DATA IS POTENTIAL

MOTR architecture overview

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Outline

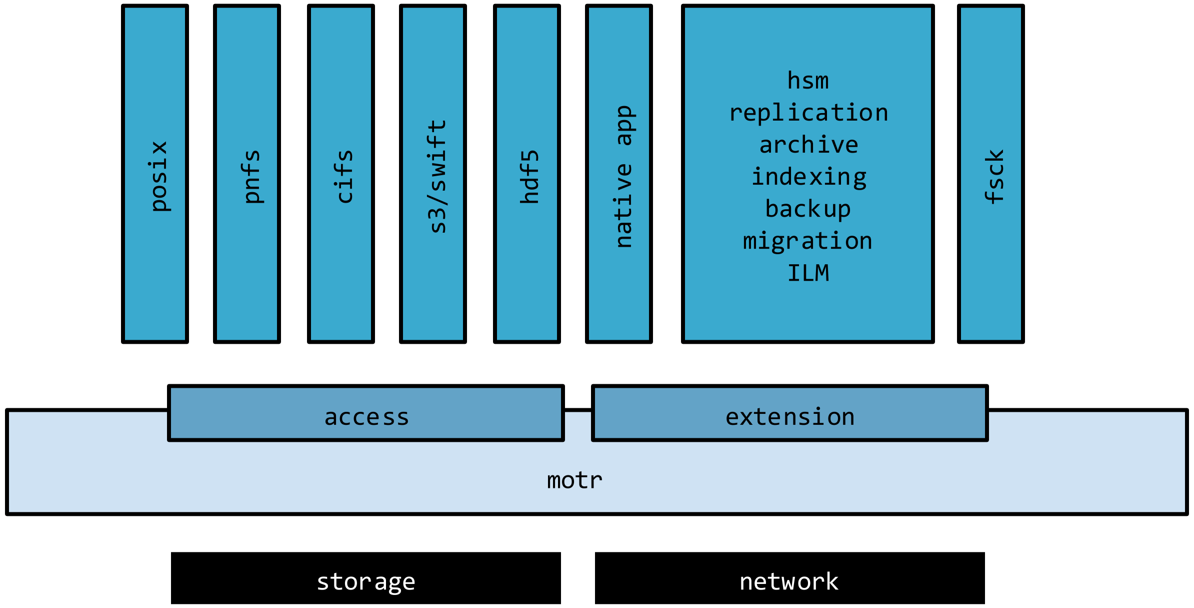
- This presentation is a beginner's guide to the motr architecture
- Tries to cover all important aspects of motr with a reasonable level of detail
- Focus on software (hardware details elsewhere)

- Overview
- Typical use cases and data flow
- How objects and indices are stored
- IO path
- Meta-data back-end (BE)
- DTM
- FDMI
- ADDB

Source/Footnote:

What is motr?

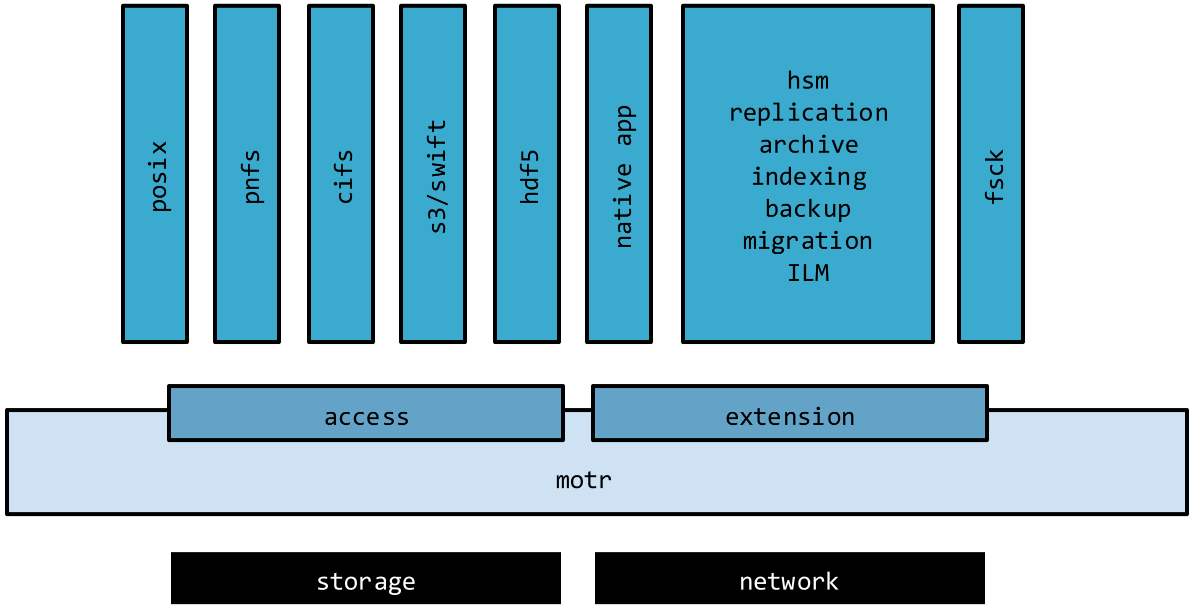
- motr is a core component of the new cloud software stack developed by Seagate
- Through its client interface motr provides:
  - object store
  - key-value store
- The complete software stack also includes other components:
  - S3 server
  - pNFS server
  - Provisioner
  - RAS
  - HA
  - Administration and monitoring toolset
- Similar products:
  - Ceph
  - ActiveScale
  - IBM/COS
  - Scality



Source/Footnote:

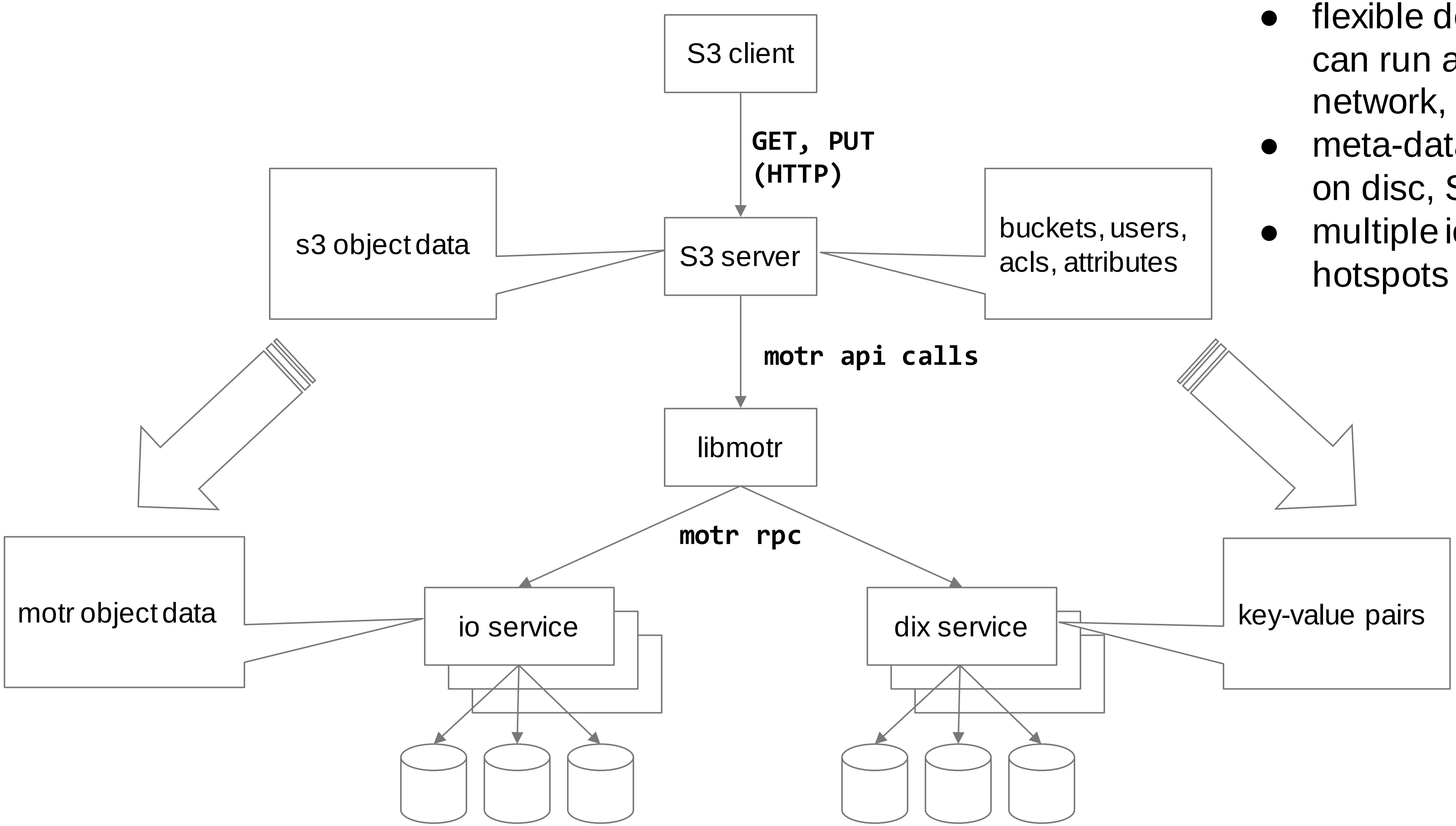
How is motr different?

