German Research School for Simulation Sciences

Application Performance Analysis on Petascale Systems

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RWTH AACHEN UNIVERSITY

German Research School
for Simulation Sciences

- Joint venture between
  - Forschungszentrum Jülich
  - RWTH Aachen University
- Founded in 2007
- Research and education in simulation sciences
  - International Master's program
  - Ph.D. program

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JÜLICH
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Jülich Supercomputing Centre

Research in

- Computational Science
- Computer Science
- Mathematics

Jülich BG/P 294,912 cores

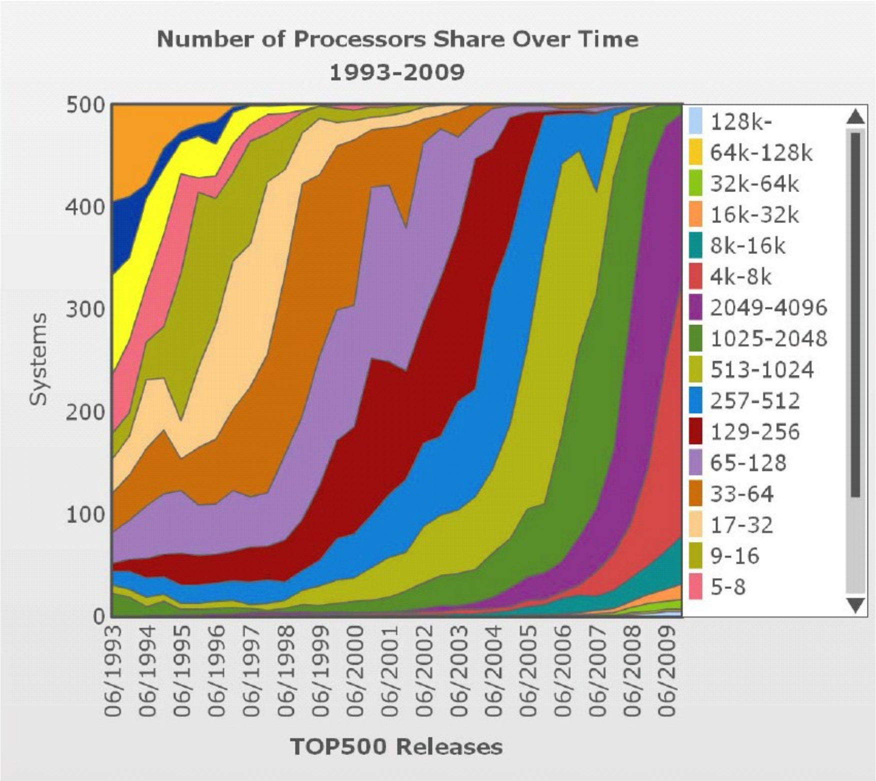
Jülich Nehalem Cluster 26,304 cores

Outline

- Motivation
- Scalasca overview
- Scalable trace analysis
- Scalable task-local I/O
- Space-efficient time-series call-path profiles
- Conclusion & outlook

Higher degrees of parallelism

- Increasing complexity of applications
  - Higher resolutions
  - Larger simulated time periods
  - Multi-physics
  - Multi-scale
- Increasing parallelism
  - Multi-core



Higher degrees of parallelism (2)

- Also new demands on scalability of software tools
  - Familiar tools cease to work in a satisfactory manner for large processor counts
- Optimization of applications more difficult
  - Increasing machine complexity
  - Every doubling of scale reveals a new bottleneck
- Need for scalable performance tools
  - Intelligent
  - Robust
  - Easy to use

scalasca

- Scalable performance-analysis toolset for parallel codes
- Integrated performance analysis process
  - Performance overview on call-path level via runtime summarization
  - In-depth study of application behavior via event tracing
  - Switching between both options without recompilation or relinking
- Supported programming models
  - MPI-1, MPI-2 one-sided communication
  - OpenMP (basic features)
  - Available under the New BSD open-source license
  - http://www.scalasca.org/

Joint project of

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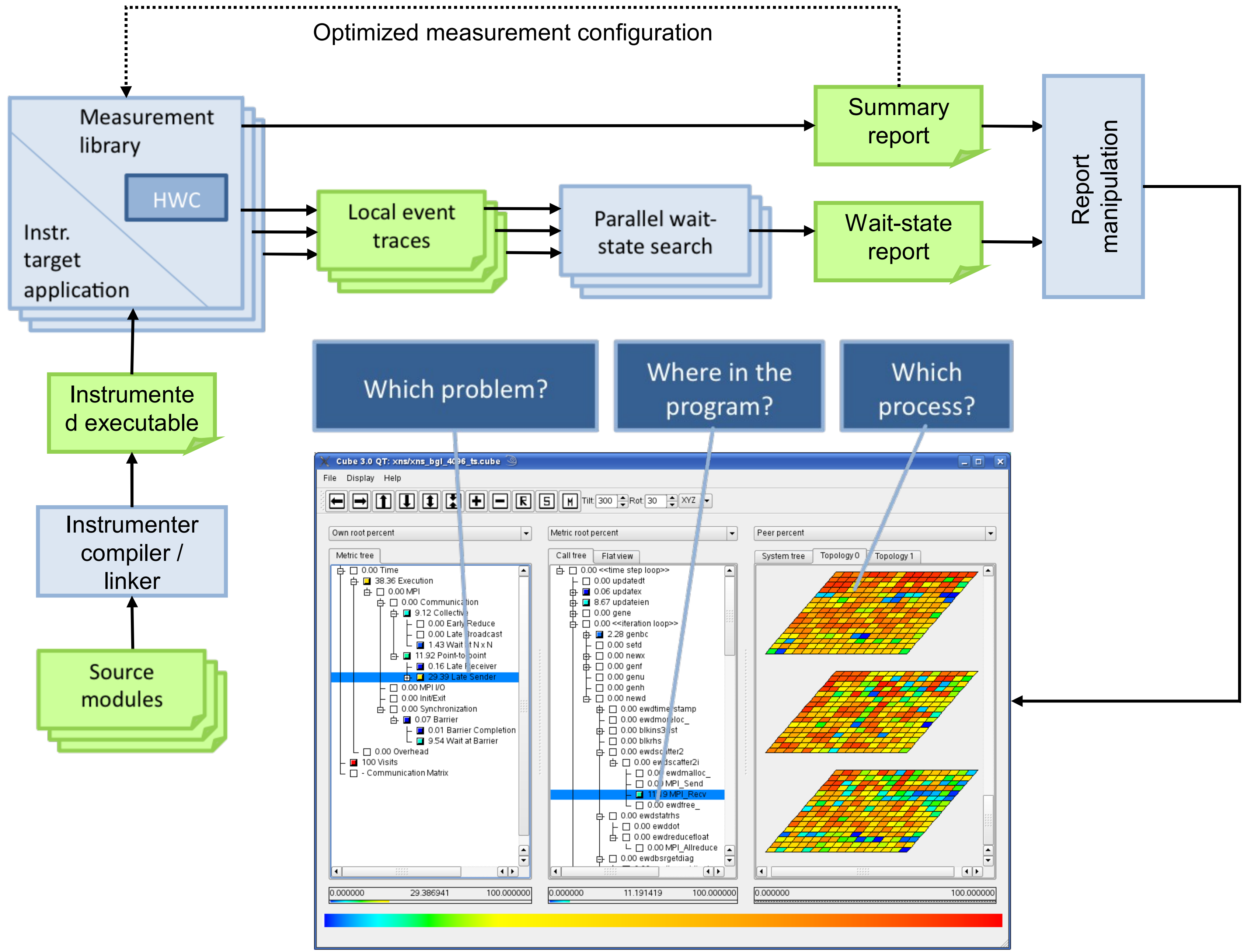
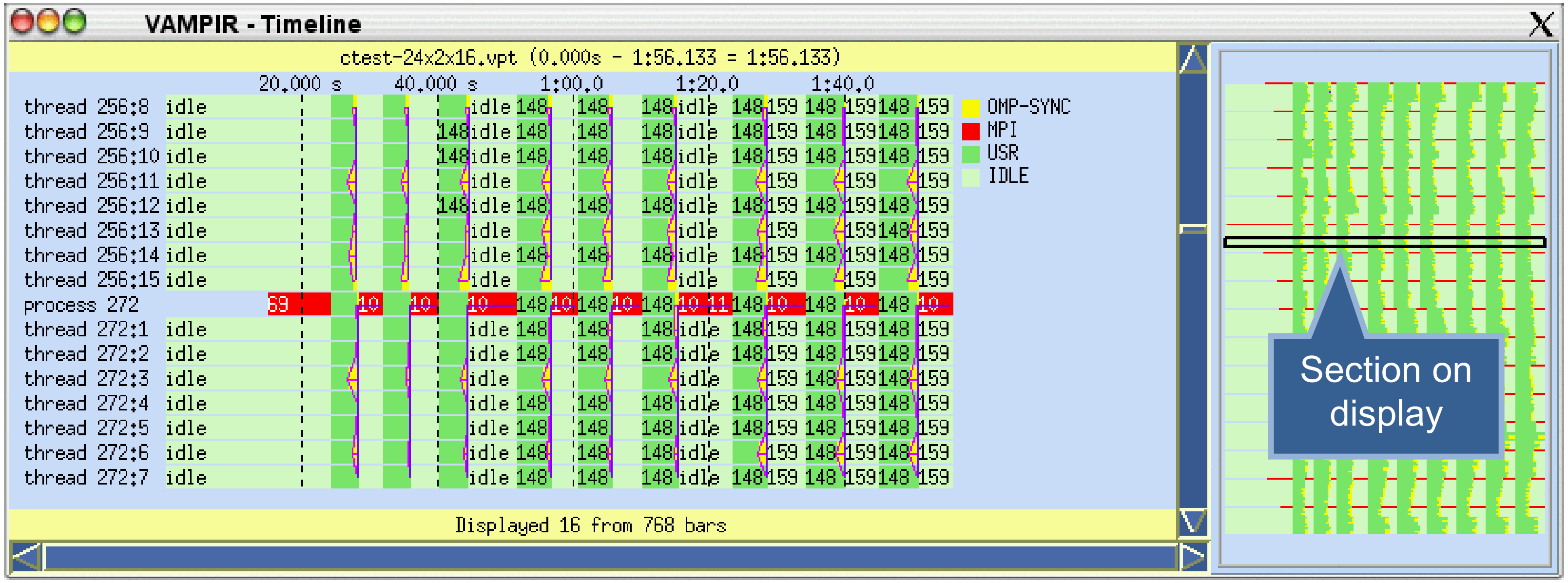
Scalasca team



