Joint digitization of heterogeneous university collections using semantic web technologies

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Abstract

In a collaborative effort between IT and museum experts, the research project "Objekte im Netz" aims at developing a joint digitization strategy for the digital documentation of heterogeneous university collections by applying semantic web technologies. The University of Erlangen-Nuremberg owns more than 20 different scientific collections. So far, each collection has documented and stored its object data in different ways, thus making it impossible to interlink the information. The data has neither been stored in a sustainable way nor has it been reusable. In summary, the stored information is not utilized to its full potential. This is a typical scenario regarding scientific collections at universities in German-speaking countries. In order to allow consistent documentation for all collections, a data model based on ICOM's CIDOC Conceptual Reference Model is currently in development. The model uses sample data of six representative collections of the University of Erlangen-Nuremberg. In the future, this model should serve as a best practice for other university collections. This approach ensures homogenous documentation as well as long-term interpretability, and offers an opportunity to participating collections to aggregate the cross-collection information in a portal, allowing research on the objects as well as their presentation. This paper outlines the current state of the data model, the resulting application ontology, and their integration into the virtual research environment "WissKI".

1 The Research Project "Objekte im Netz"

The enormous scientific potential of university collections in Germany is presently far from being exhausted. They are often inadequately developed, difficult to access - in analog format as well as digitally - and can therefore hardly be used for research and teaching. Often, there is a lack of overarching structures, digitization know-how as well as financial and human resources. There are around 1.200 of such collections at over 80 universities in Germany, covering a wide range of objects and disciplines. [1]

In the joint project "Objekte im Netz" [2], funded by the German Federal Ministry of Education and Research [3] from March 2017 until February 2020, museum and university experts aim to jointly develop a strategy for the digital documentation of university collections, based on the heterogeneous collections of the University of Erlangen-Nuremberg (FAU). In alliance between the custodians and the computer scientists of the Germanisches Nationalmuseum [4] and the FAU, a digital infrastructure is being developed which will enable sustainable collection management and improve the collection's visibility and usability for research and teaching in the long run. For this purpose, a common documentation schema is being developed based on six out of FAU's 23 collections, taking collection-specific characteristics into

account. To make it adaptable for other university collections, it is at the same time developed as generic as possible. Furthermore, a virtual research environment is needed, where collection staff can document, store and manage information and material in a sustainable way, and which allows collaborative working as well as the support of Linked Open Data. A common portal is supposed to enable an overall presentation of and research on and across the different collections.
An essential challenge of the project lies in the uniform digital recording, connection, and presentation of these heterogeneous stocks, simultaneously taking their specific characteristics into consideration.

2 Adapting and developing Software and Tools

2.1 Ontology and Metadata Schema - the CIDOC CRM as a reference ontology

As a first step, a common metadata schema was developed from the requirements for a uniform collection-wide documentation. At the core of this schema are objects, persons, organisations, and places that are linked to each other by events, e.g. production or acquisition. The implementation of this schema is based on the event-centered reference ontology "Conceptual Reference Model" (CRM) by the Documentation Committee (CIDOC) of the International Council of Museums (ICOM) [5]. At the beginning of the project, all members decided that the binding version of the CRM should be v. 6.2.2, which is the free version closest to the ISO standard.
The CIDOC Conceptual Reference Model (CIDOC CRM) has been developed for more than a decade by experts from museums, archives, and libraries in collaboration with philosophers and computer scientists in a working group for documentation (CIDOC SIG) of the ICOM. It is a formal model that aims to represent the heterogeneous information of humanities and cultural sciences in an interdisciplinary way and to make it exchangeable. The current version 6.2 defines 89 concepts and 149 relations, each explained by a short documentation (scope note) and illustrated by examples.
Two central points distinguish the CIDOC CRM from other ontologies: On the one hand, the documentation is event-centered, which means that every step in the history of a subject - e.g. a person, a physical or a conceptual object - is described by events (e.g. birth and death of a person) and not by states (“is alive”). These events connect the documented subjects with other objects, acting persons, time and place and other information (Fig. 1.). On the other hand, the CIDOC CRM separates between things and their names. Thus the identity of a person is not determined by his or her name, whereby facts can be modeled, e.g. the identity of two people is different, but the name is identical.

