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ELECTRICAL AND COMPUTER ENGINEERING
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# A Weak Scalability Study of File Aggregation in Asynchronous, Multi-Level Checkpointing

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## Motivation: The Intersection of Checkpointing and I/O Aggregation

- Checkpointing captures a globally consistent state of an application during runtime for a variety of scenarios: fault tolerance, migration, on-demand preemption using suspend-resume, algorithms revisiting previous states (e.g., adjoint computations)
- Checkpoints need to be persisted to ***stable storage*** (e.g. PFS) with minimal overhead
- Asynchronous checkpointing techniques (e.g. VELOC [1]) reduce overhead by writing to local storage and then concurrently flush to stable storage in the background
- It is desirable to aggregate local checkpoints into a smaller number of files/objects on persistent storage (for easier management and/or better I/O performance)
- State-of-art I/O aggregation techniques are designed for synchronous I/O and is insufficiently explored in the context of checkpointing

## Contribution: Weak Scalability Study of I/O Aggregation

- Our custom benchmark spawns N (1 → 1024) total processes and performs a weak scalability study using 16 processes / compute node
- Initial studies presented at SC’21 (poster and paper at the SuperCHECK workshop) showed results obtained on small-scale run (N = 1 → 128) of weak and hard scalability studies
  - weak scalability study used 1 process / compute node
  - hard scalability iteratively divides 128 / $i$ , {$\forall\ i \in S \mid S = \{1,2,4,8,16,32\}$}
- This poster complements our previous studies with larger-scale weak scalability experiments

