Development of RAMSES in the context of the EuroHPC project SPACE

Tine Colman, Benoît Commerçon (CRAL, CNRS)

ASNUM 2025

Co-funded by the European Union

Funded by the European Union. This work has received funding from the European High Performance Computing Joint Undertaking (JU) and Belgium, Czech Republic, France, Germany, Greece, Italy, Norway, and Spain under grant agreement No 101093441.

EuroHPC Joint Undertaking

SPACE

- Scalable Parallel Astrophysical Codes for Exascale
- 4 year European Center of Excellence project
- Goal: prepare state-of-the-art astro codes to efficiently use exascale computation resources
- 7 codes: OpenGadget, ChaNGa, PLUTO, iPIC3D, RAMSES, FIL, BHAC
- Collaboration: research institutes, computing centers, vendors

RAMSES in SPACE

Goal: improve time-to-solution and scaling

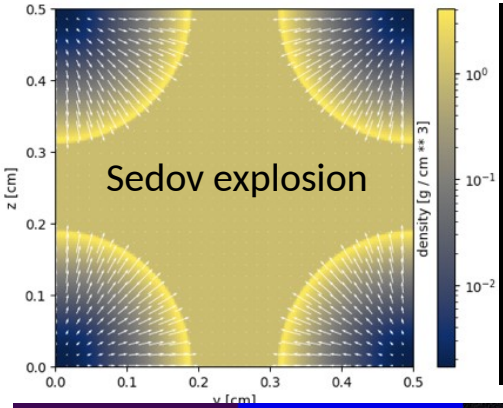
Progress:

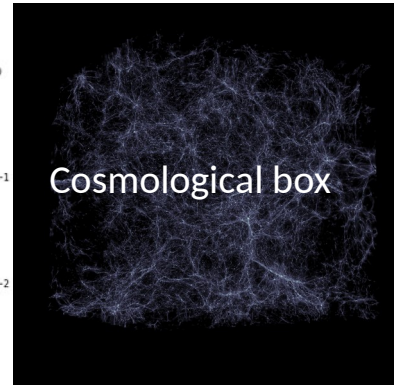
- Benchmarking on all EuroHPC machines
- Low level optimisations

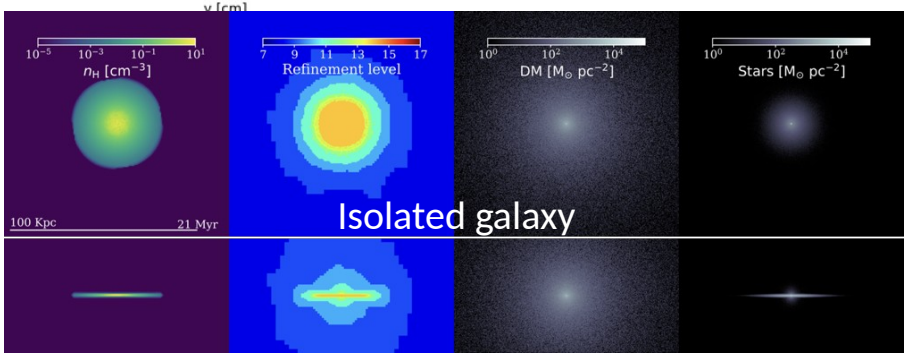
  neighbor searching, godunov solver
- OpenMP

  sedov & cosmo done, amr wip
- Also tests, doc, code cleaning

Selected representative use cases:







1 Open ✓ **48 Closed** Author Label Projects Milestones

- **Overhaul of compiler flags in Makefile** ✓ SPACE
  #185 by tinecolman was merged 3 days ago • Approved
- **Combine hydro, mhd and rhd versions of hydro_parameters.f90** ✓ code quality SPACE
  #184 by tinecolman was merged 5 days ago • Approved
- **Combine hydro and mhd versions of output_hydro.f90** ✓ code quality SPACE
  #183 by tinecolman was merged 5 days ago • Approved
- **further document the order of hydro variables** ✓ documentation SPACE
  #178 by tinecolman was merged last week • Approved
- **combine the hydro and mhd versions of init_flow_fine.f90 into one** ✓ code quality SPACE
  #174 by tinecolman was merged last week • Approved
- **fix after merge** ✗ openmp SPACE
  #171 by tinecolman was merged on Jul 15
- **change slope_type in imhd-tube and imhd-tube-nener tests** ✓ CI SPACE
  #169 by tinecolman was merged 5 days ago • Approved
- **Add 1D advection test** ✓ SPACE test case
  #166 by tinecolman was merged on Jul 9 • Approved
- **Improvements to parameter sweep of sod-tube test** ✓ CI SPACE
  #165 by tinecolman was merged on Jul 9 • Approved
- **regenerate reference solution for stellar-HII with 2 cpus** ✓ CI SPACE
  #160 by tinecolman was merged on Jul 1 • Approved
- **optimizations for hydro solver on uniform grid** ✓ performance SPACE
  #159 by tinecolman was merged 4 days ago • Approved
- **Optimize ctoprim** ✓ performance SPACE
  #158 by tinecolman was merged 5 days ago • Approved

