Automatic Identification of Application I/O Signatures from Noisy Server-Side Traces

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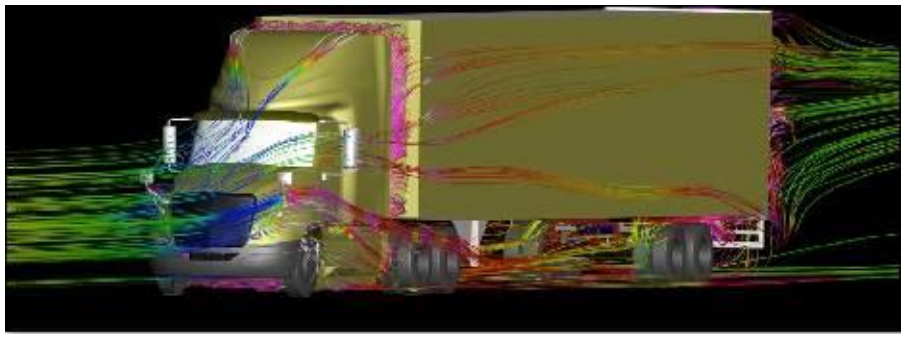
Instance of Large-Scale HPC Systems

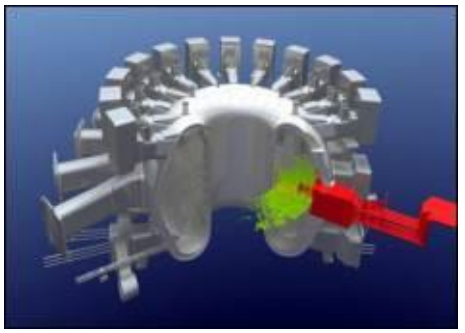
ORNL's TITAN
(World's #2 Supercomputer)

- 27.1 PF Peak performance
- 18,688 compute nodes
  - 16-core AMD Opteron
  - Nvidia Tesla GPU
  - 32 + 6 GB memory
- 3-D Torus interconnect

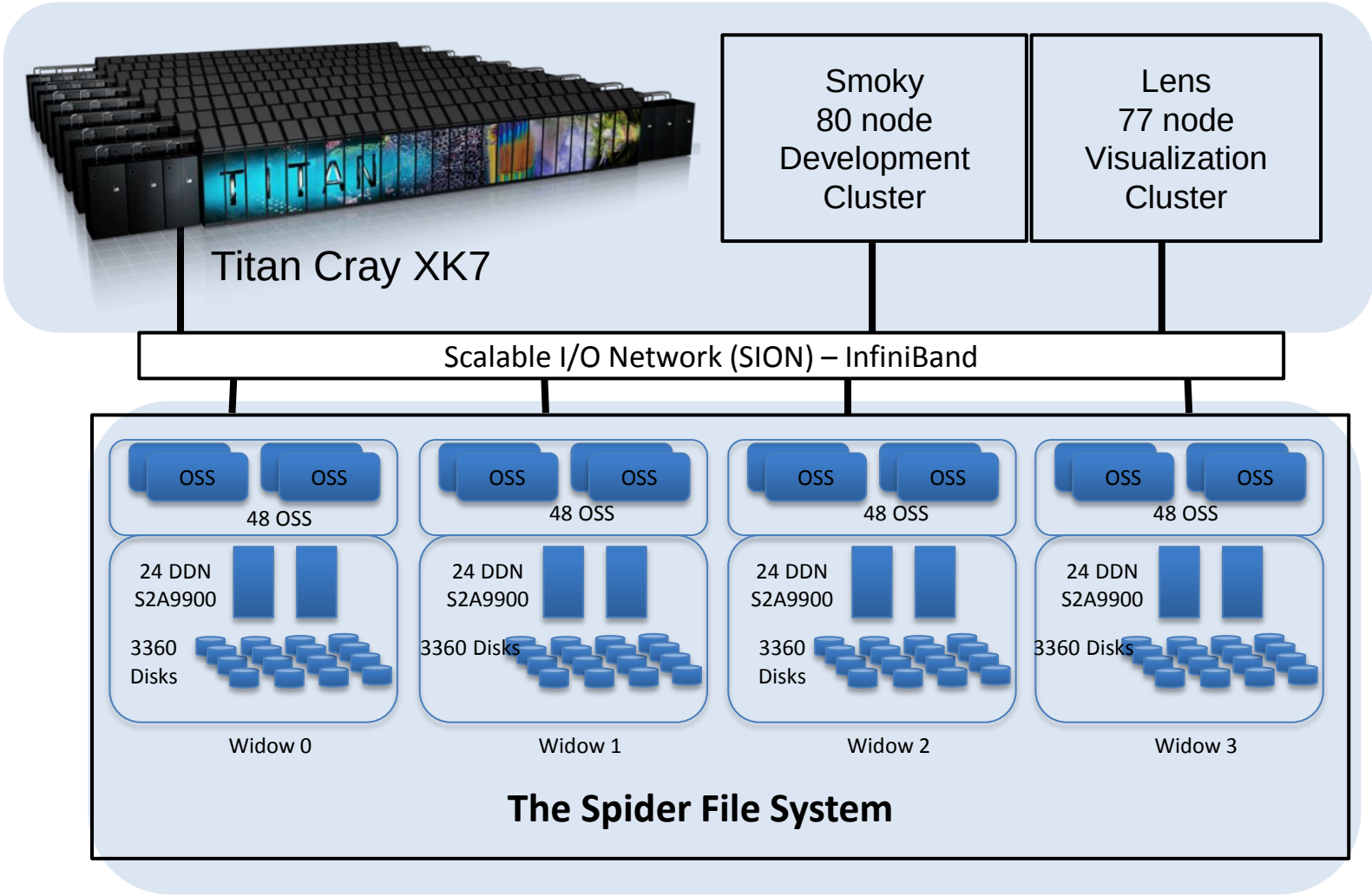
Delivering science and solving real-world problems

