An implementation architecture for crowd network simulations

Jialin Zou, Kun Wang and Hongbo Sun
School of Computer and Control Engineering, Yantai University, Yantai, China

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Abstract

Purpose – Crowd network systems have been deemed as a promising mode of modern service industry and future economic society, and taking crowd network as the research object and exploring its operation mechanism and laws is of great significance for realizing the effective governance of the government and the rapid development of economy, avoiding social chaos and mutation. Because crowd network is a large-scale, dynamic and diversified online deep interconnection, its most results cannot be observed in real world, and it cannot be carried out in accordance with traditional way, simulation is of great importance to put forward related research. To solve above problems, this paper aims to propose a simulation architecture based on the characteristics of crowd network and to verify the feasibility of this architecture through a simulation example.

Design/methodology/approach – This paper adopts a data-driven architecture by deeply analyzing existing large-scale simulation architectures and proposes a novel reflective memory-based architecture for crowd network simulations. In this paper, the architecture is analyzed from three aspects: implementation framework, functional architecture and implementation architecture. The proposed architecture adopts a general structure to decouple related work in a harmonious way and gets support for reflection storage by connecting to different devices via reflection memory card. Several toolkits for system implementation are designed and connected by data-driven files (DDF), and these XML files constitute a persistent storage layer. To improve the credibility of simulations, VV&A (verification, validation and accreditation) is introduced into the architecture to verify the accuracy of simulation system executions.

Findings – Implementation framework introduces the scenes, methods and toolkits involved in the whole simulation architecture construction process. Functional architecture adopts a general structure to decouple related work in a harmonious way. In the implementation architecture, several toolkits for system implementation are designed, which are connected by DDF, and these XML files constitute a persistent storage layer. Crowd network simulations obtain the support of reflective memory by connecting the reflective memory cards on different devices and connect the interfaces of relevant simulation software to complete the corresponding function call. Meanwhile, to improve the credibility of simulations, VV&A is introduced into the architecture to verify the accuracy of simulation system executions.

Originality/value – This paper proposes a novel reflective memory-based architecture for crowd network simulations. Reflective memory is adopted as share memory within given simulation execution in this architecture; communication efficiency and capability have greatly improved by this share memory-based architecture. This paper adopts a data-driven architecture; the architecture mainly relies on XML files to drive the entire simulation process, and XML files have strong readability and do not need special software to read.

Keywords Crowd network, Large-scale simulation, Simulation architecture

Paper type Research paper

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1. Introduction

The phenomenon of group collaboration is widespread in nature and human society, such as ant colony, industrial chain collaboration, national elections, and enterprise management; researchers refer to the above-mentioned group collaboration phenomenon as collective intelligence (Yu *et al.*, 2018). With the rapid development of network technologies, artificial intelligence and big data constantly enhance the intelligence level of individuals, enterprises and governments, and the Internet and Internet of Things continue to expand the scale of interconnection between intelligent subjects. Compared with the traditional phenomenon of collective intelligence, the phenomenon of collective intelligence in the Internet environment is larger in scale, the scope is wider, and the interactability is stronger. And the nature of intelligence is extended from homogeneous intelligence to heterogeneous intelligence; activity space has expanded from physical space to the three-dimensional superposition space of physical, conscious and information fusion. We call the more complex phenomenon of collective intelligence in the information network environment as crowd phenomenon, and network structure formed by crowd phenomenon under the support of the Internet is called crowd network. Nowadays, human beings have entered the era of crowd network.

Crowd network is a double-edged sword. In the era of crowd network, the intelligent interconnection of government, enterprises and individuals provides an effective way to gather collective intelligence, promote enterprise production and enhance management and service capabilities of government. Crowd network can greatly facilitate governances of economy society, making it more efficient, humane and sustainable and helping for avoiding disorders (Chai *et al.*, 2017). However, crowd network not only brings convenience but also has certain negative effect. In the context of the Internet, people, machines and subjects are deeply interconnected, because intelligent groups have independent thinking, their behaviors and results are unpredictable, showing the characteristics of mutation, disorder and self-organization, so the probability of destructive events increases. At the same time, once malicious damage occurs, the scale and scope of its impact are highly likely to be uncontrollable. Therefore, it is of great practical significance to study the cooperative operation of intelligent subjects and control the development of bad trends under crowd network to promote social governance. At present, the theoretical research of crowd network mainly includes five parts: co-evolution, co-decision, co-collaboration, structure evolution simulation and robust simulation.

As main mode of modern service industry and future economy society, crowd network has distinctive characteristics that are different from general systems, such as diversity, dynamics, mutation, large scale and so on. These characteristics determine that the research of crowd network cannot follow a traditional way. Simulation is the main means to put forward related research studies (Sun and Zhang, 2017a, 2017b).

Simulation architecture is the basis of building a simulation system, which determine the model composition and function of the simulation system. The research of simulation architecture of crowd network mainly includes the basic elements of the simulation system, the definition and expression methods of the elements themselves, the interaction mechanism between the elements and the basic aspects of the simulation system. For the emerging system of crowd network system, the existing simulation architecture can no longer meet the overall requirements of the system and application subjects for the simulation platform. Therefore, this paper proposes a simulation architecture based on reflective memory, which adopts a general structure and combines relevant simulation software, the architecture is suitable for the characteristics of dynamic, large-scale members and diversified.

This paper is divided into five parts to introduce the architecture. Section 2 briefly reviews the current simulation architectures and the existing research results and analyzes the applicability of the current architecture for crowd network simulation. Section 3 mainly focuses on the implementation routine, functional architecture and implementation architecture, which analyzes crowd network simulation architecture. Section 4 briefly introduces the seven types of simulation toolkits that have been initially designed and verifies the availability of the architecture and toolkits proposed in this paper through a simple simulation example. Section 5 summarizes a series of methods involved in the simulation architecture proposed in this paper.

2. Related work

Crowd network systems take intelligent digital-selves as the constituent body who have obvious autonomy and complexity, intelligent digital-selves have independent thought, and its behavior is difficult to control; in the course of its development, it will produce diversified and uncertain factors. Therefore, when constructing simulation framework of crowd network, it is necessary to consider the corresponding nature of subjects and the problems that may arise. On one hand, crowd network is not a simple linear system; in the model of the simulation framework, constraint conditions must be formulated according to its process changes. On the other hand, there are multiple subsystems within crowd network system, and these subsystems are cooperative and interdependent; therefore, in the framework of building a simulation model, it is necessary to make a multi-level distinction according to the influence of each subsystem. At present, the commonly used complex system simulation frameworks are High Level Architecture (HLA) proposes by the US Department of Defense and Agent-Based modeling and simulation (ABMS), especially in military, energy, communication and some social simulation areas. Most of the existing simulation systems build the simulation framework on the basis of both, and some scholars also integrate the two together, make full use of the advantages of both to develop new frameworks; Cicirelli *et al.* (2009) proposed an Agent support architecture based on HLA, described how to deploy theatre on HLA/RTI and established a large open simulation system based on Agent. Yin *et al.* (2016) combined the efficient coordination mechanism of HLA with the interaction and intelligence of ABMS; they designed a cooperative simulation framework of energy system and information communication system and realized the joint simulation of energy flow and information flow.

