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An Improved Seismic Damage Assessment Model for Buildings Based on Parallel Algorithms

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Abstract. The efficiency of post-quake emergency management depends heavily on the speed of seismic damage assessment software, which depends on the evaluation algorithm essentially. Traditional seismic damage assessment models based on sequence algorithms usually need tens of minutes to get visualized results. More efficient computing models for seismic damage assessment are demanded urgently. General parallel evaluation algorithm based on GPU computing framework was investigated by the authors, and an improved seismic damage assessment model for buildings was proposed in this paper. We designed a three-level parallel scheme to accelerate the computing and visualization. At the top level, the earthquake area is divided into smaller regions, such as cities or counties. At the middle level, fundamental geographic data for each region is split into layers by features. At the bottom level, buildings are grouped into several types, which can be processed by GPU cores simultaneously. The developed model can estimate and analyze the seismic damage of buildings and the spatial distribution of victims in earthquake region more rapidly than traditional models.

Keywords: parallel algorithm, seismic damage, assessment model, buildings, GPU

1. Introduction

After a destructive earthquake, the most urgent task is to get enough information about disaster areas as soon as possible, which is the foundation of other post-quake works. The information includes the destruction of buildings throughout the earthquake zone and the damage of roads, bridges and other infrastructures. The information also includes spatial distribution of casualties and trapped people, especially their concentration areas. They are both essential for emergency management and formulation of the rescue plan.

However, it is very difficult to get this information accurately in a short time, especially in the first hour after a major earthquake [1]. Therefore, seismic damage assessment software, which can estimate damage extent of structures and spatial distribution of trapped people rapidly, is utilized to support the rescue work and emergency commanding. For this reason, the efficiency of post-quake emergency management depends heavily on the speed of seismic damage assessment software, which depends on the evaluation algorithm essentially.

In the past several decades, dozens of seismic damage assessment software (such as PAGER, HAZUS, EXTREMUM, LESSLOSS, NERIES, MAEVIZ, etc.) were developed based on different assessment models [2]. They are almost based on sequence algorithms, to deploy on PCs with a single CPU. Unfortunately, they usually need tens of minutes to get visualized results when they meet a great event (such as Wenchuan Ms 8.0 earthquake). More efficient computing models for seismic damage assessment are demanded urgently.



With the development of computer hardware, multi-core CPU and many-core GPU are applied on personal computers. They are small but powerful parallel computing systems just at hand, which provide us great opportunities to solve a lot of complex problems, such as fast assessment for seismic damage.

In this paper, we investigated general parallel evaluation algorithm based on GPU computing framework firstly. Then we proposed an improved seismic damage assessment model for buildings with parallel analysis procedures. A three-level parallel computing scheme was designed to accelerate the calculation and visualization.

2. Evaluation Algorithms

After a strong earthquake occurred, energy produced by fault rupture spreads in form of seismic waves. When they reach the globe surface, the remaining energy causes ground motion with different intensity at different locations. Under the action of ground motion, structures (such as buildings, bridges, roads and other infrastructures) will be subject to different degree of damage, and then cause different casualties and financial losses. Seismic damage evaluation algorithm estimates ground motion field of disaster area and the damage level of structures, based on attenuation law of ground motion and seismic damage prediction methods.

In this section, we will discuss drawback of sequence evaluation algorithms and their performance bottlenecks in computing. Based on GPU computing framework, parallel evaluation algorithm will be drawn up in general.

2.1. Sequence Evaluation Algorithms

As we mentioned, most traditional evaluation algorithms were designed for running on single CPU. Figure 1 shows the main steps of a typical sequence evaluation algorithm, in which one step cannot be executed until previous steps finished. Furthermore, calculations in each step are usually executed in nested loops, which are processed serially from the view of CPU. That means everything has to be done one by one in order, even on a system with parallel architecture.

