



**Definition of the CRMsci**  
An Extension of CIDOC-CRM to support  
scientific observation

Proposal for approval by the CIDOC CRM-SIG

Version ~~2.4~~2

~~March~~ October 2024~~3~~

Currently maintained by FORTH

Contributors: Martin Doerr, Athina Kritsotaki, Yannis Rousakis, Gerald Hiebel, Maria Theodoridou, Athanasios Velios and others

CC BY 4.0 - 2022 Individual Contributors to CRMsci 2.~~0~~2

Definition of the CRMsci version 2.~~1~~4

This page is left blank on purpose

## Table of Contents

Introduction	5
Scope	5
Basic concepts	5
Sampling	6
Alteration	8
Observation	9
Determining positions	10
Inference making	12
Status	13
CRMsci class hierarchy, aligned with portions from the CIDOC-CRM class hierarchies	14
List of external classes used in CRMsci	15
CRMsci property hierarchy, aligned with portions from the CIDOC-CRM property hierarchy	16
List of external properties used in CRMsci	17
CRMsci Class Declarations	19
S1 Matter Removal	19
S2 Sample Taking	19
S3 Measurement by Sampling	20
S4 Observation	21
S5 Inference Making	22
S6 Data Evaluation	22
S7 Simulation or Prediction	23
S8 Categorical Hypothesis Building	23
S9 Property Type	24
S10 Material Substantial	24
S11 Amount of Matter	25
S12 Amount of Fluid	25
S13 Sample	26
S14 Fluid Body	26
S15 Observable Entity	26
S17 Physical Genesis	27
S18 Alteration	28
S19 Encounter Event	28
S20 Rigid Physical Feature	29
S21 Measurement	30
S22 Segment of Matter	31
S23 Position Determination	31
S24 Sample Splitting	32
S25 Relative Dimension	33
S26 Angle	33
CRMsci Property Declarations	35
O1 diminished (was diminished by)	35
O2 removed (was removed by)	35
O3 sampled from (was sample by)	36
O4 sampled at (was sampling location of)	36
O5 removed (was removed by)	37
O6 is former or current part of (has former or current part)	37
O7 confines (is confined by)	38
O8 observed (was observed by)	38
O9 observed property type (property type was observed by)	39
O10 assigned dimension (dimension was assigned by)	40
O11 described (was described by)	40
O12 has dimension (is dimension of)	41
O13 triggered (was triggered by)	42
O15 occupied (was occupied by)	42
O16 observed value (value was observed by)	43
O17 generated (was generated by)	43
O18 altered (was altered by)	44
O19 encountered object (was object encountered through)	44
Definition of the CRMsci version 2.24	†

O20 sampled from type of part (type of part was sampled by)	45
O21 encountered at (witnessed encounter)	45
O23 is defined by (defines)	46
O24 measured (was measured by)	46
O25 contains (is contained in)	47
O27 split (was source for)	47
O28 is conceptually greater than (is conceptually less than)	48
O29 removed sub-sample (was sub-sample removed by)	48
O30 determined position (was determined by)	49
O31 has validity time-span (is time-span validity for)	50
O32 determined position of (was located by)	50
O33 is relative to (has relative dimension)	51
O34 has vertex (is vertex of)	52
Works Cited	53

## Table of Tables

Table 1: Class Hierarchy	14
Table 2: List of external classes grouped by model and ordered by model and then by class identifier.	15
Table 3: Property Hierarchy	16
Table 4: List of external properties grouped by model and ordered by model and then by property identifier.	17

## Table of Figures

Figure 1: Subclass relations between temporal classes of the CRMsci and the CIDOC CRM.	6
Figure 2: S15 Observable Entity and subclasses describing substance.	6
Figure 3: Classes and properties for describing the process of sampling.	7
Figure 4: Classes and properties describing sample splitting.	8
Figure 5: Extending the sampling activity for the special case of samples used solely for measurements.	8
Figure 6: Events generating things without agency and causal relationships of events.	9
Figure 7: Classes and properties for describing scientific observation.	10
Figure 8: Classes and properties for describing the observation of an entity at a particular place and time.	10
Figure 9: Classes and properties for describing determining the positions of things.	11
Figure 10: Example of position determination of the Titanic after it hit an iceberg.	12
Figure 11: CRMsci classes for inference making.	12

# Introduction

This document describes work which uses and extends the CIDOC Conceptual Reference Model (CRM, ISO21127). The CIDOC CRM definition document should be read before this document. References to the CIDOC CRM in this document are taken from CIDOC CRM version 7.1.2 maintained by CIDOC.

## Scope

This text defines the “Scientific Observation Model” (CRMsci), 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.

The Scientific Observation Model has been developed bottom up from specific metadata examples from life sciences, geology, archaeology, 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.

## Basic concepts

Figure 14 and figure 22 summarise the classes that CRMsci introduces (in red) and their relations with CIDOC CRM classes (in blue).

### Events and Activities of sci

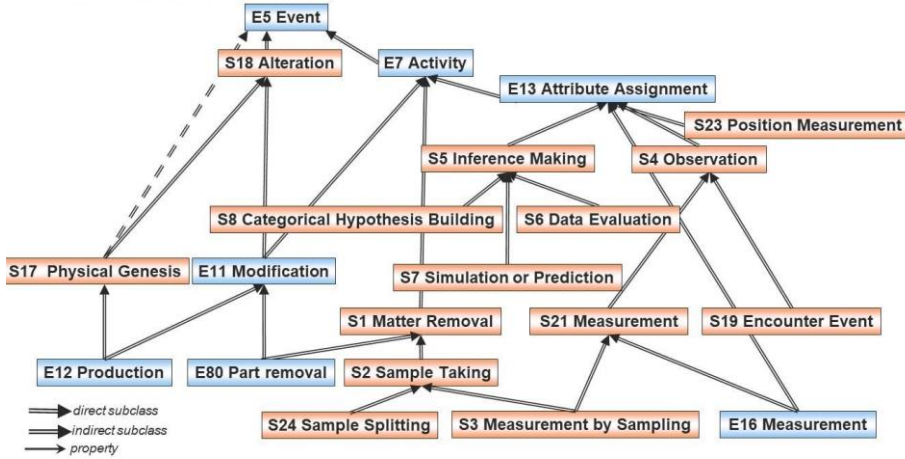


Figure 1: Subclass relations between temporal classes of the CRMsci and the CIDOC CRM.

### S15 Observable Entity

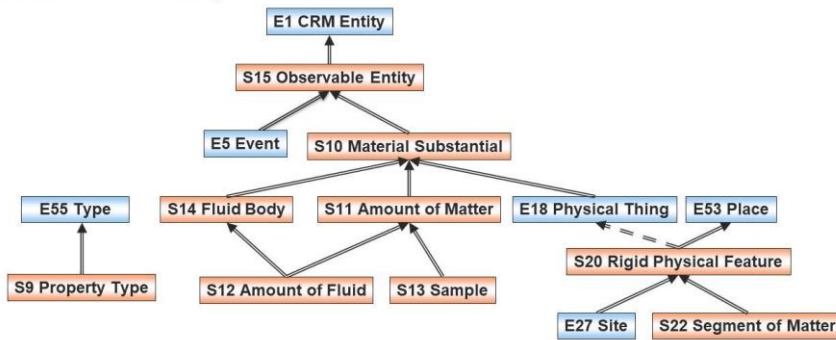


Figure 2: S15 Observable Entity and subclasses describing substance.

The class S10 Material Substantial describes instances of matter which can be identified and therefore recorded. While the material things that the CIDOC CRM describes are primarily considered solid, the CRMsci can also describe material things which are not solid, such as identifiable instances of fluids and piles of earth. The class S10 Material Substantial and its subclasses S14 Fluid Body and S11 Amount of Matter can be used to describe such instances respectively.

### Sampling

The process of taking a sample can be described by the class S2 Sample Taking, a specialisation of the more general class S1 Matter Removal, as shown in figure 33. The activity of sampling removes matter from something and creates a new identifiable entity which can be described as an instance of the class S13 Sample. This is similar to the CIDOC CRM construct of removing parts from solid things through the class E80 Part

Removal. CRMsci generalises this construct allowing sampling of fluids and other non-solid things. During sampling it is important to record the location on the sampled thing from where the sample was taken (e.g. collecting a pigment sample from the area of a canvas where an apple was painted). This can be described using the property O4 sampled at. This is distinct to the location that the sampling activity was taking place in general (e.g. the conservation studio where the sampling was done). The location of the sampling activity contains the location from where the sample was taken. In contrast, during instances of S19 Encounter Event (see section on [Error! Reference source not found.](#)[Error! Reference source not found.](#) [Error! Reference source not found.](#)[Error! Reference source not found.](#)) the two locations are the same. Partitive relationships between instances of S10 Material Substantial can be described using the property O25 contains, which generalises the CIDOC CRM property P46 is composed of used for solid things.

Commented [1]: Libre office for linking.

### S2 Sample Taking

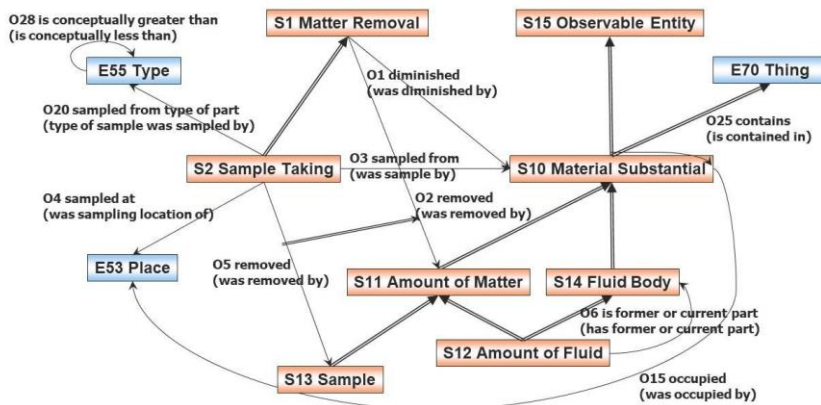


Figure 3: Classes and properties for describing the process of sampling.

A special case of sampling is when a sample is split, for example, when taking a blood sample from a patient and then splitting it to use in different diagnostic tests. This can be considered as a sub-sampling activity and can be described using class S24 Sample Splitting with its subproperties mirroring the main sampling process as shown in figure 44.

## S24 Sample Splitting

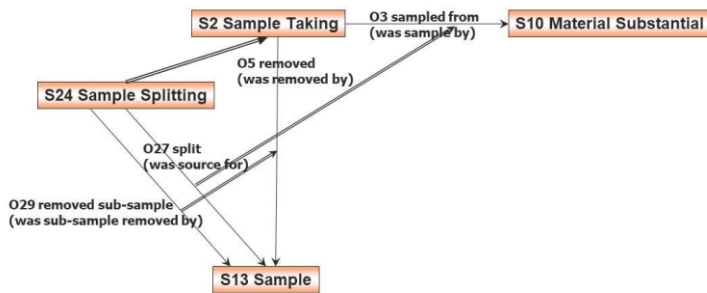


Figure 4: Classes and properties describing sample splitting.

Samples are often preserved after analysis is done. In some cases, this is not possible, for example when the sample is destroyed as part of the analysis process. The class S3 Measurement by Sampling can be used to describe such cases. This class is a subclass of both S2 Sample Taking and of S21 Measurement, therefore it inherits the properties and intention of both classes, making this activity of taking a sample also a measurement (figure 55).

