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ÚSTAV INFORMAČNÍCH SYSTÉMŮ

MONITORING THE OPENSTACK SWIFT OBJECT STORE USING BEANSTALK EVENTS

SLEDOVÁNÍ OBJEKTOVÉHO ÚLOŽIŠTĚ OPENSTACK SWIFT POMOCÍ BEANSTALK UDÁLOSTÍ

MASTER'S THESIS

DIPLOMOVÁ PRÁCE

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Assignment:

1. Explore OpenStack Swift object storage, especially its architecture and activities. Study also MinIO object storage. Learn about the object storage OpenIO Software Defined Storage and in which way it uses Beanstalk to monitor and distribute events over the storage.
2. Design a service that will monitor activities in OpenStack Swift and, following the pattern of OpenIO, publish Swift events using the Beanstalk protocol. Consider also the ability to monitor and publish events from MinIO.
3. After consulting with the supervisor, implement the proposed service over OpenStack Swift/MinIO so that compatibility with OpenIO is guaranteed. For verification, also implement a sample client that will be able to subscribe to events using Beanstalk from both OpenIO and OpenStack Swift/MinIO.
4. Test the solution, evaluate and discuss the results. Publish the resulting software as open-source.

Recommended literature:

- Raúl GRACIA-TINEDO, Josep SAMPÉ, Gerard PARÍS, Marc SÁNCHEZ-ARTIGAS, Pedro GARCÍA-LÓPEZ and Yosef MOATTI: Software-defined object storage in multi-tenant environments. *Future Generation Computer Systems*. 99, 54-72, 2019. ISSN 0167-739X. Available at [<https://doi.org/10.1016/j.future.2019.03.020>]
- OpenStack Docs: Object Storage monitoring. The OpenStack project [online]. 2021 [seen 2021-09-29]. Available at [<https://docs.openstack.org/swift/ussuri/admin/objectstorage-monitoring.html>]
- Send notifications on PUT/POST/DELETE requests - swift-specs 0.0.1.dev82 documentation. OpenStack Foundation [online]. 2016 [seen 2021-09-29]. Available at [https://specs.openstack.org/openstack/swift-specs/specs/in_progress/notifications.html]

Requirements for the semestral defence:

- Items 1 and 2 finished and item 3 in progress.

Detailed formal requirements can be found at <https://www.fit.vut.cz/study/theses/>

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Abstract

The goal of this thesis is to create software that is able to monitor and publish event notification from Openstack Swift as well as from OpenIO Software Defined Storage (SDS) to Beanstalk queue. This thesis also proposes solution for publishing event notifications from MinIO to Beanstalk queue.

To accomplish this goal, new middleware is proposed that can be run inside pipeline of Proxy Server in OpenStack Swift and as (filter) part of asynchronous service Event-Agent inside OpenIO SDS.

Proposed middleware allows users to specify if they are interested in publishing event notifications for specific objects/containers using metadata. User can specify set of rules involving object properties, such as name (prefix, suffix, substring) and size, and only events satisfying those rules will be published.

The contribution of this thesis is unique software capable of event monitoring from both OpenIO SDS and Openstack Swift.

Abstrakt

Cílem této práce je vytvořit software, který je schopen monitorovat a publikovat notifikace o události z Openstack Swift i z OpenIO Software Defined Storage (SDS) do fronty Beanstalk. Tato práce také navrhuje řešení pro publikování notifikací o událostech z MinIO do fronty Beanstalk.

K dosažení tohoto cíle je navržen nový middleware, který lze spouštět uvnitř pipeline proxy serveru v OpenStack Swift a jako (filtr) součást asynchronní služby Event-Agent uvnitř OpenIO SDS.

Navržený middleware umožňuje uživatelům určit, zda mají zájem o publikování notifikací o události pro konkrétní objekty/kontejnery pomocí metadat. Uživatel může specifikovat sadu pravidel zahrnující vlastnosti objektu, jako je název (prefix, přípona, podřetězec) a velikost, a budou publikovány pouze události splňující tato pravidla.

Přínosem této práce je unikátní software schopný monitorování událostí z OpenIO SDS i Openstack Swift.

