# Uncovering Errors: The Cost of Detecting Silent Data Corruption


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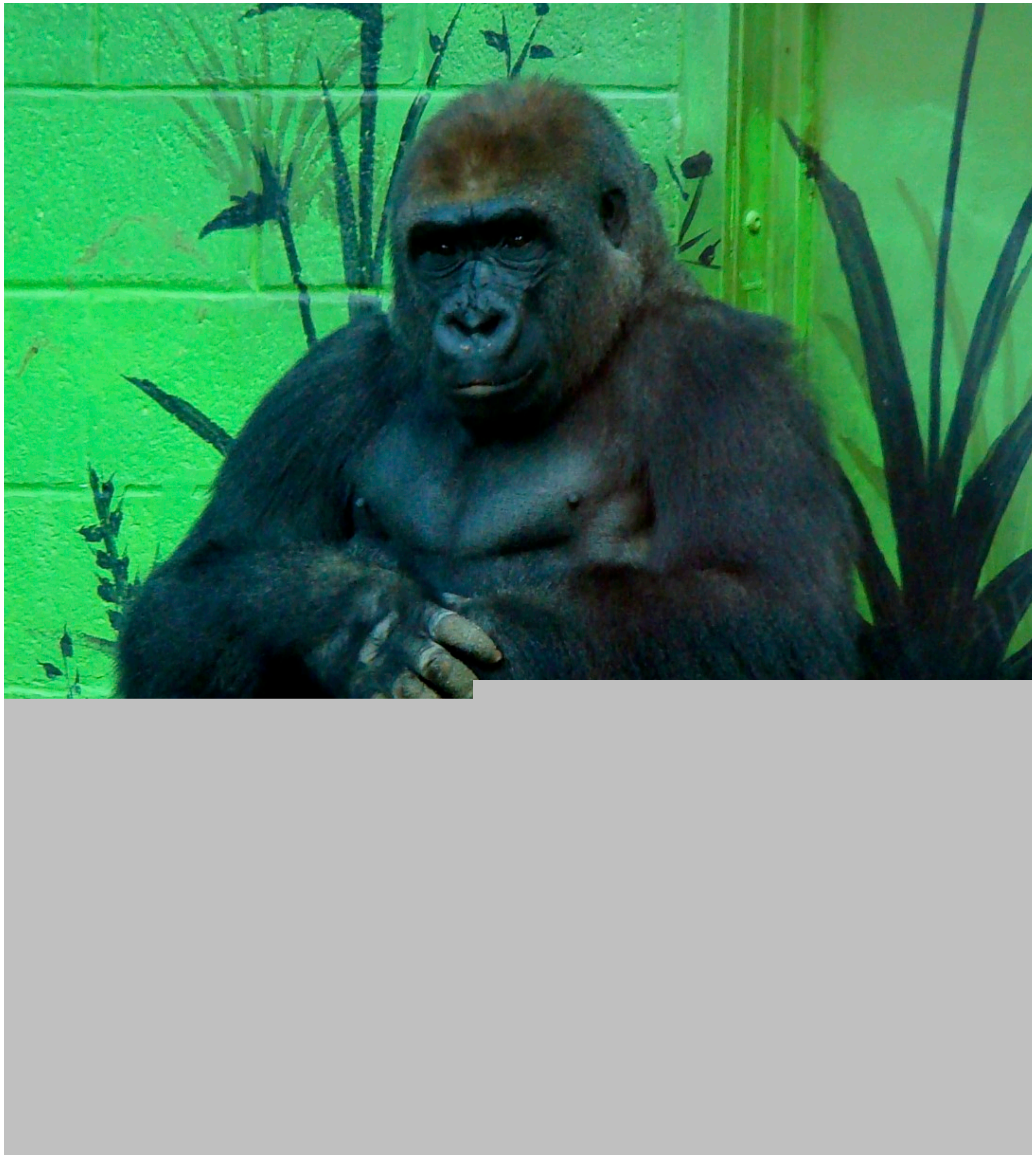
# Data Corruption





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# Silent Data Corruption

- What is *silent data corruption*?
  - Fault not detected by the system
  - Fault not communicated to the user/application
- Why does it occur?
  - misdirected writes
  - torn writes
  - data path corruption
  - bit-rot

# Silent Data Corruption

- Other sources
  - Software bugs
    - File system, device drivers, software RAID
  - Firmware bugs
    - RAID controllers, disk drives
- Faults can occur during reads or writes, or both!
- Is RAID a good solution? – No!

