Integrating Heterogeneous Coin Datasets in the Context of Archaeological Research

Achille Felicetti[1], Philipp Gerth[3], Carlo Meghini[4], and Maria Theodoridou[2]

[1] PIN, VAST-LAB, Prato, Italy
[2] FORTH-ICS, Greece
[3] DAI, Germany
[4] CNR-ISTI, Italy
achille.felicetti@pin.unifi.it,carlo.meghini@cnr.it
maria@ics.forth.gr,
philipp.gerth@dainst.de,
http://www.ariadne-infrastructure.eu/

Abstract. This paper describes the activities carried out under the ARIADNE project to demonstrate the item-level integration process of archaeological archives through the use of semantic technologies. To this end, some ancient coin records, coming from the archives of important European archaeological institutions, were selected. The subset thus created, has been carefully analysed by means of specific tools to identify similar concepts and common metadata elements that could serve as the basis for integration. CIDOC CRM was chosen as the conceptual model for encoding the identified entities, while some important numismatic vocabularies have been employed to improve standardisation. The implementation phase has benefited from the use of advanced tools for mapping and conversion of the original information in a semantic form (RDF), the creation of a triple store to place the newly integrated data and the necessary interfaces for accessing and querying them.

Keywords: Coins, Integration, CIDOC CRM, RDF

1 Introduction

Information Technology (IT for short) is quickly and widely conquering the Humanities: more and more scholars use IT methods and tools to build, access, share and preserve the knowledge that they generate in their daily research activities. This phenomenon also concerns the past: there are many projects that aim at reviving datasets and collections that have been generated in previous endeavours, whether they are in analog or digital form, in order to treat these data with the novel IT capabilities. The motivation behind this vast movement is rather obvious to anybody minimally familiar with research: the quality and quantity of knowledge generated by research activities is positively correlated with the amount of information and knowledge used in the process: the larger the latter, the greater the former.

The IT world is responding to the demand so generated by the Humanities in a positive way; new methods and tools are constantly produced that facilitate the work of the humanist, in the context of projects where IT specialists and scholars actively collaborate to the fullfillments of the project objectives. Lately, this collaboration is taking place through research infrastructures, perhaps the most relevant contribution of IT to the scientific world. This paper exemplifies one such collaboration, taking place in the context of ARIADNE[5], an FP7-INFRASTRUCTURES-2012-1 EU project (Grant agreement no: 313193), aiming at building a research infrastructure in the field of Archaeology. Specifically, the work described in this paper focuses on the integration of heterogeneous datasets containing information about coins.

From an IT point of view, this work is classified as a *data integration* activity, taking as input several datasets whose contents overlap in time, space and subject, and producing as output a novel dataset. The resulting novel dataset contains all the information of the original datasets, but integrated in a coherent whole that can be queried to discover knowledge previously inaccessible. In order to obtain the integrated dataset, several important and non-trivial problems had to be solved.

1. First of all, a deep, accurate and extensive analysis of the input data has been carried out, in order to determine the information space of each dataset, both in terms of the attributes covered and of the values used to instantiate such attributes. The analysis has allowed us to obtain important syntactic and semantic information, addressing the conceptual and lexical space of each dataset. More importantly, it has confirmed the validity of the project, by showing an effective overlapping of the knowledge in the given datasets.
2. Once the individual information space of each dataset was understood, the design of the integration has started, aimed at devising a common ontology that could serve as conceptual backbone of the integrated dataset. In achieving this specific objective, we have built on the experience gained in previous projects, and avoided to invent yet another ontology. Rather, we have relied on the CIDOC CRM ontolgoy [CRM15], the ISO 21127:2006 standard that is being successfully employed for documentation and data integration in the domain of cultural heritage since few decades. We have therefore ascertained that the CRM was rich enough to cover the integrated information space, and have set out to identify the vocabularies that we could use for integrating the values used in each dataset. This stage of the project proved difficult enough, due to the lack of individual vocabularies that could cover the value information space with the required generality and exhaustivity. A detailed account of this activity is given in the paper.
3. We have then entered the implementation stage of our project, aimed at devising mappings linking the attributes of the input datasets to the properties of the CRM, and the attribute values of the datasets to the vocabularies chosen for the integrated dataset. Also for this stage of the project we have

