CRMsci
Scientific observation model

Definition of the CRMsci

An Extension of CIDOC-CRM to support scientific observation

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1. The Scientific Observation Model

Introduction

Scope

This text defines the "Scientific Observation Model". It is a formal ontology intended to be used as a global schema for integrating metadata about scientific observation, measurements and processed data in descriptive and empirical sciences such as biodiversity, geology, geography, archaeology, cultural heritage conservation and others in research IT environments and research data libraries. Its primary purpose is facilitating the management, integration, mediation, interchange and access to research data by description of semantic relationships, in particular causal ones. It is not primarily a model to process the data themselves in order to produce new research results, even though its representations offer themselves to be used for some kind of processing.

It uses and extends the CIDOC CRM (ISO21127) as a general ontology of human activity, things and events happening in spacetime. It uses the same encoding-neutral formalism of knowledge representation ("data model" in the sense of computer science) as the CIDOC CRM, which can be implemented in RDFS, OWL, on RDBMS and in other forms of encoding. Since the model reuses, wherever appropriate, parts of CIDOC Conceptual Reference Model, we provide in this document also a comprehensive list of all constructs used from ISO21127, together with their definitions following the version 6.2 maintained by CIDOC.

The Scientific Observation Model has been developed bottom up from specific metadata examples from biodiversity, geology, archeology, cultural heritage conservation and clinical studies, such as water sampling in aquifer systems, earthquake shock recordings, landslides, excavation processes, species occurrence and detection of new species, tissue sampling in cancer research, 3D digitization, based on communication with the domain experts and the implementation and validation in concrete applications. It takes into account relevant standards, such as INSPIRE, OBOE, national archeological standards for excavation, Digital Provenance models and others. For each application, another set of extensions is needed in order to describe those data at an adequate level of specificity, such as semantics of excavation layers or specimen capture in biology. However, the model presented here describes, together with the CIDOC CRM, a discipline neutral level of genericity, which can be used to implement effective management functions and powerful queries for related data. It aims at providing superclasses and superproperties for any application-specific extension, such that any entity referred to by a compatible extension can be reached with a more general query based on this model.

Besides application-specific extensions, this model is intended to be complemented by CRMgeo, a more detailed model and extension of the CIDOC CRM of generic spatiotemporal topology and geometric description, also currently available in a first stable version [CRMgeo, version 1.0 - Doerr, M. and Hiebel, G. 2013]. Details of spatial properties of observable entities should be modelled in CRMgeo. As CRMgeo links CIDOC CRM to the OGC standard of GeoSPARQL it makes available all constructs of GML of specific spatial and temporal relationships. Still to be developed are models of the structures for describing quantities, such as IHS colors, volumes, velocities etc.

This is an attempt to maintain a modular structure of multiple ontologies related and layered in a specialization – generalization relationship, and into relatively self-contained units with few cross-correlations into other modules, such as describing quantities. This model aims at staying harmonized with the CIDOC CRM, i.e., its maintainers submit proposals for modifying the CIDOC CRM wherever adequate to guarantee the overall consistency, disciplinary adequacy and modularity of CRM-based ontology modules.

Status

The model presented in this document has so far be validated in several national and international projects[1] by implementing it in slightly different versions together with application-specific extensions and by mapping to and from related standards. This document describes a consolidated version from this experience, with the aim to present it for review and further adoption to the widest possible community. The model is not "finished", some parts such as the subclasses of inference making are not fully developed in terms of properties, and all constructs and scope notes are open to further elaboration.

Naming Conventions

All the classes declared were given both a name and an identifier constructed according to the conventions used in the CIDOC CRM model. For classes that identifier consists of the letter S followed by a number. Resulting properties were also given a name and an identifier, constructed according to the same conventions. That identifier consists of the letter O followed by a number, which in turn is followed by the letter "i" every time the property is mentioned "backwards", i.e., from target to domain (inverse link). "S" and "O" do not have any other meaning. They correspond respectively to letters "E" and "P" in the CIDOC CRM naming conventions, where "E" originally meant "entity" (although the CIDOC CRM "entities" are now consistently called "classes"), and "P" means "property". Whenever CIDOC CRM classes are used in our model, they are named by the name they have in the original CIDOC CRM.

Letters in red colour in CRM Classes and properties are additions/extensions coming by the scientific observation model.

Class and property hierarchies

The CIDOC CRM model declares no "attributes" at all (except implicitly in its "scope notes" for classes), but regards any information element as a "property" (or "relationship") between two classes. The semantics are therefore rendered as properties, according to the same principles as the CIDOC CRM model.

Although they do not provide comprehensive definitions, compact monohierarchical presentations of the class and property IsA hierarchies have been found to significantly aid in the comprehension and navigation of the model, and are therefore provided below.

The class hierarchy presented below has the following format:

- Each line begins with a unique class identifier, consisting of a number preceded by the letter "S", or "E".
- A series of hyphens ("-") follows the unique class identifier, indicating the hierarchical position of the class in the IsA hierarchy.
- The English name of the class appears to the right of the hyphens.
- The index is ordered by hierarchical level, in a "depth first" manner, from the smaller to the larger sub hierarchies.
- Classes that appear in more than one position in the class hierarchy as a result of multiple inheritance are shown in an *italic typeface*.

The property hierarchy presented below has the following format:

[1] InGeoCloudS - Inspired GEOdata CLOUD Services 01/02/2012 - 31/07/2014 EU FP7 – PSP, ARIADNE - Advanced Research Infrastructure for Archaeological Dataset Networking in Europe 01/02/2013 - 31/01/2017 EU FP7-INFRASTRUCTURES-2012-1, Geosemantics for Cultural Heritage Documentation – Domain specific ontological modelling and implementation of a Cultural Geosemantic Information System based on ISO specifications 01/09/2012 - 31/08/2014 European Commission / FP7-PEOPLE-2011-IEF, iMarine - Data e-Infrastructure Initiative for Fisheries Management and Conservation of Marine Living Resources 01/11/2011 - 30/04/2014 EU - FP7 - CP & CSA, Standards for cultural documentation and support technologies for the integration of digital cultural repositories and systems interoperability: Studies, Prototypes and Best-practices guides 14/2/2004 - 15/3/2005 EU - Op. Pr. Information Society

- Each line begins with a unique property identifier, consisting of a number preceded by the letter “O”.
- A series of hyphens (“-”) follows the unique property identifier, indicating the hierarchical position of the property in the IsA hierarchy.
- The English name of the property appears to the right of the hyphens.
- The domain class for which the property is declared.

Scientific Observation Model Class Hierarchy aligned with (part of) CIDOC CRM Class Hierarchy

E1 CRM Entity
S15 - Observable Entity
E2 - - Temporal Entity
S16 - - - State
E3 - - - - Condition State
E5 - - - - - Event
E7 - - - - - - Activity
S1 - - - - - - - Matter Removal
E80 - - - - - - - - Part Removal
S2 - - - - - - - - Sample Taking
S3 - - - - - - - - - Measurement by Sampling
E13 - - - - - - - Attribute Assignment
E16 - - - - - - - - Measurement
S21 - - - - - - - - - Measurement
S3 - - - - - - - - - - *Measurement by Sampling*
S4 - - - - - - - - Observation
S21 - - - - - - - - - *Measurement*
S19 - - - - - - - - - Encounter Event
S5 - - - - - - - - Inference Making
S6 - - - - - - - - - Data Evaluation
S7 - - - - - - - - - Simulation or Prediction
S8 - - - - - - - - - Categorical Hypothesis Building
S18 - - - - - - Alteration
S17 - - - - - - - Physical Genesis
E11 - - - - - - - Modification
E63 - - - - - - Beginning of Existence
S17 - - - - - - - *Physical Genesis*
E12 - - - - - - - - Production
E77 - - Persistent Item
E70 - - - Thing
S10 - - - - Material Substantial
S14 - - - - - Fluid Body
S12 - - - - - - Amount of Fluid
S11 - - - - - Amount of Matter
S12 - - - - - - *Amount of Fluid*
S13 - - - - - - Sample
E18 - - - - - Physical Thing
S20 - - - - - - Physical Feature
E26 - - - - - - Physical Feature
E27 - - - - - - - Site
E25 - - - - - - - Man-Made Feature

S22 - - - - - - - Segment of Matter
E28 - - - - - Conceptual Object
E55 - - - - - - Type
S9 - - - - - - - Property Type
E53 - Place
S20 - - *Physical Feature*

Scientific Observation Model PROPERTY Hierarchy

Property id	Property Name	Entity – Domain	Entity - Range
O1	diminished (was diminished by)	S1 Matter Removal	S10 Material Substantial
O2	removed (was removed by)	S1 Matter Removal	S11 Amount of Matter
O3	sampled from (was sample by)	S2 Sample Taking	S10 Material Substantial
O4	sampled at (was sampling location of)	S2 Sample Taking	E53 Place
O5	removed (was removed by)	S2 Sample Taking	S13 Sample
O6	forms former or current part of (has former or current part)	S12 Amount of Fluid	S14 Fluid Body
O7	contains or confines (is contained or confined)	E53 Place	E53 Place
O8	observed (was observed by)	S4 Observation	S15 Observable Entity
O9	observed property type (property type was observed by)	S4 Observation	S9 Property Type
O10	assigned dimension (dimension was assigned by)	S6 Data Evaluation	E54 Dimension
O11	described (was described by)	S6 Data Evaluation	S15 Observable Entity
O12	has dimension (is dimension of)	S15 Observable Entity	E54 Dimension
O13	triggers (is triggered by)	E5 Event	E5 Event
O14	initializes (is initialized by)	E5 Event	S16 State
O15	occupied (was occupied by)	S10 Material Substantial	E53 Place
O16	observed value (value was observed by)	S4 Observation	E1 CRM Entity
O17	generated (was generated by)	S17 Physical Genesis	E18 Physical Thing
O18	altered (was altered by)	S18 Alteration	E18 Physical Thing
O19	has found object (was object found by)	S19 Encounter Event	E18 Physical Thing
O20	sampled from type of part (type of part was sampled by)	S2 Sample Taking	E55 Type
O21	has found at (witnessed)	S19 Encounter Event	E53 Place
O22	partly or completely contains (is part of)	S22 Segment of Matter	S20 Physical Feature
O23	is defined by (defines)	S22 Segment of Matter	E92 Spacetime Volume
O24	measured (was measured by)	S21 Measurement	S15 Observable Entity

Scientific Observation Model Class Declaration

The classes are comprehensively declared in this section using the following format:

- Class names are presented as headings in bold face, preceded by the class's 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.
- The line "Properties:" declares the list of the class's properties;
- Each property is represented by its unique identifier, its forward name, and the range class that it links to, separated by colons;
- Inherited properties are not represented;
- Properties of properties, if they exist, are provided indented and in parentheses beneath their respective domain property.

Classes

S1 Matter Removal

Subclass of: E7 Activity
Superclass of: E80 Part Removal
S2 Sample Taking

Scope note: This class comprises the activities that result in an instance of S10 Material Substantial being decreased by the removal of an amount of matter.