Keywords

OpenIO Software Defined Storage, Openstack Swift, MinIO, Beanstalk queue, Event monitoring, Event notification, Amazon S3 event notification, Object storage

Klíčová slova

OpenIO Softwarově definované úložiště, Openstack Swift, MinIO, Beanstalk fronta, Monitorování událostí, Oznámení o událostech, Amazon S3 oznámení o události, Objektové úložiště

Reference

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Monitoring the OpenStack Swift Object Store Using Beanstalk Events

Declaration

Prohlašuji, že jsem tuto bakalářskou práci vypracoval samostatně pod vedením pana X... Další informace mi poskytli... Uvedl jsem všechny literární prameny, publikace a další zdroje, ze kterých jsem čerpal.

.....
Nemanja Vasiljević
December 30, 2021

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Chapter 1

Introduction

In the current world, cloud computing became the most popular way of delivering different types of services through Internet. One of the most popular cloud service is cloud storage, which allows users to store data in remote locations maintained by third party. Based on how cloud storage manages data, cloud storage can be divided into 3 types: Block storage, File storage and Object storage. Object storage manages data as objects, each object typically includes data itself and some additional informations stored in objects metadata. Since data are stored in remote locations, to which users don't have direct and complete access, some users or external services might want to receive informations about certain events (for example change of content) in storages where their data are located.

Importance of this thesis is to provide event informations to users in OpenIO SDS and OpenStack Swift, which will allow user to react on those events and possibly prevent/detect unwanted actions. Providing event notifications will allow users to have better picture on what is going on in their storage and improve monitoring in these object storages.

There were two attempts[9][10] to solve this issue within OpenStack Swift which were not officially accepted and their solution is outdated. Currently there is no official solution for publishing event notification in OpenStack Swift nor OpenIO Software-Defined Storage (hereinafter SDS).

My interest in this topic stems from its possible impact to extensive amount of users that OpenStack Swift and OpenIO have. Contributing to open source projects is something that I always wanted to be part of. Possibility to improve user experience in OpenStack Swift and OpenIO SDS and allow those storages to be even more competitive against commercial storages (Amazon, Google, ...) is another reason why I choose this topic.

The goal of this thesis is to create program/middleware which will publish event notification to user specified destination. One of supported destination will be Beanstalk queue, but program will allow to easily add other types of destinations (for example Kafka) using predefined interface. Proposed program will allow user to specify, using objects metadata (such as name prefix/suffix and object size) and type of event, which event notification should be published. Program will be able to run within OpenStack Swift as well as OpenIO SDS. This thesis will strive to find such solution that could be officially accepted as part of OpenStack Swift and OpenIO SDS.

Structure of thesis - TODO - there will be probably change in chapters structure

Chapter 2

Background

This chapter introduces Object storage and its core concepts along with the underlying technologies. For sufficient understanding its important to explain how Software-defined storage manages data and what types of events can occur inside. The last part of this chapter describes concept of event notifications, why are they important and current interfaces for publishing event notifications to users.

2.1 Object storage

Object storage, also known as *object-based storage* (OBS), is type of storage that handles data as objects, instead of hierarchical methods used in file systems[21]. Object stores are designed at handling data as whole objects, making them ideal solution for any unchanging data. Data in object stores are changed by replacing objects or files and therefore object stores are preferred mechanism for storing such files[22].

2.1.1 Key concepts

Key concepts of object storage are[15]:

- Objects - An object typically consist of user data and metadata uploaded to object storage.
- Containers/Buckets - represents logical abstraction that is used to provide a data container in object storage. An object with same name in two different containers represents two different objects. This concept is used to segregate data using bucket ownership and a combination of public and secret keys bound to object store accounts which allows users and application to manipulate with data that are authorized for specific type of manipulation (read/write/update).
- Metadata - Additional information about data, create and last modified date, size, hash,...
- Access Control Lists(ACLs) - used as primary security construct in object storage, stored in account or bucket level and allows owners to grant permissions for certain operations based on UUID, email, ...
- Object Data protection - two main schemes of data protections in object storage are **Replication** and **Erasure Coding**.

Replication is method to ensure data resilience. Data are copied into multiple locations/disks/partitions, in case of failure, data are used from secondary copy, either to recreate original copy or as main copy.

Erasur coding is process through the data is separated into fragments. Then fragments are expanded and encoded with redundant pieces and stored across different storage devices. Erasure coding adds redundancy and allows object storage to tolerate failures.

2.1.2 Object data

With object storage techniques, each object contains[15]:

- Data - user specified data that needs to be stored in persistent storage. It can be binary data, text file, image, etc..
- Metadata - Extra data describing objects data and can be divided into two types: Device-managed metadata is additional information maintained by storage device and used as part of object management in physical storage.[21]. Second type is Custom metadata, where user can store any additional information in key and value pairs. In object storage metadata are stored together with the object.
- A universally unique identifier (UUID) - This ID, created using hashing process based on object name and some other additional informations, is assigned to each object in a Object storage. Using ID object storage systems are capable of tell a part objects from one another and ID is used to extract data in system without knowing their physical location/drive and offset.

