# Artifact

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# 1 Open Science Platform

## 1.1 Overview

Traditional centralized systems often exhibit data silos, limited verifiability, and susceptibility to manipulation, impeding the openness and reliability of scientific practices. The decentralized model introduced in this work is designed to mitigate these challenges by enabling efficient data sharing, fostering collaboration, and enhancing the validation of research outputs, thereby strengthening reproducibility and transparency.

This chapter details the design and implementation of the Open Science Platform, a decentralized system that integrates blockchain, IPFS, and smart contracts to improve research reproducibility. By leveraging immutable records and decentralized storage, the platform ensures transparent and verifiable research artifact management. Additionally, extended services are incorporated to facilitate file indexing, metadata extraction, and search functionality. The proposed platform aligns with Open Science principles by providing verifiable and persistently traceable access to research artifacts.

## 1.2 Technology Stack

The Open Science Platform is developed using a hybrid architecture that combines decentralized and off-chain technologies to ensure secure, traceable, and efficient data management.

## 1.3 Core Services

The core services of the Open Science Platform provide the fundamental infrastructure for secure and verifiable research artifact management.

- **Hyperledger Iroha v1 Blockchain:** Acts as the core infrastructure for managing user and project accounts, recording transactions, and enforcing business rules via smart contracts to ensure secure and transparent data exchange.

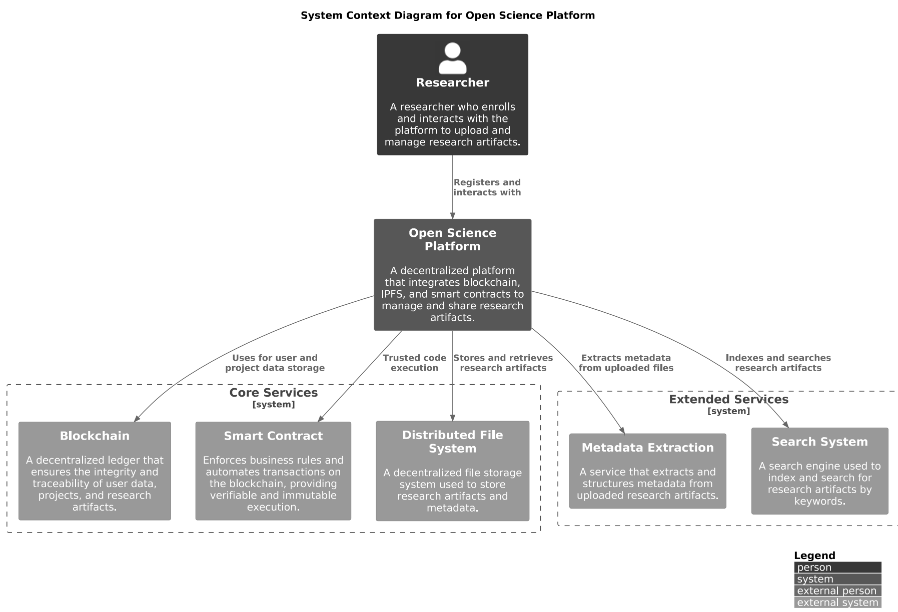



Figure 1: System context diagram for the Open Science Platform

- **InterPlanetary File System (IPFS):** Provides decentralized, tamper-proof storage for research artifacts and metadata, ensuring persistent and verifiable access to shared data.

## 1.4 Extended Services

The extended services enhance the platform's features by improving file and metadata processing.

- **Apache Tika:** Extracts metadata from uploaded files, enhancing artifact organization and searchability.

- **Whoosh:** Facilitates efficient indexing and keyword-based search for stored artifacts.

## 1.5 User Interface, integration and execution

- **Jupyter Notebooks (Python):** Powers the front-end interface, facilitating the automation and display of the execution steps. Blockchain interactions are managed via the Iroha v1 Python library, while communication with the IPFS network is handled through the HTTPS client library.

