MarFS, Marchive, and GUFI – Long Term Storage Strategies at LANL

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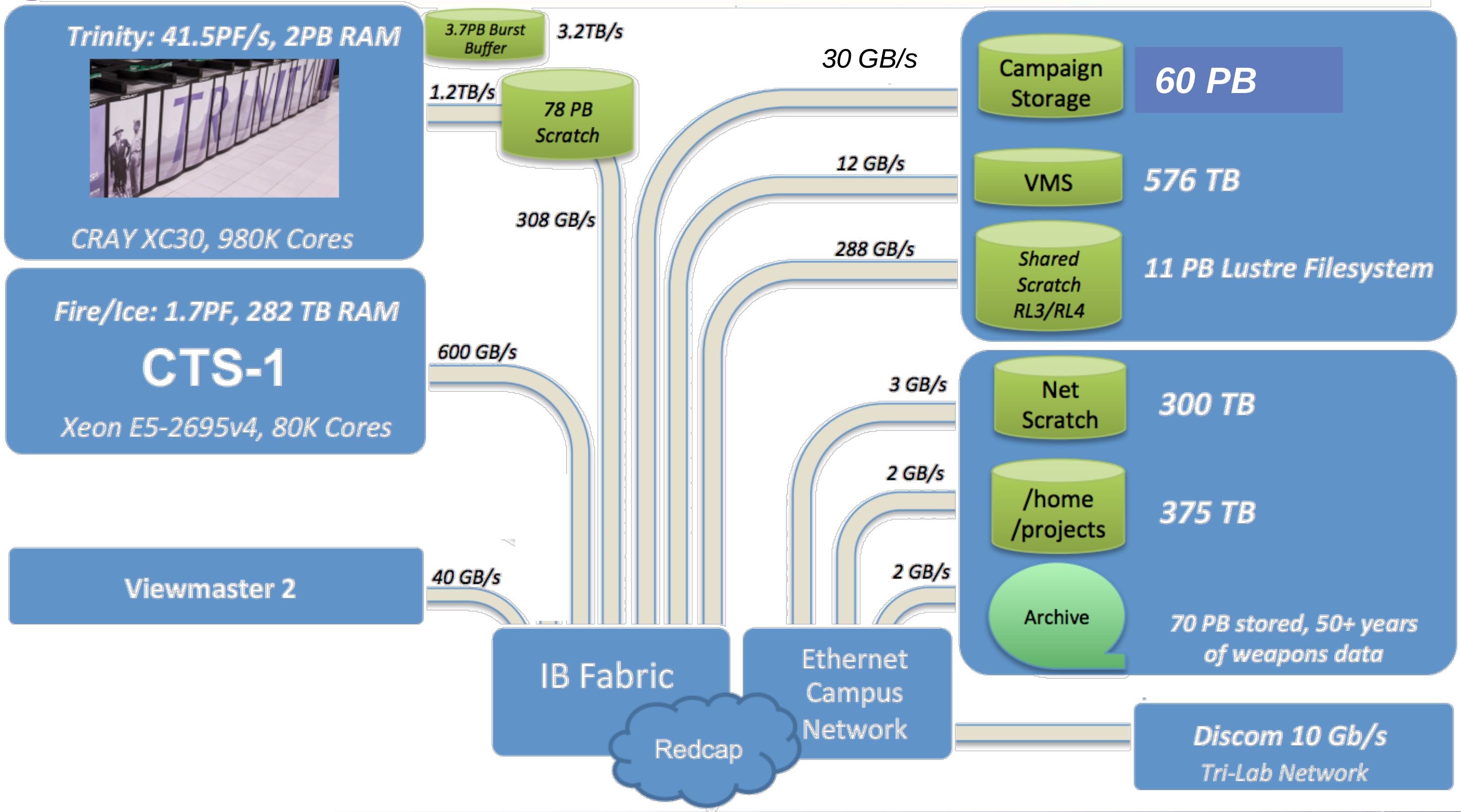
Storage @ LANL

- Simulation HPC site
  - Large jobs (30%+ of system, up to ~80%)
  - Run for 6-12 months for a computing campaign
  - Defensive checkpointing in both N-1 and N-N forms – up to petabyte scale files

Storage @ LANL



Storage @ LANL

- Many layers of storage
  - Explicit tiering between layers by users
  - 2 new layers with Trinity – Burst Buffer and Campaign
  - Complicated the user's job of shepherding data even further

Why complicate matters?

- Burst buffer for economic reasons ($ / GB/s)
- Campaign for…economic reasons ($ / GB/s and $ / GB)
  - Unintuitive at first, but much easier to scale disk than tape for bandwidth
  - …but existing POSIX solutions were expensive

Why build our own file system?

