Performance Analysis Exercises with Vampir

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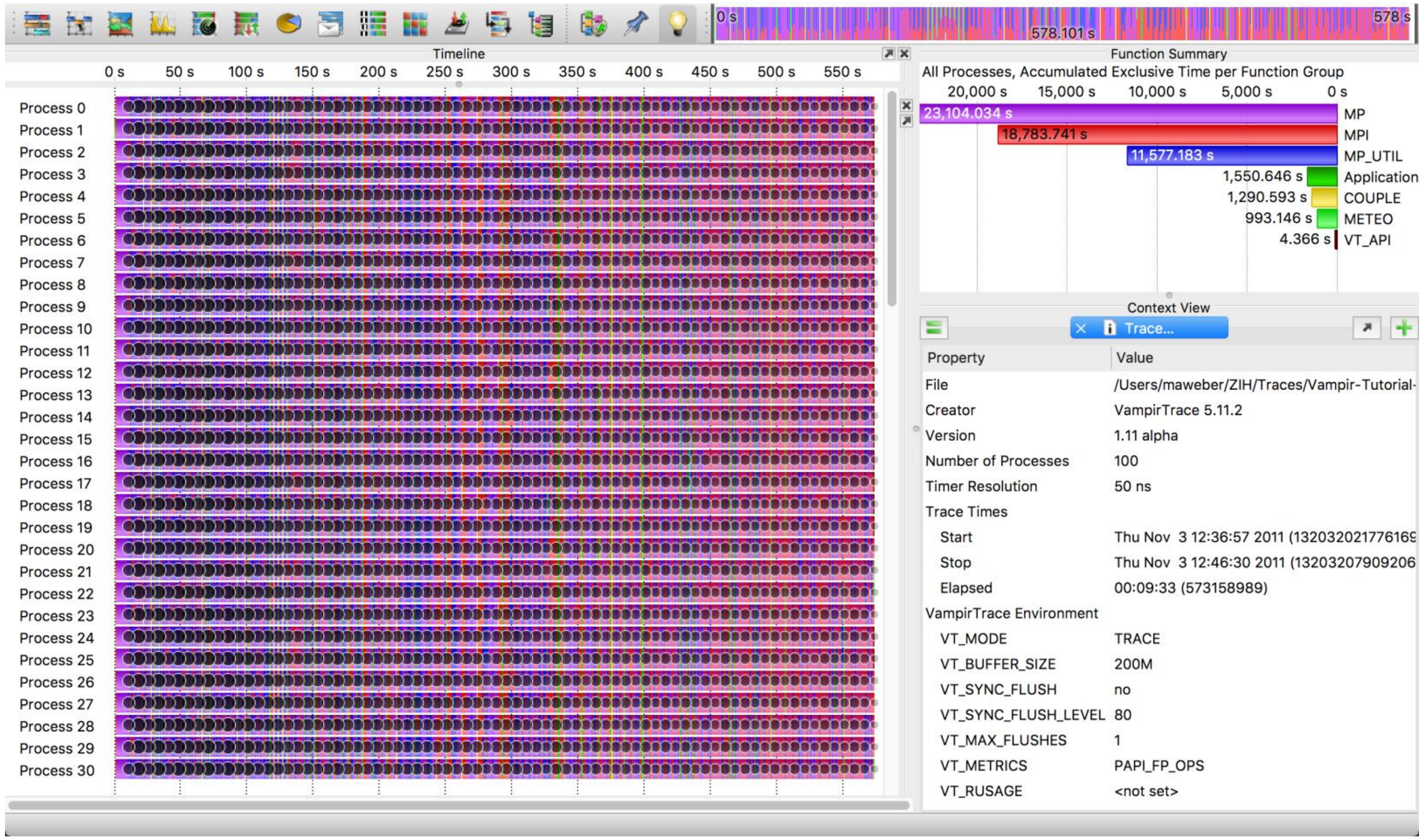
Exercise Trace Files

```
% ls $TW35/trace-examples/\
          Vampir-Tutorial-Analysis-Examples/

01-p100-cosmo-specs-orig
02-p100-cosmo-specs-fd4
03_wrf_deimos
04_sbmfd4_jugene
```

- Four trace files for exercising performance analysis with Vampir
- Traces show real application runs
- Do the traces contain performance problems?
- If yes, try to find their causes

01-p100-cosmo-specs-orig

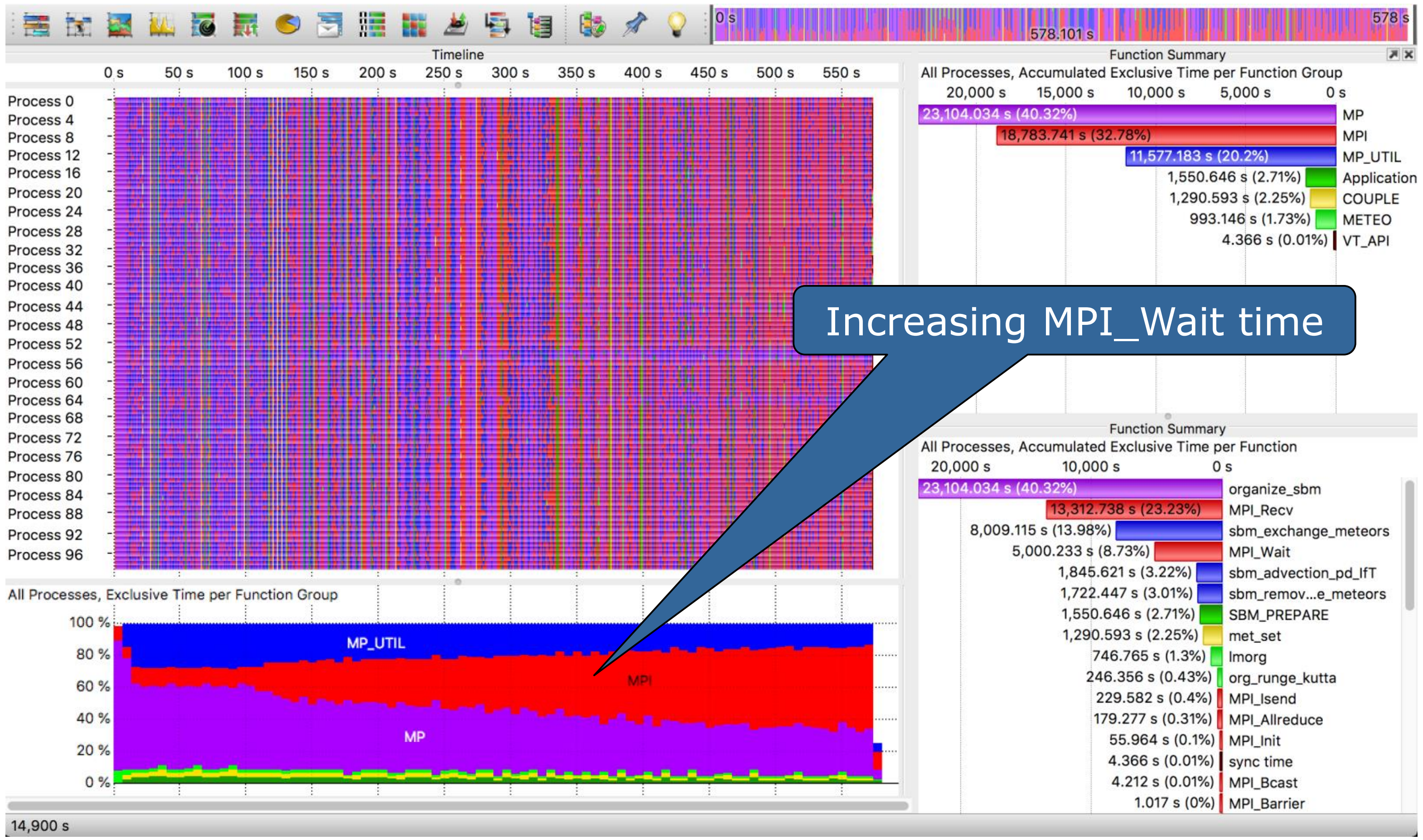


Function Group	Time
MP	23,104.034 s
MPI	18,783.741 s
MP_UTIL	11,577.183 s
Application	1,550.646 s
COUPLE	1,290.593 s
METEO	993.146 s
VT_API	4.366 s

Property	Value
File	/Users/maweber/ZIH/Traces/Vampir-Tutorial-
Creator	VampirTrace 5.11.2
Version	1.11 alpha
Number of Processes	100
Timer Resolution	50 ns
Trace Times	
Start	Thu Nov 3 12:36:57 2011 (132032021776169
Stop	Thu Nov 3 12:46:30 2011 (13203207909206
Elapsed	00:09:33 (573158989)
VampirTrace Environment	
VT_MODE	TRACE
VT_BUFFER_SIZE	200M
VT_SYNC_FLUSH	no
VT_SYNC_FLUSH_LEVEL	80
VT_MAX_FLUSHES	1
VT_METRICS	PAPI_FP_OPS
VT_RUSAGE	<not set>

- Weather forecast code COSMO-SPECS
- Run with 100 processes
- COSMO: weather model (METEO group)
- SPECS: microphysics for accurate cloud calculation (MP and MP_UTIL group)
- Coupling of both models done in COUPLE group

01-p100-cosmo-specs-orig



Function Summary

All Processes, Accumulated Exclusive Time per Function Group

Time	Function Group
23,104.034 s (40.32%)	MP
18,783.741 s (32.78%)	MPI
11,577.183 s (20.2%)	MP_UTIL
1,550.646 s (2.71%)	Application
1,290.593 s (2.25%)	COUPLE
993.146 s (1.73%)	METEO
4.366 s (0.01%)	VT_API