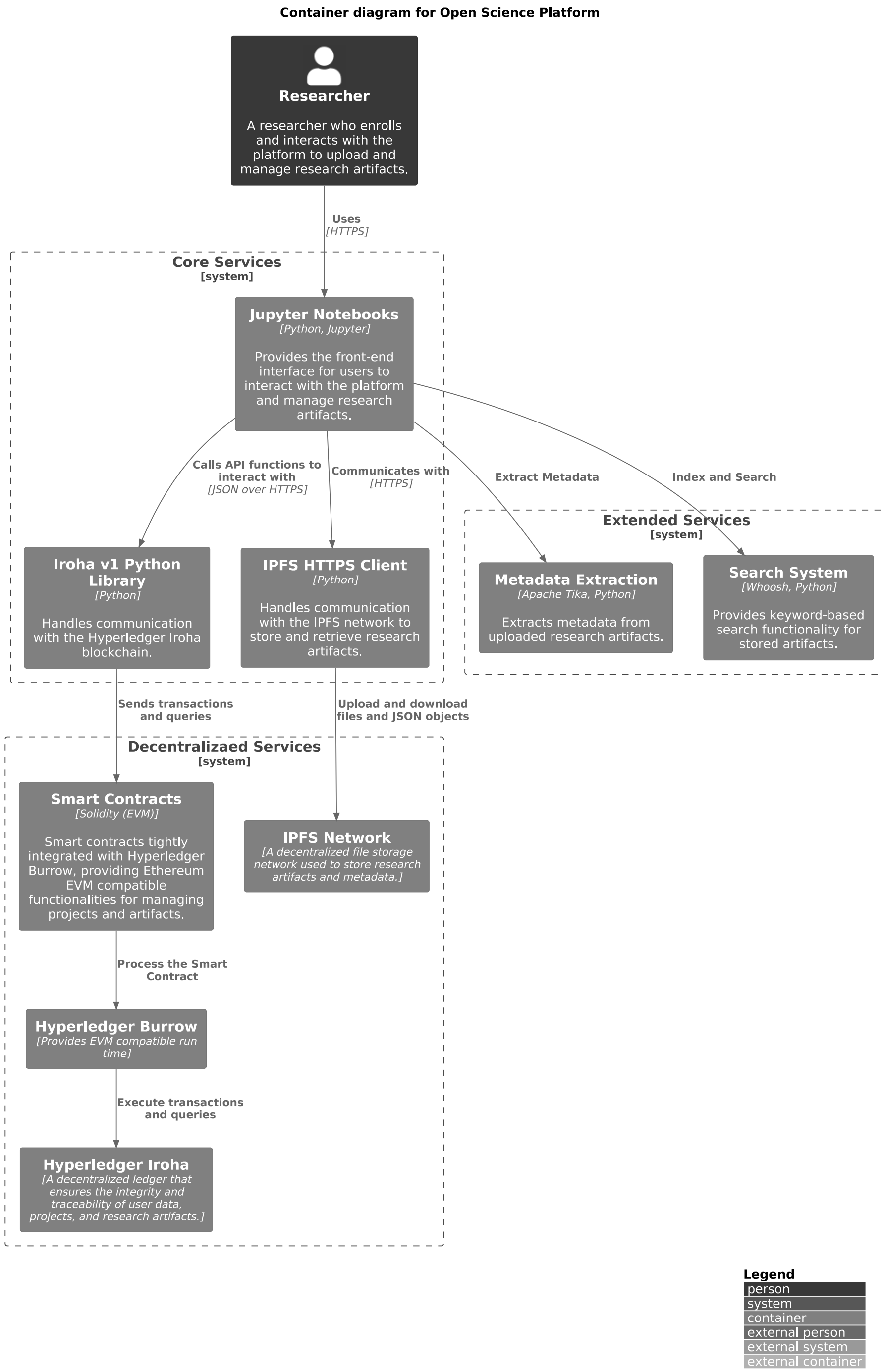



Figure 2: Container diagram for the Open Science Platform

## 1.6 System Components and Interactions in the Open Science Platform

The Open Science Platform consists of multiple interconnected components, each serving a distinct role in ensuring secure, verifiable, and reproducible research data management. The primary components include Jupyter Server, the blockchain Hyperledger Iroha v1 and the InterPlanetary File System (IPFS). Each of these elements are encapsulated within a Docker container to provide modularity, ease of deployment and reproducibility.

### 1.6.1 Jupyter Server

The Jupyter Server acts as the primary interface for users interacting with the platform. This component provides a Python kernel for the execution environment that integrates the Iroha v1 Library, the IPFS HTTPS client, Apache Tika for metadata handling, and the Woosh Indexer and Search system. It enables users to:

- Execute Python scripts to submit transactions and queries to the blockchain via smart contracts.
- Upload and retrieve files and metadata (JSON objects) stored in IPFS.
- Process and index research data using Apache Tika and Woosh for enhanced searchability.
- Access and visualize blockchain-stored metadata for Open Science applications.

### 1.6.2 Blockchain

The blockchain runs based on a Hyperledger Iroha v1 network and acts as a distributed ledger for recording transactions. It ensures immutability, transparency, and verifiability of stored research metadata. This component:

- Receives transactions from the Jupyter Server via a gRPC API.
- Stores metadata references, ensuring that uploaded research artifacts can be authenticated.
- Interacts with PostgreSQL for structured storage of blockchain metadata.
- Supports smart contracts through the integration of Hyperledger Burrow, which provides a modular blockchain client with a permissioned smart contract interpreter partially developed to the specification of the Ethereum Virtual Machine (EVM).

### 1.6.3 Storage

The InterPlanetary File System (IPFS) is a decentralized storage solution that manages the research outputs. This component:

- Stores digital research artifacts in a content-addressed manner.
- Allows the Jupyter Server to upload and retrieve files via an HTTPS API.
- Ensures long-term availability of scientific data through distributed storage principles.

### 1.6.4 Relational Database (PostgreSQL)

The PostgreSQL database provides structured storage for blockchain-related data. It is used exclusively and managed by Iroha v1 to:

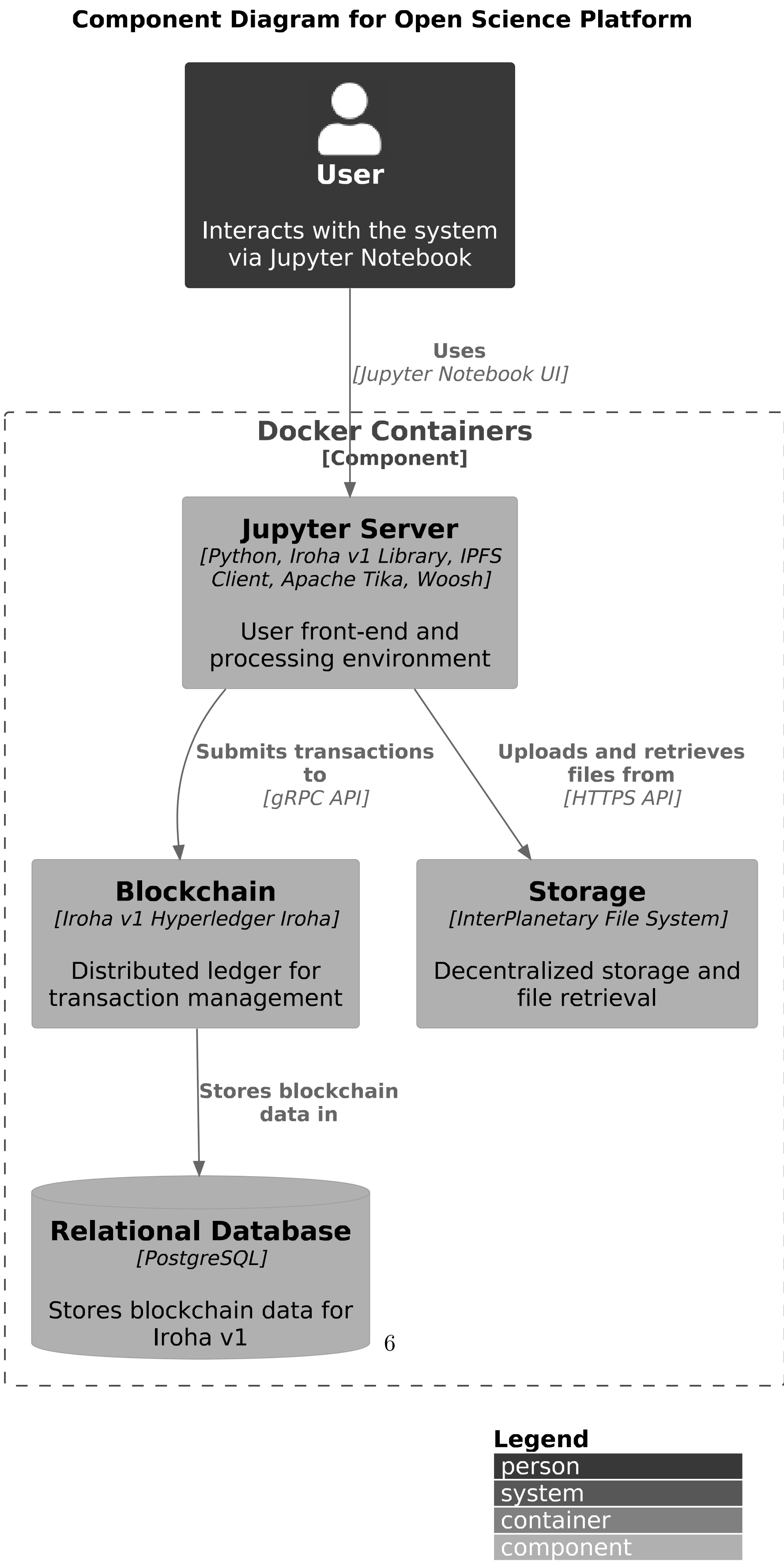
- Maintain an efficient and queryable record of transactions.
- Ensure that research metadata stored on the blockchain can be retrieved and verified.
- Support blockchain operations requiring fast access to structured data.

### 1.6.5 Component Interactions

The components interact in aseamless and decentralized manner:

1. **User Interaction**: The user submits transactions, uploads files, and queries research data through the Jupyter Server.
2. **Blockchain Transactions**: Jupyter Server sends and retrieves research metadata to the Iroha blockchain via gRPC API.
3. **Metadata Storage**: Iroha stores data in the PostgreSQL database for efficient retrieval.
4. **Decentralized Storage**: Research artifacts are stored in IPFS, with their unique file identifiers recorded on the blockchain.
5. **File Retrieval**: Users can retrieve files from IPFS using their content identifiers (CID), ensuring authenticity and reproducibility.

This architecture guarantees trustworthy and reproducible scientific research by leveraging blockchain for integrity, IPFS for decentralized storage, and Jupyter as an accessible research environment.


Component Diagram for Open Science Platform
User
Interacts with the system via Jupyter Notebook
Uses
[Jupyter Notebook UI]
Docker Containers
[Component]
Jupyter Server
[Python, Iroha v1 Library, IPFS Client, Apache Tika, Woosh]
User front-end and processing environment
Submits transactions to
[gRPC API]
Uploads and retrieves files from
[HTTPS API]
Blockchain
[Iroha v1 Hyperledger Iroha]
Distributed ledger for transaction management
Storage
[InterPlanetary File System]
Decentralized storage and file retrieval
Stores blockchain data in
Relational Database
[PostgreSQL]
Stores blockchain data for Iroha v1
Legend
person
system
container
component

## 1.7 Platform Operations

The platform supports a set of core operations that regulate user interactions with projects and data management.

- **User Self-Enrollment** – A user self-enrolls on the platform by providing a private key that complies with the ED25519 or SHA-3 standards and identity information, including full name, institution, email, ORCID, and role. An account is created for the user in the blockchain. All data provided in the enrollment is structured in key/value pairs into a JSON object and uploaded to IPFS, with the corresponding Content Identifier (CID) recorded on the blockchain attributes of the user account.

- **Project Registration** – Users can register a project by specifying a descriptive name, an abstract, relevant keywords, start and end dates, funding agency, and location. Upon registration, a blockchain account is created. This data is structured in key/value pairs into a JSON object and uploaded to IPFS, with the corresponding Content Identifier (CID) recorded on the blockchain attributes of the project account.

- **User and Project Accounts Linkage** – Once both user and project accounts are created, the system updates their attributes to establish a bidirectional association. This ensures that querying a user account reveals linked project accounts, and vice versa, facilitating traceability and efficient project management.

