Parallelization of a Magnetohydrodynamics Model for Plasma Simulation

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Research groups

CeNAT

CENTRO DE INVESTIGACIONES ESPACIALES
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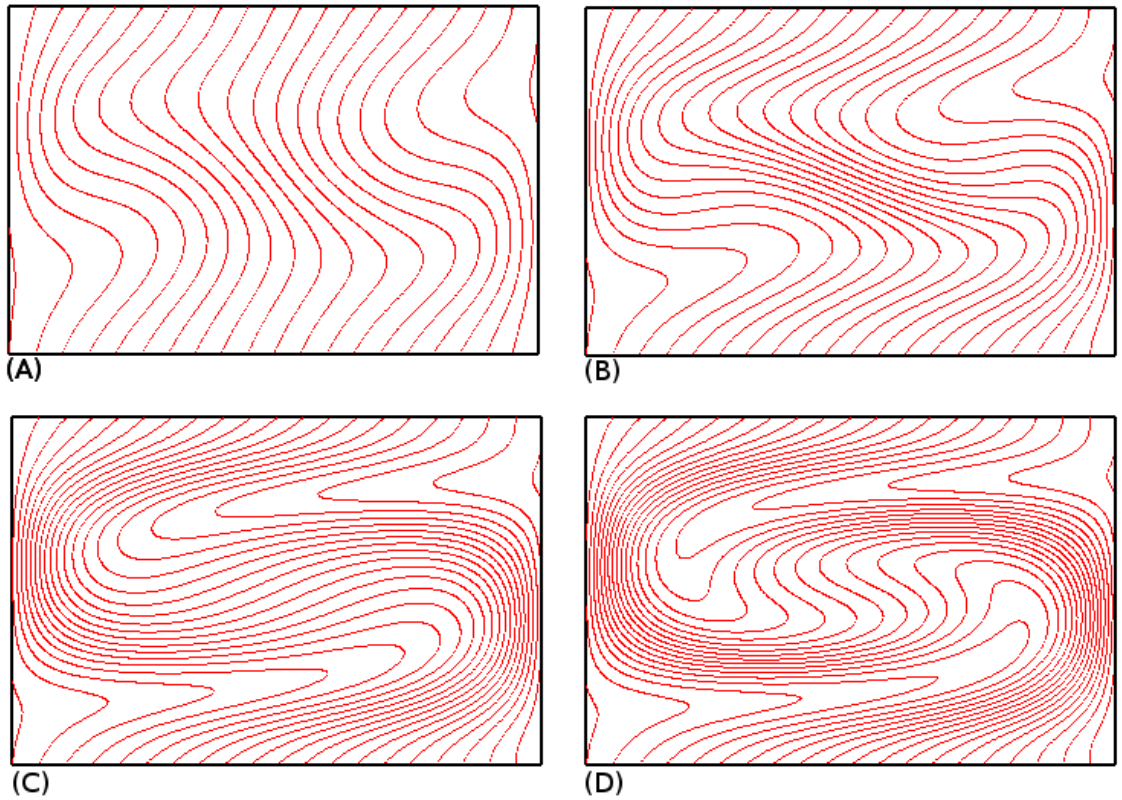
PCell

- Software for visualization and study of magnetic fields on plasma cells in 2D
- Solves a set of differential equations
- Generates visualizations of the magnetic field evolution in time



- Visualization of magnetic fields of plasma eddies with PCell

Problem definition

- The original PCell version:
  - Limited the amount of spatial points that could be simulated
  - Was inefficient, specially when increasing the time scale of the simulations

