UNIVERSITÄT AUGSBURG
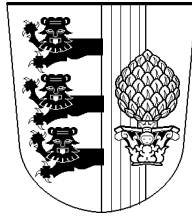
Classification of Late Roman Bronze Coins Using an Object-Oriented Database

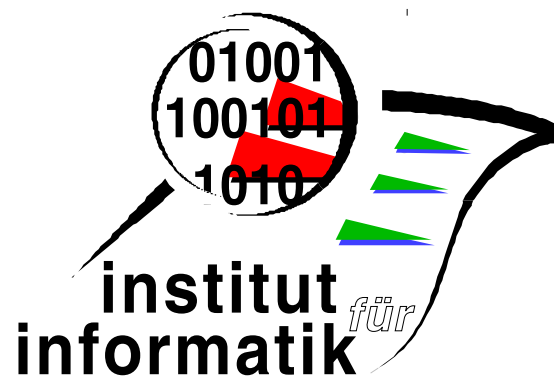Thomas Birke, Matthias Wagner, Werner Kießling

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Classification of Late Roman Bronze Coins Using an Object-Oriented Database

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Abstract

The combination of digital libraries and applications from humanities is an important emerging field that still faces great challenges. In this paper we investigate the science of numismatics and analyse how to digitize current manual practice for the classification of ancient coins from the 4th century A.C. Our contributions are twofold. From the application's point of view we develop an improved classification algorithm with special emphasis on incompletely preserved coins. We present a new approach, called COINCLASS, to indexing (partial) image contents. Secondly, we show how to make maximum use of modern database technology by developing an extensible ODMG-compliant schema. In particular we point out the advantages gained by writing declarative set-oriented OQL queries. In essence our studies support the claim that current object-oriented database technology can cope with many complex applications from humanities.

1   Introduction

Ancient coins offer all of us the unique opportunity to hold a beautiful and historic miniature piece of sculpture-like art in our hands. They provide an important basis of understanding the past and the beginnings of our society and culture. Even today, important historical findings are made all over the world. Their exact analysis and study still have an enormous impact on the research in art, history and humanities and can deepen the insights into our cultural heritage.

Everytime antique coins are part of historical findings the science of numismatics is called in, assisting the main historical sciences like archaeology or prehistory with the

identification of coins: A given coin is quoted from a numismatic dictionary, e.g. the Roman Imperial Coinage (RIC) [SCM$^+$94], with respect to a numismatic description which is made during a phase of analysis by a numismatic. How good classical numismatics manages to classify a given coin strongly depends on the kind of coin under consideration. In the case of late Roman bronze coins this task is made difficult by the very large number of coinage minted in the 4th century. Historical circumstances of this period aggravate this problem additionally because coins very often were minted in bad quality and are preserved incompletely.

In this paper we present an ODMG [CBB$^+$97] compliant object-oriented database application for the classification and quotation of late Roman bronze coins. The purpose of our new approach to coin classification is to combine a classical dictionary-based method [SC81, MSC78] with a modern approach for the classification of coins in incomplete preservation [Bru61]. To get full profit of the unified method we developed a formal language for the description of the image content of coins in the spirit of ICONCLASS [vR94], a method for indexing paintings and pictures. A prototypical application based on the new classification algorithm and database schema was implemented using the C++-binding of the object-oriented database system O$_2$ [BDK92]. The core implementation, i.e. the database schema together with the quoting algorithm, is aiming at a high degree of flexibility. Due to its object-oriented nature our application can easily be extended to support the classification of further coin types, e.g. modern coins.

Few technologies have recently offered as much potential to influence research in arts and humanities as digital libraries. However, we are not aware of any computer-based catalogue or any computer-aided classification tool in numismatics yet. Our new classification method and the resulting application have been positively evaluated by the National Numismatic Collection in Munich Germany, proving that the field of numismatics can enter the arena of modern digital libraries.

The rest of this paper is organised as follows: Section 2 is intended to give an insight into the practice of numismatics with the presentation of a classical dictionary-based numismatical quoting scheme. Furthermore this section lays the foundation of the application's conceptual design with the identification of the object classes which carry over to the further sections. The formal description of a coin's image content is the subject of Sections 3. We shortly discuss content-based cataloguing and retrieval methods as an alternative to text-based representations. In Section 4 we outline the object-oriented database schema and illustrate the structural representation of a coin's image content in the database. The purpose of Section 5 is to give an overview of the quoting algorithm. We explain how user interaction can reduce the search space and show how the use of the Object Query Language (OQL) allows for the efficient retrieval of quotation candidates during the search. We draw conclusions in Section 6 and discuss how modern multimedia retrieval methods like Query By Image Content [FSN$^+$95] might enhance our application in the future.

2 Numismatical Quotation and Description

The classification of coins is the central task of a numismatic's work: A given coin is quoted from a catalogue with respect to its detailed numismatic description.