- Existing POSIX solutions either:
  - Expensive
  - Unsafe
  - Unsuitable to workload / users
  - Combination of the above ☺

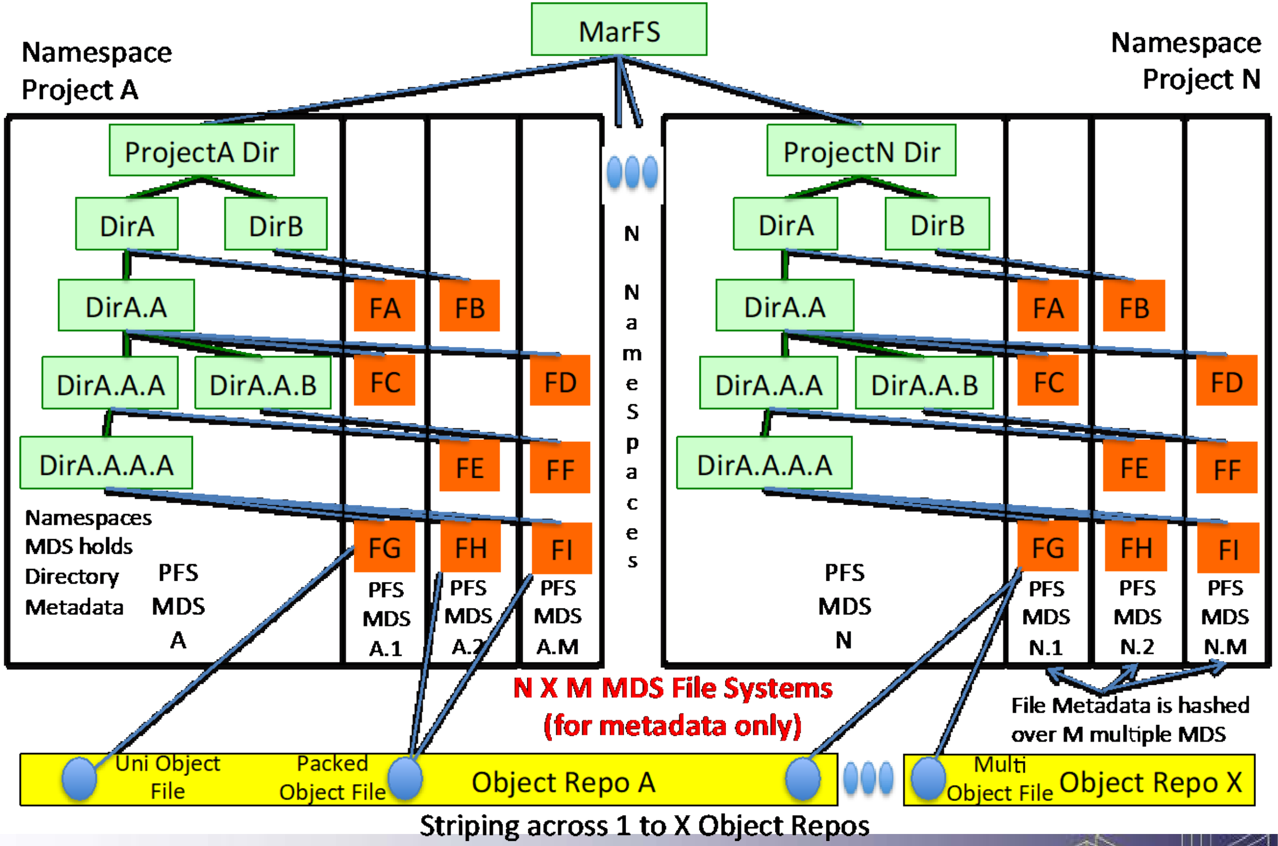
Enter MarFS

- This is our current “Campaign” tier
- We compromise a key part of POSIX:
  - Update in place / seek on write
- Given that compromise, we gain *a lot*
  - IO shaping is possible (save IOPs on write)
  - IO protection is now easy™ (batch IO efficiency)
- Design goals: transparency, protection of data above all else, recoverability, and ease of administration

MarFS in a nutshell

- FUSE daemon – full POSIX metadata, full data read access
- Library – simple API for all access, abstracted calls for simplicity via DAL/MDAL
- pftool – optimized parallel data movement tool
- Admin utilities – quota generation, trash management, offline packing

