A not so short introduction to MFront, MGIS and MFrontGallery

MFront training course

(1) CEA, DES, IRESNE, DEC, SESC, LSC, Cadarache, France

Thomas Helfer(1)

Outline

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- Graduated in Material Science Engineering (Mines de Nancy)

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  - Non linear mechanics of materials
  - Variational approaches to fracture
  - Numerical methods (FEM, HDG, HHO, etc..)
  - High performance computing

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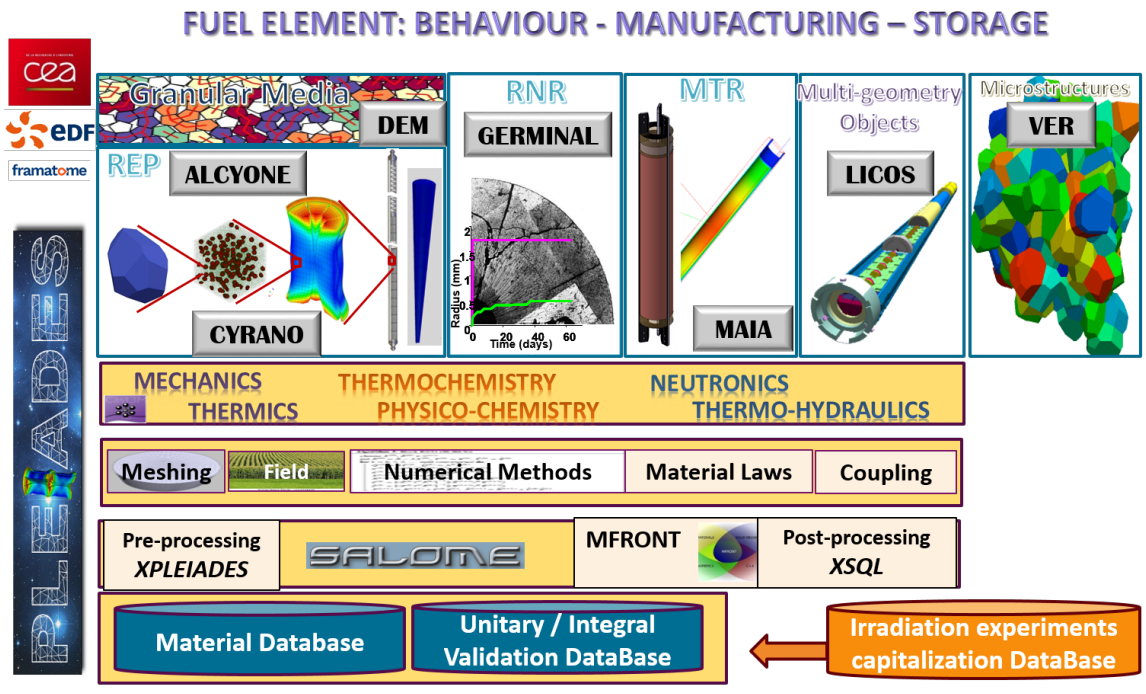
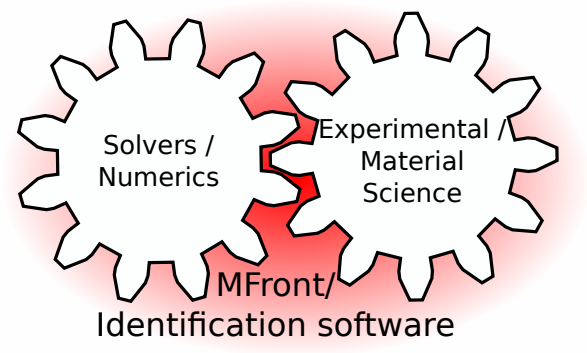
  - High performance computing
- Author and coauthor of 21 journal papers and $\approx$ 50 conference papers.

The Pleiades platform



- A wide range of materials (ceramics, metals, composites).
- A wide range of mechanical phenomena and behaviours.
  - Creep, swelling, irradiation effects, phase transitions, etc..
- A wide range of mechanical loadings.

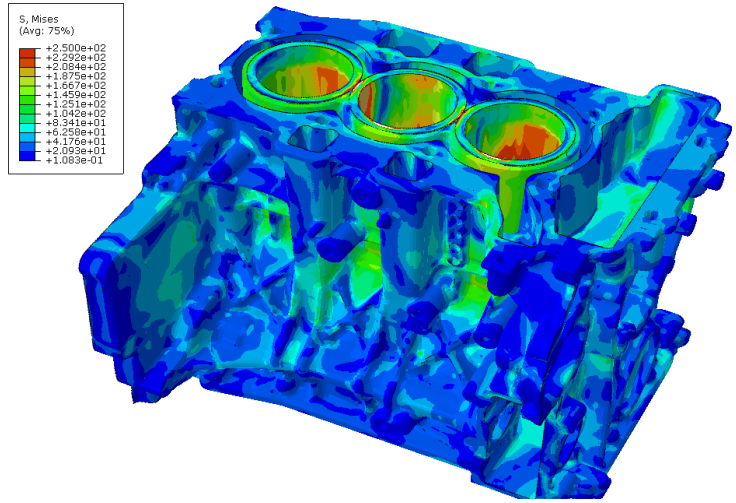
Material knowledge management



- The need to guarantee the quality of engineering studies has never been so high and is constantly growing.
- Every part of a study must be covered by strict AQ procedures:
  - The finite element solver on the one hand (see the `code_aster` documentation and unit tests).
  - The material knowledge (material properties, **mechanical behaviours**) and experimental data on the other hand.
- **One must guarantee a complete consistency from experimental data to engineering studies**
- See also the `MFrontGallery` project