In this section we consider the quoting scheme of the Roman Imperial Coinage (RIC) [SC81, MSC78] to give an impression of the state of the art of numismatical cataloguing and searching methods used today. RIC is one of the main numismatic catalogues dealing with Roman coins and is widely accepted. However, RIC is a classical text-based approach that simply relies on plain text structures. Neither was RIC digitized — not even in parts — nor have there been any efforts to design a database for it. Thus, the RIC comes as a library of books. As a whole it consists of 10 volumes with approximately 7000 pages in total.

2.1 Numismatical Quotation

Quoting — in terms of numismatics — is the process of assigning to a given coin a significant set of data which determines the coin's type and origin. In the case of Roman bronze coins a quotation is expressed as a triple consisting of Emperor, Mint and the Period of Minting.

To get a clear idea of how a quotation is expressed within the RIC catalogue we look at an example of a late Roman bronze coin titled "GLORIA ROMANORVM" in Figure 1. Note that this example comes up with a coin in exceptionally good preservation. In practice coins of equally well preserved shape and clarity are very rare!

Figure 1: Obverse and Reverse of the coin GLORIA ROMANORVM.

With a description of the coin to be quoted at his hand a numismatic browses the catalogue. In the catalogue quotes are linked to coin descriptions by corresponding catalogue numbers. Quotation candidates can thus be found by (partially) matching the given coin description with cataloged descriptions, then following the link via the indicated catalogue number. In practice the time consuming work of coin description and quotation is done manually. For an expert in numismatics the time spent on the

manual classification of an average coin typically ranges from 10 minutes to 5 hours and maybe more.

The result of a numismatic classification in terms of **Catalogue** number and **Quote** according to RIC for our example coin is displayed in Figure 2.

Catalogue		
RIC Catalogue number	:	*vol. VIII, p. 214,150*

Quote		
Emperor	:	*Magnentius Augustus*
Mint	:	*Arles*
Start Year of Minting	:	*350*
Final Year of Minting	:	*353*

Figure 2: The quotation of GLORIA ROMANORVM according to RIC.

Remark: Text-boxed tables like **Catalogue** and **Quote** will be mapped directly onto classes in the object-oriented schema design in Section 4.

How coin description exactly proceeds is explained in the sequel. Please note that Obverse and Reverse are each described and quoted separately. Each description might refer to a set of catalogue numbers and hence to an ambiguous set of quotation candidates. The selection of a coin's final quotation — respectively a set of final quotations — from the single sets of quotes is left to the expert in numismatics and strongly depends on his/her experience and expertise. Again note that the quotation of GLORIA ROMANORVM in our example has been a fortunate case, assigning a unique quote to the coin via a single catalogue number. The quality of a quotation, i.e. the size of the resulting quotation set, merely depends on the numismatic's skill and routine. One can easily imagine, how incompletely preserved coins may lead to a combinatorial explosion of candidate catalogue numbers and quotes.

2.2   Numismatical Description

The basis for our quotation of GLORIA ROMANORVM via the catalogue number is a detailed description of the coin in numismatic terminology. The science of numismatics has established exact guidelines for the construction of such a description [Göb78, Göb87, SCM⁺94].

We speak of a coin's **Basics** as the physical characteristics of the coin like metal, diameter or weight. These attributes are easily identified and important to be registered, but they do not essentially contribute to the description regarding the further quotation. This is due to the great individuality of late Roman bronze coins as a result of the large amount of coins that has been minted during the 4th century. In contrast, the visual attributes of the coin are more significant. The science of numismatics defines a clear
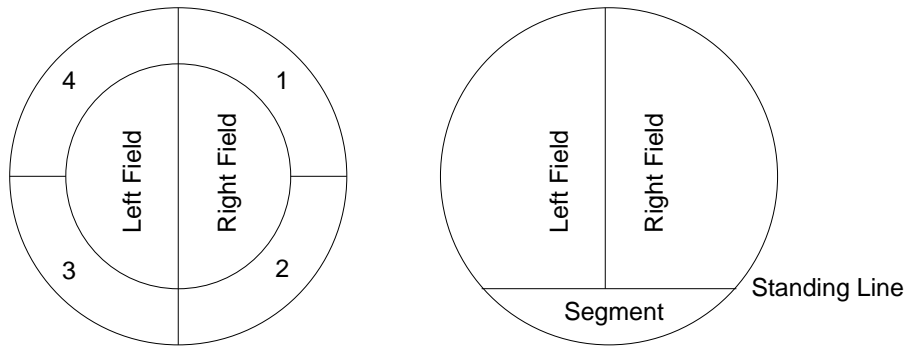
Figure 3: Description outline of Obverse and Reverse.

outline of regions which are to be described on the coin's **Obverse** and **Reverse**, i.e. the front-side and the back-side of the coin. Figure 3 displays the regions on Obverse and Reverse of a late Roman coin that are to be described, e.g. the **Bust** on the Obverse of late Roman coin typically spawns from the **Left** to the **Right Field** and is described in terms of **Type**, **Heading** and **Direction**, the writing found within the sections **1, 2, 3** and/or **4** of the border on Obverse and Reverse is annotated as the coin's **Legend**.

According to the given scheme our example GLORIA ROMANORVM yields the coin description in Figure 4.