- 400+ scientific users
- Diverse science domains

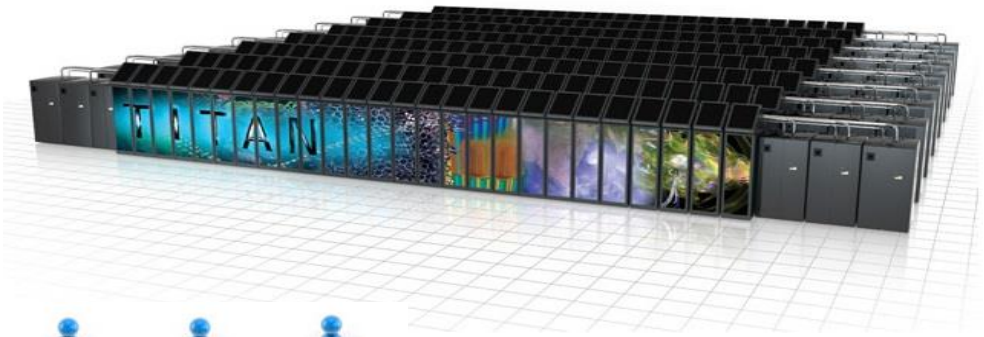




OLCF Architecture Overview

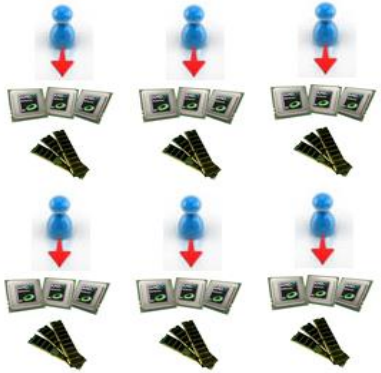


I/O Bottleneck in HPC



Processor

Memory



Interconnect network

Storage system

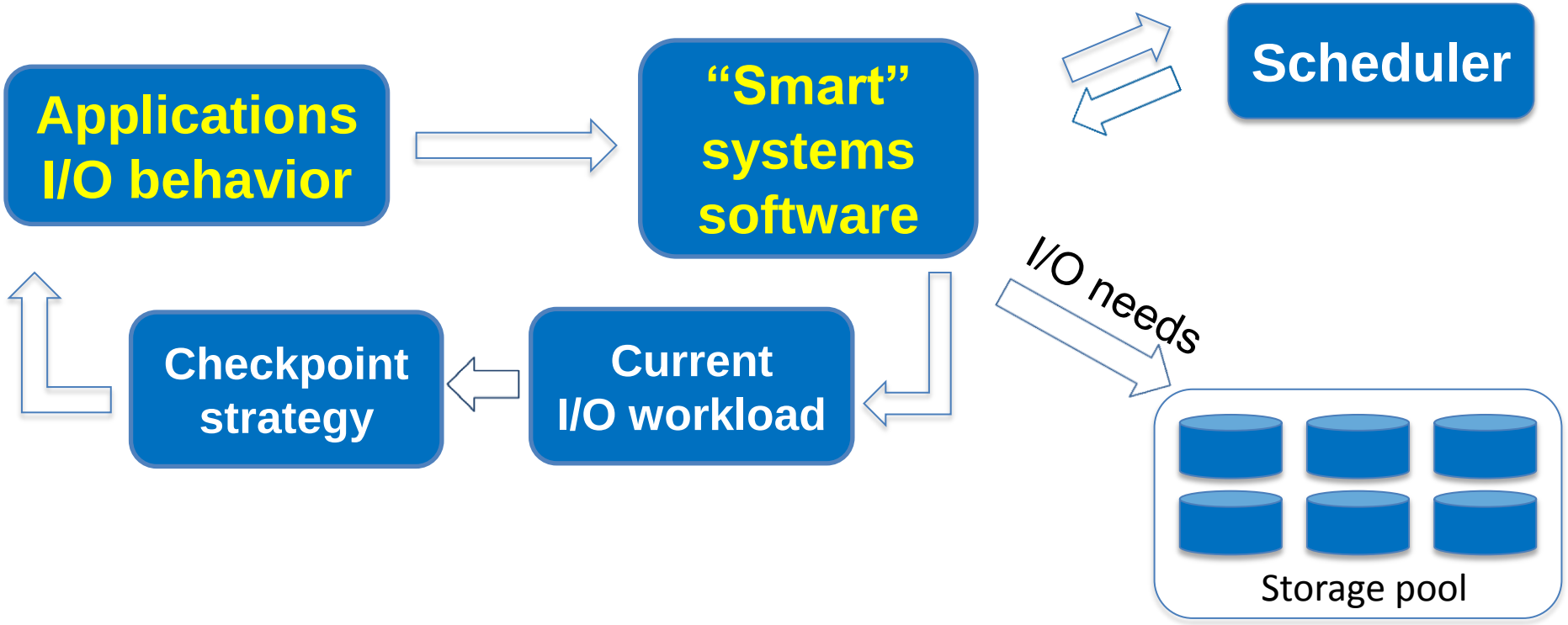
Resource contention

Longer and highly variable runtime

Lower scientific productivity

Reduced resource utilization

I/O Usage Patterns Needed to Alleviate I/O Bottleneck



We need to know application's I/O patterns and trends

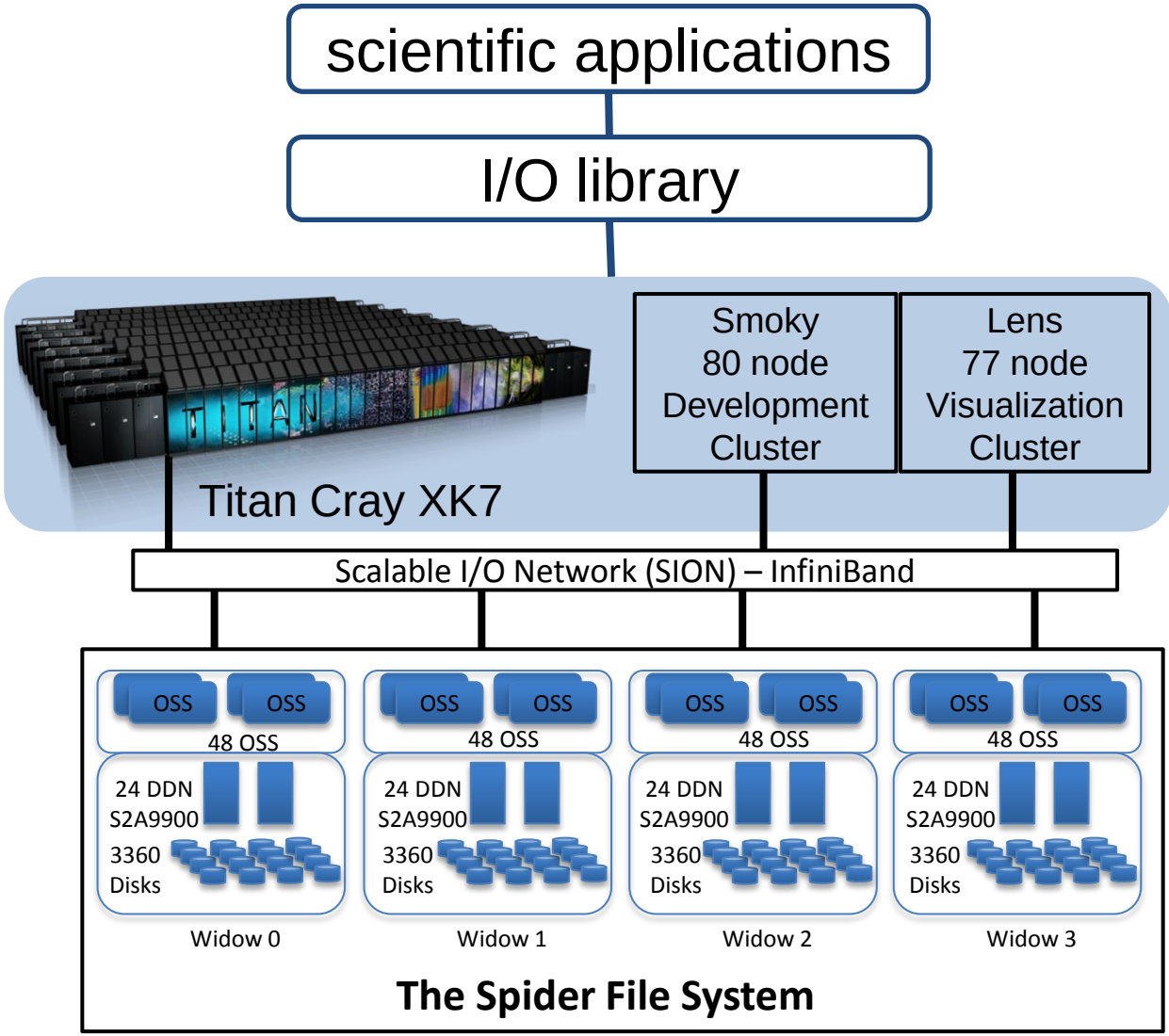
Outline

- Background
- Motivation
- Tracing approach comparison
- Problem definition
- Design
- Evaluation
- Conclusion

Client-side Tracing

Problems

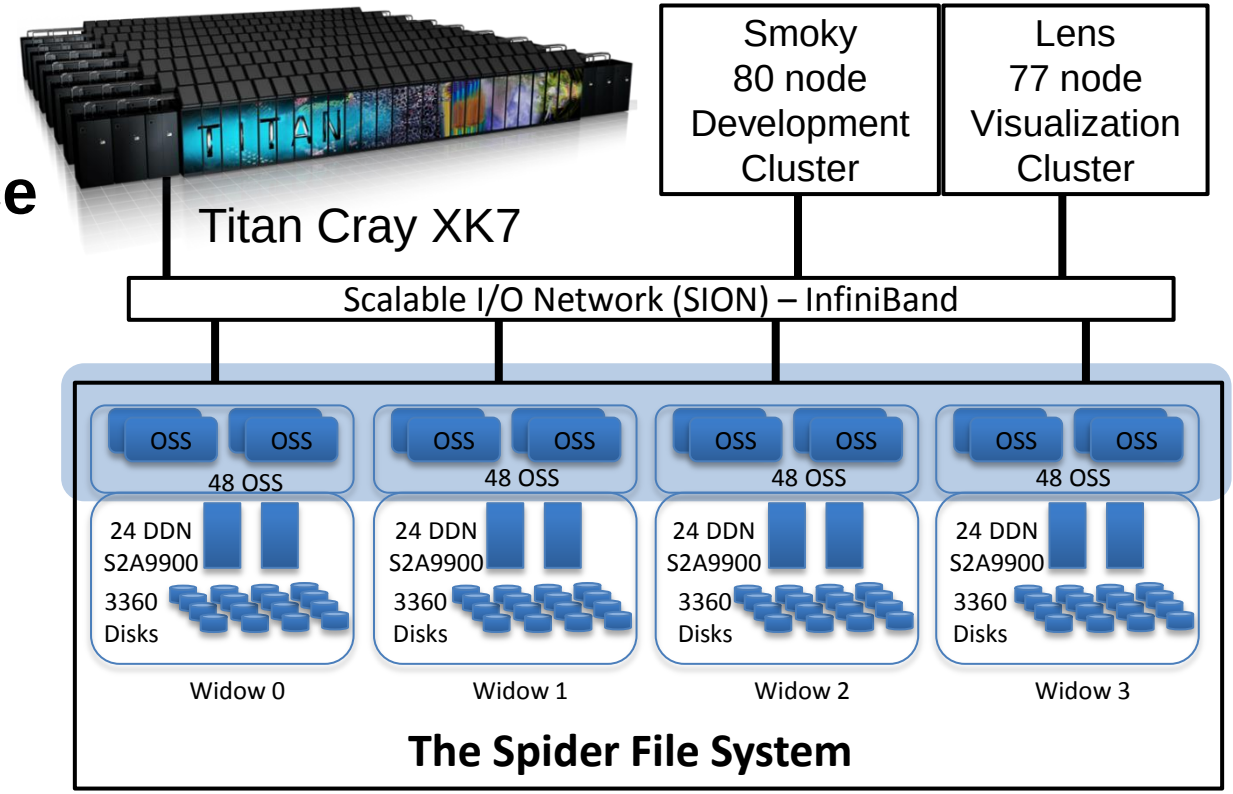
- Development effort
- Elective & Voluntary
- Performance overhead (2%-8%)
- Distinct tracing format
- Extra I/O workload



Server-side Tracing

Fine-grained RPC trace

- Detailed information
- No user effort
- Performance degradation
- Huge trace data