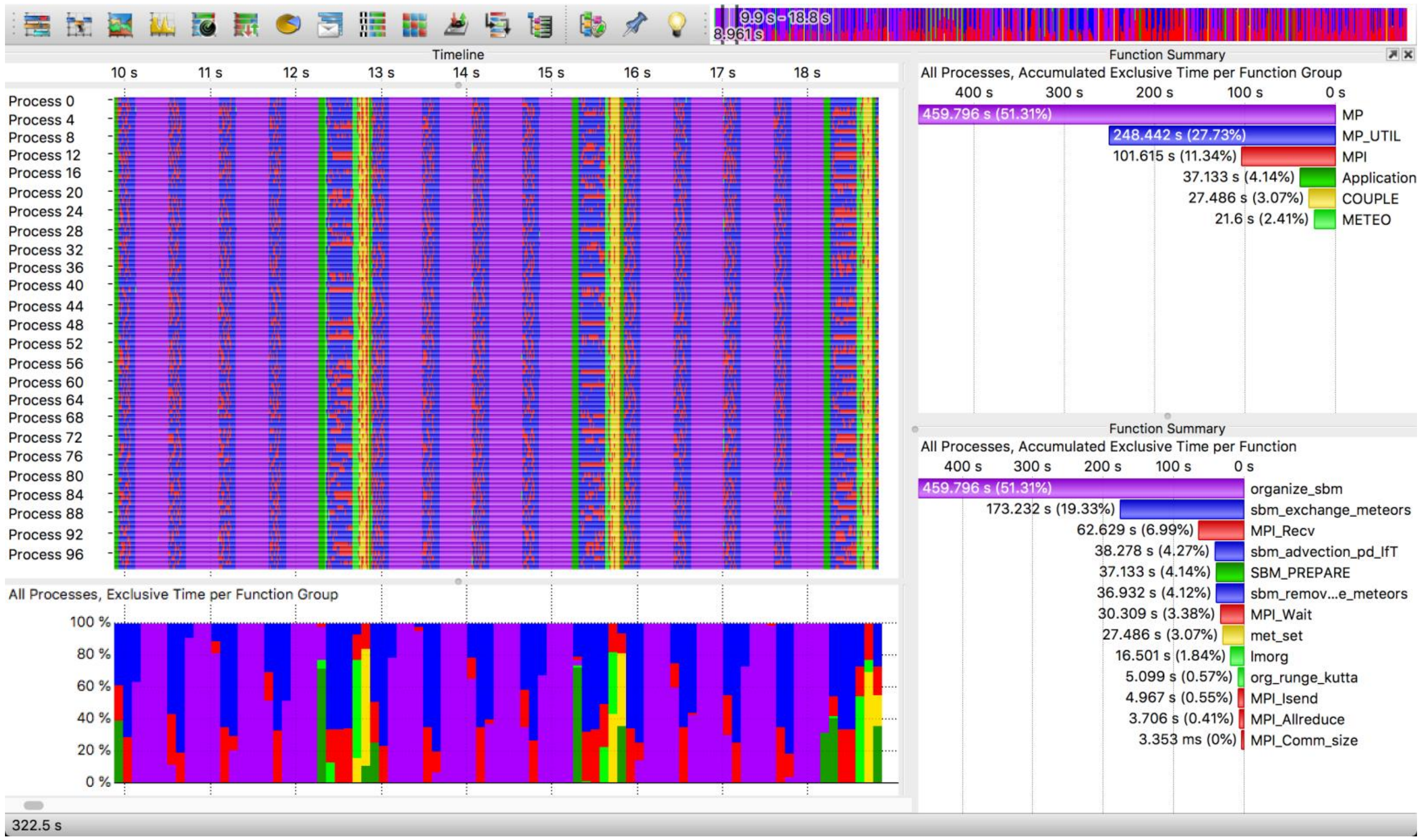
Function Summary

All Processes, Accumulated Exclusive Time per Function

Time	Function
23,104.034 s (40.32%)	organize_sbm
13,312.738 s (23.23%)	MPI_Recv
8,009.115 s (13.98%)	sbm_exchange_meteors
5,000.233 s (8.73%)	MPI_Wait
1,845.621 s (3.22%)	sbm_advection_pd_lfT
1,722.447 s (3.01%)	sbm_remov...e_meteors
1,550.646 s (2.71%)	SBM_PREPARE
1,290.593 s (2.25%)	met_set
746.765 s (1.3%)	lmorg
246.356 s (0.43%)	org_runge_kutta
229.582 s (0.4%)	MPI_Isend
179.277 s (0.31%)	MPI_Allreduce
55.964 s (0.1%)	MPI_Init
4.366 s (0.01%)	sync time
4.212 s (0.01%)	MPI_Bcast
1.017 s (0%)	MPI_Barrier

- Compared to METEO, MP and MP_UTIL are very compute intensive, however this is due to more complex calculations and no performance issue
- Problem: >32% of time spent in MPI
- MPI runtime share increases throughout the application run

01-p100-cosmo-specs-orig



Function Summary

All Processes, Accumulated Exclusive Time per Function Group

Time	Function Group
459.796 s (51.31%)	MP
248.442 s (27.73%)	MP_UTIL
101.615 s (11.34%)	MPI
37.133 s (4.14%)	Application
27.486 s (3.07%)	COUPLE
21.6 s (2.41%)	METEO

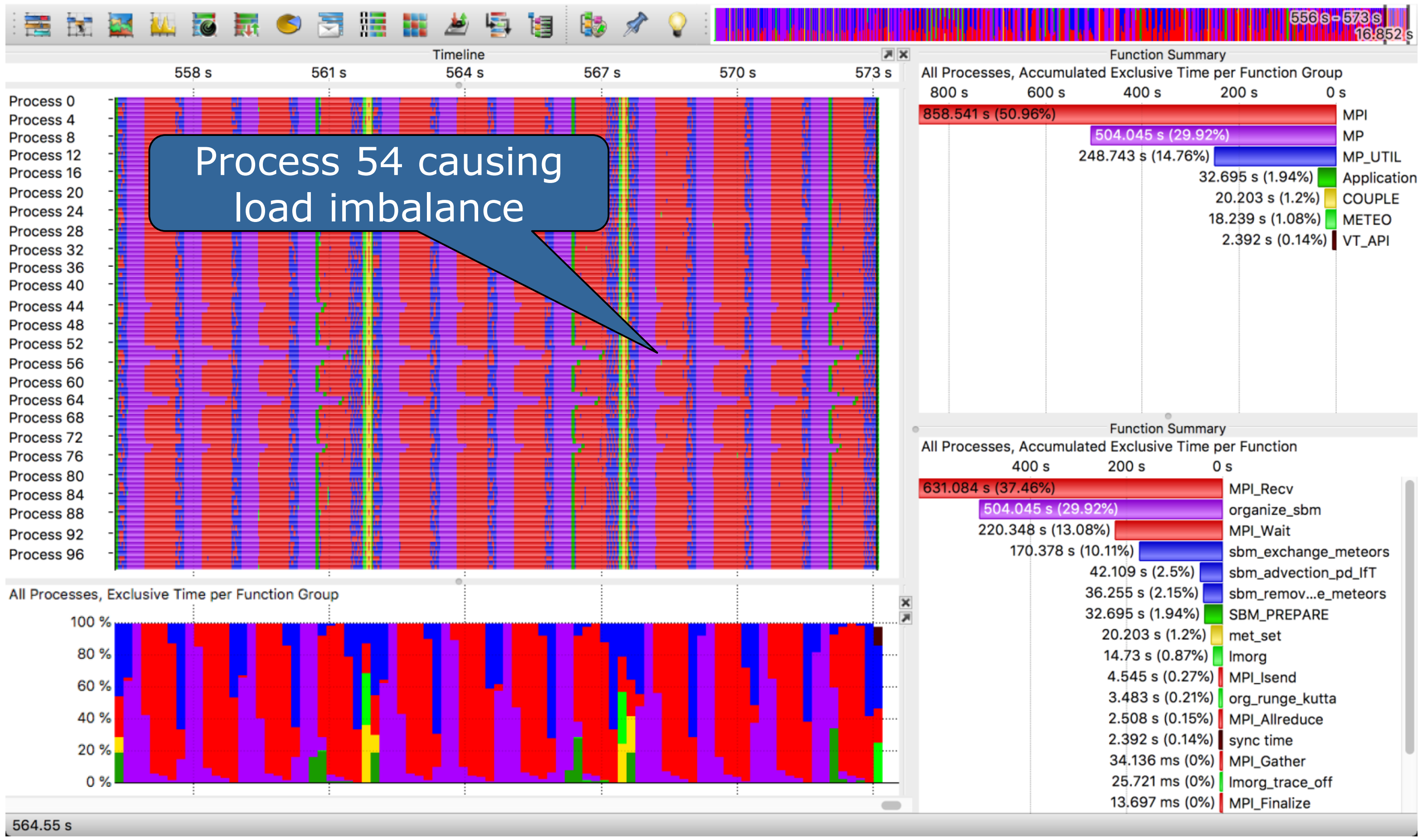
Function Summary

All Processes, Accumulated Exclusive Time per Function

Time	Function
459.796 s (51.31%)	organize_sbm
173.232 s (19.33%)	sbm_exchange_meteors
62.629 s (6.99%)	MPI_Recv
38.278 s (4.27%)	sbm_advection_pd_lfT
37.133 s (4.14%)	SBM_PREPARE
36.932 s (4.12%)	sbm_remov...e_meteors
30.309 s (3.38%)	MPI_Wait
27.486 s (3.07%)	met_set
16.501 s (1.84%)	lmorg
5.099 s (0.57%)	org_runge_kutta
4.967 s (0.55%)	MPI_Isend
3.706 s (0.41%)	MPI_Allreduce
3.353 ms (0%)	MPI_Comm_size

- Zoom into the first three iterations
- MP/MP_UTIL perform four sub-steps in one iteration
- Low MPI time share
- Everything is balanced and looks okay

01-p100-cosmo-specs-orig



Function Summary

All Processes, Accumulated Exclusive Time per Function Group

Time	Function Group
858.541 s (50.96%)	MPI
504.045 s (29.92%)	MP
248.743 s (14.76%)	MP_UTIL
32.695 s (1.94%)	Application
20.203 s (1.2%)	COUPLE
18.239 s (1.08%)	METEO
2.392 s (0.14%)	VT_API

