TAUoverMRNet (ToM): A Framework for Scalable Parallel Performance Monitoring

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Motivation

- Performance problem analysis increasingly complex
  - Multi-core, heterogeneous, and extreme scale computing
- Shift of performance measurement and analysis perspective
  - Static, offline ⇨ dynamic, online
  - Support for performance monitoring (measurement + query)
  - Enabling of adaptive applications
- Prerequisites for performance measurement
  - Low overhead and low perturbation
  - Runtime analysis antithetical to performance tool orthodoxy
- Neo-performance perspective
  - Co-allocation of additional (tool specific) system resources
  - Make dynamic, performance-driven optimization viable

Performance Observation Needs

- Performance problem type determines observation approach
  - Translates to requirements for measurement and analysis
- Standard offline performance diagnosis/tuning process
  - Compile-execute-measure-analyze cycle
  - Pre-determined performance experiment (events, measures)
  - Static application execution and optimization
- Standard approach difficult to apply to complex execution
  - Dynamic applications where performance changes
  - Extreme scale, heterogenous systems with high dimensionality
- Requires extended online performance measurement support
  - Dynamic monitoring and performance feedback
  - Raises vital concerns of overhead and perturbation
    - bigger issue in online systems due to global effects

Performance Observation Modes

- ***Post-mortem***
  - Performance data interpreted offline
  - May lack temporal detail (e.g., using profiles only)
- ***Post-mortem with temporal detail***
  - Still offline interpretation
  - Can generate prodigious data volumes (e.g., using tracing)
- ***Online***
  - Performance data queried, interpreted at runtime
  - Suitable to long running applications (especially at scale)
  - Similar in spirit to real-time visualization
- ***Online with feedback*** into ...
  - Measurement subsystem (optimize, distribute analysis)
  - Application (steering)

Monitoring for Performance Dynamics

- Runtime access to parallel performance data
  - Scalable and lightweight
  - Support for performance-adaptive, dynamic applications
  - Focus on parallel profile data
- Alternative 1: Extend existing performance measurement
  - Create own monitoring infrastructure
  - Integrate with measurement system
  - Disadvantage: maintain own monitoring framework
- Alternative 2: Couple other with monitoring infrastructure
  - Leverage scalable middleware from other supported projects
  - Challenge: measurement/monitor integration
  - ***TAU over Supemon*** (ToS) (UO, LANL)
  - ***TAU over MRNet*** (ToM) (UO, University of Wisconsin)

Talk Outline

- Motivation
- Performance observation needs
- Performance observation modes
- Monitoring for performance dynamics
- Separation of concerns and MRNet
- TAUoverMRNet (*ToM*)
  - System design
  - Monitor instantiation problem
  - *ToM* filters: distributed analysis, reduction
- System characterization
- Future plans and conclusion

Separation of Concerns

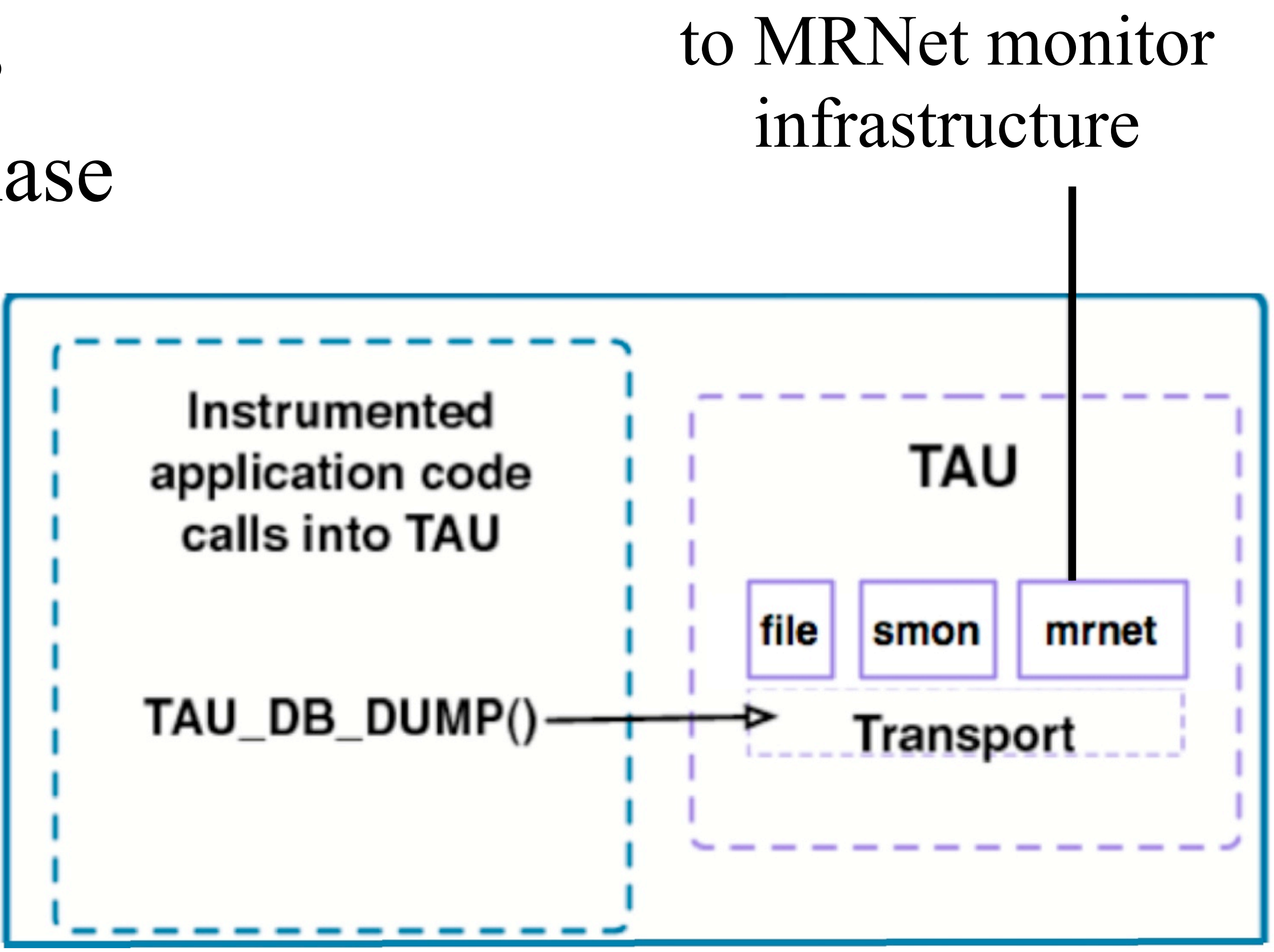
- Online *performance monitoring* decomposes into
  - Measurement
  - Access / Transport
- Measurement sub-system
  - Measures application performance
    - parallel profile per context (MPI ranks, processes, threads)
  - Maintains performance state locally (global performance data)
- Access / Transport
  - Query of distributed performance state (frequency, selection)
  - Bridges application (source) with monitors / front ends (sinks)
  - Moves performance data from source to sink
  - Distributed performance data processing (MRNet)
    - distributed performance analysis / reduction also feasible

What is MRNet?

- ***M***ulticast ***R***eduction ***Net***work
  - Software infrastructure, API, utilities (written in C++)
  - Create and manage network overlay trees (TBON model)
  - Efficient control through root-to-leaf multicast path
  - Reductions (transformations) on leaf-to-root data path
  - Packed binary data representation
- Uses *thread-per-connection* model
  - Supports multiple concurrent “streams”
- Filters on intermediate nodes
  - Default filters (e.g., sum, average)
  - Loads custom filters through shared-object interface
- MRNet-base tools (Paradyn, STAT debugger, ToM)

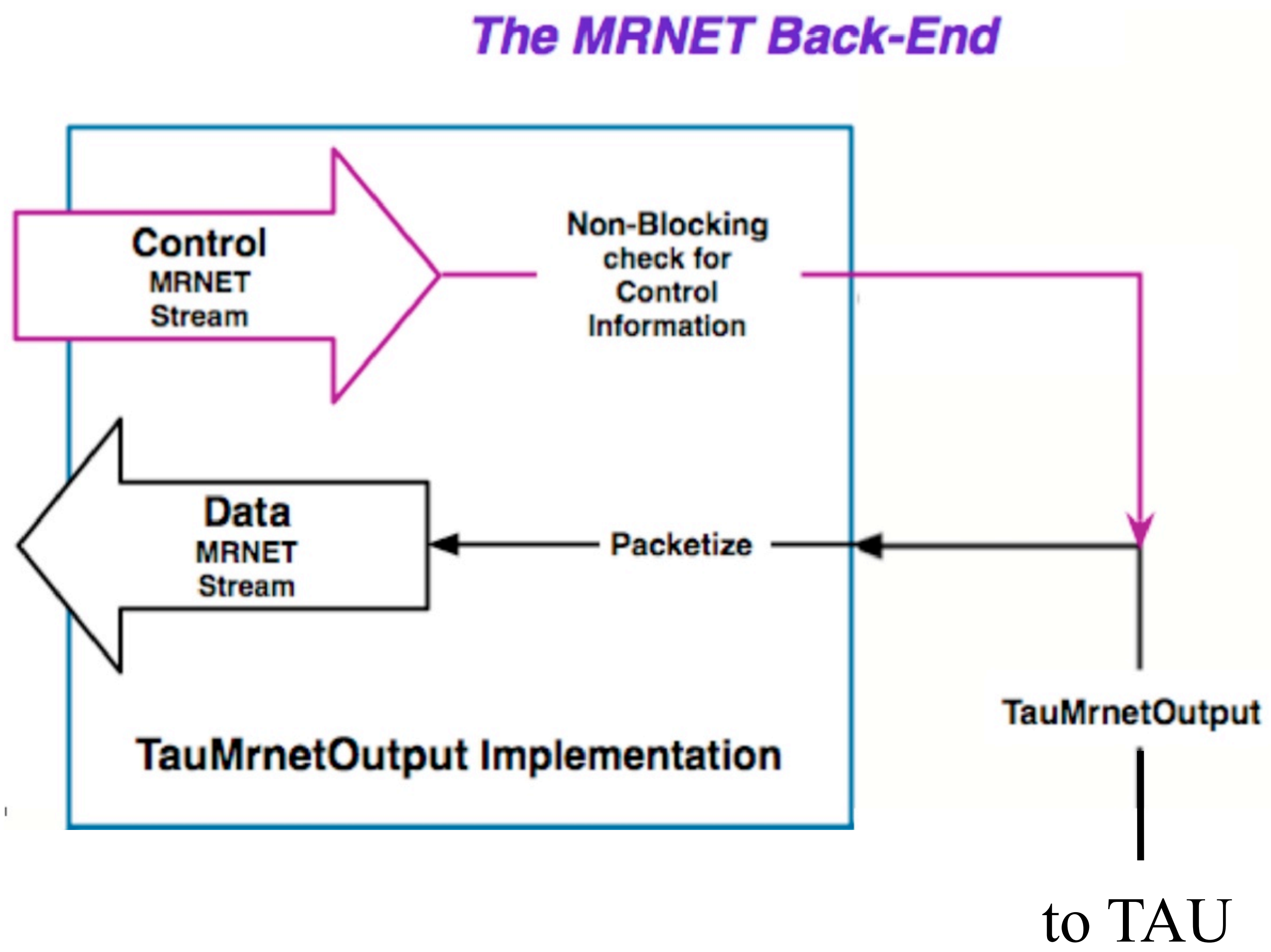
TAU Transport Abstraction Layer

- Application calls into TAU (*TAU_DB_DUMP()*)
  - Application specific intervals
    - example: per-iteration or phase
  - Regular periodic intervals
- Configuration specific
  - Compile or runtime
  - One per thread
- Develop abstract transport interface
  - Adaptors to alternative monitor infrastructure
- Push-Pull model
  - Source pushes and sink pulls

