Zest I/O

Paul Nowoczynski, Jared Yanovich

Advanced Systems, Pittsburgh Supercomputing Center

MSST '08 Baltimore, M

Zest – What is it?

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Parallel I/O system designed to optimize the compute I/O subsystem for checkpointing / application snapshotting.

- Write() focused optimizations – transitory cache with no application read() capability.
- Expose about 90% of the total spindle bandwidth to the application, reliably.
- Emphasizes the use of commodity hardware
- End-to-end design.
  - Client to the disk and everything in between.

Zest: Background

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- Designed and implemented by the PSC Advanced Systems Group (*Nowoczynski, Yanovich, Stone, Sommerfield*).
- Work began in September '06.
- Prototype development took about one year.
- Currently most major features are implemented and in test.

Zest – Why checkpointing?

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Checkpointing is the dominant I/O activity on most HPC systems.

Its characteristics lead to interesting opportunities to for optimization:

- 'N' checkpoint writes for every 1 read.
- Periodic, heavy bursts followed by long latent periods.
- Data does not need to be immediately available for reading

Zest – The impetus.

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Compute performance is greatly outpacing storage system performance.

As a result.. Storage system costs are consuming an increasing percentage of the overall machine budget.

Over the last 7-8 years performance trends have not been in favor of I/O systems

- Memory capacities in the largest machines have increased by~25x
- Disk bandwidth by ~4x

Zest: What can be optimized today?

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Opportunities for optimization in today's parallel I/O systems – do they exist? *YES*

Current systems deliver end-to-end performance which is a ***fraction*** of their ***aggregate spindle bandwidth***.

If this bandwidth could be reclaimed it would mean:

- Fewer storage system components
- Less failures
- Lower maintenance, management, and power costs
- **Improved cost effectiveness for HPC storage systems.**

Zest: Why is spindle efficiency poor?

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Several reasons have been observed:

- Aggregate spindle bandwidth is greater than the bandwidth of the at least one of the connecting busses.
- Parity calculation engine is a bottleneck.
- Sub-optimal LBA request ordering caused by the filesystem and/or the RAID layer.

The first two factors may be rectified with better storage hardware..

The last is the real culprit and is not as easily remedied!

Zest: Software stacks aren't helping.

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Today's storage software architectures (filesystems / raid) generally do not enable disk drives to work in their most efficient mode.

Overly deterministic data placement schemes result in loss of disk efficiency due to seek'ing.

- Pre-determined data placement is the result of inferential metadata models employed by:
  - **Object-based parallel filesystems**
  - **Raid Systems**
- These models are extremely effective at their task but result in data being forced to *specific* regions on *specific* disk drives.
  - ***Results in disk work queues which are not sequentially ordered.***

Zest: Other negative side-effects

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Current data placement schemes complicate performance in degraded scenarios.

In HPC environments, operations are only as fast as the slowest component...

- Object-based metadata and RAID subsystems expect data to be placed in a specific location.
- Difficult or impossible to route write requests around a slow or failed server once I/O has commenced.
- In the current parallel I/O paradigm, these factors have the potential to drastically hurt scalability and performance consistency.

Zest: Methods for optimized writes.

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Zest uses several methods to minimize seeking and optimize write performance.

- Each disk is controlled by single I/O thread.
- Non-deterministic data placement. *(NDDP)*
- Client generated parity.
- No Leased locks

Zest: Disk I/O Thread

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One thread per-disk.

- Exclusive access prevents thrashing.
- Rudimentary scheduler for managing data reconstruction requests, incoming writes, and reclamation activities.
- Maintains free block map
  - Capable of using any data block at any address
  - Facilitates sequential access through ***non-determinism***
- Pulls incoming data blocks from a single or multiple queue called "*Raid Vectors*".

