6th Annual Formation Evaluation Research Consortium Meeting

FAST NUMERICAL SIMULATIONS OF 3D DC BOREHOLE RESISTIVITY MEASUREMENTS WITH A PARALLEL SELF-ADAPTIVE HP GOAL-ORIENTED FINITE ELEMENT FORMULATION

THE UNIVERSITY OF TEXAS AT AUSTIN
WHAT STARTS HERE CHANGES THE WORLD

Maciej Paszyński [1,2] , **David Pardo** [2], **Carlos Torres-Verdin** [2], **Leszek Demkowicz** [3]

[1] Department of Computer Science, AGH University of Science and Technology

[2] Department of Petroleum Engineering, The University of Texas in Austin

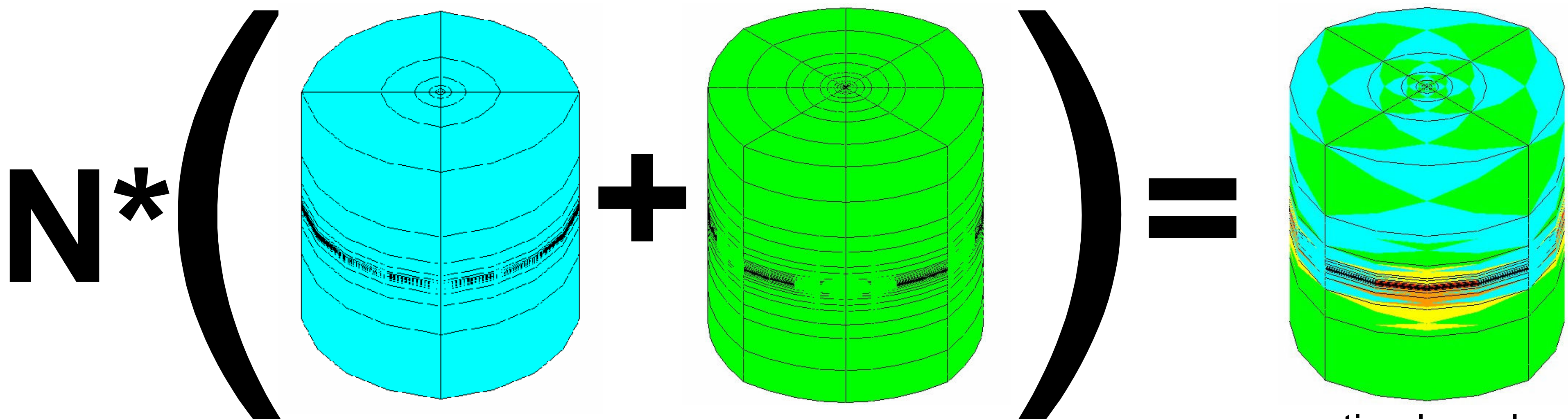
[3] Institute for Computational Engineering Sciences, The University of Texas in Austin

6th Annual Formation Evaluation Research Consortium Meeting, August 16-18, 2006

OUTLINE

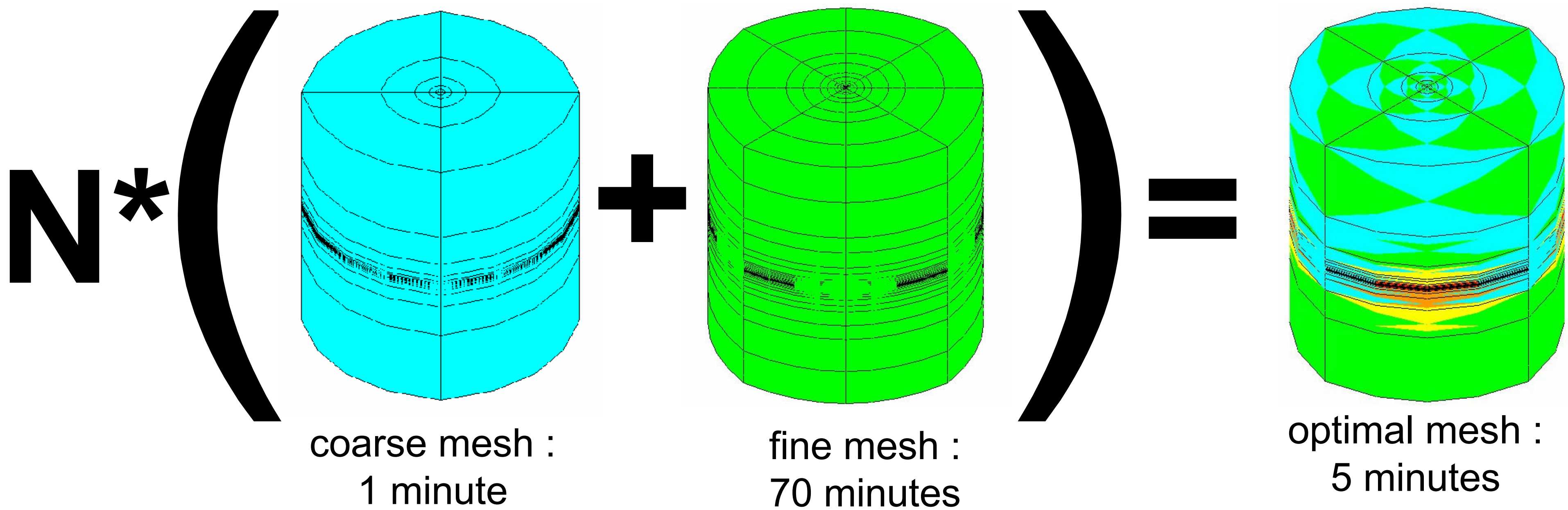
1. Motivation
2. Components of the parallel software
3. Domain decomposition
4. Nested dissections parallel direct solver
5. Parallel mesh refinements
6. Timing and efficiency of parallel solver
7. Results
8. Conclusions and future work

MOTIVATION



Goal oriented self-adaptive *hp* finite element code requires a sequence of coarse and fine mesh solutions to provide optimal finite element mesh

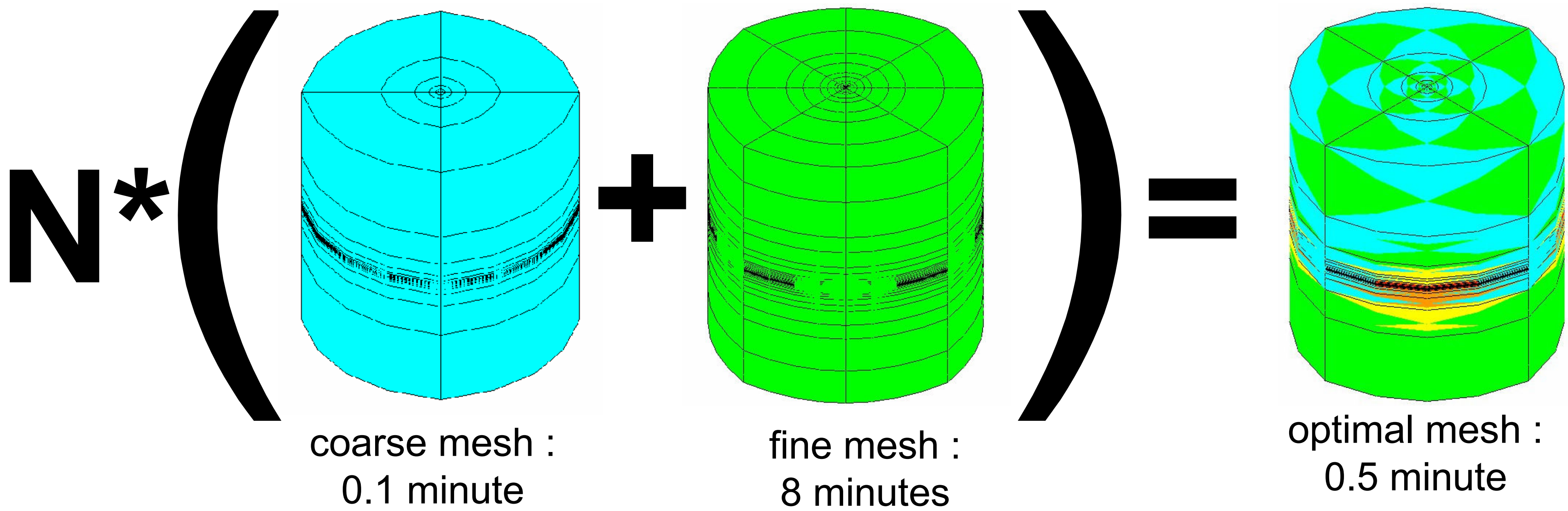
MOTIVATION



Single processor exemplary solver execution times

Several days on single processor execution required to produce optimal mesh in 3D

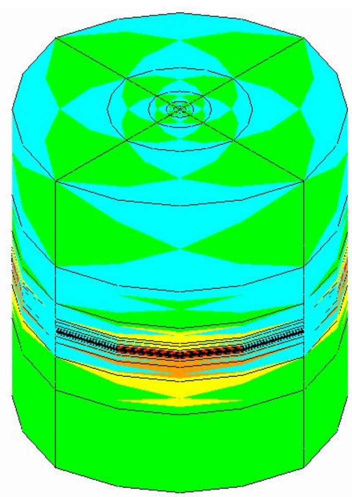
MOTIVATION



16 processors exemplary solver execution times

Several hours of execution on 16 processors parallel machine required to produce optimal mesh in 3D

MOTIVATION

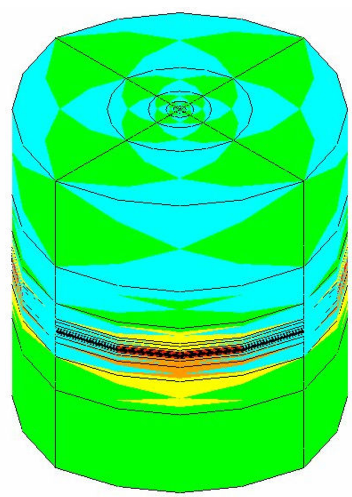
80*()

optimal mesh

80 executions of direct solver on the optimal mesh required to generate resistivity logging measurements curve