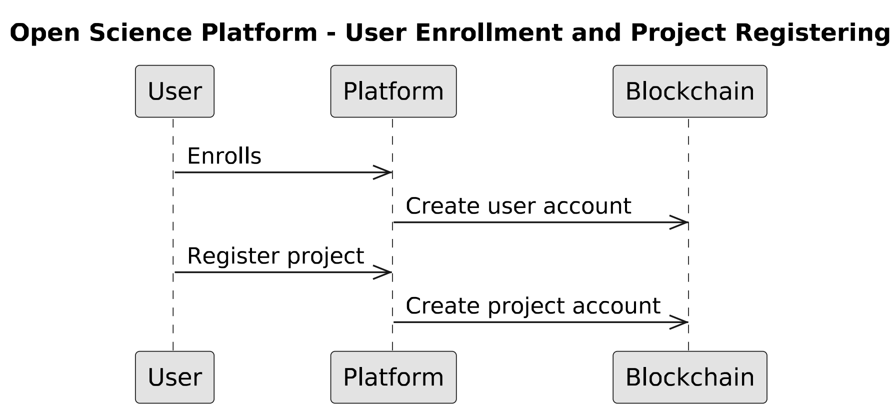



Figure 4: User enrollment and project registering for the Open Science Platform

## 1.8 Artifact Management

- **File Upload** – A user may upload research artifacts, including papers, datasets, and images. Each file is stored on IPFS, generating a unique

Content Identifier (CID) that ensures traceability and integrity. The CID is then recorded on the blockchain attributes of the project, establishing a verifiable reference to the artifact.

- **Metadata Extraction and Storage** – After the upload,the file available metadata is extracted. The extracted metadata is structured in key/value pairs into a JSON object and uploaded to IPFS, with the corresponding Content Identifier (CID) recorded on the attributes of the project account in the blockchain, ensuring metadata provenance and verification.
- **Indexing** – To facilitate efficient retrieval, the system indexes the metadata of every uploaded file, including full text indexing for text based files.
- **Searching** – Users can perform keyword-based searches to locate relevant research artifacts, with search results displaying metadata details, including descriptions, subject and authorship.

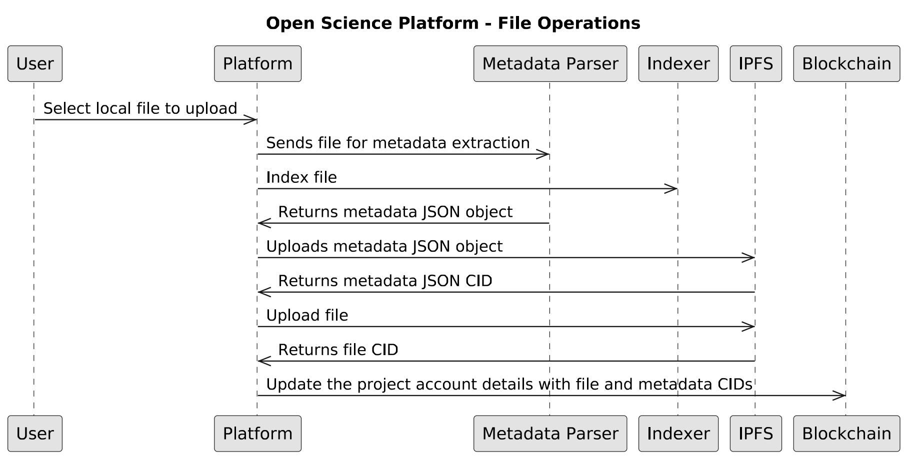



Figure 5: File operations diagram for the Open Science Platform

## 1.9 Validation and Download

- **File Validation** – To ensure data integrity and authenticity, the platform verifies whether the CID of a file stored on IPFS matches the CID recorded on the blockchain. A discrepancy between these identifiers signals potential tampering or corruption.
- **File Download** – The system retrieves and downloads validated files from IPFS to the user local file system for later usage.

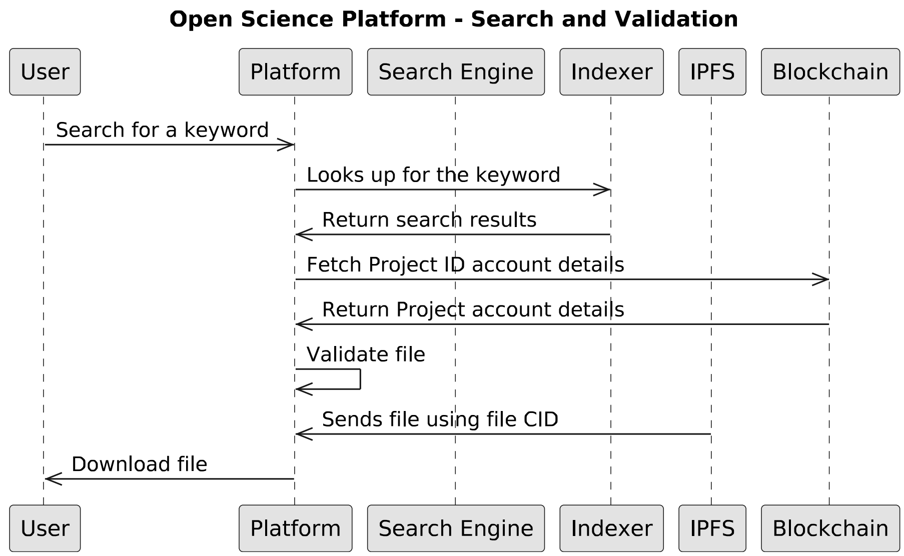



Figure 6: keyword search, file validation and download

## 1.10 Data Model for the Open Science Platform

The entity-relationship model for the Open Science Platform defines the logical structure of users and research projects, capturing the associations between these entities. The primary entities in this model are `User` and `Project`, which are connected through an ownership relationship.

## 1.11 User Entity

The `User` entity represents an individual interacting with the platform. Each user is uniquely identified by an account ID and has attributes that describe personal and institutional information. The attributes of the `User` entity are listed in Table 1.

