“mcrEngine”
a Scalable Checkpointing System using Data-Aware Aggregation and Compression

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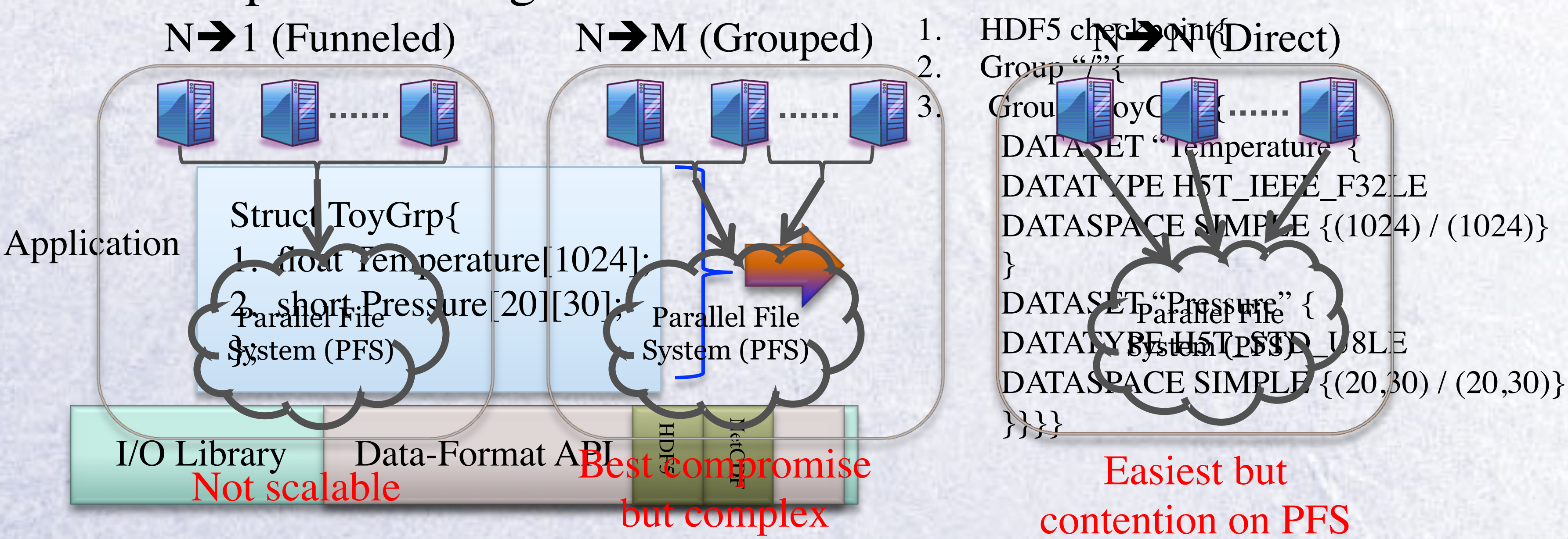
Background

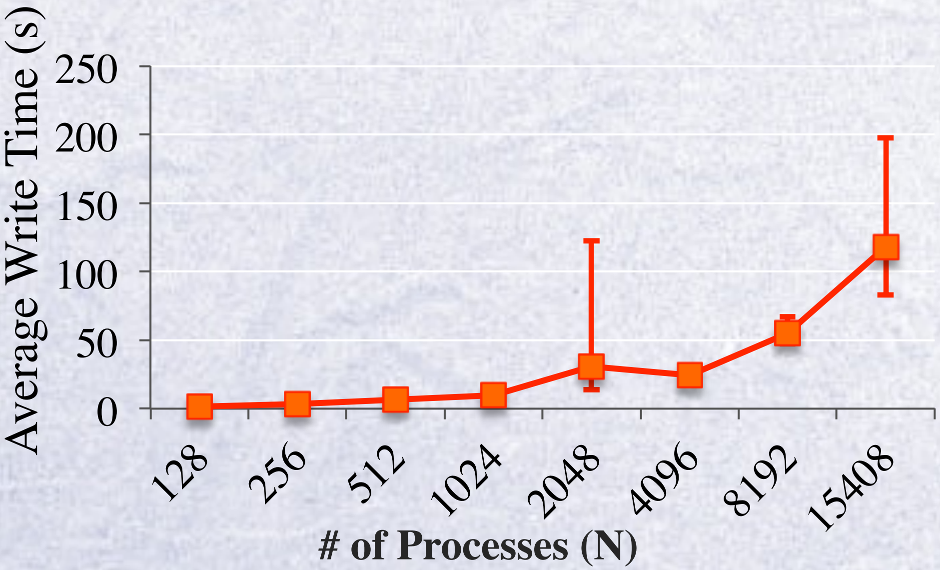
- Checkpoint-restart widely used
  - Projected MTBF at exascale 3-26 minutes
- MPI applications
  - Take globally coordinated checkpoints asynchronously
- Application-level checkpoint
- High-level data format for portability
  - HDF5, Adios, netCDF etc.
- Checkpoint writing

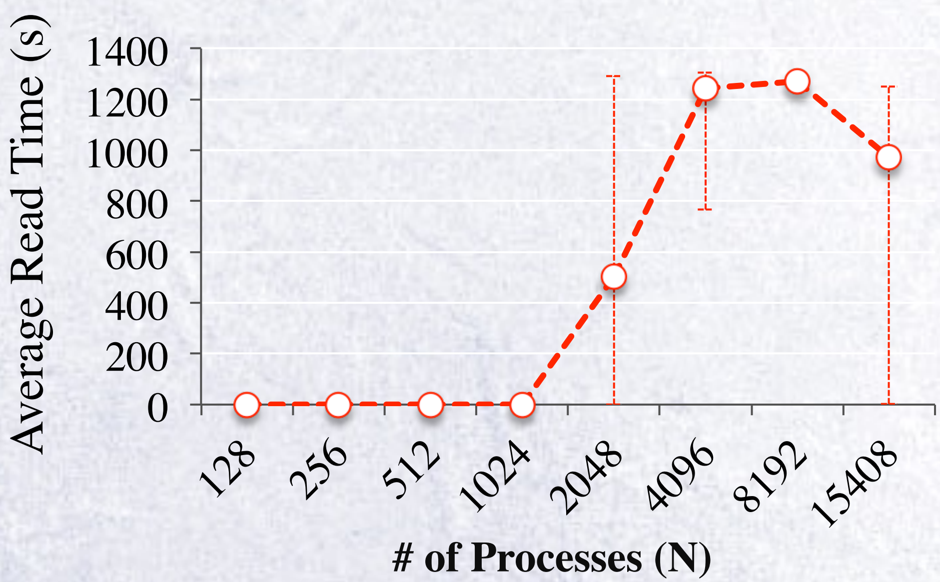


Impact of Load on PFS at Large Scale

- IOR
  - Direct (N→N): 78MB per process
- Observations:

(–) Large average write time ⇒ less frequent checkpointing
(–) Large average read time ⇒ poor application performance





What is the Problem?