Function Summary

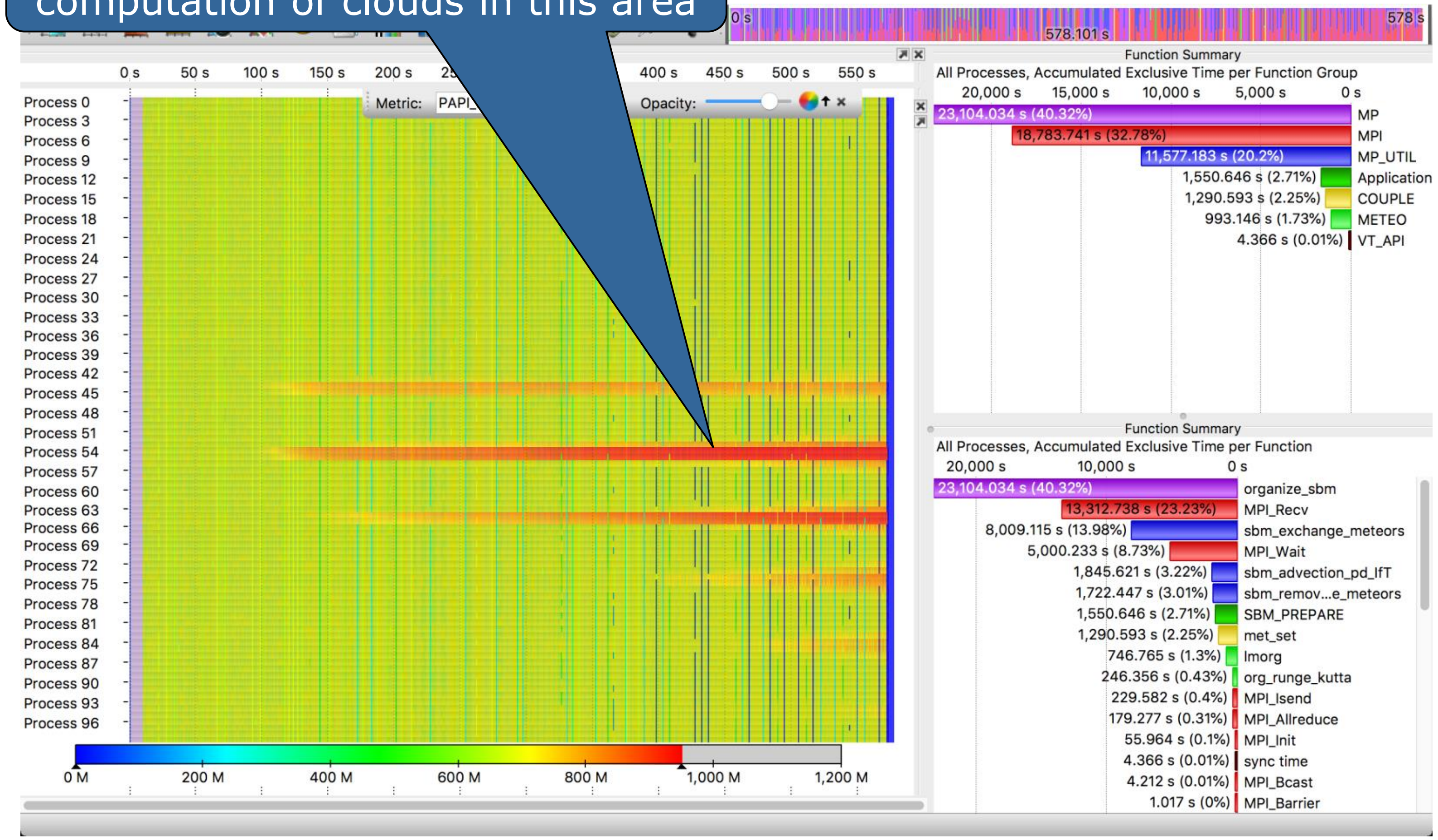
All Processes, Accumulated Exclusive Time per Function

Time	Function
631.084 s (37.46%)	MPI_Recv
504.045 s (29.92%)	organize_sbm
220.348 s (13.08%)	MPI_Wait
170.378 s (10.11%)	sbm_exchange_meteors
42.109 s (2.5%)	sbm_advection_pd_lfT
36.255 s (2.15%)	sbm_remov...e_meteors
32.695 s (1.94%)	SBM_PREPARE
20.203 s (1.2%)	met_set
14.73 s (0.87%)	lmorg
4.545 s (0.27%)	MPI_Isend
3.483 s (0.21%)	org_runge_kutta
2.508 s (0.15%)	MPI_Allreduce
2.392 s (0.14%)	sync time
34.136 ms (0%)	MPI_Gather
25.721 ms (0%)	lmorg_trace_off
13.697 ms (0%)	MPI_Finalize

- Zoom into the last three iterations
- Very high MPI time share (>50%)
- Large load imbalance caused by MP functions around **`Process 54`** and **`Process 64`**

01-p100-cosmo-specs-orig

High FLOPs rates due to computation of clouds in this area



Function Summary
All Processes, Accumulated Exclusive Time per Function Group

23,104.034 s (40.32%)	MP
18,783.741 s (32.78%)	MPI
11,577.183 s (20.2%)	MP_UTIL
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Function Summary
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746.765 s (1.3%)	lmorg
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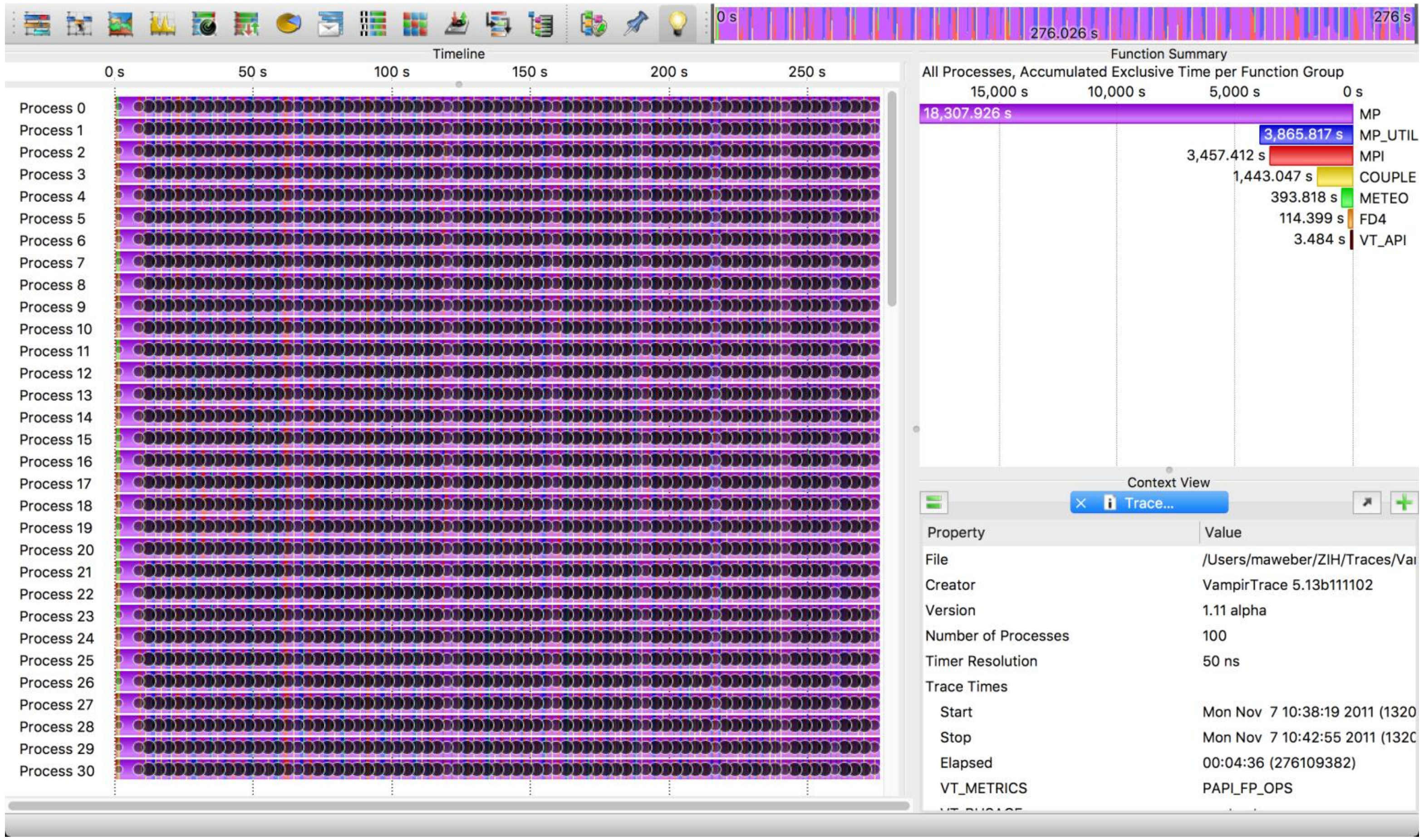
229.582 s (0.4%)	MPI_Isend
179.277 s (0.31%)	MPI_Allreduce
55.964 s (0.1%)	MPI_Init
4.366 s (0.01%)	sync time
4.212 s (0.01%)	MPI_Bcast
1.017 s (0%)	MPI_Barrier

- **`PAPI_FP_OPS`** counter showing higher FLOPs rates on processes causing the imbalance
- Reason for imbalance: Static grid used for distribution of processes. Depending on the weather, expensive cloud computations (MP group) may be only necessary on some processes