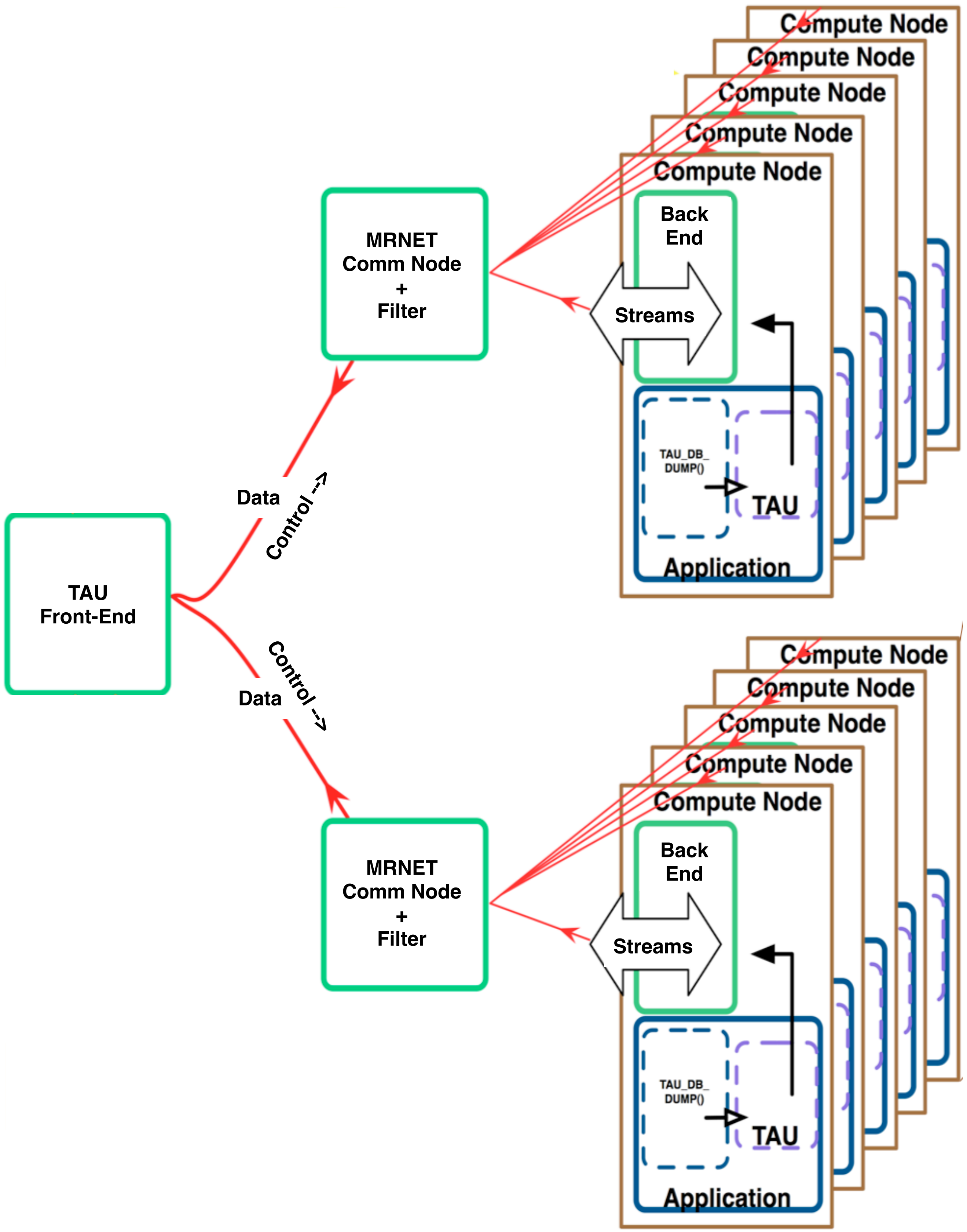


MRNet Back-End Adapter

- Adapter responsibilities
  - Initialization
  - Finalization
  - Control
  - Performance data output
- TAU MRNet Back-End
  - Two streams
    - data
    - control
  - Packetization
  - Non-blocking receive for control



Components and Data/Control Flow



- Components
  - Back-End (BE) adapter
  - Filters
    - reduction
    - distributed Analysis
    - up / down stream
  - Front-End (FE)
    - unpacks, interprets, stores
- Data path
  - Reverse reduction path
- Control path
  - Forward multicast path

Monitor Instantiation Problem

- How to co-allocate nodes (cores) for monitoring?
  - Monitor performs transport and analysis
  - General problem when utilizing additional resources
    - tool specific
- Important especially in non-interactive (batch) environments
  - Set of allocated nodes not known a priori
  - Multi-step setup procedures difficult / awkward
  - Environments vary widely
    - command-line / script interfaces and capabilities
- Need an approach ...
  - To instantiate application, transport, and front-end
  - ... that is independent of batch environment
  - ... that requires no changes to application

Monitor Instantiation: Required Steps

Monitor Instantiation: Required Steps

- Calculate (monitor + application) and request total resources
- Apportion resources based on role (monitor, application)
- Construct transport topology (Front-End, Filters)
- Help Back-Ends discover and connect to parents
- Do so transparently to application
- Do so transparently to queue manager and scheduler

Monitor Instantiation: Required Steps

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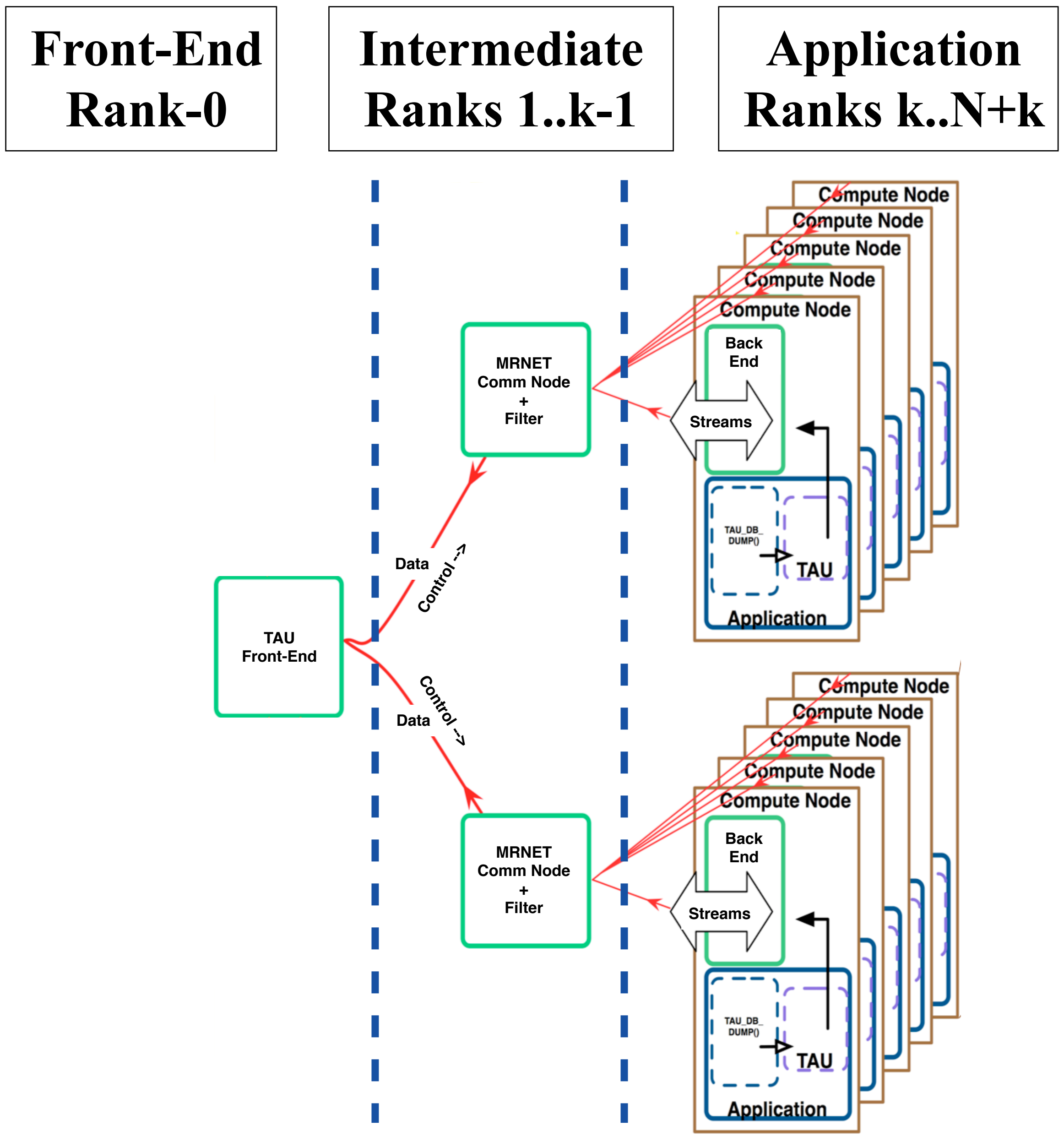
- Do so transparently to application
- Do so transparently to queue manager and scheduler

- Total resource calculation easy
  - Do so manually or through script (based on FanOut)
- MRNet already does transport topology construction and filter instantiation for us

Transparent Monitor Instantiation

- Solution for MPI Applications
- Based on interception of MPI Calls
  - PMPI interface
- Separate roles
  - Tree: Rank-0 and Ranks 1..k-1
  - Application: Ranks k..N+k
- Three parts to method:
  - Initialization
  - Application execution
  - Finalization



Transparent Monitor: Initialization

- COMM_WORLD split based on *role* of rank
- Intermediate nodes register with ToM on Rank-0 using MPI
- Rank-0 uses MRNet API to instantiate transport
- Rank-0 MPI *bcasts* tree info to application BEs to join

Rank 0

TAU MPI_Init() Wrapper

S1 : Call PMPI_Init()
S2 : Split Tree/App Comm
S3 : Recv Inter. Hostnames
S4 : Create Tree Topology file
S5 : Fork/Exec Front-End
S6 : Read Host/Port from FE
S7 : Send Host/Port to Appl.