The ABMS method combines the microscopic behavior with the macroscopic phenomenon by modeling the basic elements and their interactions in a complex system. ABMS is good at capturing the emerging behavior and self-organizing phenomena of human systems, which is similar to the needs of crowdnetworks. Armano Srbljinovic *et al.* (2003) have used Agent-based simulations to study the ethnic mobilization of the former Yugoslavia-social conflict on the basis of Swarm. At present, there are many kinds of Agent-based modeling simulation platforms in foreign countries, such as Swarm, Repast, NetLogo and so on. Le Anh Quang *et al.* (2018) has analyzed Agent-based modeling simulation platforms, summarized their applications in social physics systems, and compared the advantages and disadvantages of various simulation platforms. Developed by Santa fe Institute of the USA, Swarm is a platform for ABMS that includes conceptual framework for designing, describing and conducting experiments on ABMS. Zheng *et al.* (2016) propose a particle swarm optimization-based combinational auction model and its swarm-based simulation to solve multi-dispatching problem. On the basis of Swarm, all functions of Repast are more powerful and easy to use, so it is considered as a Swarm-like simulation toolset. Netlogo is a programmable modeling framework for simulating natural and social phenomena, especially for modeling complex systems that evolve over time. Bosse *et al.* (2013) have used Netlogo Multi-Agent tools to simulate crowd emotion rendering. However, most of the current ABMS simulation platforms are mainly operated in a stand-alone mode, which is not enough to support the distributed simulation of large scale complex systems such as crowd network systems. Therefore, ABMS cannot be used as the simulation framework of crowd network system alone.

HLA is a new generation of high-level architecture that emerged after Distributed Interactive Simulations (DIS), which uses a subjective-oriented approach to design, develop and implement a subjective model of the system, separating the development and execution of distributed simulation from the corresponding supporting environment. It realizes the interoperability between simulation systems, which is beneficial to the reuse of simulation models in different applications and effectively solves the problems of multi-event concurrency and random simulation event processing in the simulation process, thus providing an ideal integration approach and a general technical framework for large-scale complex simulations. Although HLA satisfied the diversification requirement and dynamic requirement well to a certain extent, the main use field of HLA simulation framework is still in the military aspect. When it comes to crowd network, systemic emergence is a key characteristic of complex systems, and HLA do not support this kind of simulations, therefore, HLA still does not meet the needs of crowd network. Considering all kinds of simulation systems, none of the existing simulation frameworks is fully applicable to crowd network simulations. To solve the above problems, this paper innovatively proposes a novel reflective memory-based framework to meet the different simulation requirements of crowd networks. The framework provides distributed system support through run-time infrastructure (RTI), connects various simulation toolkits by data-driven files (DDF) and realizes crowd network simulation framework with AnyLogic, Matlab, Repast, GAMS and other tools.

3. The general architecture for crowd network simulations

3.1 Implementation framework

Crowd network simulation is generally divided into three stages: typical scene simulation, simulation optimization and massive scale simulation (Figure 1). The typical scene simulation is designed for co-evolution, co-decision, co-collaboration, structure evolution simulation and robust simulation (including information propagation simulation, fixed point simulation and control condition simulation). Based on the optimization model, the simulation parameters are dynamically adjusted according to the feedback of the simulation results to achieve the effect of dynamically seeking the optimal evolution path. Finally, the influence of the scale on the simulation results is discussed, and the sensitivity analysis of the scale parameters is carried out to get the scope of applicability of the law of crowd network to the simulation results.

The models and methods involved mainly include member general model, massive member generation and interaction method, simulation advancement and execution control method, disturbance injection method, intelligent expression, comparison and operation method, Crowd network system identification and steady-state judgment method, simulation verification, validation and accreditation (VV&A) method. The member general model describes the general expression and structure of members in crowd network simulation, which is the basis of crowd network simulation. The massive member generation and interaction method is based on the member general model, according to the characteristics of intelligent body to generate corresponding simulation members, and simulation members interact in the simulation process, which is the basis of simulation

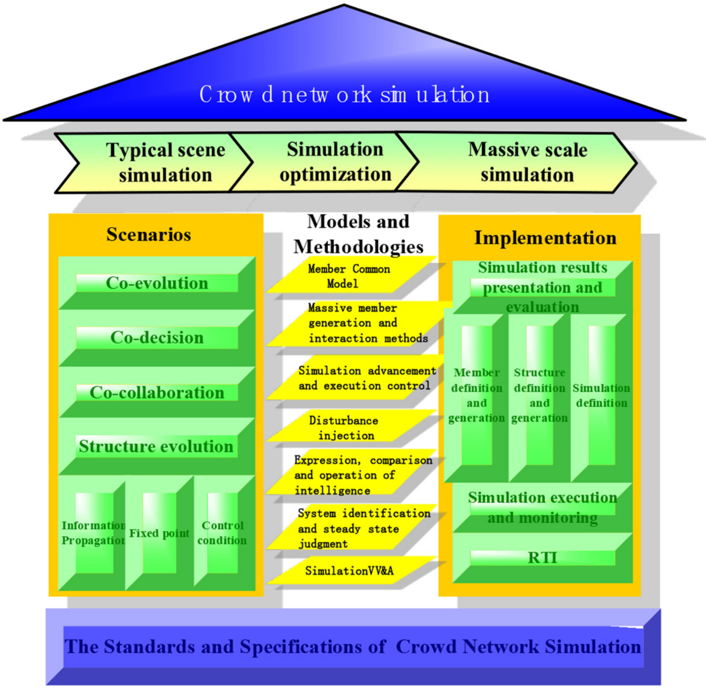

Figure 1.
Implementation framework

advancement. The simulation advancement and execution control method sets the advancement power and the advancement mode according to the characteristics of crowd network simulation, which controls the simulation execution according to the simulation advancement. The disturbance injection method loads the disturbance in some form in the process of crowd network simulation, which can be used to judge the robustness of the system. Intelligent expression, comparison and operation methods express intelligence in a certain way, and enable it to compare and operate, so as to facilitate the description and execution of simulation. Crowd network system identification and steady-state judgment method is mainly used to identify the slow parameters of crowd network system, and the existence condition of the system steady state is given according to this parameter, which is the basis of robust simulation. The simulation VV&A method is mainly used to verify the match between simulation members, simulation process, disturbance loading, simulation results and so on with the real world, and to ensure the credibility of the simulation.

At the system implementation level, crowd network simulation mainly includes RTI, simulation member definition and generation toolkits, network structure definition and generation toolkits, simulation definition toolkits, simulation execution and monitoring toolkits, simulation results presentation and analysis toolkits. RTI is the infrastructure of distributed simulation operation, enabling simulation applications on offsite computers to use remote computing resources as if they were local resources. The simulation member definition and generation toolkits define the basic composition and structure information of the simulation member in the form of XML file, and then generate the simulation member. The network structure definition and generation toolkits define the general characteristics of the network structure according to requirements on the premise that the simulation member has been generated, and write the structure information into the XML file. The simulation definition toolkits define the execution parameters of simulation according to the actual requirements of the simulation application; The simulation execution and monitoring toolkits are responsible for starting the simulation run and monitoring the execution status of the simulation, and controlling the speed of the simulation execution, then writing the intermediate results from the simulation execution into the file in XML. The simulation result presentation and analysis toolkits reproduce the simulation process in the form of image or animation based on the XML file generated by the simulation execution, and evaluate and analyze the result.

