



BSI Standards Publication

Information and documentation — A reference ontology for the interchange of cultural heritage information

National foreword

This British Standard is the UK implementation of [ISO 21127:2023](#). It supersedes [BS ISO 21127:2014](#), which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee IDT/2, Information and documentation.

A list of organizations represented on this committee can be obtained on request to its committee manager.

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Information and documentation — A reference ontology for the interchange of cultural heritage information

*Information et documentation — Une ontologie de référence pour
l'échange d'informations du patrimoine culturel*



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Contents

Page

Foreword	iv
Introduction	v
1 Scope	1
2 Normative references	1
3 Terms and definitions	1
4 Objectives	9
5 Compatibility	10
6 Applied form	10
6.1 General	10
6.2 Naming conventions	11
6.3 Inheritance and transitivity	12
6.4 Shortcuts	12
6.5 Logical expressions used in ISO 21127	12
6.6 Property quantifiers	14
7 Modelling principles	15
7.1 Reality, knowledge bases and ISO 21127	15
7.2 Authorship of knowledge base (KB) contents	17
7.3 Extensions	17
7.4 Minimality	19
7.5 Monotonicity	20
7.5.1 Open World principle	20
7.5.2 Monotonicity of the document	20
7.5.3 Monotonicity of the data	21
7.5.4 Monotonicity of the knowledge base	21
7.5.5 Monotonicity and time-dependent properties	21
7.6 Disjointness	22
8 Introduction to the basic concepts	22
8.1 General	22
8.2 Relations with events	24
8.2.1 General	24
8.2.2 Spatial relations	27
8.2.3 Temporal relations	29
8.2.4 Spatiotemporal relations	31
8.3 Specific modelling constructs	33
8.3.1 Types	33
8.3.2 Temporal relation primitives based on fuzzy boundaries	34
9 Class declarations	37
10 Property declarations	91
Annex A (informative) Scope precision — Intended scope	175
Annex B (informative) Deprecated classes and properties	176
Bibliography	179

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

ISO draws attention to the possibility that the implementation of this document may involve the use of (a) patent(s). ISO takes no position concerning the evidence, validity or applicability of any claimed patent rights in respect thereof. As of the date of publication of this document, ISO had not received notice of (a) patent(s) which may be required to implement this document. However, implementers are cautioned that this may not represent the latest information, which may be obtained from the patent database available at www.iso.org/patents. ISO shall not be held responsible for identifying any or all such patent rights.

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 46, *Information and documentation*, Subcommittee SC 4, *Technical interoperability*, in collaboration with the International Committee for Documentation (CIDOC).

This third edition cancels and replaces the second edition ([ISO 21127:2014](http://www.iso.org/iso/21127:2014)), which has been technically revised.

The main changes are as follows:

- deprecated 13 overspecialised classes and 15 overspecialized properties;
- added 8 properties to replace 8 deprecated properties in order to support chronological reasoning;
- added 4 (sub)classes and 17 properties to align with OCG standards for geospatial data;
- added 4 (sub)classes and 12 properties for more detailed conceptualizations of existing concepts;
- provided further clarification of concepts through the addition real-life examples, references, and first order logic axioms;
- extended explanatory introductory sections to clarify the standard and its maintained scope.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document is the culmination of more than a decade of standards development work by the International Committee for Documentation (CIDOC) of the International Council of Museums (ICOM). Work on this document began in 1996 under the auspices of the ICOM-CIDOC Documentation Standards Working Group. The document¹⁾ provided by CIDOC formed the basis for [ISO 21127](#) which was first published in 2006. While the initial impetus for the work came from the museum community, it has since spread to encompass other types of cultural heritage institution. This document has been appropriated and extended to meet the needs of other institutions dealing with cultural heritage.

The primary purpose of this document is to offer a conceptual basis for the integration, mediation, and exchange of information between cultural heritage organizations such as museums, libraries, and archives. This document aims to provide a common reference point against which divergent and incompatible sources of information can be compared and, ultimately, harmonized.

[ISO 21127](#) is an ontology²⁾ for cultural heritage information: a formal representation of the conceptual scheme, or “world view”, underlying the database applications and documentation systems that are used by cultural heritage institutions. It is important to note that this document aims to clarify the logic of what cultural heritage institutions do in fact document; it is not intended as a normative specification of what they should document. The primary role of this document is to enable information exchange and integration between heterogeneous sources of cultural heritage information. It aims to provide the semantic definitions and clarifications needed to transform disparate, localized information sources into a coherent global resource, be it within an institution, an intranet, or on the Internet.

The specific aims of this document are to:

- serve as a common language for domain experts and IT developers when formulating requirements;
- serve as a formal language for the identification of common information contents in different data formats; in particular to support the implementation of automatic data transformation algorithms from local to global data structures without loss of meaning. These transformation algorithms are useful for data exchange, data migration from legacy systems, data information integration, and mediation of heterogeneous sources;
- support associative queries against integrated resources by providing a global model of the basic classes and their associations to formulate such queries; and
- provide developers of information systems with a guide to good practice in conceptual modelling.

The [ISO 21127](#) ontology is expressed as a series of interrelated concepts with definitions. This presentation is similar to that used for a thesaurus. However, the ontology is not intended as a terminology standard and does not set out to define the terms that are typically used as data in cultural heritage documentation. Although the presentation provided here is complete, it is an intentionally compact and concise presentation of the ontology's 81 classes and 160 unique properties. It does not attempt to articulate the inheritance of properties by subclasses throughout the class hierarchy. However, this definition does contain all the information needed to infer and automatically generate a full declaration of all properties, including inherited properties.³⁾

1) The CIDOC CRM Special Interest Group continues to maintain a version of this original document, usually known as the “CIDOC Conceptual Reference Model” or CIDOC CRM[\[15\]](#).

2) In the sense used in computer science, i.e. it describes in a formal language the relevant explicit and implicit concepts and the relationships between them.

3) A class and property reference hierarchy can be found in Reference [\[15\]](#).

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Information and documentation — A reference ontology for the interchange of cultural heritage information

1 Scope

This document gives a curated, factual knowledge about the past at a human scale. It specifies all information required for the exchange and integration of heterogeneous scientific and scholarly documentation about the past at a human scale and the available documented and empirical evidence for this.⁴⁾

A more detailed and useful definition can be articulated by defining both the intended scope, a broad and maximally-inclusive definition of general application principles, and the practical scope, which is expressed by the overall scope of a growing reference set of specific, identifiable documentation standards and practices that this document aims to semantically describe, restricted, always, in its details to the limitations of the intended scope.

The practical scope⁵⁾ of this document is expressed in terms of the set of reference standards and de facto standards for documenting factual knowledge. This document covers the same domain of discourse as the union of these reference standards; this means that for data correctly encoded according to these documentation formats there can be an ISO 21127-compatible expression that conveys the same meaning.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

4) [Annex A](#) elaborates on this definition.

5) The practical scope of [ISO 21127](#), including a list of the relevant museum documentation standards, is discussed in more detail on the CIDOC CRM website at < <https://cidoc-crm.org/scope> >.

3.1 class

category of items that share one or more common traits serving as criteria to identify the items belonging to the class

Note 1 to entry: These properties need not be explicitly formulated in logical terms, but may be described in a text (here called a scope note) that refers to a common conceptualisation of domain experts. The sum of these traits is called the intension of the class. A class may be the domain or range of none, one or more properties formally defined in a model. The formally defined properties need not be part of the intension of their domains or ranges: such properties are optional. An item that belongs to a class is called an instance of this class. A class is associated with an open set of real-life instances, known as the extension of the class. Here “open” is used in the sense that it is generally beyond our capabilities to know all instances of a class in the world and indeed that the future may bring new instances about at any time (Open World). Therefore, a class cannot be defined by enumerating its instances. A class plays a role analogous to a grammatical noun, and can be completely defined without reference to any other construct (unlike properties, which shall have an unambiguously defined domain and range). In some contexts, the terms individual class, entity or node are used synonymously with class. For example, “Person” is a class. To be a “Person” may actually be determined by DNA characteristics, but everyone knows what a “Person” is. A “Person” may have the property of being a member of a “Group”, but it is not necessary to be member of a “Group” in order to be a “Person”. It is impossible to know all the “Persons” of the past. There will be more “Person” in the future.

3.2 complement

<of class A with respect to one of its superclasses B> set of all instances of B that are not instances of A

Note 1 to entry: Formally, it is the set-theoretic difference of the extension of B minus the extension of A. Compatible extensions of the CIDOC CRM should not declare any class with the intension of them being the complement of one or more other classes. To do so will normally violate the desire to describe an Open World. For example, for all possible cases of human gender, male should not be declared as the complement of female or vice versa. What if someone is both or even of another kind?

3.3 disjoint

having no common *instances* ([3.8](#)) in any possible world

Note 1 to entry: Classes are disjoint if the intersection of their extensions is an empty set.

3.4 domain

class ([3.1](#)) for which a property is formally defined

Note 1 to entry: This means that instances of the property are applicable to instances of its domain class. A property shall have exactly one domain, although the domain class may always contain instances for which the property is not instantiated. The domain class is analogous to the grammatical subject of the phrase for which the property is analogous to the verb. It is arbitrary which class is selected as the domain and which as the range, just as the choice between active and passive voice in grammar is arbitrary. Property names in this document are designed to be semantically meaningful and grammatically correct when read from domain to range. In addition, the inverse property name, normally given in parentheses, is also designed to be semantically meaningful and grammatically correct when read from range to domain.

3.5 endurant

entities which are wholly present at any time they are present

Note 1 to entry: See Reference [\[87\]](#), pp. 166-181.

3.6 extension

set of all real-life instances belonging to the class that fulfil the criteria of its *intension* (3.9)

Note 1 to entry: The extension of a class is “open” in the sense that it is generally beyond our capabilities to know all instances of a class in the world and indeed that the future may bring new instances about at any time (Open World). An information system may at any point in time refer to some instances of a class, which form a subset of its extension.

3.7 inheritance

duplication of properties from a class to its subclasses

Note 1 to entry: Inheritance of properties from superclasses to subclasses means that if an item *x* is an instance of a class *A*, then all properties that shall hold for the instances of any of the superclasses of *A* shall also hold for item *x*, and that all optional properties that may hold for the instances of any of the superclasses of *A* may also hold for item *x*.

3.8 instance

items having properties that meet the criteria of the *intension* (3.9) of the classes

Note 1 to entry: The number of instances declared for a class in an information system is typically less than the total in the real world. For example, the reader is an instance of Person, but they are not mentioned in all information systems describing Persons.

Note 2 to entry: For example, the painting known as the “The Mona Lisa” is an instance of the class E22 Human-Made Object. An instance of a property is a factual relation between an instance of the domain and an instance of the range of the property that matches the criteria of the intension of the property. For example, “The Mona Lisa” *has former or current owner*. The Louvre is an instance of the property *P51 has former or current owner (is former or current owner of)*.

3.9 intension

intended meaning of a class

Note 1 to entry: The intension of a class consists of one or more common traits shared by all instances of the class or property. These traits need not be explicitly formulated in logical terms, but may just be described in a text (here called a scope note) that refers to a conceptualisation common to domain experts.

3.10 interoperability

capability of different information systems to communicate some of their contents

Note 1 to entry: Interoperability may mean that two systems can exchange information, and/or that multiple systems can be accessed with a single method.

Note 2 to entry: Generally, syntactic interoperability is distinguished from semantic interoperability. Syntactic interoperability means that the information encoding of the involved systems and the access protocols are compatible, so that information can be processed as described above without error. However, this does not mean that each system processes the data in a manner consistent with the intended meaning. For example, one system may use a table called “Actor” and another one called “Agent”. With syntactic interoperability, data from both tables may only be retrieved as distinct, even though they may have exactly the same meaning. To overcome this situation, semantic interoperability has to be added. This document relies on existing syntactic interoperability and is concerned only with adding *semantic interoperability* (3.24).

3.11

inverse of

reinterpretation of a property from range to domain without more general or more specific meaning

Note 1 to entry: The inverse of a property is similar to the choice between active and passive voice in some languages. In contrast to some knowledge representation languages, such as RDF and OWL, this document regards that the inverse of a property is not a property in its own right that needs an explicit declaration of being inverse of another, but an interpretation implicitly existing for any property. The inverse of the inverse of a property is identical to the property itself, i.e. its primary sense of direction. For example, “Entity *is depicted by* Physical Human-Made Thing” is the inverse of “Physical Human-Made Thing *depicts* Entity”.

3.12

knowledge creation event

organized transfer of knowledge of a group of domain experts into an information system under preservation of the relationship between those regarding the created content as representing their knowledge and the knowledge itself

Note 1 to entry: All knowledge contained in an information system must have been introduced into that system by some human agent, either directly or indirectly. Despite this fact, many, if not most, statements within such a system will lack specific attribution of authority. That being said, in the domain of cultural heritage, it is common practice that, for the processes of collection documentation and management, there are clearly and explicitly elaborated systems of responsibility outlining by whom and how knowledge can be added and or modified in the system. Ideally these systems are specified in institutional policy and protocol documents. Thus, it is reasonable to hold that all such statements that lack explicit authority attribution within the information system can, in fact, be read as the official view of the administering institution of that system. Such a position does not mean to imply that an information system represents at any particular moment a completed phase of knowledge that the institution promotes. Rather, it means to underline that, in a CH context, a managed set of data, at any state of elaboration, will in fact embody an adherence to some explicit code of standards which guarantees the validity of that data within the scope of said standards and all practical limitations. So long as the information is under active management it remains continuously open to revision and improvement as further research reveals further understanding surrounding the objects of concern. A distinct exception to this rule is represented by information in the data set that carries with it an explicit statement of responsibility.

Note 2 to entry: In this document, such statements of responsibility are expressed through knowledge creation events such as E13 Attribute Assignment and its relevant subclasses. Any information in a model using this document that is based on an explicit creation event for that piece of information, where the creator's identity has been given, is attributed to the authority and assigned to the responsibility of the actor identified as causal in that event. For any information in the system connected to knowledge creation events that do not explicitly reference their creator, as well as any information not connected to creation events, the responsibility falls back to the institution responsible for the database/knowledge graph. That means that for information only expressed through shortcuts such as *P2 has type*, where no knowledge creation event has been explicitly specified, the originating creation event cannot be deduced and the responsibility for the information can never be any other body than the institution responsible for the whole information system. In the case of an institution taking over stewardship of a database transferred into their custody, two relations of responsibility for the knowledge therein can be envisioned. If the institution accepts the dataset and undertakes to maintain and update it, then they take on responsibility for that information and become the default authority behind its statements as described above. If, on the other hand, the institution accepts the data set and stores it without change as a closed resource, then it can be considered that the default authority remains the original steward.

3.13

monotonic

<of a knowledge base> having a set of conclusions derived through inference rules that does not reduce, irrespective of whatever additional propositions can be inserted

Note 1 to entry: Monotonic reasoning is a term from knowledge representation. A reasoning form is monotonic if an addition to the set of propositions making up the knowledge base never determines a decrement in the set of conclusions that may be derived from the knowledge base via inference rules. In practical terms, if experts enter subsequently correct statements to an information system, the system should not regard any results from those statements as invalid, when a new one is entered. The [ISO 21127](#) ontology is designed for monotonic reasoning and so enables conflict-free merging of huge stores of knowledge.

3.14 multiple inheritance

possibility for a class to have more than one immediate superclass

Note 1 to entry: The extension of a class with multiple immediate superclasses is a subset of the intersection of all extensions of its superclasses. The intension of a class with multiple immediate superclasses extends the intensions of all its superclasses, i.e. its traits are more restrictive than any of its superclasses. If multiple inheritance is used, the resulting “class hierarchy” is a directed graph and not a tree structure. If it is represented as an indented list, there are necessarily repetitions of the same class at different positions in the list. For example, Person is both an Actor and a Biological Object.

3.15 multiple instantiation

case that an instance of class A is also regarded as an instance of one or more other classes B1...n

Note 1 to entry: When multiple instantiation is used, it has the effect that the properties of all these classes become available to describe this instance. For instance, some particular cases of destruction may also be activities (e.g. Herostratos’ deed), but not all destructions are activities (e.g. destruction of Herculaneum). In comparison, multiple inheritance describes the case that all instances of a class A are implicitly instances of all superclasses of A, by virtue of the definition of the class A, whereas the combination of classes used for multiple instantiation is a characteristic of particular instances only. It is important to note that multiple instantiation is not allowed using combinations of disjoint classes.

