rCore with Log-Structured File System

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Background

- rCore
  - rcore-tutorial
  - rcore-tutorial-OS20
  - rcore-fs

rcore-fs-devfs	Revert "add inode id and file type in the return value of get_entry i...	17 days ago
rcore-fs-ext2	fix warnings	4 months ago
rcore-fs-fuse	Revert "add inode id and file type in the return value of get_entry i...	17 days ago
rcore-fs-hostfs	Revert "add inode id and file type in the return value of get_entry i...	17 days ago
rcore-fs-mountfs	implement get_entry_with_data for MNode	17 days ago
rcore-fs-ramfs	fix lock_multiple in ramfs	14 days ago
rcore-fs-sefs	Revert "add inode id and file type in the return value of get_entry i...	17 days ago
rcore-fs-sfs	Run cargo fmt	17 days ago
rcore-fs-ucore	fix warnings	4 months ago
rcore-fs	Add default impl for get_entry_with_metadata	17 days ago
sefs-fuse	add simple DevFS	10 months ago

Background

- Log-Structured File System (LFS)
  - Motivation
    - Growing system memory capacity
    - Large gap between random access and sequential access
  - Traditional FFS-like system
    - Centralized inode map, free data bitmap
    - Performance limited by numerous short, random access
    - Partly amortized by disk cache
      - New problems: Rigid cache structure, higher energy cost, …
    - No safety guarantees

LFS Introduction

- Authors
  - Co-founder of VMWare
  - Raft protocol, Tcl script language

The Design and Implementation of a Log-Structured File System

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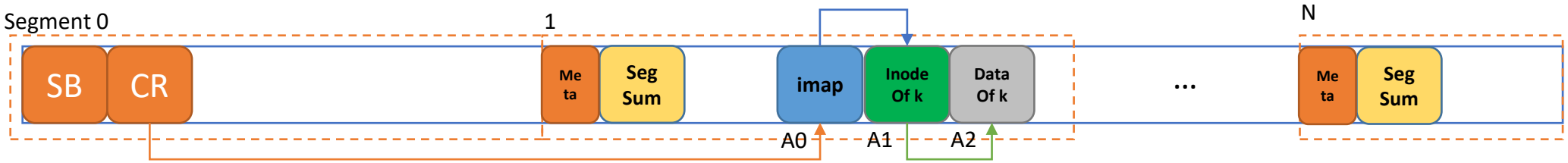
- Key ideas
  - Decentralizing inode meta -> imap
  - Coarse-grained synchronization -> Segment cache
  - Mostly appending logs to disk -> Few random accesses
  - Crash recovery provided by logs -> Roll forward process

Schedule

- What we have done
  - Implementing a basic rust OS (rCore-tutorial)
    - Familiar with rust programming
  - Integrating Driver and BlockDevice (rCore-20)
    - Disk image mounted and accessed by QEMU
  - Implementing a LFS-like system
    - File/Directory creating, accessing, modifying
    - Garbage collection
    - 1100+ lines of rust code
  - Comparison with FFS-like system
    - A HDD model
    - SimpleSSD simulation

LFS Structures

- We have implemented most structures in LFS, to construct our new alternative file system on rCore.



  - Super block (SB): meta data for entire disk partition
    - Total_blocks, total_segments, unused_blocks, …
  - Checkpoint region (CR): meta data for one checkpoint (for crash recovering)
    - begin_segment_id: u32, current_segment_id: u32, next_ino: u32
  - Segment Summary (SegSum): recording liveness of each datablock (for garbage collection)
    - blk_id -> (ino_id, dataentry_id)
  - Imap table
    - ino_id -> blk_id