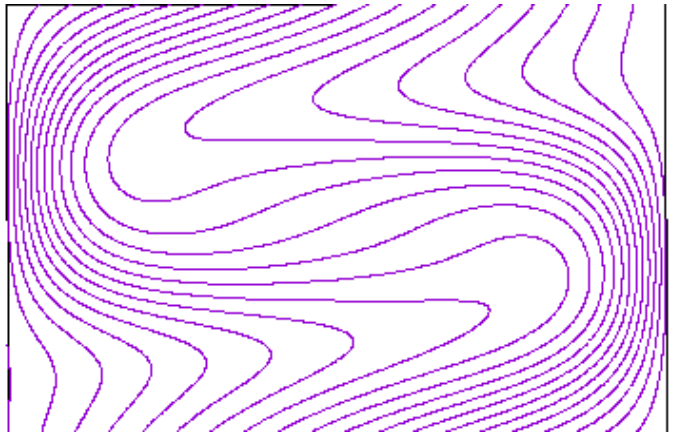
- The researchers wanted to expand the model and accelerate it to broaden the simulation ranges and decrease the execution time

Magnetohydrodynamics

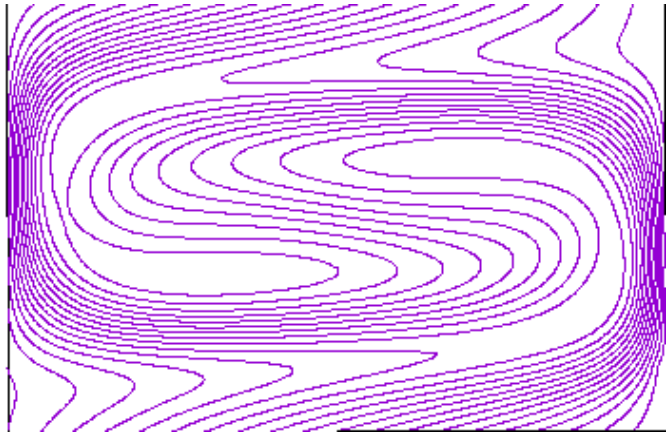
- Studies the interaction between electromagnetic fields and conductive fluids in motion
- Magnetic fields induce electric currents on conductive fluids in motion
- These currents affect the magnetic fields reciprocally
- It is a combination of Maxwell's electromagnetism and hydrodynamics
- Under this approach, plasma is seen as a single fluid with very high conductivity

Magnetic Reynolds number

- It is a scalar parameter analogous to the Reynolds number used in fluid mechanics
- It determines the turbulence of the fluid, and therefore its magnetic field



Simulation done with magnetic reynolds number = 300



Simulation done with magnetic reynolds number = 500

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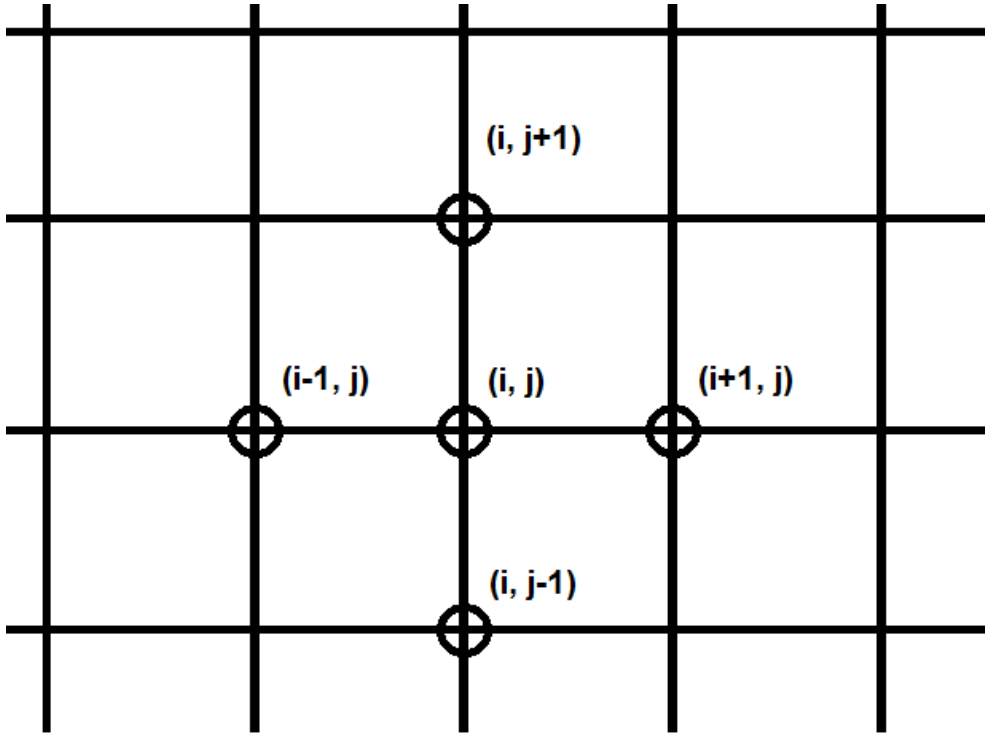
Methodology

