DIGITAL CLASSICS ONLINE

Linked Ancient World Data: Implementation, Advantages, and Barriers

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Abstract: Linked Data technologies can be hugely beneficial for modelling and representing the complexity and nuances of Humanities data, while also facilitating discoverability and reuse. In the Ancient World domain, their implementation appears to be relatively mature, with many tools and resources available that demonstrate the benefits of this approach in different ways; however, barriers to Linked Data production and consumption still remain. In this article, I provide some brief background information on the principles behind a Linked Data approach, before surveying the literature on Linked Ancient World Data. Using examples provided by existing initiatives, I explore how these tools and resources work together to widen access to digital materials, reveal connections between them, and facilitate collaboration, while also recognising obstacles faced by both users and producers. Issues discussed include identification and disambiguation, modelling complexity, communicating uncertainty, reasoning, making connections, discoverability and usability, awareness and training, openness and collaboration, and sustainability. My conclusions point towards the key role of social and institutional factors in barriers to Linked Data uptake, instead of a series of solely technological problems requiring technological solutions.

1. Introduction

Of the various approaches available for modelling and publishing Humanities data, Linked Data is perhaps the most effective for representing its complexity and nuance, while also facilitating discoverability and reuse. The term 'Linked Data' refers to a set of technologies that can be used to describe entities, such as places, people, or objects, and connect them based on features they have in common. Its rich semantic descriptions, disambiguation capabilities, and interoperability can unlock opportunities to address new research questions and reveal previously undiscovered relationships between entities. However, uptake of Linked Data among Humanities researchers has been relatively low, compared with approaches such as relational databases or text encoding. In the Ancient World domain, however, Linked Data implementation is relatively mature. Additionally, as study of the Ancient World encompasses multiple disciplines, including Archaeology, Art, History, Literature and Philosophy, it might be considered a microcosm of the Humanities, rendering the conclusions from this article more broadly applicable.

In this article, I present a survey of Linked Ancient World Data (LAWD) implementation, illustrating the advantages of and barriers to this approach. I start by providing some background to the areas of Linked Data and knowledge organisation, before discussing in detail how these technologies have been applied to tools and resources that facilitate study of the Ancient World. To conclude, I will high-light the interplay between technological and social/cultural factors in relation to the advantages of and barriers to Linked Data implementation for Ancient World research.[1]

2. Background: Linked Data and Knowledge Organisation

2.1 Linked Data Principles

Linked Data technologies are used to describe digital resources, facilitating machine-readable connections between datasets, with the potential to transform the way they are consumed – leading to new insights that would not have been possible previously. Applying a Linked Data approach facilitates the implementation of the Semantic Web: a 'Web of Data', where online resources are semantically linked in a machine-readable way, based on the information about them.[2] For a dataset to be accurately described as Linked Data, it must comply with Berners-Lee's Linked Data principles:

> "1. Use URIs as names for things.
>
> 2. Use HTTP URIs so that people can look up those names.
>
> 3. When someone looks up a URI, provide useful information, using the standards (RDF, SPARQL).
>
> 4. Include links to other URIs, so that they can discover more things."[3]

Firstly, for a resource to be described using Linked Data, that resource must have a unique and persistent identifier, known as a Uniform Resource Identifier (URI) (point 1). A URI can refer to any concept or entity in the physical or digital world (i.e., it does not necessarily denote a digital resource), but in a Linked Data representation, a URI must start with 'http://' (point 2). 'HTTP' refers to 'Hypertext Transfer Protocol', which is the standard mechanism by which digital resources are accessed via the World Wide Web.[4]

Each piece of information about the resource (e.g., its title, creator, or location) is expressed using three components: a subject (e.g., the resource, expressed using its URI), an object (e.g., the resource's creator, expressed using their URI), and a predicate (the relationship between the subject and object, e.g., 'has creator', expressed using the URI that describes this property). If the subject or object cannot be identified using a URI (e.g. the title of a book, or an object's latitude/longitude), a literal value, such as a number or text string, can be used instead.[5] The three components are expressed as a 'triple' of the form <subject> <predicate> <object>, using the Resource Description Framework (RDF), the standard format for expressing Linked Data (point 3). RDF data can be queried using the SPARQL Protocol and RDF Query Language (SPARQL) (point 3) via a SPARQL endpoint. Both RDF and

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2 Berners-Lee (1998).

3 Berners-Lee (2010).

4 W3C Network Working Group (2004).

5 van Hooland / Verborgh (2014), 48.

SPARQL are open standards, "reusable agreements that make it easier for people and organisations to publish, access, share and use better quality data".[6]

As more resources are described using RDF, connections build up between triples originating from multiple sources, which share the same URI as either the subject or object (point 4).[7] Such links are facilitated through provision of authority files, usually managed by well-known, trusted institutions, such as national libraries, which serve as central and authoritative sources of information about particular topics.

It is only possible to take full advantage of this interlinking when the datasets concerned are openly available via the World Wide Web. In response, Berners-Lee developed a five-star model for Linked *Open* Data (LOD):

"★	Available on the web (whatever format) but with an open licence, to be Open Data
★★	Available as machine-readable structured data (e.g. excel instead of image scan of a table)
★★★	as (2) plus non-proprietary format (e.g. CSV instead of excel)
★★★★	All the above plus, Use [sic] open standards from W3C (RDF and SPARQL) to identify things, so that people can point at your stuff
★★★★★	All the above, plus: Link your data to other people's data to provide context"[8]

The five-star model prioritises openness, with full compliance requiring that the dataset meets Berners-Lee's original Linked Data principles. An extension to improve data reusability has since been proposed by Hyvönen et al., which adds sixth and seventh stars where a dataset has been adequately described:

> "– The 6th star is given if the schemas (vocabularies) used in the dataset are explicitly described and published alongside the dataset, unless the schemas are already available somewhere on the Web.
>
> – For the 7th star, the quality of the dataset against the schemas used in it must be explicated, so that the user can evaluate whether the data quality matches her needs."[9]

In a similar vein, the more broadly applicable *FAIR* data management principles state that research data should be Findable, Accessible, Interoperable and Reusable.[10] Although these principles were originally developed with the Sciences in mind, their application to Ancient World research (and Humanities disciplines more broadly) are likely to improve usability of the resulting data, as well as that of the tools and resources through which it is accessed. Findability and Accessibility require persistent

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6 Open Data Institute (2018).

7 van Hooland / Verborgh (2014), 49.

8 Berners-Lee (2010).

9 Hyvönen et al. (2014), 227.

10 Wilkinson et al. (2016).

identifiers, such as URIs, while Interoperability and Reusability require open, non-proprietary standards. As such, Linked Open Data implemented using the above seven-star model should also comply with the *FAIR* principles.

More recently, work led by Robert Sanderson and championed by the *Linked Art*[11] initiative has sought to implement and advocate for 'Linked Open *Usable* Data' (LOUD). The five LOUD 'Design Principles' are aimed at data scientists and ontologists, and focus on usability by developers, to achieve a compromise between rich semantic description and comprehensibility by others, ultimately facilitating data reuse and interoperability. These principles recommend providing data that is "The right Abstraction for the audience", with "Few Barriers to entry", that is "Comprehensible by introspection", that includes "Documentation with working examples", and that has "Few Exceptions, instead many consistent patterns".[12]

2.2 Authorities and Ontologies

In addition to each individual entity in a Linked Data resource being associated with a URI, it is often helpful to define them in relation to specific classification systems. For example, Euripides might be defined as a person, author, or playwright, while Classical Athens might be defined as a place, settlement, or *polis* (city-state). Such classifications are provided by Knowledge Organisation Systems (KOS), such as thesauri, which express a series of conceptual terms and the relationships between them, often organised using some form of hierarchy.[13]

Ontologies are like thesauri, but with a greater level of expressivity. In this context, the word 'ontology' refers to a type of controlled vocabulary whose structure facilitates complex relationships between terms, which cannot be represented solely via a hierarchical format.[14] Ontologies contain classes, used to classify the subjects or objects of triples, as in the Euripides and Athens examples above, as well as properties, used as the predicates that define the relationships between them. Using terms from a well-defined ontology enhances the machine-readability of resources and enables tools and systems to search more intelligently based on meanings and relationships rather than arbitrary keywords. Several broader, more extensive, resources provide both authority files and ontologies that describe them, including *Dbpedia*[15] and *Wikidata*[16]. *Wikidata* in particular has been used widely in Digital Humanities projects, largely due to its broad coverage and freely available reconciliation tools, although it is usually combined with more subject-specific data sources.[17] Some projects have additionally used *Wikidata* to store connections between entities such as objects, places, people and chronological periods, creating new concepts and properties as required. Among the advantages of using such a platform is its provision of links between representations of the same concept in different ontologies, thereby facilitating interoperability.[18]

The benefits of a Linked Data approach therefore include richer description of digital objects, leading to more effective integration of multiple collections and datasets. Together, these information sources form an infrastructure on which to build and link other digital tools and resources, both within and outside the organisation that produced them. This process facilitates the integration of previously separate

11 https://linked.art/ (last access 20.12.2023).

