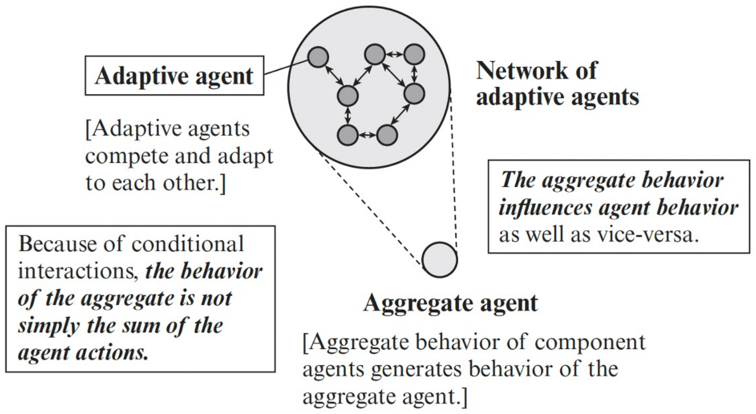
Doctor student at the National University of Defense Technology
Studies under the supervision of Researcher Yiping Yao
Mainly engaged in research directions such as high-performance simulation

Introduction

Research background and current status

Complex adaptive systems (CAS)

CAS are systems composed of autonomous, interacting agents, where the interactions between agents change **frequently** and the structure is **complex**.



Complex adaptive systems

Limitation

As the scale of CAS increases, the **complexity of interactions** between agents increases, traditional multi-agent modeling and simulation methods face the challenge of intuitively describing dynamic interactions. The static interaction structure leads to **long runtime** and **high memory consumption**.

Introduction

Research objectives and methods

Multi-Agent Interaction Graph (MAG)

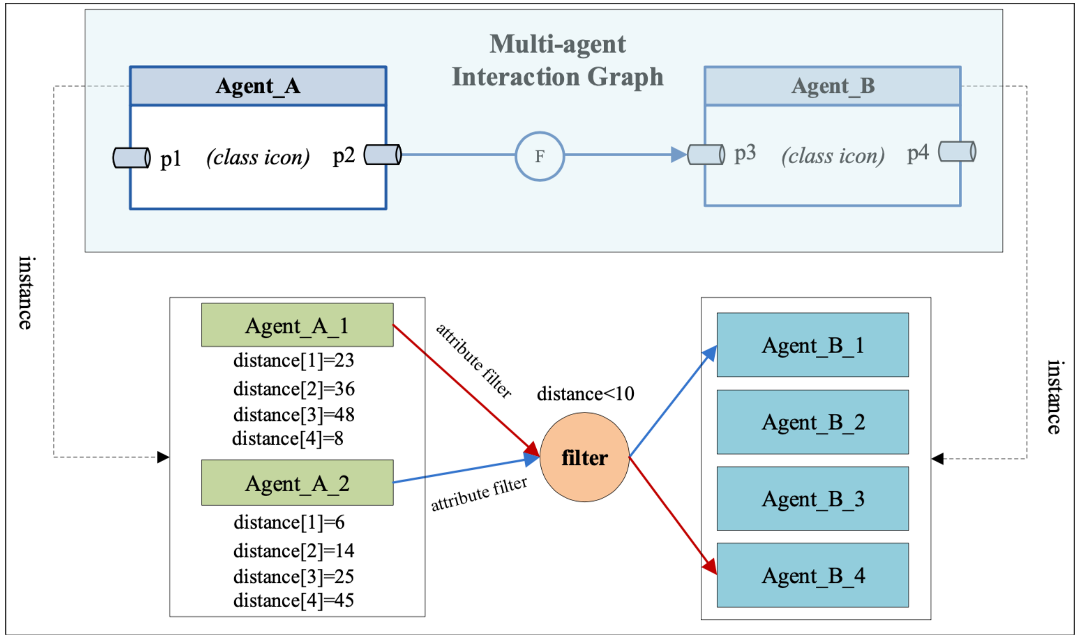
MAG **graphically** describe dynamic interactions between different agents.

Establish data communication between agent models using a publish/subscribe mechanism.

Dynamic Attribute Filtering Algorithm

Accurately determine interactions between agent instances based on a dynamic attribute filtering algorithm.

Automatically generate dynamic data filtering algorithms from MAG.



Instantiated MAG

Materials & Methods

Multi-Agent Interaction Graph

Graphical Representation of Agent Models

Ports: Represent input and output channels for communication.

