Discovering Structure in Unstructured I/O

Jun He[1,2], John Bent[3], Aaron Torres[4], Gary Grider[4], Garth Gibson[5], Carlos Maltzahn[6], Xian-He Sun[1]

[1]Illinois Institute of Technology, [2]New Mexico Consortium, [3]EMC, [4]Los Alamos National Laboratory,

[5]Carnegie Mellon University, [6]University of California Santa Cruz

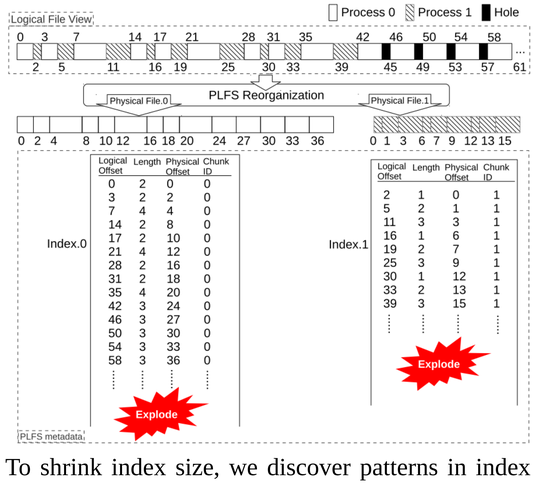
Motivation

- Extremely challenging storage requirements for exaflop supercomputers:
  - Checkpoints of 32 petabytes in size should complete in 300 seconds (DOE projection)
- PLFS (Parallel Log-structured File System) reduces checkpoint time by up to several orders of magnitude
  - By transparently transforming N-1 writes (N processes write to 1 file) to N-N.
- **However**, PLFS metadata (index) grows as the application size and number of data writes increase.
  - Considerable overhead of meatadata fetching
  - Considerable memory occupation by metadata
- Example: an anonymous application from LANL
  - Data: **4 GB**
  - PLFS metadata (on disk): 192 MB
  - PLFS metadata (in memory): **12 GB**

PLFS Index

PLFS transparently transforms shared-file writing into log-structured file-per-process writing. **Index** has a mapping between the bytes within the logical file and their location within the physical files.

The figure below shows an example of two processes writing to a traditional PLFS file. **Indices can become very large as the number of writes increases.**



To shrink index size, we discover patterns in index entries and represent them in a compact way.

For a simplified example, sequence (8,8,8,8,8,8,8,8,8,8) can be represented as 8^10 (ten eights). So the size is compressed.

Discovering Pattern Structure

Notation for Complex Patterns

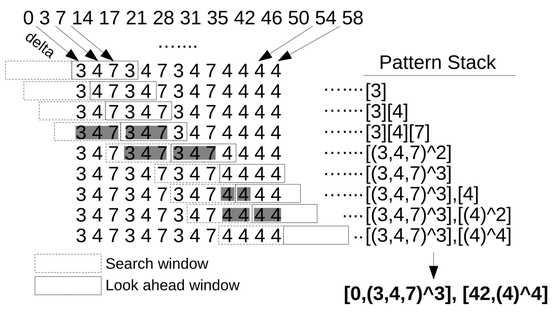
$$[i, (d[0], d[1], ...)^\wedge r]$$

- ***i*** is the first element of the original sequence.
- ***d[]*** (delta) is the repeating part of an array containing the distances of any two consecutive elements in the original sequence.
- ***r*** is the number of repetitions.

For example, (5, 7, 10, 12, 15) can be represented as [5, (2, 3)^2].

