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Simulating multi-star systems using Python (and maybe C++)

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Outline

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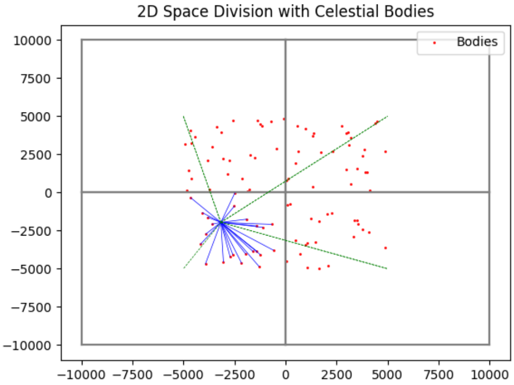
Why hard?

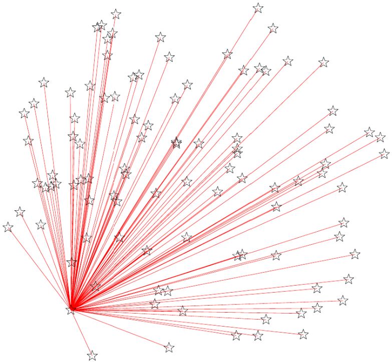
- Simulation is a model of the real world
- Simulation is always approximate, but must give insights
- Simulating real system on a classical computer takes too much time

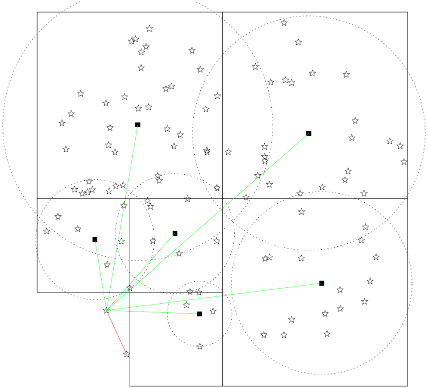
Approaches

- Body-body interactions
  - Complexity $O(n^2)$
  - 1M bodies - 1T calculations
- OctTree based object distribution
  - Complexoty $O(n \log(n))$
  - 1M bodies - 6M calculations
- Space chunking - Current choice
  - Compelxity $O(n\sqrt{n})$
  - 1M bodies - 2B calculations



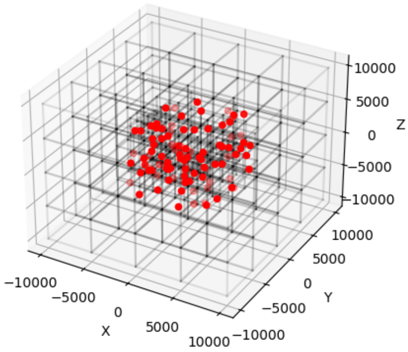
Body-body vs Tree

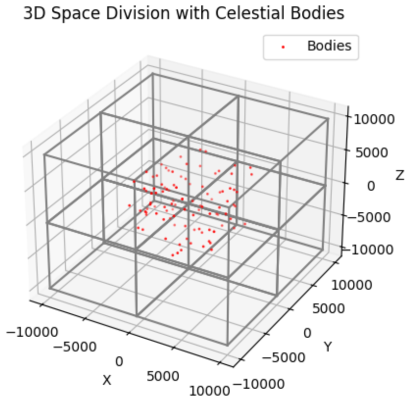




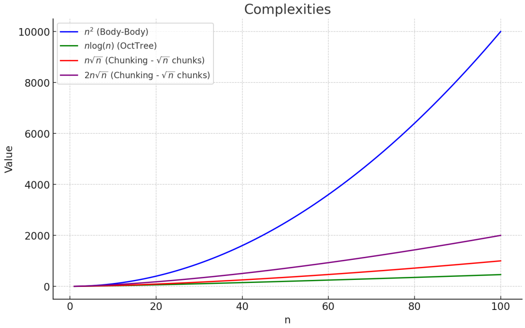
Dehnen and Read, "N-body simulations of gravitational dynamics"