Optimized measurement configuration
Measurement library
HWC
Instr. target application
Summary report
Local event traces
Parallel wait-state search
Wait-state report
Report manipulation
Instrumented executable
Instrumenter compiler / linker
Source modules
Which problem?
Where in the program?
Which process?

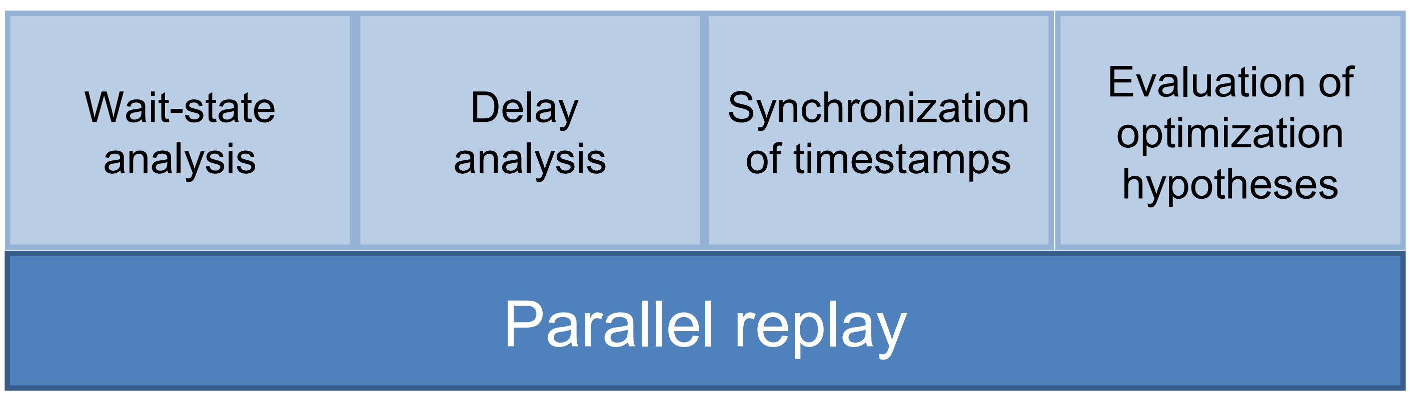
Event tracing



- Typical events
  - Entering and leaving a function
  - Sending and receiving a message
- Problem: width and length of event trace

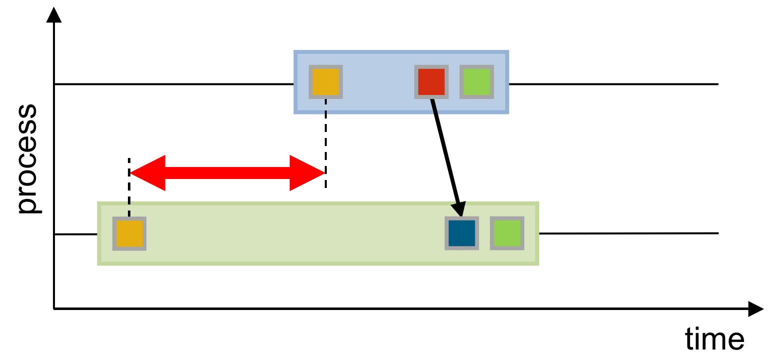
Scalable trace analysis via parallel replay

- Exploit distributed memory and processing capabilities
  - Keep trace data in main memory
  - Traverse local traces in parallel
  - Exchange data at synchronization points of target application using communication operation of similar type
- Four applications