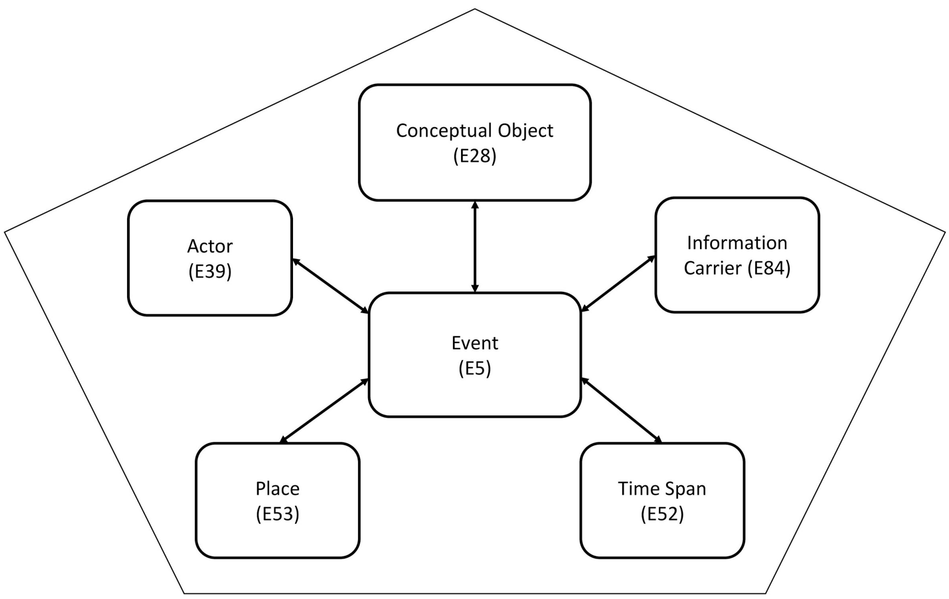


Fig. 1. Object Documentation Pattern, based on the CIDOC CRM.

The CIDOC CRM itself must, however, be implemented in a formal language that can be interpreted by computers for use in the Semantic Web, such as the Erlangen CRM [6], an implementation of the CIDOC CRM in OWL DL, a dialect of the Web Ontology Language (OWL) [7]. Erlangen CRM implements all classes and relations of the CIDOC CRM and tries to stay as close as possible to the model. It is also is the only implementation of the CIDOC CRM in OWL DL that has been maintained for several years and is recognized by the CIDOC SIG as an official implementation.

Common Application Ontology and Metadata Schema. Based on Erlangen CRM, an application ontology has been developed that contains classes and properties needed for the documentation of scientific collections, independent from the discipline they are coming from. The concept of ontology design patterns provides an excellent framework. [8]
The central entity is *S1 Collection Object*, a subclass of *E84 Information Carrier (*Scope Note: "This class comprises all instances of E22 Man-Made Object that are explicitly designed to act as persistent physical carriers for instances of E73 Information Object. [...]") [9]. Instances of *S1* are defined as objects that have been intentionally added by human activity to the inventory of a collection and are curated by one or more instances of *E39 Actor* over time. Although recent discussions have shown that *E84* should possibly be eliminated from CRM, the class is being used until a new standard is released due to the above-mentioned decision to keep modeling as close to the standard as possible and to create a stable basis for the project.
Since many objects were collected within projects and expeditions on behalf of universities themselves, such as finds by archaeological, botanical or geological departments, the class *S20 Collecting Process* was introduced as a subclass of *E7 Activity*, which corresponds to S19 Encounter Event of CRMSci. [10] The class *S20* comprises instances of an intentional action executed by an instance of the class *E39 Actor* to collect an instance of *S1 Collection Object*. The property *N23i was collected by* connects the object and the activity. E.g. the path for the documentation of the person that collected or gathered the object is:

> *samm:S1_Collection_Object -> samm:N23i_was_collected_by -> samm:S20_Collecting_Process -> ercm:P14_carried_out_by -> ecrm:E21_Person -> ecrm:P1_is_identified_by -> ecrm:E41_Appellation*

In this context, not only the question of *Who* is to be documented, but also *When* and *Where*. To document the location where a *Collecting Process* took place, the ontology distinguishes between *S40 Geographical Place* and *S39 Location*. Instances of *S40* can be referred to by gazetteers, e.g. GeoNames [11], which is the agreed upon Authority File used by the project to identify places. The class S39 *Location* comprises places that are not found in gazetteers and that are referred to by speaking titles. Instances of S39, in contrast to S40, are missing the cultural and emotional dimension of a place. [12] E.g. a specimen of the Prehistoric Collection was found close "behind the oak-tree near the creek" (*S39*), that falls within (*P89*) the municipality of Schwabthal (*S40*). *S39 Location* would also correspond to *SP2 Phenomenal Place*, and *S40 Geographical Place* to *SP6 Declarative Place* in CRMgeo. [13]

