



# EMMC-CSA

European Materials Modelling Council

## Documentation on Materials Modelling Ontology in UML

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## 1. Executive summary

### 1.1 *Description and objectives*

Document and describe the European Materials Modelling Ontology (EMMO)

Less focus has been placed on using UML in the description of EMMO. UML is a widely used standard for designing class diagrams for actual code implementations. But with the development of EMMO we have moved to a higher level of abstraction. Since W3W Web Ontology Language (OWL) is the de facto standard for describing ontologies we have chosen it instead of UML. OWL is a language specifically designed for ontologies and is much better suited than UML for this task. However, some syntactic rules of the graphical representation of EMMO has been taken from UML.

### 1.2 *Major outcome*

The outcome of this deliverable includes:

- Documentation of EMMO generated from OWL file using the Python package that is a part of the documentation on “Design and Implementation of metadata schema for syntactic and semantic interoperability”.
- Communication with and involvement of more than 100 experts in the development process of EMMO.

## 2. Progress report (main activities)

### 2.1 *Documentation of EMMO*

The EMMO is provided in the form of OWL definitions in machine readable RDF/XML format. It is building upon and formalising the Review of Materials Modelling [1], the CEN Workshop Agreement [2] and the MODA template [3]. It is currently hosted on a private github [4] repository, until it will be published and made publicly available.

However, since this deliverable is a documentation, we will here provide a human readable documentation and reference description of all relations and classes defined in EMMO. This documentation is the real deliverable and is included as an annex to this report.

The documentation has been generated with a Python package `emmo` and the open source software `pandoc` [5]. Input is the OWL definition of EMMO, a set of markdown files, a yaml file with metadata (title, version, authors, date, ...) and templates for html and pdf output. This `emmo` package can represent EMMO in a natural way as a set of related Python classes. Individuals are represented as instances of these classes. On top of this package, we have created a tool called `emmodoc` that generates the actual documentation including graphical representations of the different branches and subbranches. The markdown input includes an introduction and titles and ingresses for the automatically documented branches and subbranches. The introduction describes the primitive elements in EMMO, its theoretical foundations, some important concepts and how to read the generated graphs and documentation. This way, we will be able to easily maintain a human readable documentation of EMMO for any version of EMMO.



Figure 1 – The base branch of EMMO showing the *elementary* that constitutes all matter. All real materials will be defined in the *state* branch while natural laws, models and properties will be defined in the *abstract* branch.

## 2.2 Communication and community involvements

The communication and involvement of experts has taken place at the following events:

- Expert Meeting at SINTEF in December 2016
- IRAG meeting, Jan 2017
- Sessions at International Workshop in Vienna, Feb 2017
- A number of exchanges by email and telecon with a.o. Barry Smith and Hedi Karray
- Cambridge IntOp Workshop Nov 2017
- CWA finalised Jan 2018
- EC Materials Ontology Workshop June 2018
- IRAG online meeting and webinar July/August 2018
- IRAG workshop on EMMO Sept 2018



### 3. Conclusions

A wide community of experts has been approached during the development of EMMO. This input has been formalised in OWL, the language used to define EMMO. Based on the OWL sources, a controlled vocabulary has been extracted from which an annotated and complete documentation of EMMO has been generated.

### 4. References

- [1] <https://publications.europa.eu/en/publication-detail/-/publication/ec1455c3-d7ca-11e6-ad7c-01aa75ed71a1>
- [2] [https://www.cen.eu/news/workshops/Pages/WS\\_2016-013.aspx](https://www.cen.eu/news/workshops/Pages/WS_2016-013.aspx)
- [3] <https://emmc.info/moda-workflow-templates/>
- [4] <https://github.com/nanodome/emmo/>
- [5] <https://pandoc.org/>

### 5. Annex

Documentation of the European Materials Modelling Ontology (EMMO) in pdf and html formats (emmodoc.pdf, emmodoc.html)



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<b>Consortium</b>		
TU WIEN	Technische Universität Wien	Austria
FRAUNHOFER	Fraunhofer Gesellschaft	Germany
GCL	Goldbeck Consulting Limited	United Kingdom
POLITO	Politecnico di Torino	Italy
UU	Uppsala Universitet	Sweden
DOW	Dow Benelux B.V.	Netherlands
EPFL	Ecole Polytechnique Federale de Lausanne	Switzerland
DPI	Dutch Polymer Institute	Netherlands
SINTEF	Stiftelsen SINTEF	Norway
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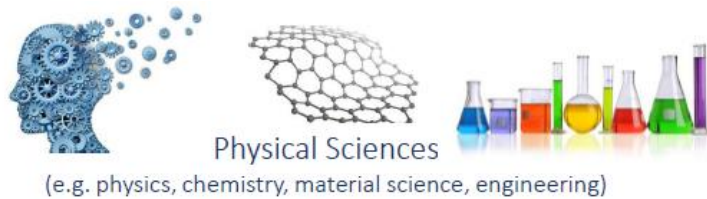
# European Materials Modelling Ontology

VERSION 1.0

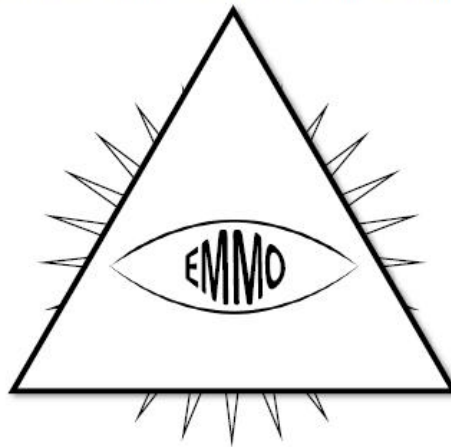
European Materials Modelling Council (EMMC)



October 04, 2018



Analytical Philosophy  
(e.g. mereotopology, semiotics, logic)



Information and Communication  
Technologies  
(e.g. reasoners, platforms, formats)

## Abstract

EMMO is an ontology that is created by the European Materials Modelling Council (EMMC) to provide a formal way to describe the fundamental concepts of physics, chemistry and materials science. EMMO is designed to pave the road for semantic interoperability providing a generic common ground for describing materials, models and data that can be adapted by all domains.

It is a representational framework of predefined classes and axioms (ontology) provided by experts (EMMC) that enables end users (industry, research, academy) to represent real life physical entities (materials, devices), models and properties using ontological signs (individuals) in a standard way to facilitate interactions and exchanges (data, software, knowledge) between all involved material modelling and characterization communities and stakeholders.

**Keywords:** EMMO, materials science, ontology

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**4 Appendix**

# Chapter 1

## Introduction

EMMO is a multidisciplinary effort to develop a standard representational framework (the ontology) based on current materials modelling knowledge, including physical sciences, analytical philosophy and information and communication technologies. This multidisciplinary is illustrated by the figure on the title page. It provides the connection between the physical world, materials characterisation world and materials modelling world.

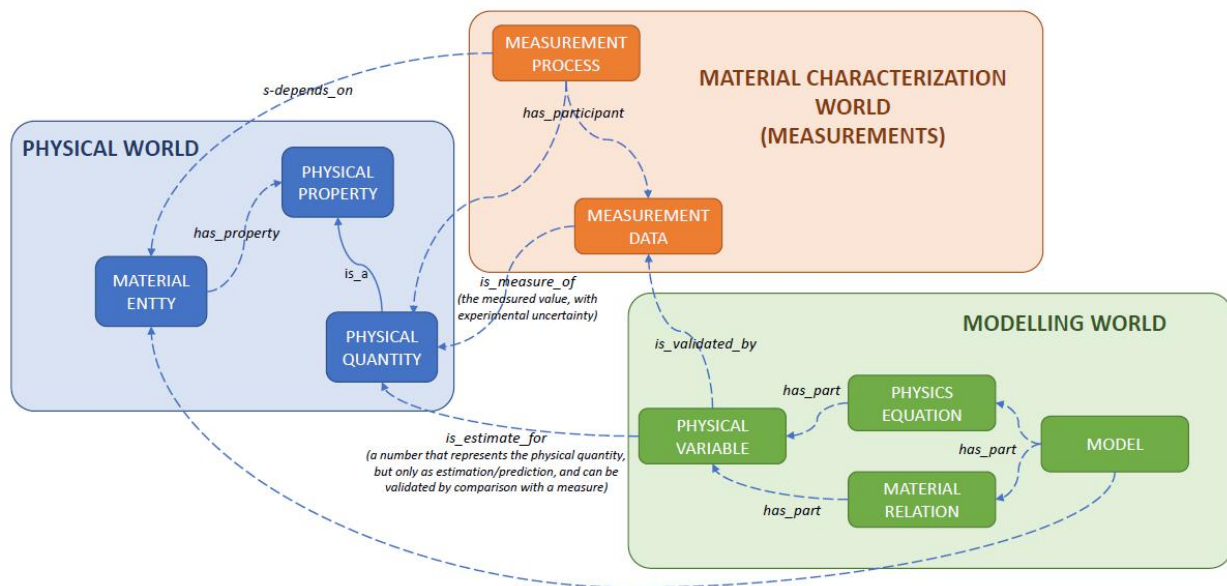


Figure 1.1: EMMO provides the connection between the physical world, materials characterisation world and materials modelling world.

EMMO is based on and is consistent with the [Review of Materials Modelling](#), [CEN Workshop Agreement](#) and [MODA template](#). However, while these efforts are written for humans, EMMO is defined using the [Web Ontology Language \(OWL\)](#), which is machine readable and allows for machine reasoning. In terms of semantic representation, EMMO brings everything to a much higher level.