- Scalable
  - horizontal scalability: grow system by adding more nodes. motr designed for horizontal scalability: no meta-data hotspots, shared-nothing IO path. Extensions running on additional nodes.
  - vertical scalability: more memory and processors on the nodes.
- Fault-tolerant:
  - flexible erasure coding taking hardware and network topology into account
  - fast network raid repairs
- Observable: built-in monitoring collecting detailed information about system behaviour
- Extensible
  - extension interface
  - flexible transactions
  - open source
- Portable: runs in user space on any version of Linux



Source/Footnote:

Data flow S3

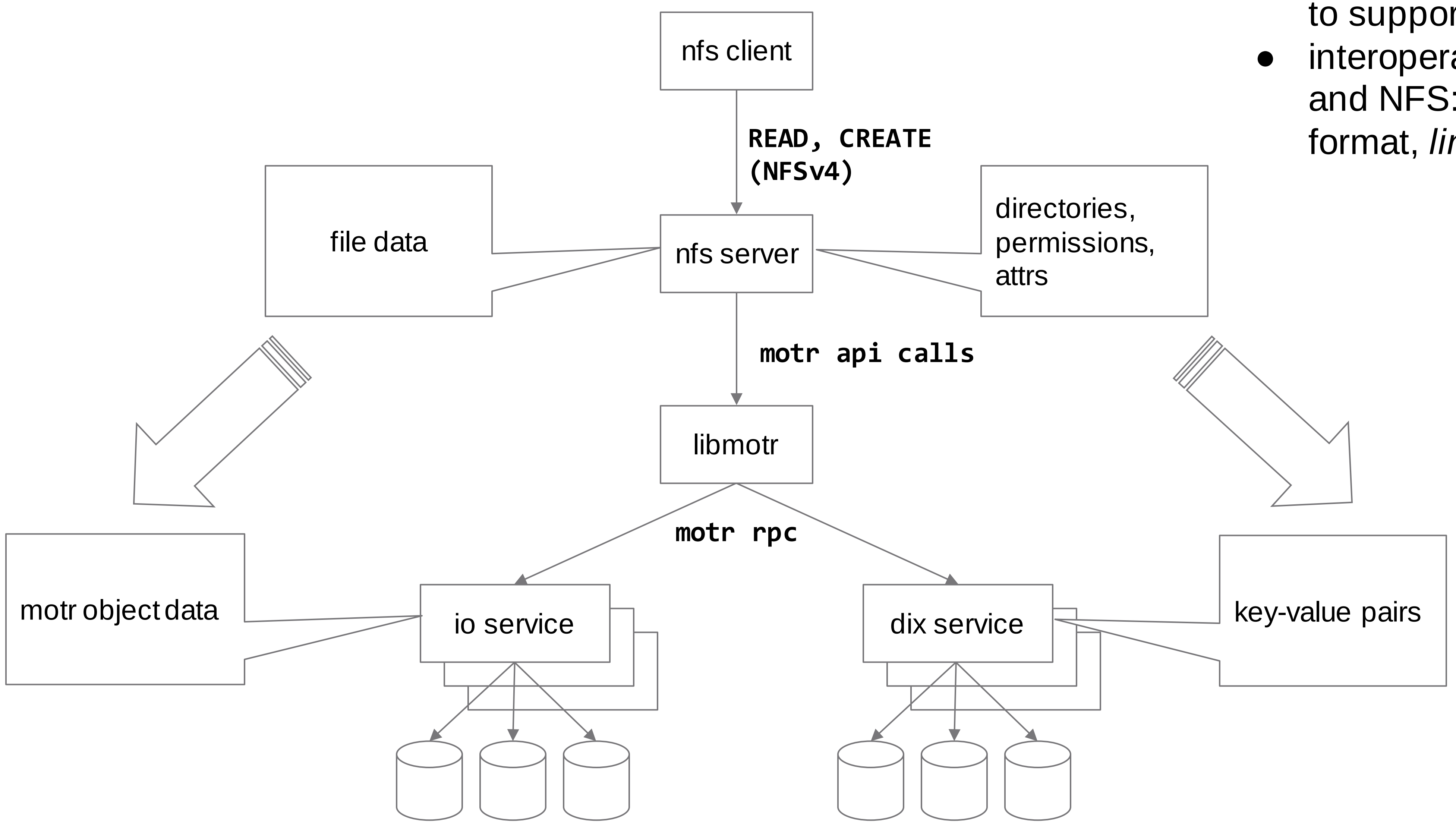


motr rpc uses RDMA when available

- s3 server linked with libmotr
- flexible deployment: services can run anywhere on the network, share storage
- meta-data (dix) can be stored on disc, SSD or NVM
- multiple io and dix services, no hotspots

Source/Footnote:

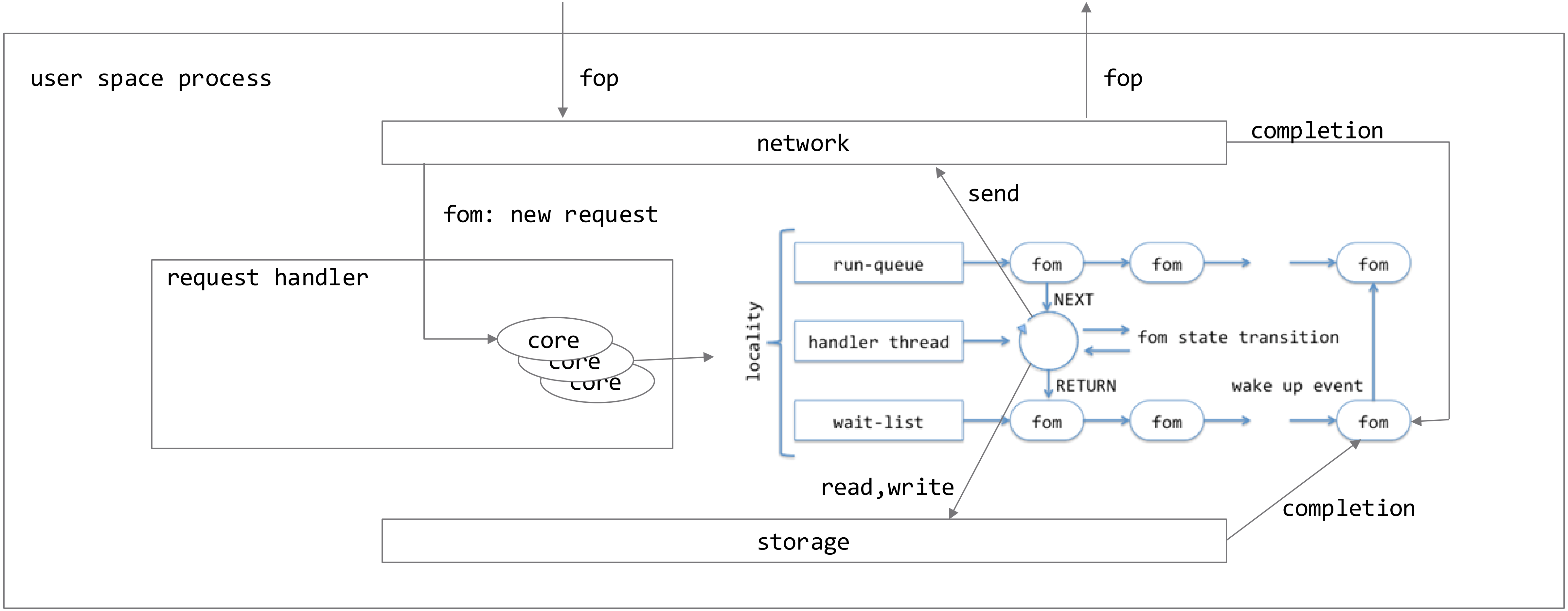
Data flow NFS



- very similar to S3
- underlying motr object and index semantics is rich enough to support S3, NFS and others
- interoperability between S3 and NFS: common meta-data format, *lingua franca*

Source/Footnote:

Anatomy of a motr instance

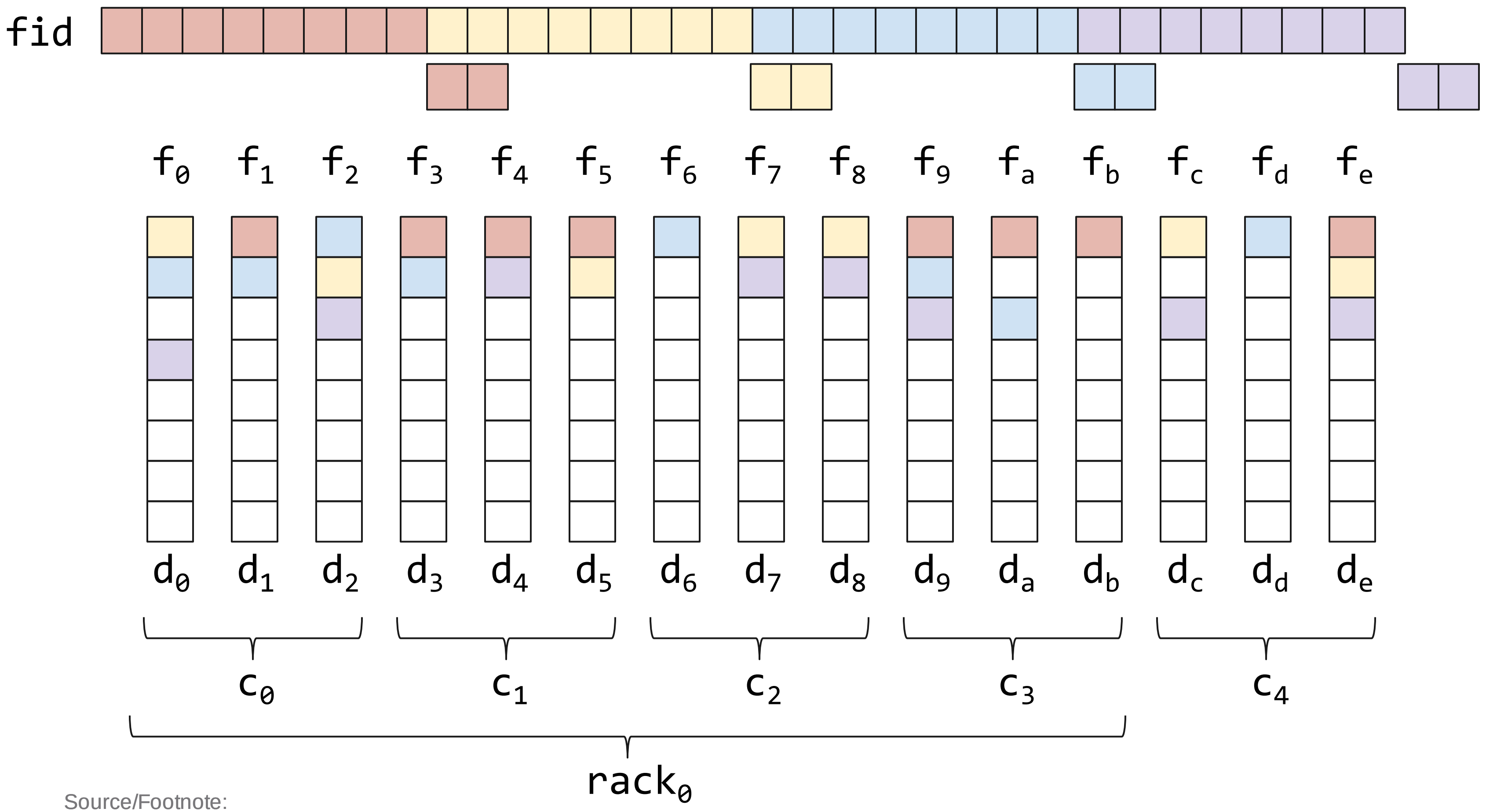


- Multiple services within the same process: io, dix, confd, rm, ha, sss, repair, addb, cas, fdmi, isc
- State machine (fom) for each request: non-blocking state transitions, few threads, reduced locking, NUMA
- Asynchronous network and storage interface
- Same on "client" (libmotr) and server.

Source/Footnote:

Object layout

- An object is an array of blocks. Arbitrary scatter-gather IO with overwrite. An object has layout.
- Default layout is parity de-clustered network raid: N+K+S striping.
- Layout takes hardware topology into account: distribute units to support fault-tolerance.

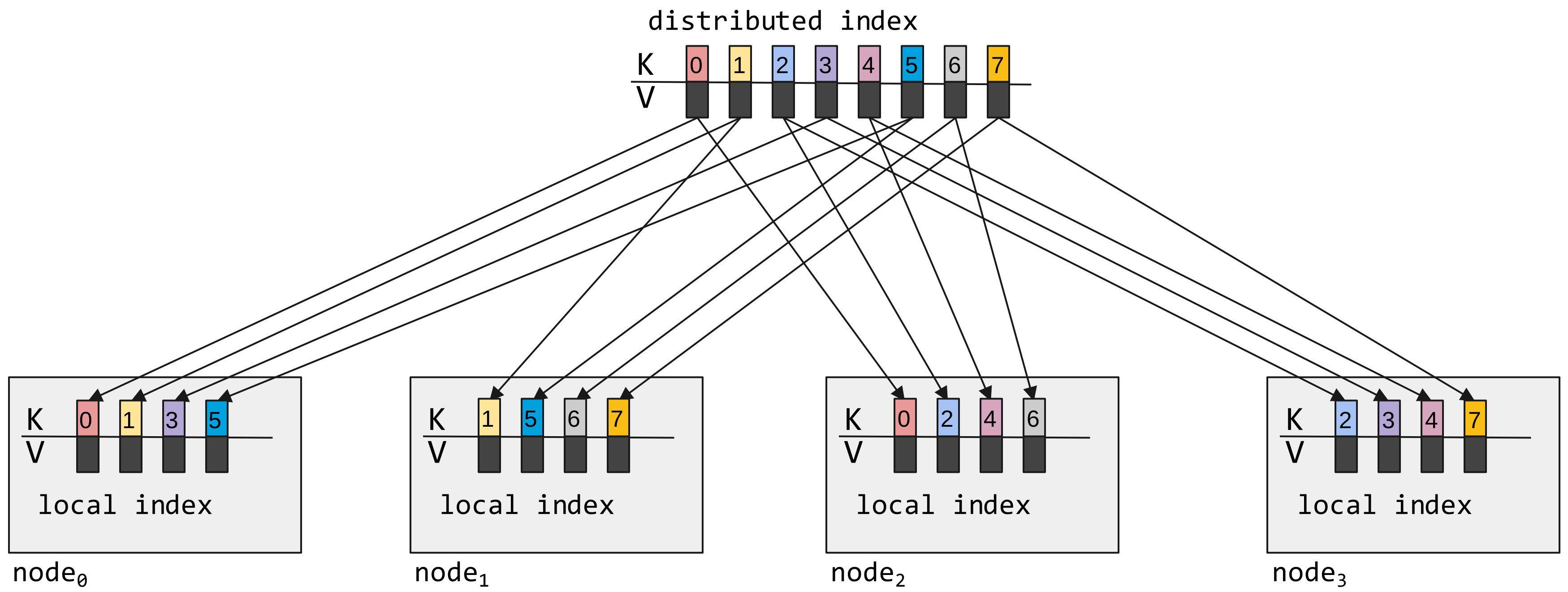


- Object raid: component object (cob) for each device.
- N data units, K parity units and S spare units (distributed spare).
- Mapping from file offsets to cob offsets is deterministic.
- Mapping from cob offsets to device blocks is done via meta-data index ("ad"), managed by io service.
- Fast scalable repairs of device failure.
- There are other layouts: composite, de-dup.

Source/Footnote:

Index layout

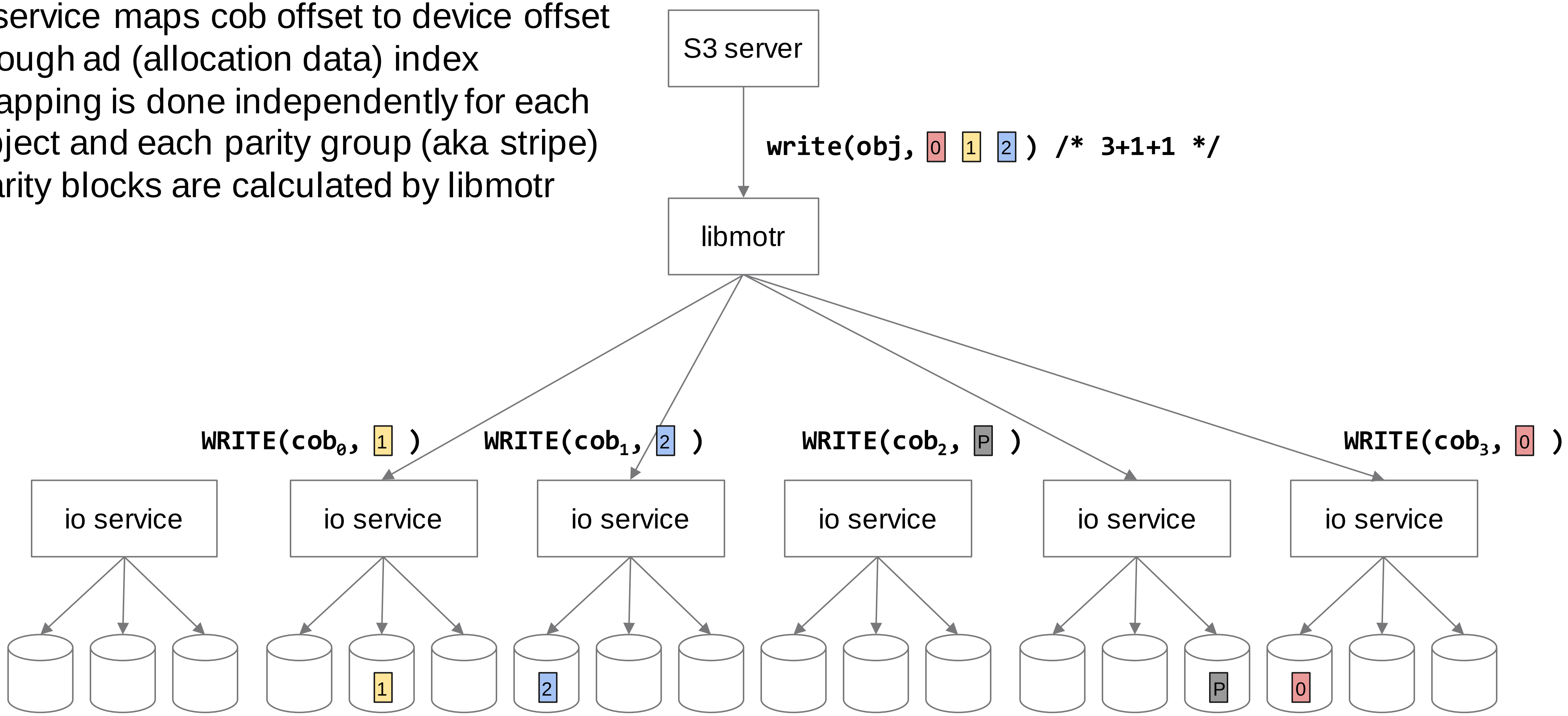
- An index is a container of key-value pairs:
    - GET(key) -> val, PUT(key, val), DEL(key), NEXT(key) -> (key, val)
    - used to store meta-data: (key: "/etc/passwd:length", value: 8192)
- Uses network raid with parity de-clustering (same as objects), but only N = 1, in N + K + S
- X-way replication (N = 1, K = X - 1), each key is replicated independently
- takes hardware topology into account (for free!)
- fast scalable repair (for free!)



