Caching less for better performance: Balancing cache size and update cost of flash memory cache in hybrid storage systems

Yongseok Oh, Jongmoo Choi, Donghee Lee, Sam H. Noh
University of Seoul, Dankook University, Hongik University (in Seoul, Korea)

Hybrid Storage System
- Combine SSDs and HDDs
- SSD-like performance for HDD-like price
- SSDs used as Flash Cache
- Issues in Flash Cache
  - Performance
    - Garbage collection (GC)
    - Lifetime
    - Erase count

Over-Provisioned Space (OPS)
- Reserved space for GC in Flash Cache
- Greatly influence GC cost and hit rate
- In typical SSDs OPS size is FIXED to an undisclosed size
  - Cannot adapt to workload changes & GC cost

Our Goal: Find Optimal OPS Size

OP-FCL (Optimal Partitioning-Flash Cache Layer): Workload Dependent Optimal Partitioning

- Flash Cache is divided based on u and r

  ![Flash Cache Division](image)

  \[\text{Read} \quad \text{Write} \quad \text{OPS}\]

  \[u = 100 - u \quad r = 100 - r\]

- Hybrid Cost Model: \(C_{HY}(u, r)\)
  - Represents expected I/O cost
  - Involves
    - Storage Cost Model
      - Flash access cost
      - HDD access cost
    - Workload Pattern
      - Hit rate
      - I/O rate
  - See the paper for derivation

- Periodically Execute Optimal Partitioning Algorithm

  ![Optimal Partitioning Algorithm](image)

  \[\text{procedure \ OPTIMAL \ PARTITIONING}\]

  \[\text{step} \leftarrow \text{segment-size} / \text{total-cache-size}\]

  \[\text{INIT \ PARMS}(op_{\text{cost}}, op_{\text{u}}, op_{\text{r}})\]

  \[\text{for} \ u \leftarrow \text{step}; \ u < 1.0; \ u \leftarrow u + \text{step} \text{ do}\]

  \[\text{for} \ r \leftarrow 0.0; \ r < 1.0; \ r \leftarrow r + \text{step} \text{ do}\]

  \[\text{cur}_{\text{cost}} \leftarrow C_{HY}(u, r)\]

  \[\text{if} \ cur_{\text{cost}} < op_{\text{cost}} \text{ then}\]

  \[\text{op}_{\text{cost}} \leftarrow cur_{\text{cost}}\]

  \[op_{\text{u}} \leftarrow u, \ op_{\text{r}} \leftarrow r\]

  \[\text{end if}\]

  \[\text{end for}\]

  \[\text{end for}\]

  \[\text{ADJUST-CACHE-SIZE}(op_{\text{u}}, op_{\text{r}})\]

  \[\text{end procedure}\]

Performance Evaluation

- Hybrid Storage Simulator
  - CMU DiskSim 4.0+MSR SSD extension
  - 16GB Flash Cache+10K RPM HDDs

- Flash Cache Layers
  - FP-FCL (Fixed Partitioning)
  - RW-FCL (Read Write Partitioning)
  - OP-FCL (Optimal Partitioning) that we propose

- Workload
  - Exchange Server
  - See the paper for more results!

Conclusion
- Trade-off exists
  - Caching Benefit vs. Update Cost
- OP-FCL balancing caching space and OPS sizes
  - Provides near optimal performance
  - Improves lifetime of Flash Cache

10th USENIX Conference on File and Storage Technologies (FAST’12)