Code analysis and profiling

% time	cumulative seconds	self seconds	calls	self ms/call	total ms/call	name
91.94	0.34	0.34	100	3.40	3.60	convect
5.41	0.36	0.02	100	0.20	0.20	mean_field
2.70	0.37	0.01	1	10.00	10.00	potinc
0.00	0.37	0.00	100	0.00	0.00	itoa
0.00	0.37	0.00	100	0.00	0.00	reverse
0.00	0.37	0.00	1	0.00	360.17	convec_plasma
0.00	0.37	0.00	1	0.00	0.00	create_form_Convection
0.00	0.37	0.00	1	0.00	0.00	create_gnuplot

Code analysis and profiling

- Search for areas where there is:
  - Data dependency
  - Functional dependency
  - Processing bottlenecks



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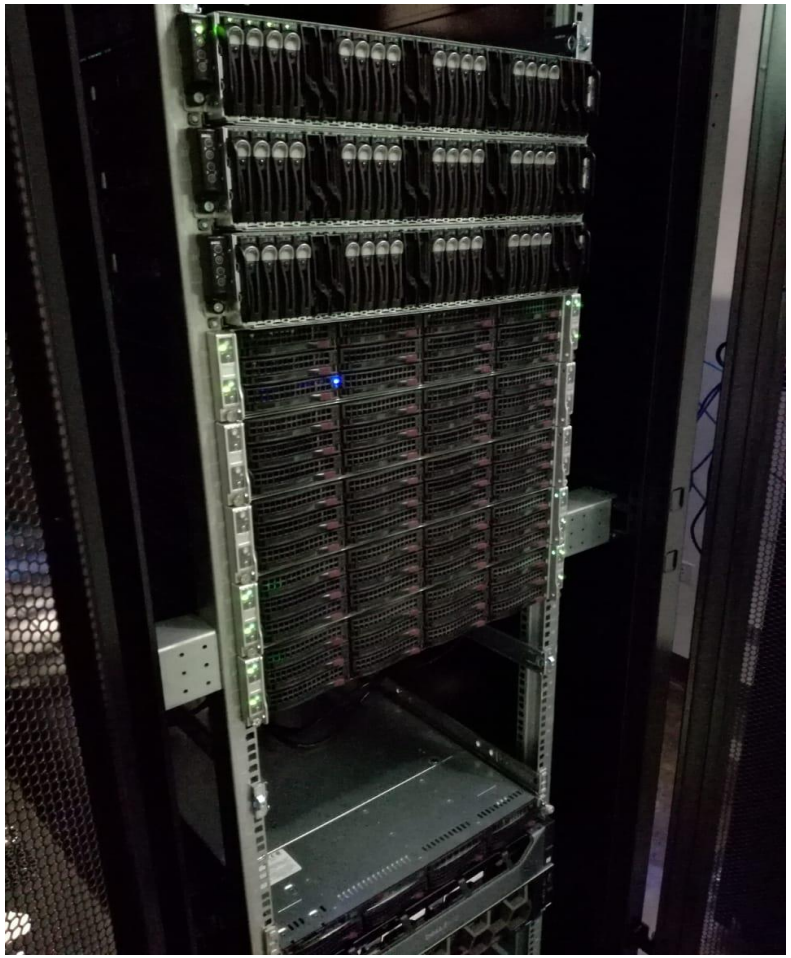
Improvements to the program