Typical scenarios include the removal of a component or piece of a physical object, removal of an archaeological or geological layer, taking a tissue sample from a body or a sample of fluid from a body of water. The removed matter may acquire a persistent identity of different nature beyond the act of its removal, such as becoming a physical object in the narrower sense. Such cases should be modeled by using multiple instantiation with adequate concepts of creating the respective items.

In First Order Logic:
S1(x) ⊃ E7(x)

Properties:
O1 diminished (was diminished by): S10 Material Substantial
O2 removed (was removed by): S11 Amount of Matter

S2 Sample Taking

Subclass of: S1 Matter Removal
Superclass of S3 Measurement by Sampling

Scope note: This class comprises the activity that results in taking an amount of matter as sample for further analysis from a material substantial such as a body of water, a geological formation or an archaeological object. The removed matter may acquire a persistent identity of different nature beyond the act of its removal, such as becoming a physical object in the narrower sense. The sample is typically removed from a physical feature which is used as a frame of reference, the place of sampling. In case of non-rigid Material Substantials, the source of sampling may regarded not to be modified by the activity of sample taking.

In First Order Logic:
S1(x) ⊃ S3(x)

Properties:
O3 sampled from (was sample by): S10 Material Substantial
O4 sampled at (was sampling location of): E53 Place
O5 removed (was removed by): S13 Sample
O20 sampled from type of part (type of part was sampled by): E55 Type

S3 Measurement by Sampling

Subclass of: S2 Sample Taking
S21 Measurement

Scope note: This class comprises activities of taking a sample and measuring or analyzing it as one managerial unit of activity, in which the sample may not be identified and preserved beyond the context of this activity. Instances of this class are constrained to describe the taking of exactly one sample, in general not further identified, and the dimensions observed by the

respective measurement are implicitly understood to describe this particular sample as representative of the place on the instance of S10 Material Substantial from which the sample was taken. Therefore the class S3 Measurement by Sampling inherits the properties of S2 Sample Taking.*O3 sampled from:* S10 Material Substantial and *O4 sampled at:* E53 Place, and the properties of S21(E16) Measurement.*P40 observed dimension:* E54 Dimension, due to multiple inheritance, whereas it needs not instantiate the properties *O5 removed:* S13 Sample and *O24 measured*: S15 Observable Entity, if the sample is not documented beyond the context of the activity.

In First Order Logic:

S3(x) ⊃ S2(x)
S3(x) ⊃ S21(x)

S4 Observation

Subclass of: E13 Attribute Assignment
Superclass of: S21 Measurement
S19 Encounter Event

Scope note: This class comprises the activity of gaining scientific knowledge about particular states of physical reality gained by empirical evidence, experiments and by measurements.

We define observation in the sense of natural sciences, as a kind of human activity: at some place and within some time-span, certain physical things and their behavior and interactions are observed, either directly by human sensory impression, or enhanced with tools and measurement devices.

The output of the internal processes of measurement devices that do not require additional human interaction are in general regarded as part of the observation and not as additional inference. Manual recordings may serve as additional evidence. Measurements and witnessing of events are special cases of observations. Observations result in a belief about certain propositions. In this model, the degree of confidence in the observed properties is regarded to be "true" by default, but could be described differently by adding a property *P3 has note* to an instance of S4 Observation, or by reification of the property *O16 observed value*.

Primary data from measurement devices are regarded in this model to be results of observation and can be interpreted as propositions believed to be true within the (known) tolerances and degree of reliability of the device.

Observations represent the transition between reality and propositions in the form of instances of a formal ontology, and can be subject to data evaluation from this point on. For instance, detecting an archaeological site on satellite images is not regarded as an instance of S4 Observation, but as an instance of S6 Data Evaluation. Rather, only the production of the images is regarded as an instance of S4 Observation.

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In First Order Logic:

S4(x) ⊃ E13(x)

Properties:

O8 observed (was observed by): S15 Observable Entity
O9 observed property type (property type was observed by): S9 Property Type
O16 observed value (value was observed by): E1 CRM Entity

S5 Inference Making

Subclass of: E13 Attribute Assignment
Superclass of: S6 Data Evaluation

S7 Simulation or Prediction
S8 Categorical Hypothesis Building

Scope note: This class comprises the action of making propositions and statements about particular states of affairs in reality or in possible realities or categorical descriptions of reality by using inferences from other statements based on hypotheses and any form of formal or informal logic. It includes evaluations, calculations, and interpretations based on mathematical formulations and propositions.

In First Order Logic:
S5(x) ⊃ E13(x)

Properties:

S6 Data Evaluation

Subclass of: S5 Inference Making

Scope note: This class comprises the action of concluding propositions on a respective reality from observational data by making evaluations based on mathematical inference rules and calculations using established hypotheses, such as the calculation of an earthquake epicenter. S6 Data Evaluation is not defined as S21/E16 Measurement; Secondary derivations of dimensions of an object from data measured by different processes are regarded as S6 Data Evaluation and not determining instances of Measurement in its own right. For instance, the volume of a statue concluded from a 3D model is an instance of S6 Data Evaluation and not of Measurement.

In First Order Logic:
S6(x) ⊃ S5(x)

Properties:
O10 assigned dimension (dimension was assigned by): E54 Dimension
O11 described (was described by): S15 Observable Entity

S7 Simulation or Prediction

Subclass of: S5 Inference Making

Scope note: This class comprises activities of executing algorithms or software for simulating the behavior and the properties of a system of interacting components that form part of reality or not by using a mathematical model of the respective interactions. In particular it implies making predictions about the future behaviors of a system of interacting components of reality by starting simulation from an actually observed state, such as weather forecasts. Simulations may also be used to understand the effects of a theory, to compare theoretical predictions with reality, or to show differences with another theory.

In First Order Logic:
S7(x) ⊃ S5(x)

Properties:

S8 Categorical Hypothesis Building

Subclass of: S5 Inference Making

Scope note: This class comprises the action of making categorical hypotheses based on inference rules and theories; By categorical hypotheses we mean assumptions about the kinds of interactions and related kinds of structures of a domain that have the character of "laws" of nature or human behavior, be it necessary or probabilistic. Categorical hypotheses are developed by "induction" from finite numbers of observation and the absence of observations of particular kinds. As such, categorical hypotheses are always subject to falsification by new evidence. Instances of S8 Categorical Hypothesis Building include making and questioning categorical hypotheses.

In First Order Logic:
S8(x) ⊃ S5(x)
Properties:

S9 Property Type

Subclass of: E55 Type

Scope note: This class comprises types of properties. Typically, instances of S9 Property Type would be taken from an ontology or terminological system. In particular, instances of this class can be used to describe in a parametric way what kind of properties the values in scientific data sets are about. By virtue of such descriptions, numeric data can be interpreted as sets of propositions in terms of a formal ontology, such as "concentration of nitrate", observed in the ground water from a certain borehole.

In First Order Logic:
S9(x) ⊃ E55(x)
Properties:

S10 Material Substantial

Subclass of: E70 Thing
Superclass of: S14 Fluid Body
S11 Amount of Matter
E18 Physical Thing

Scope note: This class comprises constellations of matter with a relative stability of any form sufficient to associate them with a persistent identity, such as being confined to certain extent, having a relative stability of form or structure, or containing a fixed amount of matter. In particular, it comprises physical things in the narrower sense and fluid bodies. It is an abstraction of physical substance for solid and non-solid things of matter.

In First Order Logic:
S10(x) ⊃ E70(x)
Properties:
P46 is composed of (forms part of): S10 Material Substantial
It has been proposed that P44, P45 and P46 are moved from E18 Physical Thing to E70 Thing. Decision of CRM SIG is pending.
O15 occupied (was occupied by): E53 Place

S11 Amount of Matter

Subclass of: S10 Material Substantial
Superclass of: S12 Amount of Fluid
S13 Sample

Scope note: This class comprises fixed amounts of matter specified as some air, some water, some soil, etc., defined by the total and integrity of their material content.

In First Order Logic:

S11(x) ⊃ S10(x)

S12 Amount of Fluid

Subclass of: S11 Amount of Matter
S14 Fluid Body

Scope note: This class comprises fixed amounts of fluid defined by the total of its material content, typically molecules. They frequently acquire identity in laboratory practice by the fact of being kept or handled together within some adequate containers.

In First Order Logic:

S12(x) ⊃ S11(x)
S12(x) ⊃ S14(x)

Properties:

O6 forms former or current part (has former or current part): S14 Fluid Body

S13 Sample

Subclass of: S11 Amount of Matter

Scope note: This class comprises instances of S11 Amount of Matter taken from some instance of S10 Material Substantial with the intention to be representative for some material qualities of the instance of S10 Material Substantial or part of it was taken from for further analysis. We typically regard a sample as ceasing to exist when the respective representative qualities become corrupted, such as the purity of a water sample or the layering of a bore core.

In First Order Logic:

S13(x) ⊃ S11(x)

S14 Fluid Body

Subclass of: S10 Material Substantial
Superclass of: S12 Amount of Fluid

Scope note: This class comprises a mass of matter in fluid form environmentally constraint in some persistent form allowing for identifying it for the management or research of material phenomena, such as a part of the sea, a river, the atmosphere or the milk in a bottle. Fluids are generally defined by the continuity criterion which is characteristic of their substance: their amorphous matter is continuous and tends to flow. Therefore, contiguous amounts of matter within a fluid body may stay contiguous or at least be locally spatially confined for a sufficiently long time in order to be temporarily identified and traced. This is a much weaker concept of stability of form than the one we would apply to what one would call a physical object. In general, an instance of Fluid Body may gain or lose matter over time through so-called sources or sinks in its surface, in contrast to physical things, which may lose or gain matter by exchange of pieces such as spare parts or corrosion.

In First Order Logic:

S14(x) ⊃ S10(x)

S15 Observable Entity

Subclass of: E1 CRM Entity
Superclass of: E2 Temporal Entity
E77 Persistent Item
Scope note:

This class comprises instances of E2 Temporal Entity or E77 Persistent Item, i.e. items or phenomena that can be observed, either directly by human sensory impression, or enhanced with tools and measurement devices, such as physical things, their behavior, states and interactions or events.
Conceptual objects can be present in events by their carriers such as books, digital media, or even human memory. By virtue of this presence, properties of conceptual objects, such as number of words can be observed on their carriers. If the respective properties between carriers differ, either they carry different instances of conceptual objects or the difference can be attributed to accidental deficiencies in one of the carriers. In that sense even immaterial objects are observable. By this model we give credit to the fact that frequently, the actually observed carriers of conceptual objects are not explicitly identified in documentation, i.e., the actual carrier is assumed having existed but is unknown as an individual.