## S3 Measurement by Sampling

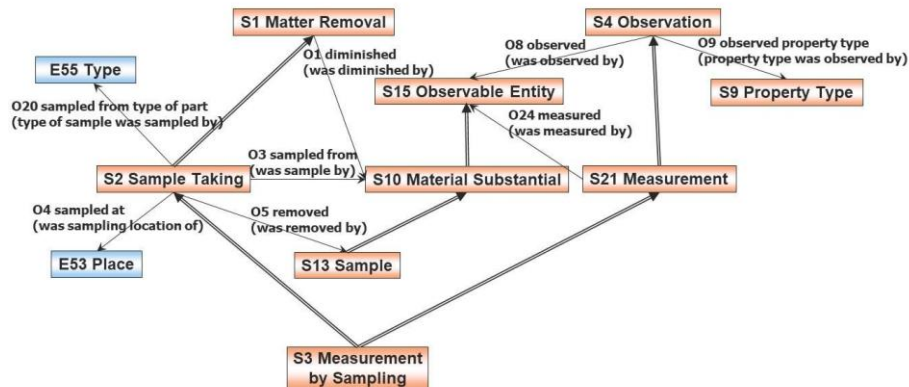


Figure 5: Extending the sampling activity for the special case of samples used solely for measurements.

## Alteration

In the CIDOC CRM the making of things is associated with an activity undertaken by an agent as indicated by the construct of the class E12 Production with a) its associated property P108 produced and b) its inherited property P14 carried out. The CRMsci provides classes that describe the making of things without any agents being involved. The class S17 Physical Genesis (figure 77) generalises the class E12 Production for things which



materialise through natural processes, such as the making of stalactites. The class S17 Physical Genesis is a subclass of E5 Event but not E7 Activity to make clear that there is no agency associated with the event. The class S18 Alteration (figure 77) is a generalisation of the CIDOC CRM class E11 Modification, therefore it cannot be used for instances of events which generate things but only for instances of events which alter things without agency (e.g. in the case of corrosion layers appearing on a metal surface due to acidic environment).

The CIDOC CRM avoids providing constructs to imply causality of events and instead describes influence and sequence of events. The CRMsci introduces the property O13 triggered (figure 77) which can be used to describe one event being the cause for another event. The triggering event may be the last of a series of events which trigger the triggered event. The association of the two events is based on their temporal proximity, i.e. the triggering event ends when the triggered event starts. This property does not indicate overall causality between events and it should not be used for analysis of social or historical causes of events.

### S17 Physical Genesis

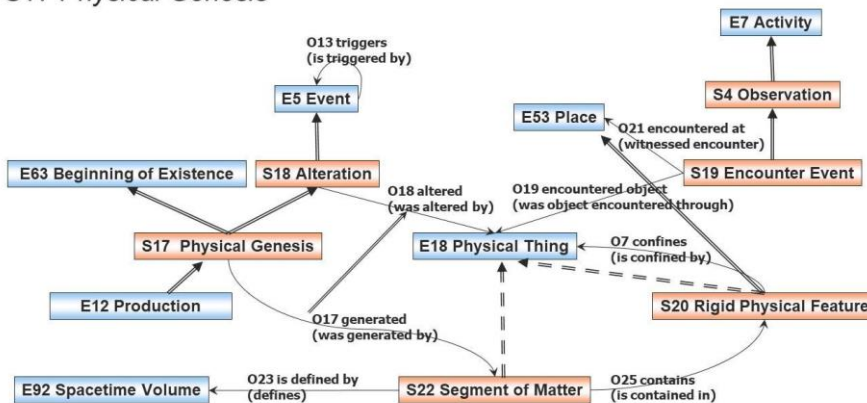


Figure 6: Events generating things without agency and causal relationships of events.

### Observation

CRMsci offers classes and properties for describing scientific observation (figure 77). Class S4 Observation can be used for all instances of activities which provide additional evidence to add knowledge, regardless of how valuable that is considered. During an instance of S4 Observation an entity is observed and a value is assigned to a type of property that is relevant to the study. This is a specialisation of E13 Attribute Assignment from the CIDOC CRM with a parallel construct which is more generalised. The class S15 Observable Entity is superclass to both E5 Event and S10 Material Substantial to indicate that an instance of S4 Observation can observe both perdurants and endurants with a material substance or interaction.

The class S21 Measurement is a specialisation of S4 Observation and a superclass of CIDOC CRM class E16 Measurement. The class E16 Measurement can be used to measure dimensions of physical things but cannot be used for dimensions of instances of classes such as E5 Event. Class S21 Measurement is broader in scope (also see figure 14) and can be used for other instances than instances of E18 Physical Thing.

Similarly the property O12 has dimension is equivalent to CIDOC CRM property P43 has dimension only when the observed entity is an instance of class E18 Physical Thing.

The class S19 Encounter Event can be used to describe the observation of entities of particular interest relevant to the research study. This can be used in species surveys or finds in archaeological excavations. It serves

documenting the fact that someone has seen the entity of interest as existing at the particular place and time. Figure 7 shows the relevant properties and includes a set of instances as examples from the field of ecology.

### S4 Observation

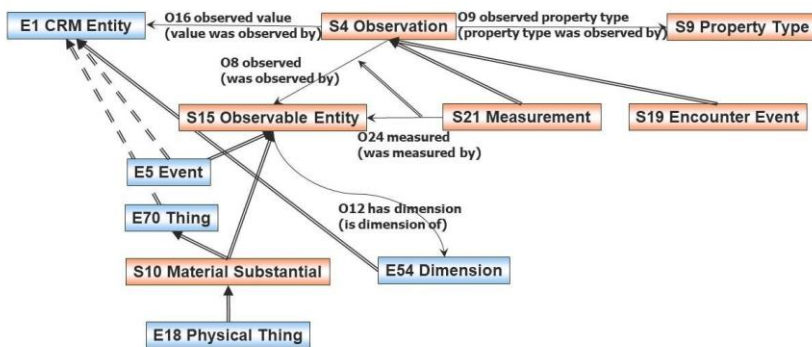


Figure 7: Classes and properties for describing scientific observation.

### S19 Encounter Event

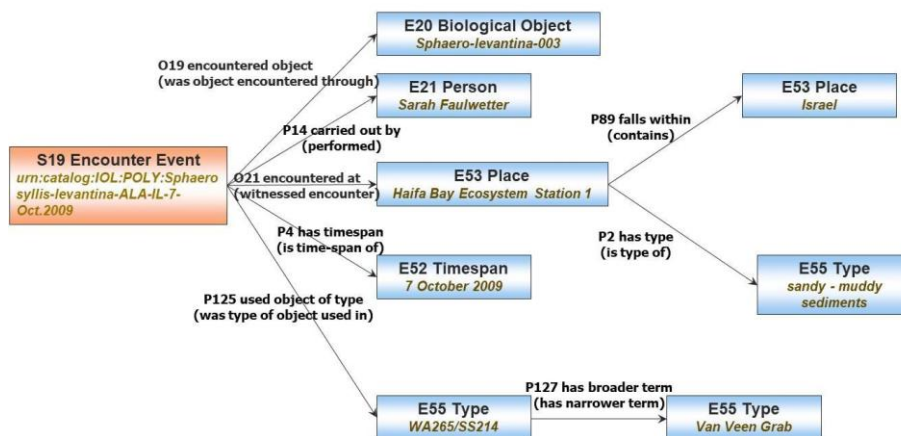


Figure 8: Classes and properties for describing the observation of an entity at a particular place and time.

### Determining positions

A specialisation of the class S4 Observation is the class S32 Position Determination. It allows the modelling of the process of determining the position of entities based on them being observed at a location in a given time-span. The properties connecting the observable entity with time and location are shown in Figure 99.

## S23 Position Determination

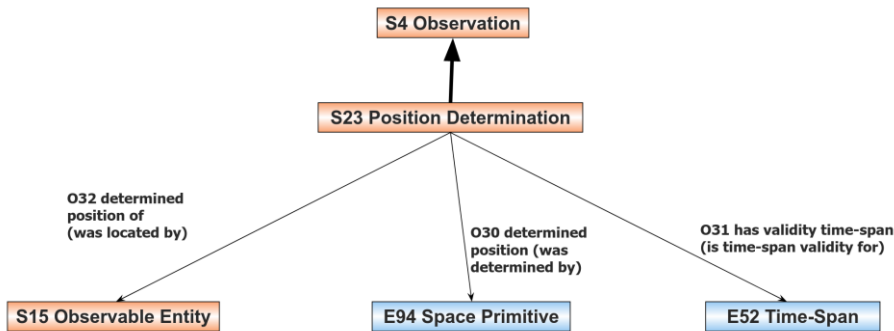


Figure 9: Classes and properties for describing determining the positions of things.

Figure 10<sup>10</sup> shows an example of determining the position of the Titanic after it hit an iceberg. Before issuing a distress signal, Titanic's captain Smith determined the position of the ship based on the distance travelled from the last known position, but this determination was inaccurate. The Titanic is an instance of S15 Observable Entity and more specifically an instance of E18 Physical Thing and its spatio-temporal extent during the determination is an instance of E93 Presence. The spatial projection of this instance of E93 Presence is the actual place where the Titanic was after hitting the iceberg. Captain Smith's determination was inaccurate and the resulting latitude and longitude coordinates determined (instance of E94 Space Primitive) defined the assumed place of the ship and not the actual place. The assumed place is a separate instance of E53 Place which can only approximate the actual place. The two are connected with the property 'P189 approximates' which allows reasoning on different views of the location of things by comparing instances of E53 Place with their corresponding provenance.

## S23 Position Determination

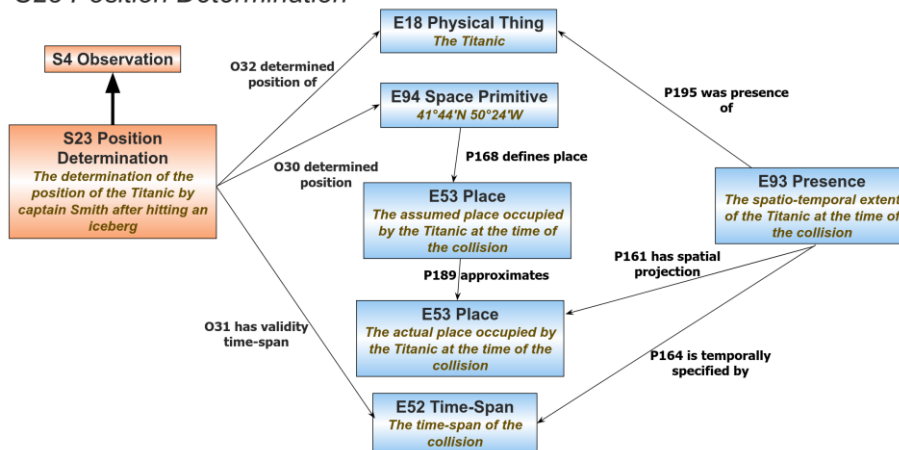


Figure 10: Example of position determination of the Titanic after it hit an iceberg.

## Inference making

In addition to a model for scientific observation the CRMsci provides classes and properties which allow the description of processing observations to produce new knowledge. This includes inferences made during data analysis, simulation or categorisation with specialised classes as shown in figure 11. Instances of S8 Categorical Hypothesis Building are activities where the definition of categories (similar to instances of CIDOC CRM E55 Type) are created based on the current observations of the instances of these categories (inductive reasoning). Through class S5 Inference Making, it is possible to connect and take advantage of the extended model for argumentation CRMInf from version 0.7 (Stead and Doerr, 2015).

### S5 Inference Making

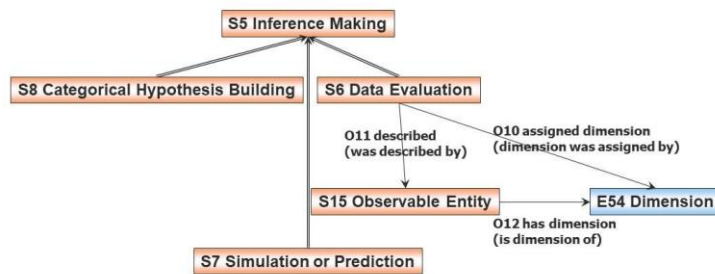


Figure 11: CRMsci classes for inference making.

## Status

The model presented in this document has been validated in several national and international projects, through implementations of slightly different versions together with application-specific extensions and through mapping to and from related standards. These projects include:

- 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

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.