**More details available in our previous work**

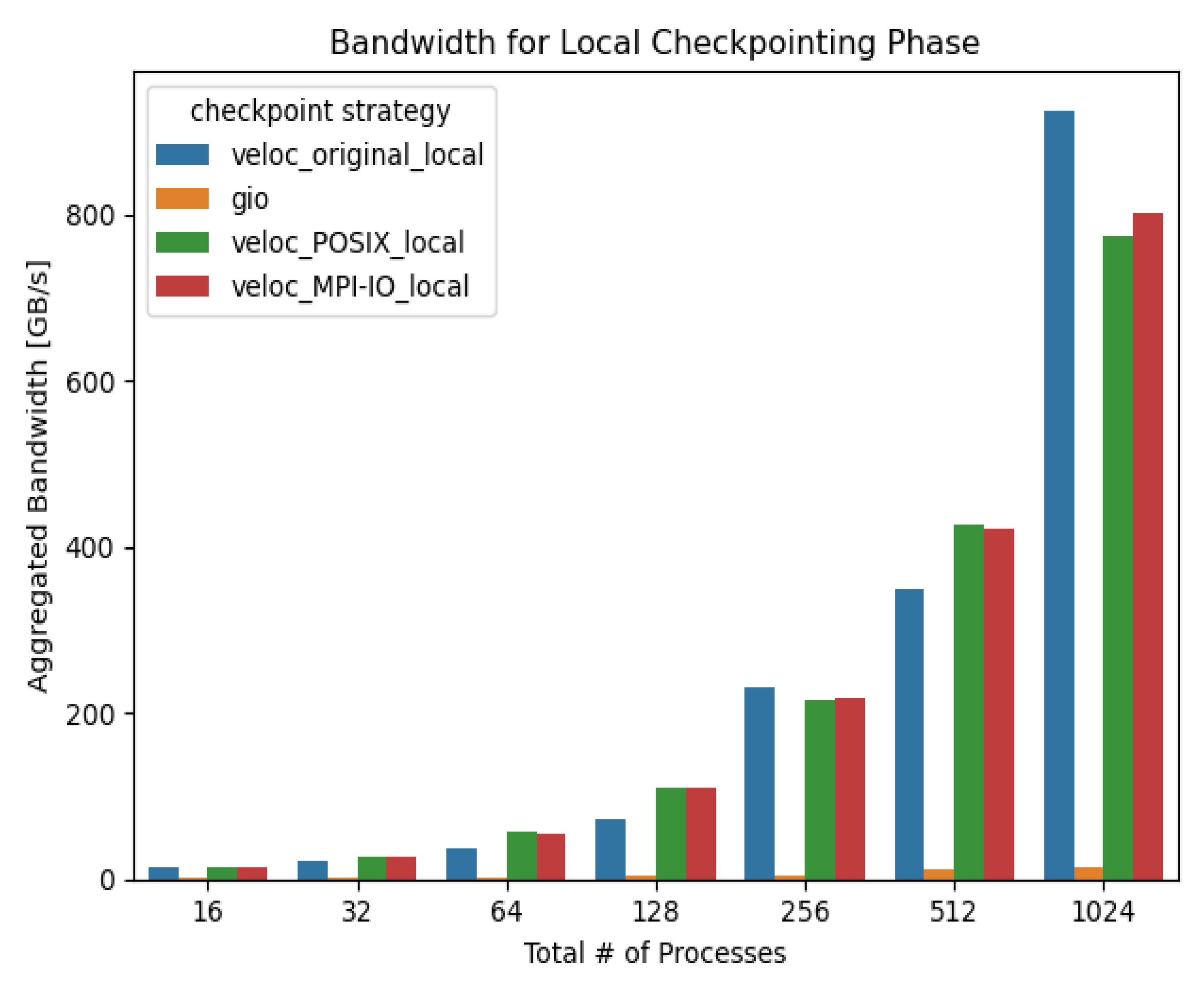
**SC’21 Poster**

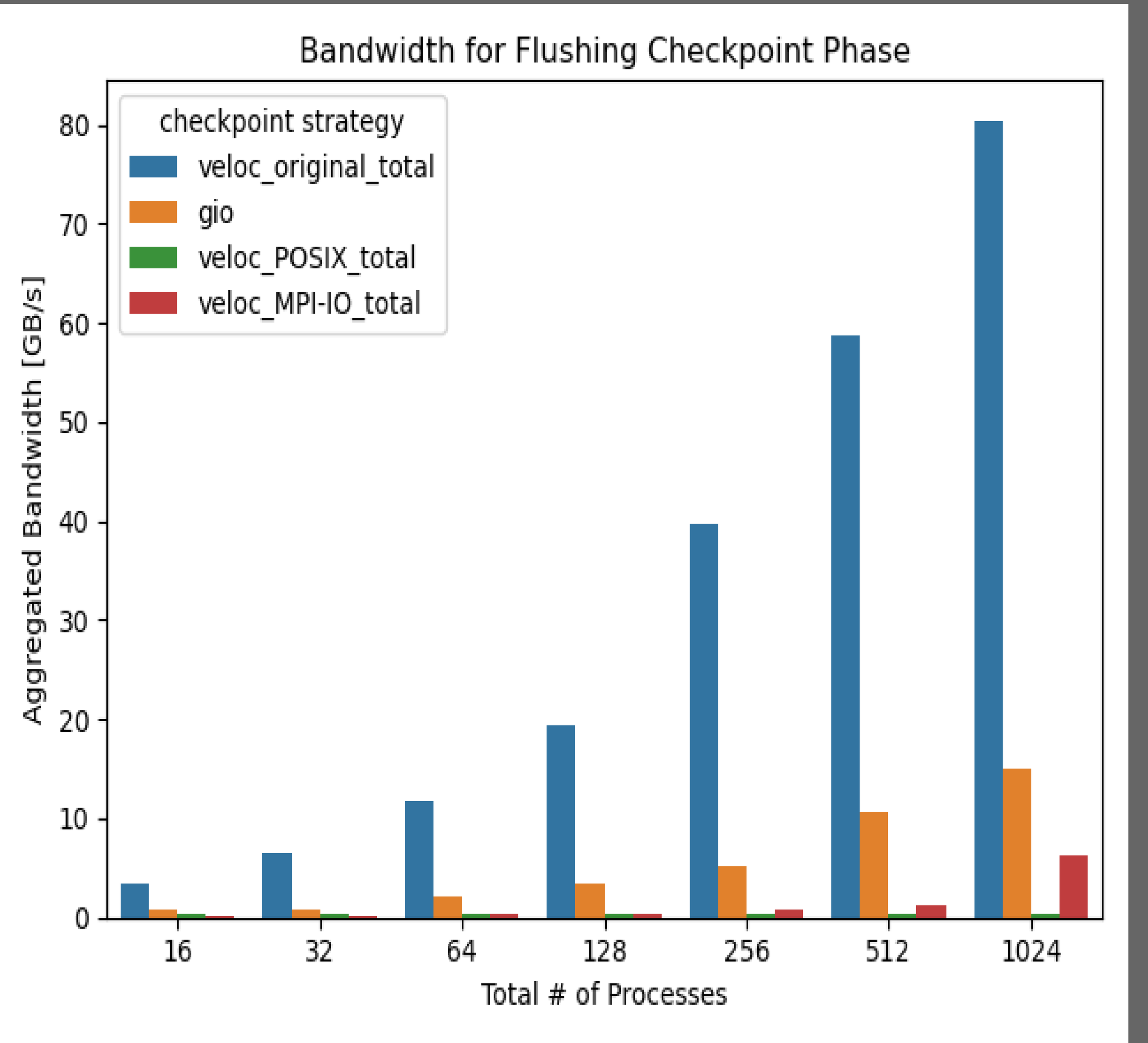
**SuperCHECK@SC'21**

## Experimental Setup

- Approaches: three aggregation strategies compared with no aggregation
  - **VELOC Default**: one file per process, (async)
  - **POSIX**: aggregates all checkpoints into 1 file; calculates each offset in global file via parallel-prefix-sum and issues a POSIX write for each checkpoint, (async)
  - **MPI-IO**: Same as POSIX but issues an MPI collective write for each checkpoint instead, (async)
  - **GenericIO**: aggregates all checkpoints into 1 file; single rank calculates total size and offset for each process and divides work among the processes, processes issue MPI collective writes to global file, (sync)
- Platform: Argonne’s Theta supercomputer
  - Persistent storage: Intel Enterprise Edition Lustre PFS (172 GB/s)
  - Local storage: in-memory temporary file system (/dev/shm)
- Weak scalability study: 16 processes / compute node, 1 GB checkpoint / process
  - Increasing number of processes (16 → 1024)

## Results




## Discussion

- The figure on the **left** shows the resulting aggregated bandwidth for the local checkpointing phase:
  - GenericIO (gio) in yellow does not use local storage resulting in significantly lower throughput
  - All VELOC methods, even with aggregation, mask the flushing speed to the application since it promptly resumes-thus we can further show that the prefix-sum operation (which requires synchronization) introduces negligible overhead
- The figure on the **right** shows the time it takes to write all checkpoints to the parallel file system (PFS):
  - Flushing speeds improved dramatically for VELOC methods compared to works presented at SC'21 by deactivating optional modules that operate during the flush phase (e.g. error correction)
  - MPI-IO performance continues to dominate POSIX performance throughout this study but still suffers serious performance degradation, as neither implemented aggregation strategies reach 1/10th of the peak write BW on Theta and even GenericIO barely reaches the 1/10th mark @ 1024 processes
- This study shows that VELOC's file-per-processes flushing style is the most efficient way to flush checkpoints
- A large gap is observable between the one-file-per-process async I/O strategy (as implemented by VELOC) and the other compared async I/O aggregation strategies, which presents a research opportunity

## Conclusions and Future Work

- MPI-IO is optimized for synchronous parallel I/O to aggregate data into single files
- POSIX (and object-store based APIs) offers the most performance potential and flexibility for implementing optimized asynchronous aggregation strategies
- We are currently working to develop a novel, resource-aware aggregation strategy designed to meet the specific challenges of asynchronous checkpointing (i.e. resource contention)

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