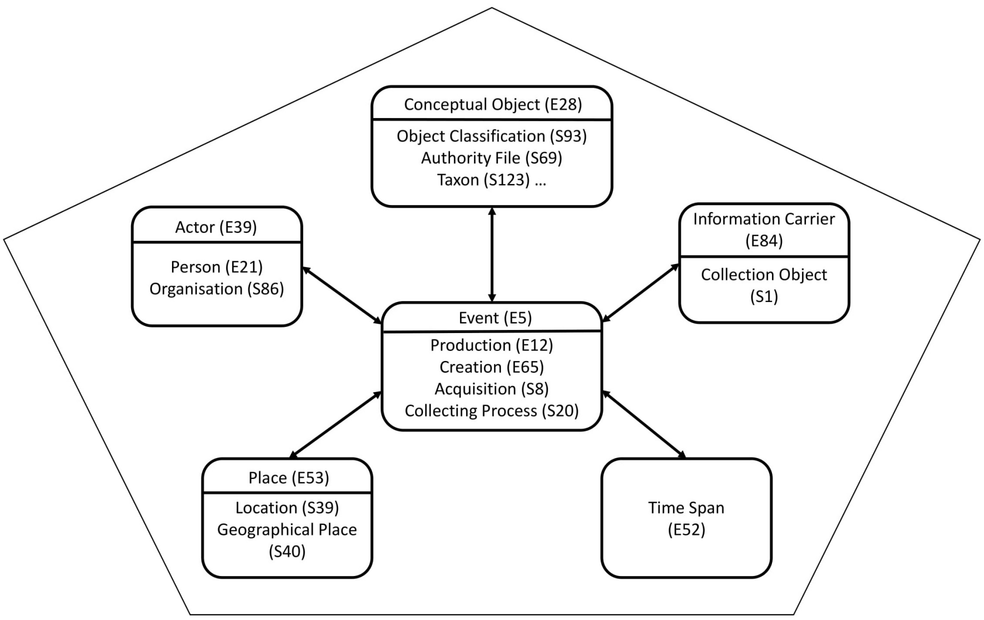


Fig. 2. Object Documentation Pattern (with a selection of classes), based on the Common Collection Ontology.

Although there are a few classes that would correspond to those from different CRM extensions, it was decided not to integrate any extensions into the common OWL-based ontology in order to keep it as lean as possible. Furthermore, all CRM extensions are only available in RDFS [14] with lower expressiveness, which would violate the agreed upon way of modeling. Also, unfortunately, a recent draft on implementing the CRM in RDF by Doerr and Light makes some suggestions which are not compatible with the actual CRM standard. [15]

In the course the documentation of the history of an object, *S20* is just one episode. Events where an object was produced (*E12 Production*), created (*E65 Creation*) or acquired (*E8 Acquisition*) and of course the actors (*E21 Person*, *S86 Organisation*), places (*S39, S40*) and time spans (*E52*) connected to them, need to be documented to enable cross-linking the information between the different collections (Fig. 2.). Not only can objects inside and outside the respective collections be filtered e.g. by equal time spans they were produced, but also objects coming from the same historical collecting-context can virtually be reconstructed, e.g. those of the collection of the Ansbach Markgraves that have been divided over the years between the various fields of knowledge [16].
Besides the documentation of the history of the objects, they also needed to be classified - according to an already existing classification system, which was merely the case - and in addition in a way users would search for an object when browsing through the digital collections. For this purpose, *S93 Object Classificatio*n, a subclass of *E55 Type*, was introduced. Types [...] "comprise concepts denoted by terms from thesauri and controlled vocabularies used to characterize and classify instances of CRM classes. Instances of E55 Type represent concepts in contrast to instances of E41 Appellation which are used to name instances of CRM classes. E55 Type is the CRM's interface to domain-specific ontologies and thesauri.[...]" [17]. Within the project, *S93* is used to develop terms for local vocabularies to classify instances of *S1 Collection Object*. Since many types of objects appear across different collections, this is one of the main characteristics that link between the heterogeneous stocks (see "Objektart" in Fig. 3). E.g. there are graphical works in the Graphical Collection, but also in the School History Collection, or in the Medical Collection.
To visualise these connections between the collections, the portal [18] is based on this common schema and therefore displays only the categories of information that all objects have in common (Fig. 3.).

