Knowledge Representation and Reasoning

A Prototype System Design and Evaluation Report

Designing an Ontology-Driven-AI-Enabled Search Framework for a Community Library.

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1. INTRODUCTION AND BUSINESS CONTEXT

Public libraries play a critical role in providing equitable access to information, education and cultural resources within local communities (Hider & Coe, 2025). Despite this, many library catalogues continue to rely on keyword-based search mechanisms that lack semantic understanding, often leading to inefficient or incomplete retrieval of relevant materials. These limitations are particularly evident when users search across multiple dimensions such as availability, format, accessibility requirements, or branch location (Huettemann, Mueller & Dinter, 2025).

The Library Manager's intention to adopt an AI-powered search solution reflects recognition that effective information retrieval requires more than surface-level text matching. AI-enabled systems depend on structured, machine-interpretable knowledge to deliver accurate, context-aware results. Ontology-based knowledge representation therefore provides a robust foundation for modelling library resources, their relationships and associated constraints (Nguyen, Do & Tran, 2024).

This report presents the design of a prototype ontology developed using Protégé to support an AI-enabled library search system, enabling reasoning-driven and semantically enriched discovery beyond traditional keyword search.

2. JUSTIFICATION OF ONTOLOGY DRIVEN APPROACH

Traditional library search systems are largely based on keyword matching and flat metadata structures, limiting their ability to interpret semantic relationships and contextual constraints within user queries. While effective for basic retrieval, such approaches struggle to support intelligent search across multiple dimensions, including format, availability, accessibility requirements and location (Hambarde & Proenca, 2023). As a result, they are poorly suited to underpin AI-enabled search systems that depend on structured, machine-interpretable knowledge.

Ontologies provide a formal knowledge representation framework by explicitly defining domain concepts, relationships and constraints using logic-based semantics. Unlike taxonomies or relational schemas, ontology-driven models support Description Logic reasoning, enabling inference of implicit knowledge and validation of logical consistency

(Staab & Studer, 2013). This capability is essential for AI-powered search, where retrieval depends on semantic interpretation rather than surface-level text matching.

Although ontology-based approaches require careful modelling to avoid overly restrictive constraints and reasoning overhead (Hitzler et al., 2012), they offer a robust and explainable semantic backbone for intelligent library search, making them an appropriate foundation for this prototype.

3. ONTOLOGY SCOPE AND CONCEPTUAL DESIGN

The ontology was deliberately scoped to support intelligent search and discovery within a community library context, rather than modelling the full range of library operations such as user accounts, borrowing history or administrative workflows. This reflects the primary objective of the prototype: enabling efficient, semantically rich retrieval of library resources in response to user search requirements.

At the core of the conceptual design is a distinction between abstract bibliographic entities and their concrete manifestations. The class *Book* represents an abstract intellectual work, capturing attributes such as title, author, genre, subject and language. In contrast, the class *Copy* represents individual physical or digital instances held by the library, allowing properties such as availability status, accessibility features and branch location to be modelled independently. This separation mirrors real-world library practice and supports queries that differentiate between a work and its available instances.

Supporting classes, including *Author*, *Genre*, *Format*, *AccessibilityFeature*, *AvailabilityStatus* and *LibraryBranch*, capture key dimensions of user search behaviour. These modelling choices balance expressiveness with maintainability, ensuring the ontology remains focused, extensible and aligned with the requirements of an AI-enabled search system.

4. OBJECT AND DATA PROPERTY MODELLING RATIONALE

The ontology distinguishes clearly between object properties and data properties to preserve semantic clarity and support effective reasoning. Object properties represent relationships between domain entities, enabling inference across the library knowledge graph, while data properties are reserved for literal metadata values that do not contribute directly to logical classification.

Key object properties, including *hasCopy*, *hasAuthor*, *locatedAt*, *hasAvailabilityStatus* and *hasAccessibilityFeature*, were defined with explicit domain and range constraints to ensure consistent usage and prevent ambiguity. These constraints allow the reasoner to infer implicit knowledge, such as identifying accessible or available copies based on associated relationships. Availability and accessibility were intentionally modelled at the level of *Copy* rather than *Book*, reflecting real-world library semantics.