2.1.3 Access to object storage

Object storage services provide RESTful interface [24] over HTTP protocol for objects store and access. This approach allows users to create, read, delete, update or even query objects anytime and anywhere simply by referencing UUID (or using certain attributes for querying), usually with proper authentication process. Most popular interfaces for communicating with object storages are Amazon S3 (Simple Storage Service) API and OpenStack Swift API.

2.1.4 Pros and cons of object storage

Pros:

- Capable of handling large amount of unstructured data
- Reduced TCO and cheap COTS - Object storage is designed to utilize cheap COTS(Commercial off-the-shelf) components, as result Total Cost of Ownership(TCO) is lower then owning home-made Network-Attached Storages(NAS)[22].
- Unlimited scalability - Since object storages are build on distributed systems, they scale very well compared to traditional storages where they often have upper limit.[14]
- Wide-open metadata - allows users to store custom metadata and possibility of creating metadata-driven policies, such as compression and tiering.

Cons:

- No in-place update - object must be manipulated as whole unit
- No locking mechanism - object storage does not manage object-level locking and it is up to applications to solve concurrent PUT/GET.
- Slower - this makes object storages poor choice for applications that need rapid and frequent access to data.

2.2 Software-Defined storage

Software-Defined storage (SDS) is storage architecture which separates software storage from hardware allowing greater scalability, flexibility and control over data storage infrastructure. With growth of Software-Defined Networks (SDN) and need of Software-Defined Infrastructure (SDI), which aims to virtualize network resources and separate control plane from data plane, this principle was needed to be applied on Object storages as well[17].

To overcome limitations of traditional storage infrastructures, the Software-Defined Storage (SDS) is imposed as proper solution to simplify data and configuration management, while improving end-to-end control functionality of conventional storage systems[20]. While traditional storages like storage area networks (SAN) and network-attached storage (NAS) provides scalability and reliability, SDS provides it with much lower cost by utilizing industry-standard or x86 system and therefore removing dependency on expensive hardware[12].

2.2.1 Principles

There is no clear definition on criteria for defining software-defined storage, although several key principles can be deduced[16]:

- Scale-out - SDS should enable low-cost horizontal scaling (by adding new commodity hardware to existing infrastructure) compared to vertical scaling with more powerful (and expensive) hardware.
- Customizable - SDS should offer system storage customization to meet specific storage QoS requirements. This will allow users to choose storage solution based on their requirements/performance and avoid unnecessary overpaying.
- Automation - once QoS is defined process of deployment and monitoring on object storage should be automated and done without need to human resources.
- Masking - SDS can mask underlying storage system and distributed system as long as they provide common storage API and meet required QoS. For SDS can offer block or File API even though data are saved in object storage (like Ceph does).
- Policy Management - SDS Software must manage storage according to specified policies and QoS requirements despite being in multi-tenant space. SDS must be capable to handle failures and autoscale in case of change in workloads.

2.2.2 Architecture

As previously described, the main characteristic of SDS is to separate storage functions into control plane and data plane.

Control plane - the control plane represents an abstraction layer with main goal to virtualize storage resources. It offers high-level functions that are needed by the customer to run the business workload and enable optimized, flexible, scalable, and rapid provisioning storage infrastructure capacity. These capabilities span functions like policy automation, analytics and optimization, backup and copy management, security, and integration with the API services, including other cloud provider services[19].

Data plane - the data plane encompasses the infrastructure where data is processed. It consists of all basic storage management functions, such as virtualization, RAID protection, tiering, copy services (remote, local, synchronous, asynchronous, and point-in-time), encryption, compression, and data deduplication that can be requested by the control plane. The data plane is the interface to the hardware infrastructure where the data is stored. It provides a complete range of data access possibilities and spans traditional access methods, such as block I/O (for example, iSCSI), File I/O (NFS, SMB, or Hadoop Distributed File System (HDFS)), and object-storage[19].