# Data Corruption is Real

- 1.5 million disk drives in NetApp database in 32 months#
  - Data corruption detected
    - 8.5% of all nearline disk drives
      - 13% of errors went undetected
    - 1.9% of all enterprise class disk drives
      - 38% of errors went undetected
- Another study of the same database over 41 months*
  - 400,000 checksum mismatches

# Bairavasundaram et al. in ACM SIGMETRICS Performance Evaluation Review 2007
* Bairavasundaram et al. in USENIX FAST 2008

# Data Corruption is Real

- Experiments at European Organization for Nuclear Research (CERN)^
  - Wrote 2 GB on 3,000 nodes every 2 hours for 5 weeks
    - 500 errors on 100 nodes
      - 10% - sector sized or page sized
      - 80% - 64K regions
- Data corruption not limited to consumer-based drives, also present on enterprise-grade disks

*^ Bernd Panzer-Steindel, CERN/IT*


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# Data Integrity

- Common algorithms used to check data integrity
  - Cyclic redundancy checks (CRCs)
  - Adler's Algorithms
  - Fletcher's Algorithms
- ECC in hard drives
  - Not sufficient
- Other algorithms
  - Secure hash algorithms (SHA), message digest algorithms (MD5)

# Data Integrity in HPC

- Same analysis of same data must give same results
- 1000s of disks and billions of data blocks
- Complex workload characteristics
  - Aligned/unaligned access patterns
  - Varying sizes
  - Concurrent
  - Reads/Writes

Loss of data + Loss of time = Loss of mind!


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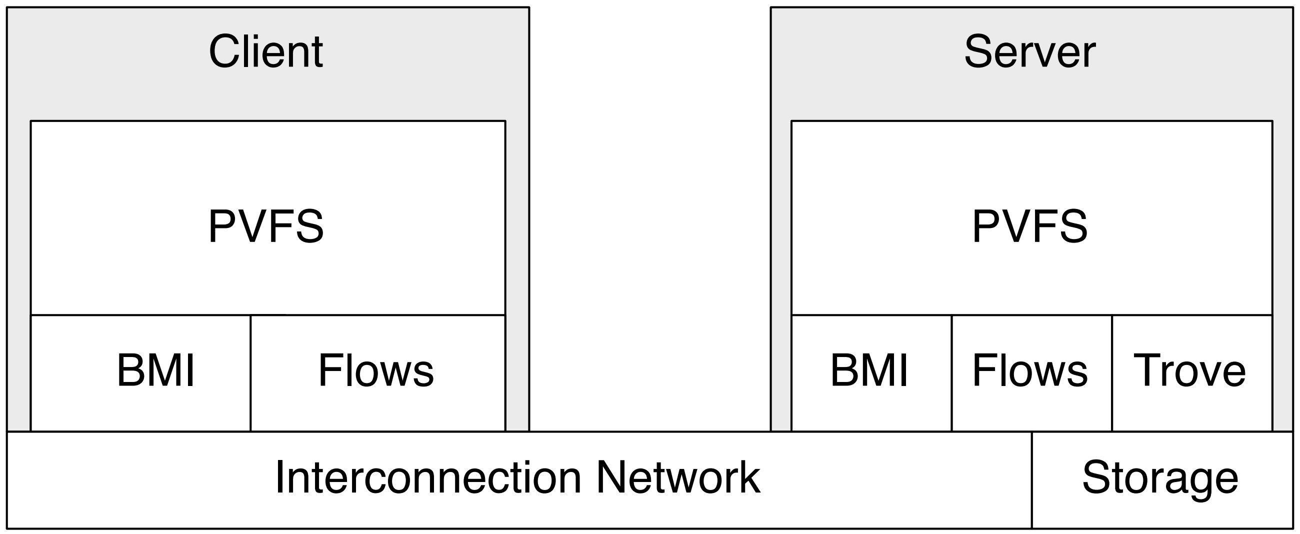
# Parallel Virtual File System (PVFS)

