High Performance Simulations based on new processor architecture for seismology and geophysics

**ANR-JST ICT French – Japanese Workshop**

Fabrice Dupros and Hideo Aochi
France’s leading public institution in Earth Science applications for the management of resources and surface and subsurface risks.

> Understanding geological processes.
> Providing necessary tools for surface, subsurface and resource management, for risk and pollution prevention.

> Over 600 researchers located in Orleans, France.
Different scales for the observation of seismic phenomena

- **Site effects associated with strong motion**
  - Local: few meters, 20-40 sec

- **Wave radiation**

- **Seismic Fault**
  - Régional: tens of km, 20-40 sec
  - National: hundreds of km > few mins
  - Global: Earth > several hrs

- **Source**
  - M6: average of 10 km < 10 seconds
Requirements from the physics

- Refinement of mesh to consider strong motion simulation.
- Increase the complexity of the model (geology, physics, coupling...)

Use of HPC for realistic three-dimensional simulation

Trends in parallel architectures

- Increase of the number of cores
- Memory hierarchy

Impact for applications in geophysics?

Which programming model to maximize performance?
NUMASIS Project
2006-2009 ANR program
« High Performance Computing »

Goal: Seismic simulation on NUMA and multicore architectures

Partners: INRIA (5 teams) – BULL – BRGM – CEA – TOTAL

Leader: J-F Méhaut (INRIA/LIG)

✓ Thread scheduling and Memory affinity
✓ Numa and multicore aware algorithm and numerical libraries
✓ Large scale numerical simulation
NUMASIS Project

Thread scheduling and OpenMP Runtime (INRIA Runtime)

NUMASIS Project

Memory Affinity Interface (INRIA MESCAL)

bind_all policy

bind_block policy

cyclic policy

NUMASIS Project

NUMA-Aware numerical solver (INRIA Scalaplix)

Finite-elements numerical method

- Mesh partitioning
- Bloc symbolic factorization

PRE-PROCESSING PHASE

- Tangent stiffness matrix assembly
- Numerical Factorization

- Initial nonlinear force assembly
- External load

Nonlinear vector force assembly

Triangular solve

Convergence check

YES

Stiffness re-assembly

NO
Sparse Direct numerical solver – Pastix (INRIA)

- Target material nonlinearity: Implicit numerical scheme
- Sparse Direct linear solver due to ill-conditioning (bottleneck)

**JADE CINES/GENCI platform**
Impact of the programming model on the memory consumption
French Riviera strong motion simulations

Magnitude 5.7

Magnitude 6.0

Magnitude 6.2

Displacement (m)

Velocity (m/s)

Epicenter

Nice
Finite differences numerical method

For $i=1,Nx$
For $j=1,Ny$
For $k=1,Nz$
init()

For $i=1,Nx$
For $j=1,Ny$
For $k=1,Nz$
compute_velocity()

For $i=1,Nx$
For $j=1,Ny$
For $k=1,Nz$
compute_stress()

Free surface condition

Absorbing Conditions

Physical domain
Memory access pattern

**REGULAR**
memory access pattern

**IRREGULAR**
memory access pattern
NUMA Penalty - Memory Affinity interface

OpenMP implementation of 3D seismic application

<table>
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<tr>
<th>Problem size</th>
<th>REGULAR memory access</th>
<th>IRREGULAR memory access</th>
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</table>

- Choice of the memory policy - knowledge of the underlying architecture
- Impact of the memory access
Ligure, SE France, en 1887 (M6.3?)

Reproduction of a historical earthquake and its scenario

Observation  Simulation 1 (bi)  Simulation 2 (uni)
Ongoing work

Timespace decomposition
- Time skewing / cache oblivious

Nested OpenMP parallelism
- Forestgomp framework (INRIA Runtime)

Very large scale simulations
- Validation of these proposition on emerging systems.
- Hybrid parallel linear solver for finite-elements method (Collaboration with INRIA)

jeudi 19 novembre 2009
New case study with Japanese colleagues
Niigata-Chuetsu-Oki, Japon, en 2007

Projet ANR DEBATE (2009-2011)
BRGM, ENS Paris, IRSN, GDS
Univ. Tokyo, Kyoto, NIED, Shimiz co.

jeudi 19 novembre 2009
French-Japanese collaboration in numerical geophysics and seismology.

Strong background of numerical scheme development in France.

Application and data-assimilation experiences in Japan.

Capitalize and extend the results of the NUMASIS project.

French-Japanese workshop on earthquake source

- 5-9 October 2009, Paris-Orleans, France
- Organized by BRGM, Univ Tokyo, AIST, IPGP, ENS Paris
Thanks for your attention