- Today's checkpoint-restart systems will not scale
  - Increasing number of concurrent transfers
  - Increasing volume of checkpoint data

Our Contributions

- Data-aware aggregation
  - Reduces the number of concurrent transfers
  - Improves compressibility of checkpoints by using semantic information
- Data-aware compression
  - Reduces data almost 2x more than simply concatenating then compressing
- Design and develop mcrEngine
  - Grouped (N→M) checkpointing system
  - Improves checkpointing frequency
  - Improves application performance

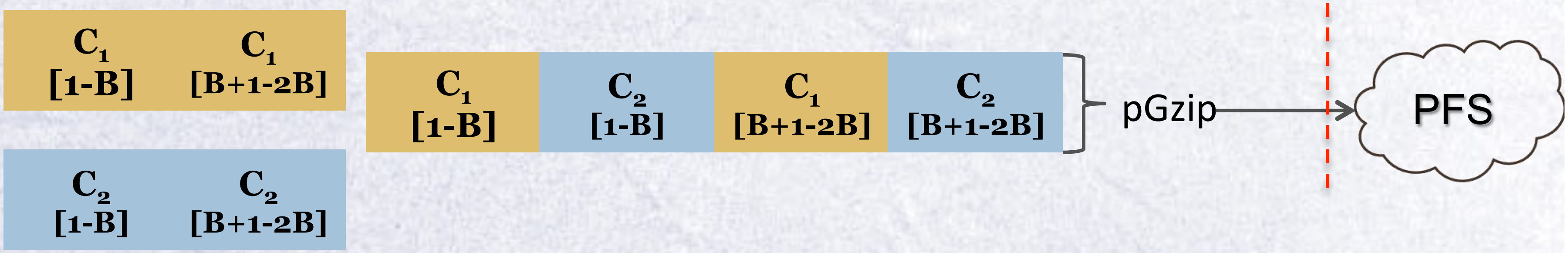
Overview

- Background
- Problem
- Data aggregation & compression
- Evaluation

Data-Agnostic Schemes

- Agnostic scheme – concatenate checkpoints

- Agnostic-block scheme – interleave fixed-size blocks



- Observations:
  - (+) Easy
  - (–) Low compression ratio

Identify Similar Variables ... Processes

P0

```
Group ToyGrp{
    float Temperature[1024];
    int Pressure[20][30];
};
```

P1

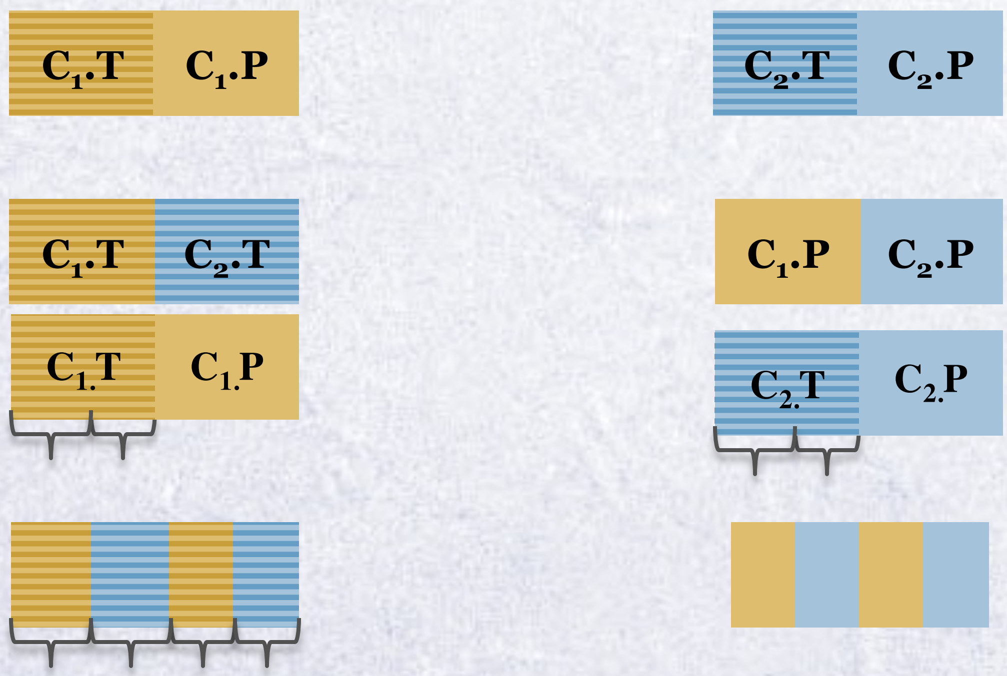
```
Group ToyGrp{
    float Temperature[100];
    int Pressure[10][50];
};
```

Meta-data:

1. Name
2. Data-type
3. Class:
   -- Array, Atomic

Concatenating similar variables

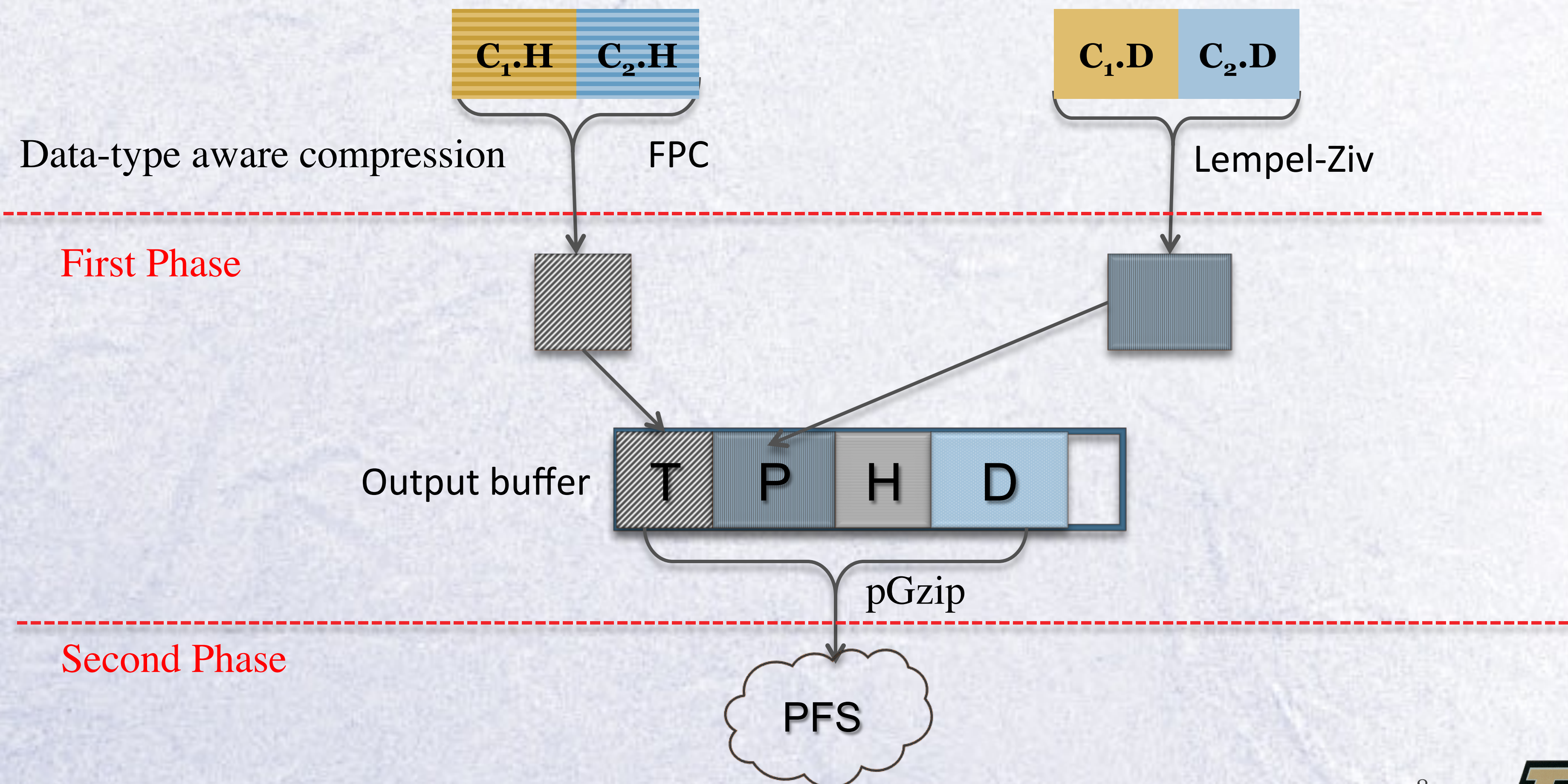
Interleaving similar variables



Next 'B' bytes / First 'B' bytes
of Temperature / of Pressure

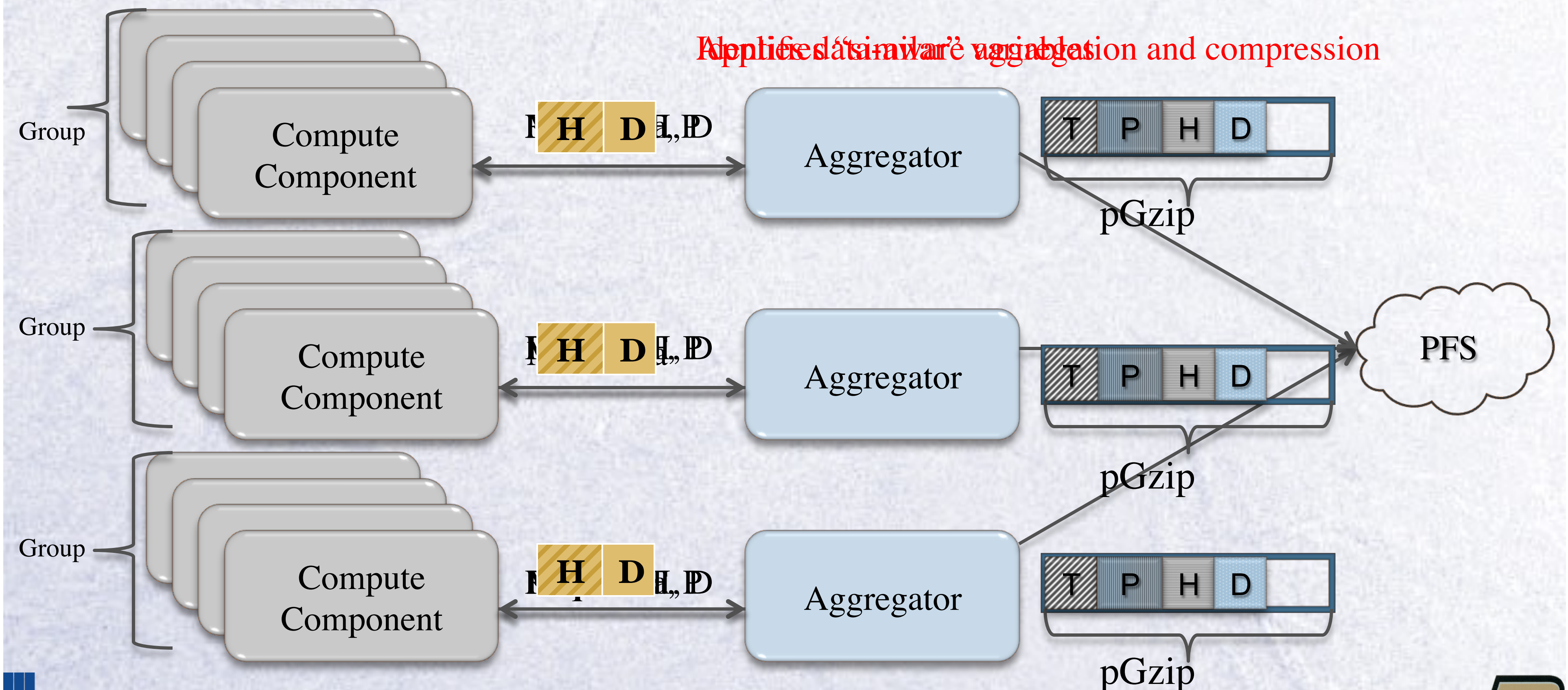
Data-Aware Aggregation & Compression

- Aware scheme – concatenate similar variables
- Aware-block scheme – interleave similar variables



How mcrEngine Works

- CNC : Compute node component
- ANC: Aggregator node component
- Rank-order groups, Grouped (N➔M) transfer



Overview

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- Problem
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Evaluation

- Applications
  - ALE3D – 4.8GB per checkpoint set
  - Cactus – 2.41GB per checkpoint set
