# Zest I/O

**Paul Nowoczynski, Jared Yanovich**

**Advanced Systems, Pittsburgh Supercomputing Center**


PDSW '08 Austin, TX

# Zest – What is it?

*Pittsburgh Supercomputing Center*

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

*Pittsburgh Supercomputing Center*

- 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?

*Pittsburgh Supercomputing Center*

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.

*Pittsburgh Supercomputing Center*

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?

*Pittsburgh Supercomputing Center*

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?

*Pittsburgh Supercomputing Center*

## 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.

*Pittsburgh Supercomputing Center*

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

*Pittsburgh Supercomputing Center*

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.

*Pittsburgh Supercomputing Center*

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

*Pittsburgh Supercomputing Center*

## 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 queues called "*Raid Vectors*".

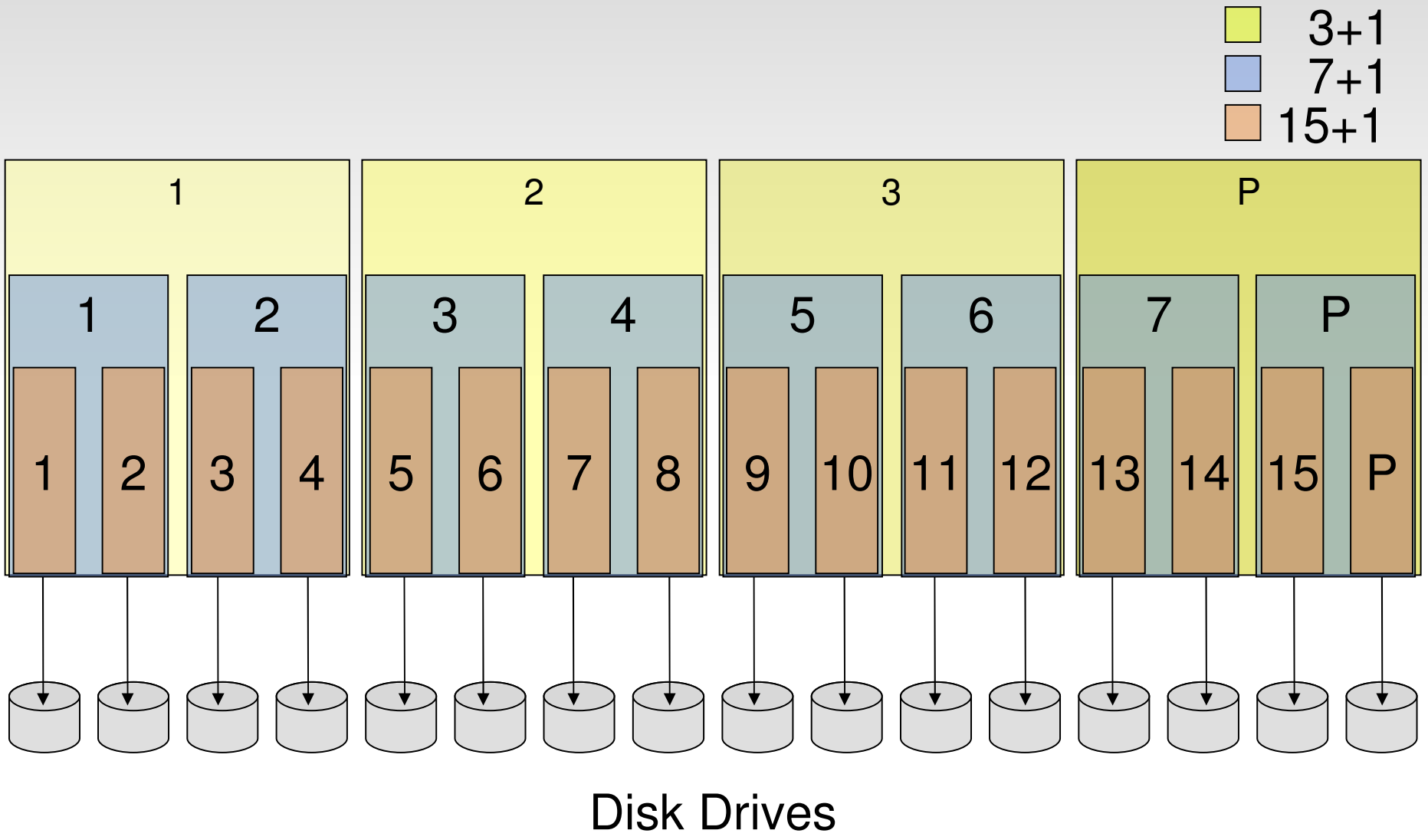
# Zest: Raid Vectors

*Pittsburgh Supercomputing Center*

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 on 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

*Pittsburgh Supercomputing Center*

## 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 choosing.
  - Encourages sequential I/O patterns.

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

# Zest: Client Parity, CRC, and Cache

*Pittsburgh Supercomputing Center*

Much of the hard work is placed onto the client preventing the 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.

