VAMPIR & VAMPIRTRACE DETAILS AND HANDS-ON

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September 2009

Overview

- Event Tracing in General
- Hands-on: NPB 3.3 BT-MPI
- Finding Performance Bottlenecks

VAMPIR & VAMPIRTRACE
Event Tracing in General

Common Event Types

- enter/leave of function/routine/region
  - time stamp, process/thread, function ID
- send/receive of P2P message (MPI)
  - time stamp, sender, receiver, length, tag, communicator
- collective communication (MPI)
  - time stamp, process, root, communicator, # bytes
- hardware performance counter values
  - time stamp, process, counter ID, value
- etc.

- Tracing Advantages
  - preserve temporal and spatial relationships
  - allow reconstruction of dynamic behavior on any required abstraction level
  - profiles can be calculated from traces
- Tracing Disadvantages
  - traces can become very large
  - may cause perturbation
  - instrumentation and tracing is complicated
    - event buffering, clock synchronization, …

Instrumentation

- Instrumentation: Process of modifying programs to detect and report events

- there are various ways of instrumentation:
  - manually
    - large effort, error prone
    - difficult to manage
  - automatically
    - via source to source translation
    - via compiler instrumentation
    - Program Database Toolkit (PDT)
    - OpenMP Pragma And Region Instrumenter (Opari)

Open Trace Format (OTF)

- Open source trace file format
- Available at http://www.tu-dresden.de/zih/otf
- Includes powerful libotf for reading/parsing/writing in custom applications
- multi-level API:
  - High level interface for analysis tools
  - Low level interface for trace libraries
- Actively developed by TU Dresden in cooperation with the University of Oregon and the Lawrence Livermore National Laboratory

- Instrumentation with VampirTrace
  - hide instrumentation in compiler wrapper
  - use underlying compiler, add appropriate options

```
CC = mpicc

CC = vtcc –vt:cc mpicc
```

- Test Run
  - user representative test input
  - set parameters, environment variables, etc.
  - perform trace run
- Get Trace

Source Code Instrumentation

```
int foo(void* arg) {

    if (cond) {

        return 1;
    }

    return 0;
}
```

```
int foo(void* arg) {
    enter(7);
    if (cond) {
        leave(7);
        return 1;
    }
    leave(7);
    return 0;
}
```

manually or automatically

VAMPIR & VAMPIRTRACE HANDS-ON: NPB 3.3 BT-MPI

Hands-on: NPB 3.3 BT-MPI

- Move into tutorial directory in your home directory

```
% cd NPB3.3-MPI
```

- Select the VampirTrace compiler wrappers

```
% gedit config/make.def
    -> comment out line 32, resulting in:
            ...
            32: #MPIF77 = mpif77
            ...
    -> remove the comment from line 38, resulting in:
            ...
            38: MPIF77 = vtf77 –vt:f77 mpif77
            ...
    -> comment out line 88, resulting in:
            ...
            88: #MPICC = mpicc
            ...
    -> remove the comment from line 94, resulting in:
            ...
            94: MPICC = vtcc  -vt:cc mpicc
            ...
```

- Build benchmark

```
% make clean; make suite
```

- Launch as MPI application

```
% cd bin.vampir; export VT_FILE_PREFIX=bt_1_initial
% mpiexec –np 16 bt_W.16

 NAS Parallel Benchmarks 3.3 -- BT Benchmark

 Size:   24x  24x  24
 Iterations:  200    dt:   0.0008000
 Number of active processes:    16

 Time step    1
 ...
 Time step  180
[0]VampirTrace: Maximum number of buffer flushes reached \
(VT_MAX_FLUSHES=1)
[0]VampirTrace: Tracing switched off permanently
 Time step  200
 ...
```

- Resulting trace files

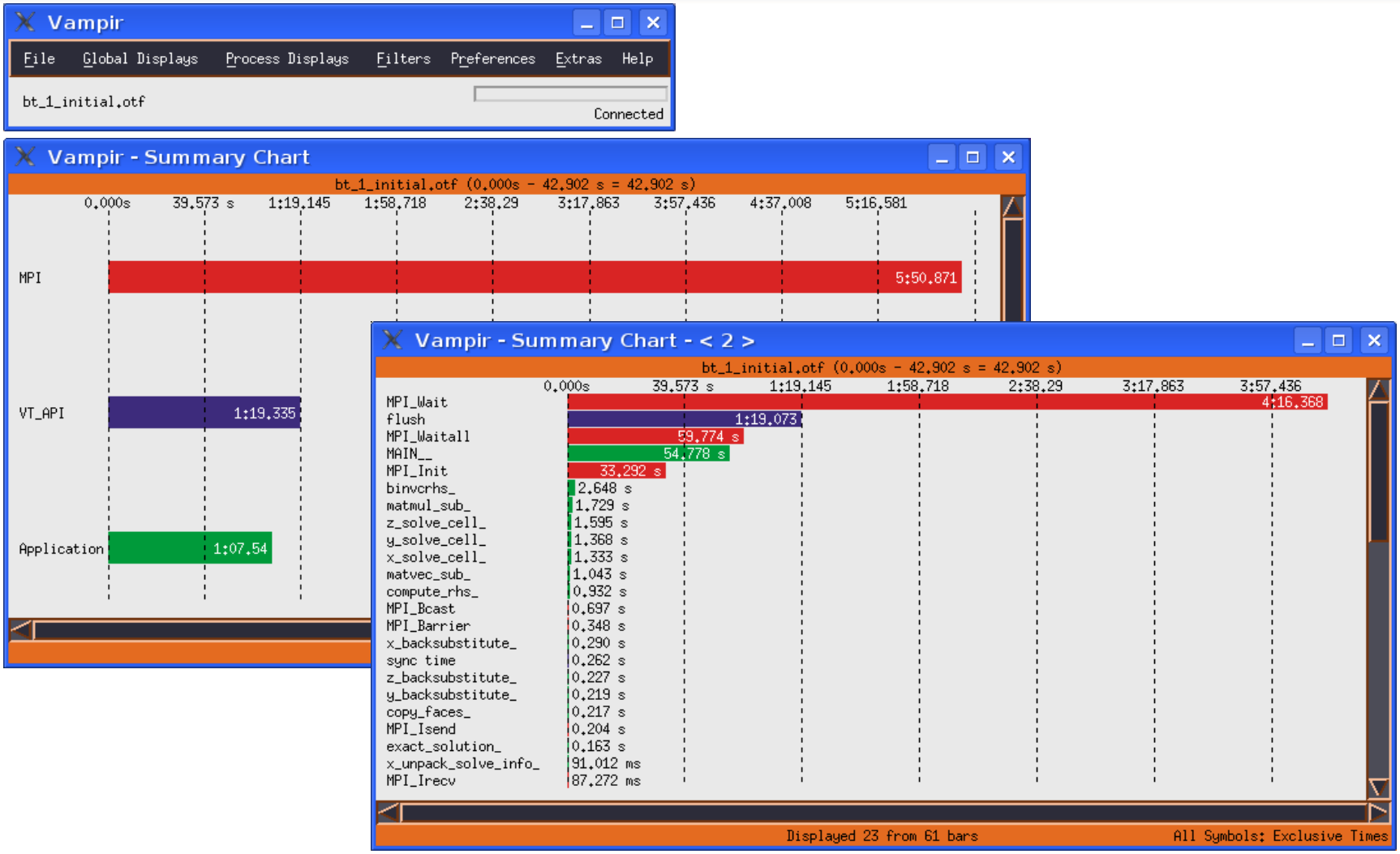
```
% ls -alh
4,1M bt_1_initial.16
4,9K bt_1_initial.16.0.def.z
29 bt_1_initial.16.0.marker.z
12M bt_1_initial.16.10.events.z
12M bt_1_initial.16.1.events.z
11M bt_1_initial.16.2.events.z
12M bt_1_initial.16.3.events.z
...
11M bt_1_initial.16.c.events.z
12M bt_1_initial.16.d.events.z
12M bt_1_initial.16.e.events.z
12M bt_1_initial.16.f.events.z
66 bt_1_initial.16.otf
```

- Visualization with VampirServer

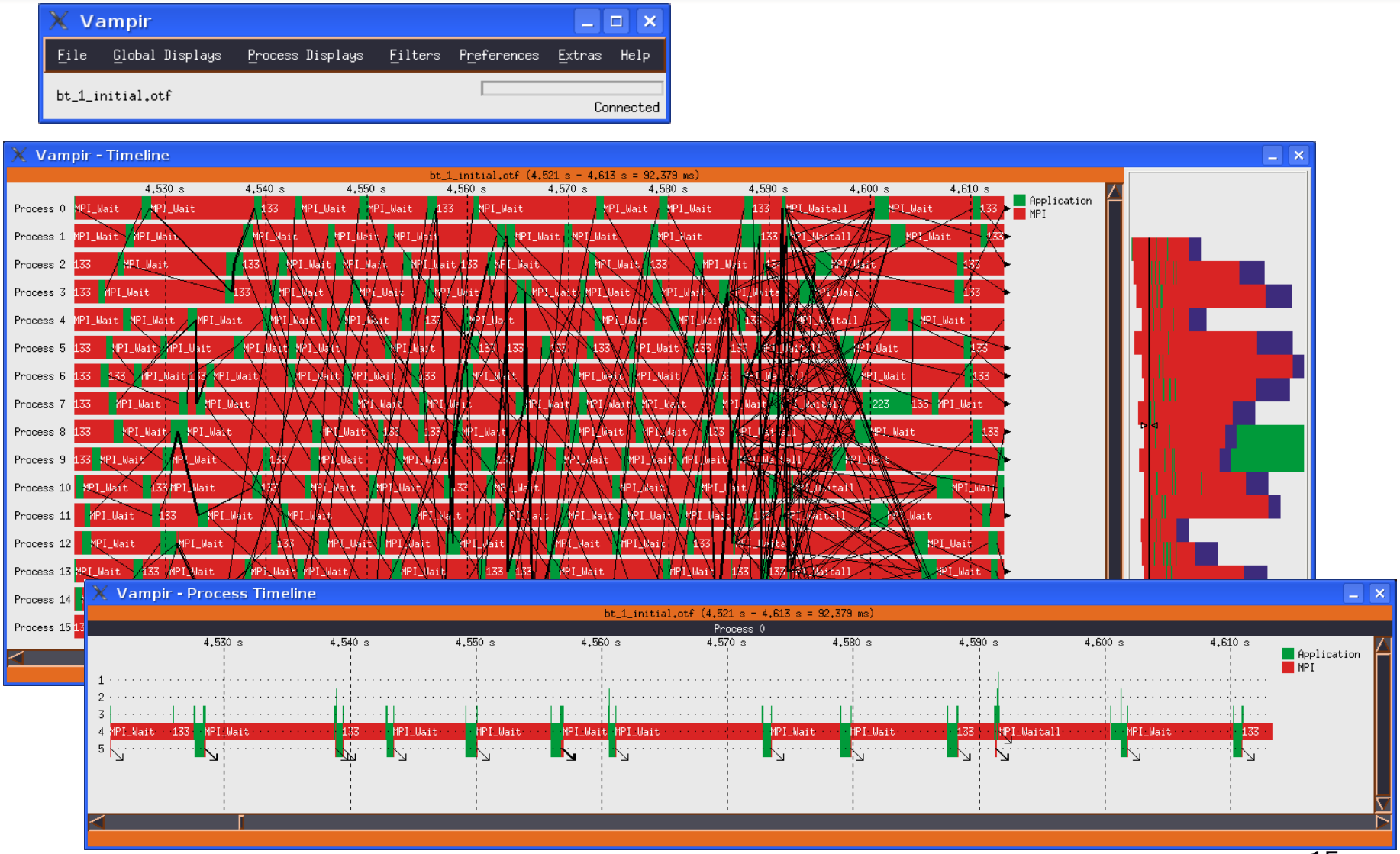
```
% mpirun –np <X> vngd
```

```
% vng &
```