  - Cosmology – 1.1GB per checkpoint set
  - Implosion – 13MB per checkpoint set
- Experimental test-bed
  - LLNL's Sierra: 261.3 TFLOP/s, Linux cluster
  - 23,328 cores, 1.3 Petabyte Lustre file system
- Compression algorithm
  - FPC [1] for double-precision float
  - Fpzip [2] for single-precision float
  - Lempel-Ziv for all other data-types
  - pGzip for general-purpose compression

Evaluation Metrics

- Effectiveness of data-aware compression
  - What is the benefit of multiple compression phases?
  - How does group size affect compression ratio?

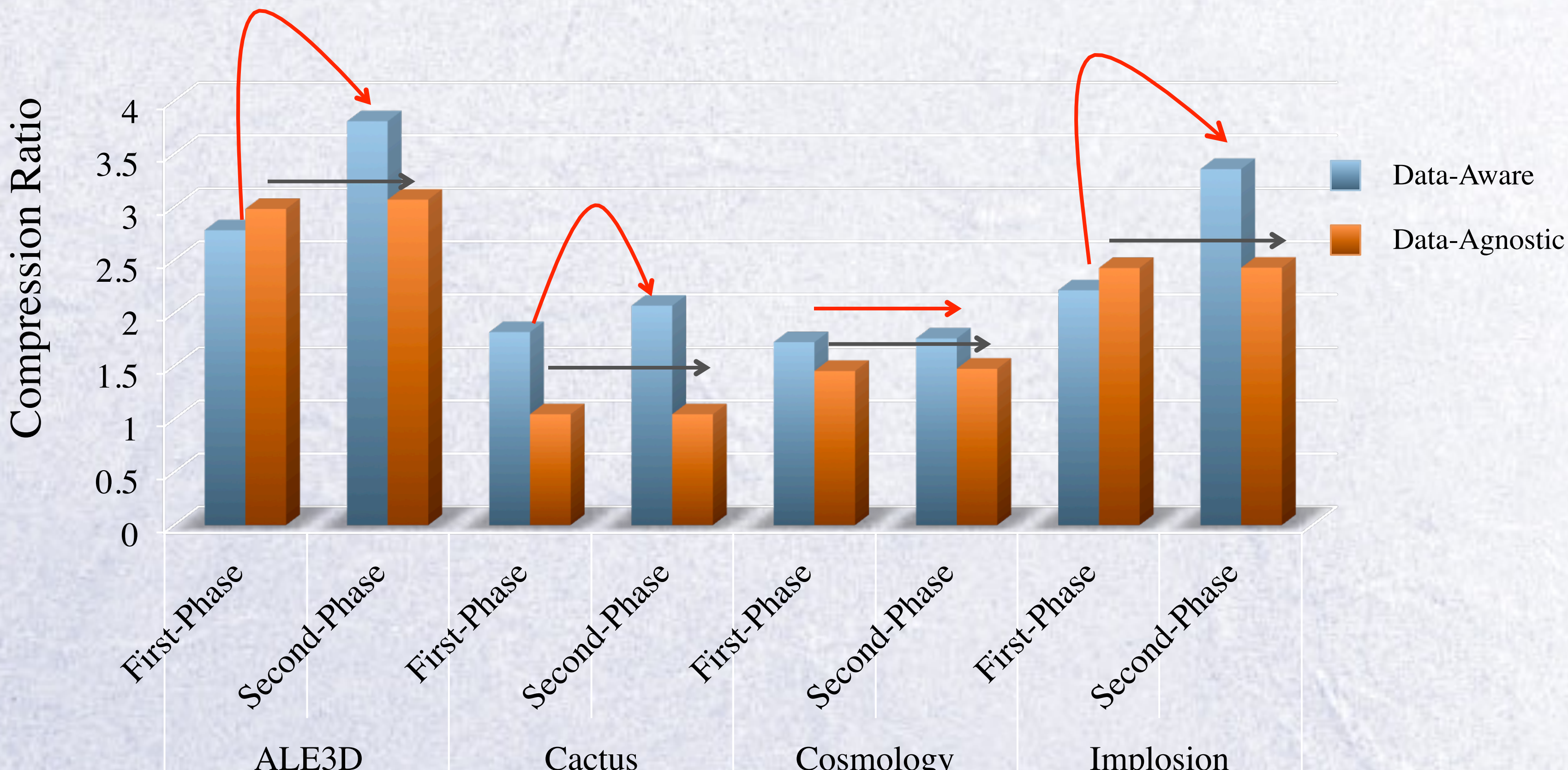
$$\text{Compression ratio} = \frac{\text{Uncompressed size}}{\text{Compressed size}}$$

- Performance of mcrEngine
  - Overhead of the checkpointing phase
  - Overhead of the restart phase