[5] `http://www.ariadne-infrastructure.eu`

relied on an existing tool, the X3ML suite [MMK+15], including an editor (3M[6]) for the mapping specification and an engine (X3ML engine[7]) for the mapping execution. The X3ML suite fills several blocks of a general architecture for data integration, named SYNERGY [ODdJ+14], [DFdJ+15], an initiative of the CIDOC CRM Special Interest Group[8], currently employed in several ongoing projects, such as the already mentioned ARIADNE, the just started PARTHENOS[9], Lifewatch[10], ResearchSpace[11], ITN-DCH[12] and Cultural Heritage Imaging [13].

4. We are presently executing the mappings and implementing the persistence of the generated dataset. To this end, we intend to exploit Semantic Web languages and technologies for representing and implementing the integrated dataset, so as to maximize interoperability and therefore re-use.

The different parts of the paper account for the just described phases of the project, providing detailed descriptions of the problems encountered and of the methods and tools employed to solve them. For the future, we foresee two main activities:

- specification of the queries on the integrated dataset, with special care for those returning knowledge coming from at least two of the input datasets;
- implementation of an access facility to the integrated dataset, both on the web and on the ARIADNE infrastructure and possibly more.

An articulation of these activities is provided in the concluding section of the paper.

2 List and Description of the Archives to be Integrated Within ARIADNE.

Numismatics is a very traditional science with a lot of experience and early initiatives in standardization of the existing data (f.e. [BV78]). In recent years the numismatics excels in terms of Linked Open Data in the Digital Humanities with a high grade of accessible datasets and standardized vocabulary. One major collaborative project is Nomisma.org[14], supported by a lot of institutions. Nomisma.org serves as a authorative resource in the numismatics. It collects and provides URIs to common numismatic concepts and terms. Furthermore

[6] http://www.ics.forth.gr/isl/3M/
[7] https://github.com/isl/x3ml
[8] http://www.cidoc-crm.org/who_we_are.html
[9] http://www.parthenos-project.eu
[10] https://www.lifewatchgreece.eu
[11] http://www.researchspace.org/
[12] http://www.itn-dch.eu/
[13] http://culturalheritageimaging.org
[14] http://nomisma.org/

a whole ontology[15] was created, which is used to integrate the open available databases. The ontology provides an easy understandable way for numismatists to describe their dataset, but as it is just limited to the numismatics, its very domain specific, other than the generic approach of CIDOC-CRM. Overall, numismatics provides a very good starting point for the item-level integration of archaeological datasets, as it is highly standardized and data is widely available to demonstrate the usefulness of using ontologies.

2.1 The dFMRÖ archive

Digitale Fundmünzen der Römischen Zeit in Österreich (dFMRÖ, digital Coin-finds of the Roman Period in Austria) is an online MySQL database of the Numismatic Research Group of the Austrian Academy of Sciences [dFM07]. Since the 1990s it documents coin-finds from the Celtic and Roman Period that have been published in various printed volumes of the FMRÖ (Fundmünzen der Römischen Zeit in Österreich / Coin-finds of the Roman Period in Austria) from the 1970s up to 2007. Starting with a Microsoft Access database, it was set up in its current form in 2007 and hosts about 76.000 finds. All coins in the database were found in Austria from the Celtic and Roman period (actually the entire Antiquity), registered properly so no illegal finds are included and most of them already published by the various projects of the FMRÖ. Because of a former project cooperation, since 2007 it also lists coins found in Romania. These are the coins that were published in: "Colonia Ulpia Traiana Sarmizegetusa", the first volume of "Coins from Roman sites and collections of Roman coins from Romania". The coins represent an important part of the Austrian cultural heritage.