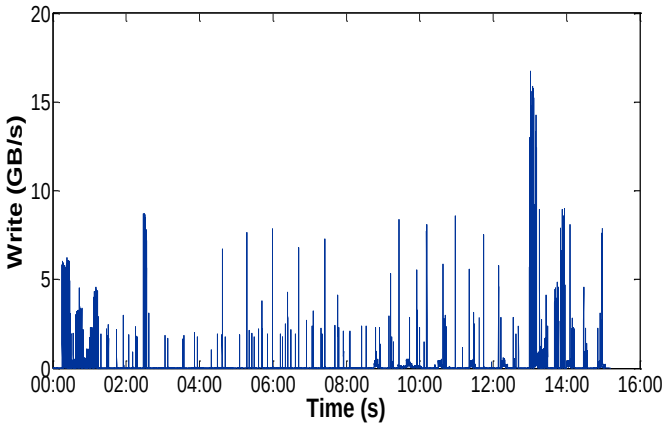
Server-side tracing tools

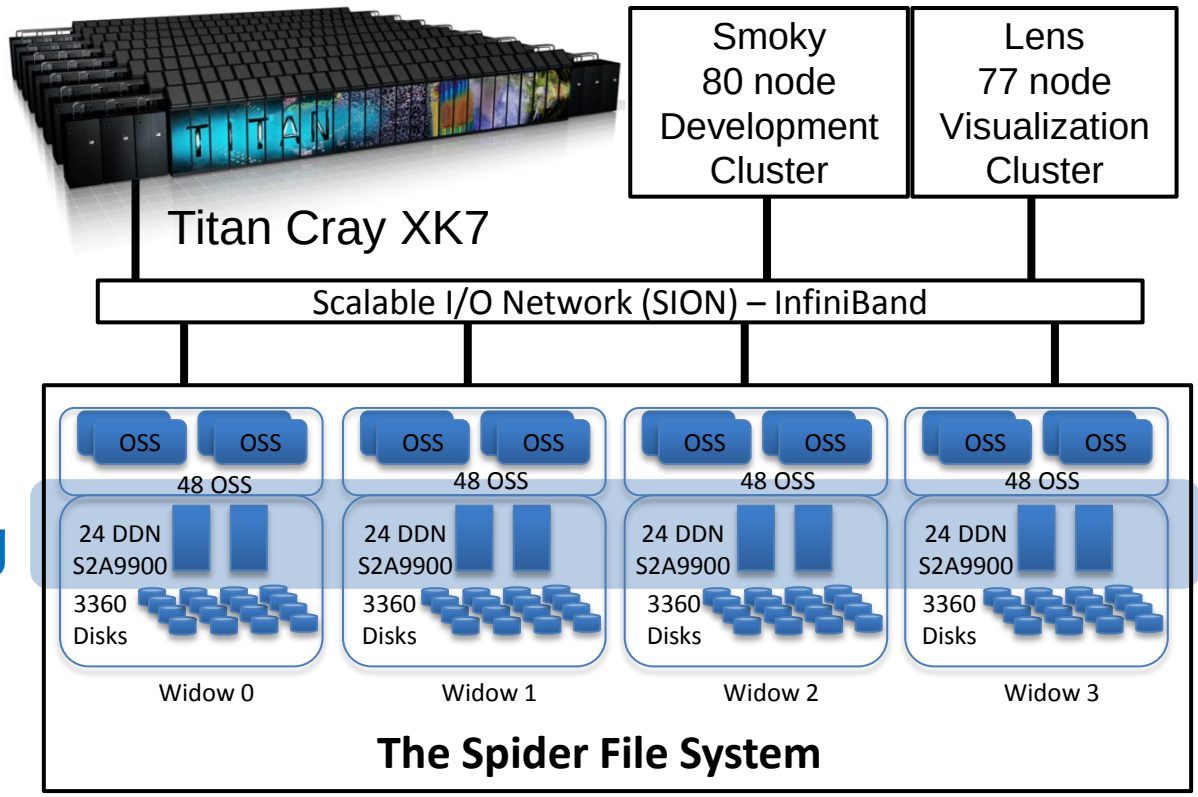
Server-side I/O Throughput Logs

I/O throughput logs

- Zero overhead
- No impact on user IO
- No user effort
- Mixed I/O traffic

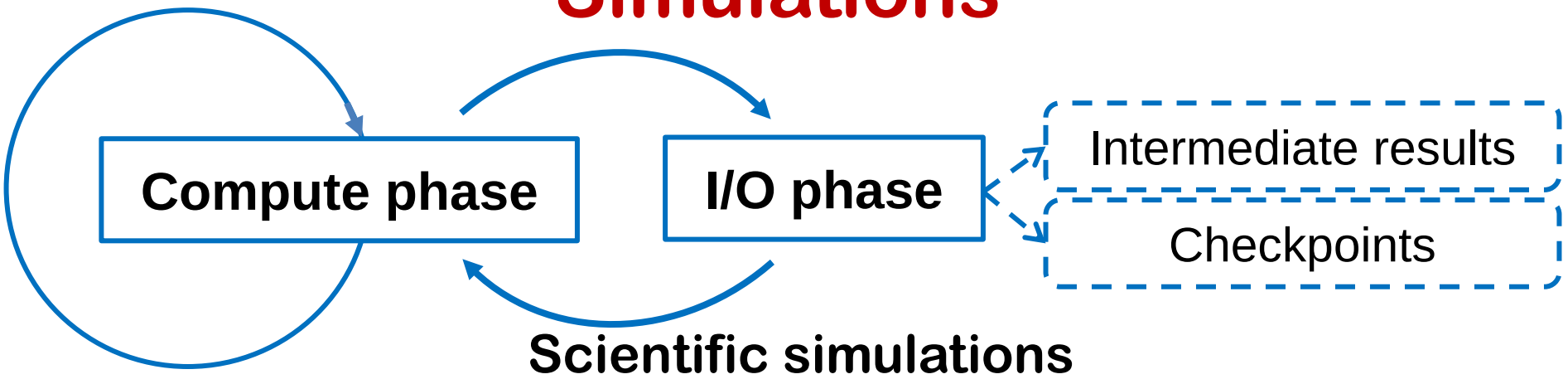
RAID controller Coarse-granule logging





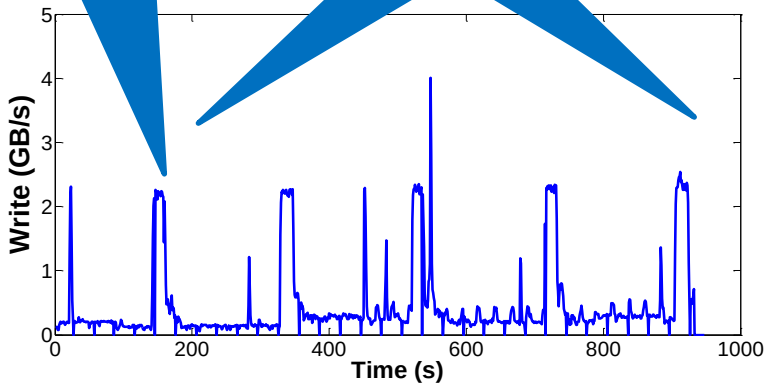
Server-side I/O throughput logs

I/O Characteristics of Scientific Simulations



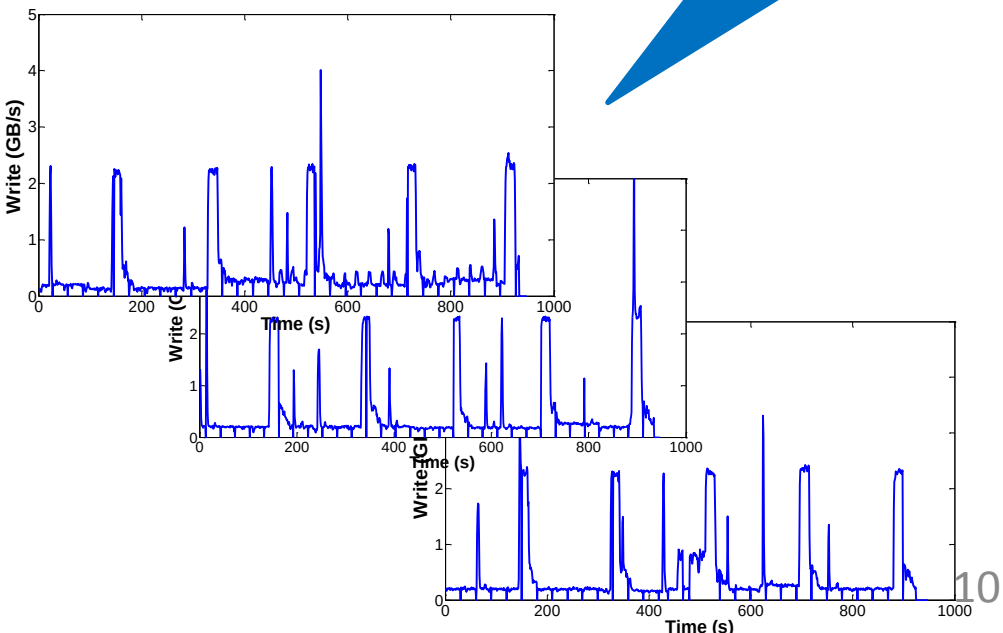
Scientific simulations

Bursty **Periodic**



Write throughput observed during one application run

Repetitive



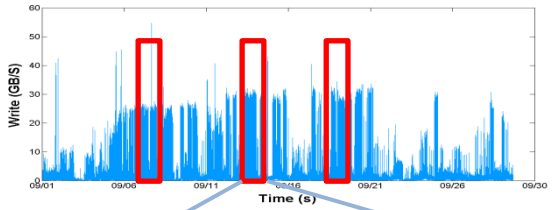
I/O Signature Identifier (IOSI)

