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Citation	Proceedings of the Thirteenth East Asia-Pacific Conference on Structural Engineering and Construction (EASEC-13), September 11-13, 2013, Sapporo, Japan, H-1-1., H-1-1
Issue Date	2013-09-13
Doc URL	http://hdl.handle.net/2115/54441
Type	proceedings
Note	The Thirteenth East Asia-Pacific Conference on Structural Engineering and Construction (EASEC-13), September 11-13, 2013, Sapporo, Japan.
File Information	easec13-H-1-1.pdf

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HIGH PERFORMANCE COMPUTING OF DYNAMIC STRUCTURAL RESPONSE ANALYSIS FOR THE INTEGRATED EARTHQUAKE SIMILATION

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ABSTRACT

This paper proposes an application of high performance computing (HPC) to dynamic structural response analysis (DSRA) in order to enhance the capability and increase the efficiency of integrated earthquake simulation (IES). Object Based Structural Analysis (OBASAN) is a candidate DSRA program for IES. With OBASAN, the reliability of structural damage prediction can be increased by means of more complicated structural analysis models, which provide a large number of parameters to generate mathematical equations containing large matrices. In HPC, the general purpose graphic processing unit (GPGPU) is designed to deal with a large amount of data and a large number of simple calculations in mathematical equations. CUDA architecture is a candidate parallel programming model which can extend C/C++ programming code to enable parallel processing in the graphic processing unit (GPU). Since HPC technique can support the solution of mathematical equations in a reasonably short time and since more complicated structural analysis models can be applied to the nonlinear dynamic structural response analysis, IES can be significantly improved to provide more reliable prediction of structural damage in earthquake scenarios.

Keywords: IES, OBASAN, HPC, GPGPU, CUDA.

1. INTRODUCTION

Integrated earthquake simulation (IES) is an advanced computer technology for predicting and visualizing structural damage in earthquake scenarios. A sample of IES is shown in figure 1 (Hori et al. 2006). In IES, all buildings in a sample area can be represented as structural models, and structural damage can be predicted using linear and nonlinear dynamic structural response analysis. Because there are a large number of buildings in a sample area for earthquake simulation and each building has unique characteristics, high performance computing (HPC) is necessary to execute the dynamic structural response analysis (DSRA) in a reasonably short time.

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The contents of this paper are as follows. In Section 2, the Object Based Structural Analysis (OBASAN) is explained, and advantages of the current OBASAN are discussed. In Section 3, an application of high performance computing (HPC) to the dynamic structural response analysis (DSRA) is explained. Subsequent applications are described in Section 4. The purpose of this research is to apply HPC to OBASAN in order to enhance the capability and increase the efficiency of IES.

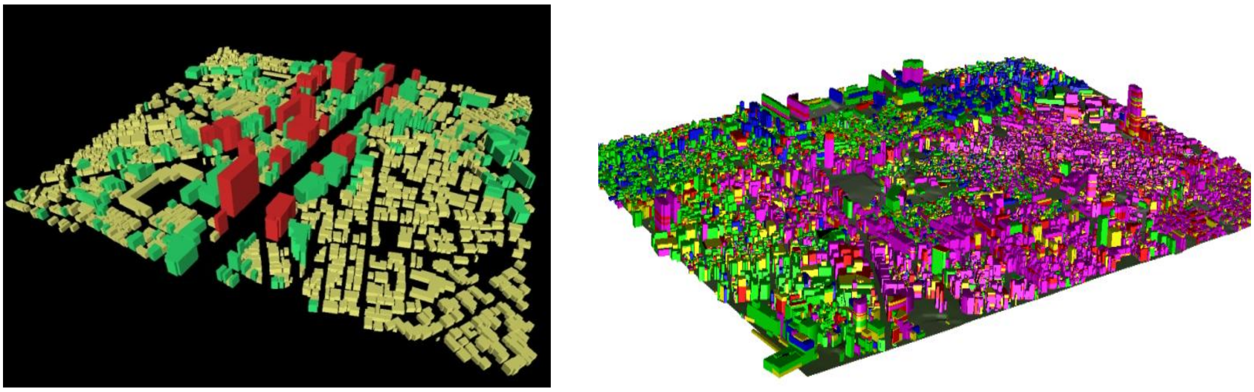

Figure 1: Integrated earthquake simulation (IES)