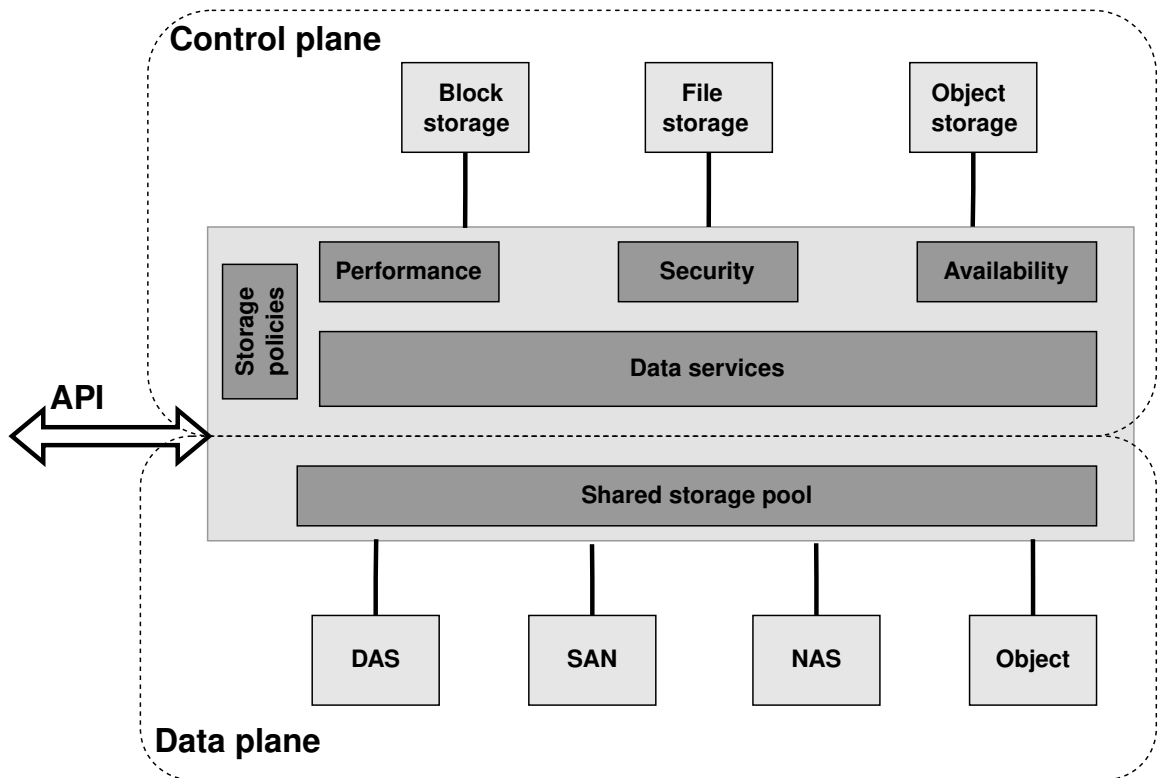


Figure 2.1: SDS data and control plane.[11], remade

2.3 Beanstalk queue

Beanstalk queue or shorter beanstalkd is fast, simple and lightweight working queue[1]. Main use case is to manage workflow between different parts of workers of application through working queues and messages. Beanstalkd was developed for need of Facebook application in order to reduce average response time[3]. Provided by simple protocol design, heavily inspired by memcached, implemented in programming language C, Beanstalkd offers lean

architecture which allows it to be installed and used very simply, making it perfect for many use cases[8].

2.3.1 Beanstalkd elements

Beanstalkd is priority queue with server-client architecture. Server represents queues where jobs are saved based on priority. Beanstalkd architecture is composed from several components:

- Jobs - tasks stored by client
- Tubes - used for storing tasks, each tube contains a ready queue and a delay queue.
- Producer - create and send jobs to beanstalkd using command „put“
- Consumer - process „listening“ on assigned tube, reserves and consumes jobs from tube

2.3.2 Job Lifecycle

Each job is uniquely assigned to one worker at a time. A job in beanstalkd is created by client using „put“ command. While being in tube, job can be in next states[4]:

- READY - the task is free and can be executed immediately by consumer.
- DELAYED - the task has assigned delay time that needs to expire before execution. After delay time expires, beanstalkd will automatically change it state to READY.
- RESERVED - the task is reserved and is being executed by consumer. Beanstalkd is responsible for checking whether the task is completed in time (TTR - Time to run).
- BURIED - reserved task, the task will not be removed nor executed until client decides. This state is often used for further inspection in debug process when failure or undefined behavior occurs during task execution.
- DELETED - the task is deleted from tube, beanstalkd no longer maintains these jobs.

