DeltaFS Indexed Massive Dir

Software-Defined Storage For Fast Query

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DeltaFS Indexed Massive Dir

Key features

1. Require no dedicated resources
2. Almost no post-processing is needed
3. Low I/O overhead

DeltaFS Indexed Massive Dir

Target workloads

1. Data-intensive HPC simulations
2. Not designed for indexing checkpoints
3. I/O bandwidth is limited

Agenda

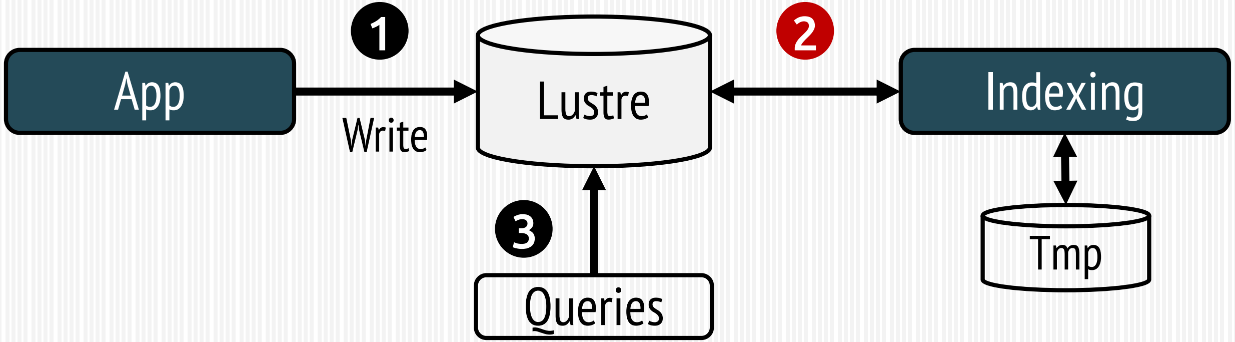
Part 1 – Motivation

Part 2 – In-situ indexing design

Part 3 – API, LANL VPIC integration

Conclusion

Existing HPC builds indexes during post-processing



Delay queries until post-processing done (5-20% simulation time)

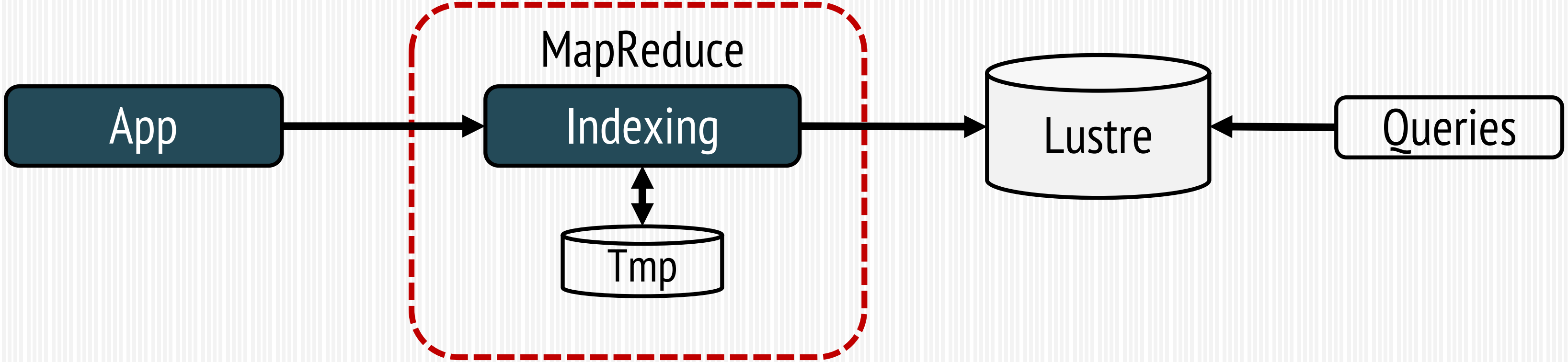
Problem faced:

