High level design of resource management interfaces

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[Text in square brackets and with a light-green background is a commentary explaining the structure of a design document. The rest is a fictional design document, used as a running example.]

This document presents a high level design (HLD) of scalable resource management interfaces for Mero. The main purposes of this document are: (i) to be inspected by M0 architects and peer designers to ascertain that high level design is aligned with M0 architecture and other designs, and contains no defects, (ii) to be a source of material for Active Reviews of Intermediate Design (ARID) and detailed level design (DLD) of the same component, (iii) to serve as a design reference document.

The intended audience of this document consists of M0 customers, architects, designers and developers.

0. Introduction

[This section succinctly introduces the subject matter of the design. 1--2 paragraphs.]

The following color marking is used in this document: incomplete or todo item, possible design extension or future directions.]

Mero functionality, both internal and external, is often specified in terms of *resources*. A resource is part of system or its environment for which a notion of ownership is well-defined.

1. Definitions

[Definitions of terms and concepts used by the design go here. The definitions must be as precise as possible. References to the M0 Glossary are permitted and encouraged. Agreed upon terminology should be incorporated in the glossary.]

- A *resource* is part of system or its environment for which a notion of *ownership* is well-defined. Resource ownership is used for two purposes:
    - concurrency control. Only resource owner can manipulate the resource and ownership transfer protocol assures that owners do not step on each other. That is, resources provide traditional distributed locking mechanism;
    - replication control. Resource owner can create a (local) copy of a resource. The ownership transfer protocol with the help of version numbers guarantees that multiple replicas are re-integrated correctly. That is, resources provide a cache coherency mechanism. Global cluster-wide cache management policy can be implemented on top of resources.
- A resource owner uses the resource via a *usage credit* (also called *resource credit* or simply *credit* as context permits). *E.g.*, a client might have a credit of a read-only or write-only or read-write access to a certain extent in a file. An owner is *granted* a credit to use a resource.
- A usage credit granted to an owner is *held* (or *pinned*) when its existence is necessary for the correctness of ongoing resource usage. For example, a lock on a data extent must be held while IO operation is going on and a meta-data lock on a directory must be held while a new file is created in the directory. Otherwise, the granted credit is *cached*.
- A resource belongs to a specific *resource type*, which determines resource semantics.
- A *conflict* occurs at an attempt to use a resource with a credit incompatible with already granted credit. Conflicts are resolved by a conflict resolution policy specific to the resource type in question.
- To acquire a resource usage credit, a prospective owner *enqueues* a resource acquisition *request* to a resource owner.
- An owner can relinquish its usage credits by sending a resource *cancel* request to another resource owner, which assumes relinquished credits.
- A usage credit can be associated with a *lease*, which is a time interval for which the credit is granted.

The usage credit automatically cancels at the end of the lease. A lease can be renewed.

- One possible conflict resolution policy would *revoke* all already granted conflicting credits before granting the new credit. Revocation is effected by sending *conflict call-backs* to the credits owners. The owners are expected to react by cancelling their cached credits.

2. Requirements

[This section enumerates requirements collected and reviewed at the Requirements Analysis (RA) and Requirements Inspection (RI) phases of development. References to the appropriate RA and RI documents should go here. In addition this section lists architecture level requirements for the component from the Summary requirements table and appropriate architecture documentation.]

The following requirements from the Summary Requirements Table are relevant:

- [R.M0.LAYOUT.LAYID.RESOURCE]: layids are handled as a distributed resource (similarly to fids)
- [R.M0.RESOURCE]: scalable hierarchical resource allocation is supported
- [R.M0.RESOURCE.CACHEABLE]: resources can be cached by clients
- [R.M0.RESOURCE.HIERARCICAL]: resources are distributed hierarchically
- [R.M0.RESOURCE.CALLBACK-REVOKE]: scalable call-back and revocation model: revocation can spawn multiple nodes, each owning a part of a resource
- [R.M0.RESOURCE.RECLAIM]: unused resources are reclaimed from users

