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Tracking Performance of a Big Application from Dev to Ops

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Classification: TLP: green

Objectives of Performance Tracking ?

- Evaluate/measure resources needed by new functionalities
  - To verify the estimated resource budget (CPU, memory)
  - To ensure the new release will cope with the current or expected new load
- Avoid performance degradation during development e.g.
  - Team of 20 developers working 6 months on a new release
  - A developer integrates X changes per month
    - If one change on X degrades the performance by 1% :
      - Optimistic: new release is 2.2 times slower : 100% + (6 months * 20 persons * 1%)
      - Pessimistic: new release is 3.3 times slower : 100% * 1.01 ^ (6 * 20)
  - => do not wait the end of the release to check performance
  - => daily track the performance during development

Developement Performance Tracking Objective:

Reliably Detect Performance Difference of <1%

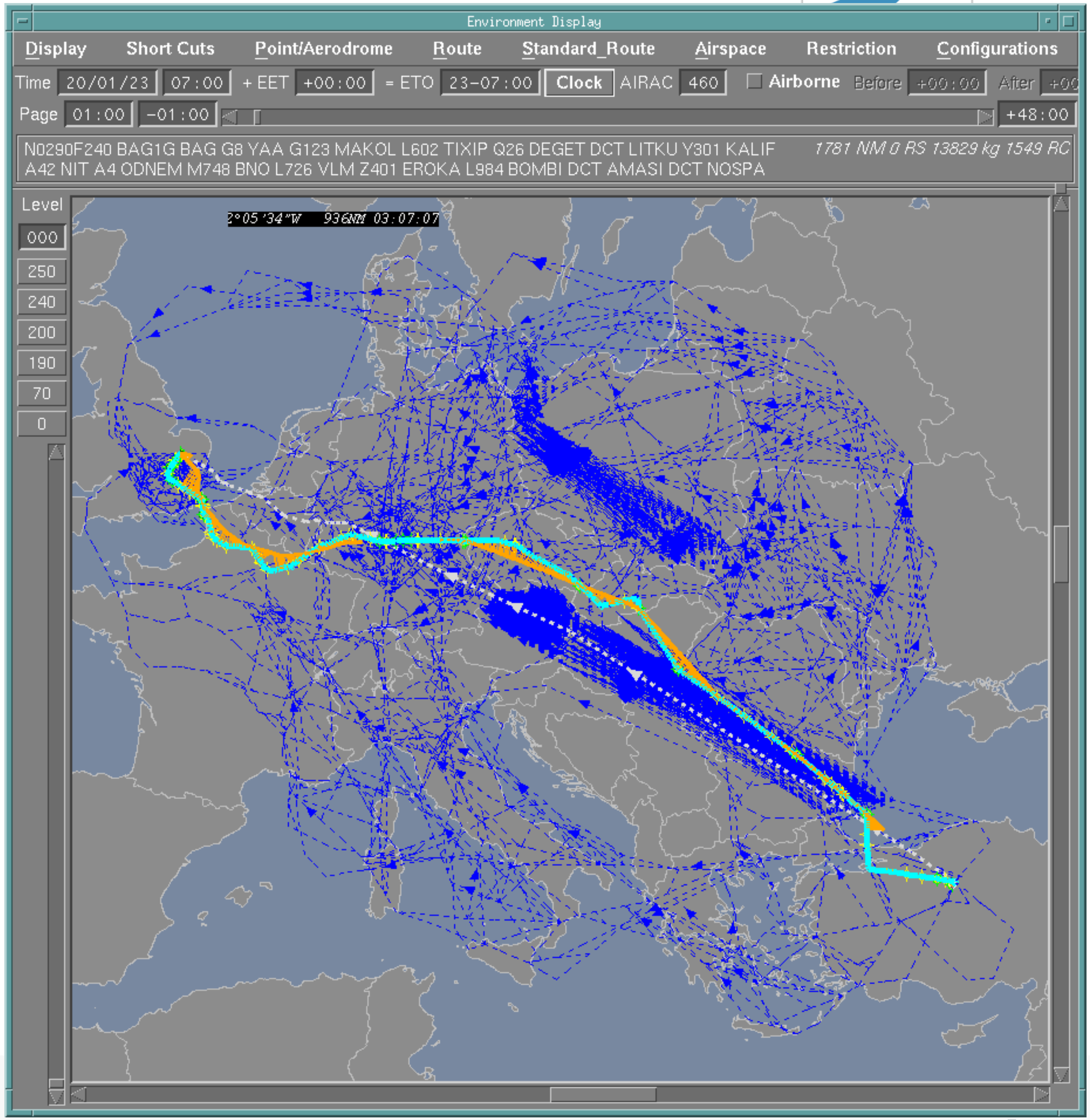
Eurocontrol

- European Organisation for the Safety of Air Navigation
  - International organisation with 41 member states
  - Several sites/directorates/…
  - Activities: operations, concept development, European-wide project implementation, …
  - More info: www.eurocontrol.int
- Directorate Network Management
  - Develop and operate the Air Traffic Management network
  - Operation phases: strategical, pre-tactical, tactical, post-operation
  - Airspace/route data, Flight Plan Processing, Flow/Capacity Management, …
- NM has 2 core mission/safety critical systems:
  - IFPS : flight plan processing
  - ETFMS : Flow and Capacity Management