The increasing time-to-science

Due to the growing gap between compute and I/O
Inefficient support on small data

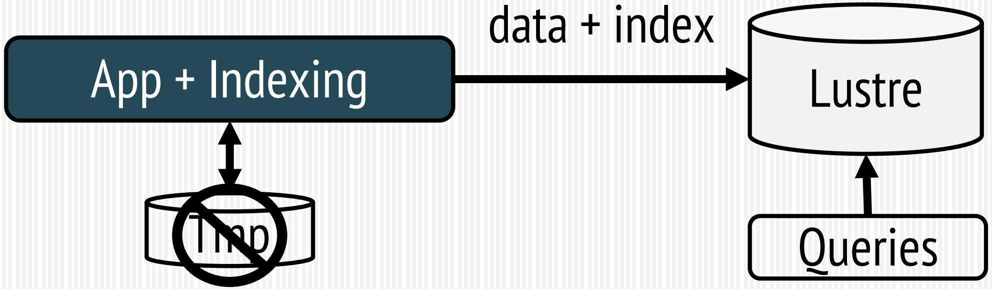
simulation start ↔ query finish

Processing data in-transit while data is written to storage



Need separate resources for sorting and indexing ✗

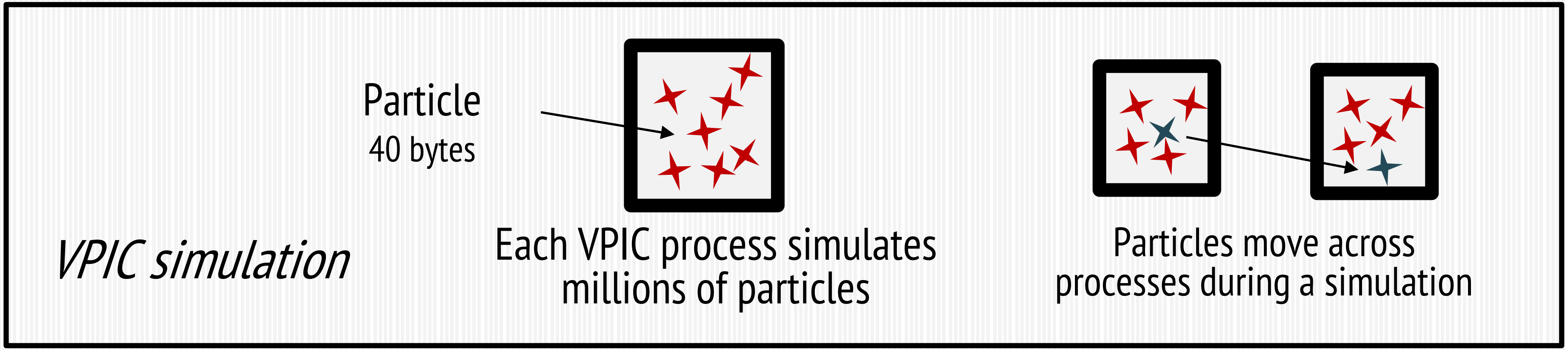
In-situ indexing directly on app nodes using app resources



No need for a separate indexing cluster ✓

Key idea:
Reuse storage write-back buffering and idle CPU cycles for in-situ indexing

