CRM sci
Scientific observation model

Definition of the CRMsci

An Extension of CIDOC-CRM to support scientific observation

Proposal for approval by CIDOC CRM-SIG

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Table of Contents

a. The Scientific Observation Model

Introduction

Scope

This text defines the "Scientific Observation Model", 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 life sciences, 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 describing semantic relationships, in particular causal ones. It is not primarily a model for processing data in order to produce new research results, even though its representations can be used for processing.

It uses and extends the CIDOC Conceptual Reference Model (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 CRM, 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 life sciences, 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 archaeological 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 been validated in several national and international projects[1], through implementations of slightly different versions together with application-specific extensions and through 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. 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.

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[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

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

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.

Examples:

- The removal of the layer of black overpainting that covered the background of "La Gioconda of the Prado" between 2011 and 2012 by the Prado Museum in Madrid (Museo del Prado, 2012)[2].
-

In First Order Logic:
$S1(x) \supset E7(x)$

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.

Examples:

- The water sampling (S2) carried out by IGME, sampled from borehole 10/G5 at 419058.03, 4506565 , 95.7 Mygdonia basin on 28/6/2005 (InGeoCloudS - INspiredGEOdata CLOUD Services D2.2 2012;D2.3 2013)[3]The collection (S2) of specimen “FHO – Benth. - 1055” (S13) from a plant (E20) of the species “spiciformis” (E55) in Zambia by Bullock, A.A. in 1939.
- The collection (S2) of micro-sample 7 (S13), from the paint layer (S10) on the area of the apple (E53, E25) shown on the painting (E22) “Cupid complaining to Venus” (Cranach) by Joyce Plesters in June 1963 (Cranach Digital Archive,

http://lucascranach.org/UK_NGL_6344).

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 unit of activity, in which the sample is typically not identified and preserved beyond the context of this activity. Instances of this class describe the taking of one or more samples regardless whether they are explicitly identified in documentation or preserved beyond this activity. The dimensions observed by the respective measurement of this particular sample are regarded as dimensions of the instance of S10 Material Substantial at the place from which the samples were 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. 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.

Examples:

- The chemical Analysis 1 on 20/4/2004 sampled from layer 50501 and observed 70 mg of Ca (InGeoCloudS - INspiredGEOdata CLOUD Services D2.2 2012;D2.3 2013)[4]The Sphaerosyllislevantina specimen length measurement on 12/3/1999 (Bekiari et al., 2014)[5]Measurement (S3) of retention times during Gas Chromatography analysis of a paint sample “mid-blue paint for the sky” (S13) which identified Linseed oil as the paint medium (Foister, S, 2015).

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 through empirical evidence, experiments and 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 by human sensory impression, and often enhanced by 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.

Examples:

- The excavation of unit XI by the Archaeological Institute of Crete in 2004[6].The observation (S4) of the density (S9) of the X-Ray image of cupid's head from the painting "Cupid complaining to Venus" (S15) as "high density" (E1), on the 19th of March 1963 (Cranach Digital Archive, http://lucascranach.org/UK_NGL_6344).
- The observation (S4) of visible light absorption (S9) of the painting "Cupid complaining to Venus" (S15) as "having red pigment", in 2015 (Foister, S., 2015).

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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
O? observed: Situation?

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.

Examples:

- The inference made by Sakellarakis in 1980 about the sacrifice of a young man (E7) in the

6 *Fake example* (fictitious)

Minoan temple of Anemospilia based on the skeleton found (and 2 more) in the west room of the temple and the ritual bronze knife (E22) on it and the hypothesis that he died from loss of blood (the evidence was that his bones (E20) remained white in contrast to the others). [7]The inference that the underdrawing (E25) of the painting "Cupid complaining to Venus" (E22) was done with red pigment (E57), based on the observation (S4) that red pigment lines appear under the top paint layers (Foister, S., 2015).

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.

Examples:

- The calculation of the earthquake epicenter of Lokris area in 1989 by IGME [8](Ganas et al., 2006)The calculation of the intensity distance and assignment of PGA_N using the gcf2sac software from the EPPO shock wave recording of 2/2/1990 in Athens (S4) [9](InGeoCloudS - INspiredGEOdata CLOUD Services D2.2 2012;D2.3 2013)The calculation of the overall height (E54) of the statue of Hercules (S15) in the Temple of Hercules in Amman from the measurement of the size of the fragment of the fingers [https://en.wikipedia.org/w/index.php?title=Temple_of_Hercules_(Amman)&oldid=827687597].