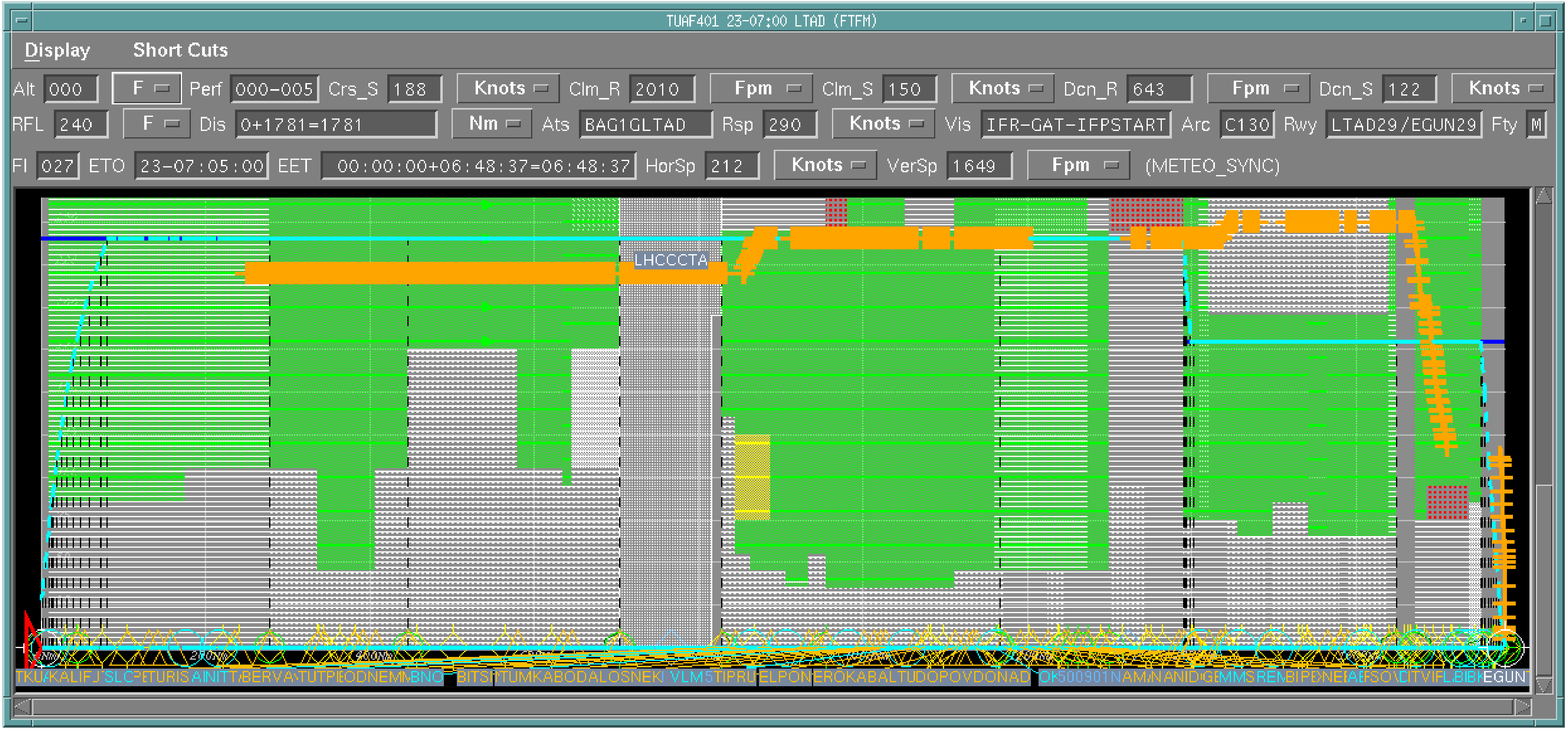
IFPS and ETFMS

- Big applications : IFPS+ETFMS is 2.3 million lines of Ada code
- ETFMS Peak day:
  - > 37_000 flights
  - > 11.6 million radar position, planned to increase to 18 millions Q1 2021
  - > 3.3 million queries/day
  - > 3.5 million messages published (e.g. via AMQP, AFTN, …)
- ETFMS hardware:
  - On-line processing done on a linux server, 28 cores
  - Some workstations running a GUI also do some batch/background jobs
- Many heavy queries, complex algorithms , called a lot, e.g.
  - Count/flight list e.g. “flights traversing France between 10:00 and 20:00”
  - Lateral route prediction or route proposal/optimisation
  - Vertical trajectory calculation
  - …

