2SC7591 – Flow management in industrial gas delivery

Instructors: Guillaume LAMÉ, Loïc Pineau
Department: DOMINANTE - VIVANT, SANTÉ, ENVIRONNEMENT, DOMINANTE - GRANDS SYSTÈMES EN INTERACTION
Language of instruction: FRANCAIS
Campus: CAMPUS DE PARIS - SACLAY
Workload (HEE): 80
On-site hours (HPE): 48,00

Description

Students will apply the tools provided in the associated course on an industrial case study proposed by a partner. In particular, they will be able to implement discrete event simulation on a long and in-depth case study.

Quarter number
ST7

Prerequisites (in terms of CS courses)

None

Syllabus

In parallel with the associated ST7 course, students will progressively apply the techniques taught in the course on a real complex industrial problem. Course reminders will be provided as needed.

Class components (lecture, labs, etc.)

Industrial case study.

Grading

Group project.

Course support, bibliography
Contents from the ST7 course.
Data from the industrial case study.

Resources

Industrial case study, with data and information on the context and the industrial challenge, supervised by a tutor.

Discrete-event simulation software Simul8, and the extension OptQuest for simulation-optimisation.

Simul8 only exists for Windows. Students using Mac OS will need to install a virtual machine, which may slow down the simulation software and compromise its general usability.

Learning outcomes covered on the course

Implementation of discrete event simulation. Conceptual modelling, implementation into a computer simulation model, model validation, experimentation.
This course will address the following competencies:

- C1 Analysing, designing and realising complex systems with scientific, technological, human and economic components
    - C1.2 Using and developping relevant models, choosing the righjt modelling scale and simplifying hypotheses to address the problem
    - C1.3 Resolving the problem through approximating, simulating and experimenting
- C2 Developing specific knowledge of a scientific or industrial domain et a professional domain
    - C2.1 Exploring a scientific or engineering domain or discipline
- C3 Acting, innovating in a scientific and technological environment
    - C3.6 Evaluating the effectiveness, feasibility and robustness of proposed solutions
- C7 Being convincing.
    - C7.1 Being clear on objectives and expected results. Being rigorous on the hypotheses and the method. Structuring ideas and arguments. Highlighting value creation.
- C8 Leading a project, a team.
    - C8.1 Working as a team/collaboratively.
    - C8.4 Working in project mode, using project management techniques as required by the situation.

Description of the skills acquired at the end of the course

Implementation of discrete event simulation on a real case-study.

ST7 – 76 – HIGH PERFORMANCE SIMULATION FOR FOOTPRINT REDUCTION

Dominante : MDS et INFONUM
Langue d'enseignement : English
Campus où le cours est proposé : Paris-Saclay

1. General description of the thematic sequence

Simulation is nowadays at the heart of many design and optimization approaches to reduce the footprint or the impact of the products created: reduction of the risk of destruction in case of natural disasters, reduction of an airplane's drag to minimize the fuel consumed and the CO2 emitted, reduction of the time of a large-scale calculation and of the resources used (the simulations themselves end up consuming a lot of energy on a lot of processors),...

But these are often complex system simulations, which require both skills in high performance and large scale simulations, and in optimization methods to limit the scope of investigations and the hours of computation required. Moreover, each study must still be done by seeking a compromise between the quality of the solution found and the number of hours of computation used, because hours of computation are expensive (especially on high-performance computation clusters or on a large scale in clouds). It is therefore essential to learn how to manage a quota of computing hours.

This ST thus includes numerical mathematics, parallel computing, optimization methods, and development and experimentation on PC clusters or in clouds. Students will learn:

- to develop parallel modeling and simulations to reduce the duration of the most expensive phase of the optimization loop,

- to associate these simulations with adapted optimization methods and algorithms, which will minimize the number of configurations to be simulated and evaluated (brute force approaches will be avoided)

- to experiment the programming of high performance computing platforms (PC clusters or clouds),

- to exploit these platforms under the constraint of a quota of hours of calculations not to be exceeded.