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.

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7 Sakellarakis Y, Sapouna-Sakellaraki E .1981. Drama of death in a Minoan temple. Natl Geogr 159, pp 205–222

Examples:

- The forecasting of the imminent flooding of Venice in November 2012 by the Hellenic Centre for Marine Research using the Poseidon Sea Level Forecast System, (72 hours before its actual occurrence) (*Poseidon System* (http://poseidon.hcmr.gr/article_view.php?id=147&cid=28&bc=28)[10]Predicting the required temperature to maintain a target RH(%) of 50 based on monthly average temperature and RH in Birmingham, UK using the "Calculator for conservation heating" hostead at: http://www.conservationphysics.org/atmcalc/consheatcalc.php.

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.

Examples:

- Hypothessizing that "no binding before the 9th century is made with spine supports" documented in section 7.1 and 7.2 of "The Archaeology of Medieval bookbinding" by Szirmai (Szirmai, J.A. 1999)

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.

Examples:

- The velocity (S9) (of a station that is observed, meaning a share-wave velocity over the first 30 m).) (InGeoCloudS - INspiredGEOdata CLOUD Services D2.2 2012;D2.3 2013)[11]Retention time (S9) (in gas chromatography, meaning the time it takes for a component to pass through the chromatographer's column) (https://en.wikipedia.org/w/index.php?title=Gas_chromatography&oldid=828895011).

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.

Examples:

- The groundwater of the 5-22 basin of Central Macedonia ((InGeoCloudS - INspiredGEOdata CLOUD Services D2.2 2012;D2.3 2013)[12].The Mesozoic carbonate sequence with **f**lysch **(S10)** extracted from the area of Nafplion that was mapped and studied by Tattaris in 1970 (Photiades, 2010)[13].Parnassos, the limestone mountain (Strid, 1986)
[14]

In First Order Logic:

S10(x) ⊃ E70(x)

Properties:

O25 contains (is contained in): S10 Material Substantial
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 order to be able to identify and recognize in practice one instance of S11 Amount of Matter, some sort of confinement is needed that serves as a constraint for the enclosed matter and the integrity of the content, such as a bottle. In contrast to instances of E18 Physical Thing, no stability of form is required. The content may be put into another bottle without losing its identity. Subclasses may define very different identity conditions for the integrity of the content, such as chemical composition, or the sequence of layers of a bore core. Whereas an instance of E18 Physical Thing may gradually change form and chemical composition while preserving its identity, such as living beings, an instance of S11 Amount of Matter may lose its identifying features by such processes. What matters for the identity of an instance of S1 Amount of Matter is the preservation of a relevant composition from the initial state of definition onwards.

Examples:

- The mass of soil (S11) that was removed from sections 1, 2, 3 and 4 of the central building of Zominthos in order to be sieved, during the excavation in 2006 (*Field Notes*, 2006)[15]. The amount of natural cement (S11) that was added in a proportion of 5% in 2016 for the development of the sample of mortar in the laboratory of Ceramic, in Boumerdes University (Kelouaz khaled et al., 2016)[16].
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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 (be they gas or liquid) 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.

Examples:

- J.K.'s blood sample 0019FCF5 for the measurement of the cholesterol blood level[17]

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 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.

Examples:

- [18]The ground water sample with ID 105293 that was extracted from the top level of the intake No32 under terrain (S13, S12). (InGeoCloudS - INspiredGEOdata CLOUD Services D2.2 2012;D2.3 2013)The micro-sample 7, taken from the painting (S10) "Cupid complaining to Venus" (Cranach) by Joyce Plesters in June, 1963 (http://lucascranach.org/UK_NGL_6344).

In First Order Logic:

S13(x) ⊃ S11(x)

S14 Fluid Body

Subclass of: S10 Material Substantial

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17 *Fake example* (fictitious)

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.