The dFMRÖ archive was chosen as the first hands-on exercise to map a relational data base schema to CIDOC CRM, since it represents a large class of well-defined traditional databases. A sample XML record from the dFMRÖ archive is shown in the Appendix.

2.2 Numismatic archives from the COINS project

Another source of information we have taken into account, comes from two numismatic archives already used within the COINS project. They include a set of 1670 numismatic records coming from the Cambridge Fitzwilliam Museum archive (FWM) and a set of 630 records coming from the Sprintendenza Archaeologica di Roma (SAR) database.

The COINS project (Combat On-line Illegal Numismatic Sales) aimed at providing a substantial contribution to the fight against illegal trade and theft of coins by using state-of-art Information Technology. The project developed standardized inventories by integrating legacy archives encoded in different formats and using different languages. The creation of a reference collection of Roman and Greek coins was also one of the most relevant outcomes of the project.

[15] `http://nomisma.org/ontology`

The FWM archive: The FWM subset comes from the Department of Coins and Medals of the Fitzwilliam Museum Database, recording information on medals and coins of different types age, discovered during excavations or coming from various acquisitions or donations, currently kept by the FW museum. Relevant fields used by FWM archive include: coin maker, production location, mint, coin type, category, coin name, inscription, dimensions, production technique, references to images. Databases also include notes concerning record creation and modification, date and time, museum acquisition information. An XML example of an FWM record is shown in the Appendix.

The SAR archive: The SAR database (originally a Microsoft Access DB) was created for the cataloguing of archaeological finds of monetary type managed by the Archaeological Superintendence of Rome, coming from public and private collections and from archaeological excavations made in the city of Rome and its immediate surroundings. The main purpose of the archive is to record to provide the date, the accurate descriptions (by indicating the precise origin or place of issue) and the physical characteristics of the various coins. In addition it also shows the conditions of discovery (excavation, auction, seizure, donation, etc.), the state of preservation and the current location location (museum, superintendences, collections and so on).

SAR database, in addition to the FWM fields reported above, also provides information concerning coins physical features and physical conditions, the region in which a specific coin was minted (apart the exact location), specific information on chronology (i.e. the age, century or period during which coin minting took place), obverse/reverse inscriptions of iconography and the current location of the specific exemplar the record refers to. An XML example of a SAR record is shown in the Appendix.

2.3 Arachne

Arachne[16] is the central object database of the German Archaelogical Institute (DAI). Currently it contains more than 2,000,000 images with corresponding metadata and over 300,000 highly structured descriptions of artifacts of archaeological interest. Also Arachne allows research projects to store, manage and publish their data in online available catalogs. Coming out of digitized museum inventory and research project data, there are currently 485 coins with varying metadata quality. Some are of excellent quality, as the 107 coins with figures related to harbours coming from the DFG founded "SPP-Häfen". Those provide beside a detailed description extensive information about bibliographic references and dating opinions of different authors.

[16] `arachne.dainst.org`

2.4 iDAI.field

Since the first usage in 2005, the field research database iDAI.field was adopted by around 35 archaeological projects. The modular system contains also a find module with specific attributes for coins, which were found during excavations or surveys. For a first integration test 517 coins of the Pergamon project were used with detailed information about the archaeological context. An XML example of selected iDAI.field attributes is shown in the Appendix.

2.5 MuseiD-Italia collections

We are also investigating the possibility to integrate the collections of MuseiD-Italia, the digital library integrated in CulturaItalia. The data are in CIDOC CRM form and can be extracted via the OAI-PMH of the repository. MuseiD-Italia includes several collections of coins from Italian museums such as:

1. *Museo archeologico nazionale di Venezia*
   Il medagliere: serie romana - imitazioni o falsificazioni moderne, 86 coins
   Il medagliere: serie greca e bizantina, 758 coins
   Il medagliere: serie romana e barbarica, 2307 coins
2. *Museo archeologico nazionale di Crotone*, Reperti archeologici e Numismatica, 31 coins
3. *Collezione Museo Archeologico Nazionale - Reggio di Calabria*, 136 coins
4. *Collezione numismatica Museo Archeologico Nazionale di Altamura*, 99 coins
5. 3008 coins from Regione Umbria