- Parallel file system
  - Separate metadata and data servers
  - Data stored on local file systems
    - bstreams



# Design

- Where do we store CRCs?
  - Metadata servers
    - single point of contact per file
    - atomic updates – major bottleneck
  - Storage servers
    - take advantage by distributing computations
    - finer granularity
    - local cache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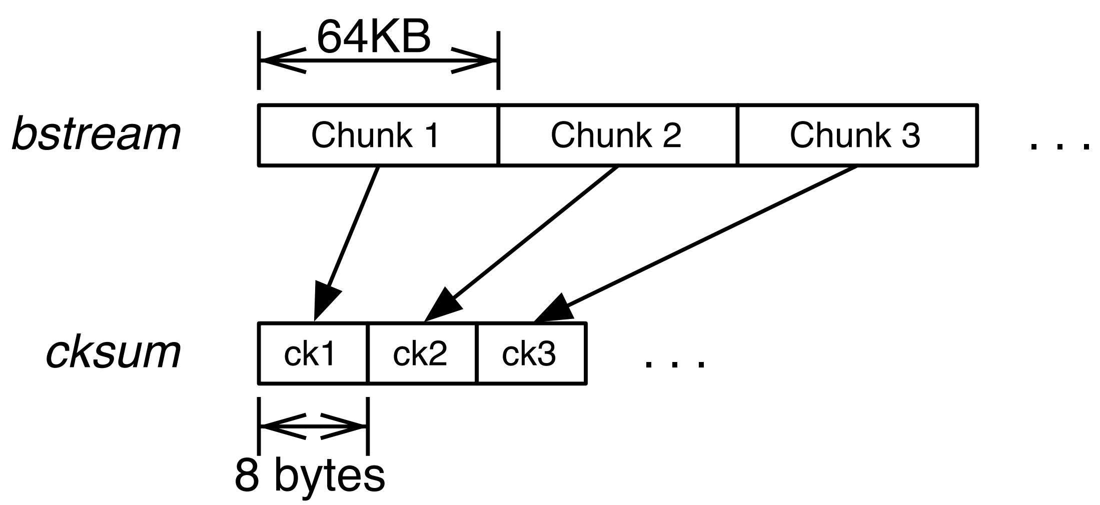
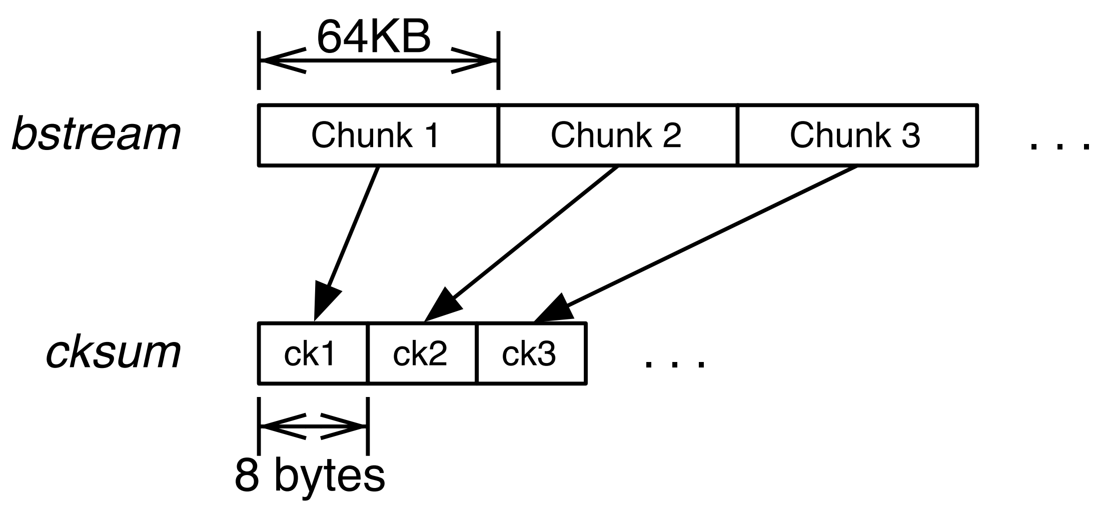
# Design