Discovering Pattern

An example to find the logical offset patterns in index.0 of the previous figure:



- New Index.0 using pattern structures:

Logical Offset	Length	Physical Offset	Chunk ID
[0,(3,4,7)^3]	[2,(0,-2,2)^2]	[0,(2,2,4)^3]	0
[42,(4)^4]	0	[24,3^4]	
	2		
	[3,0^4]		

- Time complexity: ***O(wn)***.
  - *w:* window size
  - *n:* length of input sequence

Look Up a Request in a Pattern

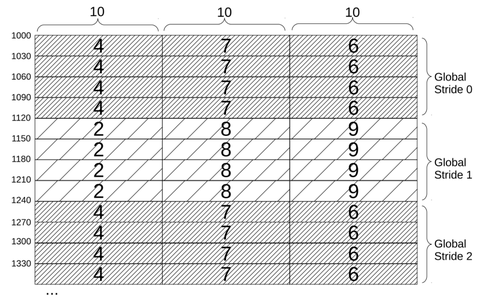
1. Assemble all indices at the time of opening PLFS file for read.
2. Request comes: read(offset=22, len=1).
3. Look up to what position offset=22 falls in the imaginary pattern matrix. For example, [0,(3,4,7)^3]

4. find the corresponding 6th length and physical offset of logical offset 22
5. Calculate and return the corresponding physical offset and length of the request.

Merging Isolated Patterns into a Global One

In order to further compress metadata, isolated per-process index patterns can be merged into a global one.

For example, in the figure below, all processes write with a fixed stride of 10 as shown.



4,7,6,2 and so on are PIDs.

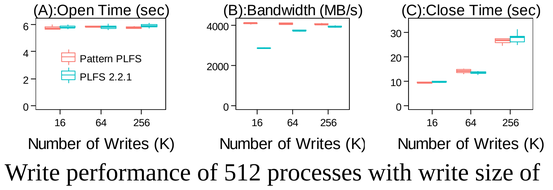
Blocks of same texture represent data area that is shared by a group of processes, e.g. global strides.

The writes from different processes in the figure above can be described by one global pattern:

id[]: [4,7,6,2,8,9,4,7,6,2,8,9]
logical: 1000,(30)^4
length: 10,(0)^4
physical: 0,(10)^4

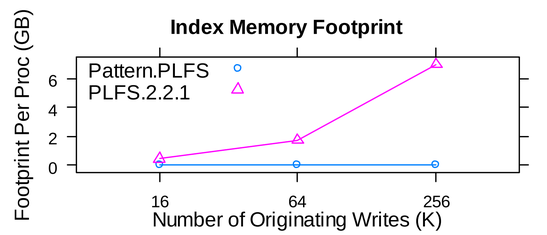
Evaluation

FS-TEST

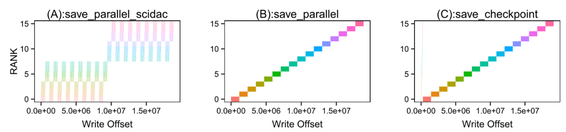


Write performance of 512 processes with write size of 4K.

Performance of uniform read (512 processes) and non-uniform read (256 processes) with originating write size of 4K.

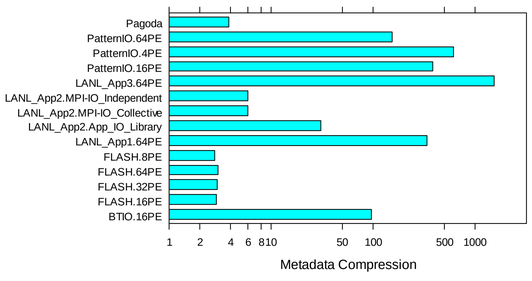


MILC



Write patterns of MILC. In-memory index compression rates by Pattern PLFS (higher is better): (A):37.0; (B):3.0;(C):3.6

Others



Conclusions

- This paper proposes efficient and practical techniques to discover structures from unstructured I/O operations, thereby enabling powerful I/O optimizations.
- Several orders of magnitude improvement in the size of the PLFS metadata.
- Up to 40% of write improvement
- Up to 480% of read improvement
- Other Possible Use Cases:
  - Pre-fetching, block pre-allocation, and index compression in SciHadoop.

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