Zest: Raid Vectors

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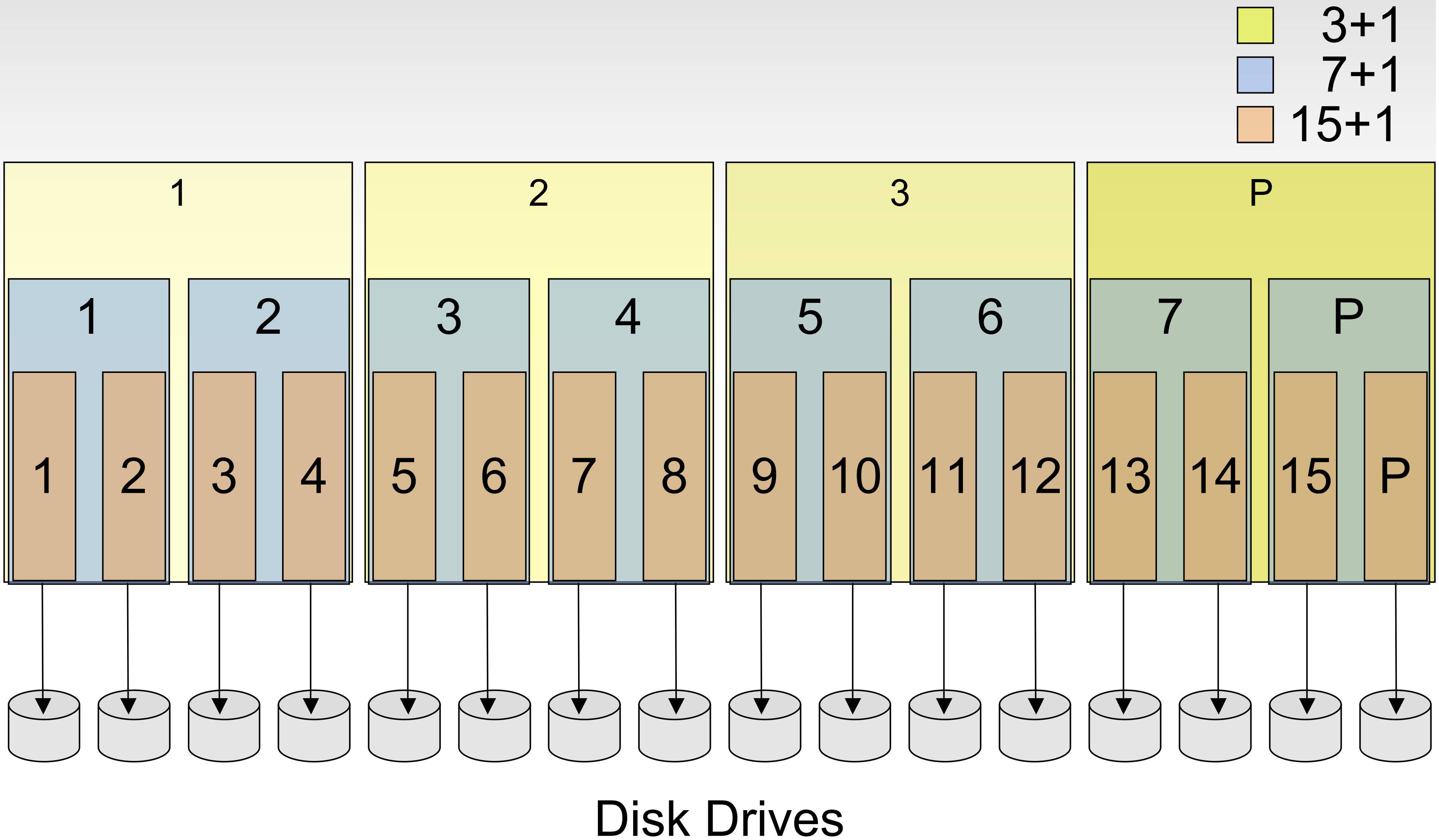
Queues on which incoming write buffers are placed to be consumed by the disk threads.

- Ensures that blocks of differing parity positions are not placed o the same disk.
- Multiple drives may be assigned to a RV.
  - Blocks are pulled from the queue as the disks are ready.
- Slow devices do less works, failed devices are removed.
- > 1 disk per RV creates a second degree of ***non-determinism.***

Raid Vectors



Zest: Non-deterministic placement

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Non-determinism on many levels:

- Any parity stripe or group may be handled by any ZestION.
  - Slow nodes may be fully or partially bypassed
- Any disk in a Raid Vector may process any block on that vector.
  - Assumes that ndisks > (2 x raid stripe width)
- Disk I/O thread may place data block at the location of his choosi
  - Encourages sequential I/O patterns.