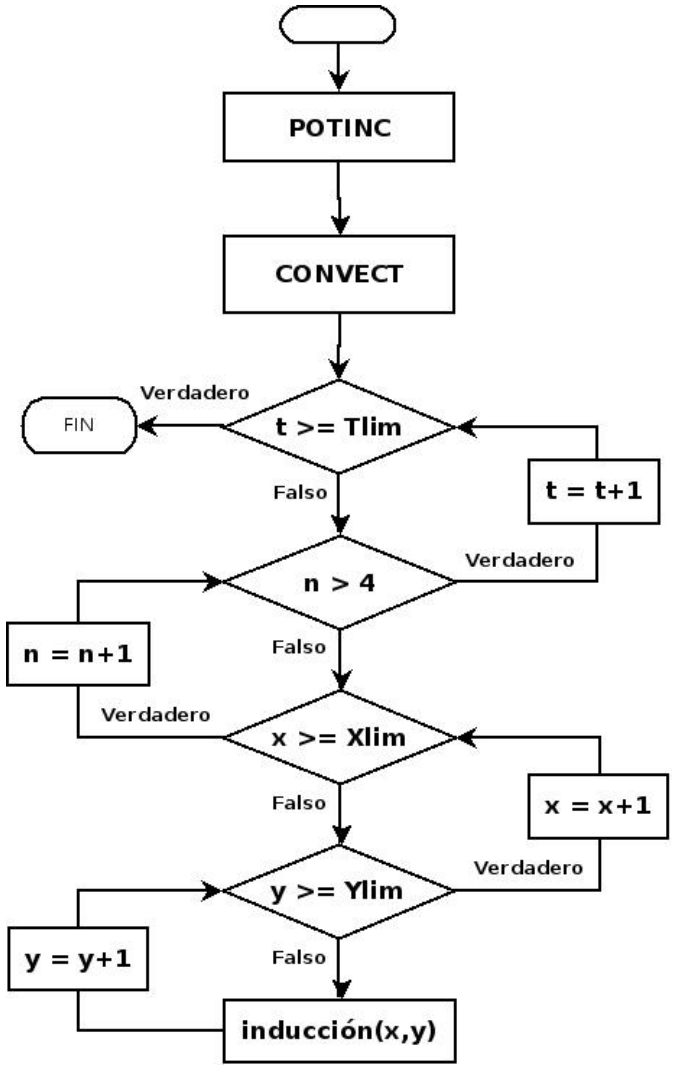
- Replacement of static, fixed-dimension arrays for dynamic ones
- Removal of unnecessary and repetitive cycles and functions
- Optimization of the iteration over the spatial matrix
- Memory leak removal with the help of Valgrind

