Innovation Intelligence®

Brief history of time in Flux

Rémy Perrin-Bit

2 June 2017

Overview

- Commercial part
- Technical part
- Frédéric part

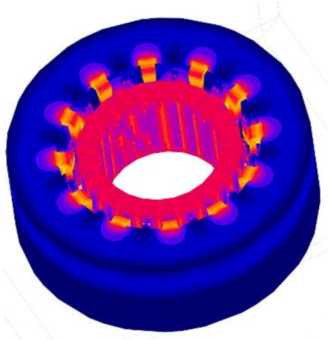
The best-in-class tool for electromagnetic simulation in Low Frequency

Flux®

Analyze, Create, Optimize

Getting accurate results in a fast way

Used in industry worldwide for more than 30 years



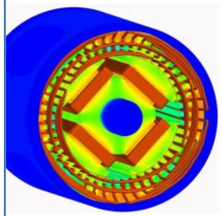
Leveraging the best simulation technologies in EM field simulation

To innovate and design energy efficient components and processes

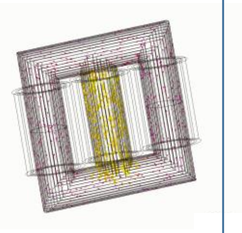
G2Elab Grenoble Génie Electrique Grenoble Electrical Engineering

Altair

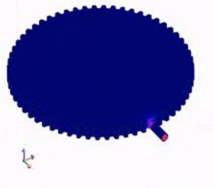
A wide range of applications



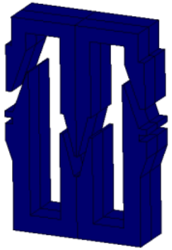
Motors & Generators



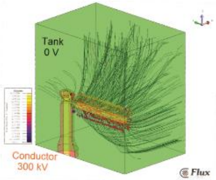
Transformers & Inductances



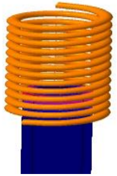
Sensors



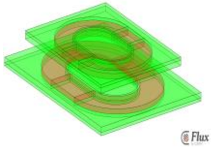
Actuators



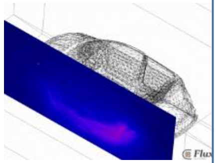
Insulation, Electric field



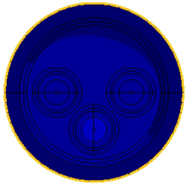
Induction heating



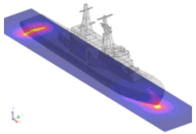
Wireless charging



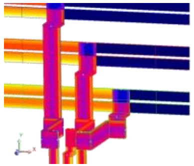
EMC



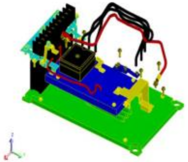
Cables



Ship magnetic signature



Busbar Systems



Power Modules

Flux, the tool to engineer

Complete workflow in a single user interface

2D, 3D and skew

Physics

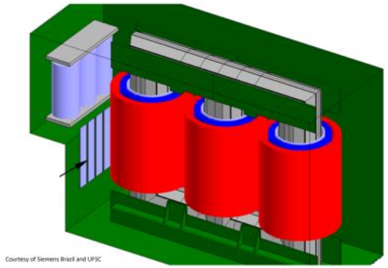
- Magnetic, Electric and Thermal

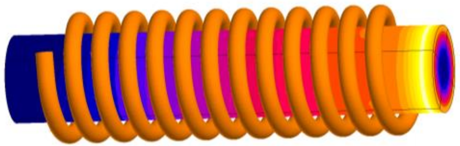
Analysis types

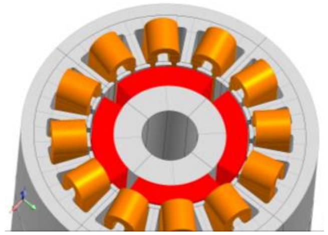
- Static, AC steady state and Transient

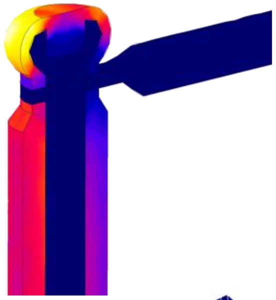
Couplings

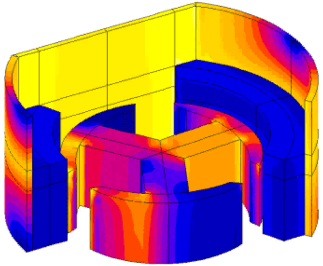
- FEM – Electric circuit - Motion
- Magneto-thermal and Electro-thermal
- Multiphysics (with 3rd party)

