Development of Pedestrian Crowd Simulation on GPU and Application to Evacuation from Large-scale Underground Shopping Mall

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INTRODUCTION

Pedestrian crowd simulations have been developed and applied to verification of the safety in buildings or urban environments. Agent based simulation are particularly well suited to pedestrian crowd behaviors from a set of simple individual rules. However, computing and visualizing crowd behaviors in real-time is a computationally intensive task because this intensity mostly comes from the O (n2) complexity of the algorithm needed for the interactions of all agents. By using special data structures such as grids, relevant previous works reduces this complexity.

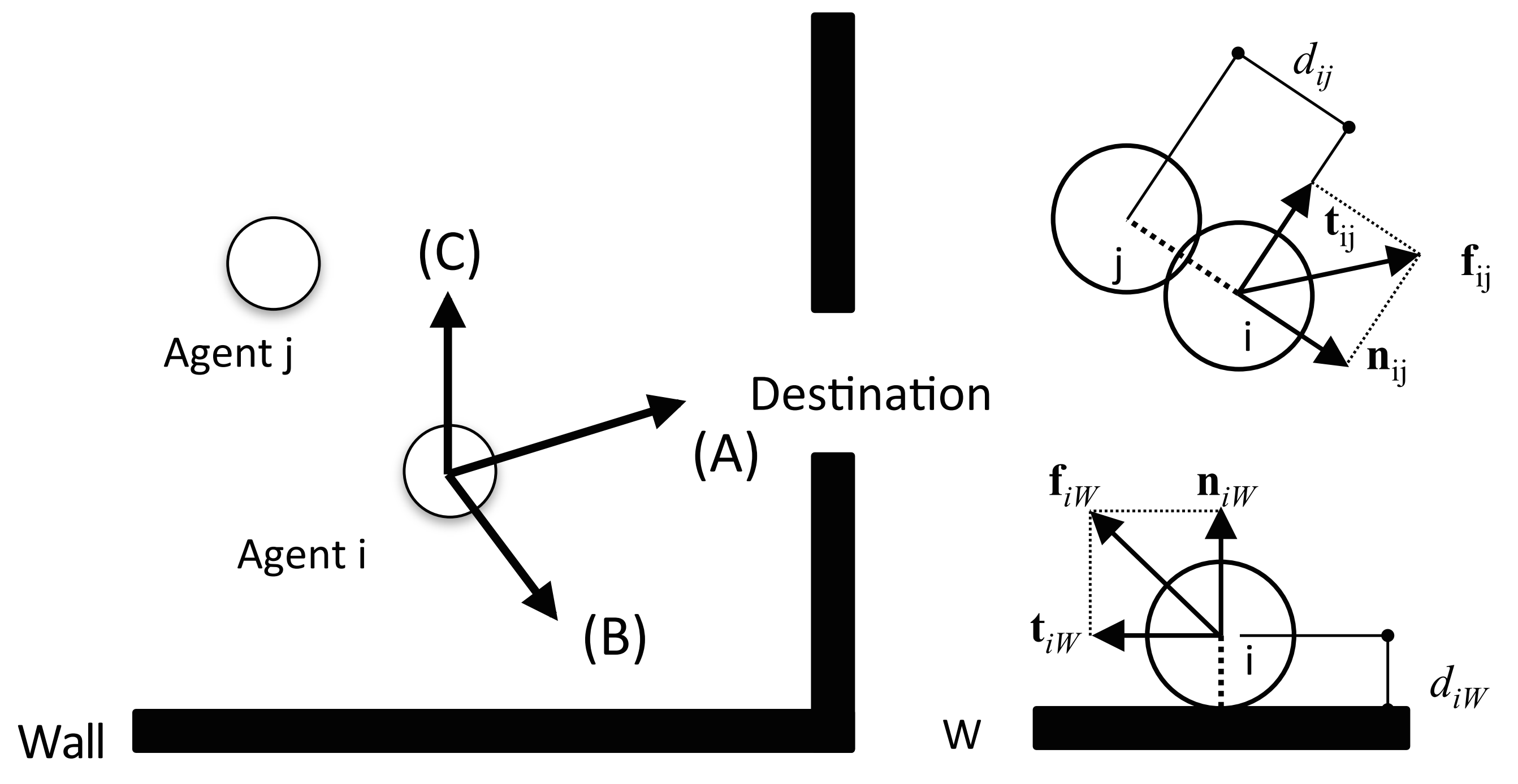
On the other hand, researchers demonstrated significantly increased speed-up after adapting existing CPU-oriented algorithms to parallel processing. Furthermore, modern GPUs have many cores; they offer large performance benefits for parallel processing at low cost. In 2007, NVIDIA released CUDA parallel-processing architecture for next-generation GPUs, letting programmers use C. It is becoming easier to develop agent based simulation on GPU.