Source/Footnote:

Data flow S3 redux

- libmotr calculates cob identities and offsets within cobs
- ioservice maps cob offset to device offset though ad (allocation data) index
- mapping is done independently for each object and each parity group (aka stripe)
- parity blocks are calculated by libmotr



Source/Footnote:

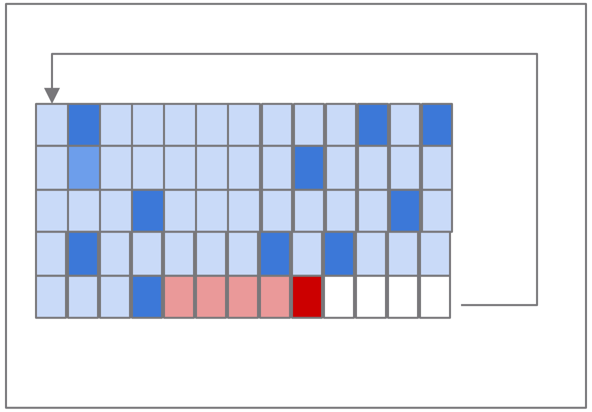
Meta-data back-end

- Meta-data:
    - internal (used by motr): object identifiers, free blocks, allocation data, configuration
    - external (used by applications): NFS directories, S3 buckets, EA, tags, arbitrary attributes
- All meta-data managed by meta-data back-end (BE)
- BE runs within each motr instance
- BE provides fast transactional engine
- Memory oriented (in-memory structures and pointers)
- Transactional memory allocator
- Structures and pointers
- B-tree as the main indexing mechanism
- Based on write-ahead logging (WAL)
- Rich transaction interface (used by DTM and FDMI)
- In-memory transaction -> no conversions -> suitable for very fast storage (like NMVe)

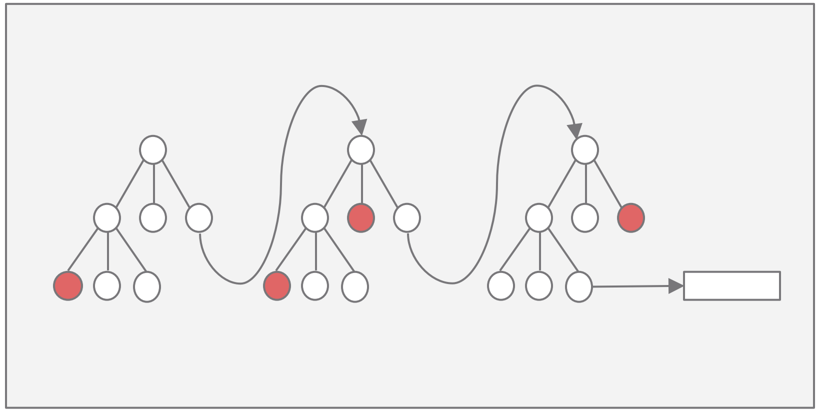
Source/Footnote:

Meta-data back-end

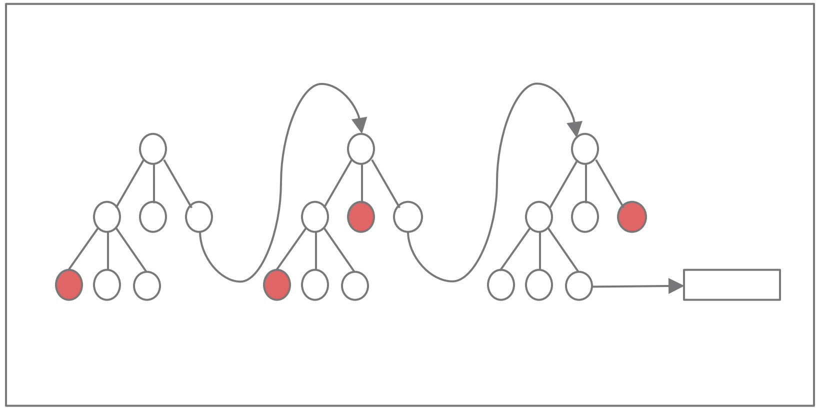
log device



memory mapped segment



segment device



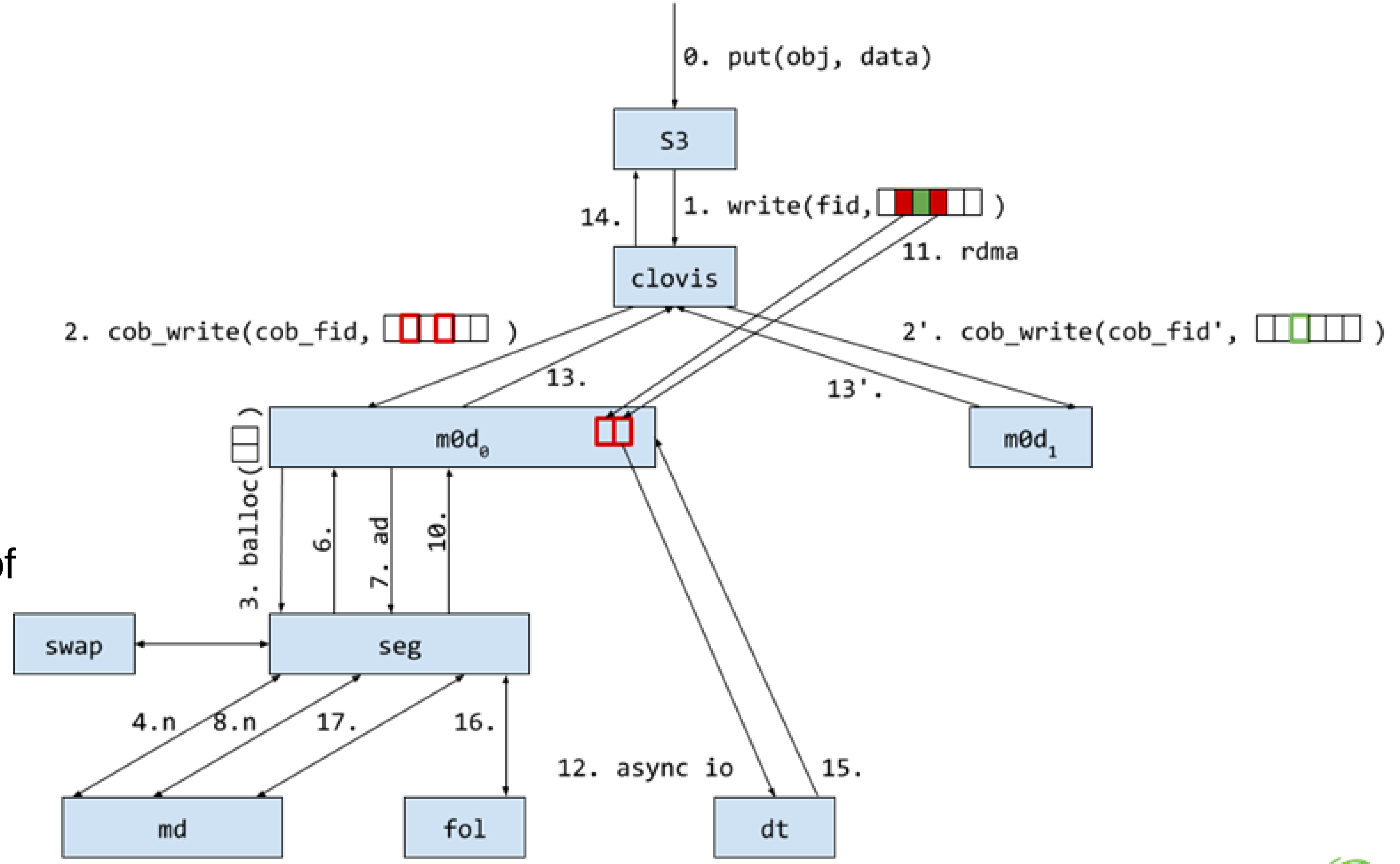
- Segment device contains meta-data
- Segment is mapped into motr process instance 1:1
- In-memory data structures written to segment
- Transactions (WAL):
  - update in memory
  - write updates into cyclic log
  - write commit record (marks end of the transaction)
  - write modified blocks into segment
  - in case of a crash and restart: scan the log and apply blocks from complete transactions

