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Hybrid modelling and simulation of huge crowd over a hierarchical Grid architecture

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ABSTRACT

The last decade has witnessed an explosion of the interest in technologies of large simulation with the rapid growth of both the complexity and the scale of problem domains. Modelling & simulation of crowd is a typical paradigm, especially when dealing with large crowd. On top of a hierarchical Grid simulation infrastructure, a simulation of evacuating tens of thousands of pedestrians in an urban area has been constructed. The simulation infrastructure can facilitate a large crowd simulation comprising models of different grains and various types in nature. A number of agent-based and computational models residing at two distinctive administrative domains operate together, which successfully presents the dynamics of the complex scenario at scales of both individual and crowd levels. Experimental results indicate that the proposed hybrid modelling & simulation approach can effectively cope with the size and complexity of a scenario involving a huge crowd.

1. Introduction

Modelling and simulation (M&S) are at the very core in many areas of science and engineering. With the rapid growth of both the complexity and the scale of problem domains, it has become a key requirement to create efficient and ever more complex simulations of large scale and/or high resolution for research, industry, and management. M&S of crowd is a typical paradigm. As a collective and highly dynamic social group, a human crowd is a fascinating phenomenon, which has been constantly concerned by experts from various areas. Recently computer-based modelling and simulation technologies have emerged to support investigation of the dynamics of crowds. Crowd M&S has now become a key design issue in many fields including military simulation, safety engineering, architectural design, and digital entertainment.

To represent the behaviour of a crowd, many behaviour models have been proposed with various types of modelling approaches [1], such as particle system models [2], flow-based models [3] and agent-based models [4]. Despite the many existing research efforts and applications in crowd M&S, it is still a young and emerging area. Work on modelling and simulation of large crowds (consisting of thousands of individuals or even more), especially at individual level, is still rare. Large agent-based systems, such as simulation of large crowds at individual level, have long been placed in the highly compute intensive world [5,4,6]. Study on crowd phenomenon still suffers from a lack of (1) an effective modelling approach to cope with the size and complexity of a scenario involving a huge crowd and (2) an appropriate platform to sustain such large crowd simulation systems.

In the last few years, there have been a lot of successful attempts of incorporating Grid [7–9] and Cloud technologies [10–16] to foster large simulations over the Internet, such as the Grid-aware Time Warp Kernel [17] and the HLA_Grid_RePast framework [18,4]. However, these simulation systems are only suited for executing coarse-grained models due to the limited network bandwidth between different administrative domains. Another issue is that only few nodes of an administrative domain are accessible to the external users due to the existing security rules of most administrative domains. The third issue concerns the reusability: large simulation developers often already have a set of simulation models/components situating over their intranet. Nevertheless, the advent of the hierarchical Grid infrastructure [5]

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paves the way to address the above problems. Existing individual bundles of simulation models be linked to form a dedicated large simulation crossing the boundaries of previously independent simulation groups and the boundaries of the administrative domains. Fine-grained models still benefit from the advantages of Grid technology. Users can have a flexible solution to the reusability issue.

This study employs the hierarchical Grid infrastructure as an effective approach to addressing the two pending issues in large crowd modelling and simulation. The resulted simulation system is hybrid in nature: (1) to capture the individuality of pedestrians, agent-based models have been developed with each agent representing a pedestrian; (2) to describe the global dynamics of the whole (or a part of interest) crowd, computational models have been used; and (3) these heterogeneous models are linked together to allow studying the interaction dynamics of a crowd at both individual and global scales.

The large crowd simulation system had been deployed over two distinctive administrative domains locating at China. The simulated crowd has a size, which is prohibitively large for traditional simulation techniques even using a cutting-edge office desktop. Our approach successfully alleviates the bottleneck in the design and analysis of particularly large and complex scenarios like huge crowd. This study is one of the first to provide a solution to simulation of a crowd with models of multiple scales and types.

The rest of this paper is organized as follows: Section 2 briefs the background and related work of crowd modelling & simulation. Section 3 recaps the hierarchical Grid simulation infrastructure. Section 4 describes the case study of exploring the dynamics of a huge crowd in an evacuation procedure. Section 5 concludes this work with a summary and proposals on future work.

