DOCUMENTATION AND REASONING ON PARTS AND POTENTIAL WHOLES

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ABSTRACT

The purpose of this paper is to explore some semantic problems related to the theory of parts and wholes of archeological findings and other mobile objects of material cultural heritage. This work was recently done in cooperation with archeologists and in the framework of designing and implementing thematic documentation systems with wider scope for museums. The aim of these systems is to organize an evolving corpus of knowledge about objects for use in scientific study, and research. The transition of information among the type or class level and instance level and the use of an application specific metamodel characterize our approach. This approach has shown to be a powerful method in a series of real applications. We emphasize here the description of partial or missing data for parts, wholes and potential wholes of the above objects. We suggest a methodology of conceptual modeling of data in order to document incomplete knowledge about parts and wholes in a way that is redundancy-free, and robust against increase of knowledge. This model allows answering questions about the actual findings and about the wholes they actually have or may have belonged to. Even though we employ an advanced knowledge representation model to express and implement these semantics in an elegant and compact way, a transformation to a Relational System is straightforward. Experimentation with this model in an actual museum environment is currently being done.

INTRODUCTION

The effective representation of parts and wholes in information systems is an interesting problem, which has drawn recently the attention from several sides. Problems range from counting items in inventories to complex relations of the properties of the respective wholes and vice versa. The complexity for long being ignored, it turns out that there is not a uniform notion of part and whole (Artale, A., Franconi E. & Guarino, N. 1996) but rather a complex of related issues; scientists talk now about "mereology", the study of part-whole problems. Parts of a chemical plant and parts of an orchestra, parts of a book and the pieces of a broken vase have few in common. This paper is devoted to the analysis of some aspects of part-whole relations as they typically appear in archaeological studies and museum documentation.

For several years knowledge about parts has usually been represented by «part-of» relations, which induce corresponding hierarchies generally called partonomies. They reflect important aspects of a domain about the structure of objects in an efficient and economical way. In the most cases these «part –of» relation has been treated as an ordinary attribute. Various cases, as members of an orchestra and the fingers of the musicians (Motschnig – Pitrik, R. 1993) have been treated the same way as the list of attributes of a data record and areas within a country. In the last years however, the logical structure and semantics of a partonomy has been discussed lots in computer science. Since the use of formal complex data models in information systems increases, the shortcomings and inconsistencies of such simplistic approach become more and more apparent. These problems reside in the properties associated with part hierarchies as:

- Parts inheriting properties from wholes (e.g. placement, creator, etc.)
- Wholes inheriting from parts (e.g. engine power, malfunction)
- Restricted transitivity in heterogeneous «part-of» hierarchies
- Consistent counting in inventories containing parts and wholes
- Multiple and contradictory ways to define parts and wholes on the same set of objects

Nowadays specialists in knowledge representation agree that there is no single property «part-of» nor one definition of a whole, but rather a complex of similar and related but nevertheless distinct concepts and properties. In (Motschnig – Pitrik, R. 1996) Renate Motschnig deals with semantics of basic modeling constructs in object-oriented and Semantic Models. She makes clear distinctions between attributes, aggregates, parts and members. She argues that the "part-of" and the "member" relationships are to be classified as a structural or organizational property and she distinguishes four types of "part-of" relationships resulting from combinations of being exclusive / shared and dependent / independent; and depending on whether a part exclusively belongs to a composite or may possibly be part of several composites, or if it can exist without its whole or not. Hence a model should allow specifying and enforcing such properties for each "part-of" link.

The Artale et al.'s article (Artale, A & Franconi, E & Guarino, N & Pazzi, L 1996) provides an extensive overview and comparative analysis of mereological approaches with a special emphasis on systems with inference mechanisms for part-whole relations and the relations between properties of parts and those of their wholes. The authors argue that formal systems like Description Logic are the suitable means to express enforce and handle such semantics. These systems focus on applications in controlled environments as machinery description, document handling and modeling of human organizations. As such, several attempts to clarify the different concepts of parthood are presented, but without a deeper analysis. For museums, which are confronted with all kinds of parts and relicts in a retrospective position, the clarification of these concepts is crucial. The modeling constructs presented in the Artale et al.'s article (Artale, A & Franconi, E & Guarino, N & Pazzi, L 1996) may nevertheless become quite useful for advanced reasoning services in cultural documentation systems.

Cultural documentation standards on the other side have hardly entered this area. The CIDOC Guidelines for Museum Object Information foresee the description of parts of an object only as part of the description of the whole: "Where records of an object are held at different levels (e.g., sets, archives, etc.), the Part and Component Information describes the items at the next record level down. For each collection it must be decided whether to describe each part of an object or set as separate records, or as a single set or object listing the separate components by name and numbering them". Isolated documented parts that refer to potential or external wholes are not foreseen. The CIDOC Relational Model from 1994 (Reed, P 1995) contains a generic typed object-object relationship, where the part-whole relation is seen as one type among others. The types are not specified. Further it distinguishes "sections" on an object from parts, things like faces of a coin. The CIDOC Conceptual Reference Model (Crofts, N & Dionissiadou, I & Doerr, M & Reed, P 1998) from 1998, where we have contributed to, brings both notions into an object-oriented Semantic Model, in the form of two attributes: "**Physical Object. is composed of: Physical Object"** and **"Physical Object. has section definition: Section Definition",** where "Section definitions" are seen as topological notions, just as in our work here.

An interesting approach is the GENREG model installed at the National Museum of Denmark (Rold, L 1995) it allows for creating part-whole hierarchies of arbitrary depth. Each part-whole relation has a description of its own and refers to an event. In this way, it allows for specifying the individual character of each part-whole connection, or more precisely in which role an object participates in the whole, and it assigns a temporal validity. In particular, it allows objects to participate in multiple part-whole hierarchies. It is a metamodel, which does not further detail the possible roles of object participation. As such it is not in contradiction to our work. GENREG does not detail the possible event types, but the intended support of hypothesis about historic facts is explicitly mentioned. In the work presented here we do not deal with the temporal dimension of parthood, but we see the GENREG temporal approach as a natural extension.

For our purposes a rather promising approach is given in (Gerstl, P. & Pribbenow, S 1996) Peter Gerstl and Simone Pribbenow investigate the nature of the criteria that lead to concepts of parthood. They come from linguistic studies and provide a general classification of part–whole relations that covers many ontological domains such as physical objects, temporal and spatial entities, situations and certain abstract entities. Having in mind technical constructs of daily life, the paper deliberately omits a detailed discussion of pieces, which are however of primary concern for museums and archeologists. Nevertheless, the basic concepts presented fit to our observations and models in the cultural heritage area. In the sequence we shall adopt some of their terminology in our models.

In this paper we focus on the retrospective, dynamic assignment of part-whole relations characteristic for archeological and museum work.

Following our activities of developing museum documentation systems (Bekiari, Ch. & Gritzapi Ch. And Kalomoirakis, D. 1998; Bekiari, Ch. & Bitzou, Th. & Calomoirakis, D. & Chronaki, D. and Costantopoulos, P., 1995; Constantopoulos, P. 1994; Dionysiadou, I. and Doerr, M., 1994), we have addressed the problem of documenting knowledge about current, historical or assumed relations between components, pieces, objects or aggregates in museums, taking into account the methods and practice of object registration in museums. The need for correlating a part with its whole is apparent in many procedures of museum documentation. Characteristics for the archaeological and museum environment are the following situations:

- We hold a part of an unknown whole,
- we try to fit parts into alternative wholes,
- we hold a main part and look for other missing parts,
- We arrange parts to demonstration wholes for exhibition purposes.

It may be that either the parts are registered and the whole is moved, or that a whole is registered and some of its parts are moved. Such cases can cause immense inventory problems in a naïve registration system.