Target App
(User ID + App ID)

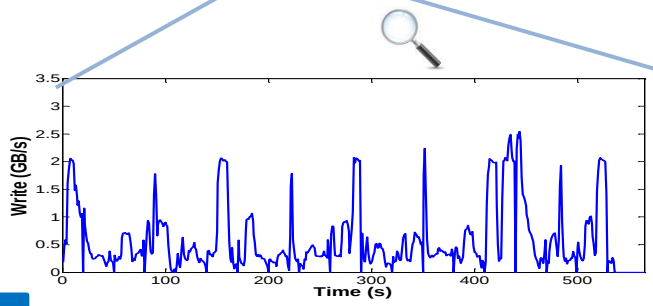
Titan's production Job scheduler logs

Start_time	End_time
2011-10-16 00:00	2011-10-16 02:01
2011-10-17 01:00	2011-10-17 04:00
2011-10-18 05:10	2011-10-18 07:20

Spider server-side Throughput logs

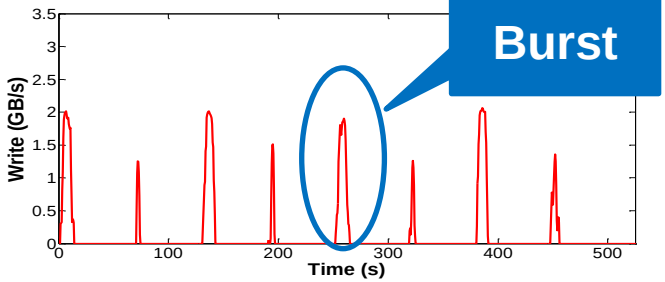


Sample



I/O throughput observed at the server side

Burst



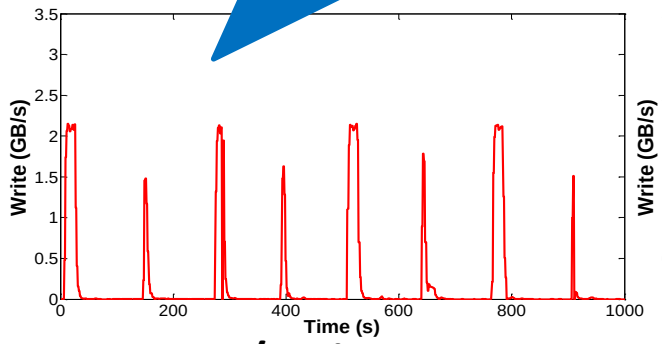
I/O signature

Commonality across multiple samples tends to belong to target application's I/O signature

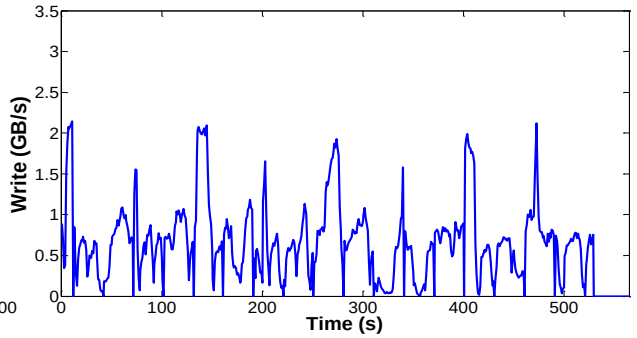
Case Study: IOR Pseudo-application

IOR: Popular parallel I/O benchmark

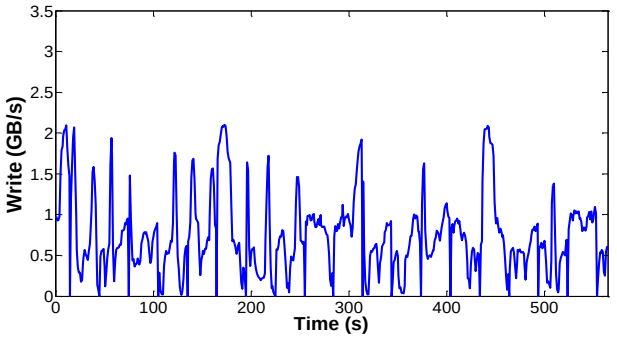
Titan's maintenance window



I/O Signature



Sample 1



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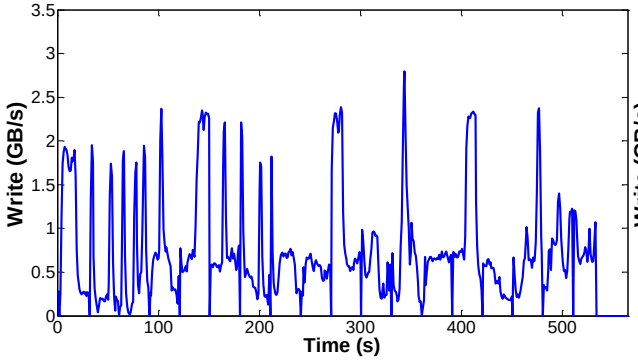
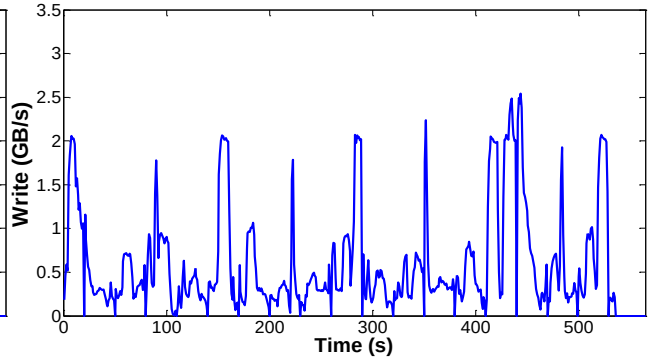
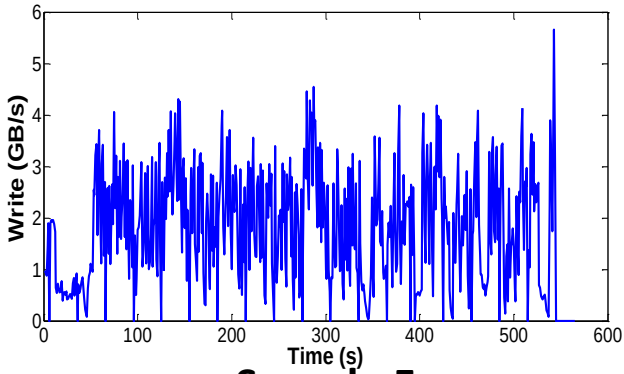


