2SC7693 – Optimization of infrasonic wave detection for verification of the Comprehensive Nuclear-Test-Ban Treaty

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Language of instruction: ANGLAIS
Campus: CAMPUS DE PARIS - SACLAY
Workload (HEE): 80
On-site hours (HPE): 48,00

Description

Project topic in partnership with CEA DAM.

Rmk : Project proposed to students of **European Union**

CEA-DAM uses high performance computing resources for its various missions, particularly in the environmental monitoring field (e.g. seismic or acoustic wave propagation phenomena). The “Département d'Ile de France” located in Bruyères-le-Châtel is thus the tsunamis and strong earthquakes french warning center. As part of its missions and based on its skills in the nuclear area as well as in detection and identification technologies, CEA-DAM also brings its expertise for fighting against nuclear proliferation and terrorism. In order to inform national authorities in case of a nuclear test, CEA-DAM thus participates in the implementation of verification means to assess the non-violation of the “Comprehensive Nuclear-Test-Ban Treaty” (CTBT).

The study proposed here concerns the characterization and detection of infrasonic waves at long distances, taking into account the topography and atmospheric conditions (e.g. wind here). A compressible 2D axisymmetric / 3D hydrocode which supports adaptive mesh refinement (AMR) and hybrid parallelism (MPI domain decomposition / OpenMP multithreading) on Cartesian grids is developed in our laboratory. It can simulate the propagation of blast and acoustic waves in the presence of relief and buildings, with or without wind. Judiciously located sensors allow overpressure signals recordings.

Two types of problems which will be solved with this AMR hydrocode are addressed here. The first one consists in localizing an explosion and determining its power on the basis of probes’ recordings located in the scene. The second one consists in defining judicious sensors locations in order to maximize the chances of detection in case of explosions in a given area. In both cases, a "brute force" investigation consisting in simulating all possible configurations before retaining the best one is unthinkable. It would consume gigantic hours of computations, which would make the design of the solution very long and overpriced.

For these two types of problems, the objective of this study is therefore twofold:

- Propose a solution to characterize the source of acoustic waves.
- Find this solution in a reasonable time on high-performance computers AND with a limited quota of computation hours.

To that end we will develop an optimization loop that uses the hydrocode the most efficiently as possible, by parsimoniously exploring the possible configurations space, to economically find a “good” solution.

Technical details of the studied systems

- **1st topic: characterization of a source at the urban scale, taking into account buildings**

  It consists in locating and determining the power of an explosion, following an accident or a malicious act, knowing only neighboring sensors recordings (whose locations are known). Buildings in the surrounding area will be taken into account. Here, the recordings will come out in practice from a simulation whose fictitious initial conditions (location and power of the source) will not be known by the students.

- **2nd topic: setting up a surveillance network**

  Here, it is question of designing a sensors network allowing the detection of hypothetic explosive experiments around an area that is under surveillance. These sensors - in limited numbers - should be judiciously located in order to maximize chances of detection whatever the weather (we will only consider wind here) and the relief are. Furthermore and for maintenance reasons, the sensors will only be located in so-called "accessible areas”.

Quarter number
ST7

Prerequisites (in terms of CS courses)
First year courses:

- SG1 common course "Systèmes d'Information et Programmation" (1CC1000)
- ST2 common course "Algorithmique et complexité" (1CC2000)

Courses of the ST:

- ST7 common course "Optimisation" (2CC3000)
- ST7 specific course "Méthodes et algorithmes parallèles pour l'optimisation" (2SC7610)

Others prerequisites:

- Parts of common course "CIP - Convergence, Intégration et Probabilités" (1SL1000)
- Parts of common course "EDP - Equations aux dérivées partielles" (1SL1500)
- Knowledge of linear algebra will also be needed

Syllabus

Main tasks of the study:

- More information at the beginning of the first part of the project (intervention of the CEA-DAM).
    - Presentation of physical principles and numerical methods used in the provided compressible hydrocode that will be used to simulate the propagation of blast and acoustic waves.
    - Identification of compressible hydrodynamic code parameters and their impact on the parallel execution time.
    - Handling resources in a remote computing center (at the CEA).
- Formalization of the problem and selection of values that are to be optimized. Choice of an optimization method adapted to the problem.
- Design and implementation in Python of an optimization code calling the parallel simulation code. The optimization code will itself be parallelized if allowed by its algorithm (we would then have a parallel master code calling on demand the parallel hydrocode).
- Tests and debugging of the complete optimization code on CEA's parallel computers, on small and medium problems: simplified reliefs or buildings on reduced maps, without weather for 2D axisymmetric configurations (much faster).
- Scale up in terms of covered land size, and addition of relief and / or buildings and wind maps.
    - Experiments on bigger problems on a more large number of nodes and computing cores.
    - Analysis of the solution quality and the performances.
    - Code optimization to improve the solution found AND the computations performances.
- Estimation of the maximum size of the problem that can be handled regarding available resources and the study duration. Analysis of the feasibility of the extension to 3D cases over the time allocated for the project.

- Submission of a report and a presentation to evaluate: the quality of the solution found, the effectiveness and the extensibility of the code in finding an optimal solution, and the computation resource quota management that will have occurred during the project.

Rmk: the different groups of students will work on different topics (topics 1 and 2) and will implement different optimization methods.

Class components (lecture, labs, etc.)

Part 1 (40HEE):

- Steps 1 and 2: course complements, handling of computing resources, formalization of the problem, choice of an optimisation algorithm.
- Step 3: Python numerical implementation of the optimisation algorithm calling the compressible hydrodynamic parallel code, supplied by CEA DAM.
- Step 4: first executions on parallel machines of 2D simulations with basic configurations, debug of the algorithm and of the optimization code, evaluation of the result quality and computation performances on small and medium size problems, and comparison to a reference solution.

- Midterm report (slides and progress summary) and talk about current results and future work (part 2).

Part 2 - *final sprint* (40HEE):

- Step 5: experiments on more complex and/or larger problems, similar to real problems, analyse of the quality of the computed solution, identification of the sources of performance locks and losses, and (if required) code improvement to push the limits of supportable problem size.
- Step 6: estimate of the maximal problem size that can be processed, function of the available computing resources and of the maximum duration of the project, analyse of the feasibility of a 3D simulation.

- Final report (slides and extended abstract) and global talk about the project approach and results.

Grading

This project will be evaluated by a midterm talk at the end of part 1 (40HEE), and by a final talk at the end of part 2 (*final sprint* 40HEE). Talks will be done by the entire team, but will lead to individual marks in case of strongly heterogeneous teams.Each talk evaluation will consider the overall quality of the talk, of the slides and of the progress summary. Each talk mark will be 50% of the total mark.

Resources

Teaching staff:

- **J. Cagnol** (CentraleSupélec & MICS) and **S. Vialle** (CentraleSupélec & LISN)
- **S. Jaouen** (CEA DAM)

Workplace and computing resources:

- During the first part of the project:
  - Students will work at CentraleSupelec, in a classroom with electrical outlets and reliable wifi Internet access.
  - Students will use their laptops to connect to **remote powerful computing resources managed by CEA DAM**.
- During the second part of the project (*final sprint*):
  - Students will work **3 days on TGCC/TERATEC site, at Bruyères-le-Châtel.** CEA DAM will ensure the daily movement of students.
  - Final oral exam will take place at CentraleSupelec the last afternoon of the project.

Learning outcomes covered on the course

When finishing the course, the students will be able to:

- Learning Outcome 1 (**AA1**): identify and parametrize an optimisation method adapted when each evaluation/iteration requires many computing resources and computation time,
- Learning Outcome 2 (**AA2**): implement and debug a sequential or parallel Python code on supercomputer (developped from scratch or using libraries), calling distributed C/C++ computing kernels,
- Learning Outcome 3 (**AA3**): deploy intensive computing applications on remote resources,
- Learning Outcome 4 (**AA4**): identify the limitations of the study, function of the available computing resources,
- Learning Outcome 5 (**AA5**): manage a computing resource quota, during an intensive computing campaign.

Description of the skills acquired at the end of the course

- C4: Have a sense of value creation for his company and his customers
- C7: Know how to convince
- C8: Lead a project, a team