- PVFS (version 2.8.1)
- CRCs
  - separate file for checksum
- Check code of 8 bytes for every 64 KB
  - Check code for 32 MB of data in 4K block of disk

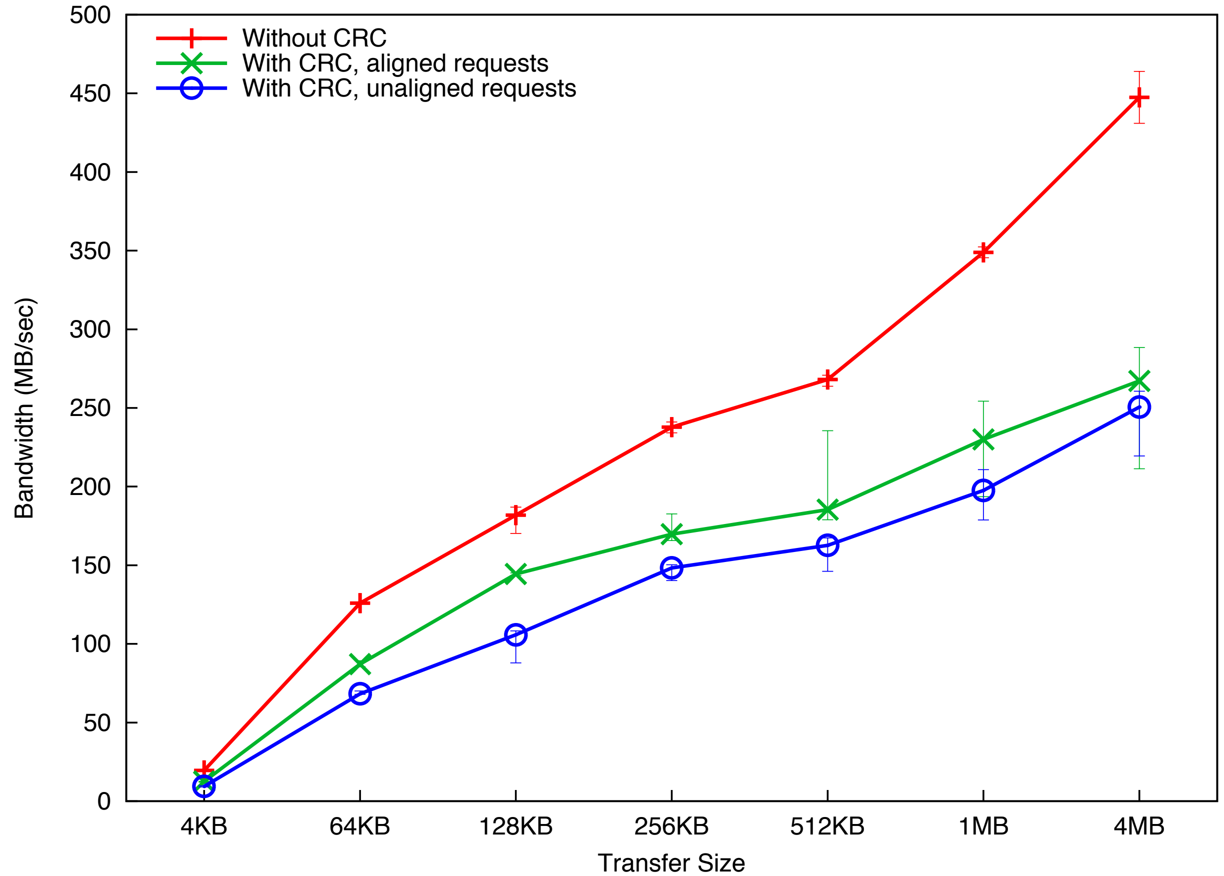


# Design

- Aligned Requests
- Unaligned Requests
  - read-verify-modify-write
- Multiple threads to operate on CRCs
  - Reads – read-ahead checksums
  - Writes – calculate checksums



