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► **To cite this version:**

Hocine Mahni, Stéphane Rubini, Jalil Boukhobza, Sebastien Gougeaud, Philippe Deniel. ADAPTING THE ARC CACHE MANAGEMENT POLICY TO FILE GRANULARITY. 7th Workshop on Performance and Scalability of Storage Systems (Per3S), May 2023, Paris, France. hal-04255285

HAL Id: hal-04255285

<https://hal.univ-brest.fr/hal-04255285>

Submitted on 23 Oct 2023

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ADAPTING THE ARC CACHE MANAGEMENT

POLICY TO FILE GRANULARITY

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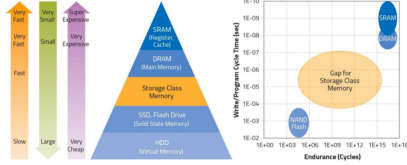
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1- HPC Data Placement on Heterogeneous and Multilevel Storage System

- The global data volume will reach 181 zettabytes in 2025.
- Exascale computing may widen the gap between computation, main memory and storage.
- Exploiting multi-tier and heterogeneous storage systems (see table below) is a key to reach trade-off between performance, cost, and capacity.



The new memory hierarchy with SCM[1].

Target Architecture : Heterogeneous three-tier architecture: SSD on the top tier for high performance. HDD as the middle tier, lower performance but higher capacity and lower cost; tape as the bottom tier for archival purposes.

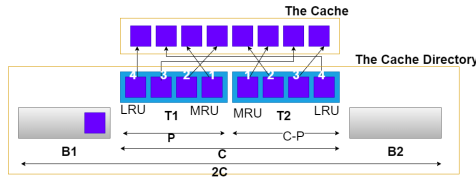
Application: File placement tasks in CEA supercomputers are performed using *Robinhood*[2], a tool for applying and planning data placement policies. This tool works at the **file granularity**.

Device	Read latency	Write Latency	Write endurance	Cell size (F) ²	Cost
NVM(STT-RAM)	2-35ns	3-50ns	>10 ¹⁵	6-50	Highest
NVM(PCM)	20-60ns	20-150ns	10 ⁸ - 10 ⁹	4-12	2-8 \$ /GB
SSD	15-35ns	200-500ns	10 ⁴ - 10 ⁵	4-6	0.5-2\$ /GB
HDD	3-5ms	3-5ms	>10 ¹⁵	N/A	0.06-0.3\$ /GB

Problem Statement: How to place and migrate data to/from storage tiers according to application QoS.

2- Background on Adaptive Replacement Cache

- Which data to cache in top performance tier can be solved at the operating system level.
- ARC (Adaptive Replacement Cache) is a reference state-of-the-art work [3].



- T1 is an LRU list for pages accessed only once, while T2 keeps items accessed more than once
- C : cache size, P: the current target size for the list T2.
- B1 and B2 are ghost lists used to keep track of the pages evicted by T1 and T2, respectively.

Algorithm 1 Pseudo code of ARC

- 1: Initialize T1=B1=T1=T2=B2, x: requested page.
- 2: x in T1 or T2: cache hit, move x to MRU T2.
- 3: x in B1: cache miss, Adapt p = min (c,p+ max(|B2|/|B1|,1)) **Replace(page)**, move x to mru T2.
- 4: x in B2: cache miss, Adapt p = max (0,p-max(|B1|/|B2|,1)) **Replace(page)**, move x to mru T2.
- 5: x not in L1U/L2 cache miss. case 1: |L1|=c : if |t1|<c then delete the LRU page of B1, **Replace(page)** else delete LRU page of T1. case 2: |L1| < c and |L1| + |L2| >= c: if |L1|+|L2| = 2c then delete the LRU page of B2.

Replace(page): If either |T1|>p or (|T1|=p and x in B2), replace the LRU page in T1
 If either |T1|<p or (|T1|=p and x in B1), replace the LRU page in T2.