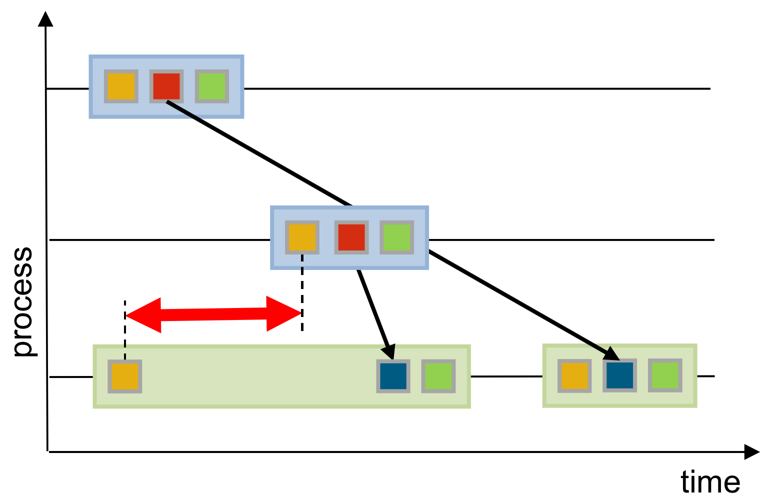


Wait-state analysis

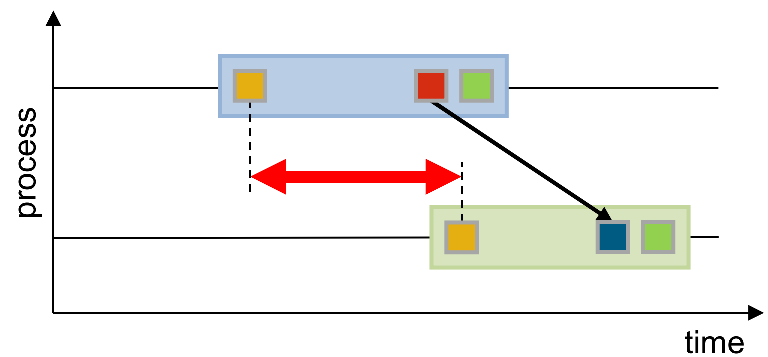
- Classification
- Quantification



(a) Late Sender

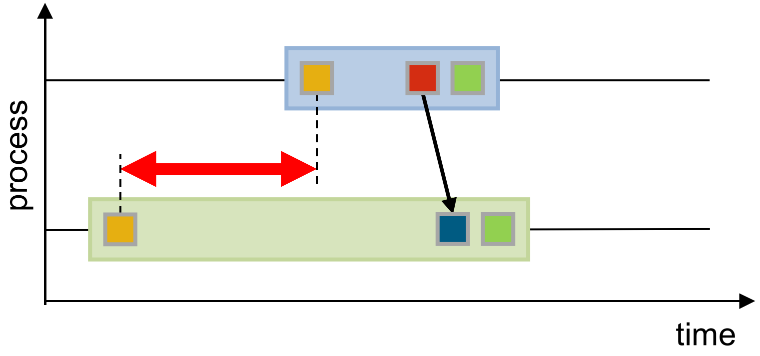


(b) Late Sender / Wrong Order

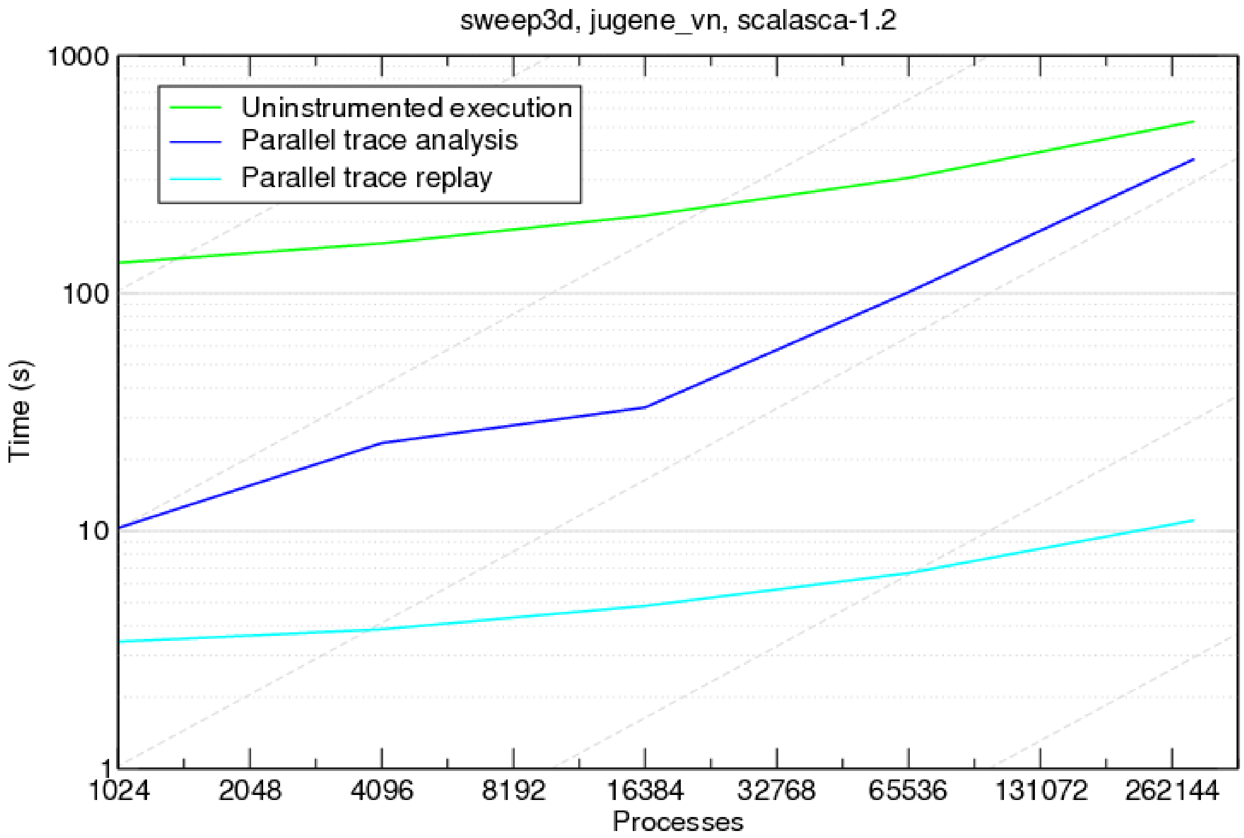


(c) Late Receiver

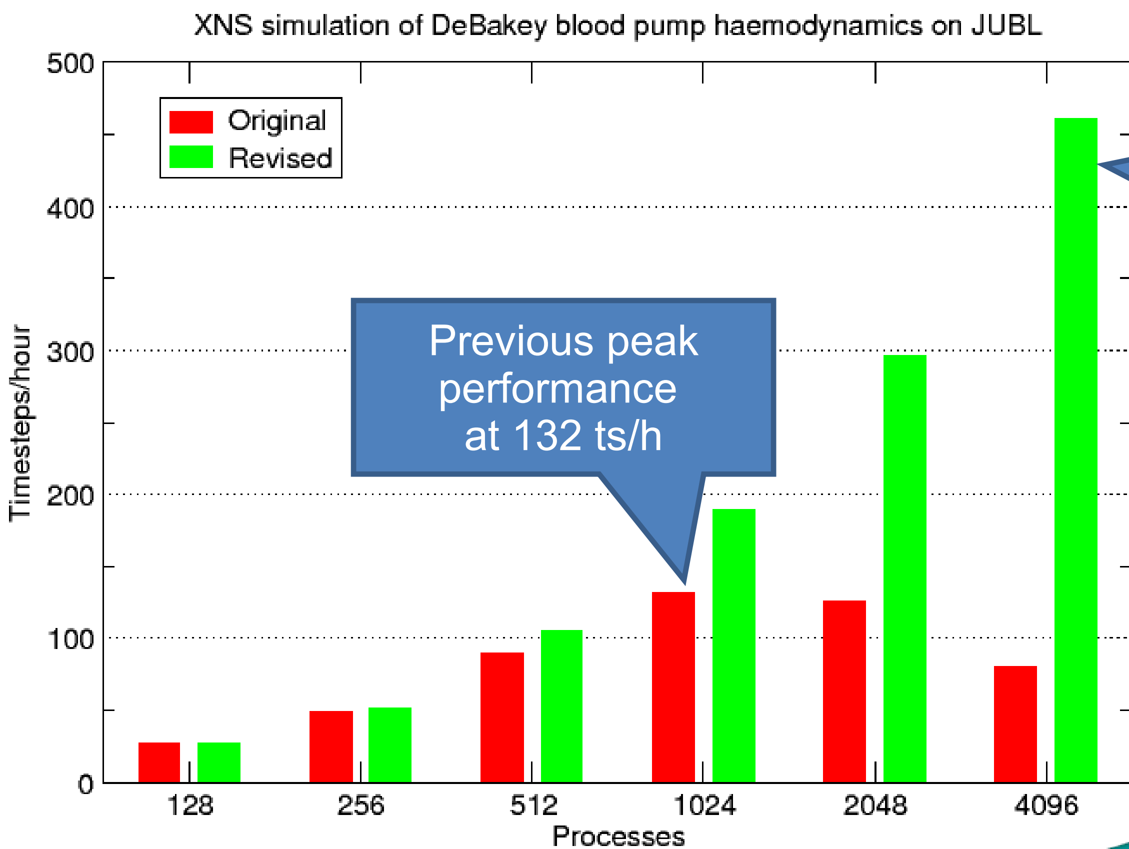
Wait-state analysis (2)