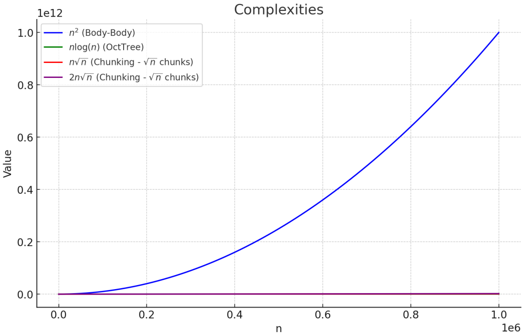
OctTree vs Space Chunking





Complexities





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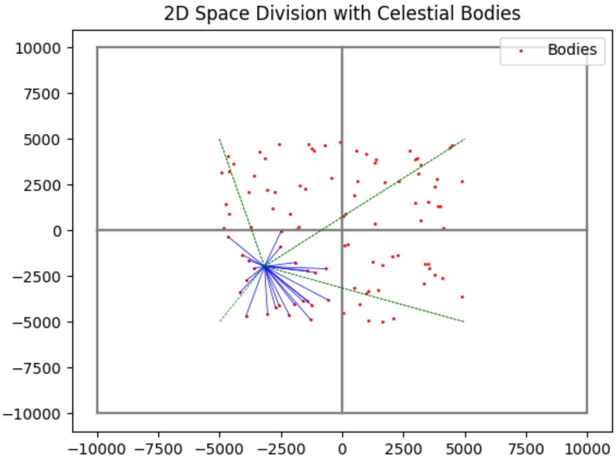
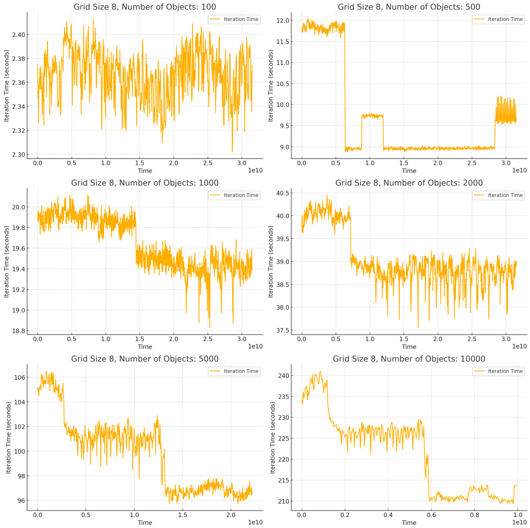
Calculations

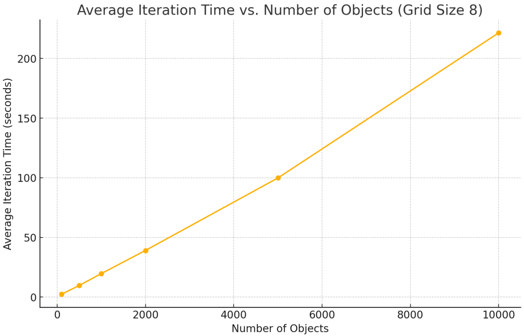
- Same calculation, as in case of an OctTree
- Leapfrog Integrator [1]:
  - $v_{i+0.5} = v_i + a_i * \frac{dt}{2}$
  - $x_i + 1 = x_i + v_{i+0.5} * dt$
  - $v_{i+1} = v_{i+0.5} + a_{i+0.5} * \frac{dt}{2}$



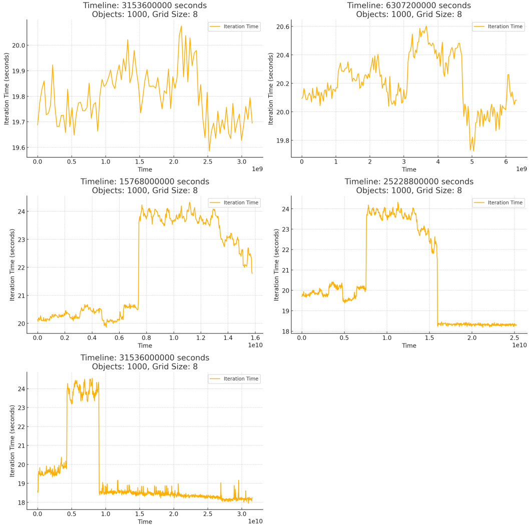
Wikipedia, *Leapfrog integration — Wikipedia, The Free Encyclopedia*

