The N-Body Problem
Dwarf Galaxy Simulations

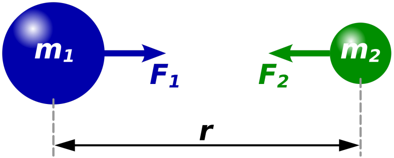
Amelie Thran, Niels Jautelat

July 7, 2025

Introduction

Dwarf galaxies are small galaxies populated by a relatively low number of stars, typically less than a billion. This presentation explores the n-body problem; simulating the moving stars in a galaxy influencing each other.

The physics behind it



$$F_1 = F_2 = G \frac{m_1 \times m_2}{r^2}$$

Figure: This but for every pair of stars in the galaxy

Problem outline

- A galaxy, even with a low number of stars, is complex.
- Every star influences every other one in their movement.
- No mathematical solution is possible
- We need to numerically simulate the movement of the stars over a period of time

Galaxy: Segue 1

Our example galaxy:
A dSph Galaxy, orbiting around the milkyway

- Roughly 1000 Stars
- Half-Light Radius of 30pc
- Mass-to-Light ratio (Darkmatter to normal matter) of 3400

Simple Sequential Solution

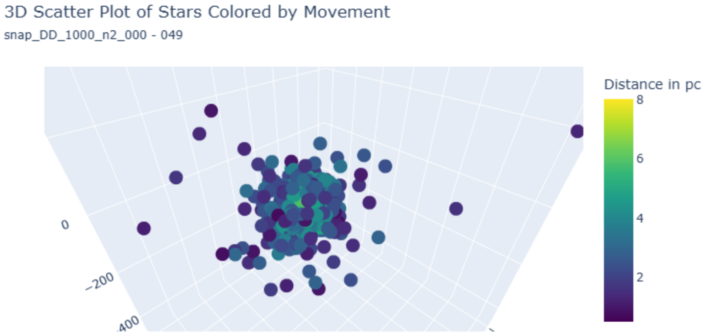
- Idea: two for-loops, within each other, starting at 0 both times calculating the stars at next position

Code	Runtime	Accuracy
Simple Sequential	21 sps	100% (reference data)

Accuracy

What is accurate enough?

- After 10.000 years how many of the stars are still where they are supposed to be?
- 0.00001pc, distance of the sun to mars as target.



Optimized Sequential Solution

- Idea: two for-loops, within each other, but starting at i=0 and j=i+1

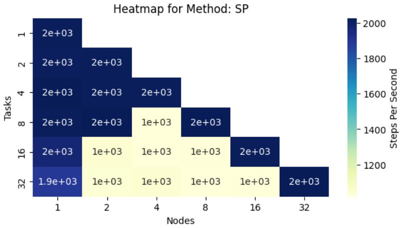
Code	Runtime	Accuracy
Simple Sequential	21 sps	100% (reference data)
Optimized Sequential	40 sps	43.1%

Simple Parallel Solution

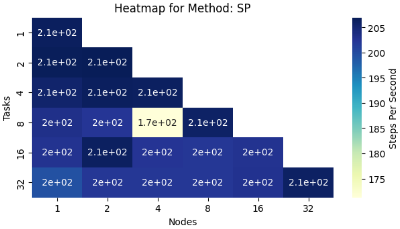
- openMP and the "pragma omp parallel for schedule(static)" command
- same code as Simple Sequential

Simple Parallel Heatmaps

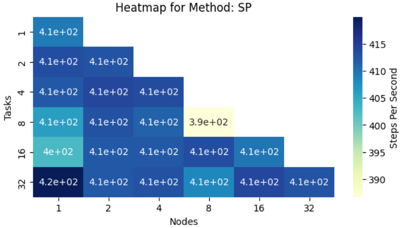
1000



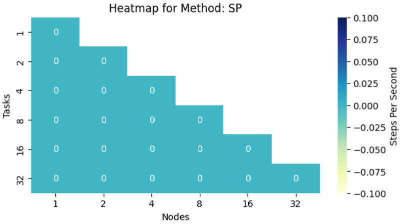
10000



5000



50000

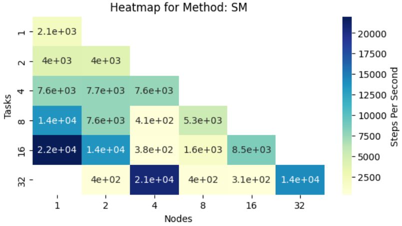


Simple Parallel II Solution

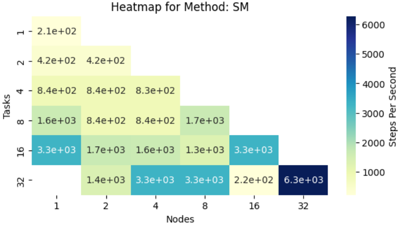
- MPI to parallelize the for loops
- same code as Simple Sequential