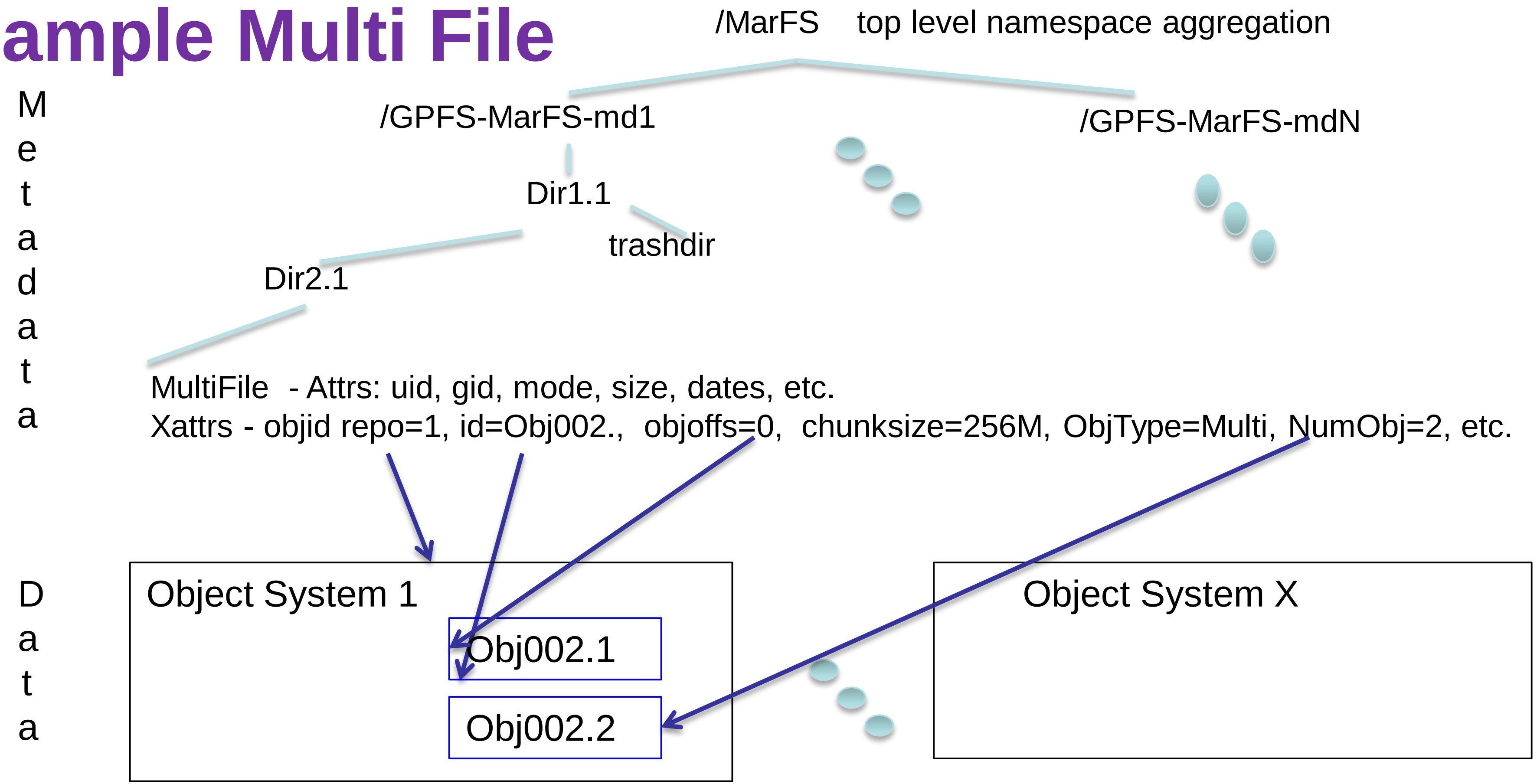
Scalability at its core



Metadata scaling stunt

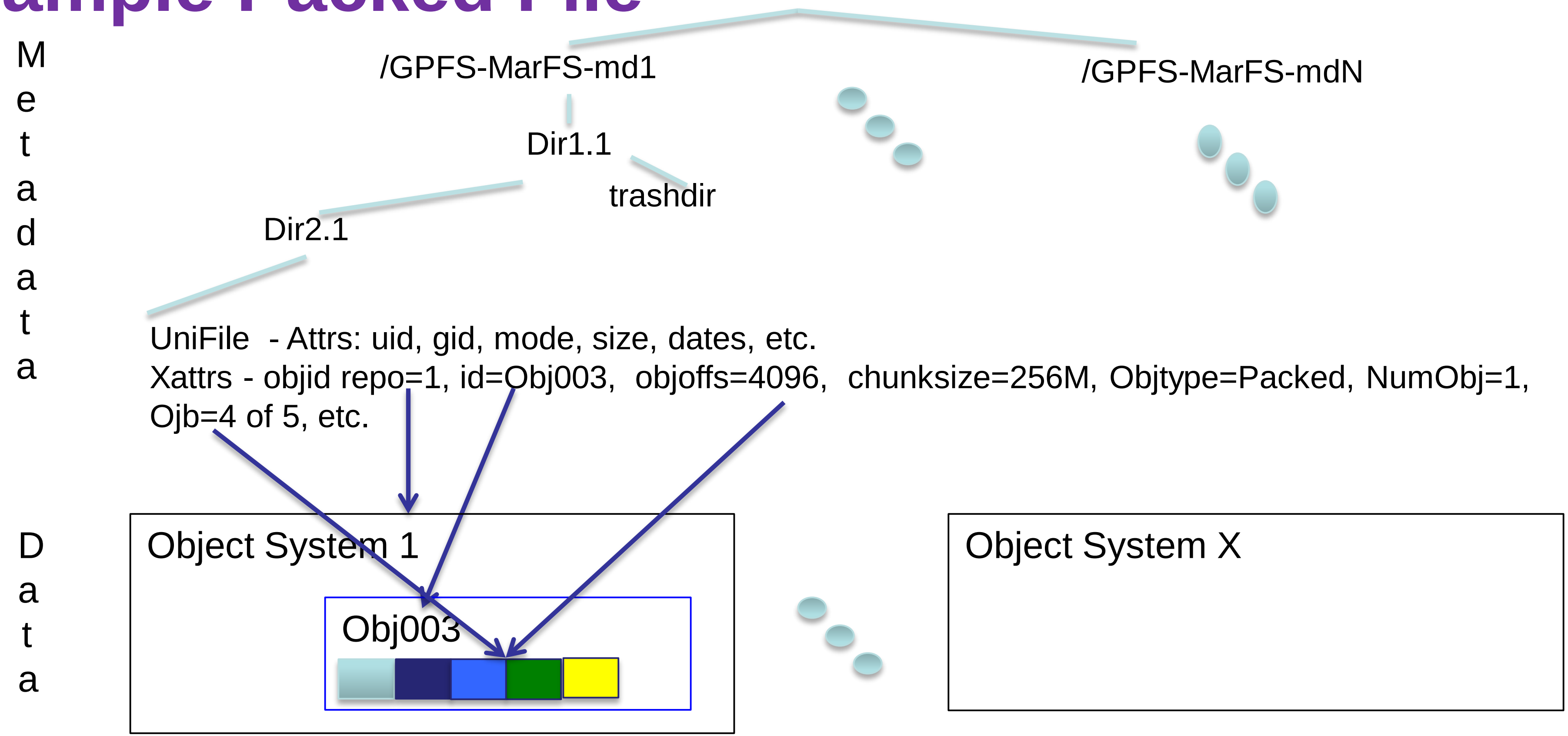
- We built a test harness with MPI to push the limits of the MarFS metadata design
- Initial MD scaling runs on Cielo (1.1 PF, ~140,000 cores, ~9000 nodes)
  - 968 billion files, one single directory
  - 835 million file creations *per second* to metadata repos on each node
  - No cheating! Every create traversed the network from client to server
    - QD=1 for each client, 8 clients per node, 8 servers per node
- Further testing on Mustang (230 TF, ~38,000 cores, ~1600 nodes)
  - Large directory readdir tested from 10-50 nodes (sequential and parallel)
  - Peak of 300 million files per second across 50 nodes
  - More than 400X speedup over a single client sequential readdir