MOTIVATION

80*(



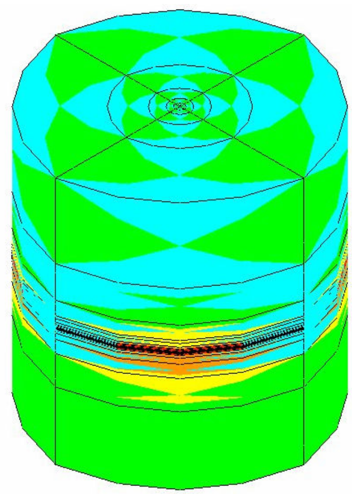
optimal mesh :
5 minutes

)

80 x 5 minutes = 7 hours of executions on single processor machine

MOTIVATION

80*(

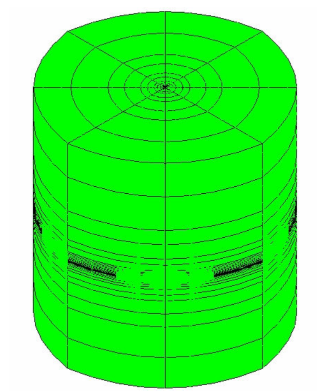


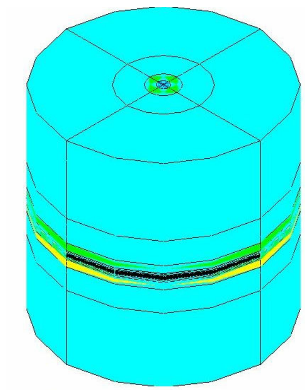
optimal mesh :
0.5 minutes

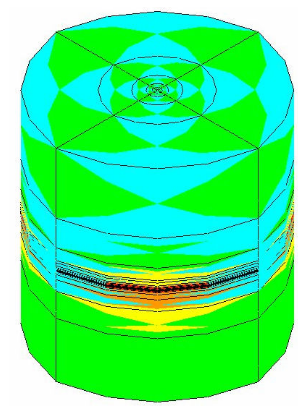
)

80 x 0.5 minutes = 40 minutes of executions on 16 processors parallel machine

MOTIVATION







Parallel solvers do not work well with *hp* meshes.

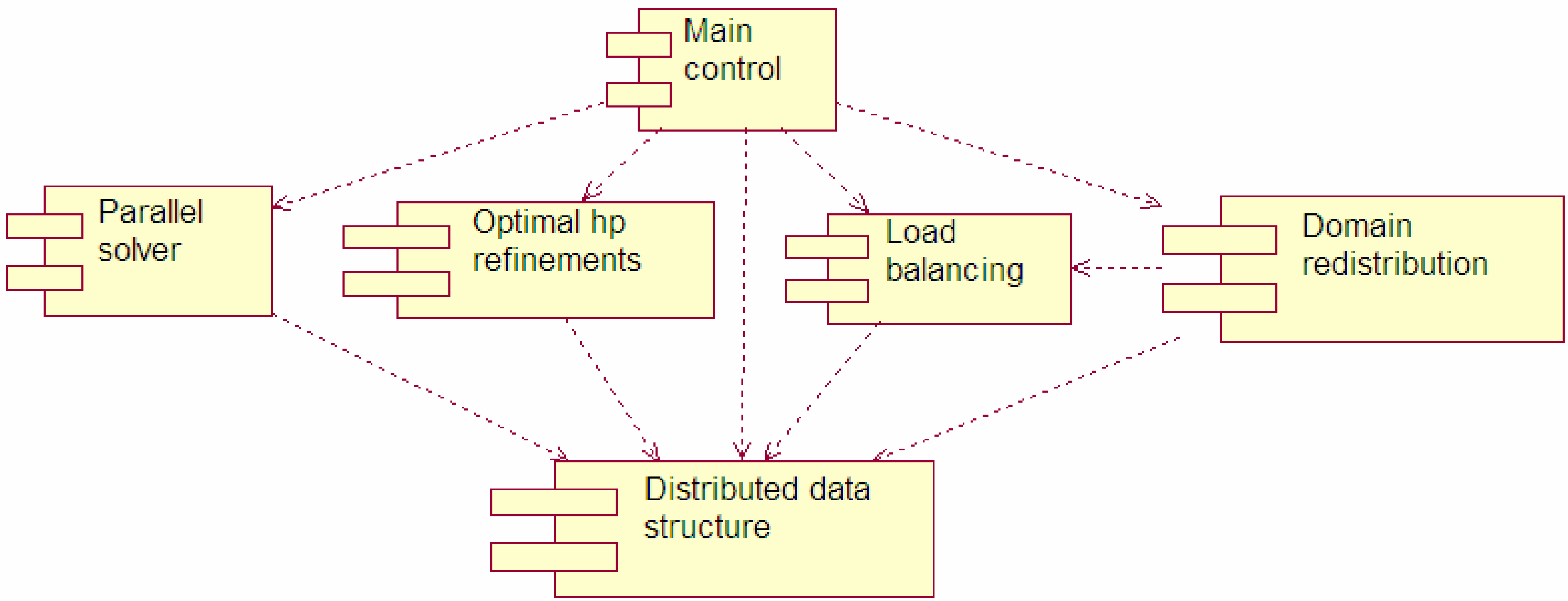
- MUMPS (MUltifrontal Massively Parallel sparse direct Solver) executed over uniform 3D mesh with 20 000 finite elements with p=3 works longer on 8 processors then 1 processor !
- SuperLU is not able to solve *hp* refined 3D mesh
- HSL solver is an older version of MUMPS
- Pardiso does not work in MPI environment

This motivated us to develop our own parallel solver.

WHY DISTRIBUTED PARALLEL COMPUTATIONS WITH PARALLEL DIRECT SOLVER?

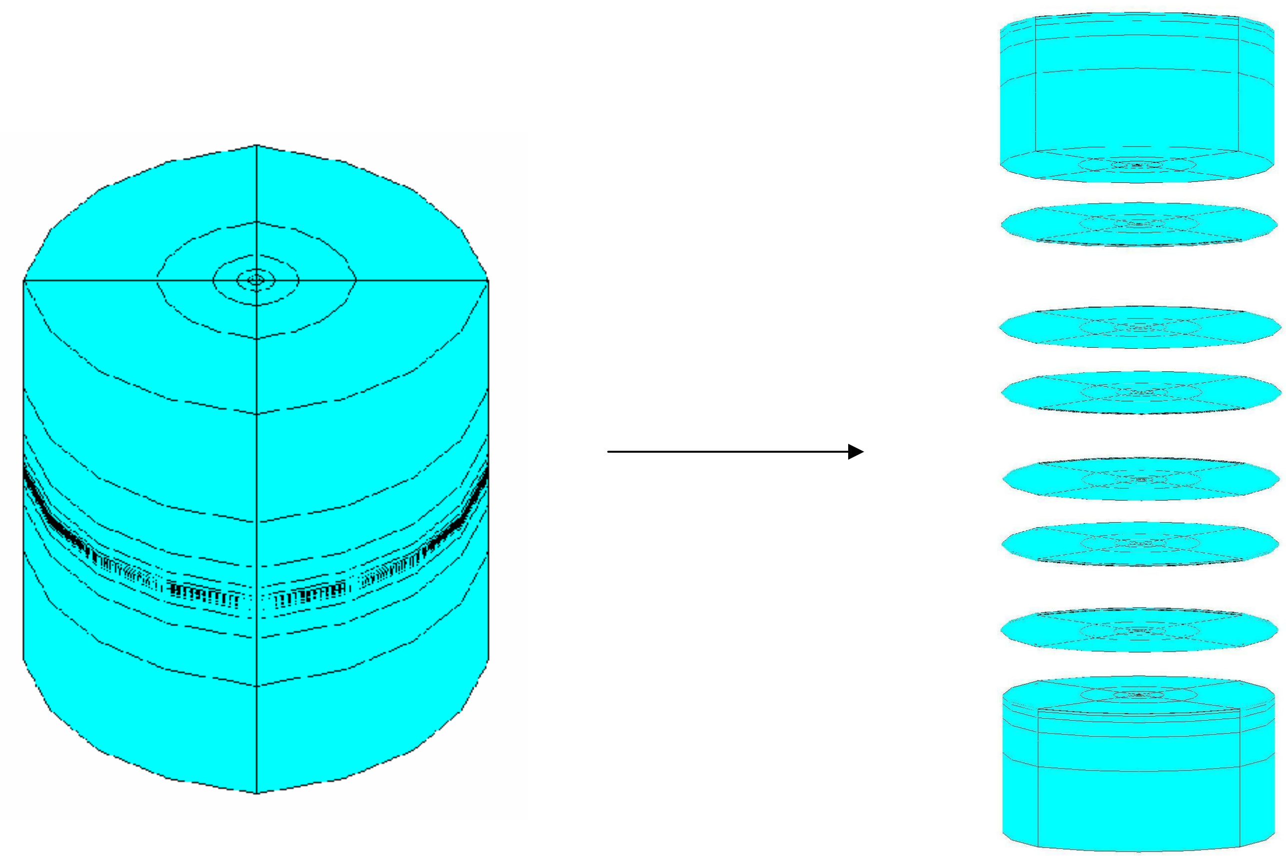
- The same parallel direct solver can be utilized for AC/DC measurements simulations, multi-physics and coupled problems.
- Parallel direct solver provides accurate and reliable solutions.
- Parallel direct solver does not suffer from convergence problems.
- Parallel code utilizes less memory.
- It can be utilized in large parallel machines (number of processors is NOT limited by number of logging positions).
- It re-utilizes information about results from previous logging positions.
- It is more suitable for inverse problems.
- It is suitable for multiple right-hand sides