Basics		
Maximal Diameter	:	*24mm*
Minimal Diameter	:	*22mm*
Weight	:	*5.07g*
Metal	:	*AE*

Obverse		
Legend	:	*DNMAGNEN-TIVS PFAVG*
Type of Bust	:	*Draped and cuirassed*
Heading of Bust	:	*Barehead*
Direction of Bust	:	*Right*

Reverse		
Legend	:	*GLORIA ROMANORVM*
Image Description	:	*Emperor in military dress galloping right, without shield, spearing barbarian kneeling left, with outstretched arm in front of horse; below horse shield and broken spear. In field to right, star.*

Figure 4: The description of GLORIA ROMANORVM according to RIC.

Remark: Again note that the text-boxed tables for **Basics**, **Obverse** and **Reverse** will be mapped onto object classes subsequently.

Late Roman bronze coins are considered to be a subset of Roman coins. Thus, further attributes are used to describe the features that distinguish those coins from the general class of Roman bronze coins: Left and right field of the **Late_Roman_Obverse** are of high significance to the quotation. Left and right field of the Reverse together with its

Segment characterise the technical process of minting and are separately described and quoted under the term **Mintmark**. The additional Obverse and Mintmark descriptions for GLORIA ROMANORVM are shown in Figure 5. Note that NULL elements account for unidentifiable coin attributes.

Mintmark		
Location	:	*S*
Segment	:	*PAR*
Left Field	:	*NULL*
Right Field	:	*NULL*

Late_Roman_Obverse		
Left Field	:	*A*
Right Field	:	*NULL*

Figure 5: Extended Mintmark and Obverse description of GLORIA ROMANORVM.

So far we focused on the description and quotation of historical coins from a rather conservative point of view: We assumed all visual traits to be complete. However, in practice it is more than common that classifying attributes appear incomplete, i.e. in fragments only. How to cope with fragmented attributes during the process of description and quotation is in todays practice left to the expert in numismatics.

3   Image Description for Reverses

The classical cataloguing method introduced above basically relies on a flat text-based description of a coin's attributes for cataloguing and search purpose (see Figure 4 and 5). A severe drawback is the Reverse image description in natural language, in general making an unambiguous quotation difficult or even nearly impossible in the case of damaged coins with fragmented Reverses. However, the image shown on the late Roman coin's Reverse is of high significance for the process of quoting: Proposals to quote late Roman bronze coins primarily by (even fragmented) Reverse images have been made in the numismatic community [Bru61]. Hence, aiming at an enhancement of Reverse image storage and retrieval by image content can build upon this work.

3.1   Choosing a Method for Image Retrieval

Currently there are two competing approaches for image retrieval based on their content: The conservative way is to manually index an image's content using some predefined vocabulary. The more recent approach attempts an automatic content-based image retrieval, based on generic features like colour, texture, shape or spatial relationships. Lately, first (commercial) versions of such systems have become available [GJ97, SC96, FSN+95, KCH95].

The current state of content-based image retrieval, while very promising, has yet to prove its applicability in the arts and humanities. This holds even more for the enormous

variety and the extremely different levels of preservation of late Roman coins. To give an idea of the scope of preservation of the coins under consideration we display a second example of a late Roman coin titled "FEL TEM REPERATIO" in Figure 6.

Figure 6: Obverse and Reverse of the coin FEL TEM REPERATIO.

For collections in arts and humanities, there are several intelligently composed cataloguing tools that have been developed for the purpose of enhancing consistent description and search access. ICONCLASS [vR94] (ICONographic CLASSification), the AAT [Soe95] and the Library of Congress Thesaurus for Graphic Materials (LCTGM) [oC97] are a few of the more formal tools that are currently available. In this paper we adopt the ICONCLASS approach for indexing of paintings to late Roman bronze coins. With ICONCLASS a hierarchy of pictorial elements is defined on paintings or pictures. Indexing a picture with ICONCLASS leads to a grouping of the essential picture fragments.

3.2 Formal Description of COINCLASS

According to [Bru61] and [vR94] we define a new method for pictorial coin description in the spirit ICONCLASS. The new method, called COINCLASS, generates a raw description of a coin's image content. The formal description language of COINCLASS identifies the features of a late Roman Reverse image and groups them hierarchically. A set of the production rules of our formal description language is shown in Figure 7. The complete set of rules containing all special cases can be studied in depth in [Bir97].

To generate a COINCLASS description of a given Reverse image a numismatic proceeds as follows:

1. All image elements are identified and grouped as partial descriptions, i.e. COIN-CLASS term structures derived by rule <Partial_Descr>.

2. All partial descriptions are ranked in a priority order. This order results from the formal description shown in 7. If there are only partial descriptions of the same order, you should start to scetch from left to right or from up to down.