Sample Multi File



Sample Packed File

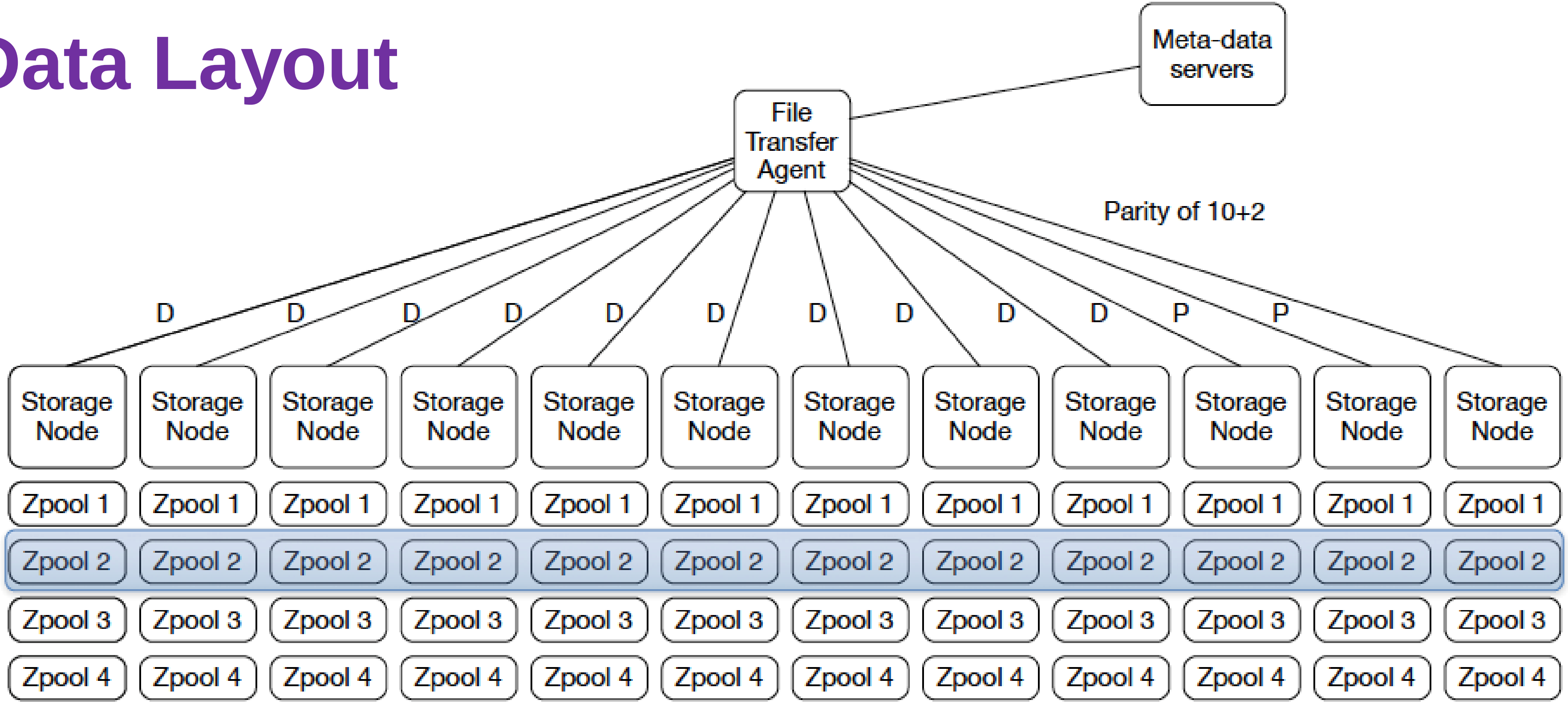
/MarFS top level namespace aggregation



Multi-Component Repositories

- Initially storage via commodity object storage
  - Very “black box”, vendor lock-in, design goals
- Developed our own “object” storage layer
  - Lean on local expertise in ZFS
  - Completely transparent layout
  - Erasure at two levels