Performance is not negatively impacted by the number of clients the degree of randomization within the incoming data streams

Zest: Client Parity, CRC, and Cache

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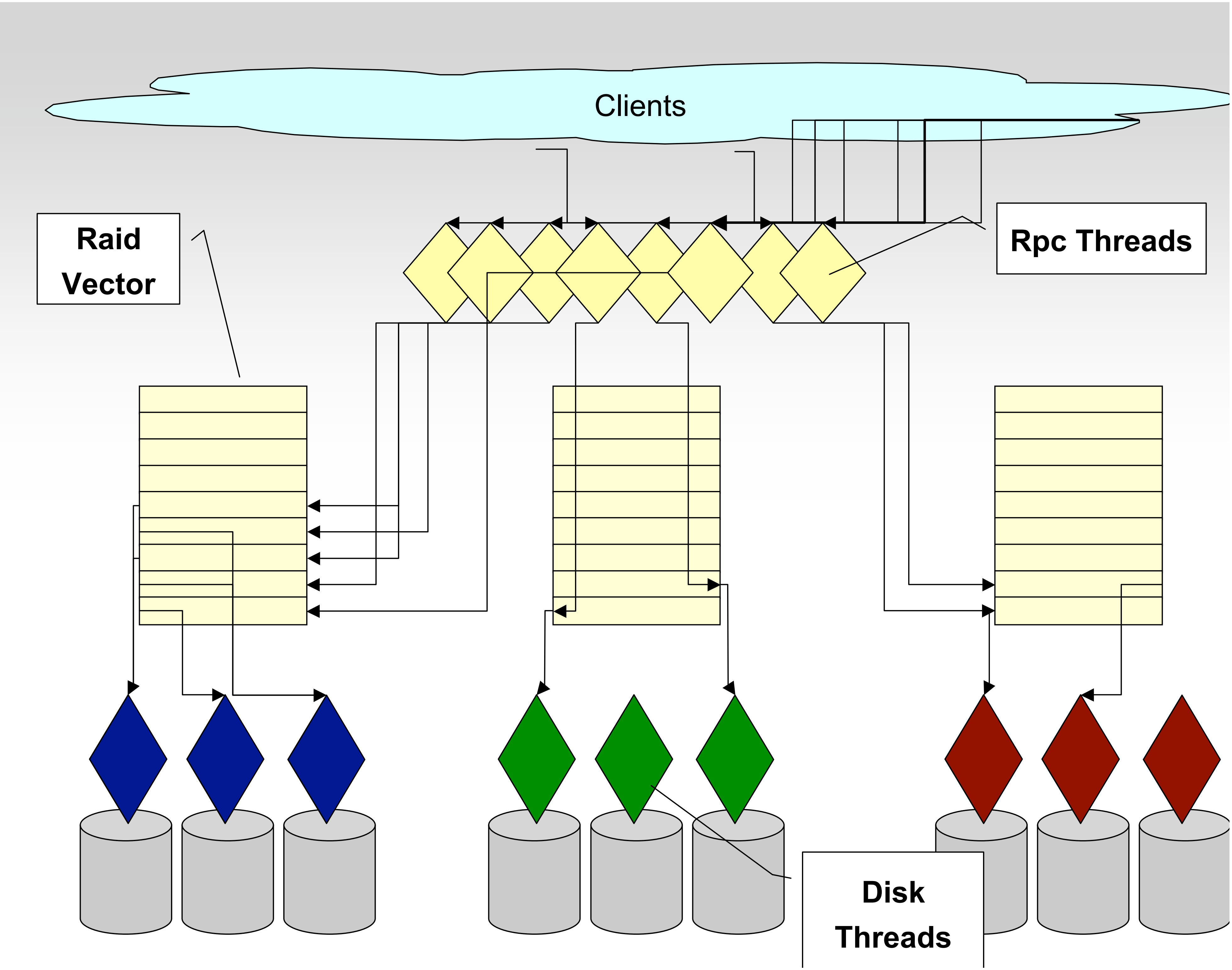
Much of the hard work is placed onto the client preventing th ZestION from being a bottleneck.

- Data blocks are Crc'd and later verified by the ZestION during the post-processing phase.
- Data verification can be accomplished without read back of the entire parity group.
- Client computed parity eliminates the need for backend raid controllers.
- Client caches are not page based but vector-based.
  - No global page locks needed.
  - Further eliminates server overhead and complexity.


Clients
Raid
Vector
Rpc Threads
Disk
Threads

Zest: NDDP – the cost..

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Increasing entropy allows for more flexibility but more bookkeeping is required.

NDDP destroys two inferential systems, one we care about th other is not as critical (right now).

- Block level Raid is no longer semantically relevant.
- Tracking extents, globally, would be expensive.

Zest: NDDP – the cost..