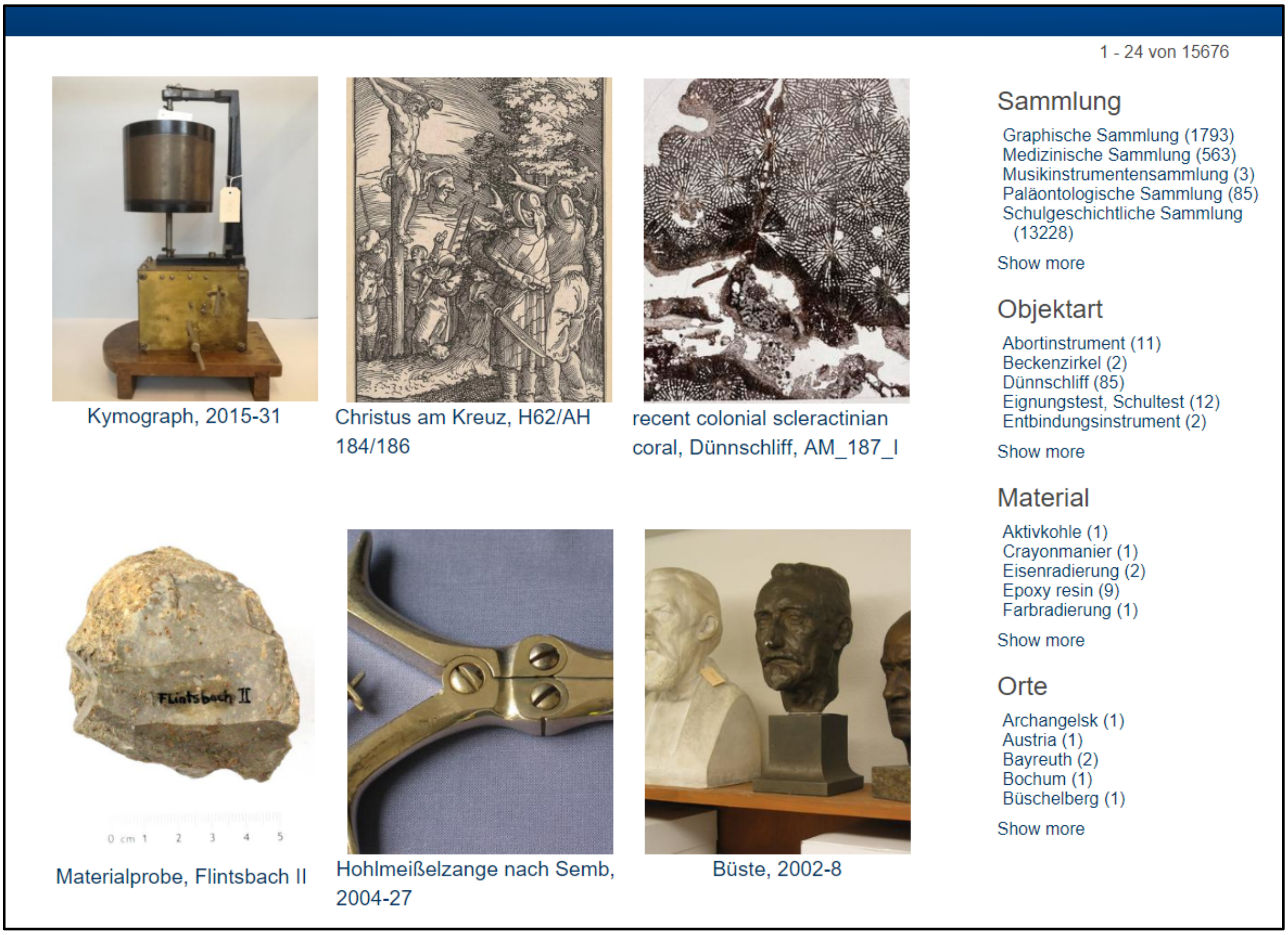


Fig. 3. Screenshot of the object overview in the beta version of the portal of the FAU's collections.

Considerations on applying the common schema - which was derived from the documentation of heterogeneous objects (some seen in Fig. 2.) - to those of natural origin can be illustrated using the example of the so called thin sections as part of the Geological Collection. Thin sections are wafer-thin polished stone samples that are applied onto a carrier in quadrangular format. By scanning or enlarging them using a slide projector, components they consist of become visible. The type, composition and orientation of components (e.g. petrified shellfish) provide information about the original

environment, climate zone or the geographical age in which the rock was formed. Thin sections have been used in teaching for decades and are made of collected samples by staff and students of the FAU's Institute of Geosciences.
The starting point of a thin section is the stone, a natural product, that was brought into existence by the event *E63 Beginning of Existence* [19] and differs in this respect from artificial products. The *Beginning of Existence* is followed in time by a *S20 Collecting Process*, where a stone sample was collected and then brought to the laboratory for further processing to thin section within an event of *E12 Production*. Until the *Collecting Process* or even until the *Production* of a thin section, the stone sample actually is just an *E18 Physical Thing* [20]. Only when a physical thing is officially assimilated to the collection on the basis of selected criteria, the thing becomes an object - or semiophor - whose materiality is extended by the dimension of meaning. [21] Nevertheless, the CIDOC CRM documents the past from today's perspective. Therefore the former physical thing is always modeled as *S1 Collection Object*, which, as subclass of *E84 Information Carrier*, is defined as man-made and designed to carry information. The fact that an instance of *S1* is based on a natural product comes to wear e.g. when there a *S20 Collecting Process* or a *E63 Beginning of Existence* is documented in context of the history of an object.

Collection Specific Ontologies and Schemas. Based on the common ontology, collection-specific ontologies were developed that consider the specific needs of the subject domain. Their top-level ontology is the common collection ontology (Fig. 4.).

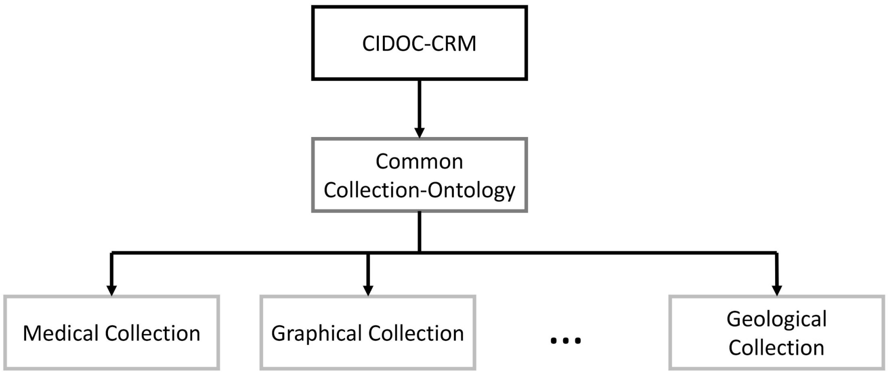


Fig. 4. Hierarchical Representation of the Ontology Structure.

