Titan Workshop - Vampir and VampirTrace

Trace Based Performance Analysis at Large Scale on Titan

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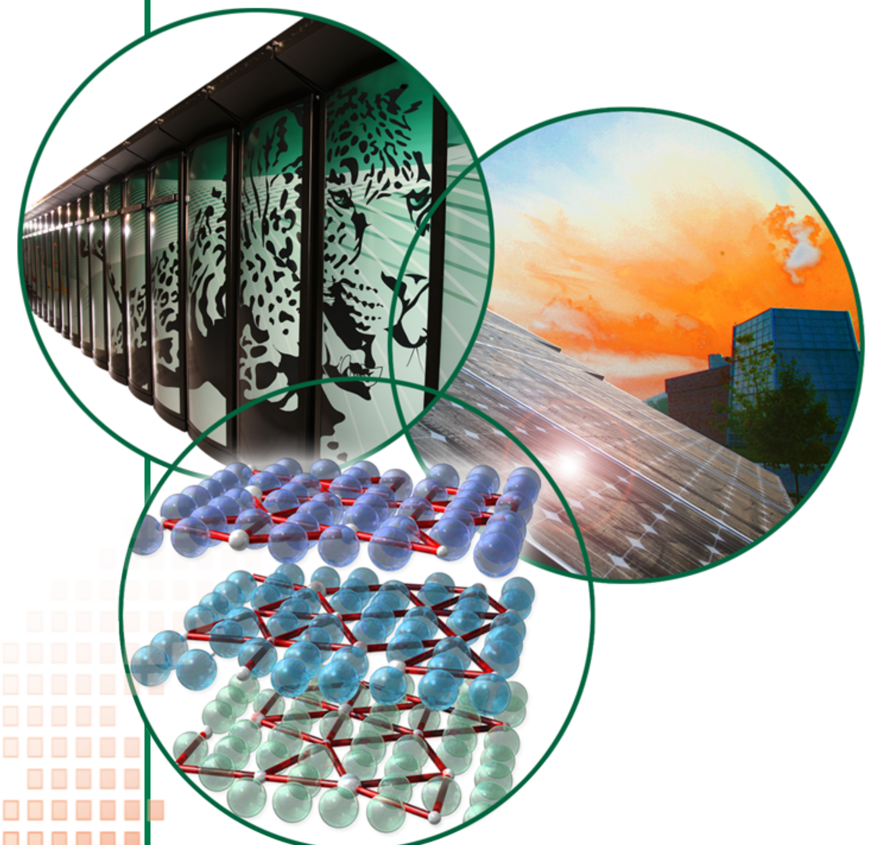

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Disclaimer

Performance tools will not automatically make you code run faster. They help you understand, what your code does and where to put in work.

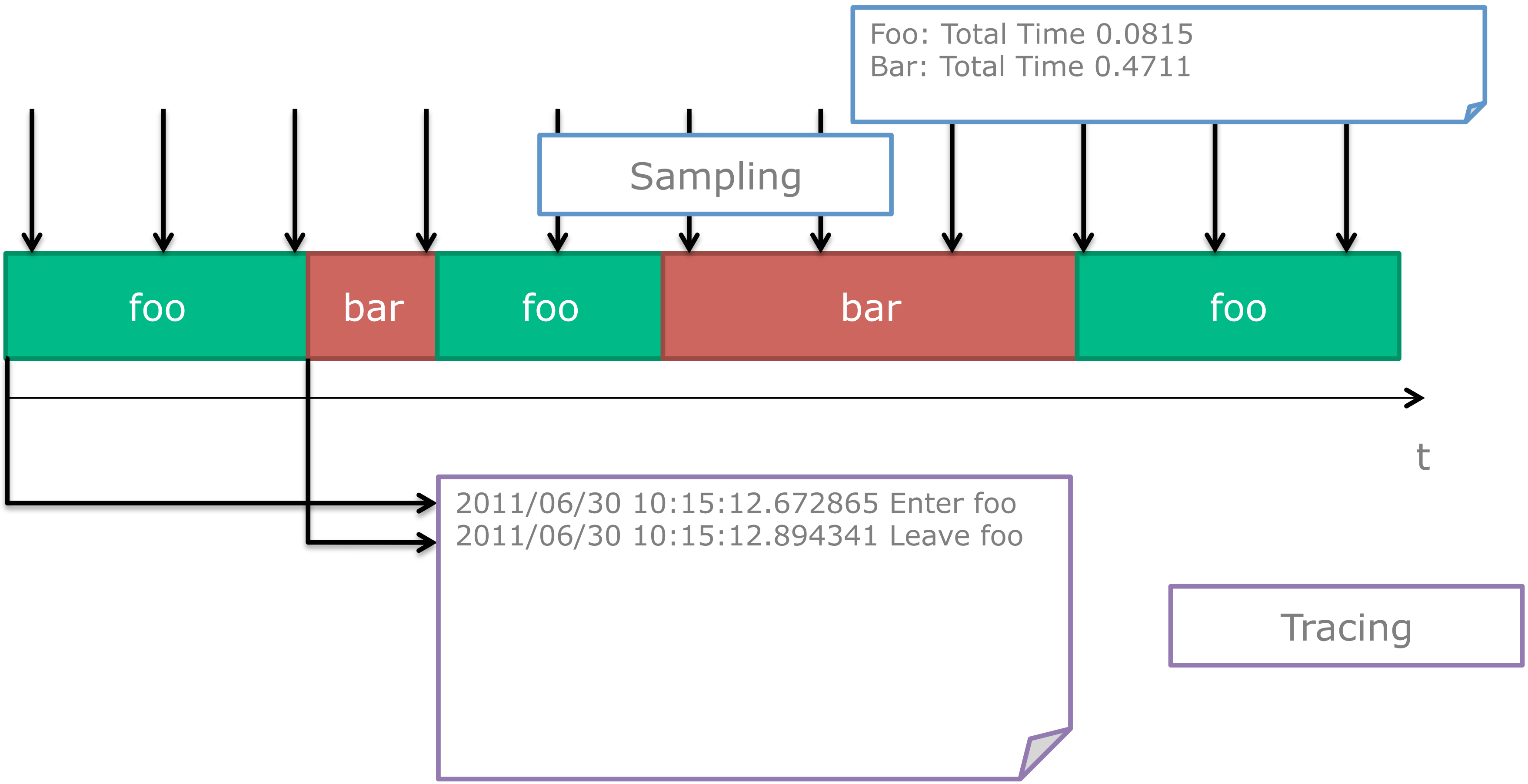
Agenda

1. **Introduction**
   – Sampling vs. Profiling vs. Tracing
2. **The Vampir Framework Workflow**
   – VampirTrace
   – Vampir
3. **Advanced Topics**
   – GPU support & Scalability
4. **Vampir Framework on Titan**
5. **Summary**
6. **Bonus Material**

1. Introduction

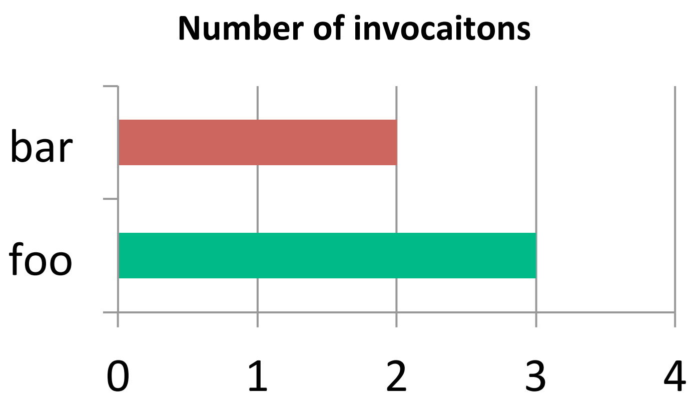
- **Why bother with performance analysis?**
  - Efficient usage of expensive and limited resources
  - Scalability to achieve next bigger simulation
- **Profiling and Tracing**
  - Have an optimization phase
    - just like testing and debugging phase
  - Use tools!
  - Avoid *do-it-yourself-with-printf* solutions, really!

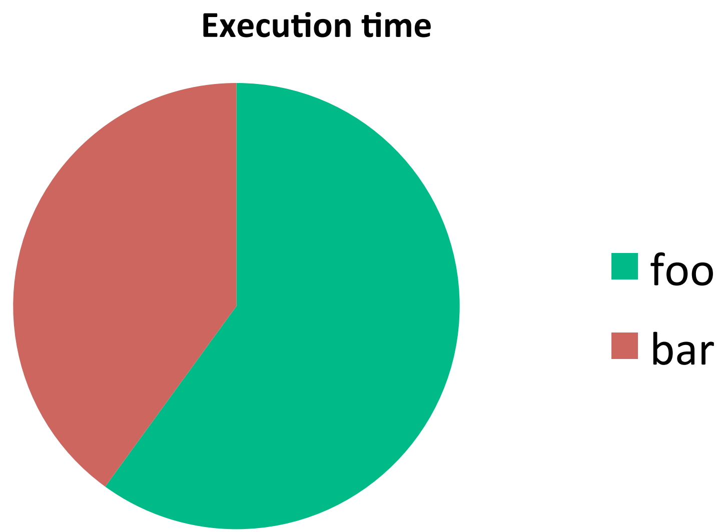
1.1 Sampling vs. Tracing



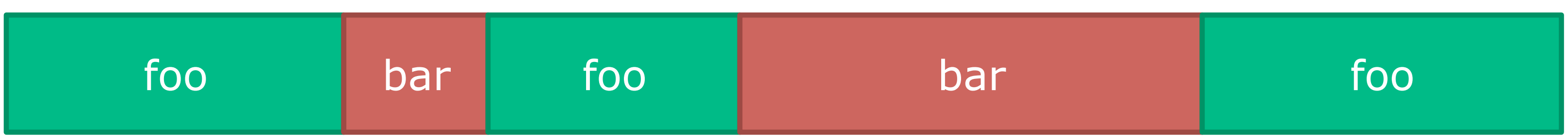
1.2 Profiling vs. Tracing

- Statistics





- Timelines



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2.1.1 Instrumentation

What does VampirTrace do in the background?

- **Instrumentation phase (pre-run):**
  - Via compiler wrappers
  - By underlying compiler with specific options
  - MPI instrumentation with replacement lib
  - OpenMP instrumentation with Opari
  - Also binary instrumentation with Dyninst
  - Partial manual instrumentation
  - By an automatic instrumentor (TAU)

2.1.2 Measurement

What does VampirTrace do in the background?