Extended Petri Net: Graphically represents the behavior logic of the agent model.

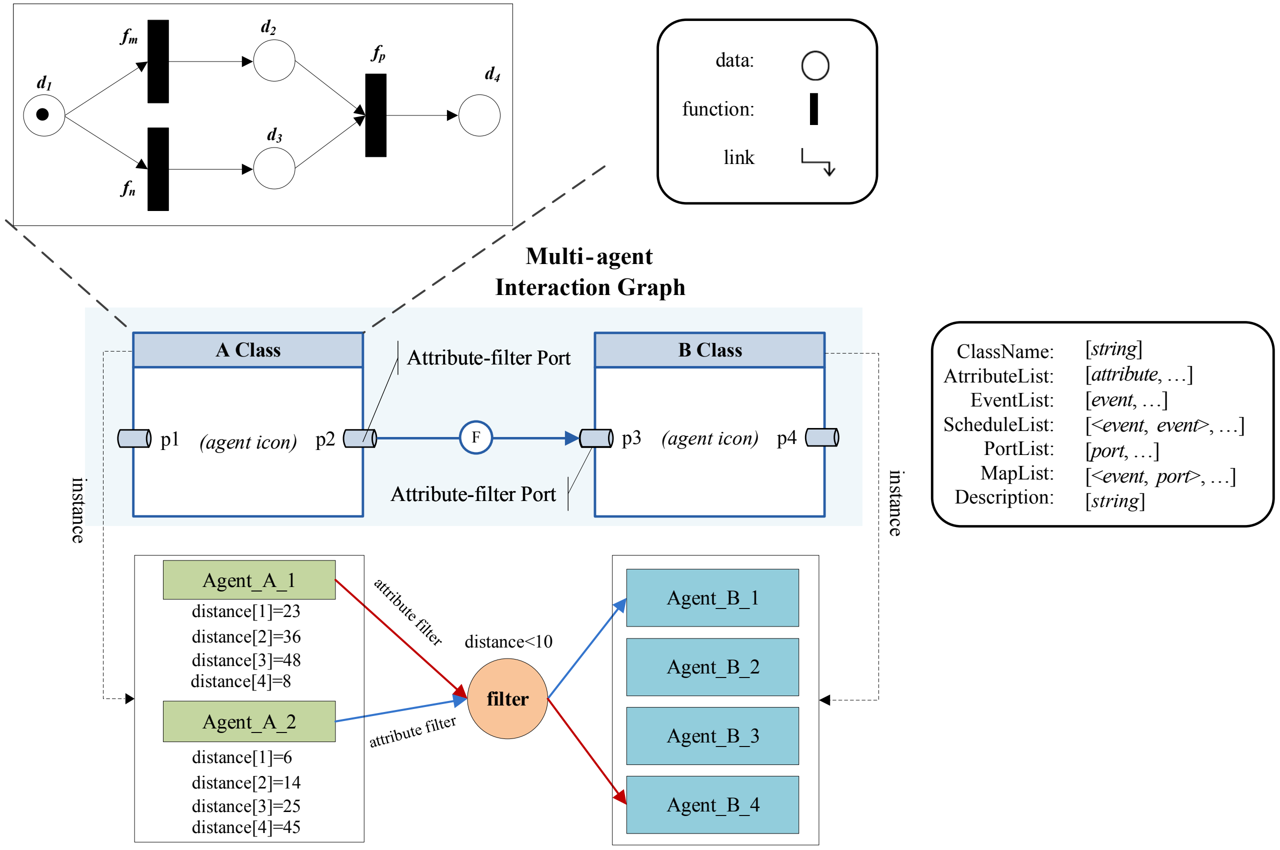
Data and Function Components: Store state data and indicate computing functions, respectively.

Links: Show control and data flow between components.

Structure of Multi-agent Interaction Graph

Attribute Filters: Define potential interactions between agent models with configurable expressions.

Dynamic Interaction: Interactions between agent instances are determined dynamically based on attribute values.