Outline

Design of a cylinder block



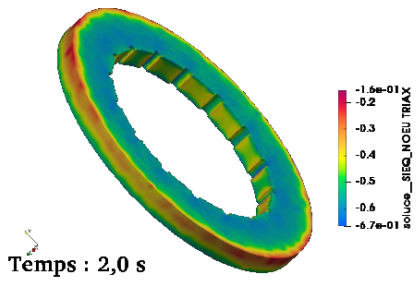
- Industrial thermomechanical design of a cylinder block with an with `MFront` and `Abaqus` at Groupe PSA.
- This study is one result of the PhD thesis of L. Jacquinot which provides a continuous modelling of the AlSi9Cu3Mg aluminium alloy behaviour from manufacturing to final usage (see the attached figure).
- The finite element model contains 11e6 dofs (3e6 elements) and has been solved using a 72 cores computers with Abaqus 2016.

Modelling of braking with code_aster et MFront

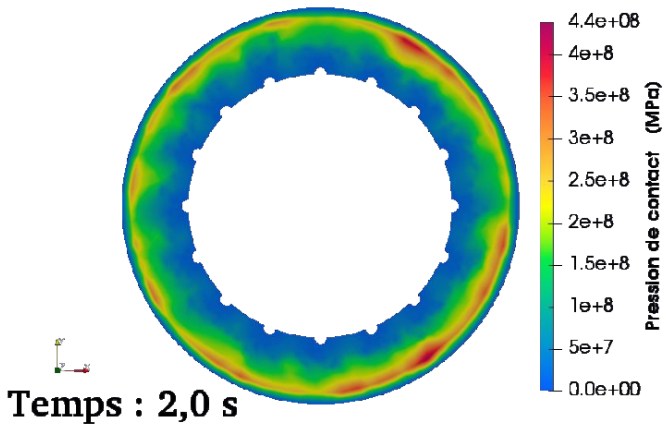
Modélisation du freinage à partir d'une formulation thermomécanique

T. Ndzana Satoh [1,2], M. Renouf [1], A. Chrysochoos [1]

[1] LMGC UMR5508 CNRS, Université de Montpellier, Montpellier, FRANCE
[2] SAFRAN Landing Systems, Velizy, FRANCE



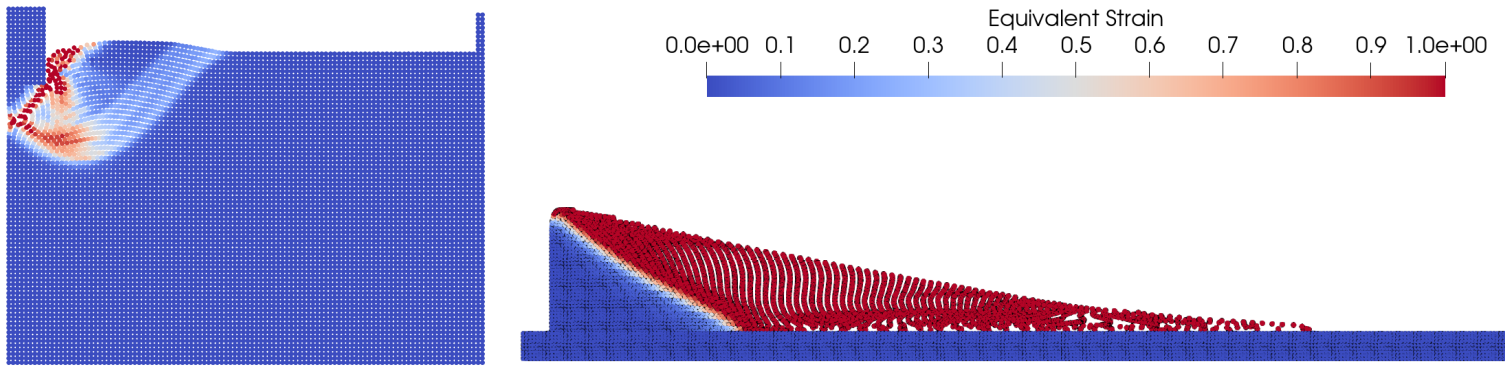
Triaxialité d'un des corps en contact



Répartition de la pression de contact sur la surface de contact après 2 s de freinage

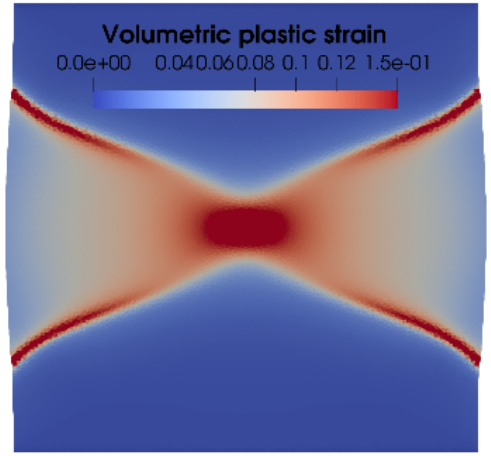
- MFront User Meeting 2020
- Thierry Ndzana Satoh (Université de Montpellier, SAFRAN Landing Systems), M. Renouf (Université de Montpellier), A. Chrysochoos (Université de Montpellier)