Data properties were introduced to capture descriptive attributes such as titles, publication years, copy identifiers, and barcodes. These were excluded from reasoning to avoid conflating metadata with semantic relationships, reducing the risk of inconsistency while preserving descriptive richness.

Overall, this modelling approach balances expressiveness with maintainability, ensuring the ontology remains logically robust, extensible and well suited to an AI-enabled library search system.

5. REASONING AND VALIDATION

Logical reasoning and consistency checking were integral to validating the proposed ontology. The HermiT Description Logic reasoner was used during development to classify the ontology, verify class hierarchies and detect modelling inconsistencies, ensuring compliance with OWL 2 DL constraints and preventing logical contradictions.

During development, the reasoner identified issues related to domain and range violations, inappropriate disjointness assertions and datatype mismatches within data properties. Addressing these issues required iterative refinement of class relationships, property definitions and datatype constraints, demonstrating that reasoning functions as a core validation mechanism rather than a post-hoc check. Following refinement, successful classification confirmed that the ontology was logically coherent and that inferred knowledge aligned with the intended conceptual model.

This reasoning-driven validation process highlights the value of formal knowledge representation in detecting hidden modelling errors and ensuring semantic reliability for AI-enabled search and inference.

6. DL QUERIES FOR AI-POWERED SEARCH

To demonstrate how the ontology can underpin an AI-enabled search system, Description Logic (DL) queries were used to simulate user search behaviour over the semantic model. Unlike keyword-based retrieval, DL queries enable structured search based on logical conditions, allowing results to be retrieved across multiple semantic constraints simultaneously. In this prototype, queries were executed across dimensions including genre, availability status, accessibility features and branch location.

The successful execution of these queries illustrates how the ontology supports intelligent retrieval by leveraging formally defined relationships and inferred knowledge. For example, queries targeting available copies at specific branches or copies with specific accessibility features returned accurate and logically consistent results without reliance on keyword matching. This demonstrates a clear improvement over traditional catalogue search mechanisms that lack semantic awareness and inference capability.

Although DL queries are not an AI interface, they act as a proxy for AI-powered search functionality. In a deployed system, AI components such as Natural Language Processing (NLP) could translate user input into structured queries over the ontology, with the ontology providing a reliable and explainable semantic backbone.

7. LIMITATIONS AND FUTURE WORK

While the proposed ontology provides a robust semantic foundation for AI-enabled library search, several limitations remain. The prototype focuses on resource discovery and does not model user profiles, borrowing behaviour or personalisation, limiting support for adaptive or recommendation-based services. Ontology population was performed manually, and large-scale deployment would require automated data ingestion and ongoing maintenance. DL reasoning may also introduce computational overhead, affecting scalability for extensive collections.

Future extensions could incorporate user interaction data to enable personalised search and recommendations. Integration with NLP techniques could support translation of natural language queries into structured semantic queries, while interoperability with existing library management systems would enable real-time availability updates.

8. CONCLUSION

This report has presented the design and validation of a prototype ontology to underpin an AI-enabled search system for a community library. By adopting formal knowledge representation and reasoning, the ontology provides a structured semantic foundation that supports intelligent discovery across dimensions such as availability, format, accessibility, and location. The use of reasoning and DL queries demonstrates how semantic models enable accurate, consistent, and explainable retrieval beyond traditional keyword-based search, highlighting the practical value of ontology-driven design for AI-enabled library search.

9. REFERENCES

Hambarde, K.A. and Proenca, H. (2023) ‘Information retrieval: recent advances and beyond’, *Institute of Electrical and Electronic Engineers* 11, pp. 76581-76604.

Hider, P. and Coe, M., Australian public library mission statements and the IFLA–UNESCO Public Library Manifesto. *IFLA Journal*, p.03400352251399851.

Hitzler, P., Krötzsch, M., Parsia, B., Patel-Schneider, P.F. and Rudolph, S. (2012) ‘OWL 2 web ontology language primer’, *W3C recommendation* 27(1), p.123.

Huettemann, S., Mueller, R.M. and Dinter, B. (2025) ‘Designing ontology-based search systems for research articles’, *International Journal of Information Management* 83, p.102901.

Nguyen, D.T., Do, N.V. and Tran, T.H. (2024) ‘Ontology-Based Solution for Designing knowledge Retrieval Systems in the Field of Artificial Intelligence’, In *Proceedings of the 2024 9th International Conference on Intelligent Information Technology* pp. 558-563.