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Declustered Parity Groups

- Parity group membership can no longer be inferred.
- Data and parity blocks are tagged with unique identifiers that prove their association.
  - ✓ Important for determining status upon system reboot.
- Parity group state is maintained on separate device.
  - ✓ Lookups are down with diskID, blockID pair.

Zest: NDDP – the cost..

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File Extent Management

Object-based parallel file systems (i.e. Lustre) use file-object maps to describe the location of a file's data.

- Map is composed of the number of stripes, the stride, and the starting stripe.
- Given this map, the location of any file offset may be computed.

Zest has no such construct!

- Providing native read support would require the tracking of a file offset, length pairs.
- Extent storage is parallelizable.

Zest: NDDP – additional benenfits.

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Since any parity group may be written to any I/O server:

- Failure of a single I/O server does not create a hot-spot in the storage network.
  - ✓ Requests bound for the failed node may be evenly redistributed tc the remaining nodes.
- Checkpoint bandwidth partitioning on a per-job basis is possibl

Zest: Post-processing

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Begins once the data ingest phase has halted or slowed.

- Current post-processing technique rewrites the data into a lustre filesystem. (*syncing*)
- In the future, other data processing routines could make use of the same internal infrastructure..

Zest: Post-processing / Syncing

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How does Zest sync file data?

- Zest files are 'objects' identified by their Lustre inode number.
  - These are hardlinked to their lustre equivalents on create().
- On write() the client:
  - The data buffer
  - Metadata slab containing:
    - Inode number, Crc, Extent list, etc.
- Syncing is done using the hardlinked immutable path, the inode, and the extent list.

Zest: Reliability

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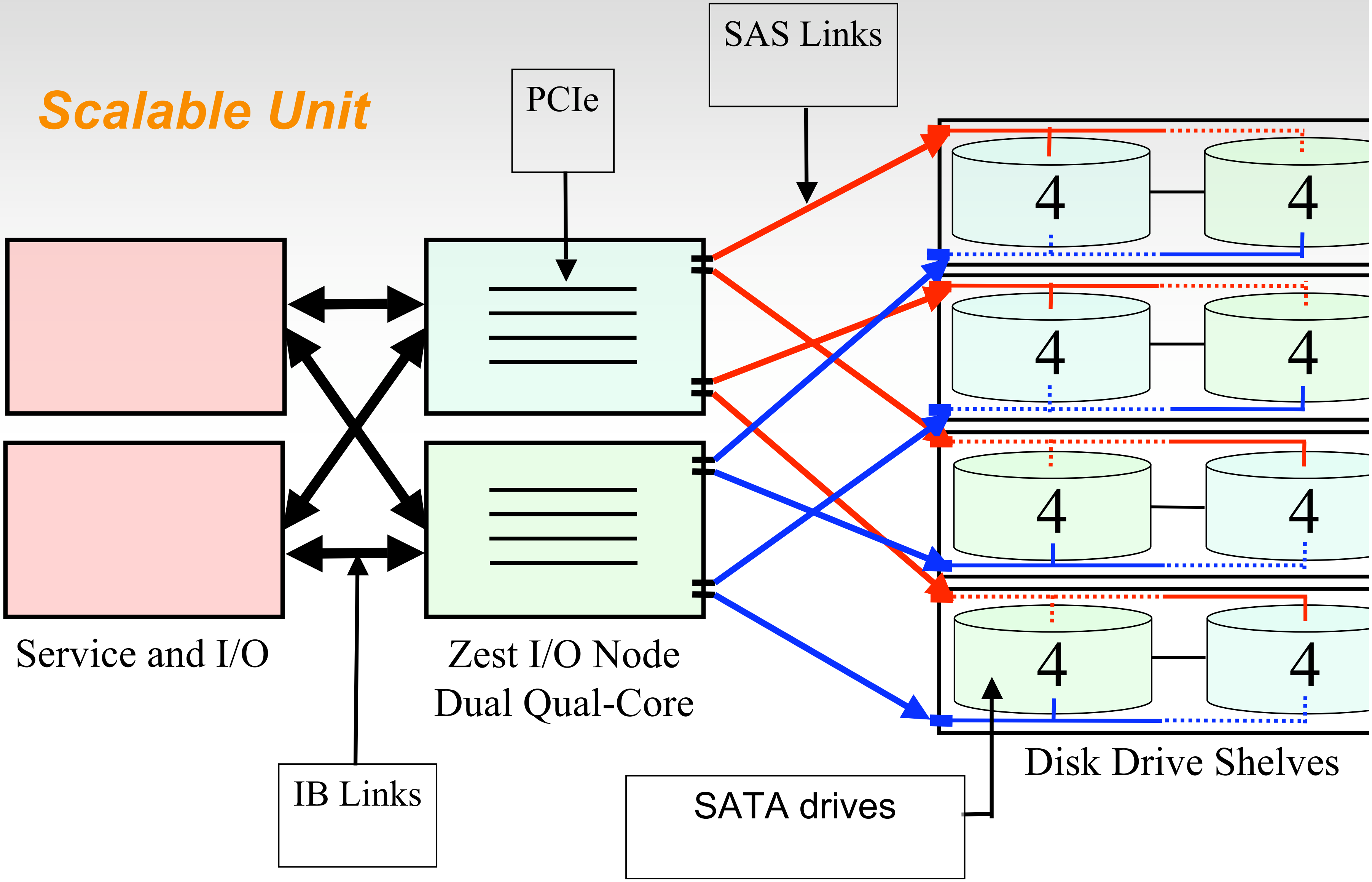
Zest provides reliability on par with a typical HPC I/O system.