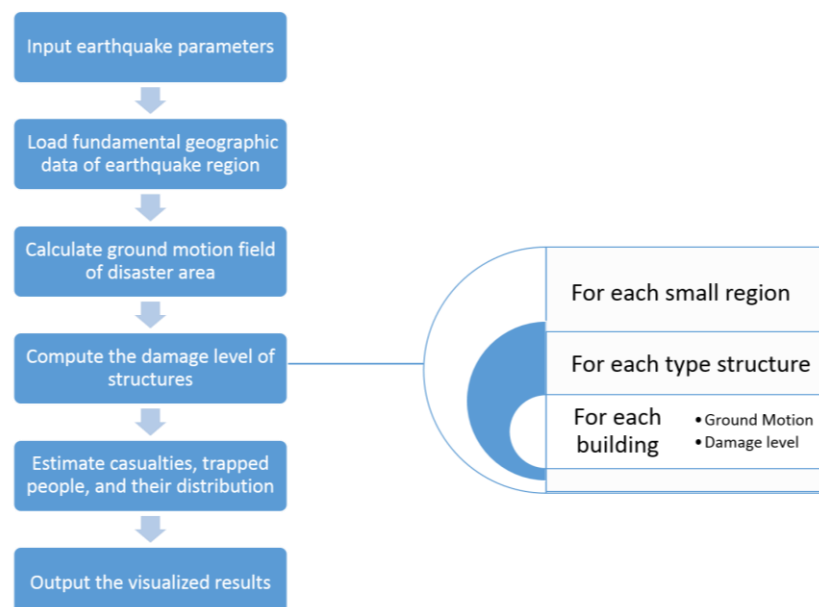


Figure 1. Flowchart of a typical sequence evaluation algorithm

For this reason, sequence evaluation algorithms cannot exploit the computing capability of mainstream computers today efficiently. Software with sequence algorithms become very slow and time consuming when they meet massive calculations. If the area influenced by the earthquake is very

large, or the data to be process is enormous, we must wait anxiously for the results in tens or hundreds of minutes.

In fact, there are some significant performance bottlenecks in sequence evaluation algorithms. 1) Loading the fundamental geographic data of earthquake area serially; 2) Calculating the ground motion intensity for each structure; 3) Computing the damage level of structures one by one; 4) Low efficient visualization method in results outputting. They all can be improved by parallelism.

2.2. Parallel Evaluation Algorithm

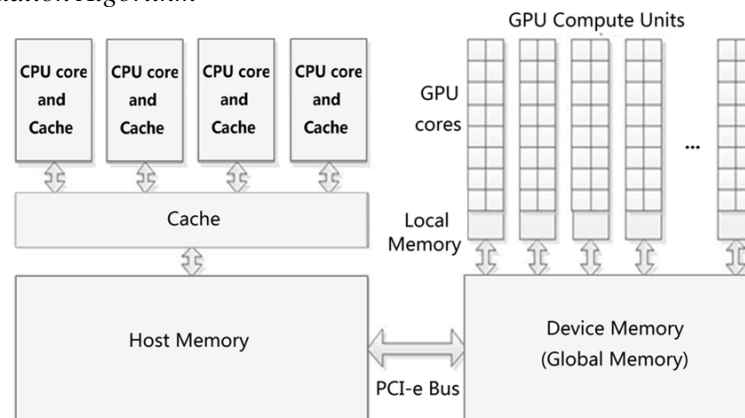


Figure 2. Computing architecture of a typical modern computer

As shown in figure 2, a typical modern computer is a heterogeneous computing platform. In this hybrid architecture, a CPU core has few ALUs and a big cache, which is good at logical judgment and serial processing. At the other hand, a GPU core has many ALUs and a small cache, which favors tremendous parallel computing [3]. To utilize the hardware efficiently, GPU is usually devoted to the portions handling intensive computing in a software, and CPU is responsible for the other things.

For seismic damage assessment, four computing tasks can be processed by the GPU in form of parallelized procedures:

1) **Ground motion field.** The ground motion intensity at a specific location depends mainly on the magnitude of the event and the distance to the epicenter [4]. The ground motion intensity at different points can be calculated simultaneously if we know the parameters about earthquake and locations. Although the intensity of this calculation is normal, the results produced are necessary for next several steps. By storing these data in groups, other tasks can be executed more smoothly.

2) **Damage of structures.** The damage level of a structure depends mainly on its vulnerability and the ground motion under it [5]. Therefore, damage of different structures can also be calculated simultaneously based on their parameters and ground motion intensity they meet. Because each type of structure must be processed by a specific evaluation algorithm, different types of structures should be cataloged into different groups before they are delivered to the GPU. To make use of the power of GPU more efficiently, the calculation in each group can also be divided into many sub-tasks, in which smaller pieces are computed by GPU ALUs respectively.