2. Organization of the thematic sequence

2.1 Context and issues modules

The modules presenting the context and the issues will begin with a presentation of the objectives and organization of the ST. Then, a succession of presentations by industrial partners will illustrate different cases of use of high performance simulation for footprint reduction (reduction of energy consumption, reduction of financial cost, reduction of simulation time, reduction of data volumes...). On this occasion, the associated scientific and technical challenges will be identified, as well as the induced needs in optimization.

The topics of the ST projects will also be presented during the context and stakes modules: in aeronautics, in seismic exploration, in infrasound wave detection, in risk calculation on the cloud, and in temporal and energy optimization of parallel calculations. These presentations will also present the economic and societal issues related to the investments required to carry out high-performance simulations, and the impact of simulation on the evolution of the technologies that surround us.

A visit of the Very Large Computing Center (TGCC) in Bruyères-le-Châtel, under the leadership of the CEA, will allow to see modern infrastructures of high performance computing, and their support infrastructures (power supply, cooling, protections). Finally, a round table with all the industrial partners will allow to discuss the trends for the future.

2.2 Specific course : *Parallel computing and optimization*

This course includes mathematical, numerical, algorithmic and programming aspects on parallel and distributed machines, associated with optimization issues.

Among the notions covered, this course describes, in a first part, the basics of parallel and distributed computing, by detailing in particular the computer architectures and parallel programming models as well as the parallel and distributed algorithms used on these architectures. In a second part, this course presents parallel optimization methods and algorithms, commonly used in parallel computing codes. Two classes of methods used for optimization problems are successively discussed, namely parallel partitioning and domain decomposition methods, and genetic algorithms and parallel meta-heuristics. These methods and algorithms will be used in the different integration courses of this ST, in order to deal with problems from the engineering sciences. In a third part, this course focuses on the performance analysis of the developed solutions. The notions of

performance metrics and scaling, as well as the analysis of experimental performances are also studied.

2.3 Industrial partners and proposed project topics

1. The CEA DAM (Direction des Applications Militaires) proposes a study of "Optimization of a seismic exploration campaign for the protection of structures"

Optimization of a seismic exploration

CEA-DAM is the French warning center for tsunamis and strong earthquakes, and uses its high-performance computing resources for various missions.

After the Fukushima accident (Japan), the use of high performance computing resources has become more and more common for the estimation of the seismic risk associated with nuclear power plants: within the framework of the design of new plants, but also in order to study the performance of existing plants in the face of extreme events, not foreseen at the time of their design.

This study concerns the optimization of a geophysical exploration campaign on an experimental site, using its digital twin. The project consists in optimizing (minimizing) the number of sensors needed to discover the geological configuration of the site of interest. Many realistic simulations using the SEM3D code (Reverse Time Migration method) will have to be called in an optimization loop. We will therefore look for an optimization method that allows us to achieve a good quality of optimization while respecting the time quota.

The calculations will be done on machines of the Moulon mesocenter, under the constraint of a quota of calculation hours.

2. ONERA (Office National d'Etudes et Recherche Aérospatial) proposes a study of "Optimization of shapes and reduction of drag in aeronautics".

(Drag reduction in aeronautics)

Recent studies show that air traffic is constantly increasing. Without improvements in aircraft performance in terms of energy consumption, the share of air transport in greenhouse gas emissions may become unbearable in the future. Reducing aircraft fuel consumption requires both an increase

in engine efficiency and an improvement in aircraft aerodynamics and weight reduction.

Numerical tools have been widely used for a long time in the aeronautical field to help in the design and optimization of systems. For example, the shape of a wing can be improved in order to reduce its drag, at constant lift, or its internal structure can be lightened. The optimization methods require successive calculations for different wing geometries. The higher the accuracy of the numerical models, the higher the computational costs for each step. The only way to reduce the computation time to be able to integrate the optimization methods in the industrial design cycle is to use parallel computers. The objective of this project is to realize the parallelization of the most expensive part of the optimization phase, i.e. the resolution of large linear systems from finite element models on large meshes, and to experiment with different sets of optimization parameters.