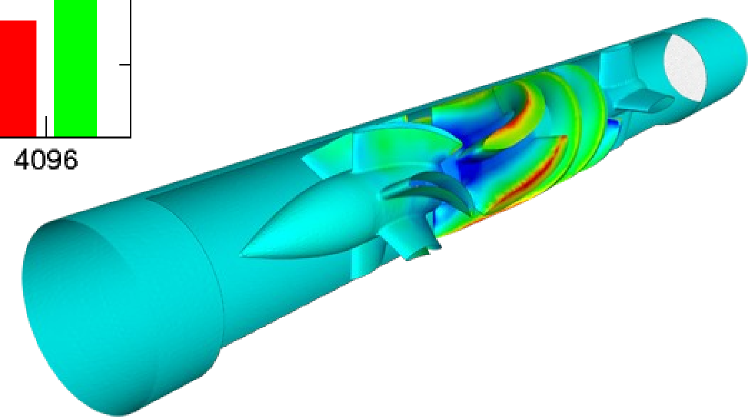
Scalability of parallel wait-state search (SWEEP3D)



Redundant messages in XNS CFD code



Now scales up to 4096 processes



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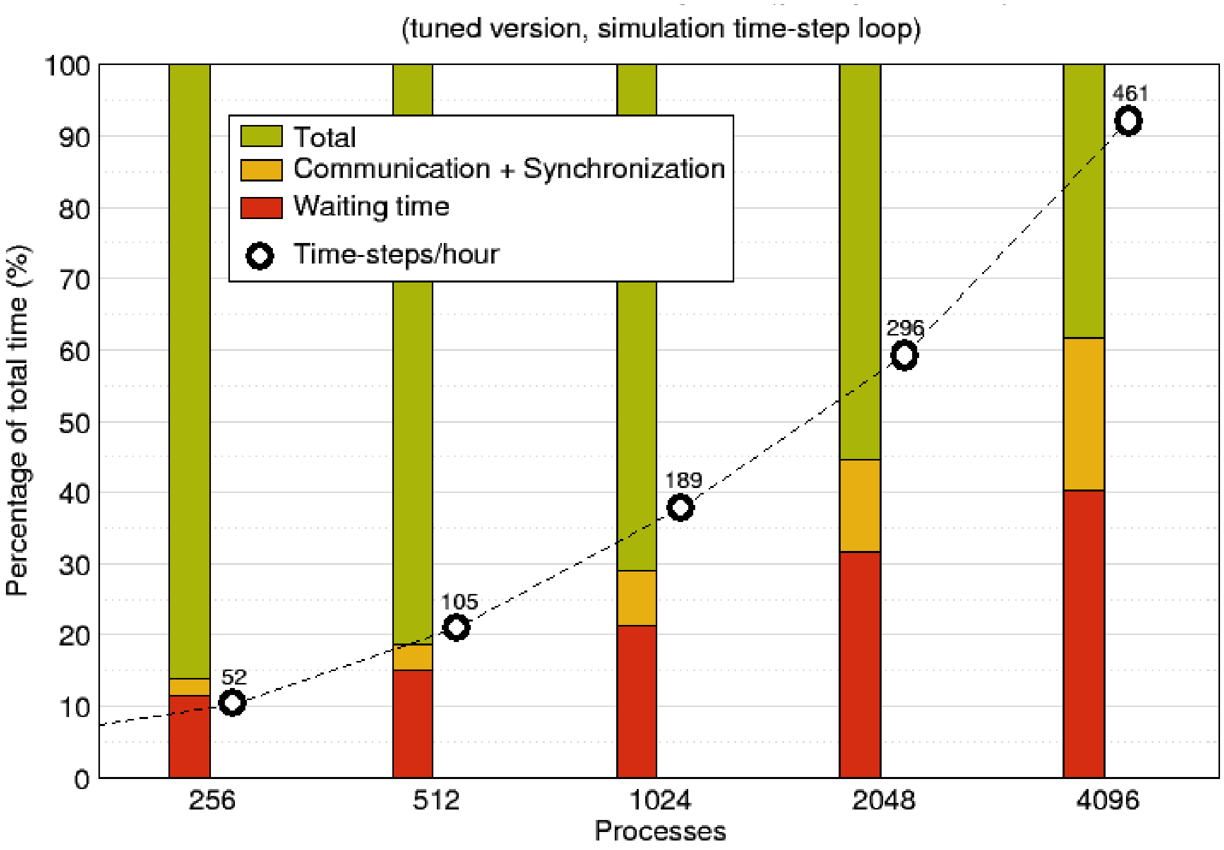
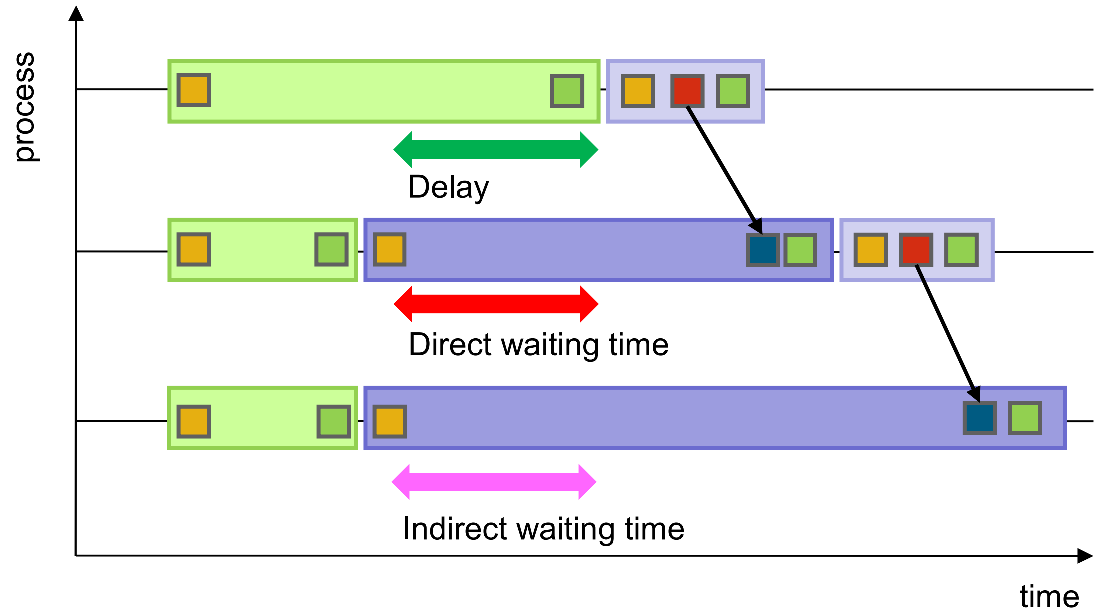
XNS wait-state analysis of tuned version