As illustrated in the figure below, EMMO covers all aspects of materials modelling and characterisation, including:

- the **material** itself, which must be described in a rigorous way
- the **observation process** involving an observer that perceives the real world
- the **properties** that is measured or modelled
- the **physics laws** that describes the material behaviour
- the **physical models** that approximate the physics laws

- the **solver** including the numerical discretisation method that leads to a solvable mathematical representation under certain simplifying assumptions
- the **numerical solver** that performs the calculations
- the **post processing** of experimental or simulated data

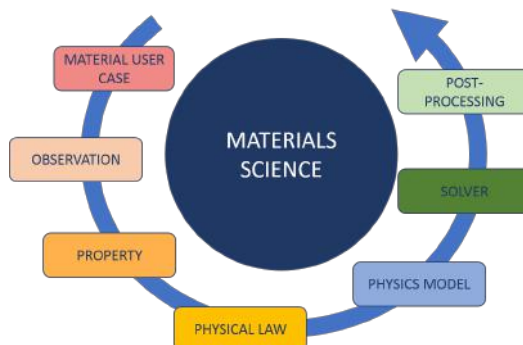


Figure 1.2: The aspects of materials modelling and characterisation covered by EMMO.

## What is an ontology

In short, an ontology is a specification of a conceptualization. The word *ontology* has a long history in philosophy, in which it refers to the subject of existence. The so-called [ontological argument](#) for the existence of God was proposed by Anselm of Canterbury in 1078. He defined God as “*that than which nothing greater can be thought*”, and argued that “*if the greatest possible being exists in the mind, it must also exist in reality. If it only exists in the mind, then an even greater being must be possible – one which exists both in the mind and in reality*”. Even though this example has little to do with today’s use of ontologies in computer science, it illustrates the basic idea; the ontology defines some basic premises (concepts and relations between them) from which it is possible to reason to gain new knowledge.

For a more elaborated and modern definition of the ontology we refer the reader to the one provided by [Tom Gruber \(2009\)](#). Another useful introduction to ontologies is the paper [Ontology Development 101: A Guide to Creating Your First Ontology](#) by Noy and McGuinness (2001), which is based on the [Protege](#) software, with which EMMO has been developed.

A taxonomy is a hierarchical representation of classes and subclasses connected via `is_a` relations. Hence, it is a subset of the ontology excluding all, but the `is_a` relations. The main use of taxonomies are for classifications. The figure shows a simple example of a taxonomy illustrating a categorisation of four classes into a hierarchy of more higher of levels of generality.

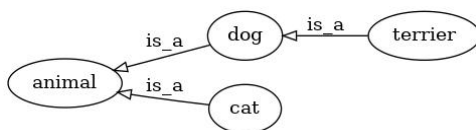


Figure 1.3: Example of a taxonomy.

In EMMO the taxonomy is a rooted directed acyclic graph (DAG). This is an important property since many classification methods rely on this property [Valentini \(2014\)](#) and [Robison et al \(2015\)](#).

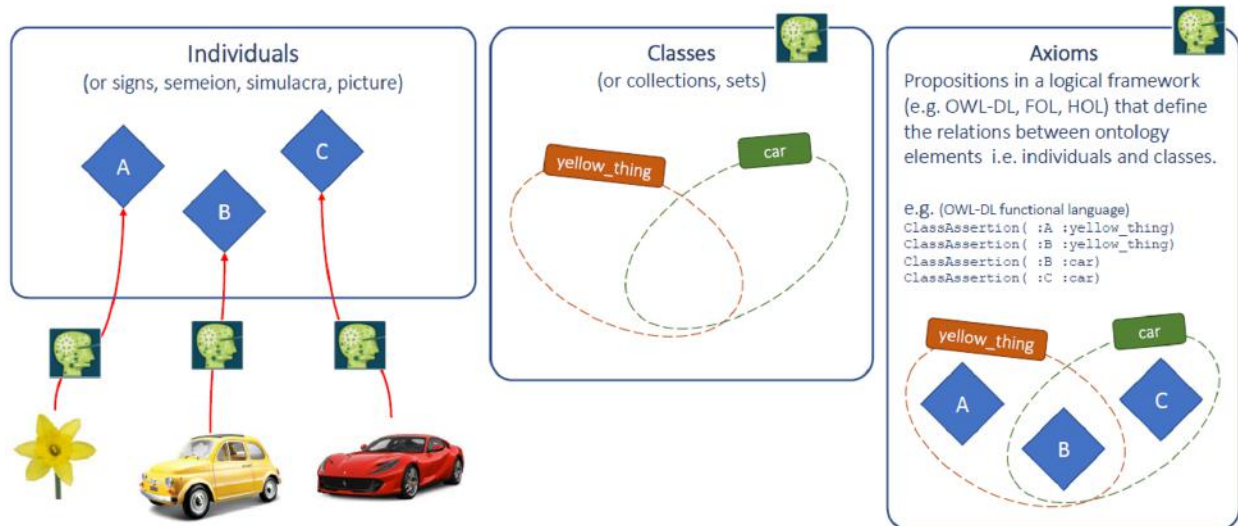


Figure 1.4: The primitive building blocks of EMMO.

## Primitive elements in EMMO

### Individuals

Individuals are the basic, “ground level” components of EMMO. They may include concrete objects such as cars, flowers, stars, persons and molecules, as well as abstract individuals such as a measured height, a specific equation and software programs.

Individuals are not simple, but possess attributes in form of axioms that are defined by the user (interpreter) upon declaration.

### Classes

Classes represents concepts. They are the building blocks that we use to create an ontology as a representation of knowledge. We distinguish between *defined* and *non-defined* classes.

Defined classes are defined by the requirements for being a member of the class. In the graphical representations of EMMO, defined classes are orange. For instance, in the graph of the top-level entity branch below, **set** and **abstract** are defined classes. **set** is defined via the `has_member` relationship, while **abstract** is defined via the `has_abstract_part` relationship.

Non-defined classes are defined as an abstract group of objects, whos members are defined as belonging to the class. They are yellow in the graphical representations.

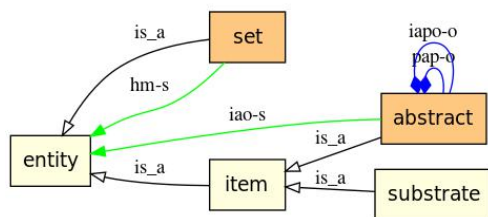


Figure 1.5: Example of the top-level entity branch showing some classes and relationships between them.



## Axioms

Axioms are propositions in a logical framework that define the relations between the individuals and classes. They are used to categorise individuals in classes and to define the *defined* classes.

The simplest form of a class axiom is a class description that just states the existence of the class and gives it a unique identifier. In order to provide more knowledge about the class, class axioms typically contain additional components that state necessary and/or sufficient characteristics of the class. OWL contains three language constructs for combining class descriptions into class axioms:

- `rdfs:subClassOf` allows one to say that the class extension of a class description is a subset of the class extension of another class description.
- `owl:equivalentClass` allows one to say that a class description has exactly the same class extension as another class description.
- `owl:disjointWith` allows one to say that the class extension of a class description has no members in common with the class extension of another class description.

See the section about [Description logic](#) for more information about these language constructs. Axioms are also used to define relations between relations. These are further detailed in the chapter on [Relations](#).

## Theoretical foundations

EMMO build upon several theoretical frameworks.

### Semiotics

Semiotics is the study of meaning-making. It is the discipline of formulating something that possibly can exist in a defined space and time in the real world. It is introduced in EMMO via the `semion` class and used as a way to reduce the complexity of a physical to a simple sign (symbol). A `semion` is a physical entity that represents an abstract object.

### Set theory

Set theory is the theory of membership. This is introduced via the `set` class, representing the collection of all individuals (signs) that represents a collection of items. Sets are defined via the `has_member` / `is_member_of` relations.

### Mereology

Mereology is the science of parthood. It is introduced via the `item` class and based on the mereological `has_part` / `is_part_of` relations.

EMMO makes a strong distinction between membership and parthood relations. In contrast to sets, items can only have parts that are themselves items. This means for instance that parthood is only between substrates of the same dimensionality. Hence, the boundary of an item is not a part of the item since it has a lower dimensionality.

For further information, see [Casati and Varzi “Parts and Places” \(1999\)](#).

### Topology

Topology is the study of geometrical properties and spatial (and time-wise) relations. It is introduced in combination with mereology (and therefore often referred to as **mereotopology**) via the `substrate` class, which represents

the place in space and time in which every real world item exists. Substrates in EMMO are always topologically connected in space and time.

Mereotopological relationships are defined with the `encloses` / `is_enclosed_by` relations.

## Metrology

Metrology is the science of measurements. It is used to introduce units and link them to properties.

## Description logic

**Description logic (DL)** is a formal knowledge representation language in which the *axioms* are expressed. It is less expressive than **first-order logic (FOL)**, but commonly used for providing the logical formalism for ontologies and semantic web. EMMO is expressed in the **Web Ontology Language (OWL)**, which is in turn is based on DL. This opens for features like reasoning.

Since it is essential to have a basic notion of OWL and DL, we include here a very brief overview. For a proper introduction to OWL and DL, we refer the reader to sources like [Grau et.al. \(2008\)](#), [OWL2 Primer](#) and [OWL Reference](#).

OWL distinguishes six between types of class descriptions:

1. a class identifier (a IRI reference)
2. an exhaustive enumeration of individuals that together form the instances of a class (`owl:oneOf`)
3. a property restriction (`owl:someValuesFrom`, `owl:allValuesFrom`, `owl:hasValue`, `owl:cardinality`, `owl:minCardinality`, `owl:maxCardinality`)
4. the intersection of two or more class descriptions (`owl:intersectionOf`)
5. the union of two or more class descriptions (`owl:unionOf`)
6. the complement of a class description (`owl:complementOf`)

Except for the first, all of these refer to *defined classes*. The table below shows the notation in OWL, DL and the **Manchester OWL syntax**, all commonly used for the definitions. The Manchester syntax is used by **Protege** and is designed to not use DL symbols and to be easy and quick to read and write. Several other syntaxes exists for DL. An interesting example is the pure Python syntax proposed by [Lamy \(2017\)](#), which is used in the open source **Owready2** Python package.