- **Measurement phase (during run):**
  - Event data collection
  - Precise time measurement
  - Parallel timer synchronization
  - Collecting parallel process/thread traces
  - Collecting performance counters (from PAPI, memory usage, POSIX I/O calls and fork/system/exec calls, CUDA, and more …)
  - Monitor accelerator (like GPU, Cell SPE) usage
  - Filtering and grouping of function calls

2.1.3 Common Event Types

- **Enter/leave of function/routine/region**
  - time, process/thread, function ID
- **Send/receive of P2P message (MPI)**
  - time, sender, receiver, length, tag, comm.
- **Collective communication (MPI)**
  - time, process, root, communicator, # bytes
- **Hardware performance counter values**
  - time, process, counter ID, value
- …

2.1.4 Tracing – Pros and Cons

- **Tracing Advantages**
  - Preserve temporal and spatial relationships of events
  - Allow reconstruction of dynamic behavior on any required abstraction level
  - Profiles can be calculated from trace

- **Tracing Disadvantages**
  - Traces can become very large
  - May cause perturbation
  - Instrumentation and tracing is complex
    (event buffering, clock synchronization, …)

2.1.5 Application Adaptations

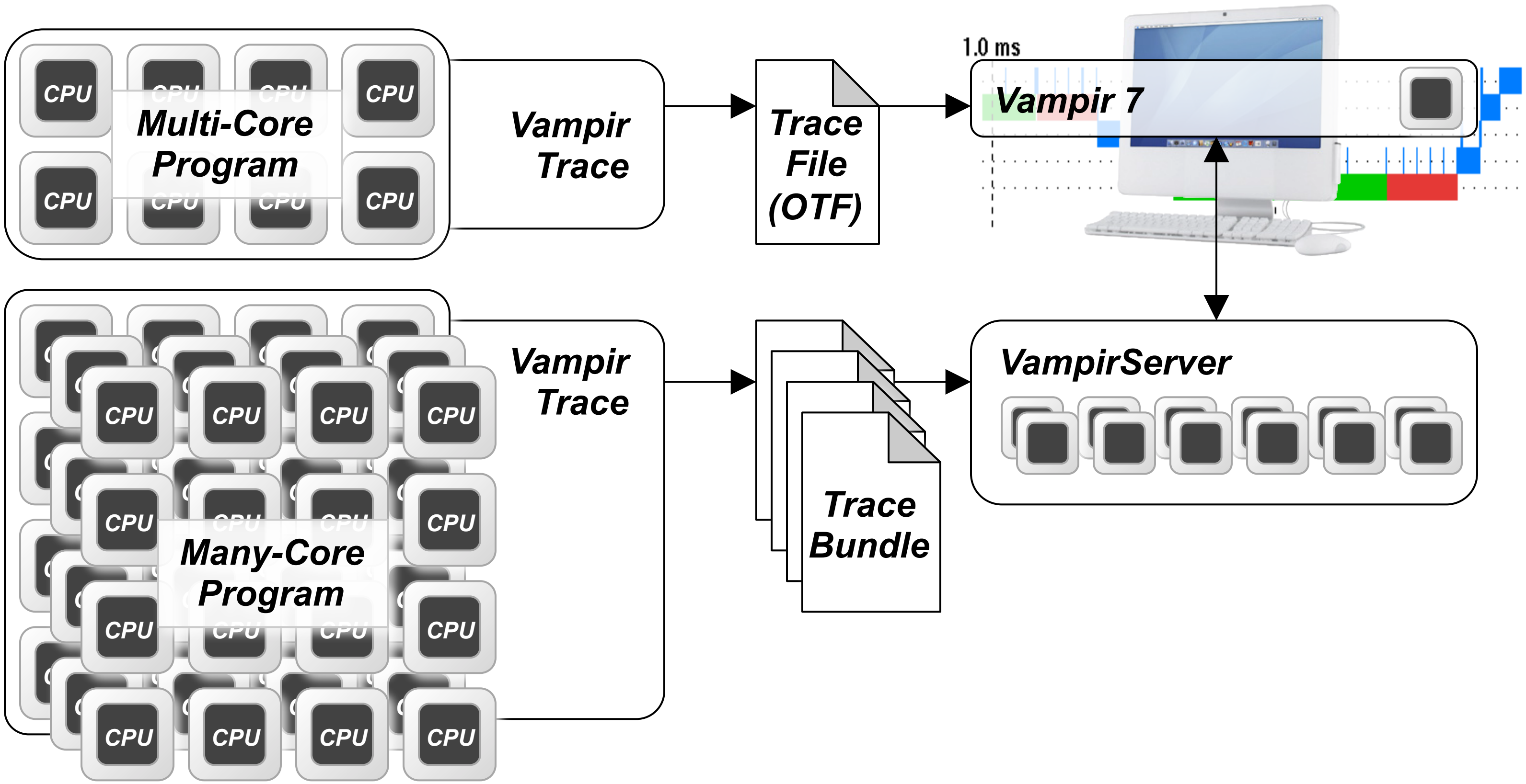
What do you need to do for it?

1. Change the compiler

CC=icc CXX=icpc F90=ifc MPICC=mpicc	CC=vtcc CXX=vtcxx F90=vtf90 MPICC=vtcc -vt:cc mpicc

2. Re-compile & re-link
3. Trace Run (run the application with an appropriate test data set)

2.2 Workflow Overview



2.3.1 Event Trace Visualization

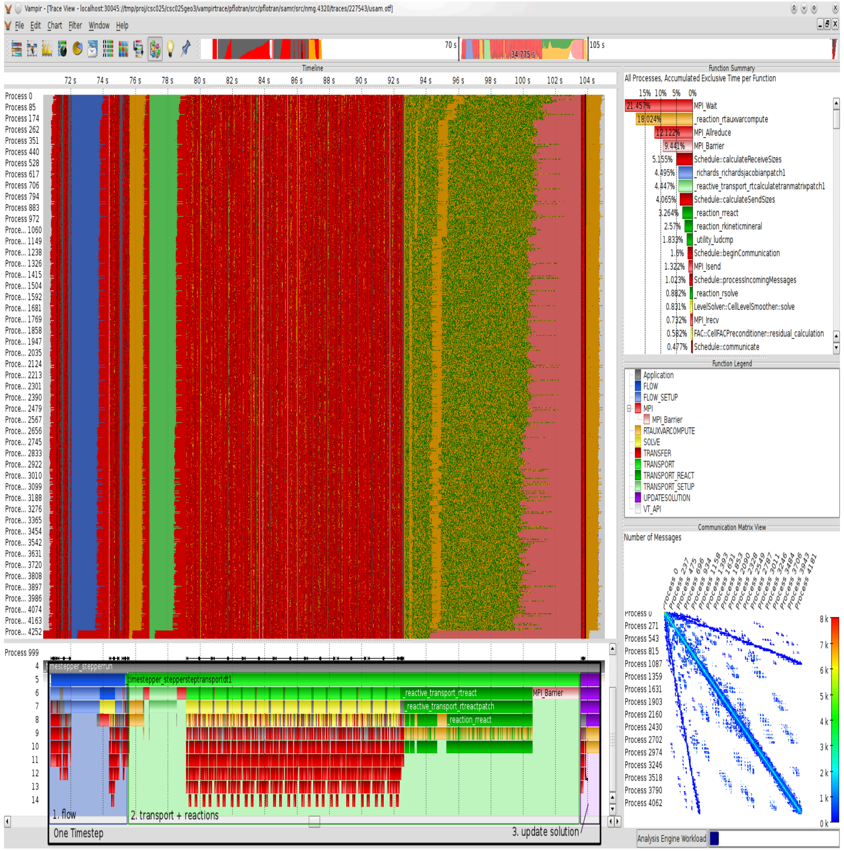
- **Trace Visualization**
  - Alternative and supplement to automatic analysis
  - Show dynamic run-time behavior graphically
  - Provide statistics and performance metrics
    - Master timeline for parallel processes/threads
    - Process timeline plus performance counters
    - Statistics summary display
    - Message statistics
    - and more
  - Interactive browsing, zooming, selecting
    - Adapt statistics to zoom level (time interval)
    - Also for very large and highly parallel traces

2.3.2 Finding Performance Bottlenecks

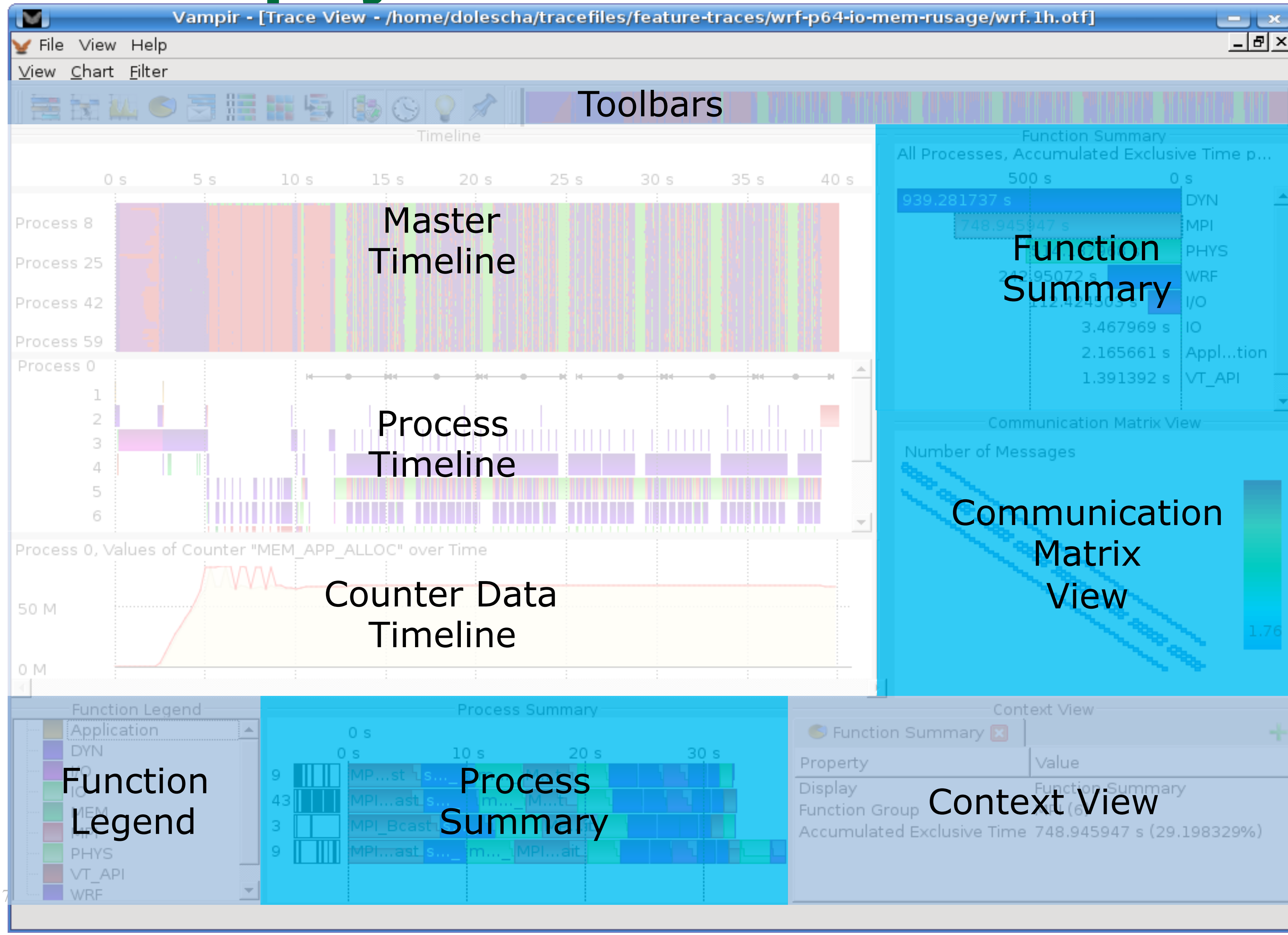
- Inefficient communication patterns
- Load imbalance / serial parts of the application
- Memory bound computation
  - Inefficient cache usage
  - TLB misses
  - Use HW counters (PAPI) to detect
- I/O bottlenecks
- Most time consuming functions
- …

2.3.3 VampirClient (Vampir 7)

- GUI to analyze trace files (OTF)
- Main concept: Timeline + statistics
- GUI is QT based – available on Linux, Mac, Windows



2.3.4 Displays for a trace with 64 cores



2.3.5 VampirServer

- Parallel analysis engine for Vampir
  - MPI parallelized for distributed memory systems
  - Pthread parallelized for shared memory systems
- Scales to > 10,000 analysis processes
- Loads the entire uncompressed trace into memory

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3.1 Challenges for VT on Titan