3) **Casualties and losses.** Major casualties and losses are usually caused by damaged structures directly, and trapped people often concentrate in the ruin buildings [6]. If we find a structure damaged badly, it is a candidate location for victims. Based on the results of damage evaluation for structures and fundamental data for population and commodity, we can predict spatial distribution of the casualties, losses, and trapped people rapidly. This calculation can also be performed in parallel by dividing a large area into smaller zones.

4) **Visualization.** The results for seismic damage evaluation usually contain enormous data, which cannot be understood by human beings unless they are converted into the forms readable (table, chart, picture and so on). Three dimensional scene has been introduced to browse and comprehend the

results more intuitively [7]. However, it is very time consuming to build a large scene using a sequence algorithm. On the GPU platform, this task can be accelerated efficiently, by building structures in parallel.

Figure 3 shows a general parallelized flowchart for seismic damage evaluation.

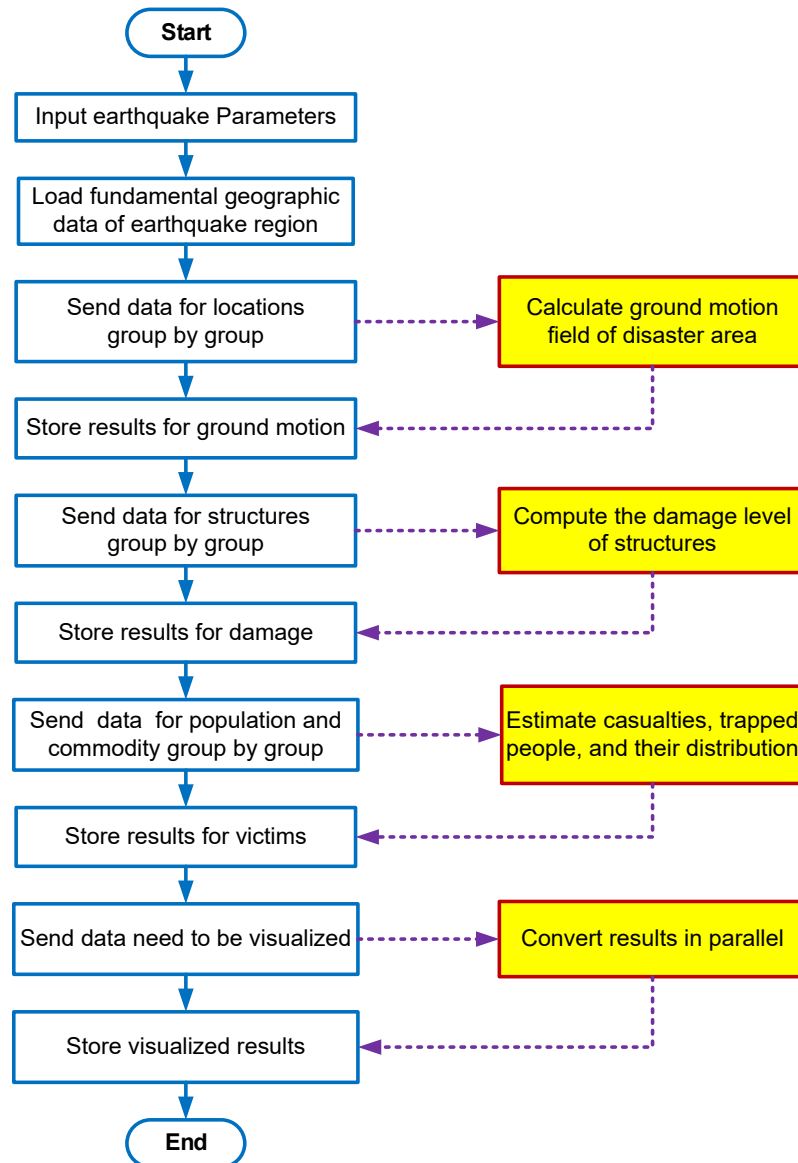


Figure 3. A general parallelized flowchart for seismic damage evaluation

3. Improved Assessment Model for Buildings

Based on the general parallelized evaluation algorithm, we can develop specific parallelized computing models for seismic damage assessment. As a start point, we focus on the assessment of buildings.

