Unit of Applied Mechanics

Parallelization of the FE-solver ICONA

2nd Workshop on Structural Analysis of Lightweight Structures

INTALES GmbH Engineering Solutions

University of Innsbruck, Faculty of Civil Engineering Sciences

University of Innsbruck, Faculty of Mathematics, Informatics and Physics

Natters/Tyrol, 30/05/2012

Introduction

Unit of Applied Mechanics

- ICONA is a FE-solver developed by Intales and the Distributed Parallel Systems group (DPS), Department of Computer Science, University of Innsbruck.
- The code is based on the Matlab code of Franz Falkner, Unit of Applied Mechanics, Institute of Basic Sciences in Civil Engineering, University Innsbruck.
- The main goal of the development at DPS was to reduce the computation time by parallelizing the solution process.

Topics

Unit of Applied Mechanics

- General information about Icona
- Structure of Icona
- Parrallelization of Icona
- Benchmark results

General information about Icona

Unit of Applied Mechanics

- ICONA is developed in C++ using PETSc and Boost libraries
- Parallelization of ICONA is done with MPI
- The code is optimized for the analysis of shell structures
- To types of shell elements: Resultant based large rotation shell element, solid shell element
- Load controlled analysis (Abaqus type load incrementation)
- Arc-length controlled analysis (modified Riks method)