Table 1: Attributes of the User entity

| **Attribute** | **Description** |
|---|---|
| `account_id` | A unique identifier assigned to the user |
| `full_name` | The complete name of the user |
| `email` | The email address used for communication |
| `institution` | The organization to which the user is affiliated |
| `orcid` | The Open Researcher and Contributor ID |
| `role` | The role of the user within the research project |
| `linked_project` | The research project the user is assigned to |

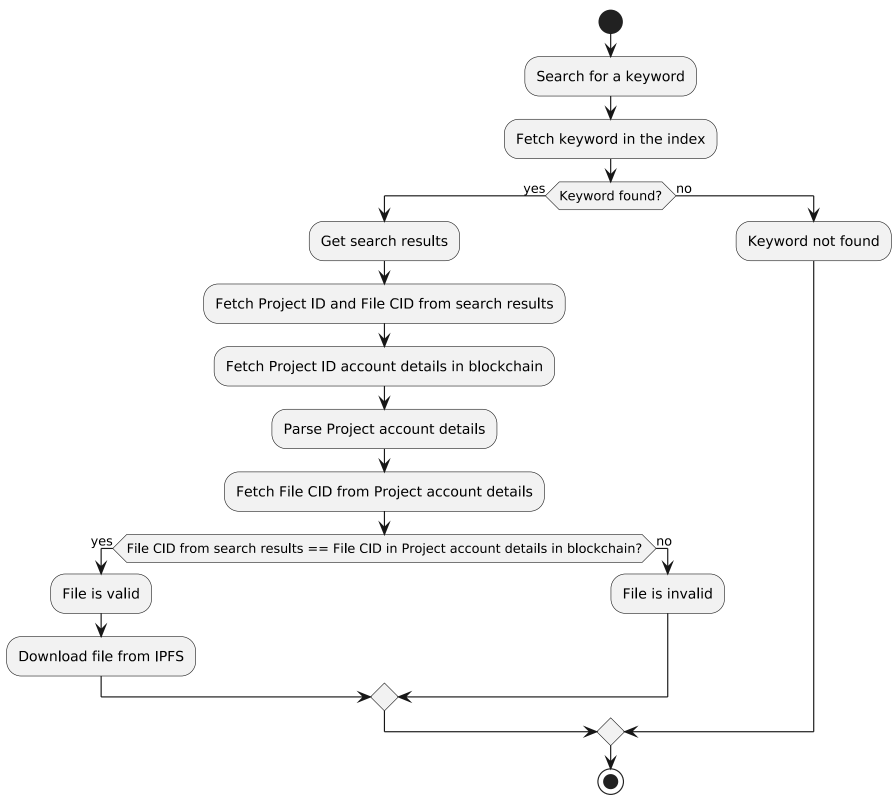



Figure 7: File validation and download

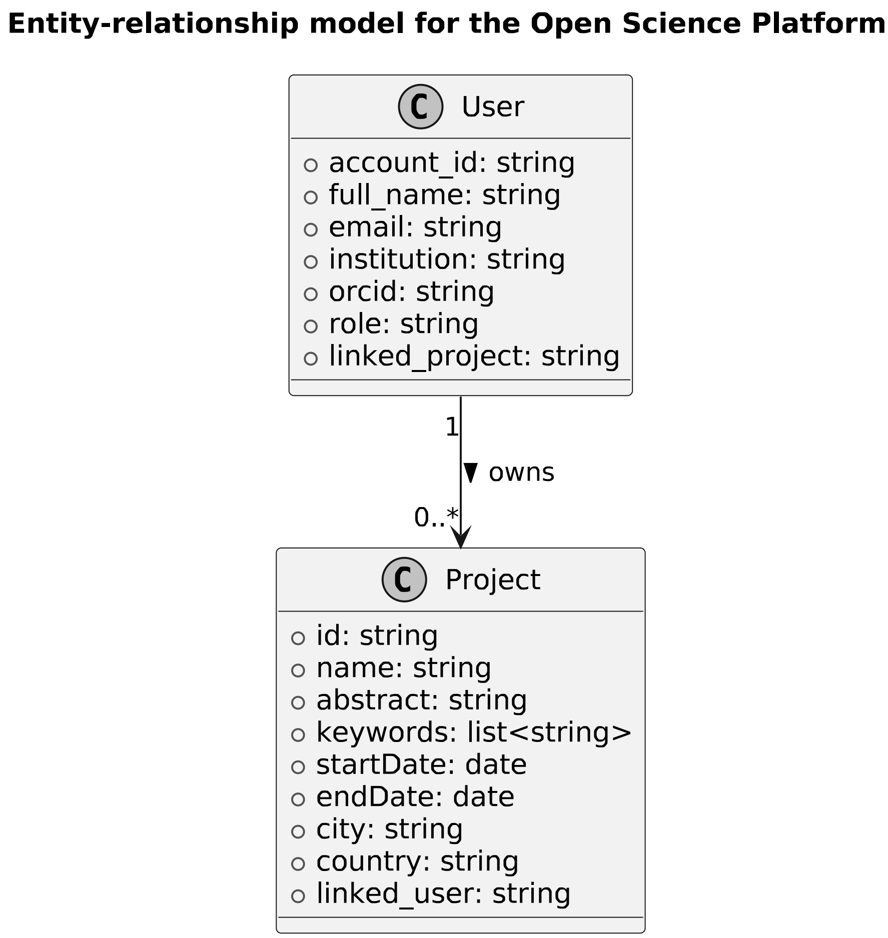



Figure 8: Entity-relationship model for the Open Science Platform

### 1.12 Project Entity

The `Project` entity represents a research project registered in the platform. It contains essential metadata to describe the project and facilitate discovery and collaboration. The attributes of the `Project` entity are listed in Table 2.

