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ICSC
Centro Nazionale di Ricerca in HPC, Big Data and Quantum Computing

Interoperable Data Lake (IDL)

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''ICSC and Spoke2 – Where Are We Now?'' ,
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Outline

- Introduction
- Space Situational Awareness use case
- Metadata Management
- The Datalake
- Data Certification

Interoperable Data Lake: Overview

"The Project aims at creating a Data Lake service, supporting a seamless access to space and ground-based observations and simulated data. The project addresses the design and commissioning of an interoperable, distributed data archive, relying on state-of-the-art open technologies, supporting both science and industry.

The service will specifically address the challenges related to the big data scenario, in terms of both data management, storage, access, identification and of access to computing resources"

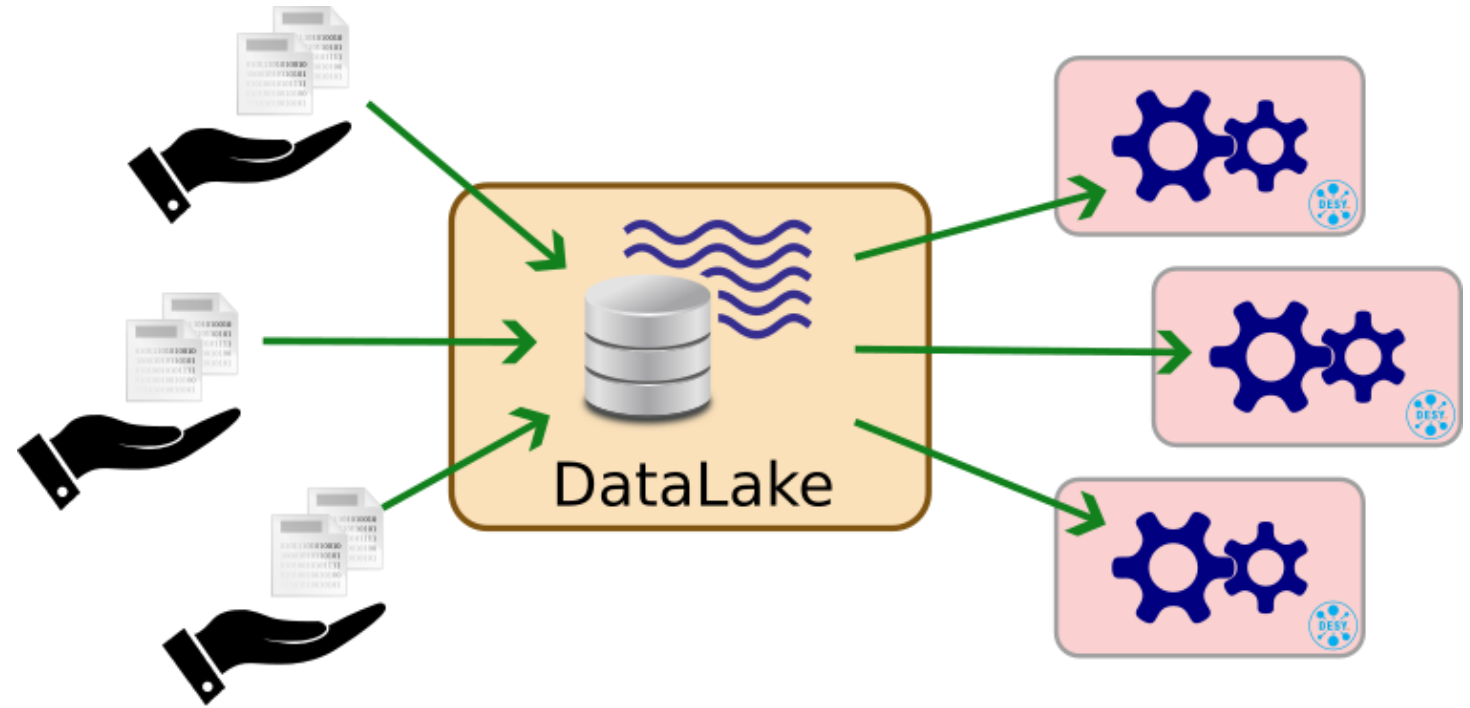
LEONARDO

ThalesAlenia Space

INAF

INFN Istituto Nazionale di Fisica Nucleare

Integration with science and industry use cases



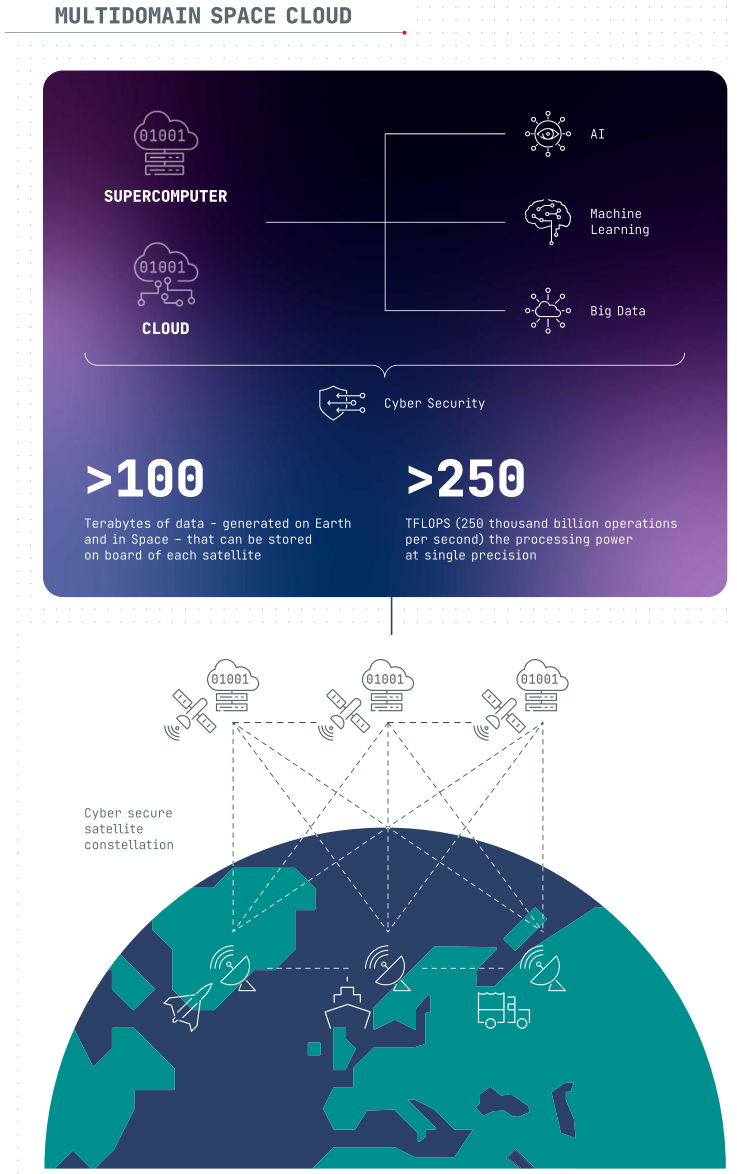
Use case: Space Situational Awareness (SSA)

SSA refers to the knowledge of the space environment, including location and function of space objects and space weather phenomena. SSA is generally understood as covering three main areas:

- Space Surveillance and Tracking (SST) of man-made objects -> Space Debris
- Space WEather (SWE) monitoring and forecast
- Near-Earth Objects (NEO) monitoring (only natural space objects)