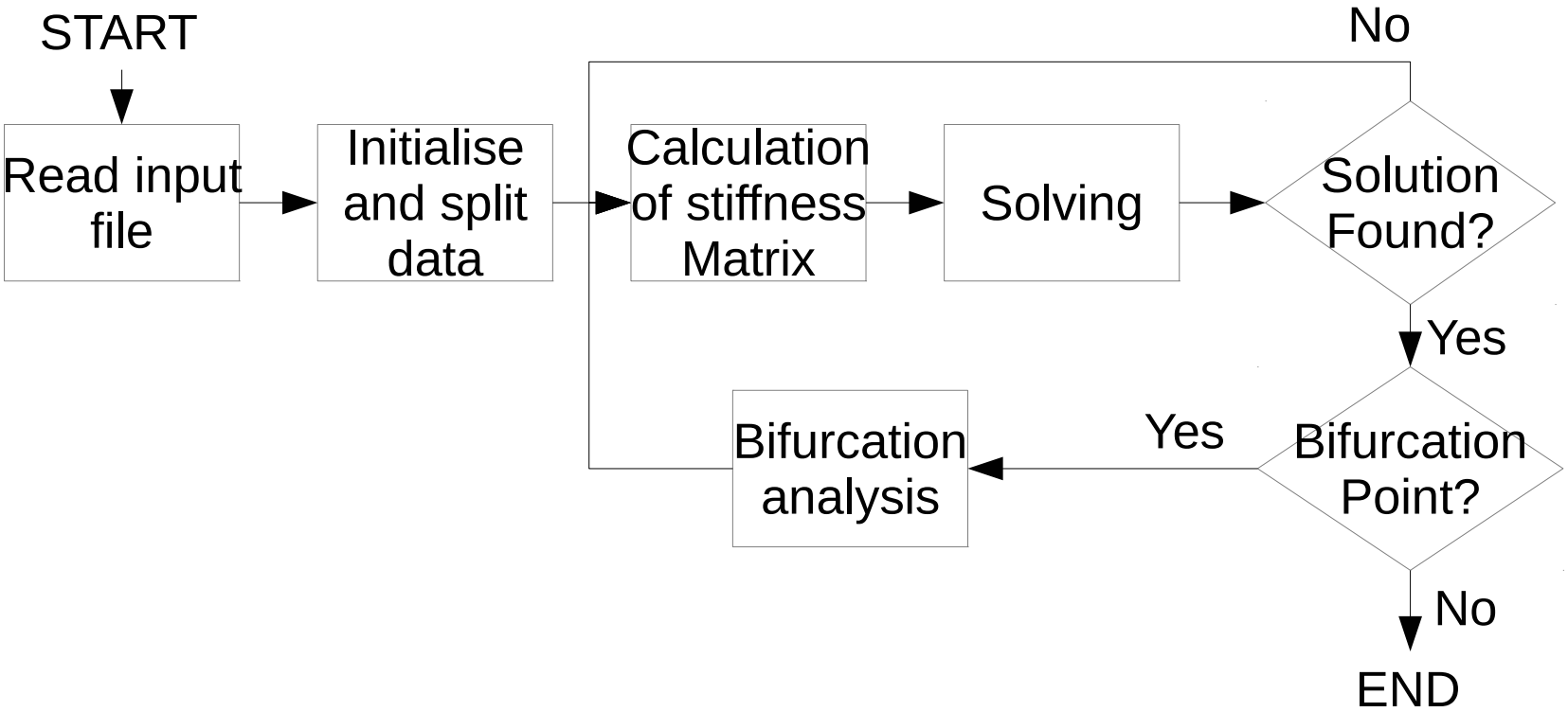
Topics

Unit of Applied Mechanics

- General information about Icona
- Structure of Icona
- Parrallelization of Icona
- Benchmark results

Structure of Icona

- Simplified program flow:



Read input file, Initialize and split Data

Unit of Applied Mechanics

Read input file

- ICONA can read input-files in Abaqus .inp format

Initialize and split Data

- After reading the problem data is prepared for calculation
- The data is split among the MPI processes

Calculation of stiffness matrix

- For every element the stiffness matrix is calculated
- The element matrices are assembled to obtain the global stiffness matrix
- Boundary conditions are applied by inserting zeros and ones

Solving the problem

Unit of Applied Mechanics

Linear equation solver

- PETSc is used to provide the interface to the linear equation solver
- Best performance obtained with the MUMPS solver
- For the detection of bifurcation points the rational Cholesky (LDLT) decomposition is applied

Bifurcation analysis

- If the occurrence of a bifurcation point is observed, an eigenvalue extraction is performed
- The lowest eigenvalue and corresponding eigenvector are applied to initialize the bifurcation analysis (iterative solution of an extended equilibrium condition)
- If the iteration converges, the exact critical load and the corresponding buckling mode are obtained
- With that the continuation of the post-buckling path can be initialized

Topics

Unit of Applied Mechanics

- General information about Icona
- Structure of Icona
- Parrallelization of Icona
- Benchmark results

Parallelisation of Icona

- Nearly all parts of Icona are parallelized with MPI
- Reading input file and initialization of data are not parallelized
- PETSc functions are written in MPI
- The parallelization of the calculation of stiffness matrix had to be done by hand