Staab, S. and Studer, R. (2013) *Handbook on ontologies*. Springer Science & Business Media.

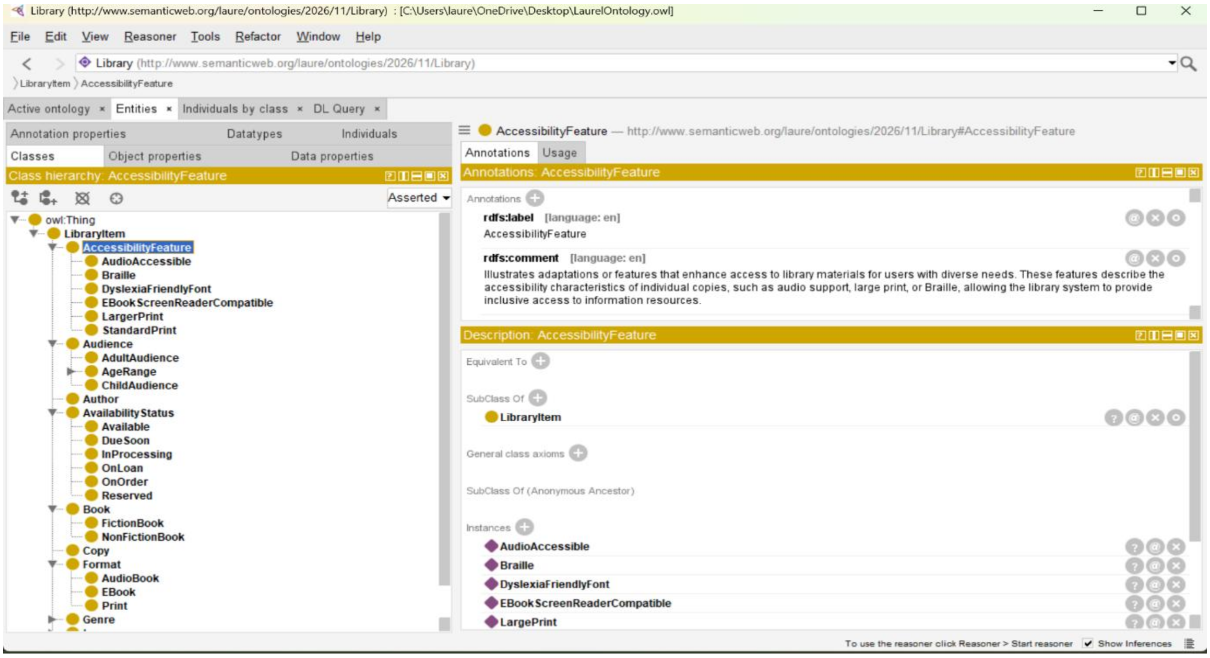
Yates, R.B. and Neto, B.R. (2011) *Modern Information Retrieval: the concepts and technology behind search.* Addison-Wesley Professional.