COMPONENTS OF THE 3D PARALLEL SELF-ADAPTIVE *HP* FINITE ELEMENT CODE



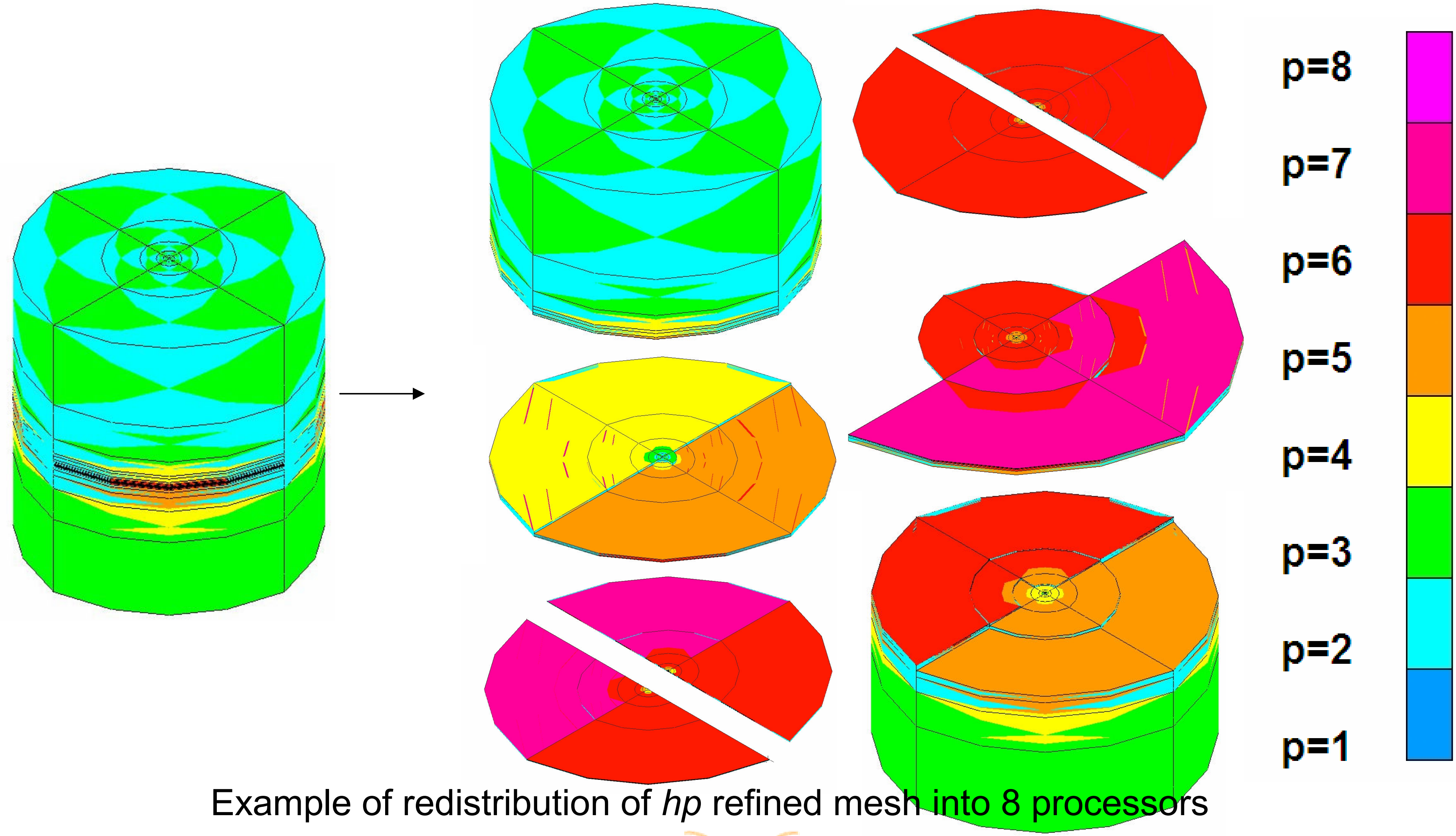
Modular structure of the system allows for an independent parallelization of each component

LOAD BALANCING AND DOMAIN REDISTRIBUTION



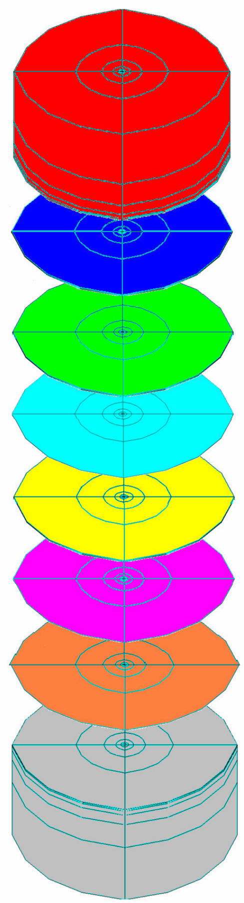
Example of redistribution of initial mesh into 8 processors

LOAD BALANCING AND DOMAIN REDISTRIBUTION

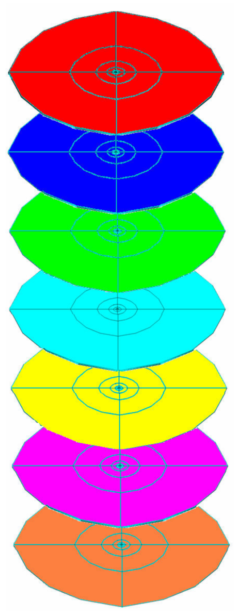


Example of redistribution of *hp* refined mesh into 8 processors

PARALLEL DIRECT SOLVER FOR DISTRIBUTED SYSTEM OF EQUATIONS



sub-domains



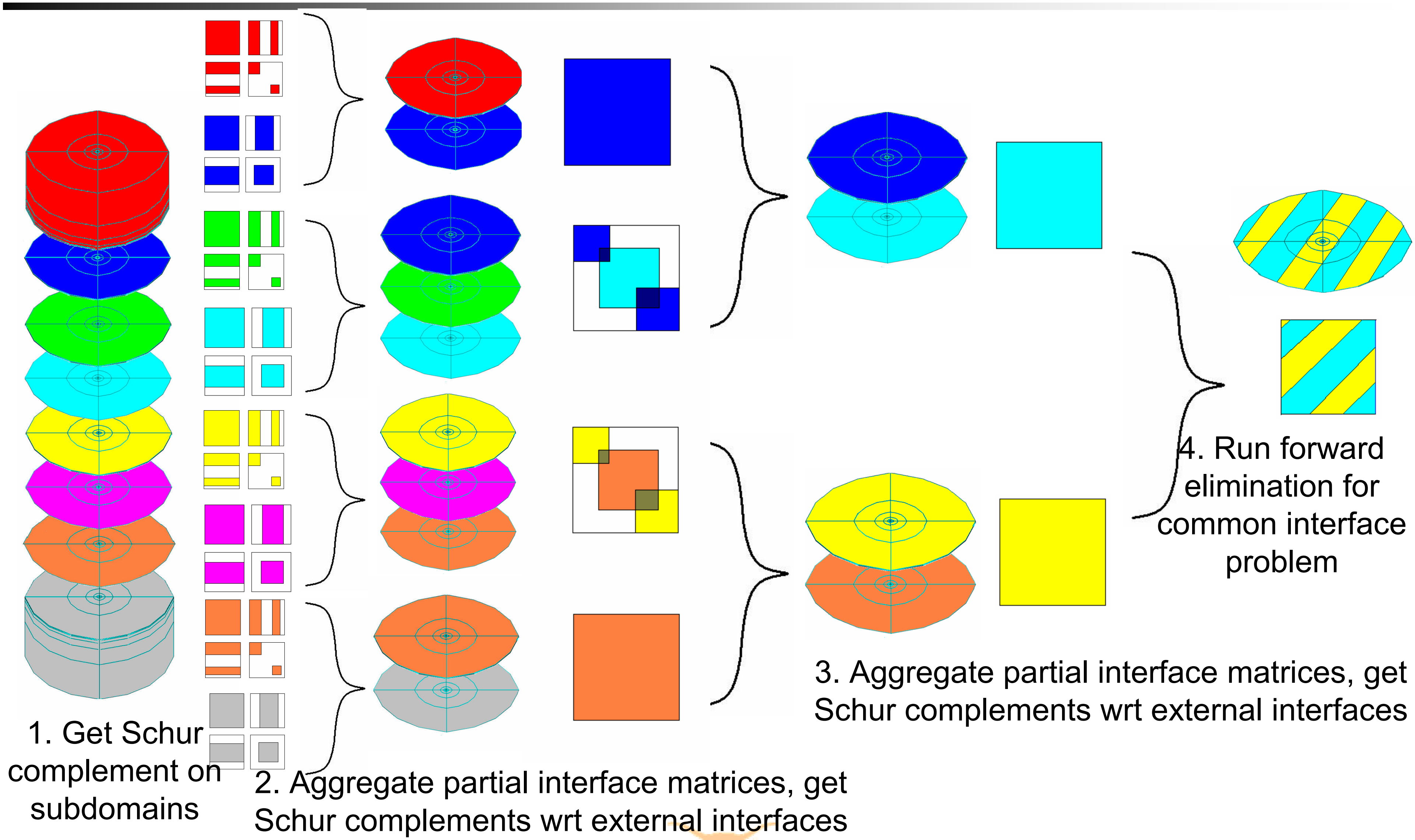
interface problem

To solve the problem distributed into sub-domains, we need to formulate and solve the interface problem first