12 Delmas-Glass / Sanderson (2020), 22; Linked Art Contributors (n.d.-b).

13 International Organization for Standardization (2011), 2.62; Mayr et al. (2016).

14 Hughes et al. (2016), 163.

15 https://www.dbpedia.org/ last access 20.12.2023).

16 https://www.wikidata.org/ (last access 20.12.2023).

17 Zhao (2023).

18 Schmidt et al. (2022), 341.

datasets, with the potential to transform research by providing insights that could not have been discovered by looking at each one in isolation. However, when Linked Data is applied in practice, various barriers emerge, as demonstrated through my discussion on its implementation in Ancient World research in the following sections.

3. Linked Ancient World Data in Practice

There are multiple examples that serve to demonstrate how Linked Data technologies have been applied to Ancient World research, with these examples themselves illustrating many of the advantages of, and barriers to, this approach. Topics covered in this section include technological issues, such as identification and disambiguation, modelling complexity, reasoning over Linked Datasets, and making connections between them. I will then go on to discuss broader social and cultural issues relating to the implementation of Linked Data technologies for Ancient World research. These include discoverability and usability of the resulting resources, researchers' awareness of Linked Data and related training, and the benefits and obstacles Linked Data can bring to the key areas of openness, collaboration, and sustainability. Initiatives included in my examples were selected due to their relatively high uptake by the research community, as evidenced by their scale, as well as the frequency with which they are mentioned in the literature. Some initiatives have broader applicability beyond the Ancient World context, particularly those from the cultural heritage domain.

3.1 Identification and Disambiguation

When Humanities researchers are exploring a topic using a digital tool or resource, their search terms usually revolve around particular concepts, or "contextual entities", categorised by Lee as Object, Agent, Occurrence, Purpose, Time, Place, Form of expression, Concept or Abstraction, and Relationship.[19] Accurate identification and description of these concepts is intrinsic to effective digital representation that facilitates their discovery. Linked Humanities Data tools, resources, and initiatives, including those relating to the Ancient World, often revolve around one of these contextual entities, while incorporating their relationships to others. In the following examples, Places, Agents (people), Time, and Objects are identified using URIs, providing a unique and consistent mechanism for referring to them, as well as disambiguating those with similar names and uniting equivalent terms in multiple languages. Place (and, more recently, time) URIs are often included in gazetteers, with person URIs are often included in prosopographies, and various academic and cultural heritage resources providing URIs for objects. Assigning URIs to digital resources is recommended by the first of Berners-Lee's Linked Data principles (section 2.1, above); even if this is the only Linked Data principle followed by a project, it can nonetheless assist interoperability, as well as the understanding of terminology by both humans and machines.

Place is a key component of research involving historical events or people, or the movement of objects and materials. Real and mythological places appear in art or are mentioned in literature, demonstrating that place additionally permeates many research topics with a less obvious geographic component. *GeoNames*[20] provides URIs for places throughout the world, integrating geographic data from multiple official sources, such as the National Geospatial-Intelligence Agency and Ordnance Survey.[21] Its near-comprehensive coverage and open licence have made it attractive to many Digital Humanities projects that incorporate a spatial element; however, it was designed to represent the world in its current state. Although alternative names for a place are permitted (and can include historic names), it is not pos-

19 Lee (2011), 106.

20 https://www.GeoNames.org/ (last access 20.12.2023).

21 Geonames (n.d.).

sible to associate them with dates or boundary changes. Berman et al. and Simon et al. suggest that one way to address this issue is to produce suitable historical gazetteers that link places to their modern equivalents in *GeoNames*.[22] This recommendation emphasises the importance of specialist resources that are semantically rich enough for Humanities research, while recognising the value of connection to major information sources.

One such specialist resource is *Pleiades*[23], a gazetteer providing persistent URIs for ancient places, which stemmed originally from the digitisation of the *Barrington Atlas of the Greek and Roman World*,[24] but has evolved into a community-driven resource with an increasingly broad geographical scope. *Pleiades* URIs are additionally linked to *GeoNames* URIs, where an appropriate place record is available;[25] however, *Pleiades* is more fluid in its definition of 'place'. Its creators were influenced by Tuan's conception of 'place' as "a center of meaning constructed by experience", with most places lying on a spectrum between "points in a spatial system" and "strong visceral feelings".[26] Unlike *GeoNames*, a *Pleiades* place need not always correspond to a physical location, which provides the flexibility to include mythological places, or those whose location is unknown.[27] *Pleiades* is therefore better suited to represent the multiplicity of places encountered in Humanities research. Furthermore, to provide historical nuance and disambiguation, *Pleiades* permits multiple names to be associated with each place, with each name having a start and end date.[28] Researchers are therefore able to identify historical places with greater precision, rather than approximating to their counterparts in the contemporary world. As such, *Pleiades* URIs have been used in multiple digital tools and resources, most notably *Pelagios* (discussed in section 3.5, below).

While initiatives to identify places using URIs are particularly mature, significant progress has also been made to identify people in a similar way. People appear in a wide variety of contexts in ancient sources. These include creators of objects and authors of texts, as well as those depicted or mentioned within them. Some might have existed in real life, while others are either fictional, or their existence cannot be confirmed with certainty. There are inherent complexities in the digital representation of person information, for which Linked Data can be a particularly effective solution. For example, multiple people often have the same name, an issue that can be addressed by assigning a distinct URI to each individual,[29] which can be aligned if further evidence is discovered.[30] Similarly, an individual can have many names, or epithets, all of which can be linked to the same URI, potentially with further information about the context in which each name is used. Person URIs can additionally be linked to relevant places, chronological periods, and events, as well as other people. Two key sources of linked person data, *VIAF* and *SNAP:DRGN*, are discussed below (section 3.5) in the context of connecting resources.

Yet more complexity is inherent in the modelling of our next contextual entity, time. While many disciplines incorporate the modelling of time as an absolute concept, where exact days, hours, minutes, seconds and beyond can be identified with absolute precision, this is not the case when representing information about the premodern world. Dates must often be reconciled to different calendrical sys-

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22 Berman et al. (2016), 124; Simon et al. (2016b), 107.

23 https://pleiades.stoa.org/ (last access 20.12.2023).

24 Elliott / Gillies (2009), para. 41.

25 Simon et al. (2016b), 102.

26 Tuan (1975), 152.

27 Gillies (2015).

28 Schneider et al. (2018), 15.

29 Bodard et al. (2017), 29.

30 Varga et al. (2018), 39.

tems (if they are provided at all). More often, dates are unclear or unavailable, in which case a relative chronology must be applied, based on aspects such as an object's style, typology or context. Such definitions are frequently contested and are subject to change if new evidence comes to light. As these characteristics vary by geographical region, each chronological period defined in this way is bound up with the concept of place; for example, the Greek Bronze Age spanned approximately 3200 to 1050 BCE, while in Britain the Bronze Age is dated to between 2500 and 700 BCE. Initiatives and resources that are primarily focused on describing place therefore often incorporate a time component.