Commits from SPACE

46 PRs merged on dev

+ 10 PRs merged on openmp

Various stuff in development on

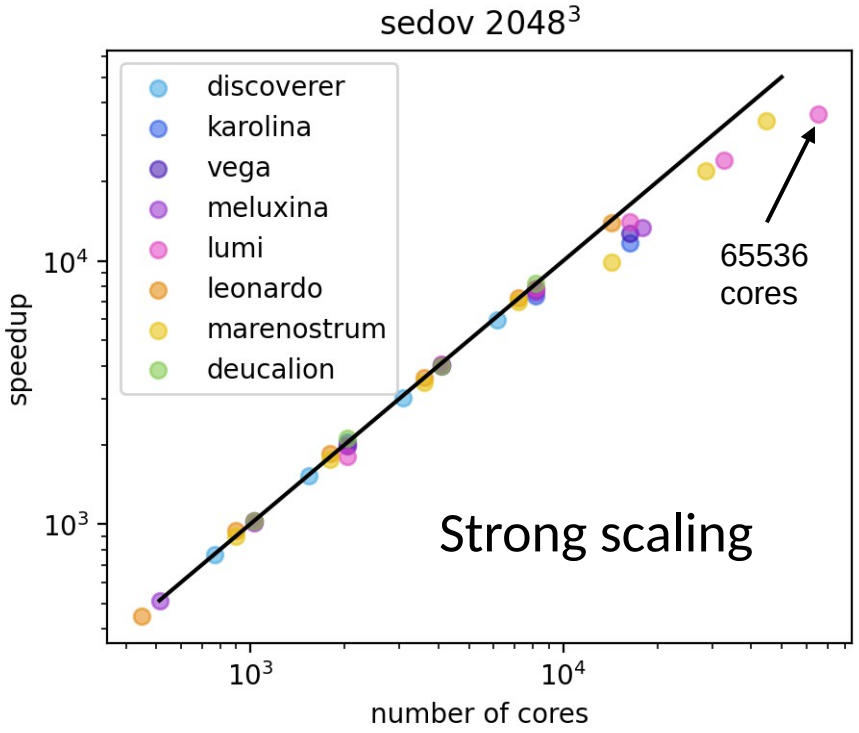
https://github.com/tinecolman/ramses

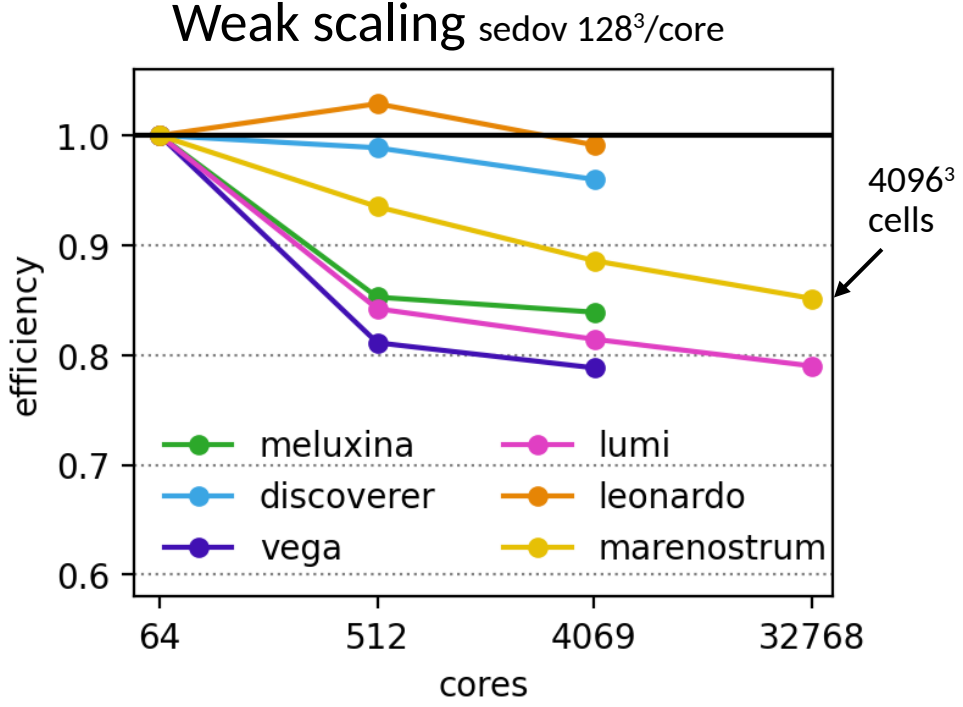
Benchmarking

EuroHPC systems (CPU partitions)

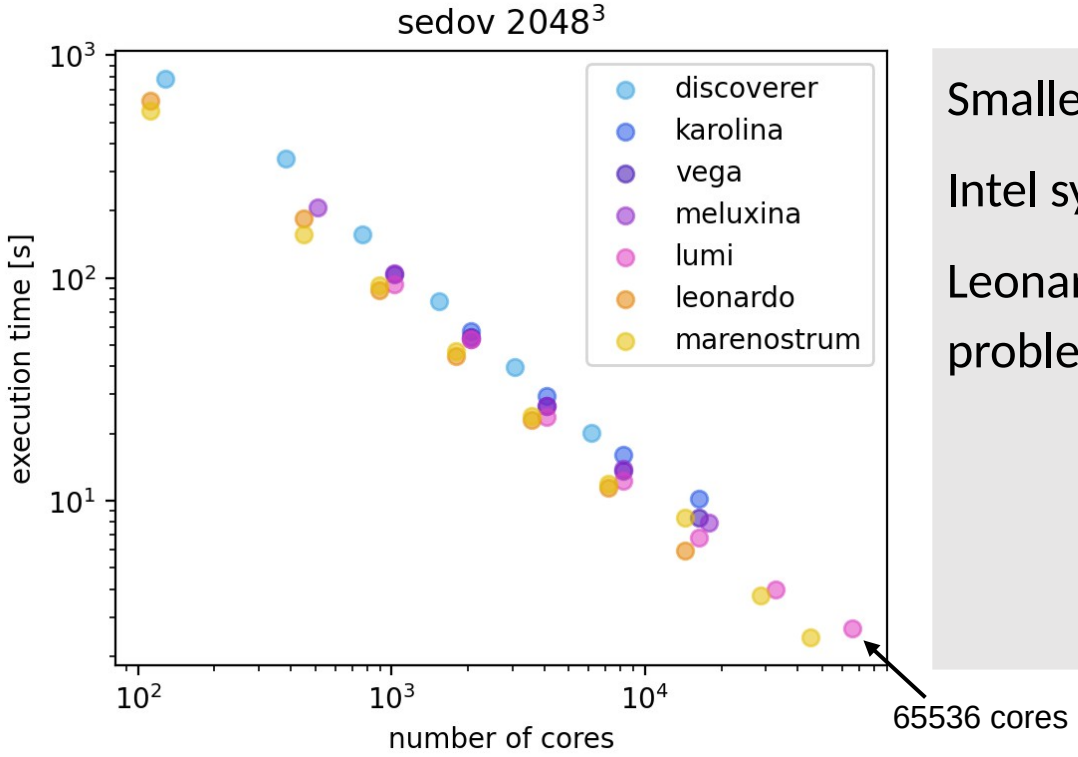
system (country)	**#nodes**	**RAM/node** [GB]	**processor** (cores)	**chosen compiler**
Discoverer (Bulgaria)	1128	256, 1024	2 x AMD EPYC 7H12 (2x64)	GNU + OpenMPI
Karolina (Czech rep.)	720	256	2 x AMD EPYC 7H12 (2x64)	GNU + OpenMPI
Vega (Slovenia)	960	256, 1024	2 x AMD EPYC 7H12 (2x64)	GNU + OpenMPI
MeluXina (Luxembourg)	573	512, 4096	2 x AMD EPYC 7H12 (2x64)	GNU + OpenMPI
Lumi (Finland)	2048	256, 512, 1024	2 x AMD EPYC 7763 (2x64)	GNU + MPICH (Cray)
Leonardo (Italy)	1536	512	2 x Intel Xeon Platinum 8480+ (2x56)	Intel + Intel MPI
Mare Nostrum (Spain)	6192	256, 1024	2 x Intel Xeon Platinum 8480+ (2x56)	Intel + Intel MPI
Deucalion (Portugal)	-	-	-	-

Scaling on EuroHPC systems





Performance on EuroHPC systems



Smaller AMD systems similar

Intel systems typically slightly faster

Leonardo best timings (but often node problems)