No Benefit with Data-Agnostic Double Compression

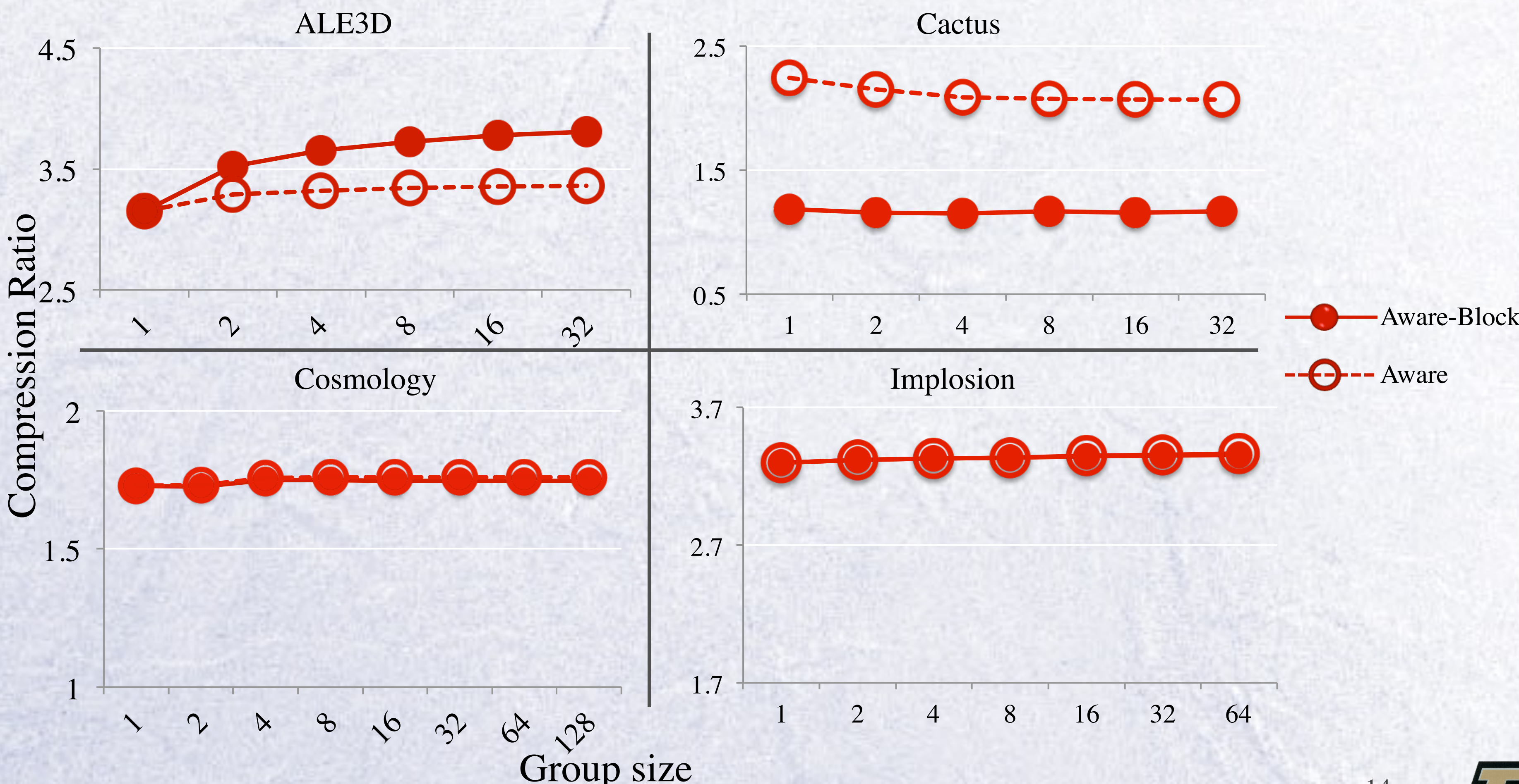
Multiple Phases of Data-Aware Compression are Beneficial

- Data-type aware compression improves compressibility
  - First phase changes underlying data format
- Data-agnostic double compression is not beneficial
  - Because, data-format is non-uniform and uncompressible