Hardware used

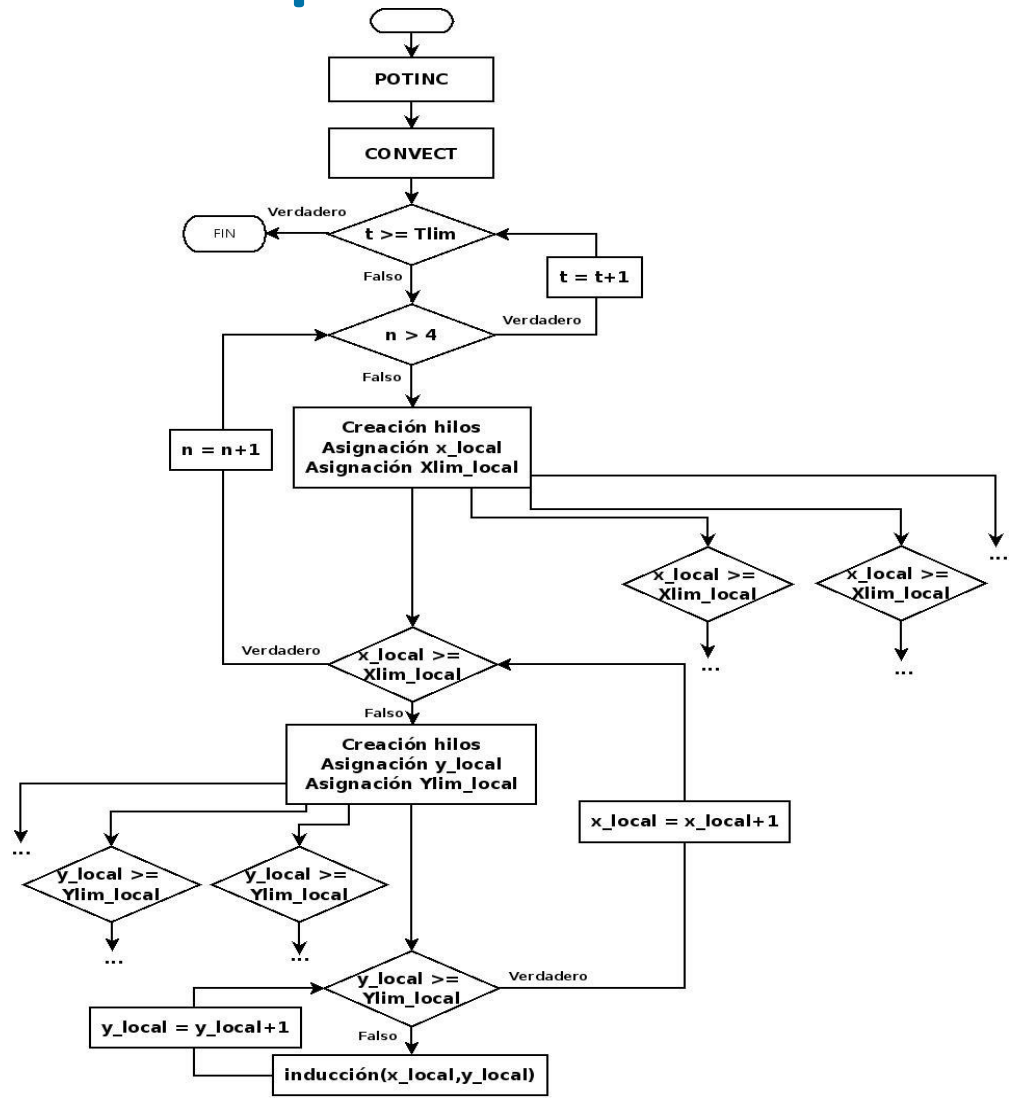


- Kabré cluster at CeNAT
- Intel Xeon Phi architecture
- 64 physical cores on each node

Original program flow



After paralellization



Evaluation of results

- Correlation index between the programs' output
- Test of difference in means
- Descriptive analysis
- Output evaluation by an expert