Tree Ranks 1 to (K-1)

TAU MPI_Init() Wrapper

S0 : Call PMPI_Init()
S1 : Split Tree/App Comm
S2 : Send Hostname to Rank0

Application Ranks

TAU MPI_Init() Wrapper

S0 : Call PMPI_Init()
S1 : Split Tree/App Comm
S2 : Recv Host/Port Parent
S3 : return

Transparent Monitor: Application Execution

- Application on Back-Ends proceeds normally
- MPI calls on COMM_WORLD are converted
  - Intercepted to use *userComm*
- MPI jobs on Ranks 0 to k-1 idle
- MRNet processes active

Rank 0

TAU MPI_Init() Wrapper

S8 : waitpid() on Front-End

Tree Ranks 1 to (K-1)

TAU MPI_Init() Wrapper

S3 : Call MPI_Irecv(fini)
S4 : sleep 5
S5 : if(MPI_Test() == false)
goto S4

Application Ranks

Other TAU MPI Wrapper

S0 : if(comm == MPI_COMM_WORLD)
comm = userComm;
S1 : Call PMPI routine
S3 : return

Transparent Monitor: Finalization

- Application ranks call *MPI_Finalize*
- ToM tree destruction initiated
- Eventually Ranks 0..k-1 also call *MPI_Finalize* to end job.

Rank 0

TAU MPI_Init() Wrapper

S9 : Send fini to Tree-ranks
S10 : Call PMPI_Finalize()

Tree Ranks 1 to (K-1)

TAU MPI_Init() Wrapper

S3 : Call MPI_Irecv(fini)
S4 : sleep 5
S5 : if(MPI_Test() == false)
goto S4
S6 : Call PMPI_Finalize()

Application Ranks

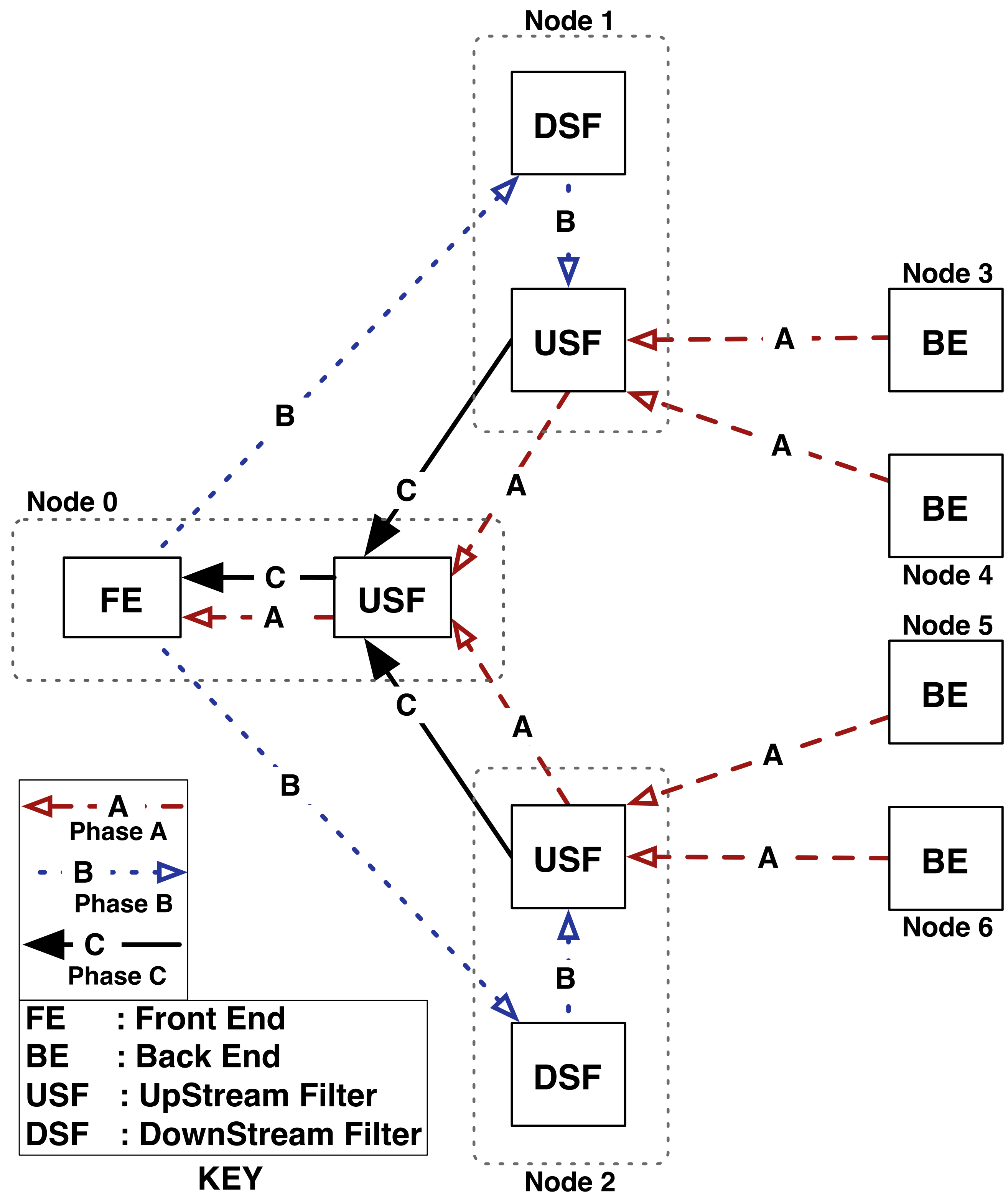
Calls MPI_Finalize()
{
Send ToM FIN to FE
Call PMPI_Finalize()
}

ToM Filters

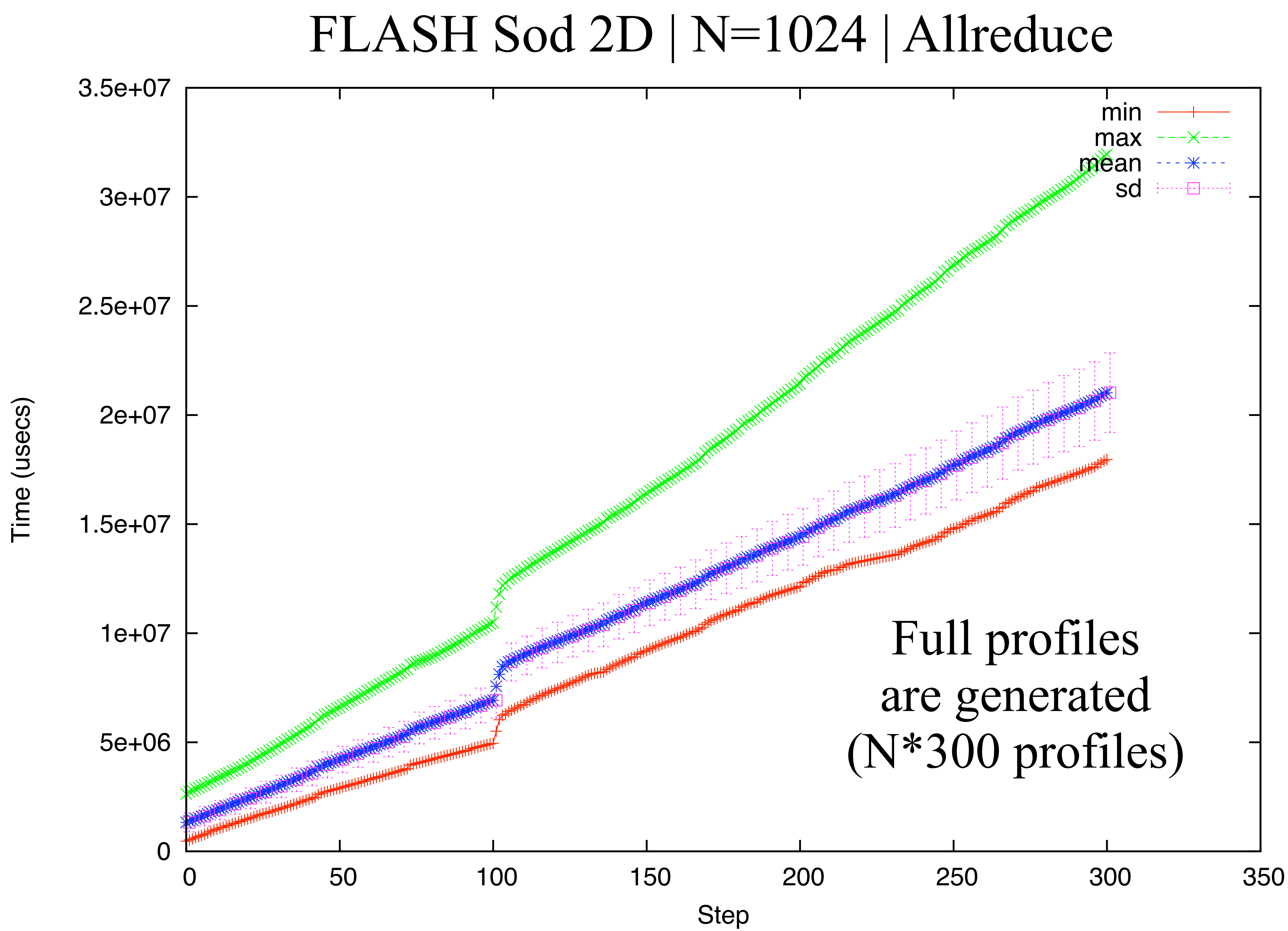
- Ideally there would be no need for filtering
  - Retrieve and store *all* performance data provided
  - Acceptability depends on performance monitor use
- High application perturbation, transport and storage costs
  - Need to trade-off queried performance data granularity
  - Which events, time intervals, application ranks?
- Reduce performance data as it flows through transport
  - Distribute Front-End analysis out to intermediate filters
- Three filtering schemes developed for ToM
  - Each builds upon and extends previous
  - Progressively provide increased temporal and spatial detail
- Upstream and downstream filters

Summary Statistics Filter

- Global summary statistics
  - Across ranks (N)
  - For each profile event
  - N parallel profiles reduced to E event statistics
  - Functions:
    - mean, min, max
    - standard deviation
- **Single phase *(A)***
  - *Up-stream filter*
- Intermediate node
  - Summarize children's data
  - Recursively arrive at FE