# CRMsci class hierarchy, aligned with portions from the CIDOC-CRM class hierarchies

This class hierarchy lists:

- all classes declared in CRMsci,
- all classes declared in CIDOC-CRM version 7.1.2 that are declared as superclasses of classes declared in the CRMsci,
- all classes declared in CIDOC-CRM version 7.1.2 that are either domain or range for a property declared in the CRMsci,
- all classes declared in CIDOC-CRM version 7.1.2 that are either domain or range for a property that is part of a complete path of which a property declared in CRMsci is declared to be a shortcut.

Table 1: Class Hierarchy

E1	CRM Entity
E52	- Time-Span
<u>S15</u>	- Observable Entity
E5	- - Event
E7	- - - Activity
E11	- - - - Modification
<u>S1</u>	- - - - Matter Removal
E80	- - - - - Part Removal
<u>S2</u>	- - - - - Sample Taking
<u>S3</u>	- - - - - - Measurement by Sampling
<u>S24</u>	- - - - - - Sample Splitting
E13	- - - - - Attribute Assignment
<u>S4</u>	- - - - - Observation
<u>S21</u>	- - - - - - Measurement
<u>S3</u>	- - - - - - - <i>Measurement by Sampling</i>
E16	- - - - - - - Measurement
<u>S19</u>	- - - - - - - Encounter Event
<u>S23</u>	- - - - - - - Position Determination
<u>S5</u>	- - - - - - - Inference Making
<u>S6</u>	- - - - - - - Data Evaluation
<u>S7</u>	- - - - - - - Simulation or Prediction
<u>S8</u>	- - - - - - - Categorical Hypothesis Building
<u>S18</u>	- - - - Alteration
<u>S17</u>	- - - - - Physical Genesis
<i>E11</i>	- - - - - <i>Modification</i>
E63	- - - - Beginning of Existence
<u>S17</u>	- - - - - <i>Physical Genesis</i>
E12	- - - - - Production

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  
 E24 - - - - Physical Human-Made Thing  
 E26 - - - - Physical Feature  
 S20 - - - - - Rigid Physical Feature  
 E27 - - - - - Site  
 S22 - - - - - Segment of Matter  
 E94 - - Space Primitive  
 E55 - - Type  
 S9 - - - Property Type  
 E53 - Place  
 S20 - - *Rigid Physical Feature*  
 E54 - Dimension  
 S25 - [Relative Dimension](#)  
 S26 - - [Angle](#)  
 E92 - Spacetime Volume

Formatted: Font color: Auto

Formatted: Widow/Orphan control

## List of external classes used in CRMsci

Table 2: List of external classes grouped by model and ordered by model and then by class identifier.

Class identifier	Class name	Model	Version
E1	Entity	CIDOC-CRM	7.1.2
E2	Temporal Entity	CIDOC-CRM	7.1.2
E5	Event	CIDOC-CRM	7.1.2
E7	Activity	CIDOC-CRM	7.1.2
E11	Modification	CIDOC-CRM	7.1.2
E12	Production	CIDOC-CRM	7.1.2
E13	Attribute Assignment	CIDOC-CRM	7.1.2
E16	Measurement	CIDOC-CRM	7.1.2
E18	Physical Thing	CIDOC-CRM	7.1.2
E24	Physical Human-Made Thing	CIDOC-CRM	7.1.2
E26	Physical Feature	CIDOC-CRM	7.1.2
E27	Site	CIDOC-CRM	7.1.2
E52	Time-Span	CIDOC-CRM	7.1.2
E53	Place	CIDOC-CRM	7.1.2

E54	Dimension	CIDOC-CRM	7.1.2
E55	Type	CIDOC-CRM	7.1.2
E63	Beginning of Existence	CIDOC-CRM	7.1.2
E70	Thing	CIDOC-CRM	7.1.2
E80	Part Removal	CIDOC-CRM	7.1.2
E92	Spacetime Volume	CIDOC-CRM	7.1.2
E94	Space Primitive	CIDOC-CRM	7.1.2



# CRMsci property hierarchy, aligned with portions from the CIDOC-CRM property hierarchy

This property hierarchy lists:

- all properties declared in CRMsci,
- all properties declared in CIDOC-CRM version 7.1.2 that are declared as superproperties or subproperties of properties declared in CRMsci,
- all properties declared in CIDOC-CRM version 7.1.2 that are part of a complete path of which a property declared in CRMsci, is declared to be a shortcut.

Table 3: Property Hierarchy

Property id	Property Name	Entity – Domain	Entity - Range
<a href="#">Q1</a>	diminished (was diminished by)	<a href="#">S1</a> Matter Removal	<a href="#">S10</a> Material Substantial
P112	- diminished (was diminished by)	E80 Part Removal	E18 Physical Thing
<a href="#">Q2</a>	removed (was removed by)	<a href="#">S1</a> Matter Removal	<a href="#">S11</a> Amount of Matter
<a href="#">Q5</a>	- removed (was removed by)	<a href="#">S2</a> Sample Taking	<a href="#">S13</a> Sample
<a href="#">Q29</a>	-- removed sub-sample (was sub-sample removed by)	<a href="#">S24</a> Sample Splitting	<a href="#">S13</a> Sample
<a href="#">Q3</a>	sampled from (was sample by)	<a href="#">S2</a> Sample Taking	<a href="#">S10</a> Material Substantial
<a href="#">Q27</a>	- split (was source for)	<a href="#">S24</a> Sample Splitting	<a href="#">S13</a> Sample
<a href="#">Q4</a>	sampled at (was sampling location of)	<a href="#">S2</a> Sample Taking	E53 Place
<a href="#">Q7</a>	confines (is confined by)	<a href="#">S20</a> Rigid Physical Feature	<a href="#">S10</a> Material Substantial
P140	assigned attribute to (was attributed by)	E13 Attribute Assignment	E1 CRM Entity
<a href="#">Q8</a>	- observed (was observed by)	<a href="#">S4</a> Observation	<a href="#">S15</a> Observable Entity
<a href="#">Q32</a>	-- determined position of (was located by)	<a href="#">S23</a> Position Determination	<a href="#">S15</a> Observable Entity
<a href="#">Q24</a>	-- measured (was measured by)	<a href="#">S21</a> Measurement	<a href="#">S15</a> Observable Entity
P39	--- measured (was measured by)	E16 Measurement	E18 Physical Thing
P177	assigned property of type (is type of property assigned)	E13 Attribute Assignment	E55 Type
<a href="#">Q9</a>	- observed property type (property type was observed by)	<a href="#">S4</a> Observation	<a href="#">S9</a> Property Type
P141	assigned (was assigned by)	E13 Attribute Assignment	E1 CRM Entity
<a href="#">Q10</a>	- assigned dimension (dimension was assigned by)	<a href="#">S6</a> Data Evaluation	E54 Dimension
<a href="#">Q11</a>	described (was described by)	<a href="#">S6</a> Data Evaluation	<a href="#">S15</a> Observable Entity
<a href="#">Q12</a>	has dimension (is dimension of)	<a href="#">S15</a> Observable Entity	E54 Dimension
<a href="#">Q33i</a>	- has relative dimension (is relative to)	<a href="#">S15</a> Observable Entity	<a href="#">S25</a> Relative Dimension
<a href="#">Q34i</a>	-- is vertex of (has vertex)	<a href="#">S15</a> Observable Entity	<a href="#">S26</a> Angle
<a href="#">Q13</a>	triggered (was triggered by)	E5 Event	E5 Event

<u>O15</u>	occupied (was occupied by)	<u>S10</u> Material Substantial	E53 Place
P141	assigned (was assigned by)	E13 Attribute Assignment	E1 CRM Entity
<u>O16</u>	- observed value (value was observed by)	<u>S4</u> Observation	E1 CRM Entity
<u>O30</u>	-- determined position (was determined by)	<u>S23</u> Position Determination	E94 Space Primitive
P40	-- observed dimension (was observed in)	E16 Measurement	E54 Dimension
<u>O18</u>	altered (was altered by)	<u>S18</u> Alteration	E18 Physical Thing
<u>O17</u>	- generated (was generated by)	<u>S17</u> Physical Genesis	E18 Physical Thing
P108	-- has produced (was produced by)	E12 Production	E24 Physical Human-Made Thing
P31	- has modified (was modified by)	E11 Modification	E18 Physical Thing
<u>O19</u>	encountered object (was object encountered through)	<u>S19</u> Encounter Event	E18 Physical Thing
<u>O20</u>	sampled from type of part (type of part was sampled by)	<u>S2</u> Sample Taking	E55 Type
<u>O21</u>	encountered at (witnessed encounter)	<u>S19</u> Encounter Event	E53 Place
<u>O23</u>	is defined by (defines)	<u>S22</u> Segment of Matter	E92 Spacetime Volume
<u>O25</u>	contains (is contained in)	<u>S10</u> Material Substantial	<u>S10</u> Material Substantial
P46	- is composed of (forms part of)	E18 Physical Thing	E18 Physical Thing
<u>O6</u>	- is former or current part of (has former or current part)	<u>S12</u> Amount of Fluid	<u>S14</u> Fluid Body
<u>O28</u>	is conceptually greater than (is conceptually less than)	E55 Type	E55 Type
<u>P4</u>	has time-span (is time-span of)	E2 Temporal Entity	E52 Time-Span
<u>O31</u>	- has validity time-span (is time-span validity for)	<u>S23</u> Position Determination	E52 Time-Span

## List of external properties used in CRMsci

Table 4: List of external properties grouped by model and ordered by model and then by property identifier.

Property identifier	Property name	Model	Version
P4	has time-span (is time-span of)	CIDOC-CRM	7.1.2
P31	has modified (was modified by)	CIDOC-CRM	7.1.2
P39	measured (was measured by)	CIDOC-CRM	7.1.2
P40	observed dimension (was observed in)	CIDOC-CRM	7.1.2
P46	is composed of (forms part of)	CIDOC-CRM	7.1.2
P108	has produced (was produced by)	CIDOC-CRM	7.1.2
P112	diminished (was diminished by)	CIDOC-CRM	7.1.2
P140	assigned attribute to (was attributed by)	CIDOC-CRM	7.1.2
P141	assigned (was assigned by)	CIDOC-CRM	7.1.2
P177	assigned property of type (is type of property assigned)	CIDOC-CRM	7.1.2

This page is left blank on purpose

# CRMsci Class Declarations

## 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 (S1) (Museo del Prado, 2012)

In First Order Logic:

$S1(x) \Rightarrow E7(x)$

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

S24 Sample Splitting

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 be regarded not to be modified by the activity of sample taking.

Examples:

- the water sampling carried out by IGME, sampled from borehole 10/G5 at 419058.03, 4506565 , 95.7 Mygdonia basin on 28/6/2005 (S2) (Lucchese et al., 2013; Kritikos et al., 2013; InGeoCloudS, 2012; InGeoCloudS, 2013)
- the collection of specimen 'FHO – Benth. - 1055' from a plant of the species 'spiciformis' in Zambia by Bullock, A.A. in 1939 (S2)
- the collection of micro-sample 7, from the paint layer on the area of the apple shown on the painting 'Cupid complaining to Venus' (Cranach) by Joyce Plesters in June 1963 (S2) (The National Gallery, London, 1963)

In First Order Logic:

$S1(x) \Rightarrow S3(x)$

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 Measurement O24 measured: S15 Observable Entity. 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 which sampled from layer 50501 and observed 70 mg of Ca (S3) (Lucchese et al., 2013; Kritikos et al., 2013; InGeoCloudS, 2012; InGeoCloudS, 2013)
- the Sphaerosyllislevantina specimen length measurement on 12/3/1999 (S3) (Bekiari et al., 2014)
- the measurement of retention times during Gas Chromatography analysis of a paint sample 'mid-blue paint for the sky' which identified Linseed oil as the paint medium (S3) (Foister, S, 2015)

In First Order Logic:

$S3(x) \Rightarrow S2(x)$   
 $S3(x) \Rightarrow S21(x)$

## S4 Observation

Subclass of:

E13 Attribute Assignment

Superclass of:

S21 Measurement

S19 Encounter Event

S23 Position Determination

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.

Observed situations or dimensions may pertain to properties confined to a single instance of S15 Observable Entity or pertain to constellations of multiple instances and relations between them, in particular distances between them.