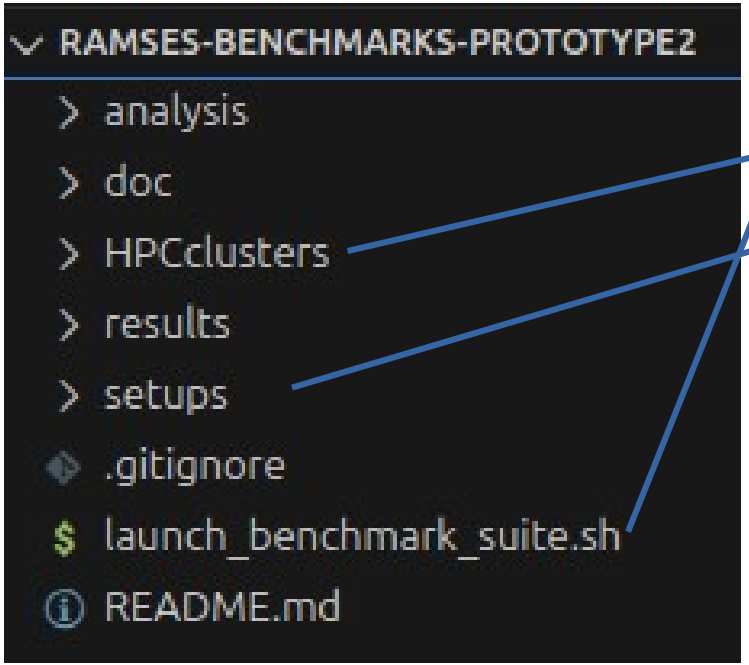
Performance benchmarking

GOAL: create script to make benchmarking ramses easy…

- for users, that need scaling plots for proposals
- for developers, that need to verify performance
- for maintainers, to verify code quality on PR

Benchmark package for RAMSES

https://github.com/tinecolman/ramses-benchmarks-prototype2



- **Main script**: compile code, create and launch jobs
- Presets for different clusters
- Collection of predefined setups
- Scripts to analyze results
- Manual
- Results and figures
- Front page of repo

Using the benchmark script

```
$ ./launch_benchmark_suite.sh -c meluxina -l "1" -h refactor_3cube_nbor_utils -t 1,2 -a p200525 -i 3
```

Parameters:

- -c: name of the preset cluster
- -l or -n: specify a list or maximum number of nodes to use
- -t: specify which benchmark setups to run
- -i: how many times to run the same benchmark (1 by default)
- -a: allocation number (can also be determined automatically)
- -w: also do weak scaling
- -m: openMP threads

```
Switched to branch 'openmp_hydro_unigrid'
Your branch is up to date with 'origin/openmp_hydro_unigrid'.
################################################
#    Launching RAMSES performance benchmarks    #
################################################
Multiple projects found. Please select one:
1) nocredit
2) p200525
#? 2
You selected allocation ID: p200525
Will launch the following benchmarks:
 [ 2] setups/sedov
-----------------------------------------
Test 1/1: sedov
Compile job submitted with Job ID: 2577666
Waiting for compile job to finish...
Compile job completed successfully.
Launched benchmark sedov on 1 nodes [JOB ID 2577669]
Launched benchmark sedov on 1 nodes [JOB ID 2577670]
Launched benchmark sedov on 1 nodes [JOB ID 2577671]
Launched benchmark sedov on 2 nodes [JOB ID 2577672]
Launched benchmark sedov on 2 nodes [JOB ID 2577673]
Launched benchmark sedov on 2 nodes [JOB ID 2577674]
Launched benchmark sedov on 4 nodes [JOB ID 2577675]
Launched benchmark sedov on 4 nodes [JOB ID 2577676]
Launched benchmark sedov on 4 nodes [JOB ID 2577677]
Submitted batch job 2577678
```

Benchmarking for users

tinecolman / **ramses-benchmarks-prototype2**

Benchmark setups

- SEDOV: classic Sedov explosion in 3D
- COSMO: dark matter-only cosmological box on a uniform grid

Benchmark results per cluster

Cluster	Benchmark results
MeluXina	SEDOV
MareNostrum	

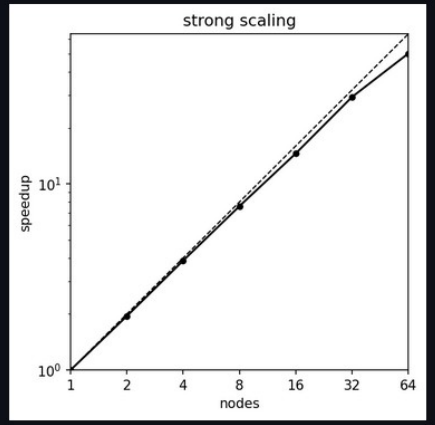
How to do your own benchmarking

- How to use the benchmark script
- How to process the results
- How to add a setup
- How to add a cluster