3.16 open world

assumption that the information stored in a knowledge base is incomplete with respect to the universe of discourse it aims to describe

Note 1 to entry: The “open world assumption” is a term from knowledge base systems. This incompleteness may be due to the inability of the maintainer to provide sufficient information or due to more fundamental problems of cognition in the system’s domain. Such problems are characteristic of cultural information systems. Our records about the past are necessarily incomplete. In addition, there may be items that cannot be clearly assigned to a given class. In particular, absence of a certain property for an item described in the system does not mean that this item does not have this property. For example, if one item is described as Biological Object and another as Physical Object, this does not imply that the latter may not be a Biological Object as well. For example, one cannot list “all Physical Objects known to the system that are not Biological Objects in the real world”, but one may of course list “all items known to the system as Physical Objects but that are not known to the system as Biological Objects”. Therefore, complements of a class with respect to a superclass cannot be concluded in general from an information system using the open world assumption.

3.17 perdurant

entities which extend in time

Note 1 to entry: “The difference between enduring and perduring entities (referred to in this document as *endurants* (3.5) and *perdurants* (3.17)) is related to their behaviour in time. Endurants are wholly present (i.e. all their proper parts are present) at any time they are present. Perdurants, on the other hand, just extend in time by accumulating different temporal parts, so that, at any time they are present, they are only partially present, in the sense that some of their proper temporal parts (e.g. their previous or future phases) may be not present. For example, the piece of paper the reader is reading now is wholly present, while some temporal parts of their reading are not present any more. Philosophers say that endurants are entities that are in time, while lacking however temporal parts (so to speak, all their parts flow with them in time). Perdurants, on the other hand, are entities that happen in time, and can have temporal parts (all their parts are fixed in time).” (Reference [87], pp. 166-181).

3.18

property

named characteristic of a class to which values can be assigned

Note 1 to entry: A property serves to define a relationship of a specific kind between two classes. The property is characterized by an intension, which is conveyed by a scope note. A property plays a role analogous to a grammatical verb, in that it shall be defined with reference to both its domain and range, which are analogous to the subject and object in grammar (unlike classes, which can be defined independently). It is arbitrary, which class is selected as the domain, just as the choice between active and passive voice in grammar is arbitrary. In other words, a property can be interpreted in both directions, with two distinct, but related interpretations. Properties may themselves have properties that relate to other classes (This feature is used in this model only in order to describe dynamic subtyping of properties). Properties can also be specialized in the same manner as classes, resulting in IsA relationships between subproperties and their superproperties. In some contexts, the terms attribute, reference, link, role or slot are used synonymously with property. For example, “Physical Human-Made Thing *depicts* Entity” is equivalent to “Entity *is depicted by* Physical Human-Made Thing”.

3.19

property quantifier

declaration of the allowed number of *instances* (3.8) of a certain *property* (3.18) that can refer to a particular instance of the range class or the domain class of that property

Note 1 to entry: Property quantifier declarations are ontological, i.e. they refer to the nature of the real world described and not to our current knowledge. For example, each person has exactly one father, but collected knowledge may refer to none, one or many.

3.20

query

request for information from an information system expressed so that the response can be calculated automatically

3.21

range

class that comprises all potential values of a property

Note 1 to entry: That means that instances of the property can link only to instances of its range class. A property shall have exactly one range, although the range class may always contain instances that are not the value of the property. The range class is analogous to the grammatical object of a phrase for which the property is analogous to the verb. It is arbitrary which class is selected as domain and which as range, just as the choice between active and passive voice in grammar is arbitrary. Property names in ISO 21127 are designed to be semantically meaningful and grammatically correct when read from domain to range. In addition, the inverse property name, normally given in parentheses, is also designed to be semantically meaningful and grammatically correct when read from range to domain.

3.22

reflexivity

binary relation on a set X that relates every element of X to itself

Note 1 to entry: Reflexivity is defined in the standard way found in mathematics or logic: A property P is reflexive if the domain and range are the same class and for all instances x, of this class the following is the case: x is related by P to itself. The intention of a property as described in the scope note will decide whether a property is reflexive or not. An example of a reflexive property is E53 Place. *P89 falls within (contains)*: E53 Place.

3.23

scope note

textual description of the *intension* (3.9) of a class or property

Note 1 to entry: Scope notes are not formal modelling constructs, but are provided to help explain the intended meaning and application of ISO 21127's classes and properties. Basically, they refer to a conceptualisation common to domain experts and disambiguate between different possible interpretations. Illustrative example instances of classes and properties are also regularly provided in the scope notes for explanatory purposes.

3.24

semantic interoperability

capability of different information systems to communicate information consistent with the intended meaning

Note 1 to entry: In more detail, the intended meaning encompasses the data structure elements involved, the terminology appearing as data, and the identifiers used in the data for factual items such as places, people, objects, etc. Obviously, communication about data structure must be resolved first. In this case, consistent communication means that data can be transferred between data structure elements with the same intended meaning or that data from elements with the same intended meaning can be merged. In practice, the different levels of generalization in different systems do not allow the achievement of this ideal. Therefore, semantic interoperability is regarded as achieved if elements can be found that provide a reasonably close generalization for the transfer or merge. This document is only concerned with semantic interoperability on the level of data structure elements.

3.25

shortcut

formally defined single property that represents a deduction or join of a data path in the ontology

Note 1 to entry: The scope notes of all properties characterized as shortcuts describe in words the equivalent deduction. Shortcuts are introduced for the cases where common documentation practice refers only to the deduction rather than to the fully developed path. For example, museums often only record the dimension of an object without documenting the Measurement that observed it. This document declares shortcuts explicitly as single properties in order to allow the user to describe cases in which he has less detailed knowledge than the full data path would need to be described. For each shortcut, this document contains in its schema the properties of the full data path explaining the shortcut.

3.26

strict inheritance

property *inheritance* ([3.7](#)) that allows no exceptions

Note 1 to entry: Some systems may declare that elephants are grey and regard a white elephant as an exception. Under strict inheritance it would hold that: if all elephants were grey, then a white elephant could not be an elephant. Obviously, not all elephants are grey; to be grey is not part of the intension of the concept elephant but an optional property. This document applies strict inheritance as a normalization principle.

3.27

subclass

specialization of another *class* ([3.1](#)), i.e. the superclass

Note 1 to entry: Specialization or the IsA relationship means that all instances of the subclass are also instances of its superclass, that the intension of the subclass extends the intension of its superclass, i.e. its traits are more restrictive than that of its superclass, and that the subclass inherits the definition of all of the properties declared for its superclass without exceptions (strict inheritance), in addition to having none, one or more properties of its own. A subclass can have more than one immediate superclass and consequently inherits the properties of all of its superclasses (multiple inheritance). The IsA relationship or specialization between two or more classes gives rise to a structure known as a class hierarchy. The IsA relationship is transitive and may not be cyclic. In some contexts (e.g. the programming language C++) the term derived class is used synonymously with subclass. For example, every Person IsA Biological Object, or Person is a subclass of Biological Object. Also, every Person IsA Actor. A Person may die. However, other kinds of Actors, such as companies, don't die. Every Biological Object IsA Physical Object. A Physical Object can be moved. Hence, a Person can be moved also.

3.28

subproperty

specialization of another *property* ([3.18](#)), i.e. the superproperty

Note 1 to entry: Specialization or IsA relationship means that all instances of the subproperty are also instances of its superproperty, that the intension of the subproperty extends the intension of the superproperty, i.e. its traits are more restrictive than that of its superproperty, that the domain of the subproperty is the same as the domain of its superproperty or a subclass of that domain, that the range of the subproperty is the same as the range of its superproperty or a subclass of that range, and that the subproperty inherits the definition of all of the properties declared for its superproperty without exceptions (strict inheritance), in addition to having none, one or more properties of its own. A subproperty can have more than one immediate superproperty and consequently inherits the properties of all of its superproperties (multiple inheritance). The IsA relationship or specialization between two or more properties gives rise to the structure called a property hierarchy. The IsA relationship is transitive and may not be cyclic. Some object-oriented programming languages, such as C++, do not contain constructs that allow for the expression of the specialization of properties as sub-properties.

Note 2 to entry: Alternatively, a property may be subproperty of the inverse of another property, i.e. reading the property from range to domain. In that case all instances of the subproperty are also instances of the inverse of the other property, the intension of the subproperty extends the intension of the inverse of the other property, i.e. its traits are more restrictive than that of the inverse of the other property, the domain of the subproperty is the same as the range of the other property or a subclass of that range, and the range of the subproperty is the same as the domain of the other property or a subclass of that domain. The subproperty inherits the definition of all of the properties declared for the other property without exceptions (strict inheritance), in addition to having none, one or more properties of its own. The definitions of inherited properties have to be interpreted in the inverse sense of direction of the subproperty, i.e. from range to domain.

3.29

superclass

generalization of one or more other classes, i.e. the subclasses

Note 1 to entry: A superclass subsumes all instances of its subclasses, and that it can also have additional instances that do not belong to any of its subclasses. The intension of the superclass is less restrictive than any of its subclasses. This subsumption relationship or generalization is the inverse of the IsA relationship or specialization. For example, “Biological Object subsumes Person” is synonymous with “Biological Object is a superclass of Person”. It needs fewer traits to identify an item as a Biological Object than to identify it as a Person.

3.30

superproperty

generalization of one or more other properties, i.e. the subproperties

Note 1 to entry: A superproperty subsumes all instances of its subproperties, and that it can also have additional instances that do not belong to any of its subproperties. The intension of the superproperty is less restrictive than any of its subproperties. The subsumption relationship or generalization is the inverse of the IsA relationship or specialization. A superproperty may be a generalization of the inverse of another property.

3.31

symmetric property

binary relation *R* on a set *X* that, for all elements *a* and *b* in *X*, whenever *R* relates *a* to *b* then *R* also relates *b* to *a*

Note 1 to entry: Symmetry is defined in the standard way found in mathematics or logic: A property *P* is symmetric if the domain and range are the same class and for all instances *x*, *y* of this class the following is the case: If *x* is related by *P* to *y*, then *y* is related by *P* to *x*. The intention of a property as described in the scope note will decide whether a property is symmetric or not. An example of a symmetric property is “E53 Place.*P122 borders with*: E53 Place”. The names of symmetric properties have no parenthetical form, because reading in the range-to-domain direction is the same as the domain-to-range reading.

3.32 transitivity

binary relation *R* on set *X* that, for all elements *a*, *b*, and *c* in *X*, whenever *R* relates *a* to *b* and *R* relates *b* to *c*, then *R* relates *a* to *c*

Note 1 to entry: Transitivity is defined in the standard way found in mathematics or logic: A property *P* is transitive if the domain and range is the same class and for all instances *x*, *y*, *z* of this class the following is the case: If *x* is related by *P* to *y* and *y* is related by *P* to *z*, then *x* is related by *P* to *z*. The intention of a property as described in the scope note will decide whether a property is transitive or not. For example, the property *P121 overlaps with* between instances of E53 Place is not transitive, while the property *P89 falls within (contains)* between instances of E53 Place and the property *P46 is composed of (forms part of)* between instances of E18 Physical Thing are both transitive. Transitivity is especially useful when the [ISO 21127](#) ontology is implemented in a system with deduction.

3.33 universal

entities that can have *instances* ([3.8](#)) in a possible world

Note 1 to entry: The fundamental ontological distinction between universals and particulars can be informally understood by considering their relationship with instantiation: particulars are entities that have no instances in any possible world; universals are entities that do have instances. Classes and properties (corresponding to predicates in a logical language) are usually considered to be universals. (after Reference [\[87\]](#), pp. 166-181).

4 Objectives

The primary role of this document is to enable the exchange and integration of information from heterogeneous sources for the reconstruction and interpretation of the past at a human scale, based on all kinds of material evidence, including texts, audio-visual material and oral tradition. It starts from, but is not limited to, the needs of museum documentation and research based on museum holdings. It aims at providing the semantic definitions and clarifications needed to transform disparate, localised information sources into a coherent global resource, be it within a larger institution, in intranets or on the Internet, and to make it available for scholarly interpretation and scientific evaluation. These goals determine the constructs and level of detail of this document.

More specifically, it defines, in terms of a formal ontology, the underlying semantics of database schemata and structured documents used in the documentation of cultural heritage and scientific activities. In particular, it defines the semantics related to the study of the past and current state of our world, as it is characteristic for museums, but also for other cultural heritage institutions and disciplines. It does not define any of the terminology appearing typically as data in the respective data structures; it foresees, however, the characteristic relationships for its use. It does not aim at proposing what cultural heritage institutions should document. Rather, it explains the logic of what they actually currently document, and thereby enables semantic interoperability.

This document intends, moreover, to provide a model of the intellectual structure of the respective kinds of mentioned documentation in logical terms. As such, it has not been optimised for implementation specific storage and processing factors. Actual system implementations may lead to solutions where elements and links between relevant elements of our conceptualizations are no longer explicit in a database or other structured storage system. For instance, the birth event that connects elements such as father, mother, birth date, birth place may not appear in the database, in order to save storage space or response time of the system. This document provides a conceptual and technical means to explain how such apparently disparate entities are semantically and logically interconnected, and how the ability of the database to answer certain intellectual questions is affected by the omission of such elements and links.

This document aims to support the following specific functionalities:

- inform developers of information systems as a guide to good practice in conceptual modelling, in order to effectively structure and relate information assets of cultural documentation;

- serve as a common language for domain experts and IT developers to formulate requirements and to agree on system functionalities with respect to the correct handling of cultural contents;
- to serve as a formal language for the identification of common information contents in different data formats; in particular, to support the implementation of automatic data transformation algorithms from local to global data structures without loss of meaning. The latter being useful for data exchange, data migration from legacy systems, data information integration and mediation of heterogeneous sources;
- to support associative queries against integrated resources by providing a global model of the basic classes and their associations to formulate such queries;
- it is further believed that advanced natural language algorithms and case-specific heuristics can take significant advantage of this document to resolve free text information into a formal logical form, if that is regarded beneficial. This document is not thought, however, to be a means to replace scholarly text, rich in meaning, by logical forms, but only a means to identify related data.

Users of this document should be aware that the definition of data entry systems requires support of community-specific terminology, guidance to what should be documented and in which sequence, and application-specific consistency controls. This document does not provide such notions.

By its very structure and formalism, this document is extensible and users are encouraged to create extensions for the needs of more specialized communities and applications.

5 Compatibility

Users intending to take advantage of the semantic interoperability offered by this document should ensure conformance with the relevant data structures. Conformance pertains either to data to be made accessible in an integrated environment or intended for transport to other environments. Any encoding of data in a formal language that preserves the relations of the classes, properties, and inheritance rules defined by this document, is regarded as conformant.

Conformance with this document does not require complete matching of all local documentation structures, nor that all concepts and structures present in this document be implemented. This document is intended to allow room both for extensions, needed to capture the full richness of cultural information, and for simplification, in the interests of economy. A system will be deemed partially conformant if it supports a subset of subclasses and subproperties defined by this document. Designers of the system should publish details of the constructs that are supported.

The focus of this document is the exchange and mediation of structured information. It does not require the interpretation of unstructured (free text) information into a structured, logical form. Unstructured information is supported, but falls outside the scope of conformance considerations.

Any documentation system will be deemed conformant with this document, regardless of the internal data structures it uses, if a deterministic logical algorithm can be constructed that transforms data contained in the system into a directly compatible form without loss of meaning. No assumptions are made as to the nature of this algorithm. “Without loss of meaning” signifies that designers and users of the system are satisfied that the data representation corresponds to the semantic definitions provided by this document.

6 Applied form

6.1 General

[ISO 21127](#) is an ontology in the sense used in computer science. It has been expressed as an object-oriented semantic model, in the hope that this formulation will be comprehensible to both documentation experts and information scientists alike, while at the same time being readily converted to machine-readable formats such as RDF Schema or OWL. An [ISO 21127](#) ontology conformant

documentation system can be implemented using RDF Schema or OWL, but also in Relational or Object-Oriented schema. [ISO 21127](#) instances can be encoded in RDF, JSON LD, XML, OWL and others.

More specifically, this document is expressed in terms of the primitives of semantic data modelling. As such, it consists of:

- classes, which represent general notions in the domain of discourse, such as the [ISO 21127](#) class E21 Person which represents the notion of person;
- properties, which represent the binary relations that link the individuals in the domain of discourse, such as the [ISO 21127](#) property *P152 has parent* linking a person to one of the person's parent;
- properties of properties, such as the property *P14.1 in the role of*, of the [ISO 21127](#) property *P14 carried out by* [see also Types ([8.3.1](#))]. They do not appear in the property hierarchy list [see Property declarations ([Clause 10](#))], but are included as part of their base property declaration and are referred to in the class declarations. They all have the implicit quantification “many to many” [see also Property Quantifiers ([6.6](#))].

Although the definition of [ISO 21127](#) provided here is complete, it is an intentionally compact and concise presentation of ISO 21127's 81 classes and 160 unique properties. It does not attempt to articulate the inheritance of properties by subclasses throughout the class hierarchy (this would require the declaration of several thousand properties, as opposed to 160). However, this definition does contain all of the information necessary to infer and automatically generate a full declaration of all properties, including inherited properties.