In First Order Logic:
S15(x) ⊃ E1(x)

Properties:

O12 has dimension (is dimension of): E54 Dimension

S16 State

Subclass of: E2 Temporal Entity
Superclass of: E3 Condition State

Scope note: This class comprises the persistence of a particular value range of the properties of a particular thing or things over a time-span.
In First Order Logic:
S16(x) ⊃ E2(x)

S17 Physical Genesis

Subclass of: E63 Beginning of Existence
S18 Alteration
Superclass of: E12 Production

Scope note: This class comprises events or processes that result in (generate) physical things, man-made or natural, coming into being in the form by which they are later identified. The creation of a new physical item, at the same time, can be a result of an alteration (modification) – it can become a new thing due to an alteration activity.

In First Order Logic:
S17(x) ⊃ E63(x)
S17(x) ⊃ S18(x)

Properties:

O17 generated (was generated by): E18 Physical Thing

S18 Alteration

Subclass of: E5 Event
Superclass of: S17 Physical Genesis
E11 Modification

Scope note: This class comprises natural events or man-made processes that create, alter or change physical things, by affecting permanently their form or consistency without changing their identity. Examples include alterations on depositional features-layers by natural factors or disturbance by roots or insects, organic alterations, petrification, etc.

In First Order Logic:

S18(x) ⊃ E5(x)

Properties:

O18 altered (was altered by): E18 Physical Thing

S19 Encounter Event

Subclass of: S4 Observation

Scope note: This class comprises activities of S4 Observation (substance) where an E39 Actor encounters an instance of E18 Physical Thing of a kind relevant for the mission of the observation or regarded as potentially relevant for some community (identity). This observation produces knowledge about the existence of the respective thing at a particular place in or on surrounding matter. This knowledge may be new to the group of people the actor belongs to. In that case we would talk about a discovery. The observer may recognize or assign an individual identity of the thing encountered or regard only the type as noteworthy in the associated documentation or report.

In archaeology there is a particular interest if an object is found “in situ”, i.e. if its embedding in the surrounding matter supports the assumption that the object was not moved since the archaeologically relevant deposition event. The surrounding matter with the relative position of the object in it as well as the absolute position and time of the observation may be recorded in order to enable inferences about the history of the E18 Physical Thing.

In Biology, additional parameters may be recorded like the kind of ecosystem, if the biological individual survives the observation, what detection or catching devices have been used or if the encounter event supported the detection of a new biological kind (“taxon”).

In First Order Logic:

S19(x) ⊃ S4(x)

Properties:

O19 has found object (was object found by): E18 Physical Thing
O21 has found at (witnessed): E53 Place

S20 Rigid Physical Feature

Subclass of: E26 Physical Feature

E53 Place

Superclass of: E27 Site

S22 Segment of Matter

Scope Note: This class comprises physical features with the following characteristics. Any instance of this class is physically attached in an integral way to particular physical object, and has a stability of form in itself and with respect to the physical object bearing it, in such a way that it is sufficient to associate a permanent reference space within which its form is invariant and at rest.

Due to this stability of form, the maximal real volume in space that an instance of S20 Rigid Physical Feature occupies at sometime within its existence with respect to the default reference space relative to which the feature is at rest defines uniquely a place for the feature with respect to its surrounding matter.

Therefore we model S20 Rigid Physical Feature as a subclass of E26 Physical Feature and of E53 Place. The latter is intended as a phenomenal place as defined in CRMgeo (Doerr and Hiebel 2013). By virtue of this multiple inheritance we can discuss positions relative to the extent of an instance of S20 Rigid Physical Feature without representing each instance of it together with an instance of its associated place. This model combines two quite different kinds of substance: an instance of E26 Physical Feature and of E53 Place. It is an aggregation of points in a geometric space. However, since the identity and existence of this place depends uniquely on the identity of the instance of S20 Rigid Physical Feature as matter, this multiple inheritance is unambiguous and effective and furthermore corresponds to the intuitions of natural language. It shortcuts an implicit self-referential path from E26 Physical Feature through *P156 occupies,* E53 Place, *P157 is at rest relative to* E26 Physical Feature.

In cases of instances of S20 Rigid Physical Feature on or in the surface of earth, the default reference is typically fixed to the closer environment of the tectonic plate or sea floor. In cases of features on mobile objects, the reference space is typically fixed to the geometry of the bearing object. Note that the reference space associated with the instance of S20 Rigid Physical Feature may quite well be deformed over time, as long the continuity of its topology does not become unclear, such as the compression of dinosaur bones in geological layers, or the distortions of the hull of a ship by the waves of the sea. Defined in this way, the reference space can be used as a means to infer from current topological relationships past topological relationships of interest

Examples:

- the temple in Abu Simbel before its removal, which was carved out of solid rock
- Albrecht Duerer's signature on his painting of Charles the Great
- the damage to the nose of the Great Sphinx in Giza
- Michael Jackson’s nose prior to plastic surgery

In First Order Logic:

S20(x) ⊃ E18(x)
S20(x) ⊃ E53(x)

S21 Measurement

Subclass of: S4 Observation
E16 Measurement
Superclass of: S3 Measurement by Sampling

Scope note: This class comprises actions measuring instances of E2 Temporal Entity or E77 Persistent Items, properties of physical things, or phenomena, states and interactions or events, that can be determined by a systematic procedure. Primary data from measurement devices are regarded to be results of an observation process.

In First Order Logic:

S21(x) ⊃ S4(x)
S21(x) ⊃ E16(x)

Properties:

O24 measured (was measured by): S15 Observable Entity

S22 Segment of Matter

Subclass of: S20 Physical Feature

Scope Note: This class comprises physical material in a relative stability of form (substance) within a specific spacetime volume (unity, extend). The spatial extend of a S22 Segment of Matter is defined by humans usually because the constellation is subject to a specific interest for and investigations of the geometric arrangement of physical features or parts of them on or within the specified S22 Segment of Matter. It comes into existence as being an object of discourse through S4 Observation or declaration and is restricted to the time span starting after the last change through an S18 Alteration before the S4 Observation or declaration and ending with the next S18 Alteration Event (identity). A S22 Segment of Matter exists as long as there is no modification of the geometric arrangement of its particles. Therefore the temporal boundaries of the defining Spacetime Volume are given by two S18 Alteration events.
The history of a S22 Segment of Matter started with the first S17 Physical Genesis event that deposited still existing matter within the defined spatial extend. The collection of all S18 Alteration events represent its history. Some of the events will not leave any physical material within the S22 Segment of Matter.
(to be elaborated further)

In First Order Logic:

$S22(x) \supset S20(x)$

Properties:

O22 partly or completely contains (is part of): S20 Physical Feature
O23 is defined by (defines): E92 Spacetime Volume

Scientific Observation Model Property Declaration

The properties are comprehensively declared in this section using the following format:

- Property names are presented as headings in bold face, preceded by unique property identifiers;
- The line “Domain:” declares the class for which the property is defined;
- The line “Range:” declares the class to which the property points, or that provides the values for the property;
- The line “Superproperty of:” is a cross-reference to any subproperties the property may have;
- The line “Scope note:” contains the textual definition of the concept the property represents;
- The line “Examples:” contains a bulleted list of examples of instances of this property.

Properties

O1 diminished (was diminished by)

Domain: S1 Matter Removal
Range: S10 Material Substantial

Scope note: This property associates an instance of S1 Matter Removal with the instance of S10 Material Substantial that this activity diminished.

In First Order Logic:
O1(x,y) ⊃ S1(x)
O1(x,y) ⊃ S10(y)

O2 removed (was removed by)

Domain: S1 Matter Removal
Range: S11 Amount of Matter
Superproperty of: S2 Sample Taking: O5 removed (was removed by): S13 Sample

Scope note: This property associates an instance of S1 Matter Removal with the instance of S11 Amount of Matter that it has removed.
In First Order Logic:
O2(x,y) ⊃ S1(x)
O2(x,y) ⊃ S11(y)

O3 sampled from (was sample by)

Domain: S2 Sample Taking
Range: S10 Material Substantial

Scope note: This property associates an instance of S2 Sample Taking with the instance S10 Material Substantial from which a sample was taken This may be a feature or a fluid body from which a sample was removed.
In First Order Logic:
O3(x,y) ⊃ S2(x)
O3(x,y) ⊃ S10(y)

O4 sampled at (was sampling location of)

Domain: S2 Sample Taking
Range: E53 Place

Scope note: This property associates an instance of S2 Sample Taking with the instance of E53 Place at which this activity sampled. It identifies the narrower spatial location from which an instance of a sample was taken. This maybe known or given in absolute terms or relative to an instance of a material substantial from which it was taken. It describes a position within the area in which the instance of the sampling activity occurred. The latter comprises the space within which operators and instruments were contained during the activity.

In First Order Logic:
O4(x,y) ⊃ S2(x)
O4(x,y) ⊃ E53(y)

O5 removed (was removed by)

Domain: S2 Sample Taking
Range: S13 Sample
Subproperty of: S1 Matter Removal. O2 removed (was removed by): S11 Amount of Matter

Scope note: This property associates an instance of S2 Sample Taking with the instance of S13 Sample that was removed during this activity. The sample is identified by a unique identifier.
In First Order Logic:
O5(x,y) ⊃ S2(x)
O5(x,y) ⊃ S13(y)
O5(x,y) ⊃ O2(x,y)

O6 forms former or current part of (has former or current part)

Domain: S12 Amount of Fluid
Range: S14 Fluid Body

Scope note: This property associates an instance of S12 Amount of Fluid with an instance of S14 Fluid Body which forms part of it. It allows instances of S14 Fluid Body to be analyzed into elements of S12 Amount of Fluid.

In First Order Logic:
O6(x,y) ⊃ S12(x)
O6(x,y) ⊃ S14(y)

O7 contains or confines (is contained or confined)

Domain: E53 Place
Range: E53 Place

Scope note: This property associates an instance of E53 Place contained or confined in an instance of E53 Place with the latter. It describes a spatial containment between places or features. It declares a type of a feature which has a kind of spatial containment. Features such as layers defined as a Place that are contained or confined by a Physical Feature behaving as a place. A place-feature that is defined by its environmental area, by another place; it conforms to the outline of its container.

In First Order Logic:
O7(x,y) ⊃ E53(x)
O7(x,y) ⊃ E53(y)

Examples: The Wadis rivers contained or confined by riverbed/riverside. (they are rivers that are dry year round except after a rain)

O8 observed (was observed by)

Domain: S4 Observation
Range: S15 Observable Entity
Subproperty of: E13 Attribute Assignment. P140 assigned attribute to (was attributed by): E1 CRM Entity
Superproperty of: S21 Measurement. O24 measured (was measured by): S15 Observable Entity

Scope note: This property associates an instance of S4 Observation with an instance of S15 Observable Entity that was observed. Specifically it describes that a thing, a feature, a phenomenon or its reaction is observed by an activity of Observation.
In First Order Logic:
O8(x,y) ⊃ S4(x)
O8(x,y) ⊃ S15(y)

O8(x,y) ⊃ P140(x,y)

O9 observed property type (property type was observed by)

Domain: S4 Observation
Range: S9 Property Type

Scope note: This property associates an instance of S4 Observation with the instance of S9 Property Type for which the observation provides a value or evidence, such as "concentration of nitrate" observed in the water from a particular borehole. Encoding the observed property by type, observed entity and value (properties O9, O10, O16) is a method to circumscribe the reification of the observed property by the respective instance of S4 Observation.