<Image_Descr>	→	<Partial_Descr> [leftImg <Image_Descr>]
		[rightImg <Image_Descr>]
		[lowerImg <Image_Descr>]
		[upperImg <Image_Descr>]
<Partial_Descr>	→	<Human&Goodness> | <Animal> | <Building>
		| <Object> | Barbarian | NULL
<Human&Goodness>	→	<Person> [holdsLeft <Item> holdsRight <Item>]
<Person>	→	Man | Woman | Soldier | Victory | Sol | Iupiter
		| HumanBeing
<Animal>	→	Horse | Bull | Eagle | Phoenix | Wolf | Snake
<Building>	→	<Structure> [withInscription <Inscription>]
<Structure>	→	Campgate | Bridge | Column | Altar | Throne | Map
<Object>	→	<Thing> [withInscription <Inscription>]
		| <Symbols> | <Articles> | Spear&Shild | Hand
		| Quadriga | Prow | Pyre | Tree | Star
<Thing>	→	Wreath | Shield | NULL
<Item>	→	Child | Victoriola | <Articles> | Spear | Sceptre | Branch
		| Lightning | Whip | Cadecus | Cornucopiae | Balance
		| Plume | NULL
<Articles>	→	Labarum | Standard | Trophy | Globe | Null
<Inscription>	→	RomLetters&Numbers | SpecialSymbol | NULL
<Symbols>	→	Christogram | Monogram

Figure 7: Formal description of Reverse images with COINCLASS.

3. All partial descriptions from this priority order are successively interrelated by the relationships rightImg, leftImg, lowerImg and upperImg according to their level of significance and their geometrical layout on the coin. As some elements also can be used for attribution holdsLeft, holdsRight and withInscription are introduced intuitively.

Interpreting the four COINCLASS relationships used to interrelate partial descriptions is straightforward, e.g. let A and B be COINCLASS descriptions of partial Reverse images with the level significance of A to the overall description prior to the level significance of B then

$$A \text{ leftImg } B$$

is interpreted as the COINCLASS description of an image showing two partial images associated with A and B with the latter situated left to the other. All the remaining relationships are interpreted analogously.

The derivation of priority order refering significance on the partial image descriptions is precisely shown in [Bir97]. For the sake of simplicity the formal definition of this priority order is neglected in this section. Instead, assume an order on the partial image descriptions induced by the priority of the COINCLASS elements derived from the rules <Human&Goodness>, <Animal>, <building> and <Object> defined by their order of appearance in the grammar. That means elements of the rule <Human&Goodness> are of higher priority than elements of the rule <Animal> and so on. The same order can be carried over to the list of elements, e.g. picture element Man is of higher preference as picture element Woman which takes precedence over HumanBeing. For example Soldier is prior to Barbarian which is in turn subordinated to Horse and so on.

The way we map images to formal descriptions is best exemplified by Figure 8, showing a formal image description that corresponds to the content of the Reverse image of GLORIA ROMANORVM.

(Man holdsLeft Spear holdsRight NULL)
lowerImg (Horse lowerImg Spear&Shield)
rightImg Barbarian

Figure 8: COINCLASS description of GLORIA ROMANORVM's Reverse image.

Here the tokens Man, Spear, Barbarian, Horse and Spear&Shield are identified as the image elements, e.g. Man corresponds to the partial image showing a man. We claim that the Man on the Reverse holds a Spear on his left side and nothing on his right yielding the partial description Man holdsLeft Spear holdsRight NULL. According to the

given priority order the highest significance is assigned to Man holdsLeft Spear holdsRight NULL which becomes the root of the COINCLASS description.

Again note that NULL elements account for unidentifiable or non existing features. The brackets in rule <Image_Descr> indicate that relationships to partial image descriptions can be omitted from the COINCLASS description if one of the related partial descriptions derives to NULL. E.g., in the formal descriptions of GLORIA ROMANORVM's Reverse image the partial description

Horse leftImg NULL rightImg NULL lowerImg Spear&Shield upperImg NULL

was reduced to

Horse lowerImg Spear&Shield .

We are now able to extend the general description of Reverses by the COINCLASS description of the coin's image content. The Late_Roman_Reverse description of GLORIA ROMANORVM is depicted in Figure 9.

Late_Roman_Reverse

Reverse Image : *(Man holdsLeft Spear holdsRight NULL)*
                             lowerImg (Horse lowerImg Spear&Shield)
                             rightImg Barbarian

Figure 9: Extended Reverse description of GLORIA ROMANORVM.

The second coin under consideration, FEL TEM REPARATIO from Figure 6, comes up with a completely destroyed Obverse which cannot be used for further classification. Hence, to classify this coin we must uniquely rely on its Reverse. However, the description of the highly fragmented Reverse remains very complicated. In fact, we are not able to assign a unique COINCLASS description to FEL TEM REPARATIO's Reverse image. Instead, with some imagination we let the descriptions shown in Figure 10 be two competing alternatives during the search for a valid quotation.

Soldier holdsLeft Spear holdsRight Shield

vs.

(Soldier holdsLeft Spear holdsRight Shield) leftImg Spear&Shield

Figure 10: Competing COINCLASS descriptions of FEL TEM REPERATIO.