Example app: LANL VPIC



VPIC simulation

Particle
40 bytes

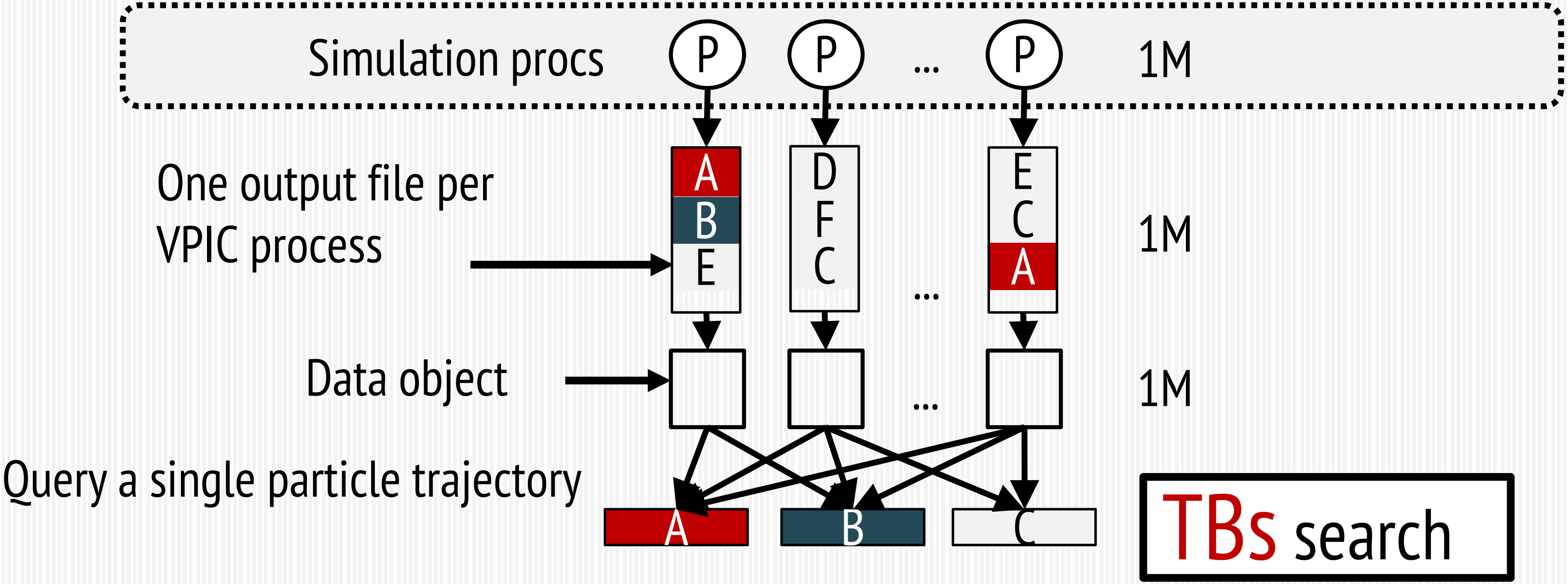
Each VPIC process simulates millions of particles

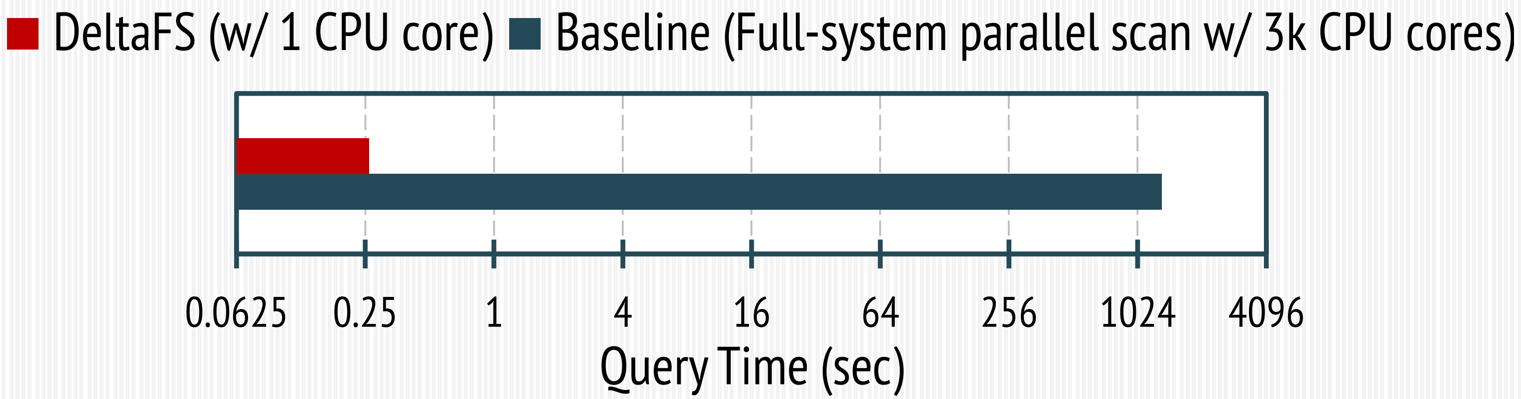
Particles move across processes during a simulation

Small random writes
After simulation: high-selective queries

TBs I/O per trajectory fetch

file-per-process





Time for reading a single particle trajectory
(10TB, 48 billion particles)