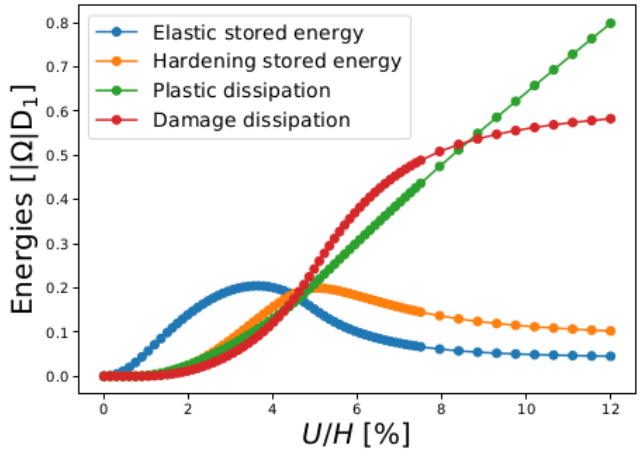
Geo-materials simulated using a material point metho



- Equivalent strain contour from the material point method simulations: the footing (left) and the column collapse
- Courtesy of Ning Guo, Wenlong Li (Zhejiang University)

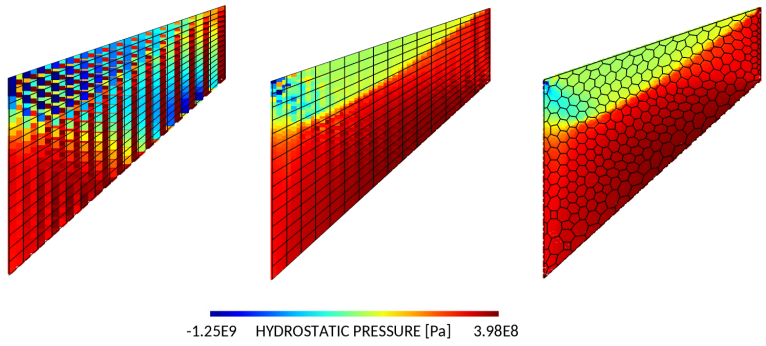
Variational approaches to geomaterials

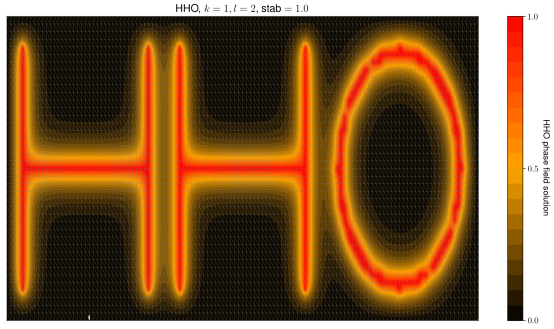




- Coupling damage and plasticity accounts for classical geomaterials behaviours (contractancy and dilatancy)
- Currently tested with the `mgis.fencis` 'python' module. Shall be introduced in `code_aster` during the PhD of G. Bacquaert.
- Courtesy of G. Bacquaert, V. Alves, Fernandes , J. Bleyer, D. Kondo, C. Maurini, S. Raude, F. Voldoire

