Εθνικό Μετσόβιο Πολυτεχνείο

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και Μηχανικών Υπολογιστών

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Thesis subject

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Εγκρίθηκε από την τριμελή εξεταστική επιτροπή την 9η Σεπτεμβρίου 9999.

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Αθήνα, Σεπτέμβριος 9999

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Όνομα Φοιτητή

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URL: http://www.softlab.ntua.gr/techrep/
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Contents

List of Figures

Chapter 1

Introduction

1.1 Introduction/Motivation

Bla-bla...

1.2 Thesis structure

Chapter 2: We define what ”cloud” means and mention some of the most notable examples. Then, we give a brief overview of the synnefo implementation, its key characteristics and why it can have a place in the current cloud world.

Chapter 3: We present the architecture of Archipelago and provide the necessary theoretical background (mmap, IPC) the reader needs to understand its basic concepts. Then, we thoroughly explain how Archipelago handles I/O requests. Finally, we mention what are the current storage mechanisms for Archipelago and evaluate their performance.

Chapter 4: We explain why tiering is important and what is the state of tiered storage at the moment (bcache, flashcache, memcached, ramcloud, couchbase). Then, we provide the related theoretical background for cached (hash-tables, LRUs). Finally, we defend why we chose to roll out our own implementation.

Chapter 5: We explain the design of cached, the building blocks that is consisted of (xcache, xworkq, xwaitq). Then, we provide extensive benchmark results and compare them to the ones of Chapter 3.

Chapter ??: TODO

Chapter ??: We draw some concluding remarks and propose some future work.

Chapter 2

Chapter 2

2.1 Section 1

This section has an important citation[aeal99]

2.1.1 Subsection 1

This subsection has code in Haskell:

```
foo [] = []
foo h:t = 9: foo t
```

Listing 2.1: Sample code

It also has a list:

Item 1 First item

Item 2 Second item and a footnote[1].

Item 3 Third item and text in *italics*.

And an enumerated list:

1. First item.
2. Second item and text in **bold**

2.2 Section 2

2.2.1 Subsection 1

This subsection has a link to the block of code 2.1 in Section 1.

2.2.2 Subsection 2

This subsection has a FIXME comment, visible only to the author.

[1] Footnote description.

Chapter 3

Chapter 3

3.1 Section 1

This how we add a url: http://www.example.org

3.2 Section 2

And this is how we point to Figure 3.1.

Figure 3.1: This is an image

3.2.1 Sub-section 3

Another way to create a list:

- Item 1

- Item 2
- Item 3
- Item 4

Chapter 4

4.1 Section 1

We can also use a special fonts to differentiate between text and $math()$.

Chapter 5

Design of cached

In the previous chapters, we have addressed the need for tiering in terms of scalability as well as performance.

We have also evaluated current caching solutions and described why they couldn’t be used as a cache tier in Archipelago.

With the results of chapter ? in mind, we can provide some more strict requirements that our solution must have:

1. Requirement 1
2. Requirement 2
3. Requirement 3
4. Requirement 4

The following two chapters are the main bulk of this thesis and they present our own implementation that aims to fill the above requirements.

More specifically, this chapter provides an in-depth description of the design of cached. Section ? provides a general overview of cached. Sections ? - ? present the building blocks of cached and their design. Section ? presents the interaction of cached and its building blocks. Finally, in Section ? we illustrate the flow of requests for cached.

5.1 General

In order to provide a caching tier for Archipelago that would blabla our requirements, we had to create our own implementation. Its name is simply cached (**cache d**aemon) and is another XSEG peer with similar structure to those seen in chapter ?

For the creation of this peer, we have created some xtypes that act as the building blocks for this peer. These xtypes are the following:

- **xcache** (for cache support)
- xwork (for job support)
- xworkq (for atomicity in execution of jobs)
- xwaitq (for conditional execution of jobs)

and their design will be discussed in-depth in the following sections.

5.2 The xcache xtype

xcache is the main component of cached. It is responsible for several key aspects of caching such as:

- object indexing
- coherency (?) and
- eviction handling
- reference counting

Below we can see a design overview of xcache:

More specifically, xcache utilizes two hash tables. One hash table is responsible for indexing objects (or more generally speaking ”cache entries”) that are active in cache. The other hash table is responsible for indexing evicted cache entries that have pending jobs. Again, more generally speaking, evicted cache entries are entries whose refcount has not dropped to zero yet.

5.2.1 Indexing

In order to index the cached objects, xcache relies on another xtype, xhash, which is a hash table. What’s more, it’s actually the C implementation of the dictionary used in Python.

We have chosen to use a hash table as our index because:

Finally, the xhash xtype gives provides us with the basic hash table functions, namely:

- Insertion
- Look-up
- Deletion

5.2.2 Eviction

When xcache reaches its maximum capacity and is requested to index a new entry, we have to resort to the eviction of an older cached entry. But, which cache entry must we evict? This is a well documented problem that was first faced when creating hardware caches (the L1, L2 CPU caches we are familiar with). In 1966, Lazlo Belady proved that the best strategy is to evict the entry that is going to be used more later on in the future[Bela66]. However, the clairvoyance needed for this strategy was a little difficult to implement, so we had to resort to one of the following, well-known strategies:

- **Random:** Simply, a randomly chosen entry is evicted. This strategy, although it seems simplistic at first, is sometimes chosen due to the ease and speed of each. It is preferred in random workloads where getting fast free space for an object is more important than the object that will be evicted.

