2EL1550 – High Performance Computing

Instructors: Stephane Vialle
Department: CAMPUS DE METZ
Language of instruction: FRANCAIS
Campus: CAMPUS DE PARIS - SACLAY
Workload (HEE): 60
On-site hours (HPE): 35,00
Elective Category : Fundamental Sciences
Advanced level : Yes

Description

Students will acquire:

- Some understanding of stakes and locks of intensive numerical simulation applied to any research and development issues.
- Some understanding of parallel algorithmic and experience of each step of a computing code parallelization.
- Some knowledge and experience about parallel computing environments.

Quarter number

SG6

Prerequisites (in terms of CS courses)

- SG1 common course « *Systèmes d'Information et Programmation* » (1CC1000)
- ST2 common course « *Algorithmique et complexité* » (1CC2000)
- *Basic knowledge in linear algebra*

Syllabus

- **Parallel and distributed architectures:** components of a supercomputer; memory hierarchy; energy aspects; need for fault tolerance.

- **Optimization and parallelization of loops in shared memory:** optimization and vectorization in series, algorithmic and multithreaded programming with OpenMP, analysis and rewriting of loops.
- **Distributed algorithms by sending messages:** data circulation and point-to-point communications in MPI (mpi4py): application deployment and distributed execution in MPI (OpenMPI + mpi4py); data distribution and collective communications in MPI (mpi4py); linear algebra, direct methods and iterative methods.
- **Parallel scientific computing:** strategies for solving large linear problems; iterative methods of substructuring; domain decomposition methods.
- **Performance measurement and analysis:** measurement methodology; speedup and efficiency metrics and limits; scaling metrics and limits.

Class components (lecture, labs, etc.)

Mathematic approaches and algorithms introduced during the lectures will be implemented and experimented on computing clusters during the tutorials, and performance will be measured and analyzed.
Experimentation will be an important part of the course, allowing a deep understanding of the lecture issues.

- **Composition of the course:** lectures 21h00, tutorials on computers 12h00 and final written exam 2h00

- **Possible course schedule:**
    - lectures 6 x 1h30 + tutorial (on computing servers) 2 x 1h30 ;
      lectures 4 x 1h30 + tutorial (on computing servers) 4 x 1h30 ;
      lectures 4 x 1h30 + tutorial (on computing servers) 2 x 1h30
    - final written exam (2h00)
- **Tutorials (close to 36% of the course):**
    - tutorials on computing servers will be grouped by 2 (i.e. 3h of experimental tutorial),
    - the groups of tutorials on machines will be made up by level of experience in IT,
    - developped codes will run on computing clusters of the *Data Center for Education* of CentraleSupélec or the Mésocentre Moulon (CentraleSupelec-ENS Paris Saclay), available from computing classrooms, or from student laptops.

Grading
Relative weights of the different examinations:

- 50% : Report of some tutorials on computing servers
- 50% : written exam of 1h30 (at the end of the course)
- In case of a justified absence to one of the tutorials on computing servers, the grade of this latter is replaced by the grade of the final examination. In case of unjustified absence a score of 0/20 will be applied for this tutorial on machines.
- The remedial exam will consist entirely of a written exam, similar to the initial exam.

Course support, bibliography
Documents supplied to the students:

- Frédéric Magoulès, François-Xavier Roux, Guillaume Houzeaux. Parallel Scientific Computing. Wiley & Sons, Inc., 2015. Hardcover 354 pages (in English). *This course support is available in other languages: in French (Dunod, 2017), in Spanish (CIMNE, 2014), in Japanese (Morikita Publishing Co Ltd, 2015), in Hungarian (Pollack Press, 2018).*
- Numerical Methods: Slides of the lectures
- Parallel and Distributed Computing: Slides of the lectures.

Others suggested books:

- W. Gropp, E. Lusk, A. Skjellum. "Using MPI". MIT Press. 1999.
- R. Chandra, R. Menon, L. Dagum, D. Kohr, D. Maydan, J. McDonald. "Parallel Programming in OpenMP". Morgan Kaufmann Publishers. 2000.
- B. Chapman, G. Jost, R. Van Der Pas.. "Using OpenMP". MIT Press. 2007.

Resources

- **Teaching staff: Frédéric MAGOULES** and **Stéphane VIALLE**
- 64% of lectures and 36% of tutorials, with tutorial groups of 25 students working on high performance computers.
- Remote access to different computing servers and clusters (Data Center for Education of CentraleSupelec, and/or mésocentre CentraleSupelec-ENS Paris Saclay).
- Experimentation based on standard Opensource software: C/C++/Python languages, multithreading library for multicore machines (OpenMP), message passing library for computing

clusters (MPI: MPICH2/OpenMPI), optimized scientific libraries (OpenBLAS).

Learning outcomes covered on the course

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

- **[Learning Outcomes 1* (AA1*)]** contributing to core skills **C1 C2 C6:**
  - to tune existing numerical methods for high performance computing (HPC)
  - to develop innovative numerical methods for high performance computing (HPC) in order to solve complex problems

- **[Learning Outcomes 2* (AA2*)]** contributing to core skills **C1 C2 C6:**
  - to design parallel algorithms for intensive simulations, according to high performance computing requirements
  - to implement parallel algorithms for intensive simulations on supercomputers or clusters of multi-core PC
  - to manage a limited set of computing resources when running an intensive simulation

- **[Learning Outcomes 3* (AA3*)]** contributing to core skills **C1 C2 C6:**
  - to implement a complete and consistent high performance simulation:
    - to choose models under both the constraints of accuracy and scalability,
    - to choose efficient parallel implementation strategies
    - to achieve a simulation campaign with (always) limited ressources

Description of the skills acquired at the end of the course

- **C1:** Analyze, design and build complex systems with scientific, technological, human and economic components
- **C2:** Develop an in-depth skills in an engineering field and in a family of professions
- **C6:** Be operational, responsible, and innovative in the digital world