Some characteristic examples of museum holdings are:

- A broken piece of sculpture from the head of either a statue, a bust or from an inlaid head.
- Two potsherds fitting. If not decayed, the fitting area is like a finger printing.
- Several potsherds, some fitting together, which may belong to the same vessel or not.
- All the potsherds of an urn.
- A Steatite rhyton in the form of a bull's head. The ears, the horns and the eyes had been constructed separately. The horns are lost and have been reconstructed.
- A Copper urn with its cover

In such cases, we would like to provide computer support for the following documentation procedures:

- The classification of parts such that they can be related to potential or original whole objects.
- The consistent retrieval of objects via wholes, classes of wholes, parts or classes of parts.
- The dynamic grouping of museum objects for the sake of exhibition independent from documentation units.
- The counting process of museum objects for inventory purposes and scientific statistical studies, including actual wholes, actual pieces, indications of historical wholes etc.

The space in which we are physically or virtually combining parts and wholes can vary widely. It may be a small spot in an excavation site, the complete holdings of a museum, or a worldwide search. The different nature (material, morphology, supposed function) of some components can lead to a distribution of related components to different departments of a museum. Trading and change of use may spread out parts over the world. Prominent example is the reconstruction of Nefertiti's temple in Karnak by electronic registration of properties of some 30.000 parts by Ray Winfield Smith and others in 1965 at the IBM computing center in Cairo (Vandenberg, Ph. 1975). Another prominent example is the distribution of some 2000 objects from the Palace of Benin after the British punishment campaign in 1897 over the world, including bronze plates that decorated the columns of the palace. A resolution of ICOM twenty years ago to return such objects to Nigeria had been ignored (Eyo, E. Willet, W., 1983) The larger the distance, the longer we eventually need to detect the parts fitting together. These example show, that the respective documentation methodology and data modeling is not only a question of good practice at an individual site, but also an issue of international standardization.

APPROACH

The current work presents a method of analysis and a conceptual model for the correlation of parts and wholes that helps in the above procedures or questions. It is oriented on the kind and quality of information that allows us to conclude on potential wholes, missing parts and their classification. It implements a principle of robustness against changes. It means that any increase of knowledge, which is not in contradiction with the previous knowledge in the human sense, should lead only to a local change in the information system. E.g., a carriage, preserved in a series of parts documented separately, turns out to have been a necrophore. The answer to the question for all carriages should not change, nor should the data records for all parts need a change. This is achieved by the use of specialization hierarchies (isA), reference instead of data replication and the separation of primary information from secondary (hypothetical or derived).

This work is based on requirements from archeologists and experiences gained in our cooperation with museums on documentation systems and with the CIDOC Documentation Standards Group. In particular it is an extension of our CLIO system, (Constantopoulos, P. 1994; Dionysiadou, I. and Doerr, M., 1994) which was created to meet the needs of thematic documentation of cultural heritage objects and is being employed in the Museum Benaki and other institutions. For the formal representation of the schema, we use SIS. SIS is an implementation of an advanced Semantic Model and derives of the knowledge representation language TELOS (Mylopoylos, J & Borgida, A & Jarke, M. & Koubarakis, M 1990) Semantic Models are becoming increasingly popular for the representation of the conceptual contents of database schemata that follow different implementation paradigms, and are easily understood by non-computer experts. The CLIO model represents scientific knowledge about objects in a neutral way view. Depending on the query, data can be seen as description of objects, of actors, of places, of period etc. The example of the CLIO model was a motivation for the CIDOC Documentation Standards Group to engage in the formulation of an object-oriented CIDOC Conceptual Reference Model.

In SIS-TELOS, we represent classes (entities) by nodes and attributes (fields, relations or references) as arcs between nodes. Attributes, binary relations and references are not distinguished. Attributes are optional and multi-valued, and can have attributes of their own. The arcs and nodes of the schema are described by a metaschema, consisting again of arcs and nodes, in the same way as instances and their properties are described by the schema. The model allows metametaschemata etc., but we make here no use of them. Between schema entities (classes **or** attributes) multiple "isA" relations (superclass/ subclass) can be declared that imply strict inheritance of the respective attributes (or relations). Data items can further belong to more than one class (multiple instantiation). The latter leads to a union of the attributes of the involved classes.

A distinct feature of our models is the use of metaclasses to declare sets of classes that can be used as domains for attribute values in the schema. This feature can be simulated in a relational system by the suitable use of "type" (Doerr, M. and Crofts, N. 1998). Attributes of the metaschema (metacategories) are used to group attributes of the schema by intrinsic properties, as e.g. part-of. Metacategories may be recursive, whereas their instances, attributes of the schema, need not be.

The model presented aims at the design of collection management systems, scientific documentation systems or data exchange formats and mediation systems. It also intends to clarify the notions and to foster good documentation practice as an intellectual guide. Up to now it contains only primitive declarations. Derived values, queries or constraints may be investigated in the future.

Following (Gerstl, P. & Pribbenow, S 1996) we distinguish kinds of parts based on the compositional structure of the whole, so-called **structure-dependent parts,** from parts of wholes, which are arbitrarily induced or driven by internal non-structural features or external criteria, the so-called **temporarily constructed parts**.

By **structure-dependent parts** we mean all the parts of an object into which an object can be decomposed, or which where distinct integral items at the time of construction. Structure-dependent parts are further subdivided into **components, elements** and **quantities**.

A **component** is an object a priori designed as part that has a specific relation to the whole different from that of the other components with respect to functional, spatial, temporal, and other features. The respective whole is an integral object, a "complex". Examples are all machines, buildings etc. The definition is not always clear cut, especially when we talk about accessories and spare parts. We are however not primarily interested in providing here a new definition, but in capturing existing archeological and museum documentation practice. Let's take a sword and its sheath. The fact that a museum would typically register it as one object and that the sheath is specifically made to fit this model of sword is enough reason to regard it as a complex and the sheath as a component.

The whole of an **element** is an **aggregate**. (We have chosen "aggregate" instead of "collection" as used in (Gerstl, P. & Pribbenow, S 1996) to avoid confusion in the museum community with "museum collection" in the narrower sense). An aggregate consists of members, elements, which are loosely aggregated, may play an individual role without the whole and typically are not of distinct nature from all the other elements. Examples are sets of cups, the members of an orchestra, a heap of potsherds. Again this definition is not always clear cut, but nevertheless useful. In any case we would regard as an aggregate: a set of like items or a set of items that cannot be assembled. A museum may have documented several components separately, thus giving the impression of an aggregate. In that case parts may change their role in the view of the documentation system from an element to a component. Likewise a heap of potsherds may be reconstructed into a vessel. Obviously, the complex or integral object is a higher form of organization, and components allow for more reasoning about their wholes than elements, and this is precisely our motivation to make the distinction. If, for instance, a pair of pistols is regarded as aggregate or complex does not make a difference here. The one or the other may be justified in the specific case.

Characteristically the aggregate lacks something that we would call it an object. Quite often there is a need to group registered items in different ways. There may be sets of furniture from a room in a castle. Historically uncorrelated objects are combined for demonstration purposes in exhibitions. We would model all such “abstract objects” as aggregates.

According to (Gerstl, P. & Pribbenow, S 1996), the whole of a quantity is a mass – an object, which totally lacks of compositional structure, like a liter of milk etc. We do however not deal with quantities here, but they may be better seen under the following category.

By **temporarily constructed parts** we mean all the notions of parts that do not conform to structural units, but are imposed by external criteria, forces or points of view. (Gerstl, P. & Pribbenow, S 1996) distinguishes between **segments**, **pieces** and **portions**.