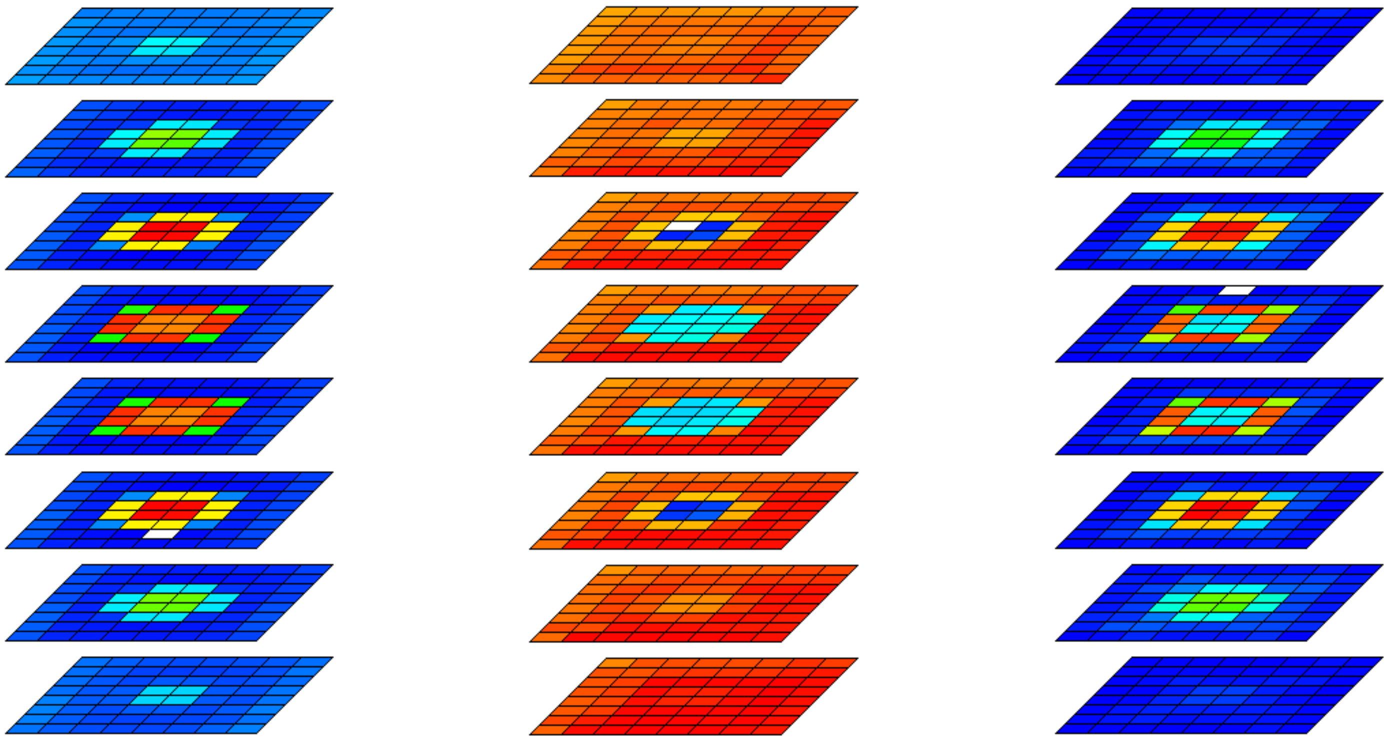


Delay analysis

- Delay counterpart of waiting time
- Distinction between direct and indirect waiting times
- Essentially scalable version of Meira Jr. et al.
- Analysis attributes costs of wait states to delay intervals



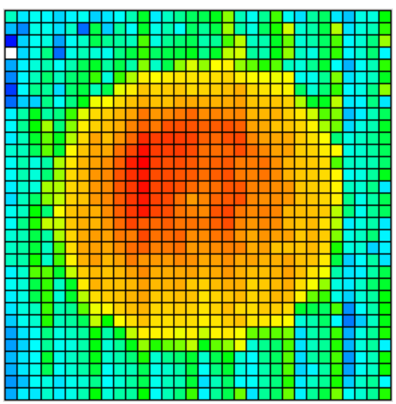
Origin of delay costs in Zeus-MP/2



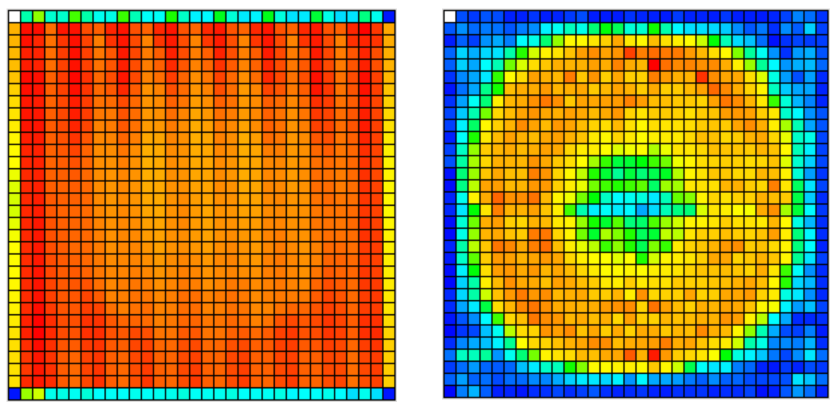
Computation | Waiting time | Delay costs

Delay analysis of code Illumination

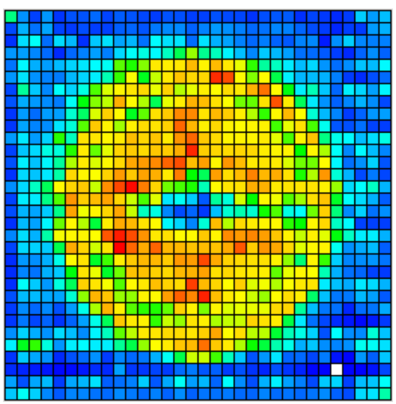
- Particle physics code (laser-plasma interaction)
- Delay analysis identified inefficient communication behavior as cause of wait states



Computation



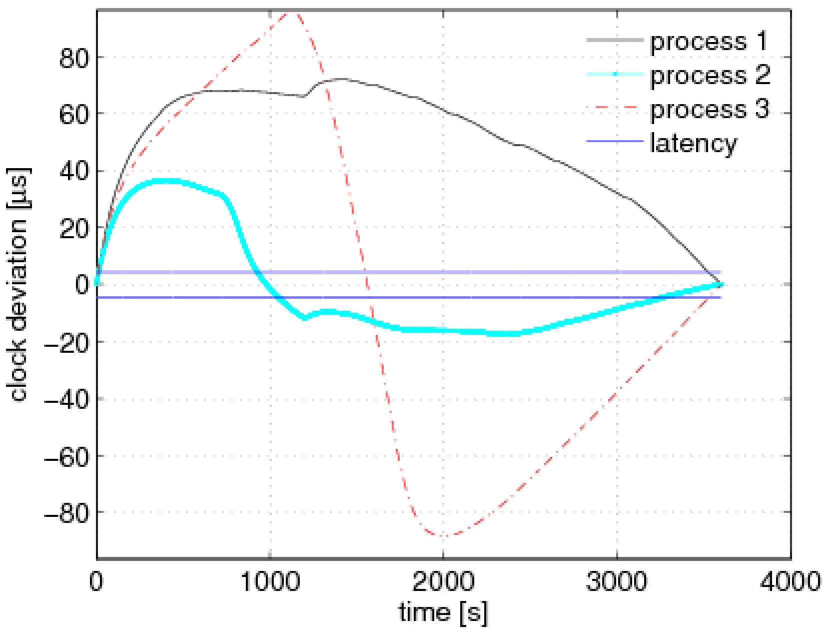
Short-term costs of indirect delay:
Original vs. optimized code