3.2 Function architecture

From a functional point of view, this paper gives a functional architecture of crowd network simulation system (Figure 2). Crowd network simulation platform needs the support of reflective memory and interface with related simulation software to help complete the corresponding function calls, such as multi-agent programming platform JADE, multi-agent simulation platform AnyLogic, operations research optimization Software GAMS, state-based modeling, simulation software Repast and mathematical calculation software Matlab.

Its own structure still belongs to the general structure, the bottom layer is RTI and the memory management part connects the reflective memory card on different devices, making the access to the distributed storage as convenient as the local. On this basis, simulation management is mainly used to manage different simulation executions to avoid interference and damage of files and execution. Simulation execution management is to manage and control the single simulation execution. Data distribution management locates all simulation members with identification and indexing to be able to find the specific location of the member in the process of simulation advancement.

Business implementation layer mainly relies on XML files to drive the entire simulation process; these XML files include member template files, member description files and simulation description files, which must be constructed according to the relevant standards

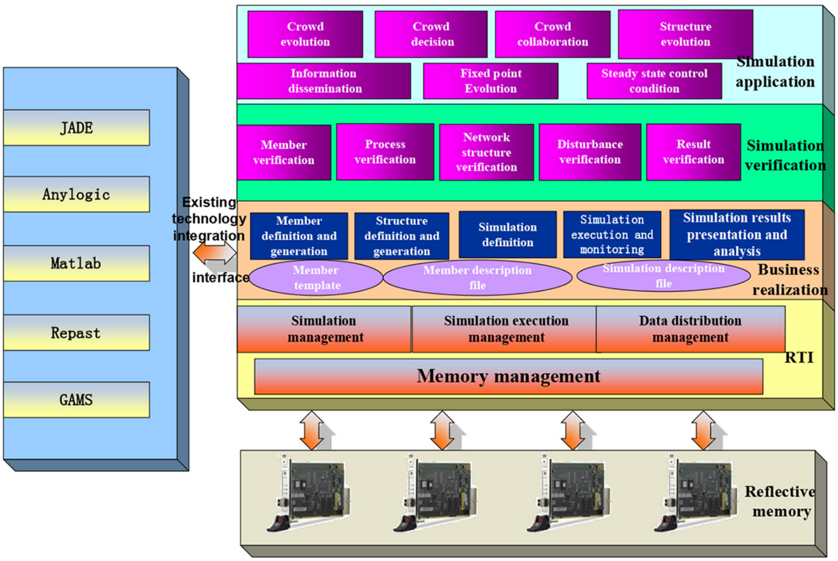

Figure 2.
Functional architecture

of crowd network simulation, so as to facilitate the intercommunication between various modules.

At the simulation verification level, there are mainly four aspects of verification: members, simulation process, disturbances and results. Member verification is mainly to verify whether the feature distribution of members conforms to the actual situation. Simulation process verification aims to verify whether the consistency between the simulation process and the actual process, that is, whether the simulation process is reliable. Network structure verification mainly verifies whether the consistency between the crowd network structure and the actual situation. Disturbance verification mainly verifies whether the consistency between the distribution and frequency of the disturbance source and the actual situation. Result verification mainly shows whether the simulation result is consistent with the actual situation, and whether it can play a role in revealing, confirming or displaying the subjective law.

3.3 Implementation architecture

From the implementation point of view, this paper gives an implementation architecture of crowd network simulation system (Figure 3). Crowd network theory simulation toolsets include simulation member definition, simulation definition, crowd network structure definition, member generation, crowd network structure generation, simulation execution and monitoring, simulation verification and evaluation, simulation result presentation and analysis; these toolsets are connected with each other in the form of DDF to form simulation toolsets of crowd network.

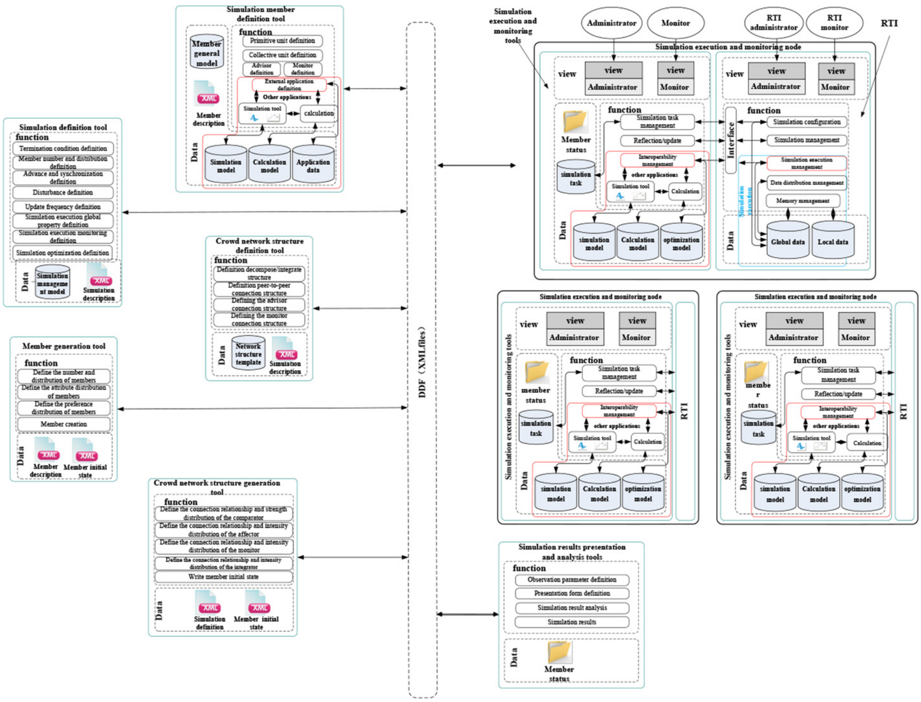

Figure 3.
Implementation architecture

Simulation member definition tools define primitive members, collective members, advisor members and monitor members according to the general member model. The definition includes type, attributes, endowment, pattern, and executor, decider, decomposer, integrator, comparator, monitor, affecter, target/commitment, etc. It also needs to define the name, parameters, models and datasets of the external application, and it ultimately produces a member description file in XML form.

Simulation definition tools define the target and direction of simulation optimization, the termination condition of simulation, the number and position distribution of members, the advancement and synchronization, the disturbance injection method, the update frequency, the global attributes, the monitored parameters and the display number, etc. According to the simulation management model, it ultimately produces a simulation description file in XML form. Crowd network structure definition tools define an overall decomposition/aggregation structure, an equivalent digital-self connection structure, an advisor connection structure, a monitor connection structure according to the network structure template (for example, a point cloud structure, a small world structure, a six-degree space structure) and write them into the simulation description file in XML form.