A **segment** is the part of an object derived by the application of an external scheme. In other words, it is a topological notion. Examples are bottom, front, head, neck, and opening. Segments comprise matterless features like holes. They are typically induced by the mental image we have about the morphology of the type of object we regard. We use other terms for houses than for a statue. The fact, that a marble statue e.g., has no interior structure separating the head from the neck etc. demonstrates the topological, non-material nature of such “parts”. Segments play an important role in the cultural object descriptions and should not be confused with components, even though the placement of a component can (and often should) coincide with a segment. In the absence of components, segments typically do not exhibit well-defined boundaries between each other. (The analogous notion in the CIDOC Relational Model is a “section”, simply described as: “. Inseparable from the documented object, and it cannot stand as an object in its own right”.).

A **piece** is a part of an object resulting from an arbitrary mechanical subdivision of it. It is physical and clear cut. It may be broken off by accident or undirected forces, or deliberately cut for purpose of destruction or reuse in another environment. The surface of broken pieces usually allows to identify uniquely neighboring pieces, a prominent source of information to argue on potential wholes, but quite difficult to encode. Other characteristics are continuing decorations from one piece to another (as in R.W. Smith’s project). Whereas components tend more to exhibit the type of their whole and less the individual whole, pieces tend to characterize their individual neighboring parts and may leave a set of interpretations about the type of the respective wholes.

The article in (Gerstl, P. & Pribbenow, S 1996) characterizes **portions** as defined by internal criteria, like "the wooden part of a house". We do not use this notion in this paper, even though it may be useful in this context.

Given that parts are typically what we have at hand, there is another conceptual dimension: the degree of reality of wholes. In order to express properties like unknown, missing, alternative or real, we define three concepts concerning the type of a whole. These are:

1. The **hypothetical whole**: Something we have only witness from or we derive from indications. Major or minor parts may exist, but the open assignment or the missing parts leave space for relevant alternatives.

2. The **genuine whole** or object: Something that has come upon us in an integral or complete form, such that we regard it as one object due to that evidence, or something that has been assembled in the original form it had at the period we are interested in with enough evidence to leave no space for alternate interpretations.

3. The **constructed whole**: Something put together for exhibition, experimental or administrational reasons, in a historically correct manner but without clear evidence, that it had been assembled in this specific way ever in the past.

The museum Benaki has given us a simple example for that. They have swords with sheaths, swords without sheaths, and sheaths without swords. The latter both give raise to hypothetical wholes -some sword may had two sheaths, some may had no sheath ? Some of the true combinations may exist in the museum, but without enough evidence, some may exist not. Some sheaths are assigned to swords for exhibition reasons, or after poor evidence, or by the previous owner, whiteout historical security. Those are the constructed wholes. Some swords have always been together with their sheaths, and some could be assigned by clear evidence, e.g. a historical painting. Those are the genuine wholes. Besides the identification and verification of more genuine wholes, these statistical questions are relevant: How many incomplete sword-sheath sets do exist? How many genuine, and for how many hypothetical ones we have some evidence.

As we have coined the latter three terms, archeologists may correct us, if there exit better, introduced terms in their field.

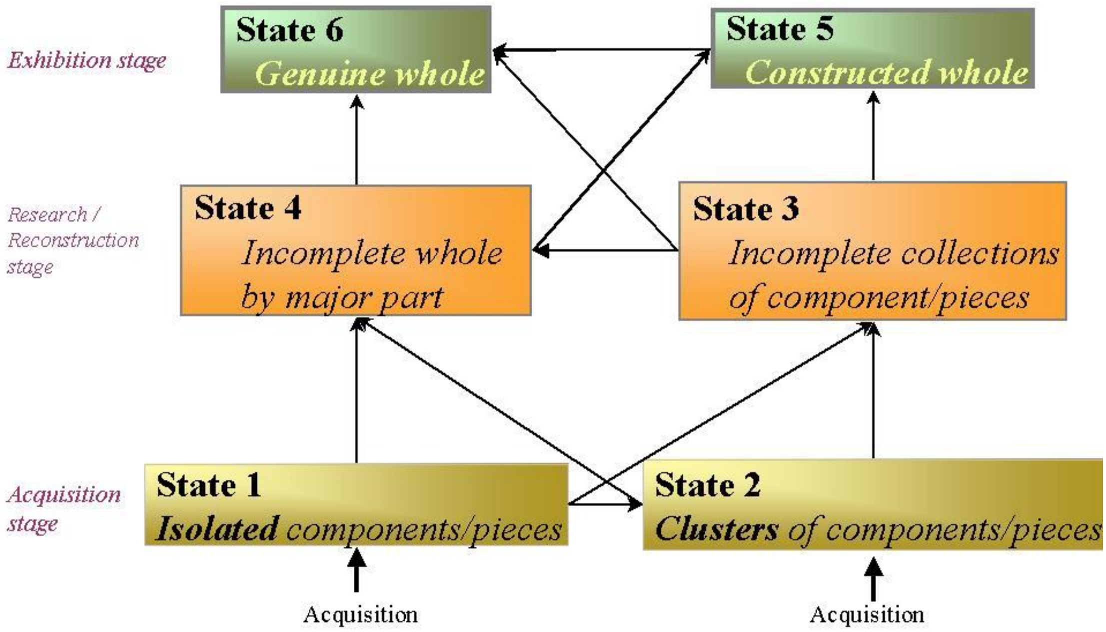

Figure 1: States and Stages of Wholes and their documentation

Let us describe in the following the relations of our model. For a better understanding of the scenario under consideration, we divide the documentation process into distinct sets of documentation actions. Each set of actions constitute a state of the documentation process, ordered by the integrity and degree of knowledge about items, which may as well constitute stages in a potential reconstruction process. It is illustrated in figure 1. The arcs in the figure 1 denote the valid transitions from one state to another.

In **state 1**, one may document isolated components or pieces, as they have been accessioned. Object identifiers are assigned to the physical pieces, in order to capture the accession process. One may describe their nature, status, descriptions or assumptions about the position of these objects with respect to the whole and assumptions about the whole to which they belong. Additional evidence may lead to a documentation state like 2 or 4.

In **state 2**, a cluster of components, elements or pieces has come upon us. During accession, it is usual practice to assign one collective object identifier to unanalyzed aggregates of somehow homogeneous items. Alternatively, one may have either gathered additional evidence about the relation between some objects and documents, which of the registered components/pieces registered in state 1 are fitting or sticking together or exhibit identical features. In both cases, still no real evidence of a whole exists. From here additional evidence may lead to state 3, if no major part emerges, else to state 4.

In **state 3**, one has gathered by research and studies enough evidence to make assumptions about a missing whole in order to create a respective record and to assign an object identifier to the incomplete aggregate of components, pieces or elements due to the evidence of their relation. Such an object is "abstract"; it does not count for the inventory, as long as its constituents are individually registered. Reassembly and/or recombination may lead to state 4, 5 or 6.

In **state 4**, a similar situation as in state 3 may exist from the time of accession, just because a part of enough central importance has been documented, which is taken right away as representative of the whole, like a sword blade, a statue without head or arm, a vase with a broken-off neck. The object id counts simultaneously for a part and the whole. The same state may be reached after research and re assembly from a state like 1, 2 or 3. There may be good reasons to abandon object identifiers of pieces that have gone into a reassembled object - an interesting case for inventory statistics. The semantic difference of state 3 and 4 is interesting, if someone states that an item is part of some object. Both cases are based on hypothesis about the whole, its precise features, and eventually if it existed at all. A building may have never been finished etc. Further reassembly or recombination may lead to state 5 or 6.