Table 2: Attributes of the Project entity

| **Attribute** | **Description** |
|---|---|
| `project_id` | A unique identifier assigned to the project |
| `name` | The official name of the project |
| `abstract` | A brief summary outlining the research objectives |
| `keywords` | A list of relevant keywords associated with the project |
| `startDate` | The date when the project officially begins |
| `endDate` | The date when the project is expected to conclude |
| `city` | The city where the project is primarily conducted |
| `country` | The country associated with the research project |
| `linked_user` | The user linked to the project |

### 1.13 Ownership Relationship

A `User` owns one or more `Project` entities, establishing a one-to-many relationship. This means that a single user can be responsible for multiple projects, but each project is owned by exactly one user. This relationship is crucial for managing project access, ensuring accountability, and maintaining provenance of research activities. This model ensures a structured representation of research projects and their associated users, supporting an organized approach to data management in the Open Science Platform.

### 1.14 Data Model for Hyperledger Iroha v1

The entity-relationship (ER) model of Hyperledger Iroha defines the core entities, attributes, and relationships that facilitate role-based access control, asset management, and multi-signature security. While Iroha v1 includes a broader set of entities, this research focuses solely on the account-related classes and attributes.

## 2 Core Entities and Their Attributes

### 2.1 Account Entity

The `account` entity represents a user or system account registered on the blockchain. Table 3 lists its attributes.

The account entity is associated with multiple other entities:

- `account_has_signatory` links accounts to public keys.

Table 3: Attributes of the Account Entity

| Attribute | Description |
|---|---|
| `account_id` | Unique identifier of the account |
| `domain_id` | Links the account to a specific domain |
| `quorum` | Required number of signatories for multi-signature transactions |
| `data` | Stores additional metadata in JSON format |

- `account_has_roles` assigns roles to accounts.
- `account_has_asset` tracks asset ownership.
- `account_has_grantable_permissions` defines access control for delegation.

## 2.2 Signatory Entity

The `signatory` entity manages cryptographic authentication.

Table 4: Attributes of the Signatory Entity

| Attribute | Description |
|---|---|
| `public_key` | Cryptographic key associated with an account |

Each account can have multiple public keys, enabling multi-signature security.

## 2.3 Asset Entity

The `asset` entity represents digital assets on the blockchain.

Table 5: Attributes of the Asset Entity

| Attribute | Description |
|---|---|
| `asset_id` | Unique identifier for the asset |
| `domain_id` | Links the asset to a domain |
| `precision` | Defines decimal precision for asset amounts |

The entity is associated with `account_has_asset`, which links assets to accounts.

# 3 Role and Permission Management

## 3.1 Role Entity

The `role` entity defines permission-based access control.

Table 6: Attributes of the Role Entity

| Attribute | Description |
|---|---|
| `role_id` | Unique identifier for the role |

`role_has_permissions` links roles to specific permissions, and `account_has_roles` assigns roles to accounts.

### 3.2 Domain Entity

The `domain` entity organizes accounts and assets within logical boundaries.

Table 7: Attributes of the Domain Entity

| Attribute | Description |
|---|---|
| `domain_id` | Unique identifier for the domain |
| `default_role` | Default role assigned to accounts created in the domain |

## 4 Permission and Transaction Management

Permissions are enforced using:

- `role_has_permissions`: Maps permissions to roles.
- `account_has_grantable_permissions`: Defines permissions that an account can delegate.
- `account_has_roles`: Assigns roles to accounts.

## 5 Relationship Cardinalities

### 5.1 One-to-Many Relationships

- A `domain` can have multiple `accounts` and `assets`.
- A `role` can have multiple `permissions`.
- An `account` can be linked to multiple `roles`, `signatories`, and `assets`.

### 5.2 Many-to-Many Relationships

- `account_has_roles`: An account can have multiple roles; a role can be assigned to multiple accounts.
- `role_has_permissions`: A role can have multiple permissions, and each permission can belong to multiple roles.

- `account_has_grantable_permissions`: An account can delegate specific permissions to multiple others.

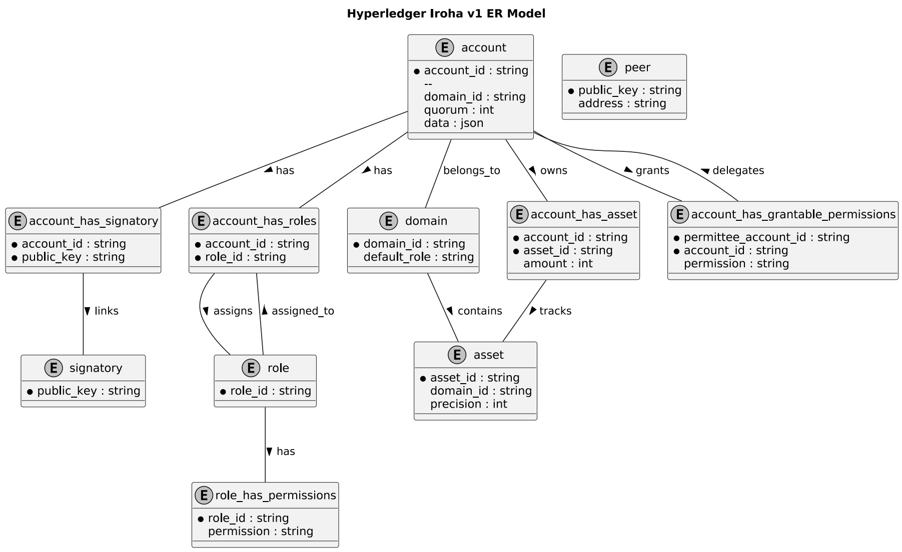



Figure 9: Iroha v1 Entity-relationship model

This ER model follows Hyperledger Iroha's permissioned blockchain structure. It ensures fine-grained access control, multi-signature security, and domain-based account management. The model enables role-based permissions and asset tracking, making it well-suited for financial applications, identity management, and blockchain-based ecosystems.