02-p100-cosmo-specs-fd4

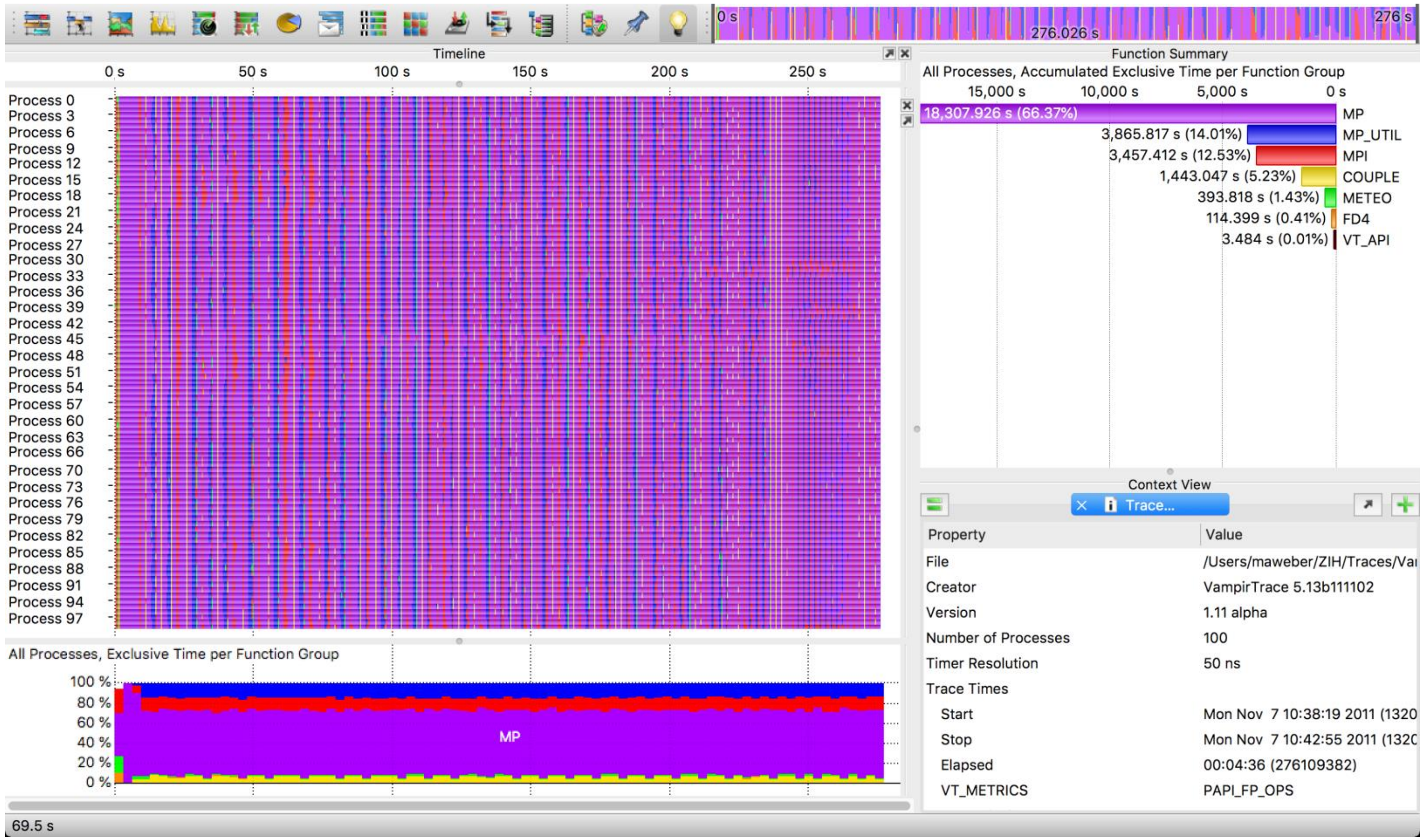


18,307.926 s	MP
3,865.817 s	MP_UTIL
3,457.412 s	MPI
1,443.047 s	COUPLE
393.818 s	METEO
114.399 s	FD4
3.484 s	VT_API

Property	Value
File	/Users/maweber/ZIH/Traces/Va
Creator	VampirTrace 5.13b111102
Version	1.11 alpha
Number of Processes	100
Timer Resolution	50 ns
Trace Times	
Start	Mon Nov 7 10:38:19 2011 (1320
Stop	Mon Nov 7 10:42:55 2011 (132
Elapsed	00:04:36 (276109382)
VT_METRICS	PAPI_FP_OPS

- Weather forecast code COSMO-SPECS
- Run with 100 processes
- COSMO: weather model (METEO group)
- SPECS: microphysics for accurate cloud calculation (MP and MP_UTIL group)
- Coupling of both models done in COUPLE group
- Dynamic load balancing (FD4 group)

02-p100-cosmo-specs-fd4

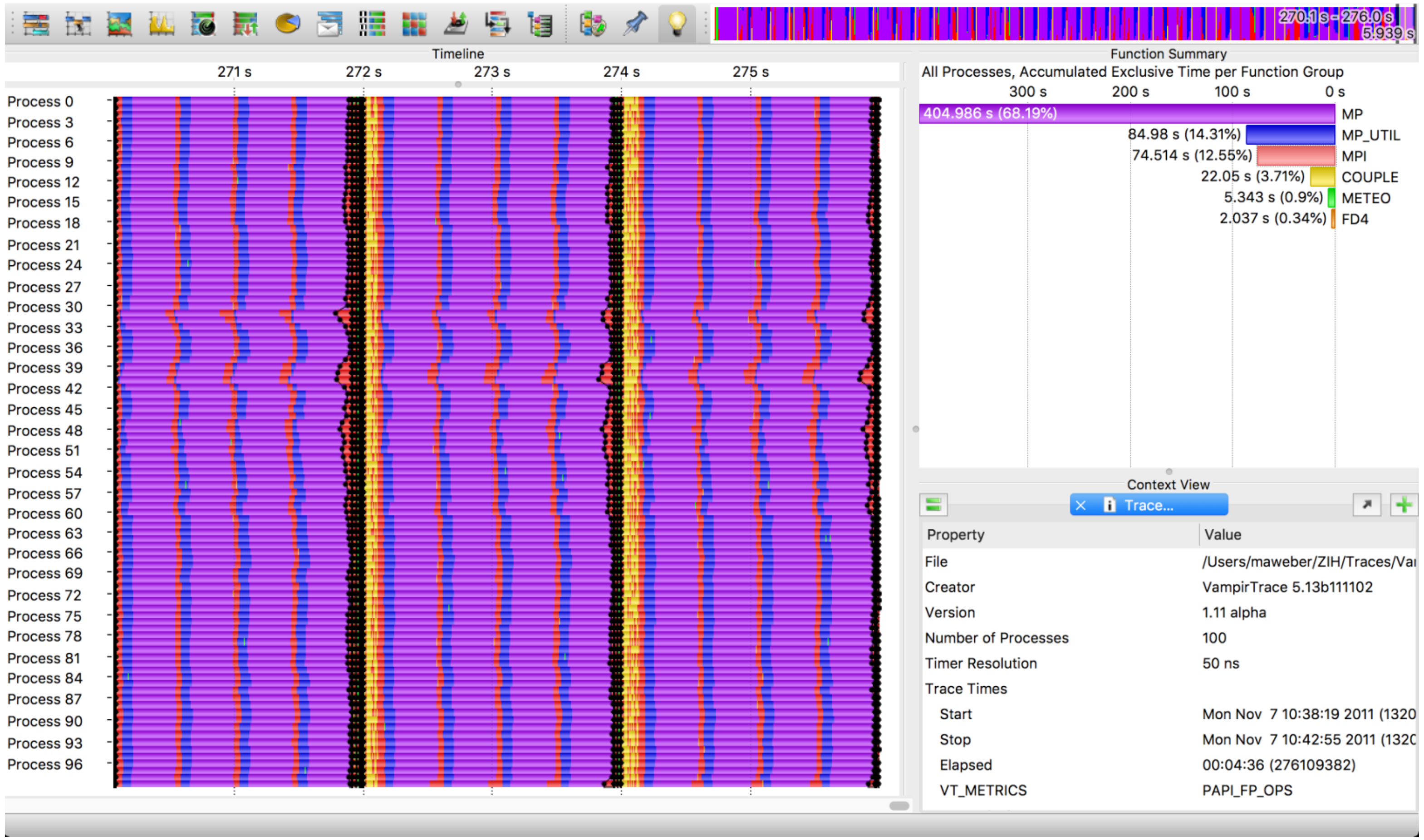


18,307.926 s (66.37%)	MP
3,865.817 s (14.01%)	MP_UTIL
3,457.412 s (12.53%)	MPI
1,443.047 s (5.23%)	COUPLE
393.818 s (1.43%)	METEO
114.399 s (0.41%)	FD4
3.484 s (0.01%)	VT_API

Property	Value
File	/Users/maweber/ZIH/Traces/Va
Creator	VampirTrace 5.13b111102
Version	1.11 alpha
Number of Processes	100
Timer Resolution	50 ns
Trace Times	
Start	Mon Nov 7 10:38:19 2011 (1320
Stop	Mon Nov 7 10:42:55 2011 (1320
Elapsed	00:04:36 (276109382)
VT_METRICS	PAPI_FP_OPS

- Dynamic load balancing mitigates the balance problems of the original COSMO-SPECS version
- MPI time share is reduced to <13%
- MPI time share stays constant throughout the application runtime
- Runtime reduced by factor of 2.1, from initially 578s to 276s