In **state 5**, one has put together items in a way that represents the idea of a whole of that sort of object. This may be done for the purpose of exhibition or research. The same parts may be combined into more than one **"constructed whole"**. Exhibitions of traditional costumes e.g. may recombine items from different owners in a traditional way. There may also be administrational reasons like transport and packaging. Finally, even historical arrangements and rearrangements of furniture (Barry Eaglestone, B & Holton, R. & Rold, L., 1996) could be seen as "constructed". One or more of those may actually represent state 6.

In **state 6**, either an integral object has come upon us, or we have achieved a nearly complete reassembly in a way, that conforms with historical and physical evidence, and leaves no space for relevant reinterpretation. We call this a "**genuine whole**", being aware that this is relative to a period, the intention of the creator, or other factors. We do not intend here to take a position on the precise distinction. Rather, we want to point out, that there is some difference in reasoning and administrational handling between the "historically correct" and the "demonstrative" or "administrational". Of course, current arrangements can again be seen as becoming historical etc. With the "genuine whole", the reasoning has come to an end.

As object-oriented models like Telos allows the user to extend the schema, our model contains only the basic notions. In particular it contains the full definitions at the metalevel, which impose a discipline to the creation of more and more specific structures at simple class level. Here we focus on that part of the above ontology concerning the different kinds of part of relationships and we propose a methodology of conceptual modeling of data in order to document knowledge about parts of heterogeneous wholes which are induced arbitrarily or by using external criteria. We relate it formally to higher entities of the CIDOC Conceptual Reference Model (CRM), in particular to the metaentities that appear in the CRM as informal comments.

Out of the various notations in use for object-oriented data models, we selected the following for ease of understanding:

Classes are named using initial capitals and stand for anything that may be called «class», «entity» «nodes».

Attributes are named using lower case letters and have bidirectional directed meaning. The meaning of the label is in the direction of the arrow head. Attributes stands for something that may be called «attribute», «property», «relation», «reference», «arrow», «role»,. see also (Artale, A & Franconi, E & Guarino, N & Pazzi, L 1996) on notations. We do however not distinguish between single-valued "attributes" and multi-valued "roles" as in Description Logic. *Attributes* are **inherited** to **subclasses** (classes again). The relation between a subclass and a class is something that may be called «isA», «subclass - superclass», «derived class - parent class», «generalization», etc., and between a superclass and a class anything that may be called «specialization», «parent class- derived class» «superclass - subclass» etc. A more formal list of the notions proposed in this paper with their relations to the CRM is given in appendix A.

The following set of metaclasses classifies an open list of classes about kinds of objects and parts, and constitutes a structured container for future definitions:

Following the CRM or CLIO, **Physical Object Type** gathers all classes of the hierarchy describing kinds of Physical Objects, the kinds of things which have weight, are created once and can be destroyed. Here in our model we specialize it into the **Structure Dependent Part** and the

Constructed Part as defined in the previous paragraph. Following the logic developed there, **Structure Dependent Part** is further specialized into **Component Type** and **Element Type,** whereas **Constructed Part** is specialized into **PieceType** and **Segment Type.** We have not modeled portions and quantities.

These six metaclasses new to the CRM interpret formally the respective entities as metaclasses, i.e. as sets of classes, or sets of sets of instances. As such, they group classes of objects which implement respective aspects of parthood, as e.g. "screws", "columns", "flint-locks", "stands", "covers", "motors", "knobs", "clasps", "chessmen", "playing cards", "keys", "potsheards", "splinters", "samples", "drill cores", "bottle necks", "faces", "fronts", "surfaces"…with respect to the above notions. This classification is not exclusive, other aspects of "objecthood" may be expressed by a single object class (stylistic, morphological, ethnological etc)

We associate with each metaclass an "abstract superclass", formally the union of all classes in this metaclass, the class of all instances in all classes of this metaclass, or the root of the respective type hierarchy. (Actually this is equivalent to top terms in thesaurus hierarchies like the AAT, and the metaclass corresponds the respective hierarchy as a notion. In the AAT distinguished by capitalization). Those classes are : **Component, Element, Piece, Segment** respectively. This is a methodological feature. It allows to disambiguate between: "What I hold in my hand is a **component** of a garment", " knobs are **components** of garments". We interpret the latter "components" as **Component Type.** Figure 2 shows a couple of subclasses of those simple classes, instances of the above respective metaclasses, that serve the subsequent examples in this paper (namely "**embedded head**" "**bust**" "**statue**" "**sculpture**" "**broken piece of sculpture**").

The metaclass **Whole Type,** another specialization of **Physical Object Type** collects all the kinds of wholes depending on the degree of their reality (see above). For the moment, we have only identified the following instances of this class: **Hypothetical Whole**, **Genuine Whole** and **Constructed Whole** (see above). This aspect of classifying classes is orthogonal to traditional classification of "complete" objects. It means, that some data record on a potsherd, e.g., may be linked to a data record for a cup following camares style, which is only an outcome of a hypothesis on the provenance of the potsherd. Hence such a record should be classified as "camaraiko[1] cup, hypothetical whole". (See figure. 4).

In the following, we use the metaclasses not only as classes of classes, but as types of entities attributes can point to. In other words, attribute values of some individual item may be classes, e.g. to express that the clasp in my hand belongs to a Celtic garment. In this case, we refer not the actual garment it belonged to, which is unknown, but to a set of objects, from which one or more have been candidates for this connection. More precisely, the semantics are in this case that "there has been at least one garment of this type the clasp belonged to". The latter can systematically be implemented in query algorithms.

A more formal theory on this point has to follow. We restrict ourselves here to an intuitive argument addressing archeologists. The idea is, that the question for potential garments the clasp belonged to, would return all instances of "Celtic garment" in the database. Of course, this list would not be exclusive, as our databases do not describe completely the world. It would help however, to identify potential wholes somewhere registered. Otherwise round, a question on all clasps of Celtic garments would return not only those registered in this abstract way, but also items linked to individual wholes, that belong to this class. This is an essential part of the model presented here, and one of the proposed mechanisms to support the search for potential wholes

As pointed out in (Doerr, M. and Crofts, N. 1998), such reasoning can be simulated in other datamodels (ooDBMS etc.) in conjunction with a system of thesaurus terms. The latter must be compatible with the class hierarchy of the database schema, be consequently used to classify all objects and be structured following a set-inclusion logic for the Broader/Narrower Term relation. Consequently, the idea is also reflected in the CIDOC CRM in the form of attribute names "general…." or "specific…" for references to classes of objects, or individual objects respectively. We follow the same convention here.

After having had evidence only for the class of a missing whole, of course we usually do not acquire by a sudden direct evidence that the part belongs to a specific object. In the course of research, the class of the missing whole may be more and more specialized, until it is no more

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[1] A Camaraiko cup is a cup following the Camares style. The style is named after the place where such cups were found. These cups are dated from the 17th century B.C…They have a very thin, egg like shell and decorations with subjects from the animal and vegetable world.

served by a reasonable thesaurus (As in the article of Dionysiadoy et al (Dionysiadou, I. and Doerr, M., 1994), we do not distinguish there between a class in the schema and a type of object in a thesaurus. We regard that rather as an implementation detail). In that case, we propose to create a node for a **Hypothetical Whole, a surrogate of the missing,** that gathers all properties derived from our knowledge on the part and independent historical records (see e.g. figure 4). These may in particular be quite peculiar morphological or decorative criteria, as continuations of a certain pattern. If finally identified with a real object, the hypothetical can be removed. Before, it can support a series of queries, that allow to compare the hypothetical object with described ones or historical references in order to gather more and more evidence.