Use case: The Graphical Collection. The Graphical Collection, housed at the FAU Library, owns a superb collection of drawings and prints from the middle ages to the present. This collection needs to document specifics that only concern their objects and are therefore only found in their own ontology, which also contains all classes and properties of the common ontology and those of the CIDOC CRM.
Objects of the Graphical Collection are in particular dealt with in an art-historical context. Here the attribution of an object to an artist or a workshop, the iconographic description and the stylistic classification play an important role. The vocabulary and the corresponding identifier from the Iconclass Thesaurus [22] are added to the respective work when the represented motifs are being documented.
Furthermore, a unique selling point in the data model and ontology of the Graphical Collection is, for example, the documentation of artistic influences on a work of art. Motifs were often modified, recombined or even copied. Such relationships between the representation of the object in question and other works are formulated as hypotheses and documented accordingly. As before, this takes place in context of an event. For this purpose, a subclass of *E13 Attribute Assignment* was created called *Influence Assignment*. An *Attribute Assignment* is an "[...] action[s] of making assertions about properties of an object or any relation between two items or concepts. [...]") [23]. The *Influence Assignment* is more specific and refers to the action of making assertions about artistic influences on a work of art. The *Influence Assignment* is recorded in the context of an *E12 Production* and connected to it by the property *recorded influence upon*, an inverse subproperty of *P140 was attributed by*.

The semantic path of a person, that influenced the production of an object is:

> *samm:S1_Collection_Object -> ecrm:P108i_was_produced_by -> ecrm:E12_Production -> samm:influence_was_recorded_by -> samm:Influence_Assignment -> samm:recorded_influenced_by_actor-> ecrm:E21_Person -> ecrm:P1_is_identified_by -> ecrm:E41_Appellation*

Also, the *Type of Influence,* a subclass of *E55 Type*, an artist had on the *Production* of an object from the Graphical Collection is being documented. In this case, a local vocabulary was developed to express and document the different influences in a standardized way, e.g. "copy after" when a work is a one-to-one copy after the work of a certain artist.

Besides the development of the common and specific metadata categories, rules for the data input for each field were established. The definition of object characteristics needs to go hand in hand with the documentation guidelines, e.g. the appropriation form of names, standardized date-formats or local vocabularies for e.g. Instances of *S93 Object Classification*.

2.2 The virtual research environment "WissKI" (Scientific Communication Infrastructure)

The central tool for documentation, interconnection and presentation of object information is the scientific communication infrastructure "WissKI" [24]. WissKI is geared towards the requirements of cooperative research in the field of cultural heritage and its digital documentation. [25] Published as open source [26], it can be used and extended accordingly. Within the project, the software had to be adapted to the specific requirements of the project and university collections.
Based on the open source content management system Drupal [27], WissKI expands the ideas and concepts of the Wiki into a web-based virtual research environment that focuses on the interests and peculiarities of research and documentation in the domain of cultural heritage. The system relies on open data formats and standards that ensure the long-term preservation of the managed data. For this purpose WissKI utilizes mechanisms of Linked Open Data and the Semantic Web.
Furthermore, the software enables interlinking a wide variety of complex information on the objects as well as other digital resources from which new research questions and considerable knowledge potential can arise. As research environment, WissKI aims to support the whole research lifecycle, beginning with acquisition and creation of information, to analysis, preservation, publishing, and access, up to their re-use.

