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Making spatio-temporal data spaces FDO-ready: concept and implementation for interoperable STAC catalogues

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Abstract: Data spaces provide structured environments that enable integration, management and sharing of heterogeneous datasets across disciplines and institutions. This approach is increasingly relevant for research, where data sources are very diverse and globally distributed. The use of FAIR Digital Objects (FDOs) enables data within and between these areas to be permanently linked, traced, and reused, thereby improving reproducibility, machine processability, and collaboration. Considering how much data there is in a wide variety of disciplines with a spatial and temporal reference, SpatioTemporal Asset Catalog (STAC) offers an open metadata standard for organizing geospatial and temporal data, which is already widely used by European initiatives such as ESA's Destination Earth the Copernicus Data Space Ecosystem, and other initiatives listed on stacindex.org. Integrating STAC with FDO principles enables machine-actionable, interoperable catalogues within research data spaces, supporting the European Open Science Cloud (EOSC) ambition for a “Web of FAIR Data and Services” advancing cross-domain research. In this work, STAC has been defined as FDOs, but the challenges of dealing with varying catalog contents, data access mechanisms, and the linking of catalogue and the data with operational processes are also considered and addressed.

Keywords: FAIR Digital Objects, STAC, FDO Specifications, data space

1. Introduction

In recent years, the concept of *data spaces* has gained prominence, particularly in industry, as a framework for organizing and sharing data across business ecosystems and institutional boundaries. Although the term is not yet widely used in the scientific community, it has clear relevance and applicability for research environments. Data spaces provide a structured environment for integrating heterogeneous datasets from diverse disciplines, methods, or domains and making them accessible for collaboration and analysis.

Climate and climate impact research, which relies on data from multiple fields such as meteorology, hydrology, and socio-economics, can particularly benefit from this approach. By

abstracting from underlying technologies and embedding persistent, typed relations, *FAIR Digital Objects (FDOs)* can achieve seamless data integration, provenance tracking, and rights management across domains. This structure promotes reproducibility, trust, and long-term sustainability in data sharing. Furthermore, the use of FDOs is being considered throughout the entire research workflow, from HPC processing to data publication, which would offer clear advantages for automation and traceability [1].

2. STAC for packaging geospatial-temporal data in catalogues

SpatioTemporal Asset Catalog (STAC) is an open metadata specification developed to make geospatial and temporally variable data - such as satellite images, model output, drone images, or point clouds - systematically describable, findable, and usable (stacspec.org). Similar to RO-Crate (https://www.researchobject.org/ro-crate/), it provides a mechanism for bundling such datasets into catalog objects. With its uniform schema (e.g., “item”, “collection”, “catalog”), STAC facilitates the indexing and querying of data across interfaces. While its specifications are well defined, it also allows the creation of domain-specific extensions. Therefore STAC has become an important tool across disciplines dealing with data with space-time reference and is used already by numerous European initiatives: For example, ESA's Destination Earth (DestinE) platform uses STAC catalogs (https://platform.destine.eu/de/tagserv/stac/) to provide transparent access to simulation and Earth observation data; the Copernicus Data Space Ecosystem (https://browser.stac.dataspace.copernicus.eu/) offers free access to comprehensive Earth observation data from the Sentinel missions via a STAC interface; and the central directory at stacindex.org.

3. STAC as FDOs

Using examples from climate research, it will demonstrate how climate model data from institutional data spaces can be combined. Specific interdisciplinary research questions are addressed by using STAC objects, which are defined as FDOs based on the handle approach and linked to the European Open Science Cloud (EOSC) data type registry (https://faircore4eosc.eu/eosc-core-components). The DTR is provided by GWDG (https://gwdg.de/), which further develops the handle-based FDO - approach in the FDO One and FDO connect projects (https://fdo-one.org/).

The initial approach of “Making STAC FDO-ready” [2] exposed several challenges: enabling machine access to catalog contents, addressing data access restrictions, managing changes in catalogs or specifications over time, and enhancing harmonization of catalogs. Continuing these activities should clarify remaining issues and illustrate not only the practical implementation of FDOs but also their potential to provide a robust framework for tackling complex scientific challenges by streamlining workflows and enabling collaboration across disciplinary and institutional boundaries.

Data availability statement

Example FDOs (resolvable using https://proxy.handle.net/):

21.T14995/bc915619-6220-4c01-aa64-0047c1026bae referencing https://stac.ceda.ac.uk/?.language=de

21.T14995/d9a69c0d-1599-4560-ae2f-e0fc2427db14 referencing
https://stac.ecodatacube.eu/?.language=de

21.T14995/e4ee4e6e-84c4-47b0-ab5c-b70efaab7808 referencing
https://cds.climate.copernicus.eu/stac-browser/?.language=en

Underlying and related material

Kulüke, M., & Krüss, B. (2025). MarcoKulueke/Application-of-the-FDO-standard: Application of the FDO Standard (v0.1). Zenodo. https://doi.org/10.5281/zenodo.16813009

Author contributions

Ivonne Anders: Conceptualization, Methodology, Writing – Original Draft, and Project Administration. Beate Krüss: Investigation, Software, and Writing – Review & Editing, with a focus on implementing STAC as FAIR Digital Objects (FDOs). Marco Kulüke: Software, Validation, and Writing – Review & Editing, contributing to the implementation of FDOs. Hannes Thiemann: Supervision, Resources, providing strategic oversight and supporting the project. Heinrich Widmann: Data Curation, Supervision, Writing – Review & Editing, contributing extensive expertise in metadata and acting as liaison to FAIRCORE4EOSC.

Competing interests

The authors declare that they have no competing interests.

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