Additional requirements are:

- [r.resource.enqueue.async]: a resource can be enqueued asynchronously
- [r.resource.ordering]: a total ordering of all resources is defined. Resources are enqueued according to the ordering, thus avoiding dead-locks.
- [r.resource.persistent]: a record of resource usage credit acquisition can be persistent (*e.g.*, for disconnected operation).
- [r.resource.conversion]: a resource usage credit can be converted into another usage credit.
- [r.resource.adaptive]: dynamic switch into a lockless mode.
- [r.resource.revocation-partial]: part of a granted resource usage credit can be revoked.
- [r.resource.sublet]: an owner can grant usage credits to further owners, thus organizing a hierarchy of owners.
- [r.resource.separate]: resource management is separate from actual resource placement. For example, locks on file data extents are distributed by a locking service that is separate from data servers.
- [r.resource.open-file]: an open file is a resource (with a special property that this resource can be revoked until owner closes the file).
- [r.resource.lock]: a distributed lock is a resource.
- [r.resource.resource-count]: a count of resource usage credit granted to a particular owner is a resource.
- [r.resource.grant]: free storage space is a resource.
- [r.resource.quota]: storage quota is a resource.
- [r.resource.memory]: server memory is a resource.
- [r.resource.cpu-cycles]: server cpu-cycles are a resource.
- [r.resource.fid]: file identifier is a resource.
- [r.resource.inode-number]: file inode number is a resource.
- [r.resource.network-bandwidth]: network bandwidth is a resource.
- [r.resource.storage-bandwidth]: storage bandwidth is a resource.
- [r.resource.cluster-configuration]: cluster configuration is a resource.

- [r.resource.power]: (electrical) power consumed by a device is a resource.

3. Design highlights

[This section briefly summarises key design decisions that are important for understanding of the functional and logical specifications and enumerates topics that a reader is advised to pay special attention to.]

- hierarchical resource names. Resource name assignment can be simplified by introducing variable length resource identifiers.

- conflict-free schedules: no observable conflicts. Before a resource usage credit is cancelled, the owner must re-integrate all changes which it made to the local copy of the resource. Conflicting usage credits can be granted only after all changes are re-integrated. Yet, the ordering between actual re-integration network requests and cancellation request can be arbitrary, subject to server-side NRS policy.

- resource management code is split into two parts: (i) generic code that implements functionality independent of particular resource type (request queuing, resource ordering, *etc.*) and (ii) per-resource type code that implement type specific functionality (conflict resolution, *etc.*).

- an important distinction with a more traditional design (as exemplified by the Vax Cluster or Lustre distributed lock managers) is that there is no strict separation of rôles between "resource manager" and "resource user": the same resource owner can request usage credits from and grant usage credits to other resource owners. This reflects more dynamic nature of Mero resource control flow, with its hierarchical and peer-to-peer caches.