Horizontal Trajectory



Vertical Trajectory



Performance needs and ETFMS scalability

- Horizontal scalability : OPS configuration
  - 10 high priority server processes handle the critical input (e.g. flight plan, radar position, external user queries, …)
  - 9 lower priority server processes (each 4 threads) handle lower priority queries e.g. “find a better route for flight AFR123”
  - Up to 20 processes running on workstations, executing batch jobs or background queries e.g. “every hour, search a better route for all flights of aircraft operator BAW departing in the next 3 hours”
- Vertical scalability, needed e.g. for “simulation”:
  - Simulate/evaluate heavy actions on the whole of European data such as: “close an airspace/country and spread/reroute/delay the traffic”
  - Starting a simulation implies e.g. to
    - clone the whole traffic from the server to the workstation
    - re-create in-memory indexes (~20_000_000 entries)
  - Time to start a simulation: < 4 seconds (muti-threaded)
    - 1 task decodes the flight data from the server, 1 task creates the flight data structure, 6 tasks are re-creating the indexes

Track Performance during Dev: "Performance Unit Tests"

- "Performance unit tests": useful to measure e.g.
  - Basic data structures: hash tables, binary trees, ...

```
INSERT 16384:      90.85 NSEC
INSERT 32768:      99.82 NSEC
INSERT 65536:     107.54 NSEC
INSERT 131072:    115.58 NSEC
INSERT 262144:    122.38 NSEC
INSERT 524288:    130.50 NSEC
INSERT 1048576:   140.84 NSEC
INSERT 2097152:   145.91 NSEC
```

  - Low level primitives: pthread mutex, Ada protected objects, ...

```
Pthread_Mutex Lock/Unlock PTHREAD_MUTEX_NORMAL:       13.32 NSEC
Pthread_Mutex Lock/Unlock PTHREAD_MUTEX_RECURSIVE:    13.65 NSEC
Pthread_Mutex Lock/Unlock PTHREAD_MUTEX_ERRORCHECK:   16.12 NSEC
Pthread_Mutex Lock/Unlock PTHREAD_MUTEX_DEFAULT:      12.96 NSEC
Protected Object Inc or Dec (= 1 lock/unlock):        15.28 NSEC
Atomic_Spin_Inc or Dec (= 1 lock/unlock) :             5.39 NSEC
Atomic_Counters Atomic Inc or Dec (= 1 lock/unlock):   4.53 NSEC
clock_gettime Clock_Monotonic:                        14.65 NSEC
clock_gettime Clock_Thread_Cputime_Id:               397.33 NSEC
Timing an action (= 4 * clock_gettime + overhead):   839.22 NSEC
clock system call:                                     3.33 NSEC
loop assign a volatile integer:                        0.24 NSEC
```

  - Low level libraries performance e.g. malloc library
  - Performance Unit tests are usually small/fast
    - and reproducible/precise (remember our 1% objective)

Pitfalls of "Performance Unit Tests"
A real life example with malloc

- Malloc Performance Unit Test: glibc malloc <> tcmalloc <> jemalloc
  - 7 years ago: switched from glibc to tcmalloc : less fragmentation, faster
  - But parallelised 'start simulation' had not understandable 25% perf variation
    - Performance was varying depending on linking a little bit more (or less) not called code in the executable.
    - Analysis with 'valgrind/callgrind' : no difference. Analysis with 'perf': shows tcmalloc slow path called a lot more
  - => malloc perf unit test: N tasks doing M million malloc, then M million free
    - glibc was slower but consistent performance
    - jemalloc was significantly faster than tcmalloc
    - But the 'real start simul' was slower with jemalloc
- => more work needed on the unit test

Pitfalls of “Performance Unit Tests”
A real life example with malloc

- After improving unit test to better reflect ‘start simulation’ work:
  - tcmalloc was slower with many threads
    but became faster when doing L loops of ‘start/stop simulation’
  - With jemalloc, doing the M millions free in the main task was slower
  - Unit test does not yet evaluate fragmentation

- Based on the above, we obtained a clear conclusion about malloc:
  - We cannot conclude from the malloc “Performance Unit Test“
  - => currently keeping tcmalloc, re-evaluate with newer glibc in RHEL 8

Pitfalls of Performance “Unit Tests”

- Difficult to have a Performance unit test representative of the real load
  - Malloc: no conclusion
  - pthread_mutex timing: measure with or without contention ?
    - And is the real load causing a lot of contention ?
  - Hash tables, binary trees, ...:
    - Real load behavior depends on the key types/hash functions/compare functions/distribution of key values/...
- If difficult for low level algorithms, what about complex algorithms:
  - E.g. have a representative ‘trajectory calculation performance unit test’ ?
    - With which data (nr of airports, routes, airspaces, ...) ?
    - With what flights (short haul ? long haul) flying where ?
- Performance unit tests are (somewhat) useful but largely insufficient
- => Solution: measure/track performance with the full system and real data :   ‘Replay one day of Operational Data’