Simple Parallel II Heatmaps

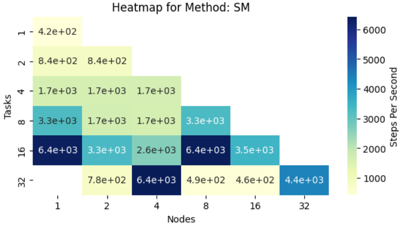
1000



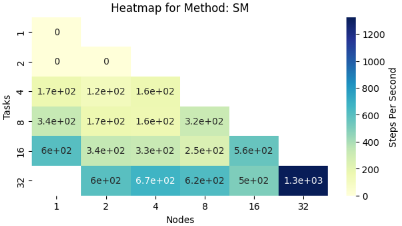
10000



5000



50000

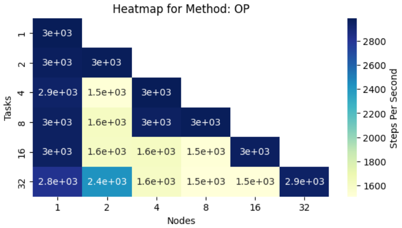


Optimized Parallel Solution

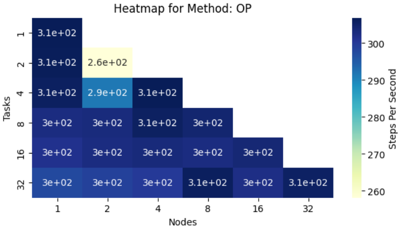
- implementation with openMP
- code same as optimized sequential

Optimized Parallel Heatmaps

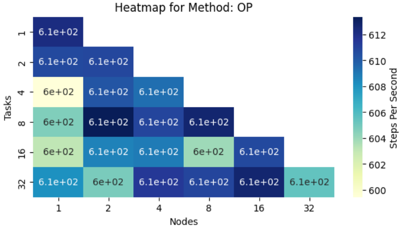
1000



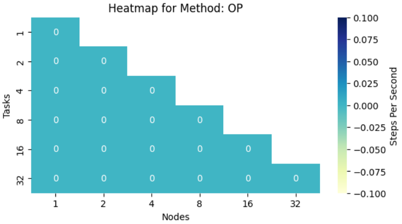
10000



5000



50000

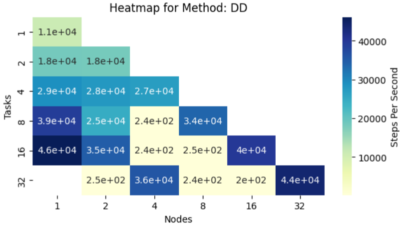


Distance Dependent Solution

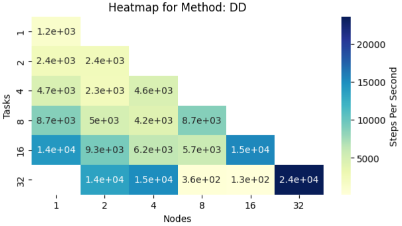
- starting from Simple Parallel MPI
- time stps are ten times bigger.
- within the inner radius of 7.5 pc we do 16 steps within one time step
- within the outer radius of 15 pc we do 8 steps within one time step