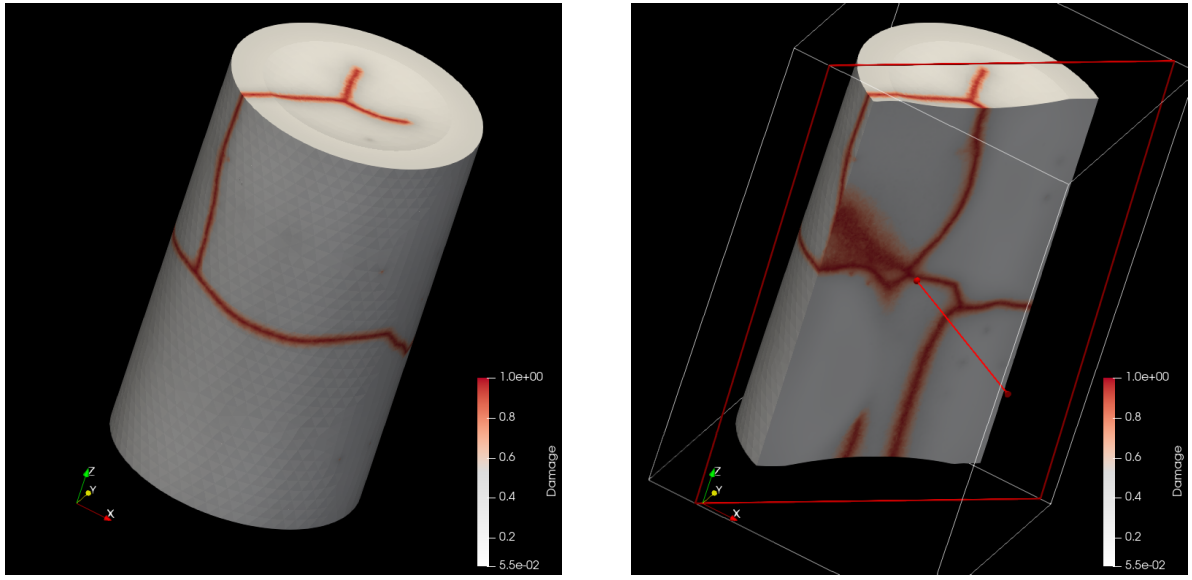
Hybrid High Order method





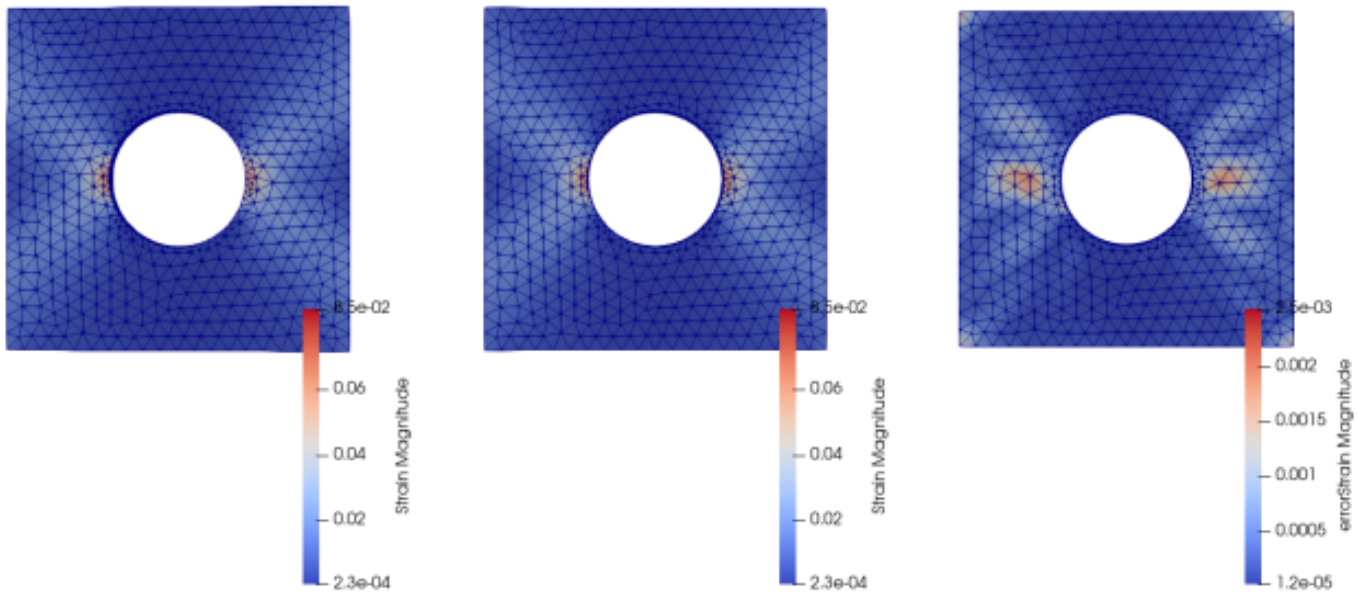
- PhD of D. Siedel.
- `Python` and `C++` libraries to test new algorithms:
  - Compare different stabilisation operators.
  - Compare different cell elimination strategies.
  - Local treatment of the irreversibility constraint at the element level.

Fuel pellet fragmentation during reactor start-up



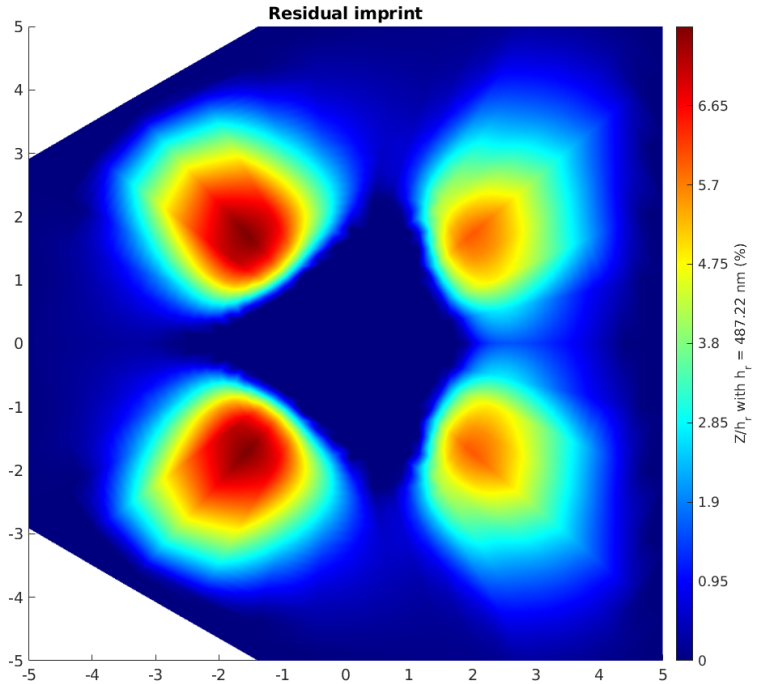
- Micromorphic damage approach (Phd Thesis of D. Siedel).
- Computations with `MFEM/MGIS` on 2 500 cores.
  - Qualified in `mgis.fenics`
  - 33 230 848 triangles, 132 923 392 nodes, 4.10^8 degrees of freedom for the mechanical problem.
  - Various classical phase-field models have been tested AT1, AT2, Lorentz...
  - Exact treatment of the irreversibility constraint at integration points.
  - Good scalability.