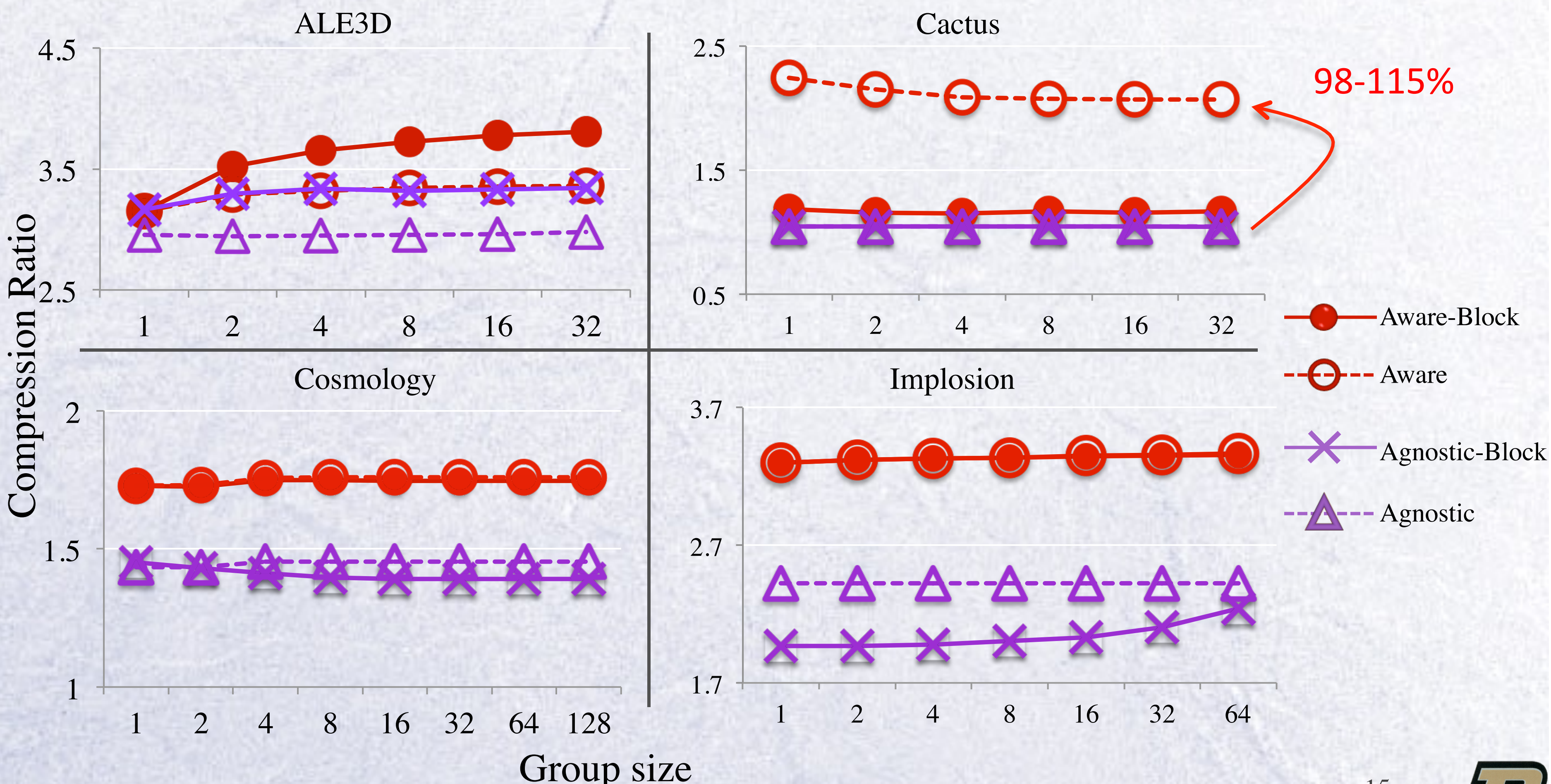
Impact of Group Size on Compression Ratio

- Different merging schemes better for different applications
- Larger group size beneficial for certain applications
  - ALE3D: Improvement of 8% from group size 2 to 32



Data-Aware Technique Always Wins over Data-Agnostic

- Data-aware technique always yields better compression ratio than Data-Agnostic technique

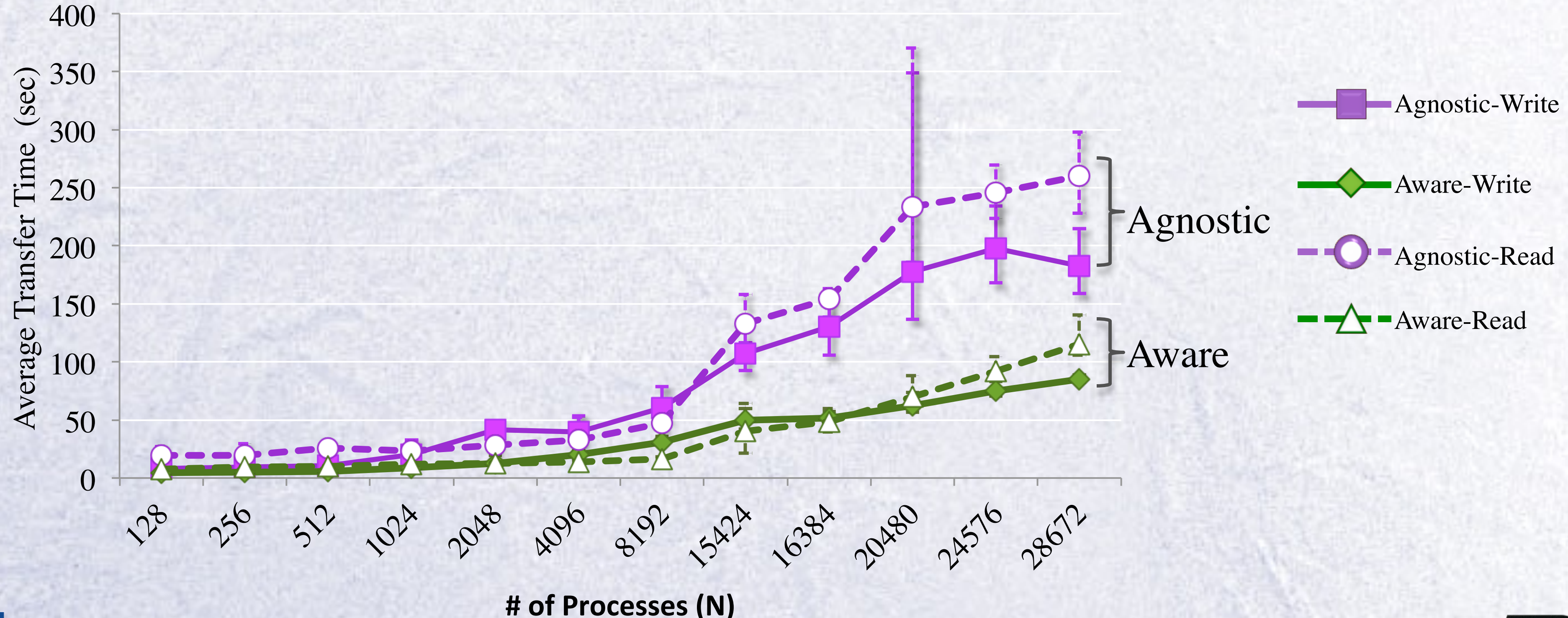


Summary of Effectiveness Study

- Data-aware compression always wins
  - Reduces gigabytes of data for Cactus
- Larger group sizes may improve compression ratio
- Different merging schemes for different applications
- Compression ratio follows course of simulation
  - Details in our paper

