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DEALING WITH DOUBTS: SITE GEOREFERENCING IN ARCHAEOLOGY AND IN THE GEOSCIENCES

1. Introduction

Archaeological research has to handle doubts, such as vagueness, uncertainty, and ambiguities in data modelling, which in the context of the NFDI4Objects research project (Bibby *et al.* 2023) are often named using the umbrella terms 'fuzziness and wobbliness' (Thiery *et al.* 2021). In our case, 'vagueness' is a measure of the precision of a statement; a vague statement is, therefore, only accurate to a certain degree. In the case of 'uncertainty', it is entirely unknown whether the statement is valid (Unold *et al.* 2019; Thiery, Mees 2023). Especially in georeferencing, the challenge of making these doubts visible can occur (Schmidt, Thiery 2022). Other famous buzzwords about this topic are 'accuracy' and 'precision'. Taking the image of an archer who shoots 'numeric' arrows at a target, he could do it in four different ways (Fig. 1A), where high accuracy and high precision is an 'X' (10 points in archery for the golden middle). Still, for not numeric questions, the target is anywhere different.

Numerical differences can also be modelled in other ways (e.g., coin weights): exact: 5.38g, range: 5g to 6g; blurry: ~5g (Fig. 1B). Relations between entities also appear in several types (e.g., person types): exact: type X; range: type X ∨ Y; blurry: probably type X ∨ Y (Fig. 1C). The term 'probably' can also be described using the perceptions of probability and numbers as median values (Nation 2017, probly.csv), e.g., 'almost certainly' (95%), 'very good chance' (80%), 'probably' (75%), 'little chance' (15%) or 'highly unlikely' (5%). The term 'probably' can also be described using the perceptions of probability and numbers as median values (Nation 2017, probly.csv), e.g., 'almost certainly' (95%), 'very good chance' (80%), 'probably' (75%), 'little chance' (15%) or 'highly unlikely' (5%).

Creating reproducible and comprehensible data for reuse while guaranteeing data quality in archaeological data involves disclosing doubts and ambiguities (Thiery, Mees 2023). This is also important for data FAIRification (Wilkinson *et al.* 2016) – making data Findable, Accessible, Interoperable, and Reusable – addressed in the German National Research Data Infrastructure, called NFDI (Hartl *et al.* 2021). In particular, vagueness and uncertainty must be modelled to work with geodata, such as a map of royal mints (Seelbach 2023, 377 ss.). However, for linking and FAIRifying data, the Linked Open Data (LOD) proposed by Berners-Lee (2006) (Schmidt *et al.* 2022) is the method and technique of choice. LODs are semantic graph-structured data (so-called 'triples') based on the W3C standard Resource Description Framework (RDF),

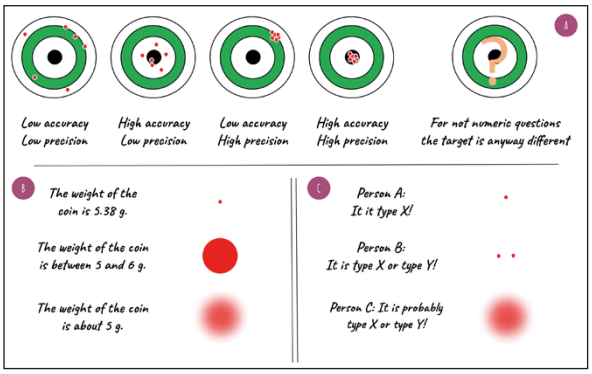

Fig. 1 – A) Accuracy vs. precision; B) visualisation of numerical differences; C) visualisation of uncertain or-relationships (F. Thiery, K. Tolle).

which are described with a URI, accessible via HTTP, structured as RDF, and interlinked with other (linked RDF-based) data. However, this leads to ambiguities and uncertainties: is 'Mainz' the 'Roman Mainz', 'Medieval Mainz', 'Mainz ~1920' or 'Mainz after World War II'? The links to the Semantic Web are also not unambiguous: GeoNames (2874225) as Mainz in Rhineland-Palatinate, Pleiades (109169) as Mogontiacum, and iDAI.gazetter (2052457) as Mainz (populated place) or GeoNames (2874226) as Mainz in Bavaria?