Sample 3



Sample 4



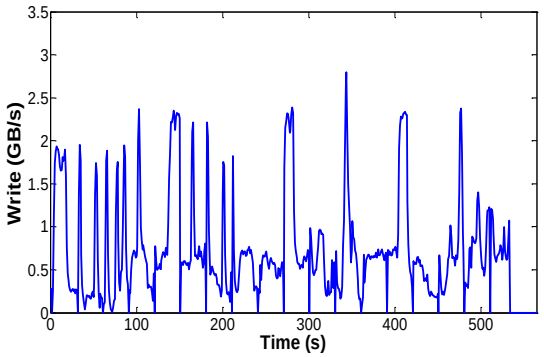
Sample 5

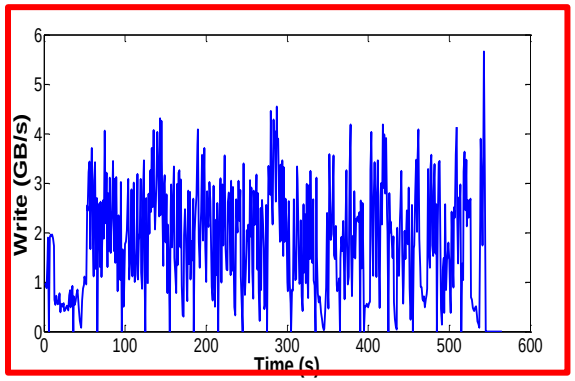
IOSI Challenges

Background noise

Random

Unpredictable

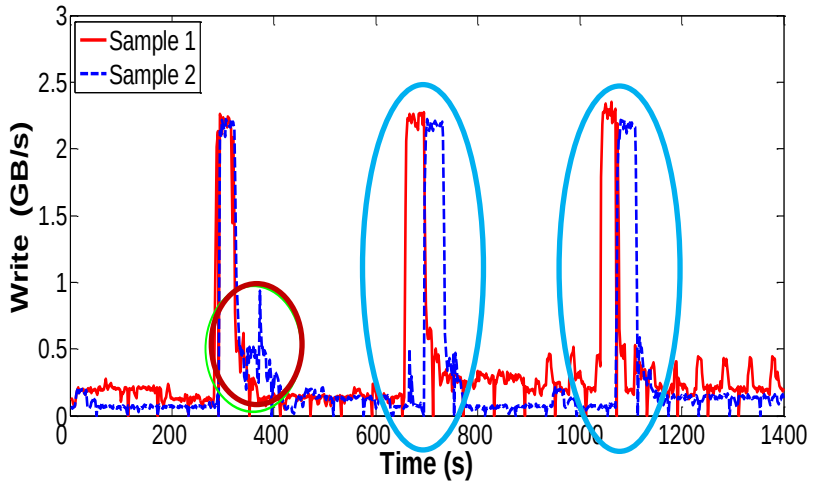




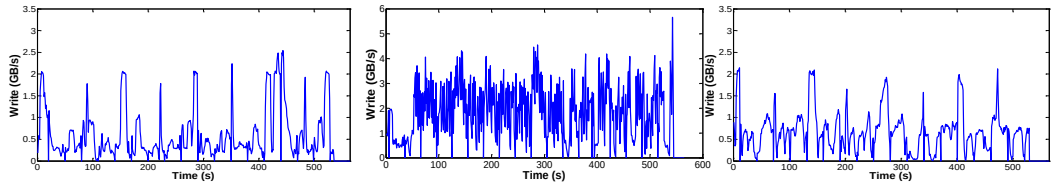
I/O drift

Distort I/O operations

Unpredictable



Processing multiple samples



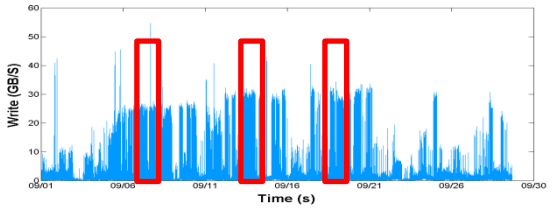
IOSI Workflow

Job scheduler logs

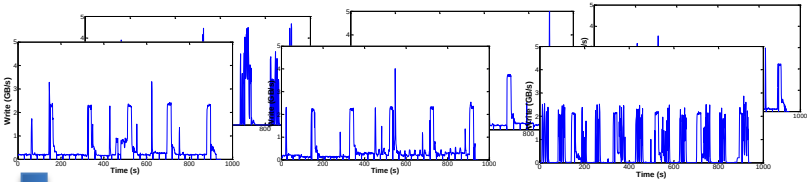
Start_time	End_time
2011-10-16 00:00	2011-10-16 02:01
2011-10-17 01:00	2011-10-17 04:00
2011-10-18 05:10	2011-10-18 07:20

Target App
(User ID + App ID)

Throughput logs



IOSI Input

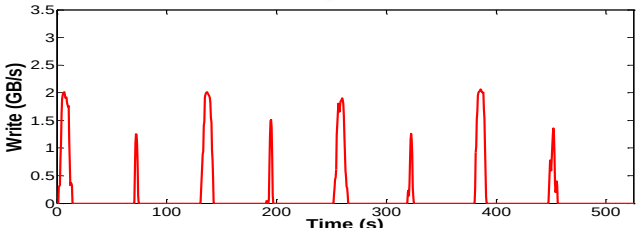


Sample set

IOSI

Data preprocessing → **Per-sample wavelet transform** → **Cross-sample I/O burst identification**

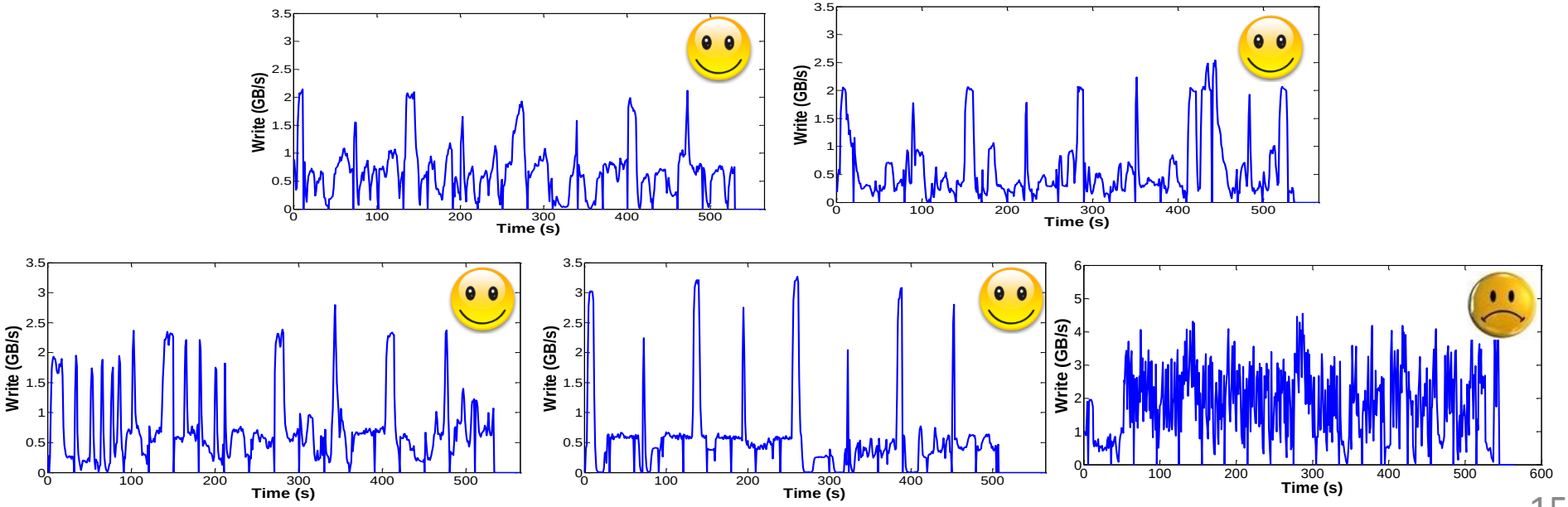
IOSI Output



Stage 1: Data Pre-processing (I)

PP1:Outlier elimination

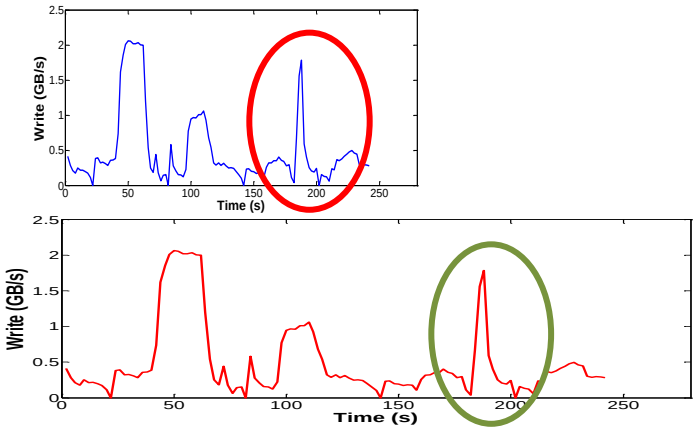
- Identify “bad samples”
- Criteria
  - Total data volume
  - Application execution time



Stage 1: Data Pre-processing (II)

PP2:Granularity refinement

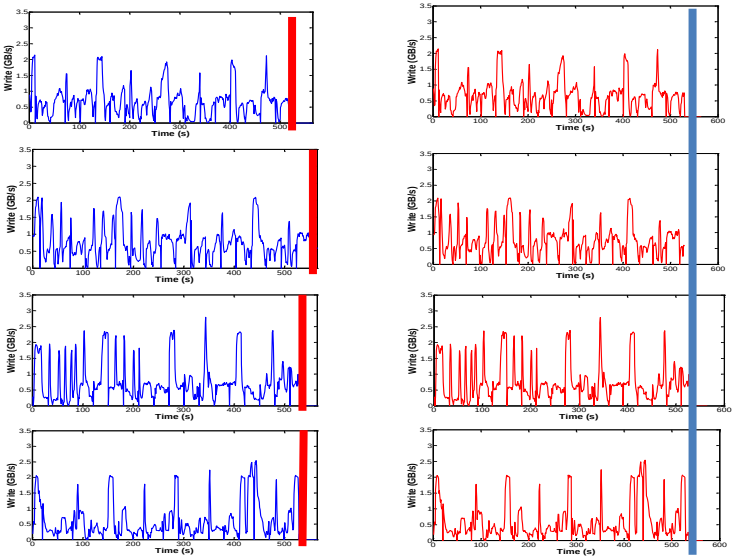
- Identify short burst
- Transform data: 2 sec -> 1 sec by inserting data points
- Linear interpolation



Linear interpolation

PP3:Duration correction

- Contention creates drifts and causes different durations
- Noise makes sample slower
- Normalize samples by discarding data points



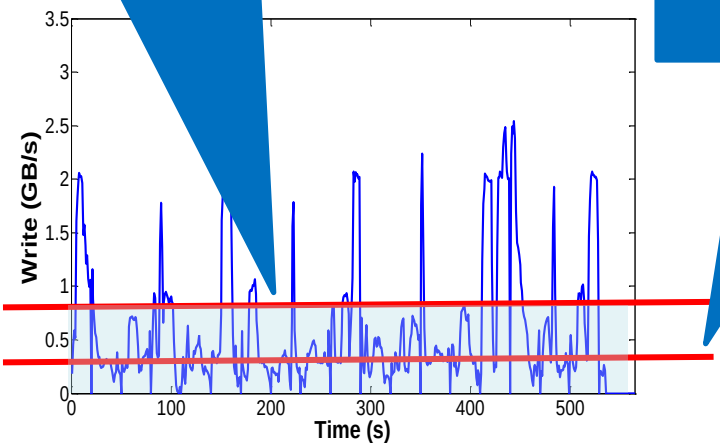
Stage 1: Data Pre-processing (III)

PP4: Noise reduction

- To remove light I/O traffic (interactive user activities, …)
- Two-level filtering