Example: Summary Statistics Filter



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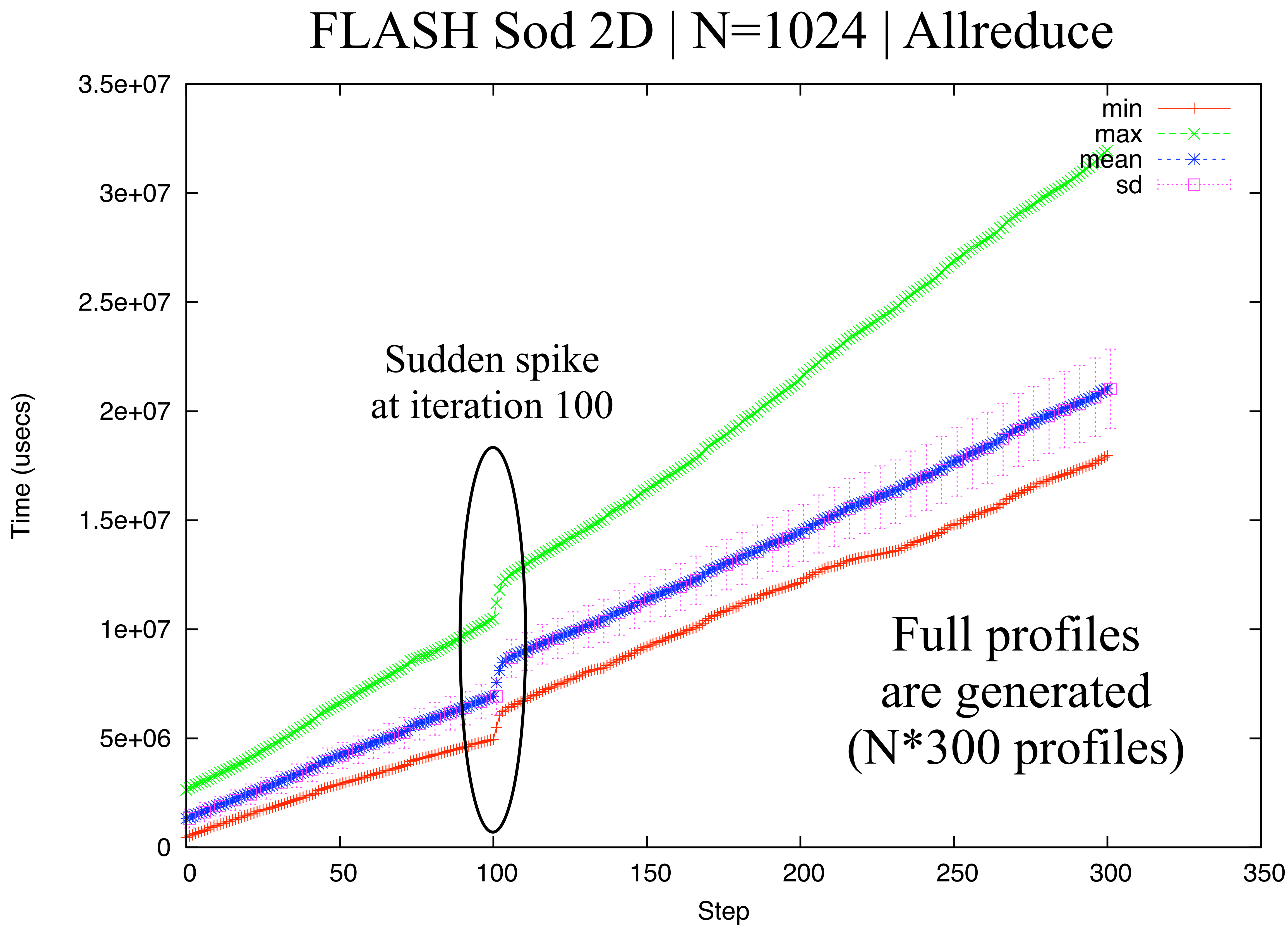
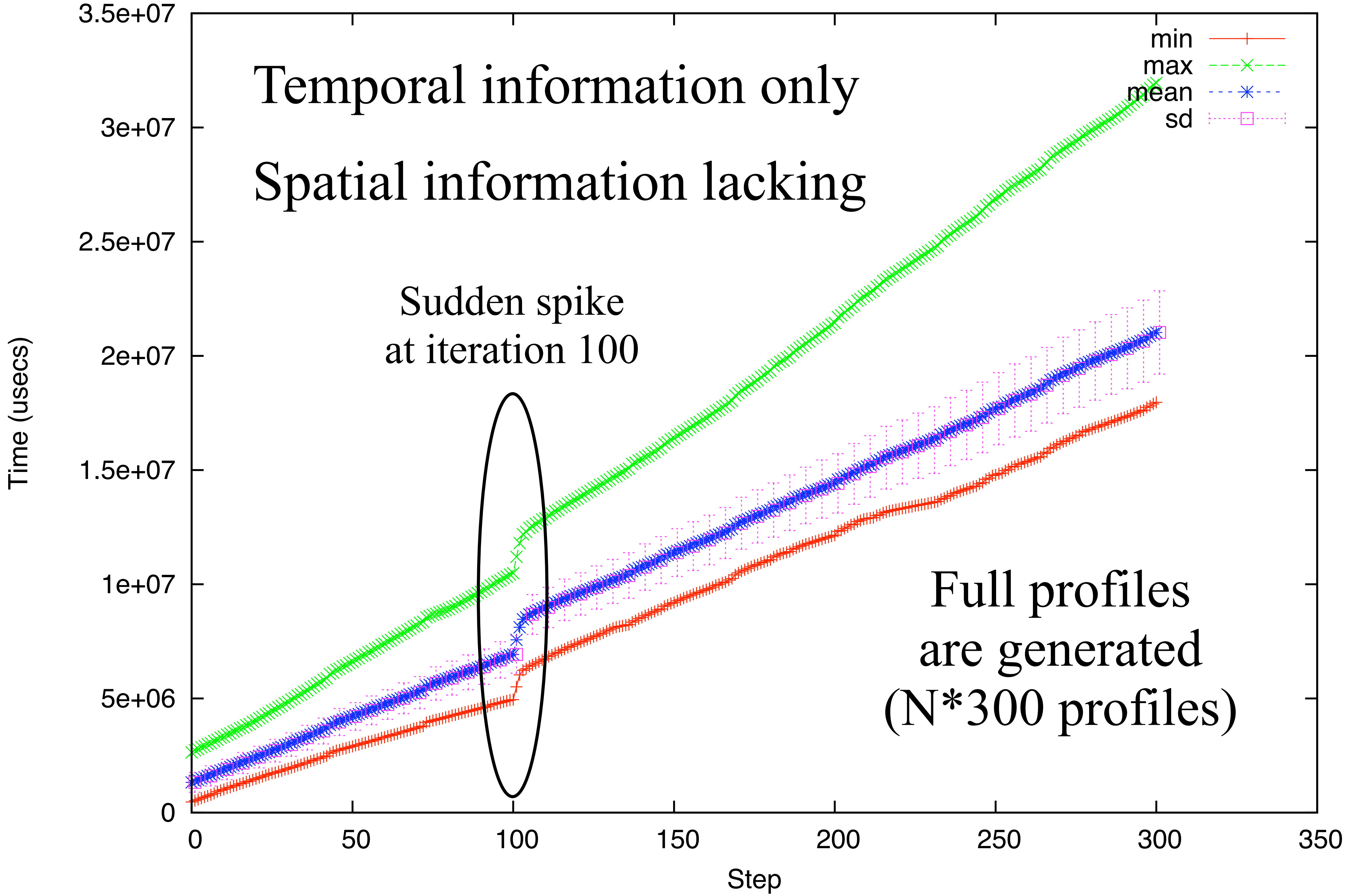


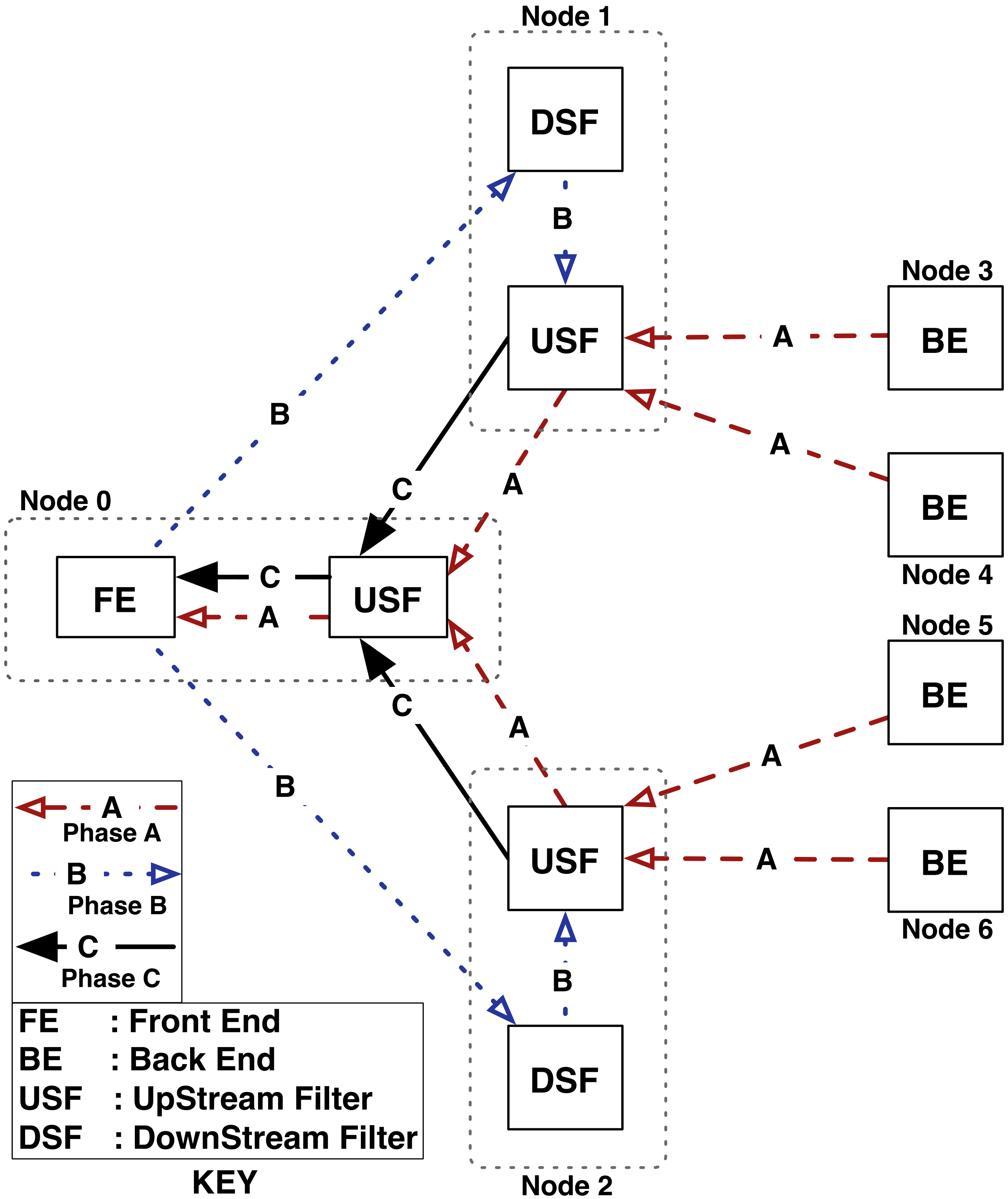
Example: Summary Statistics Filter

FLASH Sod 2D | N=1024 | Allreduce



Histogram Filter

- Maintain specified level of spatial information (# bins)
- Accurate histogram needs global min/max (range)
- Global unknown below root
- ***Three Phase (A, B, C)***
  - *A*: Push *up* min/max; buffer
  - *B*: Push min/max to DSF
  - *C*: Histogram recursively
- Model
  - Non-blocking, pipelined
  - Data parallel