In this study, we present a GPU based implementation of agent-based pedestrian crowd simulation and an application to the evacuation from a large-scale underground shopping mall.

IMPLEMENTATION

Agent-Based Modeling

We implemented the social force model in order to model pedestrian crowd behavior. The social force model solves the motion equation of an agent, which is represented by a moving disc (Figure 1). An agent that has mass and a constant radius is subjected to a force exerted by other agents and obstacles and exit position. These steps perform all operations on a GPU using CUDA (Figure 2). Parallel processing and the GPU' s many cores produce huge computational power, enough to update massive pedestrian crowds.



$$m_i \frac{d\mathbf{v}_i}{dt} = m_i \frac{v_i^0(t)\mathbf{e}_i^0(t) - \mathbf{v}_i(t)}{\tau_i} + \sum_{j(\neq i)} \mathbf{f}_{ij} + \sum_{W} \mathbf{f}_{iW}$$

$$\mathbf{f}_{ij} = \{A_i \exp[(r_{ij} - d_{ij}) / B_i] + kg(r_{ij} - d_{ij})\}\mathbf{n}_{ij} + \kappa g(r_{ij} - d_{ij}) \Delta v_{ji}^t \mathbf{t}_{ij}$$

$$\mathbf{f}_{ib} = \{A_i \exp[(r_i - d_{iW}) / B_i] + kg(r_i - d_{iW})\}\mathbf{n}_{iW} - \kappa g(r_i - d_{iW})(\mathbf{v}_i \cdot \mathbf{t}_{iW})\mathbf{t}_{iW}$$