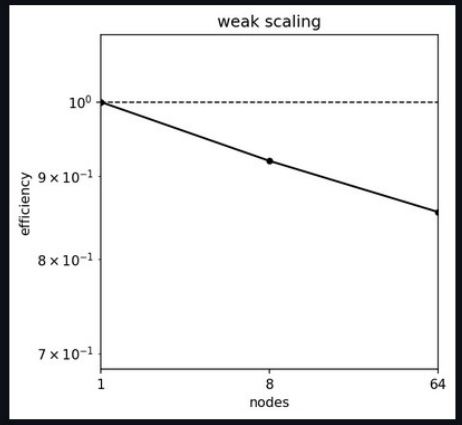
Benchmark results meluxina

SEDOV

Strong scaling



Weak scaling



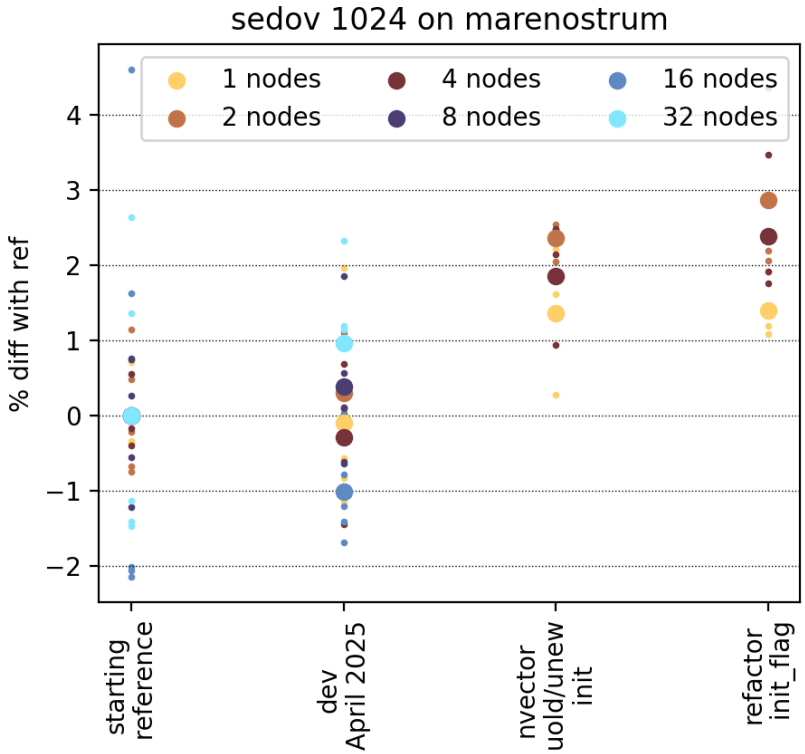
Strong scaling

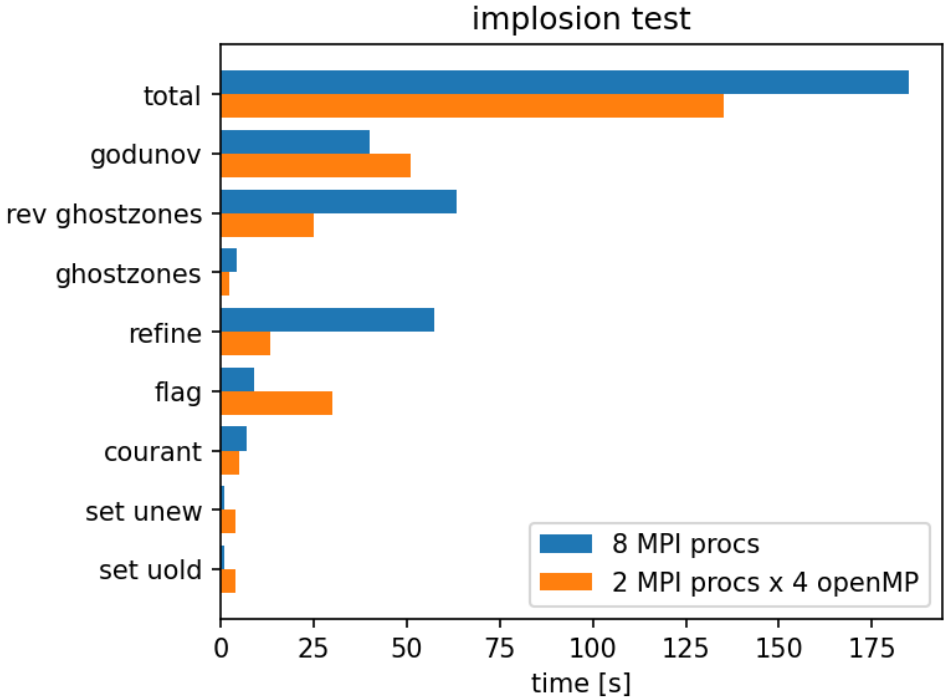
nodes	efficiency
1	100%
2	97%
4	97%
8	95%
16	91%
32	92%
64	79%

Weak scaling

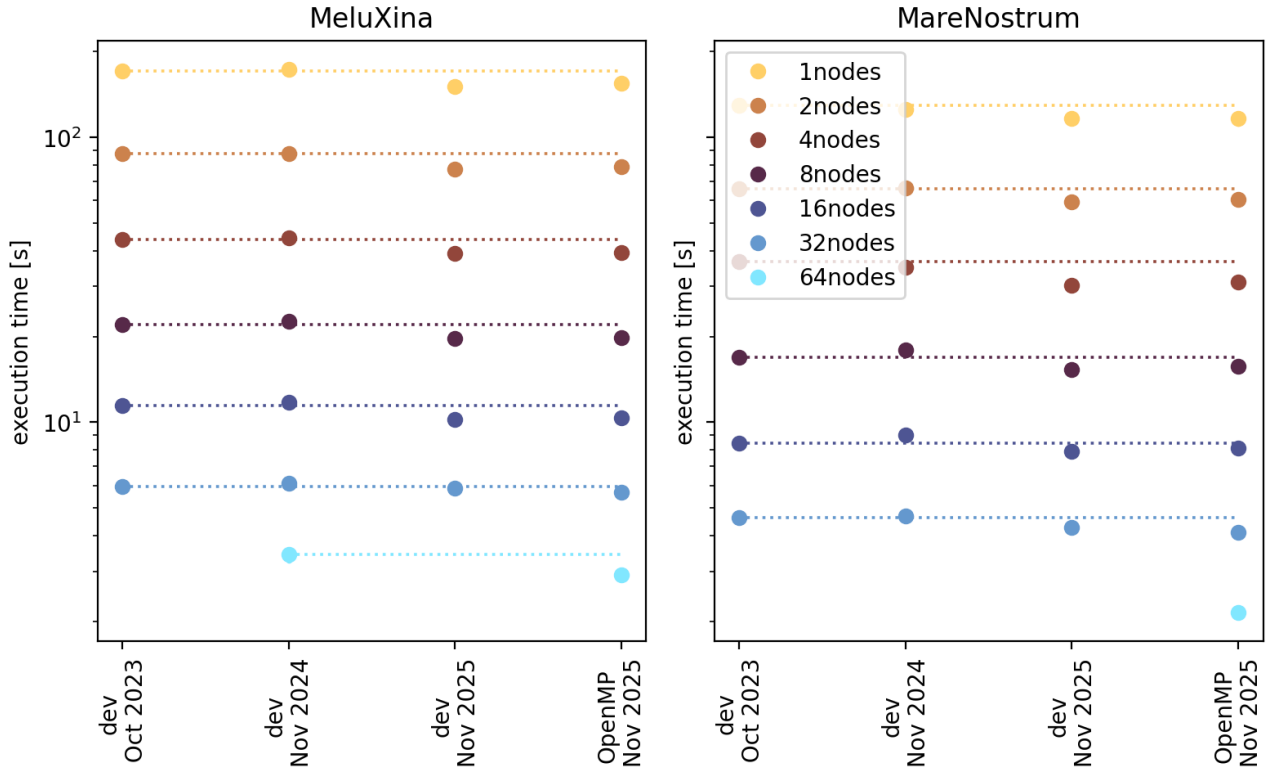
nodes	resolution	efficiency
1	256	100%
8	512	92%
64	1024	86%

Benchmarking for developers





Benchmarking for maintainers



Optimization

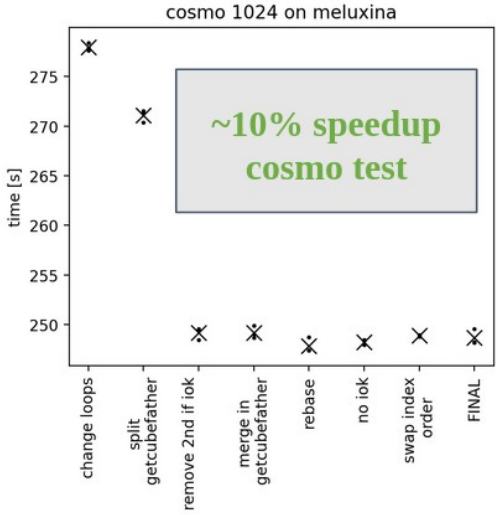
Optimization of neighbor searching

Elementary routine used in many parts of the code

Identified as bottleneck in COSMO use case

=> refactor for efficiency

cosmo profiling Name	Inclusive Time w.r.t. Wall Time(s)	
	old	new
gauss_seidel_mg_fine	15.31	15.17
interpolate_and_correct_fine	12.08	12.15
move1	9.89	9.75
sync	9.32	9.60
mca_btl_vader_poll_handle_frag	9.32	7.83
get3cubefather	17.86	0.28
cic_amr	6.92	6.64
cmp_residual_mg_fine	6.23	6.15
gauss_seidel_mg_coarse	4.16	4.03
check_tree	4.19	3.97
get3cubepos	3.85	3.79