Neural network based constitutive models



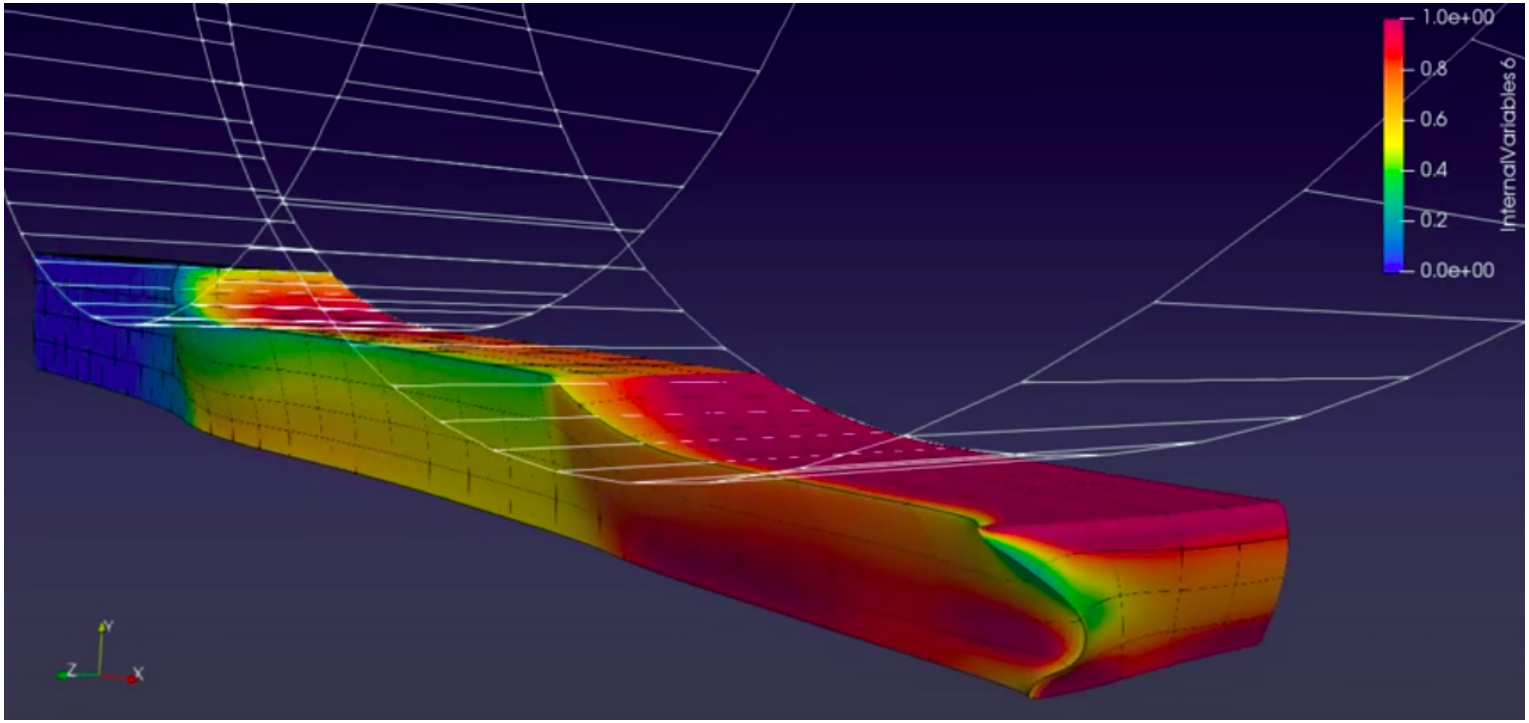
- Internship of M. Duvillard. Courtesy of L. Giraldi.
- Neural network trained on unit tests at the material point level.

Berkovich indentation on a single crystal



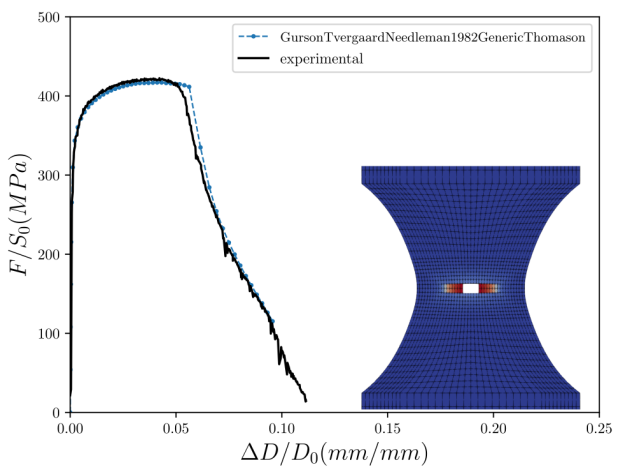
- Normalised residual topography after an indentation test on a single crsytal of copper with Méric-Cailletaud' finite stain behaviour using `Ansys`
- Courtesy of A. Bourceret, FEMTO