This paper discusses two data-driven interdisciplinary use cases for dealing with and modelling vague and uncertain geo-references (findspots) based on literature as LOD from the archaeological and geosciences domain. The use cases implement three modelling strategies: Wikidata, Linked Open Data and Wikibase.

2. Modelling strategies

In the process of dealing with doubts such as uncertainty, vagueness and ambiguities, one of the main goals could be to publish and model the following information: 1) describe where the geoinformation comes from; 2) describe the method of how the coordinate was created; 3) describe the uncertainty issue(s); 4) use references into the Semantic Web. Below, three modelling strategies are presented, modelled using LOD with the help of the Web Ontology Language (OWL) and with Wikibase instances such as Wikidata (Thiery 2023a).

2.1 *Linked Open Data*

The Fuzzy Spatial Locations Ontology (Thiery 2023b) (prefix fsl) is based on PROV-O, SKOS and GeoSPARQL (Thiery 2023a, 3-5). It follows

the PROV-O concept of Entity, Activity and Agent. In the case of this ontology, sites (entities) have a geometry and were created with a method (activity) by a person (agent) (Fig. 2, left). Site and geometry contain two properties for describing fuzziness: fsl:certaintyDesc and fsl:certaintyLevel; sites additionally receive properties for describing references, e.g. for books, fsl:hasReference or to online resources, e.g. via exact-match properties from the Simple Knowledge Organization System (SKOS) vocabulary (http://www.w3.org/TR/skos-primer) used for designing and aligning thesauri. The method can be characterised via sources (fsl:hasSource, fsl:hasSourceType), references (fsl:hasReference), method descriptions (fsl:activityDesc) and uncertainty information (fsl:certaintyLevel, fsl:certaintyDesc). The resulting LOD as RDF can be converted into human-readable HTML files using the SPARQL Unicorn Ontology Documentation Research Tool (Homburg, Thiery 2024) based on the SPARQL Unicorn (Thiery *et al.* 2020; Thiery, Homburg 2024). In nomisma.org (https://nomisma.org), for example, fuzzy locations of mints can be described with the Nomisma Ontology (Zeena, Nomisma.org 2022) (Fig. 2, right).

2.2 *Wikidata and Wikibase*

The geographical location of sites and archaeological artefacts can be described in Wikidata using coordinates and Wikidata property P625. Wikidata's (and Wikibase's as the software behind Wikidata) data model is based on statements (Schmidt *et al.* 2022, fig. 7) that can be described in more detail using so-called 'qualifiers', which are statements about statements and, on top, 'references' to verify the statement. The modelled coordinates contain uncertainty and reference information that can be modelled using Wikidata

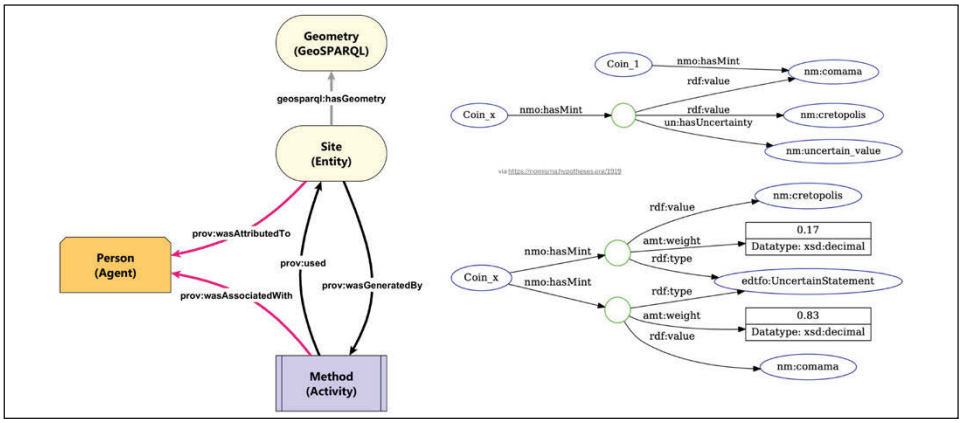

Fig. 2 – Left: Linked Open Data modelling using the Fuzzy Spatial Locations Ontology, based on the idea of PROV-O; right: modelling of hasMint in the Nomisma cookbook (left: F. Thiery; right: Zeena/nomisma.org, https://nomisma.hypotheses.org/1919).