## 5.3 Relationship Between the Open Science Platform ER Model and the Iroha v1 ER Model

The Open Science Platform ER model leverages the entity structure of the Iroha v1 ER model, particularly the `account` class, to represent both the `User` and `Project` entities. In this approach, instead of introducing separate relational tables for users and projects, the `account` entity in the Iroha v1 ER model serves as a general-purpose representation, encapsulating all necessary attributes in a structured format.

The attributes specific to users and projects, which are not natively present in the Iroha v1 `account` entity, are stored as JSON objects within the `data` field of the `account` table. This design provides a flexible and scalable means of extending the entity's attributes without modifying the core schema of the Iroha blockchain.

From a relational perspective, the `account` entity maintains its standard associations with roles, permissions, and assets as defined in the Iroha v1 ER model. This ensures that user accounts and project accounts can both participate in the blockchain's permissioning system, asset ownership model, and role-based access control without requiring modifications to the underlying structure.

By reusing the `account` entity, the Open Science Platform ER model ensures compatibility with Iroha's existing mechanisms for identity management, cryptographic signing, and permission delegation. Additionally, this approach aligns with the decentralized and immutable nature of blockchain, ensuring that both user and project entities benefit from the security and transparency features inherent to the Iroha v1 framework.

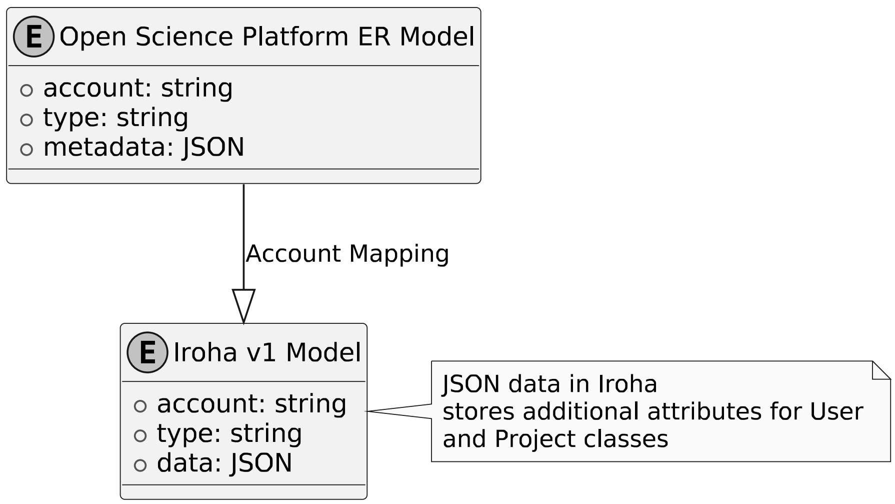



Figure 10: Comparing ER models

# 6 Role of Metadata and Use of Ontologies in the Open Science Platform

Metadata plays a crucial role in both the `Account` and `Project` classes within the Open Science platform. It is used to capture and represent essential information about the user and the research project, providing context and structure to their respective data. This metadata is stored in JSON format, following established semantic web standards and leveraging ontologies to enhance data interoperability and accessibility.

## 6.1 Account Metadata

The metadata for the `Account` class describes the attributes associated with a user on the platform. This metadata is structured using multiple ontologies, primarily `FOAF` (Friend of a Friend) and `Schema.org`, to provide detailed and interoperable information about the user. The key attributes in the `Account` metadata include the user's name, email, organizational affiliation, unique identifier (ORCID), role, public key, and linked project.

| Attribute | Description |
|---|---|
| `foaf:name` | The name of the user. |
| `foaf:mbox` | The email address of the user. |
| `foaf:organization` | The organization the user is affiliated with, described as an instance of the `foaf` |
| `schema:identifier` | A unique identifier for the user, such as an ORCID identifier. |
| `foaf:holdsAccount` | The user's account details, including their role and public key. |
| `schema:linked_project` | The project associated with the user. |

Table 8: Account Metadata Attributes

These attributes ensure that the user's profile is rich, structured, and semantically linked to relevant data across different systems. By employing these ontologies, the platform ensures that user data can be easily shared and understood by external systems, enabling better integration with other Open Science platforms.

## 6.2 Project Metadata

The metadata for the `Project` class provides essential details about the research project hosted on the platform. Similar to the user metadata, the project metadata is structured using `Schema.org` and `Dublin Core` (`dc`) ontologies. This structure allows for a comprehensive description of the project, including its name, abstract, keywords, timeline, funding details, and location.

| Attribute | Description |
|---|---|
| `schema:name` | The name of the research project. |
| `dc:abstract` | A brief abstract describing the project's objectives and focus. |
| `schema:keywords` | Keywords associated with the project, such as "precision agriculture" and "global s |
| `schema:startDate` | The start date of the project. |
| `schema:endDate` | The end date of the project. |
| `schema:funding` | The funding organization for the project, described as an instance of the `schema:Or` |
| `schema:location` | The physical location where the project is based, described as an instance of the `sc` |
| `schema:metadataCID` | A unique identifier for the metadata of the project. |
| `schema:linked_user` | The user associated with the project. |

Table 9: Project Metadata Attributes

This metadata not only captures the essential details of the project but also ensures that these details are linked to the user's profile, making it easier to track the relationship between users and their associated research efforts.