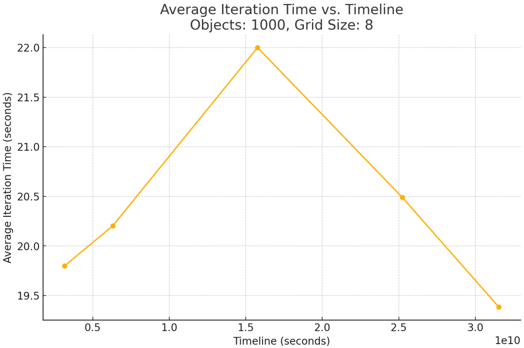
Performance



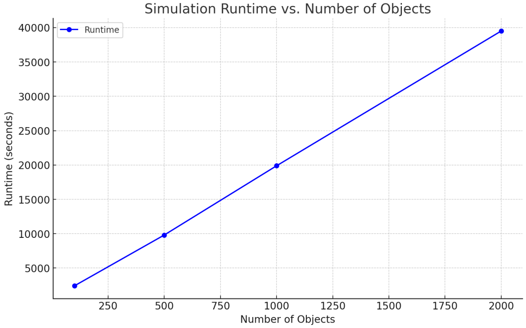


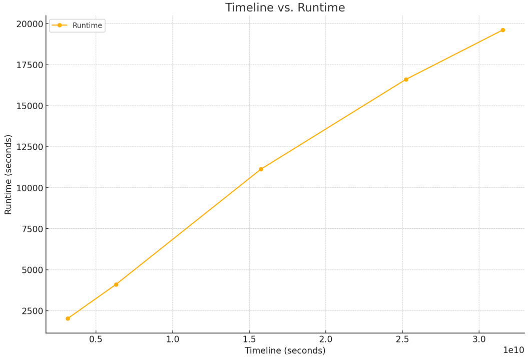
Performance



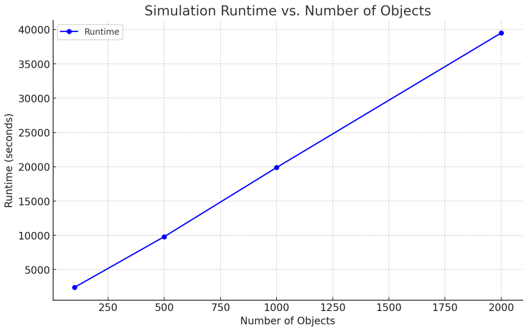


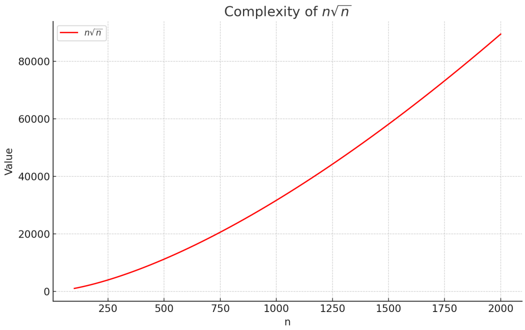
Performance





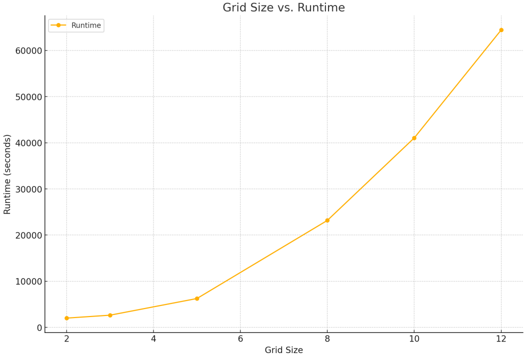
Performance





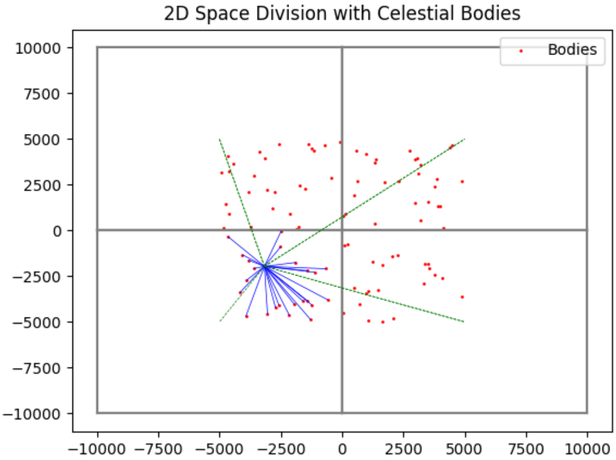
Performance

- $m = \sqrt{n}$
- $O(\frac{n^2}{m} + nm)$
- $O(n\sqrt{n} + n\sqrt{n})$



Performance

- $O(\frac{n^2}{m} + nm)$
- $m = n => O(n + n^2)$
- $m = 1 => O(n^2 + n)$
- $\frac{\sqrt{n}}{3} <= m <= 3\sqrt{n}$