- **FIFO (First-In-First-Out):** The entry that was first inserted will also be the first to evict. This is also a very simplistic approach as well as easy and fast. Interestingly, although it would seem to produce better results than Random eviction, it is rarely used though, since it assumes that cache entries are used only once, which is not common in real-life situations.
- **LRU (Least-Recently-Used)**
- **LFU (Least-Frequently-Used)**

Choosing the LRU strategy is usually a no-brainer. Not only does it *seem* more optimal than the other algorithms, but it has also been proven, using a Bayesian statistic model, that no other algorithm that tracks the last K references to an object can be more optimal.

Also, an added bonus is that we won't need to sacrifice speed over optimality, since that, our hash table approach allows us to create an O(1) LRU algorithm which you can see in the following figure:

In a nutshell, our LRU implementation uses a doubly linked list blablabla. This design allows us to do all of the following action in constant time:

- Insert a new entry to the LRU list
- Evict the LRU entry
- Update an entry's access time (i.e. mark it as MRU)
- Remove an arbitrary entry

Another interesting feature of xcache is that evictions occur implicitly and not explicitly. The user doesn't need to interact with the LRU queue.

For example, when a user tries to insert a new entry to an already full cache, the insertion will succeed and the user will not be prompted to evict an entry manually. Also, the user will be notified via specific event hook that is triggered upon eviction that an entry has been evicted.

More about hooks can be seen in the following subsection.

5.2.3 Hooks

The hooks that xcache provides to users are:

- on_ init: called on cache entry initialization.
- on_put: called when the last reference to the cache entry is put
- on_evict: called when a cache entry is evicted.
- on_node_init: called on initial node preparation.
- post_evict: called after an eviction has occurred, with cache lock held.
- on_free: called when a cache entry is freed.

- on_finalize: called to hint the user that the cache entry's ref has dropped to zero.
- on_reinsert: called when a cache entry has been in cache

5.2.4 Refcounts and locks

The refcount model in xcache should be familiar to most people:

- When an entry is inserted in cache, the cache holds a reference for it (ref = 1).
- Whenever a new lookup for this cache entry succeeds, the reference is increased by 1 (ref++)
- When the request that has issued the lookup has finished with an entry, the reference is decreased by 1. (ref–)
- When a cache entry is evicted by cache, the its ref is decreased by 1. (ref–)

Some common refcount cases are:

- active entry with pending jobs (ref > 1)
- active entry with no pending jobs (ref = 1)
- evicted entry with pending jobs (ref > 0)
- evicted entry with no pending jobs (ref = 0)

and, as always, the entry is freed only when its ref = 0.

Finally, xcache uses one lock for each hash table but when a cache entry shifts from one hash table to the other, both locks are acquired.

5.2.5 Re-insertion

In xcache, there is a concept called ”re-insertion”. In order for an entry to be re-inserted to the primary hash table (which will be called ”entries” from now on) it must first reside in the hash table that indexes the evicted cache entries (which will be called ”rm_entries” from now on). As mentioned above, an entry that is in rm_entries has probably pending jobs that delay its removal.

So, what happens if a lookup arrives for that entry while on this stage? In this case, we re-insert it to entries and increase its refcount by 2, since there is one reference by the hash table and one reference by the one who requested the lookup.

5.3 The xworkq xtype

Every object has a workq. Whenever a new request is accepted/received for an object, it is enqueued in the workq and we are sure that only one thread at a time can have access to the objects data and metadata.

For more information, see the xworkq.

5.4 The xwaitq xtype

When a thread tries to insert an object in cache but fails, due to the fact that cache is full, the request is enqueued in the xcache waitq, which is signaled every time an object is freed.

For more information, see the xwaitq.

5.5 Cached internals

5.5.1 Object states

Every object has a state, which is set atomically by threads. The state list is the following:

- READY: the object is ready to be used
- FLUSHING: the object is flushing its dirty buckets
- DELETING: there is a delete request that has been sent to the blocker for this object
- INVALIDATED: the object has been deleted
- FAILED: something went very wrong with this object

Also, object buckets have their own states too:

- INVALID: the same as empty
- LOADING: there is a pending read to blocker for this bucket
- VALID: the bucket is clean and can be read
- DIRTY: the bucket can be read but its contents have not been written to the underlying storage
- WRITING: there is a pending write to blocker for this bucket

Finally, for every object there are bucket state counters, which are increased/decreased when a bucket state is changed. These counters give us an O(1) glimpse to the bucket states of an object.

5.5.2 Per-object peer requests

Reads and writes to objects are practically read/write request from other peers, for which a peer request has been allocated. There are cases though when an object has to allocate its own peer request e.g. due to a flushing of its dirty buckets. Since this must be fast, there are pre-allocated requests hard-coded in the struct of each object which can be used in such cases.

5.5.3 Write policy

The user must define beforehand what is the write policy of cache. There are two options: writethrough and writeback. On a side note, as far as reads and cache misses are concerned, cached operates under a write-allocate policy.

Bibliography

[aeal99] Some author et al., “Name of citation”, in *Proceedings of the 99th ACM Symposium on Something (POPL’99)*, pp. 999–999, Nine, 9999.

[Bela66] L.A. Belady, “A study of replacement algorithms for a virtual-storage computer”, *IBM Systems Journal*, vol. 5, no. 2, pp. 78 – 101, 1966.