SRCC

STANFORD RESEARCH COMPUTING CENTER

LUG 19

migratefs: overlay filesystem for transparent, distributed migration of active data

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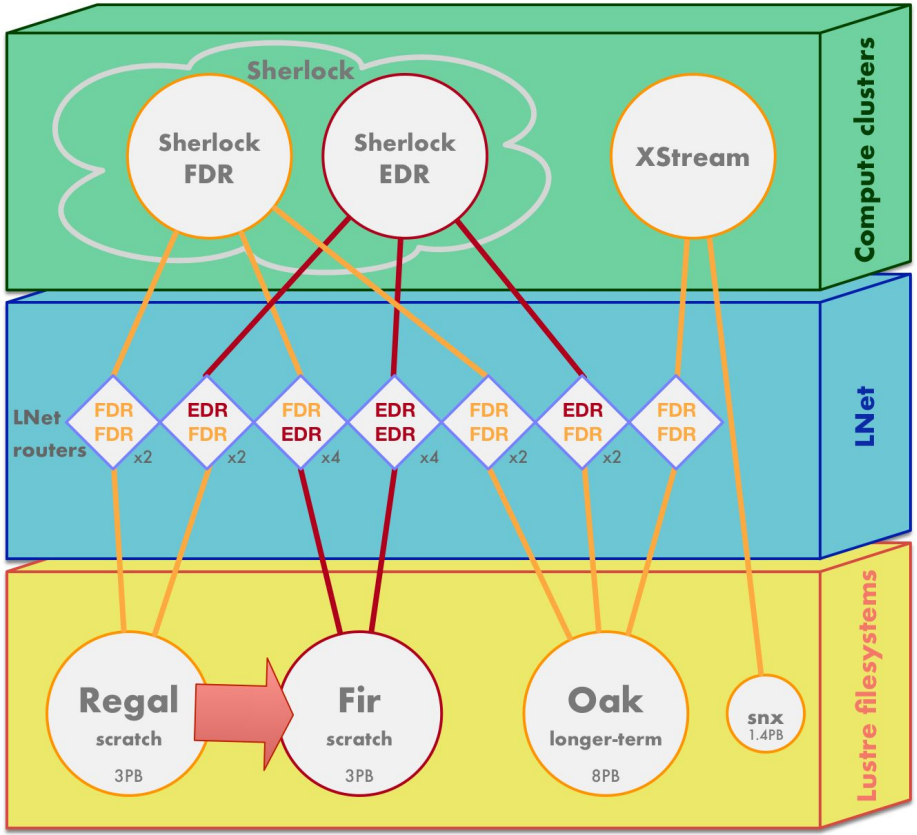
Our Lustre ecosystem

Lustre ecosystem at the SRCC (May 2019)



Sherlock at Stanford

Condo cluster constantly evolving to support research

Numbers

- **~4,000 users** in **~670 different research groups**
- Compute nodes have a **4-year lifecycle**
- Currently **1,371 nodes**
- 26,040 CPU cores; 716 GPUs; **1.876 PFlops**
- Two separate Infiniband fabrics: **FDR, EDR**

Lustre 2.12 with **DNE+DoM+PFL** since February 2019

More info @ https://www.sherlock.stanford.edu/

HPC filesystem lifecycle problem

Objectives

Replace Sherlock's scratch filesystem (Regal with Fir)

- **Data-integrity risk**: Regal's hardware is now obsolete
- Improve performance with **small files**
- **Better network bandwidth** for large streaming I/O

Migration should be **transparent** for the users

- as in **no change** in workflow and scripts
- **reasonable performance tradeoff** is acceptable
- **no prolonged downtime**: use regular cluster maintenance windows

Usual methods of data migration

Data copy: ~~rsync~~, fpsync, lustre-data-mover, etc.

- Requires multiple passes and a long downtime
- Why copy data that are going to be purged anyway?