2. Crowd modelling and simulation

As a collective and highly dynamic social group, a human crowd is a fascinating phenomenon, which has been constantly concerned by experts from various areas. A crowd may exhibit highly complex dynamics, in general pure mathematical approaches or analytic models are not adequate in characterizing the dynamics of a crowd.

Recently modelling and simulation technologies have been gaining tremendous momentum in investigating crowd dynamics. Various simulation architectures have been developed [19]. To represent the behaviour of a crowd, a number of behaviour models have been proposed with different types of modelling approaches, such as flow-based models and agent-based models. To study or mimic the dynamics of a crowd, modellers have considered a number of physical factors, social factors, and psychological factors when characterizing crowds in their models. Crowd models may also concern different aspects of a crowd. Some work aims at the "external characteristics" of a crowd, such as appearance, poses or movement patterns, coordinated positions of individuals; and some other works focus on how a crowd's social behaviours evolve over time upon some events.

Many open research issues are still very much in flux due to the complexity of individual and crowd behaviours [1]. Modelling of a crowd first needs to determine the scale (level of detail) of the model. The existing models are largely at two extreme levels: either modelling each individual as an autonomous agent equipped with some human-like behaviour modules such as locomotion, perception, and decision making, or treating the crowd as a whole or a collection of homogeneous particles with limited or no cognitive features. With the fast development of computing technology, there seems to be a trend in crowd simulation to model each individual as some kind of intelligent agent with attempts to incorporate more and more social and psychological factors into the agent behaviour model. However, we believe that the common shortcoming of the existing models is the absence of modelling the social group process and its impact on human behaviour.

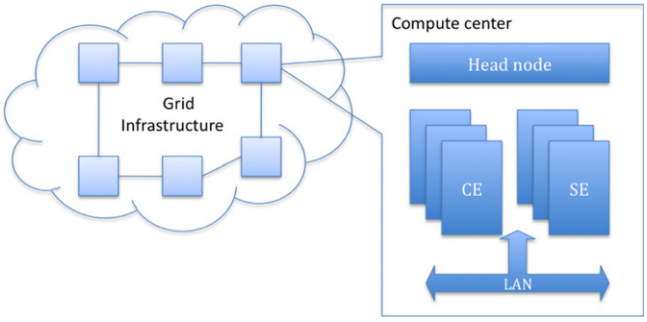

Fig. 1. Grid computing system architecture.

The interoperability issue is largely ignored by the existing research. Although there already exist a number of crowd simulation models and modelling approaches, these models can hardly work with each other: they may operate at different levels of abstraction. This makes the communication between different models difficult. In a typical crowd simulation, the crowd model is required to pass the information about individuals' actions and understand the events in the simulated world, so that the individuals can determine how to respond to these events. However, research in interoperable crowd simulation models is still rare.

This study attempts to address the two pending issues via the hierarchical Grid simulation architecture. We aim to explore an approach to constructing simulations of huge crowd constituted by models of various scales and types, thus the dynamics of a huge crowd may be investigated at different levels in a manner more comprehensive than existing approaches do.

3. The hierarchical Grid architecture for large hybrid simulation

In [5], we presented the hierarchical Grid computing architecture for large-scale simulation. The architecture serves as a simulation infrastructure, which can (1) across distributed administrative domains, (2) link multiple distributed simulation models into a large-scale simulation over Grids, and (3) reduce the communication overhead among simulation bundles. This section recaps basics of the Grid system as well as the design and functionalities of the architecture.

3.1. Grid system architecture

As shown in Fig. 1, a production Grid [20,16,21] typically contains a number of compute centres, which are linked by high-speed networking. A compute centre in general is organized at two levels. A head node, which hosts several access services and resource management functions for a compute centre, accepts incoming computing jobs and schedules them to local computing and data resources, which are termed here Compute Element (CE) and Storage Element (SE) respectively. Inside a data centre, the head node, CEs and SEs are interconnected by high performance local area network (LAN) [22,23].

3.2. HLA-based simulation model

The High Level Architecture (HLA) is a technology for simulator interoperability and the de facto standard [24] for simulations over distributed computing platforms. The HLA defines software architecture for modelling and simulation, which is designed to provide reuse and interoperability of simulation models/components, namely federates. A collection of federates interacting with each