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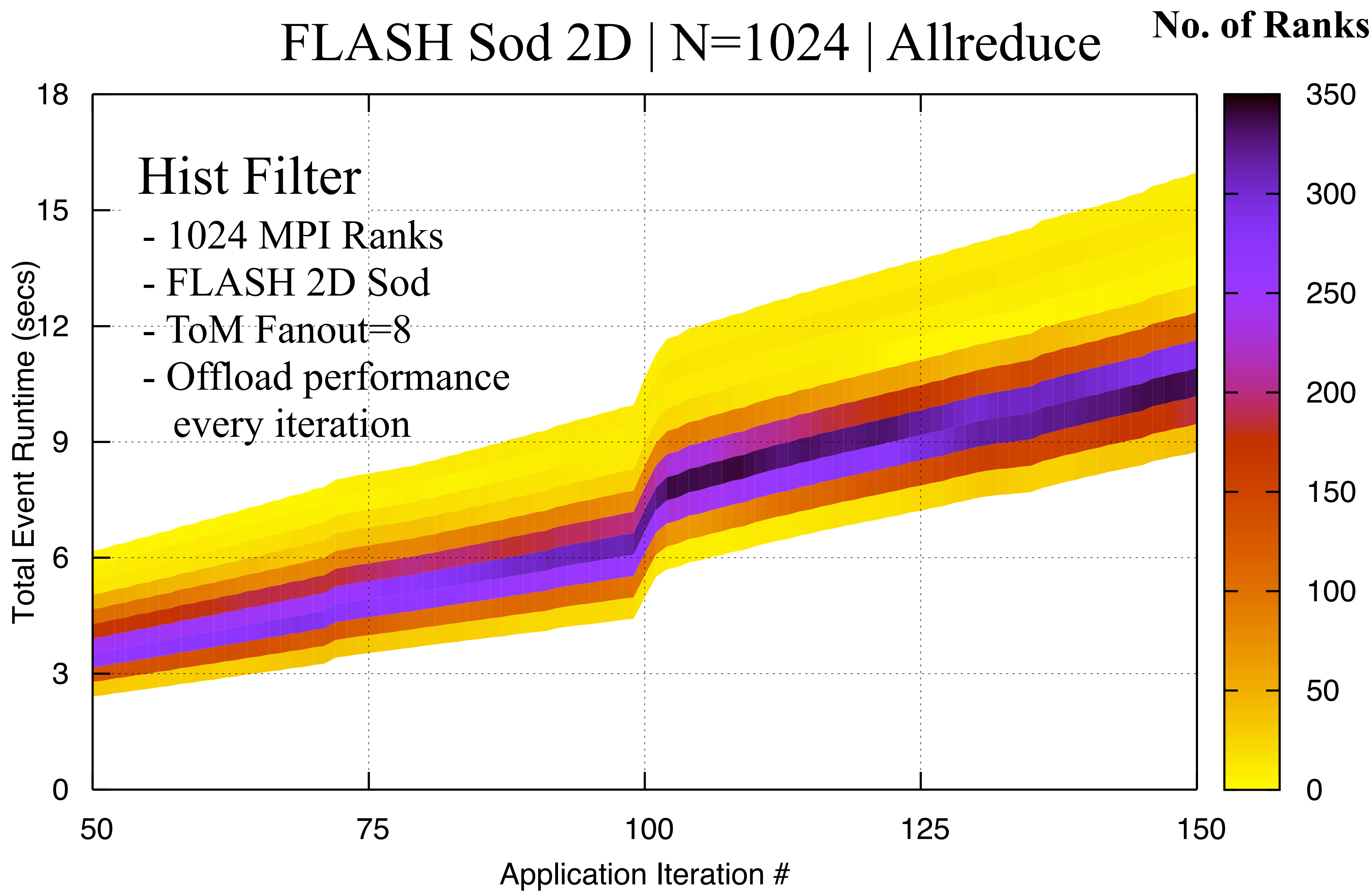

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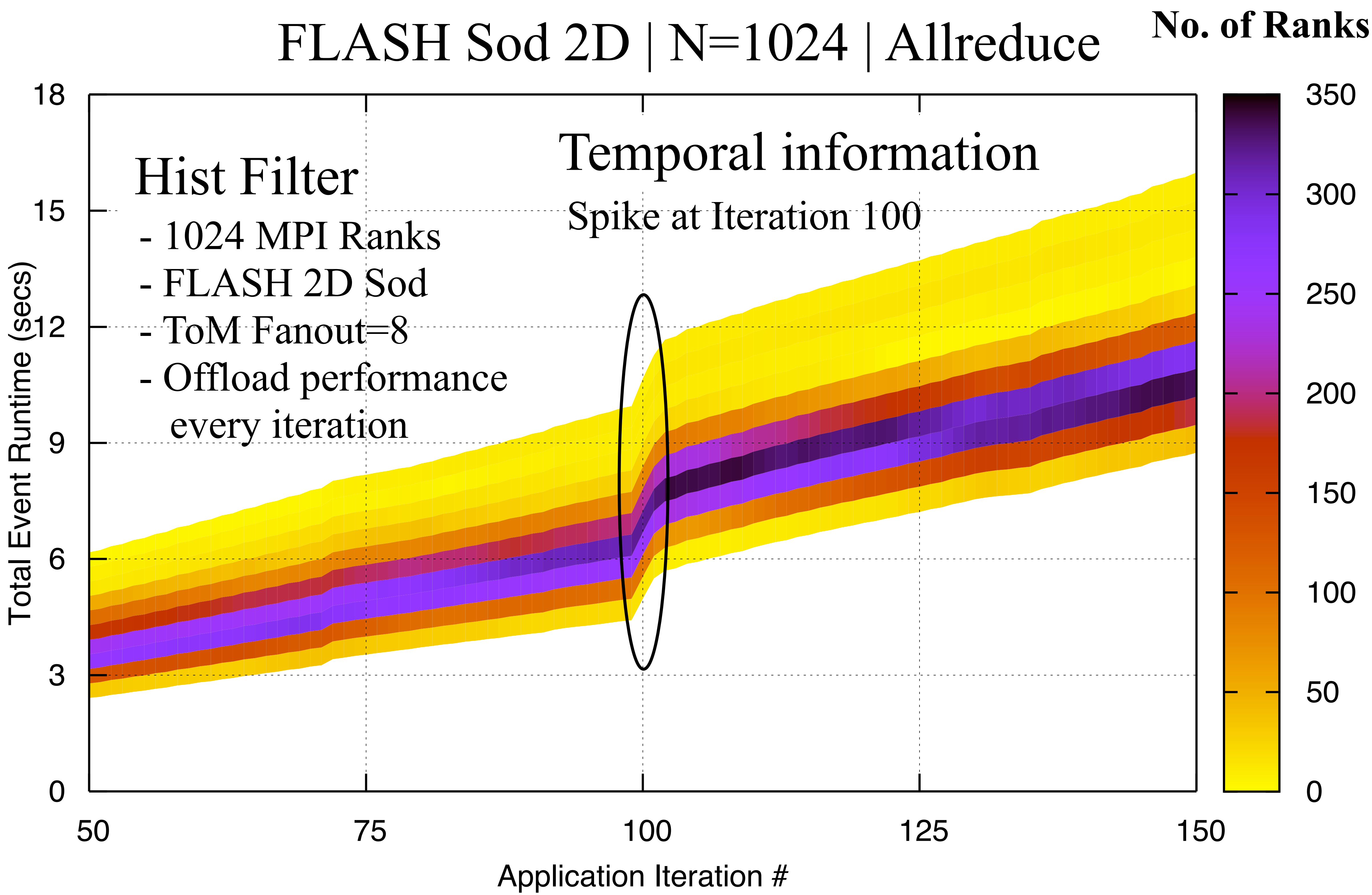

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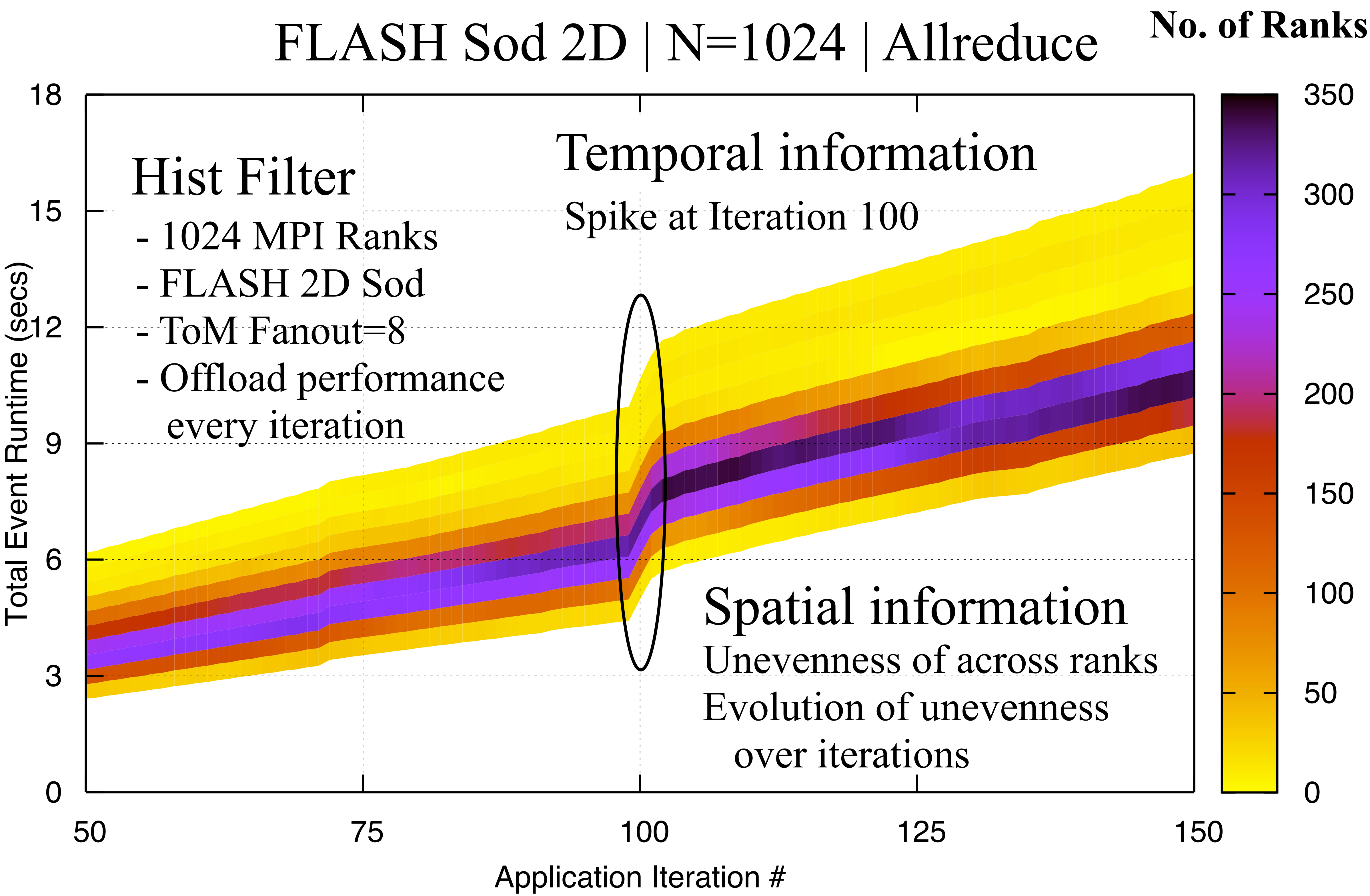
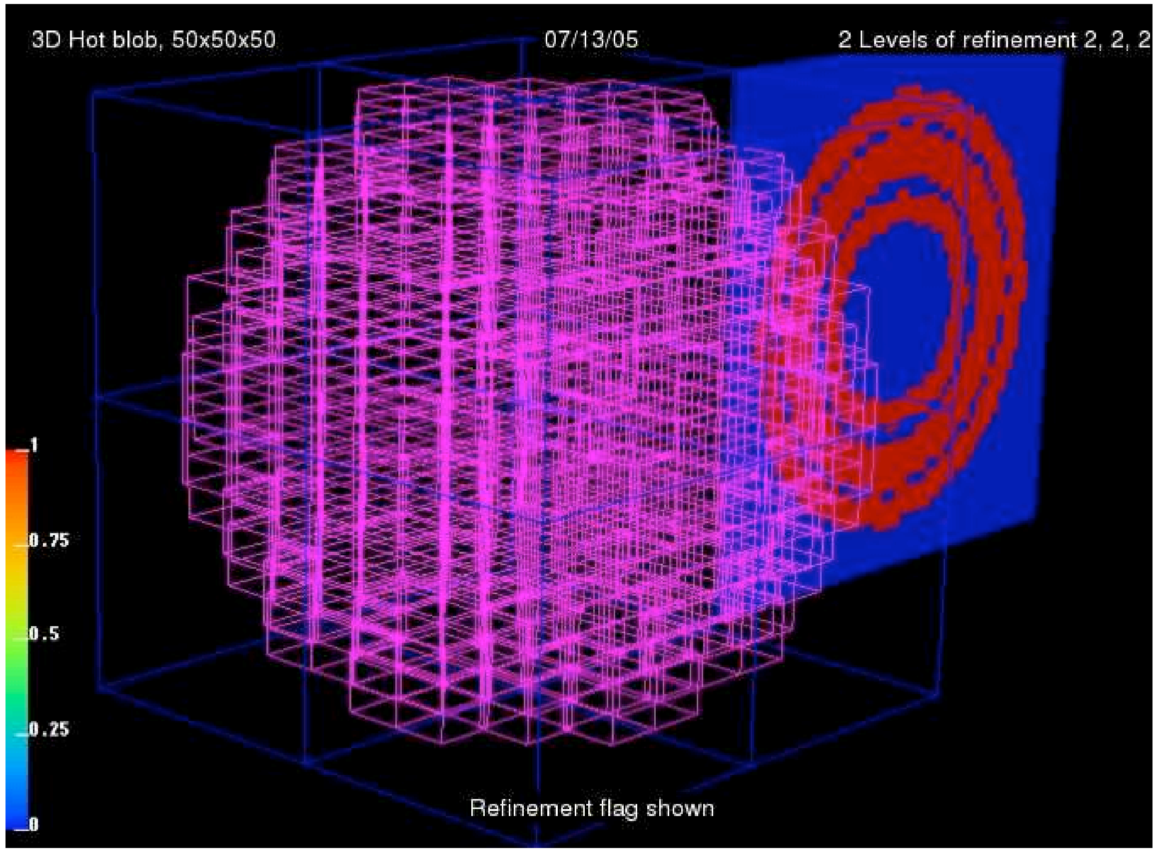