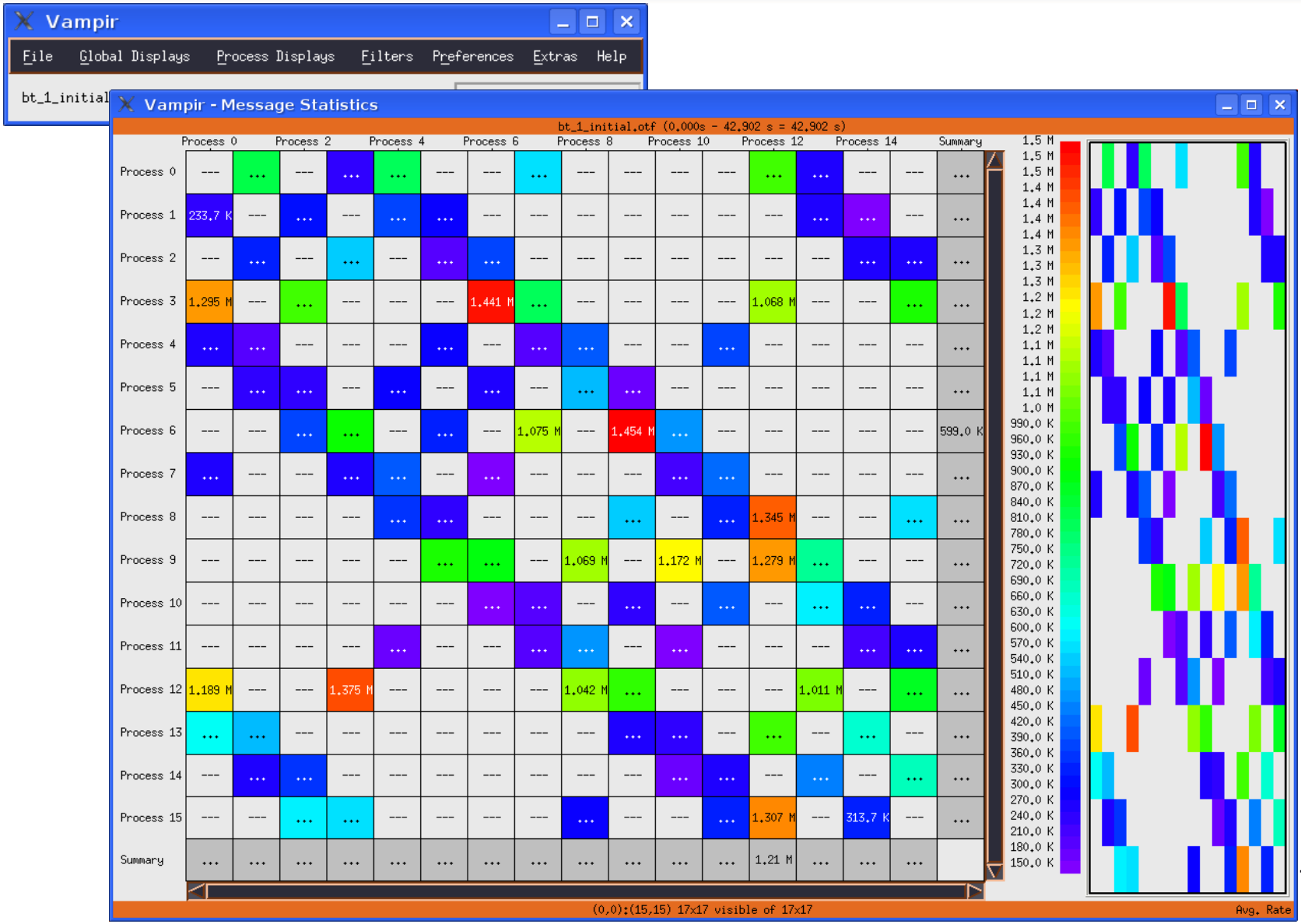
Hands-on: NPB 3.3 BT-MPI



Hands-on: NPB 3.3 BT-MPI



Hands-on: NPB 3.3 BT-MPI



- Increase the number of buffer flushes

```
% export VT_MAX_FLUSHES=10
```

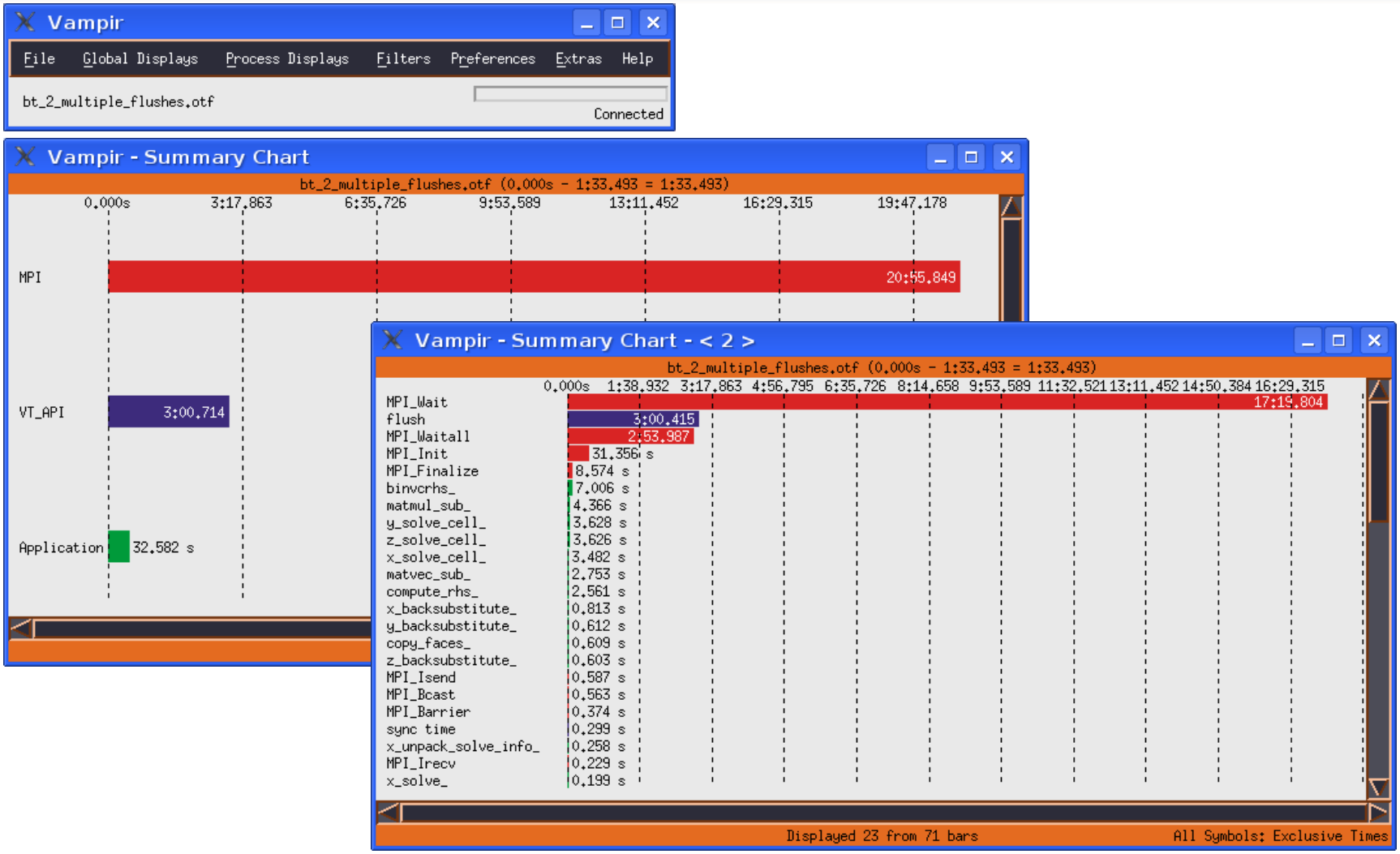
- Set a new file prefix

```
% export VT_FILE_PREFIX=bt_2_multiple_flushes
```

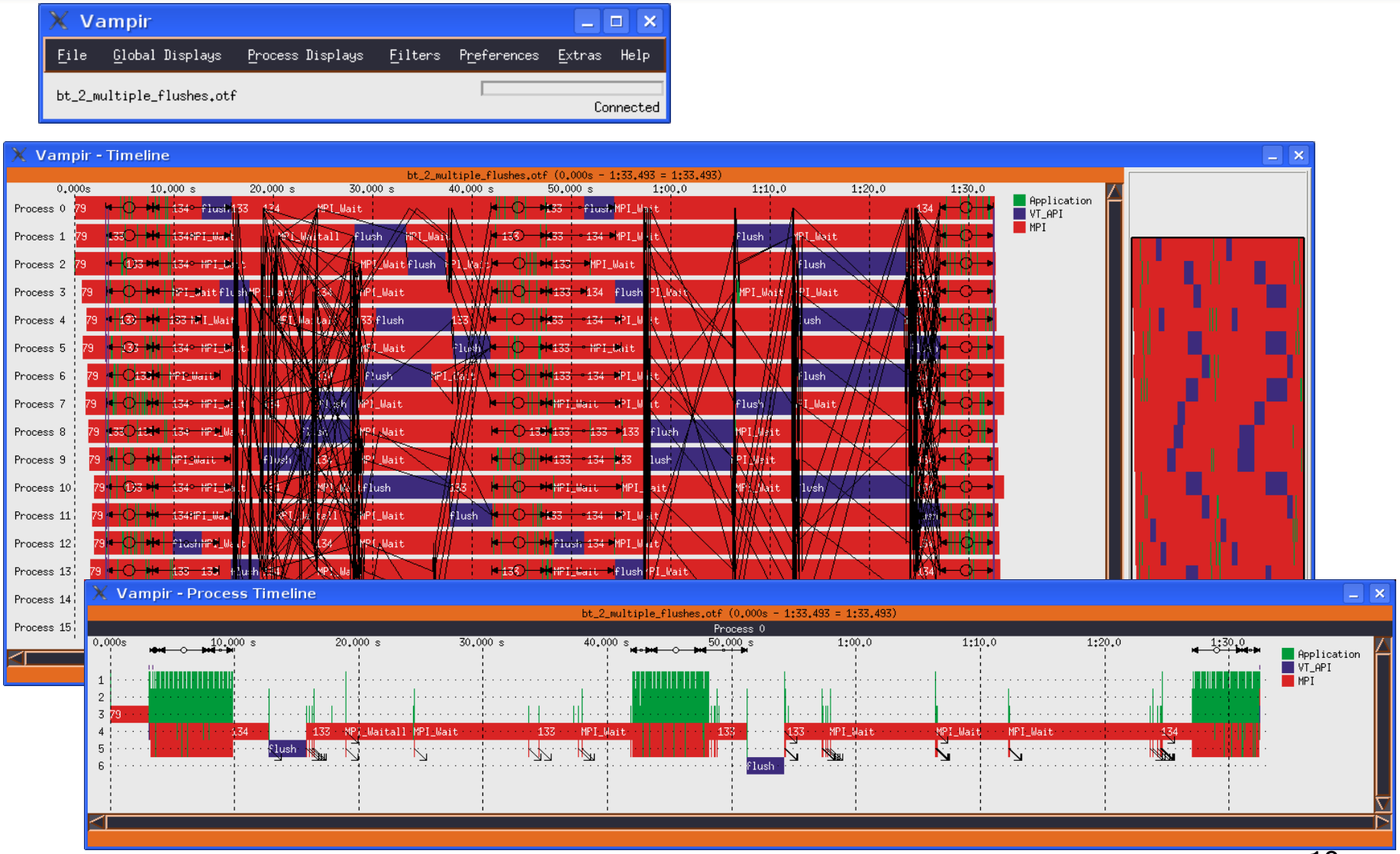
- Launch as MPI application

```
% mpiexec -np 16 bt_W.16
```

Hands-on: NPB 3.3 BT-MPI



Hands-on: NPB 3.3 BT-MPI



- Decrease number of buffer flushes by increasing the buffer size

```
% export VT_MAX_FLUSHES=1 VT_BUFFER_SIZE=120M
```

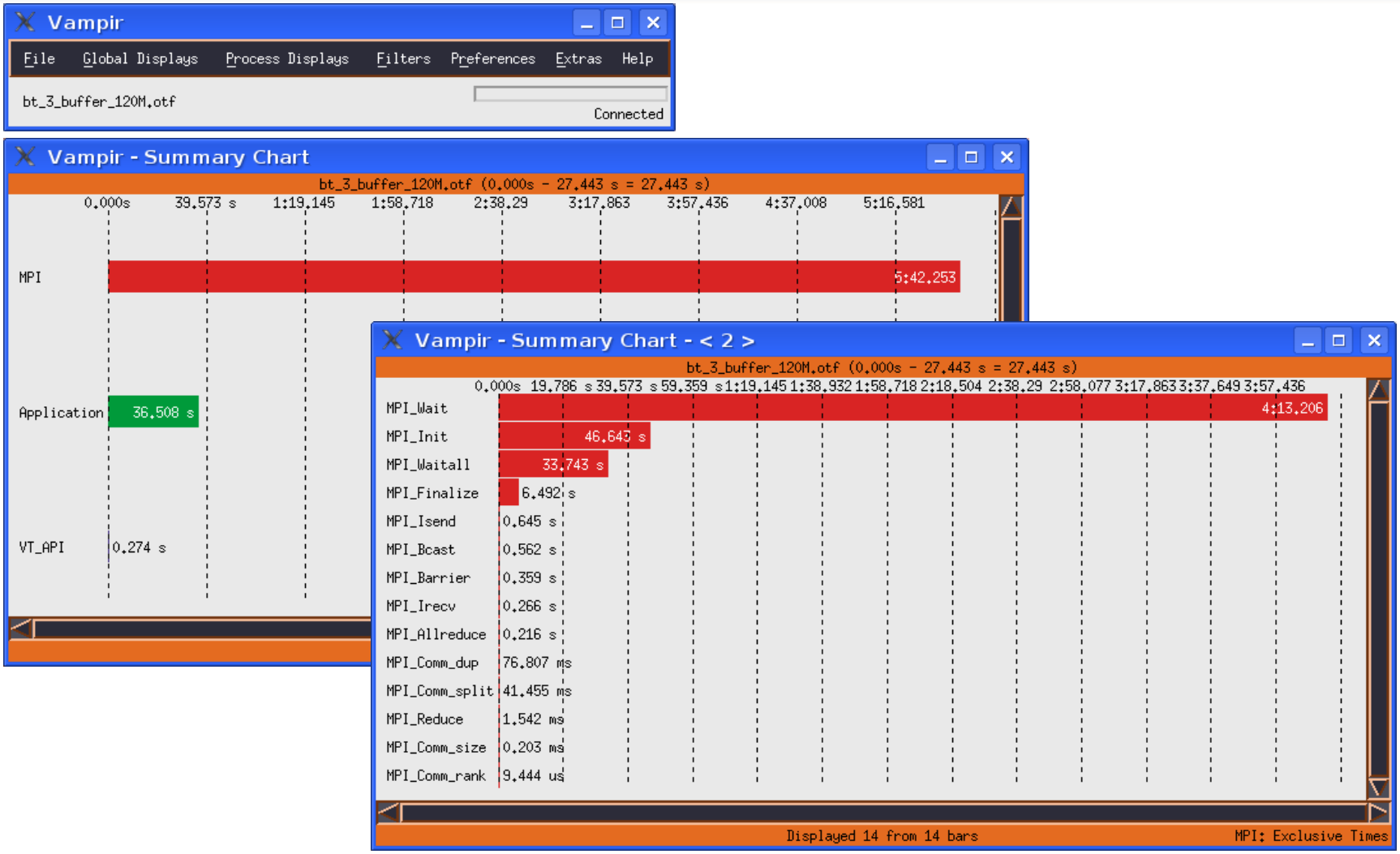
- Set a new file prefix

```
% export VT_FILE_PREFIX=bt_3_buffer_120M
```