2. OBASAN

As for the DSRA program in IES, one good candidate is Object Based Structural Analysis (OBASAN). In an earthquake simulation, each building in a sample area can be represented as a structural model for analysis of each element. Geographic information system (GIS) provides structural shape data in the form of points and polygons, as shown in Figure 2, and other database systems provide building types (e.g., reinforced concrete structure, steel structure, wooden structure and base-isolated structure). Based on Japanese building design code, structural analysis models of all buildings in IES are automatically generated from the dimensions and type of each building, and then OBASAN can be used to analyse these structural analysis models. Structural damage to all buildings in a sample area can be predicted and overall damage in a city area can be illustrated from this earthquake simulation.

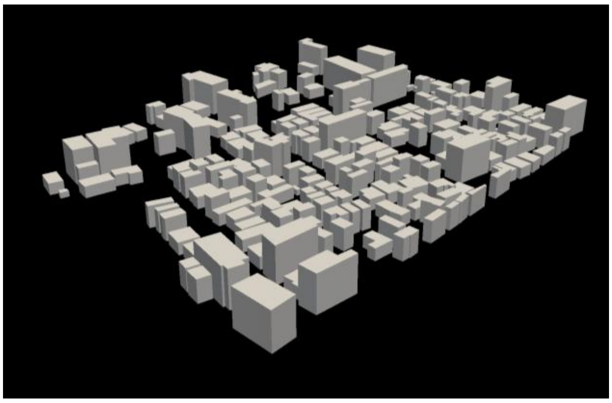

Figure 2: Structural shape data of GIS

2.1. Structural analysis models

The more complicated structural analysis models can increase the reliability of structural damage prediction, e.g., hysteresis models can be used for nonlinear dynamic structural response analysis. Models of structural elements, such as spring, beam, column and shell elements, can be used to obtain the more reliable results. These structural element models are analysed using nonlinear dynamic structural response analysis with consideration to the nonlinear properties of construction materials.

2.2. Structural analysis results

OBASAN is used to analyse the structural analysis models in order to get the node results (e.g., displacement, velocity, acceleration and reaction force) and the element results (e.g., bending moment, shear force, axial force, deformation, stress and strain) of each building in earthquake simulation, and therefore OBASAN can provide various types of structural analysis results. These results can be used to predict structural damage to all buildings, and also overall damage in a city area can be illustrated in IES.