Fig.1 Social Force Model

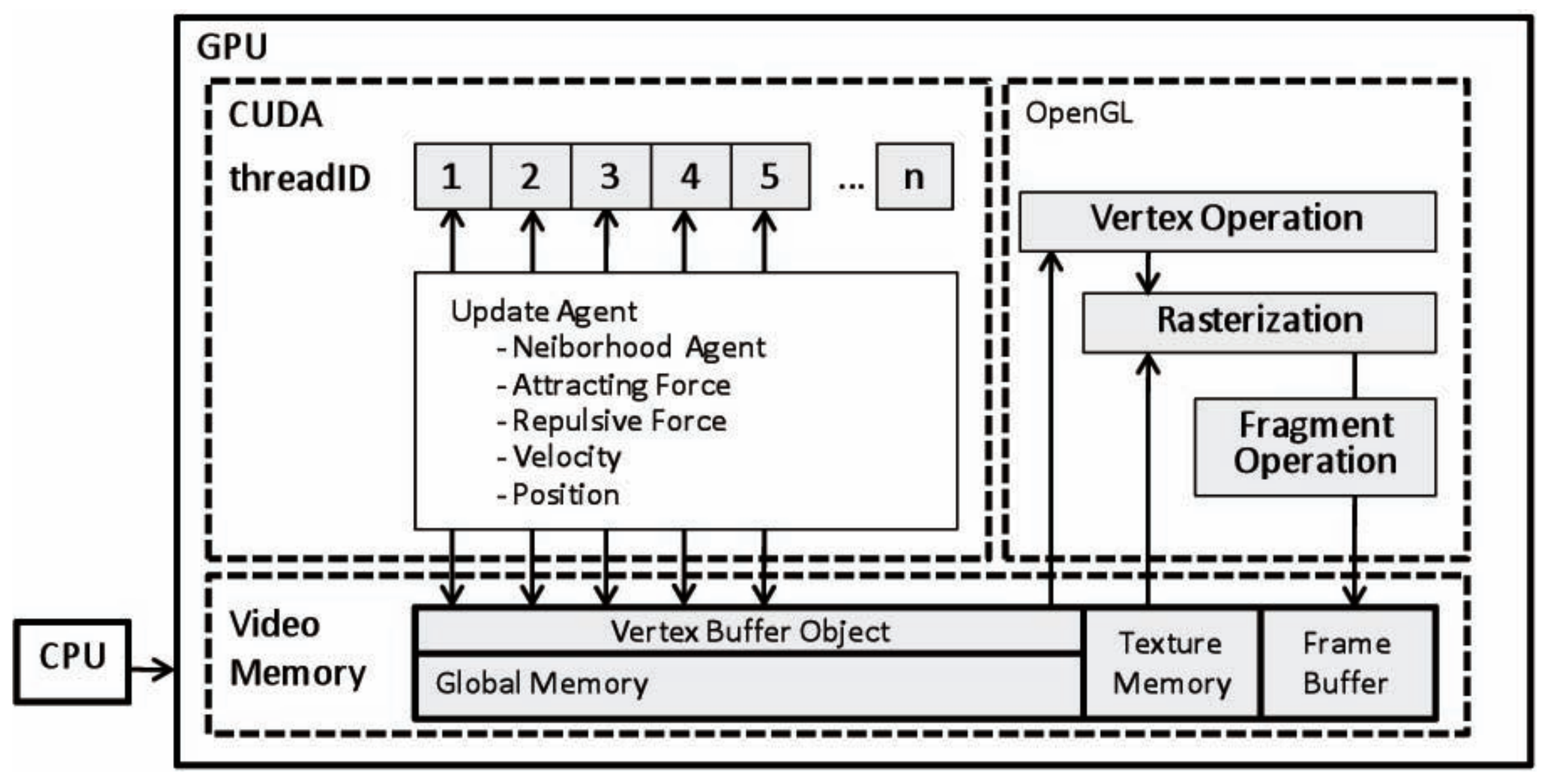


Fig2. Operations on GPU

CASE STUDY AND PERFORMANCE

As a case study of the pedestrian crowd simulation, we configured an evacuation situation in a large-scale underground shopping mall in Osaka, Japan in Figure 3.

As a performance testing, we evaluated two versions of the simulation. While the first was executed on the GPU, the second was executed on the CPU. Both versions used the same algorithm and data structure. The average time to compute the social force of all agents without rendering process is shown in Figure 4. These simulations were executed for each implementation type varying only the number of agents, ranging from 1,000 to 10,000. As a result, the GPU version presents better scalability than the CPU version. When the number of agent is 10,000, the GPU version is approximately seven times faster than the CPU version. Moreover, it is possible to see that the performance of the GPU implementation sustained interactive frame rates with rendering of complex models of agents and buildings.