User-led data migration

- Provide a new mount point to users and let them handle the data migration with a deadline
- Occasional users will miss the deadline
- Too disruptive for our users

Usual methods of data migration (cont'd)

In-place expansion (Lustre-specific method)

- Possible scenario:
  - upgrade old system
  - add new MDS, OSS and storage hardware
  - backup/restore MDT(s) to new hardware
  - use `lfs migrate` to move file objects to new OSTs
  - decommission the empty, old OSTs…
- Error prone, especially for network upgrade

None of the usual methods is satisfactory :-(

migratefs

migratefs - principle

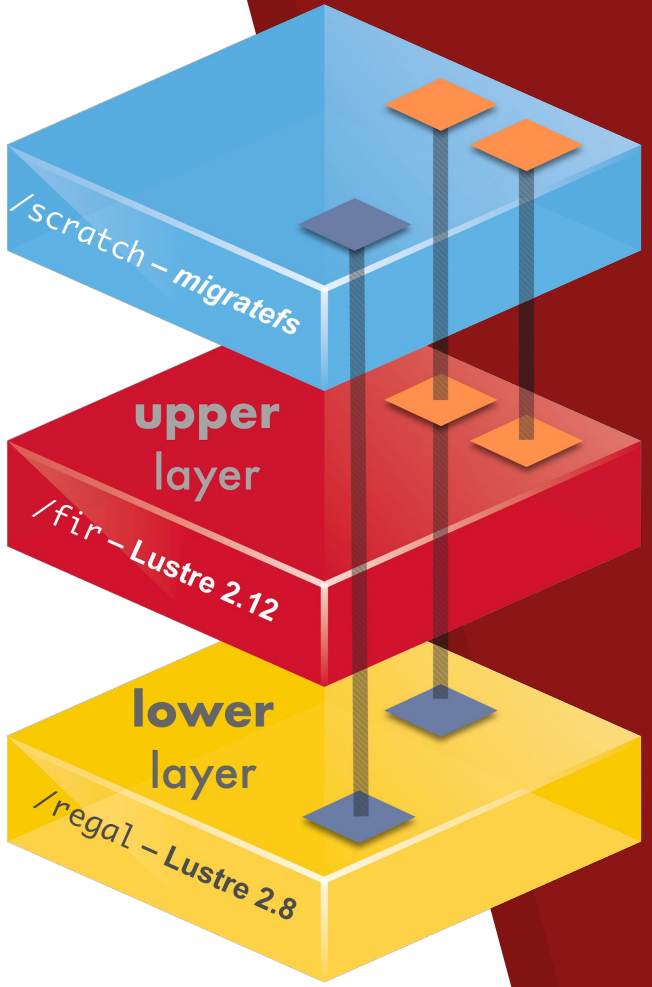
Node-local overlay filesystem in user space

Merge multiple directories/filesystems (layers) and seamlessly migrate data to upper layer when needed

Dispatch I/O syscalls to the right underlying layer

Originally forked from fuse-overlayfs

- https://github.com/containers/fuse-overlayfs



migratefs - easy to deploy and use

Launch daemon to merge /regal and /fir into /scratch

```
# migratefs -o lowerdir=/regal,upperdir=/fir /scratch
```

Track open files with:

```
# ls -l /proc/$(pidof migratefs)/fd
```

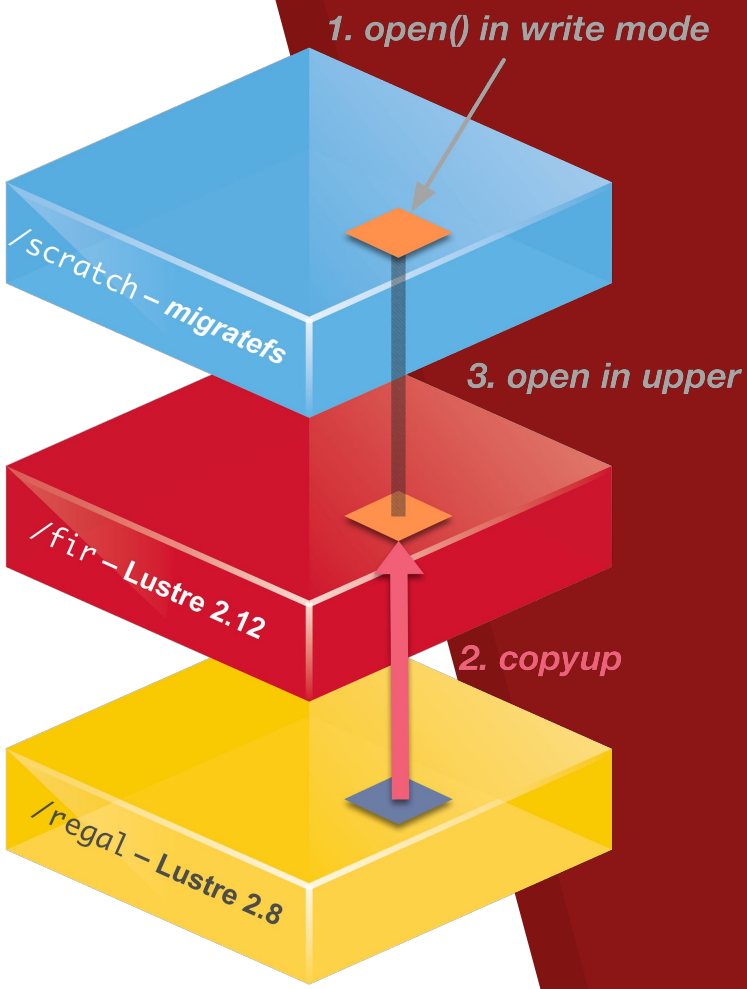
Systemd unit file available for automatic start