According to the member description file, member generation tools define the number and distribution of different types of members, the distribution of attributes, and the distribution of preferences, it generates members and writes them into the member initial state file in XML form.

According to the structure information in the simulation description, crowd network structure generation tools define member's connection relationship and intensity distribution of comparator, connection relationship and intensity distribution of affecter, connection relationship and intensity distribution of integrator, and it writes the information to the member initial state file in XML form.

Simulation execution and monitoring tools run in a multi-machine environment and may contain multiple simulation execution and monitoring nodes that are interconnected by their respective reflective memory cards, each of which includes a simulation execution, a monitoring tool and a RTI environment. The main function of RTI is to manage the local memory and the reflective memory card, so that it can access the distributed storage as the local memory, so as to expand the memory. Simulation execution and monitoring tools are used to control and manage the operation of the simulations. The main functions of RTI include memory management, data distribution management, simulation execution management, and simulation management and simulation configuration. Memory management is mainly to coordinate the relationship between reflective memory and local memory, so that users can access the distributed storage like local memory. Simulation management is mainly used to manage different simulation executions to avoid the interference and corruption of their files and execution. Simulation execution management is the management and control of a single simulation execution. Data distribution management locates all simulation members with identification and indexing so that the specific location of the member can be found during the process of simulation advancement. Simulation configuration configures some global parameters in the simulation process, such as the update frequency of reflective memory, mutual exclusion and synchronization and different nodes in the public and private areas of reflective memory and so on, and the views it uses mainly include administrator view and monitor view. Simulation execution and monitoring tools are mainly to organize and monitor the simulation operations according to simulation tasks, including simulation task management, reflection/update global attributes and interoperability management. Simulation task management acquires requirements and corresponding parameters of simulations through simulation description files, and controls the execution of simulation. Reflection/update management performs real-time reflection and update by calculating the values of global attributes to facilitate the success of simulation. Interoperability management starts the external application according to calling the format and parameters of the external application in the simulation description file, and obtains the corresponding result, the views it uses are also divided into administrator view and monitoring view. During the process of simulation execution, simulation execution and monitoring tools write each state of each simulation member to the member state file in XML form.

According to the record of the simulation description and member status, based on the evaluation model and real data, simulation verification and evaluation tools verify and evaluate the reliability of the simulation process, the distribution and characteristics of members, the structure of crowd network, disturbance mechanism and simulation results.

Simulation result presentation and analysis tools set the observation parameters and presentation forms according to the member state data in the process of simulation execution, and display and analyze the simulation results.

4. System implementation

4.1 Simulation toolkit implementation

The seven toolkits mentioned in Chapter 3 have been initially implemented. The following is a brief introduction to the implementation of various toolkits in conjunction with crowd network simulation example.

4.1.1 Member definition tool. The member definition toolkits are responsible for defining the attributes of the members and the data types involved in the attributes and generating the corresponding XML files. The XML files are provided to member generation toolkits to generate the corresponding members according to the XML constraints.