Examples:

- The Rhine River

In First Order Logic:

$S14(x) \supset S10(x)$

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, such as physical things, their behavior, states and interactions or events, that can be observed by human sensory impression, often enhanced by using tools and measurement devices.

Conceptual objects manifestthrough their carriers such as books, digital media, or even human memory. Attributes 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 address the fact that frequently, the actually observed carriers of conceptual objects are not explicitly identified in documentation, i.e., they are assumed to have existed but they are unknown as individuals.

Examples:

- The domestic goose from Guangdong/1/1996 (H5N1) (S15) that was identified in 1996 in farmed geese in southern China as circulating highly pathogenic H5N1 (Wan, 2012)[19] .The crow flight he observed over the waters of Minamkeak Lake during the summer of 2015[20]The eruption of Krakatoa volcano at Indonesia in 1883 (F.A.R., Archibald and Whipple, 1888)[21].The density of the cupid head area in the X-Ray of the painting “Cupid complaining to Venus” (http://lucascranach.org/UK_NGL_6344).

In First Order Logic:

$S15(x) \supset E1(x)$

Properties:

O12 has dimension (is dimension of): E54 Dimension

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20 *Fake example* (fictitious)

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.

Examples:

- The desertification process that resulted in the spatial distribution of 'tiger bush' pattern on the gradually sloped terrain in Western Africa, as it was studied in 1994.(Thiery et al., 1995)[22]
- The corrosion process affecting my copper samples (S13) in the artificial aging salt-spray apparatus after 10 cycles which produced layers (E25) of cuprite and malachite. (E12)[23]

In First Order Logic:

$S17(x) \supset E63(x)$

$S17(x) \supset S18(x)$

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.

Examples:

- The petrification process of the Lesvos forest related to the intense volcanic activity in Lesvos island during late Oligocene - middle Miocene period (Marinos and Greek National Group of IAEG, 1997)[24].The flattening of the Lanhydrock Pedigree parchment (E18) after humidification (Pickwoad, N., 2016).

In First Order Logic:

$S18(x) \supset E5(x)$

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

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23 *Fake example* (fictitious)

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 object.

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").

Examples:

- The finding, by Prof. Stampolidis, of a complete skeleton, *in situ*, at the site of Eleutherna during the archaeological excavation carried out by the University of Crete in 2007 (Bonn-Muller, 2010).The detection of *lagocephalos_Sceleratus* was carried out with the trawler 419in the Mediteranean sea, during the first week of August 2014
(Bekiari et al., 2014)
- [25].

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: Any instance of this class is a physical feature with sufficient stability of form in itself and with respect to the physical object bearing it in order to associate a permanent reference space within which its form is invariant and at rest. The maximum volume in space that an instance of S20 Rigid Physical Feature occupies 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. 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 form of the nose of the Great Sphinx in Giza
- The "Central Orygma" (pit-house) which dominates the central part of the excavated area of the settlement of Mavropigi, representing phases I-III. (Karamitrou-Mentessidi et al., 2015) [26]
- The surface Surf313 (created by the excavation process on 3/3/2003)[27].
-

In First Order Logic:

S20(x) ⊃ E18(x)
S20(x) ⊃ E53(x)

Properties:

O7 confines (is confined by) :S10 Material Substantial

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.

Examples:

- .

In First Order Logic:

S21(x) ⊃ S4(x)
S21(x) ⊃ E16(x)

Properties:

O24 measured (was measured by): S15 Observable Entity

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5 Early Neolithic settlement of Mavropigi in western Greek Macedonia, *Eurasian Prehistory* 12 (1-2) (2015): 47-116

27 *Fake example* (fictitious)

S22 Segment of Matter

Subclass of: S20 Physical Feature

Scope Note: This class comprises physical features with relative stability of form and structure within a declared spatial volume of interest. The spatial extent of an instance of S22 Segment of Matter may be declared or defined by a researcher or observer usually because the arrangement and composition of substance is characteristic for the surrounding matter or can be interpreted as traces of its genesis and subsequent internal and external processes it was exposed to. The defining spatial extent is typically declared on a continuous matter by means of geometric determination without observable boundaries on all sides or any side. It may however be extracted at some point in time along the declared boundaries.