migratefs - copyup!

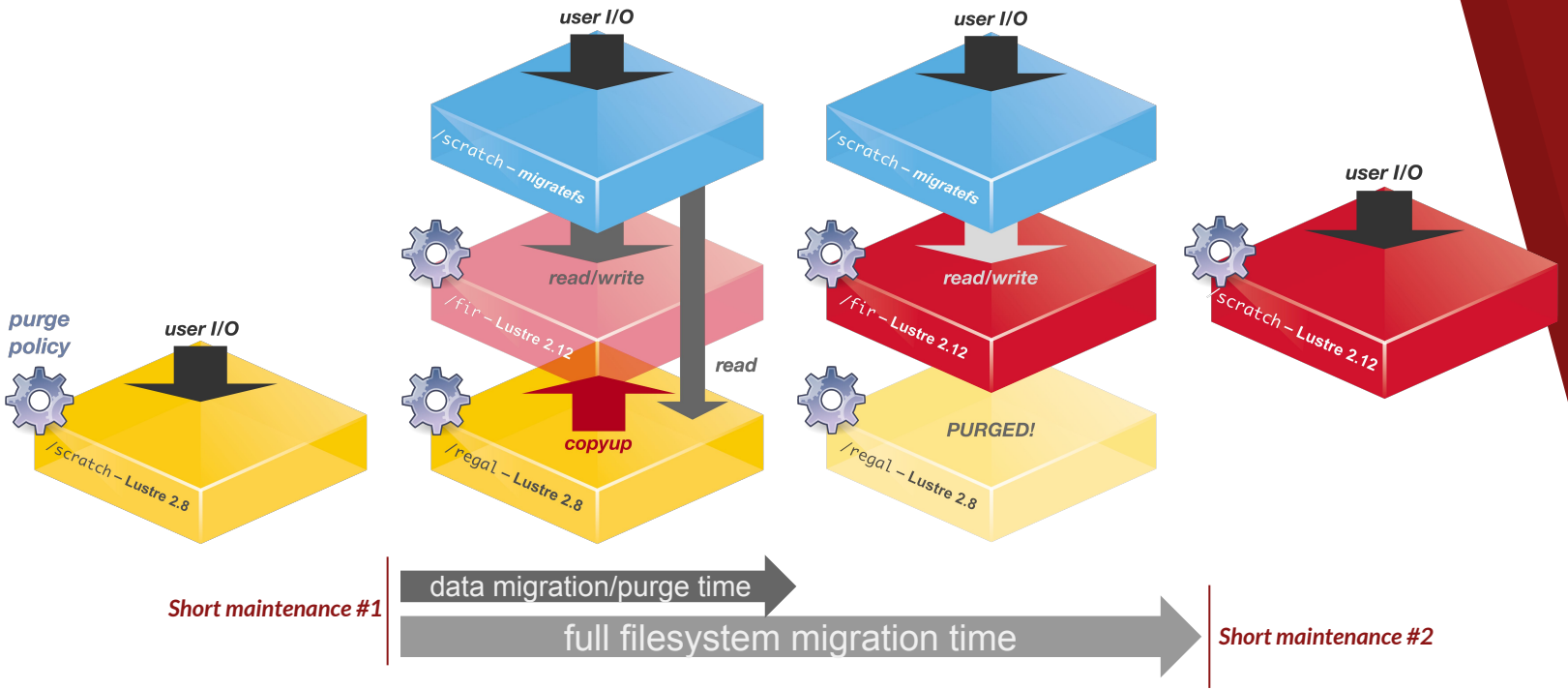
open( ) with write intent triggers a *copyup* operation, migrating the file to the upper layer