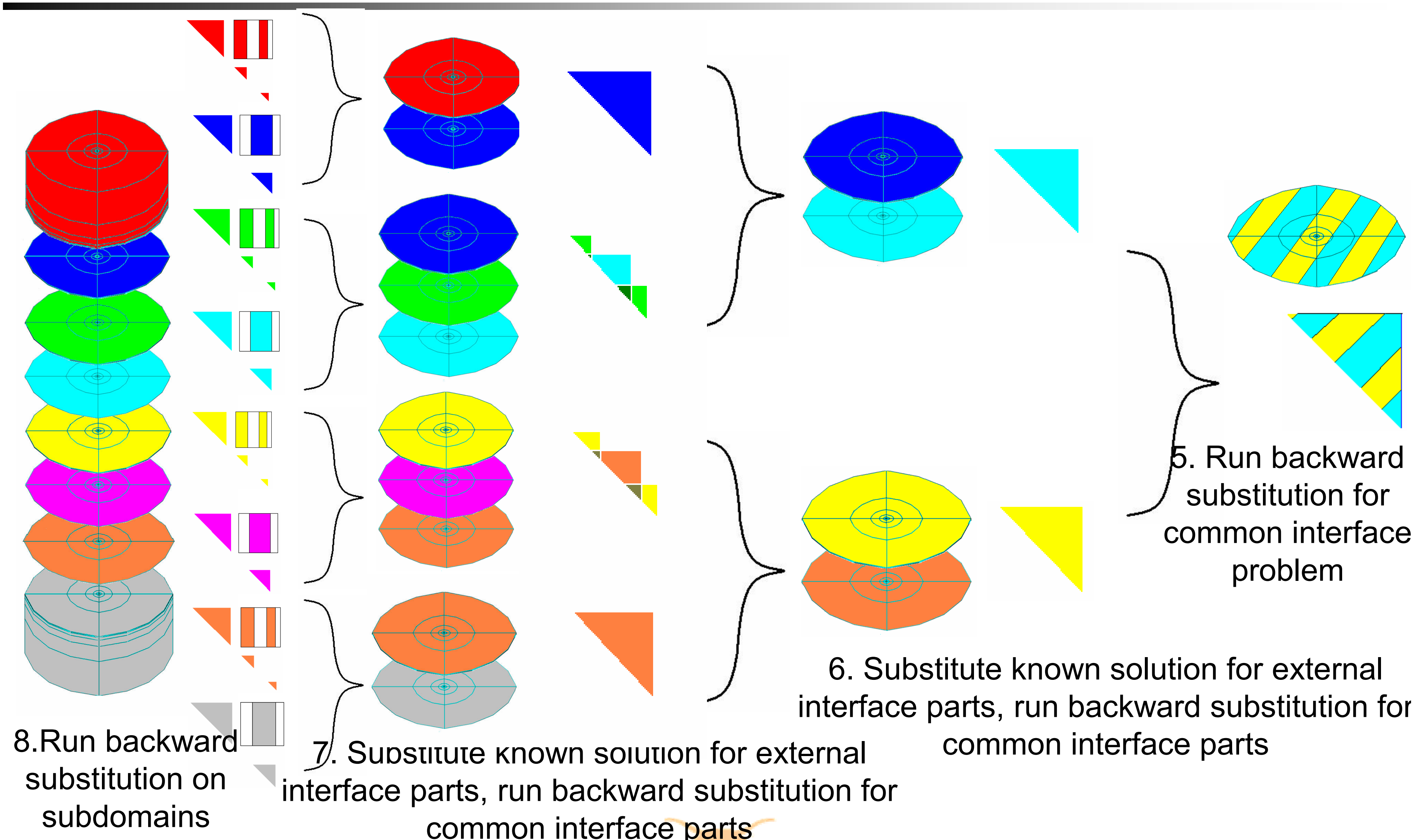
For multiple sub-domains, the interface problem is large, its matrix is dense, and the interface problem solution time is over 90% of solver execution time

We utilize the idea of **nested dissections** to reduce computational cost of the interface problem solution

NESTED DISSECTION PARALLEL DIRECT SOLVER FOR DISTRIBUTED SYSTEM OF EQUATIONS

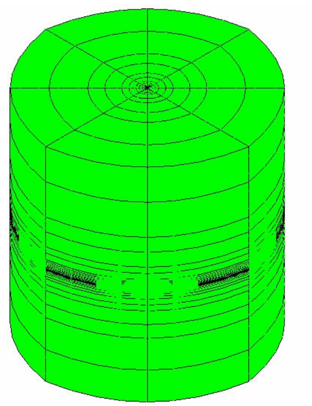


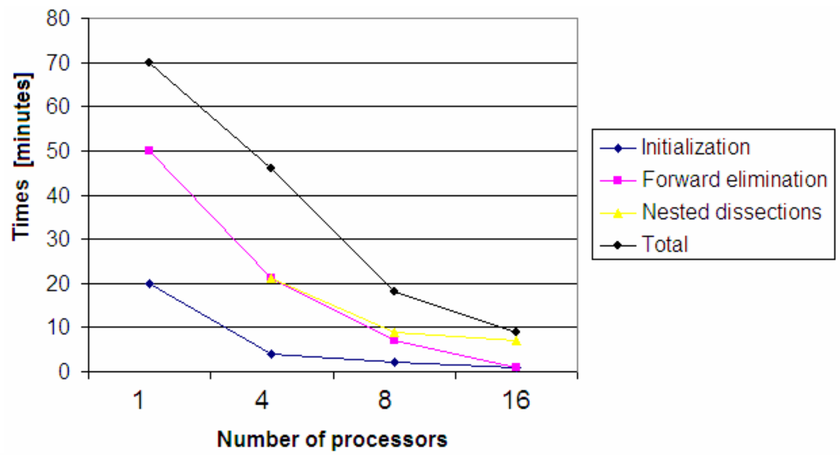
NESTED DISSECTION PARALLEL DIRECT SOLVER FOR DISTRIBUTED SYSTEM OF EQUATIONS

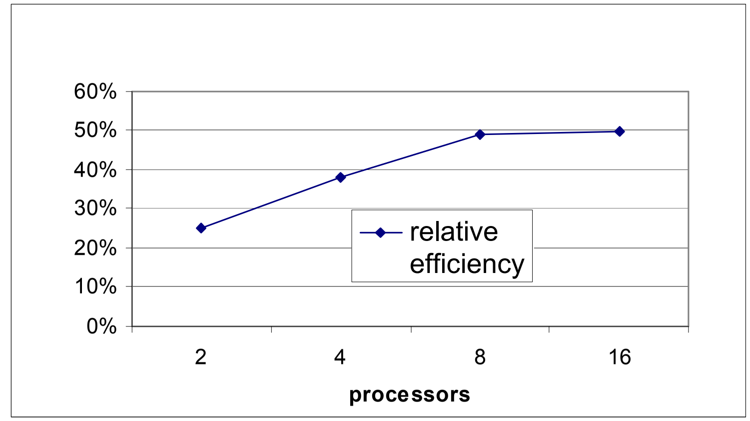


PERFORMANCE OF NESTED DISSECTON PARALLEL DIRECT SOLVER

Solver execution time for 20 000 elements, p=3 globally, 700 000 d.o.f.

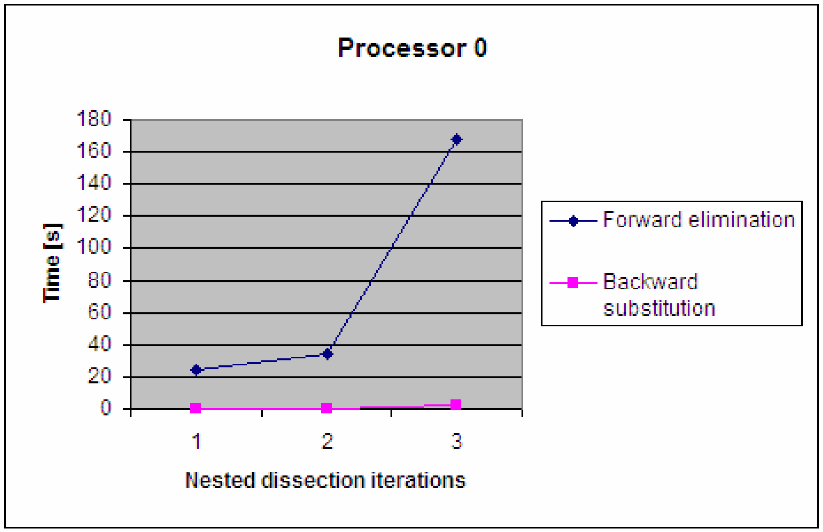


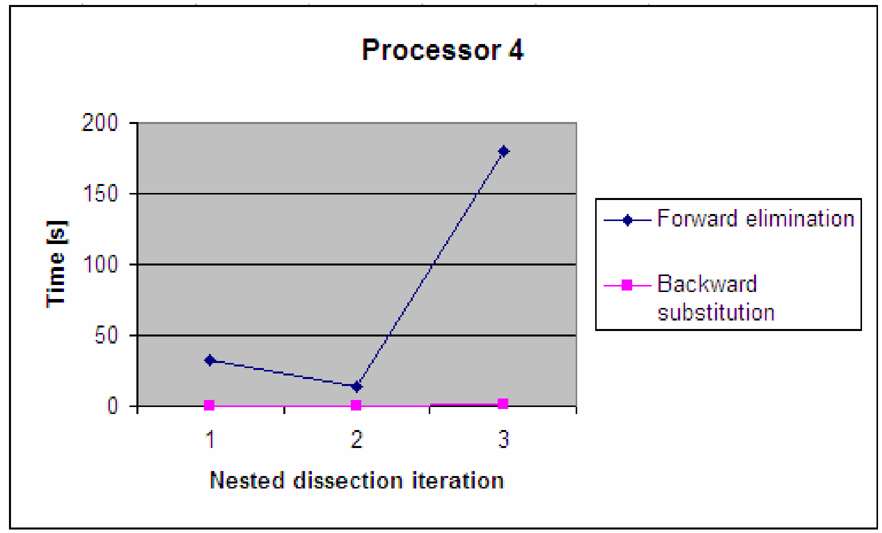




Number of processors	1	4	8	16
Mesh generation and initialization	20 minutes	4 minutes	2 minutes	1 minute
Forward elimination / Schur complement for sub-domains (parallel) Forward elimination / Backward substitution (for sequential code)	50 minutes	21 minutes	7 minutes	1 minute
Nested dissections for the interface problem (only for parallel code)	-	21 minutes	9 minutes	7 minutes
Total	**70 minutes**	**46 minutes**	**18 minutes**	**9 minutes**