- Data redundancy through Raid.
- Recoverability via multi-homed disk configuration.

Zest supports hardware configurations such as the following.

Scalable Unit



- No single point of failure

Zest: Reliability Features

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- Support for failover pairs.
  - Zest superblocks are tagged with UUIDs to avoid confusion in shared disk configurations.
- On reboot, corrupt or missing data is rebuilt, unsynchronized data is rectified.
- Certain modes of disk failure are easily detected and the I/(
thread is quarantined.
- 'Fast rebuild' is supported.
  - When a disk fails, the Zest server has an list, in memory, of all the acti
blocks.   Those blocks can rebuilt immediately without scanning the entire set.

Zest: Performance Result

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- Test consisted of sequentially writing from each PE into a separate file.
- Clients used a 7+1 Raid5 parity scheme (12.5% overhead)

Zest Server Hardware

- ✓ 2 x 4 Core Intel Processors
- ✓ Multiple PCI-e Busses
- ✓ 1 Sas Controllers
- ✓ 1 IB Interface (DDR)
- ✓ 12 Drives (@75MB/s per)

Zest: Single Disk Rate

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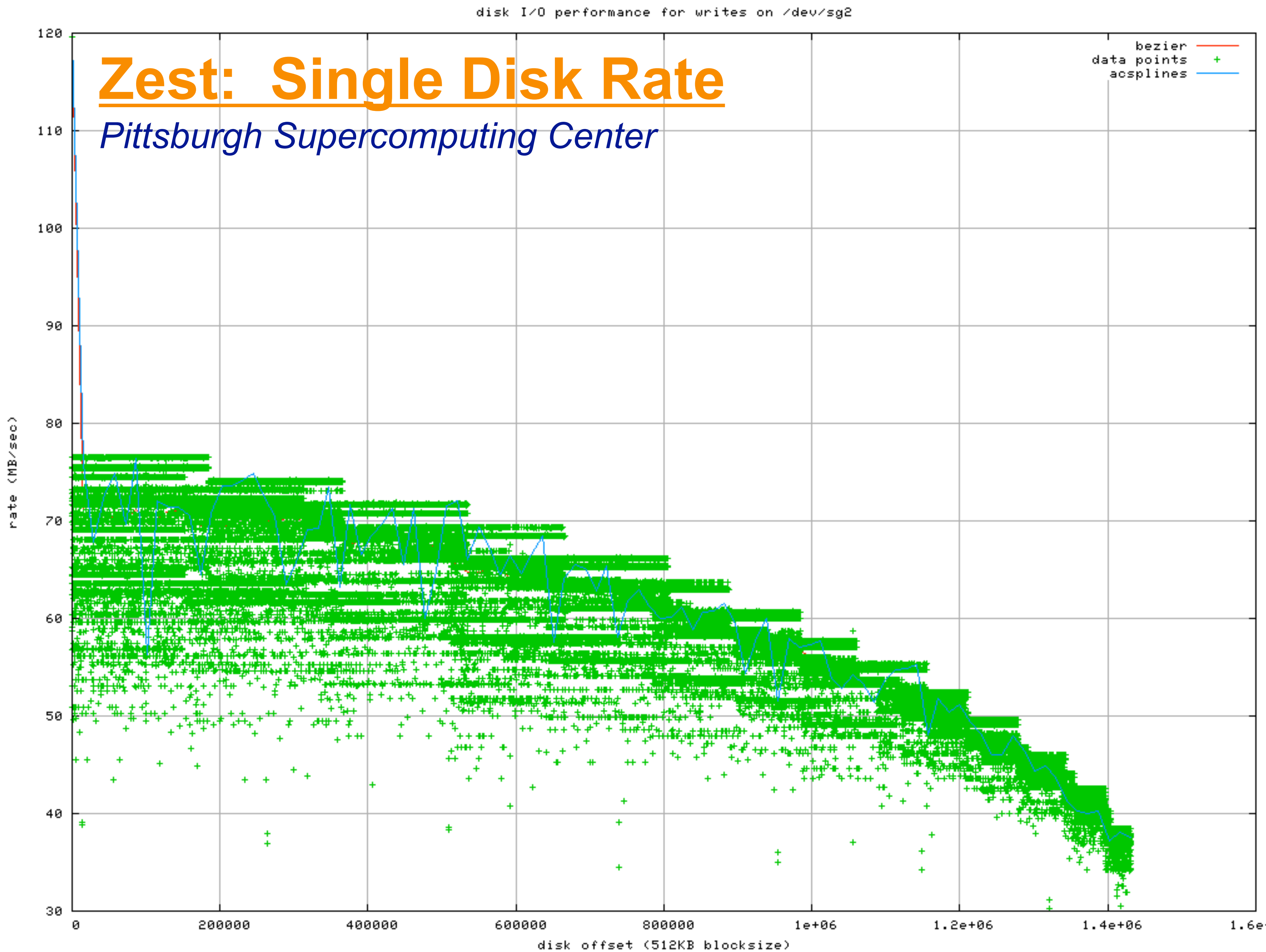