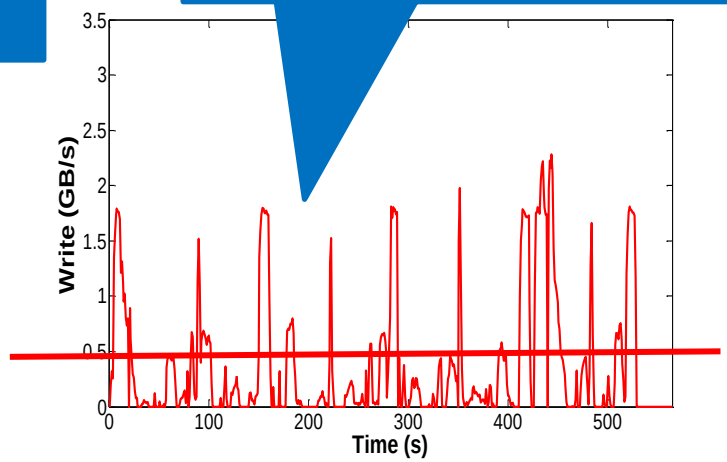
$$M = \frac{Total\ volume}{\#\ of\ data\ points}$$

$$N = \frac{Low\ points\ volume}{\#\ of\ low\ points}$$



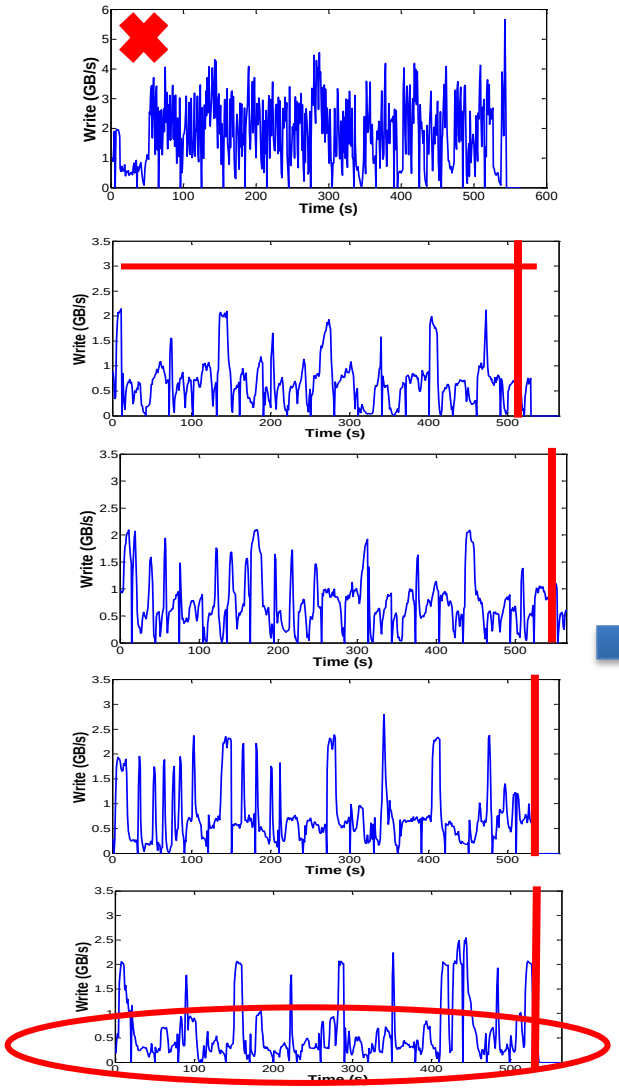
Sample before noise reduction

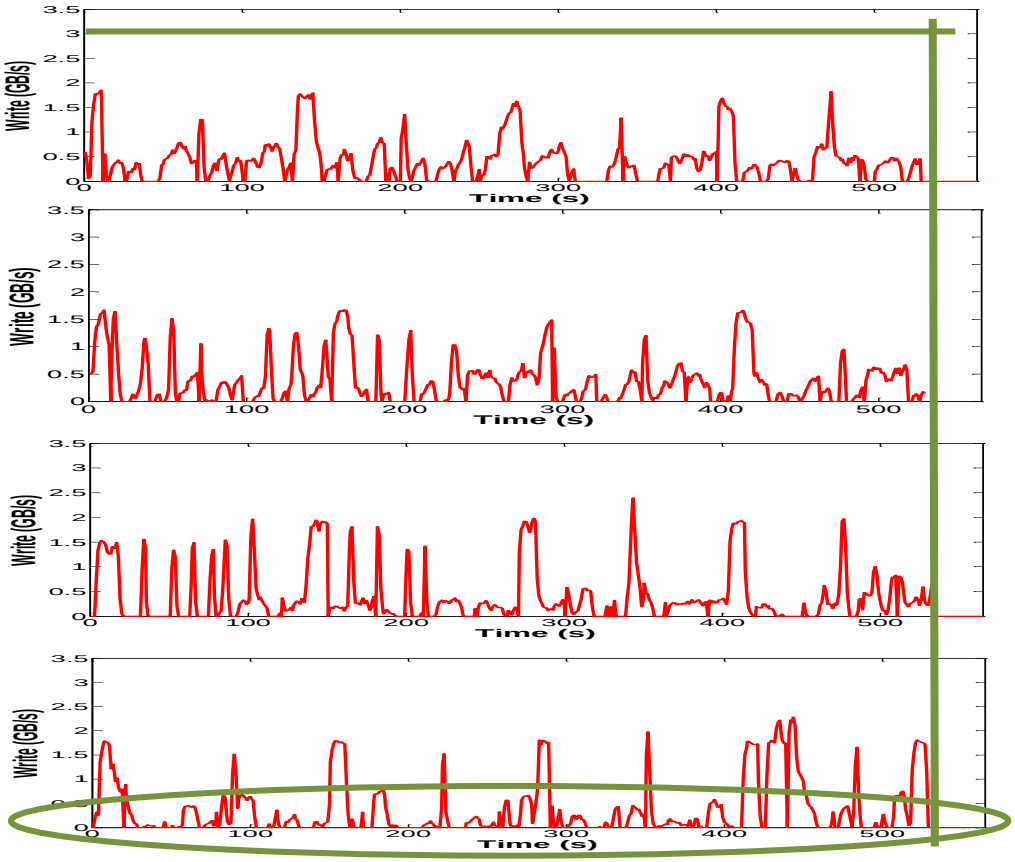
Lower all points by N



Sample after noise reduction

Effect of Data Pre-processing





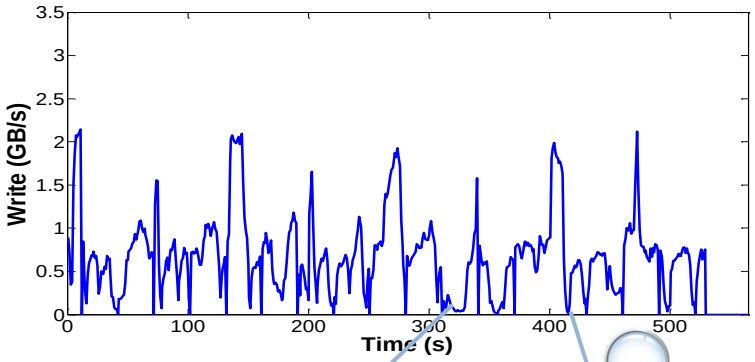
Sample **before** data pre-processing

Sample **after** data pre-processing

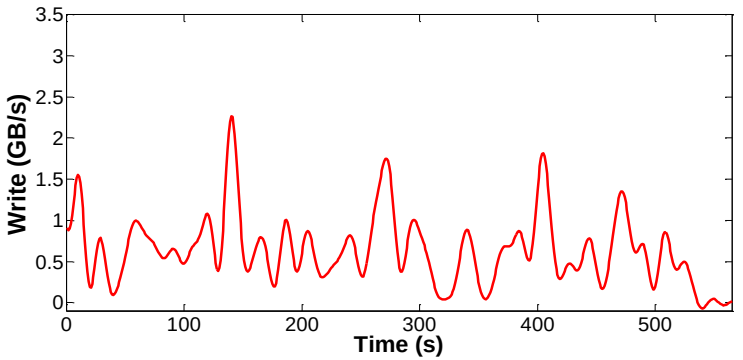
Stage 2: Per-Sample Wavelet Transform

Why wavelet transform?