Distance Dependent Heatmaps

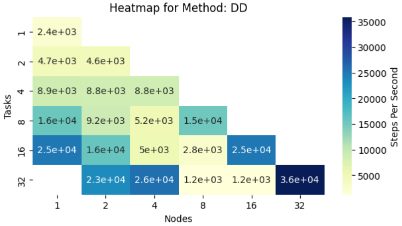
1000



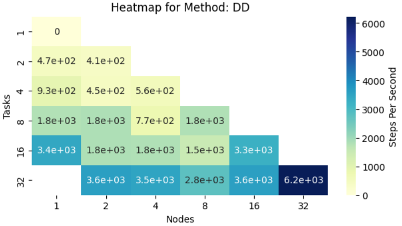
10000



5000



50000

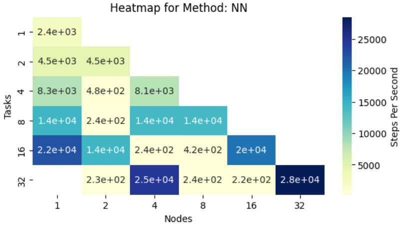


Nearest Neighbor Solution

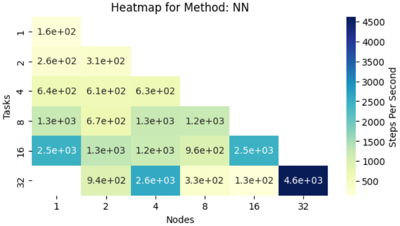
- starting again from the SM code and doing ten times bigger times steps
- Dependent on how close we are to the nearest neighbor:
- if within distance of 8pc: 8 steps per time step
- if within distance of 4 pc: 16 steps per time step

Nearest Neighbor Heatmaps

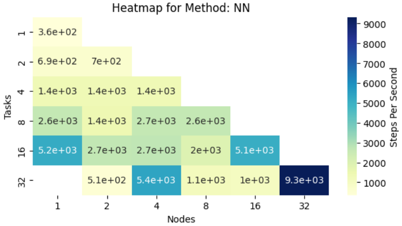
1000



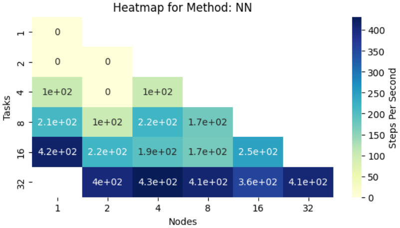
10000



5000



50000

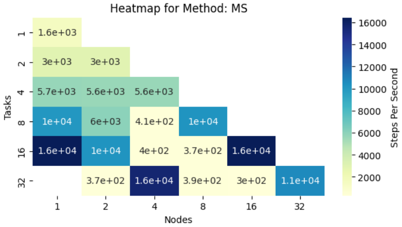


MPI Sectors Solution

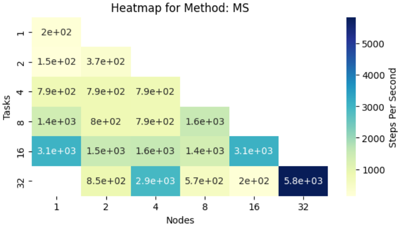
- dividing the galaxy in 1000 sectors, each sector has the edge length of 100 pc
- Within the same sector: computing the influence of every star
- Outside the sector: computing the influence of each sector
- mass of each sector is summed up as one point in the middle

MPI Sectors Heatmaps

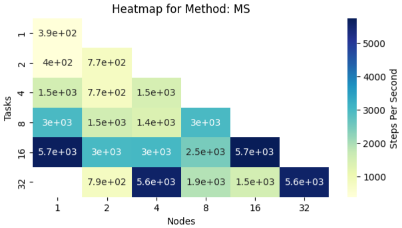
1000



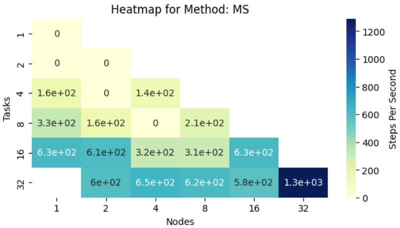
10000



5000



50000

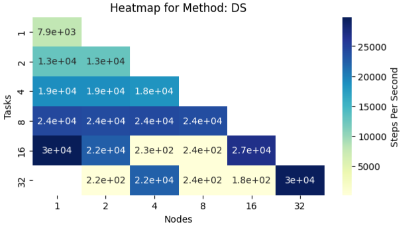


Distance Sectors Solution

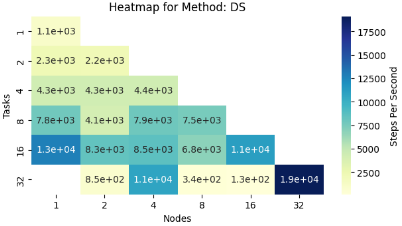
- Same sectors as in SM
- Within the middle of the galaxy:
- additionally the inner radius of distance dependent