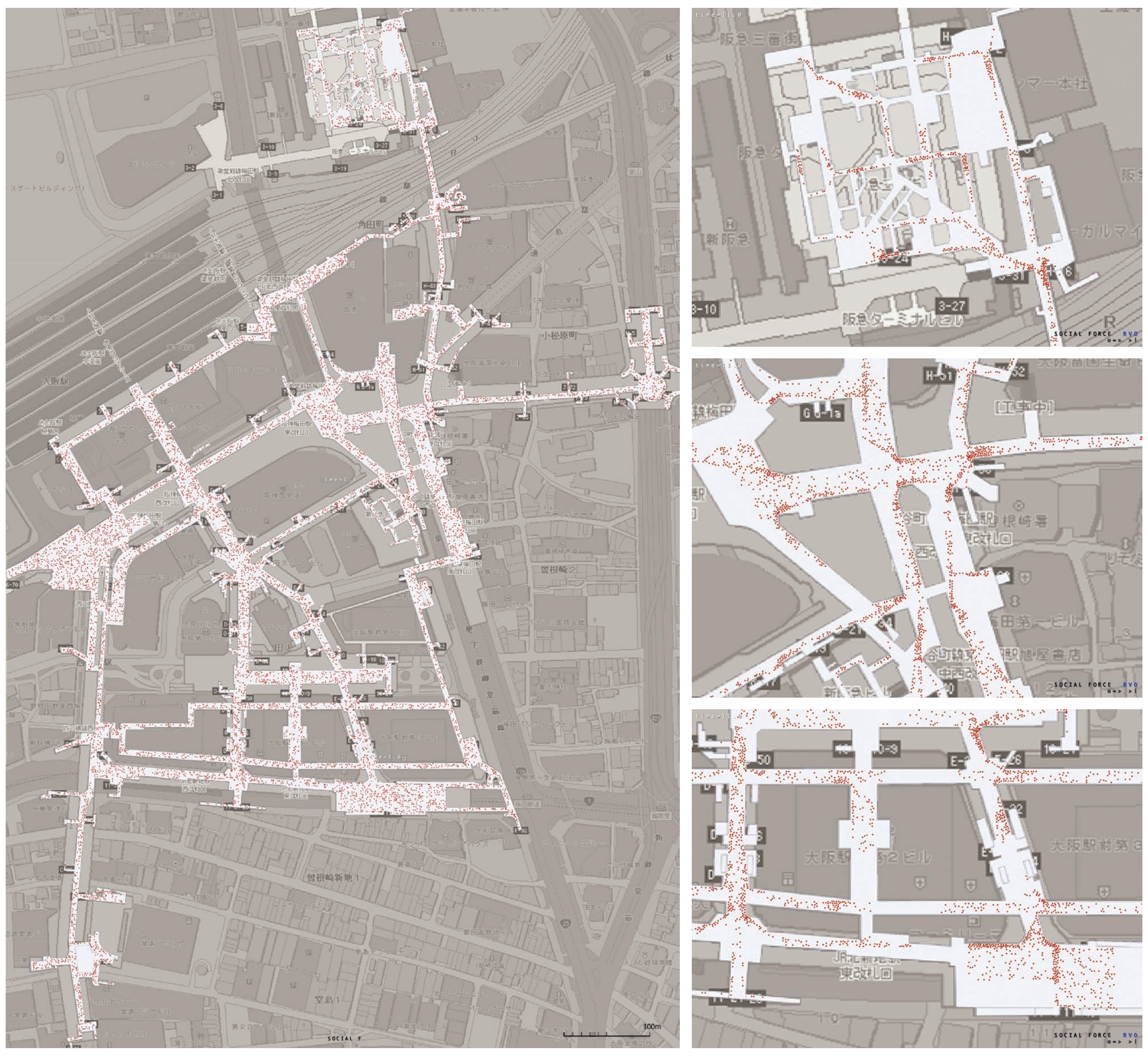
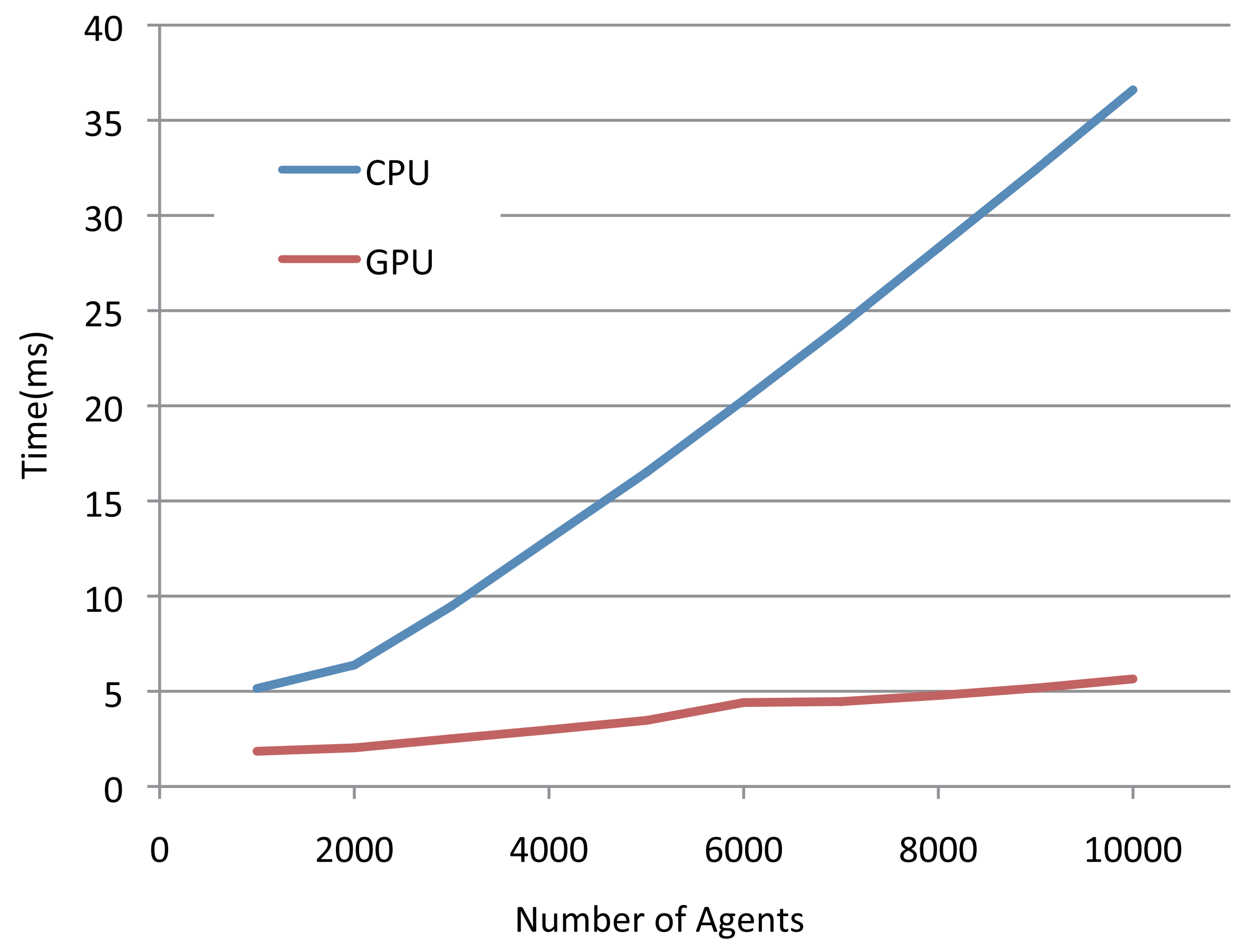


Fig3. Application to Large-scale Underground Shopping Mall



These tests were performed on an Intel Core i7 CPU 930@2.80GHz with a NVIDIA GeForce GTX 460 GPU

Fig. 4 Performance Result of CPU and GPU

Conclusion

We showed an implementation capable of running up to 10,000 abents at an interactive frame rate using current graphics hardware and CUDA technology

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