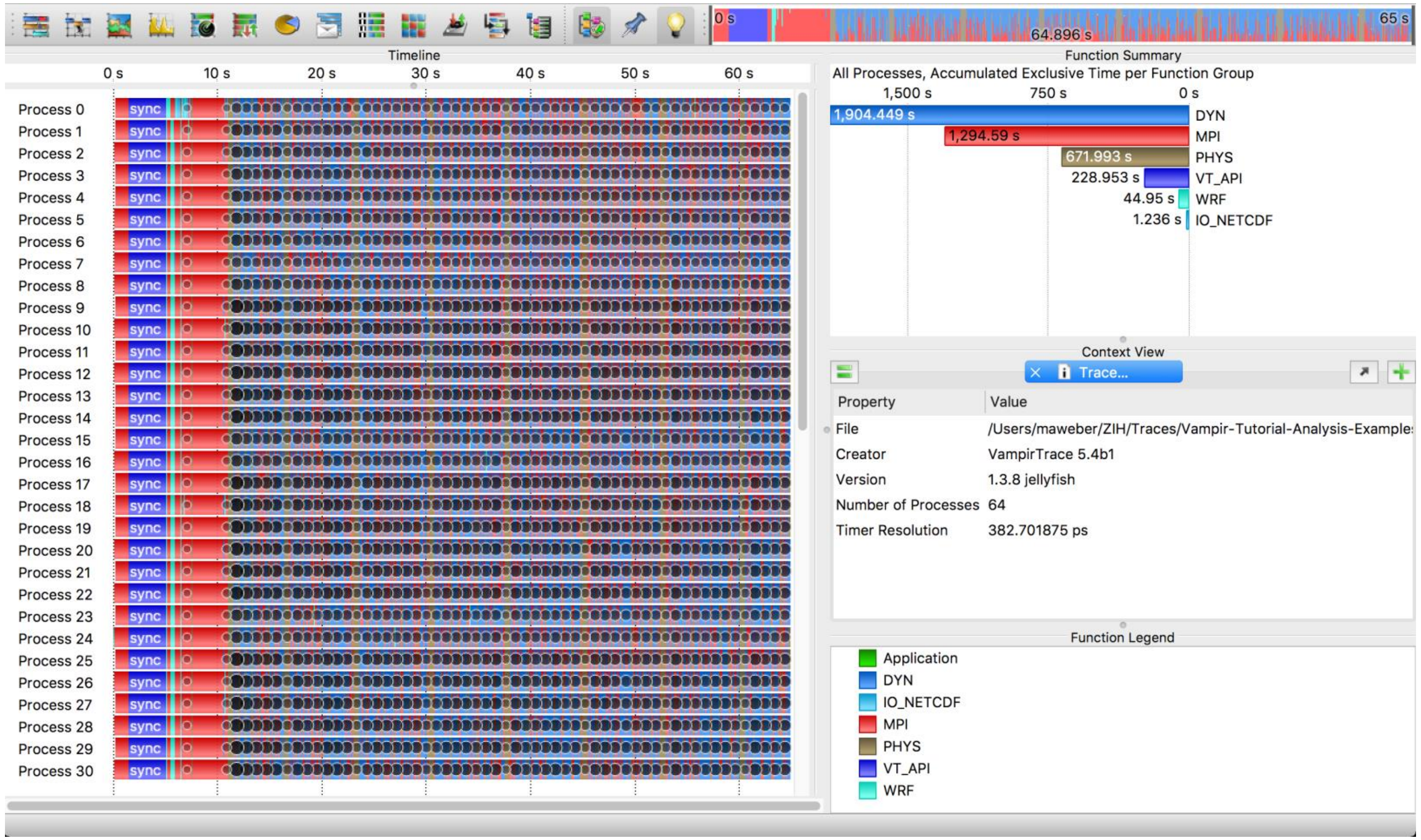
02-p100-cosmo-specs-fd4



Property	Value
File	/Users/maweber/ZIH/Traces/Va
Creator	VampirTrace 5.13b111102
Version	1.11 alpha
Number of Processes	100
Timer Resolution	50 ns
Trace Times	
Start	Mon Nov 7 10:38:19 2011 (1320
Stop	Mon Nov 7 10:42:55 2011 (132
Elapsed	00:04:36 (276109382)
VT_METRICS	PAPI_FP_OPS

- Zoom into last three iterations
- FD4 balances MP load (precipitation processes in clouds) across all available processes

03_wrf_deimos

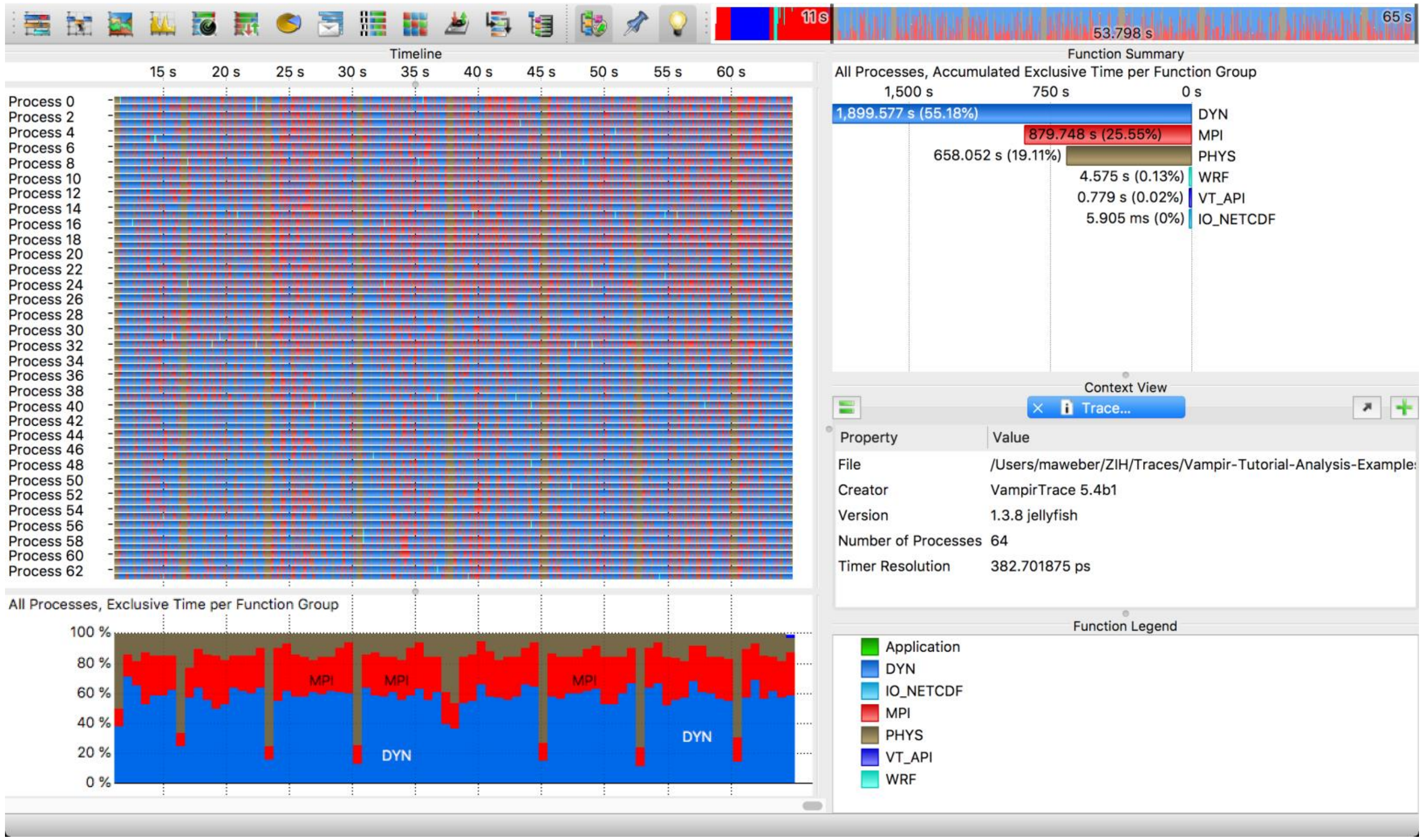


Property	Value
File	/Users/maweber/ZIH/Traces/Vampir-Tutorial-Analysis-Example
Creator	VampirTrace 5.4b1
Version	1.3.8 jellyfish
Number of Processes	64
Timer Resolution	382.701875 ps

Function Legend:
- 🟩 Application
- 🟦 DYN
- 🟦 IO_NETCDF
- 🟥 MPI
- 🟫 PHYS
- 🟦 VT_API
- 🟦 WRF

- Weather forecast code WRF
- Run with 64 processes
- *Dynamical core*: e.g., density, temperature, pressure, and winds in the atmosphere (DYN group)
- *Physical parameterization: e.g.,* clouds, rain, and radiation (PHYS group)

03_wrf_deimos



All Processes, Accumulated Exclusive Time per Function Group

1,500 s | 750 s | 0 s

1,899.577 s (55.18%)	DYN
879.748 s (25.55%)	MPI
658.052 s (19.11%)	PHYS
4.575 s (0.13%)	WRF
0.779 s (0.02%)	VT_API
5.905 ms (0%)	IO_NETCDF

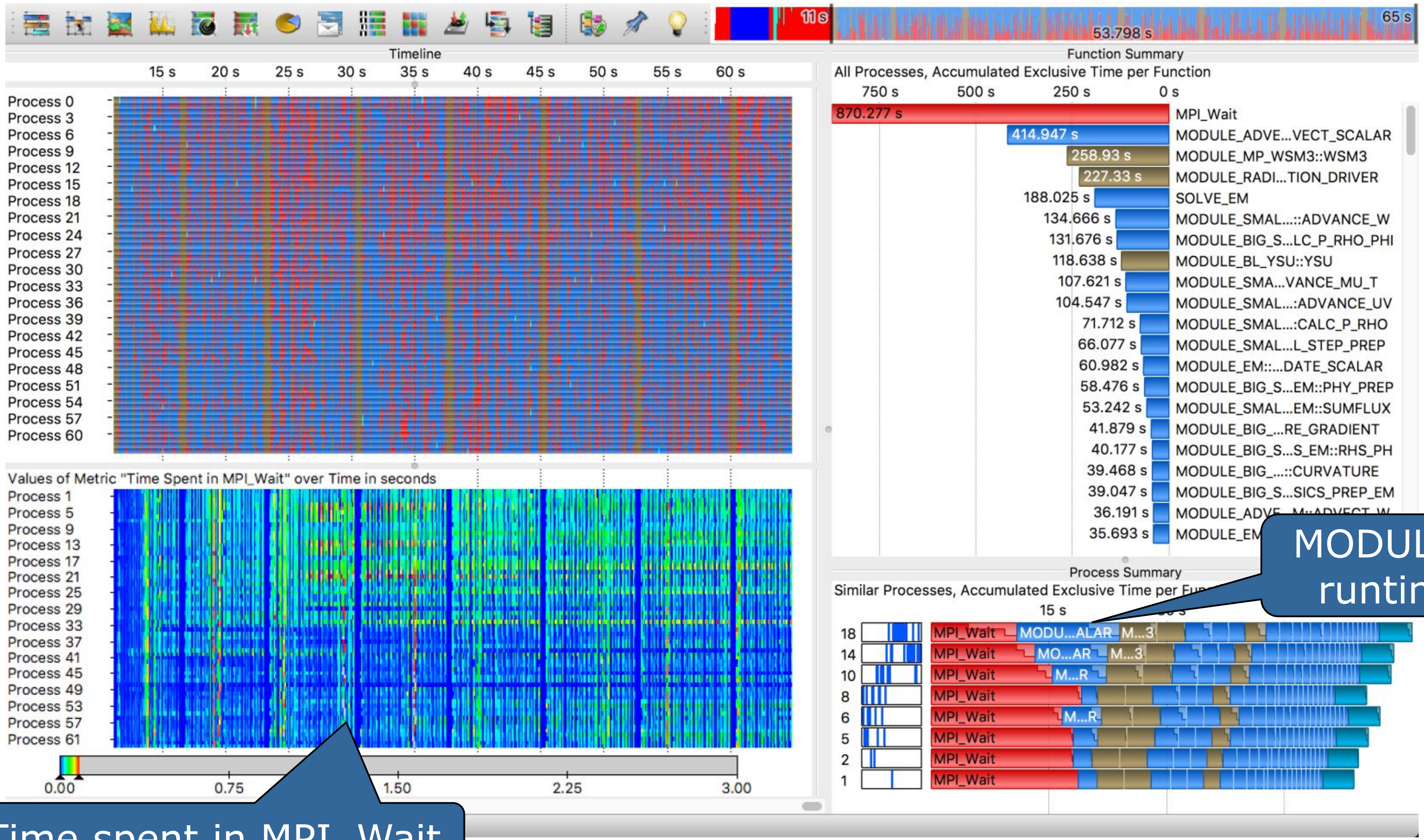
Property	Value
File	/Users/maweber/ZIH/Traces/Vampir-Tutorial-Analysis-Example:
Creator	VampirTrace 5.4b1
Version	1.3.8 jellyfish
Number of Processes	64
Timer Resolution	382.701875 ps