qualifiers and references. This can be done for on-site surveys (Thiery *et al.* 2023), as follows (Thiery 2023a, 2-3) by using the following qualifiers and references: sourcing circumstances (P1180), stated in (P248), location (P276), determination method (P459), subject has role (P2868), and OpenStreetMap node ID (P11693). Locations/artefacts that are only accessible in the literature/online databases can be modelled with this qualifier and reference properties: stated in (P248), object has role (P3831), determination method (P459), subject has role (P2868), and reference URL (P854).

The Wikibase modelling (Thiery 2023a, 5-6) is related to the Wikidata approach. Here, a location also has a latitude/longitude coordinate, which is provided with a qualifier to describe it further with the following attributes: has certainty level, certainty description, method used, acting person, has source, has source subtype, and method description.

3. Case studies

Three case studies are described below, which show examples of modelling in Wikidata (Ogham Stones), with Linked Open Data (Campanian Ignimbrite) and Wikibase (Silver Coinage of Croton).

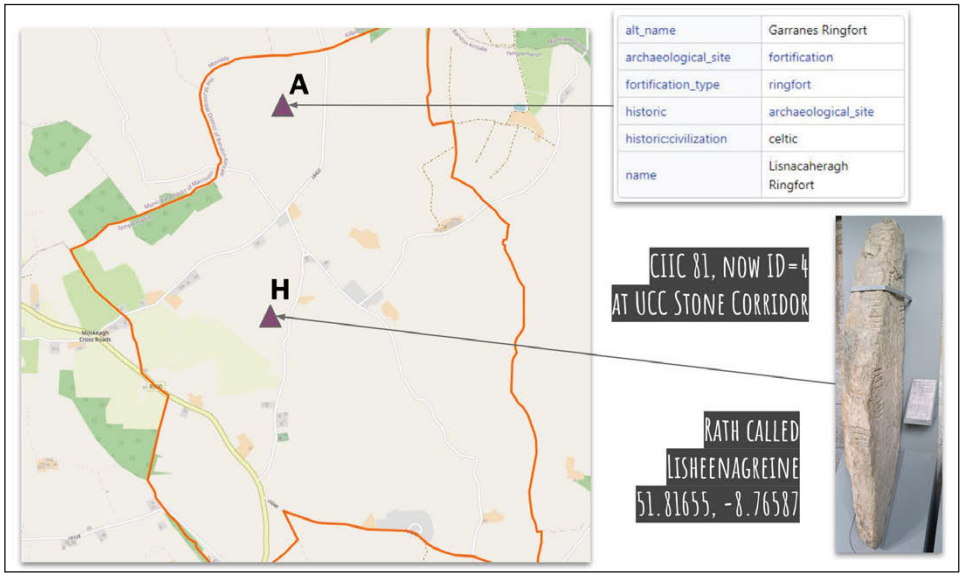

Fig. 3 – Left: current OSM map with the OSM Relation 6168494 (see A) and the possible position of CIIC 81 (see H), geo-referenced based on the path network using the plan of the location of (A) Lisnacaheragh Ringfort and (H) Lisheennagreine (from Ó Ríordáin, Ryan 1941, 80); right-top: description of OSM Way 562702954; right-bottom: Ogham Stone CIIC 81 in the UCC Stone Corridor, as well as the possible location coordinate (left/right-top: Open Street Map Contributors, ODbL, via OSM; right-bottom: F. Thiery).