Graphical representation of an agent model and its interaction

Materials & Methods

Automatic Filter Generation

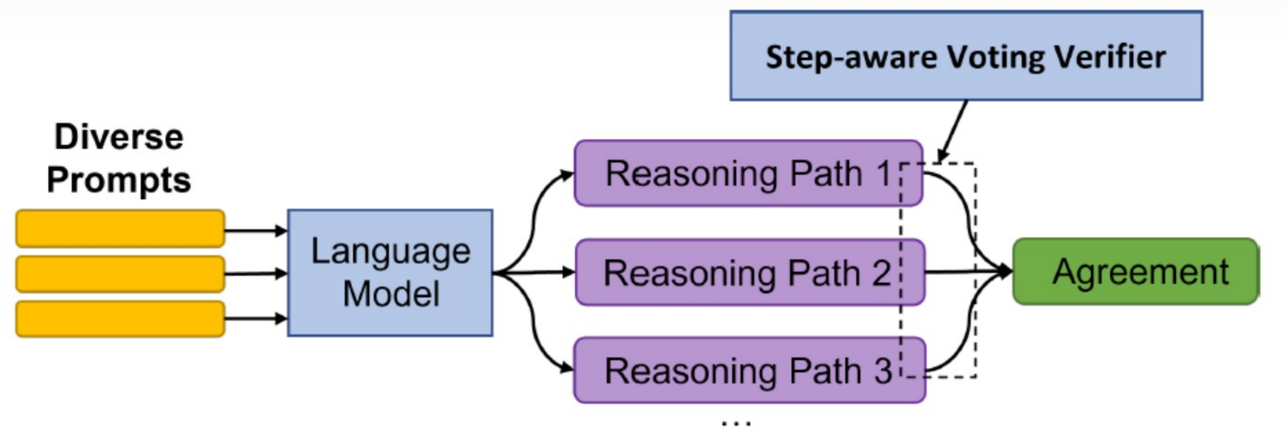
Use Chain-of-Thought (CoT) to hint at large models to improve the accuracy of generated code.

Step 1: MAG to natural language description

Use the Large Vision Model (LVM) to convert MAG into a description close to natural language, including the input parameters and the discriminant logic of the filter expression.

Step 2: Filter Code Generation

Use the Large Language Model (LLM) to convert the generated natural language description into the corresponding filter code.

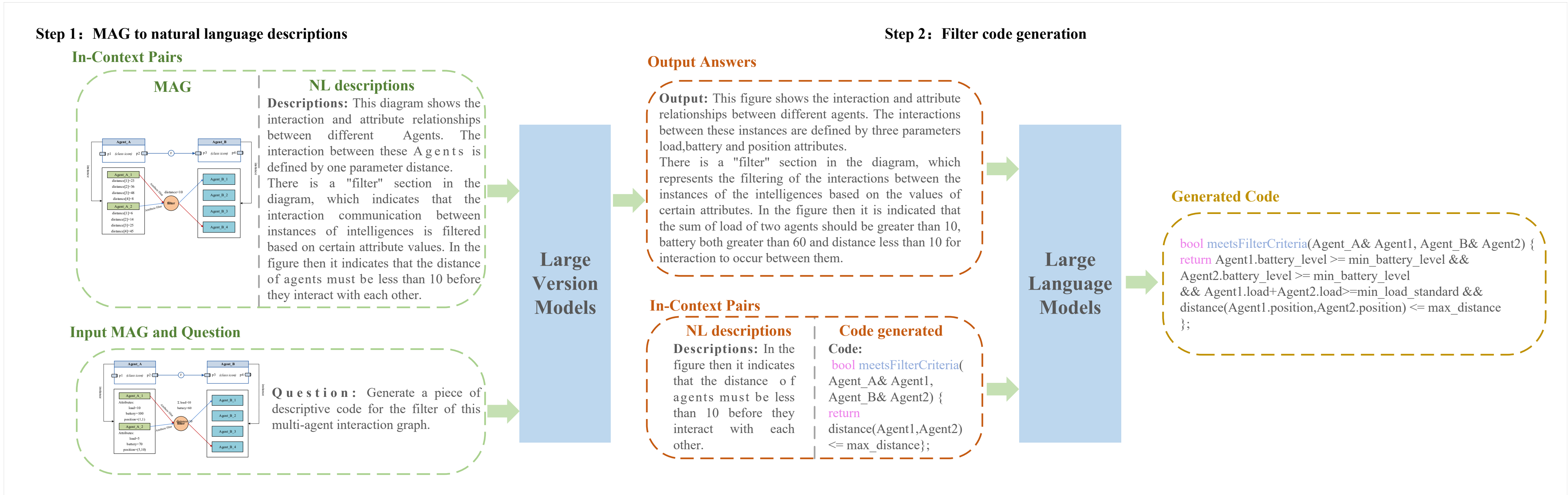


Chain-of-Thought (CoT)

Materials & Methods

Automatic Filter Generation

The figure demonstrates the transformation process from MAG to description and then to code.