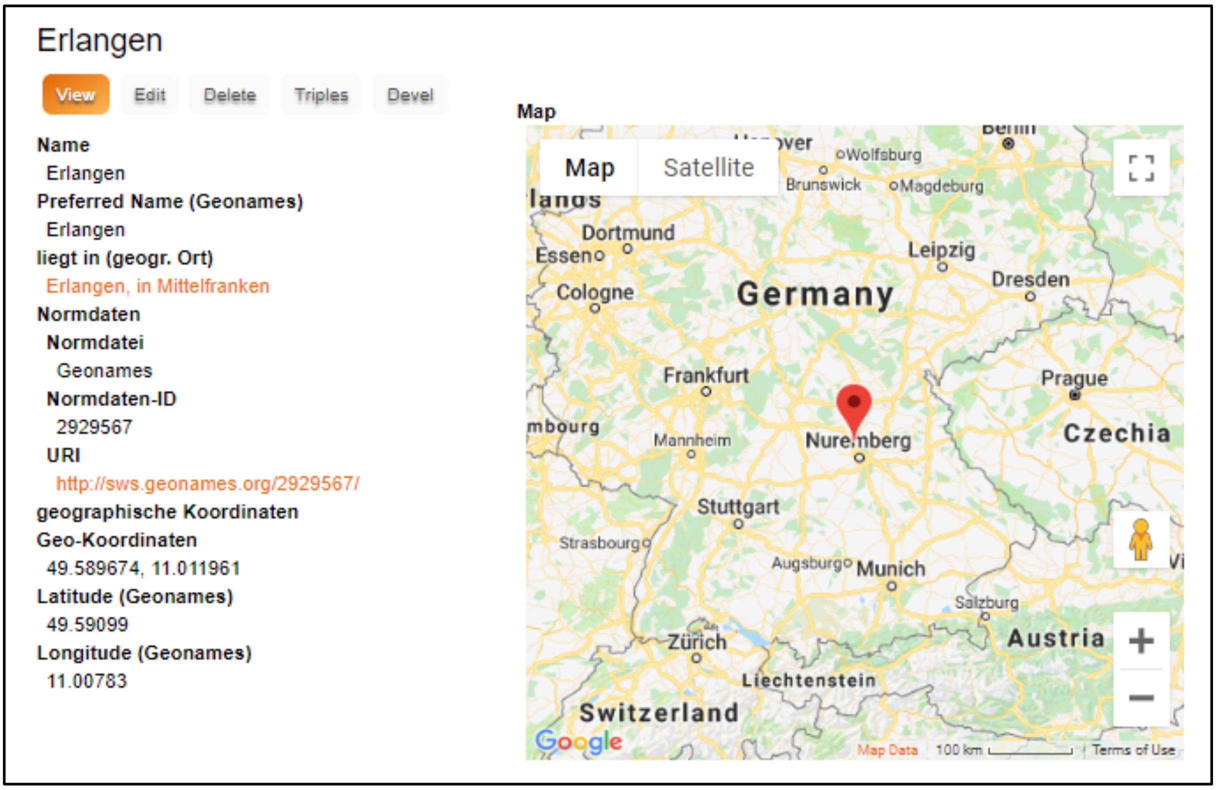


Fig. 5. Integration of GeoNames-Data in WissKI via SPARQL 1.1 GeoNames-Adapter.

Also, the system enables the integration of global as well as the development of local authority data to support the uniform collection and referencing of (research) data inside and outside the collections of the FAU. Within the project "Objekte im Netz", location data is enriched with information from GeoNames (Fig. 5.), person and corporate data are enriched with information from the Common Authority File (GND) of the German National Library [28]. For this purpose, SPARQL 1.1 [29] adapters were developed. [30]

In addition to the simple provision and open availability of source materials - structured texts, graphics, images, video, audio, and metadata in digital form - the focus of the system is also on interactive and collaborative work based on semantically enriched documentation.
The current version of the WissKI software is based on the current stable version of Drupal (Drupal 8). The functionality of Drupal can be extended and modified by third-party modules. The WissKI system is accordingly a set of modules subdivided into logical units each of which brings encapsulated functionality into the system (Fig. 6.). The modules are fully compatible to the Drupal core so that all common features, such as user control with detailed rights management or the creation of websites, are retained.

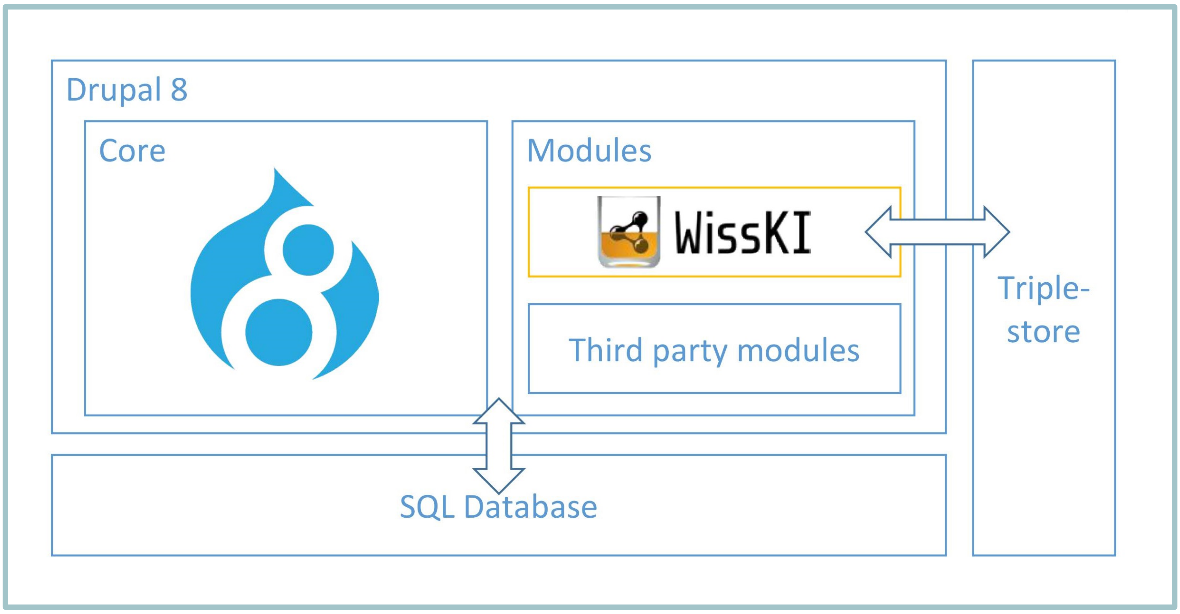


Fig. 6. WissKI System Architecture.