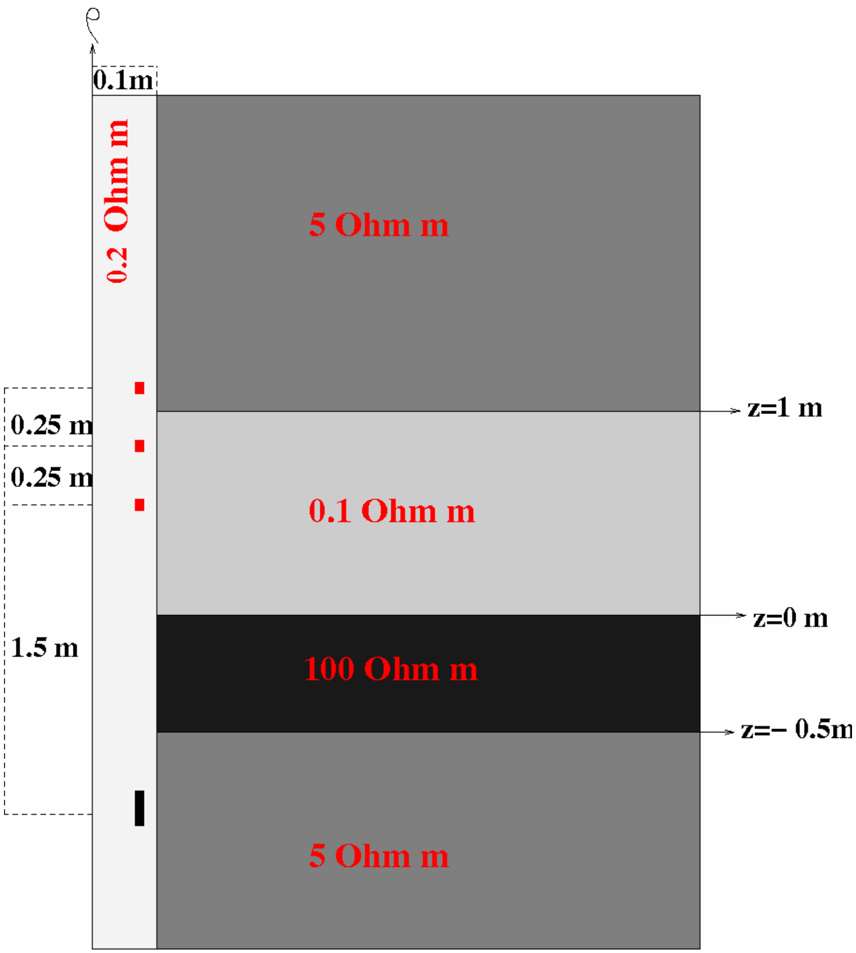
MULTIPLE RIGHT-HAND SIDES

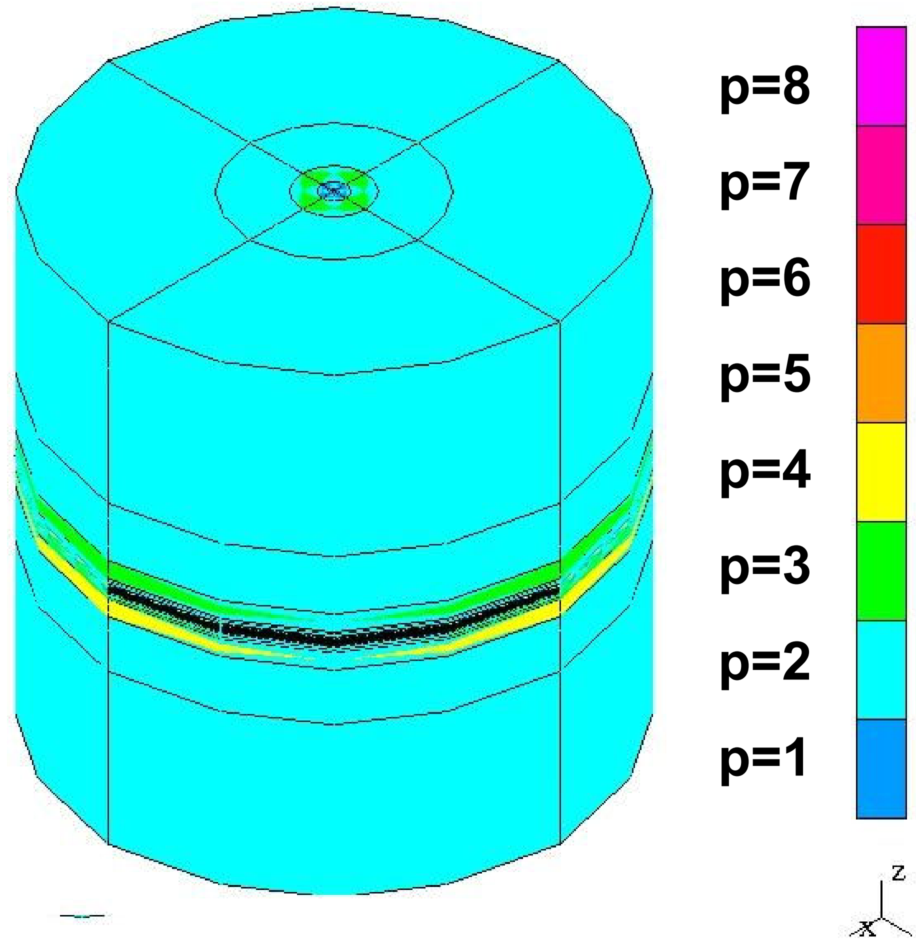




For multiple right-hand sides, the forward elimination step must be executed only once. The backward substitution must be executed for each right-hand-side. However, the backward substitution takes only up to 3 seconds.

RESULTS – 2^{nd} DIFFERENCE OF POTENTIALS (V)