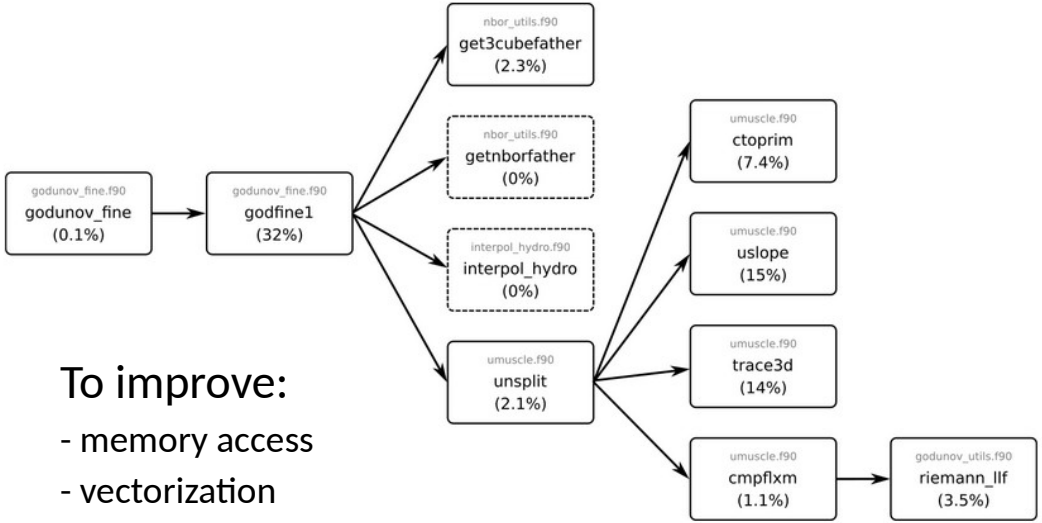


[SPACE] Optimize and document nbor utils ✓

#108 by tinecolman was merged 3 weeks ago • Approved

Optimization of Godunov solver

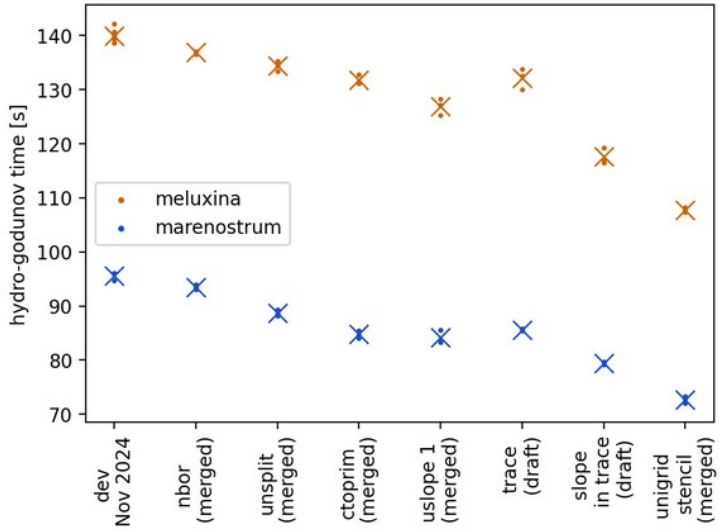
Initial profiling of sedov use-case



To improve:

- memory access
- vectorization

Progress



23% speedup for sedov test

MPI + OpenMP implementation

Shared memory parallelism with OpenMP inside nodes

=> reduce number of MPI domain

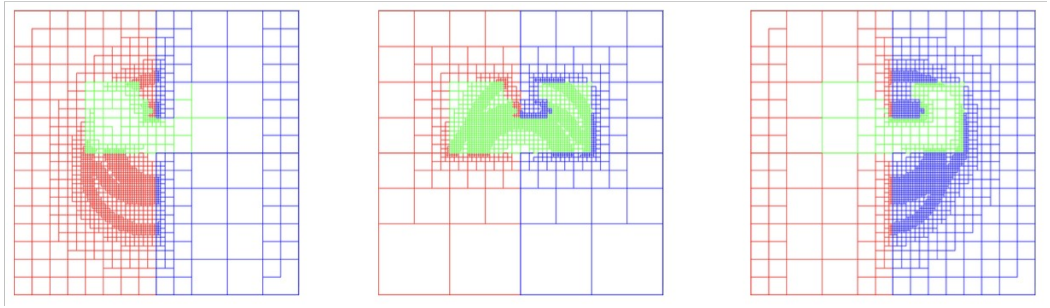
=> decrease communication &

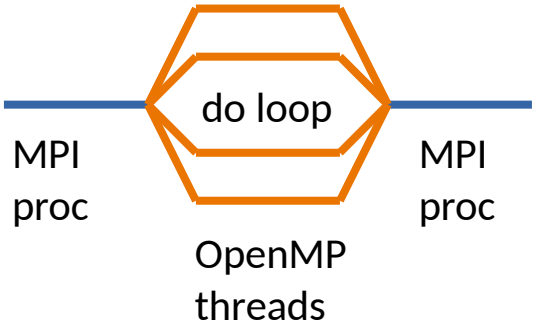
reduced memory imprint ghost zones

=> less time spent communicating

=> **improved scalability**

Starting from RAMSES-yOMP





openmp branch

Dedicated branch on RAMSES GitHub

Done:

- Hydro on uniform grid (SEDOV)
- DM-only on uniform grid (COSMO)

WIP:

- Refinement
- MHD
- RT & cooling (STROMGREN)

Working version of OpenMP in particles for COSMO (part2) openmp SPA
ramses-organisation/ramses#213 · by tinecolman was closed yesterday · ✓ 16/18

adjust omp for set_uold/unew to allow for more than 8 threads openmp
ramses-organisation/ramses#207 · by tinecolman was closed on Oct 17 · ✓ 8/8

[OpenMP] Progress of openmp for cosmo box: poisson multigrid solver
ramses-organisation/ramses#200 · by tinecolman was closed on Sep 30 · ✓ 8/8

Openmp virtual_boundaries openmp SPACE
ramses-organisation/ramses#196 · by tinecolman was closed on Sep 23 · ✓ 8/8

fix after merge openmp SPACE
ramses-organisation/ramses#171 · by tinecolman was closed on Jul 15 · ✗ 8/10

OpenMP: hydro on unigrid openmp SPACE
ramses-organisation/ramses#119 · by tinecolman was closed on Jun 6 · Approved · ✓ 8/10