Calculation of stiffness matrix

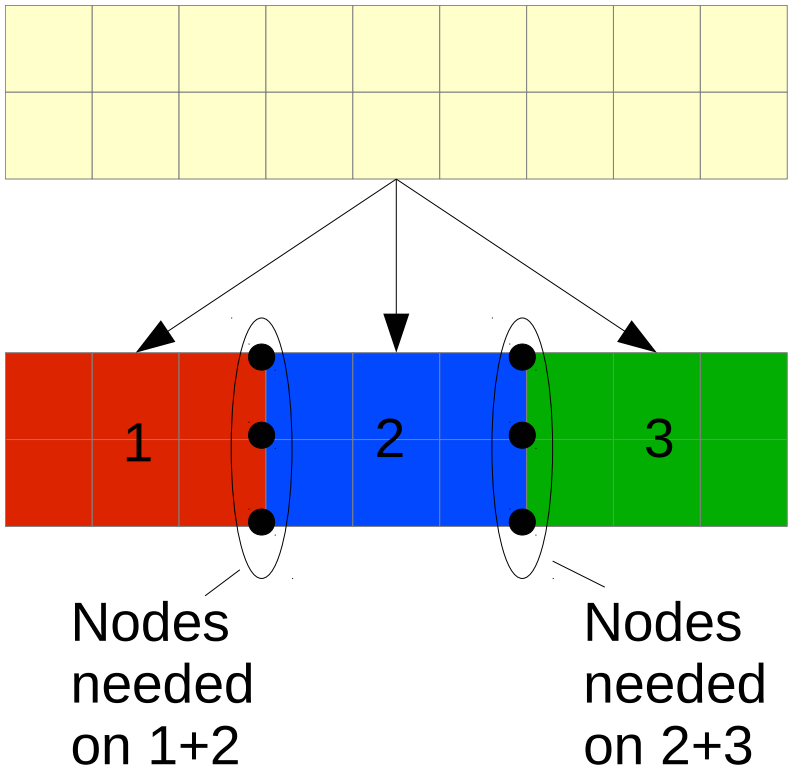
Unit of Applied Mechanics

- Every process calculates only the element stiffness matrices he is responsible for
- The data has to be split among all MPI processes for this purpose

Splitting of data

Unit of Applied Mechanics

- Splitting of data for element creation:

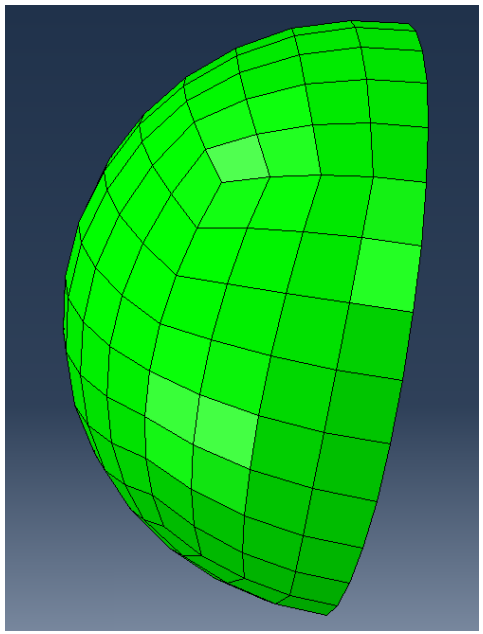


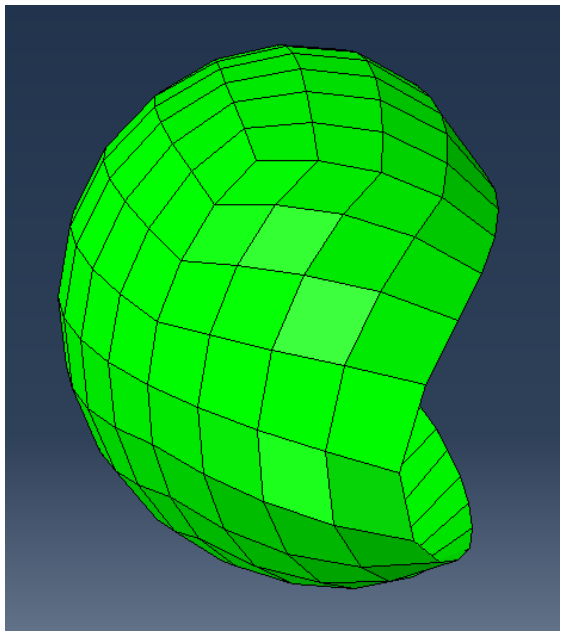
Unit of Applied Mechanics

- General information about Icona
- Structure of Icona
- Parrallelization of Icona
- Benchmark results