While several initiatives seek to represent time using a Linked Data approach, *Periods*, *Organized* (*PeriodO*)[31], a gazetteer of chronological periods, appears to be the most advanced in terms of development, and appears most frequently in the literature. Rather than seek to provide an authoritative identifier for each chronological period, *PeriodO* provides a URI for each *assertion* of a chronological period.[32] Each assertion includes the period name, date range and the geographical area to which it applies, linked to a URI from a spatial gazetteer such as *Pleiades*.[33] In this way, *PeriodO* "attempt[s] to mirror scholarly practice" by representing the 'fuzziness' and disagreements in this area of scholarship.[34] *PeriodO* has therefore been developed with existing research processes and the research community in mind: acknowledging that much Ancient World data cannot be considered authoritative, and that representing it in a way that implies otherwise would deter potential users.[35] Assertions are linked based on relationships between them, e.g. whether a particular term provides a broader or narrower definition than another for a similar chronological period.[36] Users can therefore maintain consistency by linking to periods that fall within the same sequence, as well as comparing similar definitions. *Pleiades* incorporates *PeriodO* URIs to allow datasets to define their temporal scope.[37]

Humanities research in general, and Ancient World research in particular, often involves the study of objects, including texts, artworks, and material culture, with many occupying more than one of these categories. As an example, *Trismegistos*[38] provides access to metadata about documentary texts from the Ancient World, while linking externally to the texts themselves. These texts were predominantly written on papyri, but also include ostraca (pottery sherds), wooden tablets, and inscriptions; their information and contents were previously contained in other databases and print publications.[39] Its remit was originally restricted to Egypt between 800 BCE and 800 CE but has since expanded geographically and is beginning to expand chronologically.[40] In addition to descriptive metadata about the texts, entities mentioned within them, such as places, people and chronological periods have been extracted using a combination of named entity recognition (NER) and manual editing.[41] Although *Trismegistos* data is modelled using relational databases,[42] it provides URIs in the form of TM-numbers, which are used in Linked Data resources such as *EAGLE* and *Peripleo* (both discussed below).[43]

31 https://perio.do/ (last access 20.12.2023).

32 Buchanan et al. (2016), 3; Rabinowitz (2021).

33 Shaw et al. (2018).

34 Rabinowitz (2014).

35 Rabinowitz et al. (2016), 51.

36 Rabinowitz et al. (2018), 207.

37 Rabinowitz (2021).

38 https://www.trismegistos.org/ (last access 20.12.2023).

39 Depauw (2018), 193–195; Depauw / Gheldof (2014).

40 Broux (2017b).

41 Broux (2017a), 13; Broux / Depauw (2015); Depauw (2018), 196–197.

42 Trismegistos (n.d.); Verreth (2017), 202.

43 Depauw (2018), 199; Simon et al. (2016a).

Where appropriate vocabularies and authority files to represent contextual entities already exist, their URIs can be used by other initiatives, to ensure clarity and consistency of meaning and to connect their resources to machine-readable information from external sources. For example, rather than creating a new resource-specific list of places, place information in an Ancient World resource can be represented using the relevant *Pleiades* URI(s).[44] As well as providing efficiency by avoiding duplication of effort and potential redundancy,[45] linking to established URIs (where possible) enables integration. Integrating related resources in this way leads to richer descriptions of concepts and entities throughout interlinked datasets, enhancing discoverability. Vitale et al. describe how this can facilitate the interoperability of future developments, particularly if an agreed set of standards can be used by a research community.[46] Additionally, Prag and Chartrand attest that the approach of linking to established URIs can bring much-needed consistency to resources that rely heavily on project-specific implementations of standards that are more open to interpretation, such as EpiDoc[47].[48]

However, in many cases established URIs do not sufficiently represent what needs to be described. For example, when focusing on place, *GeoNames* is often inadequate for describing historical places, while locations in *Pleiades* do not have sufficient precision to allow detailed spatial analysis.[49] There is also limited capacity in existing vocabularies for representing nuanced levels of difference and similarity between entities, i.e. values that fall between 'same as' or 'different from'.[50] As a result, data producers are often left with the choice between linking to established URIs that may not accurately represent the entity or concept they wish to describe or creating new URIs that link to their more established (but not exactly equivalent) counterparts. The latter would usually be more desirable in a scholarly context; however, it requires considerably more time than using existing resources and is often not a realistic prospect for fixed-term projects, due to the implications for long-term sustainability.

Additionally, people differ in their interpretation of the meaning of terms used to represent entities and concepts, resulting in inconsistent application, particularly in cases where there is a distinction between a URI used to represent an entity itself and a URI used to represent information about that entity.[51] Even where clear definitions are available, the suitability of a particular term in a particular context remains subject to the implementer's interpretation of its meaning, which may differ from that of the user. This discrepancy could result in misunderstandings, although these can be mitigated with clear documentation to describe the producer's understanding of their terminology.

Similarly, there are often subtle disciplinary or theoretical differences between definitions of terms that might initially appear to be equivalent, which can cause difficulties in aligning ontologies, affecting subsequent information retrieval.[52] Such differences potentially lead to incompatibility with some researchers' views, or require them to adjust existing ways of working.[53] To compound this issue, Limp states that in the archaeology domain, individual ontology development is seen as an integral part of

44 Horne (2020a).

45 Buzi et al. (2018), 40.

46 Vitale et al. (2021), 9.

47 EpiDoc (https://sourceforge.net/p/epidoc/wiki/Home/ [last access 20.12.2023]) is an extension of standards produced by the Text Encoding Initiative (TEI), initially developed for encoding epigraphic documents, but which has since been applied to papyri and manuscripts.

48 Prag / Chartrand (2018), 248.

49 Horne (2020b), 218; Middle et al. (2022).

50 Brown (2022), 4.

51 Brown (2022), 6–7.

52 Gerth (2016), 31–32.

53 Geser (2016), 12, 73; Meroño-Peñuela et al. (2014), 20.

scholarship, even when suitable terms and vocabularies already exist.[54] Without some level of cooperation between data producers, this situation potentially results in project-specific data silos with models that are more difficult to align.[55] Projects such as *Federated Archaeological Information Management Systems* have sought to mitigate issues of conflicting terminology by mapping local terms for particular concepts and entities to a core ontology;[56] however, if there is not exact alignment between term definitions, mapping is either not possible or requires extensive documentation to advise users of potential inconsistencies.

3.2 Modelling Complexity

While any form of data modelling about real-life concepts and entities is an approximation, Linked Data can provide a more accurate means of representing these complexities, facilitating the process of finding commonalities and eliciting meaning. Modelling complexity is particularly important where the information about an entity comprises a collection of relationships that do not fall into a neat, hierarchical structure, as in the examples discussed below. In many cases, these entities can often be most accurately represented in relation to events and interactions, rather than a table of characteristics or an increasingly complicated set of relational databases.

Data about objects can be particularly complex: each object is a product of a series of interventions (usually by people) over time, often in multiple places; objects can be classified into different types, with increasing levels of granularity, and their contents are often rich with textual and/or visual information. Linked Data technologies are ideally poised to capture the layered and multi-faceted nature of such objects in a way that would be difficult (if not impossible) to achieve accurately using tabular formats. In turn, object-based data is particularly amenable to a Linked Data approach, largely because it is often already available as a structured format, in collections or archaeological databases.

Many LAWD tools and resources, particularly those in the cultural heritage domain, use the *CIDOC Conceptual Reference Model* (*CIDOC CRM*)[57], an ontology that semantically describes entities, concepts and relationships relating to objects, facilitating interoperability between collections. It is the only cultural heritage ontology to be recognised as an ISO standard[58],[59] indicating its maturity and positive reception. In addition to its extensive core ontology, members of its user community have developed extensions to describe domains such as archaeological excavations[60] and buildings[61], ancient texts[62], spacetime[63], and the provenance of digital objects[64]. Rather than placing the individual object at the centre of the data model, *CIDOC CRM* models a series of events in which it was involved (e.g., production, acquisition and transformation), thereby providing an informative way of connecting the object to other entities.[65] Its relevance is not limited to a cultural heritage context; both Grossner and

54 Limp (2011), 278.

55 Geser (2016), 17.

56 Ross et al. (2015), 126–127.

57 http://www.cidoc-crm.org/ (last access 20.12.2023).

58 https://www.iso.org/obp/ui/#iso:std:iso:21127:ed-2:v1:en (last access 20.12.2023).