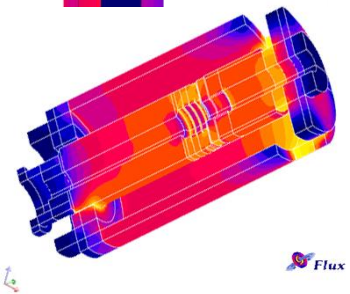












Motors & Generators

Any kind of rotating machine in 2D, 3D or skew

Templates for fast definition

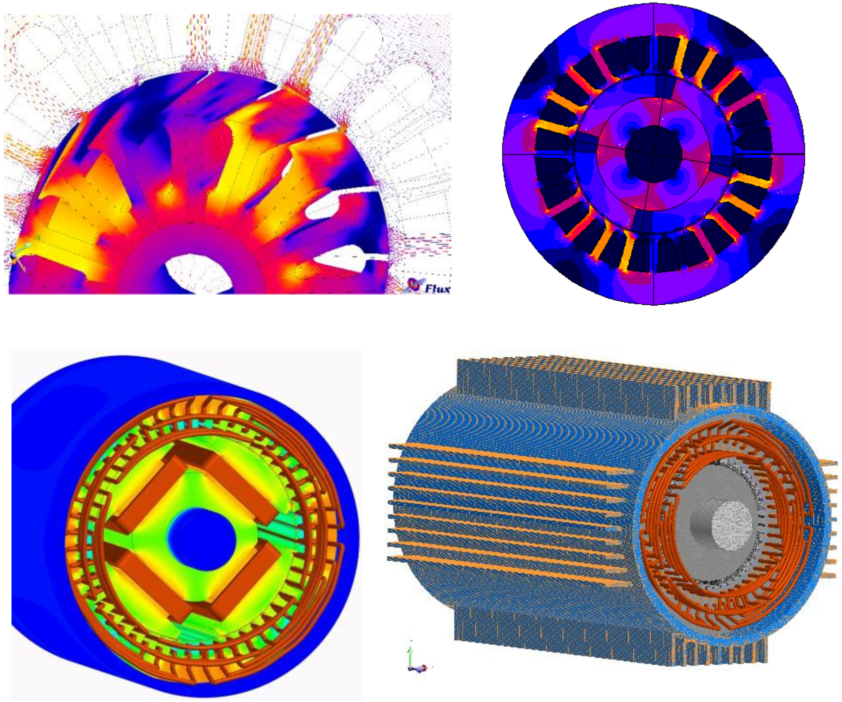
Electric circuit & rotating motion

Full analysis of the machine

Coupling with system-level tools

- Drive and control
- Model reduction to full co-simulation

Efficiency optimization

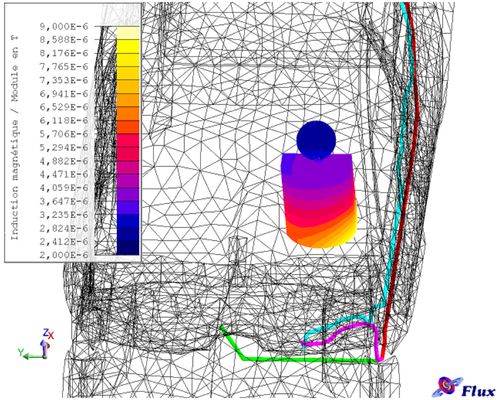


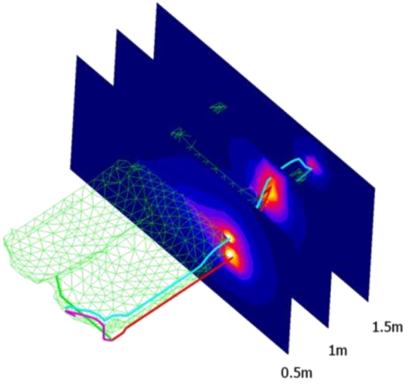
EMC with Flux

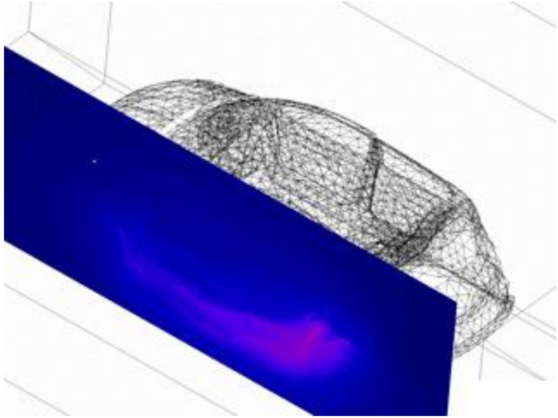
