MMO: A Lightweight Semantic and Trust Model for Metadata

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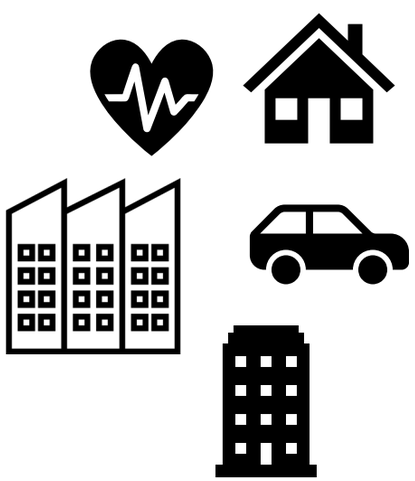
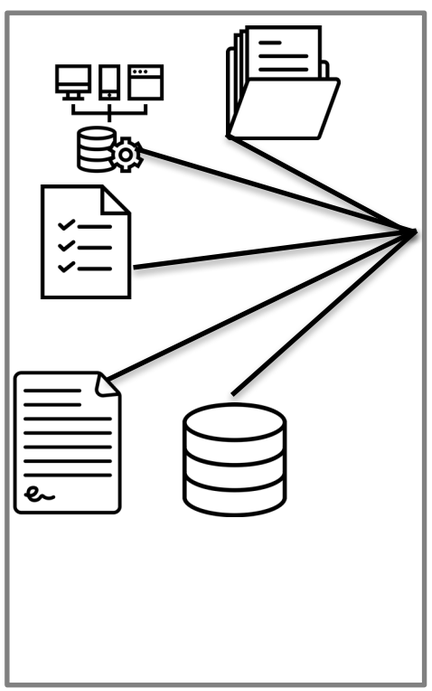
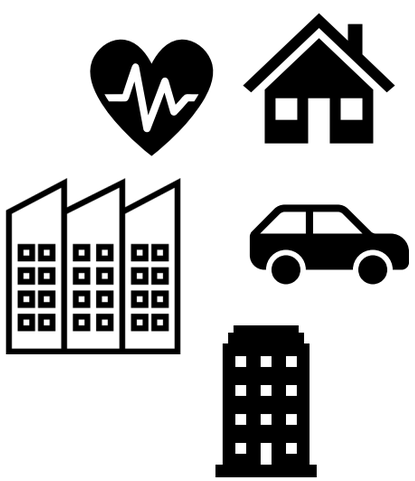