5,000x faster than baseline with DeltaFS in-situ indexing

- http://www.pdl.cmu.edu/

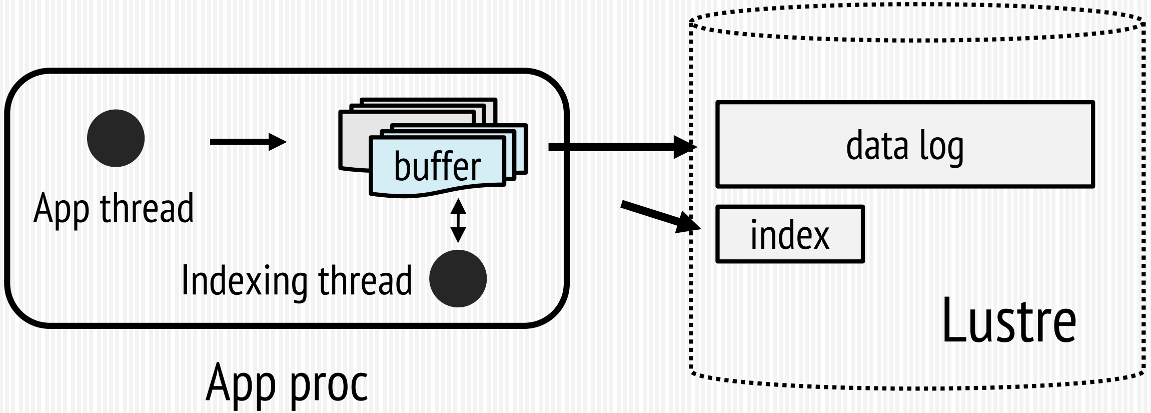
Part II

System design:

Light-weight in-situ indexing

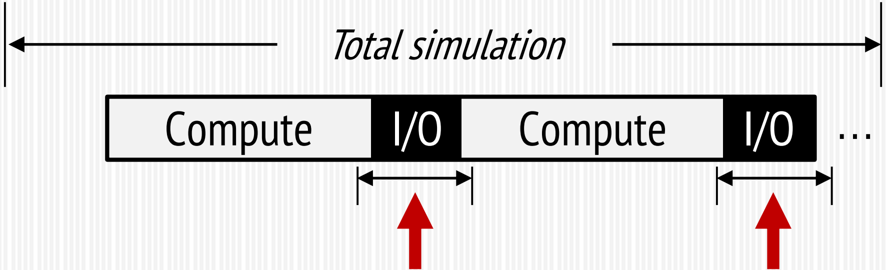
1. Tiny mem footprint
2. Zero write amplification
3. No read back

Resource-efficient indexing by log-structured I/O



Tiny mem footprint, full storage b/w util.

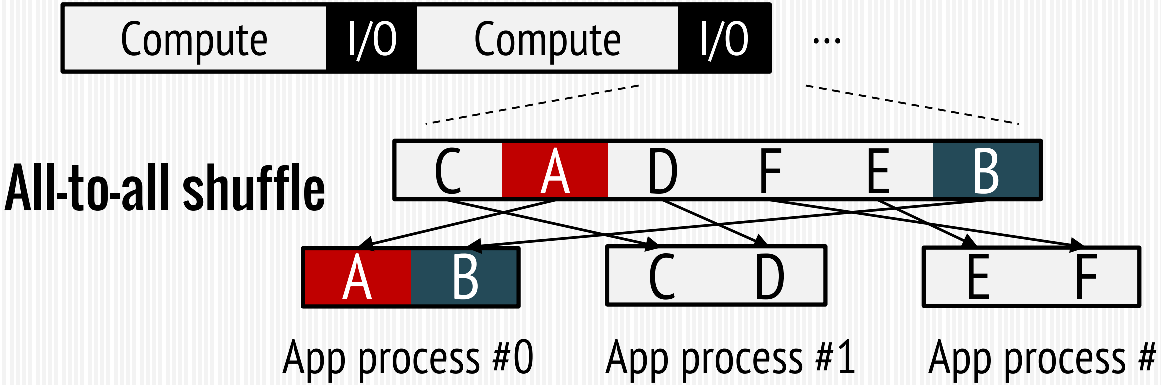
LSM-Trees compacts all the time, but we can't afford it



Must aim for low I/O overhead at 10%-20%

Compaction easily causes 1000% I/O overhead by reading/writing previously written data