- Result: There's no statistically significative difference between the outputs

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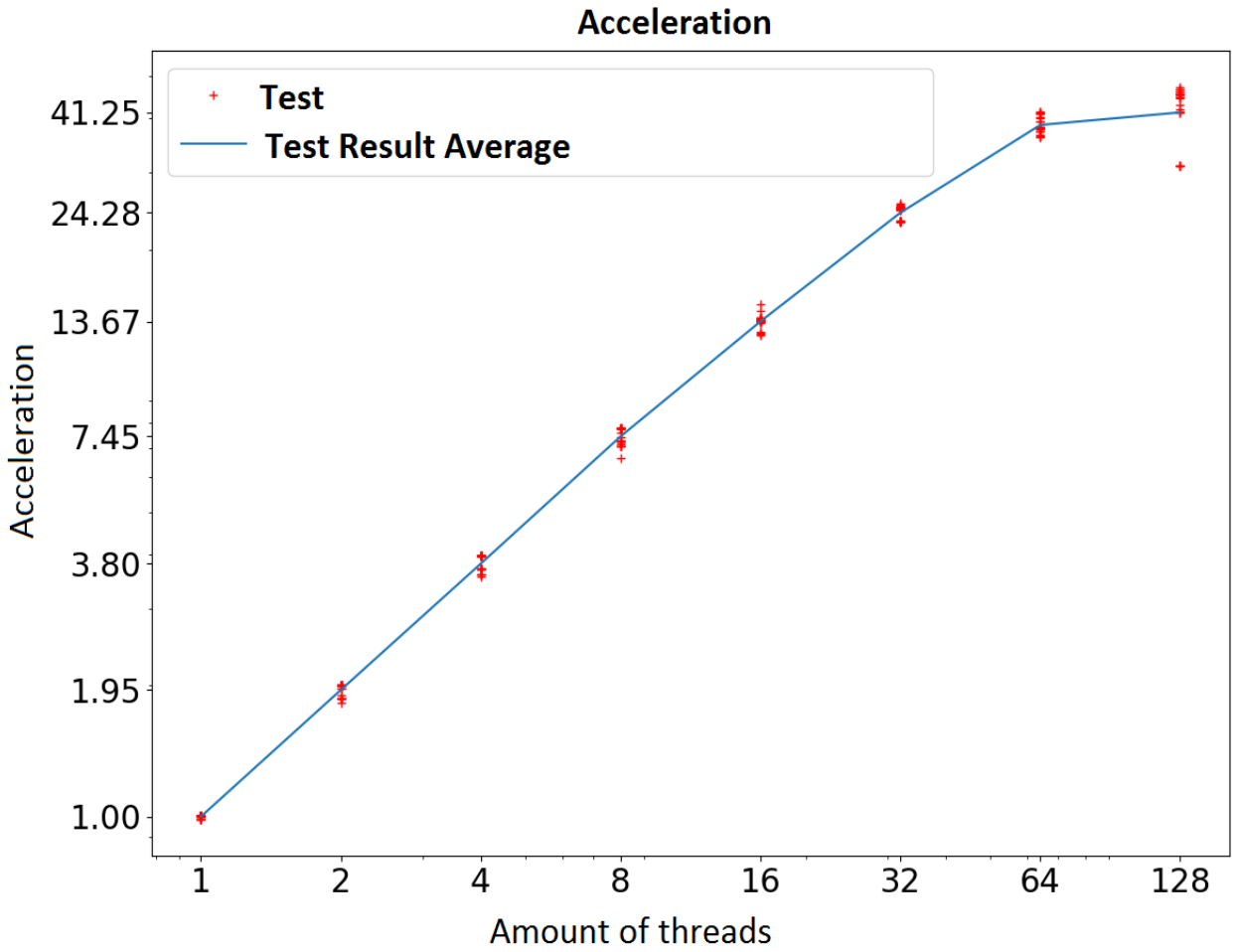
Performance tests