Table 1.1: Notation for DL and Protege. A and B are classes, R is an active relation, S is an passive relation, i and j are individuals and n is a literal.

OWL constructor	DL	Manchester	Read	Meaning
	$A \doteq B$	?	A is defined to be equal to B	Class <i>definition</i>
<code>rdf:subclassOf</code>	$A \sqsubseteq B$	A subclass_of B	all A are B	Class <i>inclusion</i>
<code>owl:equivalentTo</code>	$A \equiv B$	A equivalent_to B	A is equivalent to B	Class <i>equivalence</i>
<code>owl:intersectionOf</code>	$A \sqcap B$	A and B	A and B	Class <i>intersection (conjunction)</i>
<code>owl:unionOf</code>	$A \sqcup B$	A or B	A or B	Class <i>union (disjunction)</i>
<code>owl:complementOf</code>	$\neg A$	not A	not A	Class <i>complement (negation)</i>
<code>owl:oneOf</code>	$\{a, b, \dots\}$	$\{a, b, \dots\}$	one of a, b, ...	Class <i>enumeration</i>
<code>rdf:type</code>	$a : A$	a is_a A	a is a A	Class <i>assertion</i>

OWL constructor	DL	Manchester	Read	Meaning
	$(a, b) : R$	a object property assertion b	a is R-related to b	Property <i>assertion</i>
	$(a, n) : R$	a data property assertion n	a is R-related to n	Data <i>assertion</i>
	$\top$	?	top	A special class with every individual as an instance
owl:allValuesFrom	$\perp$ $\forall R.A$	? R only A	bottom all A with R	The empty class <i>Universal restriction</i>
owl:someValuesFrom	$\exists R.A$	R some A	some A with R	<i>Existential restriction</i>
owl:cardinality	$= nR.A$	R exactly n A		<i>Cardinality restriction</i>
owl:minCardinality	$\leq nR.A$	R min n		<i>Minimum cardinality restriction</i>
owl:maxCardinality	$\geq nR.A$	R max n		<i>Maximum cardinality restriction</i>
owl:hasValue	$\exists R\{a\}$	R value a		
rdfs:domain	$\exists R.\top \sqsubseteq A$	R domain A		
rdfs:range	$\top \sqsubseteq \forall R.A$	R range A		
owl:inverseOf	$S \equiv R^{-}$	S inverse_of R	S is inverse of R	Property <i>inverse</i>

## Examples

Here are some examples of different class descriptions using both the DL and Manchester notation.

### Inclusion (`rdf:subclassOf`)

Inclusion (*sqsubseteq*) defines necessary conditions. Necessary and sufficient ( $\equiv$ ) conditions defined with equivalence.

An employee is a person.

**DL:** `employee sqsubseteq person`

**Manchester:** `employee is_a person`

### Enumeration (`owl:oneOf`)

The color of a wine is either white, rose or red:

**DL:** `wine_color  $\equiv$  {white, rose, red}`

**Manchester:** `wine_color equivalent_to {white, rose, red}`

### Property restriction (`owl:someValuesFrom`)

A mother is a woman that has a child (some person):

**DL:** `mother  $\equiv$  woman  $\sqcap$   $\exists$ has_child.person`

**Manchester:** `mother equivalent_to woman and has_child some person`

### Property restriction (owl:allValuesFrom)

All parents that only have daughters:

**DL:**  $\text{parents\_with\_only\_daughters} \equiv \text{person} \sqcap \forall \text{has\_child.woman}$

**Manchester:**  $\text{parents\_with\_only\_daughters}$  equivalent\_to  $\text{person}$  and  $\text{has\_child}$  only woman

### Property restriction (owl:hasValue)

The owl:hasValue restriction allows to define classes based on the existence of particular property values. There must be at least one matching property value.

All children of Mary:

**DL:**  $\text{Marys\_children} \equiv \text{person} \sqcap \exists \text{has\_parent}\{ \text{Mary} \}$

**Manchester:**  $\text{Marys\_children}$  equivalent\_to  $\text{person}$  and  $\text{has\_parent}$  value Mary

### Property cardinality (owl:cardinality)

The owl:cardinality restriction allows to define classes based on the maximum (owl:maxCardinality), minimum (owl:minCardinality) or exact (owl:cardinality) number of occurrences.

A person with one parent:

**DL:**  $\text{half\_orphan} \equiv \text{person} \text{ and } =1\text{has\_parent.person}$

**Manchester:**  $\text{half\_orphan}$  equivalent\_to  $\text{person}$  and  $\text{has\_parent}$  exactly 1 person

### Intersection (owl:intersectionOf)

Individuals of the intersection of two classes, are simultaneously instances of both classes.

A man is a person that is male:

**DL:**  $\text{man} \equiv \text{person} \sqcap \text{male}$

**Manchester:**  $\text{man}$  equivalent\_to  $\text{person}$  and  $\text{male}$

### Union (owl:unionOf)

Individuals of the union of two classes, are either instances of one or both classes.

A person is a man or woman:

**DL:**  $\text{person} \equiv \text{man} \sqcup \text{woman}$

**Manchester:**  $\text{person}$  equivalent\_to  $\text{man}$  or  $\text{woman}$

### Complement (owl:complementOf)

Individuals of the union of two classes, are either instances of one or both classes.

A person is a man or woman:

**DL:**  $\text{person} \equiv \text{man} \sqcup \text{woman}$

**Manchester:**  $\text{person}$  equivalent\_to  $\text{man}$  or  $\text{woman}$

# Important concepts

## Mereotopological composition

### Substrate

A **substrate** represents the place (in general sense) in which every real world item exists. It provides the dimensions of existence for real world entities. This follows from the fact that everything that exists is placed somewhere in space and time. Hence, its space and time coordinates can be used to identify it.

Substrates are always **topologically connected spaces** (a topological space  $X$  is said to be disconnected if it is the union of two disjoint non-empty open sets. Otherwise,  $X$  is said to be connected).

**substrate** is the superclass of **space**, **time** and their combinations, like **spacetime**.

*Following Kant, space and time are a priori forms of intuition, i.e. they are the substrate upon which we place our intuitions, assigning space and time coordinates to them.*

### Hybrid

A **hybrid** is the combination of **space** and **time**. It has the subclasses **world\_line** (0D space + 1D time), **world\_sheet** (1D space + 1D time), **world\_volume** (2D space + 1D time) and **spacetime** (3D space + 1D time).

### Spacetime

EMMO represents real world entities as subclasses of **spacetime**. A **spacetime** is valid for all reference systems (as required by the theory of relativity).

### Matter

**matter** is used to represent a group of **elementary** in an enclosing **spacetime**. As illustrated in the figure, a **matter** is an **elementary** or a composition of other **matter** and **vacuum**.

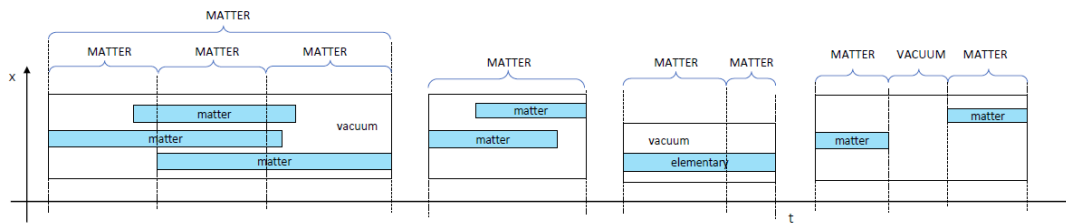


Figure 1.6: Matter.

In EMMO **matter** is always a 4D spacetime. This is a fundamental difference between EMMO and most other ontologies.

In order to describe the real world, we must also take into account the vacuum between the elementaries that composes higher granularity level entity (e.g. an atom).

In EMMO **vacuum** is defined as a **spacetime** that has no **elementary** parts.

### Existent

An **existent** is defined as a **matter** that unfolds in time as a succession of states. It is used to represent the whole life of a complex but structured state-changing **matter** entity, like e.g. an atom that becomes ionised and then recombines with an electron.

On the contrary, a **matter and not existent** entity is something “amorphous”, randomly collected and not classifiable by common terms or definitions. That is a heterogeneous heap of **elementary**, appearing and disappearing in time.

## State

A **state** is matter in a particular configurational state. It is defined as having spatial direct parts that persist (do not change) throughout the lifetime of the **state**. Hence, a **state** is like a snapshot of a physical in a finite time interval.

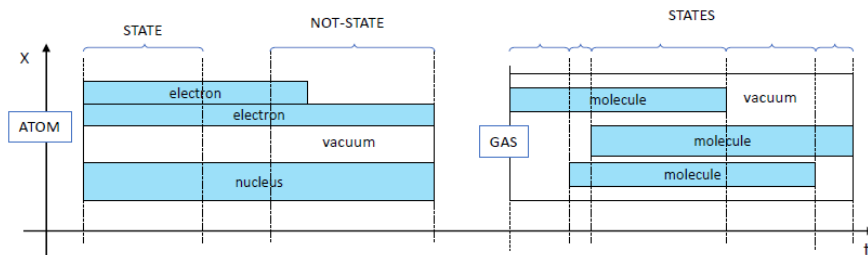


Figure 1.7: A physical can always be decomposed into a sequence of finite **states**.

The use of spatial direct parthood in the definition of **state** means that a **state** cannot overlap in space with another **state**.

An important feature of states, that follows from the fact that they are **spacetime**, is that they constitute a finite time interval.

## Elementary

The basic assumption of decomposition in EMMO, is that the most basic manifestation of **matter** is represented by a subclass of **spacetime** called **elementary**.