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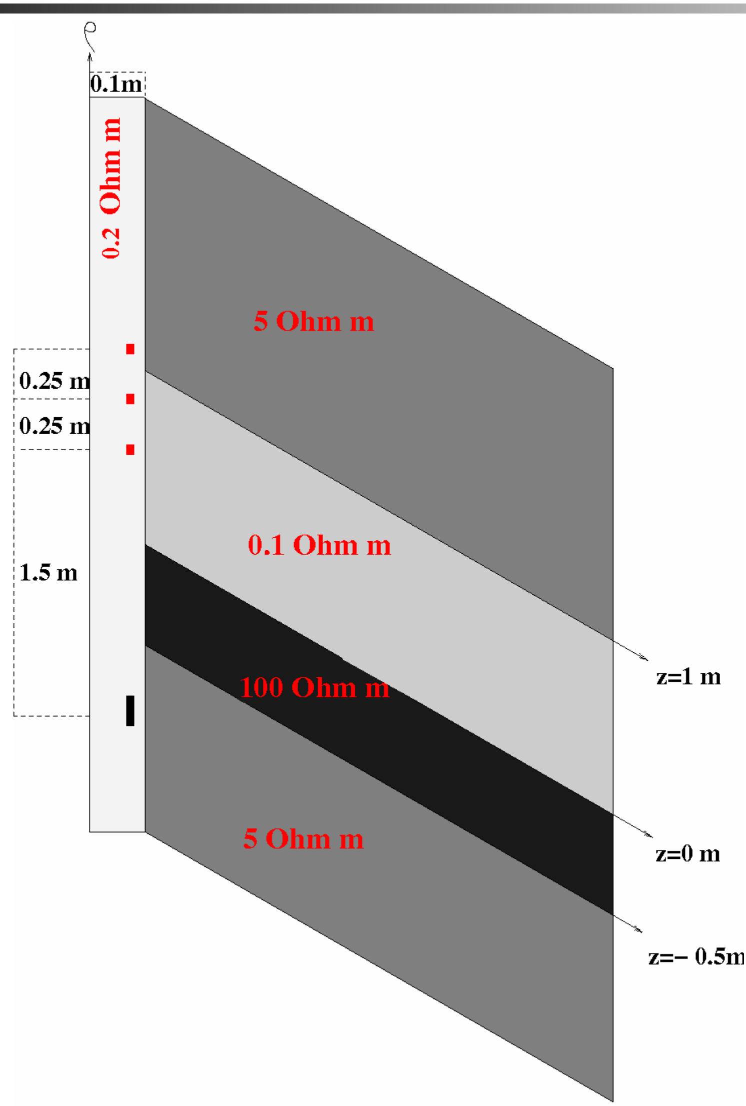
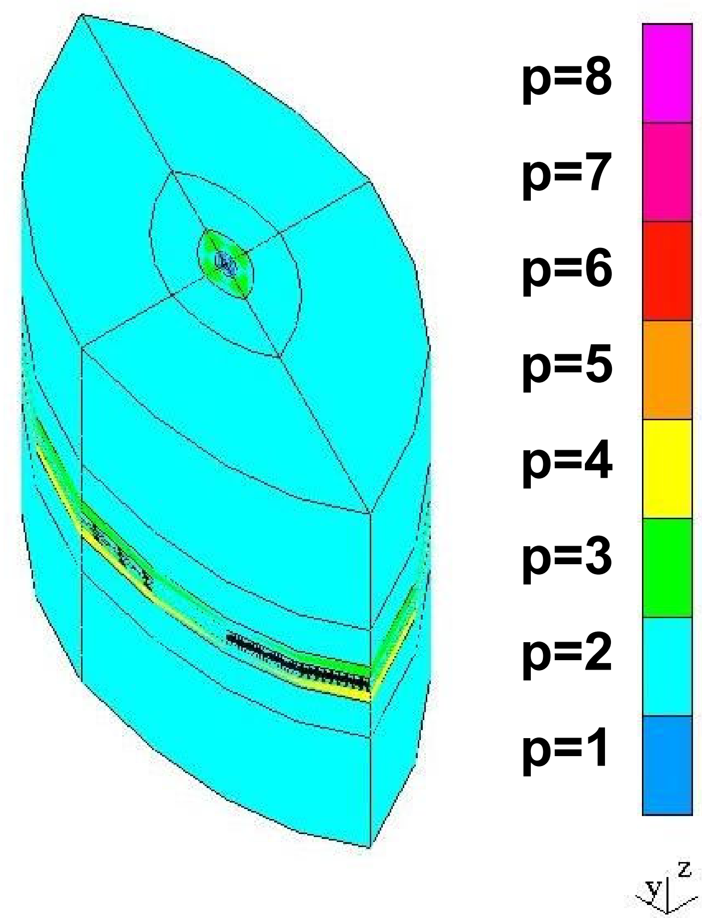
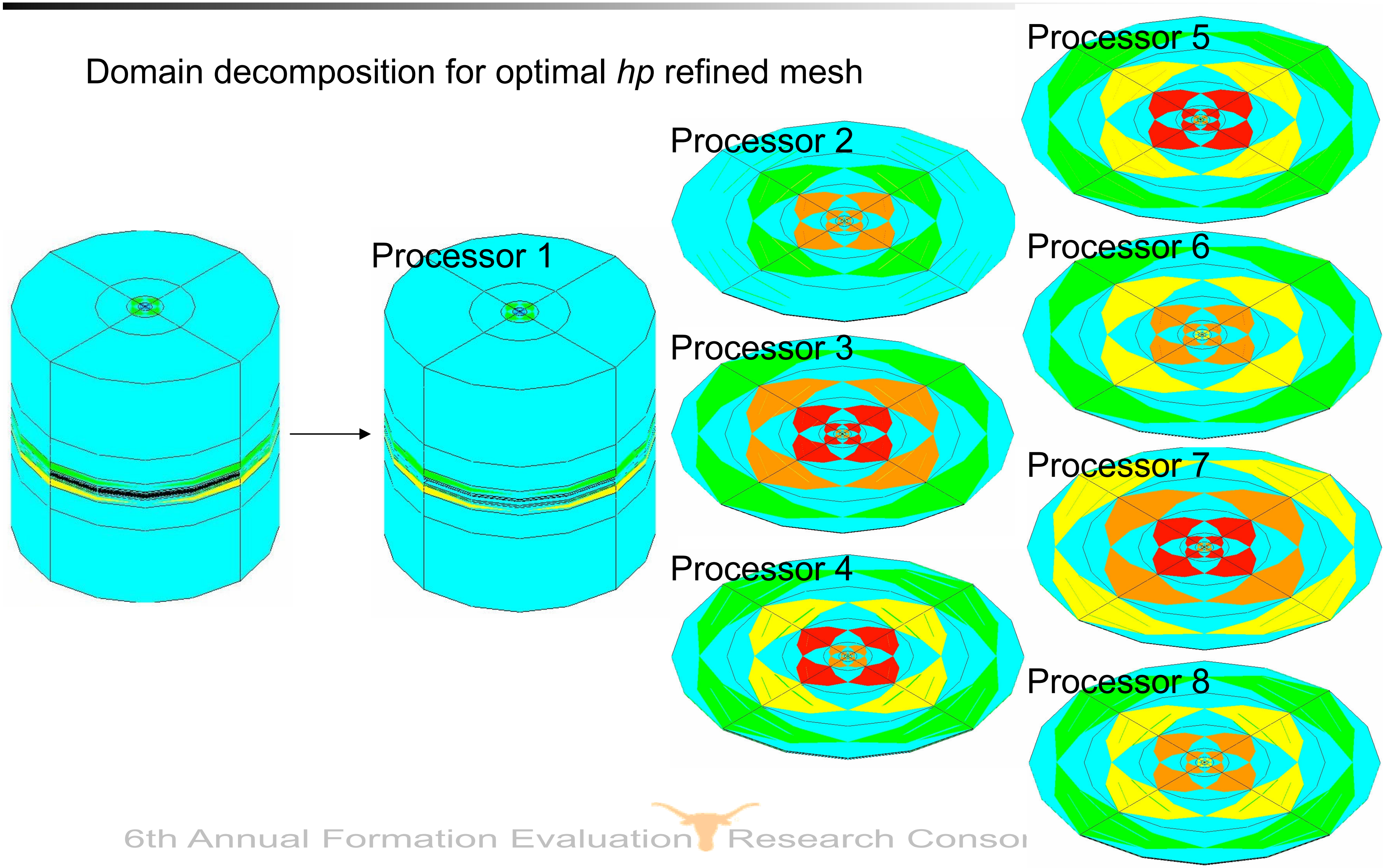


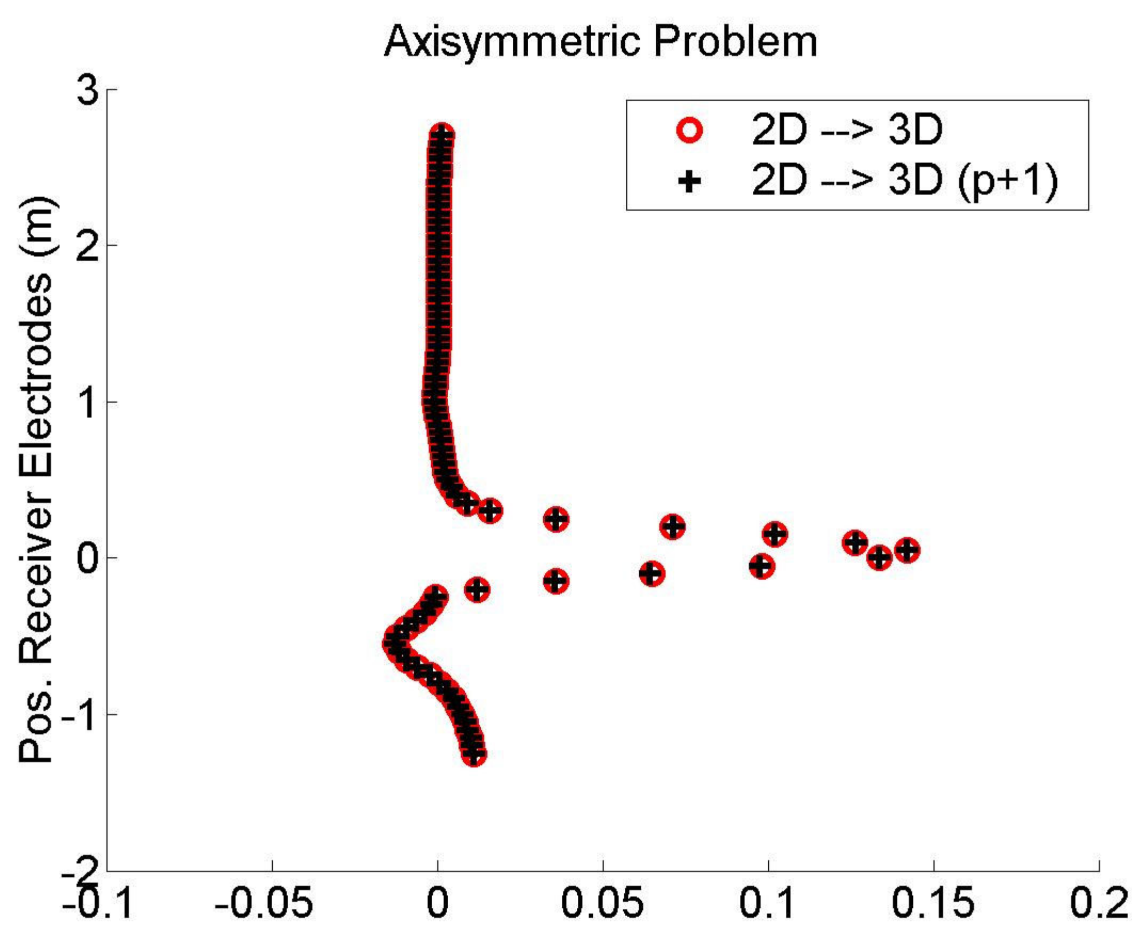


RESULTS -2nd DIFFERENCE OF POTENTIALS (V)