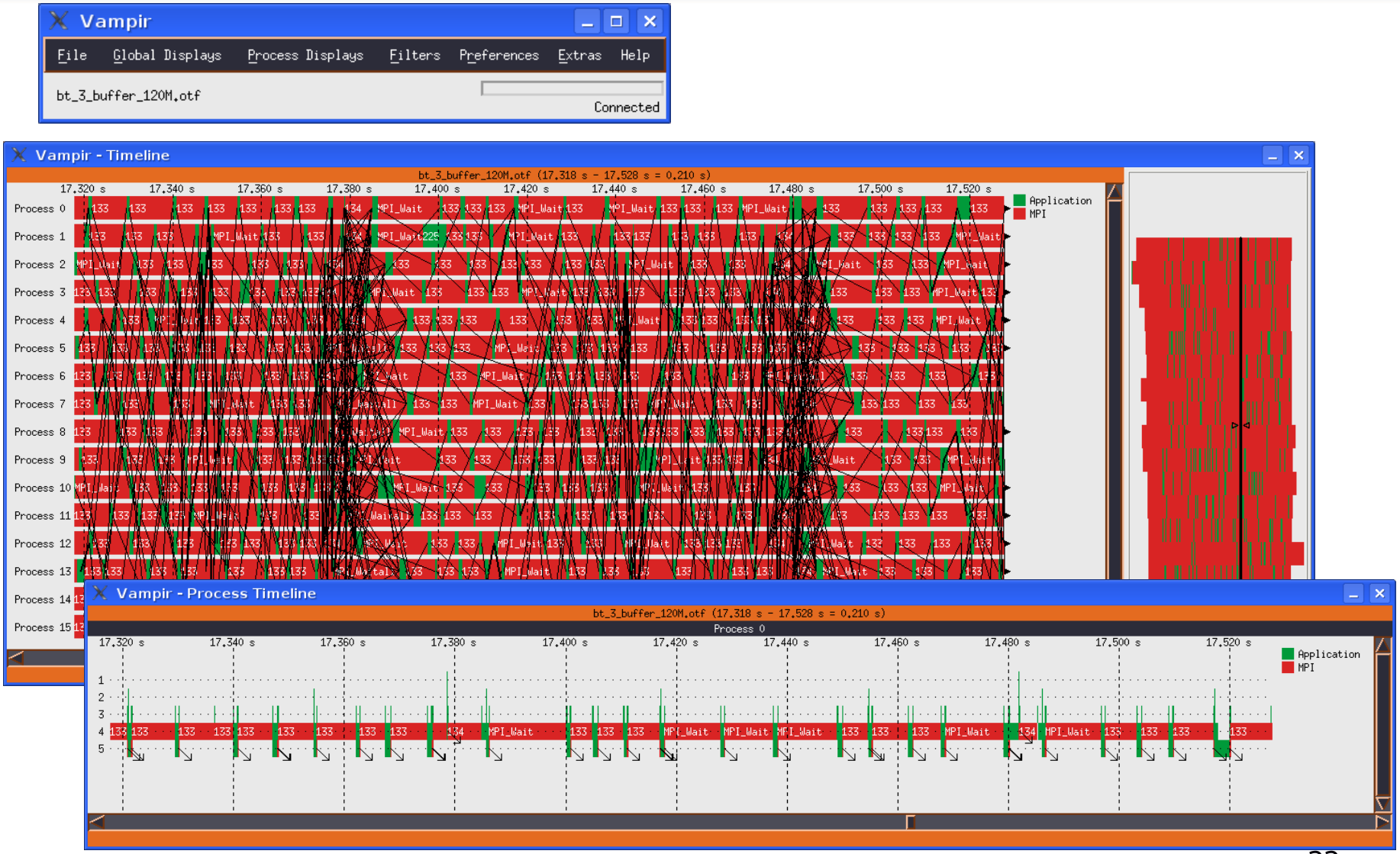
- Launch as MPI application

```
% mpiexec -np 16 bt_W.16
```

Hands-on: NPB 3.3 BT-MPI



Hands-on: NPB 3.3 BT-MPI



Function Filtering

- Filtering is one of the ways to reduce trace size
- Environment variable VT_FILTER_SPEC

```
% export VT_FILTER_SPEC = /home/user/filter.spec
```

- Filter definition file contains a list of filters

```
my_*;test_* -- 1000
debug_* -- 0
calculate -- -1
* -- 1000000
```

- See also the vtfilter tool
  - can generate a customized filter file
  - can reduce the size of existing trace files

Function Grouping

- Groups can be defined for related functions
  - Groups can be assigned different colors, highlighting different activities
- Environment variable VT_GROUPS_SPEC

```
% export VT_GROUPS_SPEC = /home/user/groups.spec
```

- Group file contains a list of associated entries

```
CALC=calculate
MISC=my*;test
UNKNOWN=*
```

- Generate filter specification file

```
% vtfilter -gen -fo filter.txt -r 10 -stats  \
  -p bt_3_buffer_120M.otf
% export VT_FILTER_SPEC=filter.txt
```

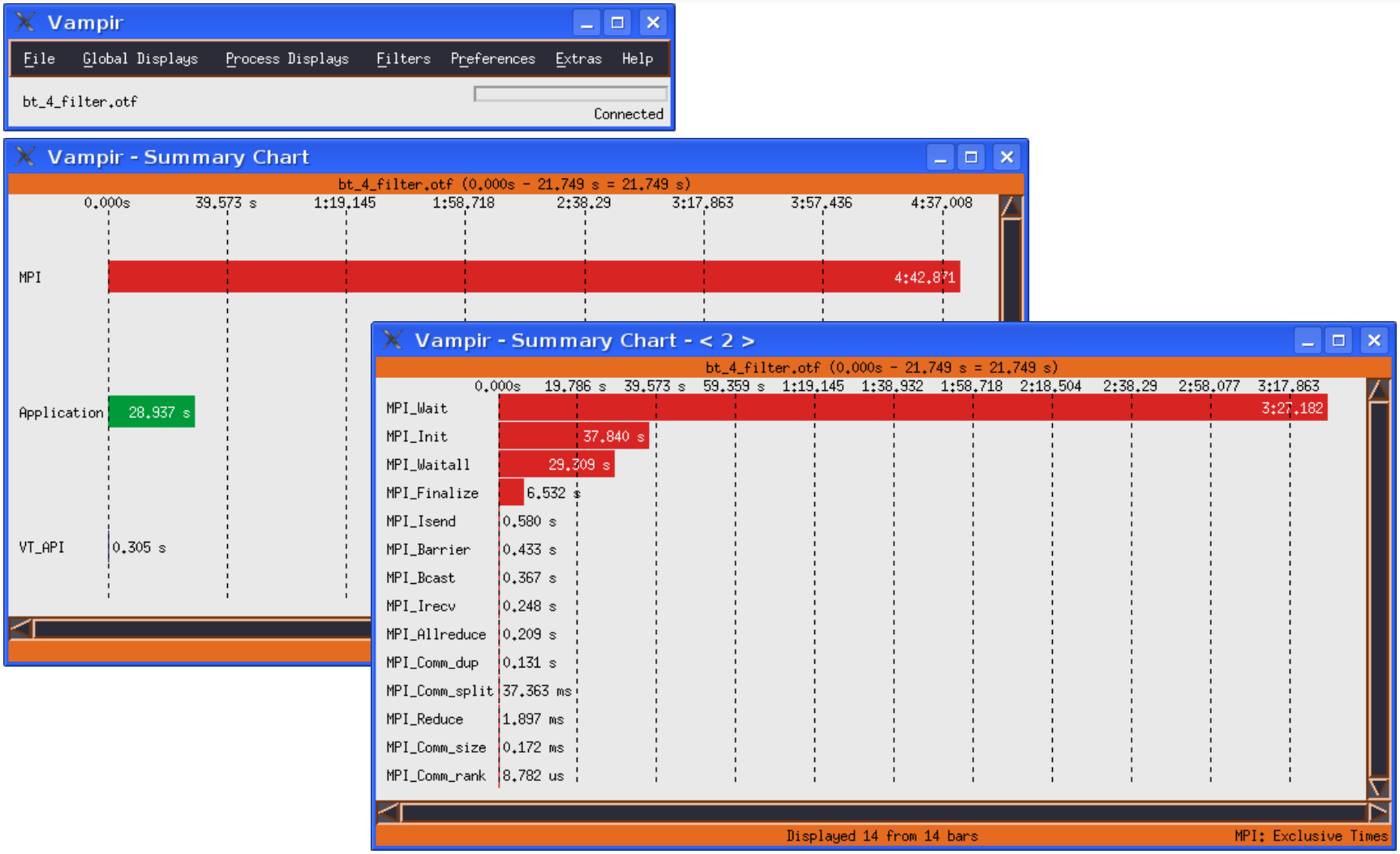
- Set a new file prefix

```
% export VT_FILE_PREFIX=bt_4_filter
```

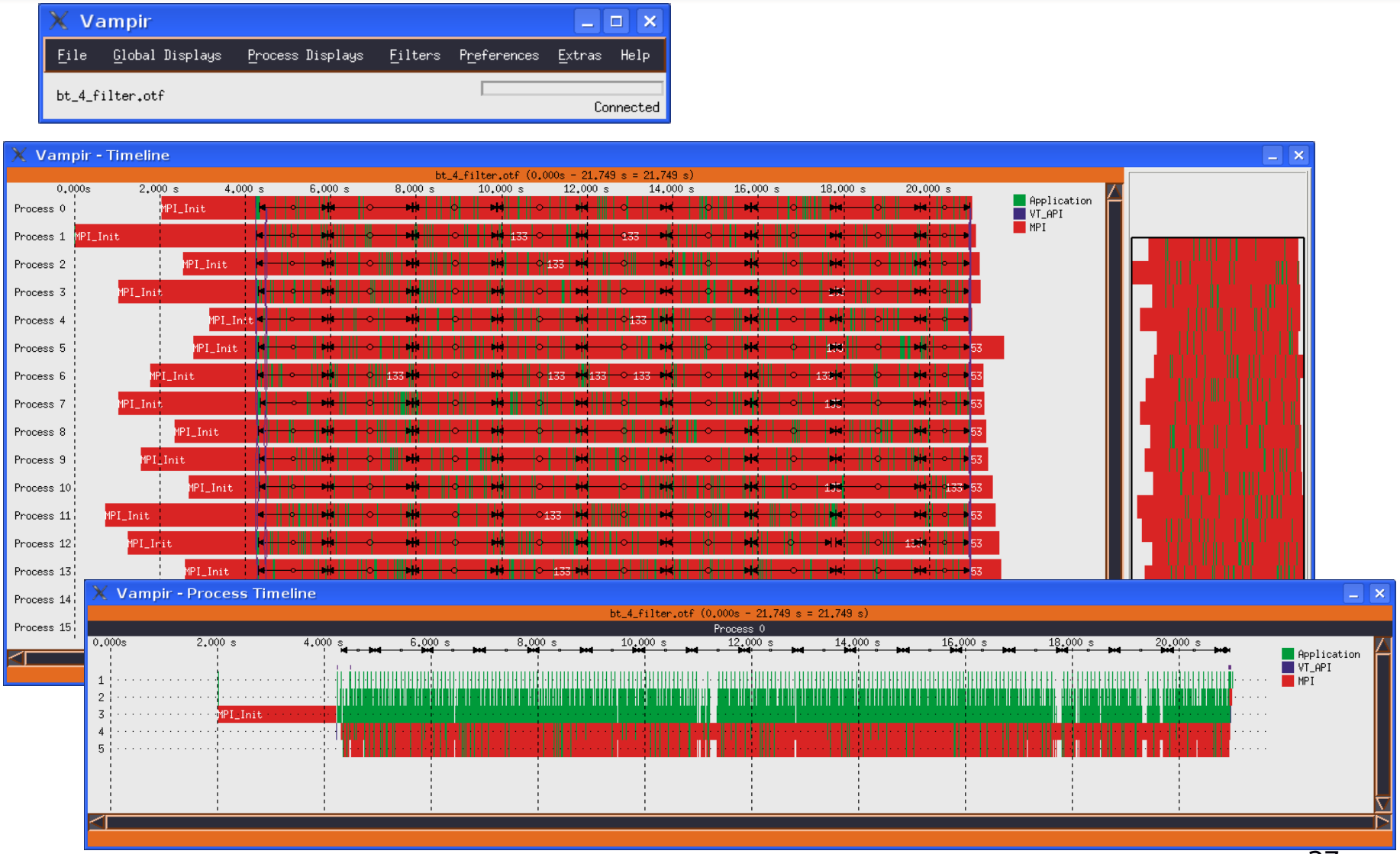
- Launch as MPI application

```
% mpiexec -np 16 bt_W.16
```