6.2 Naming conventions

The following naming conventions have been applied hereafter.

- Classes are identified by numbers⁶⁾ preceded by the letter “E” (historically, classes were sometimes referred to as “Entities”), and are named using noun phrases (nominal groups) in title case (initial capitals). For example, E63 Beginning of Existence.
- Properties are identified by numbers preceded by the letter “P,” and are named in both directions, using verbal phrases in lower case. Properties with the character of states are named in the present tense, such as “has type”, whereas properties relating to events are named in past tense, such as “carried out”. For example, *P126 employed (was employed in)*.
- Property names should be read in their non-parenthetical form for the domain-to-range direction, and in parenthetical form for the range-to-domain direction. Reading a property in range-to-domain direction is equivalent to the inverse of that property. Following a current notational practice in OWL knowledge representation language, this document represents inverse properties in this text by adding a letter “i” following the identification number and the parenthetical form of the full property name, such as *P59i is located on or within*, which is the inverse of *P59 has section (is located on or within)*.
- Properties with a range that is a subclass of E59 Primitive Value (such as E1 Entity. *P3 has note*: E62 String) have no parenthetical name form, because reading the property name in the range-to-domain direction is not regarded as meaningful.
- Properties that have identical domain and range are either symmetric or transitive. Instantiating a symmetric property implies that the relation holds for both the domain-to-range and the range-to-domain directions. An example of this is E53 Place. *P122 borders with*: E53 Place. The names of symmetric properties have no parenthetical form, because reading in the range-to-domain direction is the same as the domain-to-range reading. Transitive asymmetric properties, such as E4 Period. *P9 consists of (forms part of)*: E4 Period, do have a parenthetical form that relates to the meaning of the inverse direction.

6) Some gaps are present in the numbering sequence used for classes and properties. This is intentional: numbers assigned in previous versions of this document to deprecated classes and properties have not been reused.

- The choice of property domains, and hence the order of their names, is established in accordance with the following priority list:
 - a) temporal entity and its subclasses;
 - b) thing and its subclasses;
 - c) actor and its subclasses;
 - d) other.
- Properties of properties are identified by “P”, followed by the number of the base property extended with “.1” and are named in one direction using a verbal phrase in lower case in the present tense. For example, the property *P62.1 mode of depiction* of the property *P62 depicts (is depicted by)*.

6.3 Inheritance and transitivity

This document is formulated as a class system with inheritance. A property P with domain A and range B will also be a property between any possible subclasses of A and of B. In many cases there will be a common subclass C of both A and B. In these cases, when the property is restricted to C, that is, with C as domain and range, the restricted property could be transitive. For instance, an E73 Information Object can be incorporated into an E90 Symbolic Object and thus an Information Object can be incorporated in another Information Object.

In the definition of this document, the transitive properties are explicitly marked as such in the scope notes. All unmarked properties should be considered as not transitive.

6.4 Shortcuts

Some properties are declared as shortcuts of longer, more comprehensively articulated paths that connect the same domain and range classes as the shortcut property through one or more intermediate classes. For example, the property E18 Physical Thing. *P52 has current owner*: E39 Actor, is a shortcut for a fully articulated path from E18 Physical Thing through E8 Acquisition to E39 Actor. An instance of the fully-articulated path always implies an instance of the shortcut property. However, the inverse might not be true; an instance of the fully-articulated path cannot always be inferred from an instance of the shortcut property inside the frame of the actual knowledge base.

The class E13 Attribute Assignment allows for the documentation of how the assignment of any property came about, and whose opinion it was, even in cases of properties not explicitly characterized as “shortcuts”.

6.5 Logical expressions used in ISO 21127

The present [ISO 21127](#) specifications are annotated with logical axioms, providing an additional formal expression of the [ISO 21127](#) ontology. This subclause briefly introduces the assumptions that are at the basis of the logical expression of [ISO 21127](#) (for a fully detailed account of the logical expression of semantic data modelling, see Reference [\[202\]](#)).

In terms of semantic data modelling, classes and properties are used to express ontological knowledge by means of various kinds of constraints, such as sub-class/sub-property links, e.g. E21 Person is a sub-class of E20 Biological Object, or domain/range constraints, e.g. the domain of *P152 has parent* is class E21 Person.

In contrast, first-order logic-based knowledge representation relies on a language for formally encoding an ontology. This language can be directly put in correspondence with semantic data modelling in a straightforward way:

- classes are named by unary predicate symbols; conventionally, this document uses E21 as the unary predicate symbol corresponding to class E21 Person;

- properties are named by binary predicate symbols; conventionally, this document uses *P152* as the binary predicate symbol corresponding to property *P152 has parent*.
- properties of properties, “.1 properties” are named by ternary predicate symbols; conventionally, this document uses *P14.1* as the ternary predicate symbol corresponding to property *P14.1 in the role of*.

Ontology is expressed in logic by means of logical axioms, which correspond to the constraints of semantic modelling. In the definition of classes and properties of [ISO 21127](#), the axioms are placed under the heading ‘In first-order logic’. There are several options for writing statements in first-order logic. In this document, a standard compact notation widely used in text books and scientific papers is used. The definition is given in [Table 1](#).

Table 1 — Symbolic operators In first-order logic representation

Symbols	Name	Reads	Truth value
Operators			
$\wedge$	conjunction	and	$(\varphi \wedge \psi)$ is true if and only if both φ and ψ are true
$\vee$	disjunction	or	$(\varphi \vee \psi)$ is true if and only if at least one of either φ or ψ is true
$\neg$	negation	not	$\neg\varphi$ is true if and only if φ is false
$\Rightarrow$	implication	implies, if ... then ...	$(\varphi \Rightarrow \psi)$ is true if and only if it is not the case that φ is true and ψ is false
$\Leftrightarrow$	equivalence	is equivalent to, if ... and only if ...	$\varphi \Leftrightarrow \psi$ is true if and only if both φ and ψ are true or both φ and ψ are false
Quantifiers			
$\exists$	existential quantifier	exists, there exists at least one	
$\forall$	Universal quantifier	forall, for all	

For instance, the above sub-class link between E21 Person and E20 Biological Object can be formulated In first-order logic as the axiom:

$$(\forall x) [E21(x) \Rightarrow E20(x)]$$

(reading: for all individuals x , if x is an E21 then x is an E20).

In the definitions of classes and properties in this document the universal quantifier(s) are omitted for simplicity, so the above axiom is simply written:

$$E21(x) \Rightarrow E20(x)$$

Likewise, the above domain constraint on property *P152 has parent* can be formulated In first-order logic as the axiom:

$$P152(x,y) \Rightarrow E21(x)$$

(reading: for all individuals x and y , if x is a P152 of y , then x is an E21).

Properties of properties, indicated by a '.1' after the property number are described as ternary predicate symbols. For example, the property *P14.1in the role of* is described as the ternary predicate symbol corresponding to property *P14 carried out by (performed)*:

$$P14(x,y) \Rightarrow E7(x)$$

$$P14(x,y) \Rightarrow E39(y)$$

$$P14(x,y,z) \Rightarrow [P14(x,y) \wedge E55(z)]$$

These basic considerations should be used by the reader to understand the logical axioms that are used into the definition of the classes and properties. Further information about the first order formulation of [ISO 21127](#) can be found in Reference [\[168\]](#).

6.6 Property quantifiers

Quantifiers for properties are provided for the purpose of semantic clarification only, and should not be treated as implementation recommendations. This document has been designed to accommodate alternative opinions and incomplete information; all properties should therefore be implemented as optional and repeatable for their domain and range ["many to many (0,n:0,n)"]. The term "cardinality constraints" is avoided here as it typically pertains to implementations.

[Table 2](#) lists all possible property quantifiers occurring in this document according to their notation, together with a textual explanation. In order to provide optimal clarity, two widely accepted notations are used in this document, a verbal and a numeric one. The verbal notation uses phrases such as "one to many", and the numerical one, expressions such as "(0,n:0,1)". While the terms "one", "many", and "necessary" are fairly intuitive, the term "dependent" denotes a situation where a range instance cannot exist without an instance of the respective property. In other words, the property is "necessary" for its range[\[160\]](#).

Table 2 — Property quantifiers

Quantifier	Description
many to many (0,n:0,n)	Unconstrained: an individual domain instance and range instance of this property can have zero, one, or more instances of the property. In other words, the property is optional and repeatable for its domain and range.
one to many (0,n:0,1)	An individual domain instance of this property can have zero, one, or more instances of the property, but an individual range instance cannot be referenced by more than one instance of this property. In other words, the property is optional for its domain and range, but repeatable for its domain only. This situation is sometimes called a "fan-out".
many to one (0,1:0,n)	An individual domain instance of this property can have zero or one instance of the property, but an individual range instance can be referenced by zero, one, or more instances of the property. In other words, the property is optional for its domain and range, but repeatable for its range only. This situation is sometimes called a "fan-in".
many to many, necessary (1,n:0,n)	An individual domain instance of this property can have one or more instances of the property, but an individual range instance can have zero, one, or more instances of the property. In other words, the property is necessary and repeatable for its domain, and optional and repeatable for its range.
one to many, necessary (1,n:0,1)	An individual domain instance of this property can have one or more instances of the property, but an individual range instance cannot be referenced by more than one instance of the property. In other words, the property is necessary and repeatable for its domain, and optional but not repeatable for its range. This situation is sometimes called a "fan-out".
many to one, necessary (1,1:0,n)	An individual domain instance of this property shall have exactly one instance of the property, but an individual range instance can be referenced by zero, one, or more instances of the property. In other words, the property is necessary and not repeatable for its domain, and optional and repeatable for its range. This situation is sometimes called a "fan-in".

Table 2 (continued)

Quantifier	Description
one to many, dependent (0,n:1,1)	An individual domain instance of this property can have zero, one, or more instances of the property, but an individual range instance shall be referenced by exactly one instance of the property. In other words, this property is optional and repeatable for its domain, but necessary and not repeatable for its range. This situation is sometimes called a “fan-out”.
many to many, necessary, dependent (1,n:1,n)	An individual domain instance and range instance of this property must have at least one instance of this property. In other words, this property is necessary and repeatable for its domain and range.
one to many, necessary, dependent (1,n:1,1)	An individual domain instance of this property can have one or more instances of the property, but an individual range instance shall be referenced by exactly one instance of the property. In other words, the property is necessary and repeatable for its domain, and necessary but not repeatable for its range. This situation is sometimes called a “fan-out”.
many to one, necessary, dependent (1,1:1,n)	An individual domain instance of this property shall have exactly one instance of the property, but an individual range instance can be referenced by one or more instances of the property. In other words, this property is necessary and not repeatable for its domain, and necessary and repeatable for its range. This situation is sometimes called a “fan-in”.
one to one (1,1:1,1)	An individual domain instance and range instance of this property shall have exactly one instance of the property. In other words, the property is necessary and not repeatable for its domain and for its range.
one to one, necessary (1,1:0,1)	An individual domain instance of this property must have exactly one instance of this property, but an individual range instance cannot be referenced by more than one instance of this property. In other words, this property is necessary and not repeatable for its domain, and optional but not repeatable for its range.

This document defines some dependencies between properties and the classes that are their domains or ranges. These can be one or both of the following:

- the property is necessary for the domain;
- the property is necessary for the range, or, in other words, the range is dependent on the property.

The possible kinds of dependencies are defined in the table above. Note that if a dependent property is not specified for an instance of the respective domain or range, it means that the property exists, but the value on one side of the property is unknown. In the case of optional properties, the methodology proposed by this document does not distinguish between a value being unknown or the property not being applicable at all. For example, one may know that an object has an owner, but the owner is unknown. In an [ISO 21127](#), instance this case cannot be distinguished from the fact that the object has no owner at all. Of course, such details can always be specified by a textual note.

Note that the quantification of all properties of properties, “.1” properties, is “many-to-many” and, therefore, does not appear explicitly in their definitions.

7 Modelling principles

7.1 Reality, knowledge bases and ISO 21127

[ISO 21127](#) is a formal ontology in the sense introduced by Reference [100].⁷⁾ The present document is intended to embrace an audience not specialized in computer science and logic; therefore, it focuses on the informal semantics and on the pragmatics of [ISO 21127](#) concepts, offering a detailed discussion of

7) Nicola Guarino defines a formal ontology as a specification of a set of named concepts used to describe and approximate a part of reality, plus a first-order logical theory narrowing down the intended meaning of the named concepts.

the main traits of the conceptualization underlying this document through basic usage patterns.⁸⁾ This document aims to assist sharing, connecting and integrating information from research about the past. In order to understand the function of a formal ontology of this kind, one needs to make the following distinctions.

- The material reality. For the purpose of this document, material reality is regarded as whatever has substance that can be perceived with senses or instruments. Examples are people, a forest or a settlement environment, sea, atmosphere, distant celestial or cellular micro structures, including what is assumed to be potentially or theoretically perceived if people can be there, such as the centre of the Earth or the sun, and all that is past. It is constrained to space and time. What goes on in the minds or is produced by the minds is also regarded as part of the material reality, as it becomes materially evident to other people at least by utterances, behaviour and products.
- The units of description or particulars, i.e. the things and relations which are referred to in order to distinguish parts of reality. Examples are Mount Ida, the Taj Mahal, the formation of China by emperor Qin Shi Huang (秦始皇) in 221BC, Tut-Ankh Amun and his embalming, Prince Shotoku of Japan sending a mission to China in 607AD, the participation of Socrates in the Battle of Potidaea or the radiocarbon dating of the Iceman Ötzi^[139].

A formal ontology, such as [ISO 21127](#), constitutes a controlled language for talking about particulars. I.e., it provides classes and properties for categorizing particulars as so-called “instances” in a way that their individuation, unity and relevant properties are as unambiguous as possible. For instance, Tut-Ankh Amun as instance of E21 Person is the real pharaoh from his birth to death, and not extending to his mummy, according to the specification of the class E21 Person and its properties in this document.

For clarification, this document does not take a position against or in favour of the existence of spiritual substance nor of substance not accessible by either senses or instruments, nor does it suggest a materialistic philosophy. However, for practical reasons, it relies on the priority of integrating information based on material evidence available for whatever human experience. This document only commits to a unique material reality independent from the observer.

When descriptions of particulars are provided, reference shall be made by unique names, titles or constructed identifiers, all of which are instances of E41 Appellation in this document, in order the reference to be independent of the context. (In contrast, reference to particulars by pronouns or enumerations of characteristic properties, such as name and birth date, are context dependent). The appellation, and the relation between the appellation and the referred item or relationship, shall not be confused with the referred item and its identity. For example, Tut-Ankh Amun the name (instance of E41 Appellation) is different from Tut-Ankh Amun the person (instance of E21 Person) and also different from the relationship between name and person (*P1 is identified by*). Instances of [ISO 21127](#) classes are the real particulars, not their names, but in descriptions, names shall be used as surrogates for the real things meant. Particulars are approximate individuations, like sections, of parts of reality. In other words, the uniqueness of reality does not depend on where one draws the line between the mountain and the valley.

An ISO-21127-compatible knowledge base (KB)^[160] is an instance of E73 Information Object in [ISO 21127](#). It contains (data structures that encode) formal statements representing propositions believed to be true in a reality by an observer. These statements use appellations (e.g. <https://id.loc.gov/authorities/names/n79066005>⁹⁾) of ontological particulars and of [ISO 21127](#) concepts (e.g. *P100i died in*). Thereby users, in their capacity of having real-world knowledge and cognition, may be able to relate these statements to the propositions they are meant to characterize, and be able to reason and research about their validity. In other words, the formal instances in a knowledge base are the identifiers, not the real things or phenomena. A special case is digital content: a KB in a computer system may contain statements about instances of E90 Symbolic Object and the real thing may be text residing within the same KB. The instance of E90 Symbolic Object and its textual representation are separate entities and they can be connected with the property *P190 has symbolic content*.

8) For the readers interested in computer science and logic, the syntax and formal semantics employed by the CIDOC CRM are given in Reference ^[160], where the computational aspects are also discussed.

9) The URI (instance of E41 Appellation) of the Library of Congress for Tut-Ankh-Amun, the pharaoh

Therefore, a knowledge base does not contain knowledge, but statements that represent knowledge, as long as there exist people that can resolve the identifiers used to their referents. (Appellations described in a knowledge base, and not used as primary substitutes of other items, are of course explicitly declared as instances of E41 Appellation in the knowledge base.)

7.2 Authorship of knowledge base (KB) contents

This subclause describes a recommended good practice how to relate authority to knowledge base contents.