3.1. Prediction Method

To find out the ruin buildings quickly and locate them accurately, we need to employ a prediction method for single building. According to the study of Sun Baitao and Sun Dezhang [8], the vulnerability of a building can be roughly described by some related parameters (such as foundation

type, building type, construction standard, regularity, age, storey and material strength level), then the damage level of a building can be determined by an algorithm based on fuzzy mathematics.

Unfortunately, most fundamental geographic data cannot provide so many parameters, which makes it impossible to apply the method above directly. Therefore, we proposed a simplified method, in which the most important parameters are selected to describe the vulnerability of a building. They are building type, construction standard, age and storey. Based on these parameters and the ground motion intensity calculated in advance, we can evaluate the damage level of a building more quickly.

3.2. Computing Scheme

To accelerate the computing and visualization more efficiently, fundamental geographic data should also be processed in parallel from the beginning. To do this, we designed a computing scheme emphasized on data parallelism, which can improve the performance bottleneck in data loading and scene building.

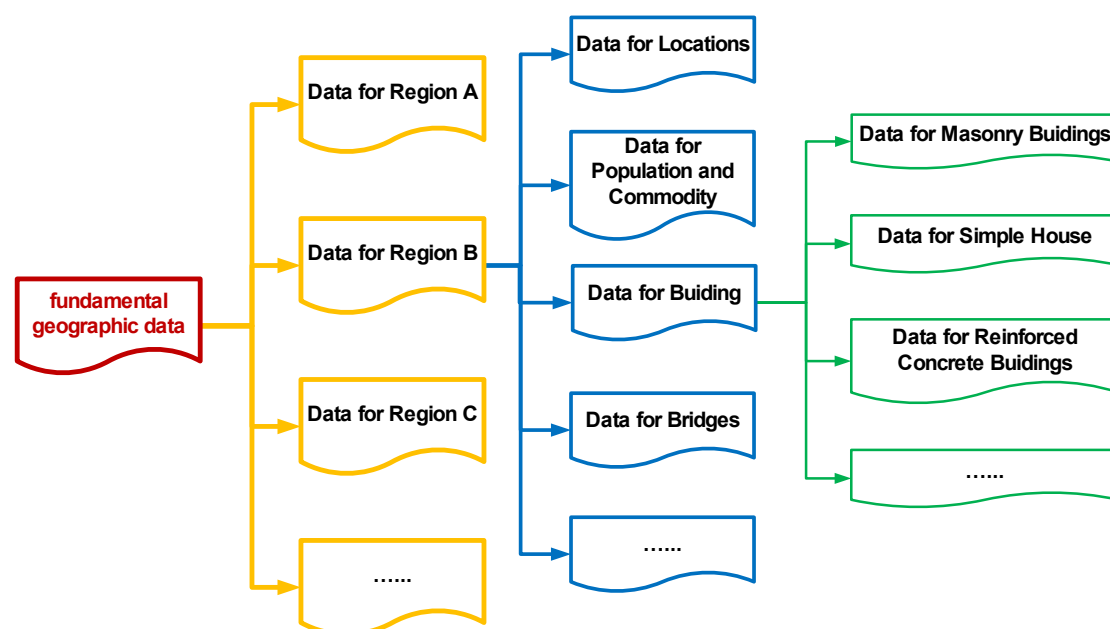


Figure 4. Data parallelism for the proposed model

As shown in Figure 4, the fundamental geographic data can be parallelized in three level. At the top level, the earthquake area is divided into smaller regions (such as cities or counties), which can be analyzed respectively. At the middle level, fundamental geographic data for each region is split into many layers (such as locations, buildings, Bridges). Data can be accessed simultaneously to/from different layers. At the bottom level, buildings are further grouped by types (such as masonry buildings, simple houses, reinforced concrete buildings), which can be processed by GPU as a sub-task.

4. Conclusion and Future Work

In this paper, we proposed an improved seismic damage assessment model for buildings based on parallel algorithms. The developed model can estimate and analyze the seismic damage of buildings and the spatial distribution of victims in earthquake region more rapidly than traditional models. Software and applications based on this model will be developed in nearly future.

Acknowledgments

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