data is copied to a temporary file which is renamed when the copy is done

copyup is performed as root to copy all file attributes and parent directory path to the upper layer



migratefs - lifecycle example (scratch)



migratefs - features

Uses FUSE 3.2 low-level API with no caching

- with added multithreading support

Metadata operations

- avoid *copyup*, `lower` layer writable for `mkdir`, `rename`

Permission handling

- runs as root and then drops privilege

Inode numbers

- *migratefs* encodes the layer ID into inode numbers

Monitoring

- distributed logging can be aggregated by Splunk or similar

splunk>enterprise App: Search & Repo... Stephane Thiell Messages Settings Activity Help Find

Search Datasets Reports Alerts Dashboards Search & Reporting

New Search

Save As Close

```
migratefs copyup=success | eval copyupGiB=written/1024/1024/1024 | timechart sum(copyupGiB) as copyupGiB
```

from Feb 6 through Mar 26, 2019

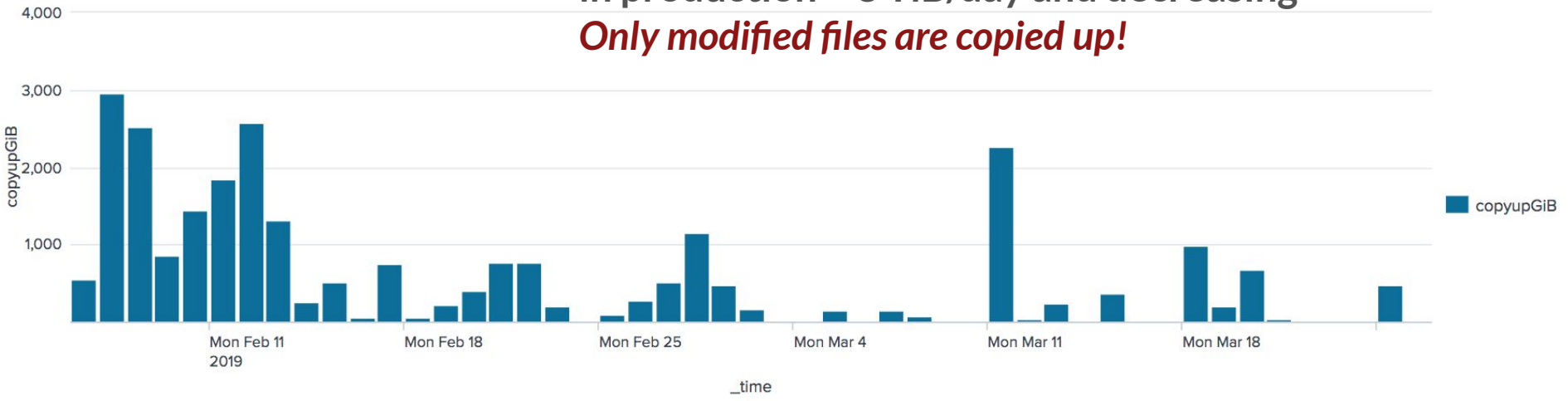
✓ 6,632,651 events (2/6/19 12:00:00.000 AM to 3/27/19 12:00:00.000 AM) No Event Sampling Job Smart Mode