- 🟩 Application
- 🟦 DYN
- 🟦 IO_NETCDF
- 🟥 MPI
- 🟫 PHYS
- 🟦 VT_API
- 🟦 WRF

- Problem: 25% MPI run time fraction during the iterations of the model
- Behaviour is constant throughout all iterations

- Question: Which user function causes the problem? And why?

03_wrf_deimos



Function Summary

All Processes, Accumulated Exclusive Time per Function

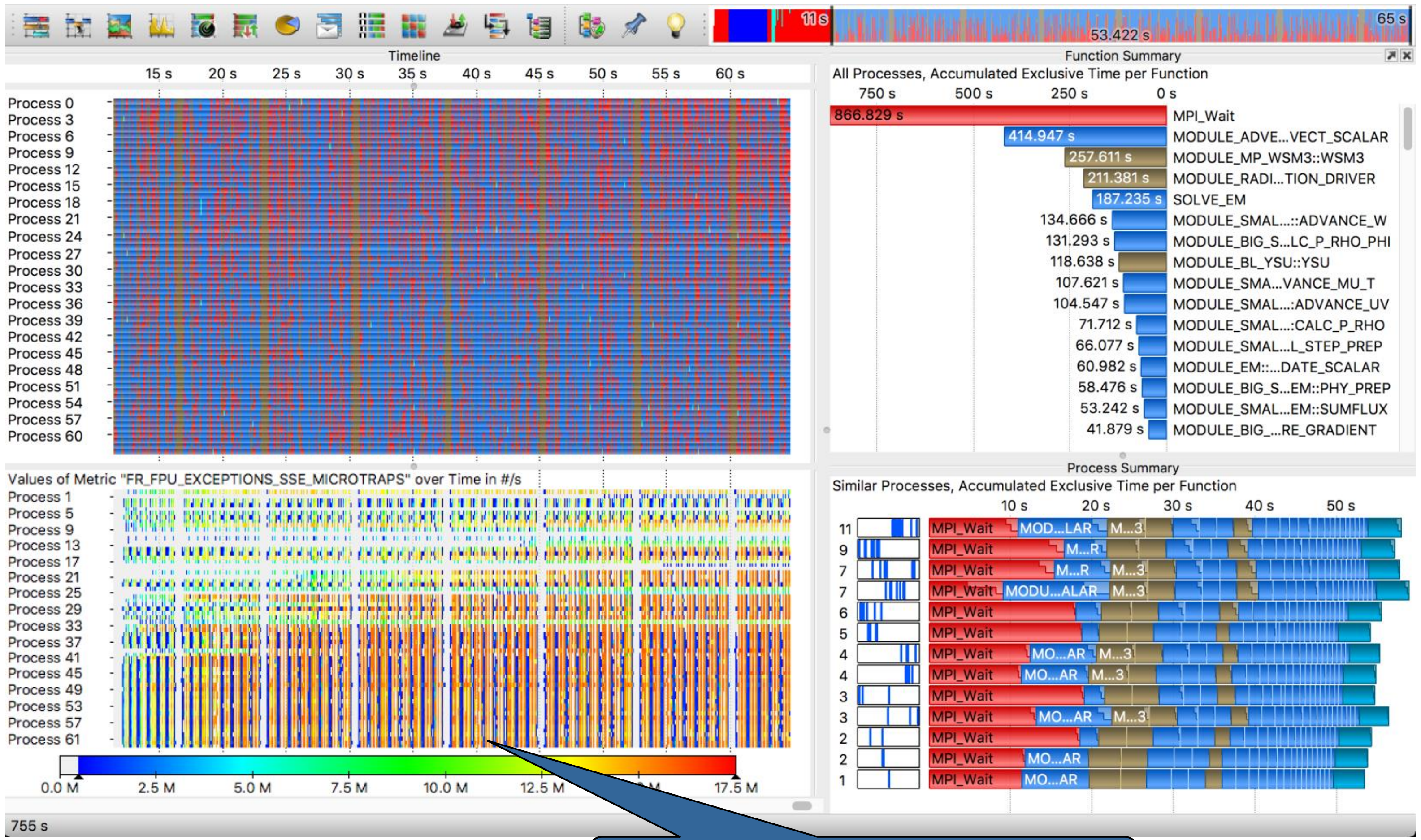
```
750 s      500 s      250 s      0 s
870.277 s   MPI_Wait
414.947 s   MODULE_ADVE...VECT_SCALAR
258.93 s    MODULE_MP_WSM3::WSM3
227.33 s    MODULE_RADI...TION_DRIVER
188.025 s   SOLVE_EM
134.666 s   MODULE_SMAL...::ADVANCE_W
131.676 s   MODULE_BIG_S...LC_P_RHO_PHI
118.638 s   MODULE_BL_YSU::YSU
107.621 s   MODULE_SMA...VANCE_MU_T
104.547 s   MODULE_SMAL...:ADVANCE_UV
71.712 s    MODULE_SMAL...:CALC_P_RHO
66.077 s    MODULE_SMAL...L_STEP_PREP
60.982 s    MODULE_EM::...DATE_SCALAR
58.476 s    MODULE_BIG_S...EM::PHY_PREP
53.242 s    MODULE_SMAL...EM::SUMFLUX
41.879 s    MODULE_BIG_...RE_GRADIENT
40.177 s    MODULE_BIG_S...S_EM::RHS_PH
39.468 s    MODULE_BIG_...:CURVATURE
39.047 s    MODULE_BIG_S...SICS_PREP_EM
36.191 s    MODULE_ADVE...M::ADVECT_W
35.693 s    MODULE_EM
```

MODULE_ADVECT_EM::ADVECT_SCALAR runtime increases in bottom processes

Time spent in MPI_Wait

- Most time is spent in **`MPI_Wait`**
- Top processes spent more time in **`MPI_Wait`** than bottom processes
- Load imbalance in DYN group

03_wrf_deimos



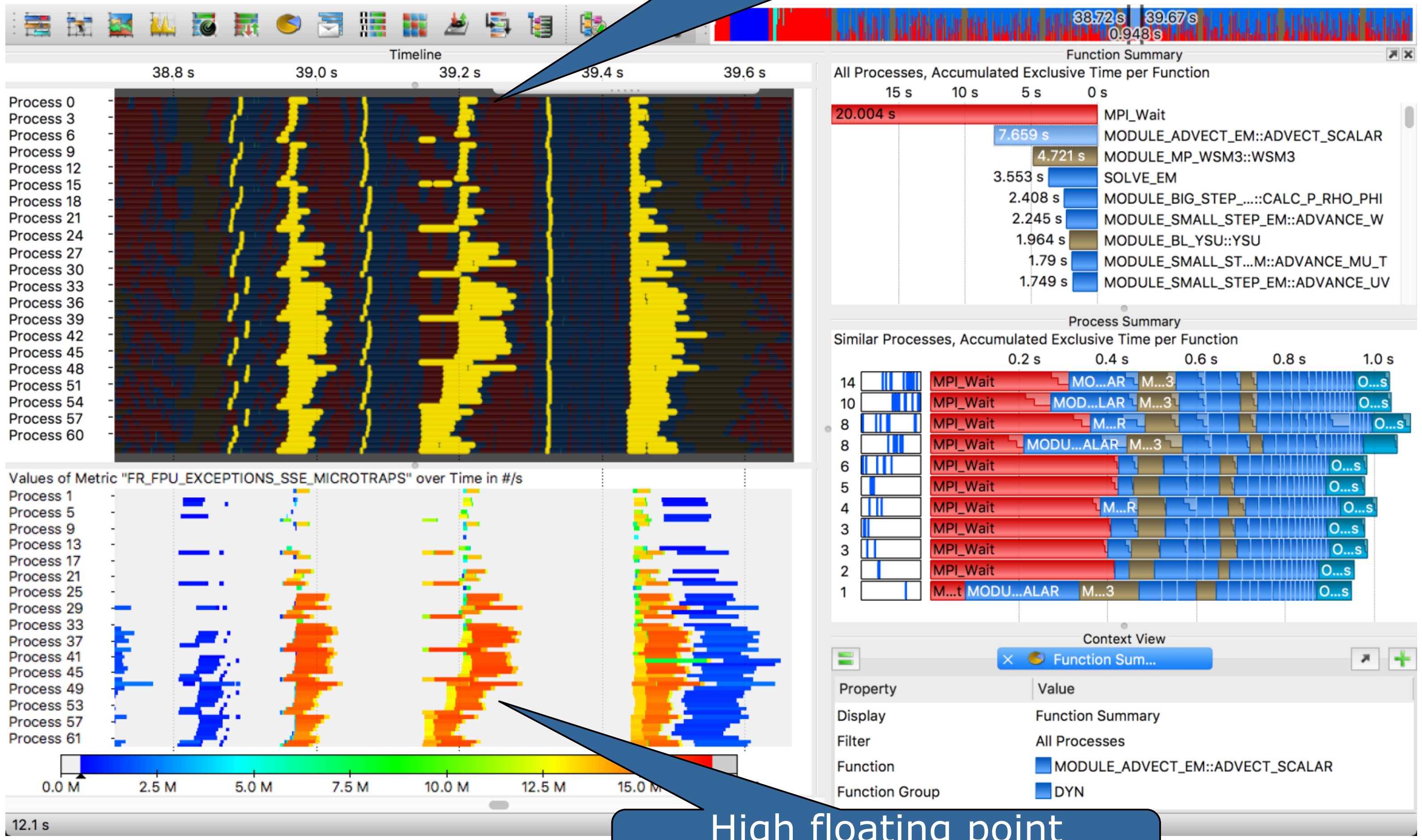
866.829 s	MPI_Wait
414.947 s	MODULE_ADVE...VECT_SCALAR
257.611 s	MODULE_MP_WSM3::WSM3
211.381 s	MODULE_RADI...TION_DRIVER
187.235 s	SOLVE_EM
134.666 s	MODULE_SMAL...::ADVANCE_W
131.293 s	MODULE_BIG_S...LC_P_RHO_PHI
118.638 s	MODULE_BL_YSU::YSU
107.621 s	MODULE_SMA...VANCE_MU_T
104.547 s	MODULE_SMAL...:ADVANCE_UV
71.712 s	MODULE_SMAL...:CALC_P_RHO
66.077 s	MODULE_SMAL...L_STEP_PREP
60.982 s	MODULE_EM::...DATE_SCALAR
58.476 s	MODULE_BIG_S...EM::PHY_PREP
53.242 s	MODULE_SMAL...EM::SUMFLUX
41.879 s	MODULE_BIG_...RE_GRADIENT