3.1 *Ogham stones via Wikidata*

Ogham stones are monoliths bearing inscriptions in the early medieval Gaelic 'primitive Irish' Ogham script (Macalister 1945; MacManus 1997), which were erected mainly on the island of Ireland and in the western part of Great Britain between the 4th and 9th centuries AD. Most stones are no longer in their original location, which is essential for cartographic recording and makes it difficult to determine their original function (Macalister 1945). These sources provide information at different levels of granularity: townlands, descriptions and coordinates in WGS84/GPS or Irish GRID references.

An example is CIIC 81 (Fig. 3, right), exhibited in the Stone Corridor of University College Cork (UCC). Information on the current and original location is given in Gippert (2001), Brash (1869, 260), Ó Ríordáin (1931, 67) and Ó Ríordáin, Ryan (1941, 78 ss.). Results of the georeferencing (Fig. 3, left) of the site coordinates and the current location can thus be modelled in Wikidata (Q106680733). The findspot can be calculated as 51.8166 °N; -8.7659 °E concerning the literature, the current exhibition site as 51.8938 °N; -8.4921 °E relating to an on-site survey and OSM node ID 11071361392.

3.2 *Campanian Ignimbrite via Linked Open Data*

About 39,940 yr b2k ± 150 years (Schenk *et al.* 2024) – ca. 37,940 BC ± 150 years – the largest eruption of the Campanian Ignimbrite (CI) took place in the Phlegraean Fields (Barberi *et al.* 1978; De Vivo *et al.* 2001; Schenk *et al.* 2024). Evidence of the ash fall from this Late Pleistocene volcanic event, which originated in the Campania region of Italy, can be found throughout Central Europe (Thiery, Schenk 2023a, 2023c, 2023e). After the eruption, massive glass deposits covered large parts of the Eastern European continent; volcanic material from the CI is often found in isolated watersheds and valleys. These sites are recorded in several publications, i.e. precise coordinates or references to cities, regions, caves and archaeological sites (Thiery, Schenk 2023a).

Georeferencing Romania's Urluia site (URL) (Thiery, Schenk 2023b, 2023d) is more complicated. The literature (Fitzsimmons, Hambach 2014, 76; Pötter *et al.* 2021, 5) provides clues here. The location 42.7790 °N / 18.4815 °E can be approximately determined from both pieces of information. Information from OpenStreetMap helps here (Fig. 4). The result can now be published with the help of LOD and the SPARQL Unicorn (Thiery, Schenk 2023b).

3.3 *Silver coinage of Croton via Wikibase*

Hoard analyses of silver coinage from Croton (Stazio 1984; Garraffo 1987; Rutter 1997, 2001), an Achaean colony in southern Italy from the 6th to 3rd century BCE, show spatial uncertainties. None of the hoard's analysed sites are precisely georeferenced (e.g., based on the documentation of excavation