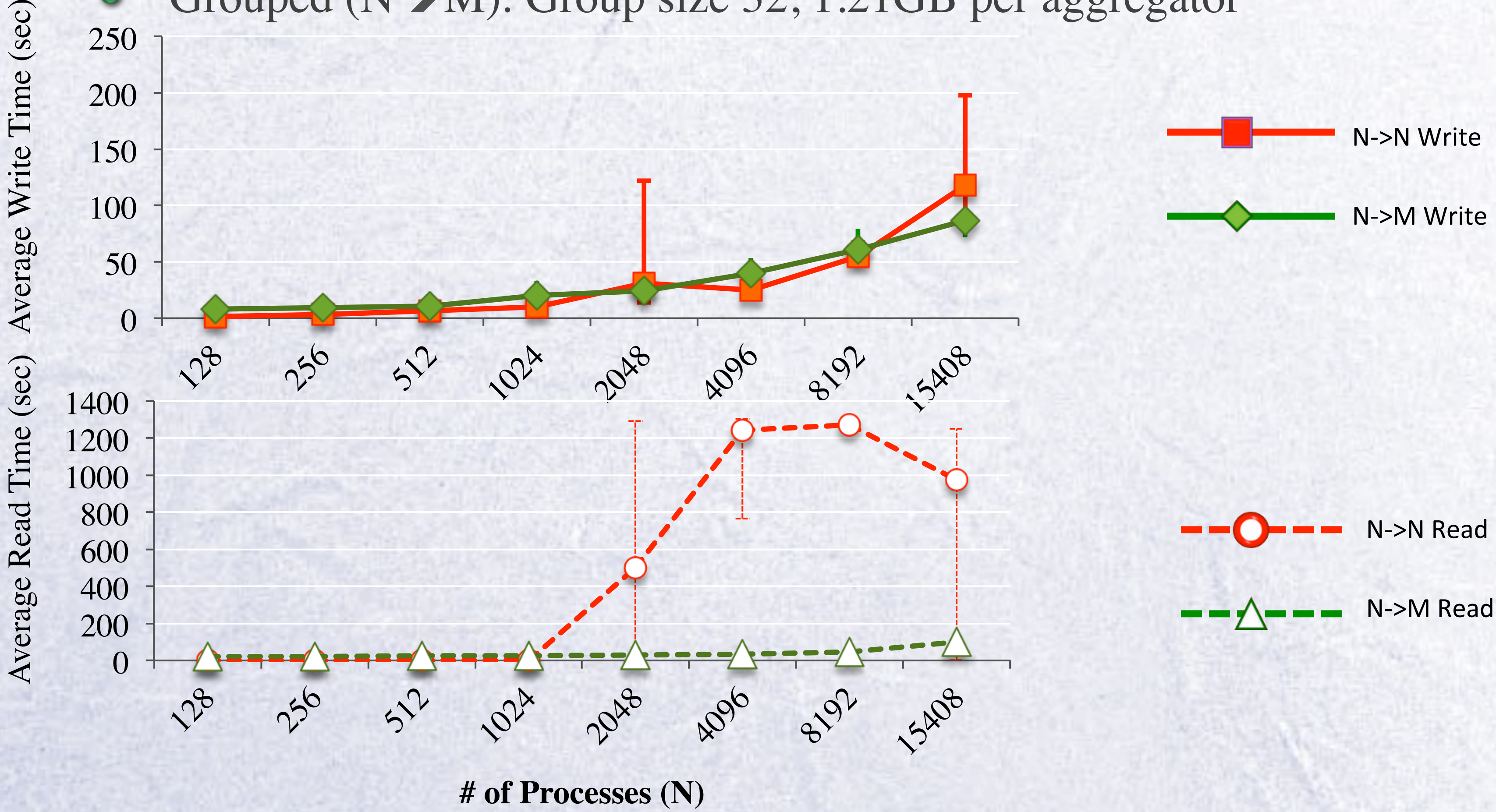
Impact of Data-Aware Compression on Latency

- IOR with Grouped(N→M) transfer, groups of 32 processes
  - Data-aware: 1.2GB, data-agnostic: 2.4GB
- Data-aware compression improves I/O performance at large scale
  - Improvement during write 43% - 70%
  - Improvement during read 48% - 70%



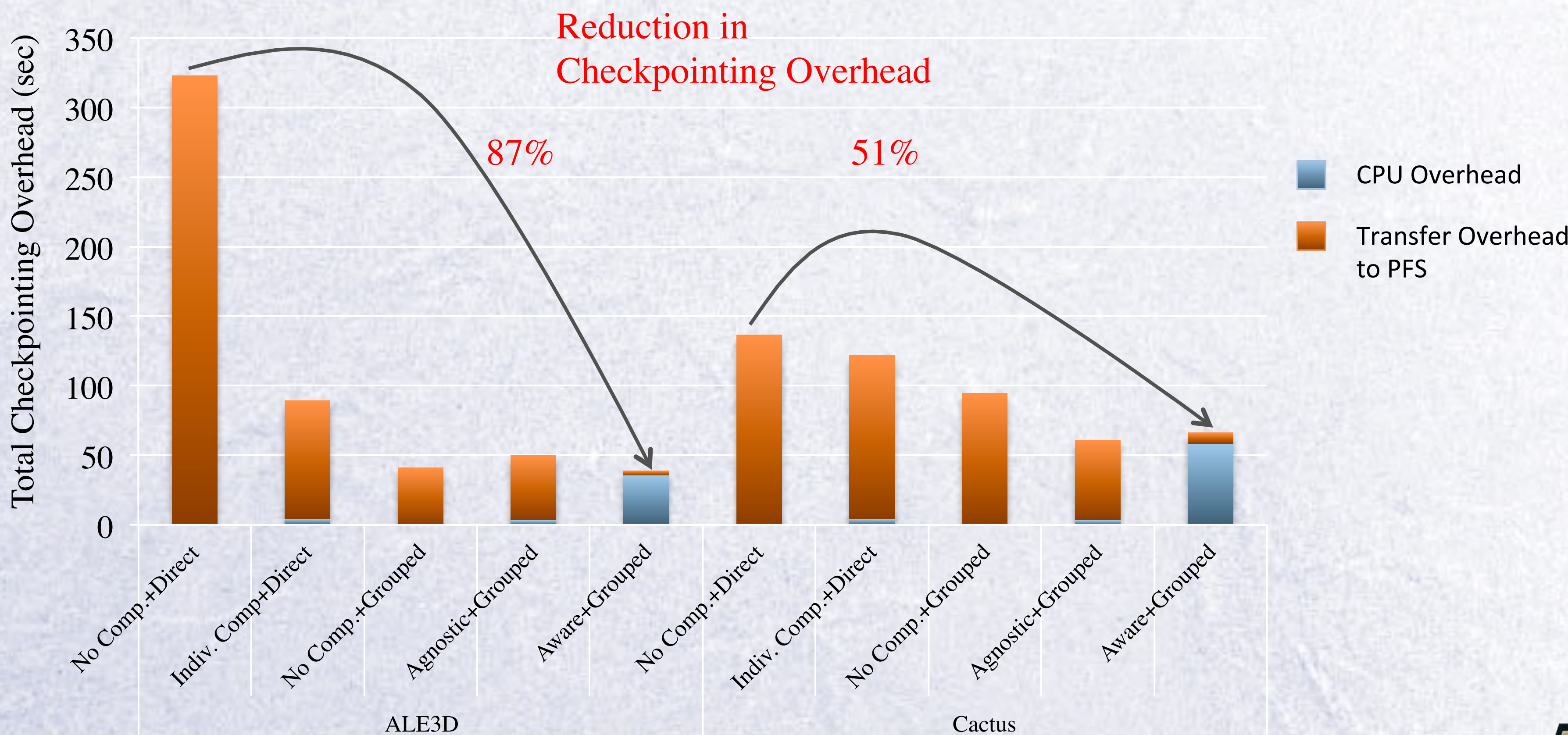
Impact of Aggregation & Compression on Latency