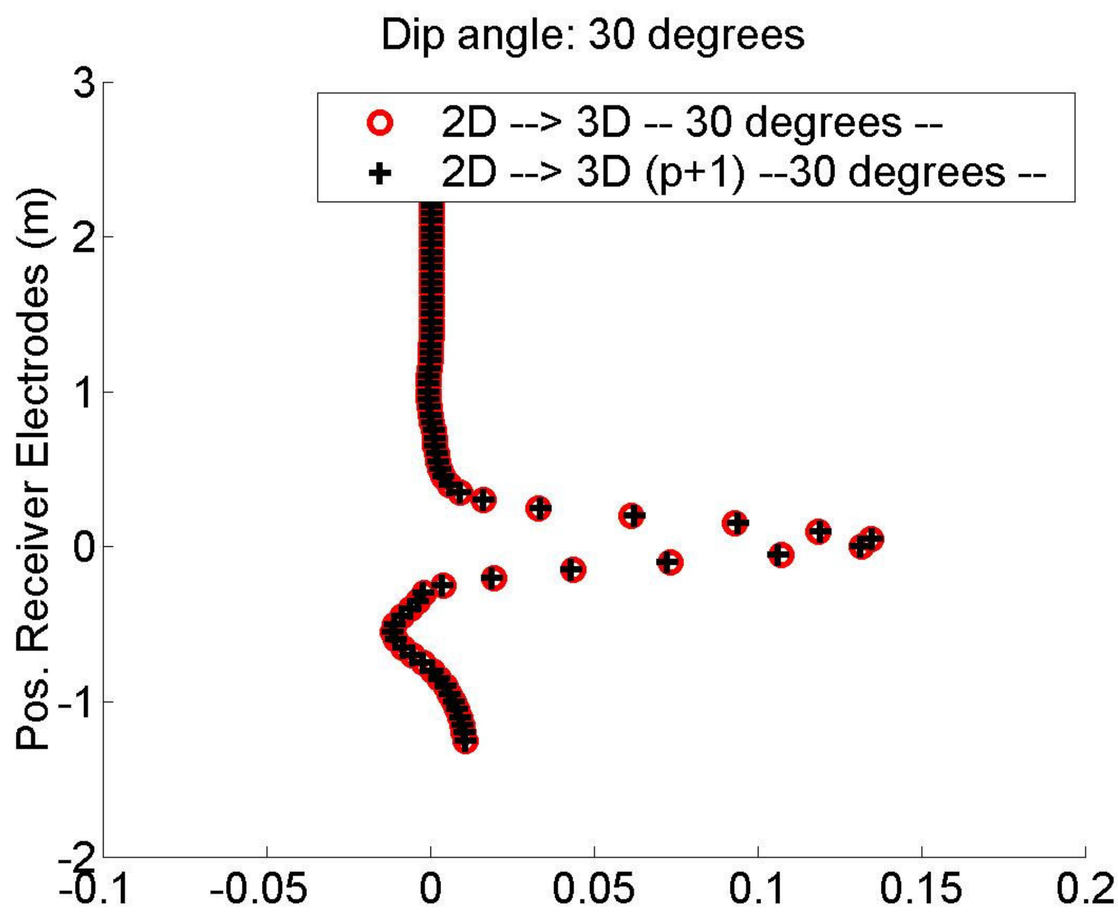
Domain decomposition for optimal *hp* refined mesh