Impedance of the car body

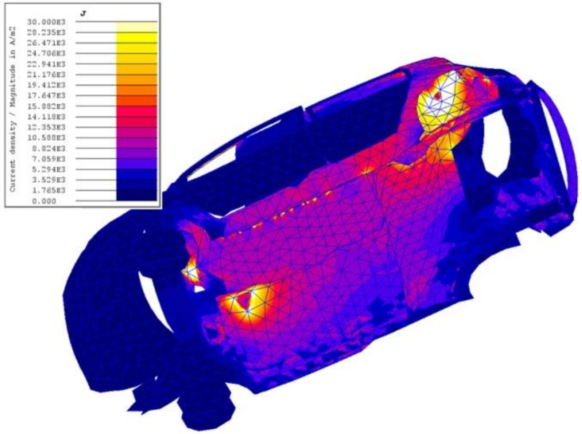
Magnetic field radiated by the cables

Advanced physical surface models with circuit coupling



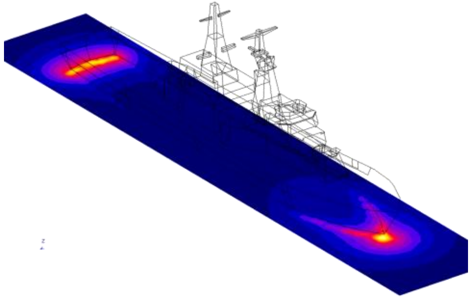


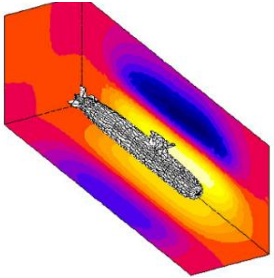


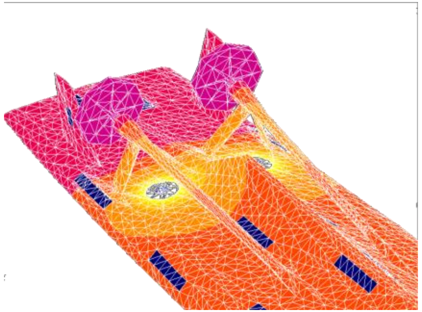


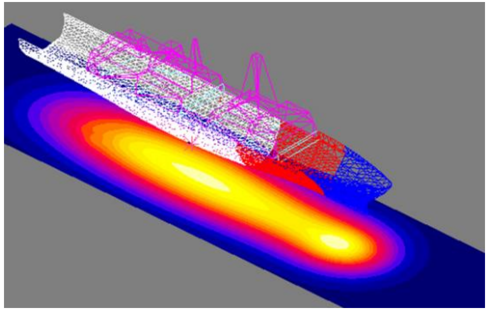
Ship magnetic signature

- Determine and minimize magnetic signature of ships
- Design of degaussing coils
- Corrosion currents
- Design of Cathodic protection systems