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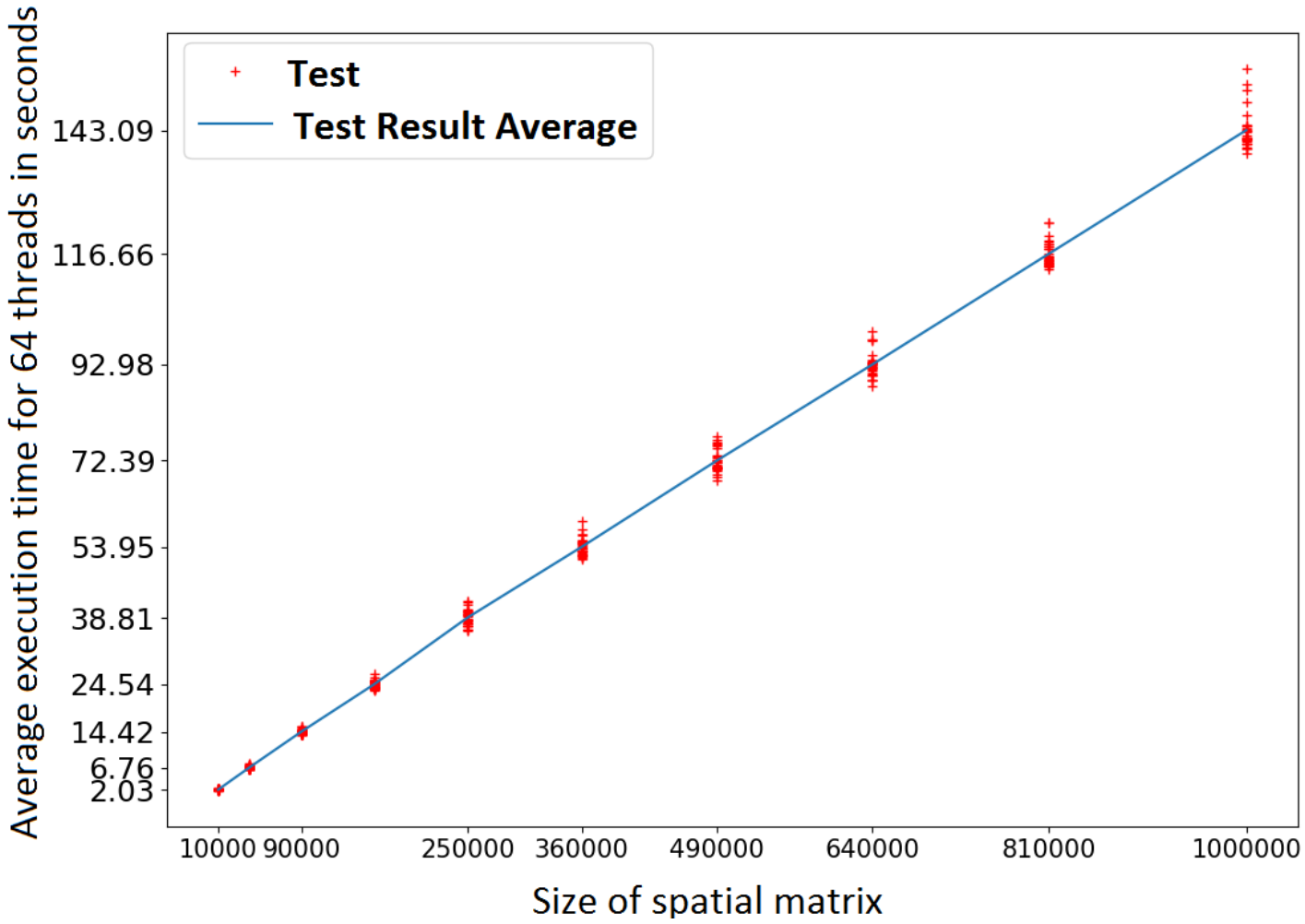
Spatial scalability