Scalability

- Overcome I/O problems
- Find ways to show that much data

GPU Support

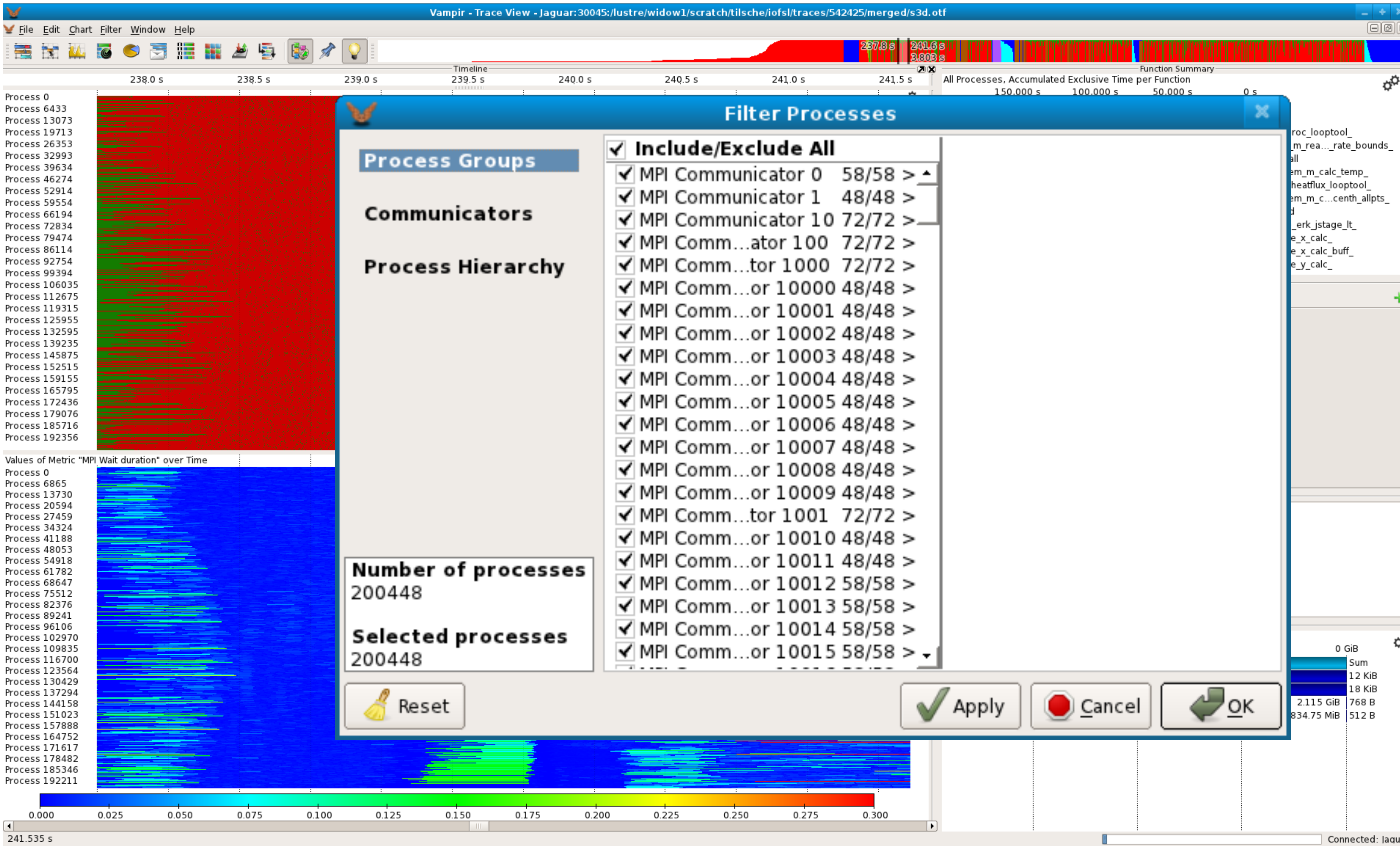
- Hitting a moving target
- Another layer of heterogeneity to display

3.1.1 Limits for Tracing on Titan

- **Current limit** is (based on user experiences):
  - Tracing up to 8,000 processes
  - I/O problem (too many file creates – one per process)

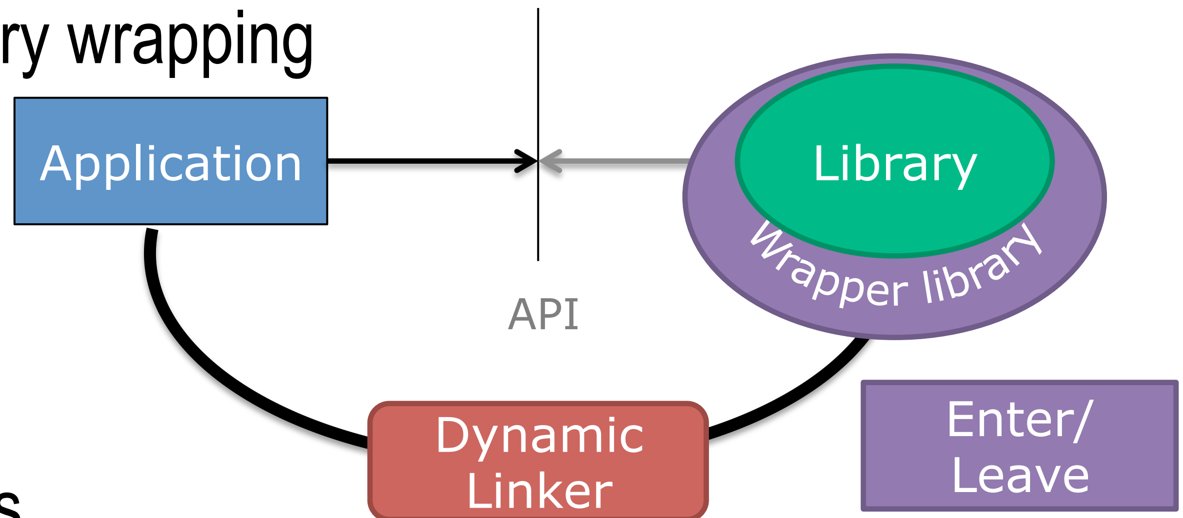
- **Prototype** was already working on Jaguar
  - Tracing 200,000+ processes
  - Based on IOFSL library
  - Opened for visualisation with 20,000 VampirServer processes

3.1.2 200,000+ Processes in Vampir



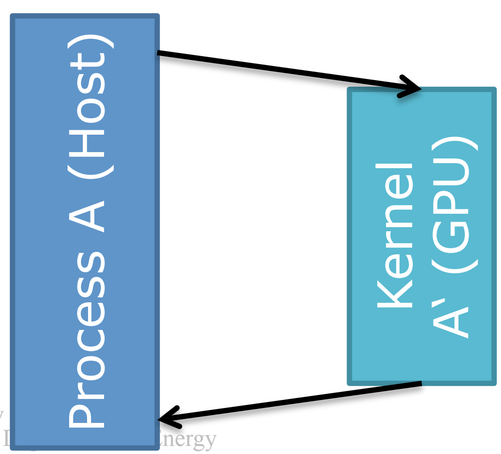
3.1.3 GPU Support: CUDA (& OpenCL)