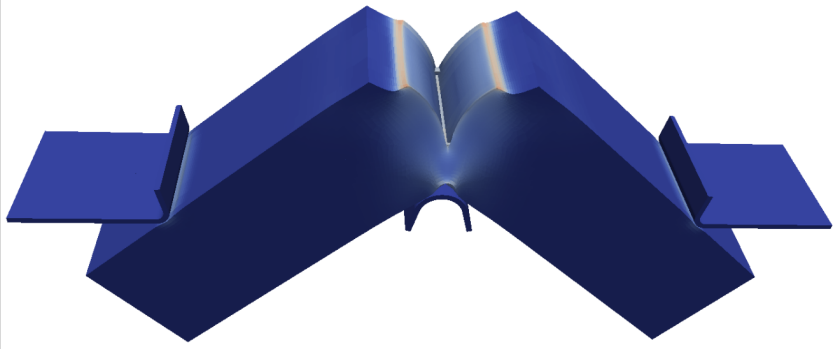
Simulation of rolling



- Simulation of rolling using the innovative CEA' proto-application `MEFISTO` (implicit/explicit solver)
- Courtesy of O. Jamond, CEA

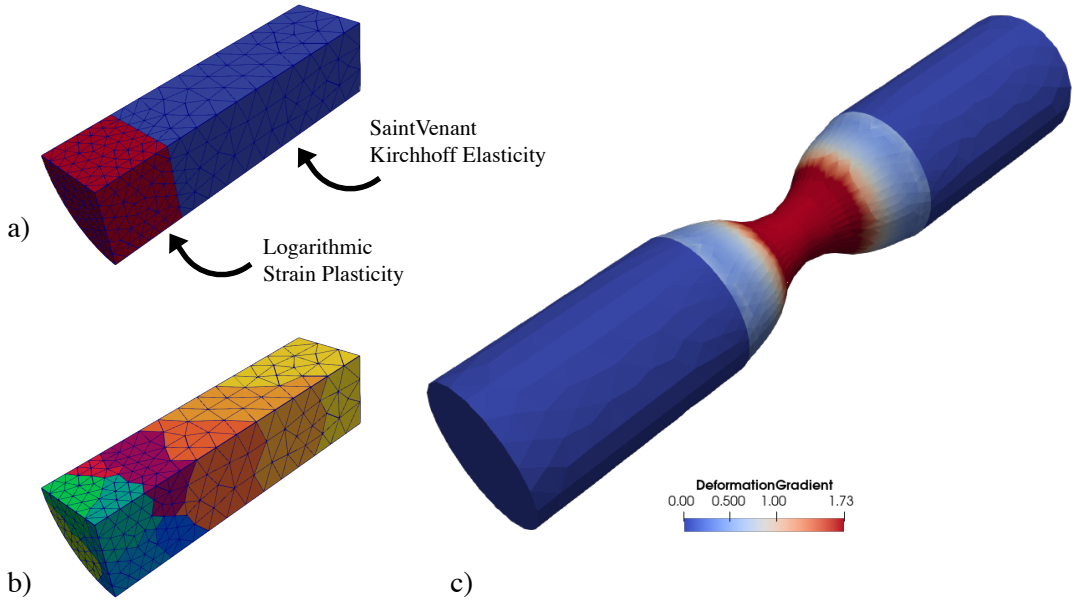
Ductile failure





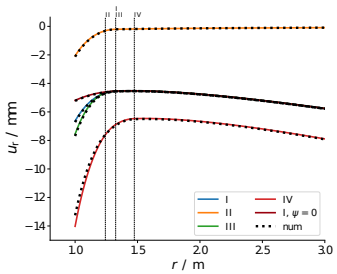
- Simulation of ductile failure using CEA' `Cast3M` finite element solver.
- GTN behaviour in the logarithmic space.
- Illustration of the extension of the `StandardElastoViscoPlasticity` brick to porous plasticity.
- Courtesy of M. Shokeir and J. Hure, CEA

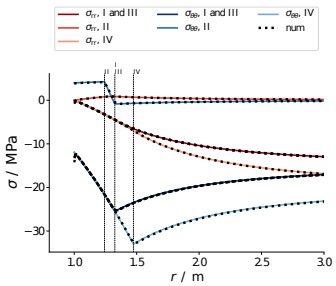
Necking of a rod in finite strain plasticity



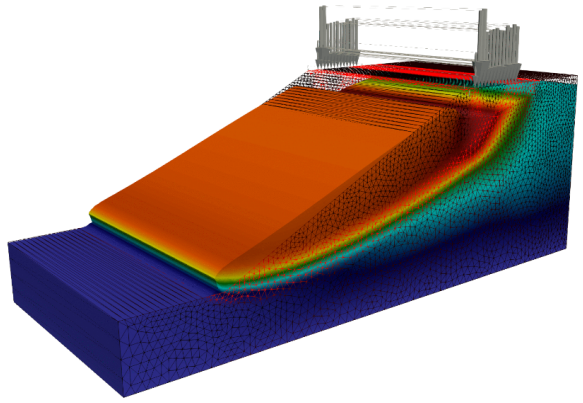
- Example of usage of `MFront` in the `MoFEM` finite element solver.
- a) Discretised one eighth of the geometry. b) Parallel domain decomposition. c) Deformed specimen and distribution of deformation gradient.
- Courtesy of K. Lewandowski and L. Kaczmarczyk, University of Glasgow.