The **elementary** class defines the “atomic” (undividable) level in EMMO. A generic **matter** can always be decomposed in proper parts down to the **elementary** level using proper parthood. An **elementary** can still be decomposed in temporal parts, that are themselves **elementary**.

Example of elementaries are electrons, photons and quarks.

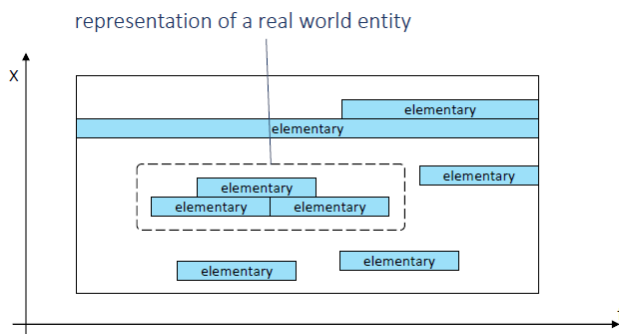


Figure 1.8: Elementary.

## Granularity - direct parthood

Granularity is a central concept of EMMO, which allows the user to perceive the world at different levels of detail (granularity) that follow physics and materials science perspectives.

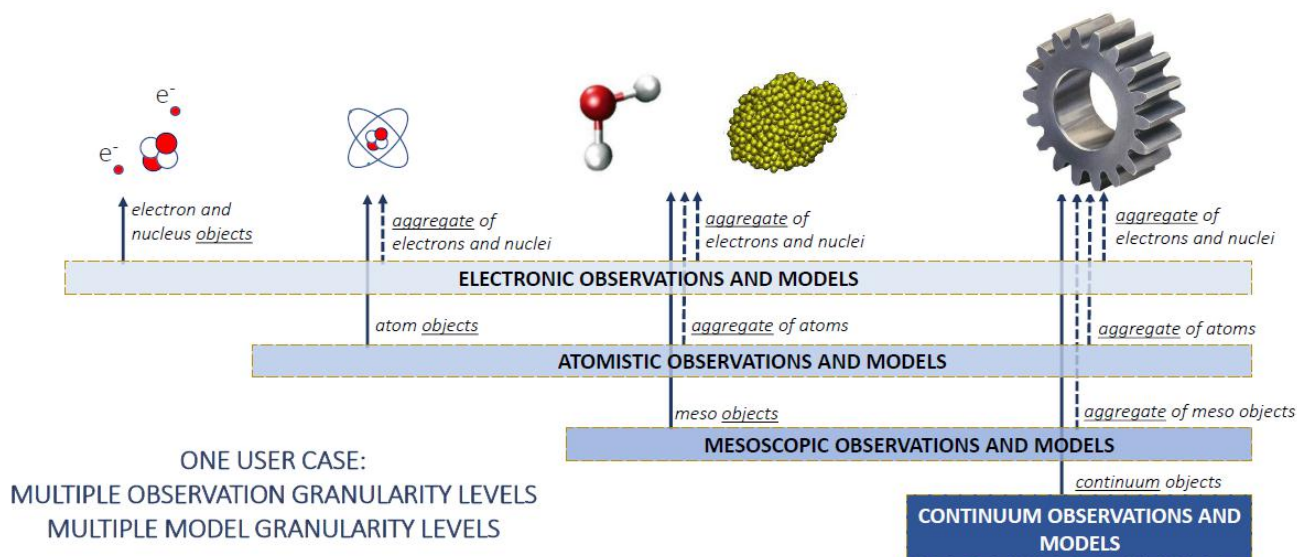


Figure 1.9: Different levels of granularity.

Every material in EMMO is placed on a granularity level and the ontology gives information about the direct upper and direct lower level classes. This is done with the non-transitive `is_direct_part_of` relation.

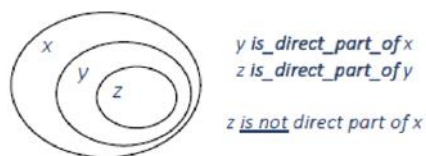


Figure 1.10: Direct parthood.

Granularity is a defined class and is useful since a reasoner automatically can put the individuals defined by the user under a generic class that clearly expresses the types of its compositional parts.

## Mathematical entities

The class `mathematical_entity` represents fundamental elements of mathematical expressions, like numbers, variables, unknowns and equations. Mathematical entities are pure mathematical and have no physical unit.

## Natural law

A `natural_law` is an abstraction for a series of experiments that tries to define a common cause and effect of the time evolution of a set of interacting participants. It is (by definition) a pre-mathematical entity.

The `natural_law` class is defined as

`is_abstraction_for` some `experiment`

It can be represented e.g. as a thought in the mind of the experimentalist, a sketch and textual description in a book of science.

`physical_law` and `material_law` are, according to the [RoMM](#) and [CWA](#), the laws behind physical equations and material relations, respectively.

## Properties

Properties are abstracts that are related to a specific material entity with the relation *has\_property*, but that depend on a **specific observation process**, participated by a **specific observer**, who catch the physical entity behaviour that is abstracted as a property.

Properties enable us to connect a measured property to the measurement process and the measurement instrument.

## How to read this document

### Annotations

All entities and relations in EMMO have some attributes, called *annotations*. In many cases, only the necessary *IRI* and *relations* are provided. However, more descriptive annotations, like *elucidation* and *comment* will be added with time. Possible annotations are:









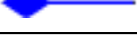
- **Elucidation** is a human readable explanation and clarification of the documented class or relation.
- **Example** clarifies the elucidation through an example. A class may have several examples, each addressing different aspects.
- **Comment** is a clarifying note complementing the definition and elucidation. A class may have several comments, each clarifying different aspects.
- **IRI** stands for *international resource identifier*. It is an identifier that uniquely identifies the class or relation. IRIs are similar to URIs, but are not restricted to the ASCII character set. Even though the IRIs used in EMMO appears to be URLs, they currently do not point to any existing content. This might change in the future.
- **Relations** is a list of relations applying to the current class or relation. The relations for relations are special and will be elaborated on in the introduction to chapter [Relations](#). Some of the listed relations are defined in the OWL sources, while other are inferred by the reasoner.

The relations are using the Manchester OWL syntax introduced in section [Description logic](#).

## Graphs

The generated graphs borrows some syntax from the [Unified Modelling Language \(UML\)](#), which is a general purpose language for software design and modelling. The table below shows the style used for the different types of relations and the concept they corresponds to in UML.

Table 1.2: Notation for arrow styles used in the graphs. Only active relations are listed. Corresponding passive relations uses the same style.

Relation	UML arrow	UML concept
is-a		inheritance
disjoint_with		association
equivalent_to		association
encloses		aggregation
has_abstract_part		aggregation
has_abstraction		aggregation
has_representation		aggregation
has_member		aggregation
has_property		aggregation



In order to reduce clutter and limit the size of the graphs, the relations are abbreviated according to the following table:

Table 1.3: Abbreviations of relations used in the graphical representation of the different subbranches.

Relation	Abbreviation
has_part only	hp-o
is_part_of only	ipo-o
has_member some	hm-s
is_member_of some	imo-s
has_abstraction some	ha-s
is_abstraction_of some	iao-s
has_abstract_part only	pap-o
is_abstract_part_of only	iapo-o
has_space_slice some	hss-s
is_space_slice_of some	isso-s
has_time_slice some	hts-s
is_time_slice_of some	itso-s
has_projection some	hp-s
is_projection_of some	ipo-s
has_proper_part some	hpp-s
is_proper_part_of some	ippo-s
has_proper_part_of some	hppo-s
has_spatial_direct_part min	hsdp-m
has_spatial_direct_part some	hsdp-s
has_spatial_direct_part exactly	hsdp-e

UML represents classes as a box with three compartment; name, attributes and operators. However, since the classes in EMMO have no operators and it gives little meaning to include the OWL annotations as attributes, we simply represent the classes as boxes.

As already mentioned, defined classes are colored orange, while undefined classes are yellow.

## Chapter 2

# Relations

In the language of OWL, relations are called *properties*. However, since relations describe relations between classes and individuals and since **properties** has an other meaning in EMMO, we call them *relations* here.

**Resource Description Framework (RDF)** is a W3C standard that is widely used for describing informations on the web and is one of the standards that OWL builds on. RDF expresses information in form of *subject-predicate-object* triplets. The subject and object are resources (aka items to describe) and the predicate expresses a relationship between the subject and the object.

In EMMO, are the subject and object classes or individuals (or data) while the predicate is a relation. An example of an relationship is the statement *dog is\_a animal*. Here is **dog** the subject, **is\_a** the predicate and **animal** the object.

All relationships have a direction. In EMMO we distinguish between **active relations** where the subject is acting on the object and **passive relations** where the subject is acted on by the object. In the graphical visualisations, we represent active relations with an arrow pointing from the subject to the object. Passive relations are represented with an arrow pointing from the object to the subject.

OWL distingues between **owl:ObjectProperty** that link classes or individuals to classes or individuals and **owl:DatatypeProperty** that links individuals to data values. Since EMMO only deals with classes, we will only be discussing object properties. However, in actual applications, datatype properties will be important.

The characteristics of the different properties is described by the following *property axioms*:

- **rdf:subPropertyOf** is used to define that a property is a subproperty of some other property. For instance, in the figure below showing the relation branch, we see that **active\_relation** is a subproperty or **relation**.

The **rdf:subPropertyOf** axioms forms a taxonomy-like tree for relations.