An instance of S22 Segment of Matter is regarded to be existing from the time on it completely solidified with a structure that is still preserved in a recognizable way at the time of its spatial definition. Its existence is regarded to end when its respective integrity is partially or completely corrupted. Uncorrupted subsections of an instance of S22 Segment of Matter may continue to exist as segments of matter in their own right beyond the existence of the containing instance, and may have solidified before it.

Typical examples are segments of archaeological or geological layers. They are regarded as uncorrupted even if they have undergone conformal deformations, such as compressions or shifts, as long as the effects of these deformations do not destroy the relevant structures of interest. This means that the defining spatial volume may be only geometrically valid for an instant of time for which it was declared, and undergo before and after deformations. In some cases, it may be possible to calculate the initial volume at the time of solidification, for instance for petrified bones compressed in Jurassic layers.

Examples:

In First Order Logic:

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

Properties:

O23 is defined by (defines): E92 Spacetime Volume

Properties

O1 diminished (was diminished by)

Domain: S1 Matter Removal
Range: S10 Material Substantial
Superproperty of: E80 Part Removal: P112 diminished (was diminished by): E24 Physical Man-Made Thing
Superproperty of: S1 Matter Removal: O2 removed (was removed by): S11 Amount of Matter
Quantification: many to many, necessary (1,n:0,n)

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

Although an instance of S1 Matter Removal activity normally concerns only one item of S10 Material Substantial, it is possible to imagine circumstances under which more than one item might be diminished by a single Matter Removal activity.
An instance S1 Matter Removal activity requires to diminish at least one item of S10 Material Substantial. This may be realized by any of the subproperties of O1 *diminished*. Therefore the instantiation of a particular subproperty of O1 *diminished* is not necessary.

Examples:

The removal of the fill from the interior of the "tomb of Lagadas" at Derveni Thessaloniki by the excavators in 1995 (S1) *diminished* the width of the cross-section of the burial chamber and the fill of the façade. (S10).) (Papasotiriou, A., Athanasiou, F., Malama, V., Miza, M., Sarantidou, M, 2010)[28].

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
Subproperty of: S1 Matter Removal: O1 diminished (was diminished by): S10 Material Substantial
Superproperty of: S2 Sample Taking: O5 removed (was removed by): S13 Sample
Quantification: many to many (0,n:0,n)

Scope note: This property associates an instance of S1 Matter Removal with the instance of S11 Amount of Matter that it has removed.

Examples:

- The "La Gioconda of the Prado" layer removal by the conservators of Prado Museum in Madrid (S1) *removed* the layer of black overpainting (S11) that covered the background of it (Museo del Prado, 2012)[29]
-

In First Order Logic:

O2(x,y) ⊃ S1(x)
O2(x,y) ⊃ S11(y)
O2(x,y) ⊃ O1(x,y)

O3 sampled from (was sample by)

Domain: S2 Sample Taking
Range: S10 Material Substantial
Subproperty of: S1 Matter Removal: O2 removed (was removed by): S11 Amount of Matter
Quantification: many to many, necessary (1,n:0,n)

Scope note: This property associates an instance of S2 Sample Taking with the instance S10 Material Substantial from which a sample was taken. In particular, it may be a feature or a fluid body from which a sample was removed.

Examples:

Water Sample Taking 74001 *sampled from* the acquifer that overlaps with borehole 10/G5 (InGeoCloudS - INspiredGEOdata CLOUD Services D2.2 2012;D2.3 2013)[30]

The collection (S2) of micro-sample 7, *sampled from* the painting (S10) "Cupid complaining to Venus" (Cranach) by Joyce Plesters in June 1963 (http://lucascranach.org/UK_NGL_6344).

In First Order Logic:

$O3(x,y) \supset S2(x)$
$O3(x,y) \supset S10(y)$
$O3(x,y) \supset O2(x,y)$

O4 sampled at (was sampling location of)

Domain: S2 Sample Taking
Range: E53 Place
Quantification: necessary one to many (1,1:0,n)

Scope note: This property associates an instance of S2 Sample Taking with the instance of E53 Place ("spot") at which this activity sampled. It identifies the narrowest relevant area on the material substantial from which the sample was taken. This may be known or given in absolute terms or relative to an instance of the material substantial from which it was taken. If samples are taken from more than one spot, the sample taking activity must be documented by separate instances for each spot.
The property P7 took place at, inherited from E4 Period, describes the position of the area in which the sampling activity occurred; this latter comprises the space within which operators and instruments were contained during the activity, and the sample taking spot.