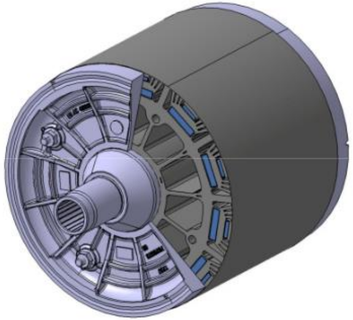




Designing EV and HEV with Flux

Challenges

- High efficiency
- Low weight
- Direct connected power electronic
- Wide range of constant power



Altair

Solar Impulse

Solar powered aircraft

Powered by 4 Electric machines

97% efficiency

Low Frequency: Magnetism Equations

- Maxwell equations

- E (Electric Field) and H (Magnetic Field) are not coupled in low frequency

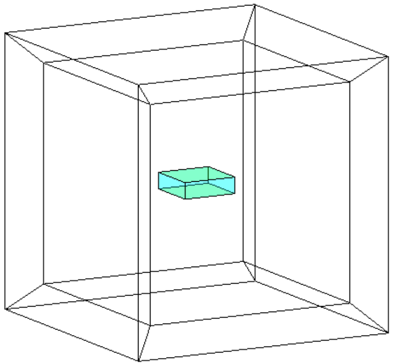
Flux and Magnetism

- Finite elements method
- 2D, 3D, skew models
- Applications
  - Magneto Static, Harmonic, Transient
  - Electric Static, Harmonic, Transient
  - Electric conduction
  - Thermic permanent, transient
  - Coupling magneto Harmonic with Thermal Transient

- Since ~1985
- Invented and Launched by G2ELab (Grenoble Electrical Engineering Laboratory)

Flux and Magnetism

- All domains are mesh
  - Air, Vacuum, Iron, Copper, etc..
- Boundaries
  - In theory, it is not possible to correctly calculate magnetic fields because E and H decrease in $1/d^2$ and they are null only at infinite
  - In practice, all geometry is surrounded by:
    - A sufficiently large box
    - “infinite box” → artefact to simulate infinite



- Formulations
  - It is not efficient to solve all Maxwell equations on all nodes.
  - We create formulations depending on materials and dimensions

Flux Solver

- 213 formulations
  - not all for commercial used
  - Not choice by user … luckily… thanks to automatic formulations
  - With different unknows types
  - Different applications
  - Coupling with different formulations
  - Nodal or edge approach
  - Circuit coupling
  - Different regions 0D to 3D in 3D domain
  - Kinematic coupling
  - Non-Linear materials
  - Hysteretic materials
  - Superconductivity materials
  - …

Flux Solver

- Linear solver
- Non-linear solver
  - Newton-Raphson method
  - Fix point method
- Parametric solver
  - All objects in Flux is potentially parametrized
    - Objects in modeler
    - Objects in mesher
    - Material definition
    - Circuit component value
    - …
  - Possibility to start a lot of parameterized studies

Flux Solver

- Distributed Solver

  - Associated with PBS – Compute Manager and Display Manager

    or

  - Associated with CDE (Cedrat Distribution Engine)

  - Possibility to start computation on distributed machines
  - All computations are independent, so speed-up is very high

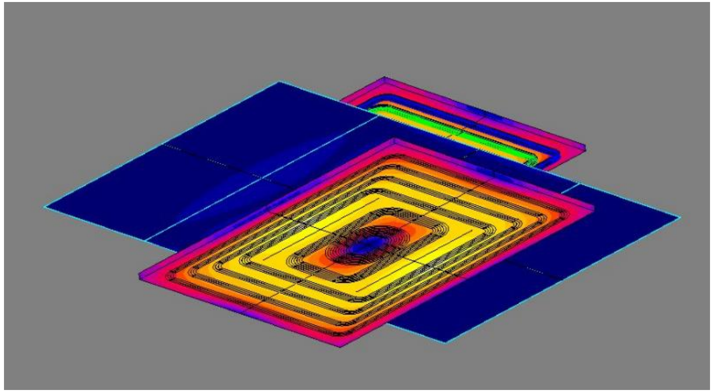
Flux Solver

- Linear solver (Double and Complex version)
  - Iterative solver
    - ICCG : Incomplete Choleski Conjugate Gradient
    - IJCG : Iterative Jacobi Conjugate Gradient
    - GMRes : Generalized Minimum Residual
    - BiCGStab : Stabilized bi Conjugate Gradient
  - Direct solver
    - SuperLU (sequential)
    - Mumps Distributed (Available soon)
    - Mumps (SMP)
    - Intel MKL Pardiso (SMP)