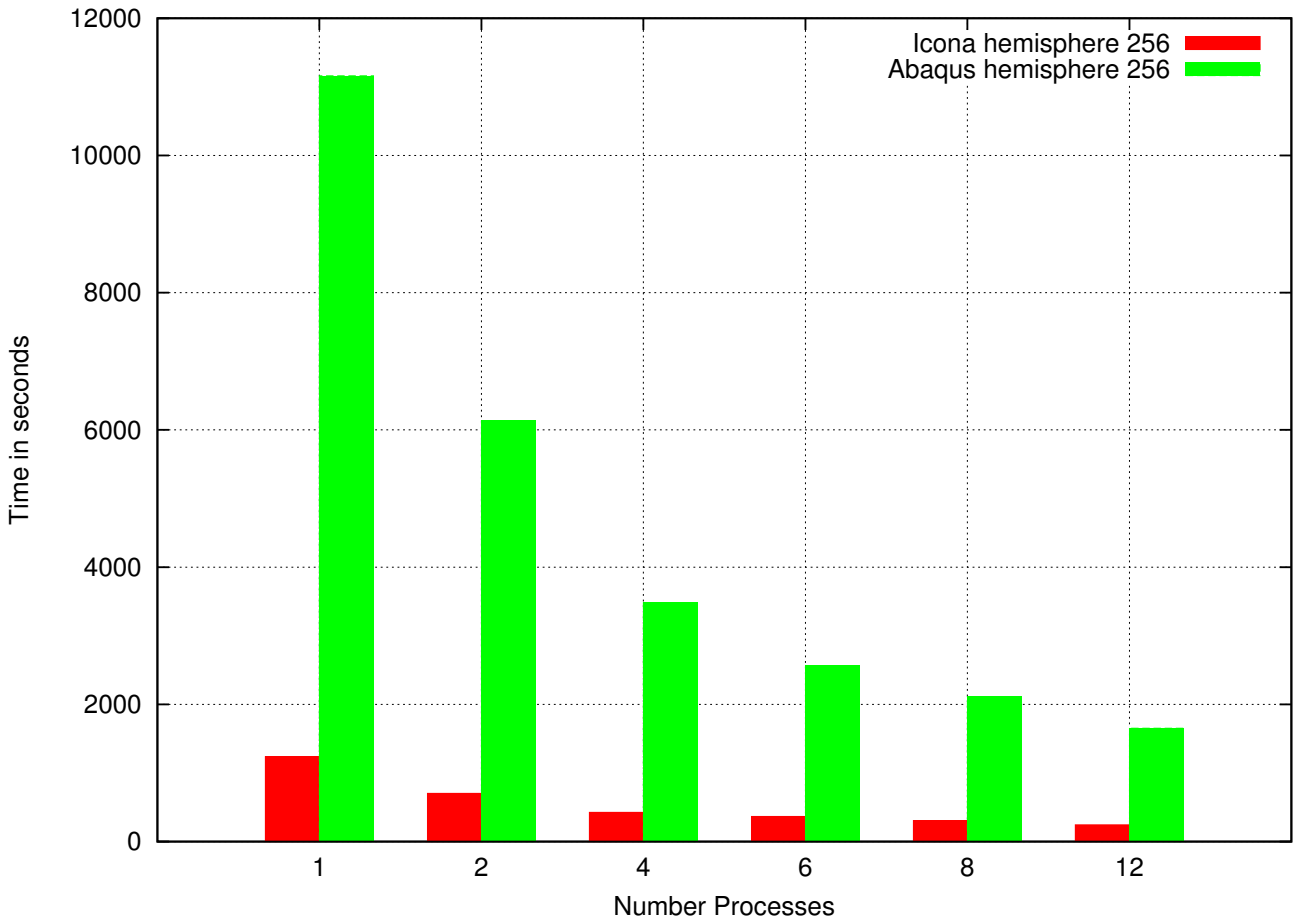
Benchmark

- One of the most popular and demanding benchmark tests for shell elements is the so-called 'pinched hemisphere'
- The hemispherical shell is subjected to four point loads at its equator pulling and pushing in opposite and perpendicular directions, respectively
- The model consists of 196608 elements and 190975 nodes, i.e. 954875 degrees of freedom