# Results – Single Client




Write

- IOR benchmarking tool
- 8 GB file
- 8 storage servers



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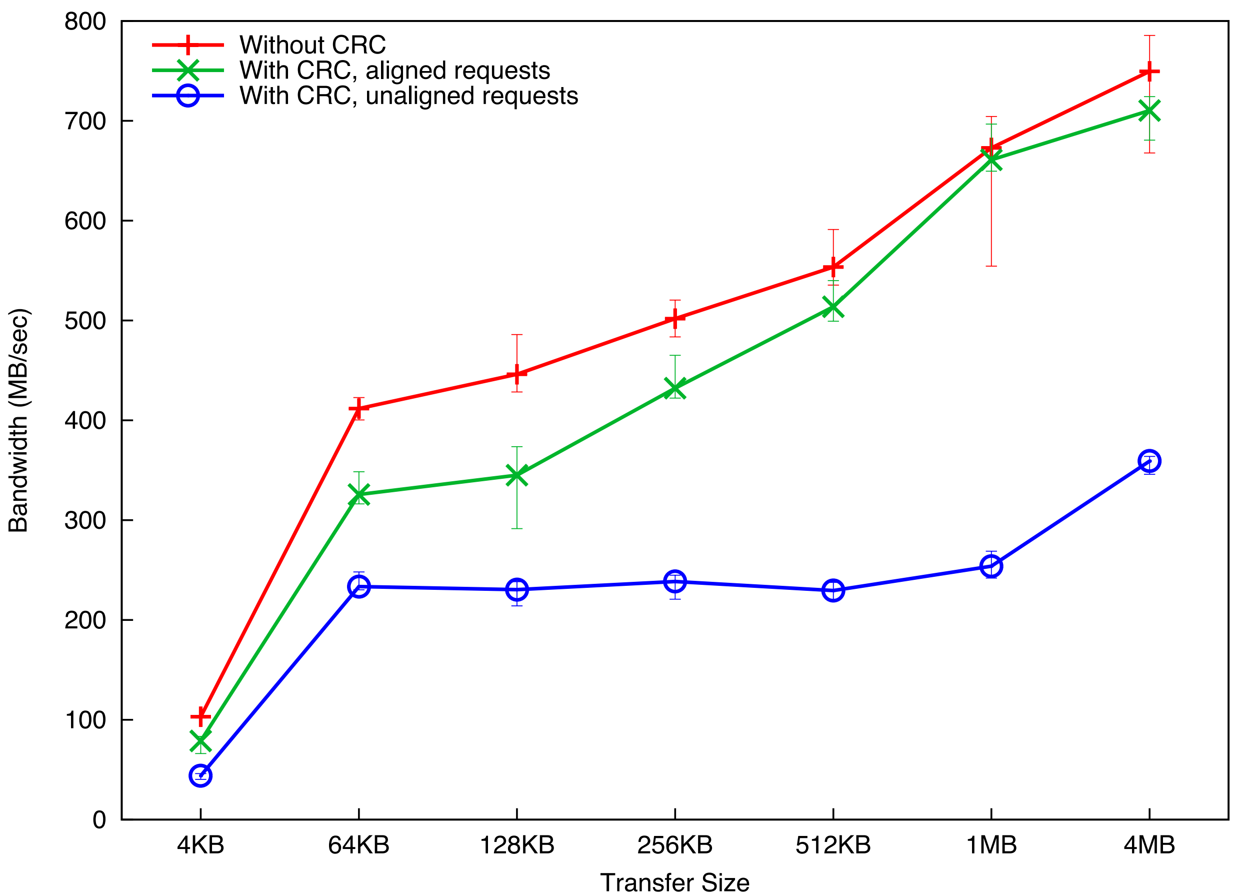
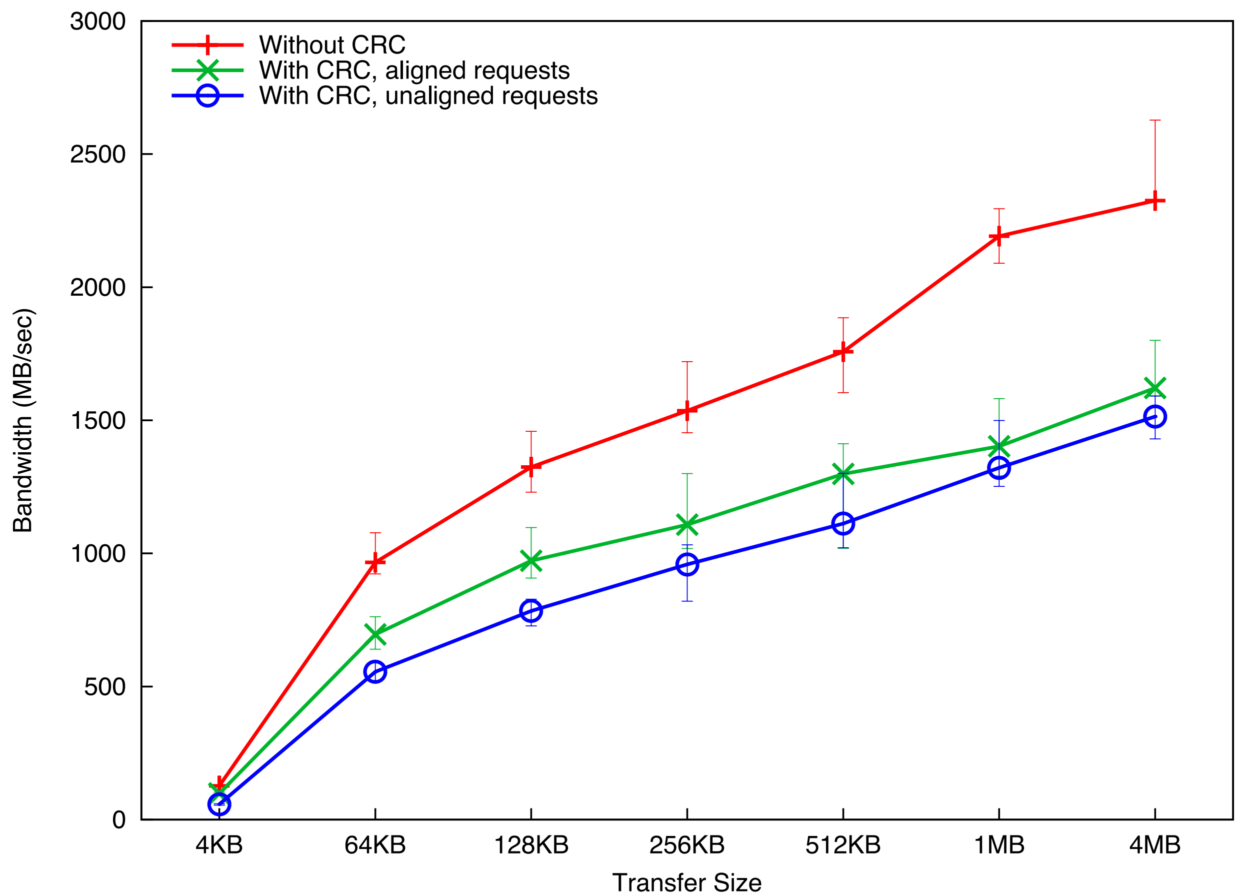
# Results – Multiple Clients