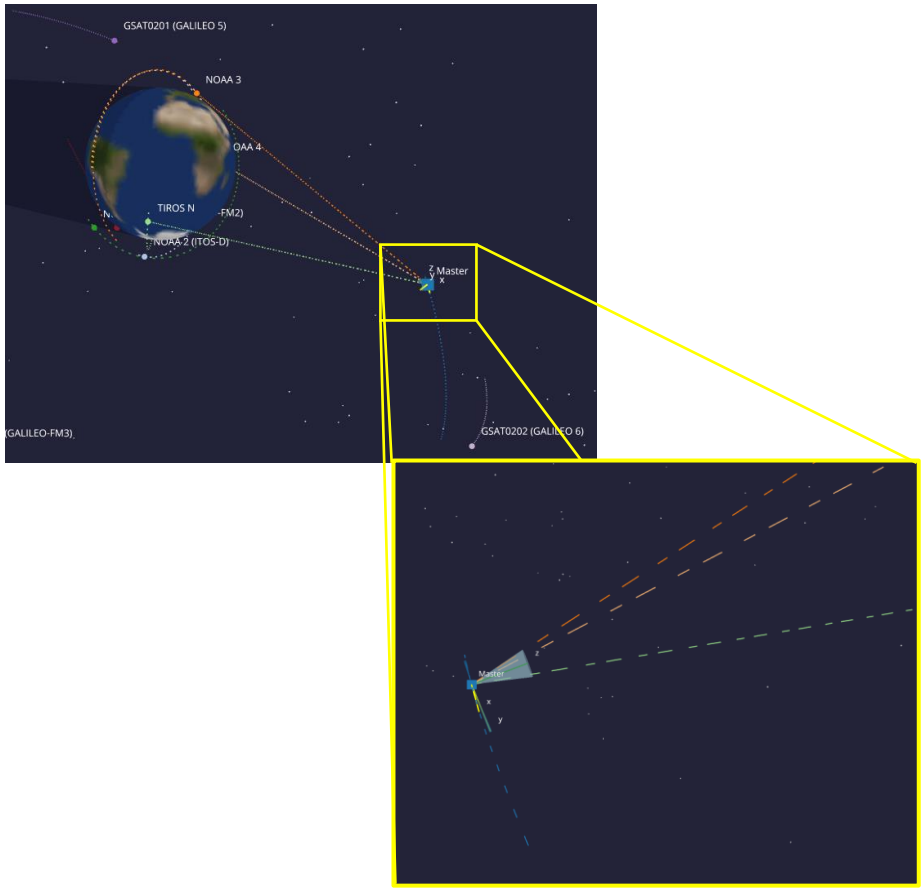
Space sensors in both in Low Earth Orbit (LEO), Medium Earth Orbit (MEO) and Geostationary Earth Orbit (GEO) are suitable to provide:

- **Operation and continuity**: space-based surveillance and tracking are not impacted by atmospheric and weather conditions and by day and night cycles
- **Accuracy**: space-based measurements are not affected by the impairments of the atmosphere
- **Global coverage**: space sensors are designed and deployed to complement and augment the coverage of ground-based assets, whose installation/operation is precluded in remote and oceanic areas
- **Responsiveness**: space sensors can improve the revisit of the space volume(s) requiring “constant” monitoring; further, space-based data relay (i.e. inter-satellite links) can provide real time tasking and fast telemetry transmission of/by space sensors.



Architecture and algorithms for data processing

Objective: To build a simulation software able to generate synthetic data coming from space-based SSA sensors whilst evaluating the computational load of the data processing chain



✓ Sensors and algorithms have been identified, the research conducted has been delivered inside the first deliverable of the WP and a report.

✓ The simulator has been designed to be composed by independent modules:
- Objects state module: tasked with objects orbit and attitude simulation and event handling
- RF module: tasked with the generation of signals and baseband digital signal processing analysis for feature extraction
- Optical module: tasked with satellites and Resident Space Objects image generation using a GAN algorithm and image feature extraction using a CNN

✓ The simulator is currently in its first integration phase (end foreseen in Q1 2025):
- The Objects state module has already been developed and validated
- The RF module is currently under validation using Monte Carlo simulations
- The optical module development is foreseen to be started in Q1 2025