Collect and organize



500 B objects connected by 2030 [cisco]



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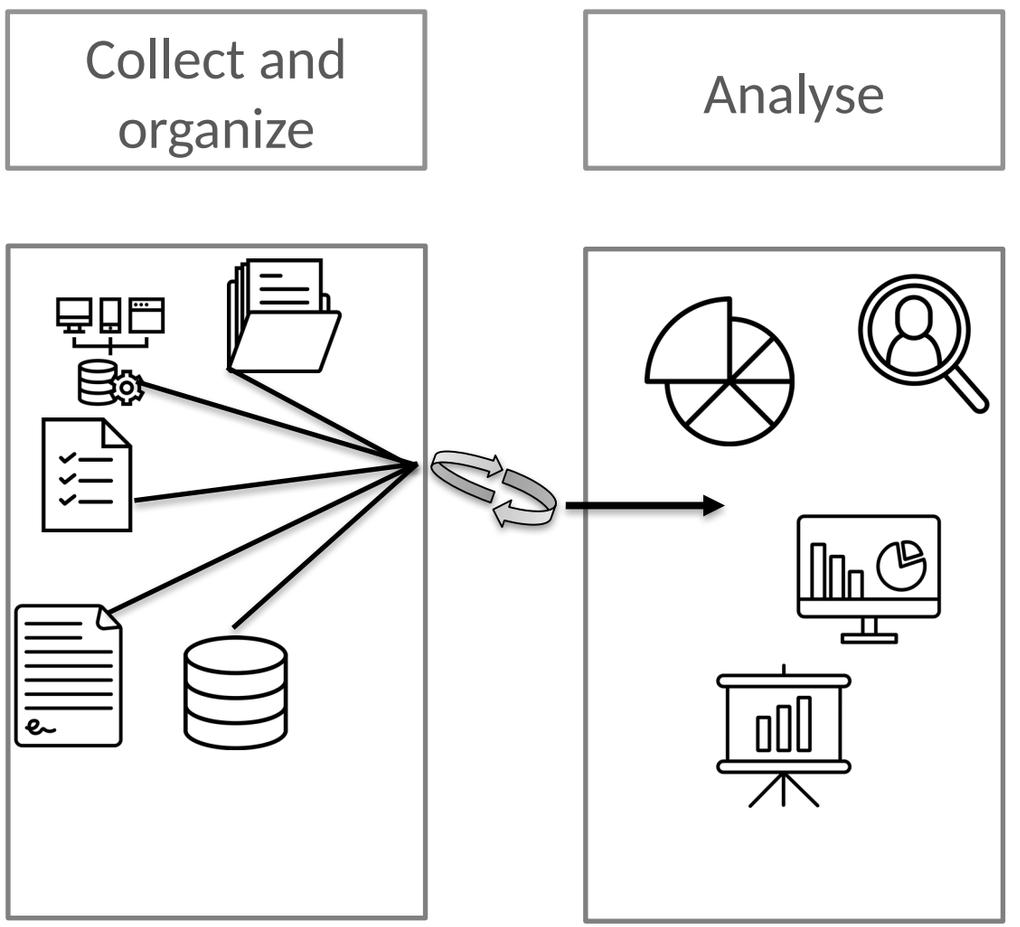
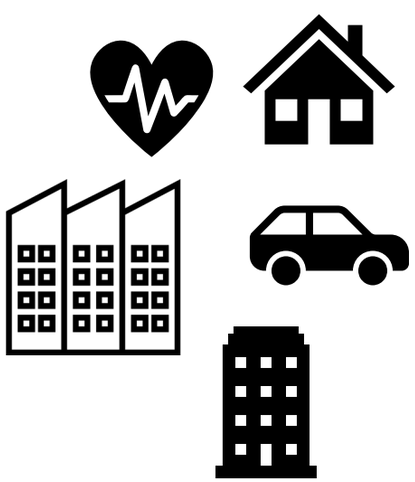


New services



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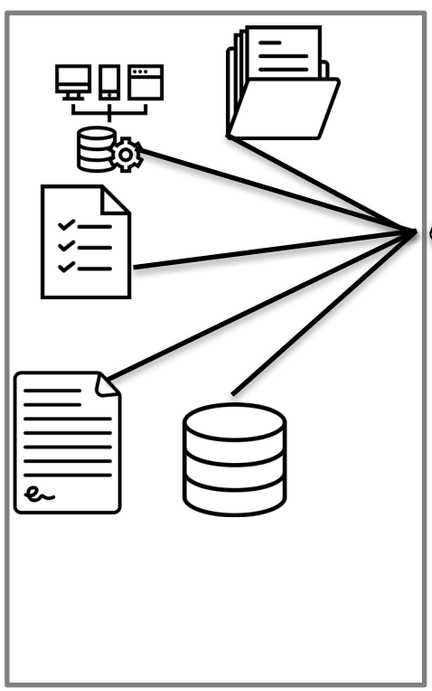
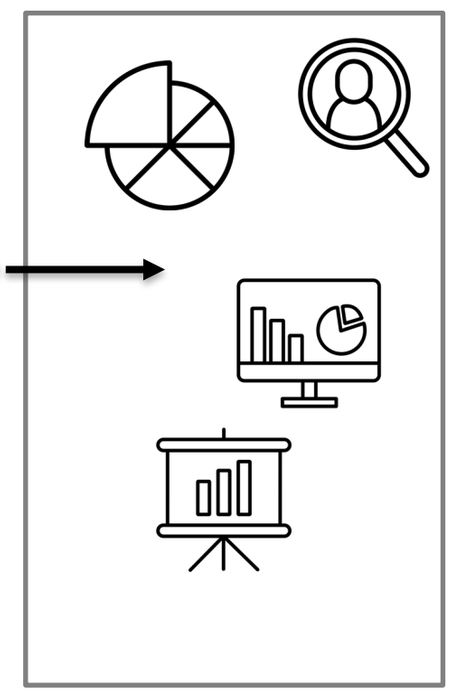


Analyse



Service

Public transport optimization

Smart buildings

Smart agriculture

Smart security systems

Patient monitoring

New services

Reliability and trustworthiness of exchanged data

Security concerns:

- Data providers have little to no control over their IoT data once shared, and therefore quickly lose his authority
- data consumers can’t assess the quality of the received data
- Semantic interoperability

Metadata

- Metadata enables easier data discovery, and can help increase understanding of a given information.
- metadata must capture operational and contextual information such as provenance, access control, usage constraints, and applied transformations.
- no universally accepted formalism → Semantic interoperability

Design methodology: MethOntology

Specification and knowledge phase:

- Ontology specification's goal is to identify the set of important concepts to be represented.
- Identifying and defining the basic concepts for the description of data security requirements to enable its integration into reasoning frameworks

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1- Specification and knowledge phase:

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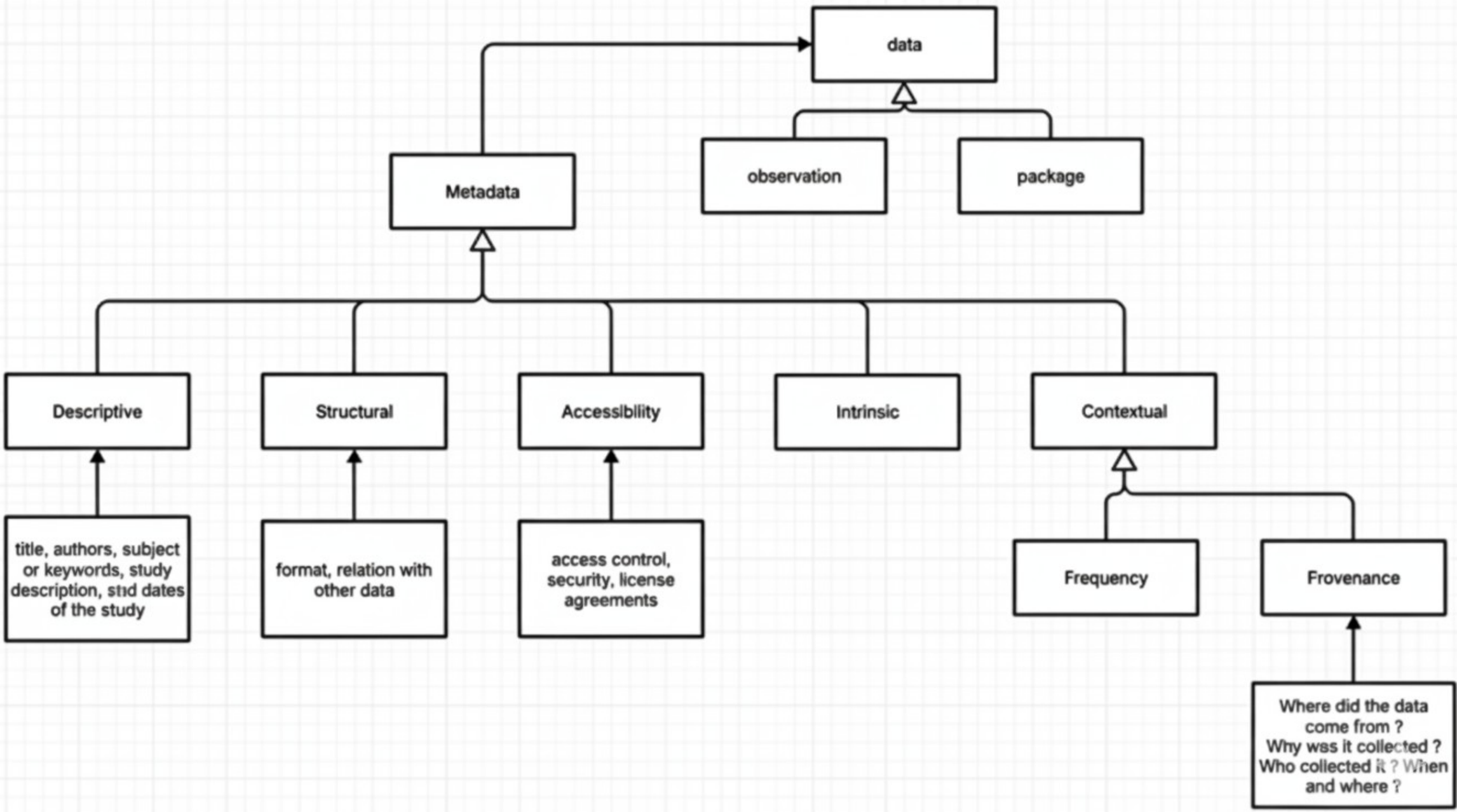
Name: Metadata Management Ontology (MMO)
Domain: Metadata quality, trust, and data governance.
Purpose: The ontology aims to provide a lightweight, extensible, and semantically rich model for describing, structuring, and reasoning over metadata across heterogeneous systems. Its main goal is to enable interoperability, traceability, and trust by formally representing key metadata dimensions (descriptive, structural, administrative, temporal, and provenance). MMO supports security-sensitive applications by ensuring semantic transparency, provenance tracking, and auditable data flows to strengthen integrity and accountability.
Level of formality: Formal (OWL ontology).
Scope:

- **Keywords:** Metadata, semantic interoperability, provenance, data quality, trust, ontology alignment, security, traceability.
- **Core concepts:** *Metadata*, *Data*, *Descriptive metadata*, *Structural metadata*, *Administrative metadata*, *Provenance*, *Access rights*, *Temporal metadata*, *Dynamic metadata*.
- **Properties:** include: *hasMetadata* (linking data instances to metadata elements), *label* (textual descriptor), *value* (literal value of metadata), *hasProvenance*, *hasAccessRights*, and *hasFrequency*.

Source of knowledge:

- Dublin Core Metadata Initiative (DCMI)
- Data Catalog Vocabulary (DCAT)
- W3C Provenance Ontology (PROV-O)
- Semantic Sensor Network Ontology (SSN)
- Prior works on metadata and security ontologies (e.g., IdSM-O, LIoPY, UCO)

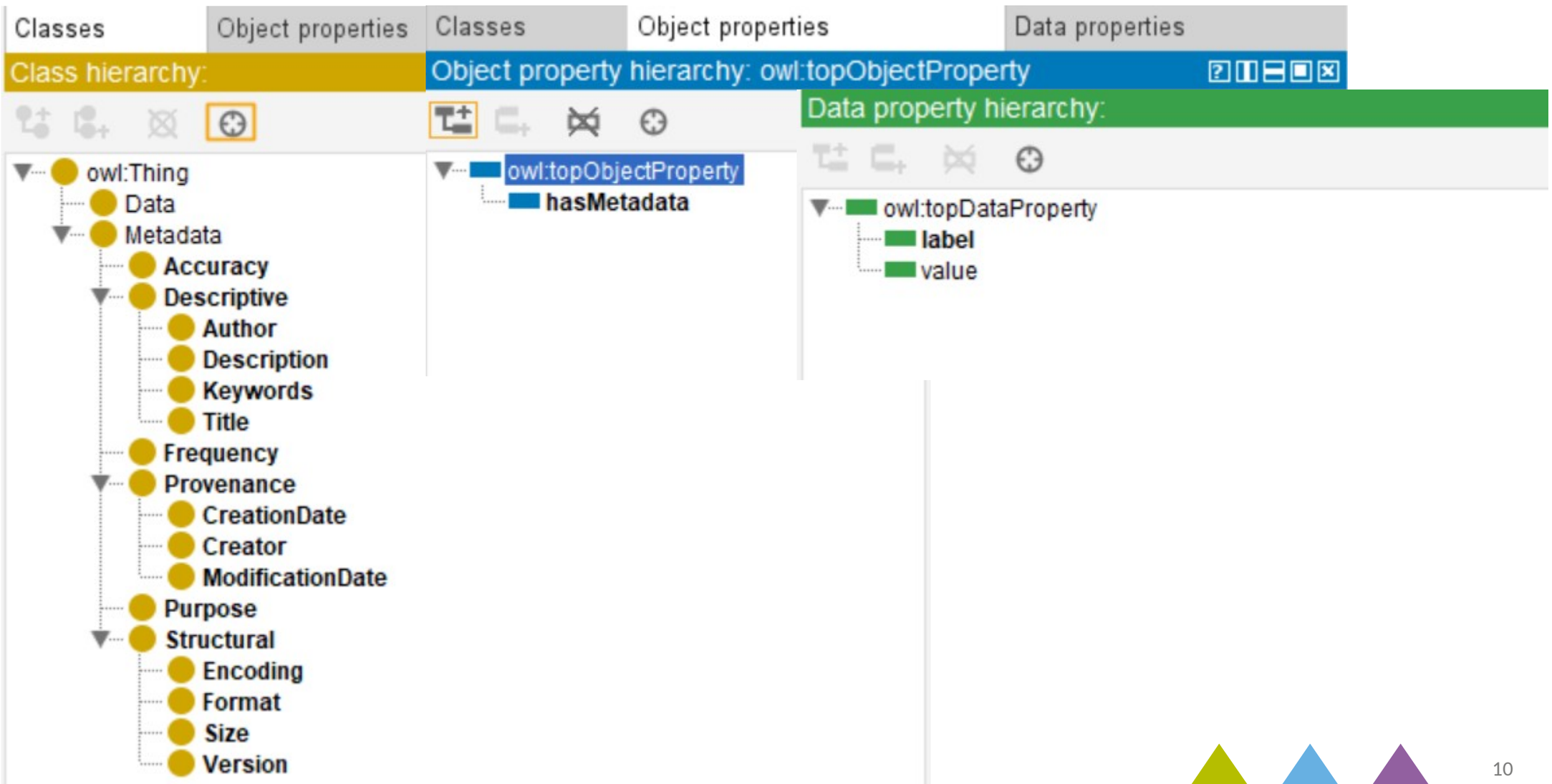
Figure 2: Metadata Management Ontology (MMO) requirement specification document