Either after of before one would be inclined to dedicate a specific data record to a missing item, one may be in the situation to have specific **candidates,** real objects to refer to. It would be misleading to use the same attribute for that case as for actual definite knowledge. We propose therefore to modify attributes by the degree of evidence, at least by "possible…" and "real…". In the case "real", we do not express the fact in the attribute name. More degrees may be introduced, but this may be counterproductive, because it introduces subjectivity and overhead to the documentation and query system. More realistic may be to encode opinions of specific groups and researchers, as discussed in (Doerr, M. 1997).

"*Real*" and "*possible*" attributes can be systematically used in queries to differentiate assumptions (for optimal recall) from definite knowledge (for optimal precision). Truth should always be between both bounds

"Possible.." attributes may also be used to refer to classes only, and without a hypothetical whole. Finally, hypothetical wholes can be related to candidates by the "*possibly identical with*" attribute.

1. Instances of **Hypothetical Whole** connect to any **Physical Object** via "*possibly identical with*" (figure 4)

By these means, we can offer a complete system of formal constructs, that allow to capture the increasing knowledge without causing inconsistencies, and without invalidating previous statements. An attribute pointing to a class is compatible with one pointing to an instance of this class, and if this is a hypothetical whole, it is again consistent with identifying it with a real one etc.

The core of our model are three attributes that correlate parts with wholes, and that are varied as above:

2. Instances of **Component** connect to any **Physical Object** via "specific component of".(figure 6)

3. Instances of **Element** connect to any **Physical Object** via "specific element of".

4. Instances of **Piece** connect to any **Physical Object** via "specific piece of" (figure 5).

Respectively we have:

5. Instances of **Component** connect to any **Physical Object Type** via "general component of" (figure 6).

6. Instances of **Element** connect to any **Physical Object Type** via "general element of".

7. Instances of **Piece** connect to any **Physical Object Type** via "general piece of" (figure 5).

The above six 6 attributes are a specialization of the "real" attribute, and may be modified by assumption, resulting in another set of 6 attributes, specialization of the "possible" attribute:

8. Instances of **Component** connect to any **Physical Object** via "possibly specific component of" (figure 6).

9. Instances of **Element** connect to any **Physical Object** via "possibly specific element of".

10. Instances of **Piece** connect to any **Physical Object** via "possibly specific piece of" (figure 5).

11. Instances of **Component** connect to any **Physical Object Type** via "possibly general component of" (figure 6).

12. Instances of **Element** connect to any **Physical Object Type** via "possibly general element of".

13. Instances of **Piece** connect to any **Physical Object Type** via "possibly general piece of' " (figure 5).

Even though we have presented the topic so far as if the kind of parthood would be just the nature of the part itself, it is indeed a relation between two objects, that may be quite incidental and change over time. The respective class can be regarded just as the set of all things having the respective relation. In that case, the class would be redundant, at least in the presence of the respective attribute. For simplicity in this paper, we have restricted our examples and reasoning on this interpretation. On the other side, all the examples listed before demonstrate cases, where objects have been explicitly made to play one specific part role. This can be recognized without the whole, and the real part-whole relation may have been quite different (think of a screw in a modern sculpture). Therefore, to classify an object as a kind of part is actually an independent feature from its historical or current use as a part.

The attributes 2-4. above constitute a specialization of the CIDOC CRM attribute "is composed of (forms part of)", actually of the inverse, the "forms part of". (Crofts,N & Dionissiadou, I & Doerr, M & Reed, P 1998). In other words, any of the three attributes implies the property "forms part of". TELOS, RDF and Description Logic foresee specialization of attributes and roles, whereas the ooDBMS do not allow that.(Heinsohn, J & Kudenko, D & Nebel, B & Profitlich, H., 1994; Analyti, A. & Spyratos, N & Constantopoulos, P., 1997)

In addition the part-whole relation, quite often the researcher cannot conclude on the whole, but on adjacent parts ("state 2", above). The article Artale et al.'s (Artale, A. , Franconi E. & Guarino, N. November 1996) describes arguments, that the definition of a whole through lists of parts only is not effective. We have the impression, that this actually holds as long as objects are completely under our control. In archeology however, recognition of adjacency only is a characteristic stage in the research on parts and wholes. Adjacency can often be concluded from morphology, in particular interrupted decorations (Vandenberg, Ph. 1975). In case of components of some technical model, components are typically interchangeable between instances. Hence we can only conclude on a class of objects as candidates for the whole. On the other side, broken-off pieces have a surface characteristic like a finger-printing if not decayed. Consequently, we model another group of attributes (figure 3) that connect physical objects at an equal level, in order to capture aggregation of parts before any evidence for the whole:

14. Instances of **Physical Object** connect to any **Physical Object Type** via "possibly general adjacent to".

15. Instances of **Physical Object** connect to any **Physical Object Type** via "general adjacent to".

16. Instances of **Physical Object** connect to any other **Physical Object** via "possibly specific adjacent to".

17. Instances of **Physical Object** connect to any other **Physical Object** via "specific adjacent to".

A similar situation arises for elements of an aggregate, like some chessmen of a lost set, or a set of cups and saucers with identical stylistic elements. Even though there is no chaining as with the above, it is convenient to denote, that one "is from the same set as" another. Obviously this property is transitive, and gives rise to unstructured clusters. Hence we declare:

18. Instances of **Physical Object** connect to any other **Physical Object** via "possibly from the same set as".

19. Instances of **Physical Object** connect to any other **Physical Object** via "from the same set as".

Relations about possible combinations can be developed into huge reasoning systems, with all kinds of positive and negative facts, constraints etc. We believe however, that such documentation exceeds the general purpose of bringing candidate objects together from different collections, and becomes useful only **after** a relevant pre-selection of many objects has been done, when the real puzzle work starts (As in the Nefer Titi case).

Finally, segments are dealt a bit different, as topological definitions. Segments like "head", "front", "neck" (figure 5) are conceptual definitions, on class level. We declare therefore:

20. Instances of **Physical Object** connect to any **Segment Type** via "possibly from segment".
21. Instances of **Physical Object** connect to any **Segment Type** via "from segment".

The position of some part with respect to the whole is an important auxiliary element in the reconstruction of wholes, and can be used to query globally for unknown missing parts by position. We may e.g. ask for marble pieces from a "right arm" of a ancient Greek statue etc. Such references could be developed into thesauri of topological hierarchies, recognizing fingers to be included by hands, hands by complete arms etc. Another modeling choice could be, to classify objects as instances of segment types (e.g. "this is a head"). But the fact, that segments do not conform with natural object boundaries in particular if broken off, makes this choice less precise. In addition, classification is usually not modified.

We believe that the above set of 21 attributes can solve most problems of relating parts and wholes in the archeological and museum practice, in particular reasoning over distributed sources. Practice will show, if we have missed some cases, if some are already too specific, or if some of our categories need redefinition. Users in particular may prefer different terminology. We shall continue this work with formal definitions of query operations and deductive rules. In the following chapter, the model will be illustrated by examples and figures.