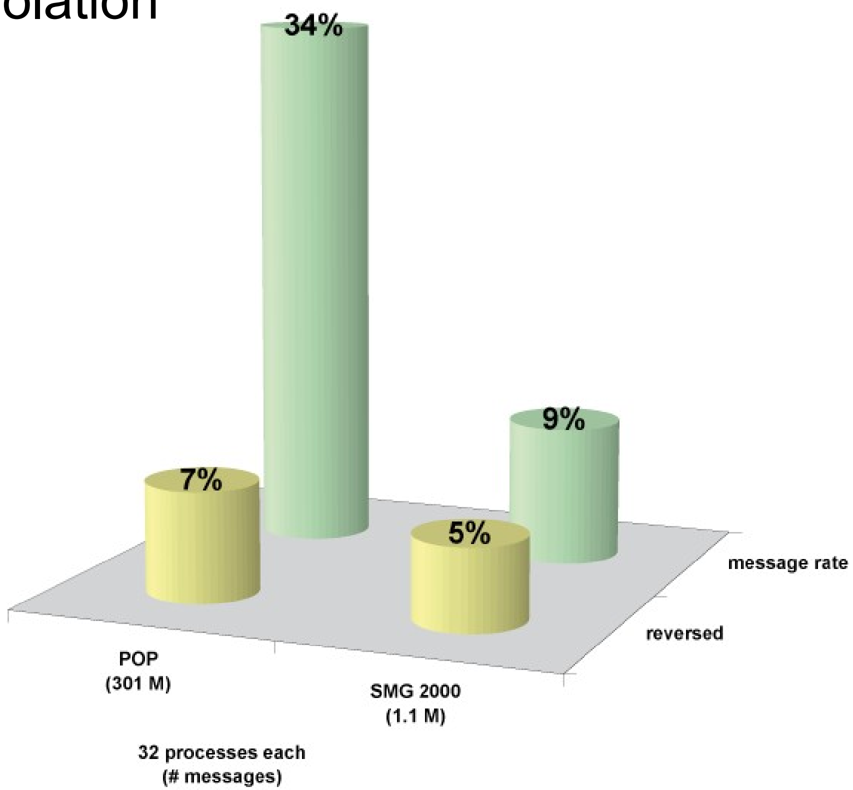


Costs of direct delay
in optimized code

Insufficiently synchronized clocks on clusters

- Misrepresentation of logical event order in traces
- Distorted interval lengths
- Simple approach: linear offset interpolation
- Problem unstable drifts





Postmortem correction using logical clocks

- Controlled logical clock algorithm by Rolf Rabenseifner
  - Restores logical event order based on happened-before relation while introducing only marginal local inaccuracies
  - Shortcoming 1: Only point-to-point communication
  - Shortcoming 2: Sequential algorithm
- Extended to cover MPI collective communication and OpenMP shared-memory programming
  - Mapped collectives and OpenMP regions onto point-to-point messages
- Parallelized through parallel replay
  - Challenge: backward replay required to smooth jump discontinuities without introducing new violations
  - Scalability tested on up to 4,000 processors

Evaluation of optimization hypotheses

- Wait states often caused by load or communication imbalance occurring much earlier in the program
  - Hard to estimate impact of potential changes
  - Requires modeling the communication infrastructure to answer "What if…?" questions
- Alternative
  - Parallel real-time replay of modified event traces to verify hypotheses on wait state formation
    - Elapse computation time
    - Re-enact communication
  - Advantage: scalability and accuracy

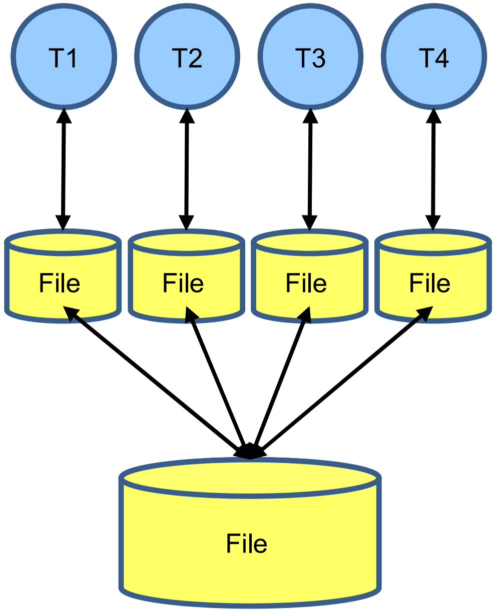
Simulated removal of redundant messages

- 1 iteration of 1024 processor-run of XNS on Blue Gene/L
- All zero-sized messages removed from trace
  - 90% of all messages > 1.2 billion messages

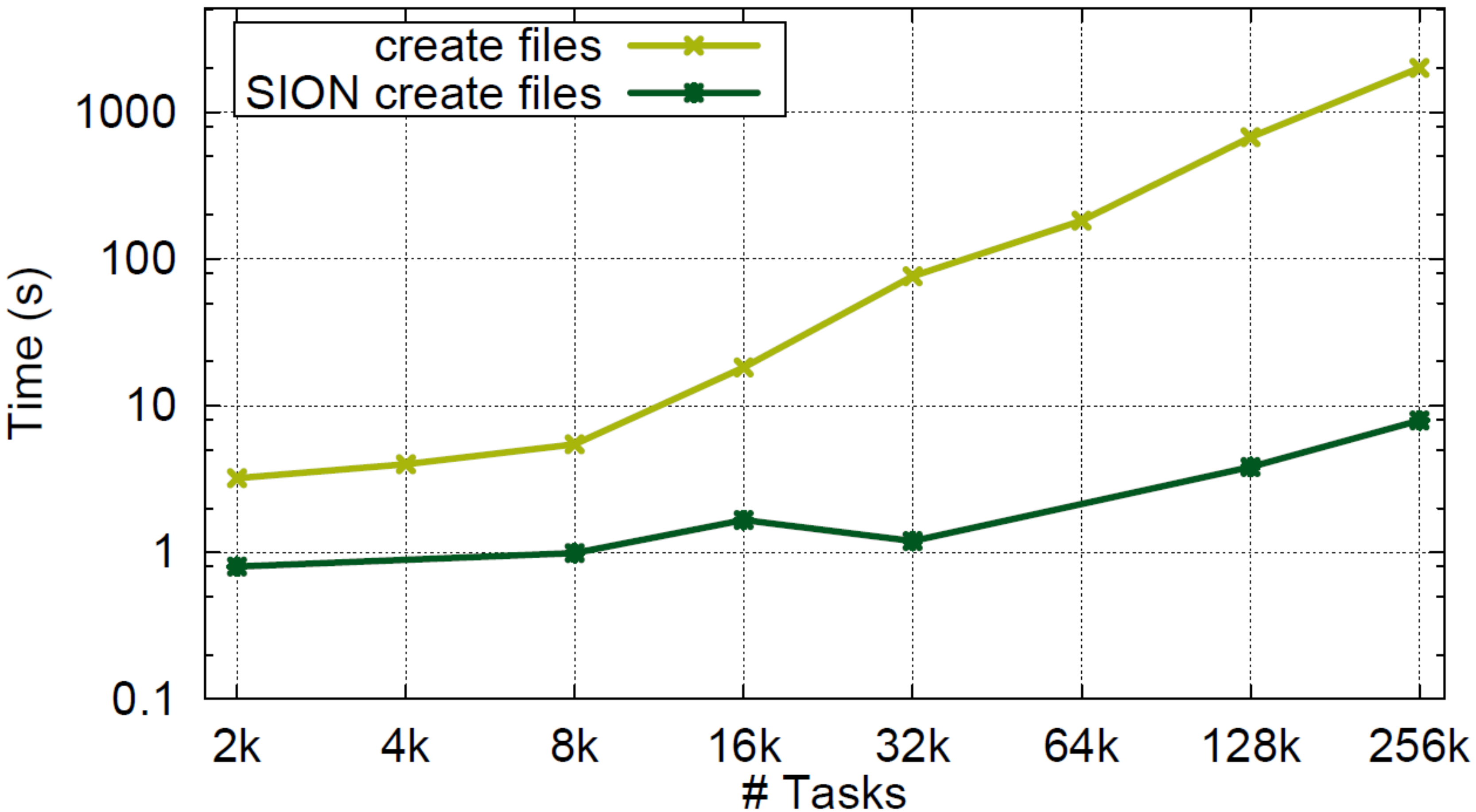
Metric	Original	Hand-Optimized	Simulated
Total	100.0	50.6	53.1
MPI	59.9	16.9	19.4
P2P	54.2	8.6	11.2
Late Sender	30.6	5.7	8.0
Wait at Barrier	5.1	7.7	7.7