data
observation
package
Metadata
Descriptive
Structural
Accessibility
Intrinsic
Contextual
title, authors, subject or keywords, study description, stid dates of the study
format, relation with other data
access control, security, license agreements
Frequency
Frovenance
Where did the data come from ?
Why wss it collected ?
Who collected it ? When and where ?

Design methodology: MethOntology

https://git.univ-pau.fr/munier/mmo

Implementation phase:



1- Ontology integration with existing ontologies

Scenario: sensors distributed across various neighborhoods collect environmental data such as CO2 concentration, with each ssn:Observation enriched using the MMO ontology to enhance semantic context.

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SWL rule:

```
ssn:Observation(?obs) ∧ mmo:hasMetadata(?obs, ?meta) ∧ mmo:Frequency(?meta) ∧ mmo:value(?meta, ?v) ∧ swrlb:greaterThan(?v, 0.7) ∧ ssn:madeBySensor(?obs, ?sensor) ∧ ssn:detects(?sensor, ?stimulus)
→ ssn:isProxyFor(?stimulus, :HighFreqProperty)
```

```
      :CO2_obs rdf:type ssn:Observation .
 :CO2_meta_frequency rdf:type mmo:Frequency ;
          mmo:value "0.9" xsd:float .
:CO2_obs mmo:hasMetadata :CO2_meta_frequency .
    :CO2_obs ssn:madeBySensor :CO2_sensor .
    :CO2_sensor ssn:detects :CO2_stimulus .
```

```
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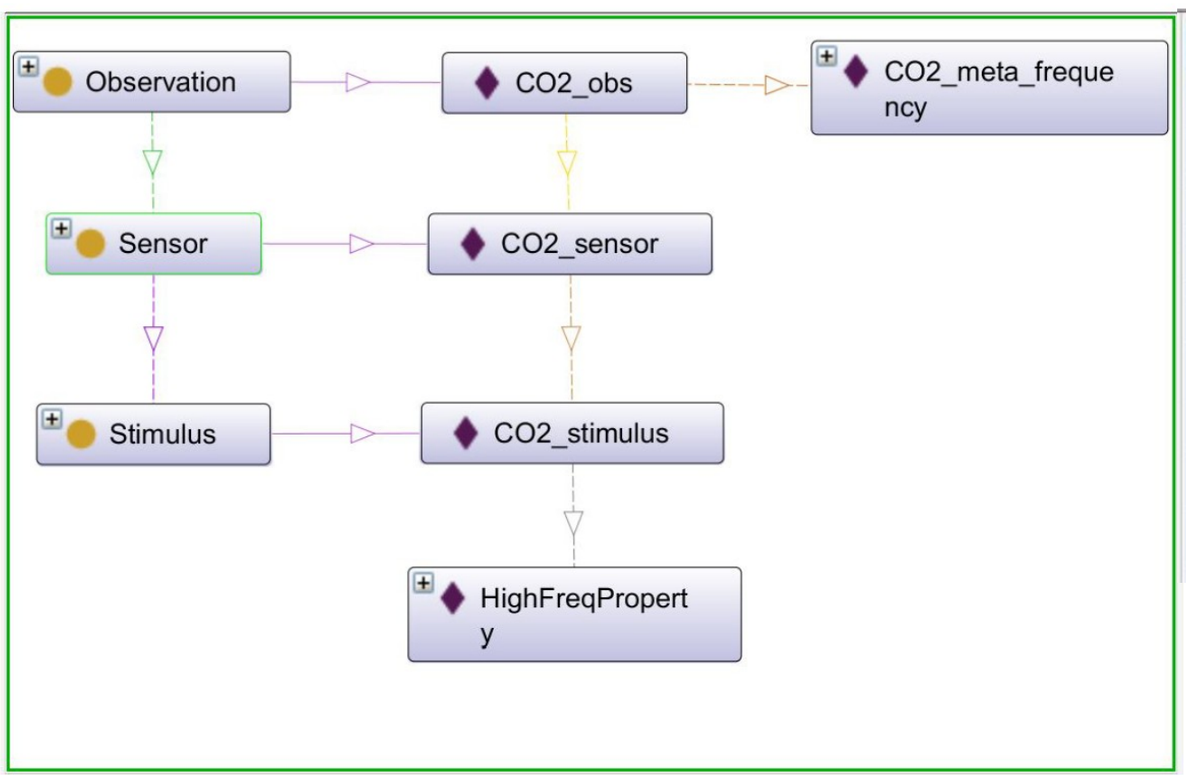
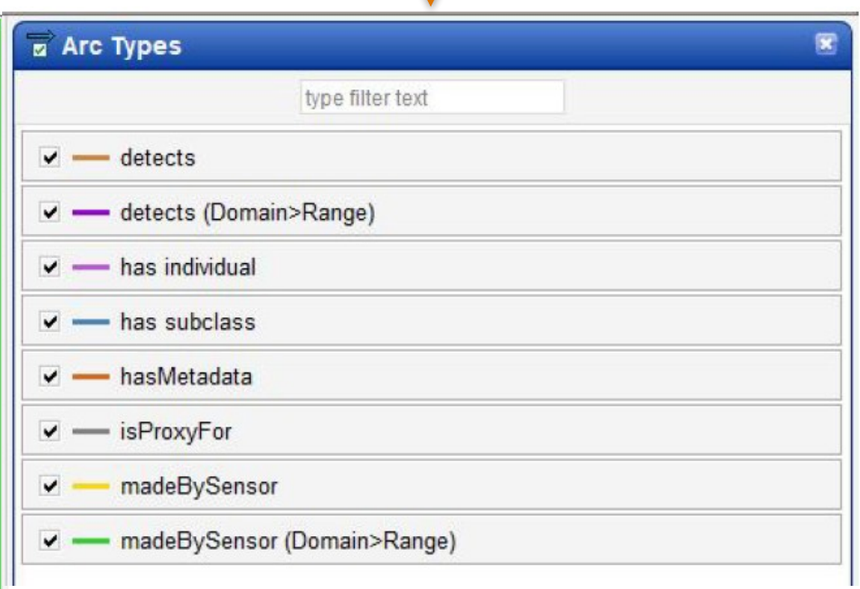
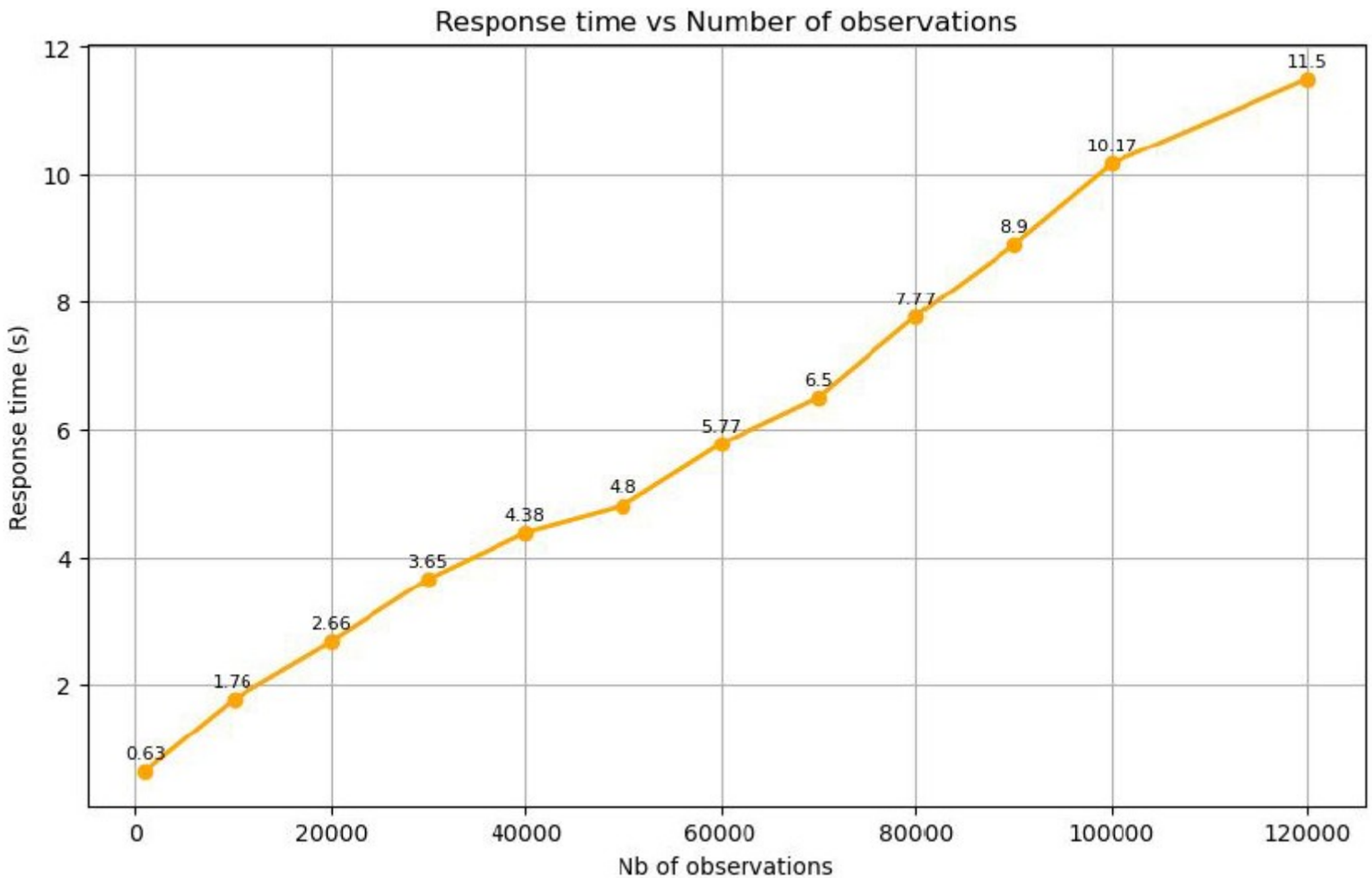
Infers





2- Scalability

OWLAPI and SWRLAPI. 50% of the observations return false, and 50% return true



CONCLUSION

- We advocate for the use of metadata as a trust metric in distributed systems.
- A lightweight ontology designed to unify the representation of metadata across heterogeneous systems.
- Validate the ontology’s semantic coherence and logical consistency through structural metrics and rule-based reasoning.

FUTURE WORK

- Enhance provenance representation
- Assessing dataset quality is critical to ensuring the reliability of model outputs.
- AI explainability.

Thank you!
Any questions?

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Outline

- General context
- Building MMO
- Implementation
- Evaluation
- Conclusion

1- Ontology correctness

	Ontology Correctness			Ontology Quality	
	Accuracy	Completeness	Conciseness	Computational Efficiency	Adaptability
Schema metrics					
Attribute richness	0.34	–	–	–	–
Inheritance richness	1.08	–	–	–	–
Relationship richness	0.44	–	–	–	–
Axiom/class ratio	–	7.45	–	–	–
Graph metrics					
Absolute sibling cardinality	–	–	–	–	20
Absolute depth	–	–	–	74	–
Total number of paths	–	–	–	32	–
Class metrics					
Class inheritance richness	5	–	–	–	–
Class children count	–	–	4	–	–
Knowledgebase metrics					
Average population	–	–	–	0.3	–
Class richness	0.25	–	–	–	–

Table 1: MMO evaluation document