We claim to identify a soldier holding a spear an a shield in the right field of the coin's Reverse image. The partial image in the left field might show the weapons spear and shield lying on the ground, but since the Reverse image is very fuzzy this can only be a guess. Therefore we consider the heuristic COINCLASS description enriched by our guess as an alternative to the description that uniquely holds the image elements which are somewhat more clearly identified.

In practice ambiguity of COINCLASS descriptions due to fuzzy Reverse images is often eliminated by consideration of further Reverse attributes. For instance in Section 5 we show how the set of COINCLASS descriptions for FEL TEM REPERATIO can be further singled out under the additional consideration of the (fragmented) Reverse legend showing the writing "ERATI".

4   Object-Oriented Schema Design

The purpose of this section is to illustrate the complete database schema of our application. It is rather straightforward to design the types and classes following the discussion of coin descriptions and quoting schemes in Section 2. The use of an object-oriented database as the underlying platform best meets the need for extensibility towards the classification of further coin types as well as the need for flexibility within the implementation of the numismatical quoting algorithm.
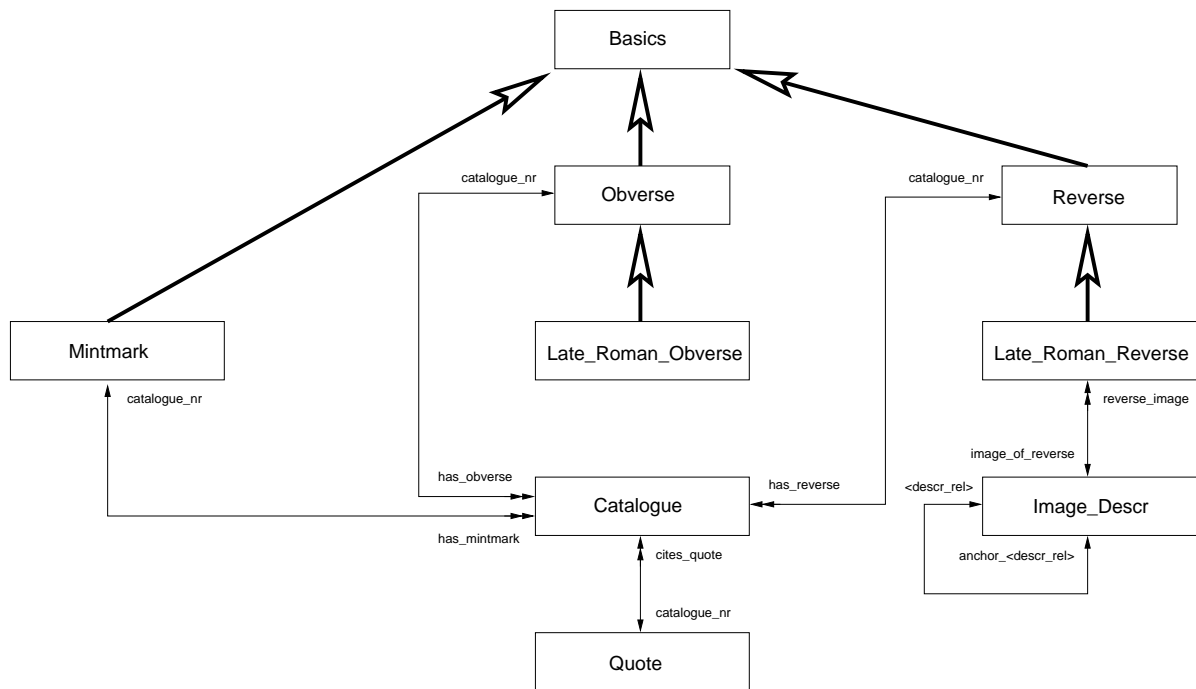

Figure 11: The database schema for late Roman bronze coins.

4.1 Classes and Relationships

The classes containing the attributes for coin description have already been represented implicitly in Section 2. They are now composed to the overall schema in Figure 11. We make use of the graphical notation of the Object Definition Language (ODL) from ODMG [CBB+97] to describe classes and relationships. As we explain in Section 5.2 our application essentially uses query methods and OQL for the retrieval of coin descriptions from the digitized catalogue.

Classes and relationships which have been informally described above directly carry over to the schema, e.g. the structural coin basics consisting of attributes like metal, diameter or weight are implemented through the class Basics. They are essential to all three categories of description, e.g Basics is inherited by the class Reverse which serves at the description of a coin's Reverse. Class Late_Roman_Reverse is in turn a specialisation of Reverse and enriches the standard class for the description of Reverses by the attributes that uniquely characterise late Roman Reverses. The relationships between the classes comply to the catalogue quoting scheme of RIC from Section 2, e.g. in the catalogue the description of a late Roman Reverse is linked to a quotation via the corresponding catalogue number. Recall that Obverse, Reverse and Mintmark are quoted separately via catalogue numbers. The structural representation of a late Roman Reverse image content, which is illustrated in the following, is represented by the class Image_Descr defined in figure 12.

```
interface Image_Descr
(
        extent reverse_images ) : persistent
{
        attribute String simple_descr;
        relationship Image_Descr leftImg
                inverse Image_Descr::anchor_leftImg
        relationship Image_Descr rightImg
                inverse Image_Descr::anchor_rightImg
        relationship Image_Descr lowerImg
                inverse Image_Descr::anchor_lowerImg
        relationship Image_Descr upperImg
                inverse Image_Descr::anchor_upperImg
        relationship Image_Descr anchor_lowerImg
                inverse Image_Descr::lowerImg
    ⋮
}
```

Figure 12: ODL definition of class Image_Descr.