Dynamic data filtering automated generation process

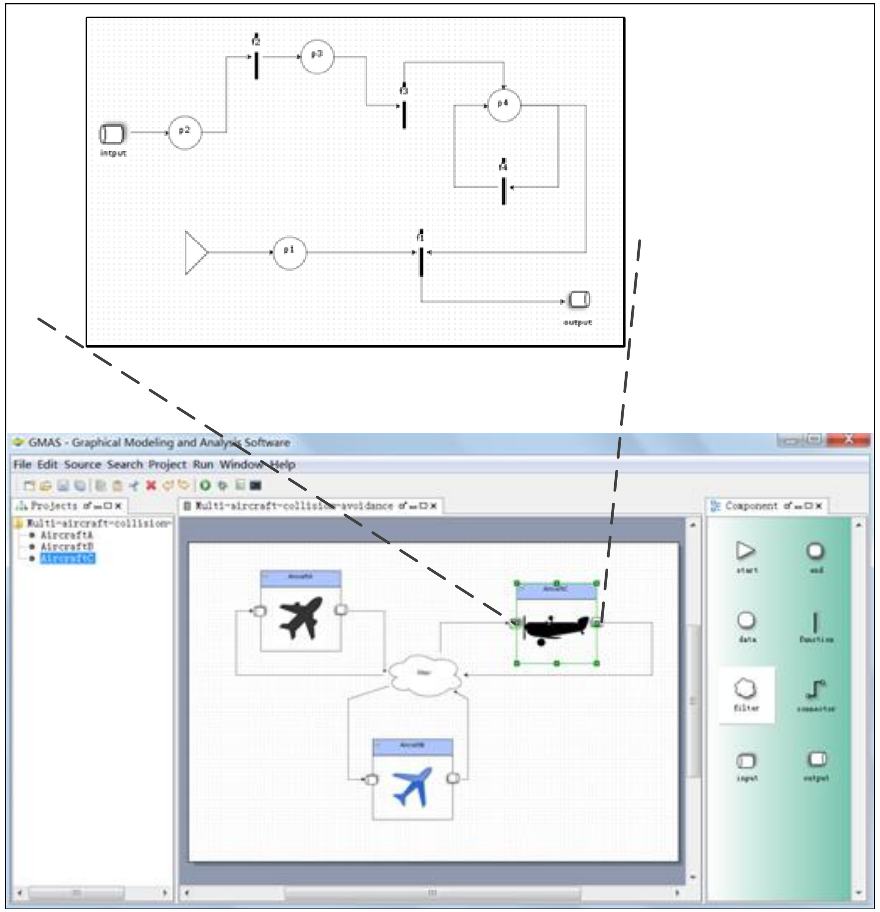
Experiments & Analysis

Test Scenarios Introduction

We designed two CAS scenarios to test the proposed simulation framework and attribute filter designed.

Aircraft Collision Avoidance Scenario:
Describe the critical issue of aircraft collision avoidance in the airspace near civilian airports.

Swarm Robot Cooperation Scenario:
Describe how swarm robots collaborate in search and rescue environments to accomplish tasks.