In an RDFS encoding, this circumscription can be transformed into an explicit representation of the observed property in terms of a formal ontology either by use of a reification construct or by the use of a Named Graph containing the observed property. The latter representation allows for more formal reasoning with the model, the former is more flexible about the kinds of observations.

O10 assigned dimension (dimension was assigned by)

Domain: S6 Data Evaluation
Range: E54 Dimension

Scope note: This property associates an instance of S6 Data Evaluation with an instance of E54 Dimension that a data evaluation activity has assigned. In that case, dimensions may be determined by making evaluations on observational data based on mathematical inference rules and calculations.

In First Order Logic:

O10(x,y) ⊃ S6(x)
O10(x,y) ⊃ E54(y)

O11 described (was described by)

Domain: S6 Data Evaluation
Range: S15 Observable Entity

Scope note: This property associates an instance of S6 Data Evaluation with an instance of S15 Observable Entity for which a data evaluation activity provides a description. This description of any Observable Entity is based on data evaluations.

In First Order Logic:

O11(x,y) ⊃ S6(x)
O11(x,y) ⊃ S15(y)

O12 has dimension (is dimension of)

Domain: S15 Observable Entity
Range: E54 Dimension

Scope note: This property associates an instance of S15 Observable Entity with an instance of E54 Dimension that the observable entity has.
It offers no information about how and when an E54 Dimension was established.

In First Order Logic:

O12(x,y) ⊃ S15(x)
O12(x,y) ⊃ E54(y)

O13 triggers (is triggered by)

Domain: E5 Event
Range: E5 Event

Scope note: This property associates an instance of E5 Event that triggers another instance of E5 Event with the latter. It identifies the interaction between events: an event can activate (trigger) other event/s; in that sense it is interpreted as the cause, the triggering factor of a situation in tension (a system); a reaction between events.
In First Order Logic:
O13(x,y) ⊃ E5(x)
O13(x,y) ⊃ E5(y)

O14 initializes (is initialized by)

Domain: E5 Event
Range: S16 State

Scope note: This property associates an instance of E5 Event with instance/s of S16 State/s that an event initializes. These states are described as the results, consequences of an E5 Event.
In First Order Logic:
O14(x,y) ⊃ E5(x)
O14(x,y) ⊃ S16(y)

O15 occupied (was occupied by)

Domain: S10 Material Substantial
Range: E53 Place
Equivalent to: E18 Physical Thing. P156 occupies (is occupied by): E53 Place

Scope note: This property associates an instance of S10 Material Substantial with the instance of E53 Place that this substance occupied. It describes the space filled (occupied) by a physical matter. This property is the development of the shortcut expressed in the proposition of classification: “S20 Physical Feature” isA “E53 Place”
In First Order Logic:
O15(x,y) ⊃ S10(x)
O15(x,y) ⊃ E53(y)

O16 observed value (value was observed by)

Domain: S4 Observation
Range: E1 CRM Entity
Subproperty of: E13 Attribute Assignment. P141 assigned (was assigned by): E1 CRM Entity
Superproperty of: E16 Measurement. P40 observed dimension (was observed in): E54 Dimension

Scope note: This property associates a value assigned to an entity observed by S4 Observation.
In First Order Logic:
O16(x,y) ⊃ S4(x)
O16(x,y) ⊃ E1(y)
O16(x,y) ⊃ P141(x,y)

O17 generated (was generated by)

Domain: S17 Physical Genesis
Range: E18 Physical Thing
Superproperty of: E12 Production. P108 has produced (was produced by): E24 Physical Man-Made Thing

Scope note: This property associates an instance of S17 Physical Genesis event with an instance of E18 Physical Thing that the event generated.

O18 altered (was altered by)

Domain: S18 Alteration
Range: E18 Physical Thing
Superproperty of: E11 Modification. P31 has modified (was modified by): E24 Physical Man-Made Thing

Scope note: This property associates an instance of S18 Alteration process with an instance of E18 Physical Thing which was altered by this activity.
In First Order Logic:
O18(x,y) ⊃ S18(x)
O18(x,y) ⊃ E18(y)

O19 has found object (was object found by)

Domain: S19 Encounter Event
Range: E18 Physical Thing

Scope note: This property associates an instance of S19 Encounter Event with an instance of E18 Physical Thing that has been found.
In First Order Logic:
O19(x,y) ⊃ S19(x)
O19(x,y) ⊃ E18(y)

O20 sampled from type of part (type of part was sampled by)

Domain: S2 Sample Taking
Range: E55 Type

Scope note: This property associates the activity of a Sample Taking with the type of the location part from which a sample was taken. It is a shortcut of the property O4 sampled at, and it is used as an alternative property, identifying features and material substantial as types of parts of sampling positions.

In First Order Logic:
O20(x,y) ⊃ S2(x)
O20(x,y) ⊃ E55(y)

Examples:
- A tissue taken from molar tooth for DNA analysis
- A sample taken from a hand/head

O21 has found at (witnessed)

Domain: S19 Encounter Event
Range: E53 Place

Scope note: This property associates an instance of S19 Encounter Event with an instance of E53 Place at which an encounter event found things. It identifies the narrower spatial location in which a thing was found at. This maybe known or given in absolute terms or relative to the thing found. It describes a position within the area in which the instance of the encounter event occurred and found something.
In First Order Logic:

O21(x,y) ⊃ S19(x)
O21(x,y) ⊃ E53(y)

O22 partly or completely contains (is part of)

Domain: S22 Segment of Matter
Range: S20 Physical Feature

Scope note:
This property identifies an S20 Physical Feature as being part of a S22 Segment of Matter. One S22 Segment of Matter usually contains several S20 Physical Features.
In First Order Logic:
O22(x,y) ⊃ S22(x)
O22(x,y) ⊃ S20(y)

O23 is defined by (defines)

Domain: S22 Segment of Matter
Range: E92 Spacetime Volume

Scope note:
This property identifies the E92 Spacetime Volume that defines a S22 Segment of Matter. The spatial boundaries of the E92 Spacetime Volume are defined through S4 Observation or declaration while the temporal boundaries are confined by S18 Alteration events.
In First Order Logic:
O23(x,y) ⊃ S22(x)
O23(x,y) ⊃ E92(y)

O24 measured (was measured by)

Domain: S21 Measurement
Range: S15 Observable Entity
Subproperty of: S4 Observation. O8 observed (was observed by): S15 Observable Entity
E16 Measurement. P39 measured (was measured by): E1 CRM Entity

Quantification: many to one, necessary (1,1:0,n)

Scope note: This property associates an instance of S21 Measurement with the instance of S15 Observable Entity to which it applied. An instance of S15 Observable Entity may be measured more than once. Material and immaterial things and processes may be measured, e.g. the number of words in a text, or the duration of an event.
In First Order Logic:
O24(x,y) ⊃ S21(x)
O24(x,y) ⊃ S15(y)
O24(x,y) ⊃ O8(x,y)
O24(x,y) ⊃ P39(x,y)

Referred CIDOC CRM Classes and Properties

Since our model refers to and reuses, wherever appropriate, large parts of ISO21127, the CIDOC Conceptual Reference Model, this section provides a comprehensive list of all constructs used from ISO21127, together with their definitions following version 6.0 maintained by CIDOC. The complete definition of the CIDOC Conceptual Reference Model can be found in its official site: http://www.cidoc-crm.org/official_release_cidoc.html.

Referred CIDOC CRM Classes

This section contains the complete definitions of the classes of the CIDOC CRM Conceptual Reference Model version 6.2 referred to by the model.

E1 CRM Entity

Superclass of: E2 Temporal Entity
E52 Time-Span
E53 Place
E54 Dimension
E77 Persistent Item
E92 Spacetime Volume

Scope note: This class comprises all things in the universe of discourse of the CIDOC Conceptual Reference Model.

It is an abstract concept providing for three general properties:
1. Identification by name or appellation, and in particular by a preferred identifier
2. Classification by type, allowing further refinement of the specific subclass an instance belongs to
3. Attachment of free text for the expression of anything not captured by formal properties

With the exception of E59 Primitive Value, all other classes within the CRM are directly or indirectly specialisations of E1 CRM Entity.

Examples:

- the earthquake in Lisbon 1755 (E5)

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 CRM Entity
Superclass of: E3 Condition State
E4 Period

Scope note: This class comprises all phenomena, such as the instances of E4 Periods, E5 Events and states, 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, we regard that the former 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, these are also called perdurants. This class is disjoint from E77 Persistent Item. This is an abstract class and 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)
- the earthquake in Lisbon 1755 (E5)
- the Peterhof Palace near Saint Petersburg being in ruins from 1944 – 1946 (E3)

In First Order Logic:

E2(x) ⊃ E1(x)

Properties:

P4 has time-span (is time-span of): E52 Time-Span
P114 is equal in time to: E2 Temporal Entity
P115 finishes (is finished by): E2 Temporal Entity
P116 starts (is started by): E2 Temporal Entity
P117 occurs during (includes): E2 Temporal Entity
P118 overlaps in time with (is overlapped in time by): E2 Temporal Entity
P119 meets in time with (is met in time by): E2 Temporal Entity
P120 occurs before (occurs after): E2 Temporal Entity

E3 Condition State

Subclass of: E2 Temporal Entity

Scope note: This class comprises the states of objects characterised 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 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 *P2 has type*. For example, the E3 Condition State "condition of the SS Great Britain between 22 September 1846 and 27 August 1847" can be characterized as E55 Type "wrecked".

Examples:

- the "Amber Room" in Tsarskoje Selo being completely reconstructed from summer 2003 until now
- the Peterhof Palace near Saint Petersburg being in ruins from 1944 – 1946
- the state of my turkey in the oven at 14:30 on 25 December, 2002 (*P2 has type: E55 Type* "still not cooked")

In First Order Logic:

E3(x) ⊃ E2(x)

Properties**:**

P5 consists of (forms part of): E3 Condition State

E5 Event

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

Scope note: This class comprises changes of states in cultural, social or physical systems, regardless of scale, brought about by a series or group of coherent physical, cultural, technological or legal phenomena. Such changes of state will affect instances of E77 Persistent Item or its subclasses.

The distinction between an E5 Event and an E4 Period is partly a question of the scale of observation. Viewed at a coarse level of detail, an E5 Event is an 'instantaneous' change of state. At a fine level, the E5 Event can be analysed into its component phenomena within a space and time frame, and as such can be seen as an E4 Period. The reverse is not necessarily the case: not all instances of E4 Period give rise to a noteworthy change of state.