Events Patterns Statistics (49) Visualization

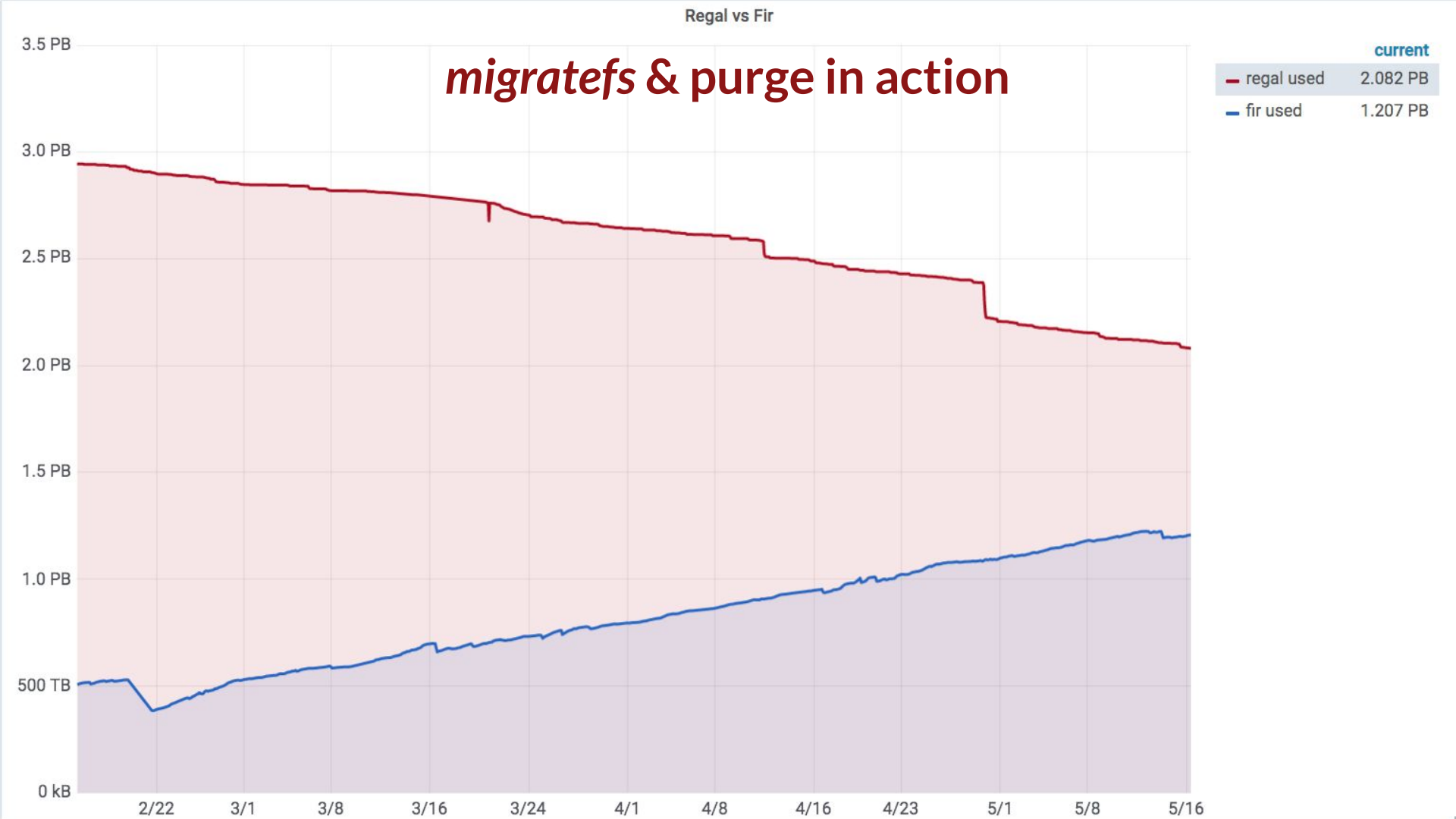
Column Chart Format Trellis

Daily volume of data copied up during the first weeks in production < 3 TiB/day and decreasing

Only modified files are copied up!



_time copyupGiB


Regal vs Fir
migratefs & purge in action
current
regal used 2.082 PB
fir used 1.207 PB
3.5 PB
3.0 PB
2.5 PB
2.0 PB
1.5 PB
1.0 PB
500 TB
0 kB
2/22
3/1
3/8
3/16
3/24
4/1
4/8
4/16
4/23
5/1
5/8
5/16

migratefs on Sherlock – changelog

Started production on February 5, 2019

- Singlethreaded

migratefs 0.3 released on February 27, 2019

- Multithreading support
- Travis-CI with fstest, stress-ng and custom tests

migratefs 0.4 released on March 11, 2019

- Bug fixes

migratefs 0.5 released on April 21, 2019

- performance improvements

migratefs - latest release 0.5.4

Skip copying data up on open(`O_TRUNC`)

Added a boolean flag (multilayer) to cached inode information

- Lookup speedup for directories that only exist in the upper

Added `st_nlink` caching for multilayer directories

- Improved performance with a directory having more than 2 million aggregated entries...

migratefs & Lustre, room for improvement

Linux kernel 4.20+

- maximum I/O size for FUSE increased from 128k to 1M
- come on, Red Hat!