- **owl:equivalentProperty** states that two properties have the same property extension.
- **owl:inverseOf** axioms relate active relations to their corresponding passive relations, and vice versa. The root relation **relation** is its own inverse.
- **owl:FunctionalProperty** is a property that can have only one (unique) value  $y$  for each instance  $x$ , i.e. there cannot be two distinct values  $y_1$  and  $y_2$  such that the pairs  $(x,y_1)$  and  $(x,y_2)$  are both instances of this property. Both object properties and datatype properties can be declared as “functional”.
- **owl:InverseFunctionalProperty**
- **owl:TransitiveProperty** states that if a pair  $(x,y)$  is an instance of  $P$ , and the pair  $(y,z)$  is also instance of  $P$ , then we can infer the the pair  $(x,z)$  is also an instance of  $P$ .
- **owl:SymmetricProperty** states that if the pair  $(x,y)$  is an instance of  $P$ , then the pair  $(y,x)$  is also an instance of  $P$ .

A popular example of a symmetric property is the **friend\_of** relation.

## relation branch

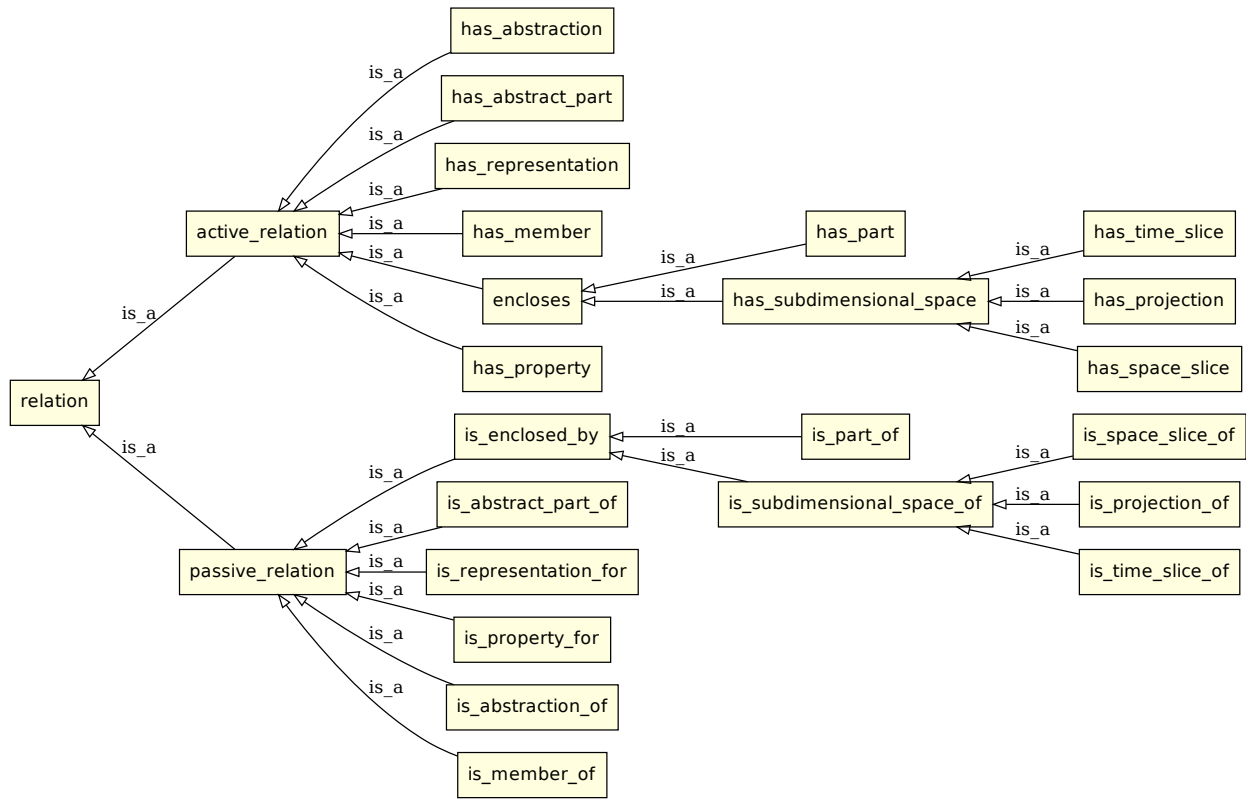


Figure 2.1: The relation branch.

## relation

IRI: <http://emmc.info/emmo#relation>

### Relations:

- is\_a owl:ObjectProperty
- is\_a owl:TransitiveProperty
- is\_a owl:topObjectProperty
- inverse\_of relation

## active\_relation

IRI: [http://emmc.info/emmo#active\\_relation](http://emmc.info/emmo#active_relation)

### Relations:

- is\_a owl:ObjectProperty
- is\_a owl:TransitiveProperty
- is\_a relation
- inverse\_of passive\_relation

## has\_abstraction

IRI: [http://emmc.info/emmo#EMMO\\_0c5131e0\\_43d3\\_4f35\\_92a4\\_fb53a279fa56](http://emmc.info/emmo#EMMO_0c5131e0_43d3_4f35_92a4_fb53a279fa56)

### Relations:

- is\_a [active\\_relation](#)
- inverse\_of [is\\_abstraction\\_of](#)

## has\_abstract\_part

IRI: [http://emmc.info/emmo#EMMO\\_3b367cb2\\_71dc\\_49a3\\_bbed\\_ca1dfb6dfa42](http://emmc.info/emmo#EMMO_3b367cb2_71dc_49a3_bbed_ca1dfb6dfa42)

### Relations:

- is\_a owl:ObjectProperty
- is\_a owl:TransitiveProperty
- is\_a [active\\_relation](#)
- inverse\_of [is\\_abstract\\_part\\_of](#)

## has\_representation

IRI: [http://emmc.info/emmo#EMMO\\_60577dea\\_9019\\_4537\\_ac41\\_80b0fb563d41](http://emmc.info/emmo#EMMO_60577dea_9019_4537_ac41_80b0fb563d41)

### Relations:

- is\_a [active\\_relation](#)
- inverse\_of [is\\_representation\\_for](#)

## has\_member

Comment: has\_member

IRI: [http://emmc.info/emmo#EMMO\\_6b7276a4\\_4b9d\\_440a\\_b577\\_0277539c0fc4](http://emmc.info/emmo#EMMO_6b7276a4_4b9d_440a_b577_0277539c0fc4)

### Relations:

- is\_a owl:IrreflexiveProperty
- is\_a [active\\_relation](#)
- inverse\_of [is\\_member\\_of](#)

## encloses

IRI: [http://emmc.info/emmo#EMMO\\_8c898653\\_1118\\_4682\\_9bbf\\_6cc334d16a99](http://emmc.info/emmo#EMMO_8c898653_1118_4682_9bbf_6cc334d16a99)

### Relations:

- is\_a [active\\_relation](#)
- inverse\_of [is\\_enclosed\\_by](#)

## has\_subdimensional\_space

IRI: [http://emmc.info/emmo#EMMO\\_2e8510db\\_ae65\\_44a7\\_b2f8\\_cc1111cdae24](http://emmc.info/emmo#EMMO_2e8510db_ae65_44a7_b2f8_cc1111cdae24)

### Relations:

- is\_a owl:ObjectProperty
- is\_a owl:TransitiveProperty
- is\_a [encloses](#)

- inverse\_of is\_subdimensional\_space\_of

## has\_time\_slice

IRI: [http://emmc.info/emmo#EMMO\\_23a627c3\\_741d\\_4030\\_ba93\\_8a5444ec53a0](http://emmc.info/emmo#EMMO_23a627c3_741d_4030_ba93_8a5444ec53a0)

### Relations:

- is\_a has\_subdimensional\_space
- inverse\_of is\_time\_slice\_of

## has\_projection

IRI: [http://emmc.info/emmo#EMMO\\_257b531b\\_afe6\\_4363\\_93b1\\_032c95b574b6](http://emmc.info/emmo#EMMO_257b531b_afe6_4363_93b1_032c95b574b6)

### Relations:

- is\_a has\_subdimensional\_space
- inverse\_of is\_projection\_of

## has\_space\_slice

IRI: [http://emmc.info/emmo#EMMO\\_43411a26\\_c4ff\\_4deb\\_a232\\_74f73e6ab8dc](http://emmc.info/emmo#EMMO_43411a26_c4ff_4deb_a232_74f73e6ab8dc)

### Relations:

- is\_a has\_subdimensional\_space
- inverse\_of is\_space\_slice\_of

## has\_property

IRI: [http://emmc.info/emmo#EMMO\\_d0875687\\_684c\\_4d0a\\_8484\\_99c9caf2239b](http://emmc.info/emmo#EMMO_d0875687_684c_4d0a_8484_99c9caf2239b)

### Relations:

- is\_a active\_relation
- inverse\_of is\_property\_for

## passive\_relation

IRI: [http://emmc.info/emmo#passive\\_relation](http://emmc.info/emmo#passive_relation)

### Relations:

- is\_a owl:ObjectProperty
- is\_a owl:TransitiveProperty
- is\_a relation
- inverse\_of active\_relation

## is\_enclosed\_by

IRI: [http://emmc.info/emmo#EMMO\\_10d3981e\\_95a7\\_472b\\_b24e\\_2be29744f1ab](http://emmc.info/emmo#EMMO_10d3981e_95a7_472b_b24e_2be29744f1ab)

### Relations:

- is\_a owl:ObjectProperty
- is\_a owl:TransitiveProperty

- is\_a [passive\\_relation](#)
- inverse\_of [encloses](#)

### is\_subdimensional\_space\_of

IRI: [http://emmc.info/emmo#EMMO\\_ba33e345\\_1293\\_4331\\_8c1c\\_9fb2c7f5f51b](http://emmc.info/emmo#EMMO_ba33e345_1293_4331_8c1c_9fb2c7f5f51b)

#### Relations:

- is\_a owl:ObjectProperty
- is\_a owl:TransitiveProperty
- is\_a [is\\_enclosed\\_by](#)
- inverse\_of [has\\_subdimensional\\_space](#)