Slope failure analysis



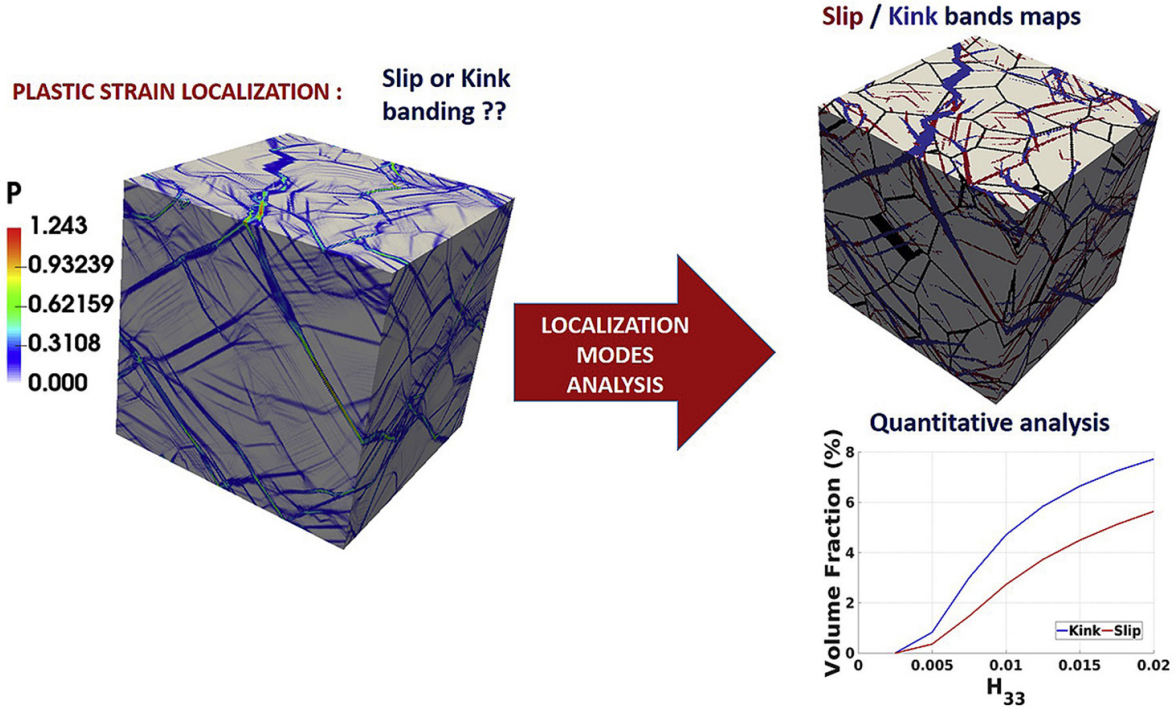


Slope failure analysis with phi-c-reduction in OpenGeoSys



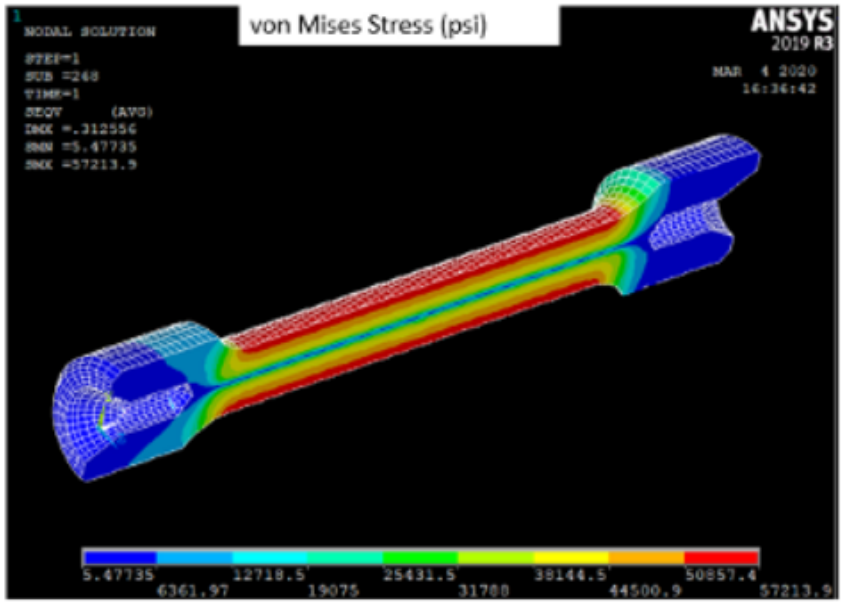
- Analytical verification (left)
- Slope failure analysis with strength reduction in `OpenGeoSys` by T. Deng and T. Nagel (Technische Universität Bergakademie Freiberg)
- For details, see `https://opengeosys.org/docs/benchmarks/small-deformations/slope_stability.pdf`.
- The implementation of the behaviour is described here: `http://tfel.sourceforge.net/MohrCoulomb.html`

Intragranular localization induced by softening crystal



- https://www.sciencedirect.com/science/article/pii/S1359645419303696
- Based on the CEA' `AMITEX_FFTP` solver
- Courtesy of L. Gelebart (CEA)