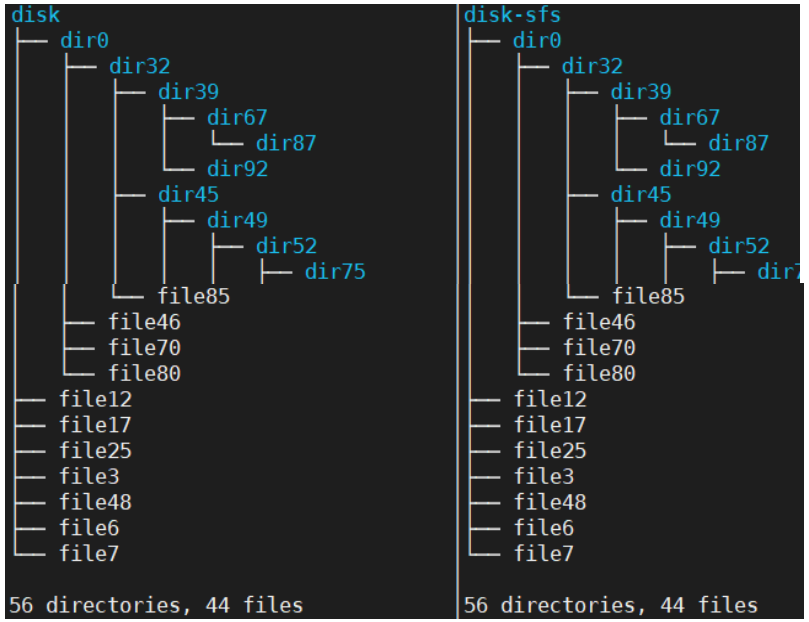
Boundary of memory and storage

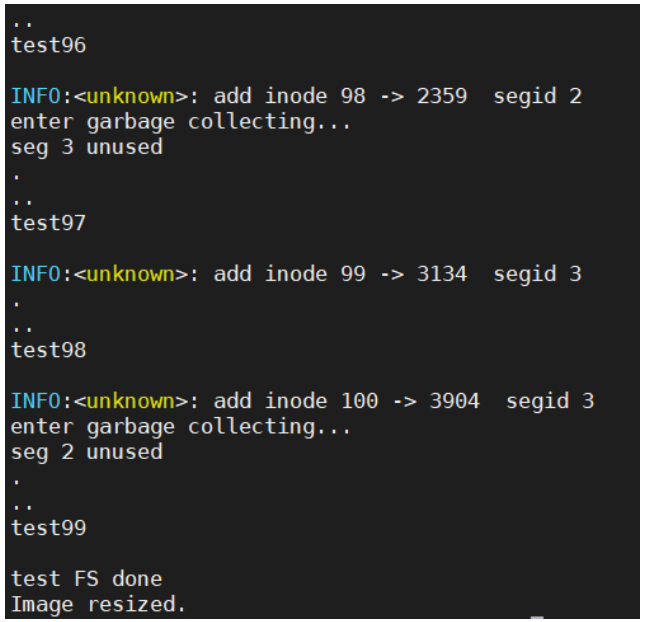
- In original LFS paper
  - Segment cache

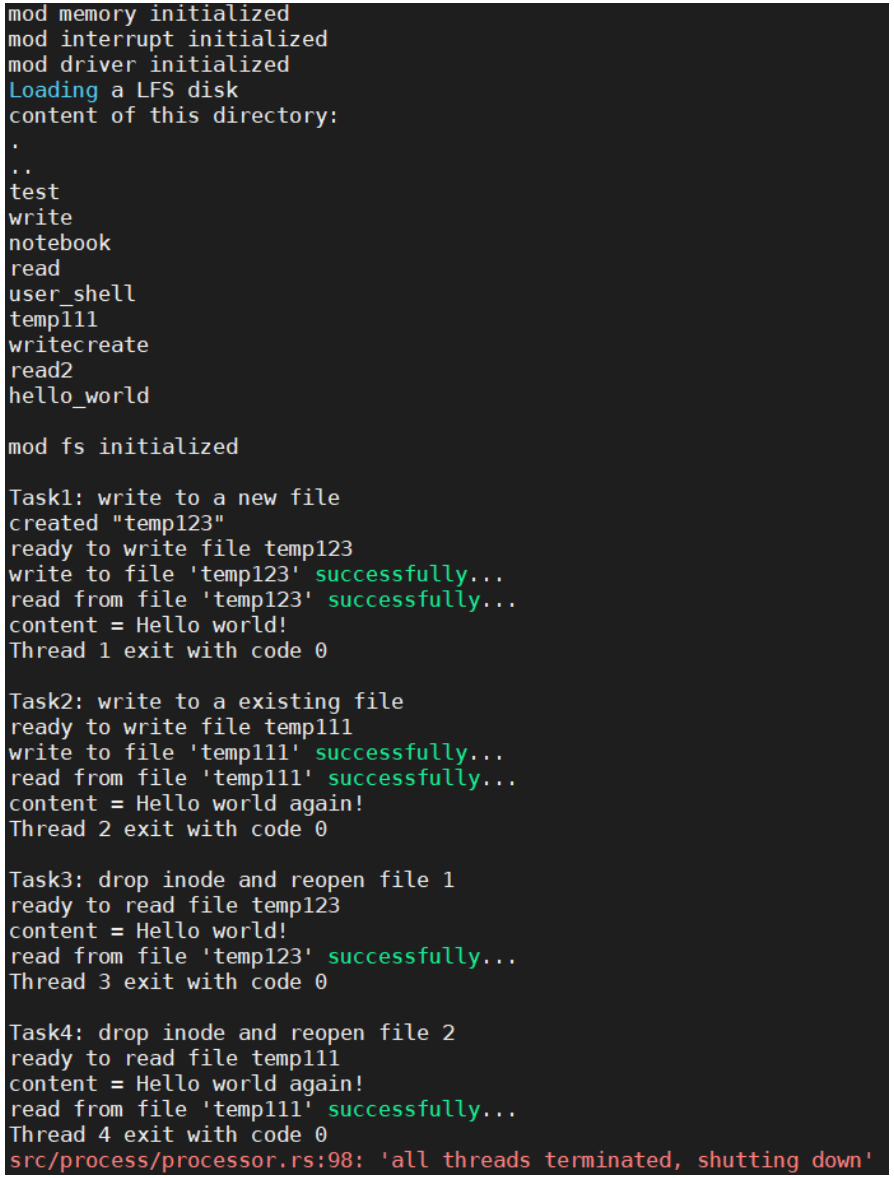
- In our LFS design
  - Synchronized in drop implementation
  - Extending the Dirty struct provided by rcore-fs
    - Dirty() -> writeback is needed
      - Set by DerefMut every time
    - Sync() -> removing dirty bit, for assertion
      - Set manually
    - Stale() -> Current in-memory structure should be allocated a new disk block
      - Set manually, to balance the writeback amount and sequential access