### is\_space\_slice\_of

IRI: [http://emmc.info/emmo#EMMO\\_16176737\\_0379\\_4a26\\_957a\\_c298abe76d21](http://emmc.info/emmo#EMMO_16176737_0379_4a26_957a_c298abe76d21)

#### Relations:

- is\_a owl:ObjectProperty
- is\_a [is\\_subdimensional\\_space\\_of](#)
- inverse\_of [has\\_space\\_slice](#)

### is\_projection\_of

IRI: [http://emmc.info/emmo#EMMO\\_3713d0eb\\_773f\\_4543\\_8ebc\\_123dfd0e472a](http://emmc.info/emmo#EMMO_3713d0eb_773f_4543_8ebc_123dfd0e472a)

#### Relations:

- is\_a [is\\_subdimensional\\_space\\_of](#)
- inverse\_of [has\\_projection](#)

### is\_time\_slice\_of

IRI: [http://emmc.info/emmo#EMMO\\_d76118fd\\_0c1d\\_42d8\\_96ec\\_6dea2d76050d](http://emmc.info/emmo#EMMO_d76118fd_0c1d_42d8_96ec_6dea2d76050d)

#### Relations:

- is\_a owl:ObjectProperty
- is\_a [is\\_subdimensional\\_space\\_of](#)
- inverse\_of [has\\_time\\_slice](#)

### is\_abstract\_part\_of

IRI: [http://emmc.info/emmo#EMMO\\_5ce48a24\\_39c4\\_49fe\\_93ba\\_61143a5b73ac](http://emmc.info/emmo#EMMO_5ce48a24_39c4_49fe_93ba_61143a5b73ac)

#### Relations:

- is\_a owl:ObjectProperty
- is\_a owl:TransitiveProperty
- is\_a [passive\\_relation](#)
- inverse\_of [has\\_abstract\\_part](#)

## is\_representation\_for

IRI: [http://emmc.info/emmo#EMMO\\_72a3342f\\_ba51\\_49b6\\_bf5b\\_4eb948e2a172](http://emmc.info/emmo#EMMO_72a3342f_ba51_49b6_bf5b_4eb948e2a172)

Relations:

- is\_a [passive\\_relation](#)
- inverse\_of [has\\_representation](#)

## is\_property\_for

IRI: [http://emmc.info/emmo#EMMO\\_8c0ee0ee\\_d4ed\\_4e99\\_a2f3\\_24891614b3bf](http://emmc.info/emmo#EMMO_8c0ee0ee_d4ed_4e99_a2f3_24891614b3bf)

Relations:

- is\_a [passive\\_relation](#)
- inverse\_of [has\\_property](#)

## is\_abstraction\_of

IRI: [http://emmc.info/emmo#EMMO\\_989463a3\\_9181\\_473c\\_85a8\\_d119ad436d96](http://emmc.info/emmo#EMMO_989463a3_9181_473c_85a8_d119ad436d96)

Relations:

- is\_a [passive\\_relation](#)
- inverse\_of [has\\_abstraction](#)

## is\_member\_of

IRI: [http://emmc.info/emmo#EMMO\\_e55ff268\\_c351\\_4caf\\_8a8a\\_2899e50e2a46](http://emmc.info/emmo#EMMO_e55ff268_c351_4caf_8a8a_2899e50e2a46)

Relations:

- is\_a owl:IrreflexiveProperty
- is\_a [passive\\_relation](#)
- inverse\_of [has\\_member](#)

## has\_part branch

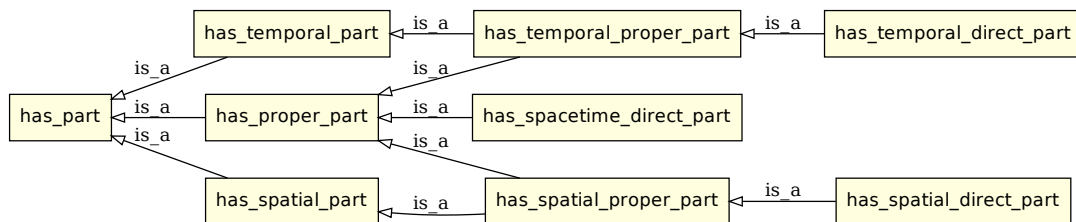


Figure 2.2: The has\_part branch.

## has\_part

IRI: [http://emmc.info/emmo#EMMO\\_17e27c22\\_37e1\\_468c\\_9dd7\\_95e137f73e7f](http://emmc.info/emmo#EMMO_17e27c22_37e1_468c_9dd7_95e137f73e7f)

### Relations:

- is\_a [encloses](#)
- inverse\_of [is\\_part\\_of](#)

## has\_spatial\_part

IRI: [http://emmc.info/emmo#EMMO\\_42eef0b0\\_cc64\\_4380\\_b912\\_8cc37e87506c](http://emmc.info/emmo#EMMO_42eef0b0_cc64_4380_b912_8cc37e87506c)

### Relations:

- is\_a [has\\_part](#)
- inverse\_of [is\\_spatial\\_part\\_of](#)

## has\_spatial\_proper\_part

IRI: [http://emmc.info/emmo#EMMO\\_05b6fce2\\_322b\\_49b4\\_84aa\\_ab3c544cf1a1](http://emmc.info/emmo#EMMO_05b6fce2_322b_49b4_84aa_ab3c544cf1a1)

### Relations:

- is\_a owl:ObjectProperty
- is\_a owl:TransitiveProperty
- is\_a [has\\_spatial\\_part](#)
- is\_a [has\\_proper\\_part](#)
- inverse\_of [is\\_spatial\\_proper\\_part](#)

## has\_spatial\_direct\_part

IRI: [http://emmc.info/emmo#EMMO\\_b2282816\\_b7a3\\_44c6\\_b2cb\\_3feff1ceb7fe](http://emmc.info/emmo#EMMO_b2282816_b7a3_44c6_b2cb_3feff1ceb7fe)

### Relations:

- is\_a owl:ObjectProperty
- is\_a owl:InverseFunctionalProperty
- is\_a owl:AsymmetricProperty
- is\_a owl:IrreflexiveProperty
- is\_a [has\\_spatial\\_proper\\_part](#)
- inverse\_of [is\\_spatial\\_direct\\_part\\_of](#)

## has\_temporal\_part

IRI: [http://emmc.info/emmo#EMMO\\_7afbed84\\_7593\\_4a23\\_bd88\\_9d9c6b04e8f6](http://emmc.info/emmo#EMMO_7afbed84_7593_4a23_bd88_9d9c6b04e8f6)

### Relations:

- is\_a [has\\_part](#)
- inverse\_of [is\\_temporal\\_part\\_of](#)

## has\_temporal\_proper\_part

IRI: [http://emmc.info/emmo#EMMO\\_90993ca7\\_7668\\_4225\\_92c9\\_3f1a20f346f2](http://emmc.info/emmo#EMMO_90993ca7_7668_4225_92c9_3f1a20f346f2)

### Relations:



- is\_a [has\\_temporal\\_part](#)
- is\_a [has\\_proper\\_part](#)
- inverse\_of [is\\_temporal\\_proper\\_part\\_of](#)

## has\_temporal\_direct\_part

IRI: [http://emmc.info/emmo#EMMO\\_65a2c5b8\\_e4d8\\_4a51\\_b2f8\\_e55effc0547d](http://emmc.info/emmo#EMMO_65a2c5b8_e4d8_4a51_b2f8_e55effc0547d)

### Relations:

- is\_a owl:ObjectProperty
- is\_a owl:InverseFunctionalProperty
- is\_a owl:AsymmetricProperty
- is\_a owl:IrreflexiveProperty
- is\_a [has\\_temporal\\_proper\\_part](#)
- inverse\_of [is\\_temporal\\_direct\\_part\\_of](#)

## has\_proper\_part

IRI: [http://emmc.info/emmo#EMMO\\_9380ab64\\_0363\\_4804\\_b13f\\_3a8a94119a76](http://emmc.info/emmo#EMMO_9380ab64_0363_4804_b13f_3a8a94119a76)

### Relations:

- is\_a owl:ObjectProperty
- is\_a owl:TransitiveProperty
- is\_a [has\\_part](#)
- inverse\_of [is\\_proper\\_part\\_of](#)

## has\_spatial\_proper\_part

IRI: [http://emmc.info/emmo#EMMO\\_05b6fce2\\_322b\\_49b4\\_84aa\\_ab3c544cf1a1](http://emmc.info/emmo#EMMO_05b6fce2_322b_49b4_84aa_ab3c544cf1a1)

### Relations:

- is\_a owl:ObjectProperty
- is\_a owl:TransitiveProperty
- is\_a [has\\_spatial\\_part](#)
- is\_a [has\\_proper\\_part](#)
- inverse\_of [is\\_spatial\\_proper\\_part](#)

## has\_spatial\_direct\_part

IRI: [http://emmc.info/emmo#EMMO\\_b2282816\\_b7a3\\_44c6\\_b2cb\\_3feff1ceb7fe](http://emmc.info/emmo#EMMO_b2282816_b7a3_44c6_b2cb_3feff1ceb7fe)

### Relations:

- is\_a owl:ObjectProperty
- is\_a owl:InverseFunctionalProperty
- is\_a owl:AsymmetricProperty
- is\_a owl:IrreflexiveProperty
- is\_a [has\\_spatial\\_proper\\_part](#)
- inverse\_of [is\\_spatial\\_direct\\_part\\_of](#)

## has\_temporal\_proper\_part

IRI: [http://emmc.info/emmo#EMMO\\_90993ca7\\_7668\\_4225\\_92c9\\_3f1a20f346f2](http://emmc.info/emmo#EMMO_90993ca7_7668_4225_92c9_3f1a20f346f2)

Relations:

- is\_a has\_temporal\_part
- is\_a has\_proper\_part
- inverse\_of is\_temporal\_proper\_part\_of