Examples:

- Water Sample Taking 74001 *sampled at* borehole 10/G5 at depth 0 which falls within the water district 10/G5 in Central Macedonia (InGeoCloudS - INspiredGEOdata CLOUD Services D2.2 2012;D2.3 2013)[31]
- The collection (S2) of micro-sample 7 (S13) *sampled at* the area of the apple (E53) shown on the painting "Cupid complaining to Venus" (Cranach) (http://lucascranach.org/UK_NGL_6344)

In First Order Logic:

$O4(x,y) \supset S2(x)$
$O4(x,y) \supset E53(y)$

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
Quantification: many to many, necessary (1,n:0,n)
Scope note: This property associates an instance of S2 Sample Taking with the instance of S13 Sample that was taken during this activity.

Examples:

- Lithology Sample Taking 201 *removed* sample 2B (S13) (InGeoCloudS - INspiredGEOdata CLOUD Services D2.2 2012;D2.3 2013)[32]
- The sampling (S2) undertaken by Joyce Plesters in June 1963 while she was working on the painting "Cupid complaining to Venus" (Cranach), *removed* micro-sample 7 (S13) (http://lucascranach.org/UK_NGL_6344).

In First Order Logic:

O5(x,y) ⊃ S2(x)
O5(x,y) ⊃ S13(y)
O5(x,y) ⊃ O2(x,y)

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

Domain: S12 Amount of Fluid
Range: S14 Fluid Body
Subproperty of: S10 Material Substantial: O25 contains (is contained in): S10 Material Substantial
Quantification: many to many (0,n:0,n)

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

Examples:

- J.K.'s blood sample 0019FCF5 (S12) *is former or current part of* J.K.'s blood (S14)[33]
-

In First Order Logic:

O6(x,y) ⊃ S12(x)
O6(x,y) ⊃ S14(y)

O7 confined (was confined by)

Domain: S20 Rigid Physical Feature
Range: S10 Material Substantial
Quantification: many to many (0,n:0,n)

Scope note: This property associates an instance of S20 Rigid Physical Feature with an instance of S10 Material Substantial that it partially or completely confines. It describes cases in which rigid features such as stratigraphic layers, walls, dams, riverbeds, etc. form the boundaries of some item such as another stratigraphic layer or the waters of a river.

In First Order Logic:

O7(x,y) ⊃ S20(x)
O7(x,y) ⊃ S10(y)

Examples:

The Stavros – Farsala artesian acquifer (S20) *confined* the overexploited groundwater of the

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[33] *Fake example* (fictitious)

area (S10) (Rozos et al., 2017)[34]

The posthole (S20) *confined the organic material (S10)* identified in the 1997 analysis *of* the post holes of the structure 2 in the Tutu archaeological village site (Righter, 2002)[35]

= Borehole No1234 *confines* intake No5 (InGeoCloudS - INspiredGEOdata CLOUD Services D2.2 2012;D2.3 2013)

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

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.

Examples:

- This document is about the rotational landslide that *was observed by* engineers on the slope of Panagopoula coastal site, near Patras, on the 25th–26th April 1971 and the 3rd May 1971 (Tavoularis et al., 2017)[36].
- The survey (S4) of Sinai MS GREEK 418 *observed* a detached triple-braided clasp strap (S15). (Honey, A. and Pickwood, N., 2010)

In First Order Logic:

$O8(x,y) \supset S4(x)$
$O8(x,y) \supset S15(y)$
$O8(x,y) \supset P140(x,y)$

O9 observed property type (property type was observed by)

Domain: S4 Observation
Range: S9 Property Type
Subproperty of: E1 CRM Entity. P2 has type: E55 Type
Quantification: one to one (1,1:0,n)

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.

Examples:

- The seismic hazard analysis and recording by EPPO in 1990 (S4), in the area of Attiki *observed and recorded property type* share wave velocity (S9) (InGeoCloudS - INspiredGEOdata CLOUD Services D2.2 2012;D2.3 2013)[37]
- The Gas Chromatography analysis (S4) of the sample “mid-blue paint from the sky” *observed property type* retention time (S9). (Foister, S. 2015)
-

O10 assigned dimension (dimension was assigned by)

Domain: S6 Data Evaluation
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 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.