Hands-on: NPB 3.3 BT-MPI



Hands-on: NPB 3.3 BT-MPI



- PAPI counters can be included in traces
  - If VampirTrace was build with PAPI support
  - If PAPI is available on the platform
- VT_METRICS specifies a list of PAPI counters

```
% export VT_METRICS = PAPI_FP_OPS:PAPI_L2_TCM
```

- see also the PAPI commands papi_avail and papi_command_line

Memory Allocation and I/O counters

- Memory allocation counters can be recorded:
  - If VampirTrace build with memory allocation tracing support
  - If GNU glibc is used on the platform
- intercept glibc functions like “malloc” and “free”
- Environment variable VT_MEMTRACE

```
% export VT_MEMTRACE = yes
```

- I/O counters can be included in traces
  - If VampirTrace was build with I/O tracing support
- Standard I/O calls like “open” and “read” are recorded
- Environment variable VT_IOTRACE

```
% export VT_IOTRACE = yes
```

- Record PAPI hardware counters

```
% papi_avail
% papi_event_chooser PRESET PAPI_FP_OPS
% export VT_METRICS=PAPI_FP_OPS:PAPI_L2_TCM
```

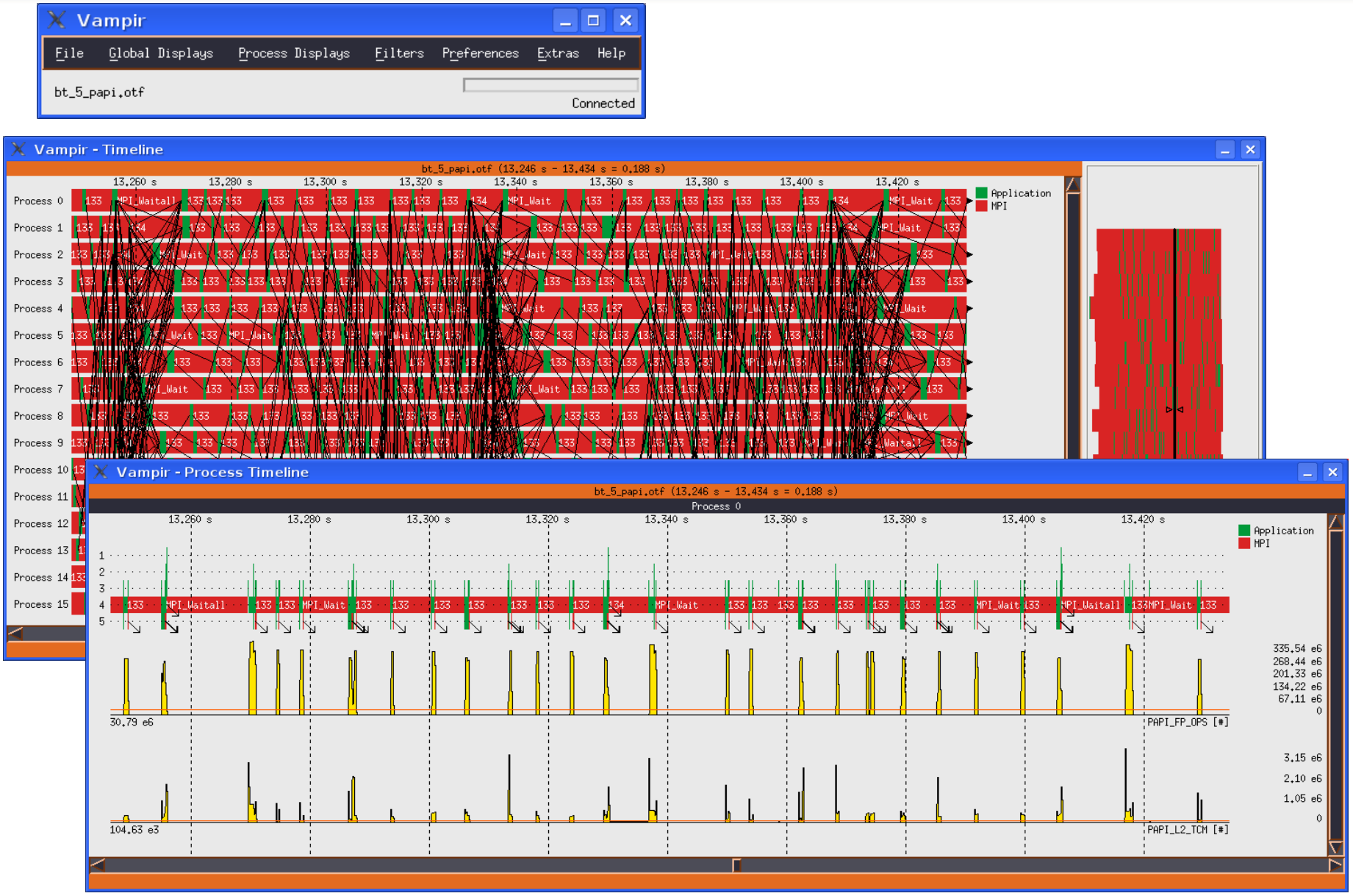
- Set a new file prefix

```
% export VT_FILE_PREFIX=bt_5_papi
```

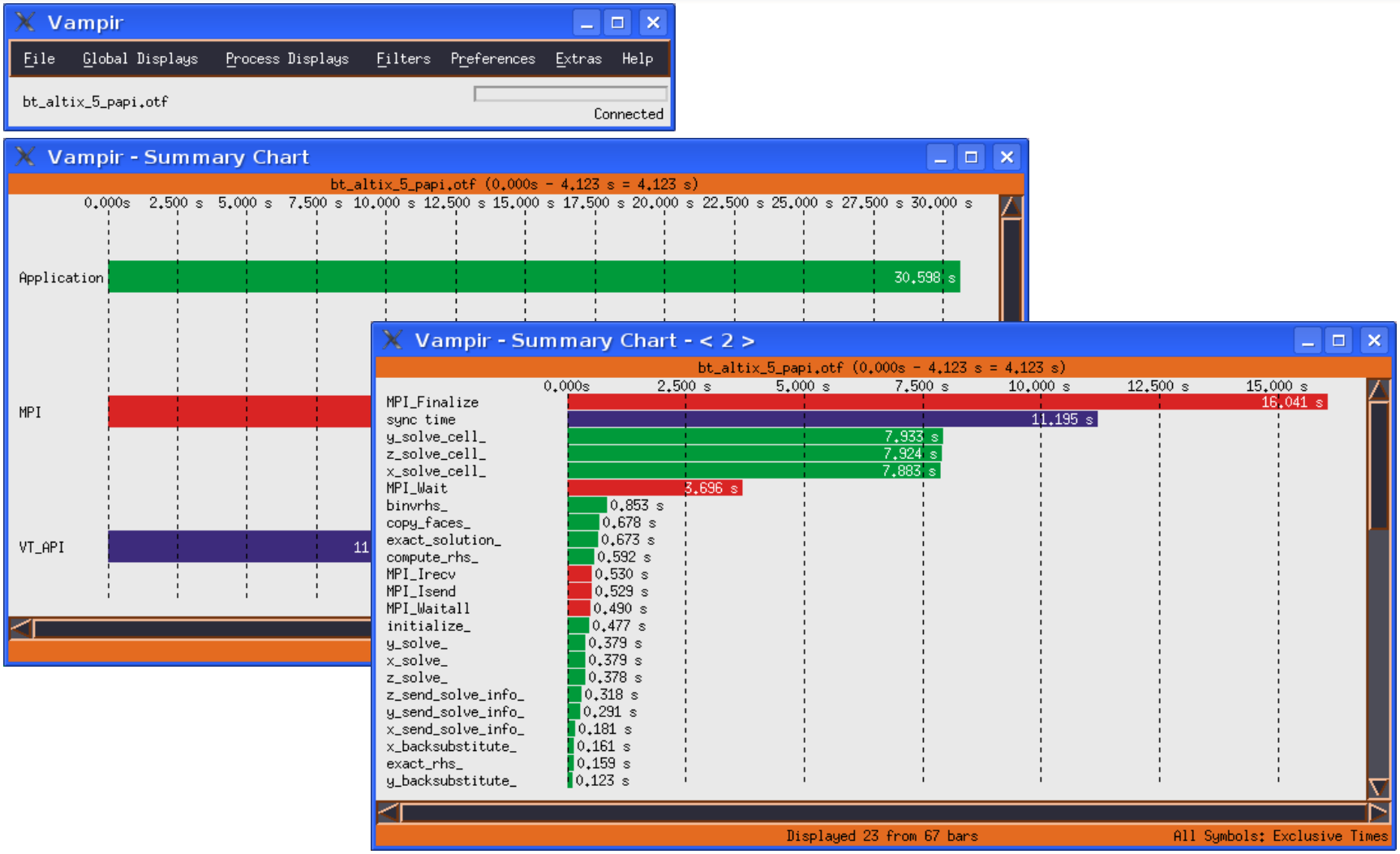
- Launch as MPI application

```
% mpiexec -np 16 bt_W.16
```

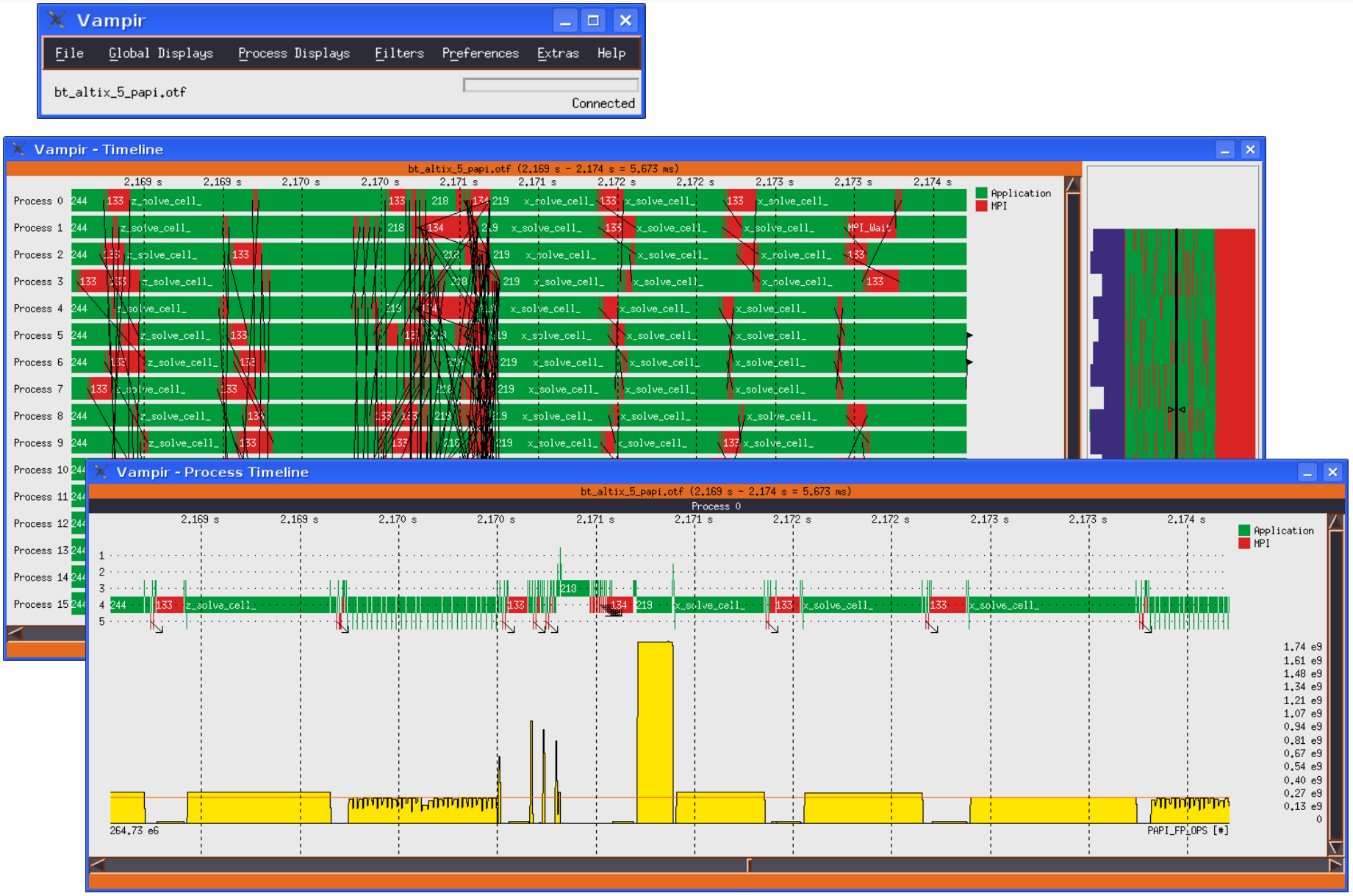
Hands-on: NPB 3.3 BT-MPI



Hands-on: NPB 3.3 BT-MPI



Hands-on: NPB 3.3 BT-MPI



VampirTrace Run-Time Options

- control options by environment variables:

– VT_PFORM_GDIR	Directory for final trace files
– VT_PFORM_LDIR	Directory for intermediate files
– VT_FILE_PREFIX	Trace file name
– VT_BUFFER_SIZE	Internal trace buffer size
– VT_MAX_FLUSHES	Mac number of buffer flushes
– VT_MEMTRACE	Enable memory allocation tracing
– VT_IOTRACE	Enable I/O tracing
– VT_MPITRACE	Enable MPI tracing
– VT_FILTER_SPEC	Name of filter definition file
– VT_GROUPS_SPEC	Name of grouping definition file
– VT_METRICS	PAPI counter selection

VAMPIR & VAMPIRTRACE
Finding Performance Bottlenecks

- Trace Visualization
  - Vampir provides a number of display types
  - each allows many different options
- Advice
  - 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

Finding Bottlenecks

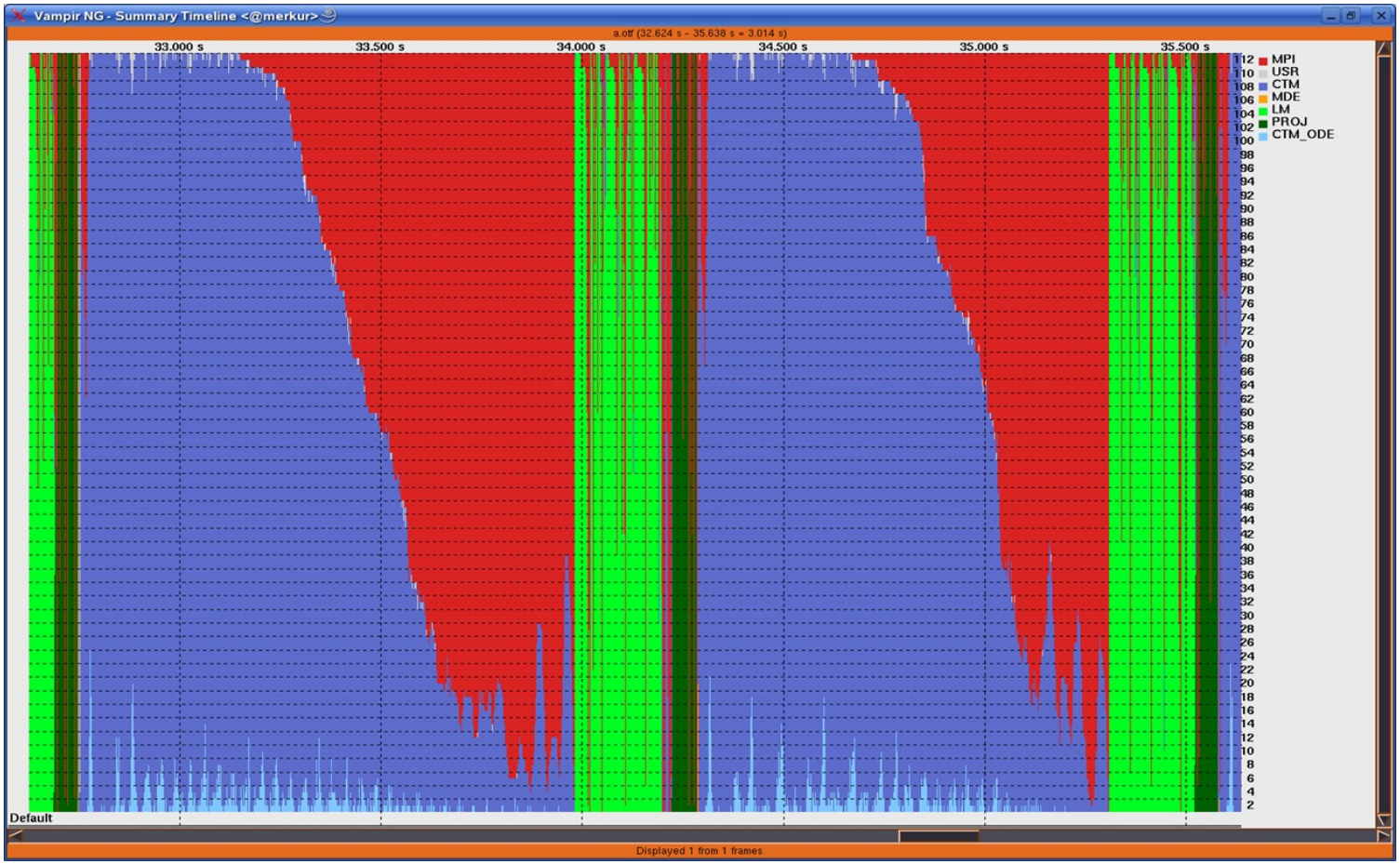
- Communication
- Computation
- Memory, I/O, etc.
- Tracing itself

Bottlenecks in Communication

- communications as such (dominating over computation)
- late sender, late receiver
- point-to-point messages instead of collective communication
- unmatched messages
- overcharge of MPI's buffers
- bursts of large messages (bandwidth)
- frequent short messages (latency)
- unnecessary synchronization (barrier)

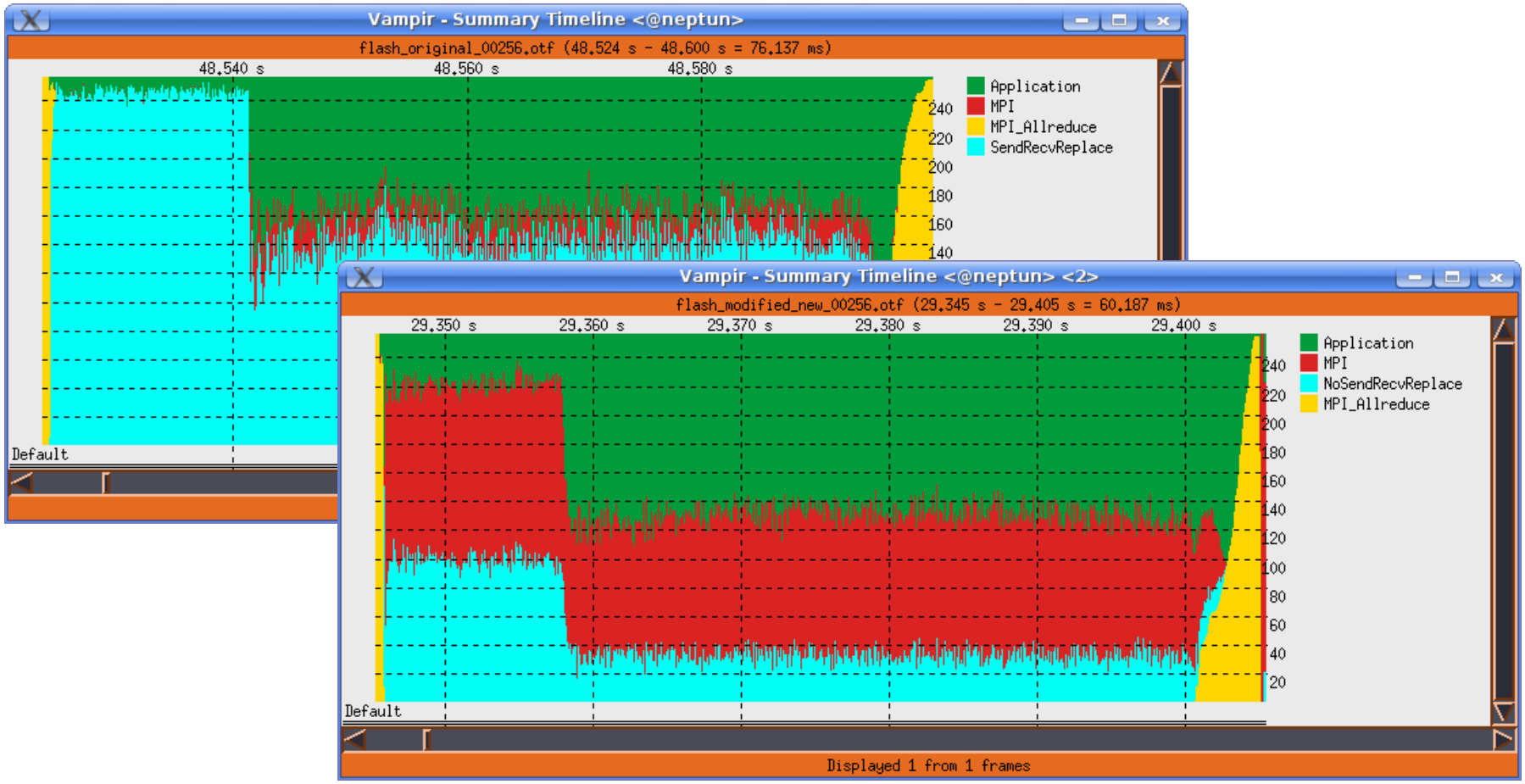
all of the above usually result in high MPI time share

