Formal Semantics and Foundational Grounding for Comparable ODRL Policies in Dataspace

Daham M. Mustafa[12], Diego Collarana[2], Christoph Lange[12], Christoph Quix[12], Rafiqul Haque[3], and Stefan Decker[12]

[1] RWTH Aachen University, Aachen, Germany
[2] Fraunhofer FIT, Sankt Augustin, Germany
[3] University of Galway, Galway, Ireland and GATE Institute, Sofia, Bulgaria

Abstract

In data spaces, the Open Digital Rights Language (ODRL 2.2) is used to express access and usage policies for data exchange. A connector must determine whether a provider's offer policy and a consumer's request policy are compatible before any data transfer. However, the ODRL specification does not have a well-defined interpretation for cross-policy comparison. In particular, spatial operands do not specify per-axis semantics, temporal operators are used for both instants and durations, constraints grounded in external sources have no defined resolution procedure, and ODRL's deontic concepts lack a foundational grounding for the normative positions a policy creates and the authority to declare a violation.

1 Introduction

The Culture Dataspace (Datenraum Kultur) [15] is a federated Dataspace that connects German libraries, archives, and museums so they can exchange digitised cultural-heritage assets under shared, machine-readable usage policies. It adopts ODRL [6] as the policy language, in line with data-space practice [1]. We take it as our running example. Its assets are scoped in space and time: many are multi-dimensional (a master TIFF image measured by width and height, a 3D manuscript scan adding depth) [7, 13], access is typically time-bound (an embargo before release, a usage or retention window), and many are described not by literals in the policy but against external catalogues and authority files. A concrete exchange runs between two of its institutions: a provider, the Bavarian State Library, publishes a 3D manuscript scan under an offer policy, and a consumer institution submits a request policy for the same asset. For a connector to clear this exchange automatically, it must compare the two policies before any data transfer and decide whether the request is admissible under the offer.

2 Requirements for Automated Policy Comparison

Comparing two policies automatically requires constraints that are precisely specified, unambiguous, and suitable for comparison. We identify five requirements; a policy language for this setting must let a connector:

- *compare* an offer and a request before any data is exchanged and return a verdict a non-expert can act on: the request is Compatible when every usage it permits is also permitted by the offer, in Conflict when it permits a usage the offer forbids, and Unknown when one policy constrains a condition the other leaves open, so on that condition there is nothing to compare (the connector then clears, blocks, or defers the exchange at negotiation time [2]);

- express a *spatial extent*, a region, a bounding box, a position, or a size, so that a bound on one axis is not silently read as a bound on another (a 3D scan capped to a maximum width, height, and depth);
- express *temporal validity*, distinguishing a point in time from an amount of time and combining the two without ambiguity (an embargo date, a usage window, and an upper bound on metered use);
- resolve a constraint against an *external source* when its value is not a literal but lives in a knowledge graph, registry, or controlled vocabulary that fixes which regions, asset classes, or roles exist and how they relate, so that two policies grounding the same notion in different sources can be reconciled (a region constraint resolved against an authority file);
- ground the *normative positions* a policy creates, fixing what a permission, a prohibition, and a duty each mean and who holds authority to declare a violation, so a connector's reading matches a legal or compliance stakeholder's (a rights holder disputing whether a duty was discharged).

3 ODRL for Cultural-Heritage Dataspace

Spatial operands without per-axis meaning. ODRL pairs a left operand with a single scalar comparison [6], but the operands needed to express constraints on multidimensional cultural-heritage assets, including `absoluteSize` and `absolutePosition`, range over two or three axes at once, and the syntax gives no way to mark which axis a bound applies to. An offer bounding a 3D scan with (`absoluteSize`, `lteq`, 1920), (`absoluteSize`, `lteq`, 1080), and (`absoluteSize`, `lteq`, 50) states three numbers that cannot be assigned to width, height, and depth, so when a request bounds the same scan, a connector has no sound basis for deciding whether the two agree.

Temporal operators that conflate instants and durations. ODRL reuses the same comparison operators for temporal instants and temporal durations. The operator `lt` denotes *earlier than* when applied to an instant, as in (`dateTime`, `lt`, 2026-12-31), but *shorter than* when applied to a duration, as in (`elapsedTime`, `lt`, P30D). The operator itself does not determine the intended temporal interpretation, nor does it distinguish temporal instants from temporal durations in a way that prevents comparisons between them. As a result, some inconsistencies remain undetected. For example, an offer fixing metered use at exactly thirty days and a request restricting access to at most ten elapsed days are each individually satisfiable but cannot be satisfied simultaneously: metered use can never exceed elapsed time, so thirty days of metered use requires at least thirty elapsed days, which the request's ten-day limit forbids. This inconsistency becomes apparent only when the two constraints are interpreted jointly.

Constraints grounded in external sources. Many constraints do not resolve against a literal in the policy but against an external source, such as a knowledge graph, registry, or controlled vocabulary, that defines regions, asset classes, or roles and their relationships. A policy may restrict use to a region identified in one authority (for example, an ISO 3166 country code), while another policy refers to the same region through a different authority. ODRL can reference such an external source for an operand's value, but specifies neither how a processor should reason over it nor whether constraints grounded in different sources can be reconciled during policy comparison. This is closely tied to the interpretation of policies under open-world and closed-world assumptions: whether what a policy leaves unspecified counts as permitted, prohibited, or simply unknown, and how the completeness of the external source bears on that reading. Without a well-defined semantic treatment, policy comparison over externally grounded constraints remains ambiguous.

The missing foundational grounding. Beyond the constraint layer, ODRL specifies what a policy contains but not, at the level a legal or compliance stakeholder requires, what a permission, a prohibition, or a duty means: which normative position each rule establishes between the parties, and who holds the authority to declare a violation. Without that grounding, the same policy can be read in incompatible ways, with no principled account of who adjudicates a breach.