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. 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.

Measurements and witnessing of events are special cases of observations. Observations result in a belief that certain propositions held at a time within the time-span of the observation. 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

Examples:

- the excavation of unit XI by the Archaeological Institute of Crete in 2004 (S4)
- the excavation (S4) in the NE section of the central court of the Knossos palace by the Ephorate of Antiquities of Heraklion in 1997 (S4) (Επιστημονική Επιτροπή Κνωσού, 2008)
- the observation of the density of the X-Ray image of cupid's head from the painting 'Cupid complaining to Venus' as 'high density', on the 19th of March 1963 (S4) (The National Gallery, London, 1963).
- the observation of visible light absorption of the painting 'Cupid complaining to Venus' as 'having red pigment', in 2015 (S4) (Foister, 2015)

In First Order Logic:

$S4(x) \Rightarrow E13(x)$

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?

**Commented [2]:** version 2.1: <https://cidoc-crm.org/Issue/ID-531-observable-entity>

<https://cidoc-crm.org/Issue/ID-583-how-to-assign-dimensions-to-relative-positions-to-distances-in-space-time-and-other>

Continue discussion O9, O16 and whether they need to be replaced by Oxx observed situation. See Martin's comment on June 7, 2021. Consider reopening 531.

## 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 in the Minoan temple of Anemospilia based on the skeleton found (and 2 more) in the west room of the temple and the ritual bronze knife on it and the hypothesis that he died from loss of blood (S5) [the evidence was that his bones remained white in contrast to the others] (Sakellarakis and Sapouna-Sakellaraki, 1981)
- the inference that the underdrawing of the painting ‘Cupid complaining to Venus’ was done with red pigment, based on the observation that red pigment lines appear under the top paint layers (S5) (Foister, 2015)

In First Order Logic:

$S5(x) \Rightarrow E13(x)$

## 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 (S6) (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 (S6) (Lucchese et al., 2013; Kritikos et al., 2013; InGeoCloudS, 2012; InGeoCloudS, 2013)
- the calculation of the overall height of the statue of Hercules in the Temple of Hercules in Amman from the measurement of the size of the fragment of the fingers (S6) (‘Temple of Hercules (Amman)’, Wikipedia, 2022)

In First Order Logic:

$$S6(x) \Rightarrow S5(x)$$

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.

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 (S7) (slide 18 in Kores et al., 2013)
- predicting the required temperature to maintain a target RH(%) of 50 based on monthly average temperature and RH in Birmingham, UK (S7) [using the ‘Calculator for conservation heating’] (Padfield, no date)

In First Order Logic:

$$S7(x) \Rightarrow S5(x)$$

### 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:

- hypothesising that “no binding before the 9<sup>th</sup> century is made with spine supports” by Szirmai (S8) [documented in section 7.1 and 7.2 of “The Archaeology of Medieval bookbinding”] (Szirmai, J.A. 1999)

In First Order Logic:

$$S8(x) \Rightarrow S5(x)$$



## 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). (Lucchese et al., 2013; Kritikos et al., 2013; InGeoCloudS, 2012; InGeoCloudS, 2013)
- the retention time (S9) [in gas chromatography, meaning the time it takes for a component to pass through the chromatographer's column] ('Gas chromatography', Wikipedia, 2018)

### In First Order Logic:

$S9(x) \Rightarrow E55(x)$

## S10 Material Substantial

### Subclass of:

E70 Thing  
S15 Observable Entity

### 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 (S10) (Lucchese et al., 2013; Kritikos et al., 2013; InGeoCloudS, 2012; InGeoCloudS, 2013)
- the Mesozoic carbonate sequence with flysch extracted from the area of Nafplion that was mapped and studied by Tattaris in 1970 (S10) (Photiades, 2010)
- Parnassos, the limestone mountain (Strid, 1986)

### In First Order Logic:

$S10(x) \Rightarrow E70(x)$

### Properties:

O25 contains (is contained in): S10 Material Substantial  
O15 occupied (was occupied by): E53 Place

**Commented [3]:** version 2.1: Depends on issue 531. It should be removed if we delete O9.

**Commented [4]:** related to issue 583, 531

### **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 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 (S11) (Archaeological Institute of America, 2006)
- 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 et al., 2016)

In First Order Logic:

$S11(x) \Rightarrow S10(x)$

### **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 (fictitious)

In First Order Logic:

$S12(x) \Rightarrow S11(x)$

$S12(x) \Rightarrow S14(x)$

Properties:

O6 is 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:

- the ground water sample with ID 105293 that was extracted from the top level of the intake No32 under terrain (S13, S12) (Lucchese et al., 2013; Kritikos et al., 2013; InGeoCloudS, 2012; InGeoCloudS, 2013)
- the micro-sample 7, taken from the painting 'Cupid complaining to Venus' (Cranach) by Joyce Plesters in June, 1963 (S13) (The National Gallery, London, 1963)

In First Order Logic:

$S13(x) \Rightarrow S11(x)$

### 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.

Examples:

- The Rhine River

In First Order Logic:

$S14(x) \Rightarrow S10(x)$

### S15 Observable Entity

Subclass of:

E1 CRM Entity

Superclass of:

E5 Event  
S10 Material Substantial

Definition of the CRMsci version 2.20

**Commented [5]:** There is no specific ref for this- there is a ref for S11 from Gangemi, A., Guarino, N., Claudio, M., Oltramari, A. & Schneider, Luc. (2002). Sweetening ontologies with DOLCE. Proceedings of the 13th European Conference on Knowledge Engineering and Knowledge Management. 2473. 166-181

**Commented [6]:** Reply to Athina Kritsotaki (15/11/2022, 13:56): "..."  
Add this to S11 and post for e-vote.

**Commented [7]:** version 2.0: <https://cidoc-crm.org/Issue/ID-332-properties-of-s10-material-substantial-of-crmsci>  
i  
Add reference to the geological definition of fluid body.

Scope note:

This class comprises instances of E5 Event or S10 Material Substantial (i.e. items or phenomena, such as physical things, their behaviour, states and interactions or events), that can be observed by measurement or detection devices or by human sensory impression including when enhanced by tools.

In order to be observable, instances of E5 Event must consist of some interaction or action of material substance. In some cases, the spatiotemporal confinement of the event itself, such as a flash, a car stopping etc. marks the limits of a documented observation of an event. In other cases, such as the situation of a car passing by a certain object, the spatiotemporal limits of the event of observing itself, as well as the direction of attention or the orientation of used instruments, may constrain the observed detail of a larger process, e.g., noticing the sight of a car passing by; a light emission, etc.

Conceptual objects manifest through 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) that was identified in 1996 in farmed geese in southern China as circulating highly pathogenic H5N1 (E20) (Wan, 2012)
- the flight of a male Bearded Vulture observed near Loukia, Heraklion, Crete in the morning of the 24<sup>th</sup> of October 2020 (E5) [The Bearded Vulture (*Gypaetus Barbatus*) is a threatened species in Crete] (Claes, 2020)
- the eruption of Krakatoa volcano at Indonesia in 1883 (E5) (Symons et al., 1888)
- the cupid head area in the X-Ray of the painting 'Cupid complaining to Venus' (E25) (The National Gallery, London, 1963)

In First Order Logic:

$S15(x) \Rightarrow E1(x)$

Properties:

O12 has dimension (is dimension of): E54 Dimension

**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 (S17) (Thiery et al., 1995)
- the corrosion process affecting my copper samples in the artificial aging salt-spray apparatus after 10 cycles which produced layers of cuprite and malachite (E12)

In First Order Logic:

$S17(x) \Rightarrow E63(x)$

$S17(x) \Rightarrow S18(x)$

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 (S18) (Marinos, 1997)
- the flattening of the Lanhydrock Pedigree parchment after humidification (E11) (Pickwood, N., 2016)

In First Order Logic:

$S18(x) \Rightarrow E5(x)$

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 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 (S19) (Bonn-Muller, 2010)
- the detection of *lagocephalos\_Sceleratus* was carried out with the trawler 419 in the Mediterranean sea, during the first week of August 2014 (S19) (Bekiari et al., 2014)
- the encounter of the marble floor of the Villa of the Papyri in Herculaneum during the digging of a well in 1750 (S19) (Sider, 1990, p. 536)
- the encounter of oak planks from a ship during a dig in a mound at the farm Lille Oseberg in Norway in 1908 (S19) (Ferguson, 2009, p.10-11)

In First Order Logic:

$S19(x) \Rightarrow S4(x)$

Properties:

O19 encountered object (was object encountered through): E18 Physical Thing  
O21 encountered at (witnessed encounter): 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 ('Abu Simbel', Wikipedia, 2022)
- Albrecht Duerer's signature on his painting of Charles the Great (Germanisches Nationalmuseum, 2022)
- the damaged form of the nose of the Great Sphinx in Giza ('Great Sphinx of Giza', Wikipedia, 2022)
- 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)
- the top surface of the clay floor A11 [Heterogeneous, yellow to grey silty clay; clear, wavy lower boundary] (illu p. 1601, Croix et al, 2019)

In First Order Logic:

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

Properties:

O7 confines (is confined by): S10 Material Substantial

## S21 Measurement

Subclass of:

S4 Observation

Superclass of:

S3 Measurement by Sampling  
E16 Measurement

Scope note:

This class comprises actions measuring instances of S15 Observable Entity, 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:

- the magnitude measurement of the earthquake of Mexico City in 2017. (S21) [It had the magnitude 6.2 Richter] (Mindock, 2017)
- the sensor measurement by IGME in 1999 which measured the landslide displacement in the area of Parnitha, Greece. (S21) (Lucchese et al., 2013; Kritikos et al., 2013; InGeoCloudS, 2012; InGeoCloudS, 2013)

In First Order Logic:

$S21(x) \Rightarrow S4(x)$

Properties:

O24 measured (was measured by): S15 Observable Entity

## S22 Segment of Matter

Subclass of:

S20 Rigid 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:

- the clay floor A11 [Heterogeneous, yellow to grey silty clay; clear, wavy lower boundary] (illu p. 1601, Croix et al, 2019)

In First Order Logic:

$S22(x) \Rightarrow S20(x)$

Properties:

O23 is defined by (defines): E92 Spacetime Volume

## S23 Position Determination

Subclass of:

S4 Observation

Scope note:

This class comprises activities of determining positions in space and time. The determined position is intended to approximate a part or all of the extent of the presence (instance of E93 Presence) of an instance of E18 Physical Thing or E4 Period of interest, such as the outer walls of an excavated settlement, the position of a ship sailing or the start and end of athlete's run in a competition. Characteristically, a theodolite or GPS device may be positioned on some persistent feature. Determining the position of the device will yield an approximation of the position of the feature of interest. Alternatively, some material item may be observed moving through a determined position at a given time.



This class does not inherit properties from class S21 Measurement. A position determination is an evaluation of a combination of measurement of multiple associated distances and/or angles (instances of E54 Dimension) from a particular spot to certain reference points of previously known position in the same reference space. A particular role is played by the Earth's magnetic field and rotational axis as reference for an angle or direction. Often, the observed constituting dimensions are not documented, or hidden in an electronic device software. The determined position is given as an E94 Space Primitive corresponding to a declarative place. Together with the measured time-span covering the time-critical observations it forms a spacetime volume, which should normally overlap with the spatiotemporal extent of the thing or phenomenon of interest.