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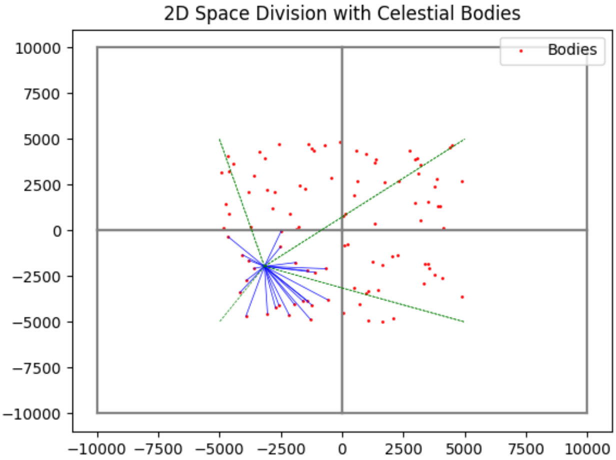
Can be Parallel

- Generation / Input read
- Calculation itself - Done
- Object-chunk tracking - Memory intensive
- Output write
- Animation

Workload Distribution

- Chunks can be distributed
- Only total masses and centres are communicated



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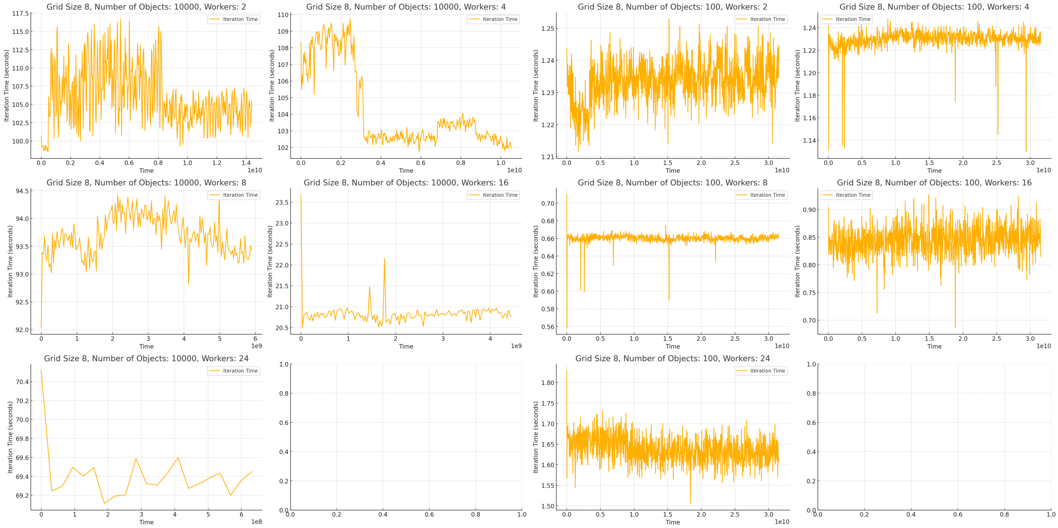
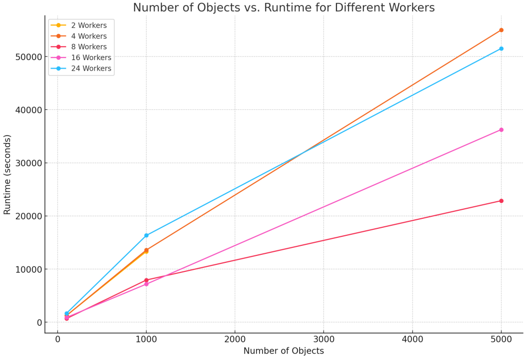
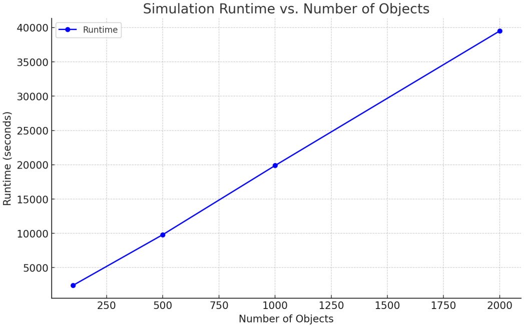
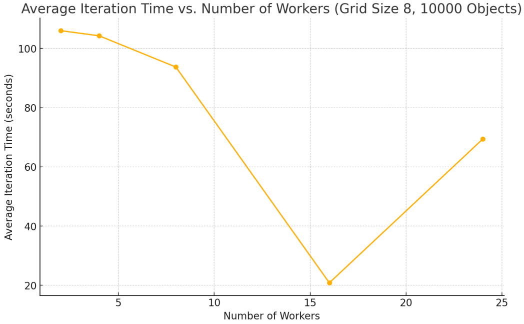