CAS Interaction Diagram for Aircraft Collision Avoidance Scenario

Experiments & Analysis

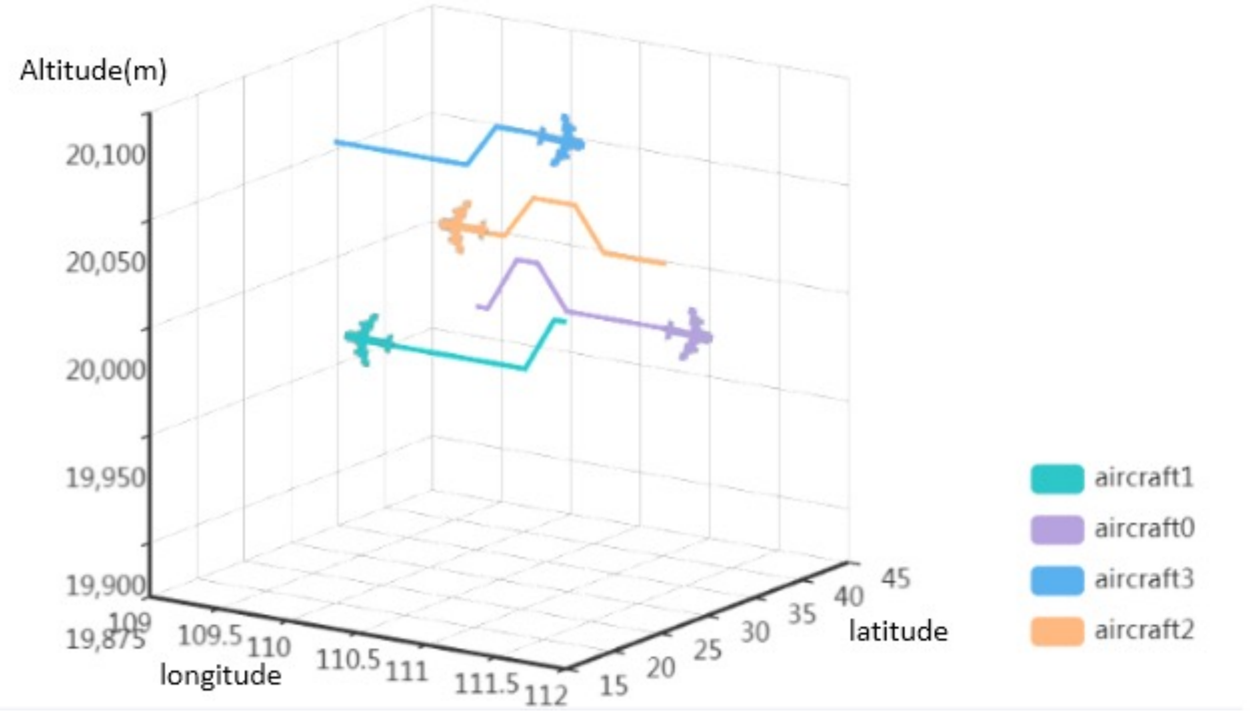
Scenarios Realization Analysis

We simulated two scenarios in a very short period of time to evaluate the attribute filter's performances.

Aircraft Collision Avoidance Scenario:
Demonstrated a 17% reduction in total communication data compared to static interaction models, showcasing the effectiveness of dynamic interaction.

Swarm Robot Cooperation Scenario:
Achieved a 34% reduction in communication data over time, highlighting significant optimization in data communication.

Execution Time and Memory Consumption:
With an increase in the number of agents, the MAG-based model showed a 20%-60% reduction in execution time and a 1.8%-4% decrease in memory consumption in aircraft scenarios. In swarm robot scenarios, execution time was reduced by approximately 30%.



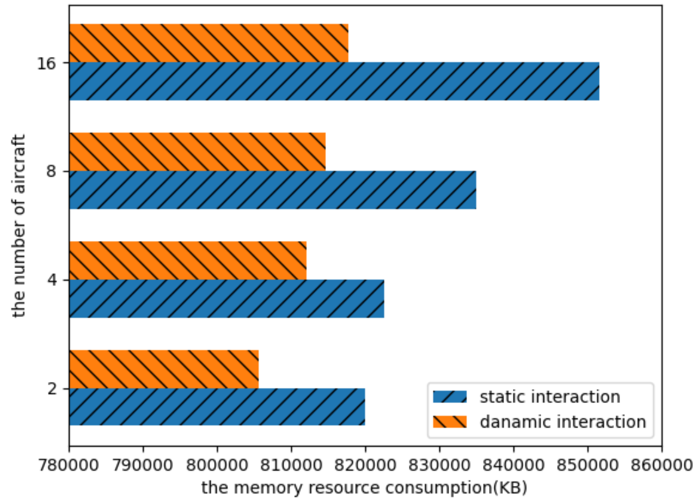
Visualized Analysis of Four-aircraft Collision Avoidance

Experiments & Analysis

Scalability, Stability, and Generality

We also analyze the system's Scalability, Stability and Generality.

Scalability Analysis:
With an increasing number of agents, the system's performance was analyzed to evaluate its scalability.
Demonstrated a 20%-60% reduction in execution time and a 1.8%-4% decrease in memory consumption for aircraft scenarios.
A 30% reduction in execution time for swarm robot scenarios.



Memory Consumption of the Aircraft Collision Avoidance Scenario

Generality Testing:
Tested filter code generation using various combinations of large models to ensure the system's versatility across different scenarios.
Successful generation of filter codes across different model combinations, highlighting the system's adaptability.

