



# From Data to Meaning in Digital Cultural Heritage

---

Bridging Knowledge Representation and Deep Learning with Neuro-Symbolic Architectures

Antonio M. Rinaldi – University of Naples Federico II

## Abstract

Digital cultural heritage is more than digitization; it is about preserving meaning, context, and interpretation. Traditional AI struggles with semantic depth, while neuro-symbolic AI offers a hybrid approach combining neural learning and symbolic reasoning. This paper explores its foundations, technologies, and applications, with a case study on Dante's *Divina Commedia*.

## 1. Introduction

Cultural heritage digitization has transformed access to historical artifacts and scholarly resources. Yet, the richness of cultural data—its layered meanings, historical contexts, and interpretative traditions—poses challenges for conventional AI. Purely statistical models lack transparency and semantic awareness. Neuro-symbolic AI bridges this gap by integrating deep learning with symbolic reasoning, enabling systems to learn patterns while reasoning over structured knowledge.

## 2. Foundations of Neuro-Symbolic AI

Neural networks excel at pattern recognition and handling unstructured data, while symbolic systems provide logical inference and domain-specific knowledge. Their integration creates systems that are both adaptive and interpretable. This dual capability is crucial for cultural heritage, where understanding relationships and historical semantics is essential.

## 3. Core Technologies

### 3.1 Ontologies and Knowledge Graphs

Ontologies formalize domain concepts and relationships, while knowledge graphs interlink these entities, enabling semantic search and contextual interpretation. Standards like CIDOC CRM provide a foundation for modeling cultural data.

### 3.2 Deep Learning and Multimodel Databases

Deep learning processes images, texts, and audio, but lacks interpretability. Multimodel databases manage heterogeneous data types, supporting flexible queries and integration of structured metadata with unstructured content.

### 3.3 Vector Indexing

Embedding techniques represent data as high-dimensional vectors, enabling semantic similarity searches and thematic clustering.

### 3.4 Retrieval-Augmented Generation (RAG)

RAG combines retrieval-based factual grounding with generative fluency, producing contextually accurate narratives and annotations.

### 3.5 Large Language Models (LLMs)

LLMs like GPT and BERT generate coherent text and summaries. When guided by ontologies and knowledge graphs, they achieve scholarly precision.

## 4. Architectural Integration

The architecture includes: Input Layer for multimodal ingestion, Deep Learning Modules for feature extraction, Symbolic Layer for semantic enrichment, Database Layer for multimodel storage, RAG Module for context-aware generation, and Output Layer for delivery of annotations, narratives, and semantic search results.

## 5. Case Study: Dante's Divina Commedia

A domain-specific ontology captures literary concepts and interpretative layers. A knowledge graph links verses, themes, and commentaries across centuries. Deep learning models classify texts and generate embeddings stored in a multimodel database. Queries like 'How did the interpretation of Francesca da Rimini evolve between the 1400s and the 1800s?' are processed using SPARQL, full-text search, and vector similarity. Results are fused via Reciprocal Rank Fusion and synthesized by an LLM with controlled prompting, ensuring transparency and scholarly rigor.

## 6. Applications

Neuro-symbolic AI supports: Semantic Search for natural language queries with contextual relevance; Automated Annotation for improved metadata and discoverability; AI-Assisted Storytelling for educational and public engagement; and Restoration Support for data-driven conservation strategies.

## 7. Challenges and Future Directions

Challenges include scalability, ethical considerations, and explainability. Future research will focus on adaptive ontologies, multimodal integration, and user-centered design.

## 8. Conclusion

Neuro-symbolic AI offers a transformative approach to cultural heritage, combining learning and reasoning for richer, more meaningful digital experiences.