Figure 2.2 describes life cycle of job in beanstalkd tube. Job is created by Producer using put command. Beanstalkd allows Producer to add delay time before task will be ready for execution, which sets job state to DELAYED. After delay time expires, beanstalkd will automatically change job state to READY. Producer can specify job priority and jobs with READY state are stored in priority queue. Job with biggest priority is reserved and executed by Consumer. After successfully executing the task, Consumer will delete job from beanstalkd. If some error occurred, Consumer can bury the task. Consumer can decide that is not interested in completing reserved task. Using release command (with optional delay) job state will be changed back to READY (or DELAY). Jobs with BURIED state will not be touch by beanstalkd server until client „kicks“ them to READY state.

2.3.3 Key characteristics

Key beanstalkd characteristics are:

- Asynchronous - beanstalkd allows producers to put jobs in queue and workers can process them later.

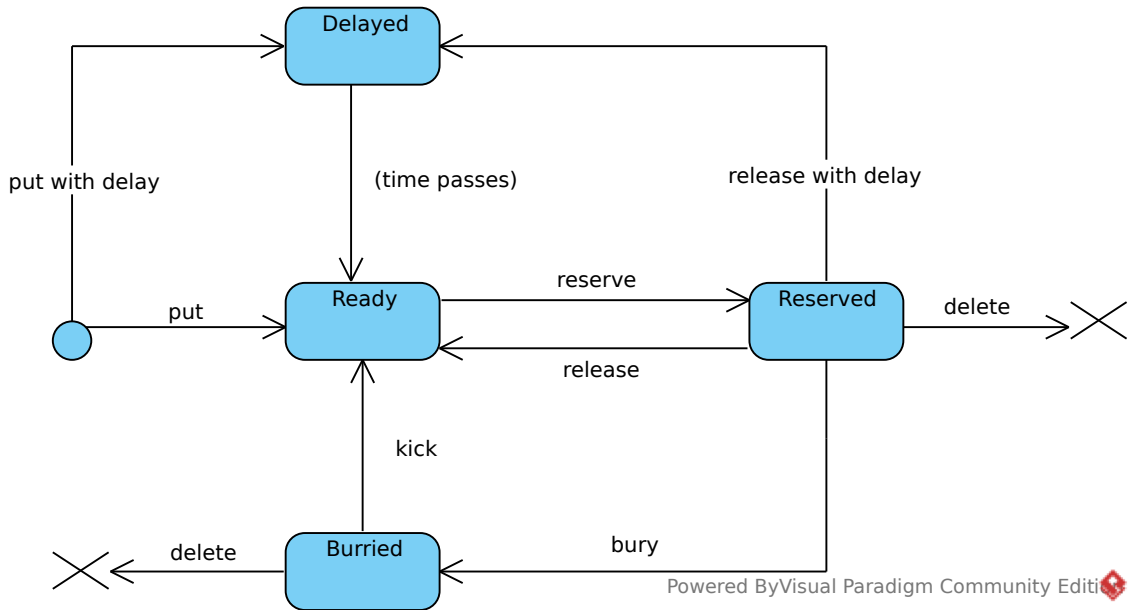


Figure 2.2: State machine diagram of job in Beanstalkd tube

- Distributed - in a same way as memcached, beanstalkd can be distributed although this distribution is handled by clients. The beanstalkd server doesn't know anything about other beanstalkd instances that are running.
- Persistent - beanstalkd offers support for persistent jobs during which all jobs are written to binlog. In case of power outage, after restarting beanstalkd instance will recover jobs content from the logs.
- Not secured - beanstalkd is designed to be run in private/secured network. Therefore it does not support authentication nor authorization.
- Scalability - beanstalkd can be scaled horizontally, although it must be done on client side, where each client would connect to multiple servers and then use specific algorithms(e.g. Round-robin) to switch between the different servers.

2.4 Event notifications

An event is a runtime operation, executed by a software element, representing significant change or occurrence in system. Event is created in order to make some information available to other software elements not specified by the operation[23].

Event notification is a message, created by system in order to inform other to notify other parts of system that an event has taken place[13]. Event notifications are used for monitoring and asynchronous job processing.

In object storage, event notifications are used as mean to notify users or tenants about specific changes and occurrences in their bucket or account. Typical event notifications are regarding creating new (or updating existing) objects in bucket. Most object vendors offer Publish/subscribe notifications, which allows users to subscribe to certain type of event notifications using predefined types of rules. Information about rules specifying event notifications are usually stored in metadata of upper level (bucket or account).