## has\_temporal\_direct\_part

IRI: [http://emmc.info/emmo#EMMO\\_65a2c5b8\\_e4d8\\_4a51\\_b2f8\\_e55effc0547d](http://emmc.info/emmo#EMMO_65a2c5b8_e4d8_4a51_b2f8_e55effc0547d)

Relations:

- is\_a owl:ObjectProperty
- is\_a owl:InverseFunctionalProperty
- is\_a owl:AsymmetricProperty
- is\_a owl:IrreflexiveProperty
- is\_a has\_temporal\_proper\_part
- inverse\_of is\_temporal\_direct\_part\_of

## has\_spacetime\_direct\_part

IRI: [http://emmc.info/emmo#EMMO\\_d0f7e48a\\_e435\\_4e55\\_bf0b\\_8579d2949214](http://emmc.info/emmo#EMMO_d0f7e48a_e435_4e55_bf0b_8579d2949214)

Relations:

- is\_a owl:InverseFunctionalProperty
- is\_a owl:AsymmetricProperty
- is\_a owl:IrreflexiveProperty
- is\_a has\_proper\_part
- inverse\_of is\_spacetime\_direct\_part\_of

## is\_part\_of branch

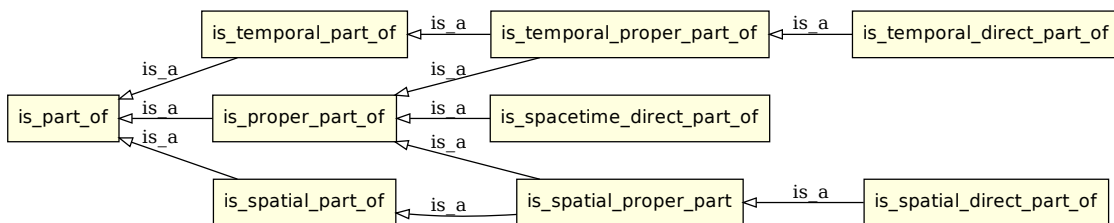


Figure 2.3: The is\_part\_of branch.

## is\_part\_of

Comment: P is the is\_part\_of relation.

Axioms: 1)  $P_{xx}$  (reflexivity) 2)  $(P_{xy} \ \&\& \ P_{yz}) \rightarrow P_{xz}$  (transitivity) 3)  $(P_{xy} \ \&\& \ P_{yz}) \rightarrow x=y$  (antisymmetry) 4)  $\text{not}(P_{yx}) \rightarrow \text{exists } z (P_{zy} \ \text{and} \ \text{not } O_{zx})$  (strong supplementation)

with:

$O_{zx} := \text{exists } z (P_{zx} \ \text{and} \ P_{zy})$  (overlap)

(Extensional Mereology)

IRI: [http://emmc.info/emmo#EMMO\\_85fc27bc\\_5e42\\_4baa\\_bf85\\_5a2dc4a26a1f](http://emmc.info/emmo#EMMO_85fc27bc_5e42_4baa_bf85_5a2dc4a26a1f)

**Relations:**

- is\_a owl:ObjectProperty
- is\_a owl:TransitiveProperty
- is\_a is\_enclosed\_by
- inverse\_of has\_part

### is\_proper\_part\_of

**Comment:** Definition:  $PP_{xy} := P_{xy} \ \&\& \ \text{not}(x=y)$

IRI: [http://emmc.info/emmo#EMMO\\_756d158a\\_cd64\\_44ba\\_b2e5\\_c3853ba2f3b2](http://emmc.info/emmo#EMMO_756d158a_cd64_44ba_b2e5_c3853ba2f3b2)

**Relations:**

- is\_a owl:ObjectProperty
- is\_a owl:TransitiveProperty
- is\_a is\_part\_of
- inverse\_of has\_proper\_part

### is\_temporal\_proper\_part\_of

IRI: [http://emmc.info/emmo#EMMO\\_548343f9\\_4257\\_47fe\\_aaab\\_488587ed41f0](http://emmc.info/emmo#EMMO_548343f9_4257_47fe_aaab_488587ed41f0)

**Relations:**

- is\_a owl:ObjectProperty
- is\_a owl:TransitiveProperty
- is\_a is\_proper\_part\_of
- is\_a is\_temporal\_part\_of
- inverse\_of has\_temporal\_proper\_part

### is\_temporal\_direct\_part\_of

IRI: [http://emmc.info/emmo#EMMO\\_0e2cb46a\\_107e\\_4c40\\_a4fd\\_4621dd77a7b8](http://emmc.info/emmo#EMMO_0e2cb46a_107e_4c40_a4fd_4621dd77a7b8)

**Relations:**

- is\_a owl:ObjectProperty
- is\_a owl:FunctionalProperty
- is\_a owl:AsymmetricProperty
- is\_a owl:IrreflexiveProperty
- is\_a is\_temporal\_proper\_part\_of
- inverse\_of has\_temporal\_direct\_part

## is\_spatial\_proper\_part

IRI: [http://emmc.info/emmo#EMMO\\_7bb33ab7\\_cc3e\\_418d\\_a57c\\_97651533c865](http://emmc.info/emmo#EMMO_7bb33ab7_cc3e_418d_a57c_97651533c865)

### Relations:

- is\_a owl:ObjectProperty
- is\_a owl:TransitiveProperty
- is\_a is\_proper\_part\_of
- is\_a is\_spatial\_part\_of
- inverse\_of has\_spatial\_proper\_part

## is\_spatial\_direct\_part\_of

IRI: [http://emmc.info/emmo#EMMO\\_0c4f91af\\_55e4\\_448b\\_9bd4\\_5dfe4007af05](http://emmc.info/emmo#EMMO_0c4f91af_55e4_448b_9bd4_5dfe4007af05)

### Relations:

- is\_a owl:FunctionalProperty
- is\_a owl:AsymmetricProperty
- is\_a owl:IrreflexiveProperty
- is\_a is\_spatial\_proper\_part
- inverse\_of has\_spatial\_direct\_part

## is\_spacetime\_direct\_part\_of

**Elucidation:**  $DP_{xy} :=$

y can be partitioned in a set of  $x_i$  proper parts that: - for all  $i, j$   $x_i$  and  $x_j$  do not overlap - the union of  $x_i$  covers the whole D - there exists no k proper part of y for which  $PP_{xk} - x$  is direct part of only y

IRI: [http://emmc.info/emmo#EMMO\\_ea69f6b1\\_95b2\\_4721\\_b24a\\_b1a1dfa643a6](http://emmc.info/emmo#EMMO_ea69f6b1_95b2_4721_b24a_b1a1dfa643a6)

### Relations:

- is\_a owl:FunctionalProperty
- is\_a owl:AsymmetricProperty
- is\_a owl:IrreflexiveProperty
- is\_a is\_proper\_part\_of
- inverse\_of has\_spacetime\_direct\_part

## is\_spatial\_part\_of

**Elucidation:** A partitioning that extends along the whole temporal dimension of a substrate.

IRI: [http://emmc.info/emmo#EMMO\\_bb7eac59\\_80cd\\_476f\\_8d66\\_c1a849056ef9](http://emmc.info/emmo#EMMO_bb7eac59_80cd_476f_8d66_c1a849056ef9)

### Relations:

- is\_a owl:ObjectProperty
- is\_a owl:TransitiveProperty
- is\_a is\_part\_of
- inverse\_of has\_spatial\_part

## is\_spatial\_proper\_part

IRI: [http://emmc.info/emmo#EMMO\\_7bb33ab7\\_cc3e\\_418d\\_a57c\\_97651533c865](http://emmc.info/emmo#EMMO_7bb33ab7_cc3e_418d_a57c_97651533c865)

### Relations:

- is\_a owl:ObjectProperty
- is\_a owl:TransitiveProperty
- is\_a is\_proper\_part\_of
- is\_a is\_spatial\_part\_of
- inverse\_of has\_spatial\_proper\_part

### is\_spatial\_direct\_part\_of

**IRI:** [http://emmc.info/emmo#EMMO\\_0c4f91af\\_55e4\\_448b\\_9bd4\\_5dfe4007af05](http://emmc.info/emmo#EMMO_0c4f91af_55e4_448b_9bd4_5dfe4007af05)

**Relations:**

- is\_a owl:FunctionalProperty
- is\_a owl:AsymmetricProperty
- is\_a owl:IrreflexiveProperty
- is\_a is\_spatial\_proper\_part
- inverse\_of has\_spatial\_direct\_part

### is\_temporal\_part\_of

**Elucidation:** A partitioning that extends along the whole spatial dimension of a substrate.

**Comment:** TP<sub>xy</sub> iff

- P<sub>xy</sub>
- for all z whose time projection is part of x time projection: P<sub>zy</sub> -> P<sub>zx</sub>

**IRI:** [http://emmc.info/emmo#EMMO\\_bc0907d3\\_f33f\\_40a4\\_a832\\_ec3e2acd00ef](http://emmc.info/emmo#EMMO_bc0907d3_f33f_40a4_a832_ec3e2acd00ef)

**Relations:**

- is\_a owl:ObjectProperty
- is\_a owl:TransitiveProperty
- is\_a is\_part\_of
- inverse\_of has\_temporal\_part

### is\_temporal\_proper\_part\_of

**IRI:** [http://emmc.info/emmo#EMMO\\_548343f9\\_4257\\_47fe\\_aaab\\_488587ed41f0](http://emmc.info/emmo#EMMO_548343f9_4257_47fe_aaab_488587ed41f0)

**Relations:**

- is\_a owl:ObjectProperty
- is\_a owl:TransitiveProperty
- is\_a is\_proper\_part\_of
- is\_a is\_temporal\_part\_of
- inverse\_of has\_temporal\_proper\_part

### is\_temporal\_direct\_part\_of

**IRI:** [http://emmc.info/emmo#EMMO\\_0e2cb46a\\_107e\\_4c40\\_a4fd\\_4621dd77a7b8](http://emmc.info/emmo#EMMO_0e2cb46a_107e_4c40_a4fd_4621dd77a7b8)

**Relations:**

- is\_a owl:ObjectProperty
- is\_a owl:FunctionalProperty
- is\_a owl:AsymmetricProperty
- is\_a owl:IrreflexiveProperty
- is\_a is\_temporal\_proper\_part\_of

- inverse\_of has\_temporal\_direct\_part

## Chapter 3

# Entities

*entity* is a class representing the collection of all the individuals (signs) that are used in the ontology. Individuals are declared by the EMMO users when they want to apply the EMMO to represent the world.