4 Formal Approaches to Addressing the Identified Gaps

For the spatial gap, an axis-aligned profile resolves the ambiguity by decomposing a multi-axis operand into one scalar operand per axis, within ODRL's own profile-extension mechanism, so that a per-axis bound becomes both expressible and machine-interpretable [8]. For the temporal gap, a sort-stratified semantics types each operand as a point in time or an amount of time, fixing every operator's reading and ruling out cross-sort comparison, which restores soundness to conflict detection. The temporal case is a sort problem rather than an axis one, and its recurrence and cross-operand conflicts need arithmetic beyond interval comparison [11]. For constraints grounded in external knowledge, a denotational semantics for externally-grounded policies gives a precise account of how an operand is interpreted against an external source [9]. And for the foundational gap, a cross-level grounding of permissions, prohibitions, and duties in the UFO-L legal ontology [5, 3] makes explicit the normative positions a policy creates and the authority to declare a violation that evaluators otherwise leave implicit [12]. This connects to a point raised in current conformance work, that conformance in ODRL applies to policies but not to processors [14]. Three of these results share a common core: for the spatial, temporal, and external-grounding barriers, deciding whether an offer and a request agree reduces to the same interval comparison behind the three-valued verdict from Section 2. The foundational grounding is different in kind: it is an ontological account of the deontic layer, not an interval computation. What the four share is method, not mechanism: each gives ODRL a precise, machine-checkable meaning, and each is accompanied by a benchmark that others can reproduce and extend [10]. These results contribute to the ongoing effort to give ODRL a formal semantics, complementing the ODRL Community Group's draft formal-semantics report [4] by addressing the constraint operands and the deontic grounding it does not yet cover. We would welcome folding this work into that effort.

References

[1] Data Spaces Support Centre. DSSC blueprint 3.0: Europe's shared reference architecture for data spaces. https://blueprint.dssc.eu/, 2026. European Union Digital Europe Programme, grant agreement no. 101083412. Accessed 1 July 2026.

[2] Eclipse Dataspace Components. EDC Documentation. https://eclipse-edc.github.io/, 2026. Accessed: 2026-02-22.

[3] Claudenir M. Fonseca, Daniele Porello, Giancarlo Guizzardi, João Paulo A. Almeida, and Nicola Guarino. Relations in ontology-driven conceptual modeling. In *Conceptual Modeling: 38th International Conference, ER 2019, Salvador, Brazil, November 4–7, 2019, Proceedings*, page 28–42, Berlin, Heidelberg, 2019. Springer-Verlag.

[4] Nicoletta Fornara, Víctor Rodríguez-Doncel, Beatriz Esteves, Simon Steyskal, Benedict Whittam Smith, Yassir Sellami, and Andrea Cimmino Arriaga. ODRL formal semantics. Draft community group report, W3C ODRL Community Group, February 2026.

[5] Cristine Griffo, João Paulo A. Almeida, João A.O. Lima, Tiago Prince Sales, and Giancarlo Guizzardi. Legal powers, subjections, disabilities, and immunities: Ontological analysis and modeling patterns. *Data & Knowledge Engineering*, 148:102219, 2023.

[6] Renato Iannella and Serena Villata. ODRL Information Model 2.2. W3C recommendation, W3C, 2018. https://www.w3.org/TR/odrl-model/.

[7] Library of Congress. Tiff tags, 2025. Accessed: 2026-05-21.

[8] Daham Mustafa, Diego Collarana, Sabrina Kirrane, Christoph Lange, Christoph Quix, Rafiqul Haque, Yixin Peng, and Stefan Decker. Axis-Aligned Semantics for ODRL: Resolving Dimensional Ambiguity in Policy Constraints. arXiv:2602.19878 [cs.LO], 2026. https://arxiv.org/abs/2602.19878.

[9] Daham Mustafa, Diego Collarana, Yixin Peng, Rafiqul Haque, Christoph Lange-Bever, Christoph Quix, and Stefan Decker. Denotational semantics for odrl: Knowledge-based constraint conflict detection, 2026.

[10] Daham M. Mustafa. ODRL conflict-detection benchmarks (spatial, temporal, and externally-grounded). https://github.com/Daham-Mustaf/odrl-benchmark, 2026. Accessed 1 July 2026.

[11] Daham M. Mustafa, Diego Collarana, Sabrina Kirrane, Christoph Lange, Christoph Quix, Sandra Geisler, Stefan Decker, and Rafiqul Haque. Sort-stratified semantics for temporal conflict detection in odrl policies, 2026.

[12] Daham M. Mustafa, Christoph Lange, Giancarlo Guizzardi, Diego Collarana, Christoph Quix, and Stefan Decker. What does odrl mean? a cross-level ontological grounding of permissions, prohibitions, and duties in ufo-l, 2026. Accepted at FOIS 2026 (16th International Conference on Formal Ontology in Information Systems), Vitória, Brazil; to appear in Frontiers in Artificial Intelligence and Applications, IOS Press.

[13] Münchener DigitalisierungsZentrum. 2D- und 3D-Digitalisierung. https://digitale-sammlungen.de/de/2d-und-3d-digitalisierung. Bayerische Staatsbibliothek, Munich Digitization Center.

[14] Víctor Rodríguez-Doncel and Nicoleta Roman. Towards conformance in odrl 3.0. *Joint Proceedings of the ESWC*, pages 1613–0073, 2025.

[15] G. Toubekis and S. Decker. The culture dataspace (datenraum kultur) – a data-sovereign open-source digital infrastructure based on the eclipse dataspace components (edc) framework. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XLVIII-M-9-2025:1515–1523, 2025.