10. APPENDICES

Appendix A- Ontology Class Hierarchy

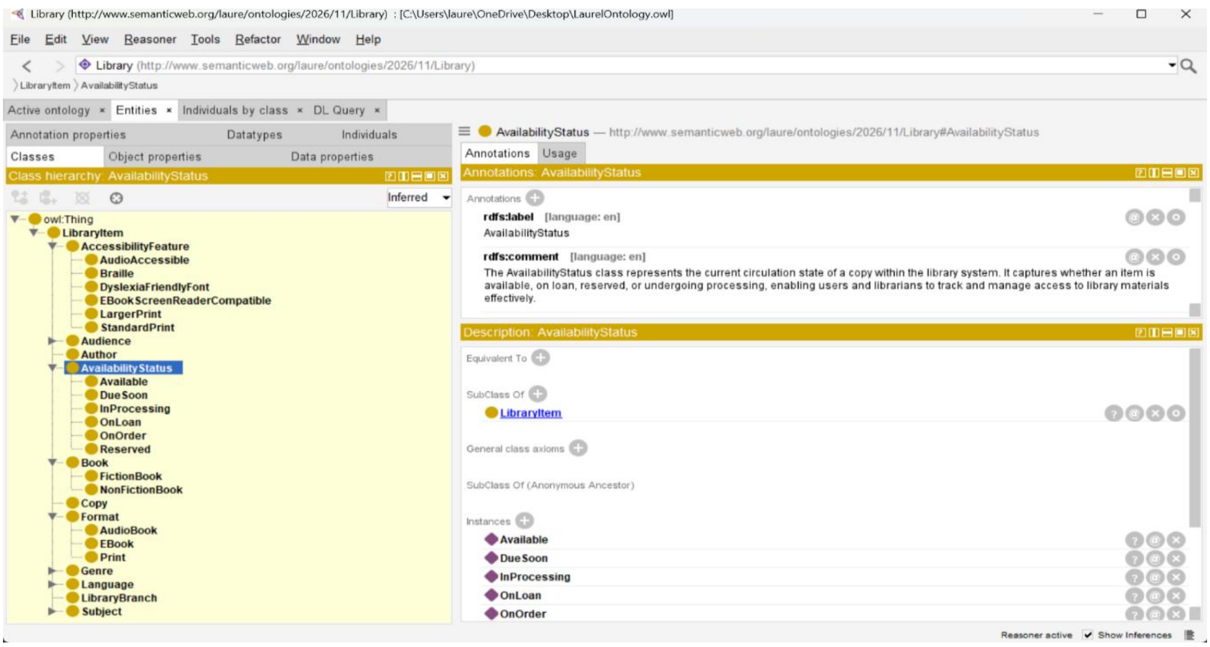
- Figure A1: Asserted Ontology Class Hierarchy

Asserted class hierarchy illustrating the core conceptual structure of the library ontology as defined by the modeller.



- Figure A2: Inferred Ontology Class Hierarchy

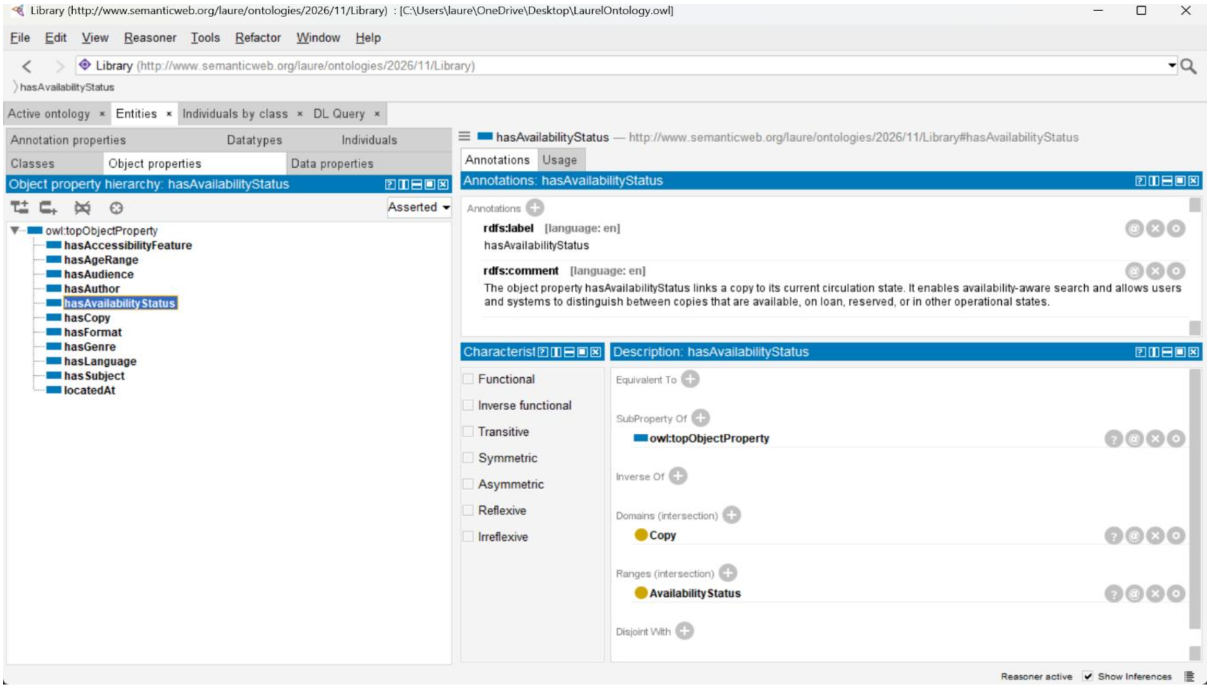
Inferred class hierarchy generated by the HermiT reasoner, demonstrating automated classification and validation of class relationships.



