Toward IOVerbs with the Memory-Centric Storage for Exascale (MCSE) Project
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Goals

- Exploration of alternative storage APIs
- Development of IO-Verbs to express elementary parallel I/O
  - Uniform interface for memory and persistent storage
- Exploit different storage classes flexible in HPC-workflows (campaigns)
- Development of the Memory-Centric Storage System (MCS2)
  - Based upon IML and MCSE
- Migration path for existing applications
The Project

Key information

- 3-years funding by BMBF
- Funding Reference: 16ME0663K
- Start date: 10/2022

Partners

- University Göttingen (Coordinator)
- Fraunhofer ITWM
- Deutsches Zentrum für Luft- und Raumfahrt e.V.
- ThinkParQ
What are IOVerbs?

- Analogon to IBVerbs but for I/O
- Describe I/O on the low-level and enabling parallel I/O
- Have a clear semantics
- Independent of storage system
- Allows high-level libraries to be layered on top
- Should be useful on local systems
- Maybe a prospective replacement of API in Linux VFS
IO Layers
Work Plan

AP1: IOVERBS
AP2: Implementation
AP3: MCS2
AP4: Campaign Storage
AP5: Anwendungsportierung
AP6: Evaluation
AP7: Management

Use Cases
- IO-Verbs API Spec
- Use Cases
- Abbildung IO-Verbs zu IML
- High-Level API Strömungsmechanik

Coding
- lib-IOVerbs Frontends
  - POSIX
  - ESDM
- Backends für
  - IML
  - BeeGFS

Evaluation
- Workflow Integration
- Slurm Einbindung
- HCPSerA Anpassung

Feedback
- Microbenchmarks
- Refinement
- Optimizations

Theory & Design

MCS2 Komponenten
- User-Client
- IML Server
- BeeGFS User-Space

Feedback
- IO500 Backend
- FDSM Integration

Use Cases
- CODA
- IO500
- NetCDF-Bench

HPC IODC Workshop
Outline

1. Introduction
2. Semantics
3. Conclusions
Aspects for Semantics (Excerpt)

- Visibility: when will another proc see changes
- Durability: when is data written back
- Concurrency: what happens with concurrent access
- Synchronous/Asynchronous API: App can proceed during I/O – background
- In-transit: Allow computation during I/O for pre-/post-processing
- Transparency: no hidden optimization
- Optimistic vs. pessimistic approaches

⇒ There are many ways to describe semantics in the API
Motivating Example: Shallow Water Model

Facts about the model

- Stores data column-wise in memory
- Separates compute phase and IO phase

Existing NetCDF code for IO phase limits performance

```c
size_t start[] = {0, 0};
size_t count[] = {nY, 1};
for(unsigned int col = 0; col < nX; col++) {
    start[1] = col; //select col (dim "x")
    nc_put_vara_float(dataFile, i_ncVariable, start, count,
                      &i_matrix[col+boundarySize[0]][boundarySize[2]]);
}
```

^1DSLs will help to separate those phases
ESDM Code for the Application (that worked)

```c
int64_t offset[] = {(int64_t) timeStep, offsetY, offsetX};
int64_t size[] = {1, (int64_t) nY, (int64_t) nX};

esdm_wstream_float_t stream;
esdm_wstream_start(&stream, dset, 3, offset, size);
for(int y = 0; y < nY; y++) {
    for(int x = 0; x < nX; x++) {
        esdm_wstream_pack(stream, i_matrix
                         [x + boundarySize[0]][boundarySize[2] + y])
        // this may trigger actual IO and postprocessing!
    }
}
esdm_wstream_commit(stream);
```

- Ultimately, using DSLs an IO phase could switch between compute and "stream output" to minimize memory pressure (and trigger initial post-processing)
IO500 Example - IOR Easy Write

Each process operates on an (independent) file

```
1  fd = open(path, O_CREAT)
2  offset = 0
3  for I in SegmentCount:
4      write(fd, offset, Blocksize)
5      offset += Blocksize
6  close(fd)
```

An alternative formulation

```
1  fd = iov_open_async(path) // we can proceed *before* file is opened
2  offset = 0
3  iov_write_limit(fd, SegmentCount * Blocksize) // organizes space - note: Stonewall
4  for I in SegmentCount:
5      res = iov_write_excl_data_ready(fd, offset, Blocksize) // caching, no sync
6      offset += Blocksize // also user must check for error
7  iov_wait_completion(fd)
8  iov_destroy(fd)
```
Processes operate on a shared file - write strided

An alternative formulation

```c
fd = iov_open_async_coll(path) // collective
// includes amount of data that this proc and all procs write
iov_write_coll_limit(fd, SegmentCount*Blocksize, nproc*SegmentCount*Blocksize)
for I in SegmentCount:
    res = iov_write_excl_data_ready(fd, offset, Blocksize) // exclusive: non-overlapping
iov_wait_completion(fd)
iov_destroy(fd)
```
IO500 Beispiel - MDTest Hard Write

Each process creates files ... (suboptimal anyway)

```python
for f in file:  # the recursive truth is too complex ;-)  
    fd = open(path/f, O_CREAT)  
    write(fd, 0, Blocksize)  
    close(fd)
```

An alternative formulation

```python
iov_limit_objects(no of files locally) // system could create container/return limits  
for f in file:  
    fd = iov_open_async(path) // we can proceed *before* file is opened  
    iov_write_limit(fd, Blocksize)  
    iov_write_excl_data_ready(fd, 0, Blocksize)  
    iov_destroy(fd)  
    err = iov_check_state() // check async if there was an error so far, alternatively  
    → use iov_register_err_handler() before  
    if err != IOV_NO_ERR invoke error()  
    iov_wait_completion_all()
```
Conclusions

- MCSE will systematically explore parallel I/O semantics
- MCSE will develop IO-verbs
  - Addressing metadata and data
- MCSE develops an integrated solution for campaigns
PMDK Read (Simple case, no transactions)

- pmemobj API version 2.3
- Example Code/Github

```c
struct my_root {
    size_t len;
    char buf[MAX_BUF_LEN];
};

void readIn()
{
    PMEMobjpool *pop;
    pop = pmemobj_open(path, LAYOUT);
    // Get the PMEMObj root
    PMEMoid root = pmemobj_root(pop, sizeof(struct my_root));
    // Pointer for structure at the root
    struct my_root *rootp = pmemobj_direct(root);
    printf("%s\n", rootp->buf);
    pmemobj_close(pop);  // Close PMEM object pool
}
```
PMDK Write

```c
void writeOut()
{
    PMEMObjpool *pop;
    pop = pmemobj_create(path, LAYOUT, PMEMOBJ_MIN_POOL, 0666);
    // Get the PMEMObj root
    PMEMoid root = pmemobj_root(pop, sizeof(struct my_root));
    // Pointer for structure at the root
    struct my_root *rootp = pmemobj_direct(root);
    // code for write:
    pmemobj_memcpy_persist(pop, rootp->buf, buf, strlen(buf));
    // Assign the string length and persist it
    rootp->len = strlen(buf);
    pmemobj_persist(pop, &rootp->len, sizeof(rootp->len));
    pmemobj_close(pop);  // Close PMEM object pool
}
```