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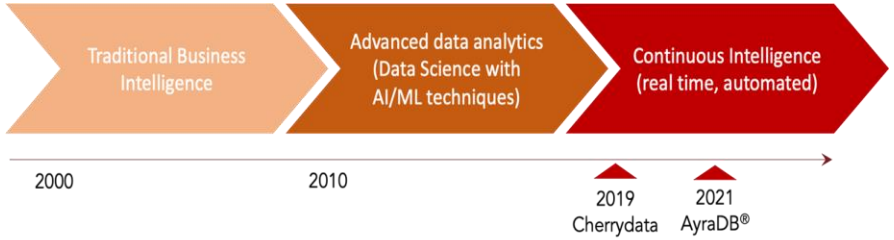
AyraDB as a metadata database for the "space debris" use case, objectives

- In the IDL system, data are stored on a data lake, while metadata are stored on a dedicated database
- AyraDB (high-performance database designed by Cherrydata, www.ayradb.com) has been chosen as metadata DB
- The objective is to maximise query performance by executing SQL queries on the metadata database (AyraDB) and retrieving from the data lake only the requested data
- The implementation of AyraDB has been designed to minimise response time to queries operating on large tables
- Preliminary tests have been performed on synthetic metadata (1 billion records)

Cherrydata is a startup (and a spinoff of PoliMi), offering consulting, innovation, and research services on big data and analytics.



- *AyraDB has been tested on Leonardo Davinci-1 supercomputer in 2022, as part of Euro NCC project.*
- *Cherrydata is involved in IDL as technology provider, to test AyraDB in the context of storing and querying astrophysical data and satellite measurements.*

Metadata: Preliminary Results

- Various queries selecting records in a specific time interval has been executed on the 1-billon rows metadata table
- An example of query is the following:

```
SELECT START_TIME, LINK FROM ayradb.IDL_dumped
WHERE START_TIME > toDateTime64('2018-04-23 15:23:57') AND
STOP_TIME < toDateTime64('2018-04-23 15:30:00')
```

- This query has scanned the metadata table and returned 1700 records (out of 1 billion records in the table), in a time of 600 milliseconds

Metadata table

Column index	Column label	SQL type	Constant value
1	IDL_L4_VERS	String	0.1
2	COMMENT	String	
3	CREATION_DATE	DateTime64	
4	ORIGINATOR	String	CELESTRAK
5	TIME_SYSTEM	String	UTC
6	EPOCH	DateTime64	
7	PARTICIPANT_1	String	NORAD
8	PARTICIPANT_2	String	
9	PATH	String	1,2,1
10	REFERENCE_FRAME	String	EME2000
11	MEAS_TYPE	String	ORBIT
12	MEAS_FORMAT	String	KEP
13	MEAS_UNIT	String	km, deg, deg, deg, deg
14	DATA_QUALITY	String	L4
15	LINK	String	