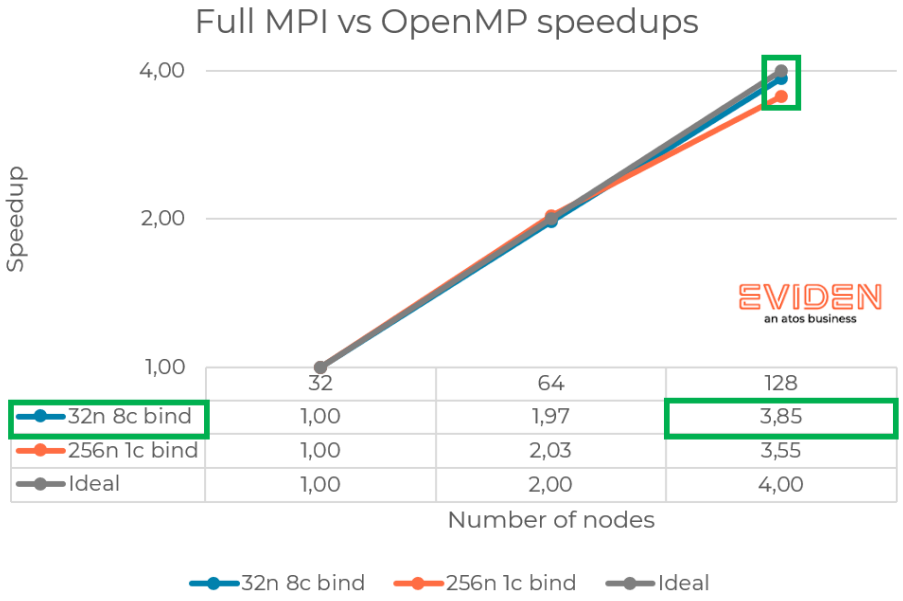
OpenMP: add variables for nthr + fix openmp SPACE
ramses-organisation/ramses#118 · by tinecolman was closed on Jun 5 · ✓ 8/10

Use the communicator active instead of the linked list openmp SPACE
ramses-organisation/ramses#103 · by tinecolman was closed on Apr 14 · Approved · ✓ 8/10

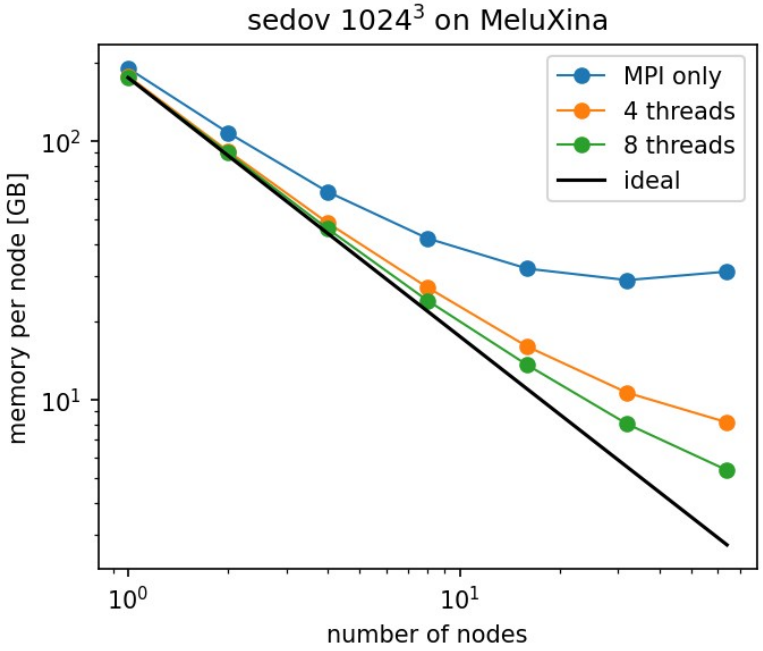
OpenMP: make saved variables threadprivate openmp SPACE
ramses-organisation/ramses#96 · by tinecolman was closed on Apr 1 · ✓ 8/10

OpenMP: compile and launch test suite with threads openmp SPACE
ramses-organisation/ramses#84 · by tinecolman was closed on Mar 19 · ✓ 15/15

OpenMP for SEDOV ✅

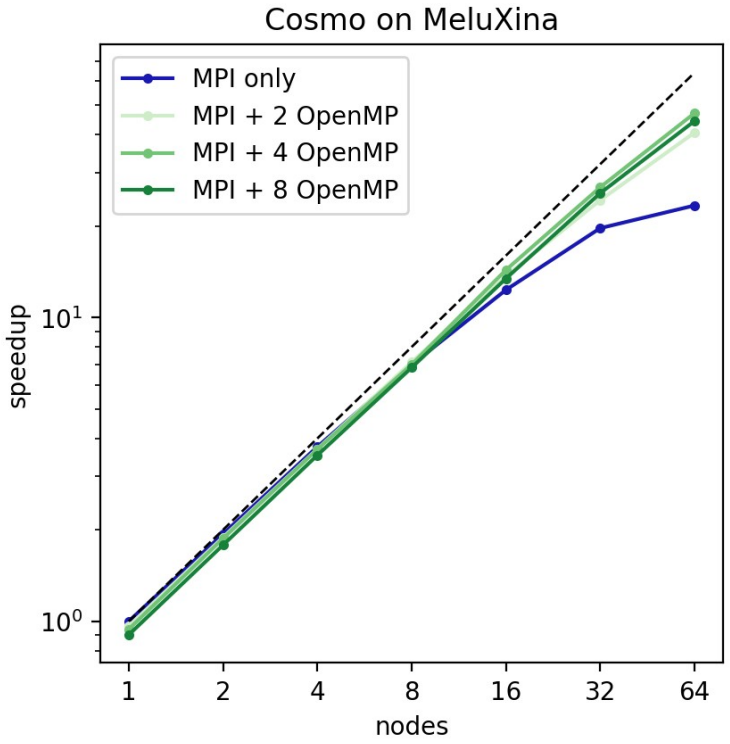


	32	64	128
32n 8c bind	1,00	1,97	3,85
256n 1c bind	1,00	2,03	3,55
Ideal	1,00	2,00	4,00



AMD Milan architecture, 128 cores (256 threads) / node, AOCC compiler

OpenMP for COSMO ✅



Modules:

- Poisson multigrid solver
- Force calculation
- Particle-mesh
- Moving of particles

Result on 64 nodes:

x2 faster

scaling 37% → 74%

CI/CD improvements

- SNO working group: test suite
- 41 PR related to tests/CI merged
- 16 new tests added, 5 tests updated
- Various infrastructure improvements
- Test suite coverage
  - Initially: 47.63 % (16828/35334 lines)
  - Current: **63.02 %** (21428/34000 lines)

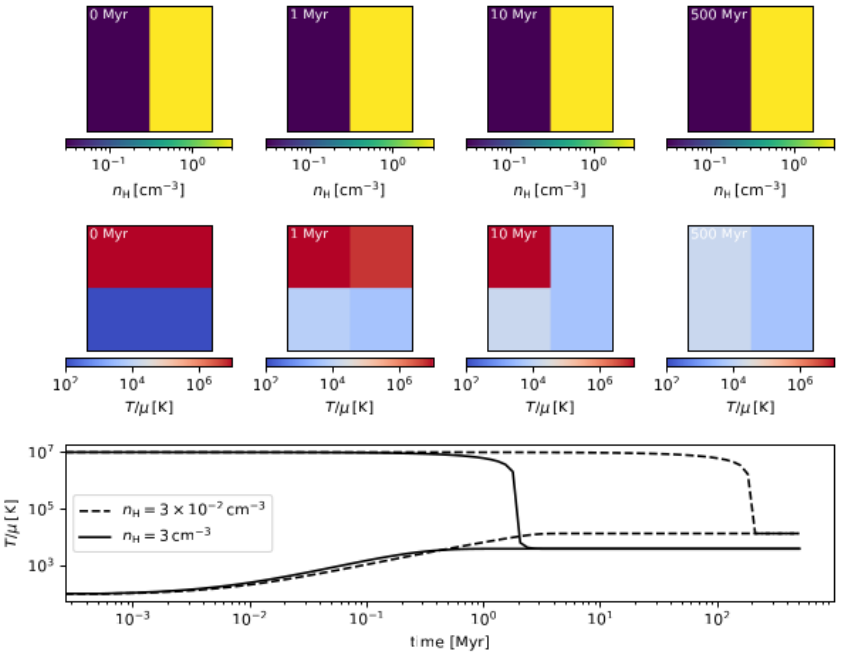


Figure 3: hydro/cooling-eq test

Summary

Benchmarking RAMSES

- on all EuroHPC systems
- Development of scripts

Optimizations: low level + OpenMP

- Hydro uniform grid:

  20% base speedup

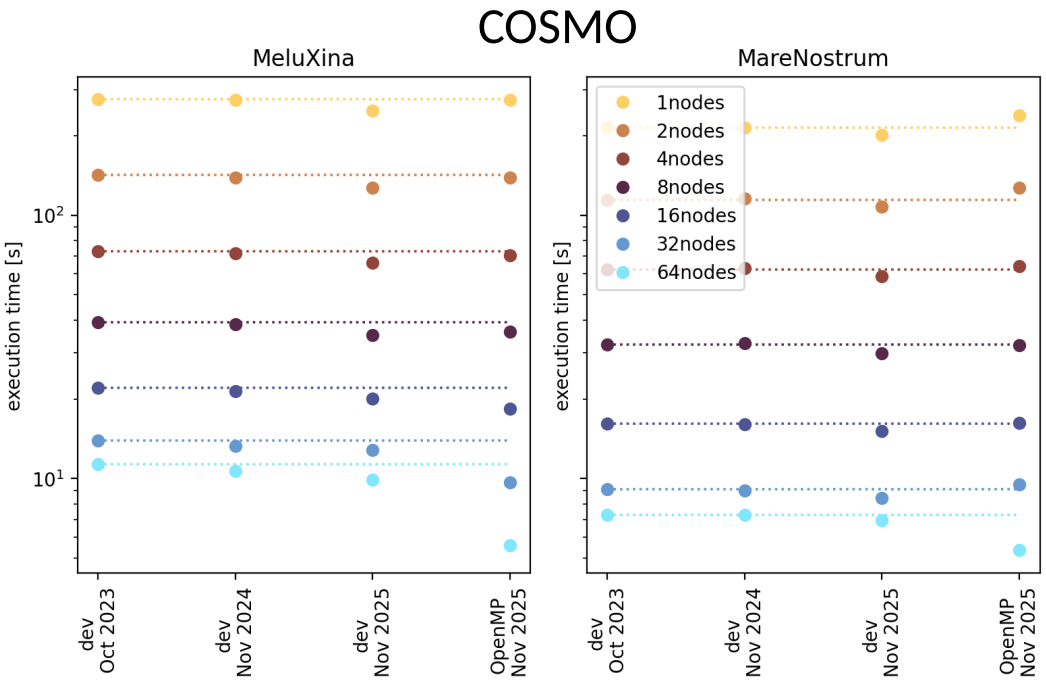
  5-10% scaling improvement

- Cosmo unifrom grid:

  10% base speedup

  30-40% scaling improvements

Test suite improvements

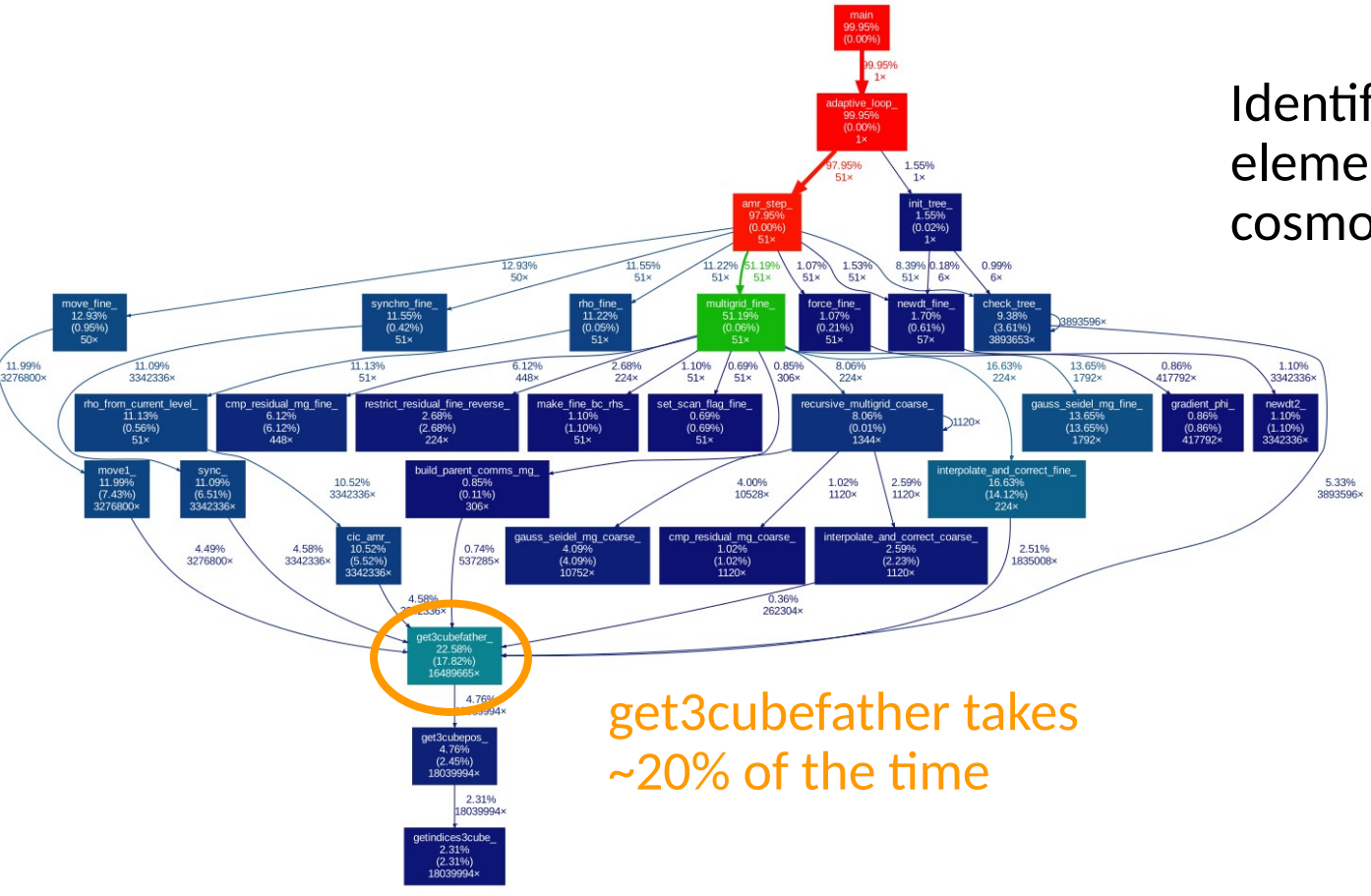


Acknowledgement & Disclaimer

Funded by the European Union. This work has received funding from the European High Performance Computing Joint Undertaking (JU) and Belgium, Czech Republic, France, Germany, Greece, Italy, Norway, and Spain under grant agreement No 101093441.

Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European High Performance Computing Joint Undertaking (JU) and Belgium, Czech Republic, France, Germany, Greece, Italy, Norway, and Spain. Neither the European Union nor the granting authority can be held responsible for them

Optimisation of neighbor searching



Identified bottleneck in an elementary routine for cosmo benchmark

get3cubefather takes ~20% of the time

```
5   subroutine get3cubefather(ind_cell_father,nbors_father_cells,&
142   else    ! else, more complicated...
147     end do
148     ! Get father grid
149     do i=1,ncell
150        ind_grid_father(i)=ind_cell_father(i)-ncoarse-(pos(i)-1)*ngridmax
151     end do
152
153     ! Loop over position
154     do ind=1,twotondim
155
156        ! Select father cells that sit at position ind
157        iok=0
158        do i=1,ncell
159           if(pos(i)==ind)then
160              iok=iok+1
161              ind_grid_ok(iok)=ind_grid_father(i)
162           end if
163        end do
164
165        if(iok>0)&
166        & call get3cubepos(ind_grid_ok,ind,nbors_father_ok,nbors_grids_ok,iok)
167
168        ! Store neighboring father cells for selected cells
169        do j=1,threetondim
170           iok=0
171           do i=1,ncell
172              if(pos(i)==ind)then
173                 iok=iok+1
174                 nbors_father_cells(i,j)=nbors_father_ok(iok,j)
175              end if
176           end do
177        end do
178
179        ! Store neighboring father grids for selected cells
180        do j=1,twotondim
181           iok=0
182           do i=1,ncell
183              if(pos(i)==ind)then
184                 iok=iok+1
185                 nbors_father_grids(i,j)=nbors_grids_ok(iok,j)
186              end if
187           end do
188        end do
189
190     end do
191
192   end if
```

Same filtering with if inside loop done trice

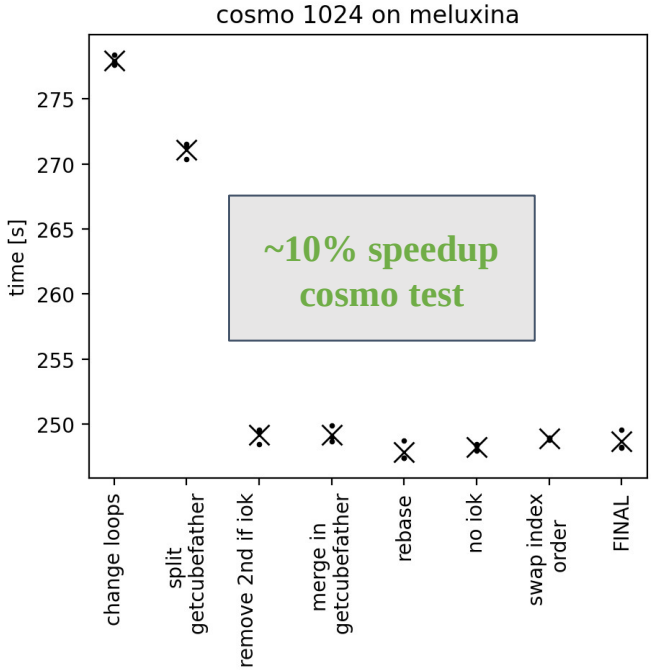
Both cells and grids are outputted but only one is used

```
48   subroutine get3cubefather(ind_cell,nbor_cells,ncell,ilevel)
70     if(ilevel==1)then  ! Easy...
126    else    ! else, more complicated...
127
128      ! Get the cell's position in its grid, that is the
129      ! index ind, between 1 and twotondim.
130      do i=1,ncell
131        pos(i)=(ind_cell(i)-ncoarse-1)/ngridmax+1  !integer devision
132      end do
133
134      ! Convert the cell's index to the index of the grid to which the
135      do i=1,ncell
136        iskip=ncoarse+(pos(i)-1)*ngridmax
137        ind_grid_father(i)=ind_cell(i)-iskip
138      end do
139
140      ! Using the grid index and cell position, get the neighbor cells
141      call get3cubepos(ind_grid_father,pos,nbor_cells,ncell)
142
143    end if
```

```
150  subroutine get3cubefather_grids(ind_cell,nbors_grids,ncell,ilevel)
170    if(ilevel==1)then  ! Easy...⋯
223    else    ! else, more complicated...
224
225      ! Get the cell's position in its grid, that is the
226      ! index ind, between 1 and twotondim.
227      do i=1,ncell
228        pos(i)=(ind_cell(i)-ncoarse-1)/ngridmax+1  !integer devision
229      end do
230
231      ! Convert the cell's index to the index of the grid to which the cel
232      do i=1,ncell
233        iskip=ncoarse+(pos(i)-1)*ngridmax
234        ind_grid_father(i)=ind_cell(i)-iskip
235      end do
236
237      ! Using the grid index and cell position to get neighbor grids
238      call get_grids_of_nbor_cells(ind_grid_father,pos,nbors_grids,ncell)
239
240    end if
```

Solutions:

- Split into two routines
- Remove filtering and artificial loop over ind. Pass array pos instead of integer ind to get3cubepos.



Implementation

Place !$omp on loops over grids

Beware of updates to neighbors or other levels

```
  ! Loop over active grids by vector sweeps
  ncache=active(ilevel)%ngrid
!$omp parallel do private(ngrid,i)      You, last mo
  do igrid=1,ncache,nvector
     ngrid=MIN(nvector,ncache-igrid+1)
     do i=1,ngrid
        ind_grid(i)=active(ilevel)%igrid(igrid+i-1)
     end do
     call godfine1(ind_grid,ngrid,ilevel)
  end do
```

```
  ! Update particles position and velocity
!$omp parallel private(ig,ip,jgrid,igrid,npart1,ipart,local_c
  ig=0
  ip=0
  ! Loop over particles that are not tracers
!$omp do
  do jgrid=1,active(ilevel)%ngrid
     igrid=active(ilevel)%igrid(jgrid)
     npart1=numbp(igrid)  ! Number of particles in the grid
     if(npart1>0)then
        ...
        ! Loop over particles in current grid
        do jpart=1,npart1
           ! Save next particle  <---- Very important !!!
           next_part=nextp(ipart)
           ...
           if(ip==nvector)then
              ! send gathered nvector particles to calculatio
              call move1(ind_grid,ind_part,ind_grid_part,ig,i
              ...
           end if
           ipart=next_part  ! Go to next particle
        end do
        ! End loop over particles
        ...      You, yesterday • Uncommitted changes
     end if
  end do
!$omp end do nowait
  ! End loop over grids
  if(ip>0)call move1(ind_grid,ind_part,ind_grid_part,ig,ip,il
!$omp end parallel
```