Source/Footnote:

Data flow with internal motr meta-data

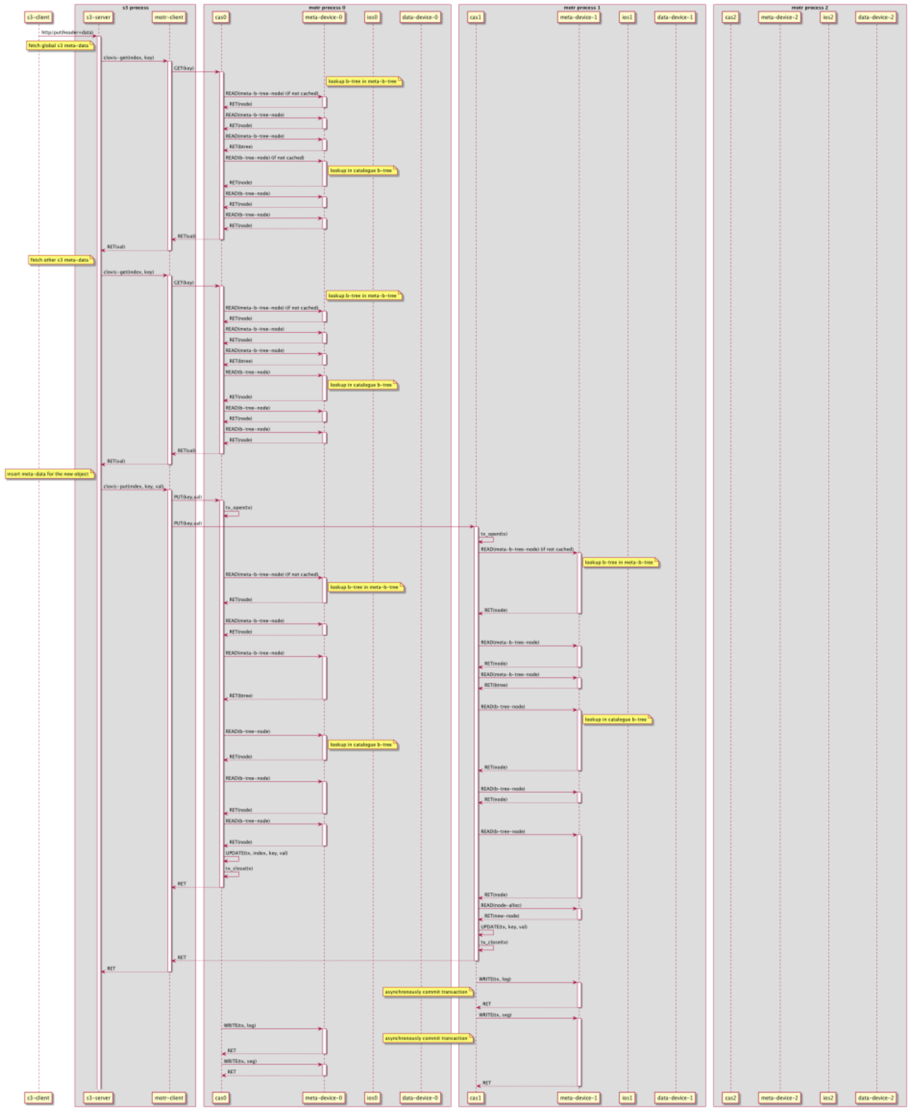
- 2, 2': rpc from a client to services (async)
- 3, 7: various meta-data lookups on the service
- {4,8}.n: meta-data storage requests (btree operations)
- 11: rdma
- 12: async direct-io to the data drives
- fol: log of meta-data transactions

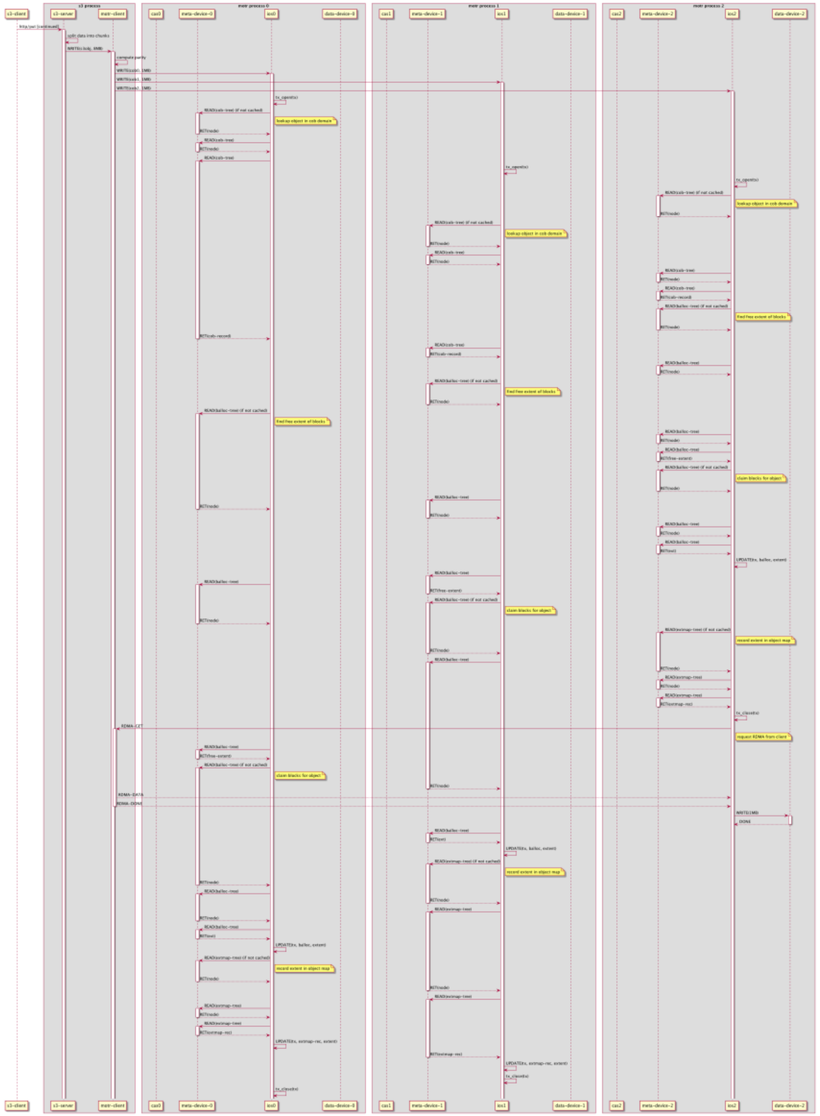
- This diagram includes only s3 data operation, no s3 meta-data operations (buckets, permissions, *etc.*)
- some requests are eliminated because of caching

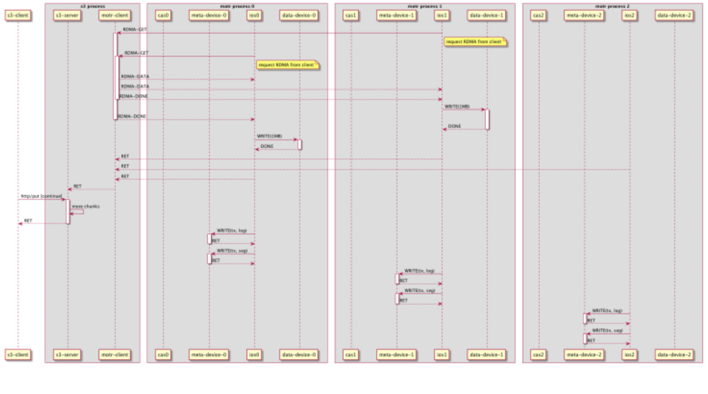


Source/Footnote:

Data flow with external s3 meta-data







Source/Footnote:

DTM

- DTM: distributed transaction manager
- motr operations affect multiple nodes. Nodes can fail independently. Error recovery is difficult.
- Multiple motr operations form logical groups:
  - S3 object creation: update bucket, store object attributes, create object, write data
  - NFS file creation: allocate inode number, write directory entry, initialise inode
  - Error recovery in the middle of a group is difficult (errors during recovery)
- a transaction is a group of motr operations that are atomic in the face of failures
- DTM guarantees that either all or none operations survive a failure
- DTM: work in progress
- one of the most complex motr components
- scalable efficient transactions are hard
- fortunately not everything is needed at once
- staged implementation: DTM0 first

```
dtx = dtx_open(...); /* NFS: create a file. */
ino = nfs_inode_alloc(dtx, superblock);
nfs_dir_entry_add(dtx, parent_dir, name, ino);
nfs_inode_init(dtx, superblock, ino);
dtx_close(dtx);
```