59 Bruseker et al. (2017), 108.

60 CRMarchaeo: http://www.cidoc-crm.org/crmarchaeo/ (last access 20.12.2023).

61 CRMba: http://www.cidoc-crm.org/crmba (last access 20.12.2023).

62 CRMtex: http://www.cidoc-crm.org/crmtex (last access 20.12.2023).

63 CRMgeo: http://www.cidoc-crm.org/crmgeo/ (last access 20.12.2023).

64 CRMdig: http://www.cidoc-crm.org/crmdig (last access 20.12.2023).

65 Bruseker et al. (2017), 113.

Hill, and Meroño-Peñuela et al. advocate the use of event-based ontologies for representing historical information in an academic research context.[66]

Elsewhere, there are relatively mature Linked Data solutions for the representation and discovery of specific objects such as coins (*Nomisma*[67]), inscriptions (*EAGLE*[68]), and papyri (*Trismegistos* and *Papyri.info*[69]). These objects form particularly interesting use cases due to their combination of textual, visual, and material culture characteristics. A complex aspect of many papyri and some inscriptions is their fragmentary nature. Parts of the same text can appear on multiple physical objects, many are incomplete, and scholars must often use their best judgement regarding missing words. Integration of multiple collections is therefore essential for a more comprehensive understanding of their contents and meaning.[70] Contrastingly, coins are mass-produced objects with a specific set of attributes that applies to all instances, irrespective of chronological period or geographical area, which can often be classified using established typologies.[71] For example, every coin has obverse (heads) and reverse (tails) sides, and every coin was minted in a particular place. This predictable structure, incorporating discrete entities and concepts that can be identified with persistent URIs, as well as the numerous potential connections to external resources, makes Linked Data particularly appropriate for modelling numismatic data.[72]

Different approaches to modelling Linked Humanities Data therefore have varying levels of complexity, with accompanying advantages and disadvantages. Simple data models might provide efficiency and a low barrier to implementation, but often do not capture the degree of nuance required for research purposes.[73] Conversely, complex models like *CIDOC CRM* provide a rich level of detail; however, as the degree of nuance increases, so do the barriers to its effective implementation. For example, incorporating multiple terms with similar definitions can cause ambiguity and inconsistency in their application and complicate analysis of the resulting data.[74] Once such a complex ontology has been applied, it becomes more difficult to make inferences from the data (see below, section 3.4) because the number of conditions required for an inference to be confirmed increases with the number of terms used.[75] Additionally, several projects have chosen not to use *CIDOC CRM* (in particular) due to the considerable time and resources required to model data in this way.[76] The latter is a particular issue for academic projects, due to the short-term nature of research grants. Producing and consuming data involving complex ontologies like *CIDOC CRM* might therefore deter researchers from working with Linked Data at all in future.

A compromise could involve implementing a simpler approach at the outset, while ensuring there is scope for adding further complexity.[77] Such an approach might be achieved by encouraging producers

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66 Grossner / Hill (2017), 9; Meroño-Peñuela et al. (2014), 13.

67 http://nomisma.org/ (last access 20.12.2023).

68 https://www.eagle-network.eu/ (last access 20.12.2023).

69 https://papyri.info/ (last access 20.12.2023).

70 Celano (2018), 139.

71 Heath (2018), 36.

72 Gruber / Meadows (2021).

73 Liu et al. (2017), 350.

74 Cayless (2019), 46; Gerth (2016), 21; Liu et al. (2017), 349.

75 Isaksen (2011), 155.

76 Bodard et al. (2017), 35; Kansa et al. (2018), 501.

77 Vitale et al. (2021), 9–10.

to map some or all of their data to a set template,[78] or by applying a simplified version of the ontology. An example of the latter approach can be found in *Linked Art*[79], a community-led data model for describing art objects. Acknowledging its complexity issues, *Linked Art* uses a simplified version of *CIDOC CRM*, to minimise confusion and ambiguity.[80] Such an approach might therefore be a potential solution to *CIDOC CRM* implementation in a Humanities research context.

3.3 Communicating Uncertainty

An additional dimension to consider when modelling in LAWD is that of uncertainty. Much of the data that supports Ancient World research is based on interpretation rather than fact. Some data will never reach the point where it can be considered 'factual'; for example, representations of mythological entities about whom there is conflicting information from different sources.[81] To take advantage of the benefits Linked Data provides, producers must consider how uncertainty can best be modelled within the data structure. For cases where several alternative values are possible, Thaller advocates a mathematical approach, where a probability is assigned to each value;[82] Niccolucci and Hermon demonstrate how a similar approach might be modelled using *CIDOC CRM*.[83] However, in many cases it is not feasible to perform a reliable calculation of probability (e.g., if the relative frequencies of different possible values cannot readily be estimated), and assigning probability based on the data producer's level of certainty would be extremely subjective.

Another example is that of the Linked Places format[84], where period definitions can start and end with a date range, rather than a single date, and geographic locations can be assigned a value of "'certain', 'less certain' or 'uncertain'",[85] although again these values rely heavily on the judgement of the person producing the data. As an alternative, *PeriodO* and *Pleiades* mirror more traditional scholarly practice by modelling information as cited assertions that link to the original source, which Golden and Shaw refer to as "nanopublications".[86] Despite these efforts, there is still no universally agreed method for expressing and communicating uncertainty in Linked Humanities Data and this is likely to remain the case. Humanities researchers should therefore always treat both digital and physical sources with an element of caution; their critical evaluation can be assisted by appropriate information about these sources' limitations.

3.4 Reasoning

Once a dataset is modelled using established ontologies and linked to appropriate identifiers, a reasoning (or inferencing) system can be used to automatically produce new knowledge, inferred from the relationships between entities, which would be difficult or impossible for a single user to discover manually. For example, in the *Sharing Ancient Wisdoms* project, automated reasoning was used to detect texts that were linked to the same translation but were not linked to each other.[87] Once the reasoner has elicited this information, it is the researcher's task to verify its likelihood based on any known gaps or

78 Binding et al. (2019), 371.

79 https://linked.art/ (last access 20.12.2023).

80 Linked Art Contributors (n.d.-a).

81 Bodard et al. (2017), 36.

82 Thaller (2020).

83 Niccolucci / Hermon (2017).

84 https://github.com/LinkedPasts/linked-places-format (last access 20.12.2023).

85 Grossner / Mostern (2021), 43.

86 Golden / Shaw (2016).

87 Tupman / Jordanous (2014).

issues inherent in the data.[88] Datasets aligned using Linked Data technologies therefore have the potential to become more than the sum of their parts. However, few publications relating to LAWD refer to the application of these capabilities, perhaps because thus far, emphasis has been placed on building tools, resources and infrastructures; substantial work on inferencing might then form the next stage of the process.

3.5 Making Connections

Humanities research topics often involve the analysis and interpretation of evidence from multiple sources of different types; using a Linked Data approach brings these research objects together, allowing them to be explored in the same virtual space. Once datasets are connected using Linked Data techniques, multiple collections and repositories that previously existed in separate silos can be searched via a single federated query, with the potential to visualise their combined data.[89] The ability to conduct one search instead of many reduces the time required for the discovery/data collection phase of a project, allowing more time to be spent on analysis and interpretation.[90] Linked Data tools and resources therefore have the potential to facilitate investigation into new research questions that would either be difficult or impossible to address using other technologies.

Pelagios[91] is one of the best known LAWD initiatives, although (like *Pleiades*, 3.1, above), it has subsequently increased its temporal and geographical scope.[92] In *Pelagios*, place names in a digitised text or image are identified and annotated with relevant gazetteer URIs, using the World Wide Web Consortium (W3C) Web Annotation Data Model[93]. Rather than expecting contributing organisations to adjust their data structures, *Pelagios* provides interconnectivity by hosting only these annotations as "stand-off markup", linking to the record for each object in its original dataset. In this way, the gazetteers provide a "central backbone" to connect multiple datasets, based on their relationships to place.[94] To ensure interoperability between different gazetteers, *Pelagios* developed a Gazetteer Interconnection Format[95], which has since been superseded by the Linked Places format.[96] Its implementation enables gazetteers with very different approaches to defining and representing the concept of 'place' to be reconciled and used alongside each other,[97] and it is now considered a "de facto standard" for "exchange of historical place name data".[98] Overall, *Pelagios* provides an example of how Linked Data from gazetteers can be brought together into an infrastructure and made available to the research community via user-friendly tools and resources. Its relative success in this regard could be due to several factors, such as openness, low barrier to entry, and an active user community.