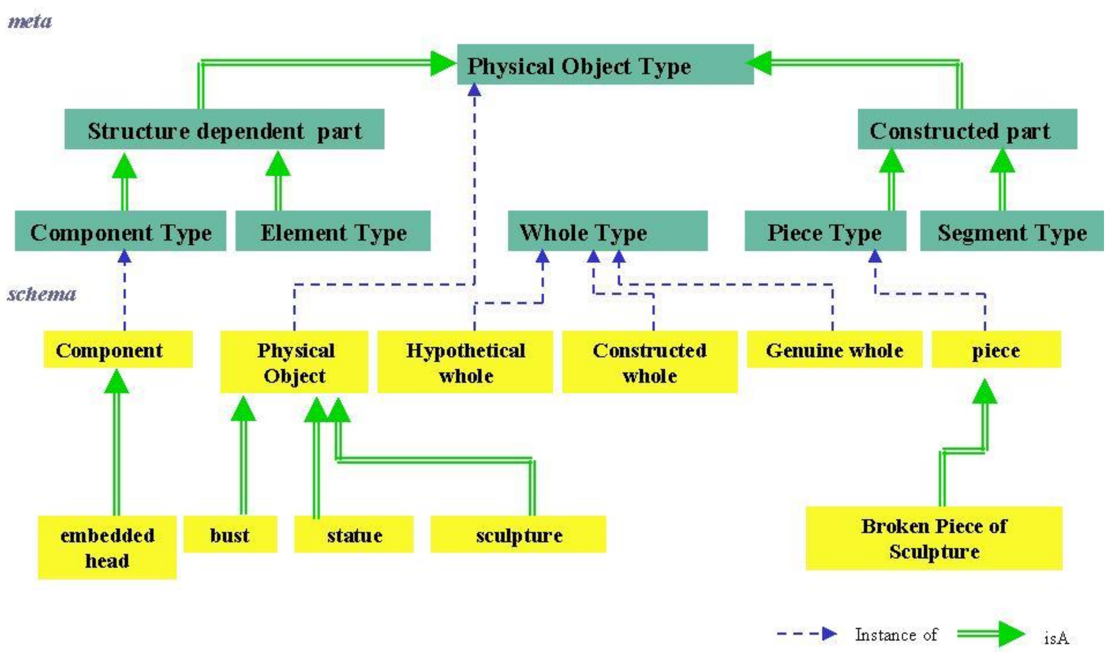

Figure 2: Entities definition

Example : documenting isolated pieces and clusters of pieces

Let us regard an example, where we want to document two isolated potsherds found in a recent excavation.

In the first stage of documentation we have registered them in a documentation system as two isolated potsherds associated with valid museum numbers “100” and “123”. We have declared them as instances to class potsherd and pottery.

After further research we found that they were adjacent on to the other, then we added the attribute *specific adjacent to* (figure 3) from potsherd100 to potsherd123 to denote the adjacency of these objects.

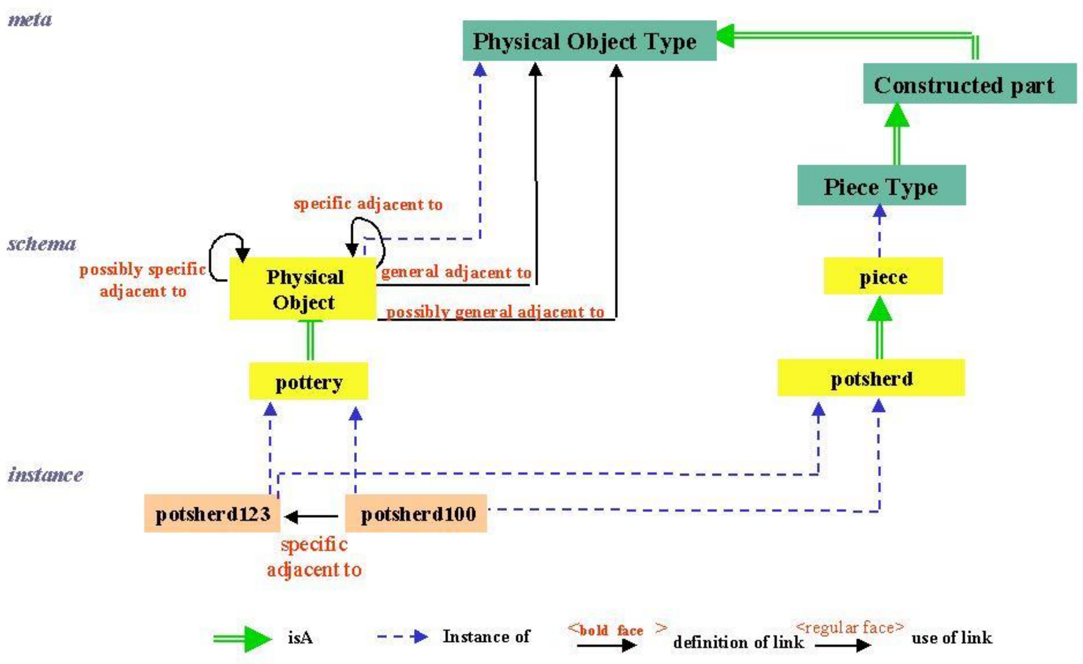

Figure 3: documenting isolated pieces and clusters of pieces

Example: Documenting hypothetical wholes

Sometimes, the whole cannot be recognized directly from the parts and we need to declare hypothetical wholes. This situation represents the third stage of documentation. For example, if we want to reason about the cup that the adjacent potsherd123 and potsherd100 were belonging to, we may add a non-counting hypothetical whole and associate it with these potsherds. Hence in figure 4 we notice the non-counting hypothetical entity **Cup100,123** at instance level, denoting the hypothetical whole of these two potsherds. The one attribute *piece of* from the **potsherd100** to **Cup100,123** is enough to denote that the cluster of these two pieces were belonging to the same Cup due to the transitivity of the property "adjacent".

Let's now regard the case where we have another cluster of adjacent potsherds (potsherd117 and potsherd158) possibly belonging to another cup or possibly belonging to the cup100,123. As shown in figure 4, we denote this situation with the use of the attributes *possibly piece of* from **potsherd117** to **Cup117,158** and from **potsherd117** to **cup100,123**.

After further research we may find that the hypothetical whole **Cup100,123** is possibly identical with the museum item **Cup1500**. We declare that by adding the attribute *possibly identical* from **Cup100,123** to **Cup1500.** This is one of the situations we referred in the beginning, where additional evidence should not invalidate. Previous information. Even if we find out, that Cup1500 is indeed identical to Cup100,123, nothing stated so far is invalid. The object count does not change. Only some attributes become superfluous. This is what we mean by a model robust against increase of knowledge. Of course this still needs to be supported by a rigid logical foundation.

