# A Parallel N-Body Integrator Using MPI

*Nuno S. A. Pereira*

Politechnical Institute of Beja
School of Technology and Management

## Summary

- The Physical Problem
- Numerical Simulation
- Parallel Algorithm
- MPI: A Message Passing Library
- Parallel Implementation
- Performance Analysis

# The Physical Problem

• The Astrophysical N-Body Problem:
*Mass points interacting through their mutual gravitational interaction.*

• Real Systems:
*Open Clusters and Globular Clusters of Stars*.

• The Mathematical Model:
*Newton's Law of Gravity.*

$$\ddot{\vec{r}}_i = -G \sum_{j=1, j\neq i}^{N} \frac{\vec{r}_i - \vec{r}_j}{\left\|\vec{r}_i - \vec{r}\right\|^3} m_j, (i = 1, \ldots, N)$$

• Exponential Instability:
*Evolution of perturbations on the initial conditions.*

# Numerical Simulation

- No Analytical Solution for N(>2)-Body Problem:
*Classical Result from Celestial Mechanics.*

- Numerical Methods:
*Particle Methods - PP Method: Direct Summation Method.;* $T_{comp}=O(N)^2$.

- Simulation of Real Systems:
*Open Clusters:* $N \approx 10^2\text{-}10^3$
*Globular Clusters:* $N \approx 10^4\text{-}10^6$

- Computationally Demanding Problem
*Parallel Algorithms + Parallel Supercomputers.*

# Parallel Algorithm

- Required Features:
*Efficiency, Scalability and good Load-Balance*.

- Message Passing Model:
*Processes Communicating by Sending and Receiving Messages.*

- **S**ingle **P**rogram **M**ultiple **D**ata:
*Programming Model.*

# MPI: A Message Passing Library

- The Message Passing Model:
*Processes sending and receiving messages.*

- **M**essage **P**assing **I**nterface:

  - *Source-code portability*

  - *Efficient implementation across a range of architectures are available*

  - *Functionality and support for heterogeneous parallel architectures.*

- Implementation with a reduced number of functions (11):

***A.*** ***MPI_INIT***

**I.** **Initialization:** **MPI_COM_SIZE**
MPI_COMM_RANK
MPI_TYPE EXTENT

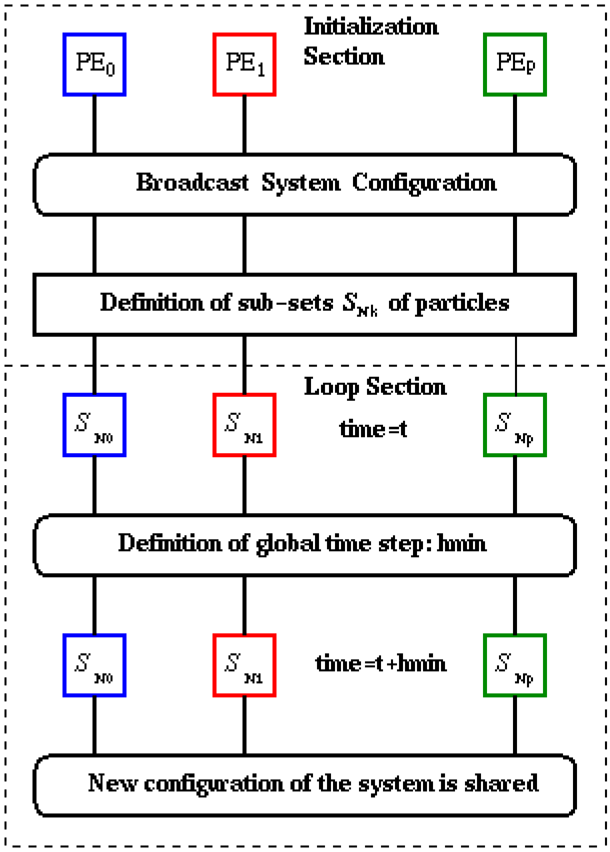
Data Structures: MPI_TYPE_STRUCT
MPI_TYPE_COMMIT
MPI_TYPE_FREE

Communication: MPI_BCAST

Global Operations: MPI_ALLREDUCE
MPI_ALL_GATHERV

Finalization: MPI_FINALIZE

# Parallel Implementation

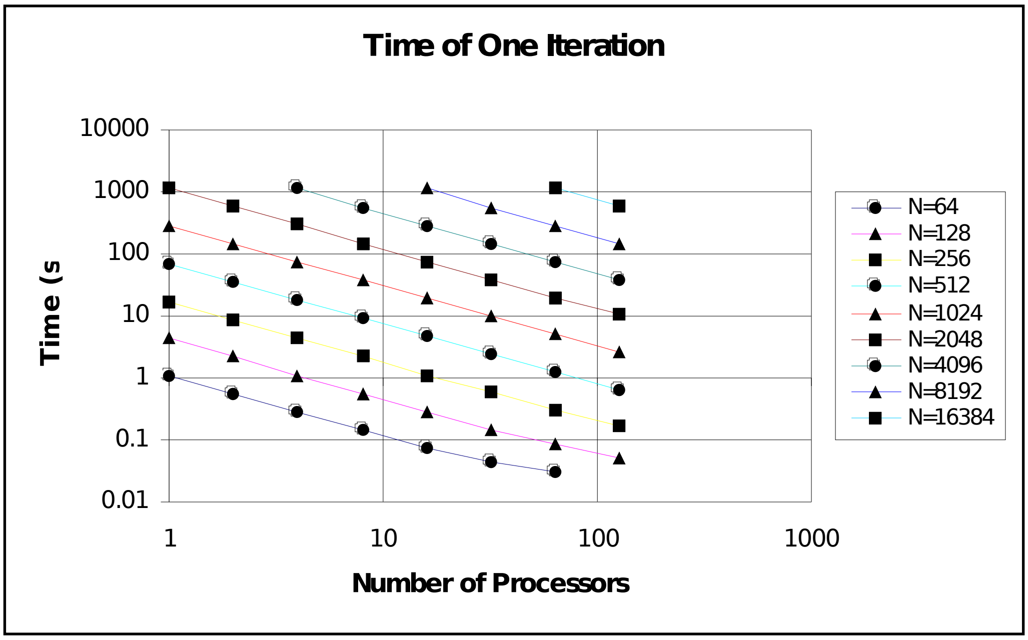



- Tested on the CRAY-T3D:
*512 DEC Alpha 21064 processors running at 150 MHz; peak performance: 76.8 Gflop/s.*

- Edinburgh Parallel Computer Centre (EPCC):
*TRACS program.*

# Performance Analysis (I)

- Metrics of Performance:
  - *Time of one iteration:* $T_{one}$
  - *Relative Speedup*: $S_r=T_1/T_p$
  - *Relative Efficiency*: $E_r=S_r/p$



# Performance Analysis (II)