Elsewhere, the *Virtual International Authority File* (*VIAF*)[99] aggregates information about people from authority files produced by libraries and cultural heritage institutions throughout the world; some or-

88 Meroño-Peñuela et al. (2014), 20–21.

89 Bagnall / Heath (2018), 184; Geser (2016), 26; Meroño-Peñuela et al. (2014), 19.

90 Gruber (2018), 59.

91 https://pelagios.org/ (last access 20.12.2023).

92 Simon et al. (2014), 105.

93 https://www.w3.org/TR/annotation-model/ (last access 20.12.2023).

94 Simon et al. (2017), 114.

95 https://github.com/pelagios/pelagios-cookbook/wiki/Pelagios-Gazetteer-Interconnection-Format (last access 20.12.2023).

96 Grossner / Mostern (2021), 41.

97 Simon et al. (2016b), 106.

98 Berman et al. (2016), 123–124.

99 http://viaf.org/ (last access 20.12.2023).

ganisations, events and places are also included, albeit to a lesser extent.[100] In recent years there has been increasing engagement with the research community, with a view to enriching the information available. In particular, an initiative called *Scholars' Contributions to VIAF* resulted in the incorporation of Ancient Greek data from the *Perseus Digital Library*[101] and Syriac data from *Syriaca.org: the Syriac Reference Portal*[102].[103] As well as broadening *VIAF*'s linguistic diversity, these additions have increased its relevance to Ancient World researchers. However, like *GeoNames*, *VIAF* does not provide the degree of nuance required for many Ancient World projects; for example, it contains relatively little information about mythological entities.[104] Again, more domain-specific resources are needed, ideally linked to *VIAF* to ensure connection to the wider web of data.

Perhaps the most extensive and well-known such resource for ancient people is *Standards for Networking Ancient Prosopographies: Data and Relations in Greco-Roman Names* (*SNAP:DRGN*)[105]. Like *VIAF*, *SNAP:DRGN* provides authority files for people, but with a focus on the Ancient World. Existing catalogues of personal names (such as that provided by *Trismegistos*, section 3.1, above) are aligned and combined into one searchable dataset, and connected based on their relationships with each other, using the SNAP data model.[106] Similarly to *Pelagios*, *SNAP:DRGN* has opted for relatively lightweight methods for data linking, to best reflect the ambiguities and incompleteness inherent in Ancient World person data, particularly where mythological entities are concerned.[107]

There are many cases where data connection has been achieved through the implementation of *CIDOC CRM*, with notable examples in the area of archaeological infrastructure. In *Arachne*[108], the object database of the German Archaeological Institute, *CIDOC CRM* has greatly facilitated its interoperability and potential for information exchange.[109] Indeed, the *CIDOC CRM* framework was used to link *Arachne* data with that of *Perseus*' art and archaeology collection as part of the *Hellespont Project*.[110] Additionally, the *Advanced Research Infrastructure for Archaeological Dataset Networking in Europe* (*ARIADNE*)[111] project integrated datasets from European national repositories by mapping the entities within them to *CIDOC CRM*. Users can access this data via the *ARIADNE Portal*, which includes visualisation and query functionality,[112] demonstrating the potential for ontologies such as *CIDOC CRM* to form the basis of LAWD access via a usable interface.

Other examples of initiatives that connect object data include those focused on specific types such as inscriptions, coins and papyri. The *Europeana Network for Ancient Greek and Latin Epigraphy* (*EAGLE*)[113] is an initiative by *Europeana*[114], a digital library based on a Linked Data model that ag-

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100 Angjeli et al. (2014), 2–3; Hickey / Toves (2014).

101 http://www.perseus.tufts.edu/hopper/ (last access 20.12.2023).

102 http://syriaca.org/ (last access 20.12.2023).

103 OCLC (2019); Smith-Yoshimura (2013); Smith-Yoshimura (2014).

104 Gerth et al. (2016), 15.

105 http://snapdrgn.net (last access 20.12.2023).

106 Bodard et al. (2017), 31; Lawrence / Bodard (2015).

107 Bodard et al. (2017), 31–36.

108 https://arachne.dainst.org/ (last access 20.12.2023).

109 Scriba / Stockinger (2016).

110 Crane (2014).

111 https://ariadne-infrastructure.eu/ (last access 20.12.2023).

112 Aloia et al. (2017); Meghini et al. (2017).

113 https://www.eagle-network.eu/ (last access 20.12.2023).

114 http://www.europeana.eu/portal/en (last access 20.12.2023).

gregates multiple European digital collections. *EAGLE* provides access to images and metadata for ancient inscriptions by bringing together existing databases. Inscription texts are structured using EpiDoc, with artefacts modelled using the *EAGLE Common Metadata Model and Schema*, predominantly comprising selected terms from *CIDOC CRM*. These approaches are united using *EAGLE*'s *Epigraphy Aggregation Conceptual Model* (*EACM*),[115] with duplicate entries disambiguated using *Trismegistos* identifiers. *Nomisma*[116] is a Linked Data ontology and resource provided by the American Numismatic Society (ANS)[117] to facilitate integration and discovery of data about coins, predominantly from the Ancient World. *Nomisma* links coin hoards, types and specific instances,[118] using terms from established ontologies and authority files, such as *CIDOC CRM* and *Pleiades*, to facilitate integration with external datasets.[119] *Papyri.info* is an aggregated collection of digitised documentary papyri that integrates several online resources[120], with disambiguation provided by *Trismegistos* URIs.[121]

Caution must be taken, however, in aligning datasets modelled using different approaches. For example, papyri often exist in the form of multiple fragments that originally belonged to the same text; simultaneously, the same writing surface may have been reused for two or more texts. This situation has resulted in different approaches to identifying and numbering texts, fragments and writing surfaces.[122] In the case of *Papyri.info*, some source collections choose to assign each text by a different scribe to a different URI (even if they appear on the same writing surface), while others choose to identify all texts written on the same surface with the same URI.[123] Therefore, using Linked Data technologies to aggregate multiple collections does not always provide a straightforward means of aligning data models, potentially resulting in inconsistency and confusion for the user.

3.6 Discoverability and Usability

Linked Data tools and resources that bring together data from multiple sources have great potential for serendipity, exposing collections and datasets previously unknown to the researcher,[124] such as those from relevant, but distantly related, subject domains,[125] or those in other languages.[126] As these datasets are often produced by a variety of organisations, for a wide range of purposes, they complement each other's information and provide the user with broader context for their object of study, potentially resulting in more accurate interpretations.[127] Searching multiple datasets simultaneously can additionally reveal relationships between (for example) objects held in separate collections,[128] as well as facilitating virtual reunification of objects from the same place.

115 Mannocci et al. (2014), 291.

116 http://nomisma.org/ (last access 20.12.2023).

117 http://numismatics.org/ (last access 20.12.2023).

118 Heath (2018), 41.

119 Gruber (2016), 100; Gruber / Meadows (2021).

120 The *Duke Databank of Documentary Papyri*, the *Advanced Papyrological Information System*, and the *Heidelberger Gesamtverzeichnis der griechischen Papyrusurkunden Ägyptens.*

121 Reggiani (2017), 227.

122 Ast / Essler (2018), 69; Polis / Razanajao (2016), 25.

123 Baumann (2013), 97; Cayless (2011), 32; Reggiani (2017), 74–75.

124 Gruber (2018), 62.

125 Geser (2016), 50; Pagé-Perron (2017), 11.

126 Koch / Koch (2017), 171.

127 Kansa et al. (2018), 503.

128 Geser (2016), 12; Rabinowitz et al. (2018), 212–213.

Use of Linked Data resources for discovery and analysis need not be restricted to researchers with an understanding of SPARQL. Queries can be facilitated via detailed filters and faceting options,[129] with data made meaningful to a variety of audiences by building narratives around curated subsets of digital objects.[130] Connections can be visualised as maps or networks and incorporated into discovery tools, to enable powerful cross-collection searching and identifying key entities and relationships.[131] New tools are being developed to facilitate the process of building user interfaces to explore and consume Linked Data.[132] These include the JavaScript-based *Sampo-UI*[133] framework, which provides a customisable filtering and faceting interface to query SPARQL endpoints,[134] as well as the collaborative knowledge base software *Wikibase*[135], which Koho et al. describe as "an easy, high-return, out-of-the-box solution".[136] Such tools and resources have the potential to break down the barriers between datasets, improve the efficiency of the research process, and provide a more holistic view of a subject domain, while reducing the need for specialist training to take advantage of the benefits that LAWD can provide.