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4.2 Structural Representation of Reverse Images

Formal descriptions of Reverse images according to COINCLASS can be parsed directly and rendered into hierarchical data structures that are easily implemented in the object-oriented application and can thus be stored directly in the object-oriented database.

An object of class Image_Descr (see Figure 12) is used to store a simple image description and to place it in the overall image context. To make the structural representation as flexible as possible regarding the use of OQL to query the image database, the relationships between elementary image elements which have already been explained in Section 3.2 not only carry over to the interface definition of class Image_Descr but are additionally defined with their corresponding inverse relationships.

The way we map formal COINCLASS descriptions to stored structural representation is again best represented by an example: Figure 13 shows the result of transforming the formal COINCLASS description of GLORIA ROMANORVM's Reverse image from Figure 8 into its structural representation. Relationships between objects are expressed as references to object identities (OIDs). According to the priority order on the elementary image elements the partial description Man holdsLeft Spear holdsRight NULL becomes the root of the data structure at OID #4531. Implicit or explicit relationships to NULL are mapped to void references in the Image_Descr structure. To make our example as compact as possible those references are neglected in Figure 13.

Image_Descr		
OID	:	#4531
simple_descr	:	Man holdsLeft Spear holdsRight NULL
lowerImg	:	#4532
rightImg	:	#4534

Image_Descr		
OID	:	#4532
simple_descr	:	Horse
anchor_lowerImg	:	#4531
lowerImg	:	#4533

Image_Descr		
OID	:	#4533
simple_descr	:	Spear&Shield
anchor_lowerImg	:	#4532

Image_Descr		
OID	:	#4534
simple_descr	:	Barbarian
anchor_rightImg	:	#4531

Figure 13: Structural description of GLORIA ROMANORVM's Reverse image.

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5   Quoting Algorithm

As mentioned earlier we heavily rely on [Bru61] and [SC81, MSC78] for classification. However, the two methods are set up with different targets: [Bru61] provides a method for raw description of coins in incomplete preservation whereas [SC81, MSC78] aims at the exact quotation of a coin preserved completely. We combine the two methods into a new quoting algorithm. The purpose of our approach is to quote coins of any preservation quality, i.e. to quote coins of incomplete preservation by a set of plausible quotations.

5.1   Quoting Combination

In practice a late Roman coin's Obverse, Reverse and Mintmark are each described and quoted separately. Quoting — in terms of our application — is the process of assigning to a given coin a set of plausible quotes (triples of Emperor, Mint and the Period of Minting) determining the coin's type and origin. The separate quotations of Obverse, Reverse and Mintmark each end up with a set of possible quotations. In turn the final quotation is constructed by intersecting the results, thus yielding a single set of quotes. Ideally, a coin is uniquely quoted, i.e. the quotation process results in a set consisting of one single quotation. This has been the case in our example GLORIA ROMANORVM from Section 2 (Figure 2).

The capability to cope with coins in incomplete preservation is the most powerful feature of our implementation. It allows for the citations of fragmented Obverses, Reverses and Mintmarks. The core of this enhanced quoting mechanism is a method for the reconstruction of fragmented attributes. Here, attribute reconstruction is understood as the calculation of a set of attributes matching the fragmented description. Matching attributes can be retrieved from the database via the standard database access and matching functions. On our system platform — the object-oriented database system O_2 — we use the Object Query Language (OQL) [CBB$^+$97] for this purpose. Implicitly every single attribute is associated with a set of catalogue numbers, i.e. a set of potential quotations.

To give an idea of the use of our reconstruction method let us consider the highly abstracted quoting method in Figure 14: Let quote be the method intended to determine a set of quotations relative to a list of attributes, i.e. the (incomplete) description of Obverse, Reverse or Mintmark. This description is passed to quote via the parameter list_of_attr as a list of (possibly fragmented) attributes. Let further reconstr be the method aiming at the reconstruction of a single attribute in the way described above. Note that reconstr is considered to be polymorphic in the sense that it works either on fragmented or complete attributes. The goal of determining the quotations corresponding to the given description is thus solved by iterating reconstr over set_of_attr and intersecting the single results. Further note that the invariant result $\neq \emptyset$ must hold

```
method quote : (list_of_attr : List<Attribute>)  ⟶  Set<Quotation>
begin
    result := reconstr(first(list_of_attr));
    for attr in rest(list_of_attr) do
    begin
        result := result ∩ reconstr(attr);
        if result = ∅
            then exception(inconsistency);
    end;
    return result;
end;
```

Figure 14: Simplified quoting algorithm for Obverse, Reverse and Mintmark.

throughout the execution of quote. If ever result becomes equal to ∅ an inconsistency within the given description is indicated and an exception is raised.