Data Layout



Each Zpool is a 17+3

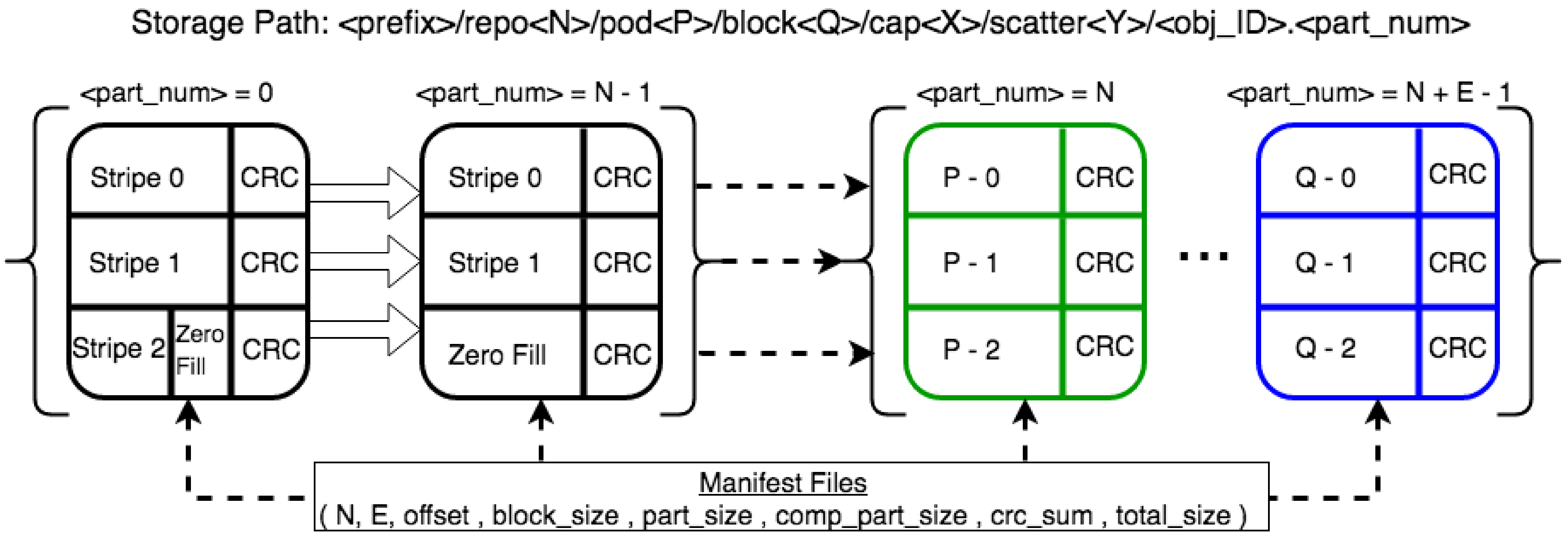
Storage nodes in separate racks

Multiple JBODs per Storage Node

Data and Parity are round-robined to storage nodes

Storage Nodes NFS export to FTAs

File Format


Storage Path: <prefix>/repo<N>/pod<P>/block<Q>/cap<X>/scatter<Y>/<obj_ID>.<part_num>
<part_num> = 0
<part_num> = N - 1
<part_num> = N
<part_num> = N + E - 1
Stripe 0
CRC
Stripe 1
CRC
Stripe 2
Zero Fill
CRC
Stripe 0
CRC
Stripe 1
CRC
Zero Fill
CRC
P - 0
CRC
P - 1
CRC
P - 2
CRC
...
Q - 0
CRC
Q - 1
CRC
Q - 2
CRC
Manifest Files
(N, E, offset , block_size , part_size , comp_part_size , crc_sum , total_size)

Lessons learned (so far)

- Transparency at the lower levels of storage is absolutely key to problem analysis and repair
- Reducing IOPs requirements at the bottom allows efficient use of un-agile disks (shingled HDDs)
- Simple design makes it easy to discover, analyze, and repair any problems as they come up

Ongoing work

- RDMA native transport
- “Fuzzy” DAL
- Fine-grained IO timing
- Live capacity/storage migration
- Something even more “cold”…

So we have this MarFS thing…

- Scalable namespaces
- Quotas
- Easy to understand/administer
- Optimized write IO characteristics
- …can we make an archive out of this?

Enter Marchive

- MarFS + Archive == Marchive
- Very simple extension of the MarFS paradigm
  - Just replace the ZFS arrays with tape!
  - Lose agile read from FUSE
  - Batch process ingest/recall on tape
  - Mostly just automation and UX challenges

Many layers of storage

- By design – users will keep everything if allowed, and HSMs only contribute to that bloat
- Data management is entirely user-driven
  - Users go find unneeded data and delete, if prodded
  - Users have no easy way to find particular datasets unless they have a good hierarchy or they remember where they put it
  - Users have bad memories and bad hierarchies…(you can see where this leads)
  - ...lower (longer) tiers of storage systems accumulate cruft over time