Statements in a KB must have been inserted by some human agent, either directly or indirectly. However, these statements often make no reference to that agent, lacking attribution of authority. An example of such statements in [ISO 21127](#) is information expressed through shortcuts such as *P2 has type*. In the domain of cultural heritage, it is common practice that the responsibility for maintaining knowledge in the KB is elaborated in institutional policy or protocol documents. Thus, it is reasonable to hold that statements which lack explicit authority attribution can be read as the official view of the administering institution of that system, i.e. the maintainers of the KB. This does not imply that the knowledge described in the KB is complete. So long as the information is under active management, it remains continuously open to revision and improvement as further research reveals further understandings.¹⁰⁾ A KB does not represent a slice of reality, but the justified beliefs of its maintainers about that reality. For simplicity, this document refers to a KB as representing some reality.

Statements in a KB may also carry explicit references to agents that produced them, i.e. further statements of responsibility. In [ISO 21127](#), such statements of responsibility are expressed through knowledge creation events such as E13 Attribute Assignment and its relevant subclasses. Any knowledge that is about an explicit knowledge creation event, where the creator's identity has been given, is implicitly attributed to be correctly referred to in the KB by the maintaining authority, whereas the responsibility for the content created by that event is assigned to the agent identified as causal to that event.

In the special case of an institution taking over stewardship of a database transferred into their custody, two relations of responsibility for the knowledge therein can be envisioned. If the institution accepts the dataset and undertakes to maintain and update it, then they take on responsibility for that information and become the default authority behind its statements as described above. If, on the other hand, the institution accepts the data set and stores it without change as a closed resource, then it can be considered that the default authority remains the original steward like for any other scholarly document kept by the institution.

7.3 Extensions

Since the intended scope of this document is a subset of the “real” world and is therefore potentially infinite, the model has been designed to be extensible through the linkage of compatible external type hierarchies.

Of necessity, some concepts covered by this document are defined in less details than others: E39 Actor and E30 Right, for example. This is a natural consequence of staying within the model's clearly articulated practical scope in an intrinsically unlimited domain of discourse. These ‘underdeveloped’ concepts can be considered as candidate superclasses for compatible extensions, in particular for disciplines with a respective focus. Additions to the model are known as extensions while the main model is known as [ISO 21127](#).

Compatibility of extensions with this document means that data structured according to an extension shall also remain valid as instances of [ISO 21127](#) base classes. In practical terms, this implies query containment: any queries based on [ISO 21127](#) concepts to a KB should retrieve a result set that is

10) Statements in a KB may be in contradiction to the ontologically defined quantification of properties without the KB being broken or invalid in any sense, either because necessary properties are unknown or there exist good reasons to assume alternative values for properties with limited cardinality, be it by the same or by different maintainers.

correct according to the model's semantics, regardless of whether the KR is structured according to ISO 21127's semantics alone, or according to [ISO 21127](#) plus compatible extensions. For example, a query such as "list all events" should recall 100% of the instances deemed to be events by [ISO 21127](#), regardless of how they are classified by the extension.

A sufficient condition for the compatibility of an extension with [ISO 21127](#) is that its classes, other than E1 Entity, subsume all classes of the extension, and all properties of the extension are either subsumed by [ISO 21127](#) properties, or are part of a path for which an [ISO 21127](#) property is a shortcut, and that classes and properties of the extension can be well distinguished from those in [ISO 21127](#). For instance, a class "tangible object" may be in conflict with existing classes of [ISO 21127](#). Obviously, such a condition can only be tested intellectually.

This document provides a number of mechanisms to ensure that coverage of the intended scope can be increased on demand without losing compatibility.

- a) Existing classes can be extended, either structurally as subclasses or dynamically using the type hierarchy [see Types (8.3.1)].
- b) Existing properties can be extended, either structurally as subproperties, or in some cases, dynamically, using properties of properties which allow subtyping [see Types (8.3.1)].
- c) Additional information that falls outside the semantics formally defined by [ISO 21127](#) can be recorded as unstructured data using E1 Entity. *P3 has note*: E62 String.
- d) Extending this document by superclasses and properties that pertain to a wider scope. They are called conservative extensions, if they preserve backwards compatibility with instances described with this document.

Following strategies a), b) and c) will have the result that [ISO 21127](#) concepts subsume and thereby cover the extensions. This means that querying an extended knowledge base only with concepts of [ISO 21127](#) will nevertheless retrieve all facts described via the extensions.

In mechanism c), the information in the notes is accessible in the respective knowledge base by retrieving the instances of E1 Entity that are domain of *P3 has note*. Keyword search will also work for the content of the note. Rules should be applied to attach a note to the item most specific for the content. For instance, details about the role of an actor in an activity should be associated with the instance of E7 Activity, and not with the instance of E39 Actor. This approach is preferable when queries relating elements from the content of such notes across the knowledge base are not expected.

In general, only concepts to be used for selecting multiple instances from the knowledge base by formal querying need to be explicitly modelled. This criterion depends on the expected scope and use of the particular knowledge base. This document prioritizes modelling the kinds of facts one would like to retrieve and relate from heterogeneous content sources, potentially from different institutions. It does not, by way of contrast, focus on the modelling of facts with a more local scope such as the administrative practices internal to an institution.

Mechanism d), conservative extension, is more complex.

With increasing use of this document, there is also a need for extensions that model phenomena from a scope wider than the original one of this document, but which are also applicable to the concepts that do fall within this document's scope. When this occurs, properties of [ISO 21127](#) may be found to be applicable more generally to superclasses of the extension than to those of their current domain or range in this document. This is a consequence of the key principle of this document to model "bottom up", i.e. selecting the domains and ranges for properties to be as narrow as they would apply in a well understood fashion in the current scope, thus avoiding making poorly understood generalizations at risk of requiring non-monotonic correction.

The fourth mechanism for extending [ISO 21127](#) by conservation extension can be seen to be split into two cases.

- A new class or property is added to an extension of [ISO 21127](#), which is not covered by superclasses other than E1 Entity or a superproperty in [ISO 21127](#) respectively. In this case, all facts described only by such concepts are not accessible by queries with [ISO 21127](#) concepts. Therefore, the extension should publish in a compatibility statement the additional relevant high-level classes and properties needed to retrieve all facts documented with the extended model. This case is a monotonic extension.
- The domain or range of an existing property in [ISO 21127](#) is changed to a superclass of the one or the other or both, because the property is understood to be applicable beyond its originally anticipated scope. In this case, all facts described by the extension are still accessible by querying with the concepts of [ISO 21127](#), but the extension can describe additional facts that [ISO 21127](#) could not. This case is a monotonic extension and generally recommended, because it enables bottom-up evolution of the model. If this change is part of a new release of [ISO 21127](#) itself, it is simply backwards compatible, and this has been done frequently in the evolution of this model. If this second case should be documented and implemented in an extension module separate from this document, it may come in conflict with the current way knowledge representation languages, such as RDF/OWL, treat it, because in formal logic changing the range or domain of a property is regarded as changing the ontological meaning completely; there is no distinction between the meaning of the property independent of domain and range and the specification of the domain and range. It is, however, similar to what in logic is called a conservative extension of a theory, and necessary for an effective modular management of ontologies.

Therefore, for the interested reader, here is a definition of this case in terms of first order logic, which shows how modularity can formally be achieved.

Assume a property P defined with domain class A and range class C also holds for a domain class B , superclass of A , and a range class D , superclass of C , in the sense of its ontological meaning in the real world. This document describes this situation by introducing an auxiliary formal property P' , defined with domain class B and range class D , and apply the following logic:

$$A(x) \Rightarrow B(x)$$

$$C(x) \Rightarrow D(x)$$

$$P(x,y) \Rightarrow A(x)$$

$$P(x,y) \Rightarrow C(y)$$

$$P'(x,y) \Rightarrow B(x)$$

$$P'(x,y) \Rightarrow D(y)$$

Then, P' is a conservative extension of P if: $A(x) \wedge C(y) \wedge P'(x,y) \Leftrightarrow P(x,y)$

In other words, a separate extension module may re-declare the respective property with another identifier, preferably using the same label, and implement the above rule.

7.4 Minimality

Although the scope of this document is very broad, the model itself is constructed as economically as possible:

- [ISO 21127](#) classes and properties are either primitive, or they are key concepts in the practical scope.
- Complements of [ISO 21127](#) classes are not declared, because, considering the Open World principle, there are no properties for complements of a class [see [Clause 3](#) and first consequence of monotonicity ([7.5.2](#))].

An [ISO 21127](#) class is declared when:

- it is required as the domain or range of a property not appropriate to its superclass;
- it serves as a merging point of two [ISO 21127](#) class branches via multiple *IsA* (e.g. E25 Human-Made Feature). When the branch superclasses are used for multiple instantiation of an item, this item is in the intersection of the scopes. The class resulting from multiple *IsA* should be narrower in scope than the intersection of the scopes of the branch superclasses;
- it is useful as a leaf class (i.e. at the end of an [ISO 21127](#) branch) to domain communities building CIDOC CRM extensions or matching key domain classes from other models to the [ISO 21127](#) (e.g. E34 Inscription).

7.5 Monotonicity

7.5.1 Open World principle

This document's primary role is the meaningful integration of information in an Open World. The adoption of the Open World principle means that [ISO 21127](#) itself must remain fundamentally open and knowledge bases implemented using it should be flexible enough to receive new insights. At the model level, new classes and properties within this document's scope may be found in the course of integrating more documentation records or when new kinds of relevant facts come to the attention of its maintainers. At the level of the KBs, the need to add or revise information may arise due to numerous external factors. Research may open new questions; documentation may be directed to new or different phenomena; natural or social evolution may reveal new objects of study.

It is the aim of the maintainers of this document to respect the Open World principle and to follow the principle of monotonicity. Monotonicity requires that adding new classes and properties to the model or adding new statements to a knowledge base does not invalidate already modelled structures and existing statements.

7.5.2 Monotonicity of the document

A first consequence of this commitment, at the level of the model, is that this document aims to be monotonic in the sense of Domain Theory. That is to say, the existing [ISO 21127](#) constructs and the deductions made from them should remain valid and well-formed, even as new constructs are added by extensions to the [ISO 21127](#). Any extensions should be, under this method, backwards compatible with previous models. The only exception to this rule arises when a previous construct is considered objectively incorrect by the domain experts and thus subjected to corrective revision. Adopting the principle of monotonicity has active consequences for the basic manner in which classes and properties are designed and declared in this document. In particular, it forbids the declaration of complement classes, i.e. classes solely defined by excluding instances of some other classes.

For example:

FRBRoo^[14] extends [ISO 21127](#). In version 2.4 of FRBRoo, F51 Name Use Activity was declared as a subclass to the [ISO 21127](#) class E7 Activity. This class was added in order to describe a phenomenon specific to library practice and not considered within ISO 21127. F51 Name Use Activity describes the practice of an instance of E74 Group adopting and deploying a name within a context for a time-span. The creation of this extension is monotonic because no existing *IsA* relationship or inheritance of properties in [ISO 21127](#) are compromised and no future extension is ruled out. By way of contrast, if, to handle this situation, a subclass "Other Activity" had been declared, a non-monotonic change would have been introduced. This would be the case because the scope note of a complement class like "Other Activities" would forbid any future declaration of specializations of E7 Activity such as F51 Name Use Activity. In the case the need arose to declare a particular specialized subclass, a non-monotonic revision would have to be made, since there would be no principled way to decide which instances of "Other Activity" were instances of the new, specialized class and which were not. Such non-monotonic changes are extremely costly to end users, compromising backwards compatibility and long-term integration.

7.5.3 Monotonicity of the data

As a second consequence, maintaining monotonicity is also required during revising or augmenting data within an [ISO 21127](#) compatible system. That is, existing [ISO 21127](#) instances, their properties and the deductions made from them, should always remain valid and well-formed, even as new instances, regarded as consistent by the domain expert, are added to the system.

For example:

If someone describes correctly that an item is an instance of E19 Physical Object, and later it is correctly characterized as an instance of E20 Biological Object, the system should not stop treating it as an instance of E19 Physical Object. This is achieved by declaring E20 Biological Object as subclass of E19 Physical Object.

This example further demonstrates that the IsA hierarchy of classes and properties can represent characteristic stages of increasing knowledge about some item during the processes of investigation and collection of evidence. Higher level classes can be used to safely classify objects whose precise characteristics are not known in the first instance. An ambiguous biological object may, for example, be classified as only a physical object. Subsequent investigation can reveal its nature as a biological object. A knowledge base constructed with [ISO 21127](#) classes designed to support monotonic revision allows for seeking physical objects that were not yet recognized as biological ones. This ability to integrate information with different specificity of description in a well-defined way is particularly important for large-scale information integration. Such a system supports scholars being able to integrate all information about potentially relevant phenomena into the information system without forcing an over or under commitment to knowledge about the object. Since large scale information integration always deals with different levels of knowledge of its relevant objects, this feature enables a consistent approach to data integration.

7.5.4 Monotonicity of the knowledge base

A third consequence, applied at the level of the knowledge base, is that in order to formally preserve monotonicity, when it is required to record and store alternative opinions regarding phenomena all formally defined properties should be implemented as unconstrained (many: many) so that conflicting instances of properties are merely accumulated. Thus, integrated knowledge can serve as a research tool for accumulating relevant alternative opinions around well-defined entities, whereas conclusions about the truth are the task of open-ended scientific or scholarly hypothesis building.

For example:

King Arthur's basic life events are highly contested. Once entered in a knowledge base, he should be defined as an instance of E21 Person and treated as having existed as such within the sense of our historical discourse. The instance of E21 Person is used as the collection point for describing possible properties and existence of this individual. Alternative opinions about properties, such as the birthplace and his living places, should be accumulated without validity decisions being made during data compilation. King Arthur may be entered as a different instance, of E28 Conceptual Object, for describing him as mythological character and accumulating possibly mythological facts.

7.5.5 Monotonicity and time-dependent properties

The fourth consequence of monotonicity relates to the use of time dependent properties in a knowledge base. Certain properties declared in this document, such as having a part, an owner or a location, may change many times for a single item during the course of its existence. Asserting that such a property holds for some item means that that property held for some particular, undetermined time-span within the course of its existence. Consequently, one item may be the subject of multiple statements asserting the instantiation of that property without conflict or need for revision. The collection of such statements would reflect an aggregation of these instances of this property holding over the time-span of the item's existence. If a more specific temporal knowledge is required/available, it is recommended to explicitly describe the events leading to the assertion of that property for that item. For example, in the case of acquiring or losing an item, it would be appropriate to declare the related event class such as

E9 Move. By virtue of this principle, this document achieves monotonicity with respect to an increase of knowledge about the states of an item at different times, regardless of their temporal order.

Time-neutral properties may be specialized in a future monotonic extension by time-specific properties, but not vice-versa. Also, many properties registered do not change over time or are relative to events in the model already. Therefore, this document always gives priority to modelling properties as time-neutral, and rather representing changes by events.

However, for some of these properties many databases may describe a “current” state relative to some property, such as “current location” or “current owner”. Using such a “current” state means that the database manager is able to verify the respective reality at the latest date of validity of the database. Obviously, this information is non-monotonic, i.e. it requires deletion when the state changes. In order to preserve a reduced monotonicity, these properties have time-neutral superproperties by which respective instances can be reclassified if the validity becomes unknown or no longer holds. Therefore, the use of such properties in [ISO 21127](#) is only recommended if they can be maintained consistently. Otherwise, they should be reclassified by their time-neutral superproperties. This holds in particular if data is exported to another repository [see also Authorship of Knowledge Base Contents ([7.2](#))].

7.6 Disjointness

Classes are disjoint if they cannot share any common instances at any time, past, present or future. That implies that it is not possible to instantiate an item using a combination of classes that are mutually disjoint or with subclasses of them [see multiple instantiation ([3.15](#))]. There are many examples of disjoint classes in this document.

A comprehensive declaration of all possible disjoint class combinations afforded by this document has not been provided here; it would be of questionable practical utility and would easily become inconsistent with the goal of providing a concise definition. However, there are two key examples of disjoint class pairs that are fundamental to an effective comprehension of the ontology:

- E2 Temporal Entity is disjoint from E77 Persistent Item. Instances of the class E2 Temporal Entity endure, whereas instances of the class E77 Persistent Item are endurants. Even though instances of E77 Persistent Item have a limited existence in time, they are fundamentally different in nature from instances of E2 Temporal Entity because they preserve their identity between events. Declaring enduring and perdurants as disjoint classes is consistent with the distinctions made in data structures that fall within the standard’s practical scope.
- E18 Physical Thing is disjoint from E28 Conceptual Object. The distinction is between material and immaterial items, the latter being exclusively human-made. Instances of E18 Physical Thing and E28 Conceptual Object differ in many fundamental ways; for example, the production of instances of E18 Physical Thing implies the incorporation of physical material, whereas the production of instances of E28 Conceptual Object does not. Similarly, instances of E18 Physical Thing cease to exist when destroyed, whereas an instance of E28 Conceptual Object perishes only when it is forgotten and its last physical carrier is destroyed.