SIONlib: Scalable parallel I/O for task-local data

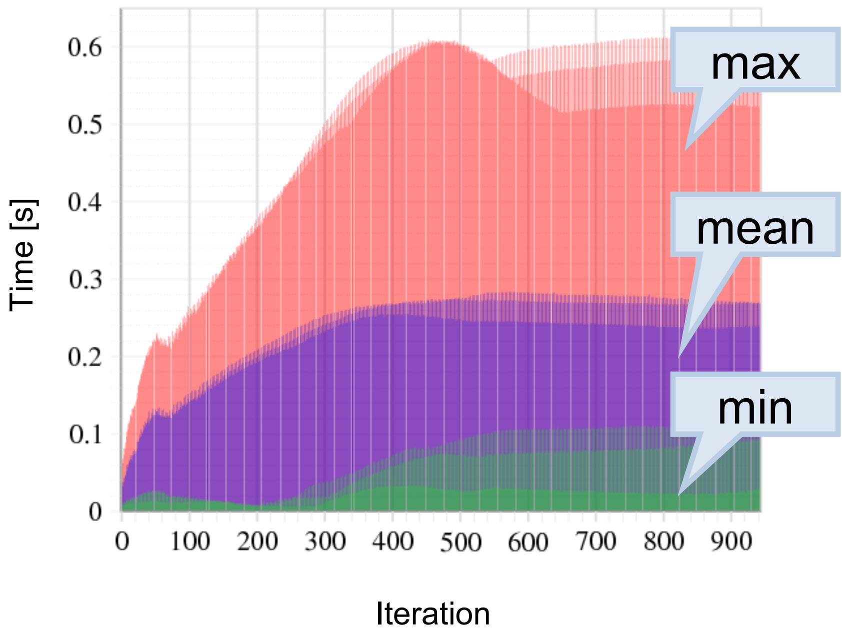
- Use case: task-local binary I/O from thousands of tasks
  - Trace files
  - Scratch/checkpoint files
- Often does not scale
  - Contention at metadata server
  - File handling (e.g., directory listing)
- Map many logical files onto a few physical files
  - Application-level file system
  - Optimized I/O via block alignment

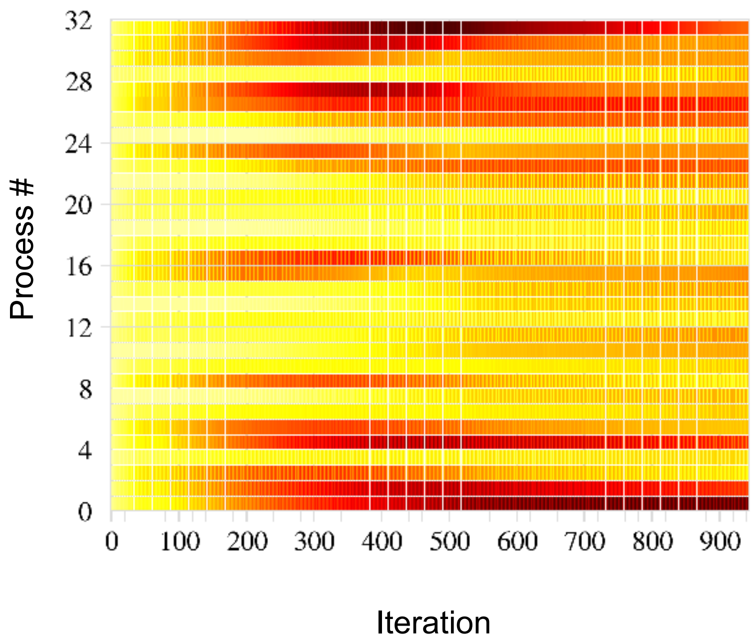


Parallel open / create on JUGENE



Time-dependent performance behavior

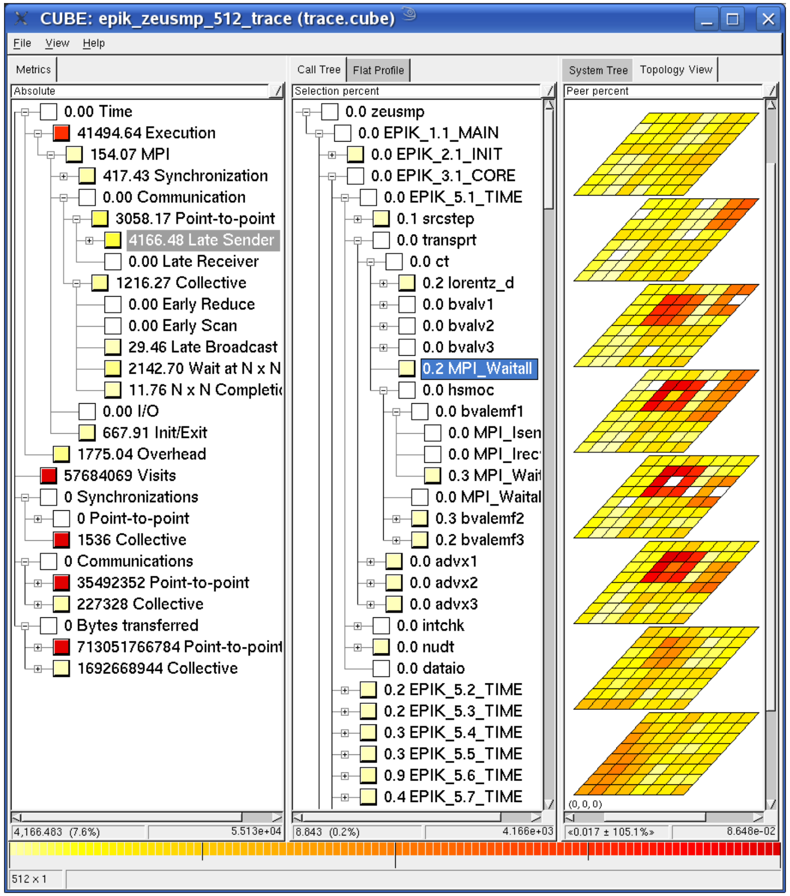




MPI point-to-point time of 129.tera_tf

Time-series call-path profiling

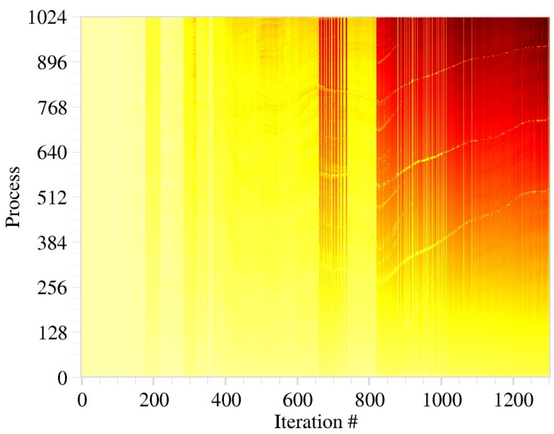
- Manual instrumentation to distinguish iterations of the main loop
- Complete call-tree recorded for each iteration
  - With multiple metrics collected for every call-path
- Huge growth in the amount of data collected
  - Reduced scalability