- Currently done via library wrapping

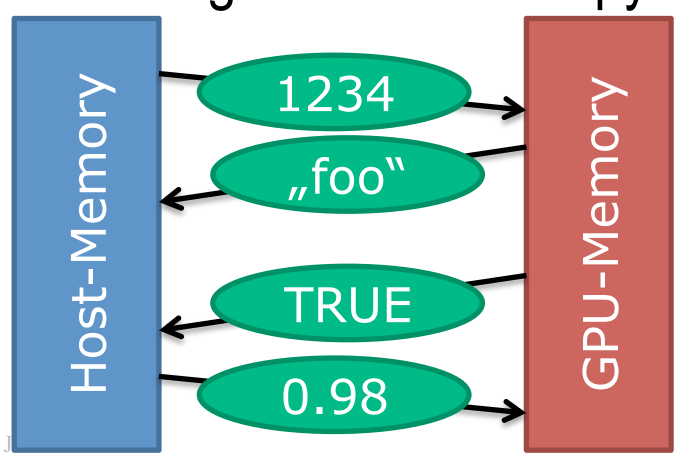


- Reuse of known metrics

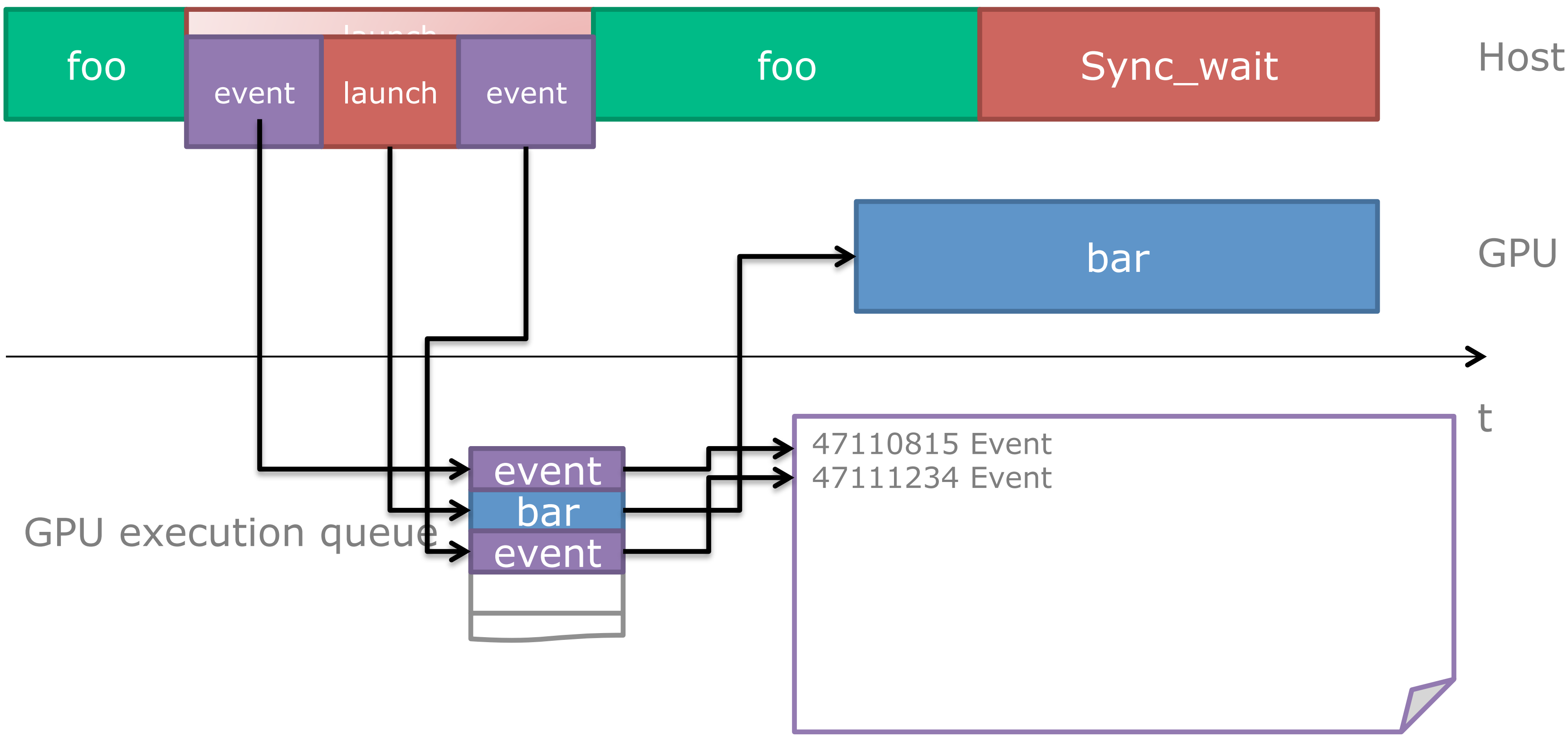
Thread = Kernel



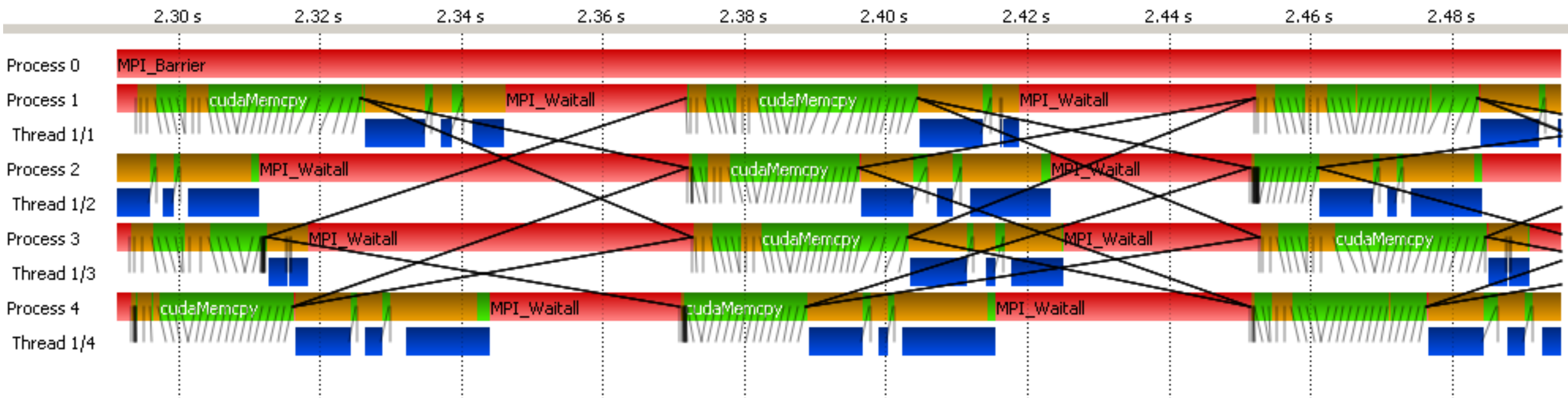
Message = cudaMemCpy



3.1.4 Time stamps for asynchronous events



3.1.5 Visualization of GPU Tracing



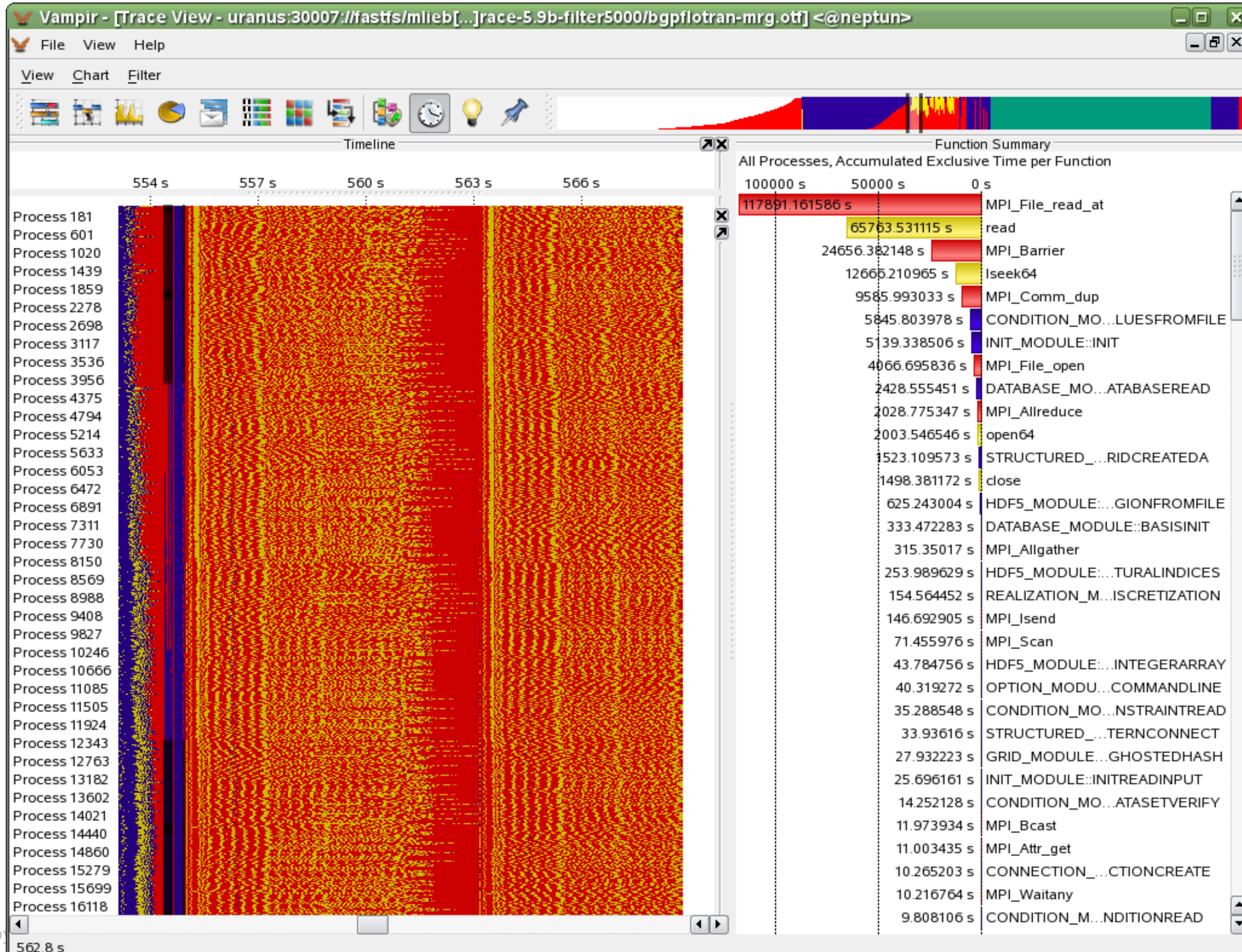
- Support for hybrid modes: GPGPU + MPI + threads
  - Function invocations in host processes (Process X) and threads
  - Kernel invocations in CUDA threads (Thread x/y)
  - Host-GPU interactions via CUDA API (light arrows)
  - Host-Host interactions via MPI (bold arrows)

*) old picture; CUDA Threads were renamed (CUDA[x] y:z)

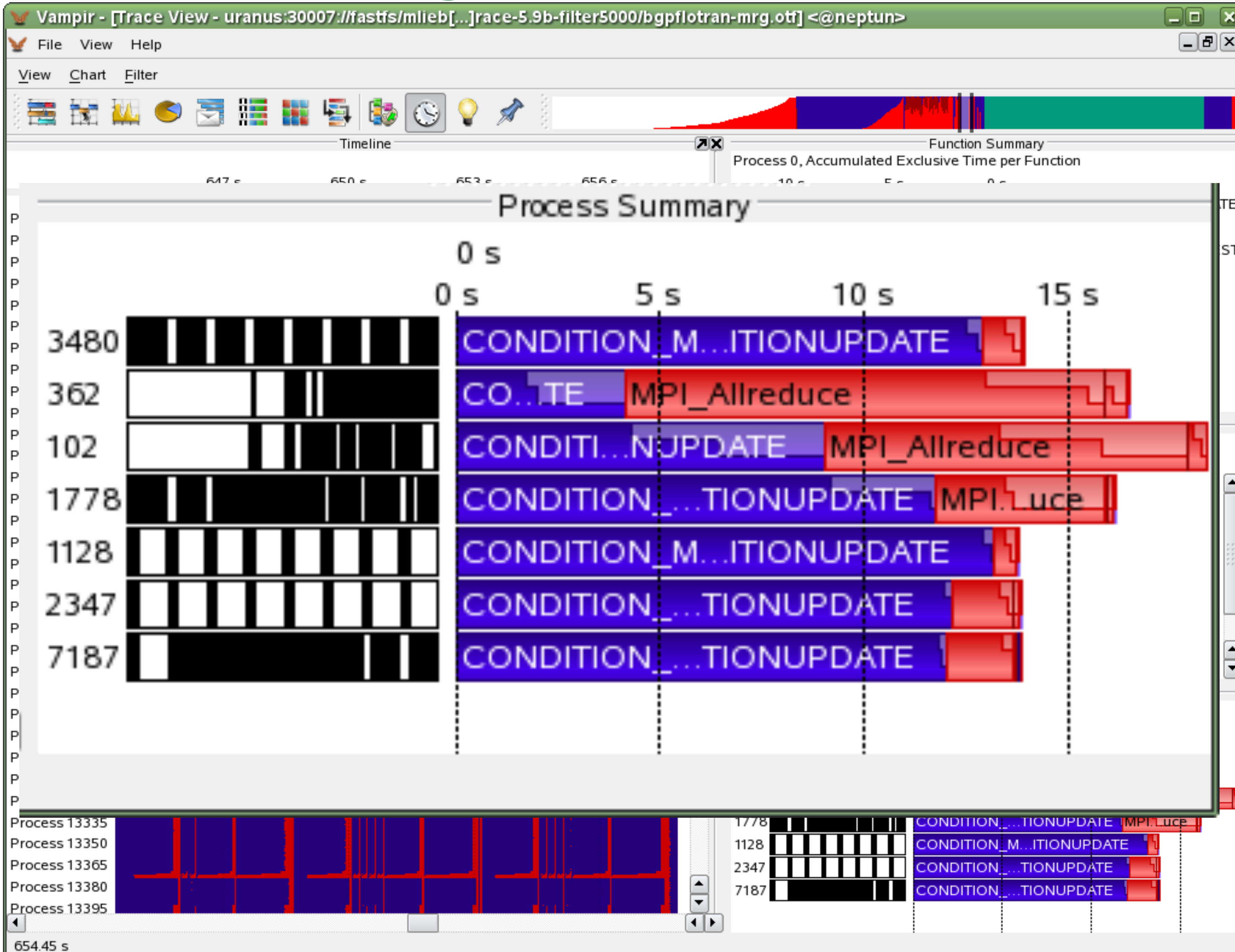
3.2 Scalability Features in Vampir

- Fit to chart height feature of master timeline and performance radar
  - Allows visualization of more processes than pixels of screen are available
- Clustering
  - Allows detection of outlier processes and groups with similar behavior
- Performance radar
  - Highlighting performance conditions of your program in a global timeline