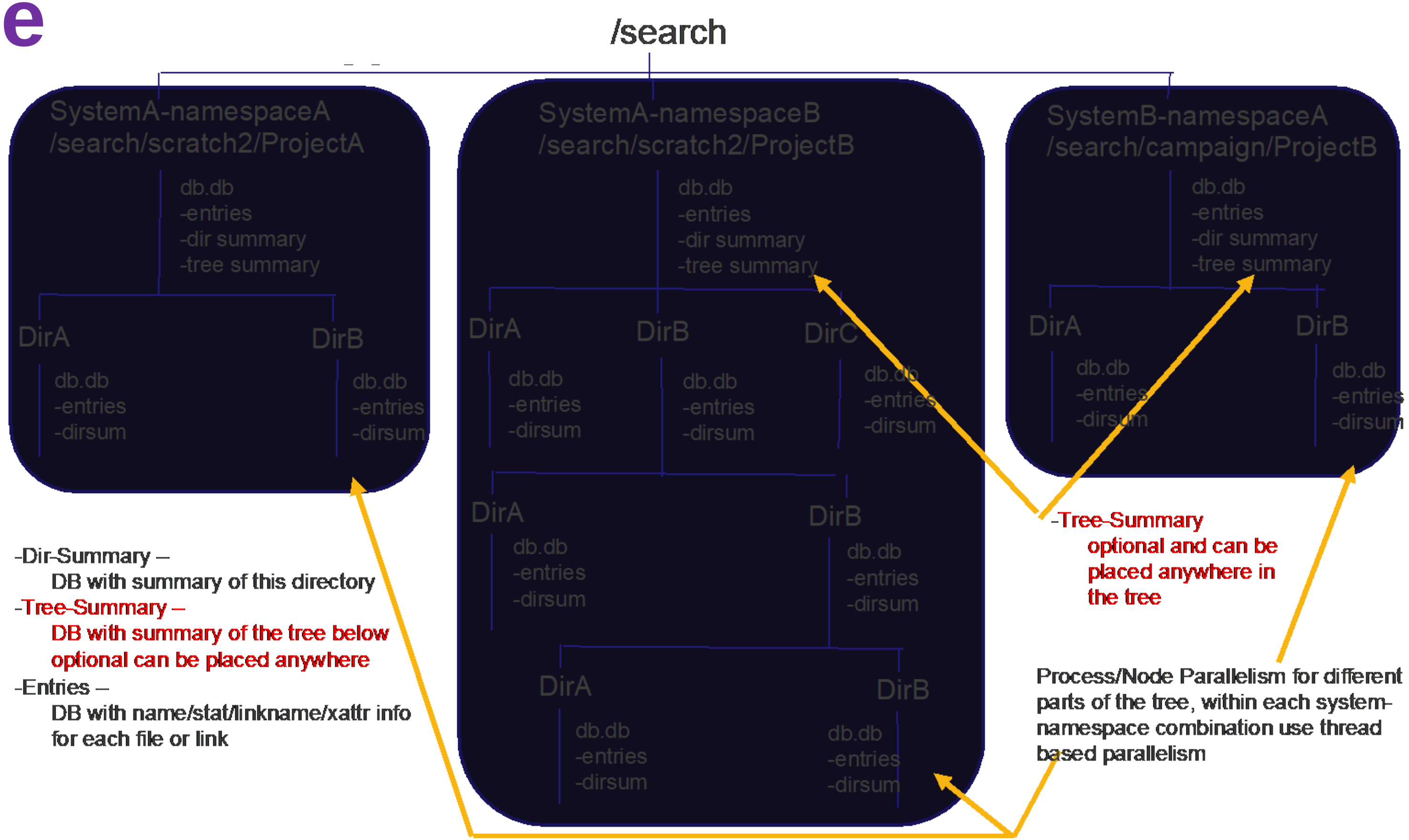
Enter GUFI

- **Unified** index over home, project, scratch, campaign, and archive
- Metadata only with attribute support
- Shared index for **users** and admins
- Parallel search capabilities that are very fast (minutes for billions of files/dirs)
- Can appear as mounted file system where you get a virtual image of your file metadata based on query input
- Full/Incremental update from sources with reasonable update time/annoyance
- Leverage **existing tech** as much as possible both hdwr and software: flash, threads, clusters, sql as part of the interface, commercial db tech, commercial indexing systems, commercial file system tech, threading/parallel process/node run times, src file system full/incremental capture capabilities, posix tree attributes (permissions, hierarchy representation, etc.), open source/agnostic to leveraged parts where possible.
- **Simple** so that an admin can easily understand/enhance/troubleshoot

Initial thoughts

- Why not a flat namespace?
  - Performance is great, but…
  - Rename high in the tree is terribly costly
  - Security becomes a nightmare if users/admins can access the namespace
- Leverage things that already work well, reduce required records to scan:
  - POSIX permissions / tree walk (readdir+)
  - Breadth first search for parallelization
  - Our trees have inherent namespace divisions for parallelism
  - Embedded DBs are fast if not many joins and individual DB size < TB
  - Flash storage is cheap enough to hold everything with order ~10K IOPs each
  - Entries in file system reduce to essentially <dir count> * 3
  - Dense directories reduce footprint dramatically
  - SQL is easily utilized for general queries of attributes

Prototype



-Dir-Summary –
DB with summary of this directory

-Tree-Summary –
DB with summary of the tree below optional can be placed anywhere