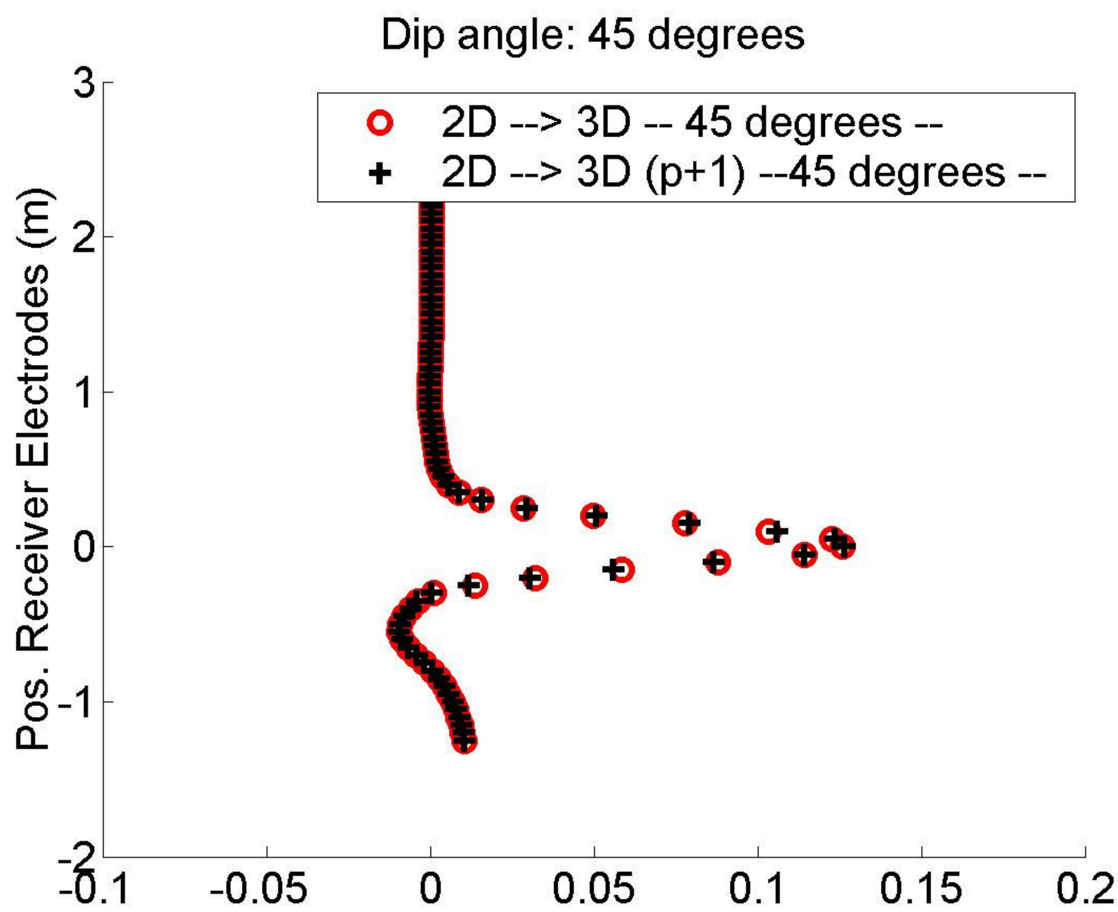
RESULTS FOR AXISYMMETRIC PROBLEM



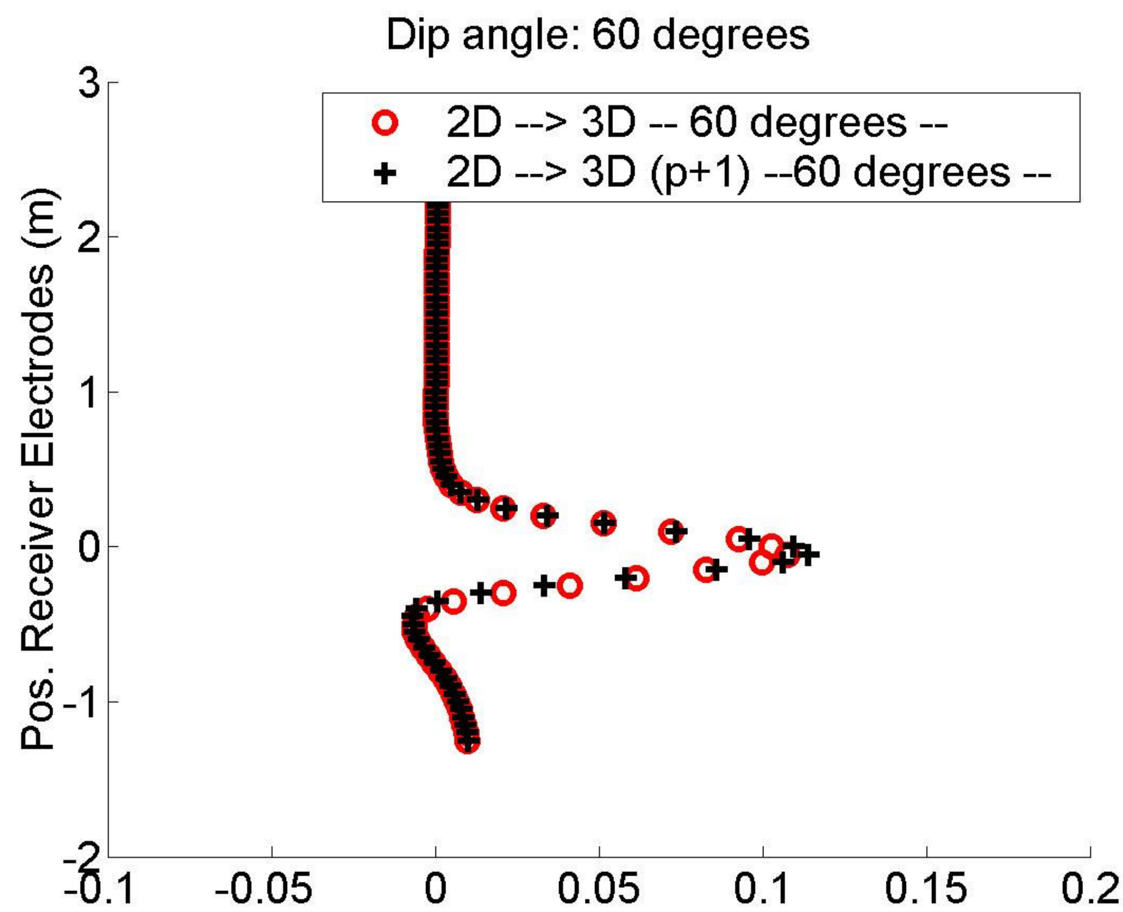
RESULTS FOR 30 DEG DEVIATED WELLS



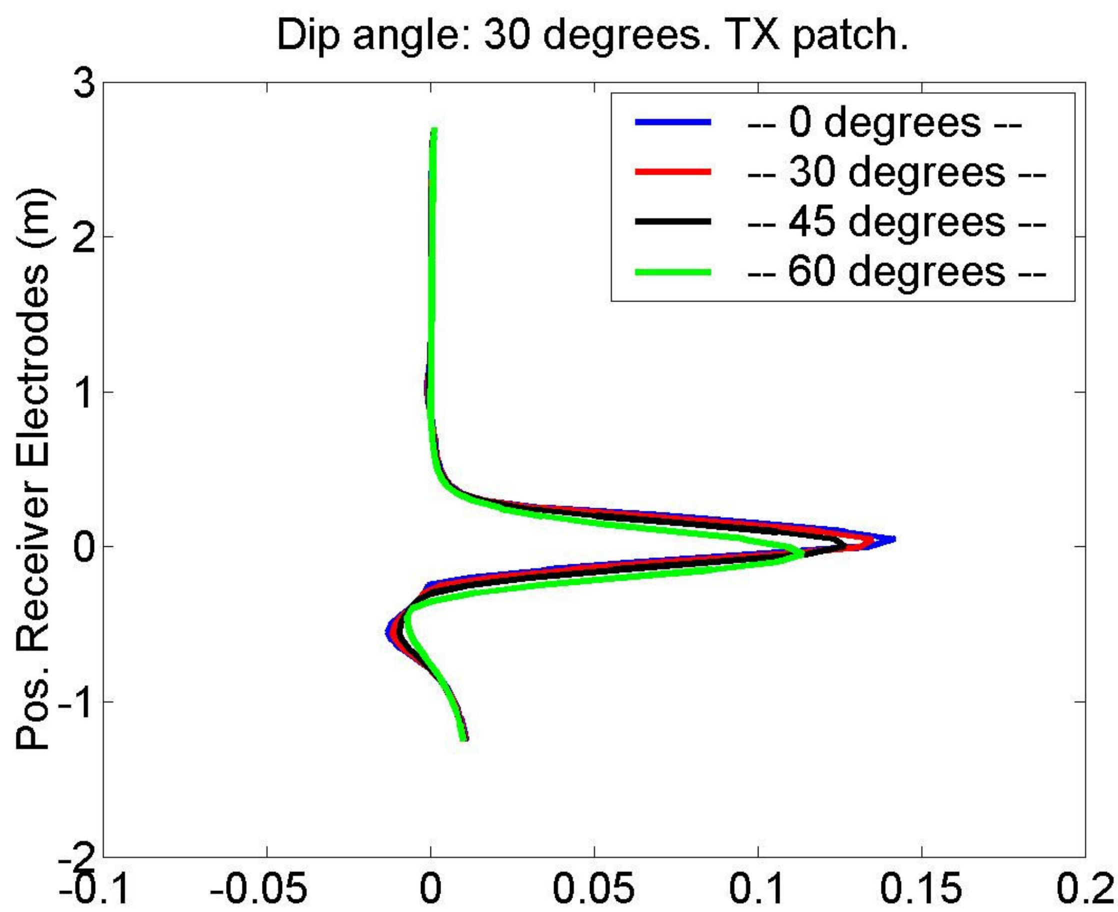
RESULTS FOR 45 DEG DEVIATED WELLS



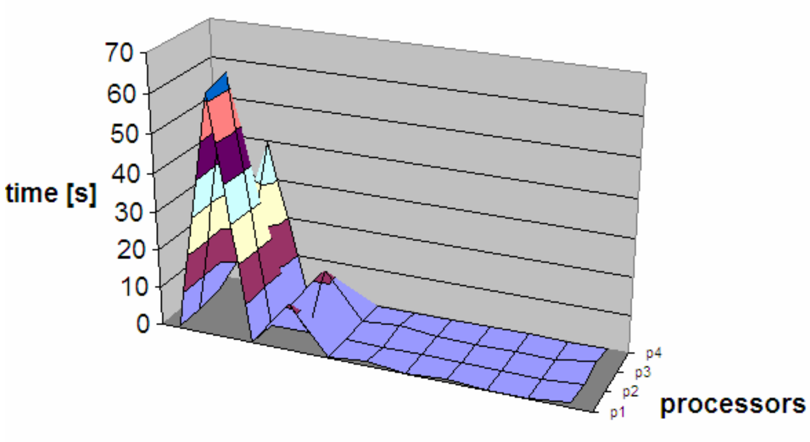
RESULTS FOR 60 DEG DEVIATED WELLS

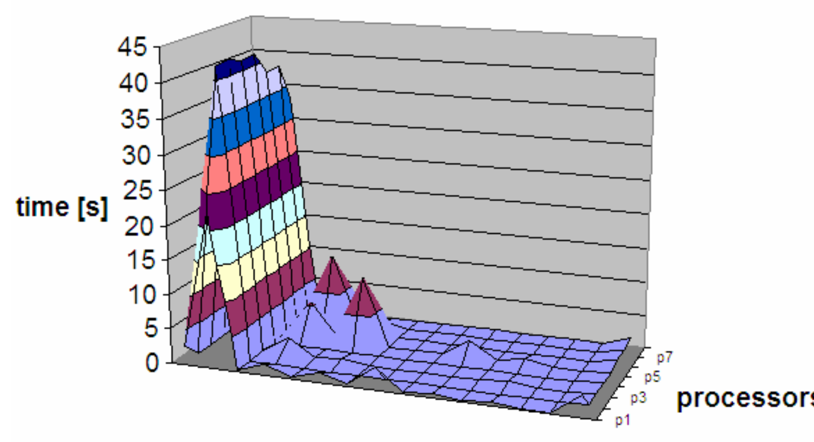


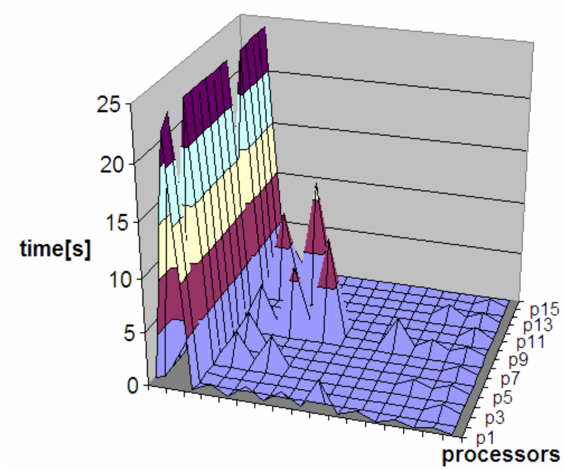
COMPARISON OF RESULTS

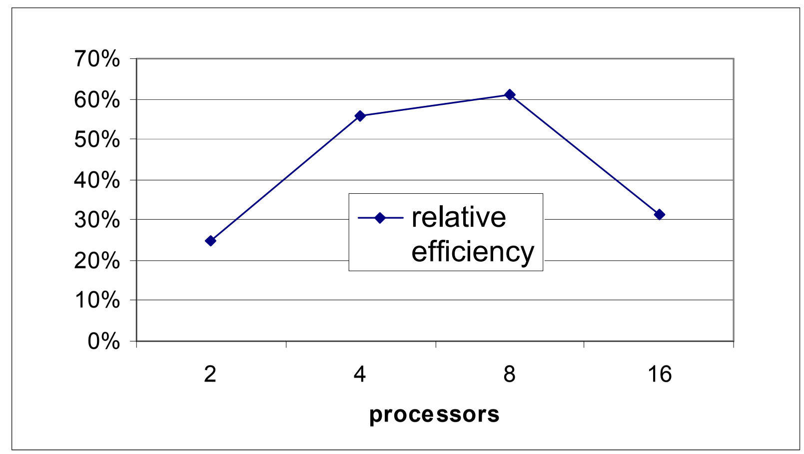


EFFICIENCY MEASUREMENTS





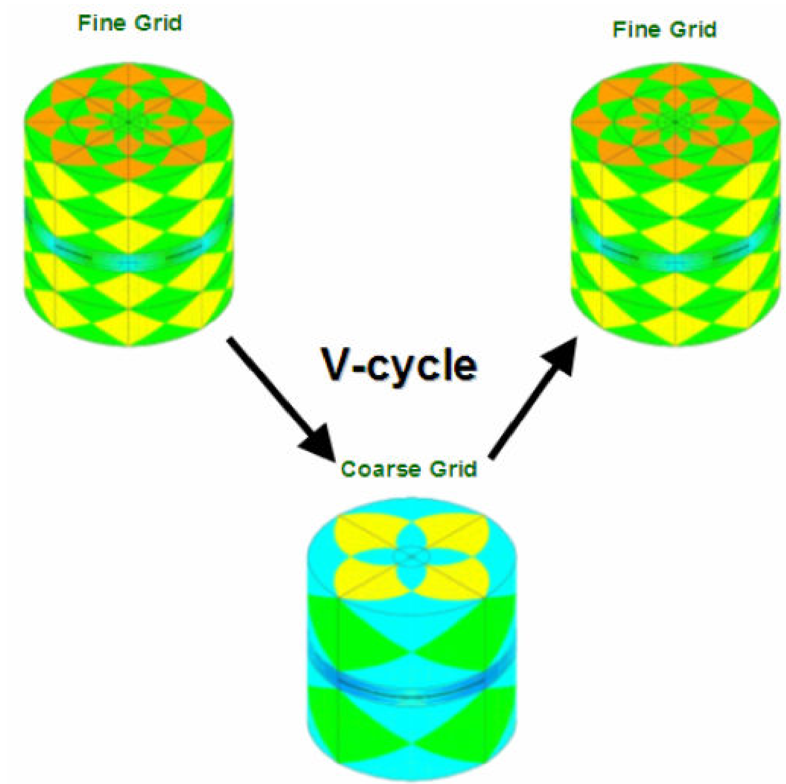




Problem size: 250 000 d.o.f.

Efficiency measurements of parallel solver executed on 2, 4, 8 and 16 processors

FUTURE WORK
PARALLEL ITERATIVE TWO GRID SOLVER



We are going to parallelize the iterative two-grid solver.
The nested dissection parallel direct solver will be used as coarse grid solver.
The parallel solver handles multiple-right hand sides in an efficient way.

CONCLUSIONS AND FUTURE WORK

- The parallel self-adaptive 3D *hp* Finite Element code (***par3Dhp***) has been applied for DC (electrostatics) measurements simulations.
- We have developed nested dissections parallel direct solver for *hp* refined meshes, the core component of the parallel ***par3Dhp*** code.
- The nested dissection solvers are known as the best parallel direct solvers.
- The current version of the solver provides 50% efficiency.
  We know how to improve its efficiency up to 75%.
- The parallel direct solver is a building block for parallel two-grid solver.
- We expect obtain 90% efficiency of the parallel two-grid solver with the nested dissection parallel solver for coarse grid problems.
- We will develop version of the parallel self-adaptive 3D *hp* Finite Element code for AC (electrodynamics)
- The parallel solver can be extended to support AC formulation

Acknowledgments

Sponsors of UT Austin's consortium on Formation Evaluation:

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