3 Mapping Operations at a Logical and Practical Level

The aggregation and integration of the datasets described in the previous section was chosen as an appropriate use case for the ARIADNE infrastructure to prove that it is possible to create a rich common repository at a data item level, useful for a range of different purposes, from research to education and engagement. In this section we present the aggregationn workflow that we have followed in order to map a set of source databases to a common target ontology and trasform the original records to resources of the common, integrated repository.

The process of aggregating a set of databases consists of four major steps as shown in figure 1:

1. **Schema matching**: this first step produces mappings from the schema of each source dataset (source schema) to the common CIDOC CRM ontology (target schema). It is very important that the mappings obtained during schema matching preserve as much as possible the meaning of the source schemas fields. To this end, a close collaboration is required amongst domain experts, who know the semantics of the source schemas, pivot ontologists, who know the semantics of the chosen pivot ontology, and the IT experts who guide the others on using the mapping specification tools; these tools include both the language for encoding the mappings and the software for creating and managing the mappings.

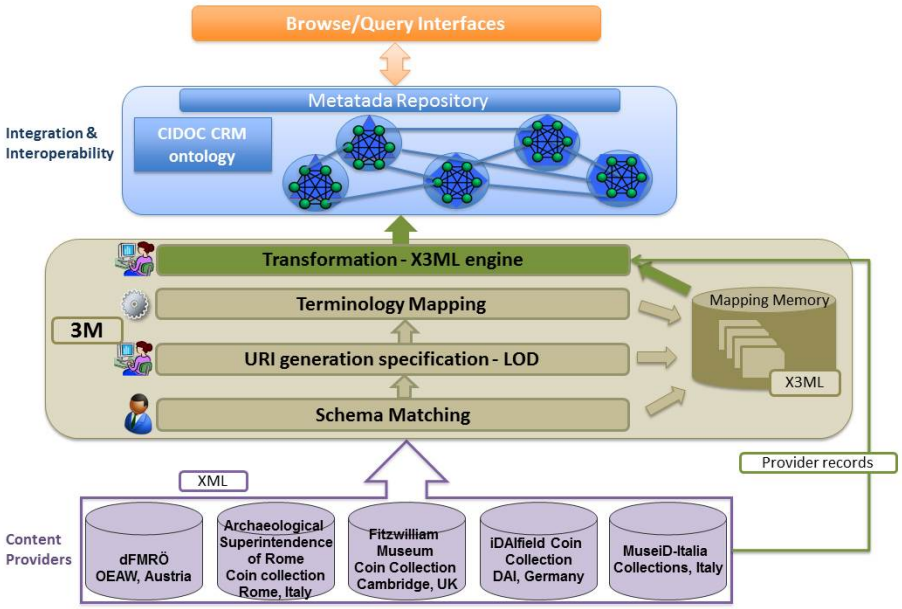

Fig. 1. Aggregation workflow

2. **URI generation specification**: this step aims at defining the functions assigning an appropriate URI to each resource found in the source datasets. Domain experts contribute to this step their expertise on namespaces as well as any policy on naming that is in place in the institution where the integrated dataset will be deployed; the task of IT experts is to properly configure the tools so that the chosen URIs are generated.
3. **Terminology mapping**: this step produces mappings from the thesaurus used by each source dataset to a common thesaurus that is used by the agreggator database. It is similar to the schema matching step, and requires the same tight collaboration amongst different experts.
4. **Transformation**: this is the final step that transforms every record of the source dataset to a set of appropriate RDF triples, subsequently stored in the resulting integrated dataset.