Benchmark results

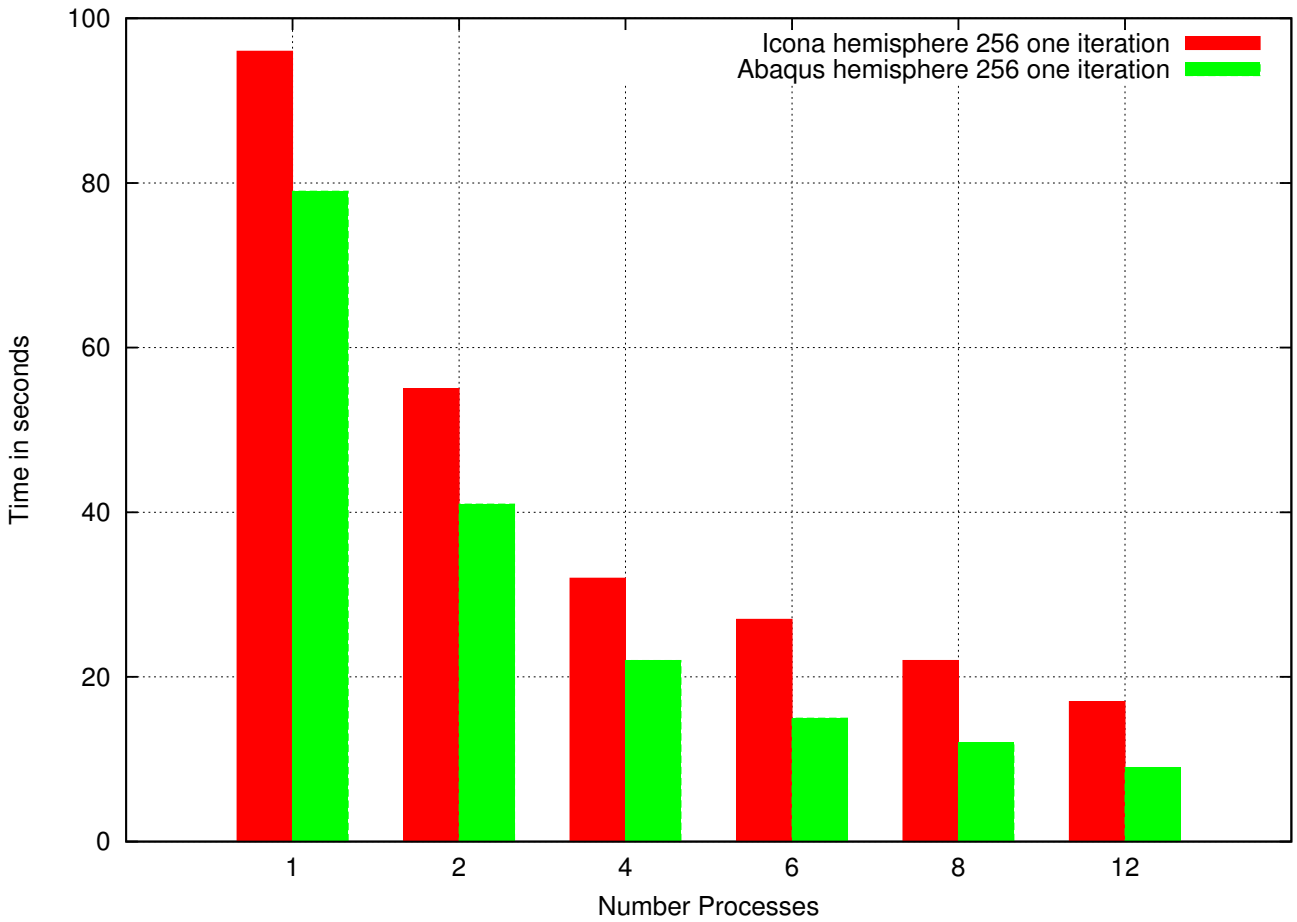


Benchmark results discussion

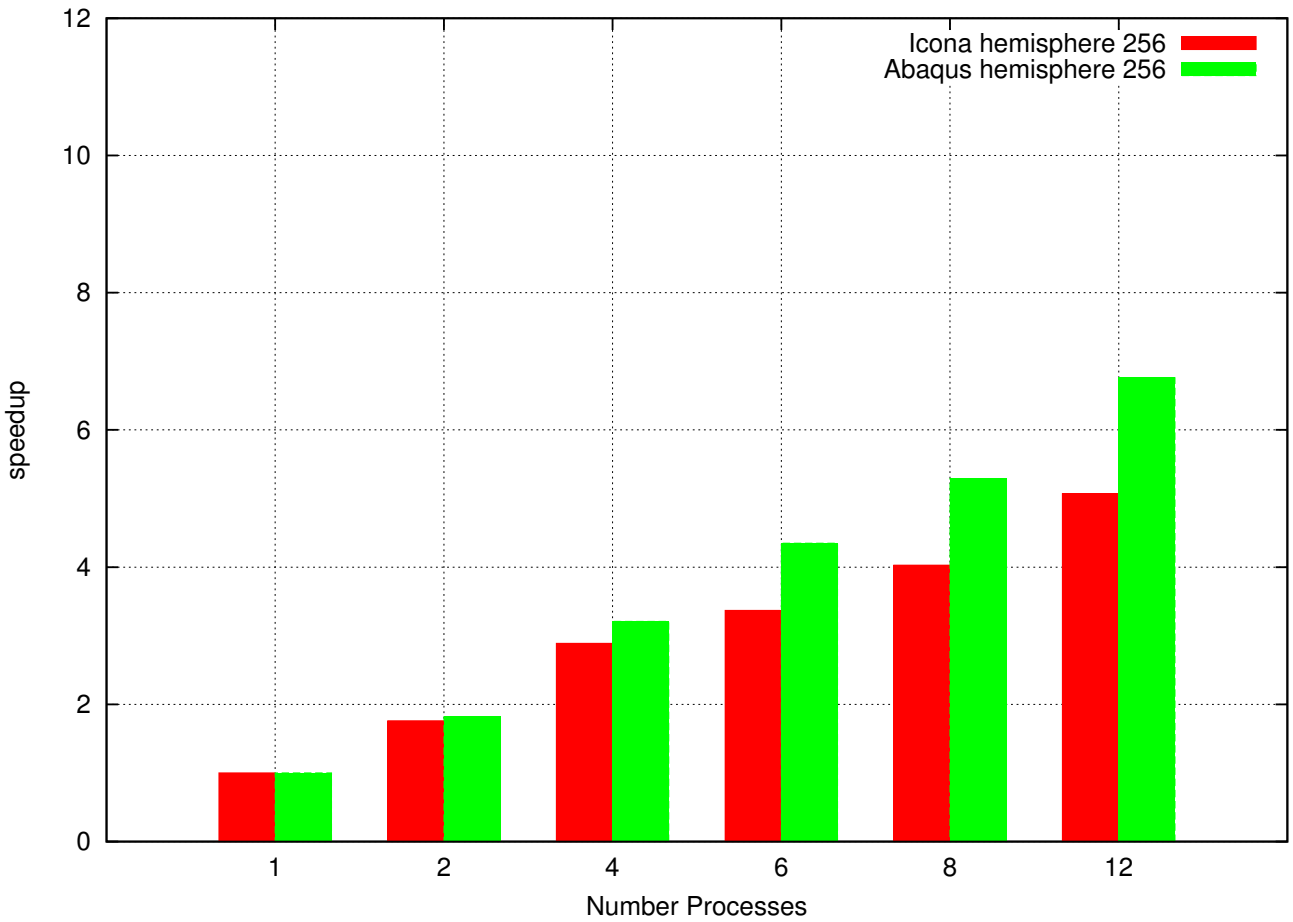
Unit of Applied Mechanics

- In that example, ICONA performs 9 times faster than Abaqus
- The reason is the extraordinary convergence behavior for bending dominated problems of the mixed-enhanced shell element of ICONA (Klinkel et al. 2008, implemented by Franz Falkner)
- To reach the final load level, ICONA needs 2 load steps (12 iterations in total) and Abaqus 21 (90 iterations)
- If the number of load steps are enforced to be the same, Abaqus performs about 20% faster than ICONA

Benchmark results per iteration



Benchmark results speedup



Benchmarks results iterations discussion

Unit of Applied Mechanics

- The overall performance of ICONA and Abaqus for the static analysis of smooth shell structures is comparable
- But the main development reason for ICONA was the bifurcation analysis

END and References

Unit of Applied Mechanics

Thank you for your attention

PETSc

`http://www.mcs.anl.gov/petsc/`

MUMPS

`http://mumps.enseeiht.fr/`