Pelagios, *EAGLE* and *Nomisma* provide some examples of how LAWD resources can be usable even for those with limited technical expertise or subject knowledge. For example, *Peripleo*[137] is a visualisation and discovery tool, developed as part of *Pelagios*, which displays data via a map interface, with searching, filtering and faceting functionality.[138] As such, it provides an intuitive, visual means of exploring and querying multiple datasets.[139] While *Peripleo* was initially restricted to data associated with *Pelagios*, the new *Peripleo Lite*[140] tool allows the user to select the datasets they require for geographical exploration and visualisation.[141]

Similarly, *EAGLE* facilitates discovery across its component databases via a single search interface that incorporates filtering, faceting, and image recognition.[142] Alongside this functionality, *EAGLE* also incorporates mobile and storytelling applications, to fulfil their aim of broadening access to inscriptions to wider audiences beyond academia. The former provides visual search capabilities to enable in situ identification of inscriptions, while the latter enables users to view and create narratives using *EAGLE* resources, with the option to incorporate maps from *Pelagios*.[143] In a review, Hedrick praised the storytelling app for its "elegant way" of integrating *EAGLE* materials, but found that *EAGLE*'s main search interface can be difficult to use effectively for users unfamiliar with its constituent data-

129 Simou et al. (2017), 221.

130 Liuzzo et al. (2017), 521.

131 Isaksen et al. (2018).

132 For a recent survey, see Bernasconi et al. (2023).

133 https://seco.cs.aalto.fi/tools/sampo-ui/ (last access 20.12.2023).

134 Rantala et al. (2023).

135 https://wikiba.se/ (last access 20.12.2023).

136 Koho et al. (2023), 56:5.

137 http://peripleo.pelagios.org (last access 20.12.2023).

138 Simon et al. (2016a).

139 Vitale et al. (2021).

140 http://pelagios.org/peripleo-lite/ (last access 20.12.2023).

141 Barker (2021).

142 Prandoni et al. (2017).

143 Liuzzo et al. (2017); Orlandi et al. (2014).

bases.[144] These comments suggest that *EAGLE*'s researcher-focused search interface might benefit from some of the usability measures incorporated into its more creative, public-facing resources.

Nomisma also benefits from other discovery mechanisms, rather than relying solely on a SPARQL endpoint. The ANS also provides searchable resources such as *Online Coins of the Roman Empire* (*OCRE*)[145], *Coin Hoards of the Roman Republic* (*CHRR*)[146], *Coinage of the Roman Republic Online* (*CRRO*)[147] and *PELLA: Coinage of the Kings of Macedonia*[148], as well as its overarching catalogue, *MANTIS*[149]. Providing multiple methods for querying *Nomisma* data ensures its consumption is neither restricted to more technically advanced users, nor limited by the confines of a visual interface.

A more recent initiative, *Modelling Ancient Narratives, Territories, Objects* (*MANTO*)[150], took a different approach. Their dataset of Greek mythological people (and person-like entities) is managed using the *Nodegoat*[151] platform, which provides flexible data modelling and visualisation options for Humanities projects. As such, existing data in *MANTO* can already be displayed as maps and networks, without requiring specific technical skills. The project team additionally consulted their potential user community during development, by asking them to test a prototype version of the tool and complete an online questionnaire.[152]

However, due to its relatively complex structure (and often, producers' lack of familiarity thereof), building a Linked Data driven resource and ensuring its usability by non-technical researchers can be more difficult and time-consuming than a similar resource based on tabular data. If insufficient development time is available within the funded period of a project to produce a usable interface, its absence significantly limits the number of people who could potentially engage with and benefit from the dataset. As a result, some resources, such as *SNAP:DRGN,* exist in the form of rich but largely inaccessible datasets that must be queried via a SPARQL endpoint. While the data has the potential to be extremely useful, the proportion of interested parties who might be able to access it is relatively small, limiting the scope for its consumption. This situation additionally demonstrates the importance of funding projects to enhance and consume existing Linked Data, rather than prioritising the production of new datasets.

Even users who are familiar with SPARQL might not always be able to make effective use of a SPARQL endpoint, however, as they first need to be familiar with the way in which new and existing ontologies and data models have been implemented in this particular context.[153] The W3C recommends that providers describe linked datasets using the Vocabulary of Interlinked Datasets (VoID), which includes specifying ontologies used.[154] However, such a description is not always included; out of 427 SPARQL endpoints, Buil-Aranda et al. found that approximately two thirds were not accompanied by a VoID description.[155] Additionally, a single query has the potential to generate huge

144 Hedrick (2018).

145 http://numismatics.org/ocre/ (last access 20.12.2023).

146 http://numismatics.org/chrr/ (last access 20.12.2023).

147 http://numismatics.org/crro/ (last access 20.12.2023).

148 http://numismatics.org/pella/ (last access 20.12.2023).

149 http://numismatics.org/search/ (last access 20.12.2023).

150 https://www.manto-myth.org/manto (last access 20.12.2023).

151 https://nodegoat.net/ (last access 20.12.2023).

152 Hawes (2020).

153 Calvanese et al. (2016), 214.

154 Alexander et al. (2011).

155 Buil-Aranda et al. (2013), 280.

amounts of data, which is both unhelpful to the consumer and computationally intensive for the host. Therefore, even for technically experienced users, direct access to a SPARQL endpoint is not always advisable; providing access via an interface or API is usually preferable.[156]

Another barrier to querying data from multiple external sources via a SPARQL endpoint is the lack of control over its availability.[157] For example, Gerth et al. had originally intended to incorporate data from the British Museum in their experiments with integrating sculpture datasets, but were prevented from doing so due to unavailability of the SPARQL endpoint.[158] Additionally, in their 27-month study of 427 SPARQL endpoints encompassing different subject areas, Buil-Aranda et al. found that only 32.2% were available 99–100% of the time, while 29.3% were available less than 5% of the time. They note that many endpoints in the latter category were produced through experimentation with the technology, rather than long-term resource provision, and are now permanently unavailable.[159] As well as causing functional issues, resource unavailability can affect citations, a particular concern when referring to online sources in scholarly publications,[160] and may perpetuate the idea that online material is not stable enough to be cited. There are, therefore, considerable sustainability issues with Linked Data tools and resources; while the same could be said of any Digital Humanities project, the impact of Linked Data unavailability has the potential for more far-reaching repercussions, as it directly affects the availability of the resources linked to it. However, Schmidt et al. suggest that hosting this data via an established, openly-available data hub such as *Wikidata*, could mitigate these issues.[161]

Similarly, it is often unclear whether data held in external resources is accurate and up to date;[162] therefore, any inaccuracies could potentially be reproduced across multiple resources.[163] Such reliability issues might explain why many 'linked datasets' contain only internal links, rather than connecting to external resources;[164] however, this phenomenon may also be due to an actual or perceived lack of relevant external datasets and ontologies, or not being aware of the benefits of linking to more general resources. Quality issues can be mitigated with appropriate documentation, including provenance information, to assure potential users that the data is trustworthy.[165]

As with any type of technology or data structure, users with the requisite skills and experience are likely to derive the most benefit from Linked Data technologies; however, as the above examples have demonstrated, if resources are carefully designed with potential audiences in mind, all interested researchers should be able to engage with them.