# Zest: NDDP – the cost..

*Pittsburgh Supercomputing Center*

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

*NDDP* destroys two inferential systems, one we care about the 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..

*Pittsburgh Supercomputing Center*

## 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..

*Pittsburgh Supercomputing Center*

## 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's offset, length pairs.
- Extent storage is parallelizable.

# Zest: NDDP – additional benenfits.

*Pittsburgh Supercomputing Center*

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 to the remaining nodes.
- Checkpoint bandwidth partitioning on a per-job basis is possible.

# Zest: Post-processing

*Pittsburgh Supercomputing Center*

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

*Pittsburgh Supercomputing Center*

## 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

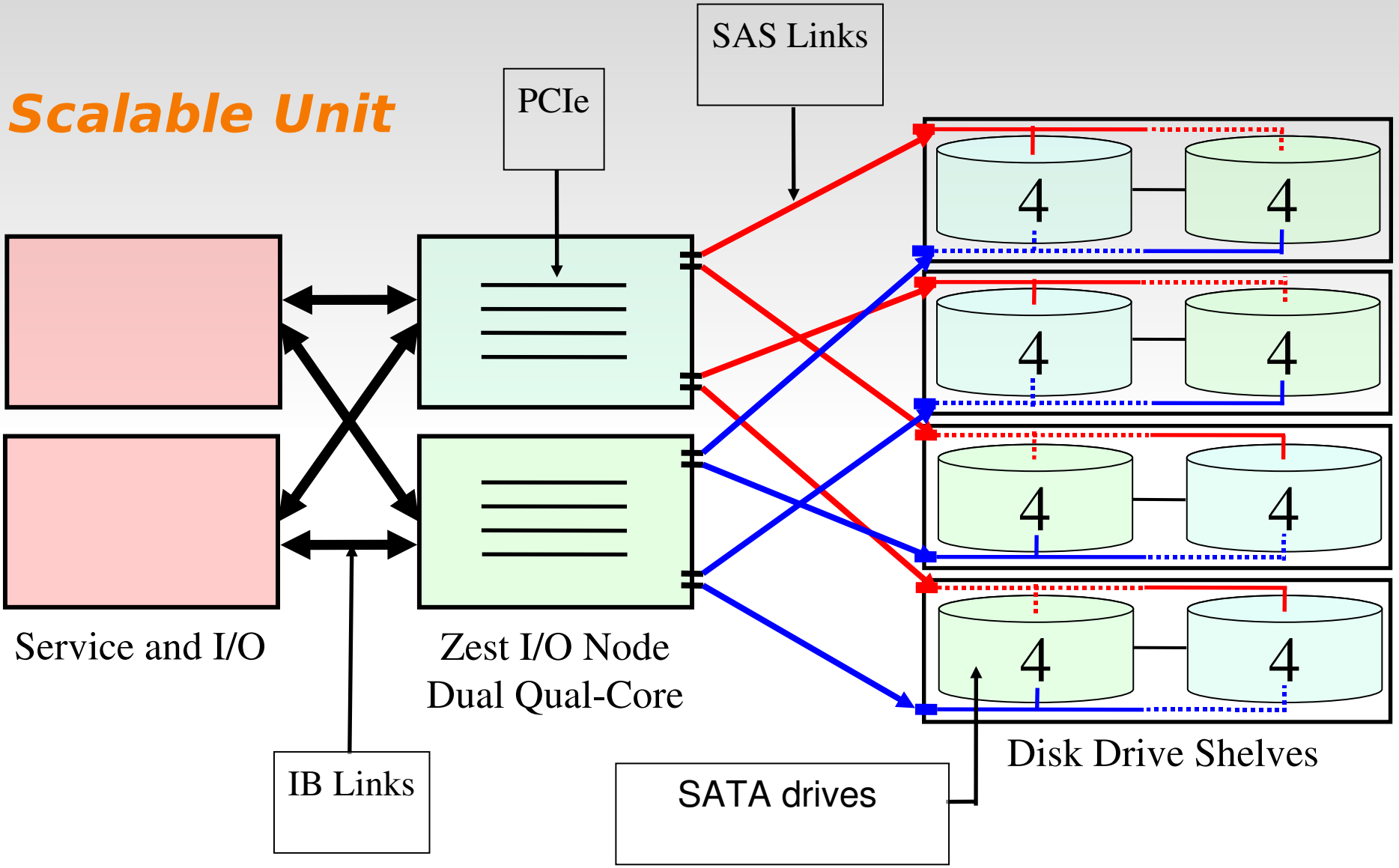
*Pittsburgh Supercomputing Center*

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

*Pittsburgh Supercomputing Center*

- 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/O thread is quarantined.
- 'Fast rebuild' is supported.
  - When a disk fails, the Zest server has an list, in memory, of all the active blocks. Those blocks can rebuilt immediately without scanning the entire set.