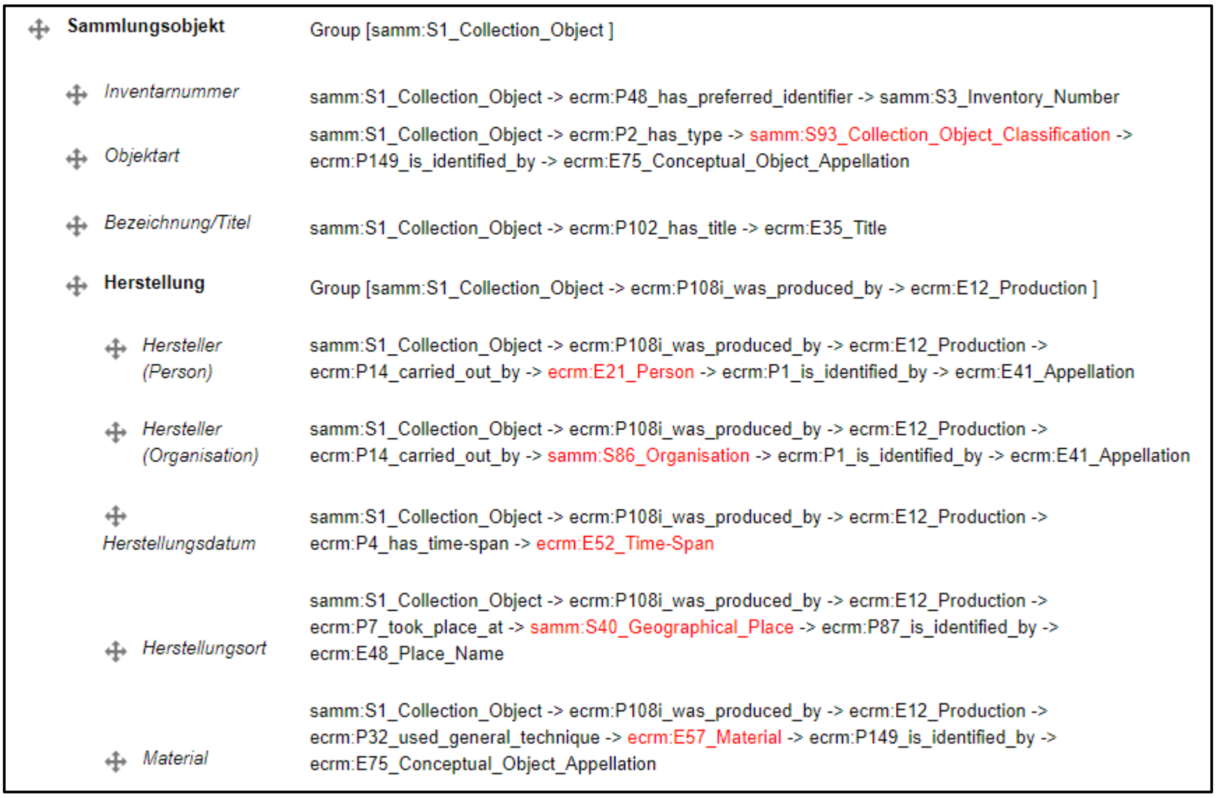
The central component of the system is the so-called Pathbuilder (Fig. 7.) which supports the system administrator in creating paths using an ontology. [30] A path is a concatenation of n concepts and n-1 relations between the concepts. When storing data using a path, first an individual is created for each concept. The resulting individuals are then connected to each other by the relations according to the specifications of the path. At the end of such a path in WissKI there is always a relation to a primitive data type, e.g. *P3 has note*, in which the actual input is stored, e.g. for the producer of an object (see "Hersteller (Person)" in Fig. 7.) the path - in the context of the project - is:

> *samm:S1_Collection_Object -> ecrm:P108i_was_produced_by -> ecrm:E12_Production -> ecrm:P14_carried_out_by -> ecrm:E21_Person-> ecrm:P1_is_identified_by -> ecrm:E41_Appellation -> P3_has_note -> "Dürer, Albrecht"*

For the storage of several inputs on the same subject, paths can be combined in groups which define the common part of all paths belonging to it, e.g. the group for all paths that concern the production (see "Herstellung" in Fig. 7.) of an object is:

> *samm:S1_Collection_Object -> ecrm:P108i_was_produced_by -> ecrm:E12_Production*

The Pathbuilder forms an intermediate layer between the triplestore, here GraphDB [32], with the data stored as triples on the one hand, and Drupal with the data storage on the basis of entity types, bundles, entities and fields on the other. It creates a mapping of groups and subgroups in the Pathbuilder to bundles and referenced bundles in Drupal and paths to data fields. This mechanism hides the full complexity of the Semantic Web approach and of the CIDOC CRM from the actual user, who only has to fill in forms.
The system offers the possibility to load any OWL-based ontology. When creating paths based on an ontology, the system can assist the administrator by calculating the concepts and relations possible for each step (based on domain and range). In order to use this approach, WissKI defines and implements its own storage interface that supports loading from and writing to any data source, so-called engines, and prepares the data for Drupal in the usual way according to the Pathbuilder's specifications. All mechanisms provided by Drupal can be used to display, edit and manage entities. WissKI comes with a storage interface for Triplestores based on SPARQL 1.1.