Search Space Reduction

Compared to the actual methods and functions that make up the quoting algorithm in our implementation the method from Figure 14 gives only a vague sketch of the way an expert user navigates through the database while searching for quotations.

Within our current application, neither the search is restricted to the sequential processing and reconstruction of attributes within a single description nor is the user forced to work on Obverse, Reverse and Mintmark in a given order. Instead, all degrees of freedom are left to the working numismatic in order to restrict the search space to a reasonable set of quotes. He/she is free to decide where to start the quoting process, whether to postpone the reconstruction of certain description attributes or to refine a reconstruction result.

The non-deterministic choice of quotation refinements, i.e. the possibility to drop quotation candidates from the set of potential quotes during the search, may lead to different classification results for a single coin among various experts. But, this corresponds very naturally to the manual quotation of a coin by several numismatic experts with differing viewpoints and experiences.

5.2 Use of OQL

Full profit is taken from the object-oriented internal representation during the retrieval of Obverse, Reverse, Mintmark and Reverse image descriptions which match given (partial)

descriptions. Here the main benefit is the use of OQL. The sample OQL-queries in the following are extracted from the source code of our implementation. They assist the reconstruction of quotations from (fragmented) attributes as discussed in Section 5.1. To make the example queries best readable we omit the C++ code used to embed and execute the OQL statements and replace formal parameters and program variables by adequate values.

Recall the informal illustration of a Mintmark description from Figure 5 which is mapped onto the object class **Mintmark** as a part of the schema design in Figure 11. We now fully define the class **Mintmark** by its complete ODL definition in Figure 15.

```
interface Mintmark
(
        extent mintmark_descriptions ) : persistent
{
        attribute String location;
        attribute String segment;
        attribute String left_field;
        attribute String right_field;
        relationship Set<Catalogue> catalogue_nr
                inverse Catalogue::has_mintmark
}
```

Figure 15: ODL definition of class **Mintmark**.

Figure 16 presents an example of an OQL-query used to retrieve all quotations associated with a given partial description of a coin's Mintmark in terms of the Mintmark's location and segment. Therefore the extent mintmark_descriptions is searched for matches of the given description. Quotations are found through the catalogue numbers associated with the matching Mintmark descriptions. The concrete values "S" and "PAR" for location and segment, respectively, correspond to the Mintmark of GLORIA RO-MANORVM.

```
SELECT DISTINCT c.cites_quote
FROM    m IN mintmark_descriptions, c IN m.catalogue_nr
WHERE   m.location = "S"
AND     m.segment = "PAR"
```

Figure 16: Retrieval of quotations for a partial Mintmark description.

In Section 3.2 we argued that the ambigous set of Reverse Image descriptions of sample coin FEL TEM REPERATIO is singled out under the additional consideration of its fragmented Reverse legend. Again recall the informal illustration of a late Roman Reverse description in Figure 9 which is mapped onto the object class Late_Roman_Reverse in the schema design in Figure 11. In addition we display the complete ODL definition of this class in Figure 17. Note that Late_Roman_Reverse is defined as a subclass of Reverse, thus inheriting all attributes of Reverse informally illustrated in Figure 4, e.g. Reverse legend.

interface Late_Roman_Reverse

(

      extent late_roman_reverse_descriptions) : **persistent**

{

      relationship Image_Descr reverse_image

            inverse Image_Descr::image_of_reverse

}

Figure 17: ODL definition of class Late_Roman_Reverse.

The writing "ERATI" is the only readable fragment of FEL TEM REPERATIO's legend. In a first step towards the classification of FEL TEM REPERATIO all quotations associated with cataloged coins having "ERATI" as a substring of their Reverse legend are easily retrieved from the extent of class Late_Roman_Reverse by the use of the OQL-predicate LIKE. Figure 18 shows the sample query that does so. Again quotations themselves are found through catalogue numbers associated with the matching Reverse descriptions having the corresponding Reverse legend.


```
SELECT DISTINCT c.cites_quote
FROM    r IN late_roman_reverse_descriptions, c IN r.catalogue_nr
WHERE  r.legend LIKE "*ERATI*"
```

Figure 18: Retrieval of quotations associated with a partial Reverse legend.

Use of Complex Query Results

Another benefit of OQL results is the fact that query results do not need to be implicitly. By implicit we mean that if a certain type or structure is filtered we will receive a result consisting exactly of this type or structure. OQL offers an additional possibility to

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construct a query result with an explicit, i.e. userdefined structure. This individual treatment of datas mean a great degree of freedom to work with query result types.

Figure 20 presents an example where the user is interested in getting information about formal image description according to RIC and the main picture element relative to a certain RIC catalogue number. In that case a userdefined, e.g. a complex query result, is required. It has to be composed of the two implicit results, one containing the formal image description, **image_des**, and the other one containing the main image component, **main_pic**.