Appendix B- Object and Data Properties

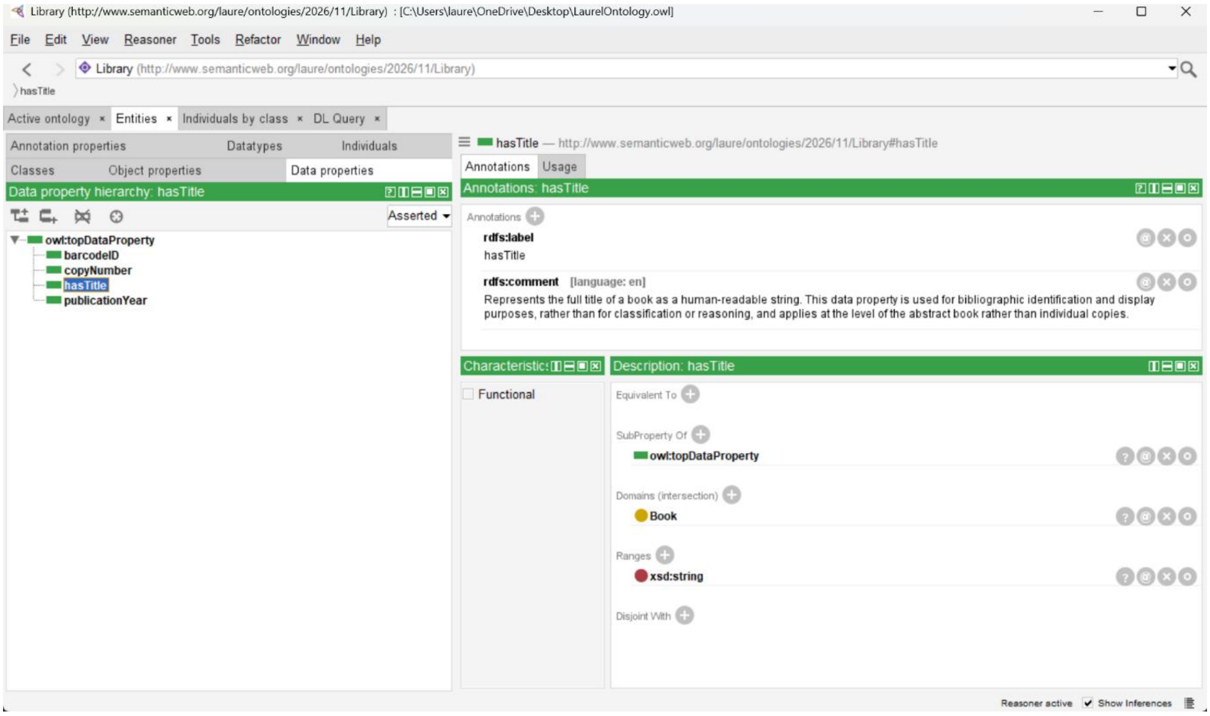
- Figure B1: Object Properties with Defined Domain Range

Object property definitions illustrating semantic relationships between ontology classes, including explicitly defined domain and range constraints.