-Entries –
DB with name/stat/linkname/xattr info for each file or link

Draft DB Schemas

- Parent-Inode mapping file “directories-parent-inode directories Inode”
  - Parent inode is only kept for directories, not for files as that kills rename/move function performance
- "CREATE TABLE entries(
  - name TEXT PRIMARY KEY, name of file (Not path due to renames)
  - type TEXT, inode INT, f for file l for link inode
  - mode INT, posix mode bits
  - nlink INT, number of links
  - uid INT, gid INT, uid and gid
  - size INT, blksize INT, size and blocksize
  - blocks INT, blocks
  - atime INT, access time
  - mtime INT, file contents modification time
  - ctime INT, metadata change time
  - linkname TEXT, if link this is path to link
  - xattrs TEXT);"; single text string, key/value pairs w/ delimiters

Draft DB Schemas (continued)

- "CREATE TABLE summary(— **summary info for this directory**
  - name TEXT PRIMARY KEY, — name not path due to rename
  - type TEXT, inode INT, — d for directory inode
  - mode INT, — posix mode bits
  - nlink INT, — number of links
  - uid INT, gid INT, — uid gid
  - size INT, blksize INT, blocks INT, — size, blocksize, blocks
  - atime INT, mtime INT, ctime INT, — access time, dir contents mod time, md chg time
  - linkname TEXT, xattrs TEXT, — if link, path to link, xattrs key/value delimited string
  - totfiles INT, totlinks INT, — tot files in dir, tot links in dir
  - minuid INT, maxuid INT, mingid INT, maxgid INT, — min and max uid and gid
  - minsize INT, maxsize INT, — minimum file size and max file size
  - totltk INT, totmtk INT, totltm INT, — total number of files lt KB mt KB, lt MB,
  - totmtm INT, totmtg INT, totmtt INT, — total number of files mt MB mt GB, mt TB
  - totsize INT, — total bytes in files in dir
  - minctime INT, maxctime INT, — min max ctime
  - minmtime INT, maxmtime INT, — min max mtime
  - minatime INT, maxatime INT, — min max mtime
  - minblocks INT, maxblocks INT, — min max blocks
  - totxattr INT, — number of files with xattrs
  - depth INT);"; — depth this directory is in the tree

Draft DB Schemas (continued)

- "CREATE TABLE treesummary(— **summary info for this tree**
  - totsubdirs INT, — tot subdirs in tree
  - maxsubdirfiles INT, maxsubdirlinks INT, — maxfiles in a subdir max links in a subdir
  - maxsubdirsize INT, — most bytes in any subdir
  - totfiles INT, totlinks INT, — tot files in tree, tot links in tree
  - minuid INT, maxuid INT, mingid INT, maxgid INT, — min and max uid and gid
  - minsize INT, maxsize INT, — minimum file size and max file size
  - totltk INT, totmtk INT, totltm INT, — total number of files lt KB mt KB, lt MB,
  - totmtm INT, totmtg INT, totmtt INT, — total number of files mt MB mt GB, mt TB
  - totsize INT, — total bytes in files in tree
  - minctime INT, maxctime INT, — min max ctime
  - minmtime INT, maxmtime INT, — min max mtime
  - minatime INT, maxatime INT, — min max mtime
  - minblocks INT, maxblocks INT, — min max blocks
  - totxattr INT, — number of files with xattrs
  - depth INT);"; — depth this tree summary is in the tree

Programs Included / In Progress

- DFW – depth first walker, prints pinode, inode, path, attrs, xattrs
- BFW – breadth first walker, prints pinode, inode, path, attrs, xattrs
- BFWI – breadth first walker to create GUFI index tree from source tree
- BFMI – walk Robinhood MySQL and list tree and/or create GUFI index tree
- BFTI – breadth first walker that summarizes a GUFI tree from a source path down, can create treesummary index of that info
- BFQ – breadth first walker query that queries GUFI index tree
  - Specify SQL for treesummary, directorysummary, and entries DBs
- BFFUSE – FUSE interface to run POSIX md tools on a GUFI search result
- Querydb – dumps treesummary, directorysummar, and optional entry databases given a directory in GUFI as input
- Programs to update, incremental update (in progress):
  - Lustre, GPFS, HPSS

Early Performance Indicators

- All tests performed on a mid 2014 Macbook (quad core + nvme SSD)
- No tree indexes used
- ~136k directories, mostly small directories, 10 1M entry dirs, 20 100K size dirs, and 10 20M size dirs
- ~250M files total represented
- Search of all files: 2m10s (~1.75M files/sec)
- Search of all files and dirs: 2m19s (~1.63 M entries/sec)
- Search of all files and dirs, but exclude some very large dirs: 1m18s
- Search of all files and dirs, but exclude all < 1000 file directories: 1m59s

- …on a laptop!

Learn more!

- https://github.com/mar-file-system/GUFI
- https://github.com/mar-file-system/marfs
- https://github.com/pftool/pftool

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