In addition to the query, shown in figure 20, we display the class **Catalogue**, see 19, by its ODL.

```
interface Catalogue
(
        extent catalogue_extent ) : persistent
{
        attribute String catalogue_number;
        relationship Quote cites_quote
                inverse Quote::catalogue_nr
        relationship Mintmark has_mintmark
                inverse Mintmark::catalogue_nr
        relationship Obverse has_obverse
                inverse Obverse::catalogue_nr
        relationship Reverse has_reverse
                inverse Reverse::catalogue_nr
}
```

Figure 19: ODL definition of class **Catalogue**.

Note that the relationships are defined in the same way as shown in figure 11. Additionally we describe an attribute **catalogue_number** in the definition of that class which contains information about RIC volume, the page and the RIC number represented as a string.

To get the first result of the complex query we have to traverse an 1:n relationship of the class **Catalogue** which is filtered by the arbitrarily used RIC catalogue number "VIII/214/150". The second result is obtained by traversing the relationship **image_reverse** of the class **Late_Roman_Reverse**. To get the desired restult we have to traverse the inverted 1:n relationship **catalogue_nr** inherited from the class **Reverse** to equal the result and the inserted RIC catalogue number. Both query results filtered by the catalogue number are then collected in the new userdefined type **Result_type**.

```
SELECT DISTINCT Result_type(
        image_des: c.has_reverse.Imagedescription
        main_pic: SELECT DISTINCT k.reverse_image
                  FROM    k IN late_roman_reverse_descriptions
                  WHERE c.catalogue_number IN (
                            SELECT DISTINCT a.catalogue_number
                            FROM    a IN k.Late_Roman_Reverse::catalogue_nr))
FROM    c IN catalogue_extent
WHERE c.catalogue_number = "VIII/214/150"
```

Figure 20: Retrieval of complex query result designed by a numismatist.

Use of Recursion

OQL by itself is not computationally complete. However, methods written in the host language C++ can include OQL-queries and conversely queries can invoke C++ methods. The latter case is illustrated by our last sample query in Figure 21 used to quote the Reverse of FEL TEM REPERATIO by the second of the competing COINCLASS descriptions of its Reverse image (see Figure 10) consisting of the simple image description Soldier holdsLeft Spear holdsRight Shield related to the simple image description Spear&Shield by leftImg. Again this query searches all stored Reverse descriptions this time making use of the recursive method image_descr_flatten defined in class Image_Descr converting a given COINCLASS data structure into a flat set of all the nodes of the hierarchical structure. The use of image_descr_flatten is essential since the given COIN-CLASS description must not necessarily match with stored COINCLASS descriptions starting from their root.

```
SELECT DISTINCT c.cites_quote
FROM    r IN late_roman_reverse_descriptions, c IN r.catalogue_nr,
        i IN r.reverse_image→image_descr_flatten
WHERE i.simple_descr = "Soldier holdsLeft Spear holdsRight Shield"
AND     i.leftImg.simple_descr = "Spear&Shield"
```

Figure 21: Retrieval of quotations associated with a COINCLASS description.

To assign a final quotation result to FEL TEM REPERATIO the single results of the queries in Figure 18 and 21 are intersected as explained in Section 5.1. Since this intersection equals to ∅, an exception is raised proving that the given legend fragment and the given image are not known to appear together on the Reverse of a late Roman

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coin. We therefore drop the COINCLASS description used above and retry the quotation of FEL TEM REPERATIO with the more compact image description consisting of just Soldier holdsLeft Spear holdsRight Shield. In contrast, intersecting the query result of the query from Figure 18 and the accordingly simplified query from Figure 21 yields a small set of reasonable quotes.

6   Summary and Outlook

We presented a new method for the description and quotation of late Roman bronze coins. A prototypical application based on the new classification algorithm and database schema was implemented with the C++-binding of the object-oriented database system O_2 [Bir97]. Our system supports a convenient graphical user interface via O_2-Tools. The system compliance to the ODMG standard ensures that the application will be portable across other compliant object-oriented database systems.

Today the use of digital libraries in arts, history and humanities is still very exceptional. Throughout the phase of evaluation and testing, our novel application has proved to be a valuable tool in the science of numismatics. The use of the formal vocabulary COINCLASS to describe images results in much improved access. The full benefit of our content representations of Reverse images became apparent through the use of OQL. But even in the enhanced representation of pictures the units of representation are searched as units of text. Compared to full-text representations ambiguity is minimised. However, the tedious and time-consuming process of cataloguing image contents via annotations remains essentially the same.

As an alternative, at the University of Augsburg we are currently evaluating the use of IBM Ultimedia Manager for a project in the field of heraldry. This project is set up with the target of archiving and cataloguing of historical shields by their image content. Ultimedia Manager is the commercial descendant of IBM's project Query By Image Content [FSN$^+$95] which has already been applied in the arts and humanities [HH94]. For us the representation of Reverse images remains a hot topic of discussion and we feel that — in the future — the use of a multimedia tool like QBIC might partially replace the current representation of image contents in our numismatic application.

Acknowledgements

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