Examples:

- the determination of the position of the Titanic for the initial distress call after hitting an iceberg (S23) [The iceberg was hit on 14 April 1912 at 23:40 ship's time. The subsequent position determination was likely done by Capt. Edward Smith and was transmitted 15 April 1912 at 00:27.] (Halpern, 2011)
- the determination of the position of the Titanic by officer Joseph G. Boxhall after the initial distress signal was sent (S23) [done between 00:27 and 00:35, when Boxhall showed the coordinates to Smith] (Halpern, 2011)
- the determination of the position of the Titanic by Robert Ballard's team after the Titanic ship-wreck was found (S23) (Ballard et al., 1987)
- Samuel Halpern's 2007 determination of the position of the Titanic at the time of the collision (S23) [based on the position of the ship-wreck] (Halpern, 2007)

In First Order Logic:

$S23(x) \Rightarrow S4(x)$   
 $S23(x) \Rightarrow (\exists y,z) [E94(y) \wedge S15(z) \wedge O30(x,y) \wedge O32(x,z)]$

Properties:

O30 determined position (was determined by): E94 Space Primitive  
 O31 has validity time-span (is time-span validity for): E52 Time-Span  
 O32 determined position of (was located by): S15 Observable Entity  
 Oxx4 observed situation (situation observed by): Sxx Observable Situation

**Commented [8]:** version 2.1: add observable situation. For the sake of completion, add Oxx5 forms part of with domain E93 Presence and range Sxx Observable Situation.

## S24 Sample Splitting

Subclass of:

S2 Sample Taking

Scope note:

This class comprises the activity of dividing an instance of S13 Sample into new instances of S13 Sample. This activity describes cases of sub-sampling where the resulting instance maintains the characteristic qualities of the original instance. Any observations of these qualities made on the new instance also apply to the original one. This class should be used to model cases of splitting a homogenous sample into multiple ones.

Examples:

- the activity of removing a part from the sample, which was originally taken from the tusk fragment GT993 by Godfrey et al. in 2000, in order to analyse it through ICP-AES analysis to reveal the composition of the original sample [A sample from a section of the tusk fragment GT993 which was originally found in the ship-wreck of Vergulde Draeck in Western Australia was taken. This sample was homogenous (ground to fine powder). Part of the sample was then removed for elemental analysis using inductively coupled plasma

atomic emission spectrometry (ICP-AES). Another part was removed for carbon/nitrogen analysis using a LECO analyser.] (Godfrey et al., 2002)

In First Order Logic:

$S24(x) \Rightarrow S2(x)$

Properties:

O27 split (was source for): S13 Sample

O29 removed sub-sample (was sub-sample removed by): S13 Sample

### S25 Relative Dimension

Subclass of:

E54 Dimension

Superclass of:

S26 Angle

Scope note:

This class comprises quantifiable properties that can be measured by some calibrated means and were holding between two or more distinct instances of S15 Observable Entity for some time.

Typical examples include relative distances between physical things or temporal distances between events such as athletes arriving at a goal or the time elapsed from production in thermoluminescence dating.

Generally, all kinds of quantifiable properties holding for a single item in isolation can be compared relative to the same of another item. Depending on the methods, such relative dimensions often constitute important primary observational data for calculating absolute values rather than being computational results from absolute values, an example being relative barometric measurements of altitude during expeditions.

Examples:

- the distance of the Moon from Earth [The distance to the Moon can be measured with millimeter precision.] ([https://en.wikipedia.org/wiki/Lunar\\_Laser\\_Ranging\\_experiment](https://en.wikipedia.org/wiki/Lunar_Laser_Ranging_experiment))

In First Order Logic:

$S25(x) \Rightarrow E54(x)$

Properties:

O33 is relative to (has relative dimension): S15 Observable Entity

### S26 Angle

Subclass of:

S25 Relative Dimension

Scope note:

This class comprises quantifiable angles that can be measured by some calibrated means and held between a spot on some instance of S15 Observable Entity forming the geometric vertex and two directions to the position of some other instances of S15 Observable Entity.

Typical examples include results of measurements with theodolites, sextants or compasses.

Examples:

■ \_\_\_\_\_

Formatted: Font color: Auto

Formatted: Indent: Before: 1", Space Before: 0 pt, Don't keep with next

Formatted: Indent: Before: 1", Space Before: 0 pt, After: 8.5 pt, Don't keep with next

Formatted: Font color: Auto

In first-order logic:

$S26(x) \Rightarrow S25(x)$

Properties:

**O34 has vertex** (is vertex of): **S15 Observable Entity** ~~Sxx Observable Situation~~

Subclass of:

Scope note:

Examples:

■

In First Order Logic:

Properties:

**Formatted:** Font: (Default) Times New Roman, Font color: Auto, Complex Script Font: Lohit Devanagari

**Commented [9]:** μήπως είναι το inverse κανονικά?

**Commented [10]:** version 2.1: related to issue 583 and 329

**Commented [11]:** version 2.1: need to define this – consider for version 2.1

**Formatted:** Font: (Default) Times New Roman, Not Bold, Font color: Auto, Complex Script Font: Lohit Devanagari

**Formatted:** Indent: Before: 1", Space Before: 0 pt, After: 0 pt, Line spacing: Multiple 1.15 li, Don't keep with next

# CRMsci Property Declarations

## O1 diminished (was diminished by)

Domain:

S1 Matter Removal

Range:

S10 Material Substantial

Superproperty of:

E80 Part Removal: P112 diminished (was diminished by): E18 Physical Thing

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 et al., 2010).

In First Order Logic:

$O1(x,y) \Rightarrow S1(x)$

$O1(x,y) \Rightarrow S10(y)$

## 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

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)

In First Order Logic:

$O2(x,y) \Rightarrow S1(x)$

$O2(x,y) \Rightarrow S11(y)$

$O2(x,y) \Rightarrow O1(x,y)$

### **O3 sampled from (was sample by)**

Domain:

S2 Sample Taking

Range:

S10 Material Substantial

Superproperty of:

S24 Sample Splitting: O27 split (was source for): S13 Sample

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(S2) *sampled from* the aquifer (S10) that overlaps with borehole 10/G5 (Lucchese et al., 2013; Kritikos et al., 2013; InGeoCloudS, 2012; InGeoCloudS, 2013)
- The collection (S2) of micro-sample 7, *sampled from* the painting (S10) ‘Cupid complaining to Venus’ (Cranach) by Joyce Plesters in June 1963 (The National Gallery, London, 1963).

In First Order Logic:

$O3(x,y) \Rightarrow S2(x)$

$O3(x,y) \Rightarrow S10(y)$

$O3(x,y) \Rightarrow O2(x,y)$

### **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(S2) *sampled at* borehole 10/G5 at depth 0 which falls within the water district 10/G5 in Central Macedonia (E53) (Lucchese et al., 2013; Kritikos et al., 2013; InGeoCloudS, 2012; InGeoCloudS, 2013)
- 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) (The National Gallery, London, 1963)

In First Order Logic:

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

**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

Superproperty of:

S24 Sample Splitting: O29 removed sub-sample (was sub-sample removed by): S13 Sample

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 the activity.

Examples:

- Lithology Sample Taking 201 (S2) *removed* sample 2B (S13) (Lucchese et al., 2013; Kritikos et al., 2013; InGeoCloudS, 2012; InGeoCloudS, 2013)
- 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) (The National Gallery, London, 1963).

In First Order Logic:

$O5(x,y) \Rightarrow S2(x)$   
 $O5(x,y) \Rightarrow S13(y)$   
 $O5(x,y) \Rightarrow O2(x,y)$

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

Domain:

S12 Amount of Fluid

**Commented [12]:** version 2.0: also include the old references despite the fact they are not accessible any more, with a note on when they were accessible.

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) (fictitious)

In First Order Logic:

$O6(x,y) \Rightarrow S12(x)$

$O6(x,y) \Rightarrow S14(y)$

### **O7 confines (is 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:

$O7(x,y) \Rightarrow S20(x)$

$O7(x,y) \Rightarrow S10(y)$

Examples:

- The Stavros – Farsala artesian aquifer (S20) *confines* the overexploited groundwater of the area (S10) (Rozos et al., 2017)
- The posthole (S20) *confines* 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)
- Borehole No1234 *confines* intake No5 (Lucchese et al., 2013; Kritikos et al., 2013; InGeoCloudS, 2012; InGeoCloudS, 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:

S23 Position Determination. O32 determined position of (was located by): S15 Observable Entity

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:

- The engineers' observation on the slope of Panagopoula coastal site, near Patras, on the 25th–26th April 1971 and the 3rd May 1971(S4) *observed* the rotational landslide at the same site (S15) (Tavoularis et al., 2017).
- The survey (S4) of Sinai MS GREEK 418 *observed* a detached triple-braided clasp strap (S15) (Honey and Pickwoad, 2010).

In First Order Logic:

$O8(x,y) \Rightarrow S4(x)$

$O8(x,y) \Rightarrow S15(y)$

$O8(x,y) \Rightarrow P140(x,y)$

### **O9 observed property type (property type was observed by)**

Domain:

S4 Observation

Range:

S9 Property Type

Subproperty of:

E13 Attribute Assignment. P177 assigned property of type (is type of property assigned): 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 EPP0 in 1990 (S4), in the area of Attiki *observed property type* share wave velocity (S9) and recorded it (Lucchese et al., 2013; Kritikos et al., 2013; InGeoCloudS, 2012; InGeoCloudS, 2013)
- The Gas Chromatography analysis (S4) of the sample 'mid-blue paint from the sky' *observed property type* retention time (S9). (Foister, 2015)

In First Order Logic:

$O9(x,y) \Rightarrow S4(x)$

$O9(x,y) \Rightarrow S9(y)$

$O9(x,y) \Rightarrow P177(x,y)$

#### **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 (S6) carried out by EPP0 in 1999 *assigned dimension* PSA\_10(E54) [The dimension had value 0.0008.] (Lucchese et al., 2013; Kritikos et al., 2013; InGeoCloudS, 2012; InGeoCloudS, 2013)

In First Order Logic:

$O10(x,y) \Rightarrow S6(x)$

$O10(x,y) \Rightarrow E54(y)$

#### **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 colour data carried out by C.T. Brown in 1999 in Yukatan, Mexico (S6) *described* the slipped sherds of Mayapan period ceramics (S15) (Ruck and Brown, 2015).
- The linear extrapolation of overall figure height from the size of the fingers (S6) *described* the statue of Hercules (S15) [The statue is located in Amman] ('Temple of Hercules (Amman)', Wikipedia, 2022).

In First Order Logic:

$O11(x,y) \Rightarrow S6(x)$

$O11(x,y) \Rightarrow S15(y)$

**O12 has dimension (is dimension of)**

Domain:

[S15 Observable Entity](#)

Range:

E54 Dimension

[Superproperty of:](#)

[S15 Observable Entity. O33i has relative dimension \(is relative to\): S25 Relative Dimension](#)

Quantification:

~~manyone~~ to many, ~~dependent~~(0,n:01,n+)

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 case the instance of S15 Observable Entity is more specifically an instance of E18 Physical Thing, using the property O12 has dimension (is dimension of) is equivalent to using the property P43 has dimension (is dimension of). In other words, using the one implies the other.

Examples:

- The earthquake of Mexico city in 2017 (E7) *has dimension* magnitude 6.2 Richter (Mindock, 2017).
- The landslide that was activated in Parnitha in 1999 after the earthquake (E26), *has dimension* crest length > 70 (Lucchese et al., 2013; Kritikos et al., 2013; InGeoCloudS, 2012; InGeoCloudS, 2013)

In First Order Logic:

$O12(x,y) \Rightarrow S15(x)$

$O12(x,y) \Rightarrow E54(y)$

$[O12(x,y) \wedge E18(x)] \Rightarrow P43(x,y)$

$[P43(x,y) \wedge E18(x)] \Rightarrow O12(x,y)$

### O13 triggered (was 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 triggered 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.

The distinction of a triggering event A from the triggered event B lies in their difference of nature. The starting of B is the result of an interaction of material constituents of A with material constituents of B. However, B does not necessarily continue the kinds of processes of A. Therefore, the triggering event A must spatiotemporally overlap with the initial time and area of the triggered event B. Any subsequent phenomena must initiate from this area and time and not from multiple independent areas. This property associates an instance of E5 Event that triggered 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 is interpreted as a cause. However, the association of the two events is based on their temporal proximity, with the triggering event ending when the triggered event starts.