3.7 Awareness and Training

Many Humanities researchers are not aware of Linked Data technologies, the potential benefits of this approach in the context of their research topics, or how it might be implemented. This situation is likely due to Linked Data rarely being covered in standard institutional training offered to staff and students, which usually focuses on spreadsheets and relational databases. As a result, researchers often tend to think in a tabular format, without considering that their data might be better represented by a

156 Gunter et al. (2019), 4–5; Schweizer / Geer (2019), 1.

157 Geser (2016), 15.

158 Gerth et al. (2016), 17.

159 Buil-Aranda et al. (2013), 289–290.

160 Hannemann / Kett (2010), 2.

161 Schmidt et al. (2022), 341.

162 Calvanese et al. (2016), 213.

163 Angjeli et al. (2014), 2.

164 Isaksen (2011), 64.

165 Geser (2016), 69–71.

networked, graph structure.[166] Even for those researchers who are aware of the potential benefits of Linked Data technologies, substantial training is often required for their effective implementation, which may not seem a realistic approach to take within the tight time constraints of funded projects.[167] For example, Granados-García found that using a Linked Open Data approach required far more time and training than initially anticipated and recommended that future data producers ensure they have sufficient technical knowledge and support (or the time to acquire them) before embarking on similar projects.[168] Similarly, Polczynski and Polczynski caution future gazetteer builders against a Linked Data approach, as their experience indicated that any benefits were outweighed by the amount of time and training required for its effective implementation.[169] In fact, Smith-Yoshimura found when surveying Linked Data producers from the cultural heritage domain that the main barrier to producing Linked Data was a "steep learning curve for staff", indicating the importance of addressing this fundamental obstacle.[170]

While I have noted implications for project timescales throughout the above discussion, time constraints are a particular concern for researchers who are unfamiliar with Linked Data and its production. This situation is compounded by difficulty in accessing, or unawareness of, adequate training, and often results in the prioritisation of immediate research objectives rather than longer-term usage of the dataset, tool, or resource beyond the lifetime of the project. To avoid these issues, and ensure that high quality, reusable data is produced, Gerth recommends that Linked Data should be produced via a collaborative process involving both technology experts and domain specialists.[171] However, Geser acknowledges that, while ideal, expert support is not always available, and that the development of usable tools to support Linked Data production could be a more effective solution to minimise the need for training.[172]

Such user-friendly tools that allow non-technical researchers to produce or enhance Linked Humanities Data are few in number.[173] Additionally, as these tools are often produced with the goal of academic experimentation rather than long-term usability, they have rarely been tested sufficiently to ensure consistency and reliability, and are often not adequately maintained.[174] Until the learning curve for developing Linked Data resources is reduced, the temptation will likely be to work with familiar data structures; a potentially 'safer' option that ensures development of a usable resource within the funded period, while maximising the amount of time available for research.

Some notable exceptions are *Pelagios*' annotation platform *Recogito*[175], and the Semantic Technologies Enhancing Links and Linked data for Archaeological Resources (STELLAR) applications[176].[177] *Recogito* provides a visual interface that allows users to annotate places, people and events in texts or images, either with tags or links to gazetteers. NER functionality is incorporated, while also allowing

166 Barbera (2013), 96; Ross et al. (2015), 118.

167 Isaksen (2011), 153–154; van Hooland / Verborgh (2014), 51.

168 Granados-García (2020), 261–264.

169 Polczynski / Polczynski (2022), 330.

170 Smith-Yoshimura (2018).

171 Gerth (2016), 14.

172 Geser (2016), 12, 56.

173 Barbera (2013), 98; Thiery / Engel (2016), 259.

174 Geser (2016), 55–56.

175 http://recogito.pelagios.org/ (last access 20.12.2023).

176 https://hypermedia.research.southwales.ac.uk/kos/stellar/stellar-applications/ (last access 20.12.2023).

177 Geser (2016), 12, 58.

manual annotation and confirmation.[178] *Recogito*'s development was substantially informed by user consultation,[179] resulting in an intuitive and widely-adopted research tool that renders Linked Data production (at least on a small scale) possible for researchers without specific training.[180] The STELLAR applications consist of tools and templates that allow conversion of archaeological data in CSV or SQL format to RDF, using the CRM-EH extension of CIDOC CRM, developed by English Heritage[181].[182] Templates were developed following a series of workshops with archaeologists to establish the most helpful and broadly applicable use cases and workflows within which they could be applied. Usability by data producers was therefore at the heart of both initiatives, although only *Recogito* remains in a current and readily available state.[183]

In cases where a usable interface can be produced in the time available, producers should acknowledge that methods for presenting and visualising Linked Data may be unfamiliar to Humanities researchers. For example, many potential users may not have prior experience or training in network analysis, which could result in an inability to use the resource to its full potential, or to inaccurate interpretations of their query results.[184] Accurate interpretation by the user is particularly important for resources with inferencing capabilities; as Hickey and Toves warn, results will reflect any ambiguities or inconsistencies in the original data, and as such should always be checked by domain experts.[185]

3.8 Openness and Collaboration

Even if Linked Data producers are not able to build a resource themselves, the fact that their data uses open standards and vocabularies means it can more easily be accessed and used by others. Similarly, providing an open dataset using Linked Data formats can encourage new collaboration opportunities that might result in the funding and expertise required to build a user-friendly interface.[186] Therefore, as well as connecting datasets, Linked Data has the potential to bring researchers together and facilitate the process of building on previous work in overlapping subject areas. As such, the majority of tools, resources and initiatives discussed in this article are a result of collaboration, usually involving some combination of Ancient World researchers, computer scientists, and information specialists. For example, *Nomisma* was developed as a result of international collaboration between experts in the field, ensuring accurate representation of information and acceptance by the research community.[187] *EAGLE*'s development took a similarly collaborative approach, with feedback on models and processes actively sought from contributors to optimise the end result.[188] On a related note, the previous section included examples where collaboration with potential users was integral to the development process.

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178 Simon et al. (2017); (2019).

179 Simon et al. (2015).

180 Vitale et al. (2021), 19.

181 https://hypermedia.research.southwales.ac.uk/kos/star/cidoc-crm-implementation-and-crm-eh/ (last access 20.12.2023).

182 May et al. (2012).

183 The source code for the STELLAR applications continues to be available via GitHub at https://github.com/cbinding/stellar (last access 20.12.2023) but, at the time of writing, has not been maintained for over four years.

184 Barker (2020).

185 Hickey / Toves (2014).

186 Buzi et al. (2018), 50.

187 Gruber (2018), 55.

188 Rocco (2017), 128; Santucci et al. (2016), 53.

This emphasis on collaboration within the Linked Ancient World Data community means that users are often active contributors to these resources, rather than being solely passive consumers of their data. Several initiatives have developed methods to encourage and facilitate these contributions, while maintaining scholarly quality and credibility. For example, to include their data in *Nomisma*, contributors need not structure it as Linked Data themselves. Instead, they provide a Google spreadsheet, with headings that can be directly mapped to *Nomisma* terms, which is then validated and converted to RDF.[189] Similarly, as well as ensuring discoverability through the *Papyrological Navigator*, *Papyri.info* additionally provides the *Papyrological Editor*, a collaborative editing tool. Texts are encoded using EpiDoc, and connected using RDF.[190] The resulting resource not only comprises a searchable collection of texts, it also provides open, dynamic and collaborative digital critical editions, to which any user can contribute.[191] Bambaci et al. have highlighted the relative ease with which users can encode text in the *Papyrological Editor*, using familiar papyrological conventions without compromising data quality and richness.[192]

Creating an open, usable resource for exploring Linked Data can, however, have some negative implications; making this data more discoverable can amplify information now known to be incorrect, terminology now considered to be offensive,[193] or potentially distressing images.[194] This issue is common to all data types, but its effects can be more pronounced where discoverability is aided via semantic enrichment. Avoiding or mitigating this issue often requires extensive work to update the dataset before linking can be considered, which poses a particular barrier for smaller institutions with limited funding. Otherwise, publishing the original dataset as Linked Data could have harmful consequences for users, as well as potentially perpetuating outdated language and interpretations in subsequent academic research.