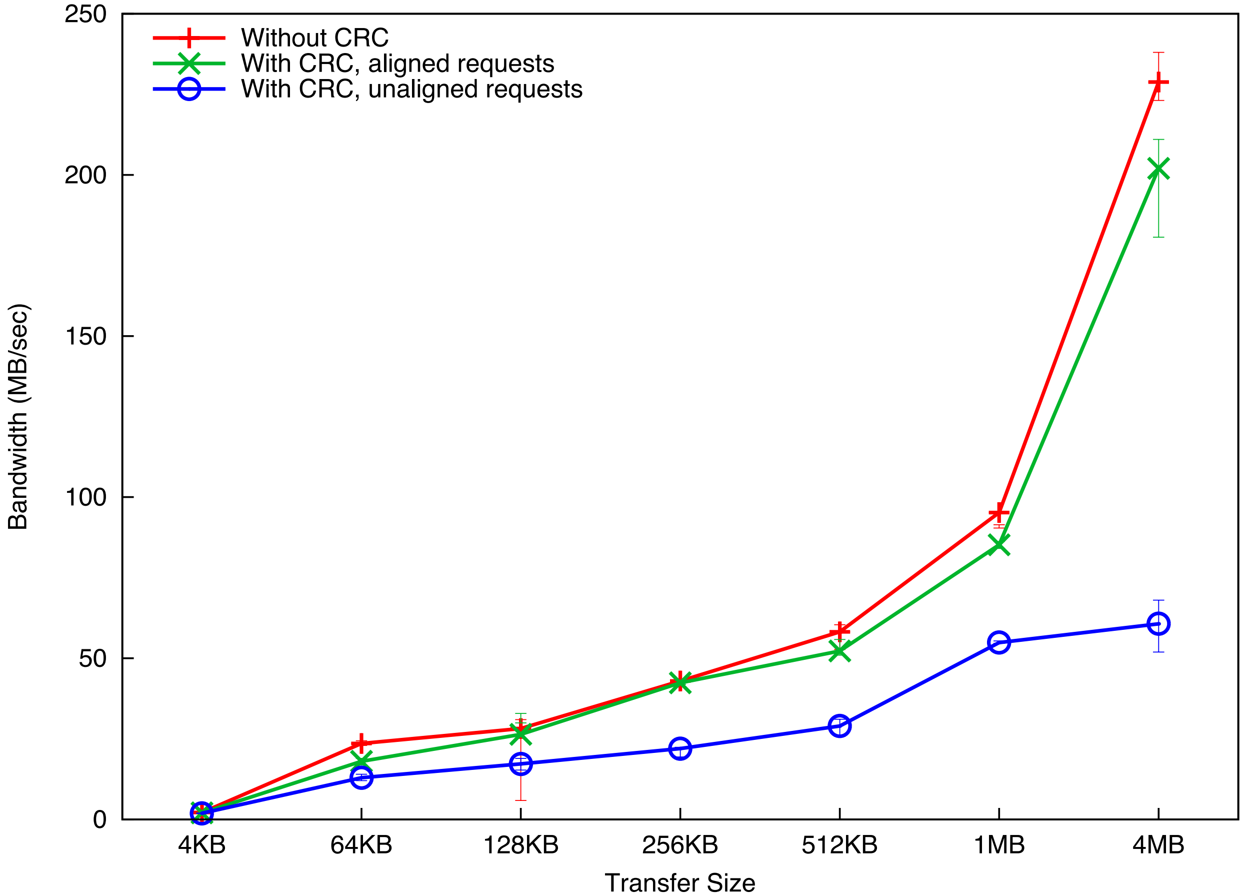

Write



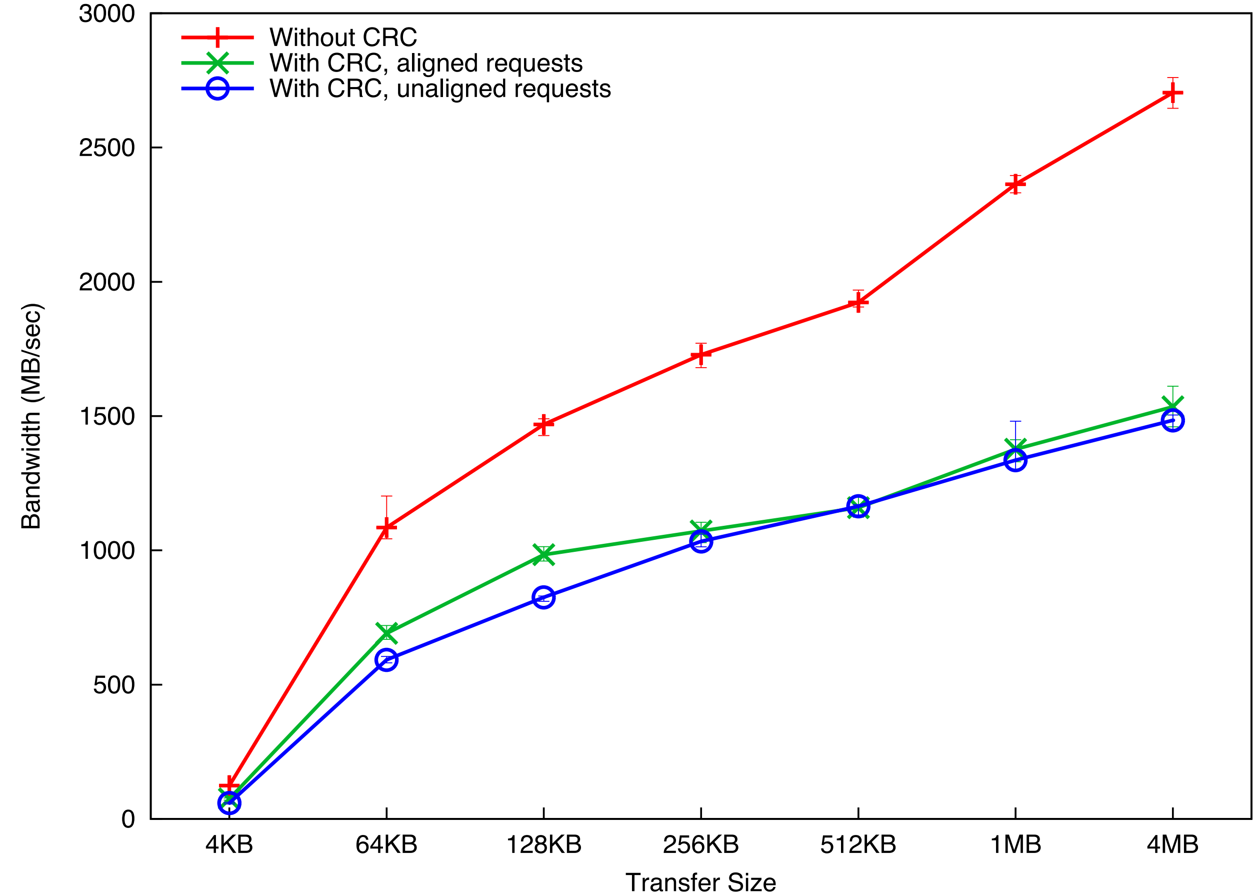

Read

- IOR benchmarking tool
- 8 GB file
- 8 clients, 8 storage servers
  - 1 GB / storage node

# Results – Multiple Clients (Sync)




Write




Read

- IOR benchmarking tool
- 8 GB file
- 8 clients
  - 1 GB / storage node
- Data sync enabled

# Related Work

- Google file system
  - multiple copies
  - in-line checksum
- Local file systems
  - ZFS, Btrfs
- Lustre, GPFS, PanFS, Ceph

# Summary

- Integrity checks necessary for all storage devices
- Provided integrity checks for parallel file system
  - Aligned request
  - Unaligned request
- Separate file for checksum
- MPI hints / POSIX attributes
- Flash-based storage
  - Limited write cycles

# Future Work

- Pipeline architecture for calculating CRCs on storage nodes
- In-line storage of CRCs in bstreams
- End-to-end checksums
- Varying parameters - checksum chunk size, algorithms etc.
- GP-GPUs
    - Reed-Solomon coding and decoding for Extended RAID on GPUs - PDSW'08

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