Replay Operational Data

- The operational system records all the external input:
  - Messages modifying the state of the system, e.g. flight plans, radar positions, …
  - Query messages, e.g. "Flight list entering France between 10:00 and 12:00"
- ETFMS Replay tool can replay the input data
  - New release must be able to replay (somewhat recent) old input format
- Some difficulties:
  - Several days of input are needed to replay one day
    - E.g. because a flight plan for the D day can be filed some days in advance
  - Elapsed time needed to replay several days of operational data?
  - Hardware needed to replay the full operational data ?
  - How to have a (sufficiently) deterministic replay in a multi-process system ?
    - (to detect difference of <1%)

Replay Operational Data
Volume of Data to Replay

- Replaying the full operational input is too heavy
- => Compromise:
  - Replay the full data that changes the state of the system
    - Flight plans, radar positions, …
  - Replay only a part of the query load:
    - Replay only one hour of the query load
      - And only a subset of the background/batch jobs
- Replaying in real time mode is too slow
    - But an input must be replayed at the time it was received on ops !
    - Many actions happen on timer events
  - => “accelerated fast time replay mode” :
    - The replay tool controls the clock value
    - Clock value “jumps” over the time periods with no input/no event
- Fast time mode: replaying one day takes about 13 hours on a (fast) linux workstation

Replay Operational Data
Sources of non Deterministic Results

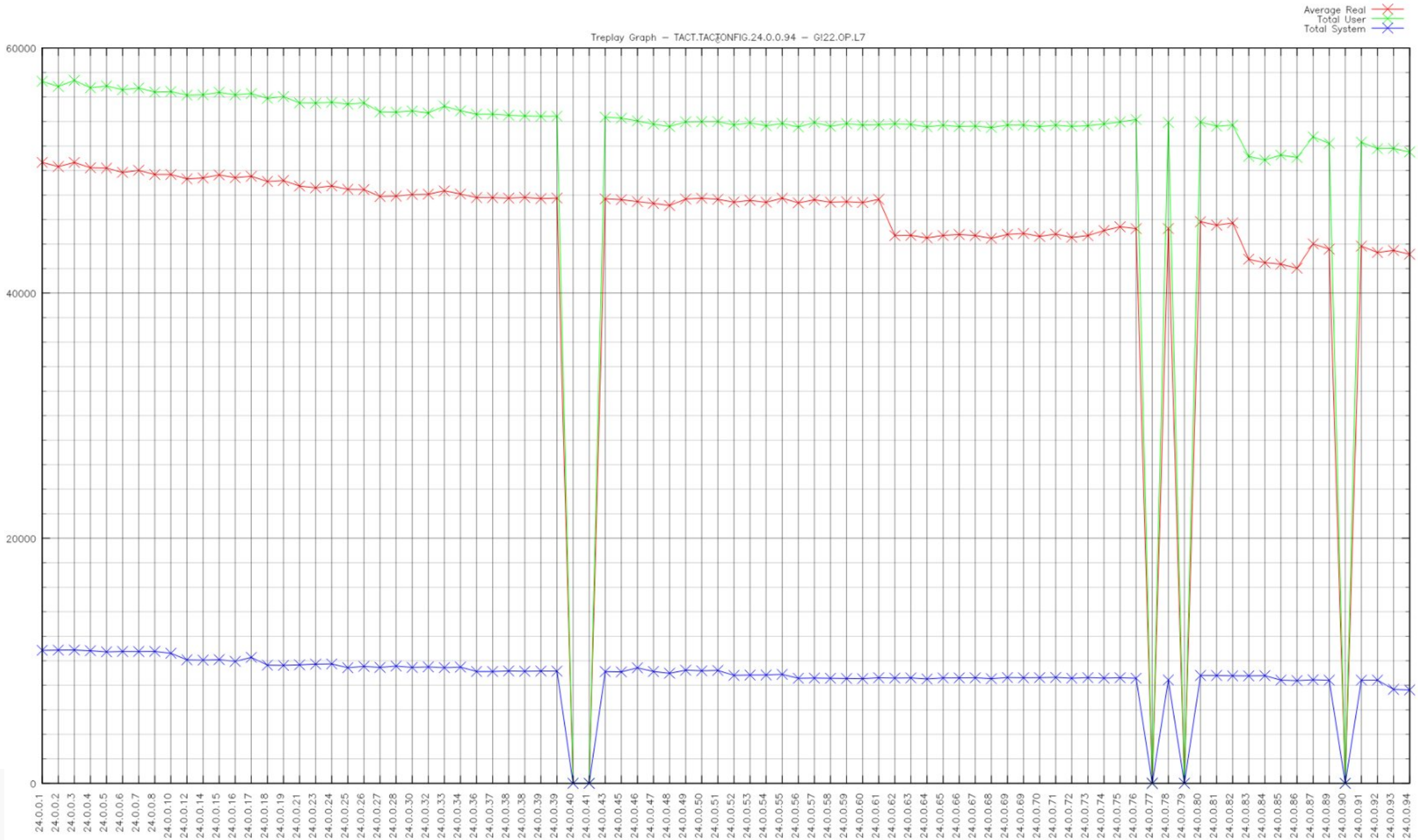
- Network, NFS, ….
  - Replay on isolated workstations: local file system, local database, …
- System Administrators
  - Are open to discussions to disable their jobs on replay workstations
- Security Officers
  - Are (somewhat) open to (difficult) discussions to disable security scans :)
- Input/Output past history
  - Removing files and clearing the database was not good enough
  - => completely recreate the file system and database for each replay
- Operating System usage history
  - => Reboot the workstation before each replay