Similarly, the exact locations of heritage sites are often considered sensitive information due to the potential for looting or vandalism.[195] To mitigate this, while allowing some discoverability, Kansa et al. reduced the level of precision to which locations are described in the *Digital Index of North American Archaeology*.[196] As well as altering newly published datasets in this way, similar actions may need to be taken for data that already exists online, but where integration with other datasets or richer description may significantly increase its visibility.

3.9 Sustainability

In some regards, the openness of Linked Data can have positive implications for sustainability, both in terms of immediate reuse potential and the relative ease of preserving data that uses open standards. However, the sustainability of any tool or resource through which that data can be accessed without requiring specific technical skills or knowledge is often a concern. The initiatives discussed above have taken differing approaches to ensuring that such tools and resources can continue to be usable over time.

189 Gruber (2016), 104–105.

190 Papyri.info (n.d.).

191 Reggiani (2017), 241, 269.

192 Bambaci et al. (2019), 28.

193 Gibson / Kahn (2016); Modest / Lelijveld (2018).

194 Holterhoff (2017).

195 Tolle / Wigg-Wolf (2016), 277.

196 Kansa et al. (2018), 494.

The *Trismegistos* team has used their data to perform statistical analyses, uncovering trends over time,[197] and to produce visualisations, particularly in the area of social network analysis.[198] However, while the data itself remains openly available, since January 2020 this additional functionality, as well as performing more complex queries via the user interface, requires users (or their institutions) to pay a subscription fee.[199] Although this move was deemed necessary to ensure long-term sustainability of the resource, it is unfortunate that features with the potential to open up *Trismegistos* to a wider audience are now only available to a restricted subset of users.

It is clear from a recent fundraising campaign to ensure *Papyri.info*'s sustainability, led by the Association Internationale de Papyrologues and the American Society of Papyrologists, that *Papyri.info* now occupies a position of fundamental importance to the wider papyrological community, rather than appealing only to those who consider themselves digital humanists.[200] These scholarly organisations have recognised that, despite considerable contributions by volunteers, a dedicated role is required for effectively managing the resource, which should not be funded by introducing subscription fees, ensuring that *Papyri.info* will remain openly available.

After initially being supported through a series of grant-funded projects, *Pelagios* now operates as a community-driven network of contributors, who drive improvements to its tools and share best practice.[201] Individual membership of the *Pelagios* community and joining the network as a partner project are both free of charge, with the expectation that partners will actively contribute to community activities. Hosting and maintenance for *Pelagios* tools and resources continue to be provided through institutional support, which is mitigated by the fact that all source code is made openly available, and that *Pelagios* does not host any of the data that can be accessed or annotated through their tools.[202]

A concern throughout this article has been the impact of short-term funding models on sustainability and usability. In the longer term, as no specific software is required to engage with Linked Data formats, the data itself should continue to be (re)usable for a variety of purposes, even if the interface for its consumption reaches the end of its life.[203] Therefore, although issues remain with the sustainability of tools and interfaces for consuming Linked Data, choosing a Linked Data format is a positive step towards ensuring longevity and reuse of the underlying data.

4. Conclusions

In this article, I have explored the current situation with regard to LAWD, including examples of relevant tools, resources and data structures; the advantages of this approach, and potential barriers to its implementation. Example initiatives focused on representation and discovery of different entity types, such as place, time, people, and objects, and applied different data modelling approaches with varying levels of complexity and granularity. Exploring these examples demonstrated the potential for using Linked Data as the basis for creative and engaging outputs for a wide variety of users, while remaining academically rigorous. Most initiatives took a collaborative approach to development, with the aim of ensuring usability and usefulness of the resulting tools and resources. Although they primarily focus on separate entity types, their producers have recognised the impact of these entities on each other; as

197 Depauw / Stolk (2015).

198 Broux (2017b); (2017c); Depauw (2018), 197–198.

199 Trismegistos (2019).

200 Torallas Tovar / Schubert (2019).

201 Barker et al. (2021), 2.

202 Kahn et al. (2021).

203 Biston-Moulin / Thiers (2018), 160; Jordanous et al. (2012).

such, there are many connections between them. Some resources are broad and multidisciplinary, and therefore ideal for making connections to the wider Linked Data ecosystem, with domain-specific initiatives often required to provide more nuanced representations.

Advantages that Linked Data can bring to Humanities research, as demonstrated through these examples, include consistent and unambiguous identification, alignment of different data models and vocabularies, the production of new knowledge via reasoning, and the effective modelling of complex concepts and entities. Once the data has been produced, there are lightweight mechanisms to connect multiple datasets, on which usable resources can be built. Incorporation of open standards facilitates collaboration and ensures sustainability of the data (if not the tools or interfaces). All the above advantages result in Linked Data facilitating research processes such as discovery, annotation, and visualisation.

However, there has been less uptake of LAWD than one might expect after exploring these advantages. This discrepancy is due to challenges and obstacles to its implementation, which often have implications for its subsequent use. Many such barriers are technical in nature and predominantly apply to tool and resource producers who are already familiar with Linked Data. These include the accurate representation of concepts and entities, the difficulty in aligning data from sources structured in different ways, the disadvantages of selecting either a simple or complex data model, the particular importance in Humanities research of effectively communicating uncertainty, and the reliability issues inherent in full or partial dependence on external sources. Even researchers with significant experience in Linked Data production will need to assess the potential impacts of these barriers on project timescales before opting to implement this approach.

Before these researchers even consider the technical obstacles to Linked Data implementation, however, there are wider issues that must be addressed. The first concerns a general lack of awareness among Humanities researchers of the benefits of Linked Data, with little training available to rectify this, and few use cases demonstrating its effective implementation. The second is the relatively small number of usable tools or resources for producing or consuming Linked Data, potentially due to their being produced for experimentation with the technology, rather than long-term availability. The third concerns instances where enhanced data discoverability is undesirable, e.g., for collections containing sensitive material. These higher-level barriers must be addressed before potential producers can even consider the above technological challenges.

Although the challenges and obstacles to production and consumption of Linked Data are substantial, they are not insurmountable. In the above discussion, I have largely focused on barriers to Linked Data production; however, the way in which each of these barriers is addressed (or not) has significant implications for the usability and uptake of the resulting tools and resources. While expert consultation is usually an ideal solution, many barriers can be mitigated with access to information, training, and the production of more usable tools and resources. In many cases, it can be preferable to start with a simpler, incremental, approach to linking data, with scope to increase the complexity at a later stage. This approach additionally allows more time to develop a usable interface; however, even where such interfaces have been developed and are well-used, it is extremely difficult to guarantee their long-term sustainability while simultaneously ensuring that they remain free to access. Time and money, therefore, continue to be the ultimate obstacles to Linked Ancient World Data implementation.

List of Abbreviations

ANS	American Numismatic Society
API	Application Programming Interface
ARIADNE	Advanced Research Infrastructure for Archaeological Dataset Networking in Europe
CHRR	Coin Hoards of the Roman Republic
CIDOC CRM	CIDOC (International Council of Museums' International Committee for Documentation) Conceptual Reference Model
CRRO	Coinage of the Roman Republic Online
CSV	Comma Separated Values
EAGLE	Europeana Network for Ancient Greek and Latin Epigraphy
EACM	Epigraphy Aggregation Conceptual Model
FAIR	Findable, Accessible, Interoperable, Reusable
HTTP	Hypertext Transfer Protocol
ISO	International Organization for Standardization
KOS	Knowledge Organisation System
LAWD	Linked Ancient World Data
LOD	Linked Open Data
LOUD	Linked Open Usable Data
MANTIS	MANTIS: A Numismatic Technologies Integration Service
MANTO	Modelling Ancient Narratives, Territories, Objects
NER	Named Entity Recognition
OCRE	Online Coins of the Roman Empire
PeriodO	Periods, Organized
RDF	Resource Description Framework
SNAP:DRGN	Standards for Networking Ancient Prosopographies: Data and Relations in Greco-Roman Names
SPARQL	SPARQL Protocol and RDF Query Language
SQL	Structured Query Language
STELLAR	Semantic Technologies Enhancing Links and Linked data for Archaeological Resources
UI	User Interface
URI	Uniform Resource Identifier
VIAF	Virtual International Authority File
VoID	Vocabulary of Interlinked Datasets
W3C	World Wide Web Consortium

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