The datasets that we adopt in the ARIADNE integration use case have several differences concerning the origin, language used, purpose of creation and use. Having been created by various institutions and for different purposes, they have quite different data structure, despite the similarity in content. The databases of the SAR and the dFMRÖ, for instance, were created with the purpose of documenting archaeological discoveries which occurred during excavations or surveys and contain many fields reporting information on provenance and discovery conditions. FWM, on the other side, is a museum database whose sole purpose is

to catalog acquisition and inventory data of objects owned and stored by the museum itself, regardless of the archaeological provenance conditions.

The mapping of the coin datasets started with the dFMRÖ archive which was chosen as the first hands-on exercise to map a relational data base schema to CIDOC CRM, since it represents a large class of well-defined traditional databases.

In close cooperation with the domain experts we tried to identify information that was implicit, hidden in forms, hidden in user interface fields or was known only by them. A detailed description of the mapping of the dFMRÖ archive to CIDOC CRM was presented in the CAA2015 conference [DTAM15]. The dFMRÖ mapping was used as a guide for the mapping of the SAR and FWM datasets. The records of the FWM archive contain fields with condensed information that needs to be preprocessed and normalized before it can be mapped to CIDOC CRM. For example, all the information concerning the dimensions of a coin (height, width, weight) is encoded in one field:

```
<Dimension>image(height), 22, mmimage(width), 20, mmweight, 3.74
</Dimension>
```

and needs to be normalized before the actual transformation takes place.

It is worth mentioning that the mapping of a schema to CIDOC CRM is not necessarily unique. There may be different ways of approaching the problem, all correct. However, what is individually correct may turn out to be problematic if considered in the context of a larger process. For example, in the dFMRÖ and SAR mappings, the coin denomination was mapped to a **E55 Type** while in the iDAIfield it was mapped to a **E54 Dimension**. Conceptually both approaches are correct, but their coexistence in the same process is clearly problematic. Rather than imposing a unique style, we have chosen to reconcile such differences at the query level.

The dates are also a crucial point in the integration of the datasets. Different formats and approaches may have been used to encode temporal information in the source databases. To mention just a simple issue, the value *zero* is used as a date in some of the datasets, possibly with different meanings. For instance, such a value might indicate the year in which Jesus was born, or the fact that the year is unknown, or not recorded. This poses several problems. First, *zero* is not a valid date in RDF (or in the underlying XML type system), so the value has to be transformed into a valid date. But in order to carry out this transformation, it is important to clarify the semantics of the zero value in each dataset.

4 Description of the Integrated Infrastructure Set Up for Item Based Management

The ultimate goal of the integration of the diverse coin datasets is to create an environment where users will be able to specify queries that will be evaluated on the common aggregated repository and will be able to combine results coming from the different datasets. The ARIADNE portal will provide a main access

point to integrated repository and an intuitive user interface will guide the user to formulate his query, browse the results and refine the search with facet view. We plan to implement a query interface that will take advantage of the principles of the Fundamental Categories and Fundamental Relatioships as defined in [TD12], [TDTF13].

Currently our work is focused on determining the type of research questions that we would like to support. We have identified the following:

- **Origin** - Where does this coin come from?
- **Tracking** - How did it arrive here?
- **Chronology** - First/last appearance
- **Practical/symbolic value, incidents** - Why is it deposited here?
- **Political message** - Why was it produced (i.e. "minted")?
- **Economic stability, power** - Why was it widely used / not used?
- **Statistics** - Material versus nominal value

There exist several queries that are trivial to be answered by each dataset separately, however they become important if they can be answered by the aggregated repository:

- Find coins minted in the same place/area or by the same authority
- Find coins produced in the same period or time span (typically the same century or half/quarter century)
- Find coins having common shape/iconography/inscriptions
- Find coins made by a specific material.

