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Fair Digital Object Enrichment: Integrating Nanopublications with RO-Crates

Subtitle

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Abstract. The abstract should summarize the contents of the paper in short terms, i.e. in up to 250 words. Please capitalize all major words in the title/heading, including the second part of hyphenated major words (e.g., Self-Report not Self-report). Please also capitalize all words of four letters or more. Please capitalize the keywords

Keywords: FDO, nanopublication, research object, ro-crate, fairification

1. Abstract

FAIR Digital Objects (FDOs) aim to provide a consistent and machine-actionable framework for representing digital objects, favoring their interoperability. In order to ensure that they are truly **Findable, Accessible, Interoperable, and Reusable**, capturing their essential semantics (i.e. the key descriptive metadata in a user and machine-readable format) becomes crucial. Two main implementations have emerged for structuring and describing the semantic content of FDOs: one based on **Nanopublications**[1] and another based on **Research Object Crates (RO-Crates)**[2], though they were conceived to address different purposes.

On the one hand, the Nanopublication model is designed to provide a minimal and uniform container that makes **individual semantic assertions and their associated provenance metadata machine-actionable**. They represent minimal units of structured information as citable entities. This technology enables researchers to publish precise statements, such as hypotheses, results, metadata, or any kind of relationship between entities together with formal provenance information and links to supporting evidence. Nanopublications are aligned with Semantic Web technologies using **Resource Description Framework (RDF)** and its serializations as knowledge representation language and can be permanently and uniquely identified using resolvable Trusty

URIs. The structure of the Nanopublication with three subgraphs (assertion, provenance, publication info) inherently promotes transparency, trust and reproducibility in research. There is no limitation in the use of metadata standards, but most nanopublications are grounded in **Dublin Core**.

On the other hand, the RO-Crate specification provides a broader framework for **describing and packaging research artifacts** used and generated throughout the research process in alignment with the FAIR principles. An RO-Crate is a rich structured metadata container, expressed in JSON-LD, that aggregates and describes data entities such as datasets, software, workflows, publications, as well as contextual entities like people, organizations, funding, including provenance information, in a lightweight and web-friendly form. Rather than focusing on individual assertions, RO-Crates capture the context and relationships among different research outputs of a research activity. It is based on common and well-known vocabularies, mainly in **Schema.org**, and it can be easily extended and profiled through the specification of RO-Crate profiles, which can leverage different metadata standards.

Our solution is based on RO-Crate profile(s) for creating FDOs that address the metadata needs of the different scientific communities, where these profiles extend the RO-Crate specification by defining a set of conventions, types, and properties that one can minimally require and expect to be present in that subset of RO-Crates. This solution adopts **RO-Crates as containers for research artifacts** with rich metadata that describe the specific content and meaning of these artifacts (as specified in the RO-Crate profile(s)), while using Nanopublications to describe semantically **assessment about those artifacts**. In this way, the RO-Crate provides a structural envelope and contextual metadata, while Nanopublications supply precise, assertion-level semantics that can be linked across different digital objects. This combination enhances the semantic interoperability of FDOs and supports richer, machine-actionable connections between data, methods, and knowledge claims. Our solution is being tested in the context of climate adaptation, as a foundation to develop comprehensive and scientifically sound climate adaptation strategies and plans for stakeholders across Europe.

This paper presents a **comparison between two alternative representations: Nanopublications and RO-Crate**, identifying points of alignment and divergence in how each model expresses provenance, metadata granularity, and contextual relationships. This analysis provides the foundation for designing a **combined approach that enables the interoperability of both systems**, while preserving their independent usage where useful, and offering a more comprehensive and accurate representation of research outputs.

This paper will demonstrate the use of the combined implementation within the FAIR2Adapt project, which aims to develop pathways for six different case studies to transform their data into knowledge to accelerate their application in specific climate adaptation strategies. In particular, we will present a first implementation for the case study FAIR-by-design national adaptation hub for Portugal, illustrating how systematic literature reviews can be made reproducible with Nanopublications within RO-Crates. This approach offers a pathway toward more transparent, reproducible, and machine-actionable research, where data and assertions can be seamlessly connected across domains and disciplines.

Data availability statement

No data available for the abstract.

Underlying and related material

No data available for the abstract.

Author contributions

All authors contributed equally to this abstract.

Competing interests

The authors declare that they have no competing interests.

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