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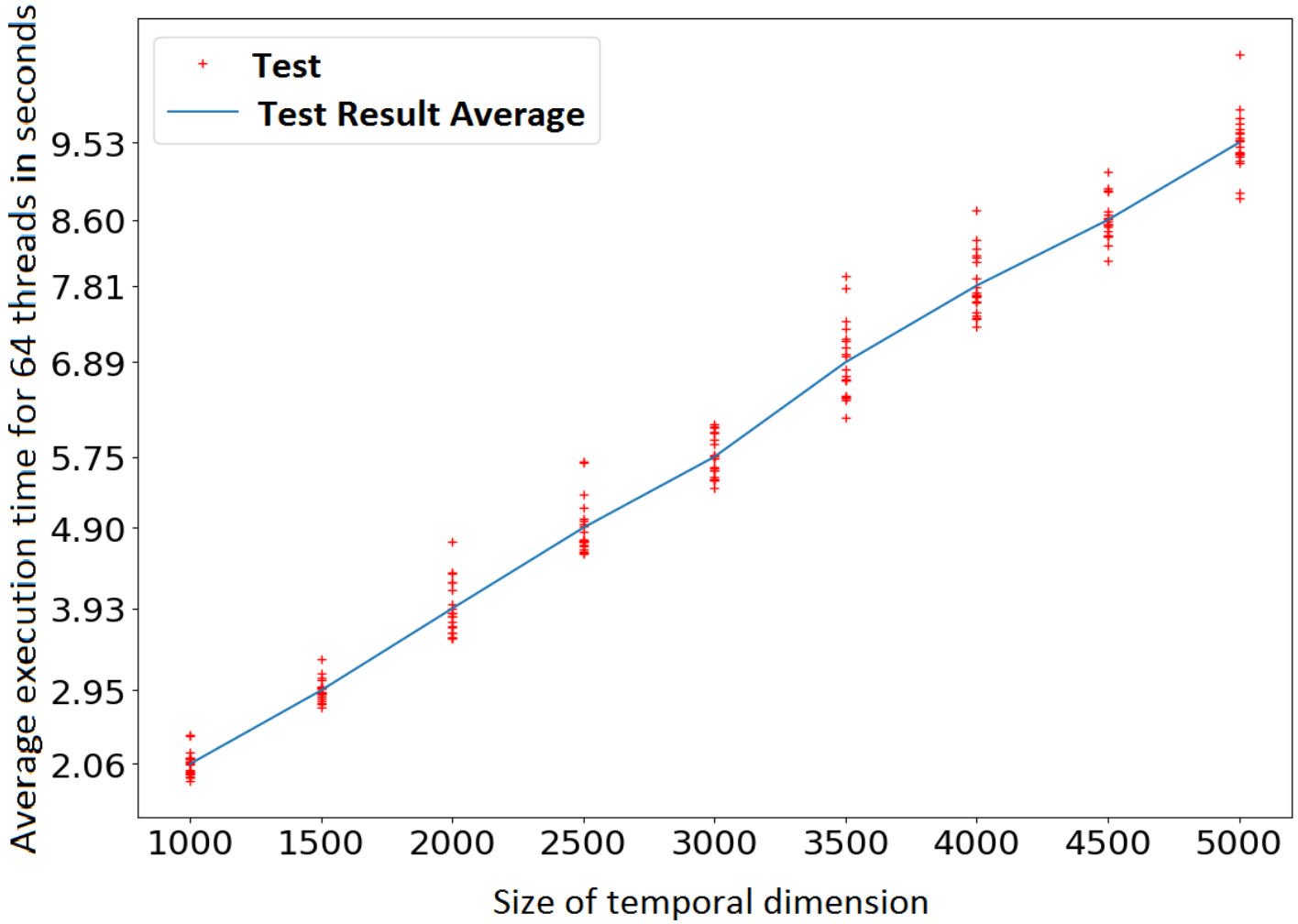
Temporal scalability



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Contributions

- Applying a parallelization methodology to a scientific software
- Improvement of spatial and temporal scales of the simulation model
- Decreasing the total execution time (~41x acceleration)
- Parallel algorithm for simulation of electromagnetic fields in convective plasma cells

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Future work

- Expand the model to three spatial dimensions
- Integrate with ParaView to improve visualization
- Parallelization with MPI