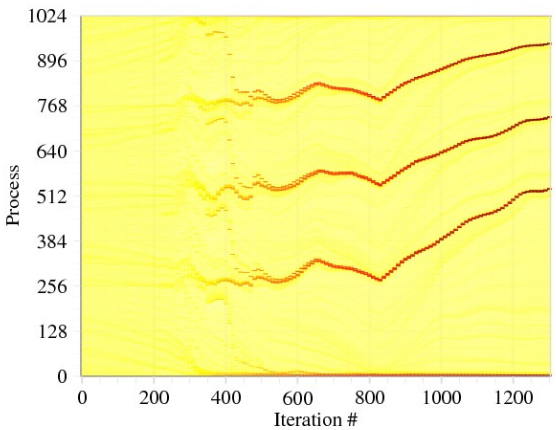
Incremental on-line clustering

- Exploits that many iterations are very similar
  - Summarizes similar iterations in a single iteration, their average
- On-line to save memory at run-time
- Process-local to
  - Avoid communication
  - Adjust to local temporal patterns
- The number of clusters can never exceed a predefined maximum
  - Merging of the two closest ones

PEPC n-body tree code



Late Sender

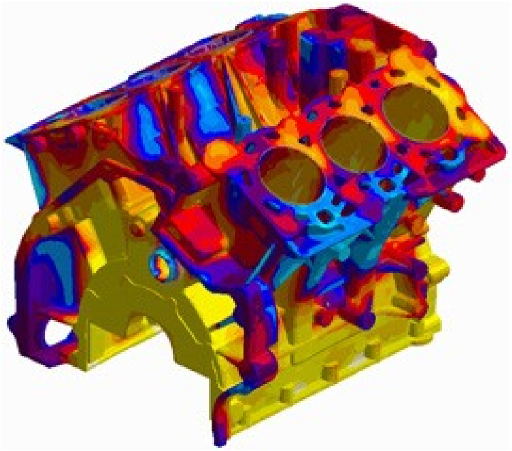


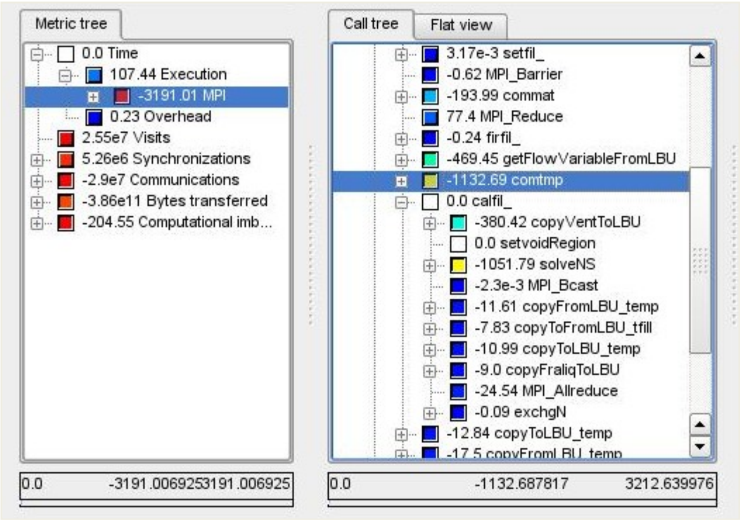
particles owned by a process

Portland, OR 2009

MAGMAfill by MAGMASOFT® GmbH

- Simulates mold-filling in casting processes
- Scalasca used
  - To identify communication bottleneck
  - To compare alternatives using performance algebra utility
- 23% overall runtime improvement
- Further investigations ongoing





Conclusion

- Integrated tool architecture
- Scalability in terms of machine size
  - Trace-processing based on parallel replay
    - Versatile: four applications
  - Parallel task-local I/O
  - Demonstrated on up to 295 K cores
- Scalability in terms of execution time
  - Runtime compression of time-series profiles

Outlook

- Further scalability improvements
  - Parallelization of internal management operations
  - Scalabale output format and GUI
  - In-memory trace analysis
- Emerging architectures and programming models
  - PGAS languages
  - Accelerator architectures
- Interoperability with 3rd-party tools
  - Common measurement library for several performance tools

Thank you!

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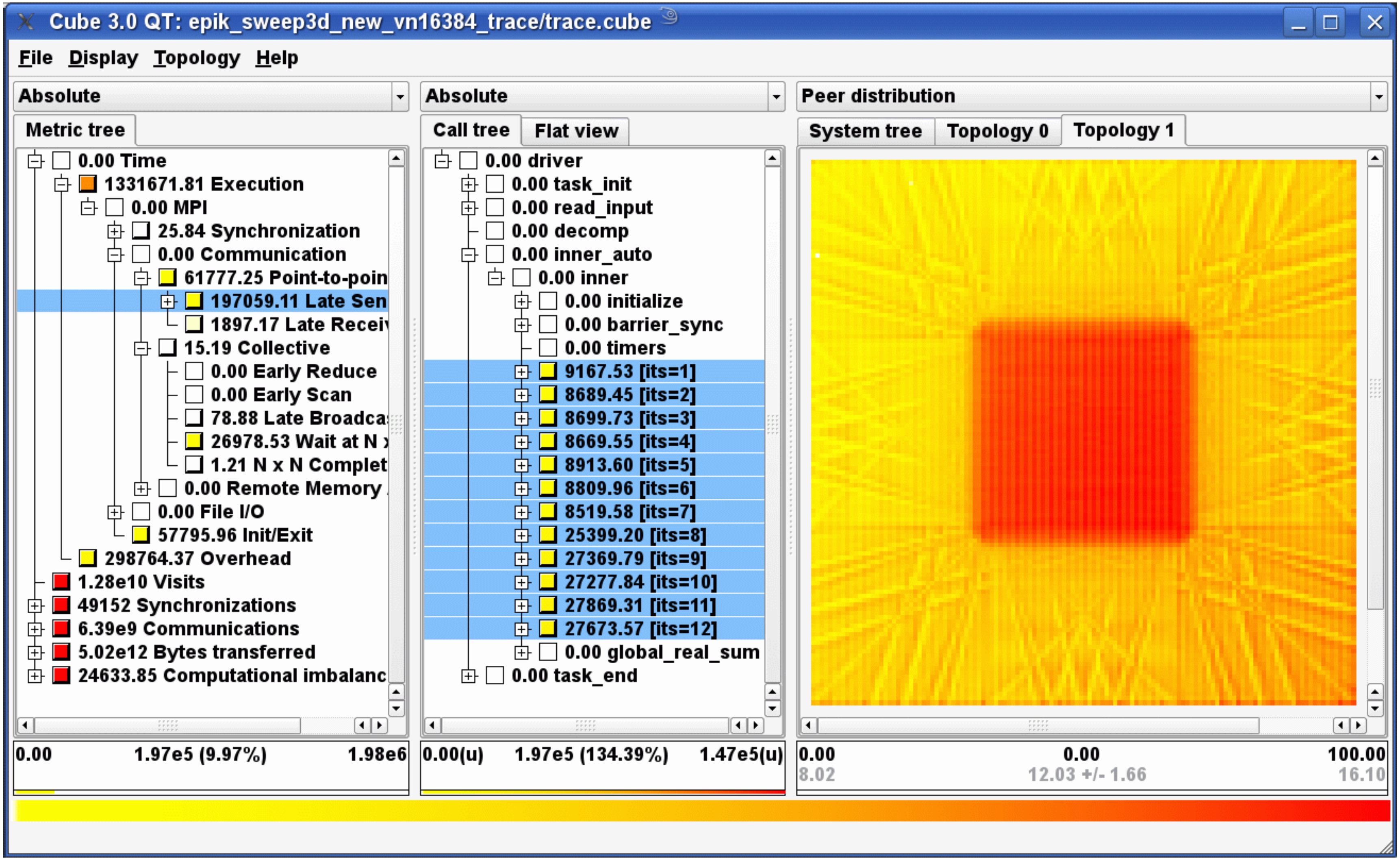
Sweep3D – late sender



Sweep3D – execution time