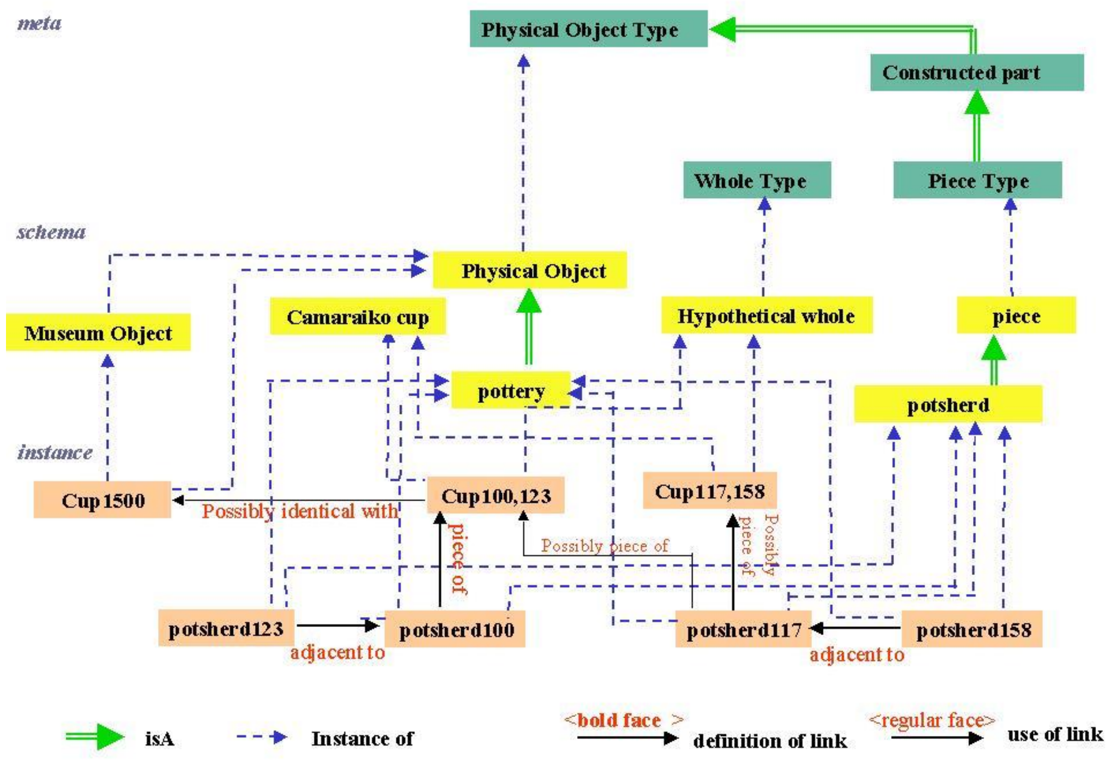

Figure 4: Documenting hypothetical wholes

Example: Documenting objects and pieces

In this case, we regard the task to document broken pieces of sculpture from the head of a bust or a statue. In the first stage of documentation we have stated that item TA64 is a broken piece of sculpture from the head of a statue or a bust. We have referred not the actual statue or bust the items TA63 or TA64 belonged to, which were unknown, but to a set of objects, from which one or more may be candidates for this connection.

The attribute “from segment” in figure 5 indicates the topology. The instantiation of TA64 under “Broken Piece of Sculpture” indicates the status of that piece. The instantiation of TA64 under Sculpture denotes the nature and the attributes “possibly general piece of” of TA64 declare the hypothesis we make.

After examination we found that this item actually was a piece of the registered statue TA63. We simply add the attribute *specific piece of* inherited from the class **Piece**, since the item TA64 is an instance of the class **Broken piece of Sculpture**, a specialization of the class **Piece**. Now the previous information is not invalid, just the attribute "possibly general piece of bust" did not become true, and the other has become superfluous.

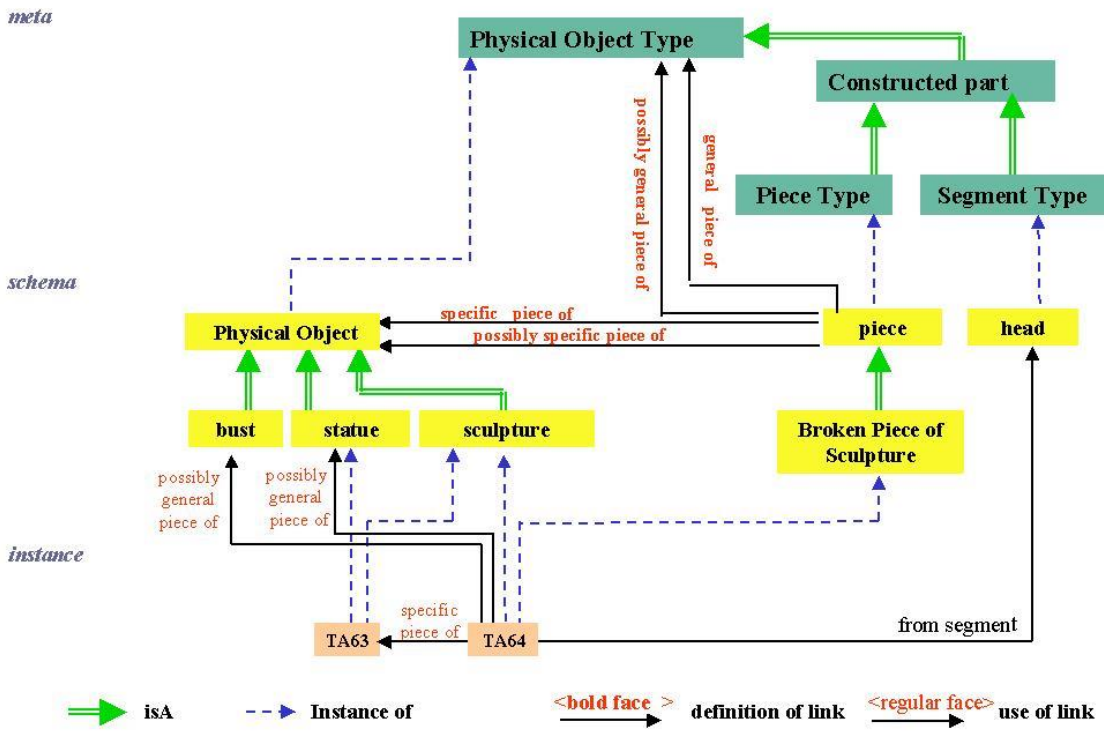

Figure 5: Documenting objects and pieces

Example: Documenting Components and Genuine wholes

In figure 6 we show the task to document a series of roman statues with embedded heads and isolated embedded heads. Embedded heads and the respective statues are **components** in our sense, as they have been constructed separately in order to be assembled in a specific way. At the first state of documentation we have denoted that Roman Statue500 is a Statue with embedded head and is a sculpture. At the same state of documentation we have declared that "embedded head600" is an embedded head.

At the second stage of documentation we found that the "Embedded head600" actually was positioned once on the Roman statue 500. Then we add the attribute "*is embedded head of*" from the entity **Embedded head600** to entity **Roman Statue 500** and we declare the **Roman statue**

500 as an *instance* of **Genuine Whole** denoting that the Roman Statue 500 has been assembled in its original form.

In figure 6, one should also notice the example of a specialization of an attribute at schema level, namely: *specific component of* into *is embedded head of* .

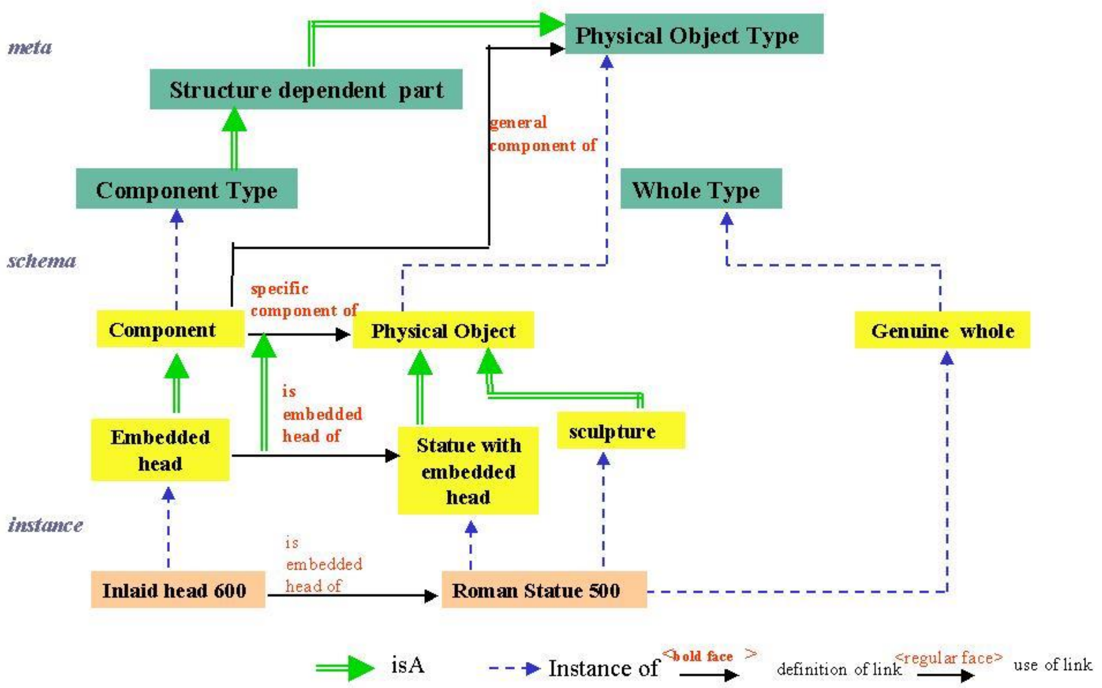

Figure 6: Documenting Components and Genuine Wholes

CONCLUSIONS

We have presented here a model, that is developed from our experience and cooperation with cultural organizations, the on-going research on mereology in Artificial Intelligence, and closely related to the emerging CIDOC CRM, where we have the pleasure to participate in the development.