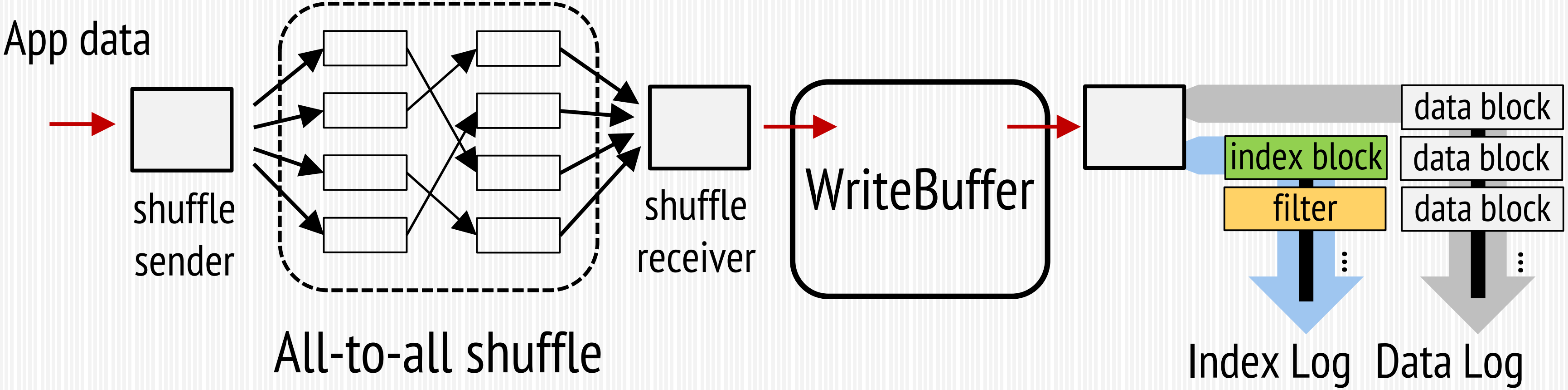
In-situ indexing by aggressive data partitioning



Bound the number of data needed per query per timestep

- http://www.pdl.cmu.edu/

In-situ indexing as a file system lib component



No dedicated cluster needed

Part III

Programming interface:

Indexed Massive Directory (IMD)

In-situ indexing keyed on filenames

```
mkdir(“./particles”, DELTAFS_IMD)
```

How to use Indexed Massive Dir (IMD)