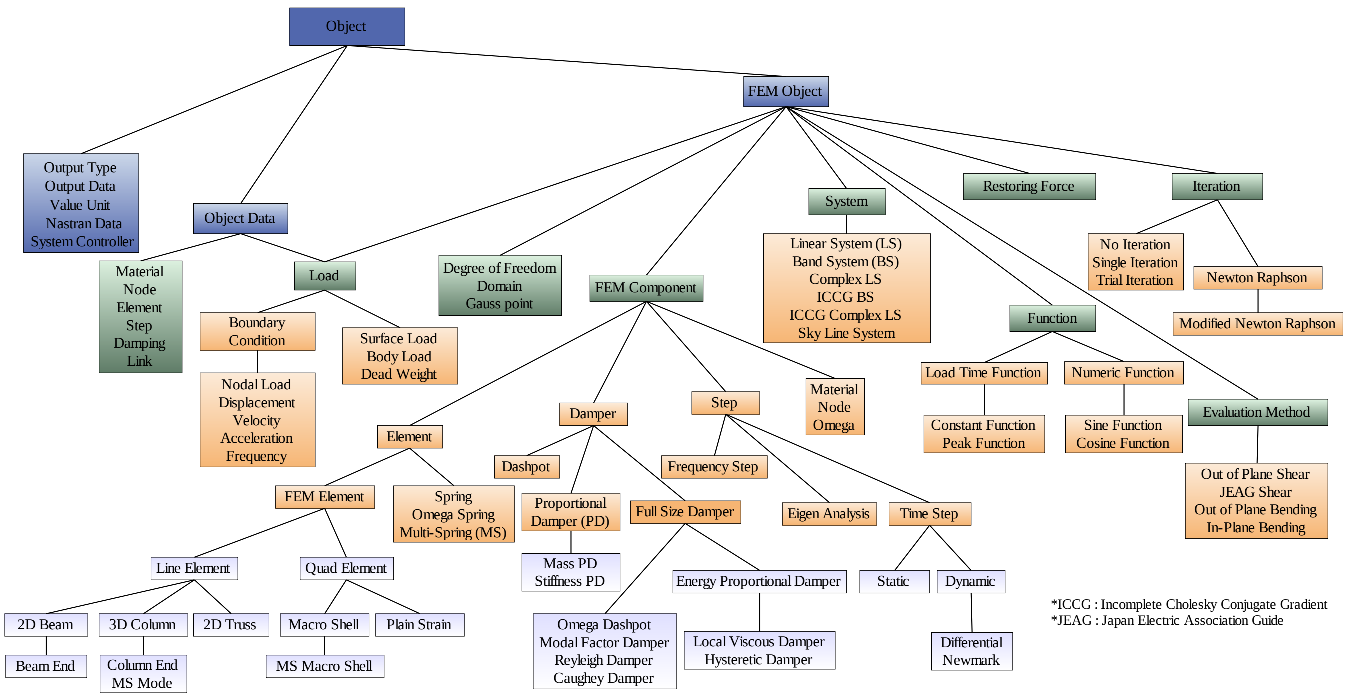

Figure 3: OBASAN

2.3. OBASAN Architecture

As shown in Figure 3, OBASAN was developed by means of class-based object-oriented programming using C++ language. The C++ programming language can be extended to enable parallel processing in GPU. As can be seen in this diagram, the OBASAN architecture is arranged systematically and is easy to understand. In OBASAN, it is very convenient for developers to modify all functions so that OBASAN can accommodate recent technologies and data types in order to increase efficiency in DSRA.

3. HPC

Since there are a large number of buildings in the earthquake simulation of each sample area, IES uses the OpenMPI architecture in order to enable parallel processing in the central processing unit (CPU). In CPU, a small subset (e.g. 10) of buildings can be run at one time with maximum number of threads in parallel processing. As in IES, the OpenMPI architecture is used for parallel processing of all buildings in a sample area, and in OBASAN, the CUDA architecture is used for parallel processing of DSRA for each building.

Since the DSRA deals with more complicated models, the structural analysis models must provide a large number of parameters, which are expressed in mathematical equations containing large matrices. For such an advanced computing task, HPC technique is a common approach to the solution of these mathematical equations in a reasonably short time. In HPC, GPGPU is designed to deal with a large amount of data and a large number of simple calculations in mathematical equations. In GPGPU, the CUDA architecture can be selected to solve these mathematical equations of DSRA for HPC. In DSRA, matrix multiplication is used for structural analysis at each time step.

Table 1 shows an example of execution time for matrix multiplication (C = AB). The matrices A, B and C are assumed to be a square matrix and the matrix size of A, B and C is N * N. The C++ programming code of the matrix multiplication is run on CPU (Intel Xeon Processor E5645), and CUDA extension is run on GPU (Tesla M2050). An execution time of CPU and GPU for the matrix multiplication is shown in table 1.