Replay Operational Data
Remaining Sources of non Deterministic Results

- Time-control replay tool serialises “most” of input processing
  - “most” but not all: serialising everything slows down the replay
    - E.g. radar positions at the same second are replayed “in parallel”
- Replays are done on identical workstations
  - Same hw, same operating system, …
  - Still observing systematic small performance difference between workstations

- We finally achieved a reasonably deterministic replay performance, with 3 levels of results:
  - Global tracking: elapsed/user/system cpu for complete system
  - Per process tracking: user/system cpu, “perf stat” results, …
  - Detailed tracking: we run one hour of replay under valgrind/callgrind
    - This is very slow (26 hours) but very precise

Replay Operational Data
Global Tracking



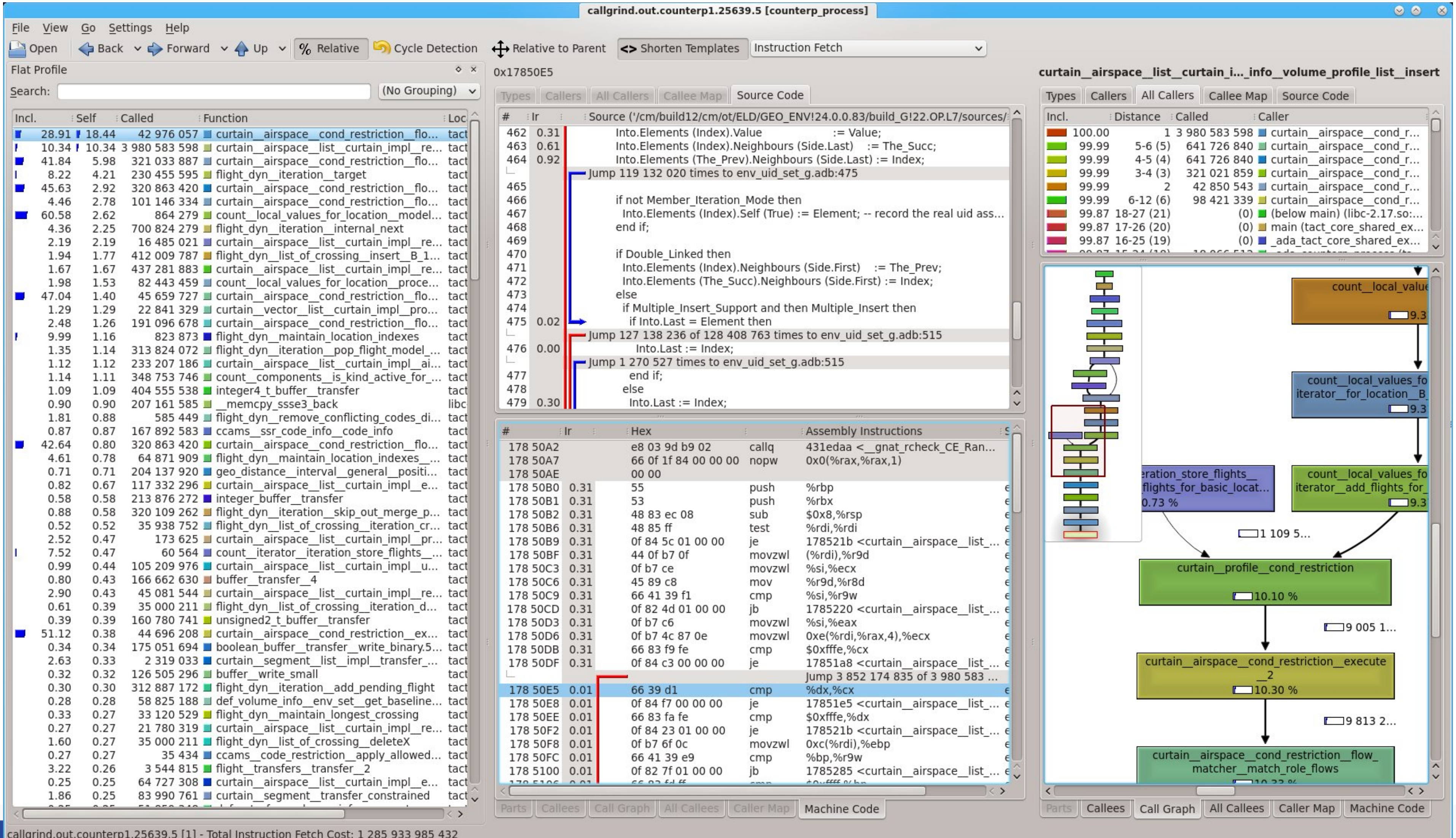
Replay Operational Data
Per Process Tracking