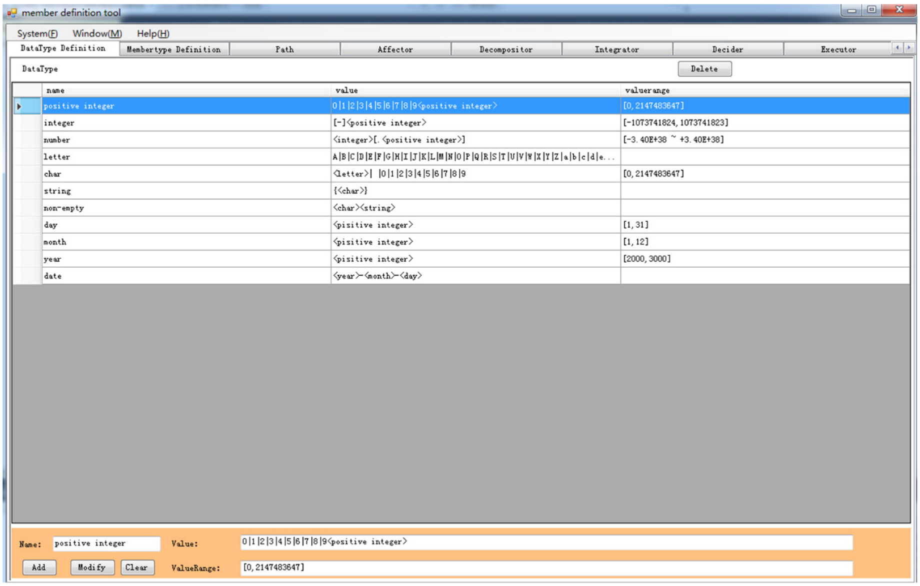

Figure 4.
Data definition interface

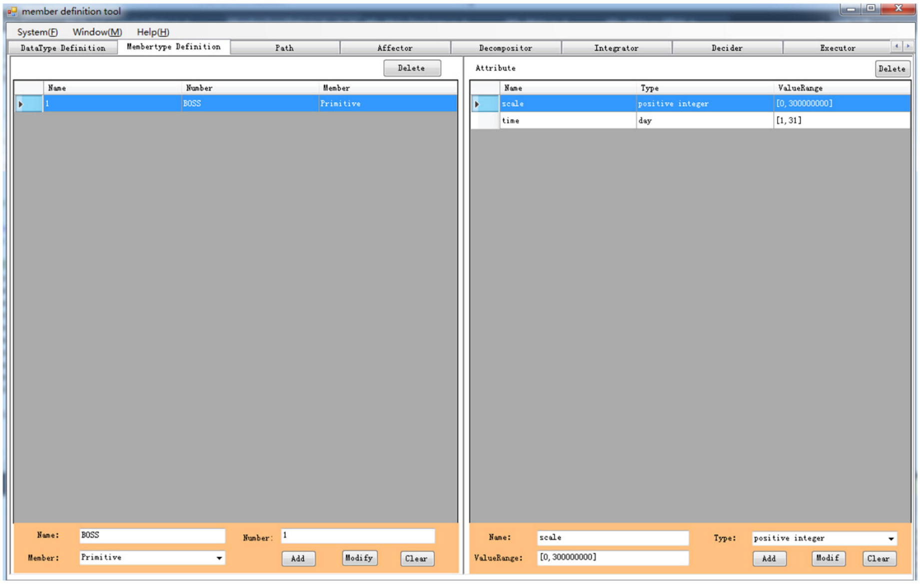

Figure 5.
Member general attribute definition interface

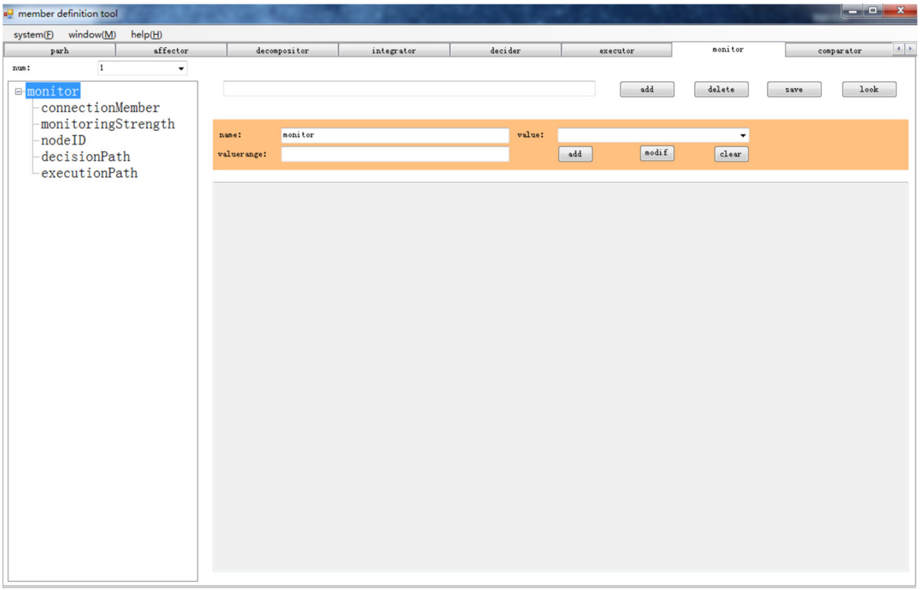

Figure 6.
Specific component attribute definition interface

The member definition toolkits first define the data types involved in the member properties (Figure 4).

The member definition toolkits are primarily responsible for defining the attributes that each member has (Figure 5). The entire simulation interface is divided into two parts. The

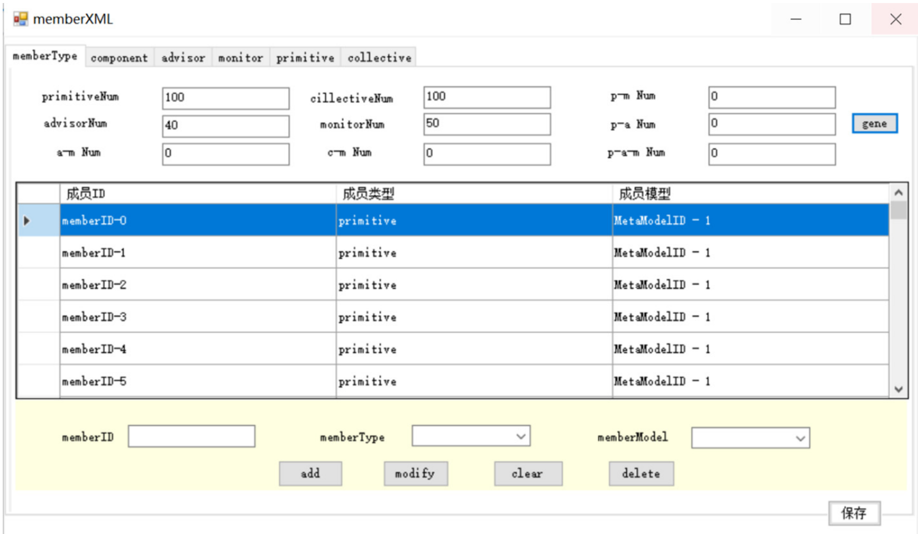

Figure 7.
Member number generation interface

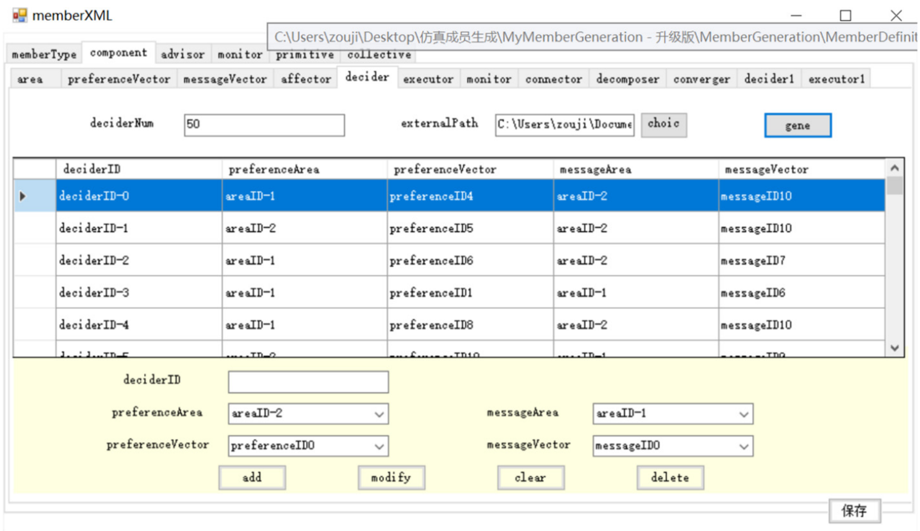

Figure 8.
Decider generation interface

left side is the member type definition, the right side is the common attribute definition of such members, and there is a cascading relationship between the left data and right data. Each type of members consist of multiple parts, and each part needs to be defined separately. Taking the monitor as an example (Figure 6), the entire simulation interface is divided into two parts. The left side is a tree list of the attributes that have been defined, and the right side is the attribute definition interface of the monitor.

4.1.2 Member generation tool. The member generation toolkits dynamically generate simulation interface by reading XML files generated by member definition toolkits. The