Source/Footnote:

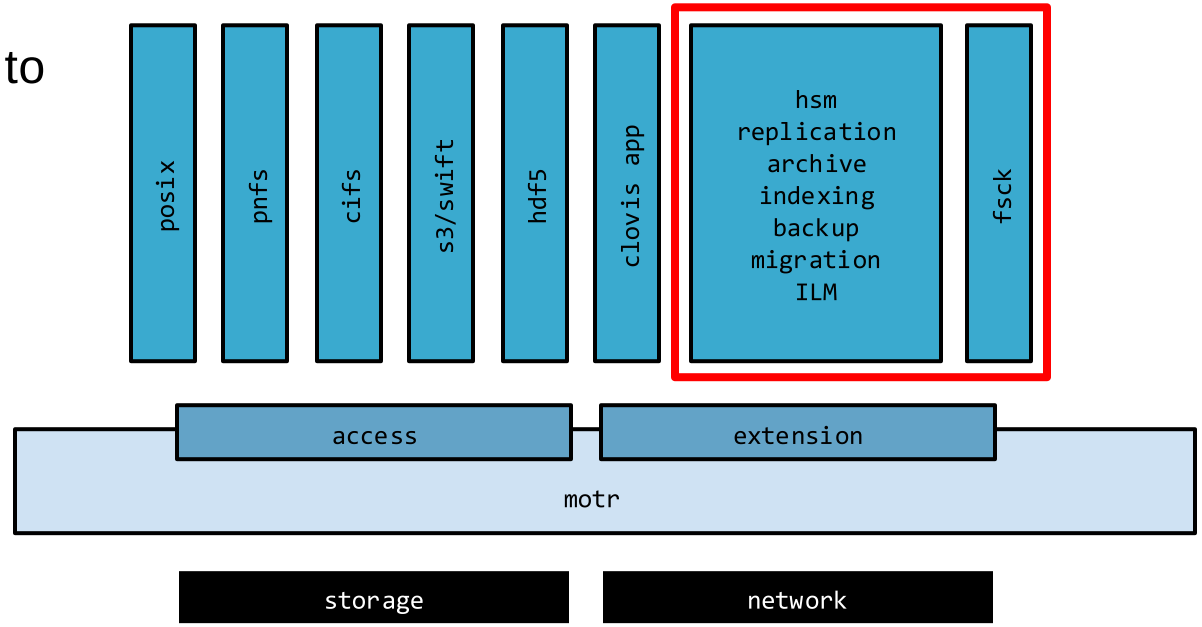
DTM implementation overview

- track distributed transactions for each operation (send transaction identifier)
- each service, before executing the operation, writes its description into FOL: file operations log
- in case of a service or a client failure, surviving nodes look through their logs and determine incomplete transactions
- first try to re-do incomplete transactions by re-sending their descriptions to the restarted service
- some transactions cannot be re-done, because too much state was lost in a failure
- such transactions have to be undone (rolled back)
- but if a transaction is rolled back, all transactions that depends on it also have to be undone:
  - **`mkdir a`** (executed on servers S0 and S1)
  - **`mkdir a/b`** (executed on servers S1 and S2)
  - **`touch a/b/f`** (executed on servers S2 and S3)
  - if **`mkdir a`** failed, **`mkdir a/b`** and **`touch a/b/f`** have to be rolled back too
- transaction dependencies must be tracked. This is difficult to do scalably and efficiently!
- fortunately, in DTM0 re-do is always possible

Source/Footnote:

FDMI

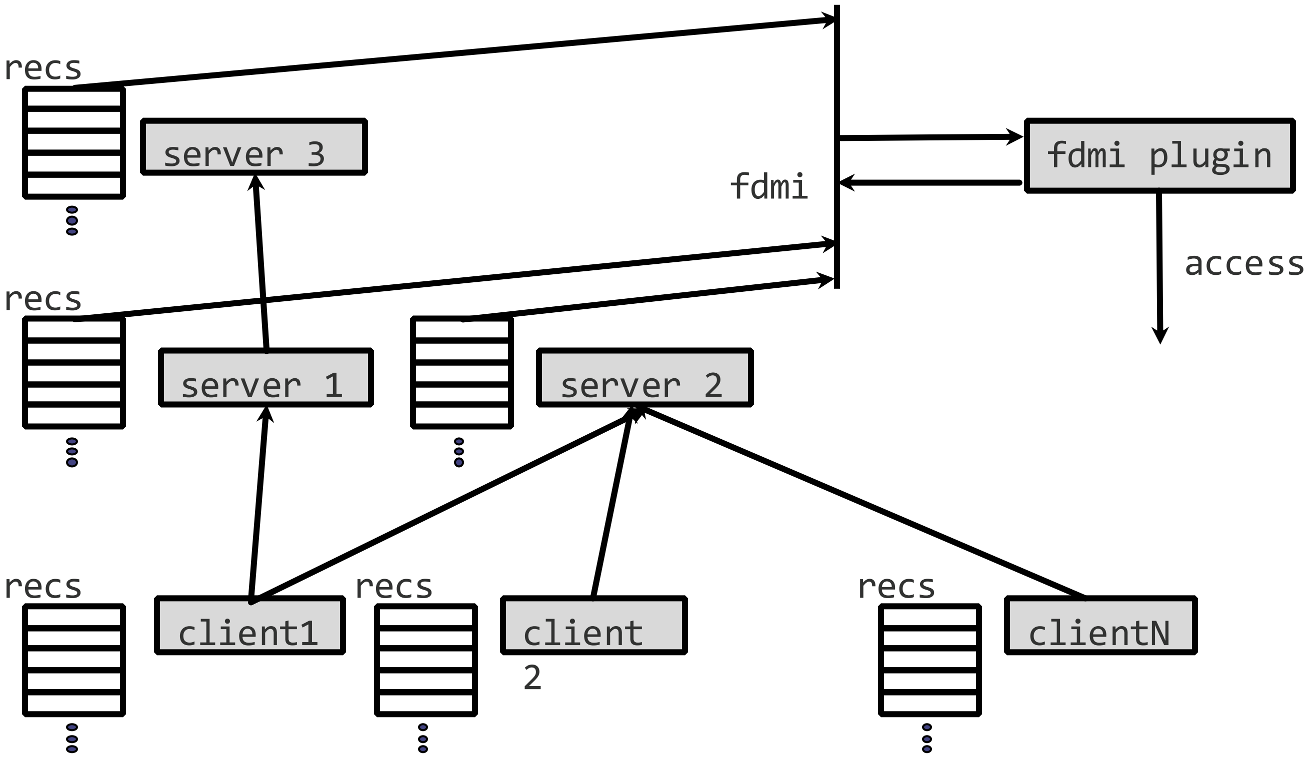
- FDMI: file data manipulation interface, motr extension interface
- motr: objects, key-value indices, transactions. Fast path
- Extensions: migration, backup, archive, replication, compression, encryption, indexing, tiering, defragmentation, scrubbing, format conversion, re-striping, *etc*.
- We want to keep motr small and clean
- Extensions must be:
  - developed independently (without modifications to the core code), possibly by 3rd parties;
  - deployed independently (on additional nodes, without compromising fast path)
  - scalable
  - reliable (transactionally coupled with the core)



Source/Footnote:

FDMI implementation overview

- FDMI is a scalable publish-subscribe interface
- each motr instance produces cross-referenced records describing operations stored in FOL
- FDMI plugin registers a filter, that selects some records
- each instance sends matching records to the plugin (in batches) together with their transactional contexts
- a plugin acts on records and sends acknowledgements back to the source instances