Examples:

- the birth of Cleopatra (E67)
- the destruction of Herculaneum by volcanic eruption in 79 AD (E6)
- World War II (E7)
- the Battle of Stalingrad (E7)
- the Yalta Conference (E7)
- my birthday celebration 28-6-1995 (E7)
- the falling of a tile from my roof last Sunday
- the CIDOC Conference 2003 (E7)

In First Order Logic:

E5(x) ⊃ E4(x)

Properties:

P11 had participant (participated in): E39 Actor
P12 occurred in the presence of (was present at): E77 Persistent Item

E7 Activity

Subclass of: E5 Event
Superclass of: E8 Acquisition
E9 Move
E10 Transfer of Custody
E11 Modification
E13 Attribute Assignment
E65 Creation
E66 Formation
E85 Joining
E86 Leaving
E87 Curation Activity

Scope note: This class comprises actions intentionally carried out by instances of E39 Actor that result in changes of state in the cultural, social, or physical systems documented.

This notion includes complex, composite and long-lasting actions such as the building of a settlement or a war, as well as simple, short-lived actions such as the opening of a door.

Examples:

- the Battle of Stalingrad
- the Yalta Conference
- my birthday celebration 28-6-1995
- the writing of "Faust" by Goethe (E65)
- the formation of the Bauhaus 1919 (E66)
- calling the place identified by TGN '7017998' 'Quyunjig' by the people of Iraq
- Kira Weber working in glass art from 1984 to 1993
- Kira Weber working in oil and pastel painting from 1993

In First Order Logic:

E7(x) ⊃ E5(x)

Properties:

P14 carried out by (performed): E39 Actor

(P14.1 in the role of: E55 Type)
P15 was influenced by (influenced): E1 CRM Entity
P16 used specific object (was used for): E70 Thing
(P16.1 mode of use: E55 Type)
P17 was motivated by (motivated): E1 CRM Entity
P19 was intended use of (was made for): E71 Man-Made Thing
(P19.1 mode of use: E55 Type)
P20 had specific purpose (was purpose of): E5 Event
P21 had general purpose (was purpose of): E55 Type
P32 used general technique (was technique of): E55 Type
P33 used specific technique (was used by): E29 Design or Procedure
P125 used object of type (was type of object used in): E55 Type
P134 continued (was continued by): E7 Activity

E11 Modification

Subclass of: E7 Activity
Superclass of: E12 Production
E79 Part Addition
E80 Part Removal

Scope note: This class comprises all instances of E7 Activity that create, alter or change E24 Physical Man-Made Thing.

This class includes the production of an item from raw materials, and other so far undocumented objects, and the preventive treatment or restoration of an object for conservation.

Since the distinction between modification and production is not always clear, modification is regarded as the more generally applicable concept. This implies that some items may be consumed or destroyed in a Modification, and that others may be produced as a result of it. An event should also be documented using E81 Transformation if it results in the destruction of one or more objects and the simultaneous production of others using parts or material from the originals. In this case, the new items have separate identities.

If the instance of the E29 Design or Procedure utilized for the modification prescribes the use of specific materials, they should be documented using property *P68 foresees use of (use foreseen by):* E57 Material of E29 Design or Procedure, rather than via *P126 employed (was employed in*): E57 Material.

Examples:

- the construction of the SS Great Britain (E12)
- the impregnation of the Vasa warship in Stockholm for preservation after 1956
- the transformation of the Enola Gay into a museum exhibit by the National Air and Space Museum in Washington DC between 1993 and 1995 (E12, E81)
- the last renewal of the gold coating of the Toshogu shrine in Nikko, Japan

In First Order Logic:

E11(x) ⊃ E7(x)

Properties:

P31 has modified (was modified by): E24 Physical Man-Made Thing
P126 employed (was employed in): E57 Material

E12 Production

Subclass of: E11 Modification
E63 Beginning of Existence

Scope note: This class comprises activities that are designed to, and succeed in, creating one or more new items.

It specializes the notion of modification into production. The decision as to whether or not an object is regarded as new is context sensitive. Normally, items are considered "new" if there is no obvious overall similarity between them and the consumed items and material used in their production. In other cases, an item is considered "new" because it becomes relevant to documentation by a modification. For example, the scribbling of a name on a potsherd may make it a voting token. The original potsherd may not be worth documenting, in contrast to the inscribed one.

This entity can be collective: the printing of a thousand books, for example, would normally be considered a single event.

An event should also be documented using E81 Transformation if it results in the destruction of one or more objects and the simultaneous production of others using parts or material from the originals. In this case, the new items have separate identities and matter is preserved, but identity is not.

Examples:

- the construction of the SS Great Britain
- the first casting of the Little Mermaid from the harbour of Copenhagen
- Rembrandt's creating of the seventh state of his etching "Woman sitting half dressed beside a stove", 1658, identified by Bartsch Number 197 (E12,E65,E81)

In First Order Logic:

E12(x) ⊃ E11(x)
E12(x) ⊃ E63(x)

Properties:

P108 has produced (was produced by): E24 Physical Man-Made Thing

E13 Attribute Assignment

Subclass of: E7 Activity
Superclass of: E14 Condition Assessment
E15 Identifier Assignment
E16 Measurement
E17 Type Assignment

Scope note: This class comprises the actions of making assertions about properties of an object or any relation between two items or concepts.

This class allows the documentation of how the respective assignment came about, and whose opinion it was. All the attributes or properties assigned in such an action can also be seen as directly attached to the respective item or concept, possibly as a collection of contradictory values. All cases of properties in this model that are also described indirectly through an action are characterised as "short cuts" of this action. This redundant modelling of two alternative views is preferred because many implementations may have good reasons to model either the action or the short cut, and the relation between both alternatives can be captured by simple rules.

In particular, the class describes the actions of people making propositions and statements during certain museum procedures, e.g. the person and date when a condition statement was made, an identifier was assigned, the museum object was measured, etc. Which kinds of such assignments and statements need to be documented explicitly in structures of a schema rather than free text, depends on if this information should be accessible by structured queries.

Examples:

- the assessment of the current ownership of Martin Doerr's silver cup in February 1997

In First Order Logic:

E13(x) ⊃ E7(x)

Properties:

P140 assigned attribute to (was attributed by): E1 CRM Entity
P141 assigned (was assigned by): E1 CRM Entity

E16 Measurement

Subclass of: E13 Attribute Assignment

Scope note: This class comprises actions measuring physical properties and other values that can be determined by a systematic procedure.

Examples include measuring the monetary value of a collection of coins or the running time of a specific video cassette.

The E16 Measurement may use simple counting or tools, such as yardsticks or radiation detection devices. The interest is in the method and care applied, so that the reliability of the result may be judged at a later stage, or research continued on the associated documents. The date of the event is important for dimensions, which may change value over time, such as the length of an object subject to shrinkage. Details of methods and devices are best handled as free text, whereas basic techniques such as "carbon 14 dating" should be encoded using *P2 has type (is type of:) E55 Type*.

Examples:

- measurement of height of silver cup 232 on the 31st August 1997
- the carbon 14 dating of the “Schoeninger Speer II” in 1996 [an about 400.000 years old Palaeolithic complete wooden spear found in Schoeningen, Niedersachsen, Germany in 1995]

In First Order Logic:

E16(x) ⊃ E13(x)

Properties:

P39 measured (was measured by): E1 CRM Entity
P40 observed dimension (was observed in): E54 Dimension

E18 Physical Thing

Subclass of: E72 Legal Object
E92 Spacetime Volume
Superclass of: E19 Physical Object
E24 Physical Man-Made Thing
E26 Physical Feature

Scope Note: This class comprises all persistent physical items with a relatively stable form, man-made or natural.

Depending on the existence of natural boundaries of such things, the CRM distinguishes the instances of E19 Physical Object from instances of E26 Physical Feature, such as holes, rivers, pieces of land etc. Most instances of E19 Physical Object can be moved (if not too heavy), whereas features are integral to the surrounding matter.

An instance of E18 Physical Thing occupies not only a particular geometric space, but in the course of its existence it also forms a trajectory through spacetime, which occupies a real, that is phenomenal, volume in spacetime. We include in the occupied space the space filled by the matter of the physical thing and all its inner spaces, such as the interior of a box. Physical things consisting of aggregations of physically unconnected objects, such as a set of chessmen, occupy a number of individually contiguous spacetime volumes equal to the number of unconnected objects that constitute the set.

We model E18 Physical Thing to be a subclass of E72 Legal Object and of E92 Spacetime volume. The latter is intended as a phenomenal spacetime volume as defined in CRMgeo (Doerr and Hiebel 2013). By virtue of this multiple inheritance we can discuss the physical

extent of an E18 Physical Thing 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 E18 Physical Thing is matter while a spacetime volume is an aggregation of points in spacetime. However, the real spatiotemporal extent of an instance of E18 Physical Thing 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 E18 Physical Thing. Therefore this multiple inheritance is unambiguous and effective and furthermore corresponds to the intuitions of natural language.

The CIDOC CRM is generally not concerned with amounts of matter in fluid or gaseous states.

Examples:

- the Cullinan Diamond (E19)
- the cave "Ideon Andron" in Crete (E26)
- the Mona Lisa (E22)

In First Order Logic:

E18(x) ⊃ E72(x)
E18(x) ⊃ E92(x)

Properties:

P44 has condition (is condition of): E3 Condition State
P45 consists of (is incorporated in): E57 Material
P46 is composed of (forms part of): E18 Physical Thing
P49 has former or current keeper (is former or current keeper of): E39 Actor
P50 has current keeper (is current keeper of): E39 Actor
P51 has former or current owner (is former or current owner of): E39 Actor
P52 has current owner (is current owner of): E39 Actor
P53 has former or current location (is former or current location of): E53 Place
P58 has section definition (defines section): E46 Section Definition
P59 has section (is located on or within): E53 Place
P128 carries (is carried by): E90 Symbolic Object
P156 occupies (is occupied by): E53 Place

E24 Physical Man-Made Thing

Subclass of: E18 Physical Thing
E71 Man-Made Thing
Superclass of: E22 Man-Made Object
E25 Man-Made Feature
E78 Collection

Scope Note: This class comprises all persistent physical items that are purposely created by human activity.

This class comprises man-made objects, such as a swords, and man-made features, such as rock art. No assumptions are made as to the extent of modification required to justify regarding an object as man-made. For example, a "cup and ring" carving on bedrock is regarded as instance of E24 Physical Man-Made Thing.

Examples:

- the Forth Railway Bridge (E22)
- the Channel Tunnel (E25)
- the Historical Collection of the Museum Benaki in Athens (E78)

In First Order Logic:

E24(x) ⊃ E18(x)
E24(x) ⊃ E71(x)

Properties:

P62 depicts (is depicted by): E1 CRM Entity
(P62.1 mode of depiction: E55 Type)

P65 shows visual item (is shown by): E36 Visual Item

E25 Man-Made Feature

Subclass of: E24 Physical Man-Made Thing
E26 Physical Feature

Scope Note: This class comprises physical features that are purposely created by human activity, such as scratches, artificial caves, artificial water channels, etc.