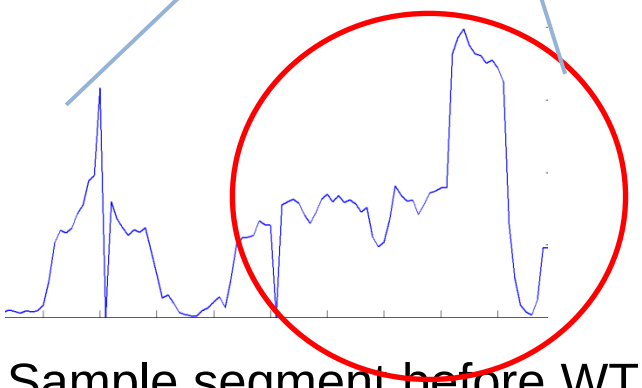
- Use burst as basic unit of signature identification
- Isolate individual burst from background noise



Sample before WT

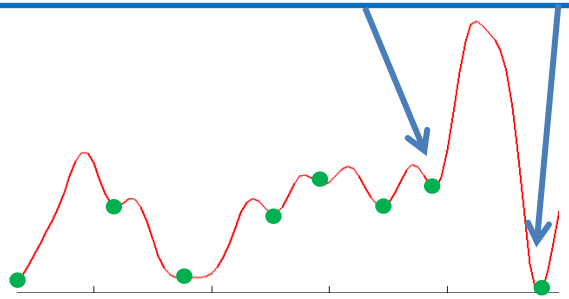


Sample after WT



Sample segment before WT

Burst: Area between two adjacent low points

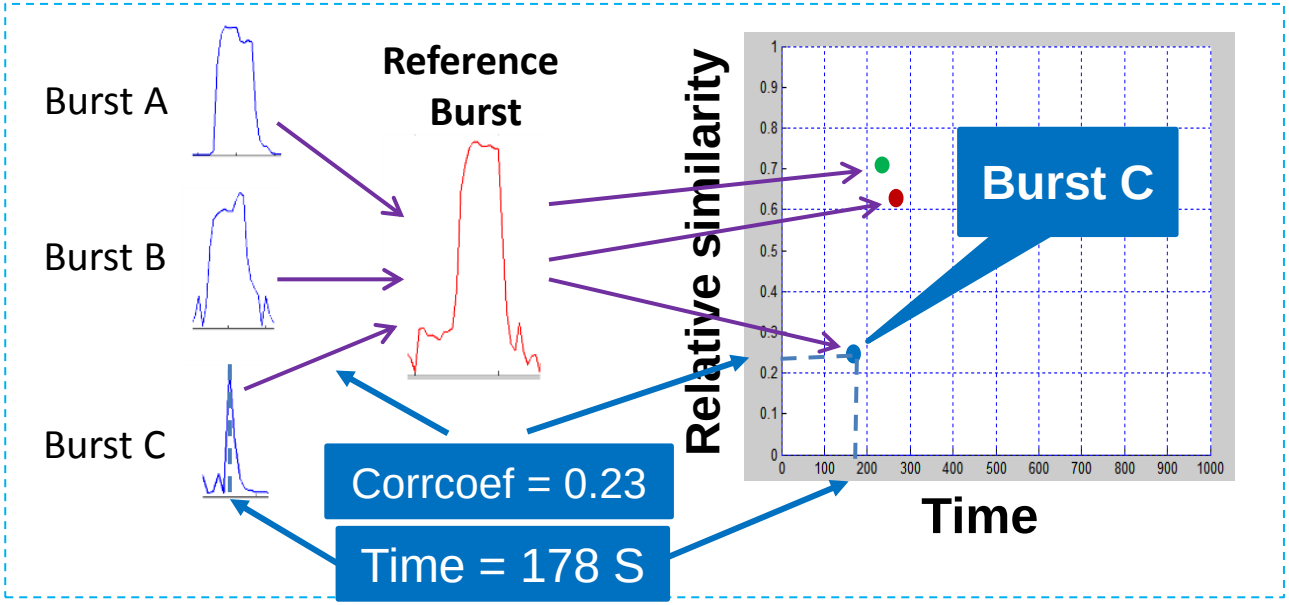


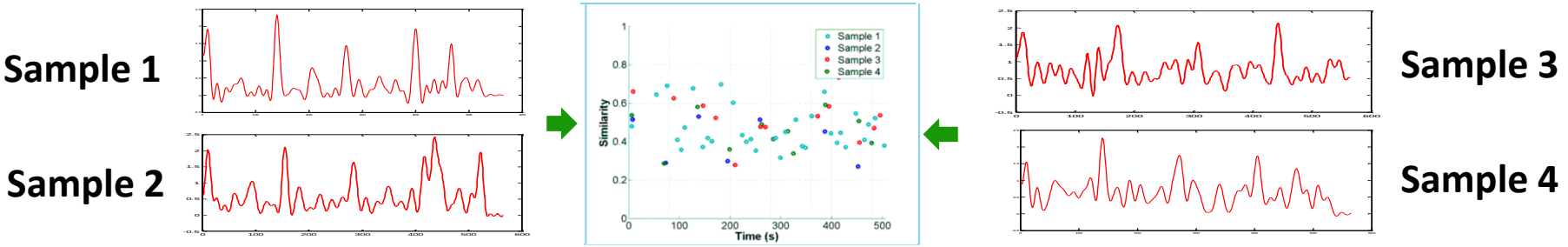
Sample segment after WT

Stage 3: Cross-sample I/O Burst Identification

Extended CLIQUE clustering *[Agrawal:SIGMOD'98]*

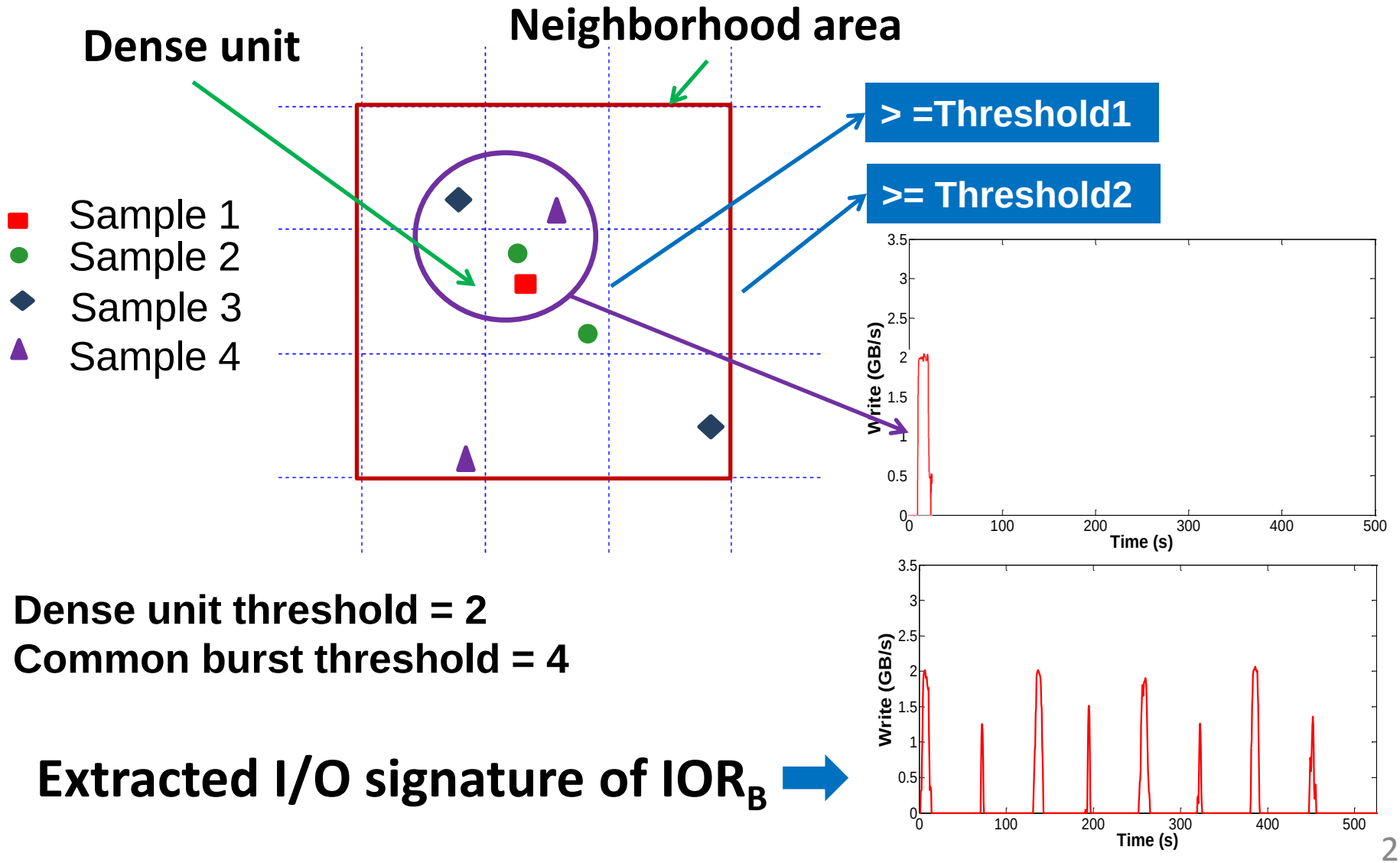
- Density-based and grid-based clustering





Map multiple samples into a 2D clustering space

Clique Clustering Example



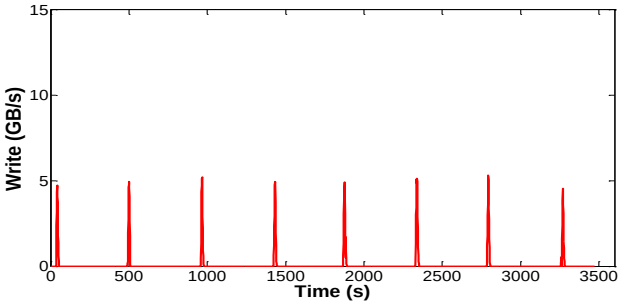
Dense unit threshold = 2
Common burst threshold = 4

Extracted I/O signature of IOR_B

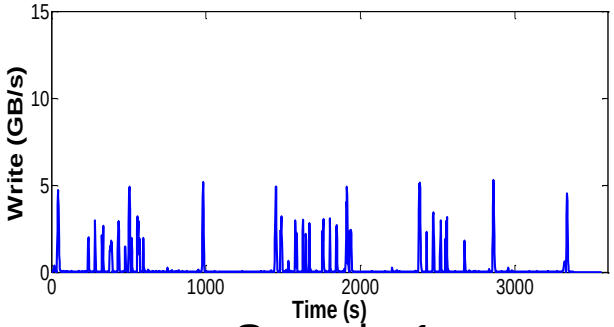
Evaluation

- IOR
  - Configurable I/O benchmark
  - Write-intensive pseudo-applications
  - Smoky, 256 processes
- S3D
  - Simulation of turbulent reacting flows
  - Titan, 18000 processes