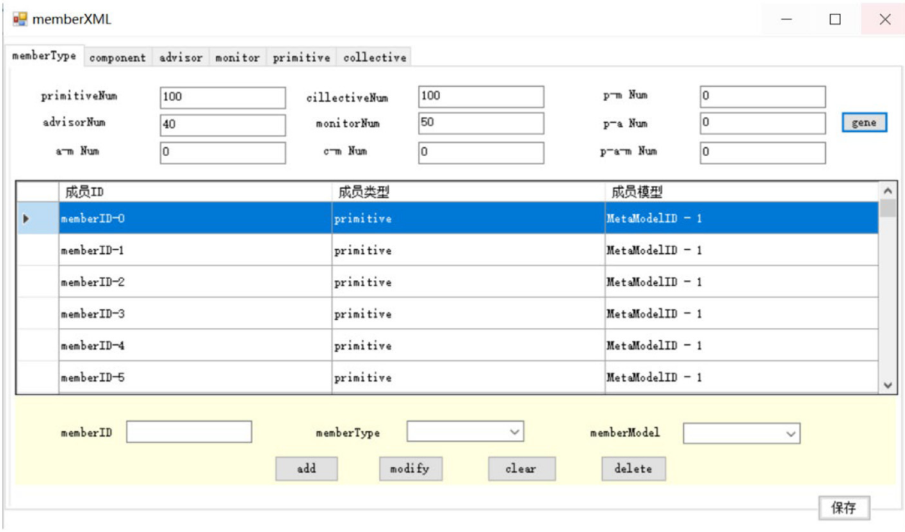

Figure 9.
Member generation interface

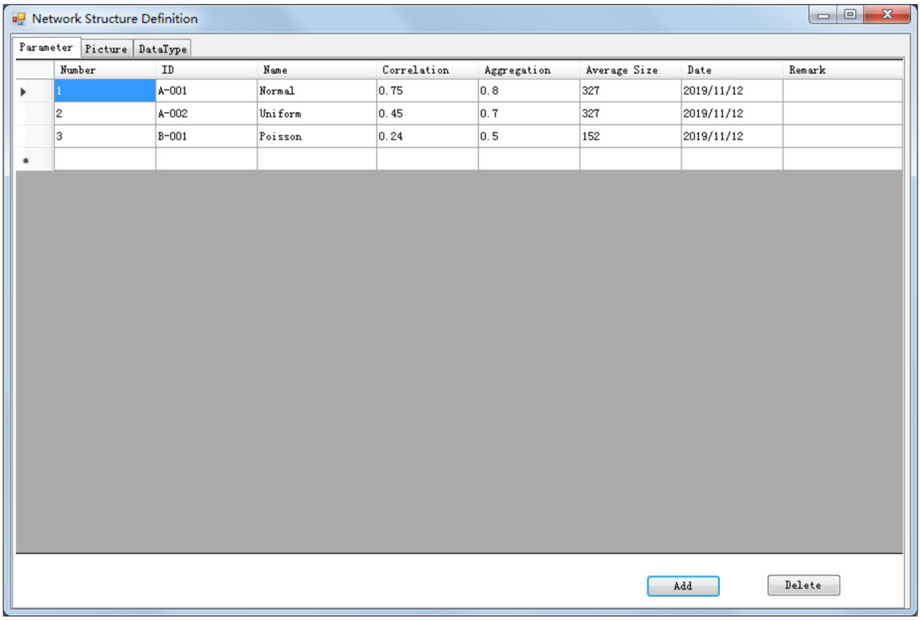

Figure 10.
Network structure general attribute definition interface

member generation tool mainly assigns values to the attributes defined by member definition toolkits according to the constraints of XML files and generates a large number of simulation members. Because the number of members that need to be generated is so large that it cannot be completely accomplished by manual addition, member generation toolkits

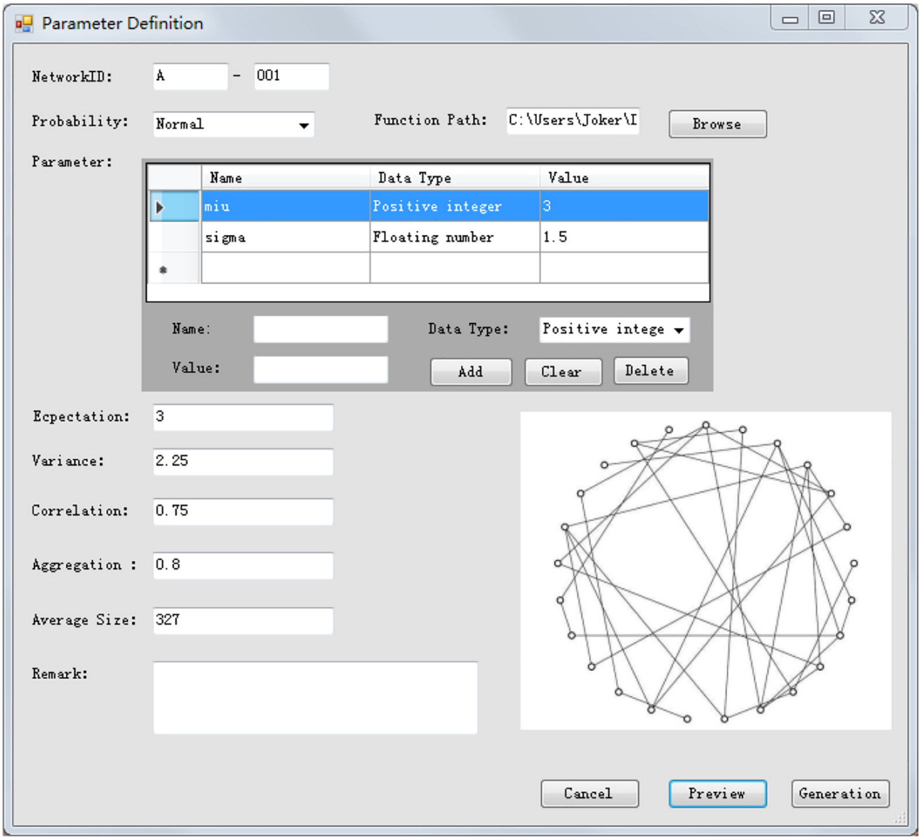

Figure 11.
Network structure detailed parameter definition interface

randomly generate a large number of members by setting the expectation and variance of its attributes.

Before generating specific members, you need to define the number of types of members (Figure 7).

Second, the component parts of members need to be generated class by class. Take the decider as an example (Figure 8).

Next, take the advisor member of crowd network simulation as an example (Figure 9).

4.1.3 Crowd network structure definition tool. Crowd network structure definition toolkits first define the general attributes of crowd network structure (Figure 10), including degree correlation, community aggregation coefficient and average size.

Crowd network structure detailed parameter definition interface defines the expectation and variance of the connection relationship between members to randomly generate the network structure (Figure 11). After completing the parameter definition, the lower right corner can preview the network structure diagram that you want to generate.

4.1.4 Crowd network structure generation tool. Crowd network structure generation toolkits implement the generation of network structure by reading the attribute definition XML file generated by crowd network structure definition toolkits (Figure 12).

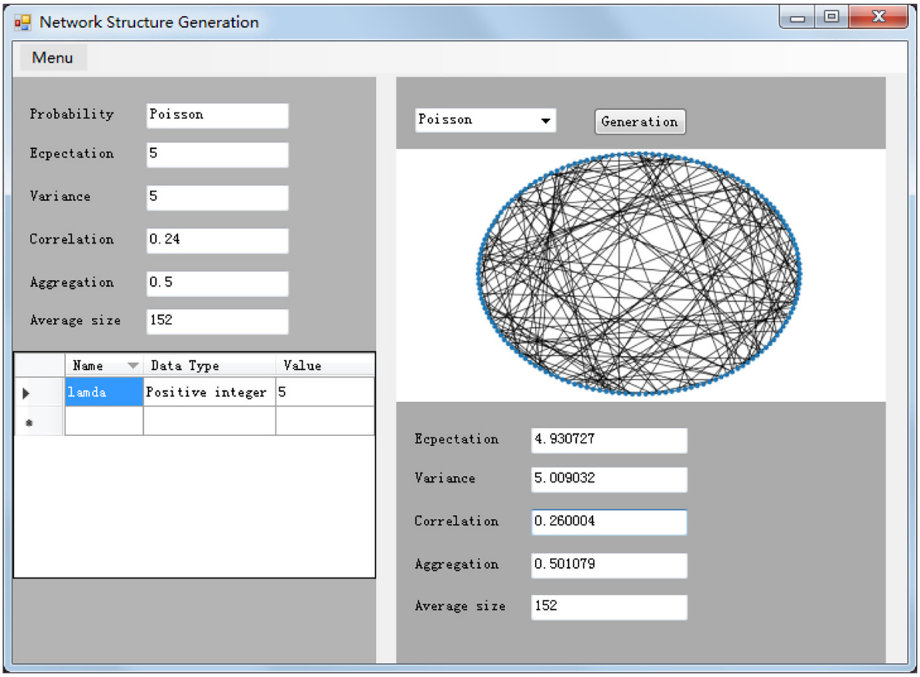

Figure 12.
Network structure generation interface

4.1.5 Simulation definition tool. Simulation definition toolkits define the simulation parameters involved in the simulation (Figure 13), such as the simulation meta model, simulation round definition and simulation member list.