Bottlenecks in Communication



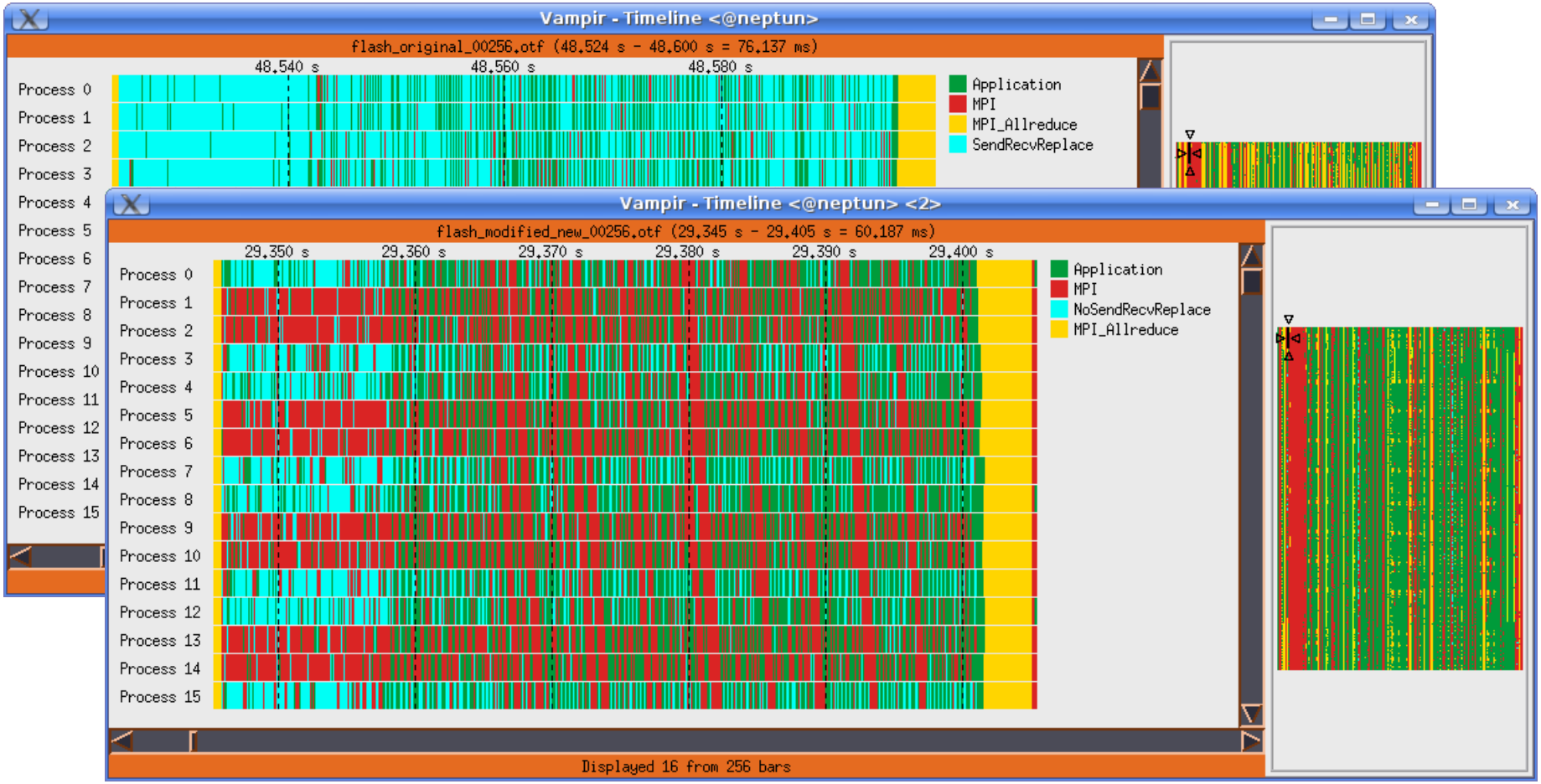
Example: prevalent communication

Bottlenecks in Communication



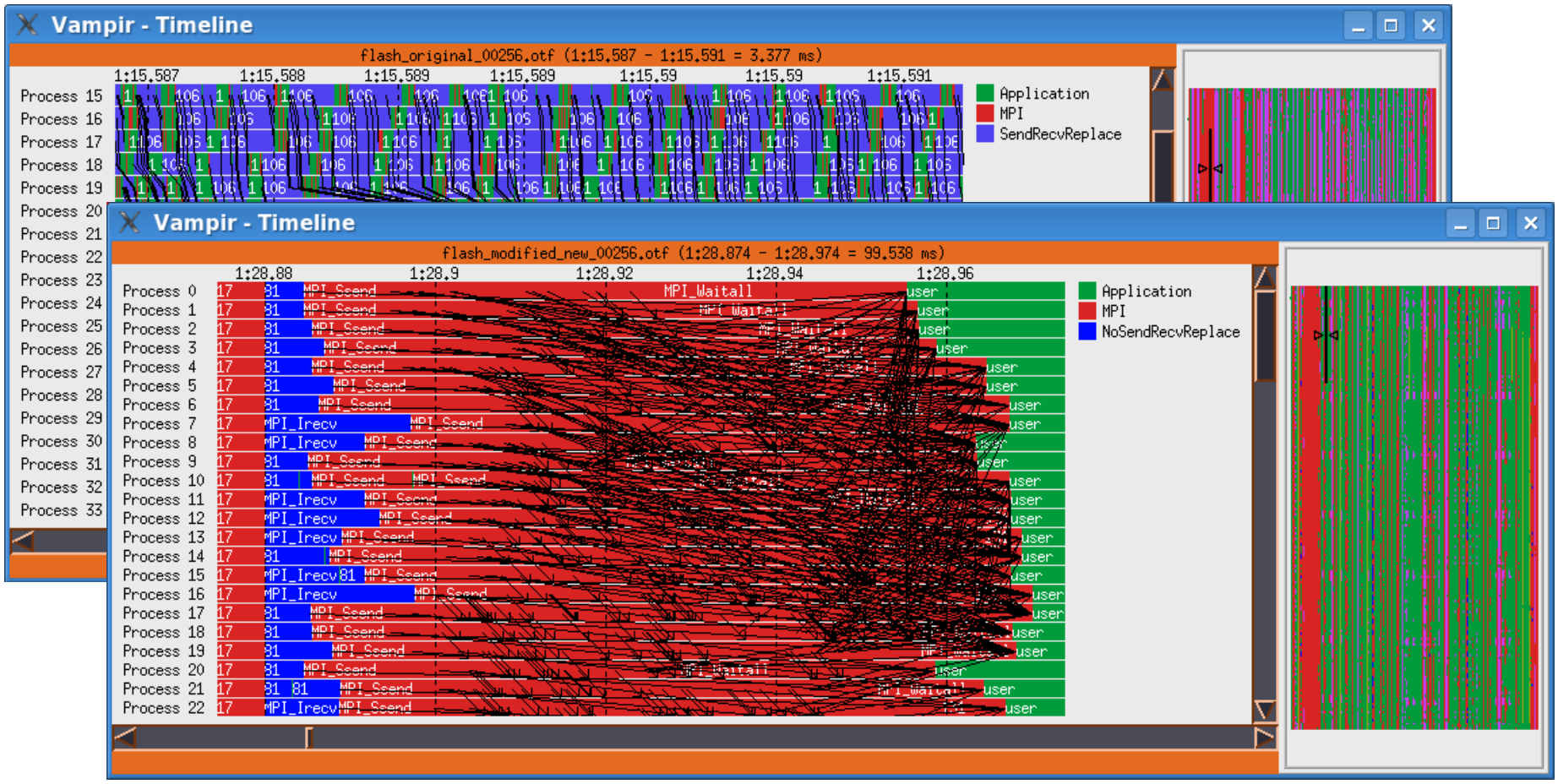
prevalent communication: MPI_Allreduce

Bottlenecks in Communication



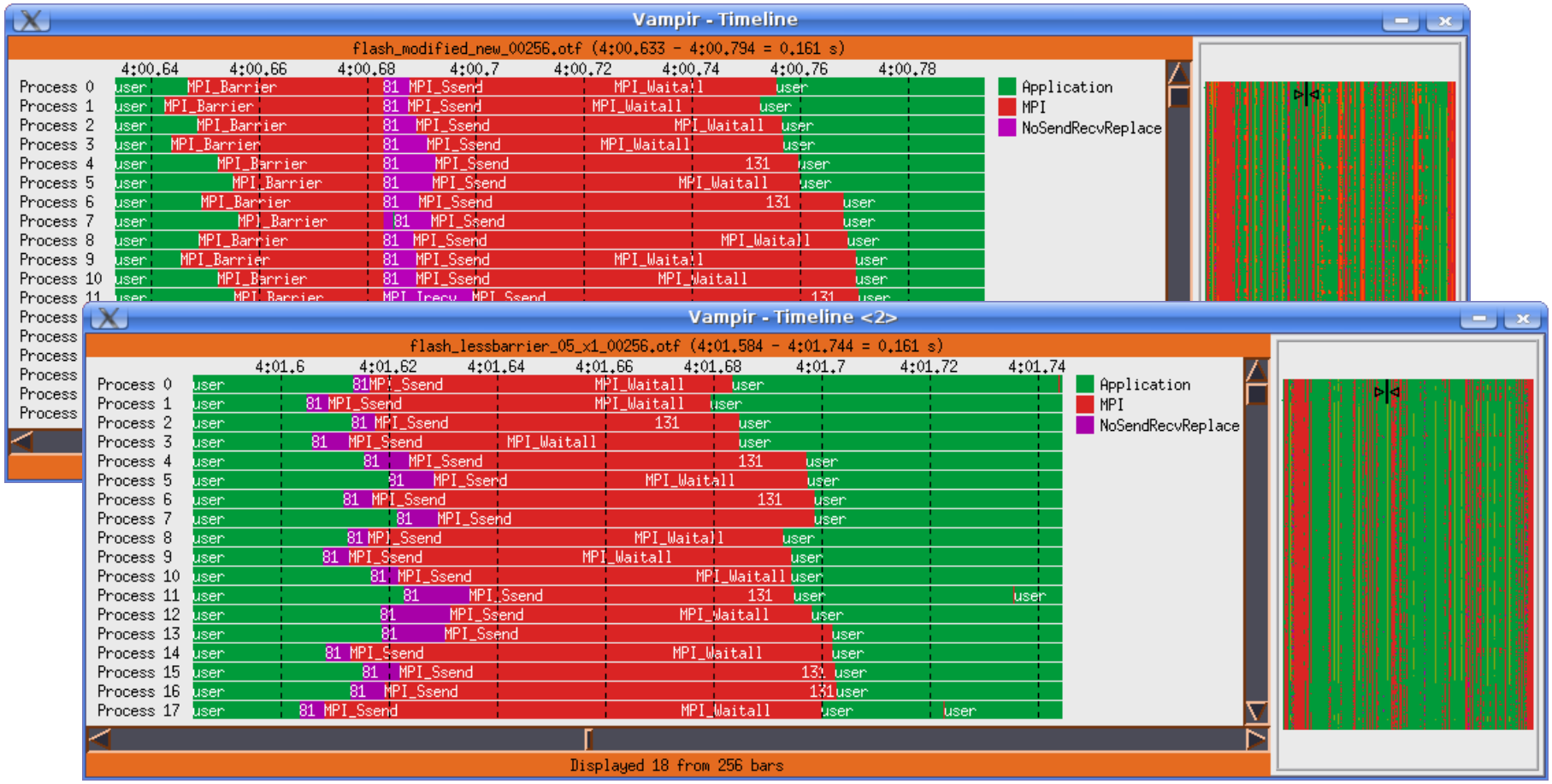
prevalent communication: timeline view

Bottlenecks in Communication



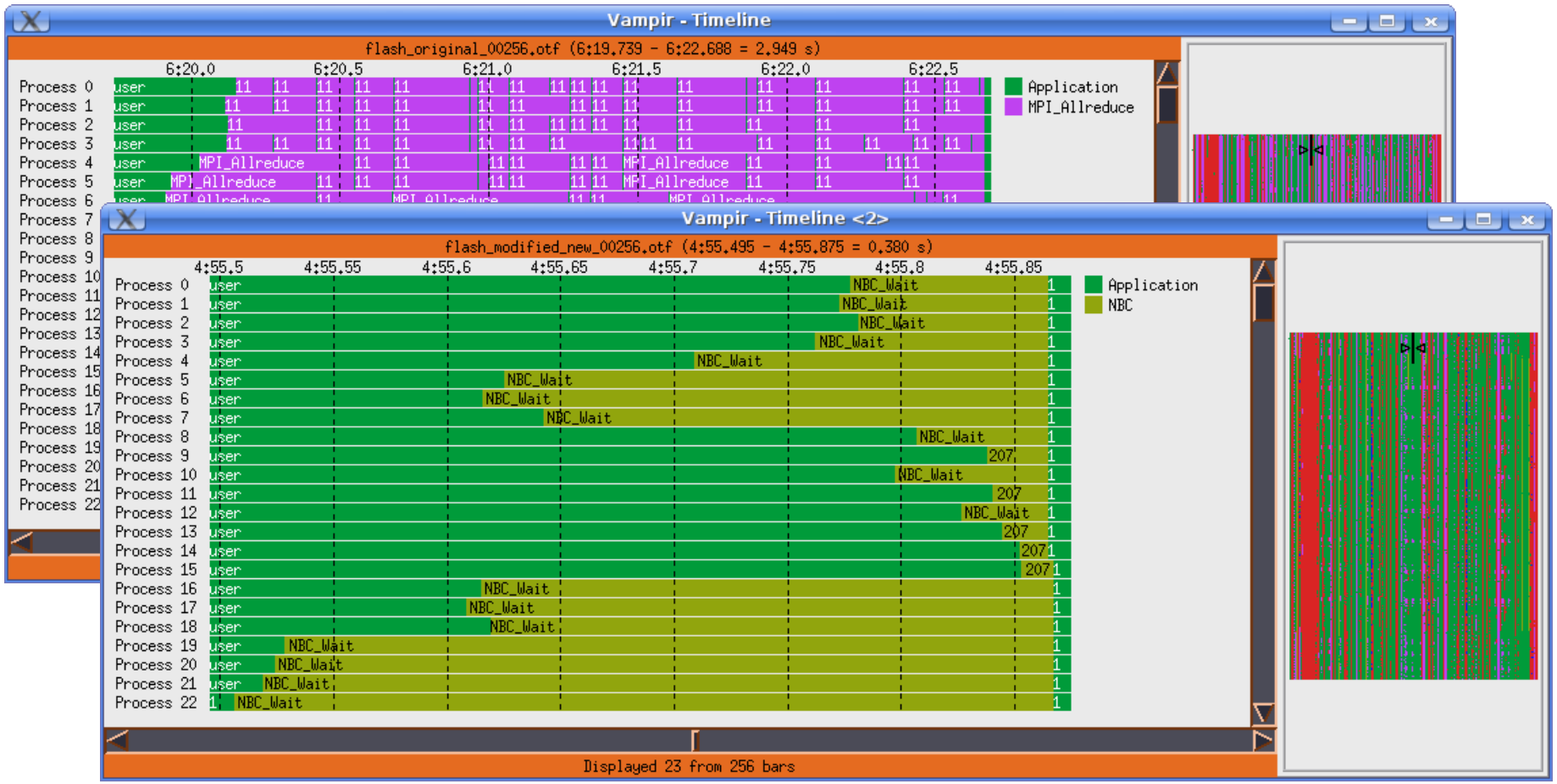
Propagated Delays in MPI_SendReceiveReplace