- Figure B2: Data Property Definitions

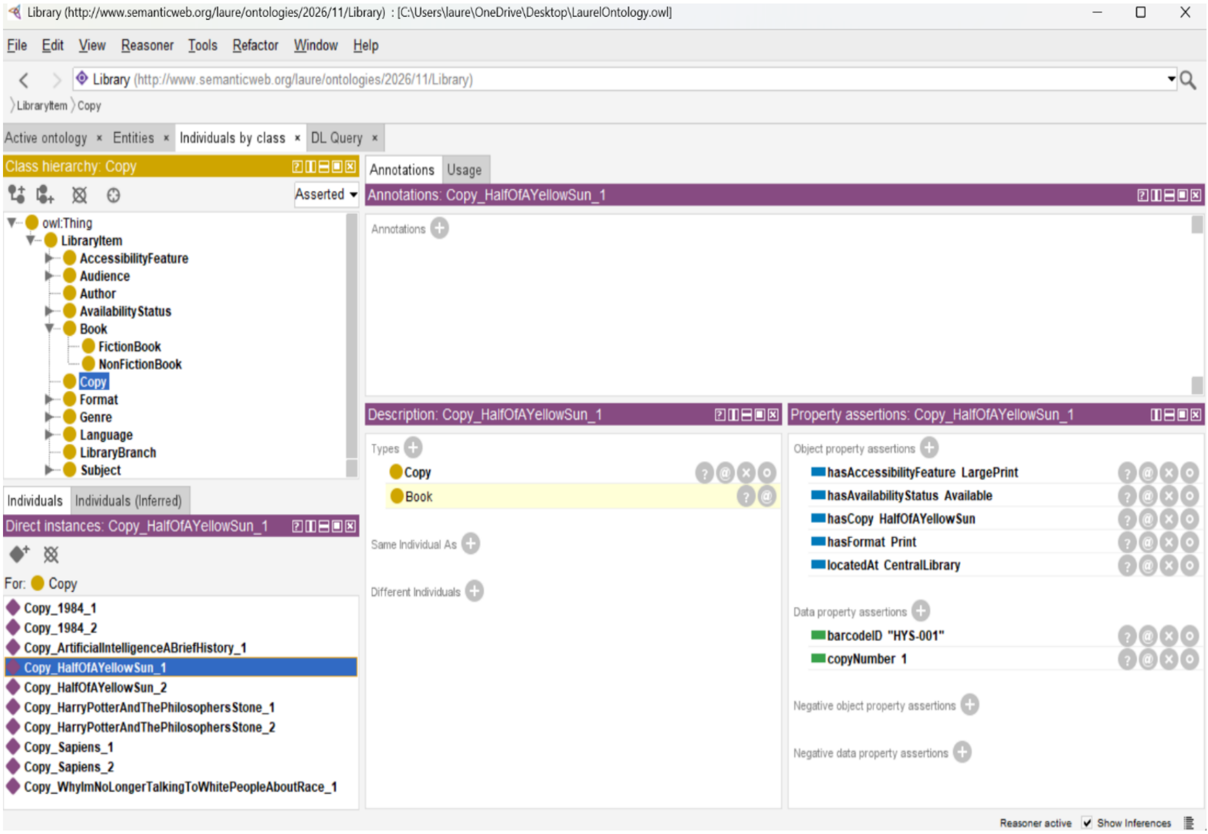
Data properties used to represent literal attributes associated with ontology individuals.



Appendix C- Individuals and Object Property Assertions

- Figure C: Example book and copy individuals illustrating object and data properties

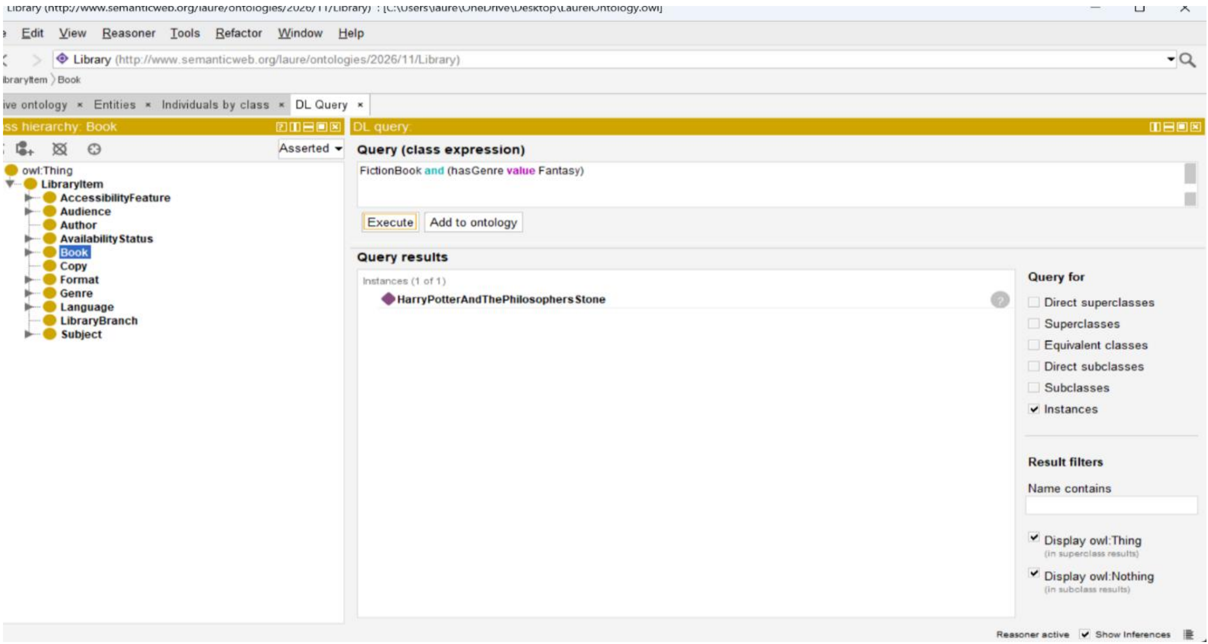
Individual-level representation of *Book* and *Copy* instances demonstrating how object and data properties are used to model real-world library resources.