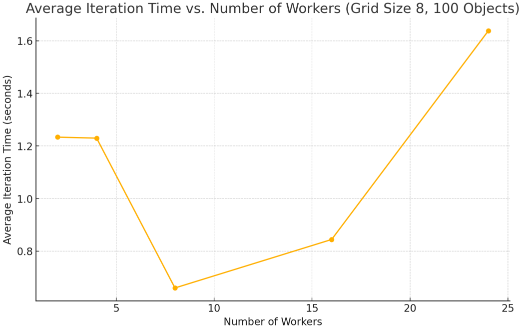
Comparison to Sequential



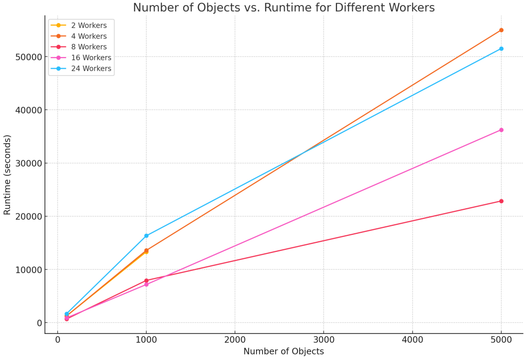


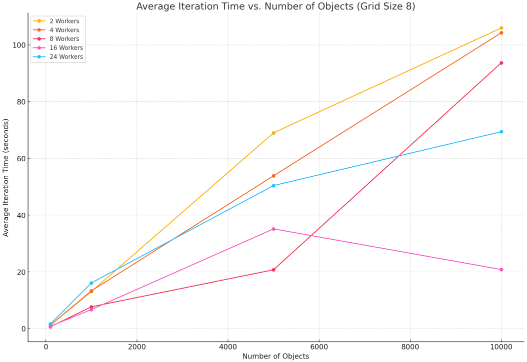
Scaling


Average Iteration Time vs. Number of Workers (Grid Size 8, 10000 Objects)
Average Iteration Time (seconds)
Number of Workers
20
40
60
80
100
5
10
15
20
25


Average Iteration Time vs. Number of Workers (Grid Size 8, 100 Objects)
Average Iteration Time (seconds)
Number of Workers
0.8
1.0
1.2
1.4
1.6
5
10
15
20
25

Scaling


Number of Objects vs. Runtime for Different Workers
2 Workers
4 Workers
8 Workers
16 Workers
24 Workers
Runtime (seconds)
Number of Objects
0
10000
20000
30000
40000
50000
1000
2000
3000
4000
5000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Number of Objects
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20
40
60
80
100
2000
4000
6000
8000
10000

LIKWID Analysis

Shell

```
attempt to index a nil value (field '?')
stack traceback:
        .../likwid-mpirun:1952: in function 'printMpiOutput'
        .../likwid-mpirun:2528: in main chunk
        [C]: in ?
```

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Overall Results

- Simulation scales overall good, but can be better
- Optimal number of nodes depends on number of objects and chunks (claim)
- Optimal number of chunks depend on the number of objects
- Real-world scale simulation might not be the best choice

What is Next

- Checkpoints
- Further scaling analysis
- OctTree parallelization
- Overhead measurement and reduction
- I/O parallelization
- Visualization parallelization
- On node parallelization with multiprocessing library
- Error handling

References

Dehnen, W. and J. I. Read. "N-body simulations of gravitational dynamics". In: *The European Physical Journal Plus* 126.5 (May 2011). ISSN: 2190-5444. DOI: 10.1140/epjp/i2011-11055-3. URL: http://dx.doi.org/10.1140/epjp/i2011-11055-3.

Wikipedia. *Leapfrog integration — Wikipedia, The Free Encyclopedia*. http://en.wikipedia.org/w/index.php?title=Leapfrog%20integration&oldid=1220184662. [Online; accessed 21-June-2024]. 2024.