Sammlungsobjekt	Group [samm:S1_Collection_Object]
Inventarnummer	samm:S1_Collection_Object -> ecrm:P48_has_preferred_identifier -> samm:S3_Inventory_Number
Objektart	samm:S1_Collection_Object -> ecrm:P2_has_type -> samm:S93_Collection_Object_Classification -> ecrm:P149_is_identified_by -> ecrm:E75_Conceptual_Object_Appellation
Bezeichnung/Titel	samm:S1_Collection_Object -> ecrm:P102_has_title -> ecrm:E35_Title
Herstellung	Group [samm:S1_Collection_Object -> ecrm:P108i_was_produced_by -> ecrm:E12_Production]
Hersteller (Person)	samm:S1_Collection_Object -> ecrm:P108i_was_produced_by -> ecrm:E12_Production -> ecrm:P14_carried_out_by -> ecrm:E21_Person -> ecrm:P1_is_identified_by -> ecrm:E41_Appellation
Hersteller (Organisation)	samm:S1_Collection_Object -> ecrm:P108i_was_produced_by -> ecrm:E12_Production -> ecrm:P14_carried_out_by -> samm:S86_Organisation -> ecrm:P1_is_identified_by -> ecrm:E41_Appellation
Herstellungsdatum	samm:S1_Collection_Object -> ecrm:P108i_was_produced_by -> ecrm:E12_Production -> ecrm:P4_has_time-span -> ecrm:E52_Time-Span
Herstellungsort	samm:S1_Collection_Object -> ecrm:P108i_was_produced_by -> ecrm:E12_Production -> ecrm:P7_took_place_at -> samm:S40_Geographical_Place -> ecrm:P87_is_identified_by -> ecrm:E48_Place_Name
Material	samm:S1_Collection_Object -> ecrm:P108i_was_produced_by -> ecrm:E12_Production -> ecrm:P32_used_general_technique -> ecrm:E57_Material -> ecrm:P149_is_identified_by -> ecrm:E75_Conceptual_Object_Appellation

Fig. 7. Screenshot of the Pathbuilder with a detail of the Common Metadata Schema of Objekte im Netz.

Using WissKI for single systems and the collection portal of the FAU. In the context of the project, WissKI plays a central role in several areas. Each collection uses its own WissKI instance to document and manage its holdings. These collection-specific systems are equipped with the common data entry schema and additionally contain fields in which the subject-specifics are entered, cf. the example of the Graphical Collection. Accordingly, the subject-specific ontology used to model the paths is also loaded in these systems.

The portal, in which all collections and their objects are presented together, also uses WissKI. It acquires the data through SPARQL 1.1 adapters from the triplestore repositories of all individual systems (Fig. 8.). Here the data is only displayed and not editable. In contrast to the individual systems, the portal is equipped with the common collection schema and ontology only. This way, only the common information on the objects can be seen and searched in the portal. A link to the individual system is set at the object level, where the user gets the subject-specific information.

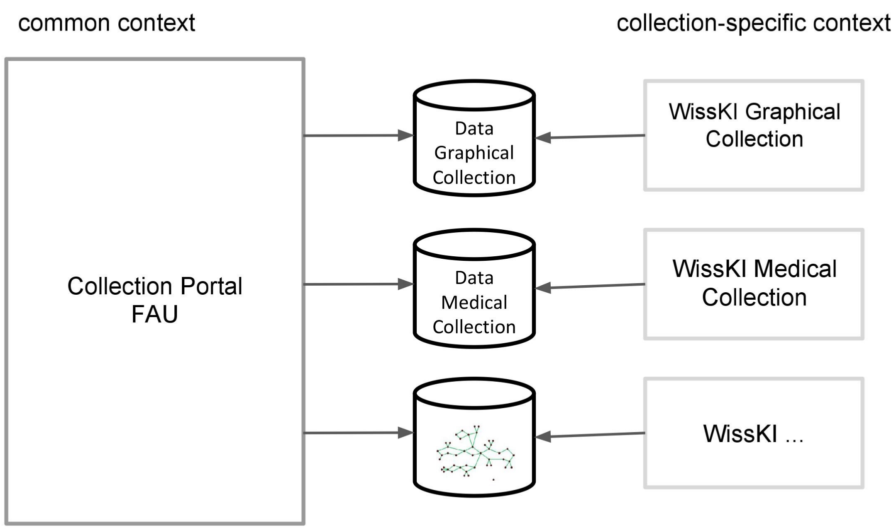


Fig. 8. The dataflow between the single systems and the portal.

3 Conclusion

The main goal of the project is to develop and adapt open source software and tools for digital data- and collection-management of scientific collections to improve their visibility and usability for research and teaching in the long term. Results are already available in the download section of the “Objekte im Netz” project website [33]. Tutorials, recommendations for working with digital collections as well as manuals for the use of the tools complete these results in order to anchor the knowledge gained in the project in the collections. For the development of a digitization strategy, software, the generated data, knowledge, and the technical infrastructure should be designed and embedded as sustainable as possible.

There are different challenges regarding the sustainability of tools and data developed within the project and especially after its end. First of all, there are concerns regarding the sustainability of the technical infrastructure. As a web-based system, WissKI and all connected software must be installed on a server and maintained continuously. Mechanisms for regular backups and mirroring of data can ensure that no data is lost in the event of technical failures. All of this requires manpower and particular knowledge.

Second, sustainable staff infrastructure is crucial, as the systems need to be maintained by the administrator, e.g. in case the modeling of additional semantic paths and the configuration of fields is necessary. Considering the virtual infrastructures as tools for efficient collection management, object data must be continuously entered and curated. If the collections - in this specific case, but also in general - do not have permanent staff resources in this area, sustainable data maintenance cannot be provided either.

The most important point is the sustainability of the data itself, stressing the long-term-interpretability of data in particular. To document the project data, coming from different collections and their disciplines, in a common context using a common "language", application-ontologies based on the CIDOC CRM are developed for the collections. Since 2006 the CIDOC CRM is ISO-certified (ISO 21127), by using it as a top-level ontology, not only exchangeability and accordingly also reusability of the data is ensured. This semantic and standardized enrichment of data ensures that they remain interpretable in a long term [34].

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