3.2.1 Fit to chart height: Pflotran initialization + I/O

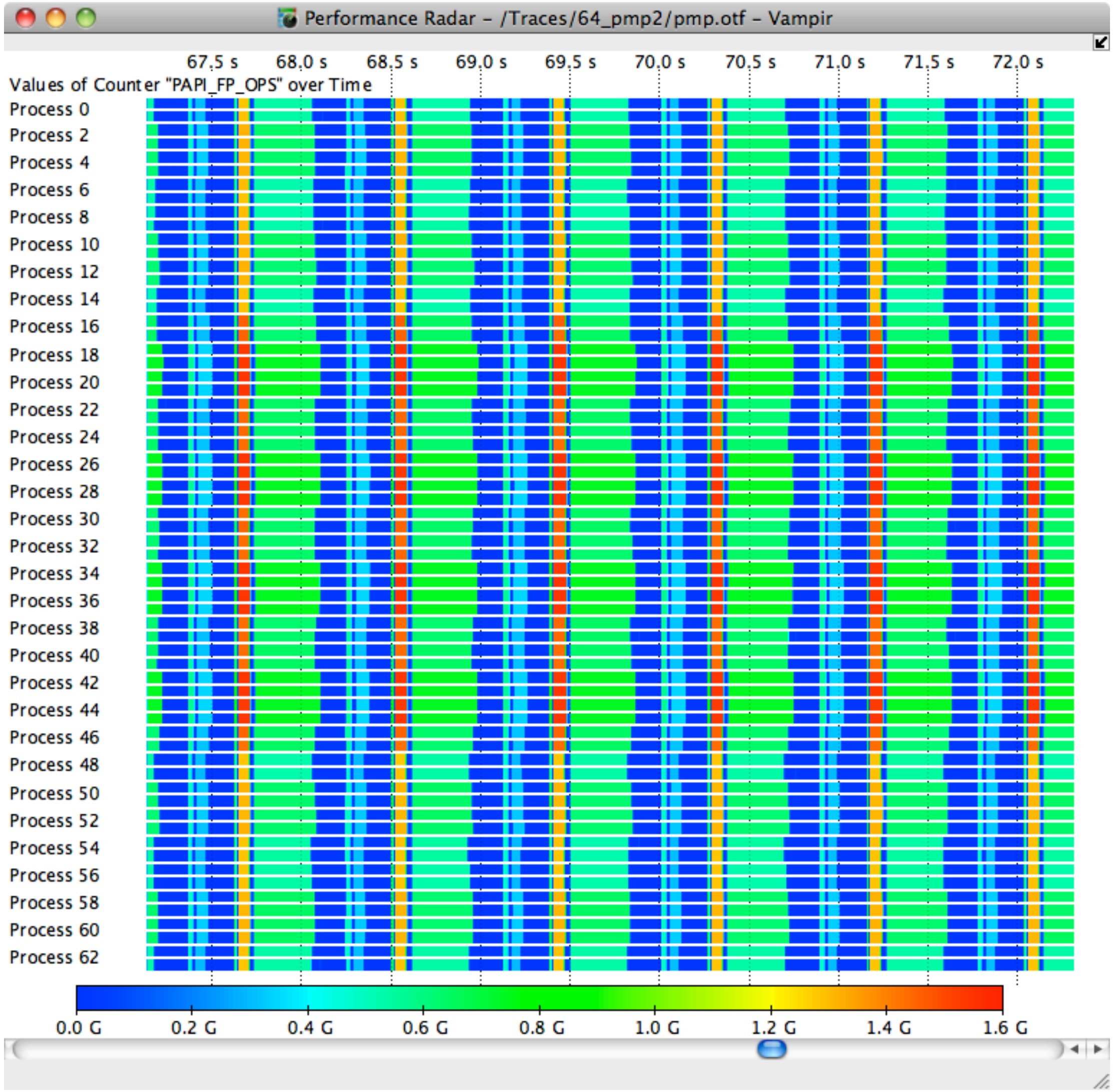


3.2.2 Clustering: Pflotran - first iteration



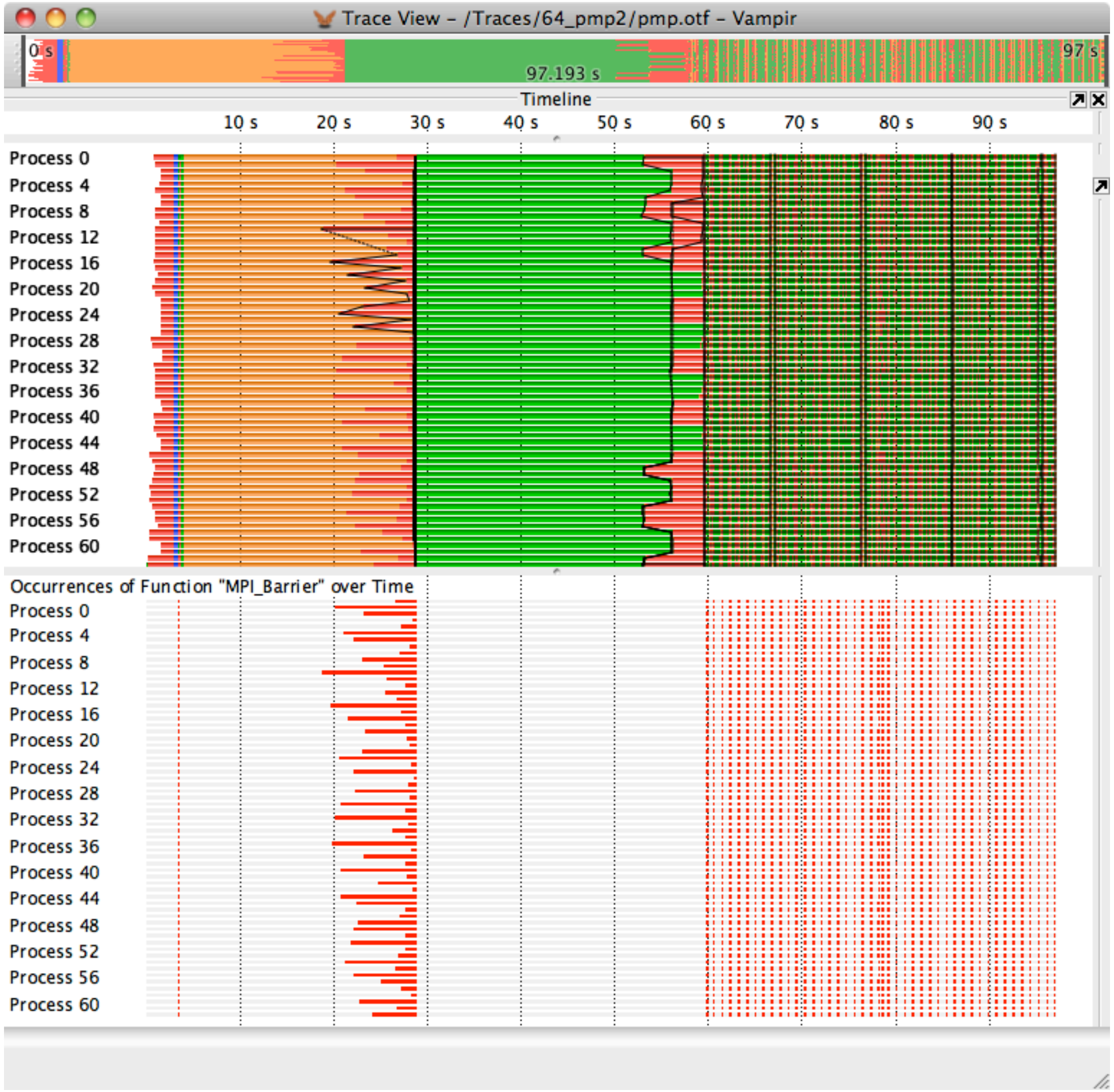
3.2.3 Performance Radar

- Display objectives:
  - Identification of performance relevant trace parts
  - Assistance to users to navigate in trace data and to spot interesting sections
  - Performance of basic arithmetics on counter data



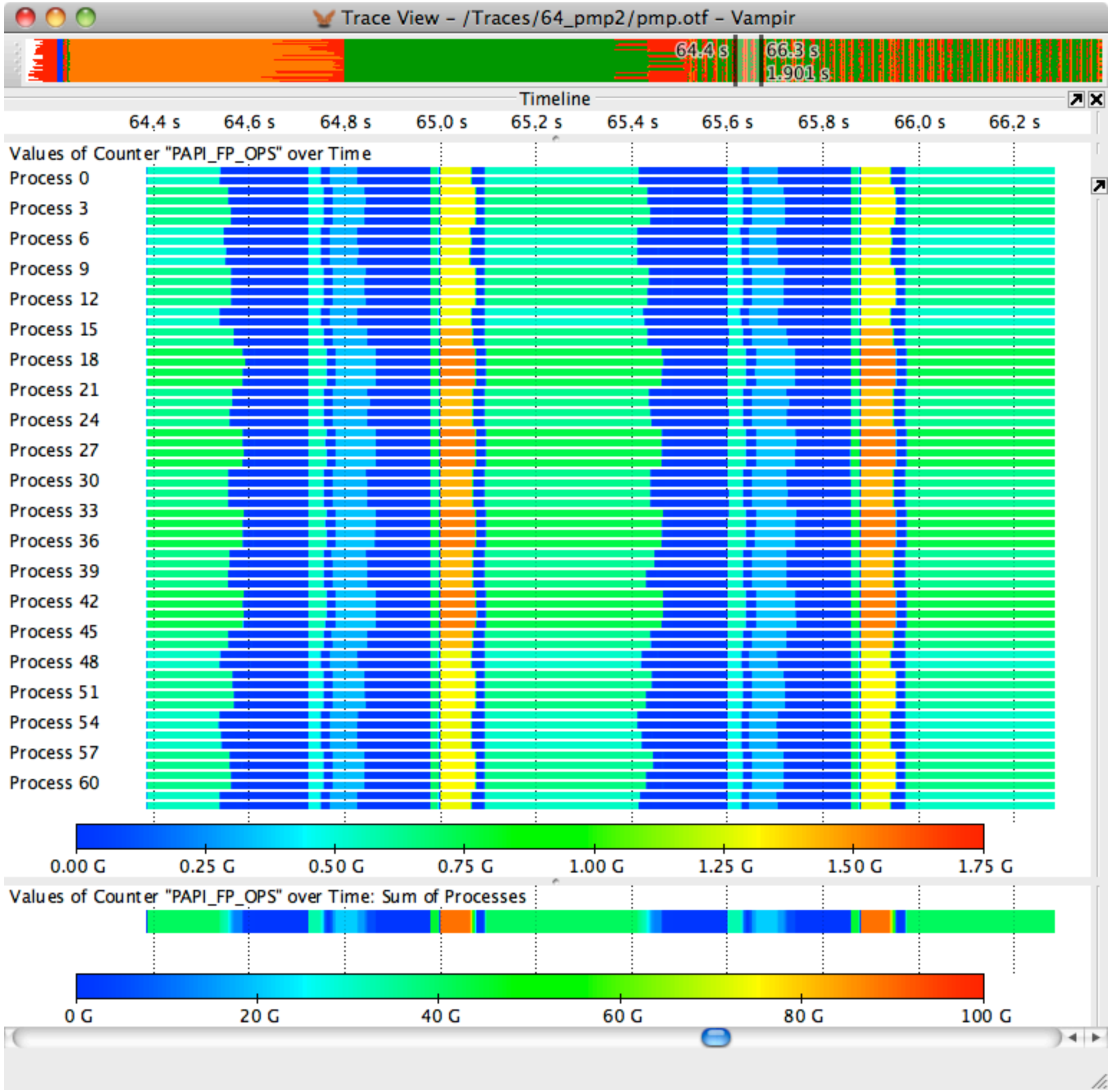
3.2.3 Performance Radar

- Features:
  - Detection of occurrences of functions/function groups
  - Visualization of call density of functions/ function groups to help to find performance relevant candidates
  - Construction of filter based on function occurrences over time for further usage in calculations



3.2.3 Performance Radar

- Features:
  - Performance of arbitrary calculations on counter data, e.g. add up all floating point operations over time, differentiation of performance counter
  - Support for concatenation of several calculations
  - Utilization of filter in calculations, e.g. only add up FLOPS of function x



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4.1 VampirTrace

titan$ module load vampirtrace

- Use the appropriate compiler wrappers
  - vtcc, vtCC, vtf77, vtf90
- Pick appropriate library (seq, mpi, mt, hyb)
  - e.g. vtcc –vt:hyb (recommended)
- Pick instrumentation type
  - –vt:inst compinst (**default**, compiler instrumentation)
  - –vt:inst manual (MPI, OpenMP, CUDA and manual inst.)
- Tell your build system to use VampirTrace
  - ./configure –with–CC="vtcc –vt:hyb" …

4.1.1 VampirTrace

- Pitfalls & Hints (especially for Titan)
  - Make sure that the VampirTrace module is loaded
    - Either ‘qsub -V’ or ‘module load vampirtrace’ within the PBS script
  - Save traces to special directory to optimize I/O performance
    - Set VT_PFORM_GDIR=traces
    - lfs setstripe -c 1 $VT_PFORM_GDIR
  - Set VT flag ‘-vt:hyb’ (VT does not identify the Cray wrapper as MPI/OMP compiler)
  - Use ‘-vt:verbose’ to see the commands executed by VT
  - Run with VT_MODE=STAT to create a profile (instead of a trace) for the first overview of you program
  - Set VT_BINDIR=/tmp/work/$USER/.vt/bin if you get something like: ‘/sw/…/vtunify No such file or directory’