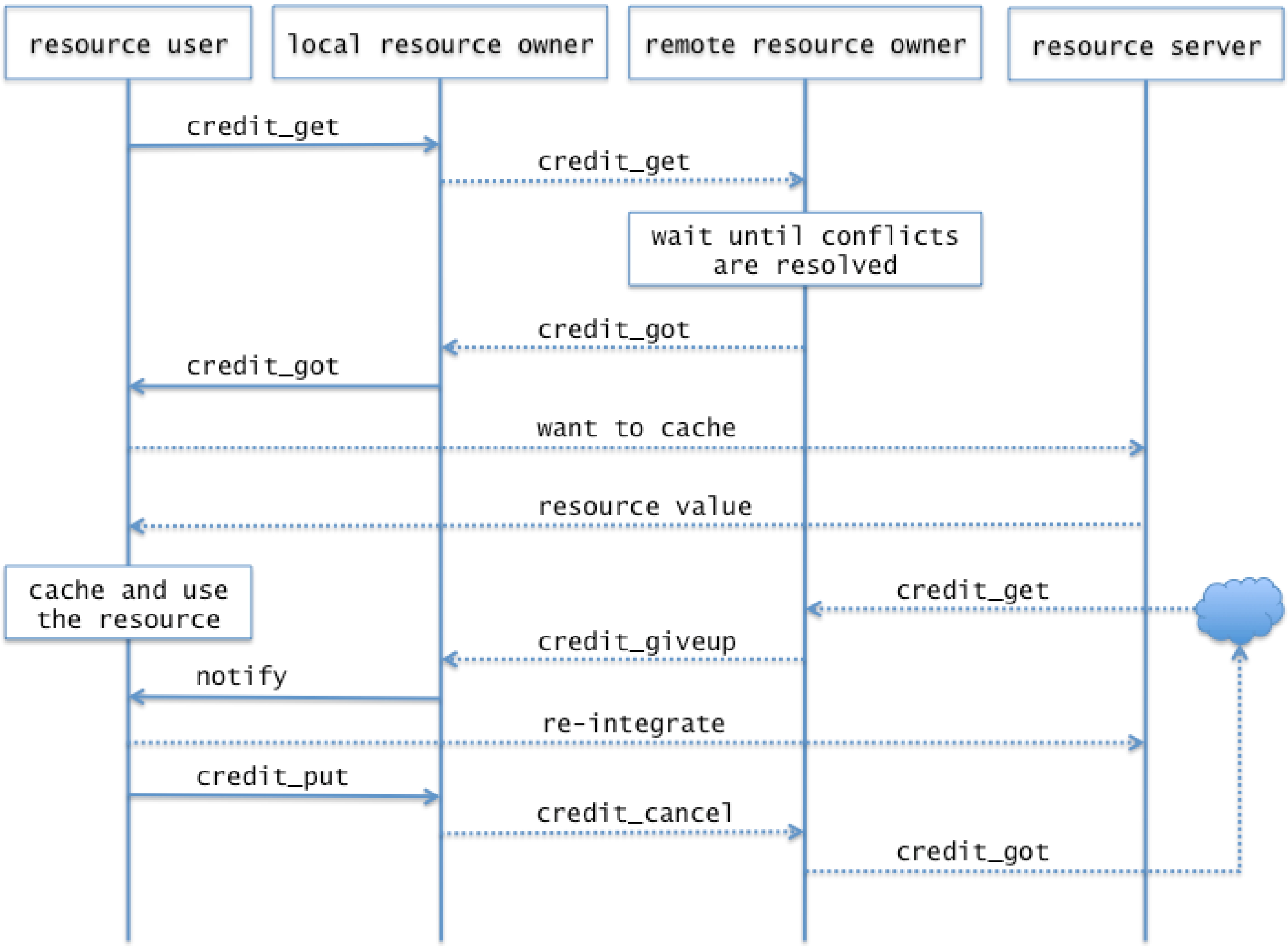
4. Functional specification

[This section defines a functional structure of the designed component: the decomposition showing *what* the component does to address the requirements.]

External resource management interface is centered around following data-types:

- a resource type;
- a resource owner;
- a usage credit;
- a request for resource usage credit.

The following sequence diagram illustrates the interaction between resource users, resource owners and resource servers.



Here a solid arrow represents a (local) function call and a dashed arrow—a potentially remote call.

External resource management interface consists of the following calls:

- credit_get(resource_owner, resource_credit_description, notify_callback): obtains the specified resource usage credit. If no matching credit is granted to the owner, the credit acquisition request is enqueued to the master resource owner, if any. This call is asynchronous and signals completion through some synchronization mechanism (*e.g.*, a condition variable). The call outcome can be one of:
    - success: a credit, matching the description is granted;
    - denied: usage credit cannot be granted. The user is not allowed to cache the resource and must use no-cache operation mode;
    - error: some other error, *e.g.*, a communication failure, occurred.

A number of additional flags, modifying call behavior can be specified:

- non-block-local: deny immediately if no matching credit is granted (*i.e.*, don't enqueue);
- non-block-remote: deny if no matching credit is granted to the master owner (*i.e.*, don't resolve conflicts).