# Zest: Performance Result

*Pittsburgh Supercomputing Center*

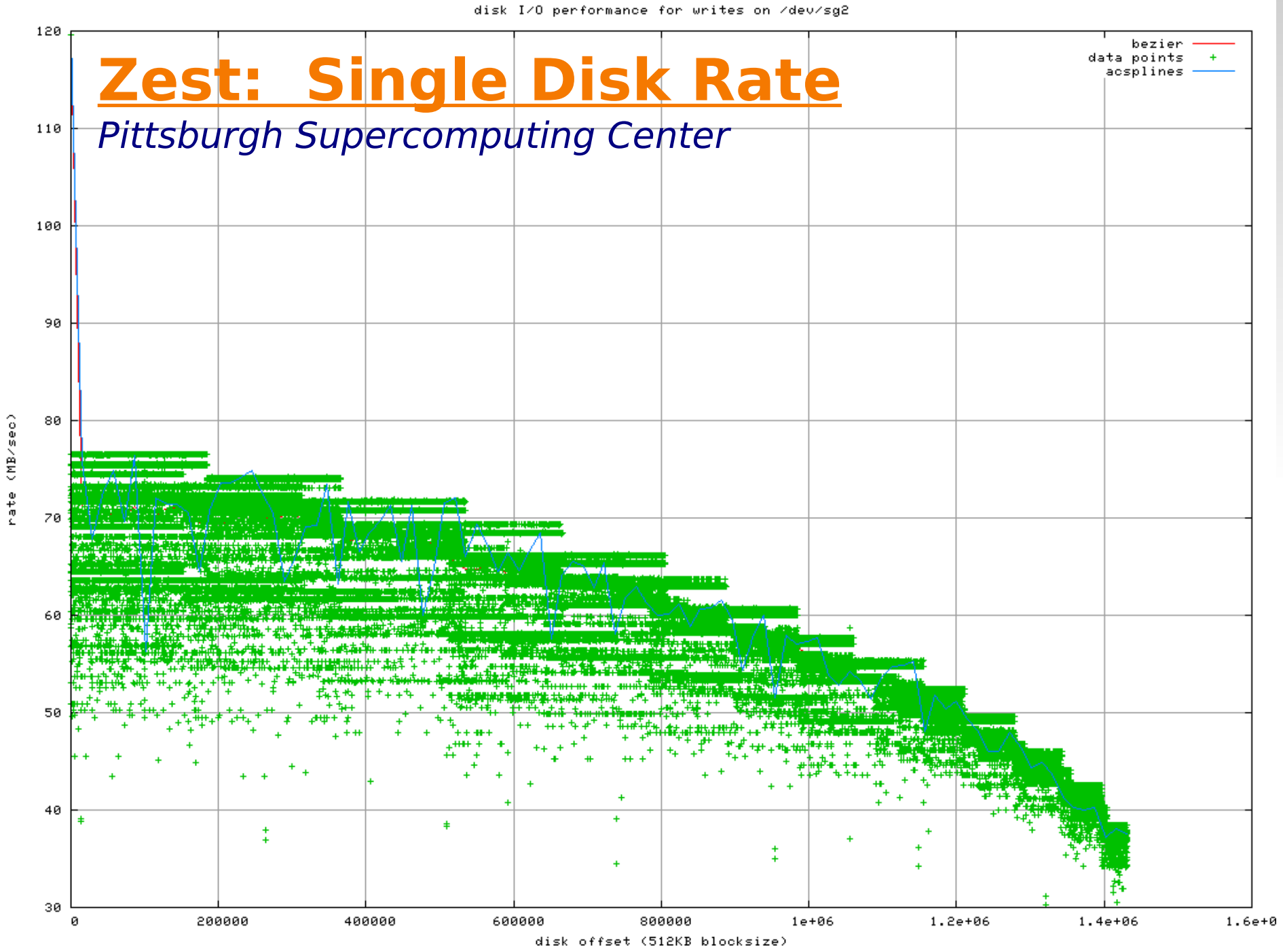
- Test consisted of sequentially writing from each PE into a separate file.
- Clients used a 7+1 Raid5 parity scheme (12.5% overhead)

## 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

*Pittsburgh Supercomputing Center*



# Zest: Performance Result

*Pittsburgh Supercomputing Center*

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