4.1.2 VampirTrace

- More Pitfalls & Hints
  - Increase VT_BUFFER_SIZE if necessary
  - Avoid VT_MAX_FLUSHES=0 when you don’t know how large your trace will get (you could write TBytes of data)
  - Some compiler instrument inline functions, some do not
  - Avoid ‘-vt:inst compinst’ (default) for large C++ codes with STL
    - Use TAU (-vt:inst tau) or Dyninst (-vt:inst dyninst) instead
  - Use VT_FILTER_SPEC to limit the number of recorded events
    - Reduces resulting trace size by filtering frequently called functions
  - Function filtering won’t reduce runtime dramatically
    - -finstrument-functions-exclude-function-list=… works for a small number
    - ‘-vt:inst tau’ with a include/exclude file is recommended for large projects

4.2 Vampir

titan$ module load vampir

titan$ vampirserver start –a <PROJ> –n <cores>

titan$ *wait until server is running and follow the instructions*

local1$ ssh –L 30XXX:nidYYYY:30ZZZ <user>@titan

local2$ ./vampir *and choose 'File –> Remote Open'*

titan$ vampirserver stop XXXXX

- Pitfalls & Hints:
  - Use enough cores to load the trace in memory (decompressed, 4x)
  - Avoid running Vampir on the login nodes (X11 is slow)

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- **VampirTrace**
  – Convenient instrumentation and measurement infrastructure
  – Hides away complicated details
  – Provides many options and switches for experts
  – Available as
    - Part of Open MPI 1.3 and higher
    - Stand-alone package: www.tu-dresden.de/zih/vampirtrace
  – Further information
    - www.nccs.gov/computing-resources/lens/software/?software=vampirtrace
    - www.tu-dresden.de/zih/vampirtrace
    - chester$ /ccs/proj/trn001/vampir/manual/vampirtrace.pdf

5. Summary

- **VampirClient & VampirServer**
  - Interactive trace visualization and analysis
  - Intuitive browsing and zooming
  - Scalable to “quite large” trace data sizes (1.5 TByte)
  - Scalable to high parallelism (200,000 processes)
  - VampirClient is available for Windows, Linux/Unix and Mac OS X
  - Further information
    - www.nccs.gov/computing-resources/lens/software/?software=vampir
    - www.vampir.eu
    - chester$ /ccs/proj/trn001/vampir/manual/vampirtrace.pdf

Acknowledgements

This work would have been impossible without the dedication of:

- Matthias Lieber (Tracing & Analysis)
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- The Vampir Team:

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Thank you!

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    Tel: 1-865-241-6293

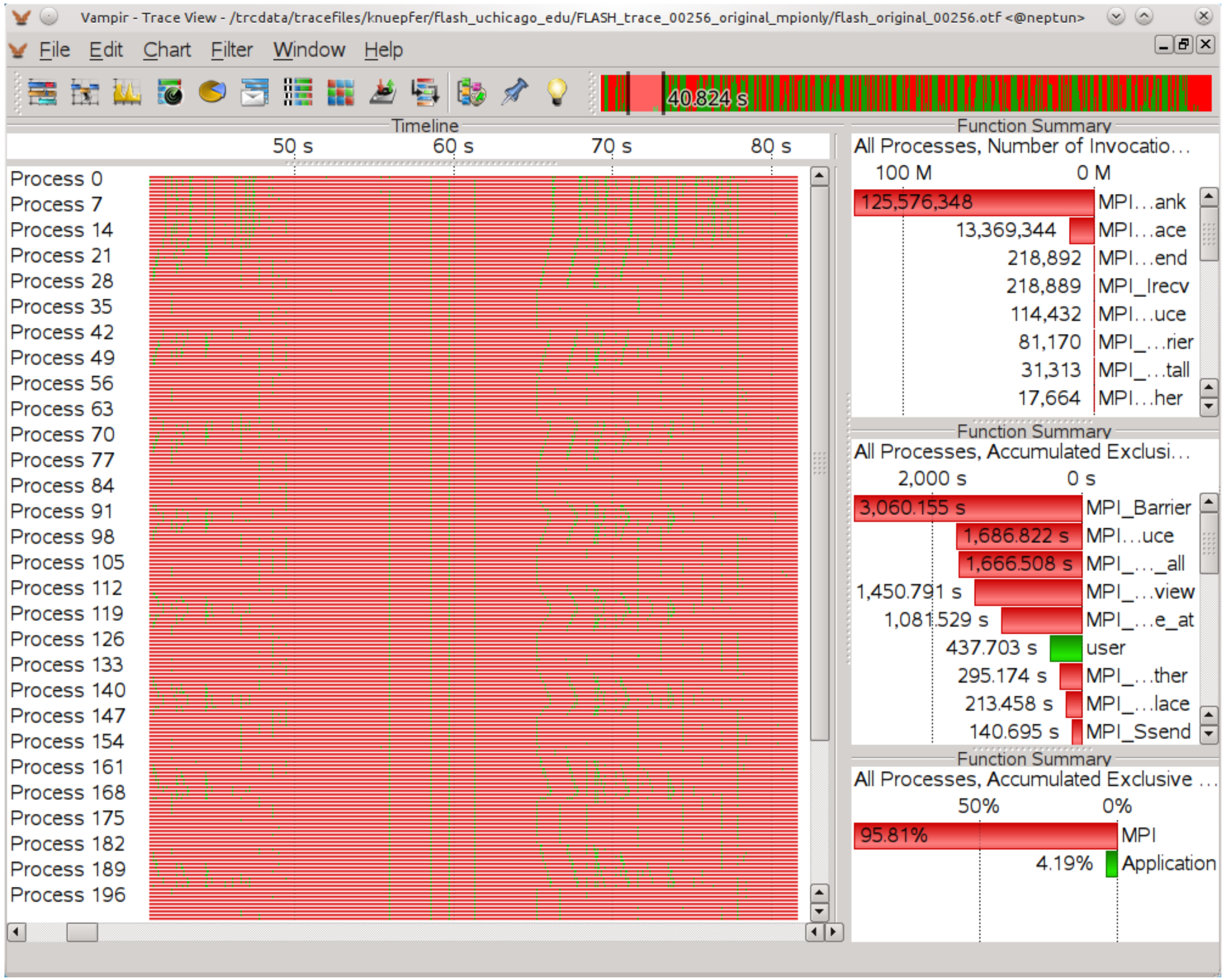
- Vampir & VampirTrace Support:
  - vampirsupport@zih.tu-dresden.de

7. Bonus Material – Bottlenecks

- Trace visualization to identify bottlenecks
  - Several displays with many options
  - Identify essential parts of an application (initialization, main iteration, I/O, finalization)
  - Identify important components of the code (serial computation, MPI P2P, collective MPI, OpenMP)
  - Make a hypothesis about performance problems
  - Consider application's internal workings if known
  - Select the appropriate displays
  - Use statistic displays in conjunction with timelines

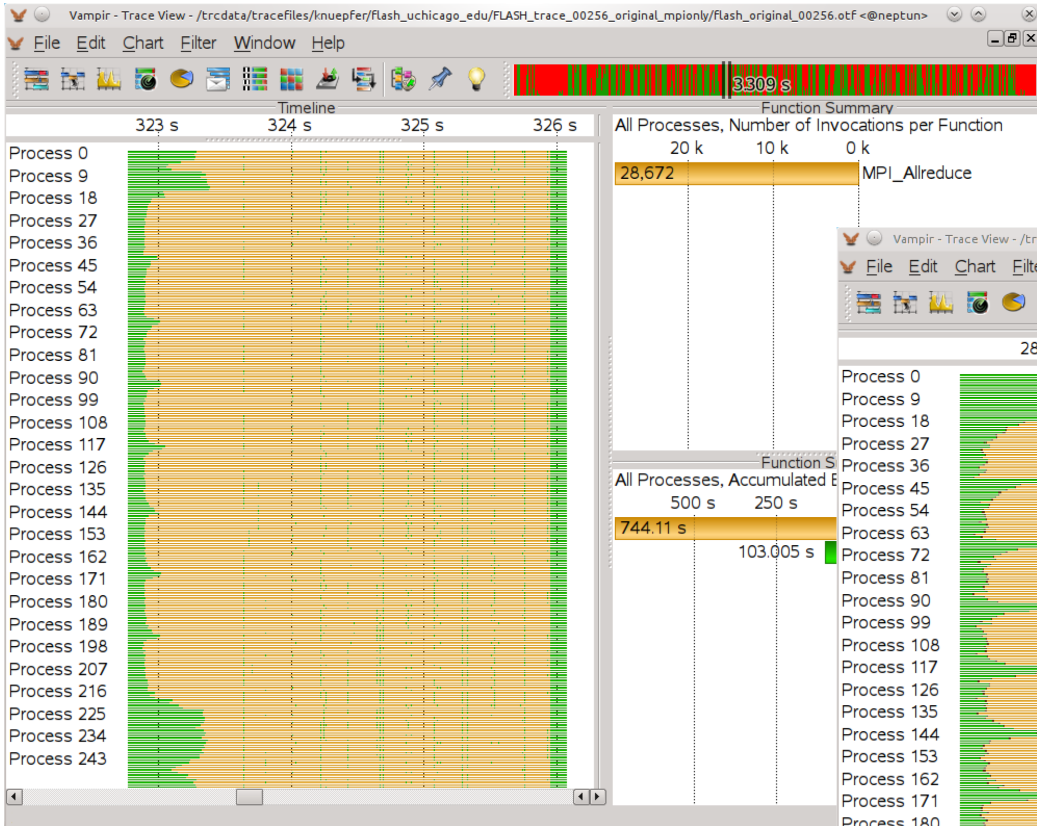
7.1 Communication it-self

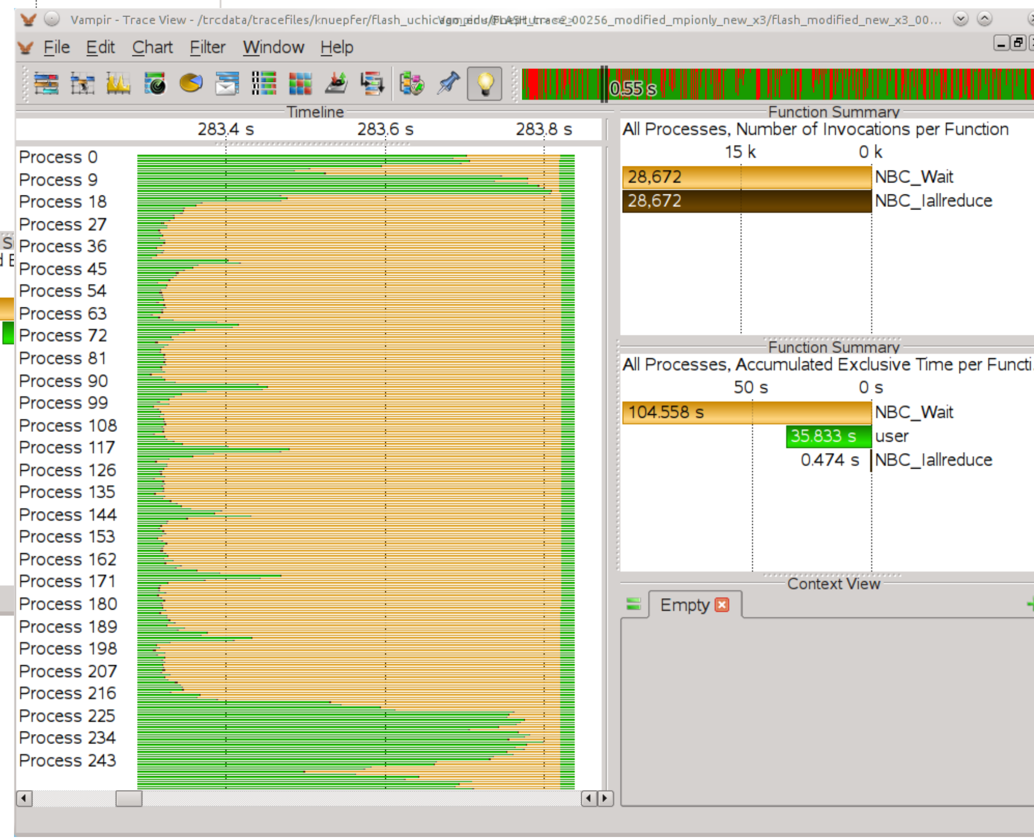
- Too much runtime share for MPI all-together