Zest: Performance Result

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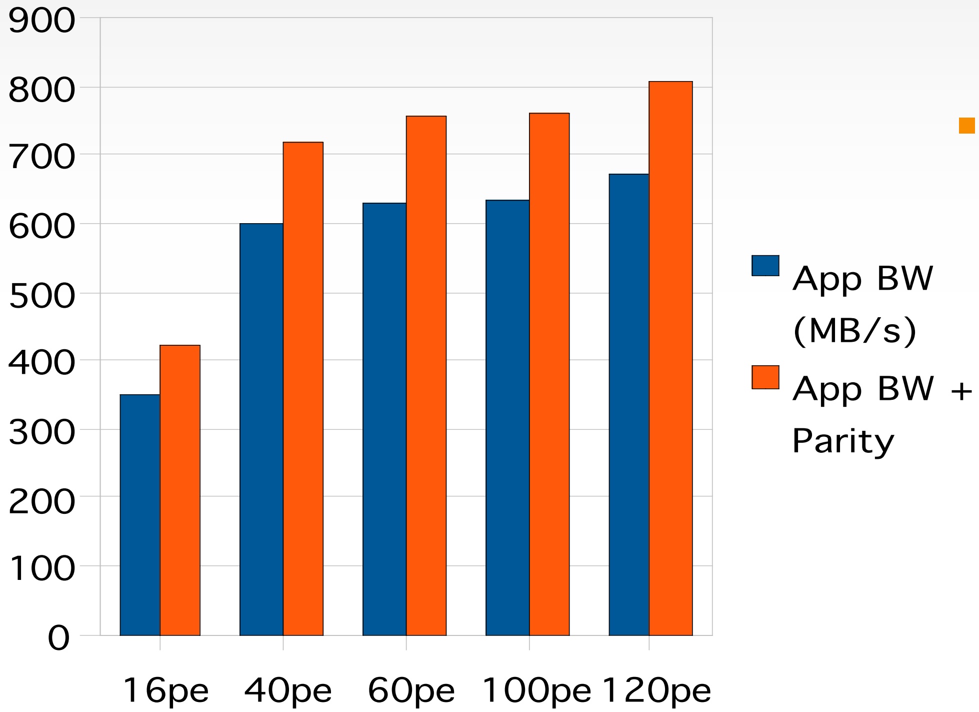
By itself, the Zest backend can easily reach 90% efficiency.

- 12 disks@860MB/s
- Very low CPU utilization due to zero-copy and scsi generic I/O (sg)
  - About 5% of 8 cores.

Zest Performance – Linux cluster



- Best case (120pe's), application sa
  75% of spindle bandwidth.
- If parity overhead is ignored the transfer rate represents 89.6% of th
  spindle bandwidth!