EFFICIENT PERFORMANCE BASED DESIGN USING PARALLEL AND CLOUD COMPUTING

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Outline

1. Why HPC in Structural Engineering

2. What is High Performance Computing (HPC)
   – Cloud Computing
   – Parallel Computing

3. Application of HPC in Performance-based Design

4. What is next
Why HPC in SE?

Capacity Design: Well-defined inelastic behavior

Performance-based Design:
- Serviceability to frequent earthquakes
- Low probability of collapse during an extremely rare event

Well-developed computer model to get a best-estimate response at the various levels of earthquake demands

Large-scale simulations requires **time, computer resources, data processing**

Speed up by **high-performance computing** resources, such as multicore, GPUs, clusters, and grid and cloud services.

What is HPC?

**High Performance Computing (HPC):** aggregating computing power to solve large problems

- Multicore computers
- Clusters
- Grids
- Clouds

Parallel Programming is essential in HPC computing to take the advantage of computer resources.

Lack of parallel programming experience by the **software community**
What is Cloud Computing?

Cloud is a metaphor for the Internet providing access to resources are though web-based tools and applications.

Cloud computing concept dates back to the 1950s. Large-scale Mainframe where used by academia and corporations allowing multiple users share both the physical access to the computer from multiple terminals as well as to share the CPU time.

High-capacity networks, low-cost computers and storage devices led to a growth in cloud computing.

Why Cloud Computing?

Low Cost: reduce the cost by pay-as-you-go based on demands, no need to spend big money on hardware, software or licensing fees, no hardware maintenance

Elasticity: add and remove compute resources to meet the size and time requirements commensurate with the size and type of building model being analyzed.

Virtualization: applications can be easily migrated from one physical server to another

Run Jobs Anytime, Anywhere: enable users to access systems using a web browser regardless of their location or what device they are using. Access in minutes instead of spending time in queues of clusters and grids.
Example of Cloud Services

NEEShub: Cloud Platform as a Service (PaaS) for research and education in earthquake engineering.

OpenSees are remotely run on the NEEShub cloud based machines (McKenna et al. 2013). Parallel applications such as OpenSeesSP and OpenSeesMP in NEEShub provides high performance computing tools for large models or repetitive runs.

Amazon EC2: Cloud Infrastructure as a Service (IaaS) that provides resizable compute capacity in the cloud.

Amazon EC2 provides flexibility to meet your computing needs by choosing from high memory CPU instances; large CPU and GPU clusters; and high storage instances.

Implementation of SE/GE Applications in Cloud Computing - UBC Approach

Purpose: implementation of a methodology to take full advantage of high-performance parallel computing using the cloud architecture for various structural and geotechnical programs

Using commercial cloud services such as Amazon EC2 to rent pay-as-you-go virtual computers giving engineer in design office very high CPU capabilities
Implementation of SE/GE Applications in Cloud Computing - UBC Approach

Developing a graphical interface to load the model information into the cloud controller, select the cluster types and nodes, and transfer the results.

Programs that have not been developed specifically for parallel computing, each virtual machine runs a single instance of the program.

Programs suited for parallel computing, each virtual machine may be responsible for running a certain component of the building computer model.

SE/GE Applications in Cloud Computing

Applications related to seismic response of structures, such as

- Sensitivity analyses in the selection of ground motions
- Incremental dynamic analysis for low- and high-rise buildings
- Risk-based calculations of the response of various types of buildings
- Estimation of damage and losses in buildings to various types of earthquake mechanisms
- Ground motion directionality effects on the response to tall buildings
- Design optimization and reliability analysis
- Soil-structure interaction in bridges

- Software
  - OpenSees
  - CANNY
  - SAP2000 (in progress)
Example of HPC Computing in PBD

Use FWT 53-storey office building in downtown Los Angeles to demonstrate methodology for non-linear response history analysis (RHA) using cloud parallel computing.

Steel frame office tower with five levels of underground parking. The FWT was designed in 1988, constructed in 1988-1980, and instrumented by CSMIP in 1990.

Structural system consists of three main components: a braced-core, twelve columns, and eight deep outrigger beams at each floor.


Building was modeled as a combination of non-linear braced frames and moment frames consisting of 58 separate columns types and 23 different beam types.

The periods and response were verified with recorded motions during the Northridge and Chino-Hills earthquakes.

Ground motions were selected using the Modal Pushover-based Scaling (MPS) method (Kalkan and Chopra 2012).
Example of HPC Computing in PBD

3D model has been modified to perform parallel non-linear RHA using the OpenSeesSP and OpenSeesMP platforms.

High memory cluster instances of the Amazon EC2 Cloud Center:
- 244 GiB of memory
- 2 x Intel Xeon E5-2670 (hyper threading, eight-core, Intel Turbo, NUMA) = 32 process units
- 2.97$/hour (Windows), 2.40$/hour (Linux)

Example of HPC Computing in PBD

3 times reduction in run time using 4 processors. No significant reduction using more than 6 processors due to the complexity of model of the building and the order of parallel computation in the model.
Example of HPC Computing in PBD

3.5 times reduction in run time for set of 6 ground using 6 processors, in which each ground motion was executed by one processor and Up to 9 times by using 18 processes and assigning 3 processors for each ground motion run for about 5$.

Incremental Dynamic Analysis for a set of 6 ground motions at 8 levels of intensity.

The runtime can be reduced from 78 hours using only one processor to about 1.5 hour using 8 high memory EC2 clusters instances with total number of 128 processors for about 50$.

Example of HPC Computing in IDA

- Median of displacement and drift of 6 ground motions at each floor of 52-storey building and at different percentage of MPS factors.
- Drift at 15th floor for set of 6 ground motions and different percentage of MPS factors.
**HPC Computing in Ground Motion Directionality**

How different could the calculated response of a high-rise building structure be when the directionality of the ground motion is considered?

![Diagram](attachment:image.png)

**HPC Computing in Ground motion directionality**

**Unscaled** Northridge ground motion at 7 different direction angles were considered: 0, 15, 30, 45, 60, 75, and 90 degrees.

7 times reduction in run time for set of 6 ground using 7 processors, in which each ground motion angle was executed by one processor and Up to 17 times by using 21 processes and assigning 3 processors for each ground motion run.
The examples presented clearly illustrated the advantages of using **parallel cloud computing** for the dynamic analysis of a tall building.

The significant reduction in the **time** required to process a suite of ground motions, and the **flexibility** of cloud computing in assigning tasks to different processor, allow engineers to perform various types of analyses in parallel.

Proposed methodology provides a tool that enables structural engineers to run high performance computer (HPC) applications such as **performance-based design, IDA, directionality, optimization, and SSI** very efficiently.

The main advantages are: **low cost: elasticity: run jobs anytime, anywhere without spending time in queues.**

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