7.2 Bursts of large messages

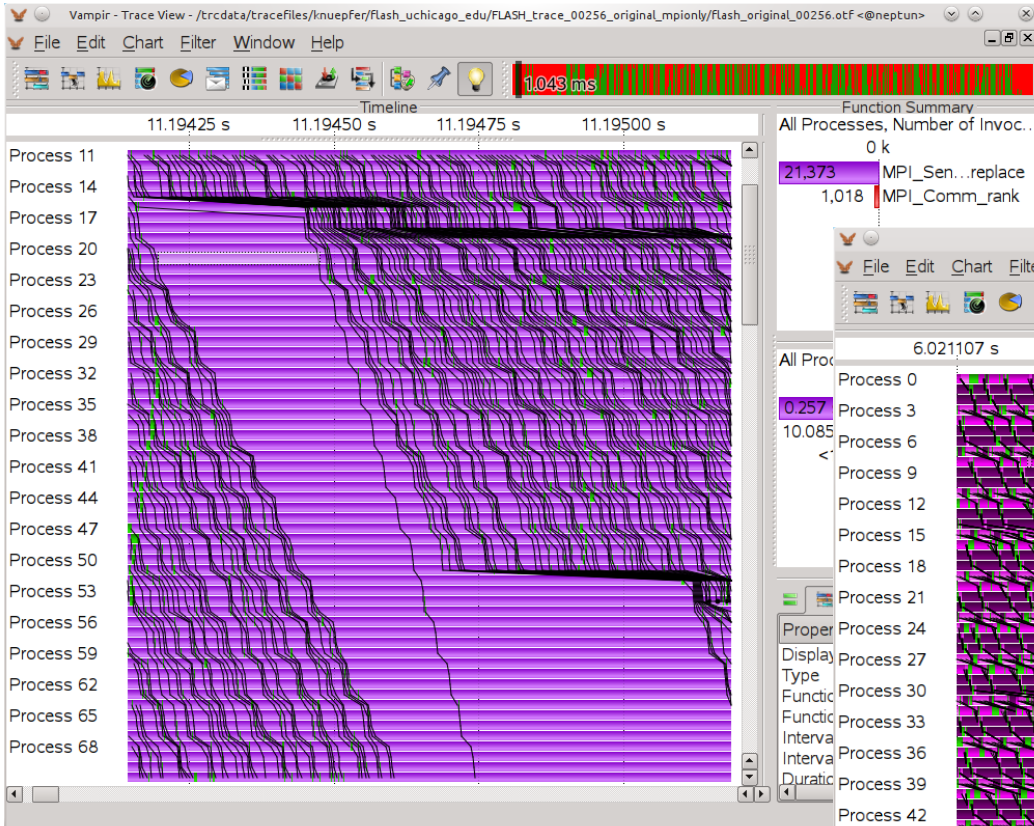
- Long bursts of MPI allreduce operations