No assumptions are made as to the extent of modification required to justify regarding a feature as man-made. For example, rock art or even “cup and ring” carvings on bedrock a regarded as types of E25 Man-Made Feature.

Examples:

- the Manchester Ship Canal
- Michael Jackson’s nose following plastic surgery

In First Order Logic:

E25(x) ⊃ E26(x)
E25(x) ⊃ E24(x)

E26 Physical Feature

Subclass of: E18 Physical Thing
Superclass of: E25 Man-Made Feature
E27 Site

Scope Note: This class comprises identifiable features that are physically attached in an integral way to particular physical objects.

Instances of E26 Physical Feature share many of the attributes of instances of E19 Physical Object. They may have a one-, two- or three-dimensional geometric extent, but there are no natural borders that separate them completely in an objective way from the carrier objects. For example, a doorway is a feature but the door itself, being attached by hinges, is not.

Instances of E26 Physical Feature can be features in a narrower sense, such as scratches, holes, reliefs, surface colours, reflection zones in an opal crystal or a density change in a piece of wood. In the wider sense, they are portions of particular objects with partially imaginary borders, such as the core of the Earth, an area of property on the surface of the Earth, a landscape or the head of a contiguous marble statue. They can be measured and dated, and it is sometimes possible to state who or what is or was responsible for them. They cannot be separated from the carrier object, but a segment of the carrier object may be identified (or sometimes removed) carrying the complete feature.

This definition coincides with the definition of "fiat objects" (Smith & Varzi, 2000, pp.401-420), with the exception of aggregates of “bona fide objects”.

Examples:

- the temple in Abu Simbel before its removal, which was carved out of solid rock
- Albrecht Duerer's signature on his painting of Charles the Great
- the damage to the nose of the Great Sphinx in Giza
- Michael Jackson’s nose prior to plastic surgery

In First Order Logic:

E26(x) ⊃ E18(x)

E27 Site

Subclass of: E26 Physical Feature

Scope Note: This class comprises pieces of land or sea floor.

In contrast to the purely geometric notion of E53 Place, this class describes constellations of matter on the surface of the Earth or other celestial body, which can be represented by photographs, paintings and maps.

Instances of E27 Site are composed of relatively immobile material items and features in a particular configuration at a particular location.

Examples:

- the Amazon river basin
- Knossos
- the Apollo 11 landing site
- Heathrow Airport
- the submerged harbour of the Minoan settlement of Gournia, Crete

In First Order Logic:

E27(x)⊃ E26(x)

E28 Conceptual Object

Subclass of: E71 Man-Made Thing
Superclass of: E55 Type
E89 Propositional Object
E90 Symbolic Object

Scope note: This class comprises non-material products of our minds and other human produced data that have become objects of a discourse about their identity, circumstances of creation or historical implication. The production of such information may have been supported by the use of technical devices such as cameras or computers.

Characteristically, instances of this class are created, invented or thought by someone, and then may be documented or communicated between persons. Instances of E28 Conceptual Object have the ability to exist on more than one particular carrier at the same time, such as paper, electronic signals, marks, audio media, paintings, photos, human memories, etc.

They cannot be destroyed. They exist as long as they can be found on at least one carrier or in at least one human memory. Their existence ends when the last carrier and the last memory are lost.

Examples:

- Beethoven's "Ode an die Freude" (Ode to Joy) (E73)
- the definition of "ontology" in the Oxford English Dictionary
- the knowledge about the victory at Marathon carried by the famous runner
- 'Maxwell equations' [preferred subject access point from LCSH, http://lccn.loc.gov/sh85082387, as of 19 November 2012]
- 'Equations, Maxwell' [variant subject access point, from the same source]

In First Order Logic:

E28(x) ⊃ E71(x)

Properties: P149 is identified by (identifies): E75 Conceptual Object Appellation

E53 Place

Subclass of: E1 CRM Entity

Scope note: This class comprises extents in space, in particular on the surface of the earth, in the pure sense of physics: independent from temporal phenomena and matter.

The instances of E53 Place are usually determined by reference to the position of "immobile" objects such as buildings, cities, mountains, rivers, or dedicated geodetic marks. A Place can be determined by combining a frame of reference and a location with respect to this frame. It may be identified by one or more instances of E44 Place Appellation.

It is sometimes argued that instances of E53 Place are best identified by global coordinates or absolute reference systems. However, relative references are often more relevant in the context of cultural documentation and tend to be more precise. In particular, we are often interested in position in relation to large, mobile objects, such as ships. For example, the Place at which Nelson died is known with reference to a large mobile object – H.M.S Victory. A resolution of this Place in terms of absolute coordinates would require knowledge of the movements of the vessel and the precise time of death, either of which may be revised, and the result would lack historical and cultural relevance.

Any object can serve as a frame of reference for E53 Place determination. The model foresees the notion of a "section" of an E19 Physical Object as a valid E53 Place determination.

Examples:

- the extent of the UK in the year 2003
- the position of the hallmark on the inside of my wedding ring
- the place referred to in the phrase: "Fish collected at three miles north of the confluence of the Arve and the Rhone"
- here -> <-

In First Order Logic:

E53(x) ⊃ E1(x)

Properties:

P87 is identified by (identifies): E44 Place Appellation
P89 falls within (contains): E53 Place
P121 overlaps with: E53 Place
P122 borders with: E53 Place
P157 is at rest relative to (provides reference space for): E18 Physical Thing
P168 place is defined by (defines place) : E94 Space Primitive

E54 Dimension

Subclass of: E1 CRM Entity

Scope note: This class comprises quantifiable properties that can be measured by some calibrated means and can be approximated by values, i.e. points or regions in a mathematical or conceptual space, such as natural or real numbers, RGB values etc.

An instance of E54 Dimension represents the true quantity, independent from its numerical approximation, e.g. in inches or in cm. The properties of the class E54 Dimension allow for expressing the numerical approximation of the values of an instance of E54 Dimension. If the true values belong to a non-discrete space, such as spatial distances, it is recommended to record them as approximations by intervals or regions of indeterminacy enclosing the assumed true values. For instance, a length of 5 cm may be recorded as 4.5-5.5 cm, according to the precision of the respective observation. Note, that interoperability of values described in different units depends critically on the representation as value regions.

Numerical approximations in archaic instances of E58 Measurement Unit used in historical records should be preserved. Equivalents corresponding to current knowledge should be recorded as additional instances of E54 Dimension as appropriate.

Examples:

- currency: £26.00
- length: 3.9-4.1 cm
- diameter 26 mm
- weight 150 lbs
- density: 0.85 gm/cc

- luminescence: 56 ISO lumens
- tin content: 0.46 %
- taille au garot: 5 hands
- calibrated C14 date: 2460-2720 years, etc

In First Order Logic:

E54(x) ⊃ E1(x)

Properties:

P90 has value: E60 Number
P91 has unit (is unit of): E58 Measurement Unit

E55 Type

Subclass of: E28 Conceptual Object
Superclass of: E56 Language
E57 Material
E58 Measurement Unit

Scope note: This class comprises concepts denoted by terms from thesauri and controlled vocabularies used to characterize and classify instances of CRM classes. Instances of E55 Type represent concepts in contrast to instances of E41 Appellation which are used to name instances of CRM classes.

E55 Type is the CRM's interface to domain specific ontologies and thesauri. These can be represented in the CRM 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.

Examples:

- weight, length, depth [types of E54]
- portrait, sketch, animation [types of E38]
- French, English, German [E56]
- excellent, good, poor [types of E3]
- Ford Model T, chop stick [types of E22]
- cave, doline, scratch [types of E26]
- poem, short story [types of E33]
- wedding, earthquake, skirmish [types of E5]

In First Order Logic:

E55(x) ⊃ E28(x)

Properties:

P127 has broader term (has narrower term): E55 Type
P150 defines typical parts of(define typical wholes for): E55 Type

E57 Material

Subclass of: E55 Type

Scope note: This class is a specialization of E55 Type and comprises the concepts of materials.

Instances of E57 Material may denote properties of matter before its use, during its use, and as incorporated in an object, such as ultramarine powder, tempera paste, reinforced concrete. Discrete pieces of raw-materials kept in museums, such as bricks, sheets of fabric, pieces of metal, should be modelled individually in the same way as other objects. Discrete used or processed pieces, such as the stones from Nefer Titi's temple, should be modelled as parts (cf. *P46 is composed of*).

This type is used categorically in the model without reference to instances of it, i.e. the Model does not foresee the description of instances of instances of E57 Material, e.g.: "instances of gold".

It is recommended that internationally or nationally agreed codes and terminology are used.

Examples:

- brick
- gold
- aluminium
- polycarbonate
- resin

In First Order Logic:

E57(x) ⊃ E55(x)

E63 Beginning of Existence

Subclass of: E5 Event

Superclass of: E12 Production
E65 Creation
E66 Formation
E67 Birth
E81 Transformation

Scope note: This class comprises events that bring into existence any E77 Persistent Item.

It may be used for temporal reasoning about things (intellectual products, physical items, groups of people, living beings) beginning to exist; it serves as a hook for determination of a terminus post quem and ante quem.

Examples:

- the birth of my child
- the birth of Snoopy, my dog
- the calving of the iceberg that sank the Titanic
- the construction of the Eiffel Tower

In First Order Logic:

E63(x) ⊃ E5(x)

Properties:

P92 brought into existence (was brought into existence by): E77 Persistent Item

E70 Thing

Subclass of: E77 Persistent Item

Superclass of: E71 Man-Made Thing
E72 Legal Object

Scope note: This general class comprises discrete, identifiable, instances of E77 Persistent Item that are documented as single units, that either consist of matter or depend on being carried by matter and are characterized by relative stability.

They may be intellectual products or physical things. They may for instance have a solid physical form, an electronic encoding, or they may be a logical concept or structure.

Examples:

- my photograph collection (E78)
- the bottle of milk in my refrigerator (E22)
- the plan of the Strassburger Muenster (E29)
- the thing on the top of Otto Hahn's desk (E19)
- the form of the no-smoking sign (E36)
- the cave of Dirou, Mani, Greece (E27)

In First Order Logic:

E70(x) ⊃ E77(x)

Properties

P43 has dimension (is dimension of): E54 Dimension
P101 had as general use (was use of): E55 Type
P130 shows features of (features are also found on): E70 Thing
(P130.1 kind of similarity: E55 Type)

E77 Persistent Item

Subclass of: E1 CRM Entity
Superclass of: E39 Actor
E70 Thing

Scope note: This class comprises items that have a persistent identity, sometimes known as "endurants" in philosophy.

They can be repeatedly recognized within the duration of their existence by identity criteria rather than by continuity or observation. Persistent Items can be either physical entities, such as people, animals or things, or conceptual entities such as ideas, concepts, products of the imagination or common names.