8 Introduction to the basic concepts

8.1 General

This subclause explains the most general logic of this document. [ISO 21127](#) is a formalized representation of historical discourse, a formal ontology. In this capacity, it is meant to support the (re)presentation of fact based, analytic discourse about what has happened in the past in a human understandable and machine-processable manner. It achieves this function by proposing a series of formalized properties (relations) and classes. The formalized properties support the making of semantically explicit statements relating classes of things. Their formal definition logically explicates the classes of things to which they may pertain. [ISO 21127](#) properties thus enable a formal, logically explicit description of relations between individual, real world items, classified under distinct ontological classes.

Encoding analytic data pertaining to the past under such a system of statements provides a standard representation for data and allows the uniform application of reasoning to large sets of data.

Grounding this high-level logic is a hierarchical system of classes and relations, that provide basic ontological distinctions by which to represent historical discourse. Familiarity with the basic ontological distinctions made in the top level of the class hierarchy provides the basic entry point to understanding how to apply [ISO 21127](#) for knowledge representation.

The highest-level distinction in this document is represented by the top-level concepts of E77 Persistent Item, equivalent to the philosophical notion of *endurant*; E2 Temporal Entity, equivalent to the philosophical notion of *perdurant* and, further, the concept of E92 Spacetime Volume.

As an event-centric model, supporting historical discourse, this document firstly enables the description of entities that are themselves time-limited processes or evolutions within the passing of time using E2 Temporal Entity and its subclasses. Their basic function is to capture the fact of something having happened over time. In addition to allowing the description of a temporal duration, the subclasses of E2 Temporal Entity are used to document the historical relations between objects, similar to the role of action verbs in a natural language phrase. The more specific subclasses of E2 Temporal Entity enable the documentation of events pertaining to individually related/affected material, social or mental objects that have been described using subclasses of E77 Persistent Item. This precise documentation is enabled through the use of specialized properties formalizing the manner of the relation or affect. Examples of specific subclasses of E2 Temporal Entity include E12 Production, which allows the representation of events of making things by humans, and E5 Event which allows the documentation, among other things, of geological events and large-scale social events such as a war. Each of these subclasses have specific properties associated to them which allow them to function to represent the specific, real-world connection between instances of E77 Persistent Item, such as the relation of an object to its time of production through *P108i was produced by* (E12) or the relation of a place to a geological phenomenon through *P7i witnessed* (E5). The entities that E2 Temporal Entity documents, being time limited processes/occurrences, are such that their existence can be declared only on the basis of direct observation or recording of the event, or indirect observation of its material outcomes. Evidence of such entities may be preserved on material objects that are permanently changed because of them. Likewise, events may have been recorded in text or remembered through oral history. E2 Temporal Entity and its subclasses are central to this document and essential for almost all modelling tasks (e.g. in a museum catalogue one cannot consider an object outside its production event).

The real-world entities, which the event centric modelling of this document aims to enable the accurate historical description of, are captured through E77 Persistent Item and its subclasses. E77 Persistent Item is used to describe entities that are relatively stable in form through the passage of time, maintaining a recognizable identity because their significant properties do not change. Specific subclasses of E77 Persistent Item can illustrate this point. E22 Human-Made Object is used for the description of discrete, physical objects having been produced by human action, such as an artwork or monument. An artwork or monument is persistent with regards to its physical constitution. So long as it retains its general physical form, it is said to exist and to participate in the flow of historical events. E28 Conceptual Object is also used to describe persistent items, but of a mental character. It is used to describe identifiable ideas that are named and form an object of historical discourse. Its identity conditions rely in having a carrier by which it can be recalled. The entities described by E77 Persistent Item are prone to change through human activity, biological, geological or environmental processes, but are regarded to continue to exist and be the same just as long as such changes do not alter their basic identity (essence) as defined in the scope note of the relevant class.

The notion of identity is key in the application of [ISO 21127](#). The properties and relations it provides are designed to allow the accurate historical description of the evolution of real-world items through time. This being the case, classes and properties are created in order to provide a definition, which will allow the accurate application of the classes or properties to the same real-world items by diverse users. Identity, in the sense of [ISO 21127](#), therefore, means that informed people are able to agree that they refer to the same, single thing in its distinction from others, both in its extent and over its time of existence. The criteria for such a determination should come from understanding the scope note of the respective [ISO 21127](#) class this thing is regarded to be an instance of, because communication via information systems may not leave space for respective clarifying dialogues between users. For

example, the Great Sphinx of Giza may have lost part of its nose, but there is no question that people are still referring to the same monument as that before the damage occurred, since it continues to represent significant characteristics and distinctness from an overall shaping in the past, which is of archaeological relevance. Things lacking sufficient stability or differentiation, such as atmosphere, soil, clouds, waves, are not instances of E77 Persistent Item, and not suited for information integration. Discourse about such items may be documented with concepts of [ISO 21127](#) as observations in relation to things of persistent identity, such as places.

Learning to distinguish and then interrelate instances of E77 Persistent Item (endurants) and instances of E2 Temporal Entity (perdurants) using the appropriate properties is key to the proper understanding and application of [ISO 21127](#) in order to formally represent analytic historical data. In the large majority of cases, the distinction this provides, and the subsequent elaboration of subclasses and properties is adequate to describe the content of database records in the cultural and scientific heritage domain. In exceptional cases, where there is a need to consider complex combinations of changes of spatial extent over time, the concept of spacetime (E92 Spacetime Volume) also needs to be considered. E92 Spacetime Volume describes the entities whose substance has or is an identifiable, confined geometrical extent in the material world that may vary over time, fuzzy boundaries notwithstanding. For example, the built settlement structure of the city of Athens is confined both from the point of view of time-span (from its founding until now) and from its changing geographical extent over the centuries, which may become more or less evident from current observation, historical documents and excavations. Even though E92 Spacetime Volume is an important theoretical part of the model, it can be ignored for most practical documentation and modelling tasks.

The key to the proper understanding of this document comes through the appropriation of its basic divisions and the logic these represent. It is important to underline that [ISO 21127](#) is not intended to function as a classification system or vocabulary tool. The basic class divisions in this document are declared in order to be able to apply distinct properties to these classes and, in so doing, formulate precise, analytic propositions that represent historical realities. The expressive power of [ISO 21127](#) comes not from the application of classes to classify entities but in the documenting the interrelation of individual historical items through well-defined properties. These properties characteristically cover subjects such as relations of identifying items by names and identifiers; participation of persistent items in temporal entities; locations of temporal entities and physical things in space and time; relations of observation and assessment; part-decomposition and structural properties of anything; influence of things and experiences on the activities of people and their products; and reference of information objects to anything.

The document explains these concepts with the help of graphical representations in the next sections.

8.2 Relations with events

8.2.1 General

[Figure 1](#) illustrates the minimal properties in this document for documenting “what has happened”, the central pattern of the model. First, consider the class E1 Entity, the formal top class of the model. It primarily serves a technical purpose to aggregate the ontologically meaningful concepts of the model. It declares however two important properties of general validity and distinct features of the model: *P1 is identified by*, with range E41 Appellation, makes the fundamental ontological distinction between the identity of a particular and an identifier (see [7.1](#)), and in practice allows for describing a discourse about resolving historical ambiguities of names and reconciliation of multiple identifiers. The property *P2 has type*, with range E55 Type, constitutes a practical interface for refining classes by terminologies, being often volatile, as detailed in [8.3.1](#).

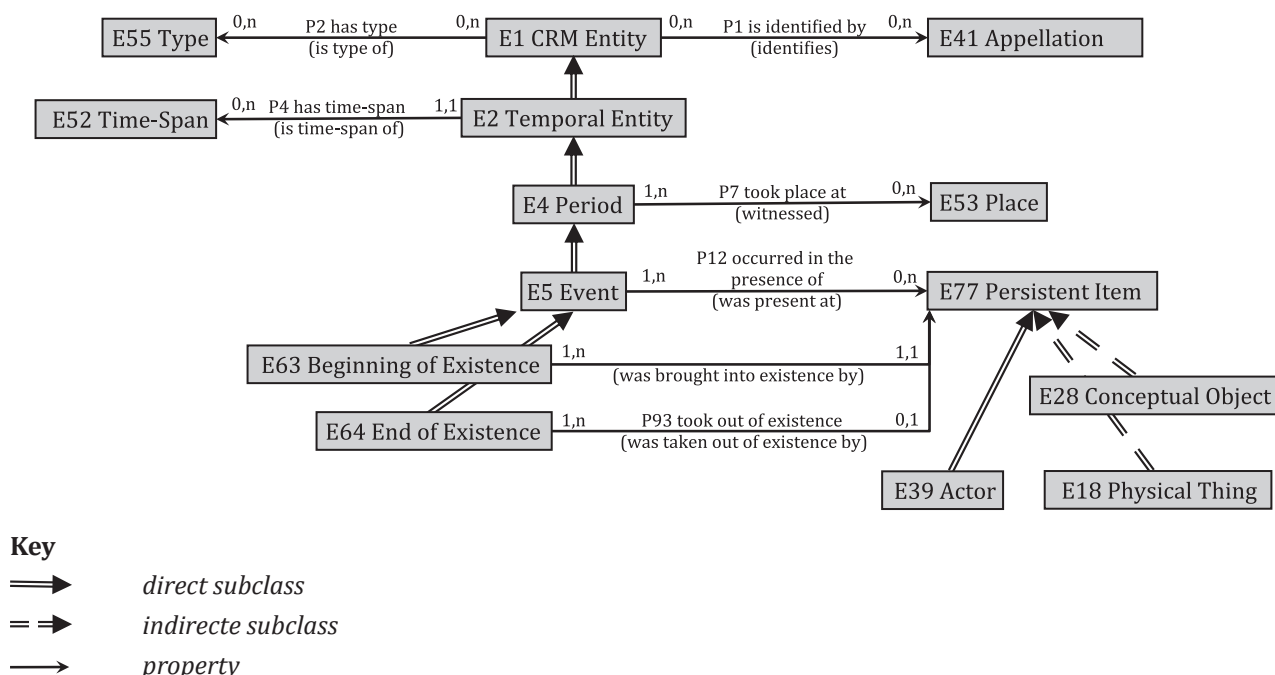


Figure 1 — High level properties and classes of ISO 21127

All classes in [Figure 1](#) are direct or indirect subclasses of E1 Entity, but for better readability, only the “subclass of” link from E2 Temporal Entity is shown. The latter comprises phenomena that continuously occur over some time-span (E52 Time-Span) in the natural time dimension, but some of them may not be confined to specific area, such as a marriage status. Further specializing, E4 Period comprises phenomena occurring in addition within a specific area in the physical space, which can be specified by *P7 took place at*, with range E53 Place. Instances of E4 Period can be of any size, such as the Warring States Period, the Roman Period, a siege or just the process of making a signature. Further specializing, E5 Event comprises phenomena involving and affecting certain instances of E77 Persistent Item in a way characteristic of the kind of process, which can be specified by the property *P12 occurred in the presence of*. This concept of presence is very powerful: it constrains the existence of the involved things to the respective places within the specified time and implies the potential of passive or active involvement and mutual impact. Via presence, events represent nodes in a network of things meeting in various combinations in the course of time at different places.

The most important specializations of E77 Persistent Item in this context are: E39 Actor, those capable of intentional actions, E18 Physical Thing, having an identity bound to a relative stability of material form, and E28 Conceptual Object, the idealized things that can be recognized but have an identity independent from the materialization on a specific carrier. The property *P12 occurred in the presence of* has 36 direct and indirect subproperties, relating these and many more subclasses of E5 Event and E77 Persistent Item. Regardless whether an [ISO 21127](#) ontology-compatible knowledge base is created with these properties only or with their much more expressive specializations, querying for the five high-level properties in [Figure 1](#) will provide answer to all “Who-When-Where-What-How” questions, and allow for retrieving potentially richly elaborated stories of people, places, times and things.

This pattern of “meeting” is complemented by two more subclasses of E5 Event: E63 Beginning of Existence and E64 End of Existence, which imply not only presence, but constitute the endpoints of existence of things and people in space and time, often in explicit presence and interaction with others, be they causal by producing or consuming or just witnessing. Note that the model supports multiple instantiation. As a consequence, particular events can be instances of combinations of these and other classes, describing tightly integrated processes of multiple nature. The representation of things connected in events by presence, beginning and end of existence is sufficient to describe the logic of termini postquos and antequos, a major form of reasoning about chronology in historical studies.

As a simple, real example of applying the above concepts this document presents a historical event, relevant for the history of art: Johann Joachim Winckelmann (a German Scholar) has seen the so-called Laocoön Group in 1755 in the Vatican in Rome (at display in the Cortile del Belvedere). He described his impressions in 1764 in his “History of the Art of Antiquity”, (being the first to articulate the difference between Greek, Greco-Roman and Roman art, characterizing Greek art with the famous words “...noble simplicity, silent grandeur”). The sculpture, in Hellenistic “Pergamene baroque” style^{[20][33]} is widely assumed to be a copy, made between 27 BC and 68 AD (following a Roman commission) from a Greek (no more extent) original. Johann Joachim Winckelmann was born 1717 as child of Martin Winckelmann and Anna-Maria Meyer and died in 1768 in Trieste.

Figure 2 presents a semantic graph of this event, as described above, using ISO 21127 concepts. The facts in parentheses above are omitted for better clarity. Instances of classes are represented by informative labels instead of identifiers, in boxes showing the class label above the instance label. Properties are represented as arrows with the property label attached. After class labels and property labels, the identifiers of the respective superclasses and superproperties from Figure 1 are shown in parentheses, in order to demonstrate that the story can be represented and queried with these concepts only. It also shows how concept specialization increases expressiveness without losing genericity. It is noteworthy that the transfer of information from the Greek original, to the copy, to the mind of Winckelmann and into his writings can be solely understood by this chain of things being present in different meetings. Note also that the degree to which a fact is believed to be real does not affect the choice of ISO 21127 concepts for description of the fact, nor the reality concept underlying the model.

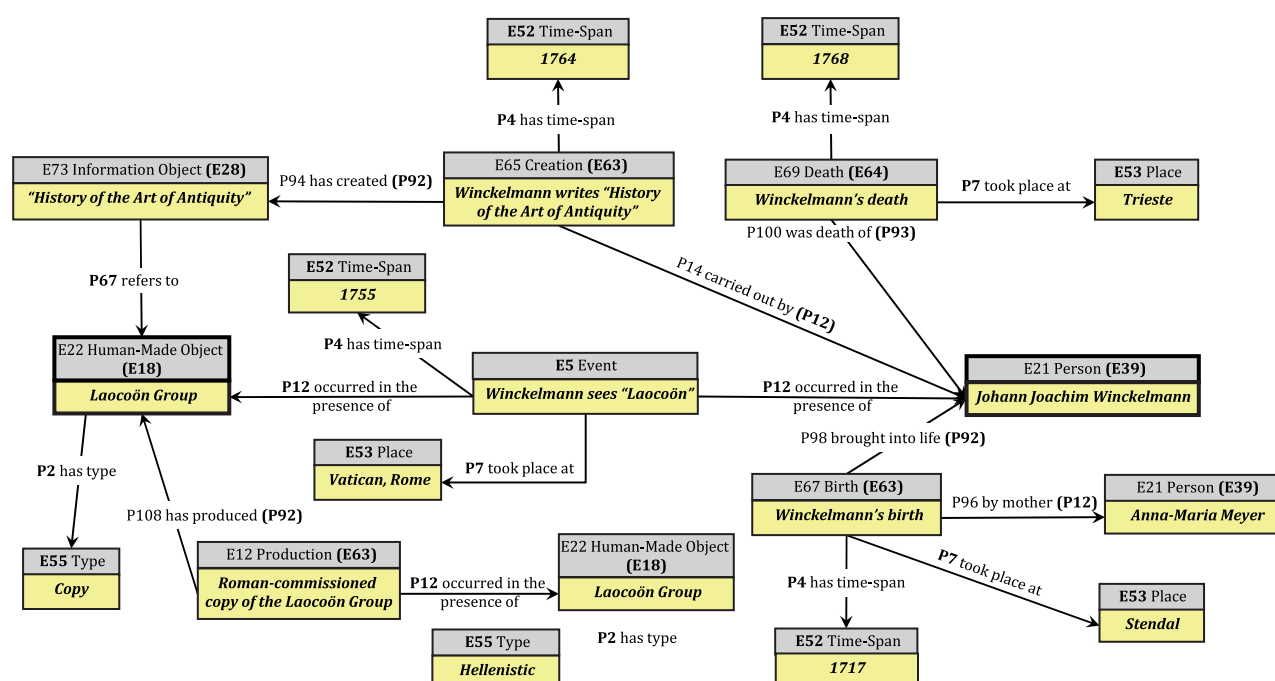


Figure 2 — ISO 21127 encoding example — Winckelmann seeing Laocoön

Figure 2 represents in addition one more top-level property of ISO 21127: *P67 refers to*, which describe an evidence-based fact that an information object makes reference to an identifiable item.