Support for `renameat2()` in Lustre

- Potential race/retry on parallel *copyup* would be avoided with `renameat2(RENAME_NOREPLACE)`
  - LU-12272: Support renameat2() with RENAME_NOREPLACE flag

migratefs - conclusion

All the cluster nodes contribute to the data migration

Only *active* data are copied to the new filesystem

No change in the user environment

- same paths, no LD_PRELOAD, etc.

Performance tradeoff during data migration

- upper layer can still be accessed directly if needed

migratefs - download & contribute

https://github.com/stanford-rc/fuse-migratefs

Extra slides

migratefs - metadata operations

Most metadata ops don't trigger a *copyup* by default

- *copyup* rules should match filesystem purge policies

Unlike *fuse-overlayfs*, with *migratefs*, the lower layer(s) must be writable

- `rename()` may create missing directories in lower layer
- Lustre disk quota can be set to 0 to avoid direct writes from users to the lower layer

migratefs - FUSE (Filesystem in Userspace)

migratefs requires FUSE 3.2

- Low level FUSE 3 API (like fuse-overlayfs)
- Not easy to find a package for CentOS 7 providing libfuse3
  - https://github.com/stanford-rc/fuse3-centos7

migratefs does not use FUSE name lookup caching

migratefs has multithreading support

- Strong requirement for decent performance over Lustre
- Supported by FUSE but not by *fuse-overlayfs*
- Can be disabled with `-o mt=0`

migratefs - permission handling

migratefs daemon runs as root

- drops privilege to run as the effective ID of the calling user
  - similar to LANL's MarFS
- root is needed for *copyup* to copy permissions
- Secondary groups are supported

Do not use FUSE's `default_permissions`

- POSIX ACLs are not supported by FUSE when `default_permissions` is enabled!
- rely on the underlying filesystem for permission and ACL checking, always under the context of the user

migratefs - inode numbers

fuse-overlayfs assumes that `/lower` and `/upper` are part of the same filesystem (common for containers)

- thus inode numbers from the upper and lower layers are just exposed *as is*, easy!

migratefs encodes the layer ID in the high 4 bits of the inode #

- works with all filesystems
- inode numbers in Lustre are flattened FID (seq, oid)

```
ino = (seq << 24) + ((seq >> 24) & 0xffffff0000ULL) + fid_oid(fid);
```

(FID's seq is 64-bit) (FID's oid is 32-bit)

Any better idea?

migratefs - monitoring

Each *migratefs* daemon prints interesting logs

- *copyup* operation results
- other unexpected errors

These distributed logs are sent to Stanford's Splunk

Logs use clear key-value pairs for use with Splunk's automatic field extraction:

```
May 09 14:43:23 sh-ln05.stanford.edu migratefs[47585]: version=0.5.4
copyup=success uid=315672 st_uid=315672 written=1130471060 truncate=false
path=users/user1/WACCM/WACCMSC_CTL_122.cam.h1.0100-01-01-00000.nc
```

migratefs on Sherlock – changelog 1/3

Started production on February 5, 2019

- Only singlethreaded versions at first (0.1.x-0.2.x)
- Improved error handling for cluster-awareness
  - For example: handle ENOENT on `mkdirat()`
- Fixed a deadlock due to recursion because of calling `{get/set/remove}xattr` instead of `l{get/set/remove}xattr`
- Disabled FUSE's `default_permissions` to support Lustre's POSIX ACLs
- Adjusted OOM score in systemd unit file to avoid killing of the *migratefs* daemon (because of the user context switching)

migratefs on Sherlock – changelog 2/3

Version 0.3 released on February 27, 2019

- First multithreaded version
- Use direct syscall for per-thread `setresuid()`
- Got rid of `umask()` (not thread safe) and honor umask at `open()` instead from `fuse_ctx`
- Set up Travis-CI with fstest, stress-ng and custom tests

Version 0.4 released on March 11, 2019

- improve FUSE inode lookup count handling
- also fixed defects and race conditions in 0.4.x

migratefs on Sherlock – changelog 3/3

Version 0.5 released on April 21, 2019

- performance improvements (st_nlink, multilayer flag)
- now encoding layer ID in inode numbers
- fixed an issue reported by a user with “du” when inodes were not refreshed correctly (now added as custom test)

```
du: WARNING: Circular directory structure.
This almost certainly means that you have a corrupted file system.
NOTIFY YOUR SYSTEM MANAGER.
The following directory is part of the cycle:
‘./scripts’
```

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