### 6.3 Ontologies and Their Role

An ontology is a formal representation of knowledge as a set of concepts within a domain and the relationships between those concepts. In the context of the Open Science platform, ontologies help structure data in a way that promotes interoperability, consistency, and clarity. The use of ontologies such as `FOAF`, `Schema.org`, and `Dublin Core` ensures that data is standardized and can be easily shared and understood across different systems.

| Ontology | Description |
|---|---|
| **FOAF (Friend of a Friend)** | A vocabulary used to describe people, their activities, and their relationshi |
| **Schema.org** | A collaborative initiative that provides a structured vocabulary for data m |
| **Dublin Core (DC)** | A metadata standard used for describing a wide range of resources. It is p |

Table 10: Ontologies Used in the Open Science Platform

These ontologies were chosen because of their widespread adoption, their ability to standardize data across different systems, and their support for rich, machine-readable representations. By aligning with these ontologies, the platform ensures that its metadata is compatible with other Open Science initiatives and services, facilitating seamless integration and data exchange.

### 6.4 Conclusion

In summary, metadata plays a vital role in the Open Science platform by enabling the structured and interoperable representation of user and project information. The use of ontologies like `FOAF`, `Schema.org`, and `Dublin Core` enhances the platform's ability to share and integrate data, ensuring that the platform contributes effectively to the broader Open Science ecosystem.

## 7 Account Metadata JSON

The following JSON structure describes the metadata for an `Account` in the Open Science platform:


```
{
    "@context": {
        "schema": "http://schema.org/",
        "foaf": "http://xmlns.com/foaf/0.1/"
    },
    "@graph": [
        {
            "@type": "foaf:Person",
            "foaf:name": "Zealous Ptolemy",
            "foaf:mbox": "zealous_ptolemy@email.com",
            "foaf:organization": {
```

```
                "@type": "foaf:Organization",
                "foaf:name": "Ashkelon Academic College"
            },
            "schema:identifier": {
                "@type": "PropertyValue",
                "propertyID": "ORCID",
                "value": "6153-7096-0437-X"
            },
            "foaf:holdsAccount": {
                "schema:identifier": "zealous_ptolemy@test",
                "schema:roleName": "reviewer",
                "schema:publicKey": "ca4c00c0a43bbd2caf070ab780886906ebb70e2c3d975972ccab4e
            },
            "schema:linked_project": "02226@test"
        }
    ]
}
```


# 8 Project Metadata JSON

The following JSON structure describes the metadata for a `Project` in the Open Science platform:


```
{
    "@context": {
        "schema": "http://schema.org/",
        "dc": "http://purl.org/dc/terms/"
    },
    "@graph": [
        {
            "@type": "schema:ResearchProject",
            "schema:identifier": "02226@test",
            "schema:publicKey": "1c6b8d00c8382c93eb0dd3eeb24a20bfece56a28326bbaebb647cadaf4
            "schema:description": {
                "@context": {
                    "schema": "http://schema.org/",
                    "dc": "http://purl.org/dc/terms/"
                },
                "@type": "schema:ResearchProject",
                "schema:name": "Assessing the Benefits of precision agriculture for global
                "dc:abstract": "This research focuses on the benefits and challenges posed
                "schema:keywords": [
                    "precision agriculture",
                    "global supply chains",
                    "disease prevention"
```

```
                ],
                "schema:startDate": "2023-12-18",
                "schema:endDate": "2027-01-02",
                "schema:funding": {
                    "@type": "schema:Organization",
                    "schema:name": "World Wildlife Fund"
                },
                "schema:location": {
                    "@type": "schema:Place",
                    "schema:name": "Los Angeles, California, USA"
                }
            },
            "schema:metadataCID": "Qmay4cDaxUaZaHoJKqzN69XkiX8wMx17aG4VMmwmkLcL1a",
            "schema:linked_user": "zealous_ptolemy@test"
        }
    ]
}
```

### 8.1 Smart Contract

The platform deploys standard Ethereum EVM contracts in Solidity for account creation and detail setting. These contracts are deployed through the Iroha v1 Python Library.

### 8.2 Benefits

The Open Science platform offers numerous benefits for researchers and members of the scientific community, including:

- Secure data sharing: By utilizing blockchain technology and IPFS, the platform ensures tamper-proof data exchange.
- Transparent data management: The use of smart contracts and decentralized storage guarantees transparency in data access and modification history.
- Collaborative research environment: The platform enables researchers to collaborate on projects, share artifacts and results, and track progress.

### 8.3 Challenges

The Open Science platform faces several challenges, including:

- Scalability: As the number of users increases, the platform needs to be able to handle a growing amount of data and transactions efficiently.
- Interoperability: Ensuring seamless integration with existing research platforms and tools is crucial for widespread adoption.

- User Adoption: Educating researchers about the benefits of decentralized technologies and the Open Science platform can be an uphill battle.

### 8.4 Future Work

The Open Science platform has several areas for future development, including:

- Integration with existing research platforms: Collaborations with established research platforms to expand the platform's reach and user base.
- Enhanced security measures: Implementing additional security protocols to protect against potential threats and maintain the integrity of shared information.
- User interface improvements: Enhancing the web interface to make it more user-friendly and accessible for researchers from diverse backgrounds.

## 9 Conclusion

The Open Science platform is a comprehensive solution for secure, transparent, traceable, and tamper-proof data sharing and collaboration. By leveraging decentralized technologies, the platform empowers researchers to share project artifacts and data in a reliable and trustworthy manner.