Examples:

- The shock wave recording carried out by EPPO in 1999 *assigned* PSA_10 with value 0.0008..(InGeoCloudS - INspiredGEOdata CLOUD Services D2.2 2012;D2.3 2013)[38]
-

In First Order Logic:

O10(x,y) ⊃ S6(x)
O10(x,y) ⊃ E54(y)

Must be connected to CRMInf and CRMDig. Issue 293

O11 described (was described by)

Domain: S6 Data Evaluation
Range: S15 Observable Entity
Quantification: many to many, necessary (1,n:0,n)

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.

Examples:

The quantitative analysis of Munsell color data carried out by by C.TBrown in 1999 (S6) *described* the slipped sherds of Mayapan period ceramics (S15) in Yukatan, Mexico (Ruck and Brown, 2015)[39].
The linear extrapolation of overall figure height from the size of the fingers (S6) described the statue of Hercules (S15) in Amman [https://en.wikipedia.org/w/index.php?title=Temple_of_Hercules_(Amman)&oldid=827687597].

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

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.

Examples:

- The earthquake of Mexico city in 2017 *had dimension* magnitude 6.2 Richter (Mindock, 2017, http://www.independent.co.uk/news/world/americas/mexico-earthquake-today-latest-mexico-city-magnitude-6-tremor-damage-a7963211.html)[40].
- The landslide that was activated in Parnitha in 1999 after the earthquake, *had* dimension crest length > 70 (InGeoCloudS - INspiredGEOdata CLOUD Services D2.2 2012;D2.3 2013)[41]
- 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
Quantification: many to many (0,n:0,n)

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 events in a target system that is in a situation of sustained tension, such as a trap or an unstable mountain slope giving way to a land slide after a rain or earthquake. In that sense the triggering event it is interpreted as a cause.

Examples:

- The earthquake of Parnitha in 1999 triggered the rotational landslide that was observed along the road on the same day.[42]
- The explosion at the Montserrat massif in 2007 (near Barcelona, Spain) *triggered the* rock fall event happened on 14 February 2007 (Vilajosana et al., 2008)[43].
- The 1966 flood in Florence *triggered* mould growth on books stored in flooded library rooms.(Rubinstein, N., 1966)
-

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

---

42 *Fake example* (fictitious)

initializes. These states are described as the results, consequences of an E5 Event.

Examples:

- The shallow landslide 1234 reactivated in flysch happened on October 21, 1992 initialized problems in the buildings and other technical works (bending of pipelines) in the area of Karpenisi.[44]
- Ground fractures, human losses and buildings collapse in Athens on 6/6/1996 *were initialized by*/were the result of the earthquake in1996[45].
- The introduction of my copper samples in the artificial aging salt-spray apparatus *initialized* their corrosion.[46]

In First Order Logic:

$O14(x,y) \supset E5(x)$
$O14(x,y) \supset S16(y)$

To be questioned! An event may initialize a period.

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"

Examples:

- AThe layer of pink plaster that *occupied*/covered the block 30 floor of the area X. on 3/2/2009[47].
-

In First Order Logic:

$O15(x,y) \supset S10(x)$
$O15(x,y) \supset E53(y)$

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 (inconsistent with E21 Measurement as long as Observable Entity is not moved to CRM.
Quantification: many to one, necessary (1,1:0,n)

Scope note: This property associates a value assigned to an entity observed by S4 Observation.

Examples:

- The surface survey at the bronze age site of Mitrou in east Lokris carried out by Cornell University in 1989 *observed value* 600 (of sherds).) (Kramer-Hajos and O'Neill , 2008). [48].
-

[44] *Fake example* (fictitious)
[45] *Fake example* (fictitious)
[46] *Fake example* (fictitious)
[47] *Fake example* (fictitious)

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

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

Examples:

- The landslide of Parnitha in 1999 generated the head of the landslide feature[49].
- The mud flow in the western region of Thessaly million years ago *generated* the deposits of solidified mud with irregular surface in the area[50].
- The introduction of my copper samples in the salt-spray apparatus (S17) *generated* new corrosion layers of cuprite and malachite (E18).[51]

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

Scope note: This property associates an instance of S18 Alteration process with an instance of E18 Physical Thing which was altered by this activity.