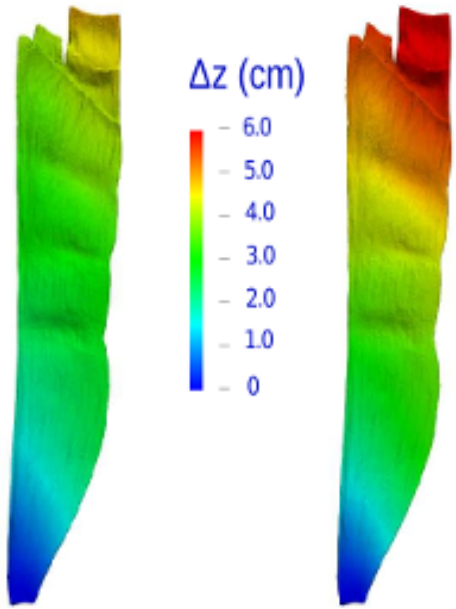
Torsional twist of a bar



Torsional twist of a notched bar using an Hosford plastic behaviour with a bilinear hardening law
Alex Grishin
Ansys MAPDL 2020

- Plastic behaviour based on the Hosford criterion. Implementation described here: http://tfel.sourceforge.net/hosford.html

Modelling of abdominal muscles

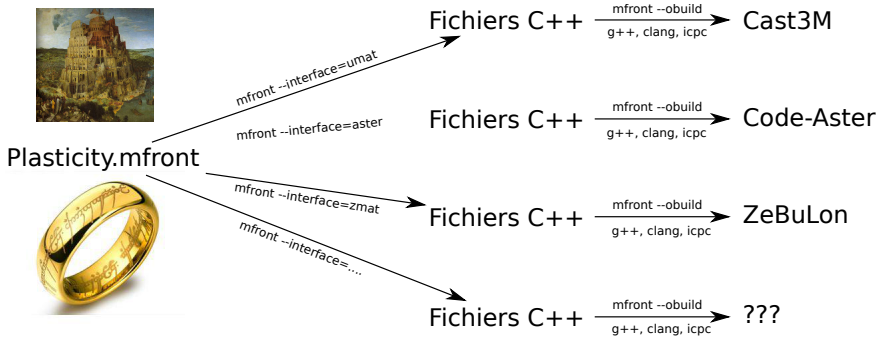


Modelling of abdominal muscles
Lluís Tuset, Gerard Fortuny, Joan Herrero, Dolors Puigjaner, Josep M. López
Code_Aster
2019

- Hyperelastic behaviour in `code_aster`

Outline

MFront: overview



- `MFront` is a code generation tool dedicated to material knowledge (material properties, mechanical behaviours, point-wise models):
  - Support for small and finite strain behaviours, cohesive zone models, **generalised behaviours** (non local and or multiphysics).
- Main goals:
  - Numerical efficiency (see various benchmarks on the website).
  - Portability (`Cast3M`, `Cyrano`, `code_aster`, `Europlexus`, `TMFTT`, `AMITEX_FFTP`, `Abaqus`, `CalculiX`, `MTest`).
  - **Ease of use**: *Longum iter est per praecepta, breve et efficax per exempla* (It's a long way by the rules, but short and efficient with examples).

Software quality: an industrial strength software

- Very stringent compilers warnings:
  - `g++ -Wall -W -Wextra -pedantic -Wdisabled-optimization -Wlong-long -Winline -Wswitch -Wsequence-point -Wignored-qualifiers -Wzero-as-null-pointer-constant -Wvector-operation-performance -Wtrampolines -Wstrict-null-sentinel -Wsign-promo -Wsign-conversion -Wold-style-cast -Wnoexcept -Wmissing-include-dirs -Wmissing-declarations -Wlogical-op -Winit-self ...`
- Continuous integration based on `Jenkins` and `Github Actions`
- Tested on `Linux`, `Mac OS` and `FreeBSD` with `gcc`, `clang` and `icc`.
- 18 227 test cases in 4.0 (18 208 in `3.4.3`, 16 316 in `3.4.0`)
  - Most of them are based on `mtest`
- More tests inside `PLEIADES` applications, `MFrontMaterials`, `MFrontGallery`, etc...
- `TFEL` is mainly developed on `LiNuX`. Ports have been made to various POSIX systems, `Mac Os`, `FreeBSD`, `OpenSolaris`, `cygwin`, `Windows Subsystem for LiNuX`, `Haiku` etc... and `Windows !`

Open-source projects developped in the Pleiades plat

- MFront.
  - https://www.sciencedirect.com/science/article/pii/S0898122115003132
  - https://thelfer.github.io/tfel/web/index.html
  - https://thelfer.github.io/tfel/web/gallery.html
- MGIS (MFrontGenericInterfaceSupport).
  - https://joss.theoj.org/papers/10.21105/joss.02003
  - https://thelfer.github.io/mgis/web/index.html
  - https://thelfer.github.io/mgis/web/bindings-cxx.html
- MFrontGallery.
  - https://github.com/thelfer/MFrontGallery/tree/master/docs/papers/joss
  - https://thelfer.github.io/MFrontGallery/web/index.html

Outline

Training course

- Small introduction to `C++`
- Material properties
- Point-wize models and `mtest`
- Isotropic viscoplastic behaviours
- The `StandardElastoViscoplasticity` brick
- The `Implicit` DSL