Benchmark

- Induction plate
- Since 2007
- Magneto Harmonic 3D → Complex solver
- Non-linearity → Non-linear Solver
- Thin plate with eddy current → Thin mesh
- 28 coils → Parametric Solver

- 4 M unknows, 400 M NZ



The Time History

- 1980
  - First vectorial/parallelization of Flux with Alliant FX machine (8 vectorial processors)
- 1990 -> 2005 machines with Mhz to Ghz processor (thanks to Hz)
- 2007
  - Just one-time resolution with linear solver
  - Iccg Solver
  - 40 days
- 2010
  - Rewrite the build of topological matrix
  - 40 hours
- 2013
  - **Mumps** SMP with "out of core" mode
  - 8 hours

The time History

- 2016
  - New formulation: “Edge formulation” before “Nodal formulation”
  - 3 hours
- **June 2016: Altair acquires Cedrat/Flux**
- Begin 2017
  - First tests with Mumps “distributed”
  - 1 hour
- In one decade
  - Divided the solving time by 960
  - No only with solver
    - Change algorithms
    - Change formulations
    - Change machines
    - Change solver

BenchMark

- But:
  - No non-linear solver ➔ called almost ten times linear solver
  - No parametric solver ➔ 30 geometric parameters, 6 physical parameters

Future … no Now

- Mumps DMP
- Frédéric Vi

Altair

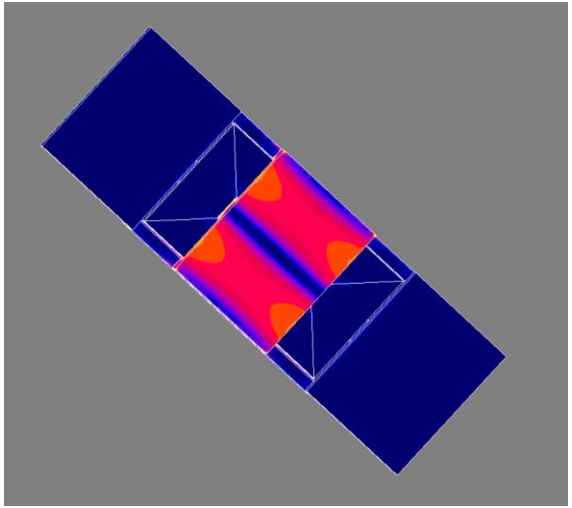
Innovation Intelligence®

First results

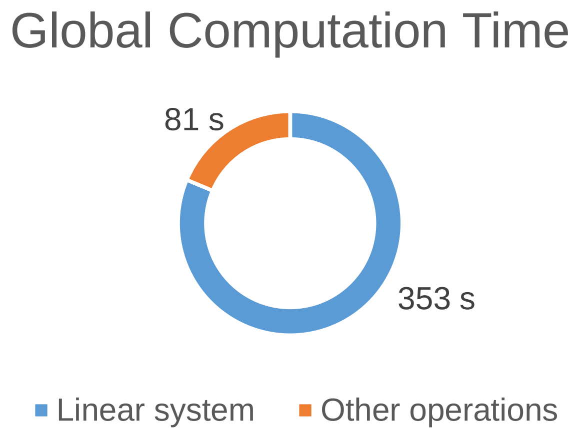
Frédéric Vi

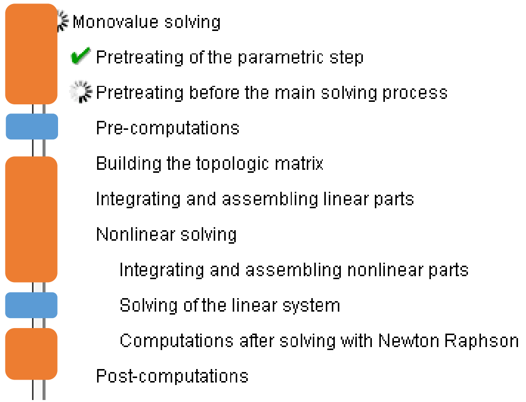
MUMPS User Days, Inria, Montbonnot Saint-Martin, 1-2 June 2017