- Used IOR
  - Direct (N➔N): 87MB per process
  - Grouped (N➔M): Group size 32, 1.21GB per aggregator



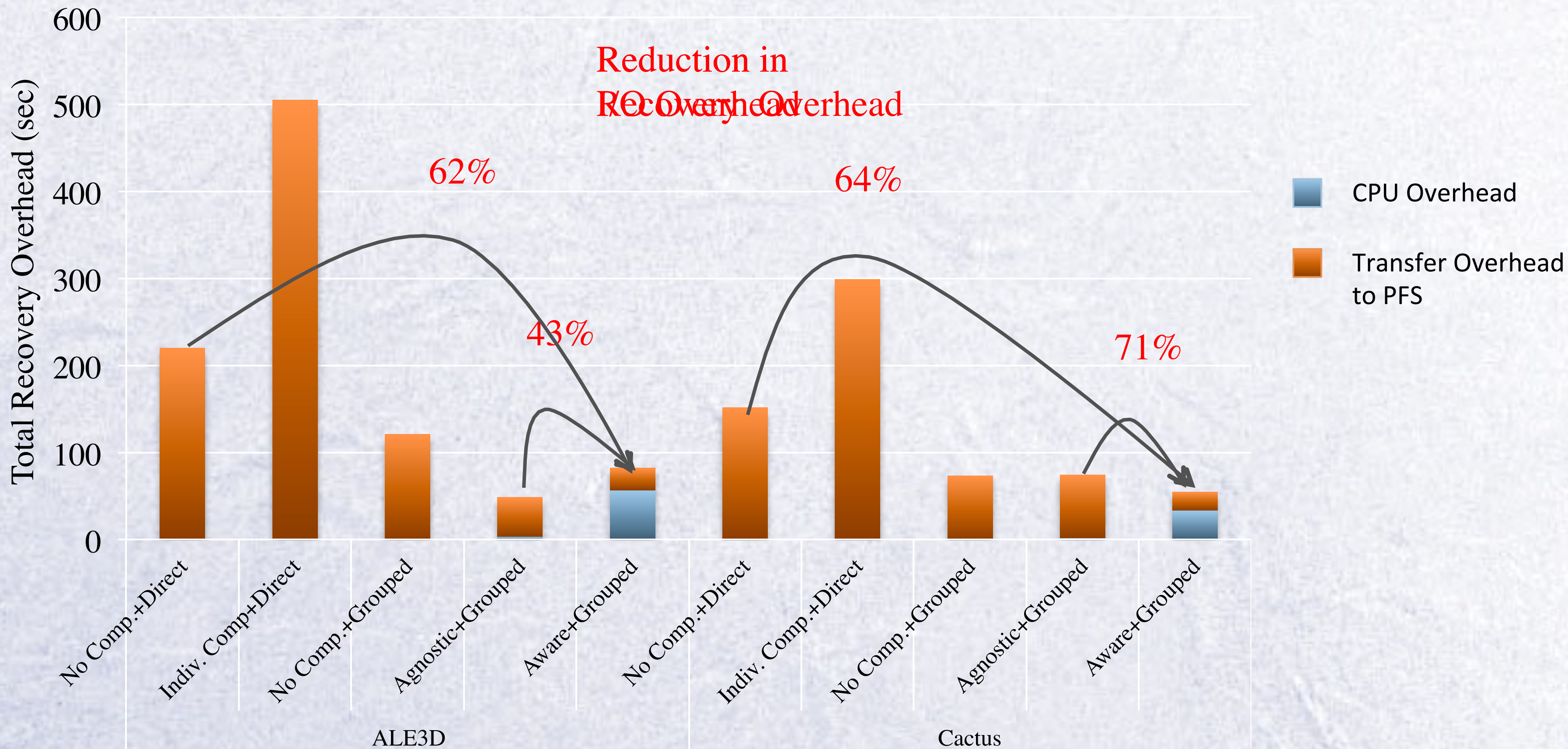
End-to-End Checkpointing Overhead

- 15,408 processes
  - Group size of 32 for N➔M schemes
  - Each process takes a checkpoint
- Converts network bound operation into CPU bound one



End-to-End Restart Overhead

- Reduced overall restart overhead
- Reduced network load and transfer time



Conclusion

- Developed data-aware checkpoint compression technique
  - Relative improvement in compression ratio up to 115%
- Investigated different merging techniques
  - Demonstrated effectiveness using real-world applications
- Designed and developed mcrEngine
  - Reduces recovery overhead by more than 62%
  - Reduces checkpointing overhead by up to 87%
  - Improves scalability of checkpoint-restart systems

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