Bottlenecks in Communication



unnecessary MPI_Barriers

Bottlenecks in Communication

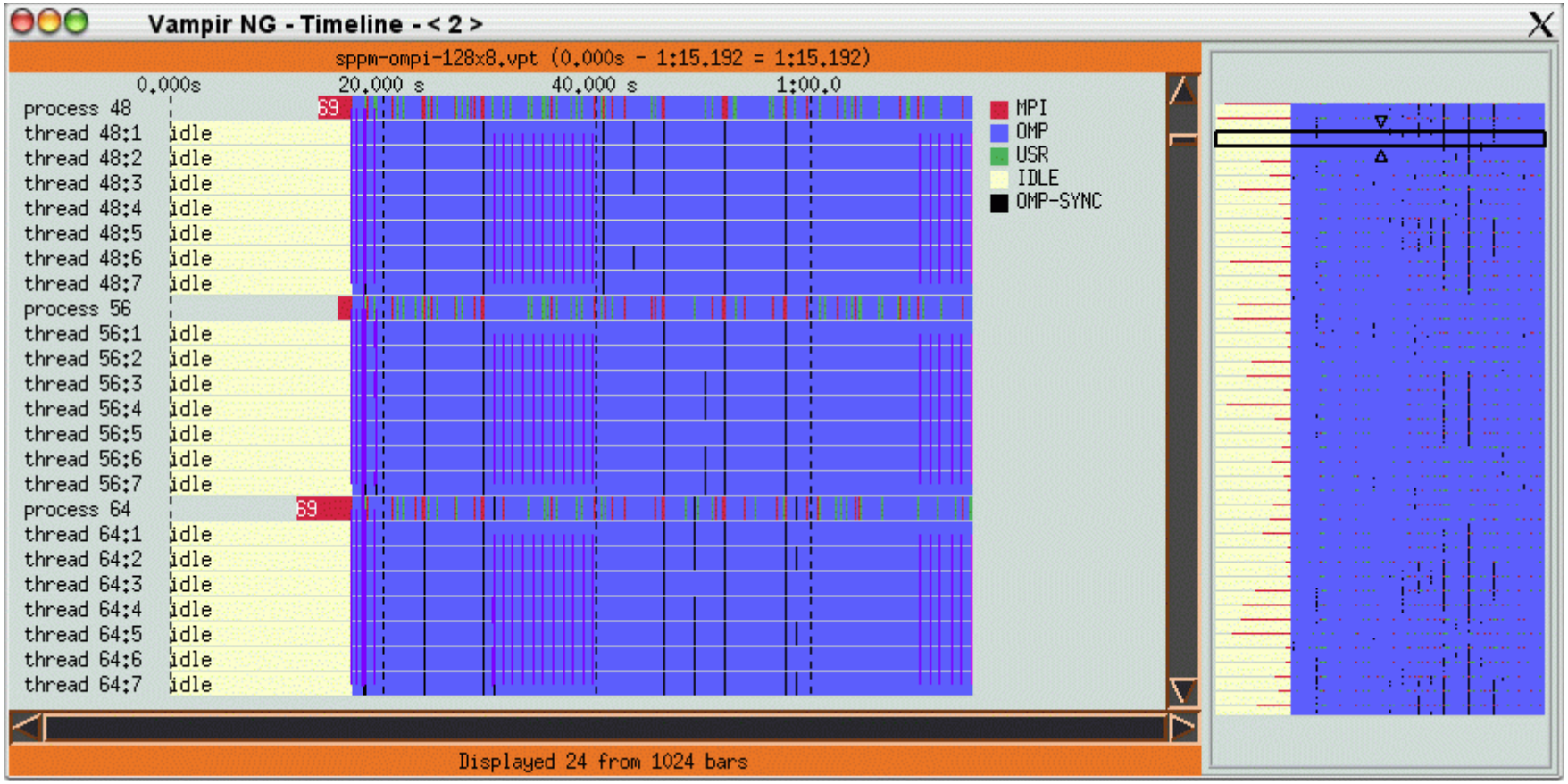


Patterns of successive MPI_Allreduce calls

Further Bottlenecks

- unbalanced computation
  - single late comer
- strictly serial parts of program
  - idle processes/threads
- very frequent tiny function calls
- sparse loops

Further Bottlenecks

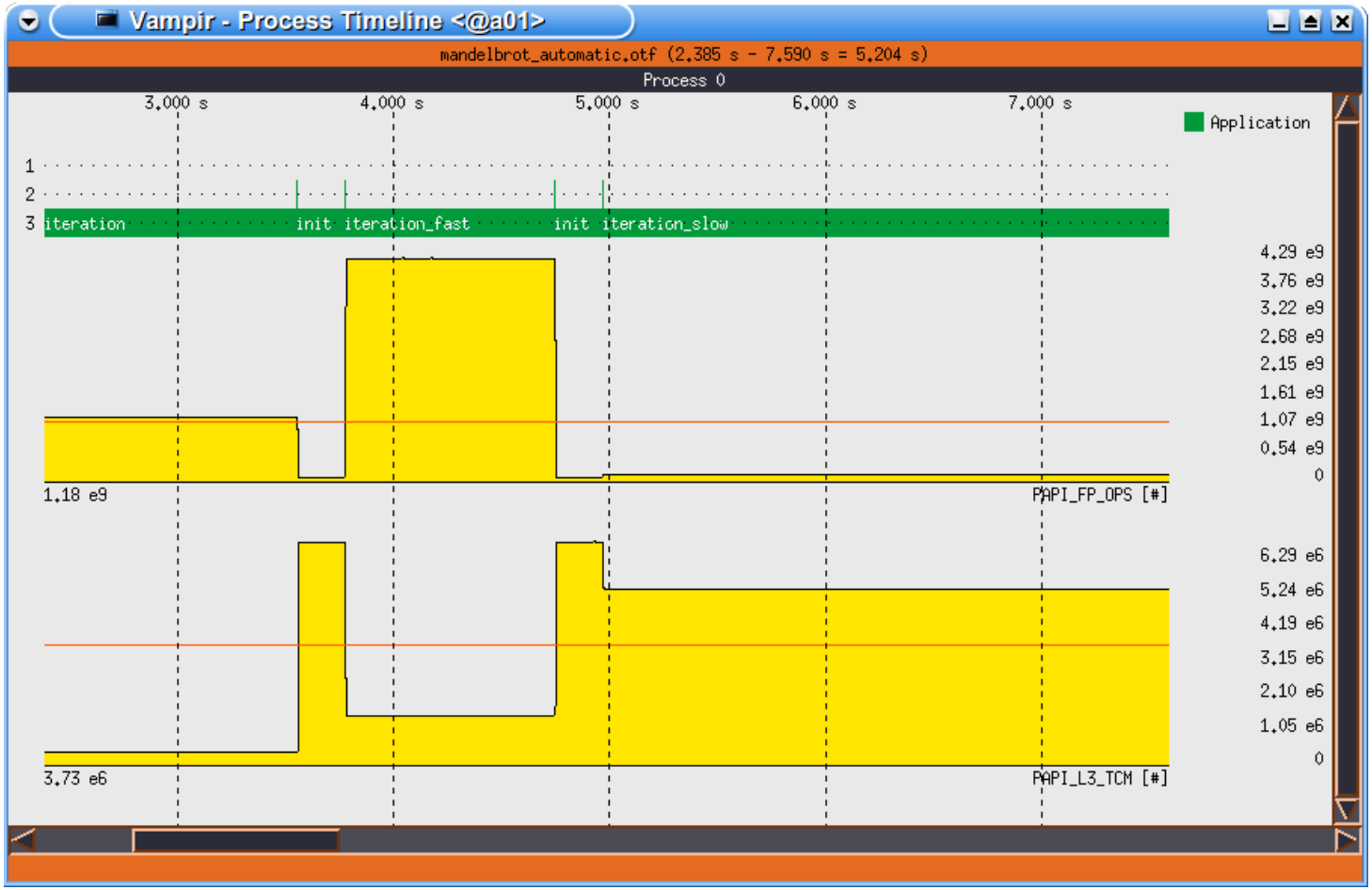


Example: Idle OpenMP threads

Bottlenecks in Computation

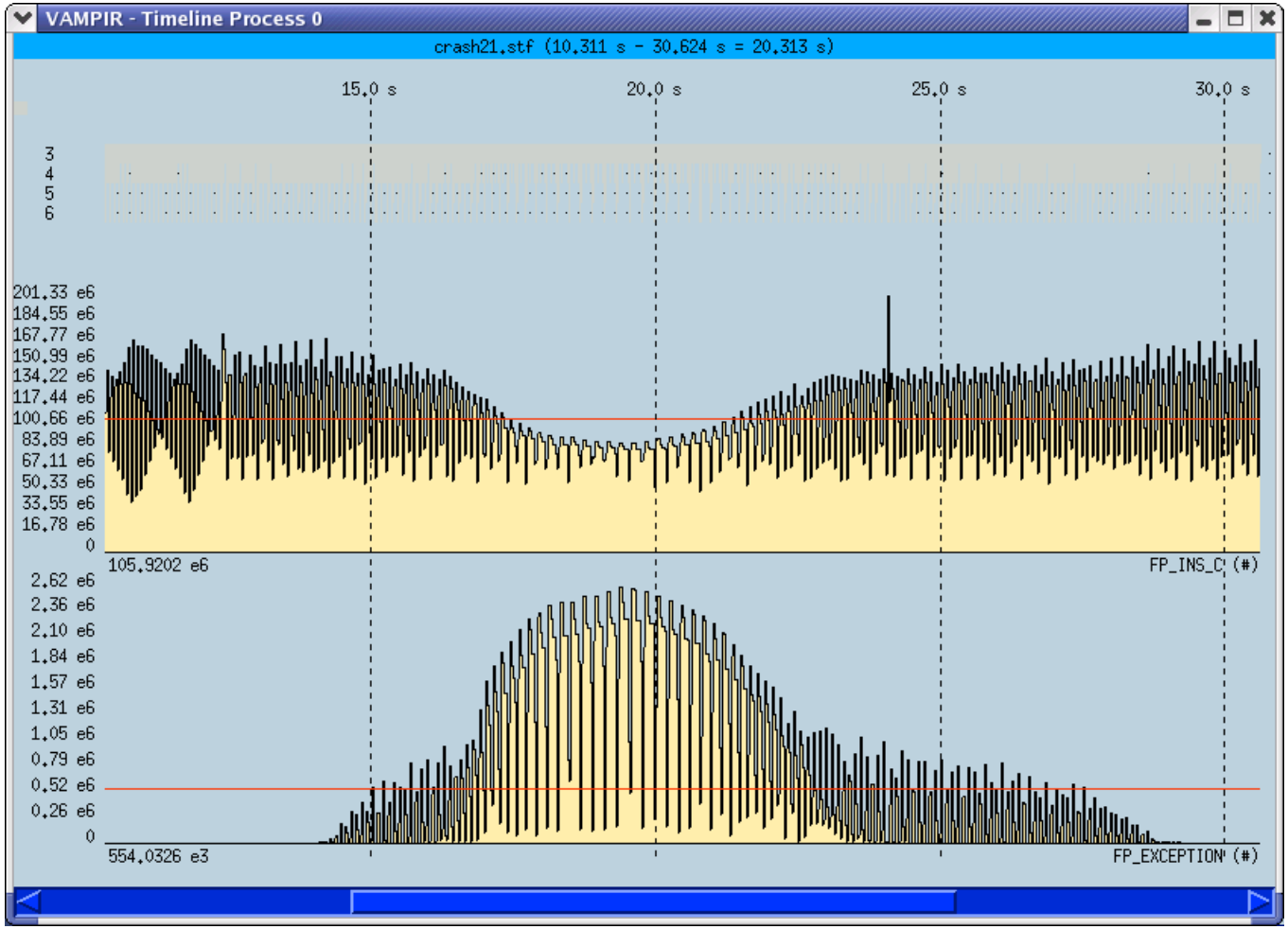
- memory bound computation
  - inefficient L1/L2/L3 cache usage
  - TLB misses
  - detectable via HW performance counters
- I/O bound computation
  - slow input/output
  - sequential I/O on single process
  - I/O load imbalance
- exception handling