Classified Histogram Filter

- What was the cause for the unevenness in last example?
- Are there "classes" of ranks performing specific roles?
- Can we identify them from the performance profile?
- Definition of *class*
  - *Class-id*: hash of concatenated event-names
  - Ranks with same *class-id* belong to same class
  - Application-specific or tailored to observer's wishes
  - *Class-id* generated based on call-depth or only for MPI events
- Histograms generated within class
  - Output: set of histograms per-event, one for each class
- More detail than simple histograms
  - Trade-off detail from classification scheme against the costs

Example: Uintah (Hot Blob)

- Uintah Computational Framework UCF (University of Utah)
- Computational Fluid Dynamics (CFD) code
  - 3 dimensional validation problem
- Spatial domain decomposition
  - *Patch* - unit of partitioning
  - *8 outer patches* at AMR level 0
  - Inner cubes selected at level 1

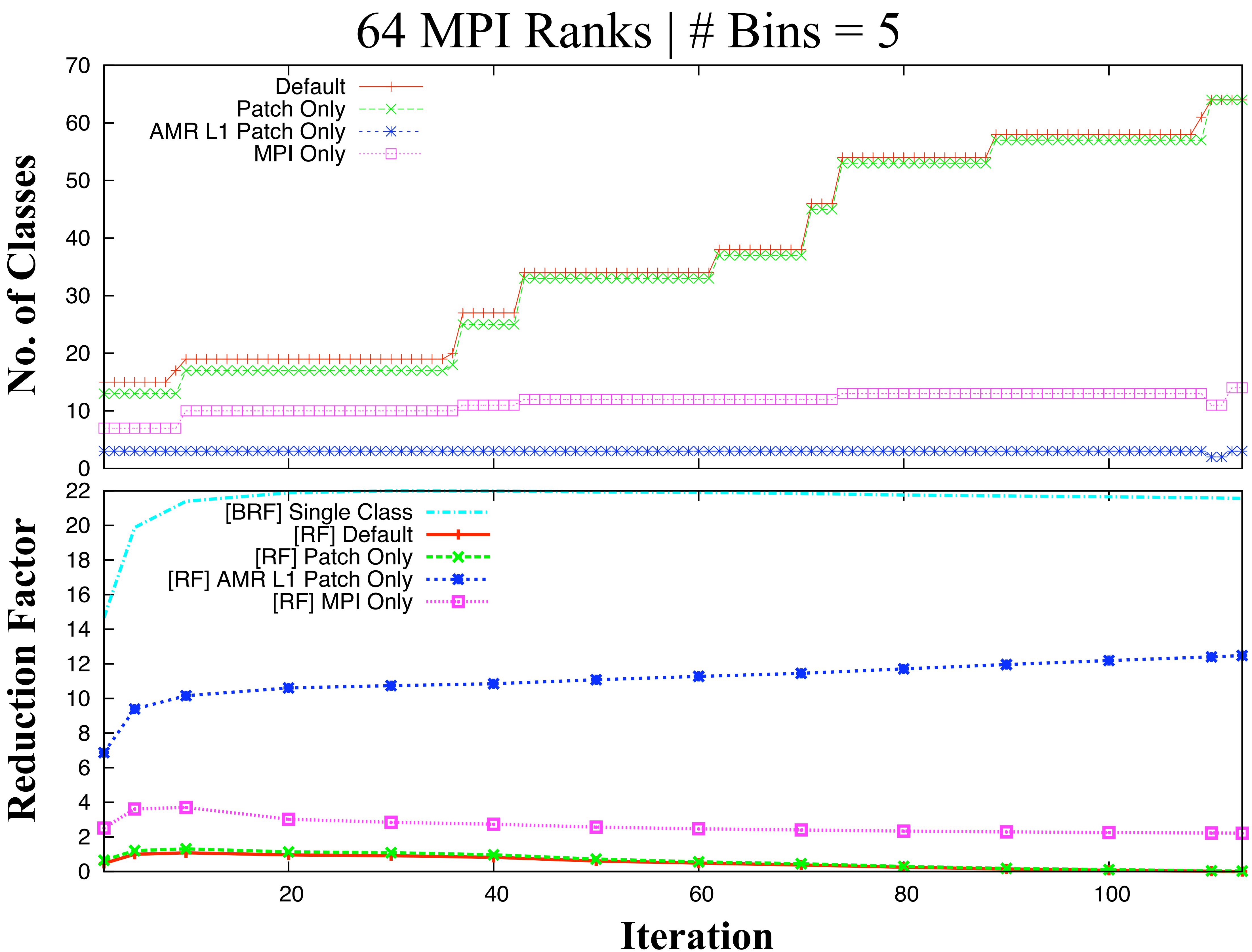


- TAU instrumentation strategy
  - Map low-level performance to patches
  - Mapping expressed through event-name
    - Patch index + AMR Level 0 ⇨ "Patch 2 -> 0"

Example: Uintah (Hot Blob)

- Classification scheme
  - *Default* : all event names used for class-id
  - *Patch Only* : only high-level Patch events used
  - *AMR L0 Patch Only* : only "* -> 0" type events
  - *MPI Only* : only MPI events
- Depending on scheme ...
  - Different number of classes generated
  - Different reduction ractor = unreduced bytes / reduced bytes
- Classification scheme allows control of trade-off
  - Savings from reduction
  - Performance detail

Example: Classified Histogram Filter | Uintah



Characterization

- Performance monitoring parameters
  - Frequency of interaction
  - Performance data granularity and size
  - # of processors
- In what circumstances is doing reduction beneficial?
  - No free lunch - requires extra work and resources
- Characterization methodology to optimize trade-off
  - Monitoring overhead
  - Additional resource assignment
- Compare reduced (*ToM Hist*) vs. non-reduced (*ToM*) runs
  - Amount of data is usually less (that’s the point)
  - Need a better metric