Floating point exceptions

- Load imbalance is caused by floating point (FP) exceptions in WRF
- Counter **FR_FPU_EXCEPTIONS_ SSE_MICROTRAPS** shows FP exceptions

03_wrf_deimos

MODULE_ADVECT_EM::ADVECT_SCALAR occurrences shown in yellow



Function Summary

All Processes, Accumulated Exclusive Time per Function

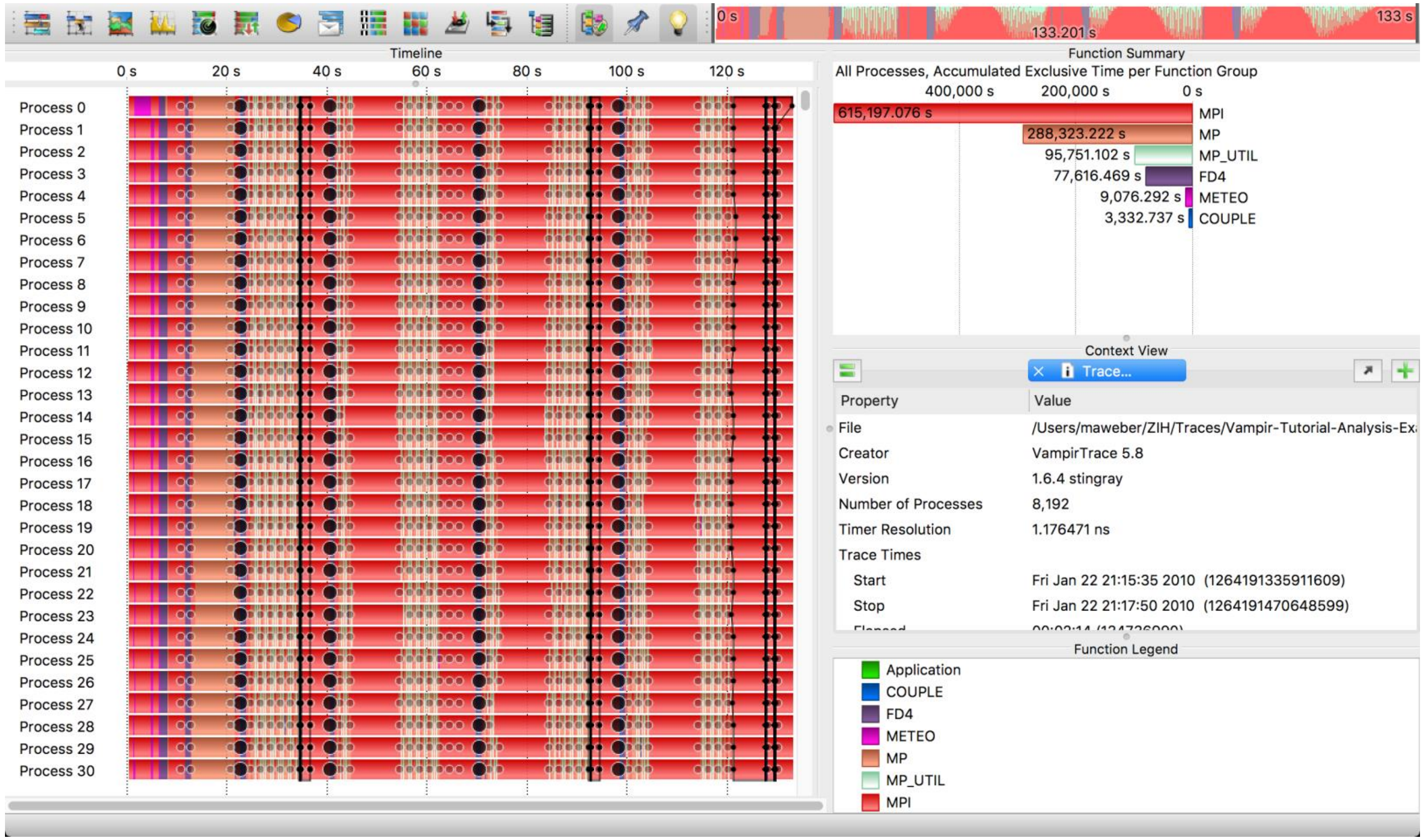
Time	Function
20.004 s	MPI_Wait
7.659 s	MODULE_ADVECT_EM::ADVECT_SCALAR
4.721 s	MODULE_MP_WSM3::WSM3
3.553 s	SOLVE_EM
2.408 s	MODULE_BIG_STEP_...::CALC_P_RHO_PHI
2.245 s	MODULE_SMALL_STEP_EM::ADVANCE_W
1.964 s	MODULE_BL_YSU::YSU
1.79 s	MODULE_SMALL_ST...M::ADVANCE_MU_T
1.749 s	MODULE_SMALL_STEP_EM::ADVANCE_UV

Property	Value
Display	Function Summary
Filter	All Processes
Function	MODULE_ADVECT_EM::ADVECT_SCALAR
Function Group	DYN

High floating point exceptions

- Zoom into one iteration
- Function invocations of **`MODULE_ADVECT_EM::ADVECT_SCALAR`** (shown in yellow) match high floating point exception occurrences indicated by the counter at the bottom

04_sbmfd4_jugene



Function Summary

All Processes, Accumulated Exclusive Time per Function Group

Time	Function Group
615,197.076 s	MPI
288,323.222 s	MP
95,751.102 s	MP_UTIL
77,616.469 s	FD4
9,076.292 s	METEO
3,332.737 s	COUPLE

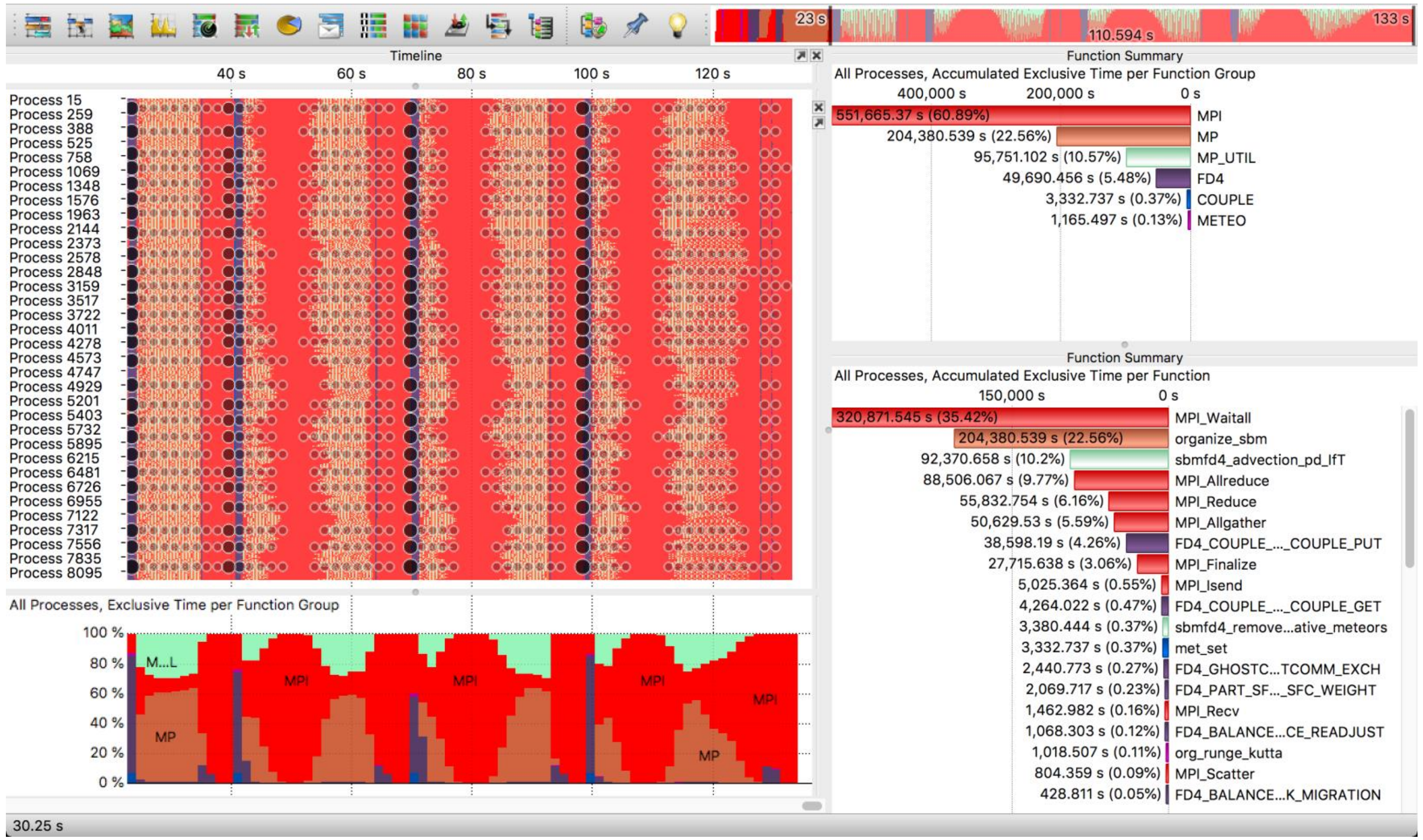
Property	Value
File	/Users/maweber/ZIH/Traces/Vampir-Tutorial-Analysis-Ex
Creator	VampirTrace 5.8
Version	1.6.4 stingray
Number of Processes	8,192
Timer Resolution	1.176471 ns
Trace Times	
Start	Fri Jan 22 21:15:35 2010 (1264191335911609)
Stop	Fri Jan 22 21:17:50 2010 (1264191470648599)