Appendix D: DL Queries and Reasoning

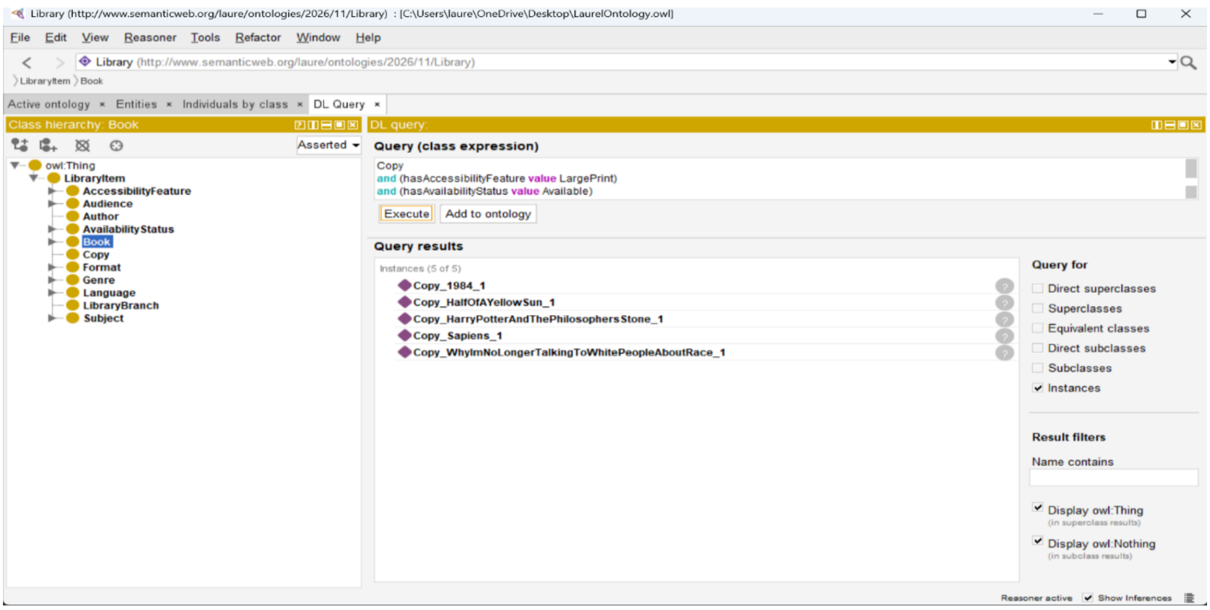
- Figure D1: DL Query executed to retrieve fiction books by genre

DL query demonstrating class-level reasoning by retrieving instances of *FictionBook* constrained by the object property *hasGenre*, returning books classified as Fantasy.



- Figure D2: DL Query illustrating reasoning-driven retrieval of accessible and available copies

DL query demonstrating instance-level reasoning by identifying *Copy* individuals that satisfy multiple semantic constraints, including *accessibility feature* (*Large Print)* and current *availability status.*



- Figure D3: DL Query demonstrating availability and location-based reasoning

DL query retrieving available *Copy* individuals located at a specific library branch, illustrating how spatial and operational constraints are supported through ontological reasoning.