- User and system cpu
- heap status : used/free, tcmalloc details, …
- …

```
...
43836.82s real  5762.10s user   895.71s system   counterp1_out_01
43836.83s real  7744.71s user  1280.37s system   flight1_out_01
43836.60s real  7716.72s user  1278.94s system   flight2_out_01
43836.78s real  7695.46s user  1263.85s system   flight3_out_01
43836.82s real  7762.09s user  1281.87s system   flight4_out_01
...
              process_name          Clib(used)        Clib(free)
counterp_process-28348-27-04      4026449248          59458208
flight_process-28400-27-04         650265680         153271216
flight_process-28428-27-04         648387288         160982312
flight_process-28429-27-04         643411488         211112416
flight_process-28432-27-04         643439200         210757024
...
```

Replay Operational Data

Detailed Tracking with valgrind/callgrind/kcachegrind



Dev Performance Tracking: Detection of a real life ~~missed~~ failed optimisation

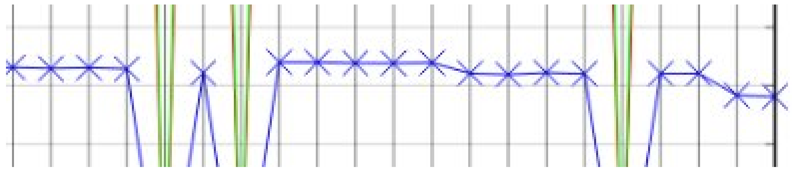
```
task body Monitor is
  Locks : Natural := 0;
  select
    accept Unlock;
    Locks := Locks - 1;
  or
    accept Get_Lock_Count (Lock_Count : out Natural) do
      Lock_Count := Locks;
    end Get_Lock_Count;
  or
    ...
```

Optimisation idea: decrease the number of rendez-vous by using lower level synchronisation based on **Volatile**

```
Locks : Natural := 0 with Volatile;
function Get_Lock_Count return Natural is (Locks);
task body Monitor is
  select
    accept Unlock do
      Locks := Locks - 1;
    end Unlock;
  or
    ...
```

This should be faster: we will have the same number of **Unlock** rendez-vous but we will have much faster **Get_Lock_Count** calls.

Performance tracking detected this was a pessimisation: the compiler optimises the ‘no body’ rendez-vous, and the nr of **Unlock** calls is significantly bigger than the nr of **Get_Lock_Count** calls



Dev Performance Tracking: A Summary

- We have a good dev performance tracking, using a mix of:
  - Performance Unit Tests
  - Replay Operational Data in a as deterministic as possible setup
    - The replayed day is changed ~every year to match new usage patterns
  - Various tools : valgrind/callgrind + kcachegrind, perf, top, …
  - Beware of blind spots of your tools e.g.
    - Valgrind/callgrind + kcachegrind is very easy to use but
      - very slow and serialises multi-thread applications
      - Limited system call measurement can be misleading
  - Have global indicators, zoom on the details when needed

- Some improvements to the tooling done or in the pipe-line :
  - callgrind next release can now measure system call CPU
  - working on developing “callgrind_diff” to help visualising differences

Dev Performance Tracking:
Good Enough/Sufficient to Go Operational ?