TABLE I. NUMBER OF SUCCESSFUL FILTER CODE GENERATION FOR DIFFERENT MODELS COMBINATION

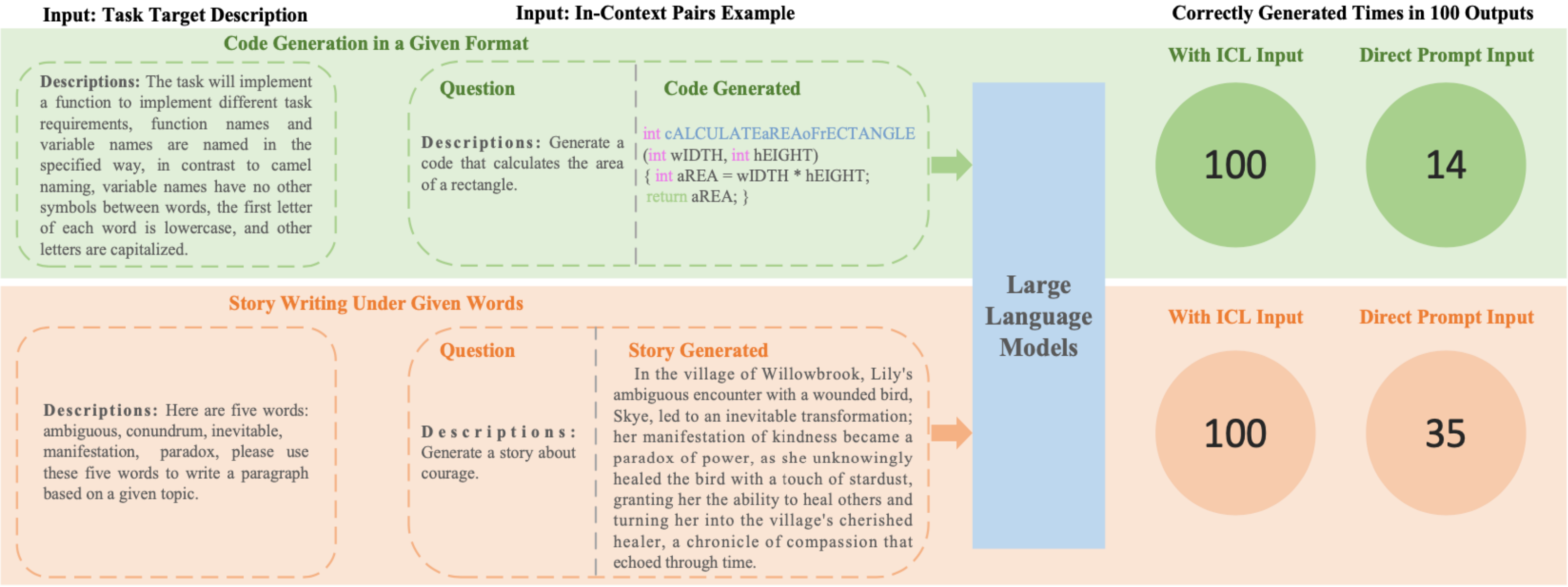
Large models (portfolios) used	Successful generation number
LLaVa+LLaMa3	78
Qwen-VL+Qwen2	74
LLaVa-only	17

Experiments & Analysis

Scalability, Stability, and Generality

We tested whether In-Context Learning (ICL) brings the stability and consistency to large model-based methods. Conducted tests using a non-ICL approach (direct prompt input) alongside the ICL method for comparison. Bottom figure illustrates the different text generation tasks, the ICL pairs utilized, and the success rate of generating the correct target text over 100 trials with varying inputs.

Findings indicate that ICL significantly improves the stability of output results in text generation tasks.



Conclusion & Future

We propose The Multi-Agent Interaction Graph (MAG) effectively models dynamic interactions in Complex Adaptive Systems (CAS). At the same time, the filtering algorithm based on dynamic interaction reduces irrelevant communication, leading to decreased simulation execution time and memory consumption.

Performance Improvements:
Demonstrated a 20%-60% reduction in execution time and 1.8%-5.5% reduction in memory usage across various scenarios. Showcased the scalability and efficiency of the MAG-based modeling approach.

Stability and Generality:
In-Context Learning (ICL) enhanced the stability and consistency of the system's output.
The system's generality was validated through successful filter code generation across different model combinations.

Future Research Directions:
Further development of more complex simulation models using the MAG framework.
Exploration of additional applications in diverse complex systems to validate the versatility of the MAG approach.

Thank you for listening