The tests will be carried out on the parallel machines of the CentraleSupélec Teaching Data Center, under the constraint of a quota of computing hours.

3. The CEA DAM (Direction des Applications Militaires) proposes a study of "Optimization of infrasound detection for the verification of the Comprehensive Nuclear Test Ban Treaty".

Detection of infrasound waves

CEA-DAM is the French warning center for tsunamis and strong earthquakes, and also participates in the implementation of the verification means of the Comprehensive Nuclear Test Ban Treaty (CTBT) by using its high performance computing resources.

A parallel compressible hydrodynamics code has been developed at CEA DAM, which allows the simulation of blast wave and acoustic wave propagation in the presence of terrain and buildings, with or without wind. On the other hand, it is considered that judiciously placed sensors allow the recording of overpressure signals in case of an explosion. Two types of problems can then be studied: (1) find the location of an explosion and determine its power from the recordings of sensors located in the field, (2) define where to judiciously position sensors to maximize the chances of detecting an explosion within a given area.

A "brute force" investigation simulating all possible configurations of the parameters would consume too many hours of computation. We will therefore develop an optimization loop exploring the space of possible configurations sparingly and using the hydrodynamics code efficiently.

The computations will be done on CEA clusters under constraints of a quota of computation hours, and three of the last days of the study will take place on the Bruyères-le-Châtel site. This study is reserved for students from the European Union.

4. ANEO is an IT company expert in high performance computing and cloud operation, which proposes a study of "Energy optimization and acceleration of a financial computation graph on cloud".

Graph of financial calculations

One of the difficulties in assessing the accounts of an insurance company (or a bank) lies in the valuation of financial assets (shares, life or car insurance contracts, etc.) and the underlying risks. Depending on the valuation of the risks taken, the regulations resulting from the various economic crises oblige the insurance company or the bank to immobilize a certain amount of equity capital.

The steps of such a calculation, managed by ANEO, form a task graph with numerous dependencies, and the sum of the execution times corresponds to the equivalent of 413177 hours of calculation. On an infrastructure of 1700 cores the computation time would be a little more than 10 full days if all cores could work at any time. But because of the dependencies between the computational tasks, it happens that there are not enough tasks to occupy all the allocated resources, and the process finally takes more than 10 days.

In order to optimize the cost of this computation, we want to: (1) use on-demand resources available in the cloud, and (2) optimize the execution of the task graph by looking for the best turn-on/off strategy for the compute nodes, and the best scheduling of tasks on the available nodes. To do this, we will develop a cost function that calculates the execution time of the task graph as a function of a node management and task scheduling strategy, and we will implement an optimization algorithm that seeks the best parameterization of this strategy.

5. INTEL proposes a study of "Low Cost Optimization of Acoustic Wave Propagation Code Performance".

Reducing the footprint of a code

Any high performance application running on a parallel machine has many configuration parameters in its source code and compilation, which have a significant impact on its performance and energy footprint. But the behavior of the application depends on the architecture of the processors used, the test case data and the software configuration of the machine. In the end, this behavior is extremely difficult to model, and the configuration parameter space can be very large. The use of optimization algorithms therefore appears fundamental to converge towards a configuration of the application minimizing its execution time and its energy footprint on the machine used.

However, each execution of a test case of an HPC application can be long, even on a parallel machine. We will therefore target optimization methods that are not too greedy in terms of the number of experiments, so that the pre-stage of optimizing the HPC code does not itself consume too many computing resources! This amounts to looking for a compromise between the energy spent to optimize an HPC code, and the energy saved by this application once optimized.

The tests will be carried out on the parallel machines of CentraleSupélec's Teaching Data Center, under the constraint of a quota of computing hours.