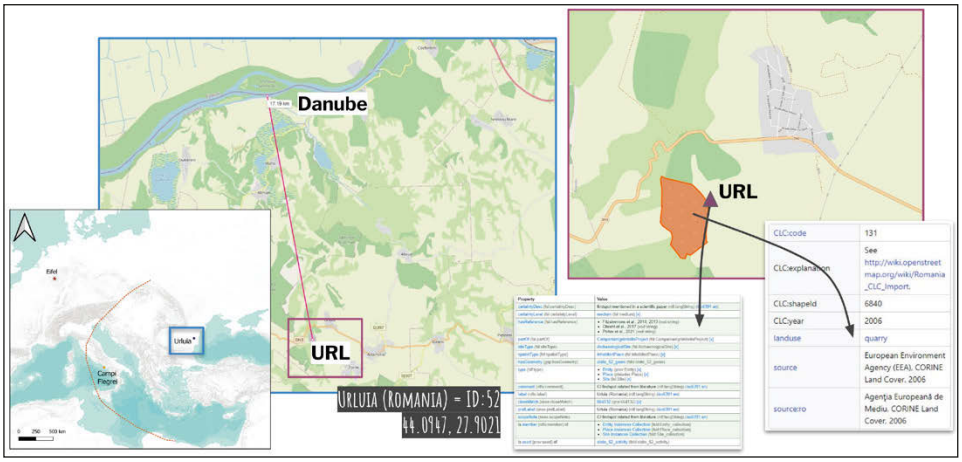

Fig. 4 – Left: schematic view of the distribution of the CI tephra in Europe (dashed orange line open to the E); Campi Flegrei as eruption site (orange dot; 40.8275° N, 14.1402° E); Urluia as find spot (blue dot/ rectangle; 44.0947° N, 27.9021° E); Eifel Lake sediment cores (red star); scale 1:20,000,000, EPSG: 3857, bounding box: –27,431.587, 3,598,880.852, 4,408,568.450, 7,668,605.656, created with QGIS, base map WorldTerrain by USGS, Esri, TANA, DeLorme, and NPS; middle: aerial line measurement between the possible location of Urluia (URL; purple rectangle) and the Danube. According to the literature, this is approx. 15 km, here 17.19 km; right: map showing the opencast mine (OSM way 84975654) and the possible Urluia coordinate point 44.0947 °N / 27.9021 °E as cisite_52 (purple rectangle) (left: F. Schenk, F. Thiery, https://codeberg.org/ResearchSquirrels/ci-map; middle/right: Open Street Map Contributors, ODbL, via OSM).

reports). The sites identified are derived from the literature and have varying degrees of precision about their geographical location (Fig. 5). The used IGCH numbers refer to Thompson *et al.* (2024), where the 'CoinHoards' database is currently based on. The hoard finds of 'Tarentum 1938' (IGCH 1902) in the via Oberdan in Tarentum, i.e., provide a reasonably precise indication. Indications of the location of the find in the modern and/or ancient city centres are provided, for example, by 'Paestum 1937' (IGCH 1925) or 'Strongoli 1955' (IGCH 1885); in the area of the ancient city of Petelia). In some cases, there are only references to more significant regions, e.g. hoards were found in 1864 in 'Calabria' (IGCH 1873) or 1964 in 'Southern Italy' (IGCH 1894) or come from the 'Ionian Coast' (IGCH 1916). This information can be displayed in a Wikibase instance in the wikibase.cloud: https://fuzzy-sl.wikibase.cloud

One more challenging example could be hoard find no. 3001 (Fig. 5, red dot): 'San Giorgio Ionico 1949, San Giorgio Ionico (near Taranto), on the property of E. De Finis' poses the question: 'Where was the property of E. De Finis located?'. With the help of Lo Porto (1990), Siciliano (2002) and OSM Node 68530185, the coordinate Point 40.4579 °N / 17.3787 °E can be determined. In Wikibase (https://fuzzy-sl.wikibase.cloud/entity/Q13), this information can