Flux = sequential code



- 500 000 nodes project
- 4 + 1 linear system resolutions



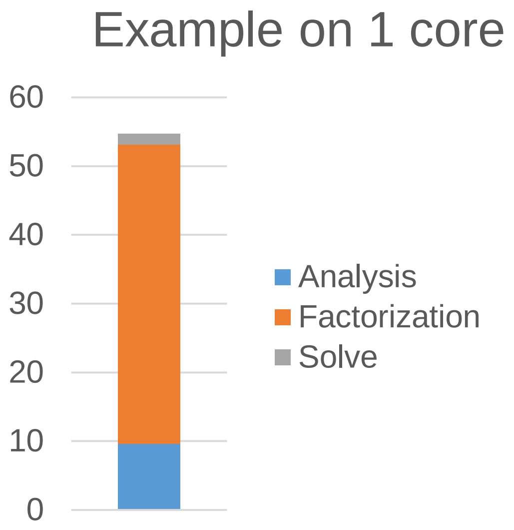


- **81%** of the global solving time spent in linear system resolutions
- Flux with MUMPS parallel should speed-up linear system resolution

Environment and specificities

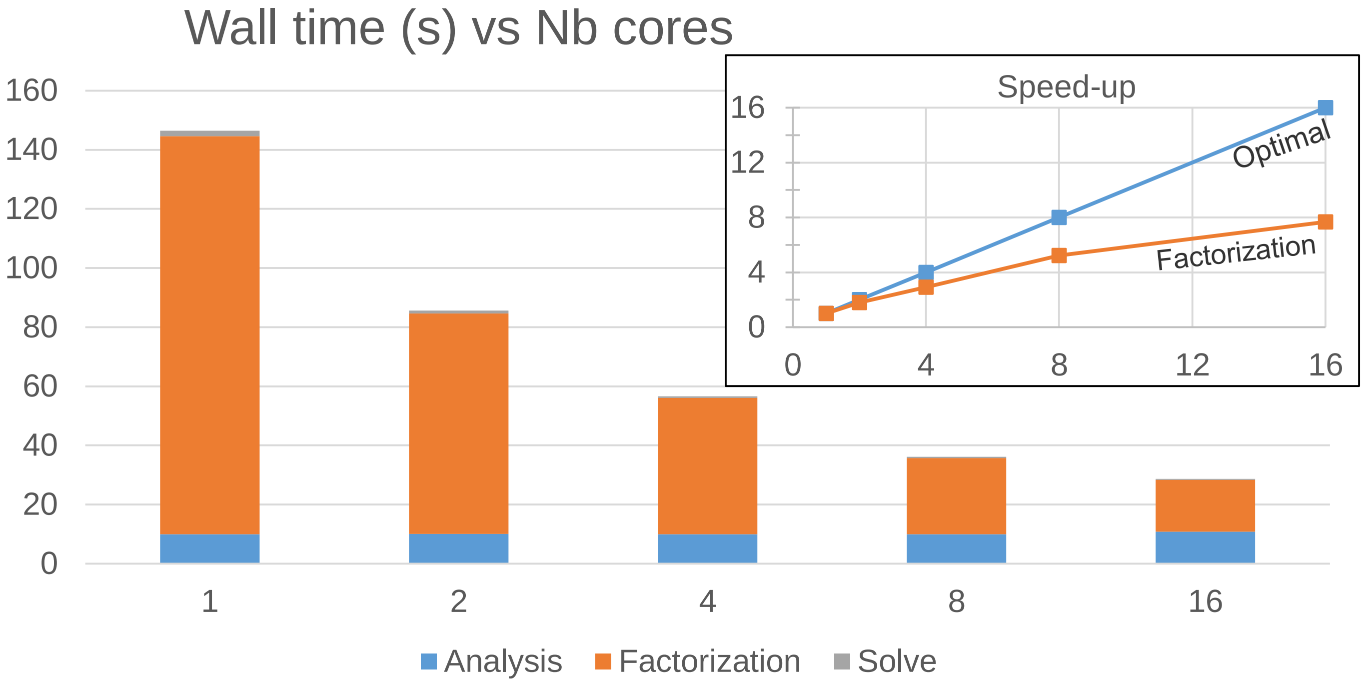
- Hardware specifications :
  - 4 CPU / E7-8890 @ 2,2 GHz
  - 24 cores / CPU
  - 96 cores in total
  - 264 GB RAM

