High Performance Computing Based Simulation for Healthcare Decision Support

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Abstract *- Due to the complexity and crucial role of an Emergency Department (ED) in the healthcare system. The ability to more accurately represent, simulate and predict performance of ED will be invaluable for decision makers to solve management problems. One way to realize this requirement is by modeling and simulation. The objective of this research is to grasp the non-linear association between macro-level features and micro-level behavior with the goal of better understanding the bottleneck of ED performance and provide ability to quantify such performance on defined condition. Agent-based modeling approach was used to model the healthcare staff, patient and physical resources in ED. Instead of describe all the potential causes of this complex issue. Rather, in this thesis, a layer-based application framework will be presented to discover knowledge of a complex system through simulating micro-level behaviors of its components to facilitate a systematic understanding of the aggregate behavior.*

I. Introduction

An emergency department (ED), also known as accident & emergency (A&E), emergency room (ER), or casualty department, is a medical treatment facility specializing in acute care of patients who present without prior appointment, either by their own means or by ambulance, some of which may be life-threatening and must be treated quickly. Such that, ED must operate to provide 24/7 year-round service. Since emergency department is the main entrance to a healthcare system that faces uncertainty everyday. The efficiency and quality of service in ED have big influence on the whole healthcare system. Making decisions under multi-constraint to meet uncertainty is a big challenge for ED managers. Simulation methods have long been used to model elements of healthcare systems with a view to analyzing new system designs, retrofitting to existing systems and proposing changes to operating rules. The modeling and simulation provide a quantitive way to analyze the behavior and predict the performance of an ED. There have been fruitful efforts in developing simulation models for solving healthcare management problems. The emergency department is a typical complex system. To perform intensive study, a realistic computational model is compulsory. An approach to modeling this kind of system is by using agent-based modeling and simulation, which is a kind of bottom-up modeling approach to investigate macro-level behavior from macro-level interactions among its components.

The final object of this study is to grasp the association between individual interaction and aggregate behavior with the goal of better understand a complex system. It includes two main parts, a pure agent based model for full emergency department and an application framework to discover knowledge from micro-level interaction data generated by the agent based model. Due to the complexity of both the real system and model, high performance computing techniques are used to deal with the big number of simulation scenarios and the massive data analysis (see publication [3]).

II. Results so far

A. A Generalized Agent-Based Model to Simulate ED

As a typical complex system, the functionality of an emergency department is reflected by the interaction of its components. Therefore, the most important part of the ED model is the behavior model of these components (i.e. patients, sanitary staff and test technicians). Based on this, we created a generalized agent-based model of the emergency departments. It was designed based on the survey of different EDs and with the participation of sanitary staff in ED. More specifically, the following sanitary staff were considered: admission staff for registration service, triage nurses for classifying patients according to their body condition, doctors, nurses and auxiliaries for helping patients move around the ED for tests. All the sanitary staff is modeled as junior or senior according to their expertise. As for the environment model, there are two areas work independently for high acuity patients (area A) with some careboxes (a room with bed and essential equipment) and low acuity patients (area B) with some chairs. Doctors and nurses are specified for different zones but the two zones share all the test services.

The proposed generalized model is a parametric model (same model, different parameter value configuration), the behavior of the agents as well as state transferring model is configurable. Therefore, it is not dedicated with one specific ED, which can be used to simulate different EDs through calibration process. The details about the generalized agent-based model can be found in our publication [2].

B. *The Simulator for a Real ED*

The flexibility and adaptability features of this generic model provide a platform for emergency department simulation to accommodate different scenarios without significant modification of the underlying model. It enables the simulation researchers to focus their effort on the understanding of ED behavior rather than developing a theoretical model each time. Based on the generalized model and real data provided by Hospital of Sabadell, we implemented the agent-based model by using Netlogo simulation environment and validated for simulating a real ED in Hospital of Sabadell. Several case studies have been carried out for proving the potential uses of the simulator. For example, to meet the increasing patient arrival overcrowding

problem, a quantitative analysis of the influence of ambulance response time (for departure) over the ED behavior. The features of this validated model as well as case studies can be found in our publication [1].

C. Application Framework for Knowledge Discovery

We proposed a framework to discover knowledge through simulating individual behavior of system components. The agent-based model was considered as the core as well as data source of the knowledge discovery system. The behavior simulation model can generate interaction information under various configuration scenarios. Analyzing this interaction enables knowledge discovery towards better understanding the complex systemic behavior thoroughly. This makes it possible to explore association between micro-level behaviors of individuals and macro-level patterns that emerge from their interactions, thus enabling users to better understand system's behavior under various conditions without any influence on the real system. Additionally, a layer-based architecture was used to achieve flexibility and metadata monitoring configurability. The application framework to Discover knowledge from micro-level behavior is an in-depth the root causes way to fully insight into the complex system, it not only able to do prediction, but also provide knowledge on how predictions are made. Several demonstrated case studies were provided to show the potential use of the presented framework as well as how small changes in procedure yield important changes in flow.

III. FUTURE WORK

ED is the main entrance to the healthcare service; some problems of the healthcare service system are caused by the performance of ED. However, the ED is not independent, all the departments of healthcare system influence each another. Thus, our future work also include creating the simulator of other healthcare departments, for example the hospital wards to close the simulation loop of the whole healthcare service system.

In addition, in order to assess the impact of the parameters and decision rules within the model, a sensitivity analysis was performed to determine how model is sensitive to changes in the parameters value. Sensitivity analyses are necessary to explore the behavior of complex system models, because the structural complexity of the modeled process and the model is coupled with a high degree of uncertainty in estimating the values of many of the input parameters. Sensitivity analysis for agent-based models provides understanding of the influence of the different input parameters and their variations on the model outcomes. Therefore, global sensitivity analysis of the emergency department will be a scope of my future work.

Furthermore, look deep into the system in one side is for providing information, another challenge for supporting critical decision is to find a balance or tradeoff between different parameter configurations, for instance service for patients and efficiency for providers. Accordingly, optimization based framework for managing complex processes in the healthcare domain is another scope of future work.

PUBLICATIONS

[1] **Zhengchun Liu**, Eduardo Cabrera, Manel Taboada, Francisco Epelde, Dolores Rexachs and Emilio Luque. Quantitative Evaluation of Decision Effects in the Management of Emergency Department Problems. International Conference on Computational Science, Reykjavík, Iceland. June, 2015. (*Accepted*)

[2] **Zhengchun Liu**, Eduardo Cabrera, Dolores Rexachs and Emilio Luque. A Generalized Agent-Based Model to Simulate Emergency Departments. The Sixth International Conference on Advances in System Simulation, Nice, France. October, 2014. (*Published*)

[3] **Zhengchun Liu**, Eduardo Cabrera, Dolores Rexachs and Emilio Luque. Study of Emergency Department by Using High Performance Computing. XXV Jornadas de Paralelismo Valladolid, Spain. Septiembre 2014. Jornadas sarteco 2014 (*Published*)

[4] **Zhengchun Liu**, Emilio Luque, Dolores Rexachs, Francisco Epelde, Eduardo Cabrera, Manel Taboada González. A Simulator of Emergency Departments for Decision Support and QoS Improving. V CONFERENCE: R+D+I Research and Development in ICT and Health. Girona, Spain, June 2014. (*Poster*)

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