Examples:

- The earthquake of Parnitha in 1999 (E5) *triggered* the rotational landslide that was observed along the road on the same day (E5). (fictitious)
- The explosion at the Montserrat massif in 2007 (E5) (near Barcelona, Spain) *triggered* the rock fall event (E5) which happened on 2007-02-14 (Vilajosana et al., 2008).
- The 1966 flood in Florence (E5) *triggered* mould growth on books (E5) stored in flooded library rooms (Rubinstein, N., 1966)

In First Order Logic:

$O13(x,y) \Rightarrow E5(x)$

$O13(x,y) \Rightarrow E5(y)$

$O13(x,y) \Rightarrow P182(x,y)$

### O15 occupied (was occupied by)

Domain:

S10 Material Substantial

Range:

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

Formatted: Indent: Before: 1", Space Before: 0 pt, After: 8.5 pt, Don't keep with next

Formatted: Font color: Auto

property is the development of the shortcut expressed in the proposition of classification: “S20 Physical Feature” isA “E53 Place”. This property is equivalent to P156 occupies (is occupied by) with domain E18 Physical Thing and range E53 Place.

Examples:

- The layer of pink plaster that *occupied* the block 30 floor of the area X. on 2009-02-03. [The plaster covered the floor] (fictitious)

In First Order Logic:

$O15(x,y) \Rightarrow S10(x)$   
 $O15(x,y) \Rightarrow E53(y)$   
 $O15(x,y) \wedge E18(x) \Leftrightarrow P156(x,y)$

### **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:

S23 Position Determination. O30 determined position (was determined by): E94 Space Primitive  
E16 Measurement. P40 observed dimension (was observed in): E54 Dimension

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 (S4) *observed value* 600 (of sherds) (E1) (Kramer-Hajos and O’Neill, 2008).

In First Order Logic:

$O16(x,y) \Rightarrow S4(x)$   
 $O16(x,y) \Rightarrow E1(y)$   
 $O16(x,y) \Rightarrow P141(x,y)$

### **O17 generated (was generated by)**

Domain:

S17 Physical Genesis

Range:

E18 Physical Thing

Subproperty of:

S18 Alteration. O18 altered (was altered by): E18 Physical Thing

Superproperty of:

E12 Production. P108 has produced (was produced by): E24 Physical Human-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. (fictitious)
- The mud flow in the western region of Thessaly million years ago *generated* the deposits of solidified mud with irregular surface in the area. (fictitious)
- The introduction of my copper samples in the salt-spray apparatus (S17) *generated* new corrosion layers of cuprite and malachite (E18). (Velios, 1998)

### **O18 altered (was altered by)**

Domain:

S18 Alteration

Range:

E18 Physical Thing

Superproperty of:

E11 Modification. P31 has modified (was modified by): E18 Physical Thing  
S17 Physical Genesis. O17 generated (was generated by): E18 Physical 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 death of the trees caused by beetle infestation in 1995 (S18), *altered* the Brazilian forest (E18) (Paine, 2008).
- The application of tension (S18) *altered* the humidified parchment of the Lanhydrock Pedigree (E18) (Pickwoad, 2010).

In First Order Logic:

$O18(x,y) \Rightarrow S18(x)$

$O18(x,y) \Rightarrow E18(y)$

### **O19 encountered object (was object encountered through)**

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 was encountered or observed as present during the event.

Examples:

- The encounter of a marble floor during the digging of a well in 1750 (S19) *encountered object* the Villa of the Papyri in Herculaneum (E18). (Sider, 1990, p. 536)
- The encounter of oak planks from a ship during a dig in a mound at the farm Lille Oseberg in Norway, in 1904 (S19) *encountered object* the Oseberg Ship (E18). (Ferguson, 2009, p.10-11)

In First Order Logic:

$O19(x,y) \Rightarrow S19(x)$

$O19(x,y) \Rightarrow E18(y)$

$O19(x,y) \Rightarrow (\exists z)[E53(z) \wedge O21(x,z)]$

**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.

Examples:

- The sampling (S2) of tissue for DNA analysis of human remains in an archaeological site, *sampled from type of part* molar tooth (E55). (fictitious)
- 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). (The National Gallery, London, 1963)

In First Order Logic:

$O20(x,y) \Rightarrow S2(x)$

$O20(x,y) \Rightarrow E55(y)$

**O21 encountered at (witnessed encounter)**

Domain:

S19 Encounter Event

Range:

E53 Place

Quantification:

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

**Commented [13]:** version 2.1: 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 the things, which were encountered, were observed to be present. This may be given in absolute terms or in terms relative to the observed thing. The associated place must be within the boundaries of the E53 Place at which the S19 Encounter Event took place, if that has been given. Note, that the encountered object may be larger and extend beyond the place of encounter, such as a corner of a building being excavated.

Examples:

- The encounter of the Oseberg Ship in 1904 (S19) *encountered at* the farm Lille Oseberg in Norway (E53). (Ferguson, 2009, p.10-11)

In First Order Logic:

$O21(x,y) \Rightarrow S19(x)$

$O21(x,y) \Rightarrow E53(y)$

$O21(x,y) \Rightarrow (\exists z)[ E53(z) \wedge P161(x,z) \wedge P89(y,z) ]$ : There exists a place z which is the spatial projection P161 of the encounter event S19, and contains P89i the place of encounter.

$O21(x,y) \Rightarrow (\exists z,v,w)[ E93(w) \wedge E18(z) \wedge E52(v) \wedge O19(x,z) \wedge P195(w,z) \wedge P4(x,v) \wedge P164(w,v) \wedge P197(w,y) ]$ : The presence E93 of P195 the encountered object O19 at the time E52 of P4 the encounter P197 covered parts of (or P167 was within) the place of encounter.

**Commented [14]:** version 2.1: remove from version 2.0 and consider for 2.1 once an agreed method is in place, issue 570.

**Commented [15]:** version 2.1: remove from version 2.0 and consider for 2.1 once an agreed method is in place, issue 570.

**O23 is defined by (defines)**

Domain:

S22 Segment of Matter

Range:

E92 Spacetime Volume

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:

- The accumulation zone (S22) of the landslide *is defined by* the evolution of the landslide of Santomerion village in 2008 (E92) (Litoseliti et al., 2014).

In First Order Logic:

$O23(x,y) \Rightarrow S22(x)$

$O23(x,y) \Rightarrow E92(y)$

**O24 measured (was measured by)**

Domain:

S21 Measurement

Range:

S15 Observable Entity

Subproperty of:

S4 Observation. O8 observed (was observed by): S15 Observable Entity

Superproperty of:

E16 Measurement. P39 measured (was measured by): E18 Physical Thing

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 (Lucchese et al., 2013; Kritikos et al., 2013; InGeoCloudS, 2012; InGeoCloudS, 2013)

In First Order Logic:

$O24(x,y) \Rightarrow S21(x)$

$O24(x,y) \Rightarrow S15(y)$

$O24(x,y) \Rightarrow O8(x,y)$

#### **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

S12 Amount of Fluid. O6 is former or current part of (has former or current part): S14 Fluid Body

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 whether 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:

- The opal specimen from Jalisco in Mexico (E18) contains the fluid inclusion of the specimen (S14). (Rentro, 2019)

In First Order Logic:

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

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

#### **O27 split (was source for)**

Domain:

S24 Sample Splitting



Range:

[S13 Sample](#)

Subproperty of:

[S2 Sample Taking](#): [O3 sampled from \(was sample by\)](#): [S10 Material Substantial](#)

Quantification:

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

Scope note:

This property associates an instance of [S24 Sample Splitting](#) with the instance of [S13 Sample](#) which is the original sample being split.

Examples:

- The subsampling activity by Godfrey et al. in 2000 ([S24](#)) *split* the homogenous [Sample](#) ([S13](#)). [Part of the finely ground sample from fragment GT993 was taken to be used in ICP-AES analysis.] (Godfrey et al., 2002)

In First Order Logic:

$O27(x,y) \Rightarrow S24(x)$

$O27(x,y) \Rightarrow S13(y)$

### **O28 is conceptually greater than (is conceptually less than)**

Domain:

[E55 Type](#)

Range:

[E55 Type](#)

Quantification:

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

Scope note:

This property allows an instance of [E55 Type](#) from a particular concept scheme or vocabulary to be declared as having an order relative to other instances of [E55 Type](#) in the same or other concept schemes, without necessarily having a specific value associated with either instance. This allows, for example, for an [E55 Type](#) instance representing the concept of "good" in a conservation report vocabulary to be greater than the [E55 Type](#) instance representing the concept of "average" in the same vocabulary. This property is transitive, and thus if "average" is greater than "poor", then "good" is also greater than "poor". In the domain of statistics, types that participate in this kind of relationship are called "Ordinal Variables"; as opposed to those without order which are called "Nominal Variables". This property allows for queries that select based on the relative position of participating [E55 Types](#).

Examples:

- [In the condition survey of the manuscripts of the library of the Saint Catherine Monastery, the option 'supple' ([E55](#)) *is conceptually greater than* the option 'stiff' ([E55](#)). [These options are used for assessing parchment on page 2, section 2 of the survey form and within the context of the dry conditions of the Sinai desert where the Monastery is, 'supple' is considered better because it is less brittle] (Pickwood, 2004)]

### **O29 removed sub-sample (was sub-sample removed by)**

Domain:

[S24 Sample Splitting](#)

Definition of the CRMsci version 2.20

**Commented [16]:** version 2.1: Discussion of this becoming a new class Sxx Sortable Type. Not all types may be sortable.

**Commented [17]:** version 2.1: Example applies to a possible superproperty without strict quality assesement in the sense of good better best

Range:

S13 Sample

Subproperty of:

S2 Sample Taking: O5 removed (was removed by): S13 Sample

Quantification:

many to many (0..n..n)

Scope note:

This property associates an instance of S24 Sample Splitting with the resulting instance of S13 Sample that has been removed from the original sample. The new sample (i.e. the sub-sample) maintains the characteristic qualities of the original.

Examples:

- The subsampling activity by Godfrey et al. in 2000 (S24) *removed sub-sample* the ICP-AES subsample (S13). [This sub-sample was used for elemental analysis using inductively coupled plasma atomic emission spectrometry (ICP-AES) to reveal the composition of the original sample.] (Godfrey et al., 2002)

In First Order Logic:

$O29(x,y) \Rightarrow S24(x)$

$O29(x,y) \Rightarrow S13(y)$

### **O30 determined position (was determined by)**

Domain:

S23 Position Determination

Range:

E94 Space Primitive

Subproperty of:

S4 Observation: O16 observed value (value was observed by): E1 CRM Entity

Quantification:

many to many (0..n..n)

Scope note:

This property associates an instance of S23 Position Determination with the instance of E94 Space Primitive which is the result of that determination. The instance of E94 Space Primitive approximates the place occupied by the entity whose position is being determined.

Examples:

- The determination of the position of the Titanic for the initial distress call after hitting an iceberg (S23) *determined position* 41°44'N 50°24'W (E94). [This was quickly determined via 'dead reckoning', i.e. based on the distance travelled since the previous known location, extrapolating a previous dead reckoning for 14 April 1912 20:00] (Halpern, 2011, Boxhall, 1962)
- The determination of the position of the Titanic by officer Joseph G. Boxhall after the initial distress signal was sent (S23) *determined position* 41°46'N 50°14'W (E94). [This was again determined via dead reckoning but extrapolating Boxhall's own determination shortly after 20:00, and revised the original position.] (Halpern, 2011, Boxhall, 1962)
- The calculation of the position of the Titanic by Robert Ballard's team after the Titanic shipwreck was found (S23) *determined position* 41°43'32"N 49°56'49"W (E94). [This was the position of the centre of the 'boiler field', part of the Titanic debris] (Ballard et al., 1987)

- Samuel Halpern's 2007 determination of the position of the Titanic at the time of the collision (S23) *determined position 41°45.5'N 49°55'W* (E94). [This was based on the position of the boiler field and the ocean drift at the time.] (Halpern, 2007)

In First Order Logic:

$O30(x,y) \Rightarrow S23(x)$   
 $O30(x,y) \Rightarrow E94(y)$

### O31 has validity time-span (is time-span validity for)

Domain:

S23 Position Determination

Range:

E52 Time-Span

Subproperty of:

E2 Temporal Entity: P4 has time-span (is time-span of): E52 Time-Span

Quantification:

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

Scope note:

This property associates an instance of S23 Position Determination with the instance of E52 Time-Span for which the determination is valid according to the observer at the time of the observation. No inferences can be made in relation to the validity of the determination outside this time-span despite the fact that some entities are relatively stable and their positions may remain the same after the determination. The time-span of validity should fall within the overall time-span of the process of determination.