Function Legend

- 🟩 Application
- 🟦 COUPLE
- 🟪 FD4
- 🟪 METEO
- 🟧 MP
- 🟩 MP_UTIL
- 🟥 MPI

- Weather forecast code COSMO-SPECS
- Run with 8192 processes
- COSMO: weather model (METEO group)
- SPECS: microphysics for accurate cloud calculation (MP and MP_UTIL group)
- Coupling of both models done in COUPLE group
- Dynamic load balancing (FD4 group)

04_sbmfd4_jugene



Function Summary

All Processes, Accumulated Exclusive Time per Function Group

```
400,000 s        200,000 s        0 s
551,665.37 s (60.89%)    MPI
204,380.539 s (22.56%)   MP
95,751.102 s (10.57%)    MP_UTIL
49,690.456 s (5.48%)     FD4
3,332.737 s (0.37%)      COUPLE
1,165.497 s (0.13%)      METEO
```

Function Summary

All Processes, Accumulated Exclusive Time per Function

```
150,000 s        0 s
320,871.545 s (35.42%)   MPI_Waitall
204,380.539 s (22.56%)   organize_sbm
92,370.658 s (10.2%)     sbmfd4_advection_pd_lfT
88,506.067 s (9.77%)     MPI_Allreduce
55,832.754 s (6.16%)     MPI_Reduce
50,629.53 s (5.59%)      MPI_Allgather
38,598.19 s (4.26%)      FD4_COUPLE_..._COUPLE_PUT
27,715.638 s (3.06%)     MPI_Finalize
5,025.364 s (0.55%)      MPI_Isend
4,264.022 s (0.47%)      FD4_COUPLE_..._COUPLE_GET
3,380.444 s (0.37%)      sbmfd4_remove...ative_meteors
3,332.737 s (0.37%)      met_set
2,440.773 s (0.27%)      FD4_GHOSTC...TCOMM_EXCH
2,069.717 s (0.23%)      FD4_PART_SF..._SFC_WEIGHT
1,462.982 s (0.16%)      MPI_Recv
1,068.303 s (0.12%)      FD4_BALANCE...CE_READJUST
1,018.507 s (0.11%)      org_runge_kutta
804.359 s (0.09%)        MPI_Scatter
428.811 s (0.05%)        FD4_BALANCE...K_MIGRATION
```

- Problem: Large MPI runtime fraction (>60%) during iterations
- Especially in **`MPI_Waitall`** and **`MPI_Allreduce`**
- Behaviour is constant throughout all iterations

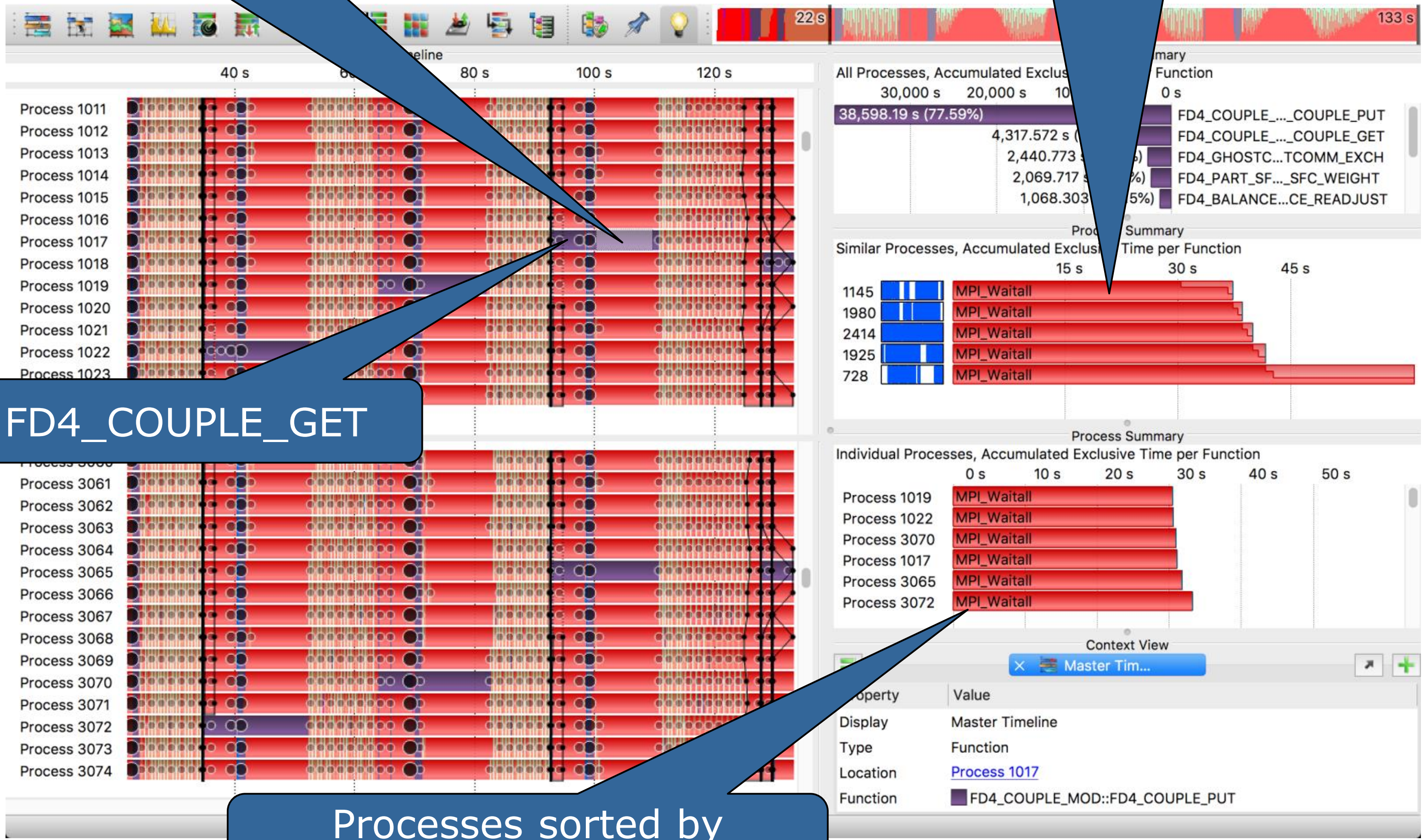
04_sbmfd4_jugene

High MPI_Allreduce variance between processes

FD4_COUPLE_PUT

FD4_COUPLE_GET

Processes sorted by MPI_Allreduce timeshare



All Processes, Accumulated Exclus... Function

```
30,000 s   20,000 s   10...   0 s
38,598.19 s (77.59%)   FD4_COUPLE_..._COUPLE_PUT
4,317.572 s (          FD4_COUPLE_..._COUPLE_GET
2,440.773 ...%)        FD4_GHOSTC...TCOMM_EXCH
2,069.717 ...%)        FD4_PART_SF..._SFC_WEIGHT
1,068.303 ...5%)       FD4_BALANCE...CE_READJUST
```

Similar Processes, Accumulated Exclus... Time per Function

```
      15 s     30 s     45 s
1145  MPI_Waitall
1980  MPI_Waitall
2414  MPI_Waitall
1925  MPI_Waitall
728   MPI_Waitall
```

Process Summary

Individual Processes, Accumulated Exclusive Time per Function

```
              0 s   10 s   20 s   30 s   40 s   50 s
Process 1019  MPI_Waitall
Process 1022  MPI_Waitall
Process 3070  MPI_Waitall
Process 1017  MPI_Waitall
Process 3065  MPI_Waitall
Process 3072  MPI_Waitall
```

Context View — Master Tim...

Property	Value
Display	Master Timeline
Type	Function
Location	Process 1017
Function	FD4_COUPLE_MOD::FD4_COUPLE_PUT

- Large runtime variation in **`MPI_Allreduce`**
- Sorted profile reveals processes with small **`MPI_Waitall`** timeshare
- Reason: Load imbalance in **`FD4_COUPLE_PUT`** and **`FD4_COUPLE_GET`**
- Most processes need to wait at **`MPI_Allreduce`** and **`MPI_Waitall`** (asynchronously)

Summary

- Performance flaws can lead to significant runtime overheads
- Use resources efficiently
- Analyze your code
- Performance analysis tools are there to help you

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