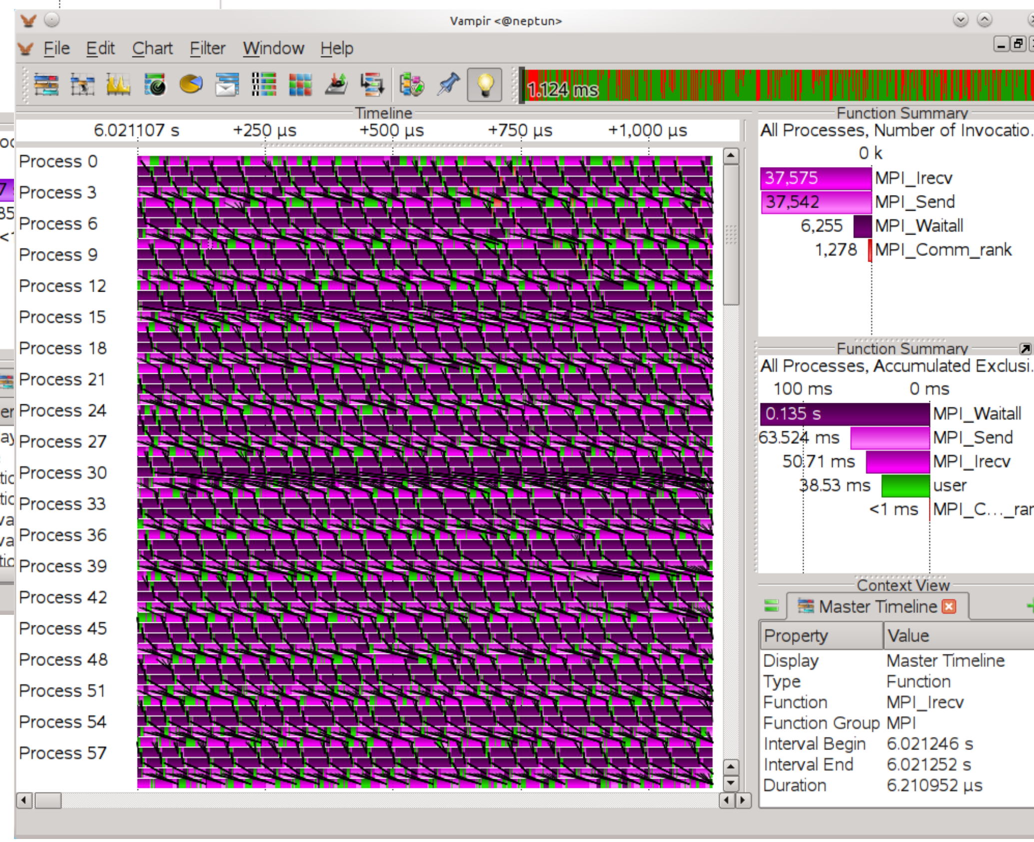


→ Replace by NBC non-blocking Allreduce plus wait

7.3 Sequential point-to-point messages

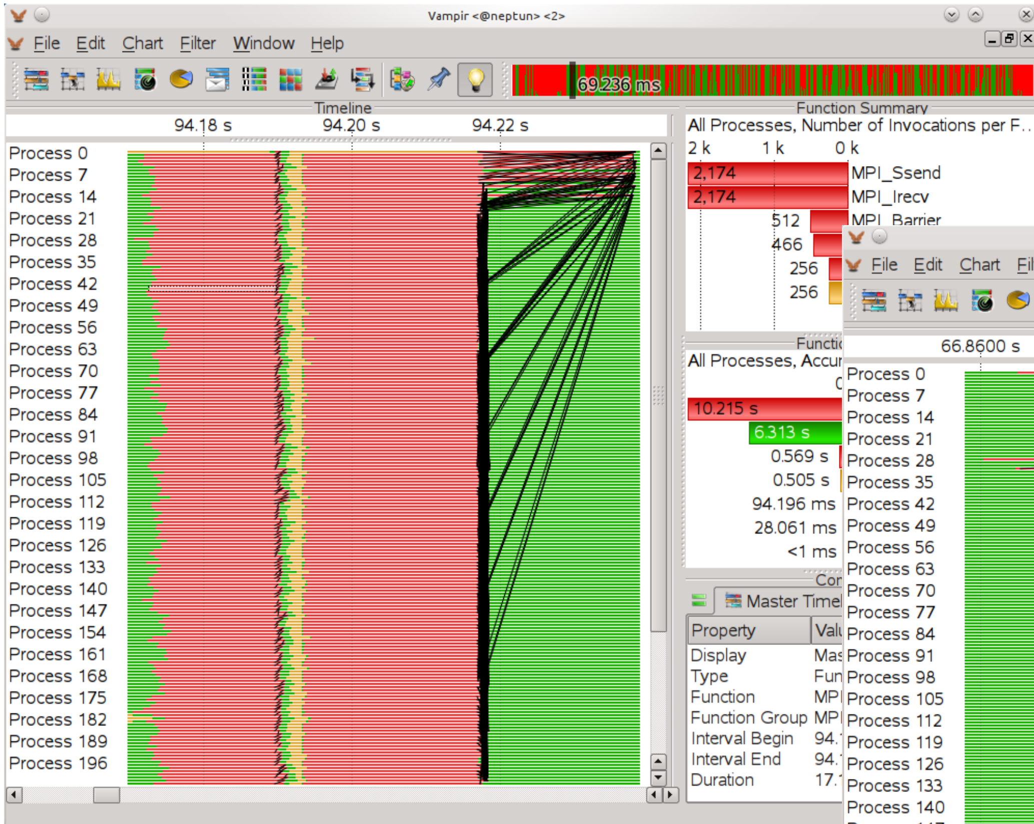


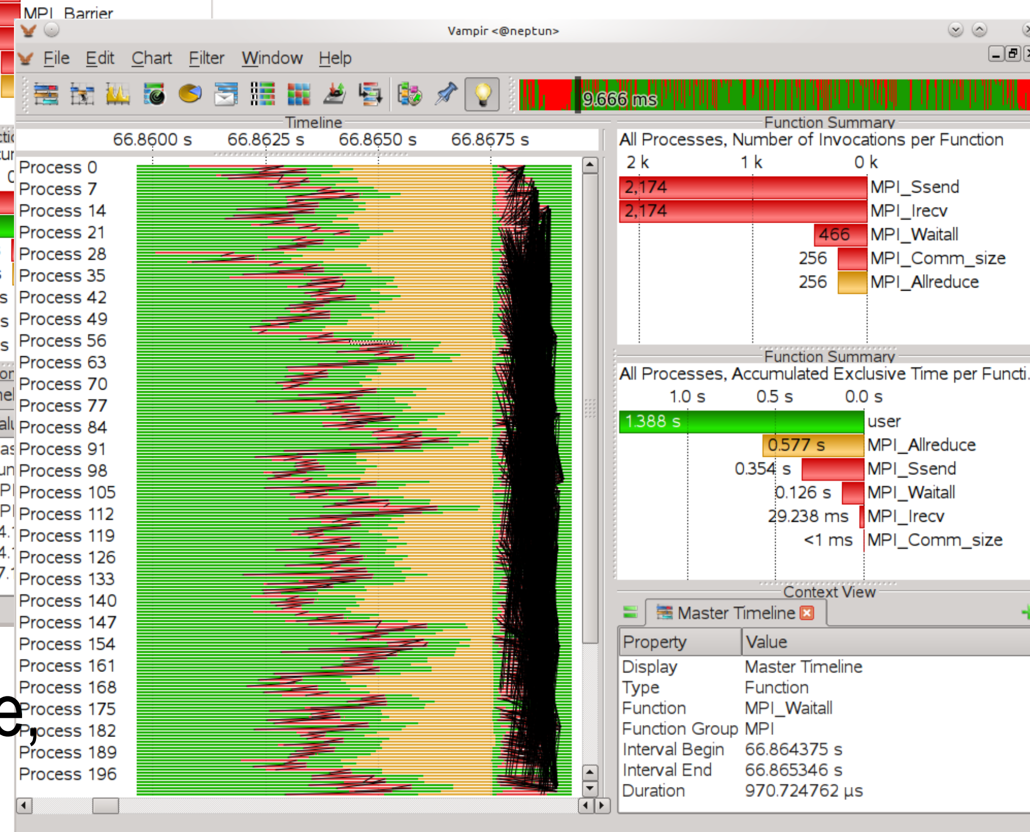
- Chains of MPI Sendrecv



→ Replace by faster over-lapping series of Send, Irecv, and Waitall

7.4 Unnecessary synchronization

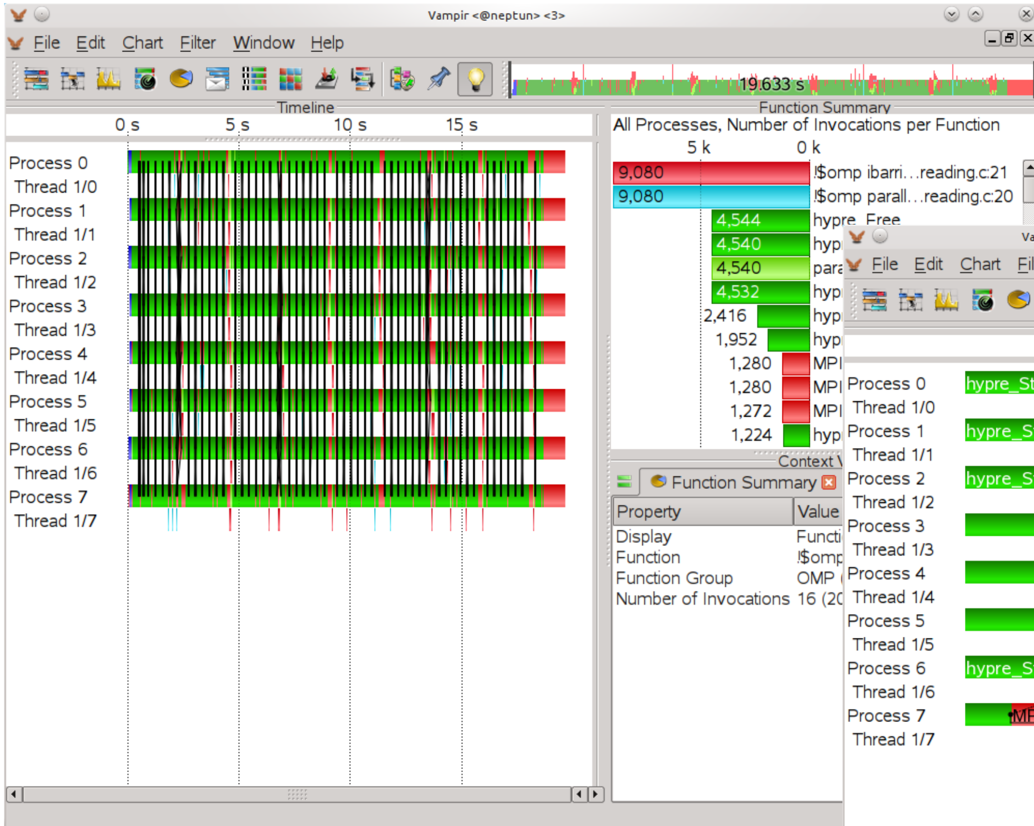




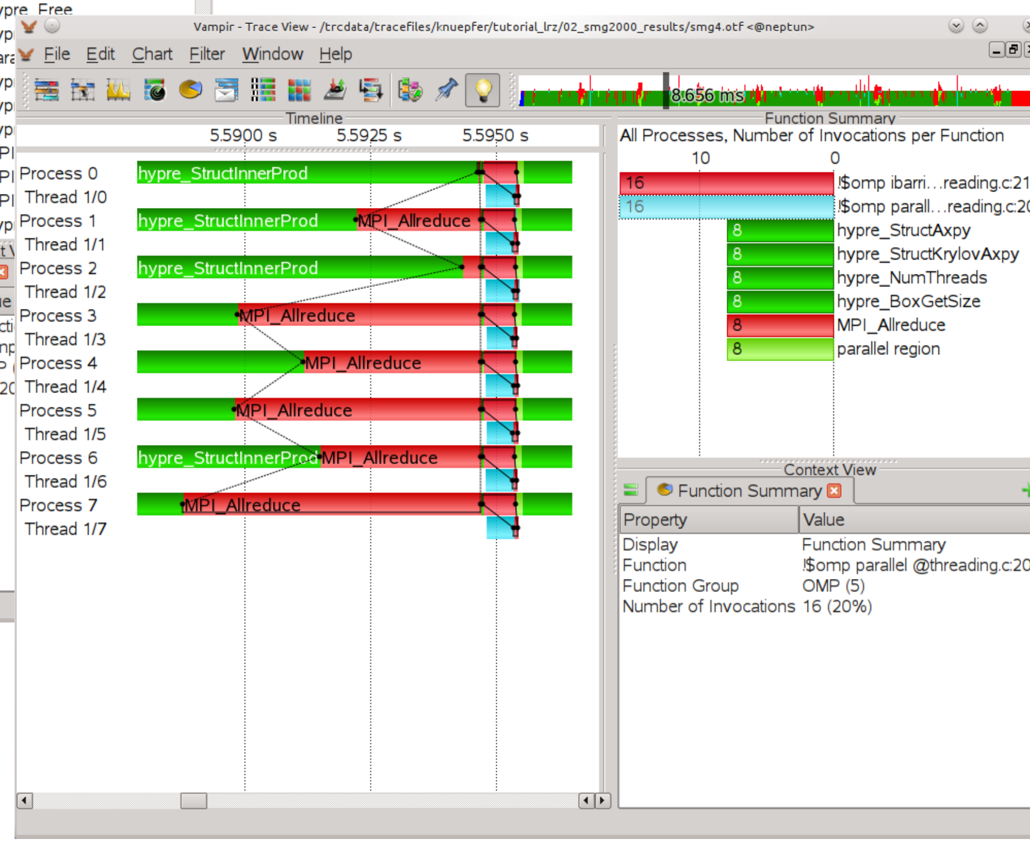
- Many MPI barriers are unneeded

→ Remove barriers if possible, following operations start less regular but are faster.

7.5 Low parallel efficiency

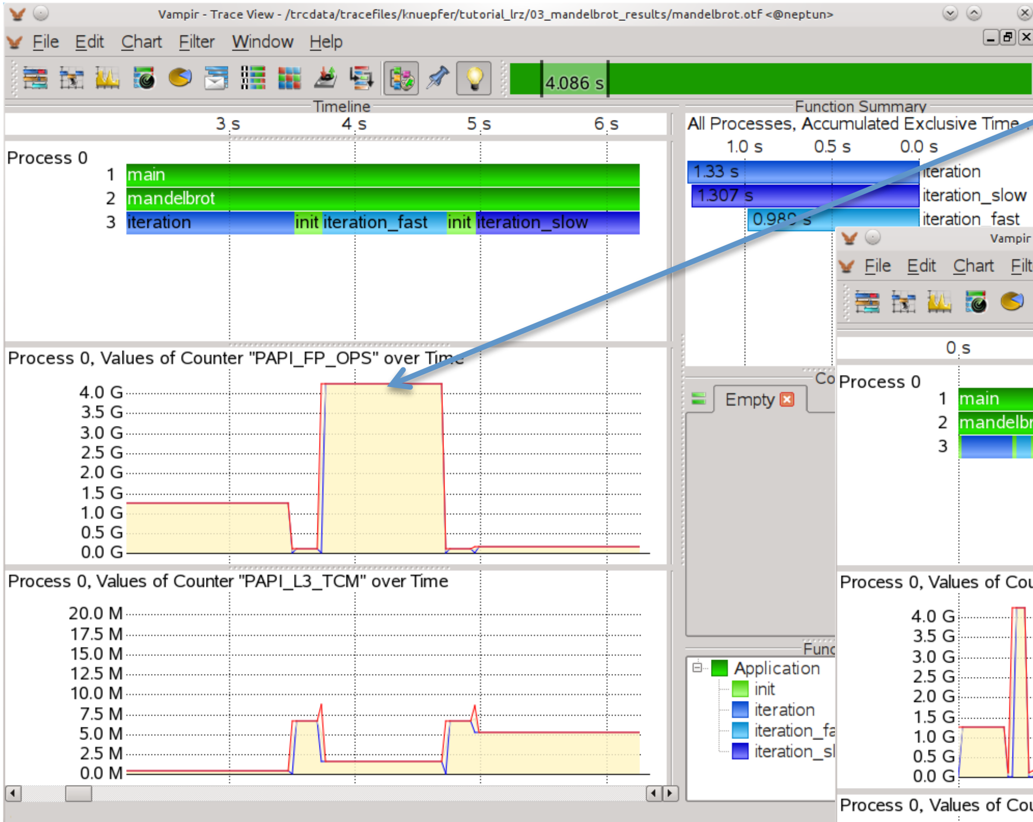


- Mostly idle OpenMP threads

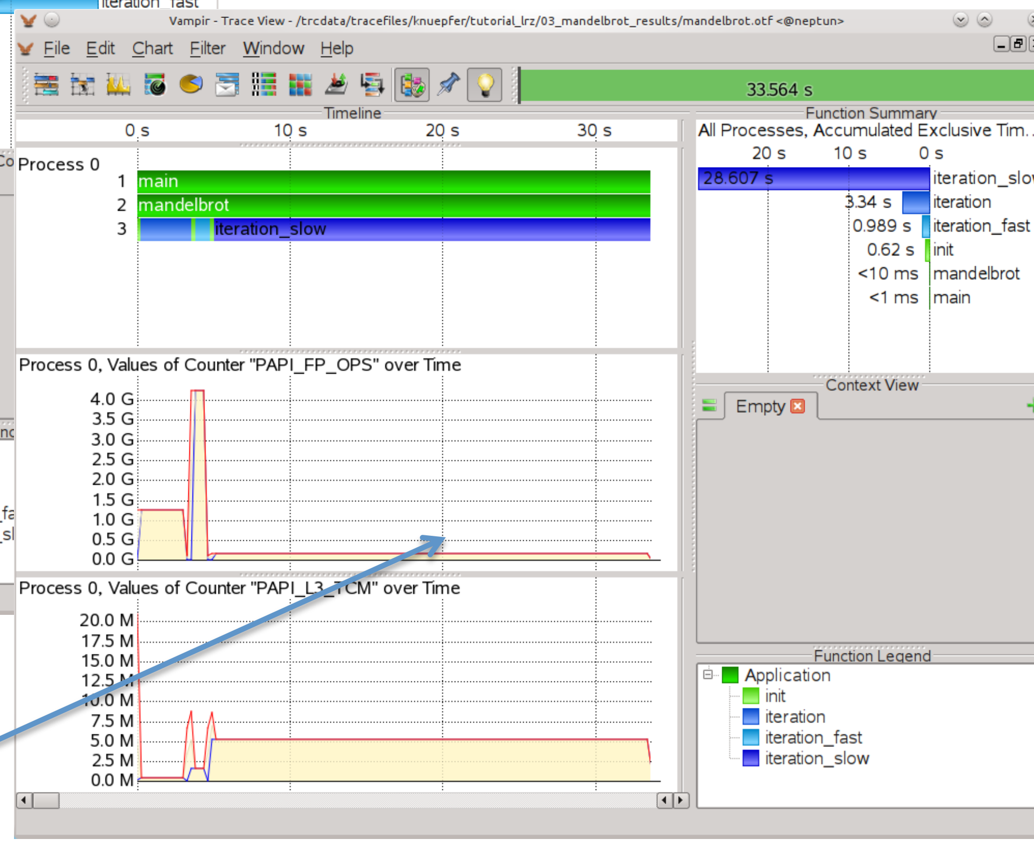


(Zoom)

7.6 Inefficient L1/L2/L3 cache usage



High rate of Flop/s with low rate of L3 cache misses



Low Flop/s rate due to a high L3 miss rate