Examples:

- The determination of the position of the Titanic for the initial distress call after hitting an iceberg (S23) *has validity time-span* the time of the collision (E52). [This is a plausible guess based on Boxhall's account; the collision was on 14 April 1912 23:40 ship's time.] (Halpern, 2011, Boxhall, 1962)
- The determination of the position of the Titanic by officer Joseph G. Boxhall after the initial distress signal was sent (S23) *has validity time-span* the time of the collision (E52). [Boxhall was convinced of the correctness of his position determination until his death.] (Halpern 2011, Boxhall, 1962)
- The determination of the position of the Titanic by Robert Ballard's team after the Titanic ship-wreck was found (S23) *has validity time-span* the time of the position determination (E52). [This time period falls within the 1<sup>st</sup> of September 1985 00:48, i.e. the first encounter of a piece of Titanic debris and 1987] (Ballard et al., 1987)
- Samuel Halpern's 2007 measurement of the position of the Titanic at the time of the collision (S23) *has validity time-span* the time of the collision (E52) (Halpern, 2007)

Commented [18]: Remove from version 2.0 but discuss again for version 2.1

In First Order Logic:

$O31(x,y) \Rightarrow S23(x)$   
 $O31(x,y) \Rightarrow E52(y)$   
 $Oxx2(x,y) \Rightarrow P4(x,z) \wedge P86(y,z)$

### O32 determined position of (was located by)

Domain:

S23 Position Determination

Range:

[S15](#) Observable Entity

Subproperty of:

[S4](#) Observation: [O8](#) observed (was observed by): [S15](#) Observable Entity

Quantification:

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

Scope note:

This property connects an instance of [S23](#) Position Determination with the instance of [S15](#) Observable Entity whose position is being determined.

Examples:

- The determination of the position of the Titanic for the initial distress call after hitting an iceberg ([S23](#)) *determined position of* the Titanic ([E22](#)). (Halpern, 2011)
- The determination of the position of the Titanic by officer Joseph G. Boxhall after the initial distress signal was sent ([S23](#)) *determined position of* the Titanic ([E22](#)) (Halpern, 2011)
- The determination of the position of the Titanic by Robert Ballard's team after the Titanic ship-wreck was found ([S23](#)) *determined position of* the Titanic. [More precisely it determined the position of the centre of the 'boiler field' of Titanic's debris] ([E22](#)) (Ballard et al., 1987)
- Samuel Halpern's 2007 determination of the position of the Titanic at the time of the collision ([S23](#)) *determined position of* the Titanic ([E22](#)). (Halpern, 2007)

In First Order Logic:

$O32(x,y) \Rightarrow S23(x)$

$O32(x,y) \Rightarrow S15(y)$

$O32(x,y) \Rightarrow (\exists z,u,v,w) [E93(z) \wedge P195(z,y) \wedge E52(w) \wedge O31(x,w) \wedge P164(z,w) \wedge E94(v) \wedge O30(x,v) \wedge E53(u) \wedge P161(z,u) \wedge P121(v,u)]$ ; ["There exist a presence \(E93\) of the positioned entity at the time of measurementdetermination \(E52\) that has a spatial projection \(E53\) overlapping with the measureddetermined position \(E94\)"](#)

Commented [19]: version 2.1

### **O33 is relative to (has relative dimension)**

Domain:

[S256](#) Relative Dimension

Range:

[S15](#) Observable Entity

Subproperty of:

[E54](#) Dimension: [O12i](#) is dimension of ([has dimension](#)): [S15](#) Observable Entity

Superproperty of:

[S26](#) Angle. [O34](#)-has vertex (is -vertex of): [S15](#) Observable Entity

Quantification:

[many to many, necessary \(2,n:0,n\)](#)

Scope note:

[This property associates an instance of S25 Relative Dimension with one of the instances of S15 Observable Entity between which it was holding](#)~~This property connects an instance of S23 Position Determination with the instance of S15 Observable Entity whose position is being determined.~~

Examples:

- The Moon *is relative to* the distance between the Moon and the Earth [The distance to the Moon can be measured with millimeter precision.] ([https://en.wikipedia.org/wiki/Lunar\\_Laser\\_Ranging\\_experiment](https://en.wikipedia.org/wiki/Lunar_Laser_Ranging_experiment))
- The Earth *is relative to* the distance between the Moon and the Earth ([https://en.wikipedia.org/wiki/Lunar\\_Laser\\_Ranging\\_experiment](https://en.wikipedia.org/wiki/Lunar_Laser_Ranging_experiment))

In First Order Logic:

$O33(x,y) \Rightarrow S25E54(x)$   
 $O33(x,y) \Rightarrow S15(y)$   
 $O33(x,y) \Rightarrow O12(yx,xy)$

**O34 has vertex (is vertex of)**

Domain:

S26 Angle

Range:

S15 Observable Entity

Subproperty of:

S25 Relative Dimension. O33 is relative to (has relative dimension): S15 Observable Entity

Quantification:

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

Scope note:

This property associates an instance of S26~~Sxx3~~ Angle with the instance of S15 Observable Entity that includes in its extent the vertex of the former.

Typical examples are respective marked spots on Earth or a ship where a theodolite, a sextant or a compass (<https://en.wikipedia.org/wiki/Theodolite>) is positioned during a position measurement.

Examples:

- 

In First Order Logic:

$O34(x,y) \Rightarrow S26(x)$   
 $O34(x,y) \Rightarrow S15(y)$   
 $O34(x,y) \Rightarrow O33(x,y)$

**Oxx4-observed-situation (situation-observed-by)**

Domain:

S23 Position Measurement

Range:

Sxx Observable Situation

Subproperty of:

Quantification:

Scope note:

Examples:

Commented [20]: version 2.1

- Formatted: Space Before: 5 pt, After: 5 pt, Don't keep with next
- Formatted: Space Before: 5 pt, After: 5 pt, Line spacing: single, Don't keep with next
- Formatted: Indent: Before: 0", Space Before: 5 pt, After: 5 pt, Line spacing: single
- Formatted: Space Before: 5 pt, After: 5 pt, Line spacing: single, Don't keep with next
- Formatted: Indent: Before: 0", Space Before: 5 pt, After: 5 pt, Line spacing: single
- Formatted: Space Before: 5 pt, After: 5 pt, Line spacing: single, Don't keep with next
- Formatted: Indent: Before: 0", Space Before: 5 pt, After: 5 pt, Line spacing: single
- Formatted: Space Before: 5 pt, After: 5 pt, Line spacing: single, Don't keep with next
- Formatted: Indent: Before: 0", Space Before: 5 pt, After: 5 pt, Line spacing: single
- Formatted: Space Before: 5 pt, After: 5 pt, Line spacing: single, Don't keep with next

■

In First Order Logic:

**Oxx5 forms part of (consists of)**

Domain:

E93-Presence

Range:

Sxx Observable Situation

Subproperty of:

Quantification:

Scope note:

Examples:

■

In First Order Logic:



**Formatted:** Space Before: 5 pt, After: 5 pt, Line spacing: single, No bullets or numbering

**Formatted:** Space Before: 5 pt, After: 5 pt, Line spacing: single, Don't keep with next

**Formatted:** Indent: Before: 0", Space Before: 5 pt, After: 5 pt, Line spacing: single

**Formatted:** Space Before: 5 pt, After: 5 pt, Don't keep with next

**Formatted:** Space Before: 5 pt, After: 5 pt, Line spacing: single, Don't keep with next

**Formatted:** Indent: Before: 0", Space Before: 5 pt, After: 5 pt, Line spacing: single

**Formatted:** Space Before: 5 pt, After: 5 pt, Line spacing: single, Don't keep with next

**Formatted:** Indent: Before: 0", Space Before: 5 pt, After: 5 pt, Line spacing: single

**Formatted:** Space Before: 5 pt, After: 5 pt, Line spacing: single, Don't keep with next

**Formatted:** Indent: Before: 0", Space Before: 5 pt, After: 5 pt, Line spacing: single

**Formatted:** Space Before: 5 pt, After: 5 pt, Line spacing: single, Don't keep with next

**Formatted:** Indent: Before: 0", Space Before: 5 pt, After: 5 pt, Line spacing: single

**Formatted:** Space Before: 5 pt, After: 5 pt, Line spacing: single, Don't keep with next

**Formatted:** Indent: Before: 0", Space Before: 5 pt, After: 5 pt, Line spacing: single

**Formatted:** Space Before: 5 pt, After: 5 pt, Line spacing: single, Don't keep with next

**Formatted:** Space Before: 5 pt, After: 5 pt, Line spacing: single, No bullets or numbering

**Commented [21]:** version 2.1

**Formatted:** Space Before: 5 pt, After: 5 pt, Line spacing: single, Don't keep with next

**Formatted:** Font: (Default) Times, Not Bold, Font color: Auto, Complex Script Font: Times

**Formatted:** Space Before: 5 pt, After: 5 pt, Don't keep with next

## Works Cited

- 'Abu Simbel' (2022) *Wikipedia*. Available at: [https://en.wikipedia.org/w/index.php?title=Abu\\_Simbel&oldid=1121643922](https://en.wikipedia.org/w/index.php?title=Abu_Simbel&oldid=1121643922) (Accessed: 22 November 2022).
- Archaeological Institute of America (2006) *Interactive Digs - Zominthos, Crete, Archaeological Institute of America*. Available at: <https://www.archaeological.org/interactive-dig/zominthos-crete/> (Accessed: 25 October 2022).
- Ballard, R.D. (1987) *The Discovery of the Titanic*. Warner.
- Bekiari, C. *et al.* (2014) *MARINETLO - iMarine - Data e-Infrastructure Initiative for Fisheries Management and Conservation of Marine Living Resources*. version 4. FORTH, p. 124. Available at: [https://projects.ics.forth.gr/isl/MarineTLO/documentation/MarineTLO\\_documentation\\_v4.pdf](https://projects.ics.forth.gr/isl/MarineTLO/documentation/MarineTLO_documentation_v4.pdf).
- Bonn-Muller, E. (2010) *Dynasty of Priestesses, Archaeology*. Available at: <https://archive.archaeology.org/online/features/eleutherna/>.
- Boxhall, J. (1962) 'Joseph Groves Boxhall - Radio Interview'. Available at: <https://www.encyclopedia-titanica.org/boxhall.html> (Accessed: 10 February 2023).
- Claes, J. (2020) *Bearded Vulture - Gypaetus barbatus, Observation.org*. Available at: <https://observation.org/observation/203043133/> (Accessed: 20 December 2022).
- Clausen, J.P. (1976) 'Circulatory adjustments to dynamic exercise and effect of physical training in normal subjects and in patients with coronary artery disease', *Progress in cardiovascular diseases*, 18(6). Available at: [https://doi.org/10.1016/0033-0620\(76\)90012-8](https://doi.org/10.1016/0033-0620(76)90012-8).
- Croix, S. *et al.* (2019) 'Single Context, Metacontext, and High Definition Archaeology: Integrating New Standards of Stratigraphic Excavation and Recording', *Journal of Archaeological Method and Theory*, 26(4), pp. 1591–1631. Available at: <https://doi.org/10.1007/s10816-019-09417-x>.
- Doerr, M. and Hiebel, G. (2013) 'CRMgeo: Linking the CIDOC CRM to GeoSPARQL through a Spatiotemporal Refinement'.
- Foister, S. (2015) 'LUCAS CRANACH THE ELDER', in *National Gallery Catalogues - The German Paintings before 1800*. London: National Gallery Company Limited, p. 10.
- Ganas, A. *et al.* (2006) 'Coulomb stress triggering of earthquakes along the Atalanti Fault, central Greece: Two April 1894 M6+ events and stress change patterns', *Tectonophysics*, 420(3), pp. 357–369. Available at: <https://doi.org/10.1016/j.tecto.2006.03.028>.
- 'Gas chromatography' (2018) *Wikipedia*. Available at: [https://en.wikipedia.org/w/index.php?title=Gas\\_chromatography&oldid=828895011](https://en.wikipedia.org/w/index.php?title=Gas_chromatography&oldid=828895011) (Accessed: 26 October 2022).
- Germanisches National Museum (no date) *Kaiser Karl der Große*. Available at: <http://objektkatalog.gnm.de/objekt/Gm167> (Accessed: 22 November 2022).
- Godfrey, I.M. *et al.* (2002) 'The Analysis of Ivory from a Marine Environment', *Studies in Conservation*, 47(1), pp. 29–45. Available at: <https://doi.org/10.1179/sic.2002.47.1.29>.
- 'Great Sphinx of Giza' (2022) *Wikipedia*. Available at: [https://en.wikipedia.org/w/index.php?title=Great\\_Sphinx\\_of\\_Giza&oldid=1122851051#Missing\\_nose](https://en.wikipedia.org/w/index.php?title=Great_Sphinx_of_Giza&oldid=1122851051#Missing_nose) (Accessed: 22 November 2022).
- Halpern, S. (2011) 'Chronology of events with references and notes', in *Report into the loss of the SS Titanic: a centennial reappraisal*. Stroud, Gloucestershire [U.K.]: History Press.