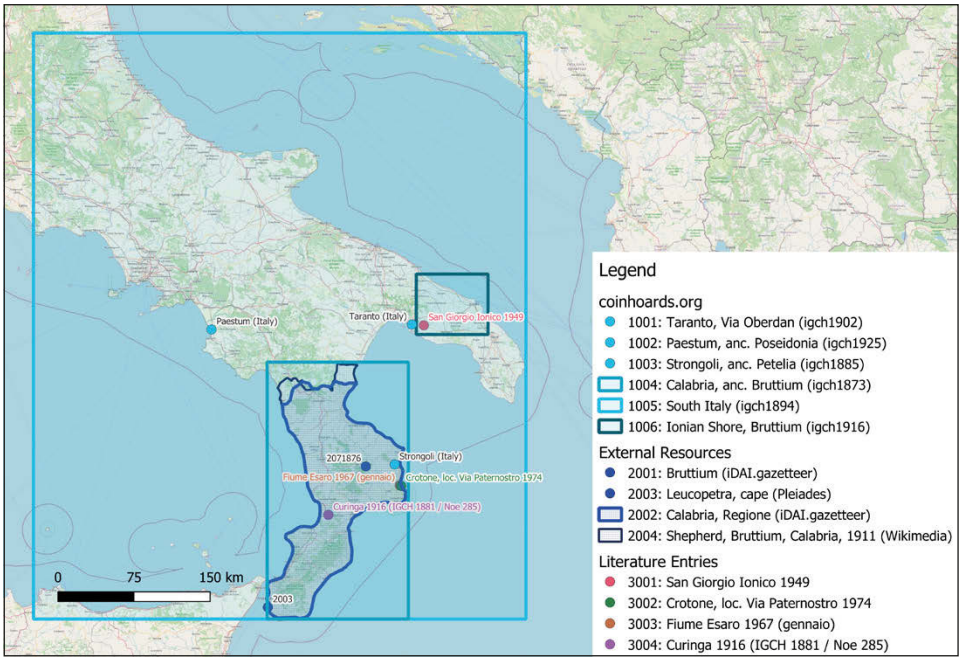

Fig. 5 – Visualisation of find spots for coins from Croton from coinhoards.org, external resources and literature entries (F. Thiery, S. Baars).

be described as, e.g.: (1) *related to* (P10) wd:Q52035 and osm:node/68530185 using *related to type* (qP12) fsl:spatialCloseMatch; (2) *has reference* (P11) F.G. Lo Porto (1990) und A. Siciliano (2002); (3) *has coordinate* (P4) '40°27'28.4" N, 17°22'43.3" E', using has *certainty level* (qP5) 'Medium', *certainty description* (qP13) 'property of E. De Finis?', *method used* (qP7) 'Georeferencing', *acting Person* (qP14) 'S. Baars' as well as *method description* (qP15) 'set a point based on F.G. Lo Porto (1990) and A. Siciliano (2002) using OSM Node 68530185'.

4. Conclusion

This paper showed two modelling approaches for doubts, e.g., uncertainty and ambiguities, in interdisciplinary fields such as archaeology and geosciences using Linked Open Data, Wikidata/Wikibase. All of them have their own advantages and disadvantages.

Looking at the OWL/LOD approach, on the one hand, the pros are (1) the freedom of modelling (2) the possibility to include primary and community-accepted ontologies such as PROV-O, SKOS and GeoSPARQL (3) and the direct possibility to integrate that modelling idea into international

activities like the NFDI, on the other hand, the cons are: (a) creating even the 11th standard of the ten existing ones, (b) the challenge of building a community to make this modelling sustainable, (c) and the challenge of maintaining sustainable IT infrastructures. However, looking at the Wikidata/Wikibase approach, on the one hand, the pros are: (1) the possibility to integrate the modelling discussions within the existing communities, (2) the possibility of being directly into the LOD cloud, and (3) the Open Science principle by using Open Source (FOSS) software and creating Open Data in a FAIR way; on the other hand, the cons (a) are a limited set of predefined properties (in Wikidata) and a community-process to add more (in Wikibase instances you are free to create your own properties, however, they do not have a direct connection to their 'Wikidata sisters', which makes interoperability challenging), (b) the community-approach, which is challenging in terms of modelling approaches and software development, and (c) the sustainability issue with Open Source (FOSS) software that volunteers and the community itself curate.

We believe that Semantic Web technologies such as Linked Open (Usable) Data, in combination with community-driven hubs and FOSS like Wikidata and Wikibase (developed and maintained by the Wikimedia Foundation), serve as FAIRification services that offer a real possibility to implement the FAIR principles and the Open Science idea, by disclosing doubts and uncertainties and generating comprehensibility and reusability in research data.

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ABSTRACT

Archaeological research must handle issues such as vagueness and uncertainty in data modelling. Especially vagueness and uncertainty must be modelled to work with geodata. However, for linking data and FAIRification graph-based modelling as Linked Open Data (LOD) proposed by Berners-Lee is the method and technique of choice. This paper discusses three data-driven interdisciplinary use cases of dealing with and modelling vague and uncertain geo-references (here especially findspots) based on literature as LOD from the archaeological and geosciences domain (Irish Ogham Stones, Campanian Ignimbrite, and Silver Coinage of Croton), implementing three modelling strategies using Wikidata, Linked Open Data and Wikibase.