Table 1: An example of matrix multiplication

*Matrix size (N * N)*	*CPU time (sec)*	*GPU time (sec)*
250 * 250	0.1343	0.0006
500 * 500	1.2111	0.0027
750 * 750	4.2088	0.0071
1000 * 1000	10.3524	0.0157
1250 * 1250	20.8688	0.0290
1500 * 1500	41.5084	0.0468
1750 * 1750	71.0964	0.0737
2000 * 2000	91.2003	0.1026
2250 * 2250	198.0169	0.1525
2500 * 2500	269.6148	0.2171

*Matrix size (N * N)*	*CPU time (sec)*	*GPU time (sec)*
2750 * 2750	389.9368	0.2829
3000 * 3000	447.8122	0.3573
3250 * 3250	692.1258	0.4498
3500 * 3500	878.4347	0.5626
3750 * 3750	1086.8954	0.6909
4000 * 4000	1133.5968	0.7412
4250 * 4250	1484.2185	0.9687
4500 * 4500	1855.4903	1.1724
4750 * 4750	1866.9938	1.3547
5000 * 5000	2000.5736	1.5680

In DSRA, matrix size is defined by the total number of degrees of freedom (DOF) in a whole building, so matrix size depends on the dimensions of each building. Small buildings such as houses are represented by small matrices and large buildings are represented by larger matrices. As can be seen in table 1, GPUs are much faster than CPUs for any case of matrix multiplication. CPU time and GPU time are the execution time for only one time step of DSRA. If there are many time steps for each building, then GPU is more powerful.

From the data in table 1, figure 4 shows the comparison of execution time of matrix multiplication in CPU and GPU. As can be seen in this graph, execution time is directly related to matrix size both in CPU and in GPU. The larger matrix size needs more execution time to solve the matrix multiplication, and GPU times are much less than CPU times. The larger the matrix size, the more the speed performance of GPU is greater than that of CPU. For matrix size larger than 2000 * 2000, GPUs are faster than CPUs more than 1000 times. Therefore, in DSRA, GPU is more effective than CPU for all dimensions of buildings. In addition, the larger the dimension of each building, the greater is the speed advantage of GPU over CPU.