Honey, A. and Pickwood, N. (2010) 'Learning from the Past: Using Original Techniques to Conserve a Twelfth-Century Illuminated Manuscript and Its Sixteenth-century Greek-Style Binding at the Monastery of St Catherine, Sinai', *Studies in Conservation*, 55(sup2), pp. 56–61. Available at: <https://doi.org/10.1179/sic.2010.55.Supplement-2.56>.

*InGeoCloudS - INspiredGEOdata CLOUD Services. Deliverable D2.2: Interface of Web Services and models of data (D2.2)* (2012). Project deliverable D2.2. Available at: <https://www.ingeoclouds.eu/> (Accessed: 1 December 2012).

*InGeoCloudS - INspiredGEOdata CLOUD Services. Deliverable D.2.3: InGeoCloudS Web Services covering Use Cases (D2.3)* (2013). Project deliverable D2.3. Available at: <https://www.ingeoclouds.eu/> (Accessed: 1 July 2013).

Karamitrou-Mentessidi, G. *et al.* (2015) 'EARLY NEOLITHIC SETTLEMENT OF MAVROPIGI IN WESTERN GREEK MACEDONIA', *Eurasian Prehistory*, 12(1–2), pp. 47–116.

Kelouaz, K. *et al.* (2016) 'Mortar of lime and natural cement for the restoration of built cultural heritage', *International Journal of Engineering Research & Science*, 2(1), pp. 1–3.

Korres, G. *et al.* (2013) 'Forecasting at the Mediterranean and the Aegean Sea scale: the POSEIDON System', in *2nd GODAE OceanView Coastal Oceans and Shelf Seas Task Team (COSS-TT) International Coordination Workshop (COSS-ICW2)*, Lecce, Italy. Available at: [https://www.godae.org/~godae-data/OceanView/Events/COSS-TT-workshop-Feb-2013/presentations/1.3-Korres\\_Poseidon2013.pdf](https://www.godae.org/~godae-data/OceanView/Events/COSS-TT-workshop-Feb-2013/presentations/1.3-Korres_Poseidon2013.pdf).

Kramer-Hajos, M. and O'Neill, K. (2008) 'The Bronze Age Site of Mitrou in East Lokris: Finds from the 1988–1989 Surface Survey', *Hesperia: The Journal of the American School of Classical Studies at Athens*, 77(2), pp. 163–250.

Kritikos, K., Rousakis, Y. and Kotzinos, D. (2013) 'Linked open GeoData management in the cloud', in *Proceedings of the 2nd International Workshop on Open Data*. New York, NY, USA: Association for Computing Machinery (WOD '13), pp. 1–6. Available at: <https://doi.org/10.1145/2500410.2500414>.

Litoseliti, A., Koukouvelas, I. and Nikolakopoulos, K. (2014) 'Hazard due to earthquake-induced rock falls: The use of remote sensing data and field mapping in the case of Skolis Mountain, NW Peloponnese', *Bulletin of the Geological Society of Greece*, 48, p. 4. Available at: <https://doi.org/10.12681/bgsg.11045>.

Lucchese, C. *et al.* (2013) 'InGeoCloudS: A Cloud-Based Platform for Sharing Geodata Across Europe', *undefined* [Preprint]. Available at: <https://www.semanticscholar.org/paper/InGeoCloudS%3A-A-Cloud-Based-Platform-for-Sharing-Lucchese-Perego/6a4b95d67328d4dcc72c9ea4799af09e749a9554> (Accessed: 21 November 2022).

Marinos, P.G. (1997) *Engineering geology and the environment: proceedings International Symposium on Engineering Geology and the Environment, organized by the Greek National Group of IAEG, Athens, Greece, 23-27 June 1997*. Rotterdam, Brookfield: A.A. Balkema.

Mindock (2017) *Strong 6.2-magnitude earthquake hits Mexico City, The Independent*. Available at: <https://www.independent.co.uk/news/world/americas/mexico-earthquake-today-latest-mexico-city-magnitude-6-tremor-damage-a7963211.html> (Accessed: 25 October 2022).

Museo del Prado (2012) *El Museo del Prado presenta las conclusiones del estudio técnico y*, *studylib.es*. Available at: <https://studylib.es/doc/7697536/el-museo-del-prado-presenta-las-conclusiones-del-estudio> (Accessed: 21 November 2022).

Padfield, T. (no date) *Calculator for conservation heating, Conservation physics*. Available at: <http://www.conservationphysics.org/atmcalc/consheatcalc.php> (Accessed: 26 October 2022).

Paine, T.D. (2006) *Invasive Forest Insects, Introduced Forest Trees, and Altered Ecosystems: Ecological Pest Management in Global Forests of a Changing World*. Dordrecht: Springer Netherlands. Available at: <https://doi.org/10.1007/1-4020-5162-X>.



- Papasotiriou, A. *et al.* (2010) ‘Damage Assessment to the Macedonian “Tomb of Macridy Bey” at Derveni, Thessaloniki’, in *International Symposium of the Conservation of the Monuments in the Mediterranean Basin*, Patras, p. 12. Available at: [http://library.tee.gr/digital/m2616/m2616\\_papasotiriou.pdf](http://library.tee.gr/digital/m2616/m2616_papasotiriou.pdf).
- Photiades, A. (2010) ‘GEOLOGICAL CONTRIBUTION TO THE TECTONO- STRATIGRAPHY OF THE NAFPLION AREA (NW ARGOLIS, GREECE)’, *Bulletin of the Geological Society of Greece*, 43(3), pp. 1495–1507. Available at: <https://doi.org/10.12681/bgsg.11324>.
- Pickwood, N. (2004) ‘The condition survey of the manuscripts in the monastery of Saint Catherine on Mount Sinai’, *The Paper Conservator*, 28(1), pp. 33–61. Available at: <https://doi.org/10.1080/03094227.2004.9638640>.
- Pickwood, N. (2016) ‘The Lanhydrock Pedigree: Mounting and framing an oversize parchment document’, in M.J. Driscoll (ed.) *Care and Conservation of Manuscripts*. Copenhagen: Museum Tusulanum Press, University of Copenhagen, pp. 233–248. Available at: <http://www.mtp.hum.ku.dk/details.asp?eln=203745> (Accessed: 29 March 2018).
- Rentro, N. (2019) ‘Mexican Opal with Large Fluid Inclusion’, *Gems & Gemology*, 55(2), pp. 260–269.
- Righter, E. (2002) *The Tutu Archaeological Village Site: A Multidisciplinary Case Study in Human Adaptation*. Routledge.
- Rozos, D. *et al.* (2010) ‘LAND SUBSIDENCE DUE TO EXCESSIVE GROUND WATER WITHDRAWAL. A CASE STUDY FROM STAVROS - FARSALA SITE, WEST THESSALY GREECE’, *Bulletin of the Geological Society of Greece*, 43(4), pp. 1850–1857. Available at: <https://doi.org/10.12681/bgsg.11376>.
- Rubinstein, N. (1966) ‘Libraries and archives of Florence’, *Times Literary Supplement*, 1133.
- Ruck, L. and Brown, C.T. (2015) ‘Quantitative analysis of Munsell color data from archeological ceramics’, *Journal of Archaeological Science: Reports*, 3, pp. 549–557. Available at: <https://doi.org/10.1016/j.jasrep.2015.08.014>.
- Sakellarakis, Y. and Sapouna-Sakellarakis, E. (1981) ‘Drama of death in a Minoan temple’, *National Geographic*, 159(2), pp. 205–222.
- Sider, S. (1990) ‘Herculaneum’s Library in 79 A.D.: The Villa of the Papyri’, *Libraries & Culture*, 25(4), pp. 534–542.
- Stead, S. and Doerr, M. (2015) *CRMInf*. 0.7. Pavprime Ltd. Available at: <https://cidoc-crm.org/crmInf/sites/default/files/CRMInf-0.7%28forSite%29.pdf> (Accessed: 29 January 2016).
- Strid, A. and Tan, K. (1986) *Mountain Flora of Greece*. CUP Archive.
- Symons, G.J. *et al.* (1888) *The Eruption of Krakatoa: And Subsequent Phenomena*. Trübner & Company.
- Szirmai, J.A. (1999) *The archaeology of medieval bookbinding*. Aldershot, Hants.; Brookfield, Vt.: Ashgate.
- Tavoularis, N. *et al.* (2018) ‘The Contribution of Landslide Susceptibility Factors Through the Use of Rock Engineering System (RES) to the Prognosis of Slope Failures: An Application in Panagopoula and Malakasa Landslide Areas in Greece’, *Geotechnical and Geological Engineering*, 36(3), pp. 1491–1508. Available at: <https://doi.org/10.1007/s10706-017-0403-9>.
- ‘Temple of Hercules (Amman)’ (2022) *Wikipedia*. Available at: [https://en.wikipedia.org/w/index.php?title=Temple\\_of\\_Hercules\\_\(Amman\)&oldid=1106380105](https://en.wikipedia.org/w/index.php?title=Temple_of_Hercules_(Amman)&oldid=1106380105) (Accessed: 26 October 2022).
- The National Gallery, London (1963) *Cupid complaining to Venus*, *Cranach Digital Archive*. Available at: [https://lucascranach.org/en/UK\\_NGL\\_6344/](https://lucascranach.org/en/UK_NGL_6344/) (Accessed: 26 October 2022).
- Thiery, J.M., D’Herbes, J.-M. and Valentin, C. (1995) ‘A Model Simulating the Genesis of Banded Vegetation Patterns in Niger’, *Journal of Ecology*, 83(3), pp. 497–507. Available at: <https://doi.org/10.2307/2261602>.

Velios, A. (1998) *Mechanical properties of the corrosion layers of copper*. BA thesis. Technological Educational Institute of Athens.

Vilajosana, I. *et al.* (2008) 'Rockfall induced seismic signals: case study in Montserrat, Catalonia', *Natural Hazards and Earth System Sciences*, 8(4), pp. 805–812. Available at: <https://doi.org/10.5194/nhess-8-805-2008>.

Wan, X.F. (2012) 'Lessons from emergence of A/goose/Guangdong/1996-like H5N1 highly pathogenic avian influenza viruses and recent influenza surveillance efforts in southern China', *Zoonoses and Public Health*, 59 Suppl 2, pp. 32–42. Available at: <https://doi.org/10.1111/j.1863-2378.2012.01497.x>.

Επιστημονική Επιτροπή Κνωσού (2008) *Κνωσός 2000-2008. Συντήρηση, στερέωση και ανάδειξη του ανακτόρου και του αρχαιολογικού χώρου*. Υπουργείο Πολιτισμού.