As mentioned above, the central concept of ISO 21127 is the representation of a part of reality that can be approximated as a network of things meeting in various combinations in spacetime. Using the same example from above, Figure 3 illustrates this concept via an alternative symbolic representation. It aims at rendering the idea that people and things in the past have performed mostly unknown trajectories in spacetime, and the historical facts known constrain their possible whereabouts for some limited time-spans to having been together at some known or unknown place.

This document uses a one-dimensional representation of space, as used in archaeology to describe the spatial evolution of periods or cultures over time, and a vertical time axis. This document symbolizes

the trajectories of things and people as fuzzy lines between events in order to render their relative indeterminacy between known events. Non-animate things use to be stationary if not transferred, whereas people may move around on their own. This document symbolizes events as fuzzy ovals to render the fuzzy boundaries of events in space and time. Note that in this representation, as a general pattern, things may “survive” events, emerge from events or end in events. Beginning and ending of existence impose an additional temporal order on events of causal nature, which can be stronger than explicit dates. This document symbolizes the unreported ends of existence of people and things, which are also events, by a dot at the end of the trajectory.

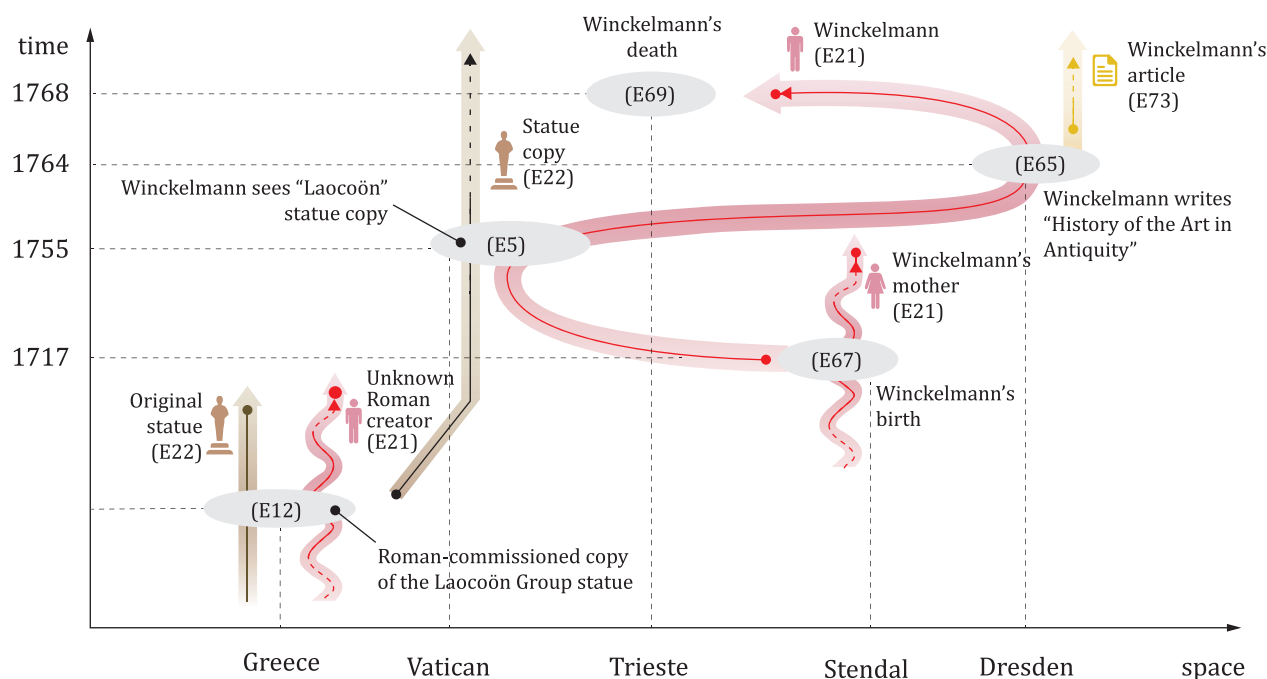


Figure 3 — Symbolic representation of "Winckelmann seeing Laocoön" as an evolution in space and time

In 8.2.2, an overview of the system of spatial and temporal relations in ISO 21127 is presented, because it constitutes an important tool for precise documentation of the past and has a certain complexity that needs to be understood in a synopsis.

8.2.2 Spatial relations

8.2.2.1 Documenting spatial relations

A major area of documentation and historical research centres around positioning in space of what has happened and the things involved, as well as reasoning about respective spatial relations. The key class ISO 21127 provides for modelling this information is E53 Place. E53 Place is used to document geometric extents in the physical space containing actual or possible positions of things or happenings. The higher-level properties and classes of ISO 21127 that centre around E53 Place allow for the documentation of: relations between places; recording the geometric expressions defining or approximating a place and their semantic function; tracing the history of locations of a physical object; identifying the places where an individual or group have been located; identifying places on a physical object and the spatial extent of certain temporal entities.

8.2.2.2 Geometric expressions of place

Contemporary documentation of spatial information has access to advanced equipment for accurately recording location and libraries of georeferenced place information. For this reason, documentation of place now often includes the recording of precise coordinates for a referenced place. Of great importance

semantically, is to understand the manner in which such a geometric place expression actually relates to a referenced place. The cluster of relations *P168 place is defined by*, *P171 at some place within*, and *P172 contains* allows the user to link to geometric place expressions while also accurately indicating how this expression relates to the documented place. Geometric place expressions are instances of E94 Space Primitive, a primitive class for expressing values in data systems not further analysed in this document. These properties provide a valid interface to the OGC standards, as elaborated in CRMgeo[78].

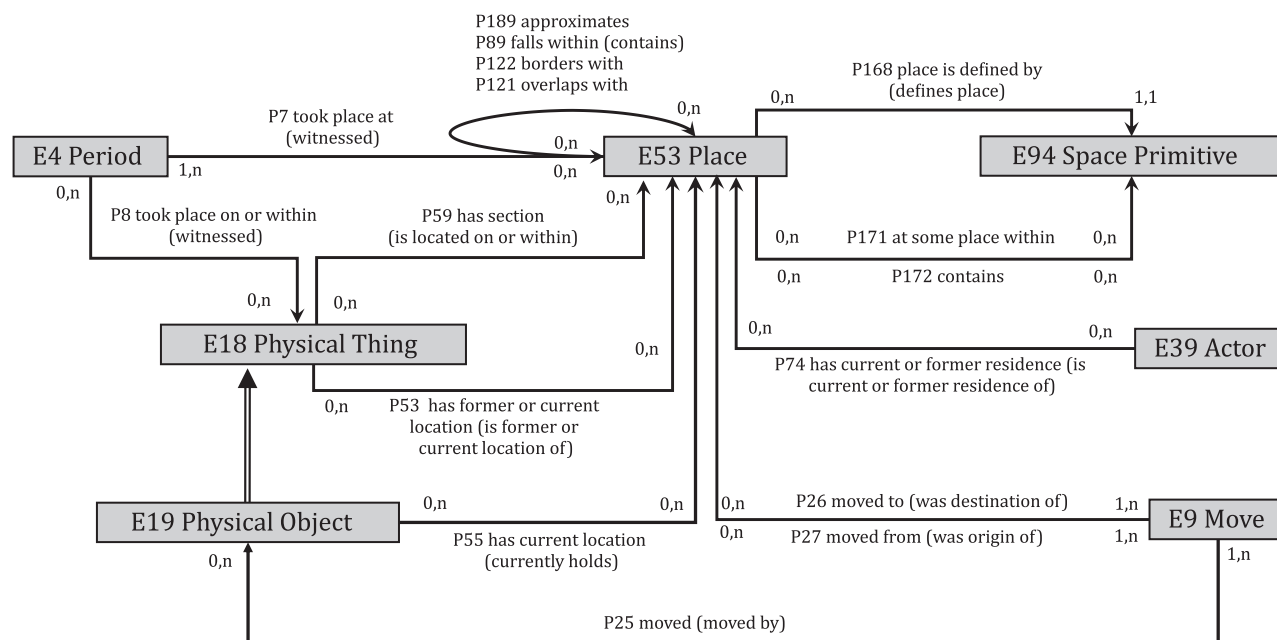


Figure 4 — Basic ISO 21127 properties and classes for reasoning about spatial information

8.2.2.3 Relations between places

The cluster of relations *P89 falls within (contains)*, *P122 borders with*, *P121 overlaps with* and *P189 approximates* can express relative relationships held between places. These properties hold between instances of E53 Place and allow interordering places using common mereotopological concepts.

8.2.2.4 History of object locations

Instances of place are often referenced in order to record the location of some object. When the movement of the object to different locations through time is of interest, it is also important to be able to analytically record the different locations at which an object was and at what point. This document offers two top level mechanisms for tracing the relation of objects to places. If the aspect of time is unknown or not of interest, then an object can be related to a place through the properties *P53 has former or current location* and *P55 has current location*. The former property is the conservatively appropriate choice for documenting the object-to-place relation when time elements are not known. If one is actively tracking current location, the latter property is also of use. When an accurate history of the temporal aspect of location should be provided, the user should take advantage of the class E9 Move, a temporal entity class. Instantiating E9 Move allows the user to document the origin, destination and concerned object of a move event using the collection of properties *P27 moved from*, *P26 moved to*, *P25 moved*. Being a temporal class E9 Move further allows the tracing of time, agency etc. Note that things may be moved indirectly as parts of or within other things.

8.2.2.5 Actor locations

Tracking the history of the location of actors is related to the history of object location with a significant difference: in [ISO 21127](#) an actor is defined as an entity featuring agency which is not the case in objects and physical entities in general. Not being physical, an Actor cannot be the subject of an instance of E9 Move which documents physical relocations. [ISO 21127](#) thus offers the notion of *P74 has current residence*.

former residence in order to document the relation of a person or group to a location as residing there at some time.

8.2.2.6 Places on a physical object

In the recording of cultural heritage and other scientific data, particularly about mobile objects, including ships, it is often necessary to identify where on an object or a certain feature is located and where a certain phenomenon is observed. For this, [ISO 21127](#) offers the relation *P59 has section* relating the object to the places which are defined upon it. Note that Earth is the physical object people relate places to per default. In geological times, a narrower relation to a tectonic plate may be necessary.

8.2.2.7 Spatial extent of temporal entities

In order to spatially define the extent of temporal phenomena, [ISO 21127](#) offers two properties that apply to all instances of temporal entity under the class E4 Period: *P7 took place at* and *P8 took place on or within*. The former is used to relate a temporal phenomenon directly to an instance of E53 Place which provides the geometric context in which that phenomenon took place. The latter property allows the documentation of a temporal phenomenon taking place in relation to a physical object. This is useful for recording information such as the occurrence of an event on a moving ship or within a particular storage container, where the geometric location is not known or indirectly relevant.

8.2.3 Temporal relations

8.2.3.1 Documenting temporal relations

Historical and scientific discourse about the past deals with different levels of knowledge regarding events and their temporal ordering that feed into chronology. Chronology is fundamental to understanding social and natural history, and reasoning about temporal relations and causality is directly related. An immense wealth of physical observations allows for inferring temporal relations and vice-versa. It is important to be able to document temporality both with regards to known dates but also according to relative positioning within a historical timeline. The top-level properties of [ISO 21127](#) relating to temporal entities support the documentation of: dates as time-spans or dimensions, mereological relations between temporal entities as well as a complete suite of topological relations.

8.2.3.2 Dates and durations

When some absolute dates limiting a temporal entity are known, this can be documented by instantiating the *P4 has time-span* property and creating an instance of E52 Time-span. Dates should then be recorded as instances of E61 Time Primitive and related to the time-span through properties *P81 ongoing throughout* or *P82 at some time within*. Time is recorded as a span and not an instant in this document. The choice of property *P81 ongoing throughout* allows the documentation of knowledge that a temporal phenomenon was occurring at least at all points of a known time-span. The property *P82 at some time within* allows the weaker claim that the phenomenon must have occurred within the limits of a particular time-span without further specifying as to when precisely. It is the default for historical dates, given, for instance, in years for events of much smaller duration. The actual mode of encoding the documented date is outside the scope of this document, which defines this with a primitive class, E61 Time Primitive. Finally, the property *P191 had duration* can be deployed in order to document a temporal phenomenon with known duration but with less precisely temporal positioning. For instance, a birth may be known with the precision of a year, but with a duration of 3 hours. For documenting exact time-spans that are result of a declaration rather than observation, for instance in order to describe a time-span multiple events may fall into, the property *P170 defines time* allows for specifying the time-span uniquely by a temporal primitive, rather than by *P81 ongoing throughout* or *P82 at some time within* using an identical time primitive.

P173 starts before or at the end of (ends with or after the start of)
P174 starts before (starts after the start of)
P175 starts before or with the start of (starts with or after the start of)
P176 starts before the start of (starts after the start of)
P182 ends before or at the start of (starts with or after the end of)
P183 ends before the start of (starts after the end of)
P184 ends before or with the end of (ends with or after the end of)
P185 ends before the end of (ends after the end of)

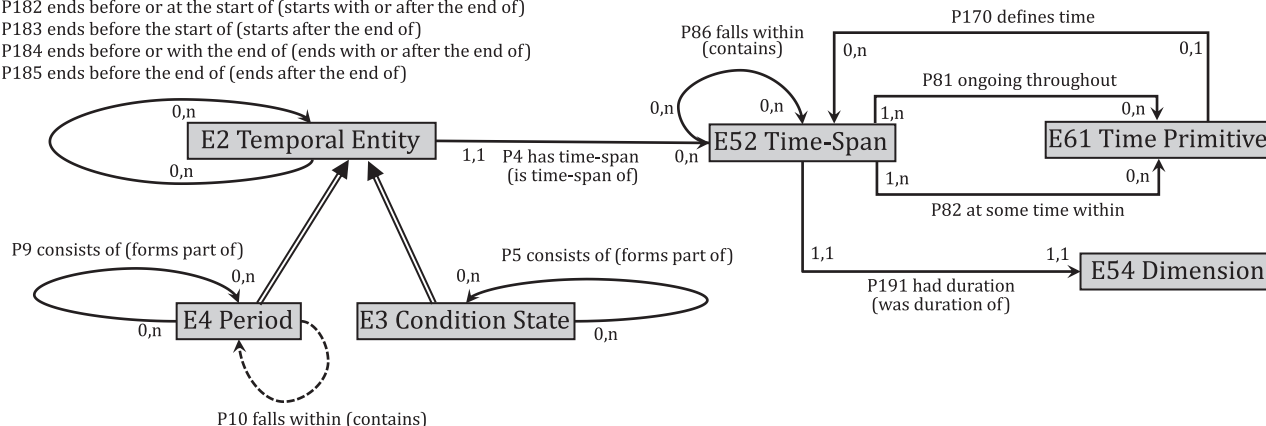


Figure 5 — Basic ISO 21127 properties and classes for reasoning about temporal information

8.2.3.3 Mereological relations

The documentation of the part-whole relationship of temporal phenomena is crucial for historical reasoning. This document distinguishes under temporal entities two immediate specializations: E4 Period is a high-level concept for the documentation of temporal phenomena of change and interactions in space and time, comprising but not limited to historical periods such as Ming or Roman, and is further specialized in rich hierarchy of more specific processes and activities. The second specialization is E3 Condition State, a rather specific class for the documentation of static phases of physical things. This document so far does not describe a higher-level class of static phases, because they are normally deductions from multiple observations, problematic in information integration and vulnerable to non-monotonic revision. For both classes, two different mereological relations are articulated: The property *P9 consists of* is used to document proper parthood between instances of E4 Period, i.e. to describe how the phenomena that make up an instance of E4 Period can causally be subdivided into more delimited phenomena. In contrast, the property *P10 falls within*, explained further in the section about spatiotemporal relations, describes only a non-causal co-occurrence in the same spatiotemporal extent. The property *P5 consists of* indicates, in analogy, proper parthood between instances of E3 Condition State.

8.2.3.4 Topological relations

A lot of semantic relations have implications on the temporal ordering of temporal entities. For instance, meeting someone must occur after birth and before death of the involved parties. Information can only be transferred after it has been learned. On the other side, direct information about temporal order has implications on possible or impossible semantic relations. This form of reasoning is of paramount importance for research about the past. It turned out that the popular temporal relations defined by Reference [5], which this document had adopted in previous versions, are not well suited to describe inferences from semantic relations, as detailed in 8.3.2. Instead, this document introduces a theory of fuzzy boundaries in time that enables the accurate interpositioning of temporal entities between themselves taking into account the inherent fuzziness of temporal boundaries. This model subsumes the earlier introduced Allen temporal relations which may continue to be used in extensions of this document.