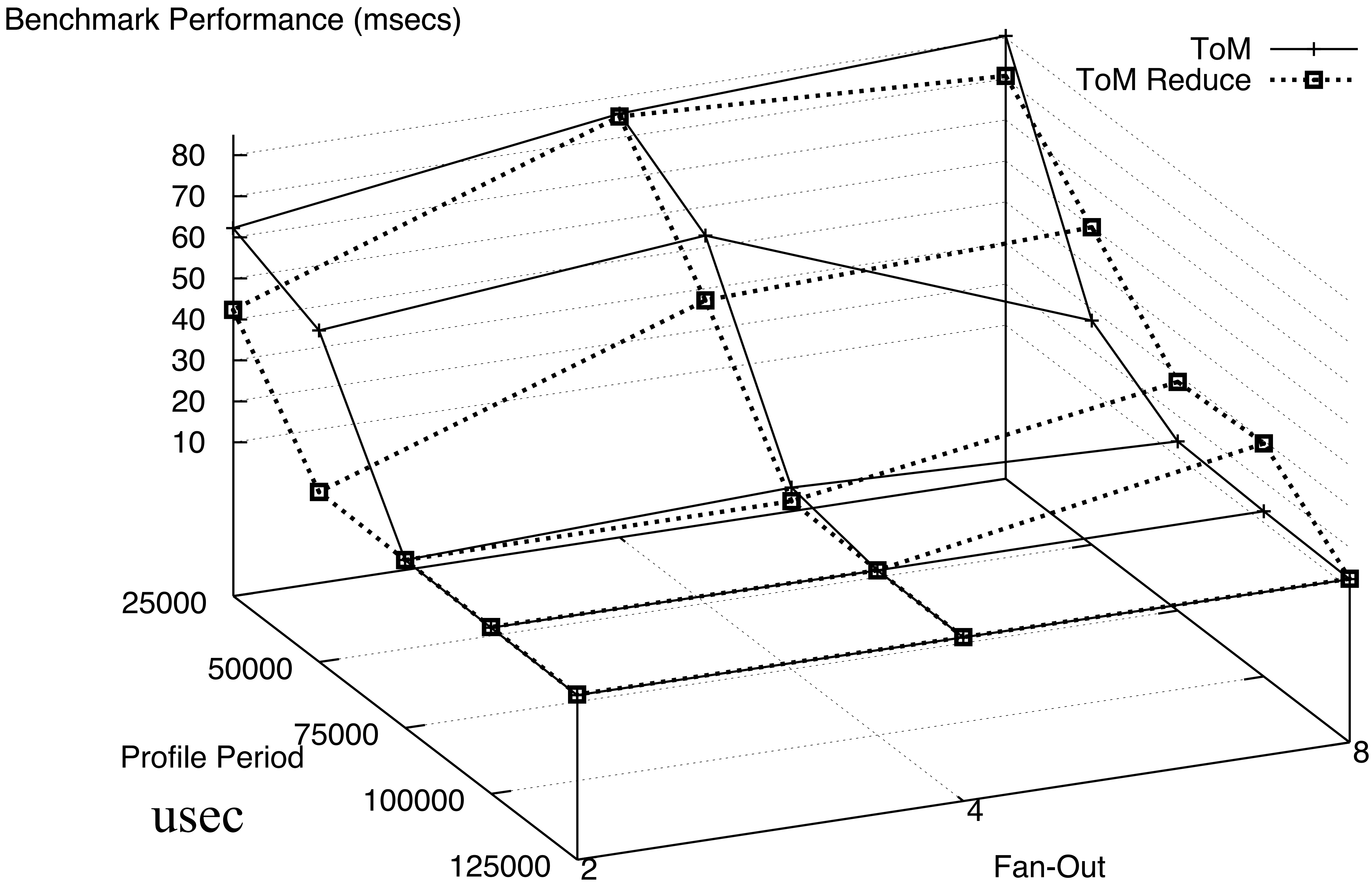
Characterization: Metric, Benchmark

- Average time for *global offload*

```
time = get_time();
for(i=0; i<iterations; i++) {
  work(usecs);
  TAU_DB_DUMP();
  MPI_Barrier();
}
tot.time = get_time()-time;
tot.dump.time = time - work_time - barrier_time;
dump.time = tot.dump.time/iterations;
```

- Increasing offload rate (function of *usecs* above)
  - Overtakes service rate of *ToM* (and underlying system)
  - Eventually lead to queueing and blocked send() call
  - Reflected in the average time for offload (*dump.time*)
- Stress test of *ToM*

Characterization: N=64, FO=8



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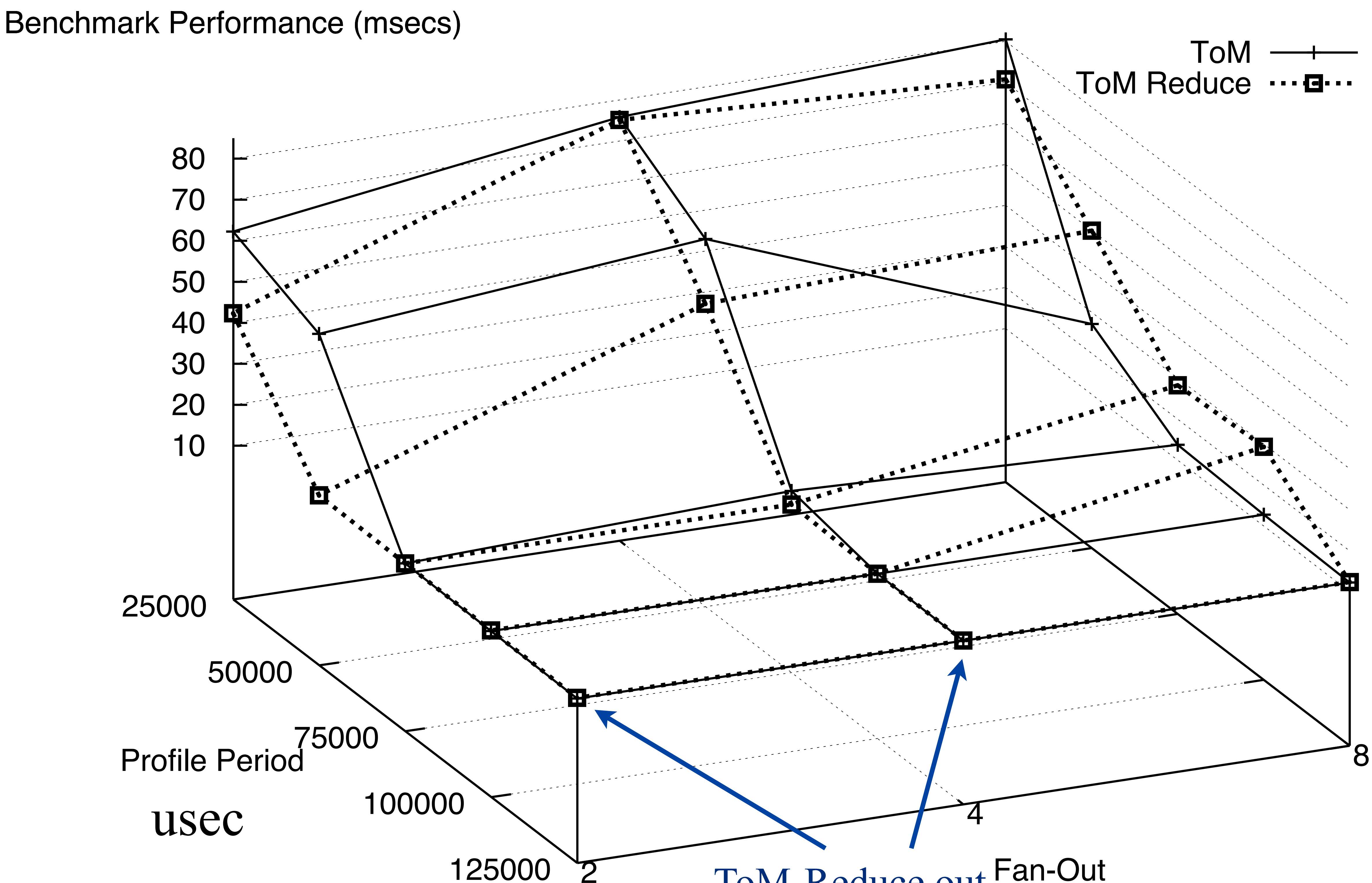
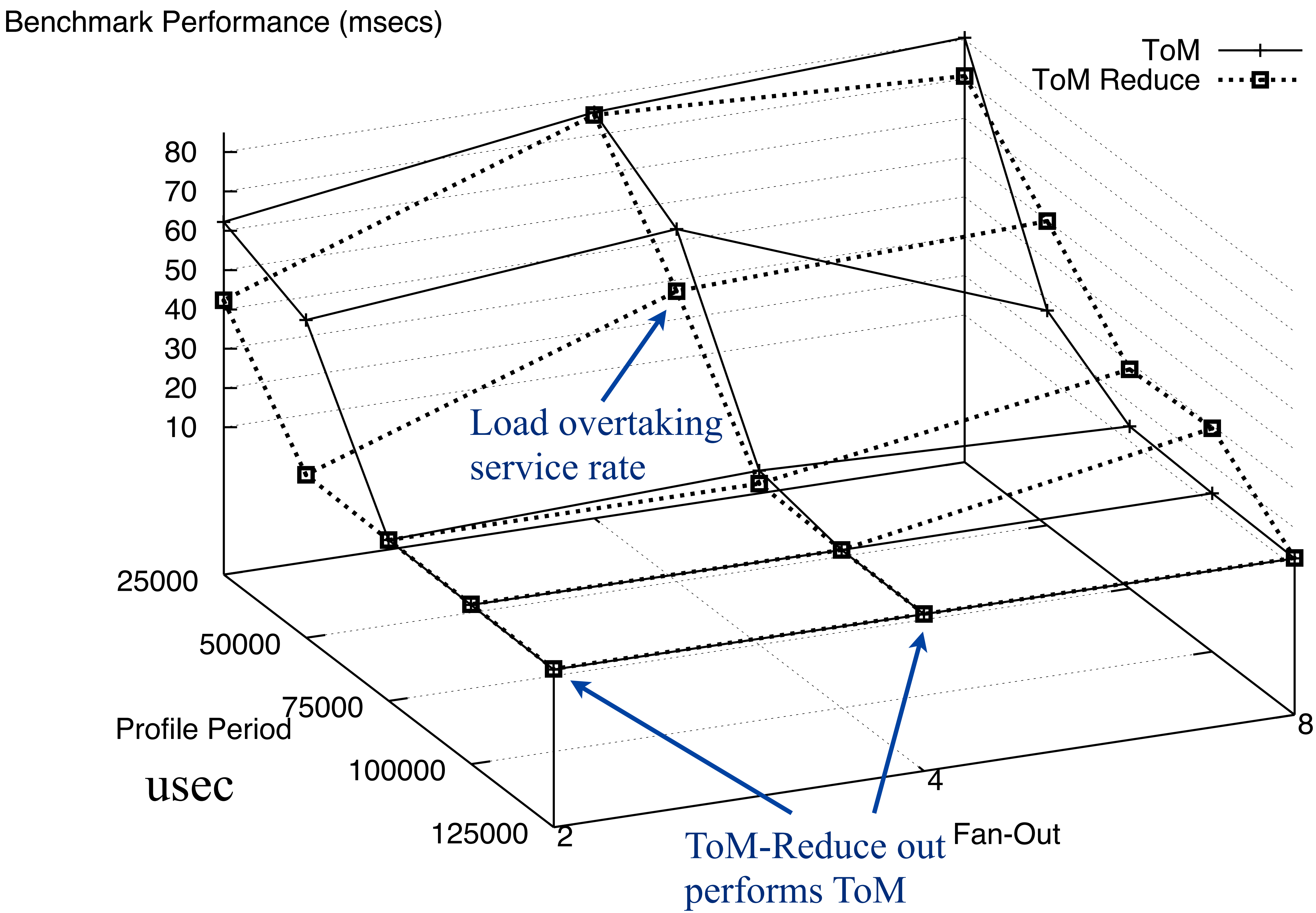