On successful completion the granted credit is held. notify_callback is invoked by the resource manager when the cached resource credit has to be revoked to satisfy a conflict resolution or some other policy.

- credit_put(resource_credit): release held credit.

5. Logical specification

[This section defines a logical structure of the designed component: the decomposition showing *how* the functional specification is met. Subcomponents and diagrams of their interrelations should go in this section.]

A resource owner maintains:

- an owned resource usage credit description. The exact representation of this is up to the resource type. This is the description of the resource credits that are actually held by this owner at the moment. Examples:
  - for (meta-data) inode resource type: credit description is a lock mode;
  - for quota resource type: credit description is a quota amount assigned to the owner (a node, typically);
  - for a component data object: credit description is a collection of locked extents together with their lock modes. This collection could be maintained either as a list or a more sophisticated data-structure (*e.g.*, an interval tree);

- a queue of granted resource usage credits. This is a queue of triples `(credit, owner, lease)` that this owner granted to other owners. Granted credits no longer belong to this owner;

- a queue of incoming pending credits. This is a queue of incoming requests for usage credits, which were sent to this resource owner and are not yet granted, due to whatever circumstances (unresolved conflict, long-term resource scheduling decision, *etc.*);

- a queue of outgoing pending credits. This is a queue of usage credits that users asked this resource owner to obtain, but that are not yet obtained.

5.1. Conformance

[For every requirement in the Requirements section, this sub-section explicitly describes how the requirement is discharged by the design. This section is part of a requirements tracking mechanism, so it should be formatted in some way suitable for (semi-)automatic processing.]

- [R.M0.LAYOUT.LAYID.RESOURCE], [r.resource.fid], [r.resource.inode-number]: layout, file and other identifiers are implemented as a special resource type. These identifiers must be globally unique. Typical identifier allocator operates as following:
  - originally, a dedicated "management" node runs a resource owner that owns all identifiers (*i.e.*, owns the `[0, 0xffffffffffffffff]` extent in identifiers name-space);
  - when a server runs short on identifiers (including the time when the server starts up for the first time) it enqueues a credit request to the management node. credit description is simply the number of identifiers to grant. The management node's resource owner finds a not-yet

    granted extent of suitable size and returns it to the server's resource owner;
  - depending on identifier usage, clients can similarly request identifier extents from the servers;
  - there is no conflict resolution policy;
  - identifiers can be cancelled voluntary: *e.g.*, an inode number is cancelled when the file is deleted and fid range is cancelled when client disconnects or is evicted.

- [R.M0.RESOURCE], [R.M0.RESOURCE.HIERARCICAL]: resource owner can enqueue credit requests to other ("master") owners and at the same time bestow credits to "slave" owners. This forms a hierarchy of owners allowing scalable resource management across the cluster.

- [R.M0.RESOURCE.CACHEABLE]: it is up to resource type to provide conflict resolution policy such that an owner can safely use cached resource while it possesses corresponding usage credits.

- [R.M0.RESOURCE.CALLBACK-REVOKE]: scalable call-back and revocation model: revocation can spawn multiple nodes, each owning a part of a resource.

- [R.M0.RESOURCE.RECLAIM]: a resource owner can voluntary cancel a cached usage credit.

Additional requirements are:

- [r.resource.enqueue.async]: credit_get entry point is asynchronous by definition.

- [r.resource.ordering]: a total ordering of all resources is defined. Resources are enqueued according to the ordering, thus avoiding dead-locks.
- [r.resource.persistent]: a record of resource usage credit acquisition can be persistent (*e.g.*, for disconnected operation).
- [r.resource.conversion]: a resource usage credit can be converted into another usage credit.
- [r.resource.adaptive]: dynamic switch into a lockless mode.
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- [r.resource.storage-bandwidth]: storage bandwidth is a resource.
- [r.resource.cluster-configuration]: cluster configuration is a resource.
- [r.resource.power]: (electrical) power consumed by a device is a resource.