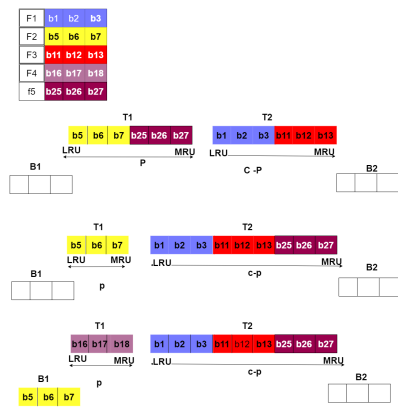
3- Adapting the ARC cache management policy to file granularity

Assumptions: files have the same size + move entire files between T1 and T2

Algorithm 2 Pseudo ARC algorithm with file-level granularity(V1)

- 1: Initialize T1=B1=T1=T2=B2, f: requested file such as $\forall f \text{ sf} = \sum_{i=1}^m b_i$ and all files's size is equal to sf, block b's size is designated as sb.
- 2: f in T1 or T2: cache hit, move f to MRU T2.
- 3: f in B1: cache miss, Adapt p = min (c,p+ max(|B2|/|B1| *sf/sb, sf/sb)) **Replace(file)**, move f to mru T2.
- 4: f in B2: cache miss, Adapt p = max (0,p-max(|B1|/|B2|*sf/sb, sf/sb)) **Replace(file)**, move f to mru T2.
- 5: f not in L1U/L2 cache miss. case 1: |L1|=c : if |t1|<c then delete the LRU file of B1, **Replace(file)** else delete LRU file of T1. case 2: |L1| < c and |L1| + |L2| >= c: if |L1|+|L2| = 2c then delete the LRU file of B2.

Replace(file): is the same as that of the original ARC algorithm, the only difference being that it replaces a file instead of a page.



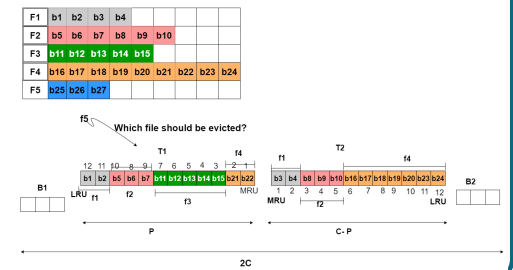
Assumptions: files have different sizes and data are moved between T1 and T2 with a page granularity while data are moved between tiers at a file granularity.

Algorithm 3 Pseudo ARC algorithm with file-level granularity(V2)

- 1: Initialize T1=B1=T1=T2=B2, b: requested BLOCK, each block is associated with a given file and sf: files's size, block b's size is designated as sb.
- 2: b in T1 or T2: cache hit, move b to MRU T2.
- 3: b in B1: cache miss, Adapt p = min (c,p+ max(|B2|/|B1|)sf/sb, sf/sb)) **Replace(file)**, move b to mru T2.
- 4: b in B2: cache miss, Adapt p = max (0,p-max(|B1|/|B2|)sf/sb, sf/sb)) **Replace(file)**, move b to mru T2.
- 5: b not in L1U/L2 cache miss. case 1: |L1|=c : if |t1|<c then delete the LRU blocks of B1, **Replace(file)** else delete file f with highest score. case 2: |L1| < c and |L1| + |L2| >= c: if |L1|+|L2| = 2c then delete the LRU page of B2.

Replace(file): To decide which file to delete and replace, we calculate a score that favors evicting files with a high proportion in the LRU portion of T1 and T2 while protecting files that have more blocks in the MRU portion of T1 and T2. Such as:

$$S = \frac{\sum_{bi \in T1rf} (index(bi) + \alpha \sum_{bi \in T2rf} (index(bi)))}{cardf}$$



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4- Related work

20 years after its introduction, ARC remains a reference strategy [4][5][6][7][8]. Several studies were based on the principle of using recency and frequency of access to manage caches, such as Lecar[7] and its enhanced version, Cacheus[6]. These approaches maintain two lists, LRU (Least Recently Used) and LFU (Least Frequently Used), and prioritize recency or frequency based on a regret ratio while using machine learning algorithms to select the best strategy.

6- Conclusion and Future Work

We have proposed a version of the ARC algorithm for managing a two-tier (HDD-SSD) storage architecture at the file level. Our strategy is based on striking a balance between the recency and frequency of access to keep recently and frequently used files in the top tier, while preserving the logic of ARC.
For future work: Evaluation of both versions in a multi-tier simulator, including additional parameters to consider for score calculation, such as file lifespan.