Examples:

- The alteration by the invasion of the beetles in 1995 (S18) which killed the trees, *altered* the forest (E18) in the areas of Brazil (Paine, 2008)\[52].
- The application of tension (S18) *altered* the humidified parchment of the Lanhydrock Pedigree (E18) (Pickwoad, N., 2010).

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

Scope note: This property associates an instance of S19 Encounter Event with an instance of E18 Physical Thing that has been found.

Examples:

49 *Fake example* (fictitious)
50 *Fake example* (fictitious)
51 *Fake example* (fictitious)

- The preservation followed the in situ finding (S19) that *has found*/detected the 18 arrowheads (E18) from Lerna in Argolis in 1994[53].
-

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
Quantification: many to many (0,n:0,n)

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
- The sampling (S2) undertaken by Joyce Plesters in June 1963 while she was working on the painting "Cupid complaining to Venus" (Cranach), *sampled from type of part* paint (E55). (http://lucascranach.org/UK_NGL_6344)

O21 has found at (witnessed)

Domain: S19 Encounter Event
Range: E53 Place
Quantification: many to many, necessary (1,n:0,n)
If more than one place is given they should contain each other.

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.

Examples:

- The "urn:catalog:IOL:POLY:Sphaerosyllis-levantina-ALA-IL-7-Oct.2009" (S19) *has found at* Haifa Bay (E53).

In First Order Logic:

O21(x,y) ⊃ S19(x)
O21(x,y) ⊃ E53(y)

O23 is defined by (defines)

Domain: S22 Segment of Matter
Range: E92 Spacetime Volume

[53] *Fake example* (fictitious)

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

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.

Examples:

This google earth image marks in red the accumulation zone (S22) of the landslide which is defined by the evolution (E92) of the landslide of Santomerion village in 2008 (Litoseliti et al., 2014)[54].

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.

Examples:

- The sensor measurement by IGME in 1999 (S21) *measured* the landslide displacement (S15) in the area of Parnitha.(InGeoCloudS - INspiredGEOdata CLOUD Services D2.2 2012;D2.3 2013)[55]

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)

O25 contains (is contained in)

Domain: S10 Material Substantial
Range: S10 Material Substantial
Superproperty of: E18 Physical Thing. P46 is composed of (forms part of): E18 Physical Thing
Quantification: many to many (0,n:0,n)

Scope note: This property describes that an instance of S10 Material Substantial was or is contained in another instance of S10 Material Substantial regardless of if the identity of the involved instances is based on the persistence of the form of material or on material substance that may change form.

Examples:

In First Order Logic:

$$O25(x,y) \supset E18(x)$$
$$O25(x,y) \supset E18(y)$$

Referred CIDOC CRM Classes and Properties

This model refers to and reuses parts of ISO21127, the CIDOC Conceptual Reference Model. 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.

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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:

$S20(x) \supset E18(x)$
$S20(x) \supset E53(x)$

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) ⊃ 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.

Amendments version 1.2.4 - 39th meeting of the CIDOC CRM

O22 partly or completely contains (is part of):
is deleted because it is covered by the property O25 contains.

O25 contains:
is a superproperty of P46 is composed of
Examples are updated and added:

Specifically, the example of O8 observed was changed and time was added.

BEFORE:
The field examination by IGME institute observed a rotational landslide in the area of Attiki

AFTER:
A rotational landslide was observed by engineers on the slope of Panagopoula coastal site, near Patras on the 25th–26th April 1971 and the 3rd May 1971.

An event instance was added in the example of S10 Material Substantial:

BEFORE:
Mesozoic carbonate sequence with **flysch (S10)** extracted from the area of Nafplion

AFTER:
Mesozoic carbonate sequence with **flysch (S10)** extracted from the area of Nafplion was mapped and studied by Tattaris in 1970.

Most of the examples now have references in footnotes.

Quantification of properties has been edited.

State is deleted from CRM sci and should be part of CRM inf.