The criteria that determine the identity of an item are often difficult to establish -; the decision depends largely on the judgement of the observer. For example, a building is regarded as no longer existing if it is dismantled and the materials reused in a different configuration. On the other hand, human beings go through radical and profound changes during their life-span, affecting both material composition and form, yet preserve their identity by other criteria. Similarly, inanimate objects may be subject to exchange of parts and matter. The class E77 Persistent Item does not take any position about the nature of the applicable identity criteria and if actual knowledge about identity of an instance of this class exists. There may be cases, where the identity of an E77 Persistent Item is not decidable by a certain state of knowledge.
The main classes of objects that fall outside the scope the E77 Persistent Item class are temporal objects such as periods, events and acts, and descriptive properties.

Examples:

- Leonard da Vinci
- Stonehenge
- the hole in the ozone layer
- the First Law of Thermodynamics
- the Bermuda Triangle

In First Order Logic:

E77(x) ⊃ E1(x)

E80 Part Removal

Subclass of: E11 Modification

Scope note: This class comprises the activities that result in an instance of E18 Physical Thing being decreased by the removal of a part.

Typical scenarios include the detachment of an accessory, the removal of a component or part of a composite object, or the deaccessioning of an object from a curated E78 Collection. If the E80 Part Removal results in the total decomposition of the original object into pieces, such that the whole ceases to exist, the activity should instead be modelled as an E81 Transformation, i.e. a simultaneous destruction and production. In cases where the part removed has no discernible identity prior to its removal but does have an identity subsequent to its removal, the activity should be regarded as both E80 Part Removal and E12 Production. This class of activities forms a basis for reasoning about the history, and continuity of identity over time, of objects that are removed from other objects, such as precious gemstones being extracted from different items of jewelry, or cultural artifacts being deaccessioned from different museum

collections over their lifespan.

Examples:

- the removal of the engine from my car
- the disposal of object number 1976:234 from the collection

In First Order Logic:

E80(x) ⊃ E11(x)

Properties:

P112 diminished (was diminished by): E24 Physical Man-Made Thing
P113 removed (was removed by): E18 Physical Thing

E92 Spacetime Volume

Subclass of: E1 CRM Entity
Superclass of: E4 Period
E18 Physical Thing
E93 Presence

Scope note: This class comprises 4 dimensional point sets (volumes) in physical spacetime regardless its true geometric form. They may derive their identity from being the extent of a material phenomenon or from being the interpretation of an expression defining an extent in spacetime. Intersections of instances of E92 Spacetime Volume, Place and Timespan are also regarded as instances of E92 Spacetime Volume. An instance of E92 Spacetime Volume is either contiguous or composed of a finite number of contiguous subsets. Its boundaries may be fuzzy due to the properties of the phenomena it derives from or due to the limited precision up to which defining expression can be identified with a real extent in spacetime. The duration of existence of an instance of a spacetime volume is trivially its projection on time.

Examples:

- the spacetime Volume of the Event of Ceasars murder
- the spacetime Volume where and when the carbon 14 dating of the "Schoeninger Speer II" in 1996 took place
- the spatio-temporal trajectory of the H.M.S. Victory from its building to its actual location
- the spacetime volume defined by a polygon approximating the Danube river flood in Austria between 6th and 9th of August 2002

In First Order Logic:

E92(x) ⊃ E1(x)

Properties:

P10 falls within (contains): E92 Spacetime Volume
P132 overlaps with: E92 Spacetime Volume
P133 is separated from: E92 Spacetime Volume
P160 has temporal projection: E52 Time-Span
P161 has spatial projection: E53 Place

1.1. Referred CIDOC CRM Properties

This section contains the complete definitions of the properties of the CIDOC CRM Conceptual Reference Model version 6.2 referred to. We apply the same format conventions as in mentioned above.

P31 has modified (was modified by)

Domain: E11 Modification
Range: E24 Physical Man-Made Thing
Subproperty of: E5 Event. P12 occurred in the presence of (was present at): E77 Persistent Item
Superproperty of: E12 Production. P108 has produced (was produced by): E24 Physical Man-Made Thing
E79 Part Addition. P110 augmented (was augmented by): E24 Physical Man-Made Thing
E80 Part Removal. P112 diminished (was diminished by): E24 Physical Man-Made Thing
Quantification: many to many, necessary (1,n:0,n)

Scope note: This property identifies the E24 Physical Man-Made Thing modified in an E11 Modification.

If a modification is applied to a non-man-made object, it is regarded as an E22 Man-Made Object from that time onwards.

Examples:

- rebuilding of the Reichstag (E11) *has modified* the Reichstag in Berlin (E24)

In First Order Logic:

P31(x,y) ⊃ E11(x)
P31(x,y) ⊃ E24(y)
P31(x,y) ⊃ P12(x,y)

P39 measured (was measured by)

Domain: E16 Measurement
Range: E1 CRM Entity
Subproperty of: E13 Attribute Assignment. P140 assigned attribute to (was attributed by): E1 CRM Entity
Quantification: many to one, necessary (1,1:0,n)

Scope note: This property associates an instance of E16 Measurement with the instance of E1 CRM Entity to which it applied. An instance of E1 CRM Entity may be measured more than once. Material and immaterial things and processes may be measured, e.g. the number of words in a text, or the duration of an event.

Examples:

- 31 August 1997 measurement of height of silver cup 232 (E16) *measured* silver cup 232 (E22)

In First Order Logic:

P39(x,y) ⊃ E16(x)
P39(x,y) ⊃ E1(y)
P39(x,y) ⊃ P140(x,y)

P40 observed dimension (was observed in)

Domain: E16 Measurement
Range: E54 Dimension
Subproperty of: E13 Attribute Assignment. P141 assigned (was assigned by): E1 CRM Entity
Quantification: many to many, necessary (1,n:0,n)

Scope note: This property records the dimension that was observed in an E16 Measurement Event.
E54 Dimension can be any quantifiable aspect of E70 Thing. Weight, image colour depth and monetary value are dimensions in this sense. One measurement activity may determine more

than one dimension of one object.
Dimensions may be determined either by direct observation or using recorded evidence. In the latter case the measured Thing does not need to be present or extant.
Even though knowledge of the value of a dimension requires measurement, the dimension may be an object of discourse prior to, or even without, any measurement being made.

Examples:

- 31 August 1997 measurement of height of silver cup 232 (E16) *observed dimension* silver cup 232 height (E54) *has unit* mm (E58), *has value* 224 (E60)

In First Order Logic:

P40(x,y) ⊃ E16(x)
P40(x,y)⊃ E54(y)
P40(x,y) ⊃ P141(x,y)

P44 has condition (is condition of)

Domain: E18 Physical Thing
Range: E3 Condition State
Quantification: one to many, dependent (0,n:1,1)

Scope note: This property records an E3 Condition State for some E18 Physical Thing.

It is a shortcut of the more fully developed path from E18 Physical Thing through *P34 concerned (was assessed by)*, E14 Condition Assessment *P35 has identified (was identified by)* to E3 Condition State. It offers no information about how and when the E3 Condition State was established, nor by whom.

An instance of Condition State is specific to an instance of Physical Thing.

Examples:

- silver cup 232 (E22) *has condition* oxidation traces were present in 1997 (E3) *has type* oxidation traces (E55)

In First Order Logic:

P44(x,y) ⊃ E18(x)
P44(x,y) ⊃ E3(y)

P45 consists of (is incorporated in)

Domain: E18 Physical Thing
Range: E57 Material
Quantification: many to many, necessary (1,n:0,n)

Scope note: This property identifies the instances of E57 Materials of which an instance of E18 Physical Thing is composed.

All physical things consist of physical materials. *P45 consists of (is incorporated in)* allows the different Materials to be recorded. *P45 consists of (is incorporated in)* refers here to observed Material as opposed to the consumed raw material.

A Material, such as a theoretical alloy, may not have any physical instances.

Examples:

- silver cup 232 (E22) *consists of* silver (E57)

In First Order Logic:

P45(x,y) ⊃ E18(x)
P45(x,y) ⊃ E57(y)

P46 is composed of (forms part of)

Domain: E18 Physical Thing
Range: E18 Physical Thing
Subproperty of: E92 Spacetime Volume. P132 overlaps with: E92 Spacetime Volume
Superproperty of: E19 Physical Object. P56 bears feature (is found on): E26 Physical Feature
Quantification: many to many (0,n:0,n)

Scope note: This property allows instances of E18 Physical Thing to be analysed into component elements.

Component elements, since they are themselves instances of E18 Physical Thing, may be further analysed into sub-components, thereby creating a hierarchy of part decomposition. An instance of E18 Physical Thing may be shared between multiple wholes, for example two buildings may share a common wall. This property does not specify when and for how long a component element resided in the respective whole. If a component is not part of a whole from the beginning of existence or until the end of existence of the whole, the classes E79 Part Addition and E90 Part Removal can be used to document when a component became part of a particular whole and/or when it stopped being a part of it. For the time-span of being part of the respective whole, the component is completely contained in the place the whole occupies.

This property is intended to describe specific components that are individually documented, rather than general aspects. Overall descriptions of the structure of an instance of E18 Physical Thing are captured by the *P3 has note* property.

The instances of E57 Material of which an item of E18 Physical Thing is composed should be documented using *P45 consists of (is incorporated in)*.

Examples:

- the Royal carriage (E22) *forms part of* the Royal train (E22)
- the "Hog's Back" (E24) *forms part of* the "Fosseway" (E24)

In First Order Logic:

P46(x,y) ⊃ E18(x)
P46(x,y) ⊃ E18(y)
P46(x,y) ⊃ P132(x,y)
P46(x,y) ⊃ (∃uzw)[E93(u) ∧ P166 (x,u) ∧ E52(z) ∧ P164(u,z) ∧ E93(w) ∧ P166 (y,w) ∧ P164(w,z) ∧ P10(w,u)]

P108 has produced (was produced by)

Domain: E12 Production
Range: E24 Physical Man-Made Thing
Subproperty of: E11 Modification. P31 has modified (was modified by): E24 Physical Man-Made Thing
E63 Beginning of Existence. P92 brought into existence (was brought into existence by): E77 Persistent Item
Quantification: one to many, necessary, dependent (1,n:1,1)

Scope note: This property identifies the E24 Physical Man-Made Thing that came into existence as a result of an E12 Production.

The identity of an instance of E24 Physical Man-Made Thing is not defined by its matter, but by its existence as a subject of documentation. An E12 Production can result in the creation of multiple instances of E24 Physical Man-Made Thing.