8.2.4 Spatiotemporal relations

8.2.4.1 Introducing spatiotemporal relations

Treating space and time as separate entities is normally adequate for describing events and where things are. When more precise documentation and reasoning is required about phenomena spreading out over time, such as Bronze Age, a settlement, a nation, moving reference frames such as ships, things being stored in containers and moved around, built structures being partially destroyed, rebuilt and altered etc., space and time shall be understood as a coherent continuum, the so-called spacetime. This is not a familiar concept for many users, and those not interested in such details may therefore skip this section.

However, the respective model this document adopts constitutes a valid interface to the OGC standards, as elaborated in CRMgeo[28] and important for connecting to GIS applications. The key class [ISO 21127](#) provides for modelling this information is E92 Spacetime Volume. E92 Spacetime Volume is used to document geometric extents in the physical spacetime containing actual or possible positions of things or happenings, in particular in those cases when the changes of place to be documented cannot be reduced to distinct events, because the spatial extent changes continuously. The higher-level properties and classes of [ISO 21127](#) that centre around E92 Spacetime Volume allow for the documentation of: relations between spacetime volumes, relations to space and time as separate entities, and treating the exact extent of physical things and periods in space at any time of their existence as spacetime volumes. Its use is particularly elegant for the description of temporal gazetteers.

8.2.4.2 Defining a spacetime volume

There are three ways to define a spacetime volume.

- a) The property *P169 defines spacetime volume* should be used to declare a spatiotemporal container for some things or happenings in terms of spatial coordinates that may vary over time, be it in discrete steps or continuously with the help of spacetime expressions. The latter are instances of E95 Spacetime Primitive, a primitive class for expressing values in data systems not further analysed in [ISO 21127](#).
- b) Instances of E4 Period are regarded to be specialized instances of E92 Spacetime Volume that are formed by the spreading out of the phenomena that make up an instance of E4 Period. As such they are fuzzy but in general observable.
- c) The continuous sequence of spatial extent that the matter of an instance of E18 Physical Thing occupies in the course of time, defines a spacetime volume unique to it from the beginning of its existence to its end, which can also be understood as its trajectory through the universe. The property *P169 defines* allows for referring to this spacetime volume, in order to document its additional properties. As such this spacetime volume is fuzzy but in general observable. It is not easy to make a mental picture of the spacetime volume of a physical thing, but the construct simplifies all reasoning about where things have been.

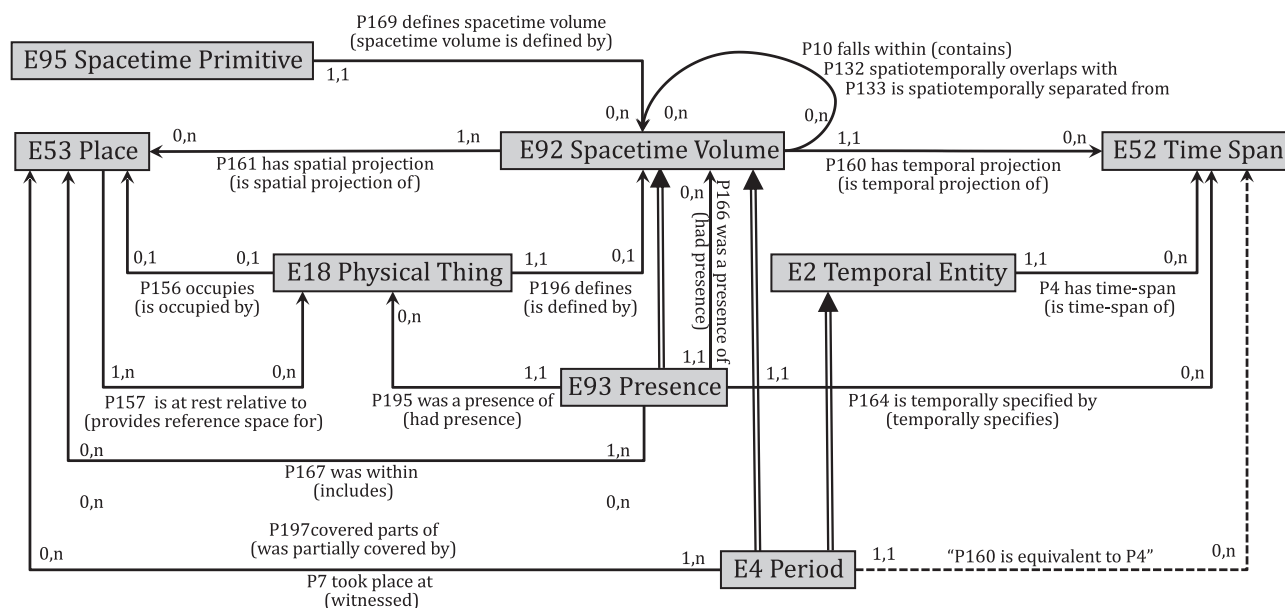


Figure 6 — Basic ISO 21127 properties and classes for reasoning with spacetime volumes

8.2.4.3 Relations with places and physical things

The property *P161 has spatial projection* associates a spacetime volume with the complete spatial extent it has occupied during its time-span of definition. Due to relativity of space, the definition of an instance of E53 Place shall be relative to some physical thing as geometric reference. This can explicitly be documented with the property *P157 is at rest relative to*. If the place where something is at a certain point in time is given in multiple reference spaces in relative movement, such as with respect to a ship versus to the seafloor, these differently defined places may later move apart. Therefore, a spacetime volume, even though uniquely defined, can have any number of spatial projections, depending on the reference space. Currently, the GPS system defines a default reference space on the surface of Earth. In art conservation and other descriptions of mobile object of fixed shape, it is useful to refer to the precise place a physical thing occupies with respect to itself as reference space via *P156 occupies*, for further analysis. *P156 occupies* constitutes a particular projection of the spacetime volume of this thing. In contrast, the property *P53 has former or current location* only describes that a thing was within a specific place given in some reference space for an undefined time.

8.2.4.4 Relations with time-spans and periods

The property *P160 has temporal projection* associates a spacetime volume with the complete temporal extent it has covered comprising all places of its definition. In contrast to places, the reference system of time is unique¹¹⁾ except for the choice of origin. For instances of E4 Period and its subclasses, which inherit *P160 has temporal projection*, the property is actually identical with the property *P4 has time-span* inherited from E2 Temporal Entity, because it describes the temporal extent of the phenomena that make up an instance of E4 Period. Therefore, it is recommended to use *P4 has time-span* for instances of E4 Period and its subclasses, rather than *P160 has temporal projection*.

8.2.4.5 Relations of presence

Instances of E3 Presence are specialized instances of E2 Spacetime Volume that are identical with the spatial evolution of a larger spacetime volume specified by *P166 was presence of*, but delimited to a, normally short, time-span declared by *P164 is temporally specified by*. In other words, they constitute “snapshots” or “time-slices” of another spacetime volume, such as the extent of the Roman Empire

11) This holds for applications in the scope of [ISO 21127](#), which are in the non-relativistic area, but not strictly, for instance, for satellites.

during 30AD. They are the basic construct to describe exactly where something was or happened at a particular time(-span), in connection with the property *P161 has spatial projection*. In particular, it allows for describing the whereabouts of mobile objects, be it in the storage of a museum, a palace, deposited in the ground, or transported in a container, such as the bone of a saint. For ease of use, a shortcut *P195 was presence of* is defined directly to E18 Physical Thing, bypassing the definition of its spacetime volume.

8.2.4.6 Topological Relations

Finally, the model defines truly spatiotemporal topological relations. *P10 falls within (contains)* is the complete inclusion of one spacetime volume in another. It should not be confused with inclusion in the spatial and temporal projection, which may be larger. For example, in 14 AD, Mesopotamia was not within the Roman Empire. Further, the properties *P132 spatiotemporally overlaps with* and its negation *P133 is spatiotemporally separated from* are fundamental to argue about temporary parthood, possible continuity etc.

8.3 Specific modelling constructs

8.3.1 Types

Virtually all structured descriptions of museum objects begin with a unique object identifier and information about the “type” of the object, often in a set of fields with names like “classification”, “category”, “object type”, “object name”, etc. All these fields are used for terms that declare the object belongs to a particular category of items. The class E55 Type comprises concepts denoted by terms. Instances of E55 Type represent concepts (universals) in contrast to instances of Appellation which are used to name instances of [ISO 21127](#) classes.

For this purpose, this document provides two basic properties that describe classification with terminology, corresponding to what is the current practice in the majority of information systems. The class E1 Entity is the domain of the property *P2 has type (is type of)*, which has the range E55 Type. Consequently, every class in [ISO 21127](#), with the exception of E59 Primitive Value, inherits the property *P2 has type (is type of)*. This provides a general alternative mechanism to specialize the classification of [ISO 21127](#) instances to any level of detail, by linking to external vocabulary sources, thesauri, classification schemas or ontologies.

Analogous to the function of the *P2 has type (is type of)* property, some properties in [ISO 21127](#) are associated with an additional property. These are numbered in the [ISO 21127](#) documentation with a ‘.1’ extension. The range of these properties of properties always falls under E55 Type. The purpose of a property of a property is to provide an alternative mechanism to specialize its domain property through the use of property subtypes declared as instances of E55 Type. They are included as part of the property declarations and referred to in the class declarations. For example, *P62.1 mode of depiction*: E55 Type is associated with E24 Physical Human-Made Thing. *P62 depicts (is depicted by)*: E1 Entity.

The class E55 Type also serves as the range of properties that relate to categorical knowledge commonly found in cultural documentation. For example, the property *P125 used object of type (was type of object used in)* enables this document to express statements such as “this casting was produced using a mould”, meaning that there has been an unknown or unmentioned object, a mould, that was actually used. This enables the specific instance of the casting to be associated with the entire type of manufacturing devices known as moulds. Further, the objects of type “mould” would be related via *P2 has type (is type of)* to this term. This indirect relationship can help in detecting the unknown object in an integrated environment. On the other side, some casting may refer directly to a known mould via *P16 used specific object (was used for)*. So, a statistical question to how many objects in a certain collection are made with moulds could be answered correctly following both paths through *P16 used specific object (was used for)* - *P2 has type (is type of)* and *P125 used object of type (was type of object used in)*. This consistent treatment of categorical knowledge enhances ISO 21127’s ability to integrate cultural knowledge.

Types, that is, instances of E55 Type and its subclasses, can be used to characterize the instances of an [ISO 21127](#) class and hence refine the meaning of the class. A type ‘artist’ can be used to characterize

persons through *P2 has type (is type of)*. On the other hand, in an art history application of [ISO 21127](#) it can be adequate to extend the [ISO 21127](#) class E21 Person with a subclass E21.xx Artist. What is the difference of the type 'artist' and the class Artist? From an everyday conceptual point of view there is no difference. Both denote the concept 'artist' and identify the same set of persons. Thus, in this setting a type could be seen as a class and the class of types may be seen as a metaclass. Since current systems do not provide an adequate control of user defined metaclasses, [ISO 21127](#) prefers to model instances of E55 Type as if they were particulars, with the relationships described in the previous paragraphs.

Users may decide to implement a concept either as a subclass extending the [ISO 21127](#) class system or as an instance of E55 Type. A new subclass should only be created in case the concept is sufficiently stable and associated with additional explicitly modelled properties specific to it. Otherwise, an instance of E55 Type provides more flexibility of use. Users that may want to describe a discourse not only using a concept extending the [ISO 21127](#) but also describing the history of this concept itself, may choose to model the same concept both as subclass and as an instance of E55 Type with the same name. Similarly, it should be regarded as good practice to foresee for each term hierarchy refining an [ISO 21127](#) class a term equivalent of this class as top term. For instance, a term hierarchy for instances of E21 Person may begin with "Person".

One role of E55 Type is to be ISO 21127's interface to domain specific ontologies and thesauri or less formal terminological systems. Such sets of concepts can be represented in this document as subclasses of E55 Type, forming hierarchies of terms, i.e. instances of E55 Type linked via *P127 has broader term (has narrower term)*. Such hierarchies may be extended with additional properties. Other standard models, in particular richer ones, used to describe terminological systems can also be interfaced with this document by declaring their respective concept class as being equivalent to E55 Type, and their respective broader/narrower relation as being identical with *P127 has broader term (has narrower term)*, as long as they are semantically compatible.

In addition to being an interface to external thesauri and classification systems, E55 Type is an ordinary class in [ISO 21127](#) and a subclass of E28 Conceptual Object. E55 Type and its subclasses inherit all properties from this superclass. Thus, together with the [ISO 21127](#) class E83 Type Creation the rigorous scholarly or scientific process that ensures a type is exhaustively described and appropriately named can be modelled inside [ISO 21127](#). In some cases, particularly in archaeology and the life sciences, E83 Type Creation requires the identification of an exemplary specimen and the publication of the type definition in an appropriate scholarly forum. This is very central to research in the life sciences, where a type would be referred to as a "taxon," the type description as a "protologue," and the exemplary specimens as "original element" or "holotype".

Finally, instances of E55 Type or suitable subclasses can describe universals from type systems not organized in thesauri or ontologies, such as industrial product names and types, defined and published by the producers themselves for each new product or product variant.

8.3.2 Temporal relation primitives based on fuzzy boundaries

8.3.2.1 General

It is characteristic for sciences dealing with the past, such as history, archaeology or geology, to derive temporal topological relations from stratigraphic and other observations and from considerations of causality between events. For this reason, [ISO 21127](#) introduced, in version 1, the whole set of temporal relationships of Allen's temporal logic (the now deprecated properties *P114* to *P120*). It was regarded at that time as a well-justified, exhaustive and sufficient theory to deal with temporal topological relationships of spatiotemporal phenomena relevant to cultural historical discourse. Allen's temporal logic is based on the assumption of known, exact endpoints of time intervals (time-spans), described by an exhaustive set of mutually exclusive relationships.

Since many temporal relations can be inferred from facts causal to them, e.g. a birth necessarily occurring before any intentional interaction of a person with other individuals, or from observations of material evidence without knowing the absolute time, the temporal relationships pertain in the [ISO 21127](#) to E2 Temporal Entities, and not their Time-Spans, which require knowledge of absolute time. If absolute times are known, deduction of Allen's relation is a simple question of automated calculus and

not the kind of primary scientific insight [ISO 21127](#), as a core model, is interested in. However, their application turned out to be problematic in practice for two reasons:

Firstly, facts causal to temporal relationships result in expressions that often require a disjunction (logical or condition) of Allen's relationships. For instance, a child may be stillborn. Ignoring states at pregnancy as it is usual in older historical sources, birth may be equal to death, meet with death or be before death. The knowledge representation formalism chosen for [ISO 21127](#) however does not allow for specifying disjunctions, except within queries. Consequently, simple properties of [ISO 21127](#) that imply a temporal order, such as *P134 continued*, cannot be declared as subproperties of the temporal relationship they do imply, which would be, in this case: "before, meets, overlaps, starts, started-by, contains, finishes, finished-by, equals, during or overlapped by" (see *P174 starts before the end of*).

Secondly, nature does not allow observing equality of points in time. There are three possible interpretations to this fact. Common to all three interpretations is that they can be described in terms of fuzzy boundaries. The model proposed here is consistent with all three of these interpretations.

- a) Any observable phenomenon that can be dated has a natural temporal extent with fuzzy boundaries of gradual transition from not existing to definitely existing and then to no longer existing.
- b) These fuzzy boundaries can also be interpreted as the time intervals about which experts, even with a complete knowledge of the described phenomenon, may not agree as to whether this phenomenon is already ongoing or not, or still ongoing or not.
- c) Under a third interpretation, the fact that an instance of E2 Temporal Entity is ongoing is not observable within the fuzzy boundaries.

Consider, for instance, a birth. Extending over a limited and non-negligible duration in the scale of hours it begins and ends gradually (a), but can be given alternative scientific definitions of start and end points (b), and neither of these can be determined with a precision much smaller than on a scale of minutes (c). The fuzzy boundaries do not describe the relation of incomplete or imprecise knowledge to reality. Assuming a lowest granularity in time is an approach which does not help, because the relevant extent of fuzziness varies at a huge scale even in cultural reasoning, depending on the type of phenomena considered. The only exact match is between arbitrarily declared time intervals, such as the end of a year being equal to the beginning of the next year, or that "Early Minoan" ends exactly when "Middle Minoan" starts, whenever that might have been. Consequently, this document introduces here a new set of "temporal relation primitives" with the following characteristics:

- It is a minimal set of properties that allows for specifying all possible relations between two time intervals given by their start and end points, either directly, or by conjunction (logical and condition) of the latter.
- Start and end points are interpreted as "thick" fuzzy boundaries as described above.
- Conditions of equality of end points are relaxed to the condition that the fuzzy boundaries overlap. Therefore, knowledge of the shape of the fuzzy function is not needed.
- All of Allen's relationships can be expressed either directly or by conjunctions of these properties.
- In case of time intervals without or with negligibly short fuzzy boundaries, all of Allen's relationships can exactly be described by adequate conjunctions of these properties.