5.2. Dependencies

[This sub-section enumerates other system and external components the component depends on. For every dependency a type of the dependency (uses, generalizes, *etc.*) must be specified together with the particular properties (requirements, invariants) the design depends upon. This section is part of a requirements tracking mechanism.]

5.3. Security model

[The security model, if any, is described here.]

5.4. Refinement

[This sub-section enumerates design level requirements introduces by the design. These requirements are used as input requirements for the detailed level design of the component. This sub-section is part of a requirements tracking mechanism.]

In addition to external entry points, resource management introduces some internal interfaces:

5.a. resource type methods

Implementations of these methods are provided by each resource type. See examples below.

- matches(credit_description0, credit_description1) method: this method returns true iff a credit with description credit_description0 is implied by a credit with description credit_description1. For example, extent lock L0 matches extent lock L1 iff L0's extent is part of L1's extent and L0's lock mode is compatible with L1's lock mode. More generally, for lock-type resources, matching is the same as lock compatibility.

5.2. credit_get(owner, credit_description)

- if matches(credit_description, owner.credit_description)

6. State

[This section describes the additions or modifications to the system state (persistent, volatile) introduced by the component. As much of component behavior from the logical specification should be described as state machines as possible. The following sub-sections are repeated for every state machine.]

6.1. States, events, transitions

[This sub-section enumerates state machine states, input and output events and state transitions incurred by the events with a table or diagram of possible state transitions. UML state diagrams can be used here.]

6.2. State invariants

[This sub-section describes relations between parts of the state invariant through the state modifications.]

6.3. Concurrency control

[This sub-section describes what forms of concurrent access are possible and what forms on concurrency control (locking, queuing, *etc.*) are used to maintain consistency.]

7. Use cases

[This section describes how the component interacts with rest of the system and with the outside world.]

7.1. Scenarios

[This sub-section enumerates important use cases (to be later used as seed scenarios for ARID) and describes them in terms of logical specification.]

Scenario	[usecase.component.name]
Relevant quality attributes	[*e.g.*, fault tolerance, scalability, usability, re-usability]
Stimulus	[an incoming event that triggers the use case]
Stimulus source	[system or external world entity that caused the stimulus]
Environment	[part of the system involved in the scenario]
Artifact	[change to the system produced by the stimulus]
Response	[how the component responds to the system change]
Response measure	[qualitative and (preferably) quantitative measures of response that must be maintained]
Questions and issues	

[UML use case diagram can be used to describe a use case.]

7.2. Failures

[This sub-section defines relevant failures and reaction to them. Invariants maintained across the failures must be clearly stated. Reaction to Byzantine failures (*i.e.*, failures where a compromised component acts to invalidate system integrity) is described here.]

8. Analysis

8.1. Scalability

[This sub-section describes how the component reacts to the variation in input and configuration parameters: number of nodes, threads, requests, locks, utilization of resources (processor cycles, network and storage bandwidth, caches), *etc.* Configuration and work-load parameters affecting component behavior must be specified here.]

8.2. Other

[As applicable, this sub-section analyses other aspects of the design, *e.g.*, recoverability of a distributed state consistency, concurrency control issues.]

8.2. Rationale

[This sub-section describes why particular design was selected; what alternatives (alternative designs and variations of the design) were considered and rejected.]

Why revocation call-back is different from credit_get()?

9. Deployment

9.1. Compatibility

[Backward and forward compatibility issues are discussed here. Changes in system invariants (event ordering, failure modes, *etc.*)]

9.1.1. Network

9.1.2. Persistent storage

9.1.3. Core

[Interface changes. Changes to shared in-core data structures.]

9.2. Installation

[How the component is delivered and installed.]

10. References

[References to all external documents (specifications, architecture and requirements documents, *etc.*) are placed here. The rest of the document cites references from this section. Use Google Docs bookmarks to link to the references from the main text.]