The simulation round method needs to be defined in detail (Figure 14), such as the type of simulation instance currently executed and the global attributes involved.

4.1.6 Simulation execution and monitoring tool. Simulation execution and monitoring toolkits read the xml file generated by simulation definition toolkits and crowd network structure generation toolkits, and select the members participating in the simulation and the type of simulation to be executed according to the requirements, and monitor various problems occurring in the simulation operation in real time, thereby realizing the smooth running of the simulation (Figure 15).

4.1.7 Simulation result presentation and analysis tool. Simulation result presentation and analysis toolkits analyze and display the simulation results obtained during simulation execution. The entire simulation interface is divided into two parts (Figure 16).

The upper part of the interface is used to read the simulation result files obtained by the simulation run, the information obtained will be automatically filled in the corresponding text box, and the presentation of the simulation results can be controlled by the progress bar and various control buttons. The lower part of the interface is used to show the various attribute of the specified members within the simulation results and to present the overall results.

4.1.8 Simulation flowchart. The specific simulation process of the entire simulation toolkits is shown in Figure 17.

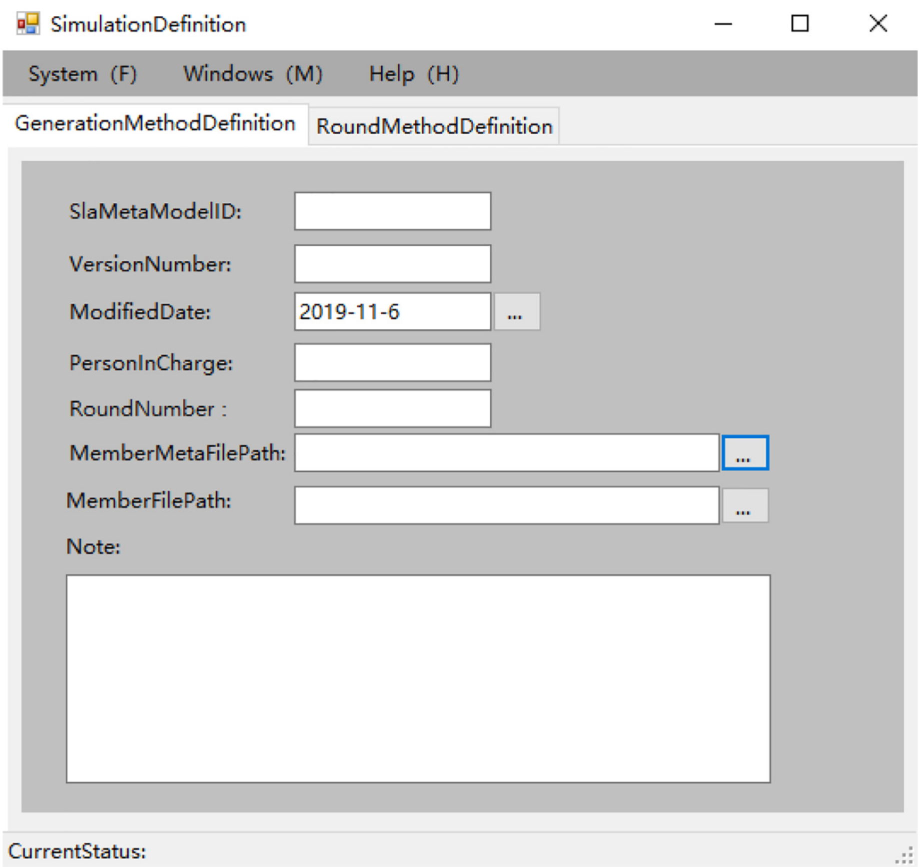

Figure 13.
Network structure generation interface

4.2 Simulation example

To prove the availability of the proposed simulation architecture and simulation toolkits, this paper finally verifies it through a co-evolution simulation example (Figure 18).

The content of the co-evolution simulation experiment is taking the perspective of an individual in the group as the main body when facing a particular scene, the individual will obtain favorable information from other individuals by constantly adjusting the weight of the connection relationship between himself and other individuals. To achieve this goal at a minimum cost when dealing with this particular scenario.

5. Conclusion

Crowd network simulations have the characteristics of dynamic and diversified. At the same time, the population of simulation members is large, the simulation scale is large, and the complexity of the overall simulation environment is very high. Existing simulation architecture s are difficult to meet the characteristics of crowd network simulations. Compared with existing simulation architecture s, the proposed crowd network simulation architecture has the following advantages:

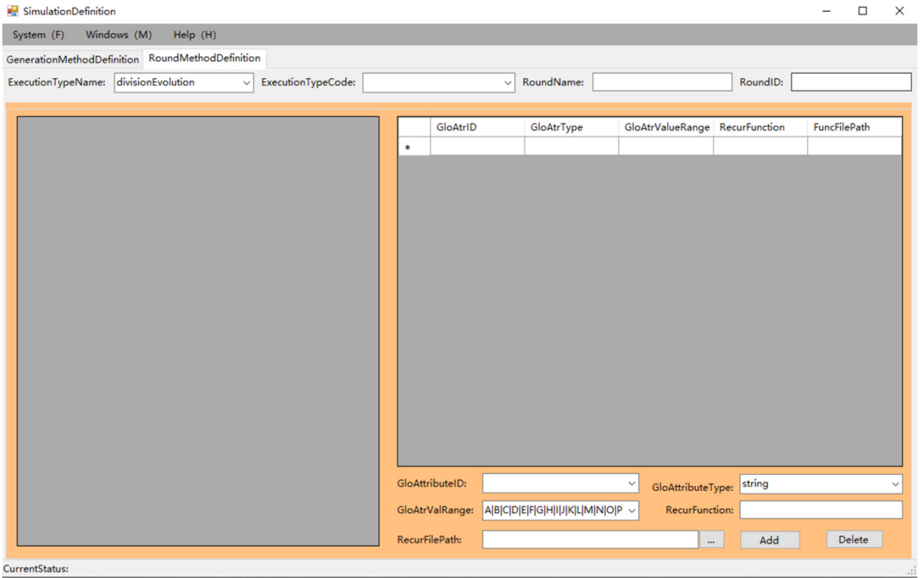

Figure 14.
Simulation round method definition interface

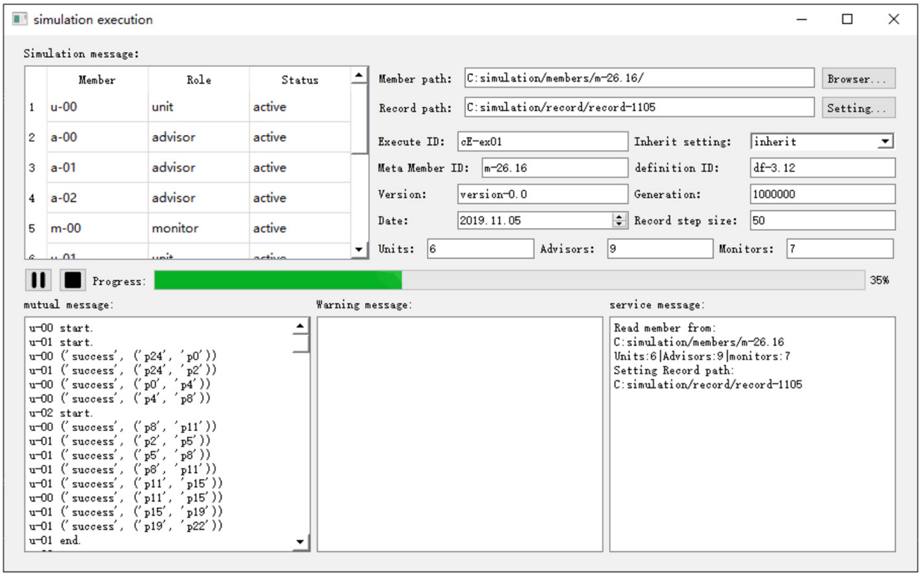

Figure 15.
Simulation execution and monitoring interface

- To solve the characteristics of large scale and large number of populations of crowd network, this paper proposes a novel reflective memory-based architecture for crowd network simulations. Reflective memory is adopted as shared memory within given simulation execution, and the architecture based on

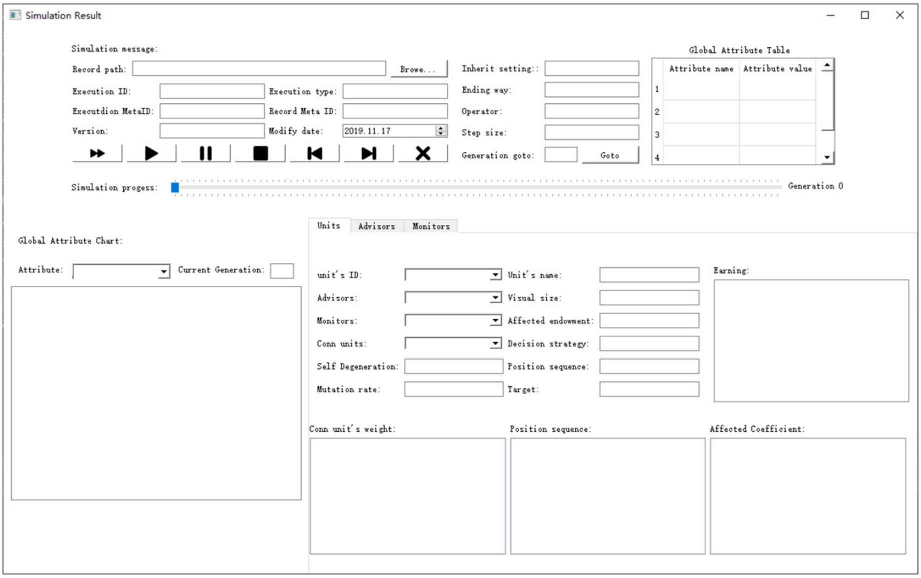

Figure 16.
Simulation result presentation and analysis interface

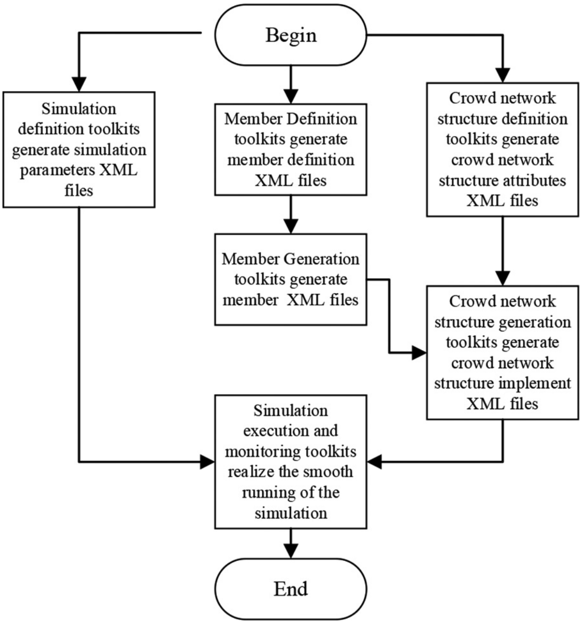

Figure 17.
Simulation flowchart

this shared memory greatly improves communication efficiency and functionality. All federations can be perceived, which greatly enhances the scalability of such simulations, making access the distributed storage as the local memory, to achieve large-scale simulation; and

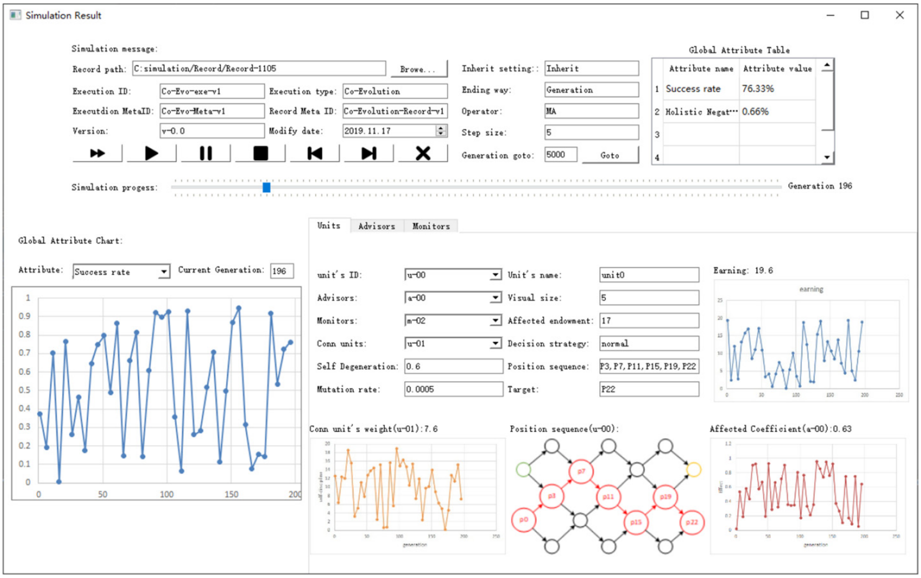

Figure 18.
Simulation example

- This paper adopts a data-driven architecture, the architecture mainly relies on XML files to drive the entire simulation process. XML files have strong readability and do not need special software to read. XML files isolate the various stages of crowd network simulation with static files and construct several simulations at the same time, which improves the efficiency. In the playback process of the simulation results, The XML file can be read directly for playback without considering the efficiency of the machine.

The research of crowd network simulation is still in progress, and the next step is to further modify various toolkits based on this architecture to achieve large-scale dynamic simulations and verify the relevant theoretical results of crowd network.

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Corresponding author
Hongbo Sun can be contacted at: hsun@ytu.edu.cn