ToM-Reduce out performs ToM

Characterization: N=64, FO=8



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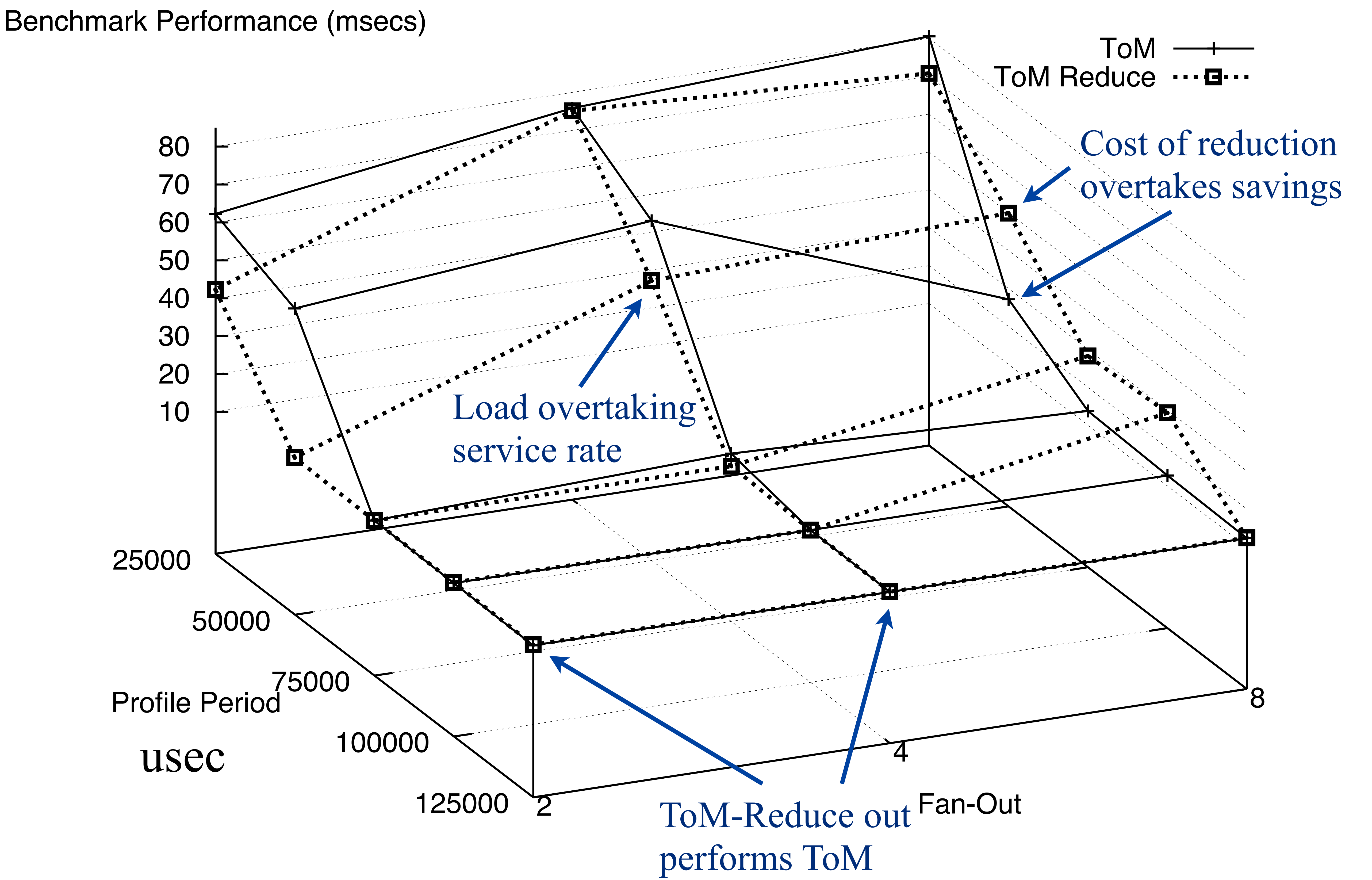
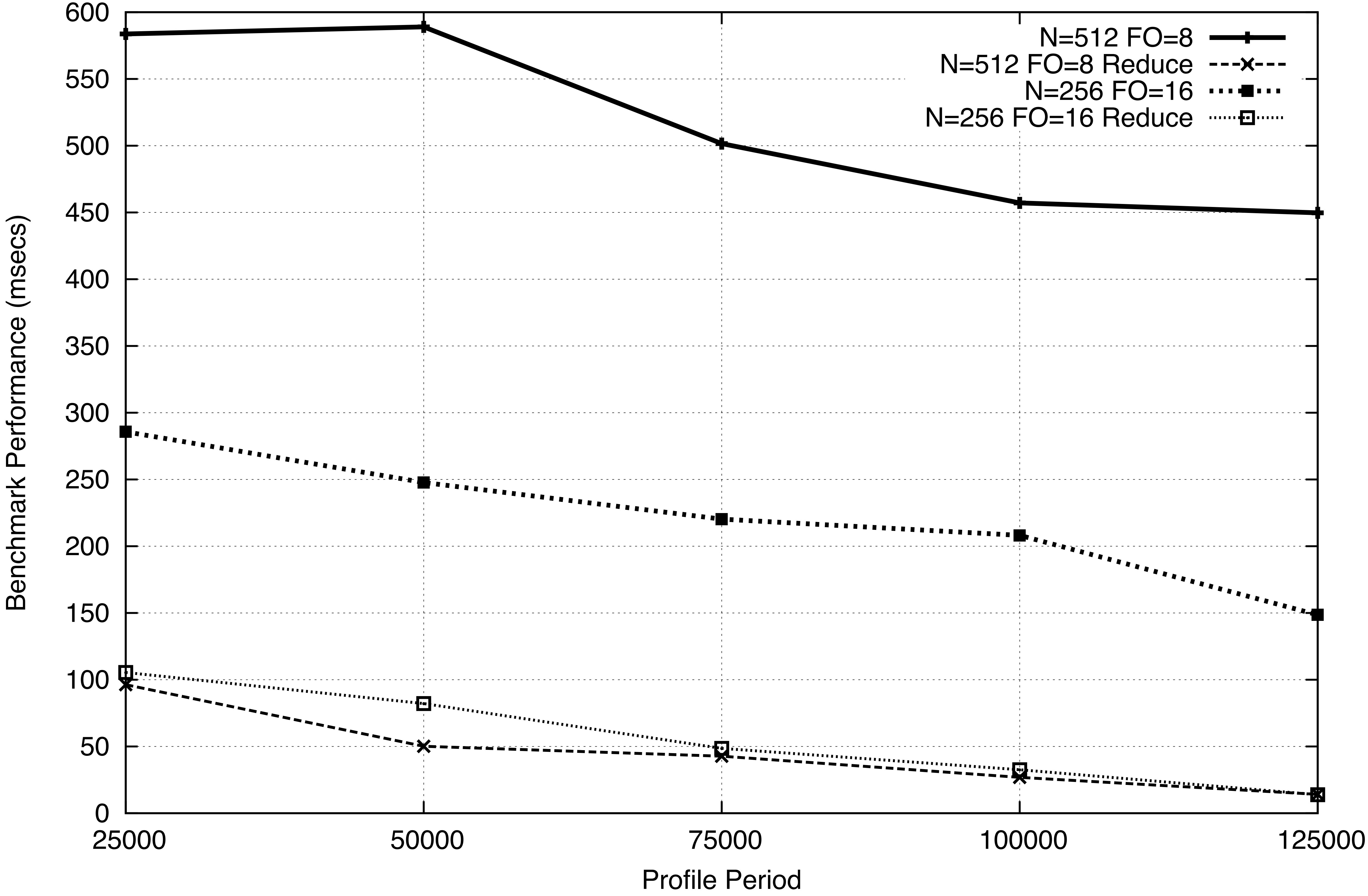


Characterization: Large N (256, 512)



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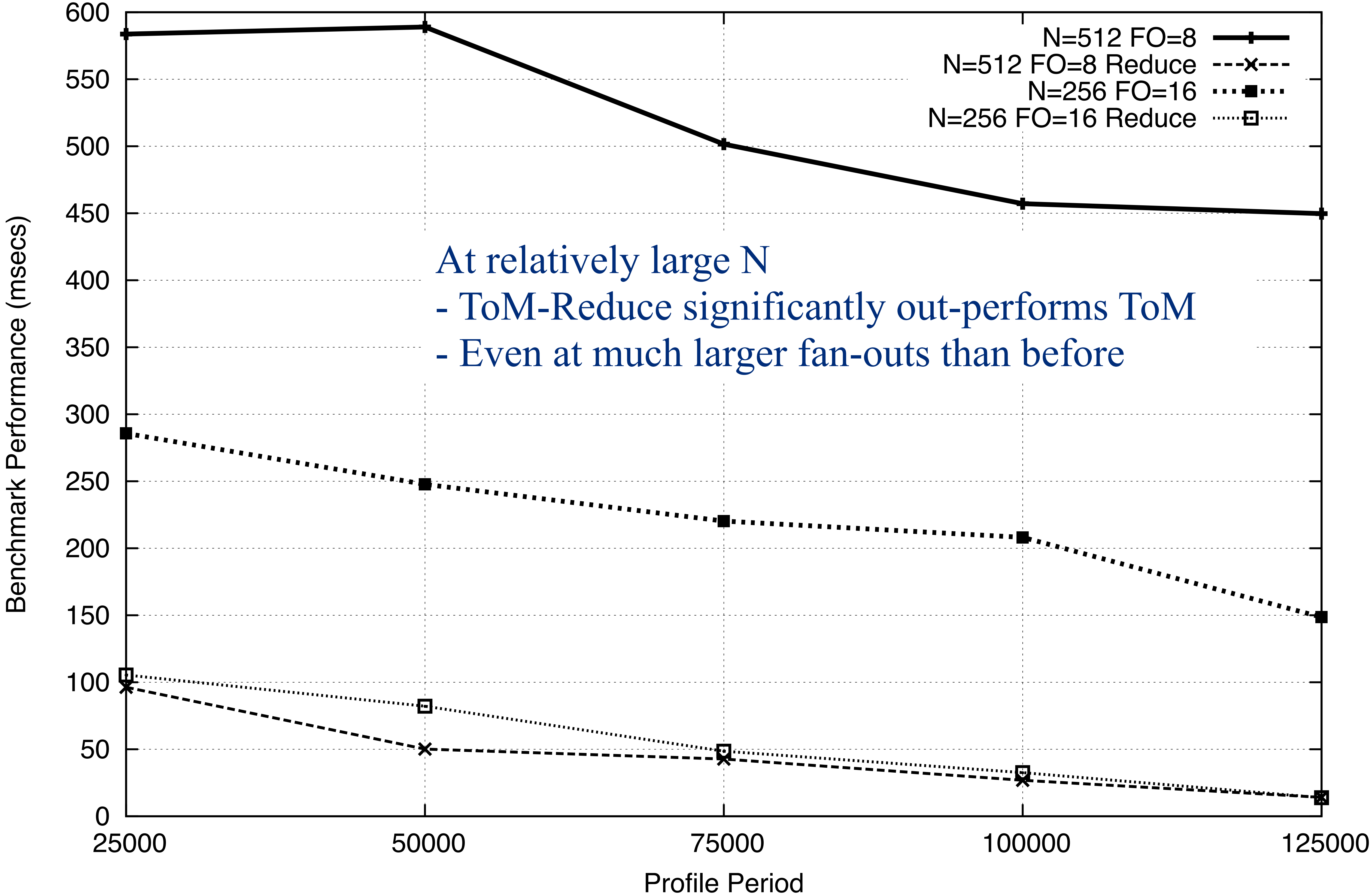

Conclusion and Future Work

- High *return on investment* from additional resources
  - Fan-out of 64 is only 1.5% extra resources
- Have only scratched the surface
  - Interesting distributed performance analysis to explore
  - Support of feedback into application
    - based on performance dynamics
  - Load-balancing and resource (re-)allocation
- Interest in experimentation on very large scales
  - Looking for candidate applications
- Would like to hookup system to real-time visualizations

Credits

- University of Oregon
  - Aroon Nataraj
  - Alan Morris
  - Allen D. Malony
  - TAU group members

- University of Wisconsin
  - Dorian C. Arnold
  - Michael Brim
  - Barton P. Miller