Result

- Basic FS operations
  - Randomly generating files/directories
  - Full system test
- Garbage collection
  - Consistently creates and delete files until exceeding capacity







Result

- Capacity comparison
  - After qcow2 compression, LFS has a 53% storage overhead over SFS
- Performance simulation
  - Basic IO statistics

	Write count	Read count	IO Transfer length (Bytes)	Image capacity (compressed)
LFS	34582	11419	47120712	4.9MB
SFS	34215	22442	93869060	3.2MB

  - SSD model result

	LFS	SFS
Simulation Tick	1215821831777725	1221120730998634
Min Latency	2.871473ms	3.376592ms
Max Latency	3052.497074ms	3983.285137ms
Average Latency	1019.119791ms	1481.942723ms
Stdev Latency	3425.016061ms	1460.266471ms
Event Handled	156314	184877

Discussion

- Comparing with FFS-like system
  - Access “/foo/bar”
  - FFS-like system: reading 3 inodes in inodemap, 3 data blocks in data blocks
  - LFS system: reading CR (in memory), 1 imap, 3 inodes and 3 data blocks
    - Likely in one segment

- How to balance stale and dirty blocks
  - Use append mode except
    - INode metadata modification (atime, mtime, …)
    - Parent direntry appending/removing
  - Adaptive approach: future work
    - Tradeoff between random access cost and log storage overhead

Future work

- It is a rough prototype so far!
  - Not support for double indirect data blocks (easy)
  - Use dedicated inode/meta struct instead of 4K block (easy)
  - Requiring refactoring to enjoy Rust language features (medium)
  - Not support for roll forward process (medium)

- Repo links
  - https://github.com/leepoly/aoslab
  - https://github.com/Pingziwalk/rCore
  - https://github.com/leepoly/rcore-fs/

Q&A

Reference

- [1] Rosenblum M, Ousterhout J K. The design and implementation of a log-structured file system[J]. ACM Transactions on Computer Systems (TOCS), 1992, 10(1): 26-52.
- [2] rcore-tutorial. https://rcore-os.github.io/rCore_tutorial_doc/
- [3] rcore-tutorial-OS20. https://os20-rcore-tutorial.github.io/rCore-Tutorial-deploy
- [4] SFS Analysis. https://os20-rcore-tutorial.github.io/rCore-Tutorial-deploy/docs/lab-5/files/rcore-fs-analysis.pdf
- [5] Jung M, Zhang J, Abulila A, et al. Simplessd: modeling solid state drives for holistic system simulation[J]. IEEE Computer Architecture Letters, 2017, 17(1): 37-41.