Distance Sectors Heatmaps

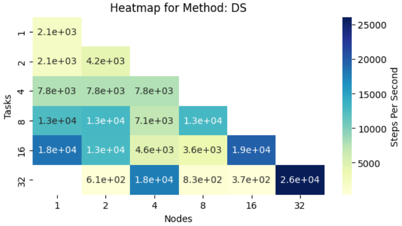
1000



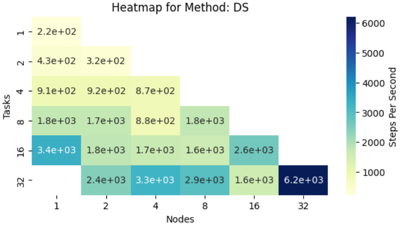
10000



5000



50000

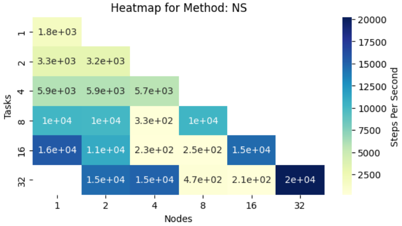


Nearest Sectors Solution

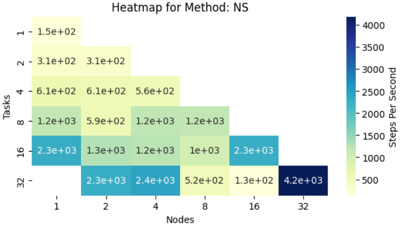
- Same sectors as in SM
- when the next star is within a distance of 4pc:
- use the nearest neighbor solution and do 16 steps within one time step

Nearest Sectors Heatmaps

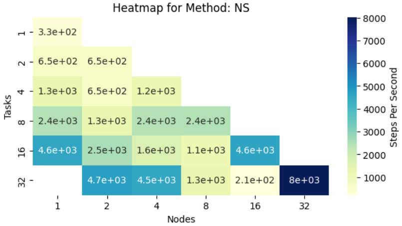
1000



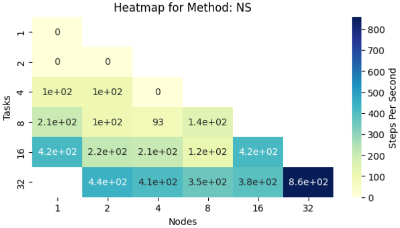
10000



5000



50000



Parallelized analyses

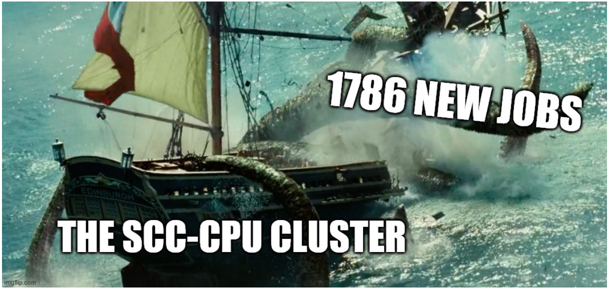
Readingnote: (N nodes n tasks) steps per second

Code	Accuracy	1000 Stars	5000 Stars	10 000 Stars	50 000 Stars	100 000 Stars
Simple Parallel (OpenMP)	100%	(N2n32) 208073	(N16n16) 41491.7	(N2n2)20753.9	(N1n2)3860.56	(N1n8) 1892.4
Simple Parallel (MPI)	100%	(N1n16) 21997	(N1n16) 6429	(N32n32) 6281	(N32n32) 1326	(N32n32) 661
Optimized Parallel	0%	(N1n1) 2988.19	(N2n8) 613.37	(N1n1) 306.9	(N1n1) 6025.5	(N1n4) 3011.57
Distance Dependent	99.9%	(N1n16) 46106	(N32n32) 35875	(N32n32) 23641	(N32n32) 6228	(N32n32) 2610
Distance Sectors	81.4%	(N32n32) 29843	(N32n32) 26096	(N32n32) 19106	(N32n32) 6210	(N32n32) 3344
Sectors MPI	81.3%	(N1n16) 21997.63	(N4n32) 6429.6	(N32n32) 6281.63	(N32n32) 1326.48	(N32n32) 661.71
Nearest Neighbor	99.9%	(N32n32) 28499	(N32n32) 9331	(N32n32) 4626	(N4n32) 431	(N32n32) 355
Nearest Sectors	81.4%	(N32n32) 20245.6	(N32n32) 81197.8	(N32n32) 42932	(N32n32) 8874	(N32n32) 4388.16

Conclusion

- The action is mostly in the middle of the galaxy DistanceDependent & NearestNeighbor give practically the same result.
- With enough stars you need to divide it into sectors to get good perfomance
- While we accomplished our goals, a better time management could have also allowed us to sleep this weekend.

Questions



Thank you for your attention!
Do you have any questions?