- Software specifications :
  - Linux
  - MUMPS 5.1.1 consortium version
  - 64-bit integers
  - METIS for the analysis phase



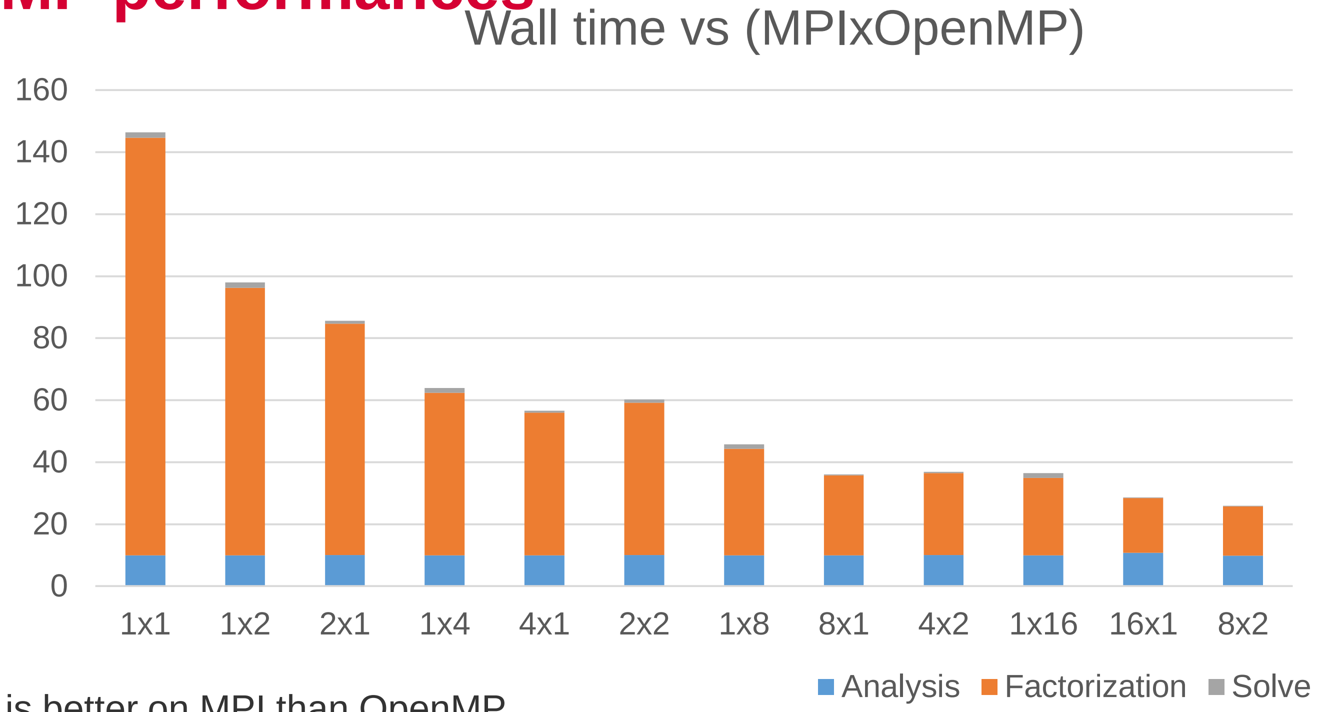
MPI performances

- On 1 linear system resolution :
  - Complex case
  - N = 498 250
  - NNZ = 15 854 848