Examples:

- The building of Rome (E12) *has produced* The Colosseum (E22)

In First Order Logic:

P108(x,y) ⊃ E12(x)
P108(x,y) ⊃ E24(y)

P108(x,y) ⊃ P31(x,y)
P108(x,y) ⊃ P92(x,y)

-

P140 assigned attribute to (was attributed by)

Domain: E13 Attribute Assignment
Range: E1 CRM Entity
Superproperty of: E14 Condition Assessment. P34 concerned (was assessed by): E18 Physical Thing
E16 Measurement. P39 measured (was measured by): E70 Thing
E17 Type Assignment. P41 classified (was classified by): E1 CRM Entity
Quantification: many to many (0,n:0,n)

Scope note: This property indicates the item to which an attribute or relation is assigned.
Examples:

- February 1997 Current Ownership Assessment of Martin Doerr's silver cup (E13) *assigned attribute to* Martin Doerr's silver cup (E19)
- 01 June 1997 Identifier Assignment of the silver cup donated by Martin Doerr (E15) *assigned attribute to* silver cup 232 (E19)

In First Order Logic:
P140(x,y) ⊃ E13(x)
P140(x,y) ⊃ E1(y)

P141 assigned (was assigned by)

Domain: E13 Attribute Assignment
Range: E1 CRM Entity
Superproperty of: E14 Condition Assessment. P35 has identified (identified by): E3 Condition State
E15 Identifier Assignment. P37 assigned (was assigned by): E42 Identifier
E15 Identifier Assignment. P38 deassigned (was deassigned by): E42 Identifier
E16 Measurement. P40 observed dimension (was observed in): E54 Dimension
E17 Type Assignment. P42 assigned (was assigned by): E55 Type
Quantification: many to many (0,n:0,n)

Scope note: This property indicates the attribute that was assigned or the item that was related to the item denoted by a property P140 assigned attribute to in an Attribute assignment action.
Examples:

- February 1997 Current Ownership Assessment of Martin Doerr's silver cup (E13) *assigned* Martin Doerr (E21)
- 01 June 1997 Identifier Assignment of the silver cup donated by Martin Doerr (E15) *assigned* object identifier 232

In First Order Logic:
P141(x,y) ⊃ E13(x)
P141(x,y) ⊃ E1(y)

P156 occupies (is occupied by)

Domain: E18 Physical Thing
Range: E53 Place
Subproperty of: E92 Spacetime Volume. P161 has spatial projection: E53 Place

Quantification: one to one (0,1:1,1)

Scope note: This property describes the largest volume in space that an instance of E18 Physical Thing has occupied at any time during its existence, with respect to the reference space relative to itself. This allows you to describe the thing itself as a place that may contain other things, such as a box that may contain coins. In other words, it is the volume that contains all the points which

the thing has covered at some time during its existence. In the case of an E26 Physical Feature the default reference space is the one in which the object that bears the feature or at least the surrounding matter of the feature is at rest. In this case there is a 1:1 relation of E26 Feature and E53 Place. For simplicity of implementation multiple inheritance (E26 Feature IsA E53 Place) may be a practical approach.

For instances of E19 Physical Objects the default reference space is the one which is at rest to the object itself, i.e. which moves together with the object. We include in the occupied space the space filled by the matter of the physical thing and all its inner spaces.

This property is a subproperty of P161 has spatial projection because it refers to its own domain as reference space for its range, whereas P161 has spatial projection may refer to a place in terms of any reference space. For some instances of E18 Physical Object the relative stability of form may not be sufficient to define a useful local reference space, for instance for an amoeba. In such cases the fully developed path to an external reference space and using a temporal validity component may be adequate to determine the place they have occupied.

In contrast to P156 occupies, the property P53 has former or current location identifies an instance of E53 Place at which a thing is or has been for some unspecified time span. Further it does not constrain the reference space of the referred instance of P53 Place.

In First Order Logic:

$$P156(x,y) = [E18(x) \wedge E53(y) \wedge P161(x,y) \wedge P157(y,x)]$$

REFERENCES:

Patrick Le Boeuf, Martin Doerr, Christian Emil Ore, Stephen Stead (current main editors), Definition of the CIDOC Conceptual Reference Model version 6.2 May 2015

Doerr, M., Hiebel, G., 2013. CRMgeo : Linking the CIDOC CRM to GeoSPARQL through a Spatiotemporal Refinement. Heraklion.

Amendments version 1.2.3

37th joined meeting of the CIDOC CRM SIG and ISO/TC46/SC4/WG9 and the 30th FRBR - CIDOC CRM Harmonization meeting

S20 Physical Feature

The crm-sig resolving the ***issue 311*** changed the label, the scope note and the superclasses of S20

FROM:

S20 Physical Feature

Subclass of: E18 Physical Thing
E53 Place
Superclass of: E25 Man-Made Feature
E27 Site
S22 Segment of Matter

Equivalent to: E26 Physical Feature (CIDOC-CRM)

Scope Note: This class comprises identifiable features that are physically attached in an integral way to particular physical objects. An instance of S20 Physical Feature also represents the place it occupies with respect to the surrounding matter. More precisely, it is the maximal real volume in space that an instance of S20 Physical Feature is occupying during its lifetime with respect to the default reference space relative to which the feature is at rest. In cases of features on or in the surface of earth, the default reference is typically fixed to the closer environment of the tectonic plate or sea floor. In cases of features on mobile objects, the reference space is typically fixed to the geometry of the bearing object.

Instances of E26 Physical Feature share many of the attributes of instances of E19 Physical Object. They may have a one-, two- or three-dimensional geometric extent, but there are no natural borders that separate them completely in an objective way from the carrier objects. For example, a doorway is a feature but the door itself, being attached by hinges, is not.

Instances of E26 Physical Feature can be features in a narrower sense, such as scratches, holes, reliefs, surface colors, reflection zones in an opal crystal or a density change in a piece of wood. In the wider sense, they are portions of particular objects with partially imaginary borders, such as the core of the Earth, an area of property on the surface of the Earth, a landscape or the head of a contiguous marble statue. They can be measured and dated, and it is sometimes possible to state who or what is or was responsible for them. They cannot be separated from the carrier object, but a segment of the carrier object may be identified (or sometimes removed) carrying the complete feature.

This definition coincides with the definition of "fiat objects" (Smith &Varzi, 2000, pp.401-420), with the exception of aggregates of “bona fide objects”.

Examples:

- the temple in Abu Simbel before its removal, which was carved out of solid rock
- Albrecht Duerer's signature on his painting of Charles the Great
- the damage to the nose of the Great Sphinx in Giza
- Michael Jackson’s nose prior to plastic surgery

In First Order Logic:

S20(x) ⊃ E18(x)
S20(x) ⊃ E53(x)

TO:

S20 Rigid Physical Feature

Subclass of: E26 Physical Feature

E53 Place

Superclass of: E27 Site

S22 Segment of Matter

Scope Note: This class comprises physical features with the following characteristics. Any instance of this class is physically attached in an integral way to particular physical object, and has a stability of form in itself and with respect to the physical object bearing it, in such a way that it is sufficient to associate a permanent reference space within which its form is invariant and at rest.

Due to this stability of form, the maximal real volume in space that an instance of S20 Rigid Physical Feature occupies at sometime within its existence with respect to the default reference space relative to which the feature is at rest defines uniquely a place for the feature with respect to its surrounding matter.

Therefore we model S20 Rigid Physical Feature as a subclass of E26 Physical Feature and of E53 Place. The latter is intended as a phenomenal place as defined in CRMgeo (Doerr and Hiebel 2013). By virtue of this multiple inheritance we can discuss positions relative to the extent of an instance of S20 Rigid Physical Feature without representing each instance of it together with an instance of its associated place. This model combines two quite different kinds of substance: an instance of E26 Physical Feature and of E53 Place. It is an aggregation of points in a geometric space. However, since the identity and existence of this place depends uniquely on the identity of the instance of S20 Rigid Physical Feature as matter, this multiple inheritance is unambiguous and effective and furthermore corresponds to the intuitions of natural language. It shortcuts an implicit self-referential path from E26 Physical Feature through *P156 occupies*, E53 Place, *P157 is at rest relative to* E26 Physical Feature.

In cases of instances of S20 Rigid Physical Feature on or in the surface of earth, the default reference is typically fixed to the closer environment of the tectonic plate or sea floor. In cases of features on mobile objects, the reference space is typically fixed to the geometry of the bearing object. Note that the reference space associated with the instance of S20 Rigid Physical Feature may quite well be deformed over time, as long the continuity of its topology does not become unclear, such as the compression of dinosaur bones in geological layers, or the distortions of the hull of a ship by the waves of the sea. Defined in this way, the reference space can be used as a means to infer from current topological relationships past topological relationships of interest.

Examples:

- the temple in Abu Simbel before its removal, which was carved out of solid rock
- Albrecht Duerer's signature on his painting of Charles the Great
- the damaged nose of the Great Sphinx in Giza
- The bones of the Ichtyosaur in Holzmaden, Germany.

- The “Schliemann cut” in Troy

S4 Observation

The crm-sig resolving the ***issue 308*** changed the scope note of S4

FROM:

Scope note: This class comprises the activity of gaining scientific knowledge about particular states of physical reality gained by empirical evidence, experiments and by measurements. We define observation in the sense of natural sciences, as a kind of human activity: at some Place and within some Time-Span, certain Physical Things and their behavior and interactions are observed, either directly by human sensory impression, or enhanced with tools and measurement devices. The output of the internal processes of measurement devices that do not require additional human interaction are in general regarded as part of the observation and not as additional inference. Manual recordings may serve as additional evidence. Measurements and witnessing of events are special cases of observations. Observations result in a belief about certain propositions. In this model, the degree of confidence in the observed properties is regarded to be “true” per default, but could be described differently by adding a property P3 has note to an instance of S4 Observation, or by reification of the property O16 observed value. Primary data from measurement devices are regarded in this model to be results of observation and can be interpreted as propositions believed to be true within the (known) tolerances and degree of reliability of the device. Observations represent the transition between reality and propositions in the form of instances of a formal ontology, and can be subject to data evaluation from this point on..

In First Order Logic:

$S4(x) \supset E13(x)$

Properties:

O8 observed (was observed by): S15 Observable Entity
O9 observed property type (property type was observed by): S9 Property Type
O16 observed value (value was observed by): E1 CRM Entity

TO:

Scope note: This class comprises the activity of gaining scientific knowledge about particular states of physical reality gained by empirical evidence, experiments and by measurements.

We define observation in the sense of natural sciences, as a kind of human activity: at some place and within some time-span, certain physical things and their behavior and interactions are observed, either directly by human sensory impression, or enhanced with tools and measurement devices.

The output of the internal processes of measurement devices that do not require additional human interaction are in general regarded as part of the observation and not as additional inference. Manual recordings may serve as additional evidence. Measurements and witnessing of events are special cases of observations. Observations result in a belief about certain propositions. In this model, the degree of confidence in the observed properties is regarded to be “true” by default, but could be described differently by adding a property *P3 has note* to an instance of S4 Observation, or by reification of the property *O16 observed value*.

Primary data from measurement devices are regarded in this model to be results of observation and can be interpreted as propositions believed to be true within the (known) tolerances and degree of reliability of the device.

Observations represent the transition between reality and propositions in the form of instances of a formal ontology, and can be subject to data evaluation from this point on. For instance, detecting an archaeological site on satellite images is not regarded as an instance of S4 Observation, but as an instance of S6 Data Evaluation. Rather, only the production of the images is regarded as an

instance of S4 Observation.