Combinations of the above queries can be found useful by the researchers of the numismatic community and our first experiments with such queries on the aggregated repository are quite promising. Our experimental aggregated repository contains 72 records (all Roman coins) of the dFMRO archive, 627 records (all Roman coins) of the SAR archive, 517 records (12 Roman coins 1 empty record) of the Pergamon archive (iDAIfield) and 1 record from MuseiD-Italia. The results of some simple queries can be seen in the following table:

Query	Total	dFMRO	SAR	Pergamon	MuseiD
Find all coins	1216	72	627	516	1
Find Roman coins	711	72	627	12	
Find bronze assarius	82	29	52	1	
Find bronze coins	676	50	270	355	1
Find bronze sextans	47		46		1
Find coins produced in -32	22	4	18		

5 Conclusions and Further Work

The activities carried out so far have shown that datsets of different origin, language, property, and of heterogeneous information content, can be successfully

integrated by relying on an ontology that is adequate to capture in conceptual terms the real nature and meaning of the objects described in these datasets. Although the relative homogeneity of the coin class of objects has made much easier the mapping and conversion work, the validity of the methodological approach is universal for any type of archaeological object. CIDOC CRM has proven to be a particularly able ontology to express the conceptual meaning of archaeological entities. However some issues remain still open, such as, for example, the design and implementation of appropriate and efficient user interfaces able to view and query semantically integrated archives like the one we implemented in this case study. The ARIADNE Portal, still under development, is already in the process of providing satisfactory answers to such questions. Once released it should provide all the necessary functionality for querying information thorough all the archaeological archives, regardless of their level of integration. Beside the wide use of CIDOC CRM, there are important domain specific ontologies, where further work will concentrate on a showcase mapping between the numismatic specific ontology Nomisma.org and the generic, global ontology CIDOC CRM. As a result it will be possible to integrate further datasets, which are already using the numismatics ontology Nomisma.org. Future activities would build on the results achieved so far to try to extend the methodology used for the archives of coins to other archaeological archives part of the ARIADNE project, to define the depth at which the integration could be achieved. The release of the CRMarchaeo archaeological extension, expected by the end of the project, will surely simplify the implementation of an interoperability framework at item level.

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Appendix: Samples of records from the four datasets

iDAI.field sample record

```
<Aufbewahrungsort>Grabungshaus, Depot</Aufbewahrungsort>
<Auto_Objektkennung>PE08 So 02 - KFN 0002</Auto_Objektkennung>
<Beschreibung>BMC (Mysien) S. 128-129, Nr. 150-157</Beschreibung>
<Erhaltung_Durchmesser>174</Erhaltung_Durchmesser>
<Erhaltung_Gewicht>4,03</Erhaltung_Gewicht>
<Funddatum>09.08.2008</Funddatum>
<Herkunft>Archol. Befund</Herkunft>
<Kampagne>2008</Kampagne>
<KurzbeschreibungMuenze>hellenistische Mnze</KurzbeschreibungMuenze>
<Lage_Details>Auffllung, durch byz. Grber  gestrt</Lage_Details>
<Metall>Bronze</Metall>
<Muenzstaette>Pergamon</Muenzstaette>
<Nominal>Einer (Chalkus)</Nominal>
<Nummer_Fund>2</Nummer_Fund>
<Praegeherr>stdtische Prgung</Praegeherr>
<PS_MuenzeID>49005</PS_MuenzeID>
<Rckseite_Beischrift>[A]KHIO[Y  THPO]</Rckseite_Beischrift>
<Rckseite_Freitext>Schlangenstab</Rckseite_Freitext>
<Rckseite_Motiv></Rckseite_Motiv>
<Stempelstellung>6</Stempelstellung>
<Vorderseite_Beischrift>keine</Vorderseite_Beischrift>
<Vorderseite_Freitext>Belorbeer. Asklepioskopf<Vorderseite_Freitext>
```