Altair

OpenMP performances

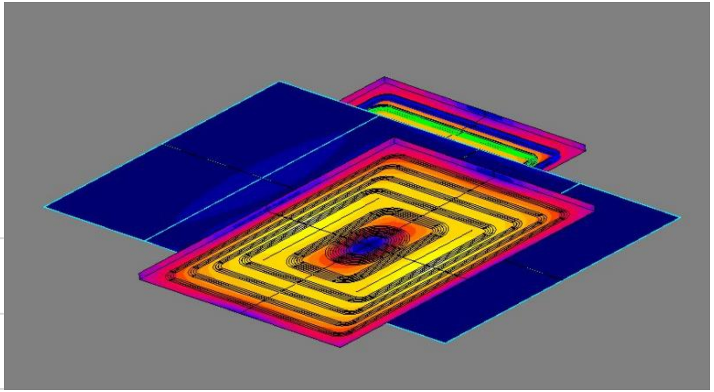


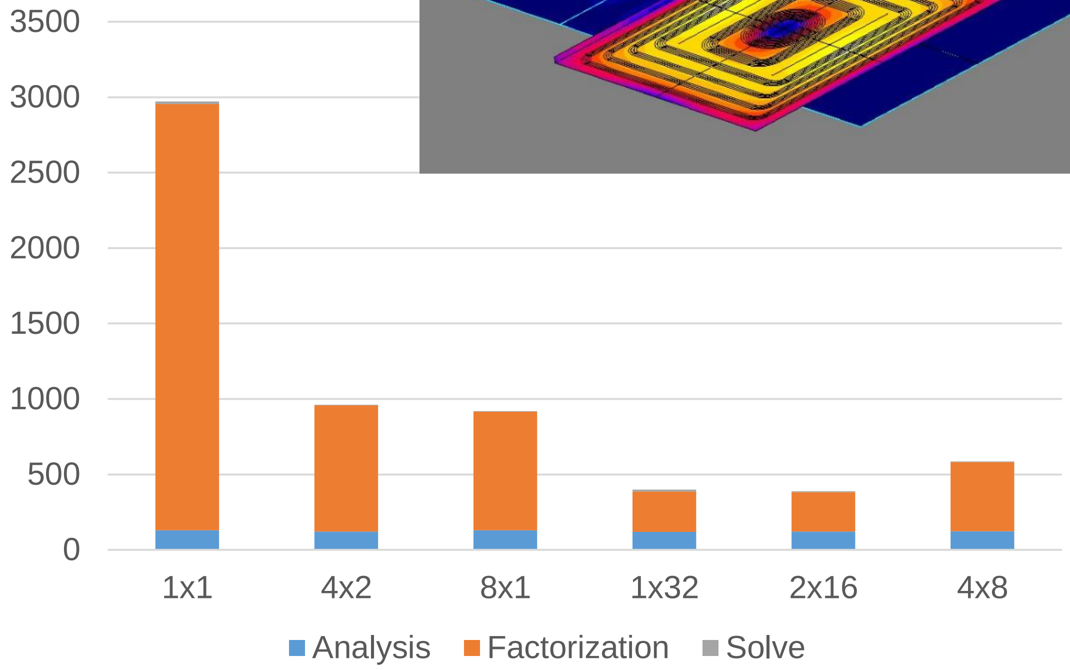
- Scaling is better on MPI than OpenMP
  - Keep #MPI > #OpenMP
- Use OpenMP when MPI does not scale anymore

Test Case

- Hardware specifications :
  - 2 CPU / E5-26974 @ 2,6 GHz
  - 16 cores / CPU
  - 32 cores in total
  - 512 GB RAM

- Complex linear system:
  - N= 4 716 803
  - NNZ= 421 964 241
  - 1 linear system resolution
- From sequential to 2x16:
  - Speed-up= 10,8 on factorization
  - Speed-up= 7,6 on linear system





Conclusions and future works

- Significant reduction of computation time with MUMPS
  - Parallel speed-up of factorization step
  - Solving step negligible

- Performances are still to improve :
  - Make the analysis phase parallel
    - Any alternative to METIS ?
  - BLR robustness problems
  - Bad memory estimation may cause crash
    - Differences between memory estimation/allocated and memory used
    - Need to specify a value in ICNTL(23)

Thank you