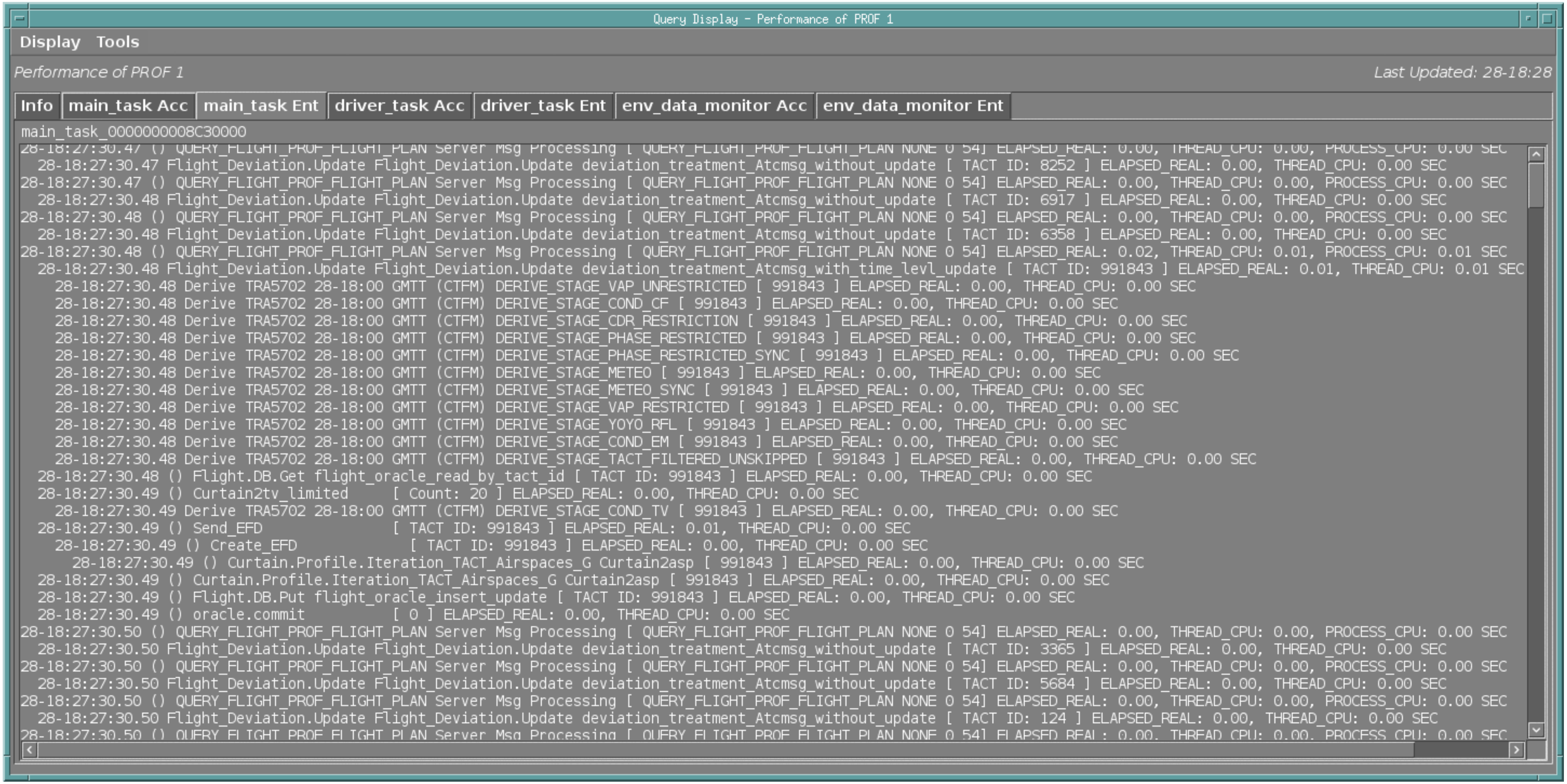
- What about : you are on-call, waken up Saturday 4:00 AM because “users are complaining that the system is slow”
  - You need something else than:
    “I will replay the day and get back to you Monday morning”
- What about: is the reference replayed day representative of what happens on OPS ?
- What about: evolution of the OPS workload and capacity planning
  - E.g. what functionalities/queries/… are increasing ?
  - E.g. what additional capacity is needed to support X times more queries of that type ?

- Solution: “permanently activated response time monitoring and statistics”

On-line “TACT Response Time” Monitoring

- Application contains measurement code at “critical points” such as:
  - Remote Procedure Call invocation begin/end (i.e. “client side”)
  - Remote Procedure Call execution begin/end (i.e. “server side”)
  - Database access begin/end
  - Significant algorithms begin/end, such as: “calculate a vertical trajectory”
  - ...
- Measurements typically nested, e.g. inside a RPC execution begin/end
- The “TACT response time” package maintains:
  - A circular buffer with the last M measurements
  - For each begin/end measurement:
    - Elapsed time, Thread CPU time, optionally full Process CPU time
  - Statistics :
    - How many measurements
    - Histogram of Elapsed/Thread CPU
    - Details about the N worst cases
- Reasonable overhead ~1.7% CPU => always activated