1. Data searched together go into a single IMD file

e.g. one file for each particle

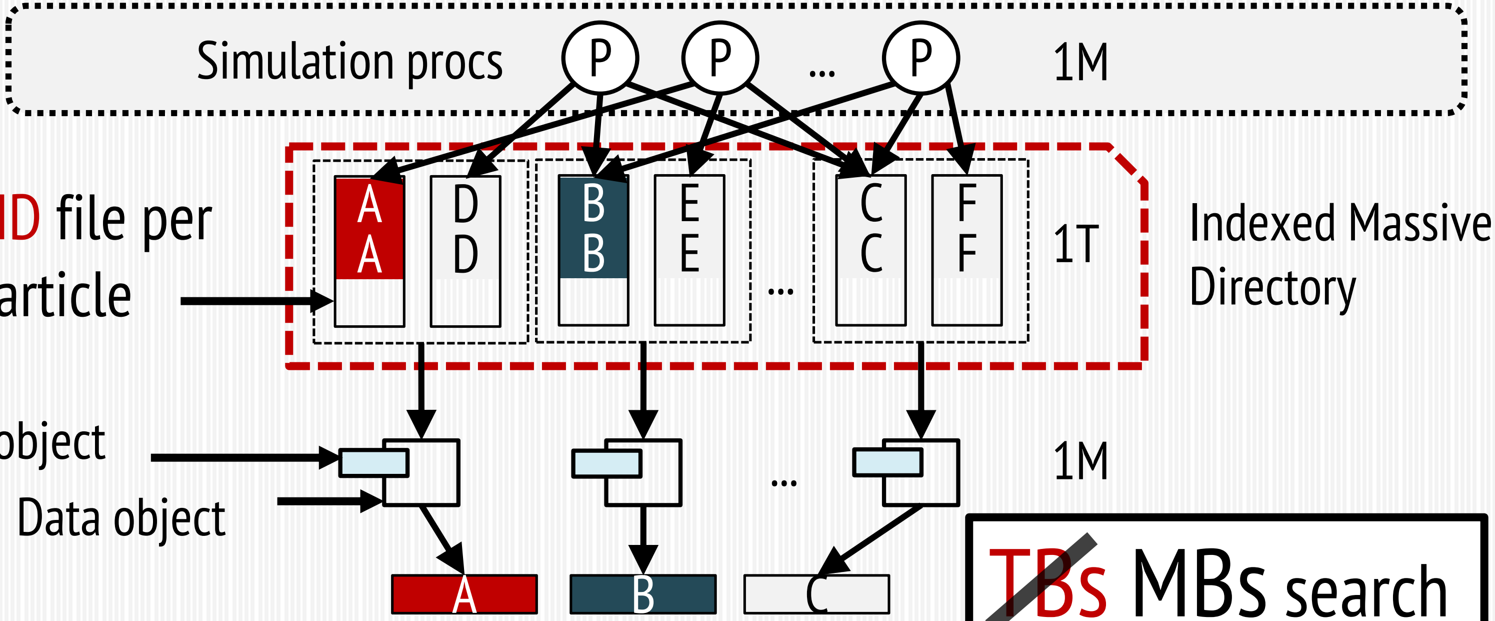
2. Create as many IMD files as you want

e.g. 1 trillion files for 1 trillions particles

Query you data by “open-read-close”