No relationship is equal to the inverse of another. Inverses are specified by exchanging the roles of domain and range.

8.3.2.2 Notation

This document uses the following notation:

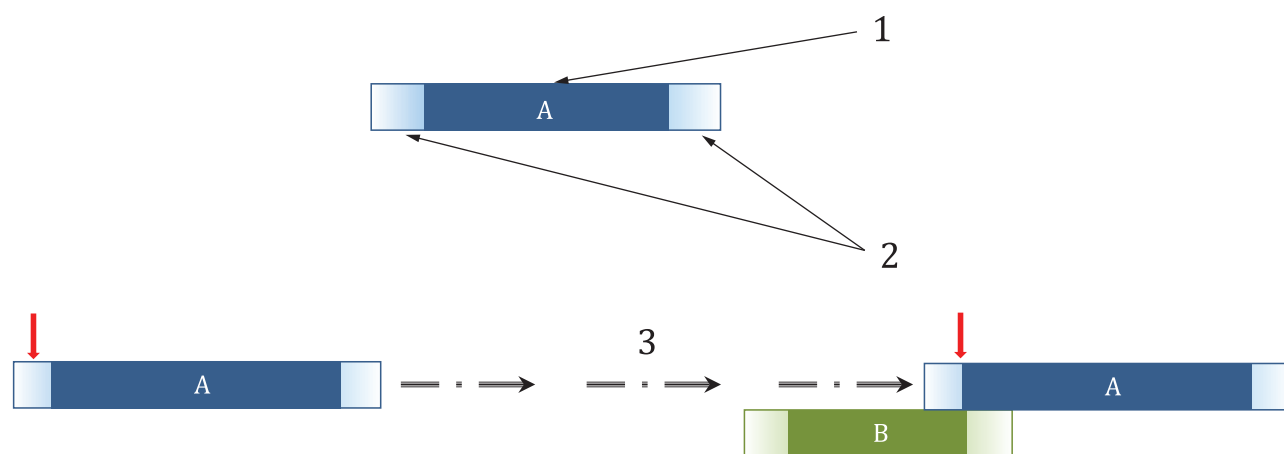
Comparing two instances of E2 Temporal Entity, this document denotes one with capital letter A, its (fuzzy) starting time with A^{start} and its (fuzzy) ending time with A^{end} , such that $A = [A^{\text{start}}, A^{\text{end}}]$; it

denotes the other with capital letter B, its (fuzzy) starting time with B^{start} and its (fuzzy) ending time with B^{end} , such that $B = [B^{\text{start}}, B^{\text{end}}]$.

This document identifies a temporal relation with a predicate name (label) and define it by one or more (in)equality expressions between its end points, such as:

A starts before the end of B if and only if ($\Leftrightarrow$) $A^{\text{start}} < B^{\text{end}}$

This documents shows a temporal relation symbolizing the temporal extents of two instances A and B of E2 Temporal Entity as horizontal bars, considered to be on a horizontal time-line proceeding from left to right. The fuzzy boundary areas are symbolized by an increasing/decreasing colour gradient. The different choices of relative arrangement the relationship allows for are symbolized by two extreme allowed positions of instance A with respect to instance B connected by arrows. The reader may imagine it as the relative positions of a train A approaching a station B. If the relative length of A compared to B matters, two diagrams are provided.



Key

- 1 **Interior** time points for which the described Temporal Entity is definitely on-going
- 2 **Boundary** fuzzy transitions zones in which the described Temporal Entity is developing or vanishing
- 3 A starts before the end of B

Figure 7 — Explanation of interior and boundary and an example of use from P174 starts before the end of (ends after the start of)

8.3.2.3 Overview of temporal relation primitives

The final set of temporal relation primitives can be separated into two groups:

- a) Those based on improper inequalities, such as $A^{\text{start}} \leq B^{\text{end}}$ (odd number items in [Table 3](#)).
- b) Those based on proper inequalities, such as $A^{\text{start}} < B^{\text{end}}$ (even number items in [Table 3](#)).

Improper inequalities with fuzzy boundaries are understood as extending into situations in which the fuzzy boundaries of the respective endpoints may overlap. In other words, they include situations in which it cannot be decided when one interval has ended and when the other started, but there is no knowledge of a definite gap between these endpoints. In a proper inequality with fuzzy boundaries, the fuzzy boundaries of the respective endpoints must not overlap, i.e. there is knowledge of a definite gap between these endpoints, for instance, a discontinuity between settlement phases based on the observation of archaeological layers.

Table 3 — Temporal relation primitives

	Property	Interpretation
1	P173 starts before or with the end of	$A_{start} \leq B_{end}$
2	P174 starts before the end of	$A_{start} < B_{end}$
3	P175 starts before or with the start of	$A_{start} \leq B_{start}$
4	P176 starts before the start of	$A_{start} < B_{start}$
5	P182 ends before or with the start of	$A_{end} \leq B_{start}$
6	P183 ends before the start of	$A_{end} < B_{start}$
7	P184 ends before or with the end of	$A_{end} \leq B_{end}$
8	P185 ends before the end of	$A_{end} < B_{end}$

9 Class declarations

All classes are declared in this Clause using the following format.

- Class names are presented as headings in bold face, preceded by the class' unique identifier.
- The line **Subclass of** declares the superclass of the class from which it inherits properties.
- The line **Superclass of** is a cross-reference to the subclasses of this class.
- The line **Scope note** contains the textual definition of the concept the class represents.
- The line **Examples** contains a bulleted list of examples of instances of this class. If the example is also instance of a subclass of this class, the unique identifier of the subclass is added in parenthesis. If the example instantiates two classes, the unique identifiers of both classes is added in parenthesis. Non-fictitious examples may be followed by an explanation in brackets.
- The line **In first-order logic** expresses the formal constraints of the class in terms of logical axioms in a first-order logic notation.
- The line **Properties** declares the list of the class' properties.
- Each property is represented by its unique identifier, its forward and reverse names, and the range class that it links to, separated by colons.
- Inherited properties are not represented.
- Properties of properties are shown indented and in parentheses beneath their respective domain property.

E1 Entity

Subclass of	
Superclass of	E2 Temporal Entity E52 Time-Span E53 Place E54 Dimension E59 Primitive Value E77 Persistent Item E92 Spacetime Volume
Scope note	This class comprises all things in the universe of discourse of the ontology. It is an abstract concept providing for three general properties:

	a) identification by name or appellation, and in particular by a preferred identifier; b) classification by type, allowing further refinement of the specific subclass to which an instance belongs; c) attachment of free text and other unstructured data for the expression of anything not captured by formal properties. All other classes within the ontology are directly or indirectly specializations of E1 Entity.
Examples	The earthquake in Lisbon 1755 (E5)[51]
In first-order logic	E1(x)
Properties	P1 is identified by (identifies): E41 Appellation P2 has type (is type of): E55 Type P3 has note: E62 String (P3.1 has type: E55 Type) P48 has preferred identifier (is preferred identifier of): E42 Identifier P137 exemplifies (is exemplified by): E55 Type (P137.1 in the taxonomic role: E55 Type)

E2 Temporal Entity

Subclass of	E1 Entity
Superclass of	E3 Condition State E4 Period
Scope note	This class comprises all phenomena, such as the instances of E4 Periods and E5 Events, which happen over a limited extent in time. This extent in time must be contiguous, i.e. without gaps. In case the defining kinds of phenomena for an instance of E2 Temporal Entity cease to happen, and occur later again at another time, this document regards that the former instance of E2 Temporal Entity has ended and a new instance has come into existence. In more intuitive terms, the same event cannot happen twice. In some contexts, such phenomena are also called perdurants. This class is disjoint from E77 Persistent Item and is an abstract class that typically has no direct instances. E2 Temporal Entity is specialized into E4 Period, which applies to a particular geographic area (defined with a greater or lesser degree of precision), and E3 Condition State, which applies to instances of E18 Physical Thing.
Examples	Bronze Age (E4)[52] The earthquake in Lisbon 1755 (E5)[51] The Peterhof Palace near Saint Petersburg being in ruins from 1944 to 1946 (E3)[155]
In first-order logic	$E2(x) \Rightarrow E1(x)$

Properties	P4 has time-span (is time-span of): E52 Time-Span P173 starts before or with the end of (ends after or with the start of): E2 Temporal Entity P174 starts before the end of (ends after the start of): E2 Temporal Entity P175 starts before or with the start of (starts after or with the start of): E2 Temporal Entity P176 starts before the start of (starts after the start of): E2 Temporal Entity P182 ends before or with the start of (starts after or with the end of): E2 Temporal Entity P182 ends before the start of (starts after the end of): E2 Temporal Entity P184 ends before or with the end of (ends with or after the end of): E2 Temporal Entity P185 ends before the end of (ends after the end of): E2 Temporal Entity
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E3 Condition State

Subclass of	E2 Temporal Entity
Superclass of	
Scope note	This class comprises the states of objects characterized by a certain condition over a time span. An instance of this class describes the prevailing physical condition of any material object or feature during a specific instance of E52 Time-Span. In general, the time-span for which a certain condition can be asserted may be shorter than the real time-span, for which this condition held. The nature of that condition can be described using <i>P2 has type</i>. For example, the instance of E3 Condition State “condition of the SS Great Britain between 22nd September 1846 and 27th August 1847” can be characterized as an instance “wrecked” of E55 Type.
Examples	The "reconstructed" state of the “Amber Room” in Tsarskoje Selo from summer 2003 until now^[179] The "ruined" state of Peterhof Palace near Saint Petersburg from 1944 to 1946^[155] The state of my turkey in the oven at 14:30 on 25th December 2002 [<i>P2 has type</i>: E55 Type “still not cooked”] (fictitious) The topography of the leaves of Sinai Printed Book 3234.2361 on the 10th July 2007 [described as: of type “cockled”] (fictitious)
In first-order logic	$E3(x) \Rightarrow E2(x)$
Properties	P5 consists of (forms part of): E3 Condition State

E4 Period

Subclass of	E2 Temporal Entity E92 Spacetime Volume
Superclass of	E5 Event

Scope note	This class comprises sets of coherent phenomena or cultural manifestations occurring in time and space. It is the social or physical coherence of these phenomena that identify an instance of E4 Period and not the associated spatiotemporal extent. This extent is only the “ground” or space in an abstract physical sense that the actual process of growth, spread and retreat has covered. Consequently, different periods can overlap and coexist in time and space, such as when a nomadic culture exists in the same area and time as a sedentary culture. This also means that overlapping land use rights, common among first nations, amounts to overlapping periods. Often, this class is used to describe prehistoric or historic periods such as the “Neolithic Period”, the “Ming Dynasty” or the “McCarthy Era”, but also geopolitical units and activities of settlements are regarded as special cases of E4 Period. However, there are no assumptions about the scale of the associated phenomena. In particular all events are seen as synthetic processes consisting of coherent phenomena. Therefore, E4 Period is a superclass of E5 Event. For example, a modern clinical birth, an instance of E67 Birth, can be seen as both a single event, i.e. an instance of E5 Event, and as an extended period, i.e. an instance of E4 Period, that consists of multiple physical processes and complementary activities performed by multiple instances of E39 Actor. E4 Period is a subclass of E2 Temporal Entity and of E92 Spacetime Volume. The latter is intended as a phenomenal spacetime volume as defined in CIDOC CRMgeo. [74] By virtue of this multiple inheritance, it is possible to discuss the physical extent of an instance of E4 Period without representing each instance of it together with an instance of its associated spacetime volume. This model combines two quite different kinds of substance: an instance of E4 Period is a phenomenon while an instance of E92 Spacetime Volume is an aggregation of points in spacetime. However, the real spatiotemporal extent of an instance of E4 Period is regarded to be unique to it due to all its details and fuzziness; its identity and existence depends uniquely on the identity of the instance of E4 Period. Therefore, this multiple inheritance is unambiguous and effective and furthermore corresponds to the intuitions of natural language. Typical use of this class in cultural heritage documentation is for documenting cultural and artistic periods. There are two different conceptualisations of ‘artistic style’, defined either by physical features or by historical context. For example, “Impressionism” can be viewed as a period in the European sphere of influence lasting from approximately 1870 to 1905 during which paintings with particular characteristics were produced by a group of artists that included (among others) Monet, Renoir, Pissarro, Sisley and Degas. Alternatively, it can be regarded as a style applicable to all paintings sharing the characteristics of the works produced by the Impressionist painters, regardless of historical context. The first interpretation is an instance of E4 Period, and the second defines morphological object types that fall under E55 Type. A geopolitical unit as a specific case of an instance of E4 Period is the set of activities and phenomena related to the claim of power, the consequences of belonging to a jurisdictional area and an administrative system that establishes a geopolitical unit. Examples from the modern period are countries or administrative areas of countries such as districts whose actions and structures define activities and phenomena in the area that they intend to govern. The borders of geopolitical units are often defined in contracts or treaties although they may deviate from the actual practice. The spatiotemporal properties of Geopolitical units can be modelled through the properties inherited from E92 Spacetime Volume. Another specific case of an instance of E4 Period is the actual extent of the set of activities and phenomena as evidenced by their physical traces that define a settlement, such as the populated period of Nineveh.
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Examples	Jurassic^[103] Populated Period of Nineveh Imperial Rome under Marcus Aurelius European Bronze Age^[106] Italian Renaissance^[154] Thirty Years War^[144] Sturm und Drang^[17] Cubism^[60] The Capital of Russia (E4) [the capital of Russia in the sense of an administrative unit moved in historical times from Moscow to St Petersburg and then back to Moscow. This exemplifies an administrative unit changing place over time without temporal discontinuity] The settling activity of the community of Helsinki (a.k.a. Helsingfors) (E7) [the original settlement called Helsinki was located in the area of the modern airport. The community moved later to settle on the coast. This exemplifies a continued activity changing place over time without temporal discontinuity] Bronze Age (E4) [Bronze Age, in the sense of technological adoption, spread over disjoint areas including islands such as the British Isles without temporal discontinuity] Japan, the state (E4) [In 2021, the Japanese state as a political unit comprised in 6852 islands extending along the Pacific coast of Asia]
In first-order logic	$E4(x) \Rightarrow E2(x)$ $E4(x) \Rightarrow E92(x)$
Properties	P7 took place at (witnessed): E53 Place P8 took place on or within (witnessed): E18 Physical Thing P9 consists of (forms part of): E4 Period

E5 Event

Subclass of	E4 Period
Superclass of	E7 Activity E63 Beginning of Existence E64 End of Existence

Scope note	This class comprises distinct, delimited and coherent processes and interactions of a material nature, in cultural, social or physical systems, involving and affecting instances of E77 Persistent Item in a way characteristic of the kind of process. Typical examples are meetings, births, deaths, actions of decision taking, making or inventing things, but also more complex and extended ones such as conferences, elections, building of a castle, or battles. While the continuous growth of a tree lacks the limits characteristic of an event, its germination from a seed does qualify as an event. Similarly, the blowing of the wind lacks the distinctness and limits of an event, but a hurricane, flood or earthquake would qualify as an event. Mental processes are considered as events, in cases where they are connected with the material externalization of their results; for example, the creation of a poem, a performance or a change of intention that becomes obvious from subsequent actions or declarations. The effects of an instance of E5 Event may not lead to relevant permanent changes of properties or relations of the items involved in it, for example an unrecorded performance. Of course, in order to be documented, some kind of evidence for an event must exist, be it witnesses, traces or products of the event. While instances of E4 Period always require some form of coherence between its constituent phenomena, in addition, the essential constituents of instances of E5 Event should contribute to an overall effect; for example, the statements made during a meeting and the listening of the audience. Viewed at a coarse level of detail, an instance of E5 Event may appear as if it had an 'instantaneous' overall effect, but any process or interaction of material nature in reality have an extent in time and space. At a fine level, instances of E5 Event may be analysed into component phenomena and phases within a space and timeframe, and as such can be seen as a period, regardless of the size of the phenomena. The reverse is not necessarily the case: not all instances of E4 Period give rise to a noteworthy overall effect and are thus not instances of E5 Event.
Examples	The birth of Cleopatra (E67)[192] The destruction of Herculaneum by volcanic eruption in 79 AD (E6)[45] World War II (E7)[10] The Battle of Stalingrad (E7)[120] The Yalta Conference (E7)[105] My birthday celebration 28-6-1995 (E7) The falling of a tile from my roof last Sunday (fictitious) The CIDOC Conference 2003 (E7)
In first-order logic	$E5(x) \Rightarrow E4(x)$
Properties	P11 had participant (participated in): E39 Actor P12 occurred in the presence of (was present at): E77 Persistent Item

E6 Destruction

Subclass of	E64 End of Existence
Superclass of	