2.4.1 CloudEvents

Publishers tend to describe event data differently due to non-existing standard or format. The lack of common way to describe events means that developers have to learn how to handle events for each event source. To solve this problem CloudEvents was created.

CloudEvents is a specification for describing event data in a common way[6] hosted by Cloud Native Computing Foundation (CNCF)[5]. CloudEvents goal is to dramatically simplify event specification and delivery across services, platform and beyond. CloudEvents has been integrated by many popular object storage vendors, such as Oracle Cloud, IBM Cloud Code Engine, Azure, Google Cloud etc.

Specification Attributes in CloudEvents specification can be divided into 3 categories.

REQUIRED Attributes - set of attributes that are required to be included in all events[7]:

- id (string) - event identifier, must not be empty.
- source (URI-reference) - identifies context in which event occurred, must not be empty.
- specversion (string) - the version of CloudEvents specification, must not be empty.
- type (string) - value describing type of occurred event. Often this attribute is used for policy enforcement, routing and monitoring.

Event data attributes are attributes containing and describing event data:

- datacontenttype (string) - content type of data value (allows data to carry any type of content).
- dataschema (URI) - identifies the schema that data adheres to.
- data - data payload

OPTIONAL attributes:

- time - timestamp
- subject (string) - the subject of the event in the context of the event producer.
- extension attributes - custom attributes allowing external systems to attach metadata to an event.

Example:

```
{
  "specversion" : "1.0",
  "type" : "com.github.pull_request.opened",
  "source" : "https://github.com/cloudevents/spec/pull",
  "subject" : "123",
  "id" : "A234-1234-1234",
  "time" : "2018-04-05T17:31:00Z",
  "comexampleextension1" : "value",
  "comexampleothervalue" : 5,
  "datacontenttype" : "text/xml",
  "data" : "<much wow=\"xml\"/>"
}
```

2.4.2 Amazon S3 event notifications

Amazon Simple Storage Service (S3) is one of the most popular cloud object storages providing REST web service interface. Amazon S3 is reliable, scalable and commercial object storage that manages Web-Scale computing by itself[18]. Amazon S3 had big impact on object storage and most of other object storage vendors created compatible S3 API for their services.

One of the monitoring features that Amazon S3 provides is Event Notification, feature offering users to receive notifications when certain event happens in their S3 bucket. To enable such notifications, users need to create notification configuration that identifies which events Amazon S3 should publish[2]. Notifications are configured at the bucket level and then applied to each object in the bucket.

Amazon S3 provides limited event destinations to which event notification messages can be sent[1]:

- Amazon Simple Notification Service (Amazon SNS) - flexible, fully managed push messaging service, can be used to send messages to mobile phones or distributed services.
- Amazon Simple Queue Service (Amazon SQS) queues - reliable and scalable hosted queues for storing messages as they travel between computers.
- AWS Lambda - serverless, event-driven compute service. Lambda can run custom code in response to Amazon S3 bucket event (if lambda function writes to same bucket that triggers the notification, it can create an execution loop).
- Amazon EventBridge - serverless event bus used for receiving events from AWS. It allows users to define rules to match events and deliver them to defined targets.

By this date, Amazon S3 does not support CloudEvents specification and describes event data in their own way. Some of event types that Amazon S3 can publish are[1]:

Event type	Description
s3:TestEvent	after enabling the event notifications, Amazon S3 publishes a test notification to ensure that topic exist and bucket owner has permissions to publish specified topic.
s3:ObjectCreated:*	An object was created (regardless on operation).
s3:ObjectCreated:Put	An object was created by an HTTP PUT operation.
s3:ObjectCreated:Post	An object was created by HTTP POST operation.
s3:ObjectCreated:Copy	An object was created an S3 copy operation.
s3:ObjectCreated:CompleteMultipartUpload	An object was created by the completion of a S3 multi-part upload.
s3:ObjectRemoved:*	An object was removed (regardless on operation).
s3:ObjectRemoved:Delete	An object was deleted by HTTP DELETE operation.
s3:ObjectRemoved:DeleteMarkerCreated	An versioned object was marked for deletion.

Chapter 3

OpenIO SDS

Chapter 4

OpenStack Swift

Chapter 5

MinIO

Chapter 6

Solution draft

6.1 Current state

6.2 Middleware for OpenStack Swift and OpenIO SDS

6.3 Adapter for MinIO

Chapter 7

Implementation, experiments and assessment

Chapter 8

Conclusion

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