VPIC using DeltaFS IMD

file-per-particle



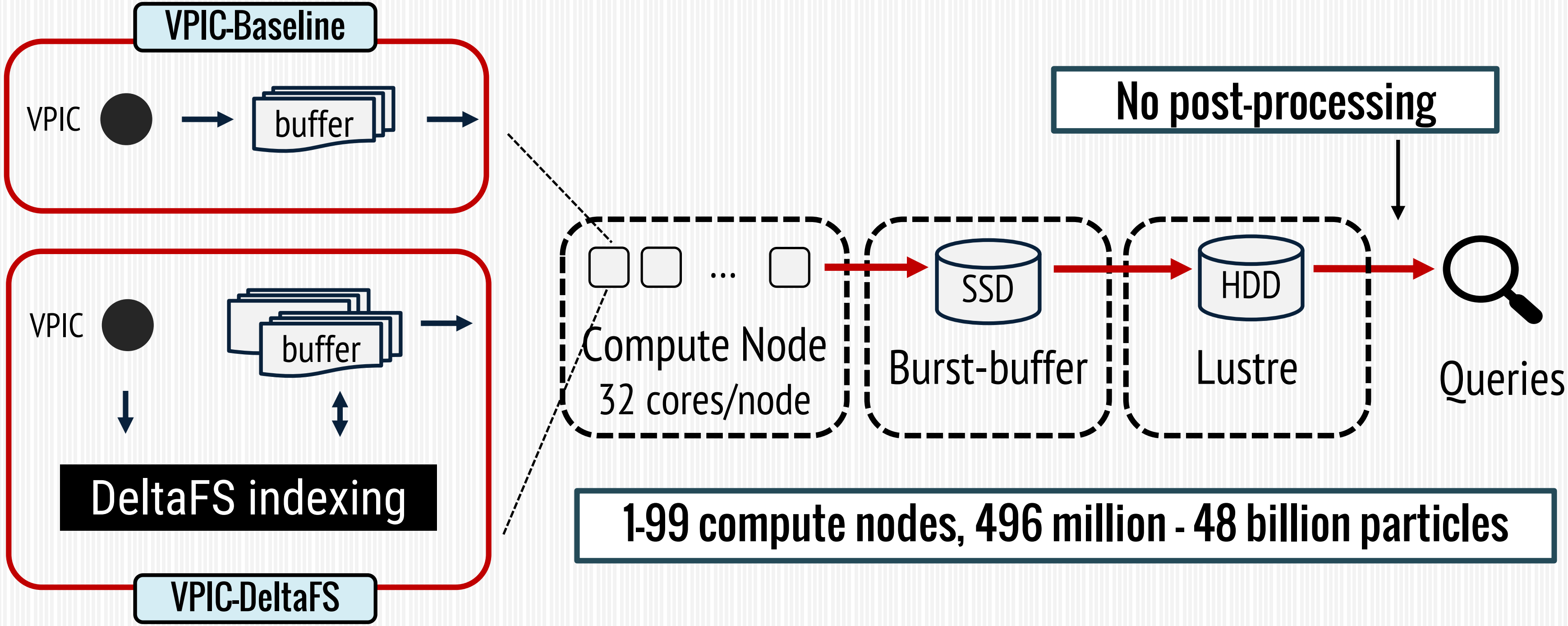
One IMD file per VPIC particle

Index object

Data object

~~TBs~~ MBs search

LANL Trinity Experiments



VPIC-Baseline

VPIC

buffer

VPIC

buffer

DeltaFS indexing

VPIC-DeltaFS

…

Compute Node

32 cores/node

SSD

Burst-buffer

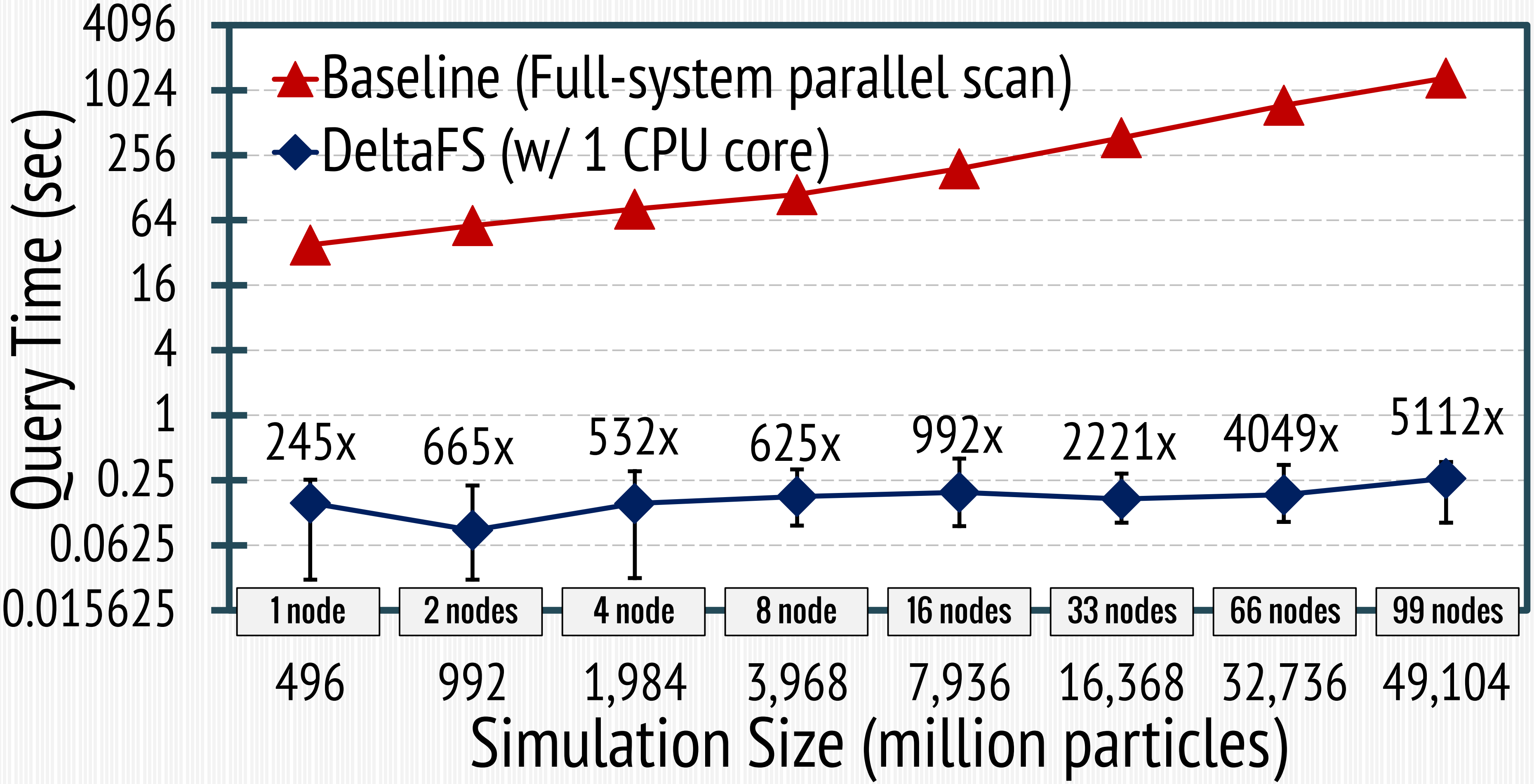
HDD

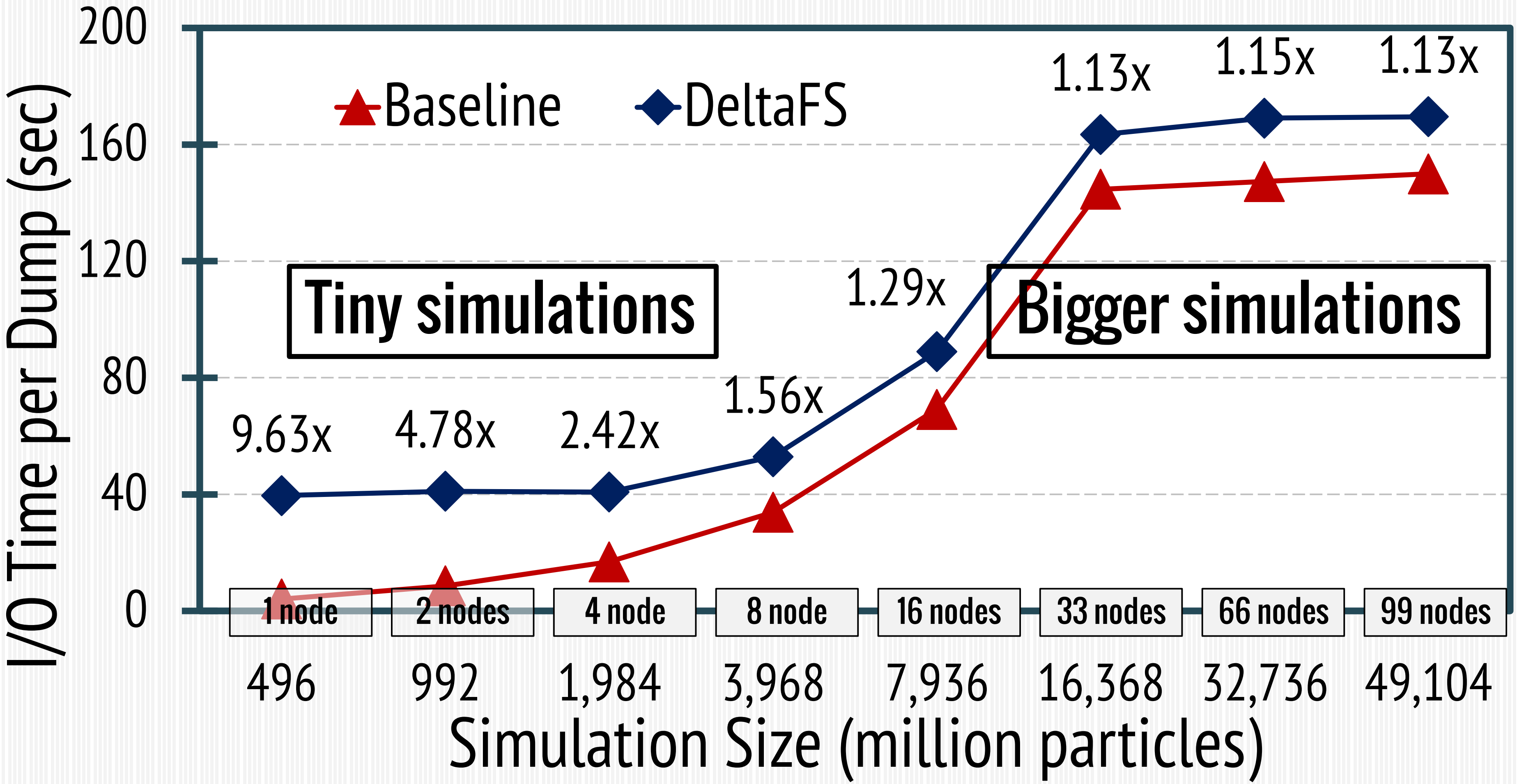
Lustre

Queries

No post-processing

1-99 compute nodes, 496 million - 48 billion particles


Baseline (Full-system parallel scan)
DeltaFS (w/ 1 CPU core)
Query Time (sec)
4096
1024
256
64
16
4
1
0.25
0.0625
0.015625
245x
665x
532x
625x
992x
2221x
4049x
5112x
1 node
2 nodes
4 node
8 node
16 nodes
33 nodes
66 nodes
99 nodes
496
992
1,984
3,968
7,936
16,368
32,736
49,104
Simulation Size (million particles)



Tiny simulations

Bigger simulations

Conclusion

https://github.com/pdlfs/deltafs

In-situ indexing for transparent, almost-free query acceleration

no dedicated nodes, no post-processing, ~15% I/O overhead

- Indexed Massive Dir (~3% app mem, compaction-free, POSIX API)
- Powered by Mercury RPC

  https://mercury-hpc.github.io/

- DeltaFS is one of the Mochi micro-services

  https://press3.mcs.anl.gov/mochi/