Metadata: Work in Progress

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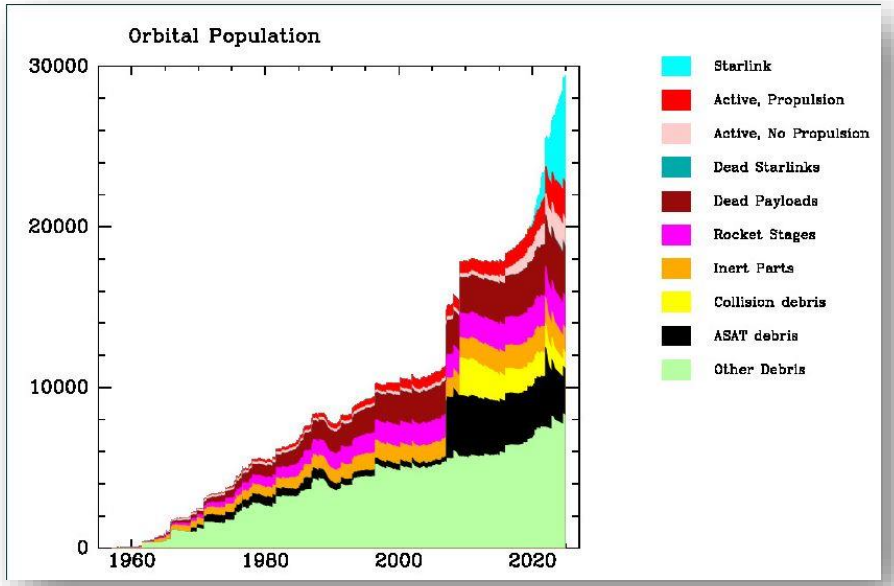
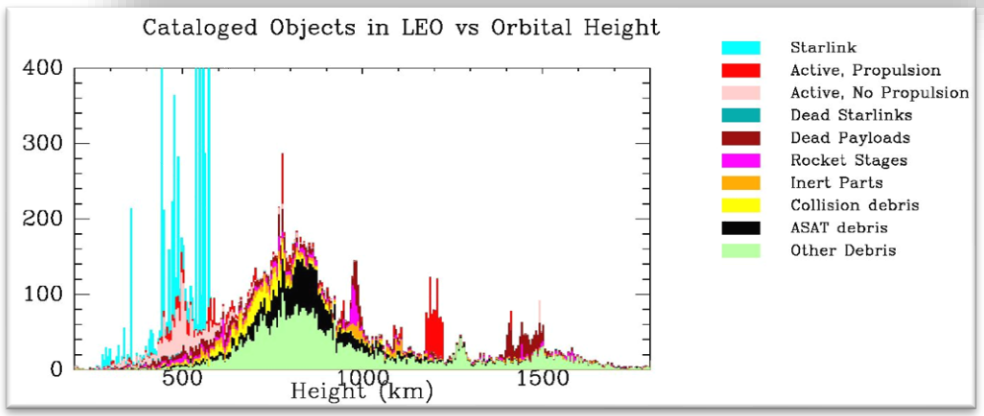
Current work is focused on the following activities:

- Integrating the metadata database into the overall IDL system.
- Testing and benchmarking the overall end-to-end query process (including data retrieval).
- Populating the metadata database with real data (https://celestrak.org/NORAD/elements).
- Planning and executing a broader set of queries on the real dataset.





IDL prototype deployment

- **Test solutions for managing data in a geographically distributed environment (aka the DataLake)** by building end-to-end prototype and testbeds to demonstrate the capability to analyze the astrophysical observations and simulations available data in a cloud environment.

- **The Data Management capability**
  - Store/inject data (meant as files or data objects) in the DataLake

- **The data and compute integration for a effective processing and analysis**
  - deploy Platform as a Service (PaaS) services for the actual processing of the data ingested into the Datalake.