Bottlenecks in Computation



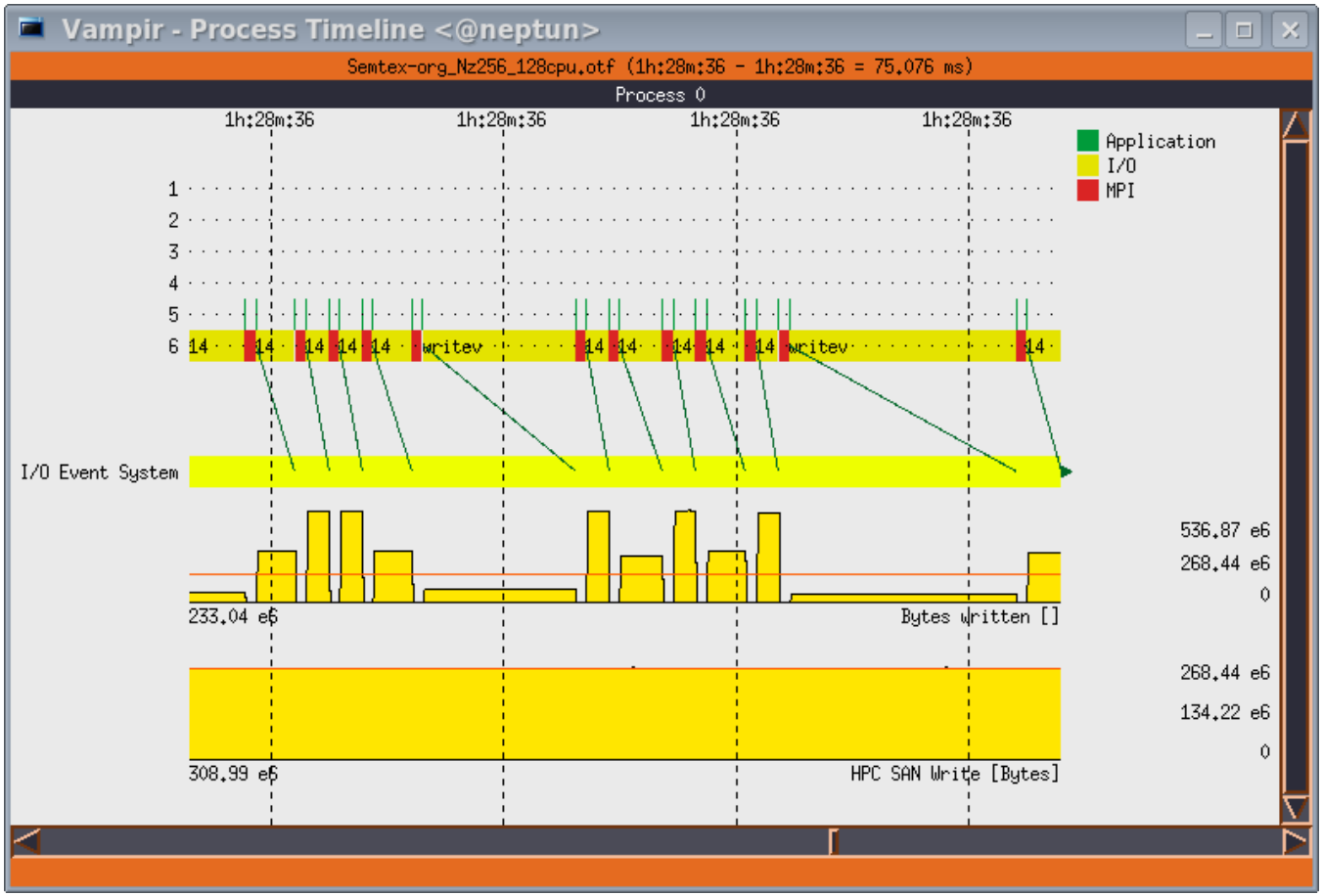
low FP rate due to heavy cache misses

Bottlenecks in Computation



low FP rate due to heavy FP exceptions

Bottlenecks in Computation

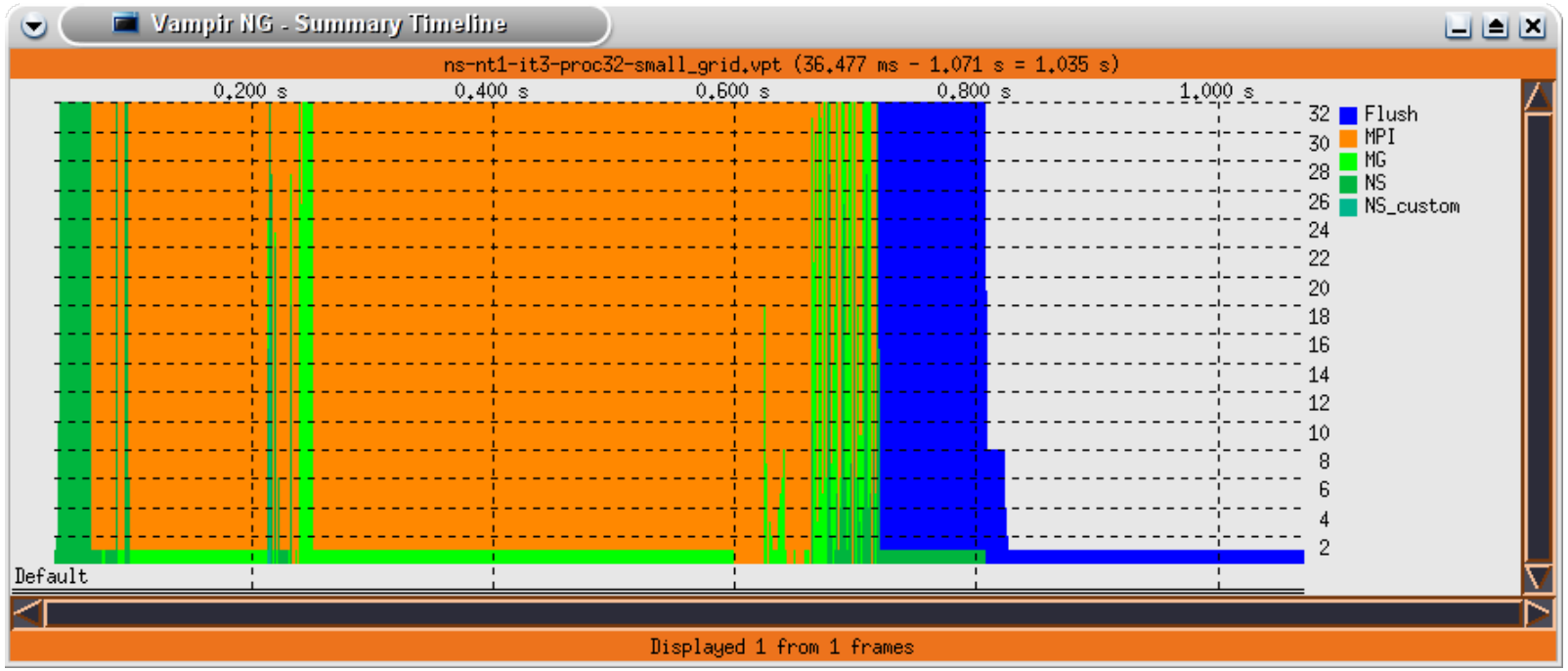


irregular slow I/O operations

Effects due to Tracing

- measurement overhead
  - especially grave for tiny function calls
  - solve with selective instrumentation
- long/frequent/asynchronous trace buffer flushes
- too man concurrent counters
- heisenbugs

Effects due to Tracing



Trace buffer flushes are explicitly marked in the trace.
It is rather harmless at the end of a trace as shown here.

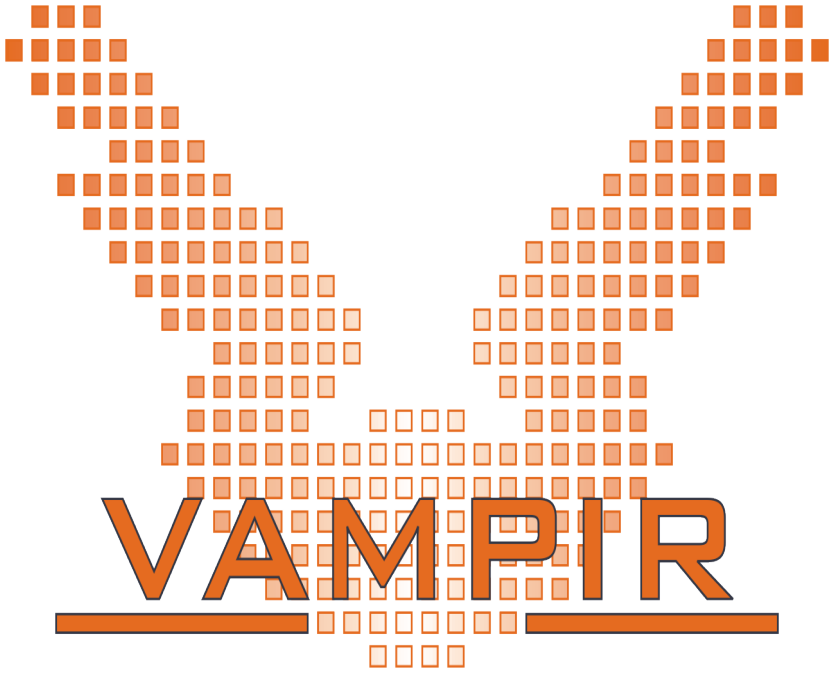
Conclusions and Outlook

- performance analysis very important in HPC

- use performance analysis tools for profiling and tracing
- do not spend effort in DIY solutions,
  e.g. like printf-debugging

- use tracing tools with some precautions
  - overhead
  - data volume

- let us know about problems and about feature wishes
- vampirsupport@zih.tu-dresden.de



Vampir and VampirTraces are

available at http://www.vampir.eu and

http://www.tu-dresden.de/zih/vampirtrace/ ,

get support via vampirsupport@zih.tu-dresden.de

Wrapper Functions

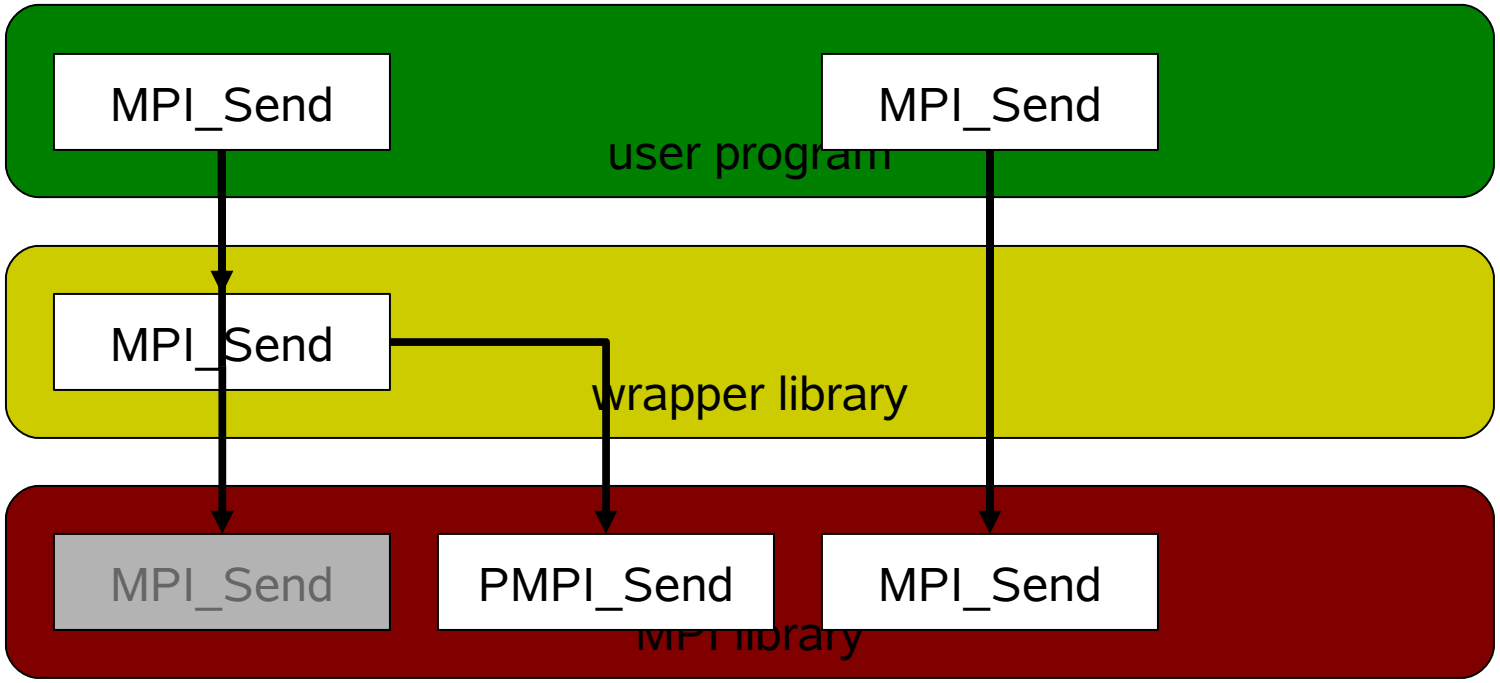
- provide wrapper functions
  - call instrumentation function for notification
  - call original target for functionality
  - via preprocessor directives:

```
#define MPI_Init WRAPPER_MPI_Init

#define MPI_Send WRAPPER_MPI_Send
```

- via library preload:
  - preload instrumented dynamic library
- suitable for standard libraries (e.g. MPI, glibc)

- Each MPI function has to names:
  - MPI_xxx and PMPI_xxx
- Replacement of MPI routines at link time



gcc –finstrument-functions –c foo.c

```
void __cyg_profile_func_enter( <args> );
void __cyg_profile_func_exit( <args> );
```

- many compilers support this: GCC, Intel, IBM, PGI, NEC, Hitachi, Sun Fortran, …
- no source code modification necessary

Dynamic Instrumentation

- modify executable in file or binary in memory
- insert instrumentation calls
- very platform/machine dependent, expensive

- DynInst project (http://www.dyninst.org)
  - common interface
  - supported platforms: Alpha/Tru64, MIPS/IRIX, PowerPC/AIX, Sparc/Solaris, x86/Linux x86/Windows, ia64/Linux

Partners with pictures

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- Jülich Supercomputing Centre

RWTH Aachen University
- Center for Computing and Communication

Technical University of Dresden
- Center for Information Services and High Performance Computing

University of Tennessee
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