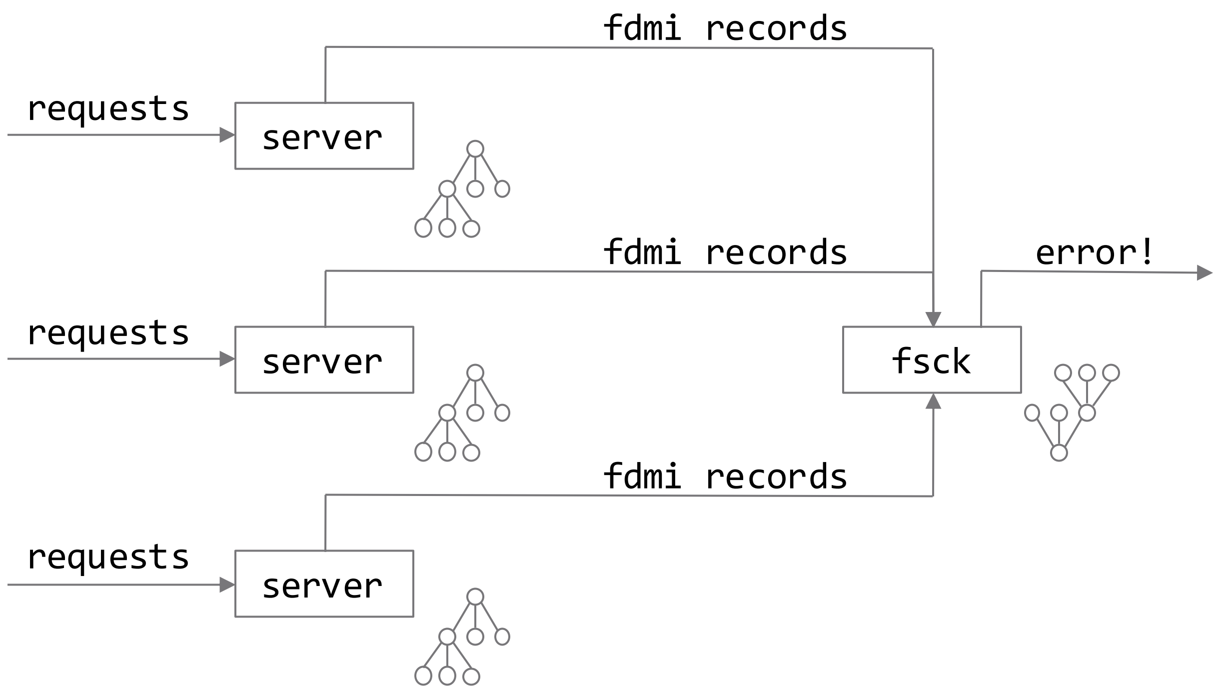


FDMI example plugin: integrity checking

- How to recover from catastrophic failures?
- Redundancy, fancy metadata: not an answer (has been tried)
  - bugs (more important over time)
- traditional fsck
  - not distributed
  - specific to the meta-data format
  - does not scale
    - time
    - space
- need scalable integrity checking
  - run it all the time, on dedicated separate nodes (horizontal scalability)
  - maintain redundant "inverse" meta-data,
  - update meta-data to match system evolution (through FDMI publish subscribe)
  - detect inconsistencies, report, recover from redundancy

Source/Footnote:

FDMI example plugin: integrity checking



inverse meta-data

- block allocation
- pdclust structure
- key distribution
- b-tree structure
- application specific invariants
  - POSIX tree
  - hdf5

Source/Footnote:

ADDB

- ADDB (analytics and diagnostics data-base): built-in fine grained telemetry sub-system
- Why?
  - systems grow larger and more complex
  - how well the system is utilised?
  - is it failure or expected behaviour?
  - is it system or application behaviour?
  - sources of data:
    - system logs
    - operating system
    - application traces
  - very large amount of collected data
  - ... or insufficiently detailed, or both
  - difficult to analyse and correlate

Source/Footnote:

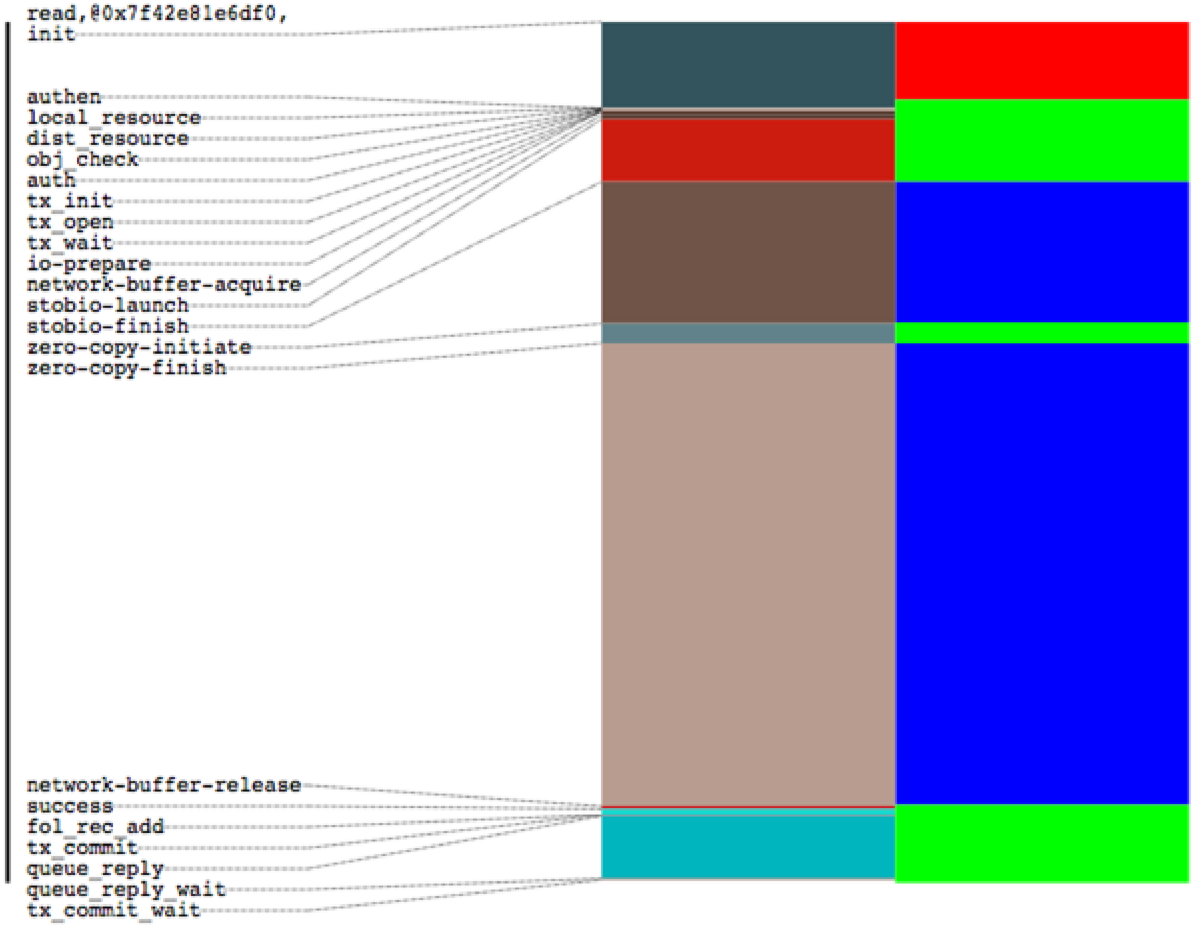
ADDB

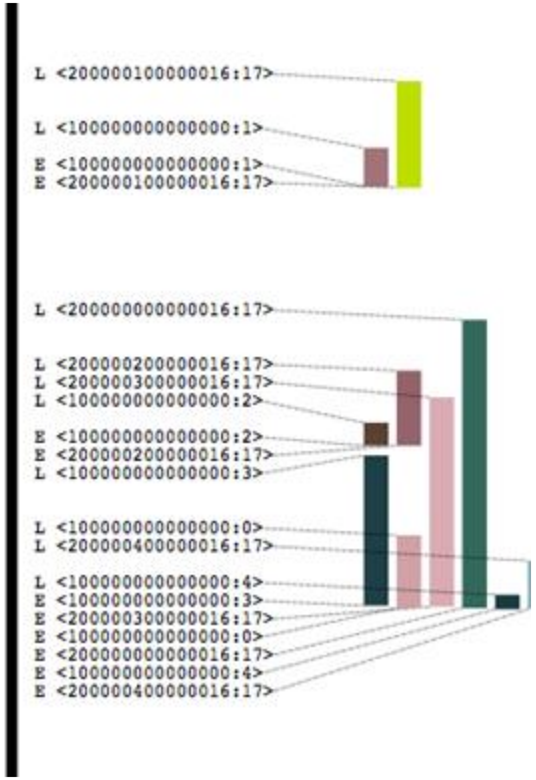
- instrumentation on client and server
- data about operation execution and system state
- passed through network
- cross-referenced
- measurement and context
- timestamped
- labels: identify context
- payload: up to 16 64-bit values,
- interpreted by consumer
- always on (post-mortem analysis, first incident fix)
- simulation (change configuration, larger system, load mix)

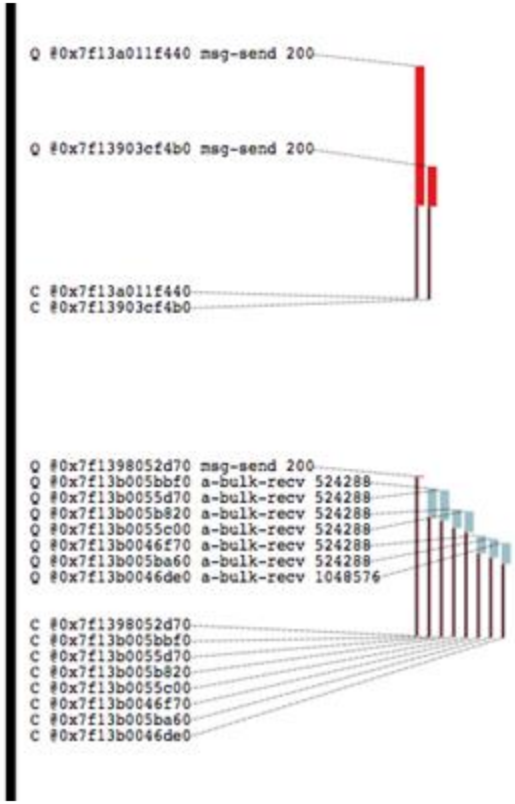
```
* 2020-02-20-14:36:13.687531192 alloc size: 40, addr: @0x7fd27c53eb20
|  node             <f3b62b87d9e642b2:96a4e0520cc5477b>
|  locality         1
|  thread           7fd28f5fe700
|  fom              @0x7fd1f804f710, 'IO fom' transitions: 13 phase: Zero-copy finish
|  stob-io-launch   2020-02-20-14:36:13.629431319, <200000000000003:10000>, count: 8, bvec-nr: 8, ivec-nr: 1, offset: 0
|  stob-io-launch   2020-02-20-14:36:13.666152841, <100000000adf11e:3>, count: 8, bvec-nr: 8, ivec-nr: 8, offset: 65536
```