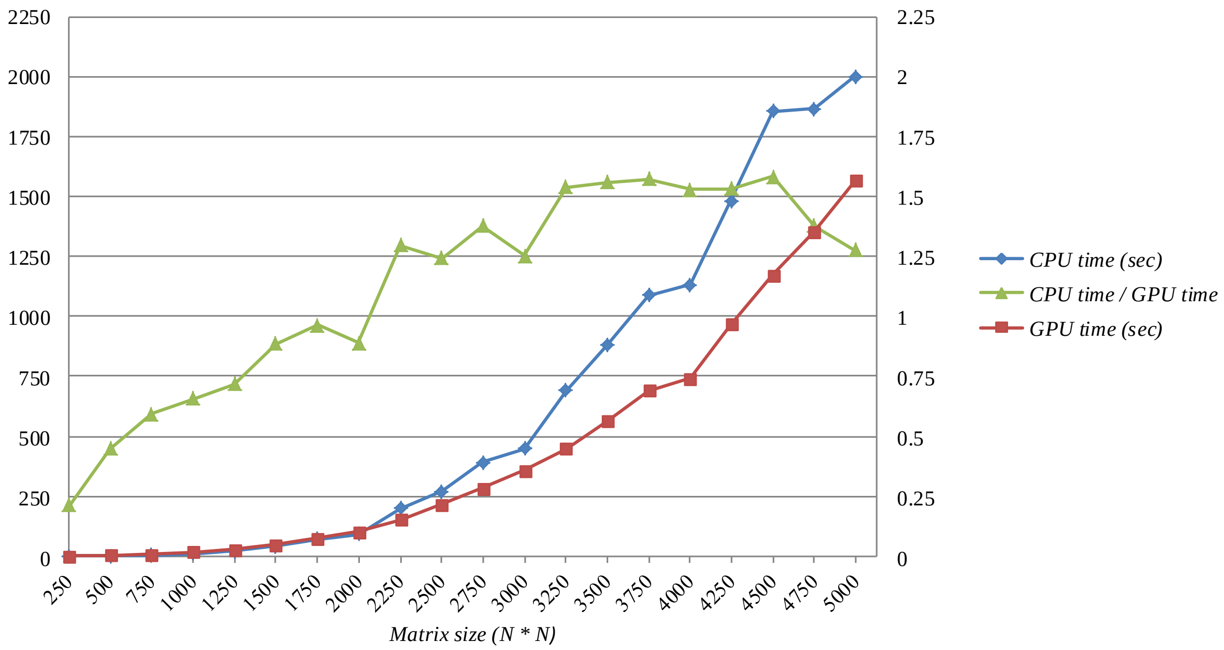

Figure 4: Comparison of CPU time and GPU time

Above example of matrix multiplication is a simple CUDA technique. The high performance computing (HPC) of DSRA can be increased using CUDA libraries. CUDA libraries, such as CUBLAS (linear algebra), CUFFT (Fast Fourier Transform) and CUSPARSE (sparse matrix), can solve the mathematical equations used in DSRA. Moreover, all CUDA libraries are optimized for HPC. In OBASAN, CUDA can be used in the equation solving functions to execute these functions in a reasonably short time. In addition, OBASAN with CUDA extension appears likely to achieve good scalability in IES. This will be investigated in near future research.

In OBASAN, CSystem and CStep are two programing classes related to the solution of mathematical equations. As shown in Figure 5, CSystem has six independent methods for solving matrices in OBASAN. Therefore, CUSPARSE and CUBLAS is a candidate method for solving matrices in CSystem. In CStep, CFrequencyStep calls some functions from Fast Fourier Transform (FFT) algorithm, so CUFFT can replace FFT algorithm.

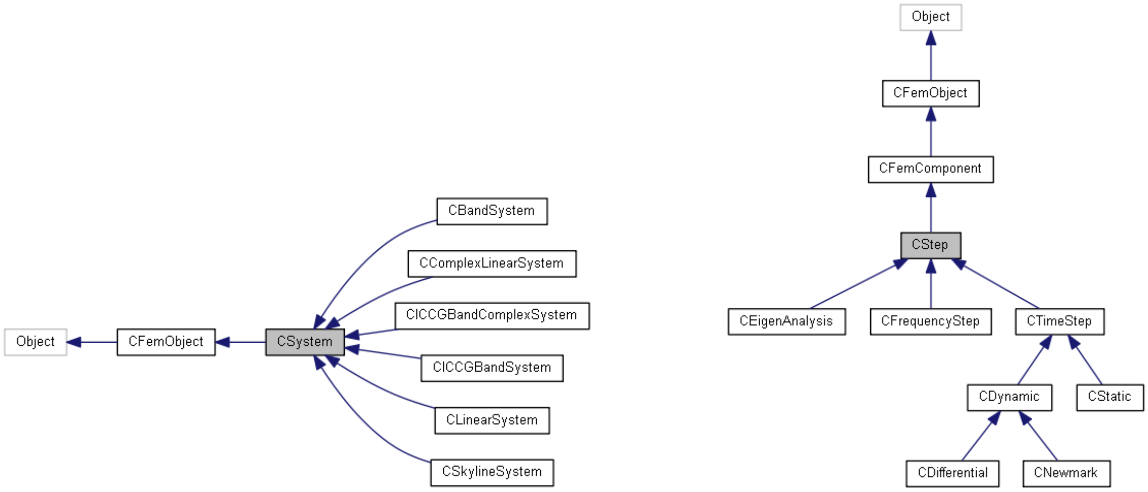

Figure 5: CSystem class and CStep class

4. CONCLUSIONS

In order to reduce the social and economic impact of earthquakes, researchers are attempting to apply new technologies and the latest data to IES. Numerical simulation is used to predict possible damage in earthquake scenarios. In earthquake simulation, reliable prediction of damage to society is very important to disaster management. This approach to mathematical problem solving by means of HPC and CUDA can be applied to various engineering fields including earthquake engineering. Since HPC technique can support a solution of mathematical equations in a reasonably short time and since more complicated structural analysis models can be applied to the nonlinear dynamic structural response analysis, IES can be significantly improved to provide more reliable prediction of structural damage in earthquake scenarios.

Given a reliable set of predictions, a strengthening plan and a guideline for new building construction can be constructed to prevent structural damage in earthquake scenarios. In addition, an evacuation plan and a transportation plan can be prepared to demonstrate the escape routes for people and the emergency routes for urgent help. These prevention measures can protect human life and property in earthquake scenarios.

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