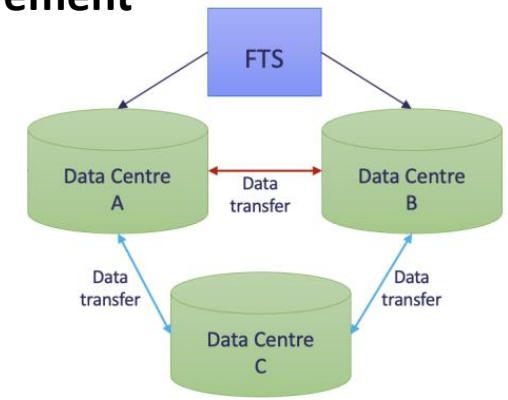
The pillars of the IDL Data Lake

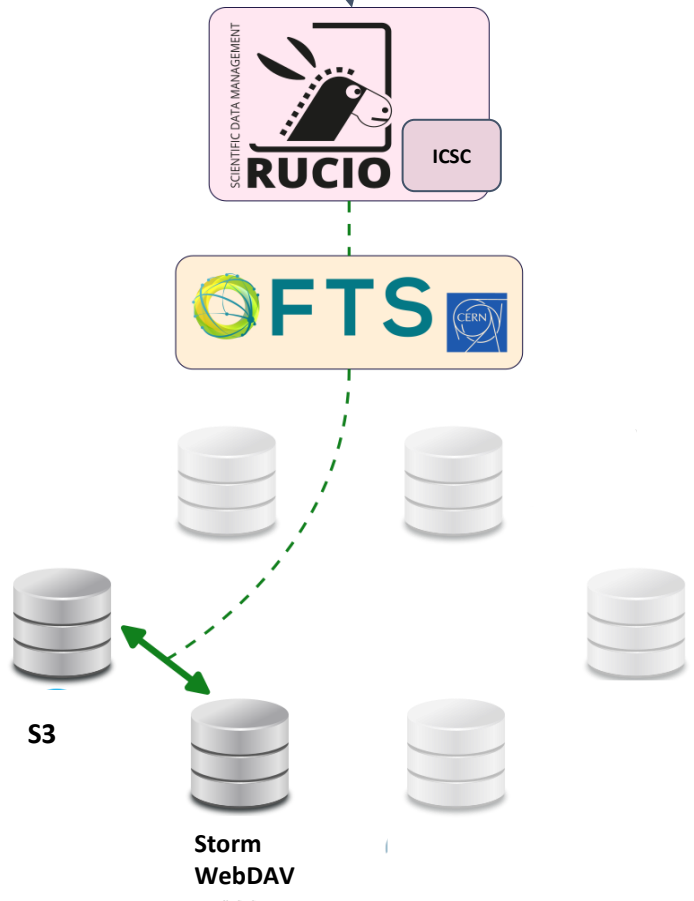
Rucio provides a mature and modular scientific data management federation

- Seamless integration of **scientific and commercial storage** and their network systems
- Data is stored in global single namespace and **can contain any potential payload**
- Facilities can be distributed at **multiple locations** belonging to **different administrative domains**
- Designed with more than a decade of operational experience in very large-scale **(ExaBytes)** data management
  - Rucio is free and open-source software licenced under Apache v2.0
  - Open community-driven development process

FTS : File Transfer Service responsible for Bulk data movement

- Efficiently **schedules data transfers**
- **Maximizes** use of available **network** & **storage** resources whilst respecting any limits





Enhancing the existing services

- to provide a seamless integration with external metadata
- to integrate datalake and compute environment

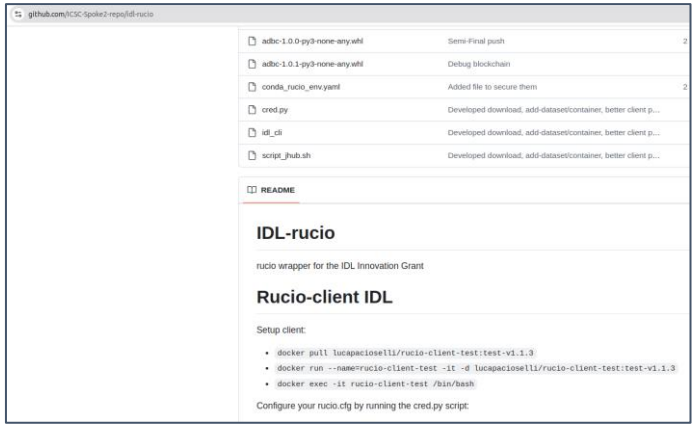
See Lightning Talk by L. Pacioselli on Thursday for details

IDL prototype current status

- The first prototype is ready to support an end-to-end test
- Exploiting INFN Cloud resources to develop the prototype (both central services and cloud storage endpoint)
- Documentation being prepared. Together with developed code it will be available on Spoke2 git repo

✓ Deployed an automated (custom Docker image) Rucio server instance on a k8s cluster (nginx, HTTPS, etc…)
✓ Functional prototype of a **DID-metadata plugin** to communicate with an external database (**AyraDB**) provided by CherryData
✓ Support for the BlockChain integration
✓ First prototype of the **IDL Rucio client**