In order to describe the different aspects of parthood relevant for museum objects and archeological findings, we have based our model on groups of basic attribute categories and seven basic entities. The attribute categories are:

1) modifiers to denote the level of abstraction of the reference: “general” / “specific”,

2) modifiers to denote the degree of evidence (rather than confidence!) for the reference: “possibly”/ “real”

3) attributes for the parthood role that one object plays with respect to another:

   - “piece of”
   - “component of”
   - “element of”
   - “adjacent”

These three groups are combined into the actual 16 attributes. Each group might be refined or extended. There are further two attributes to denote like items, two to refer to segments, and one attribute to relate hypothetical wholes with existing incomplete objects. These attributes are embedded into a complete logical structure of classes and metaclasses, that define explicitly all entities connected by these attributes, and the instantiation and specialization relations between the latter and to the immediately above entities of the CRM.

The new entities, the “anchors” of those attributes or relations are:

1) The parthood group, that classifies objects by their role to the whole:

   - Component
   - Element

- Piece
- Segment

2) The group of wholes, that determines the degree of evidence for a referred whole:

- Hypothetical Whole
- Constructed Whole
- Genuine Whole

These entities are organized in a suitable system of metaclasses and simple classes as described above, and these entities are regarded as root concepts for subsequent specialization.

We regard parthood in the first line as a relation, a property expressed by an attribute between two entities. However, many artificial objects are designed a priori as parts, or their current form is that of a part (e.g. piece). This introduces the necessity to define classes to characterize an isolated object as a part, as done above. To which degree a parthood relation, in particular a hypothetical one, makes any object a part in the proper sense, is debatable. E.g., is something, which is "element of" something else, always an "Element"? We have adopted this view here for simplicity, as it does not change anything in the basic reasoning.

We have illustrated in examples, how this model can be used to support basic reasoning on parts and wholes in museums and archeology. The testing of this model in a real information system in a museum is underway. We wish to express our special gratitude to the staff of the museum Benaki in Athens , Ifi Dionisiadoy & Letta Menti… for the intensive discussions in this matter. We wish to apologize in advance for our naïve understanding of the way archeologists work, and are always eager to acquire better knowledge about that.

Future work will address the formalization of the qualitative reasoning presented here, the development of suitable reasoning algorithms and queries, and their embedding into real information systems. Further, we would like to initiate with this discussion an awareness about this problem as a subject of standardization of documentation practice, such that the vision of a computer supported reasoning on lost parts and wholes across databases in many nations may become truth.

APPENDIX A

This appendix includes a formal list of the proposed notions with a reference to the CRM. (Reed, P 1995). This list describes only the additions to the CRM. For more explanatory notes see the introductory notes and comments of the CRM' s article ((Reed, P 1995).

Entity: **Component Type**
Belongs to:
Subclass of Structure Dependent Part
Superclass of
Scope Note It is a metaclass and describes all the abstract properties of components.
Properties:

Entity: **Constructed Part**
Belongs to:
Subclass of Physical_Object_Type
Superclass of Piece Type
Segment Type
Scope Note This metaclass collects all the abstract properties of parts of a whole induced by internal features or external criteria.
Properties::

Entity: **Element Type**
Belongs to:
Subclass of Structure Dependent Part
Superclass of
Scope Note It is a metaclass and describes all the abstract properties of elements.
Properties::

Entity: **Physical Object Type**
Belongs to:
Subclass of
Superclass of Structure Dependent Part
Constructed Part
Scope Note It is a metaclass. It gathers all the classes of the hierarchy describing kinds of physical objects
Properties:

Entity: **Piece Type**
Belongs to:
Subclass of Constructed Part
Superclass of
Scope Note This metaclass describes all the abstract properties of pieces.
Properties:

Entity: **Segment Type**
Belongs to:
Subclass of Constructed Part
Superclass of
Scope Note This is a metaclass collecting all the abstract properties of topological notions induced by the mental image we have about the morphology of the type of objects we regard. The analogous CIDOC notion is E45.
Properties:

Entity: **Structure dependent part**
Belongs to:
Subclass of Physical_Object_Type
Superclass of Component Type
Element Type
Scope Note This metaclass collects all abstract properties of parts of wholes which have homogeneous, uniform or heterogeneous compositional structure
Properties::

Entity: **Whole Type**
Belongs to:
Subclass of Physical Object Type
Superclass of
Scope Note This is a metaclass that collects all the kinds of wholes depending of the degree of their reality.
Properties:

The following entities belong to schema level

Entity: **Component**
Belongs to: Component Type
Subclass of
Superclass of i.e. embedded head
Scope Note This is a root class of the components hierarchy . The notions describing types of components (e.g. embedded head etc) are subclasses to this class while individual objects like embedded head600, sheath567 are instances of this class.
Properties: *specific component of : Physical object*
general component of: Physical Object Type
possibly specific component of: Physical object
possibly general component of: Physical Object Type

Entity: **Constructed Whole**
Belongs to: Whole Type
Subclass of
Superclass of
Scope Note Instances of this class are any object that has been reconstructed for exhibition, experimental or administration reasons.
Properties:

Entity: **Element**
Belongs to: Element Type
Subclass of
Superclass of
Scope Note Instances of this class are items belonging to an aggregate or a set.
Properties: *specific element of : Physical Object*
general element of: Physical Object Type
possibly specific element of : Physical Object
possibly general element of: Physical Object Type

Entity: **Genuine Whole**
Belongs to: Whole Type
Subclass of
Superclass of
Scope Note Instances of this class are anything that has come upon us in an integral or complete form, such that we regard it as one object
Properties:

Entity: **Hypothetical Whole**
Belongs to: Whole Type
Subclass of
Superclass of
Scope Note This class represents all the potential wholes. Instances of this class aren't existent museum objects and are non counting objects. Major or minor parts may exist, but the open assignment or the missing parts leave space for relative alternatives.
Properties: *possibly identical with : Physical object*

Entity: **Physical Object (E19 CRM class)**
Belongs to: Physical Object Type
Subclass of
Superclass of
Scope Note Physical object is anything existing in the material world. The notions of material world(e.g. statue, bust sculpture) are subclasses of Physical Objects, whereas individual material objects (Roman Statue500, potsherd100 etc) are instances of this class. .
Properties: *possibly general adjacent to : Physical object type*
general adjacent to : Physical object type
possibly specific adjacent to: Physical object
specific adjacent to:Physical object
possibly from the same set as : physical object
from the same set as : physical object
possibly from segment: Segment type
from segment: Segment type

Entity: **Piece**
Belongs to: Piece Type
Subclass of

Superclass of

Scope Note: Subclasses of this class are all the types of parts of an object resulting from an arbitrary mechanical subdivision of it.(e.g. Broken piece of sculpture) and instances are parts of objects which are arbitrary partitions of it like the item TA64 which is a broken piece of sculpture in figure5.

Properties:: *specific piece of: Physical Object*
general piece of: Physical Object Type
possibly specific piece of: Physical Object
possibly general piece of: Physical Object Type

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