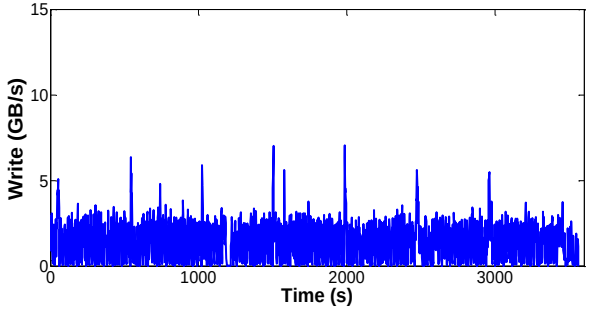
Result Comparison in S3D



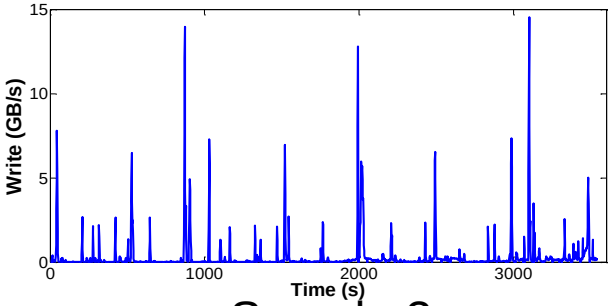
I/O Signature



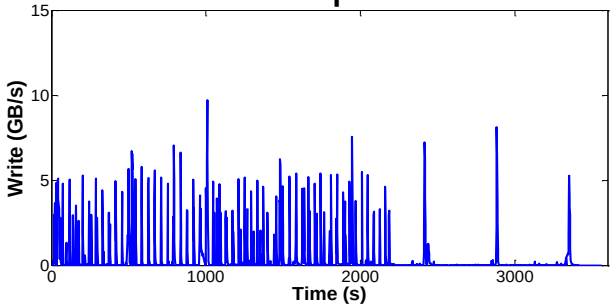
Sample 1



Sample 2



Sample 3



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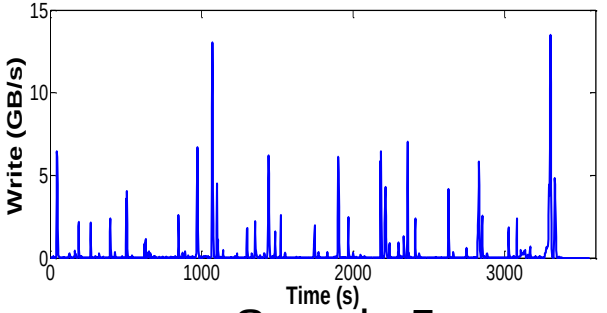
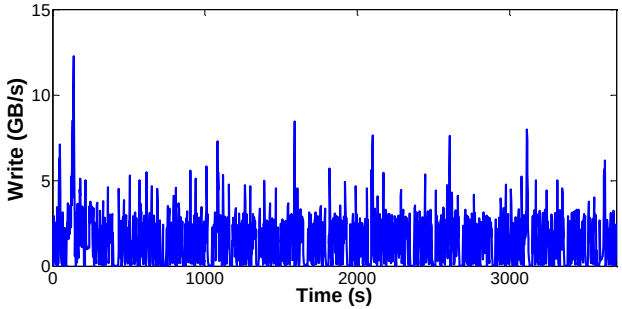
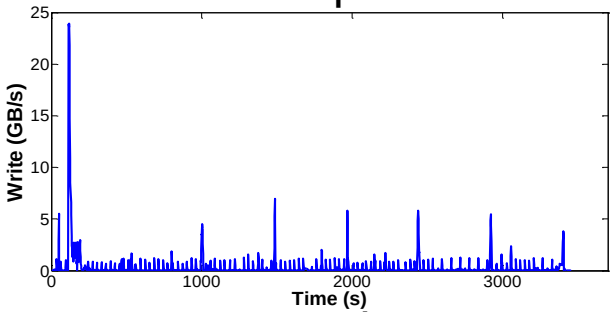


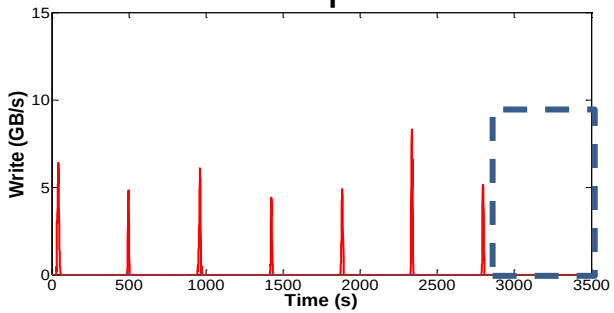
Sample 5



Sample 6



Sample 7

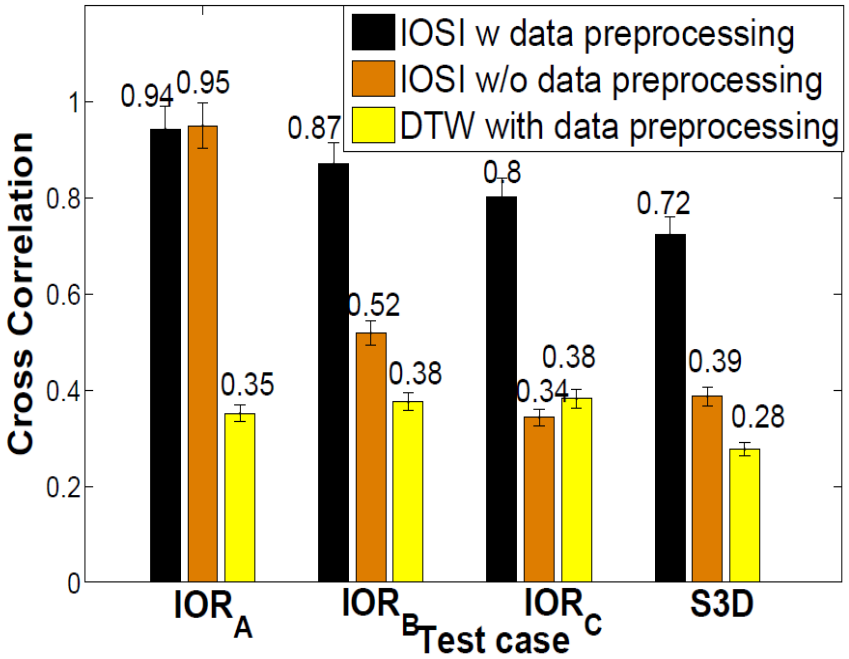


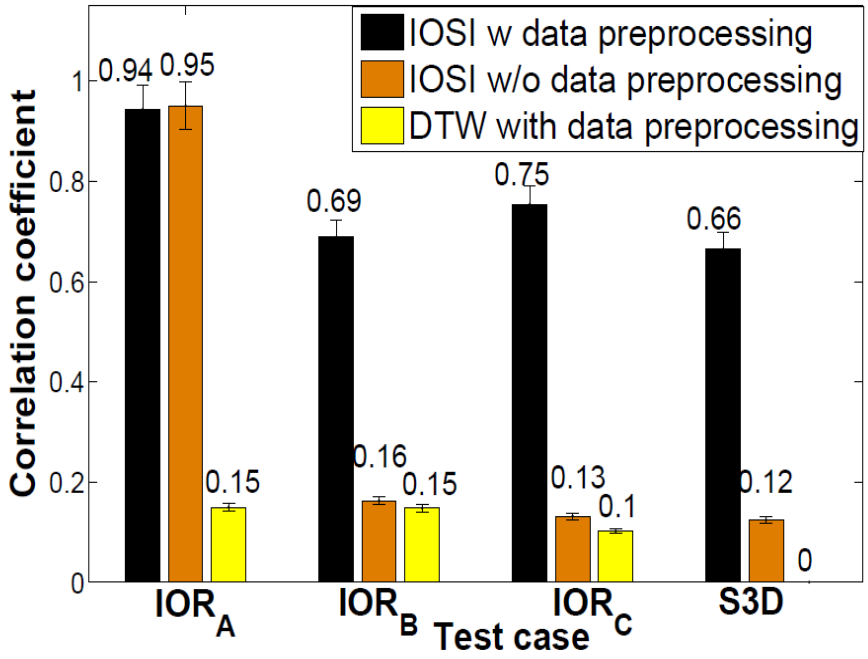
Extracted I/O signature by IOSI with data preprocessing

Accuracy Comparison

Dynamic Time Warping (DTW)

- Pair-wise data alignment technique
- Widely used in speech pattern matching





Accuracy comparison between alternative approaches

More evaluation in the paper

Closing Remarks

- Feasible and cost-effective to identify individual I/O-intensive applications' bandwidth demands
  - From aggregate, course-granule traffic logs
  - Without involving user effort

- Applicable to commercial settings?
  - Useful in addressing “I/O smear” from VMs
  - Key requirement: repeated I/O pattern
    - MapReduce, data analytics, sequential scientific computing
  - Extra challenges
    - Signal vs. noise level
    - Complexity brought by caching
      - Signatures more resource-dependent

Q&A

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Reference

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