Source/Footnote:

ADDB: monitoring

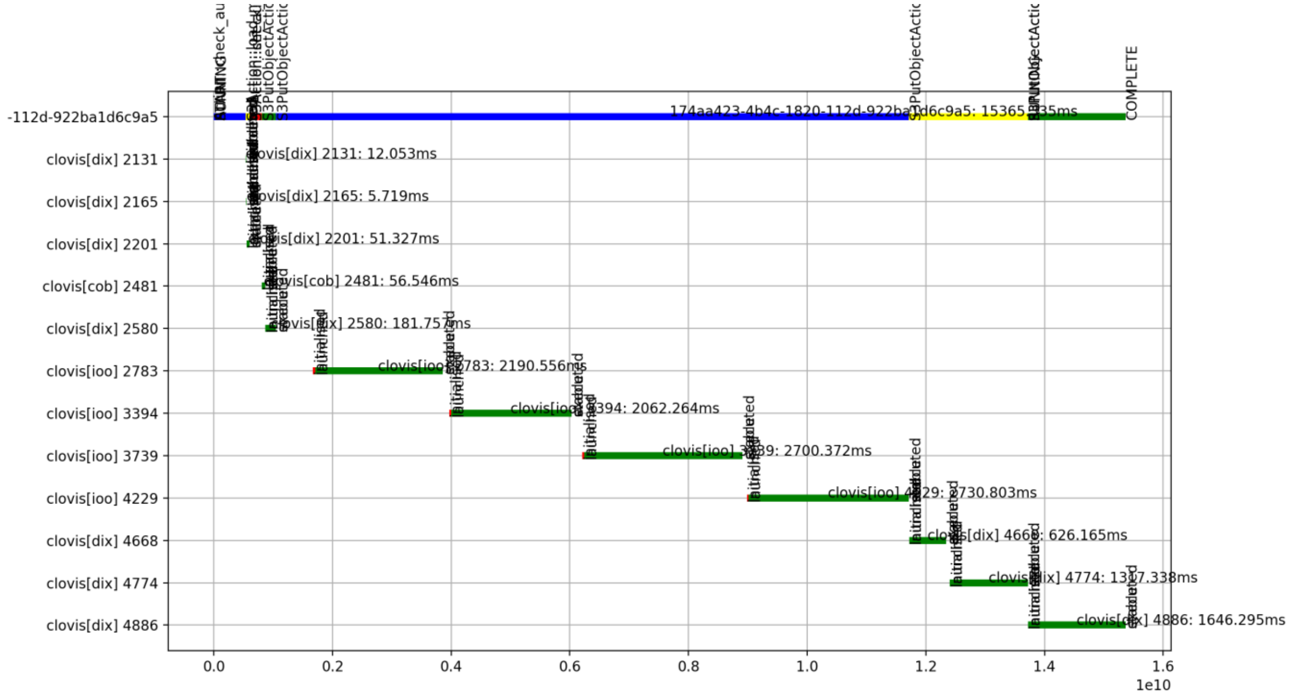


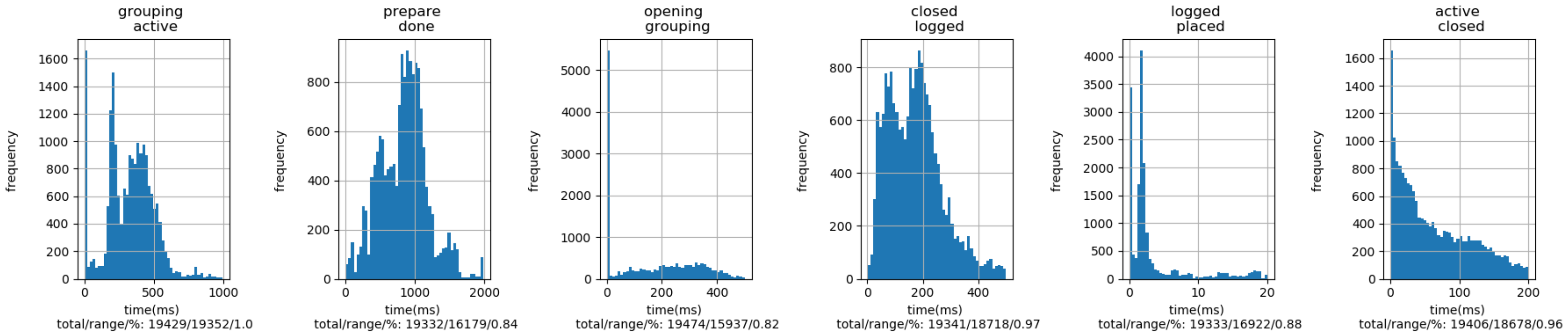




Source/Footnote:

ADDB: performance profiling, timelines and histograms

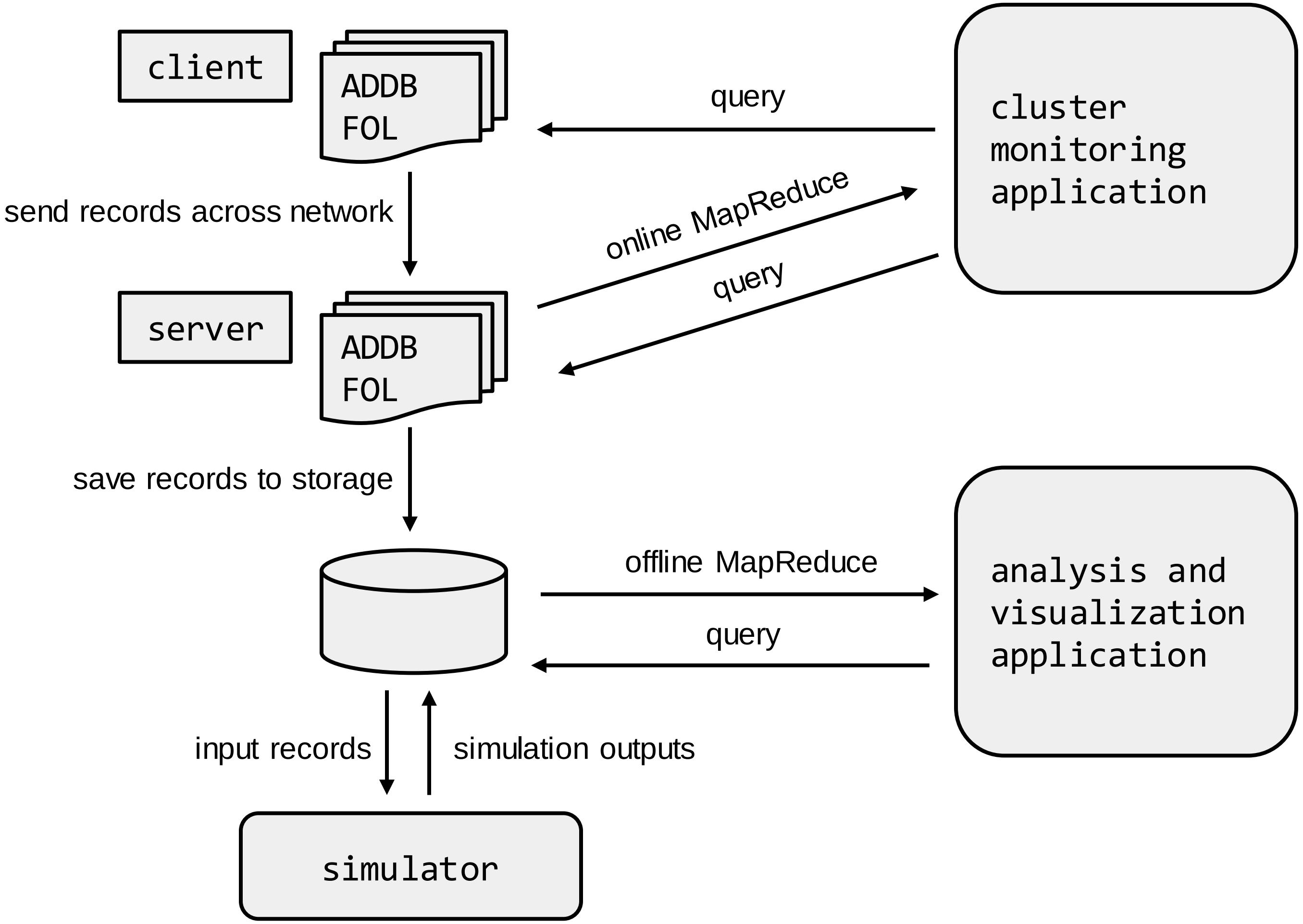




Source/Footnote:

ADDB: advanced use cases

- collect system execution traces
- use them to calibrate a simulator
- use the simulator to:
  - model systems before hardware is available (very large, very fast)
  - answer "what if?" questions
  - combine workloads



Questions?