TACT Response Time
Last M Measurements Circular Buffer



TACT Response Time : Statistics

Query Display - Performance of PROF 1

Display Tools

Performance of PROF 1 *Last Updated: 28-18:28*

Info | main_task Acc | main_task Ent | driver_task Acc | driver_task Ent | env_data_monitor Acc

```
main_task_0000000008C30000 SINCE_RESET at 20_01_27-09:49:40.55
Path_Finder_NORMAL_GRAPH_CREATION
SINCE_CREATION
NR_SAMPLES : 36566
TOTAL : ELAPSED_REAL: 1548.67, THREAD_CPU: 1520.62 SEC
AVERAGE : ELAPSED_REAL: 0.04, THREAD_CPU: 0.04 SEC
     TIME_RANGE (in SEC)  ELAPSED_REAL     THREAD_CPU
<=                  0.00         19741          19915
<=                  0.01          5178           5159
<=                  0.02          2489           2466
<=                  0.04          2369           2332
<=                  0.08          1832           1780
<=                  0.16          2177           2191
<=                  0.32          1978           1959
<=                  0.64           718            692
<=                  1.28            84             72
ELAPSED_REAL Maximum 10 1.10 SEC 27-12:45:07.71 () Path_Finder_NORMAL_GRAPH_CREATION [ 980866 ]
ELAPSED_REAL Maximum  9 1.07 SEC 27-10:19:51.44 () Path_Finder_NORMAL_GRAPH_CREATION [ 975847 ]
ELAPSED_REAL Maximum  8 1.07 SEC 28-02:18:07.85 () Path_Finder_NORMAL_GRAPH_CREATION [ 984406 ]
ELAPSED_REAL Maximum  7 1.04 SEC 27-22:30:46.29 () Path_Finder_NORMAL_GRAPH_CREATION [ 985277 ]
ELAPSED_REAL Maximum  6 0.97 SEC 28-04:55:20.92 () Path_Finder_NORMAL_GRAPH_CREATION [ 10614 ]
ELAPSED_REAL Maximum  5 0.97 SEC 27-19:30:36.42 () Path_Finder_NORMAL_GRAPH_CREATION [ 985307 ]
ELAPSED_REAL Maximum  4 0.96 SEC 27-10:33:12.62 () Path_Finder_NORMAL_GRAPH_CREATION [ 976715 ]
ELAPSED_REAL Maximum  3 0.95 SEC 28-09:21:03.19 () Path_Finder_NORMAL_GRAPH_CREATION [ 10982 ]
ELAPSED_REAL Maximum  2 0.94 SEC 28-07:25:58.75 () Path_Finder_NORMAL_GRAPH_CREATION [ 998811 ]
ELAPSED_REAL Maximum  1 0.93 SEC 28-16:35:16.33 () Path_Finder_NORMAL_GRAPH_CREATION [ 16617 ]
THREAD_CPU   Maximum 10 1.03 SEC 27-22:30:46.29 () Path_Finder_NORMAL_GRAPH_CREATION [ 985277 ]
THREAD_CPU   Maximum  9 1.03 SEC 27-10:19:51.44 () Path_Finder_NORMAL_GRAPH_CREATION [ 975847 ]
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THREAD_CPU   Maximum  6 0.95 SEC 27-10:33:12.62 () Path_Finder_NORMAL_GRAPH_CREATION [ 976715 ]
THREAD_CPU   Maximum  5 0.94 SEC 28-07:25:58.75 () Path_Finder_NORMAL_GRAPH_CREATION [ 998811 ]
THREAD_CPU   Maximum  4 0.93 SEC 27-19:30:36.42 () Path_Finder_NORMAL_GRAPH_CREATION [ 985307 ]
THREAD_CPU   Maximum  3 0.93 SEC 28-16:35:16.33 () Path_Finder_NORMAL_GRAPH_CREATION [ 16617 ]
THREAD_CPU   Maximum  2 0.91 SEC 28-09:21:03.19 () Path_Finder_NORMAL_GRAPH_CREATION [ 10982 ]
THREAD_CPU   Maximum  1 0.91 SEC 28-07:12:24.55 () Path_Finder_NORMAL_GRAPH_CREATION [ 998811 ]
```

TACT Response Time
Used from Dev to Ops

- Dev
  - Helps to understand how the system works, e.g. to see messages exchanged between processes, algorithms executed, …
  - Statistics used to analyse Performance Operational Data Replay
  - Compare the profile of the “replayed reference day” with OPS profile
  - Measure resource consumption for new functionalities
  - …
- Ops
  - On-line investigation of performance problems
  - Bug investigation:
    - Policy: exceptions are used for bugs, not for normal behaviour
    - In case of exception: take a core dump, drop input, process next message
    - => the core dump contains in memory the details of the last M measured actions
  - Post-ops analysis, trend analysis
  - Input for capacity planning

Performance Tracking of a Big Application Summary

- (Reasonably) deterministic performance tracking during development:
  - Allows to detect performance regression on a daily basis
  - Allows to verify that optimisations really have the desired effect
  - Allows to plan capacity for demand growth and new functionalities
  - …
- A mix of various techniques and tools are needed, e.g.
  - Performance unit test
  - Replay real data
  - Application self-measurement (“TACT response time”).
  - Avoid blind spots by using various tools: perf, valgrind/callgrind, …
- Tooling can be used for various purposes e.g. Replay Tool:
  - Is also the (automated) testing tool
  - Is used by our users to analyse/optimise operational actions/procedures
- Performance tracking and statistics also on the operational system

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Questions ?