The FWM archive sample record

```
<Coin>
 <Accession>Object Number: CM.YG.1008-R(Coins and Medals)</Accession>
 <Acquisition>bequeathed; 1936-07-07; Young, Arthur W.</Acquisition>
 <AlternativeNumber>RRC; 452/2ordering; RR-2672</AlternativeNumber>
 <Category>coin</Category>
 <Collection>Young Collection</Collection>
 <Date>48-07-13 B.C.  47 B.C.</Date>
 <Dimension>
 image(height), 22, mmimage(width), 20, mmweight, 3.74
 </Dimension>
 <Inscription>
 design; obverse; female head wearing wreath and diadem; behind,
 IITdesign; reverse; Trophy with Gallic shield and carnyx; on r.,
 axe; below, CAE SAR
 </Inscription>
 <Maker>
 Caesar, Gaius Julius; moneyer; Roman, 100-44 B.C.Rome; place of use
 </Maker>
 <Material>silver</Material>
 <Name>Roman Republic; Seriesdenarius; denomination</Name>
 <PermanentIdentifier>
 http://data.fitzmuseum.cam.ac.uk/id/object/114778
 </PermanentIdentifier>
 <ProductionNote>mint moving with Caesar</ProductionNote>
 <ProductionPlace>Rome, place of use, state</ProductionPlace>
 <Technique>struck</Technique>
 <obverseImg>
 http://www-img.fitzmuseum.cam.ac.uk/img/cm/cm7/CM.YG.1008-R(1).jpg
 </obverseImg>
 <reverseImg>
 http://www-img.fitzmuseum.cam.ac.uk/img/cm/cm7/CM.YG.1008-R(2).jpg
 </reverseImg>
</Coin>
```

The SAR archive sample record

```
<coins_sar>
  <ID>2680</ID>
  <inv>1812-1</inv>
  <weight>38.36</weight>
  <diam_min>36.5</diam_min>
  <diam_max>37</diam_max>
  <posit>0</posit>
  <authority>Anonimo</authority>
```

```
  <metal>AE</metal>
  <mint>Roma</mint>
  <nominal>As</nominal>
  <class>repubblicane</class>
  <car_fisiche>integra</car_fisiche>
  <regio_naz>Latium</regio_naz>
  <crono>secolo</crono>
  <from_year>-225</from_year>
  <to_year>-201</to_year>
  <century>III a.C.</century>
  <part_century>ultimo qua</part_century>
  <calc_century>III a.C.</calc_century>
  <armadio>1</armadio>
  <cassetto>3</cassetto>
  <d_leggenda>ANEPIGRAFE</d_leggenda>
  <r_leggenda>NON REGISTRATA</r_leggenda>
</coins_sar>
```

The dFMRÖ archive sample record

```
<COIN>
<ID>626</ID>
<COUNTRY_ID>1</COUNTRY_ID>
<FIND_SPOT_ID>242</FIND_SPOT_ID>
<FIND_MANNER_ID>2</FIND_MANNER_ID>
<FIND_DATE>-</FIND_DATE>
<AUTHORITY_ID>565</AUTHORITY_ID>
<ISSUER_ID>243</ISSUER_ID>
<DENOMINATION>239</DENOMINATION>
<MINT_ID>2291</MINT_ID>
<OFFICINA>99</OFFICINA>
<DATE_CA>1</DATE_CA>
<DATE_FROM>-100</DATE_FROM>
<DATE_TO>0</DATE_TO>
<DAT_VAL>1090010001</DAT_VAL>
<WEIGHT>0.43</WEIGHT>
<DIE_AXE>9</DIE_AXE>
<STATUS_ID>1</STATUS_ID>
<ARCH_INFO>neben der Bundesheerkaserne</ARCH_INFO>
<PH_NAME>000626</PH_NAME>
<DAT_TXT>ca. 100 v. - 0 n. Chr.</DAT_TXT>
</COIN>

<AUTHORITY>
<AUTH_ID>565</AUTH_ID>
<AUTH_NAME>KELTEN</AUTH_NAME>
```

```
<AUTH_NAME_EN>CELTS</AUTH_NAME_EN>
<AUTH_ORDER_KEY>20</AUTH_ORDER_KEY>
<AUTH_S_ORDER_KEY>000020</AUTH_S_ORDER_KEY>
</AUTHORITY>

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