DESCRIPTION	DEPLOYMENT IDENTIFIER	STATUS	CREATION TIME	DEPLOYED AT	ACTIONS
Client Container test	11ef3dcb-3827-4e05-a163-76b2587994cf	CREATE_COMPLETE	2024-07-09 08:14:00	CLOUD-INFN-CATANIA	Details
vm-minio-test	11ef3940-97d9-fb88-a163-76b2587994cf	CREATE_COMPLETE	2024-07-03 13:31:00	CLOUD-INFN-CATANIA	Details
Rucio-VM-8GB	11ef27d1-9bff-427c-ad50-22533e954eeb	CREATE_COMPLETE	2024-06-11 09:04:00	CLOUD-INFN-CATANIA	Details



Data certification

A virtuous example of a research topic of interest in the context of both

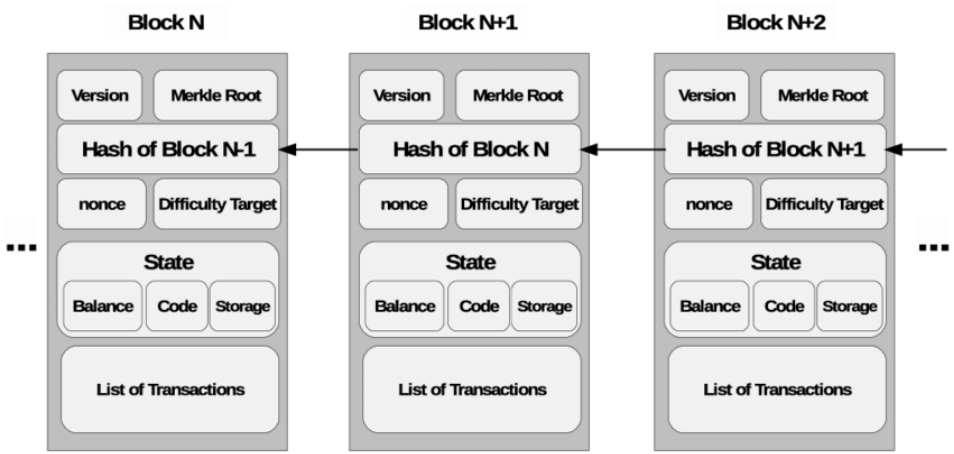
- the **industrial environment**
  - to protect data ownership
  - to detect tampering
- in **several scientific domains**
  - data provenance
  - data analysis reproducibility
  - scientific output certification

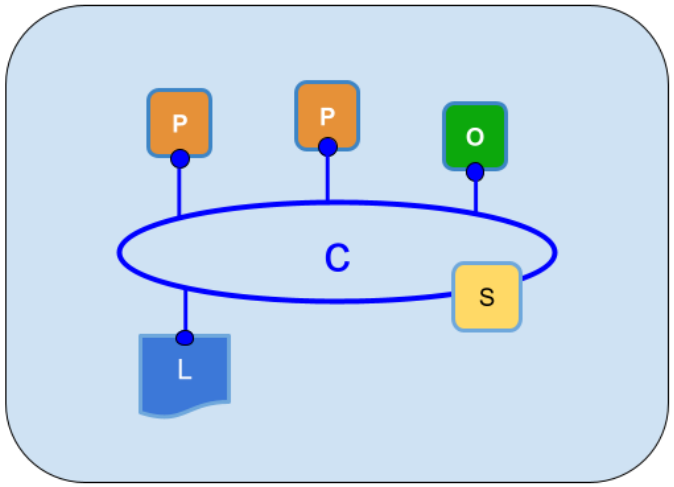
Define a strategy and solutions to certify that objects in the Datalake (i.e. datasets, individual files)

- Have not been corrupted or modified without permission
- Are physically present in the expected location on the storage
- Have a traceable history, including who made the changes

Blockchain Technology

Blockchain ensures data integrity and protection against unauthorized tampering leveraging cryptographic techniques





P	Peer
O	Orderer
S	Smart contracts
L	Ledger (Blockchain and World state DB)

- Deployed a Blockchain network
- Integrated with the IDL infrastructure, storing blockchain information during file upload and using it for validation during file retrieval

See Lightning Talk by D. Ranieri on Thursday for details