### entity branch

The root of all classes used to represent the world. It has two children; *set* and *item*.

*set* is the class representing the collection of all the individuals (signs) that represents a collection of items. It is the branch of *membership*.

- a set is declared using the *has\_member* primitive relation
- a set individual has no parts but only members
- a set is not of the same entity types as its members (e.g. the set of men is not a man)
- a set individual has a determinate number of members

*item* Is the class that collects all the individuals that are members of a set (it's the most comprehensive set individual). It is the branch of parthood (mereology).

- based on *has\_part* mereological relation that can be axiomatically defined
- a fusion is the sum of its parts (e.g. a car is made of several mechanical parts, an molecule is made of nuclei and electrons)
- a fusion is of the same entity type as its parts (e.g. a physical entity is made of physical entities parts)
- a fusion can be partitioned in more than one way

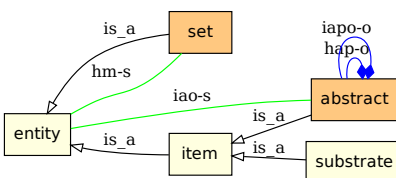


Figure 3.1: The entity branch.

### entity

**Elucidation:** The class representing the collection of all the individuals (signs) that are used in the ontology.

**Comment:** ‘entity’ is the disjoint union of ‘Item’ and ‘set’.

‘entity’ individuals can exist as ‘item’ individuals (for which mereology applies) or ‘set’ individuals (for which set theory applies).

**IRI:** [http://emmc.info/emmo#EMMO\\_802d3e92\\_8770\\_4f98\\_a289\\_ccaaab7fdddf](http://emmc.info/emmo#EMMO_802d3e92_8770_4f98_a289_ccaaab7fdddf)

**Relations:**

- is\_a owl:Thing

## set

**Comment:** How to decide if an individual must be declared as ‘set’ or ‘item’ individual?

A ‘set’ is a collection of other individuals using the membership relation (e.g. the ‘set’ of red objects).

An ‘item’ is a whole made of parts that constitute a whole (e.g. a car made of components).

Some world objects can have two representations, as ‘item’ or ‘set’.

For example, the user can define the molecules contained in a closed bottle as a ‘set’ of individual things. But, if he is interested in the temperature or pressure of this molecule collection, then he needs to represent them as a whole: a gas, for which each molecule is a part, since temperature and pressure are properties of a whole.

**Comment:** We can consider the ‘set’ branch as the meta-ontology branch, since it contains ‘item’ and all its subclasses.

It means that the usefulness of the ‘set’ class is to declare collection of things that the EMMO designer did not consider to be general or significant enough to be part of the ‘item’ branch.

e.g. the set of users of a particular software, the set of atoms that have been part of that just dissociated molecule.

**Comment:** A ‘set’ individual cannot be member of a ‘set’ (to avoid Russell’s paradox).

**IRI:** [http://emmc.info/emmo#EMMO\\_2d2ecd97\\_067f\\_4d0e\\_950c\\_d746b7700a31](http://emmc.info/emmo#EMMO_2d2ecd97_067f_4d0e_950c_d746b7700a31)

**Relations:**

- is\_a **entity**
- equivalent\_to has\_member some **entity**

## item

**Comment:** ‘item’ individuals are subjected to mereological relations (parthood).

They are whole made of sub-parts, or parts of some whole.

Parthood relations occurs only between ‘item’ individuals (wholes and parts) that have a common superclass type.

‘item’ is the highest superclass for all wholes and parts.

**Comment:** The ‘item’ class and all its sub-classes are ‘set’ individuals.

The ‘item’ branch will be used to represent the world things and can be seen in practice as the ontology core.

**IRI:** [http://emmc.info/emmo#EMMO\\_eb3a768e\\_d53e\\_4be9\\_a23b\\_0714833c36de](http://emmc.info/emmo#EMMO_eb3a768e_d53e_4be9_a23b_0714833c36de)

**Relations:**

- is\_a **entity**



## substrate branch

It represents the place (in general sense) in which every real world item exists.

A substrate provides the dimensions of existence for real world entities. It follows the fact that everything that exists is placed somewhere and space and time coordinates can be used to identify it.

Substrate is a mereotopological entity.

Substrates are always topologically connected spaces (a topological space  $X$  is said to be disconnected if it is the union of two disjoint nonempty open sets. Otherwise,  $X$  is said to be connected)

It is the disjoint union of *spacetime* (4D), *space* (3D), *surface* (2D) and *time* (1D).

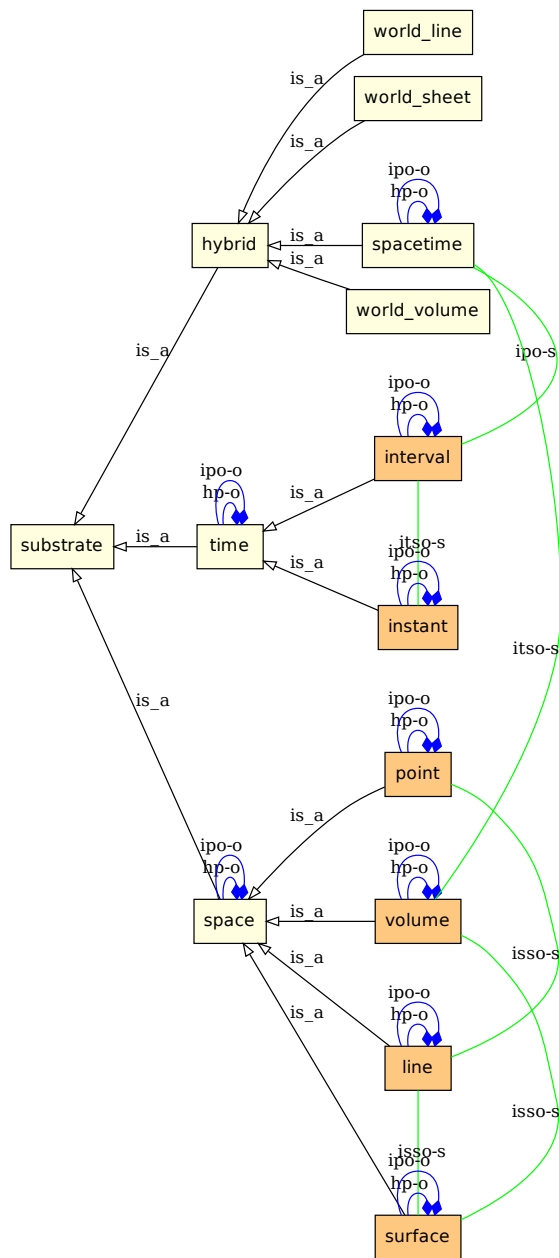


Figure 3.2: The substrate branch.

## substrate

**Elucidation:** The plane of existence upon which reality exists.

**Comment:** A substrate exists a priori, without need to be a place for a physical (e.g. Minkowsky metric is spacetime without matter-energy).

However, quantum field theories state that there always be matter-energy even in void at Planck scales. We do not consider this, since we place ourselves on a higher time/space scale, far above Planck scales.

**Comment:** A substrate is a topological entity, so that the primitive property of enclosure can be defined for it.

Substrates are always topologically connected spaces (a topological space  $X$  is said to be disconnected if it is the union of two disjoint nonempty open sets. Otherwise,  $X$  is said to be connected)

**Comment:** Being  $Cxy$  a primitive connection relation between two entities, the mereotopological description of substrates is done by the following axioms,;

- 1)  $Cxx$  (reflexive)
- 2)  $Cxy \rightarrow Cyx$  (symmetric)
- 3)  $Pxy \rightarrow Exy$  (x part of y implies that y encloses x)

$E$  enclosure relation) is defined as:

$Exy$  iff  $(Czx \rightarrow Czy)$

$E$  is reflexive, transitive and antisymmetric.

**Comment:** Parthood relations does not change dimensionality of a 'substrate' individual (e.g. a 4D individual has only 4D parts, a spacetime has no space parts).

Changes in dimensionality come from pure topological relations between subspaces (i.e. slicing).

**Comment:** This restriction in the mereological relations is done in order to overcome a typical misuse of the partitioning procedure, that occurs when the user wants to stretch the `is_part_of` relation beyond its applicability limit.

e.g. you can slice a 3D+1D cake in 3D+1D thin parts (3 spatial + 1 temporal dimension), but it's impossible to slice the cake in infinitely thin 2D+1D slices (2 spatial + 1 temporal dimension). The relation of parthood applied to material entities cannot reduce spatial dimensions for a material object, since a 2D+1D material object does not exist!

Slicing a 3D+1D entity in a 2D+1D entity can still be done, but within the substrate level (the topological level) using the `is_slice_of` relation working on geometrical concepts and not actual materials.

**Comment:** A 'substrate' individual represents a place (in general sense) in which real world item exists.

A 'substrate' individual provides the dimensions of existence for real world entities. It follows the fact that everything that exists is placed somewhere and space and time coordinates can be used to identify it.

**Comment:** Substrate is the disjoint union of spacetime (4D), space (3D), surface (2D) and time (1D).

**IRI:** [http://emmc.info/emmo#EMMO\\_f67528f5\\_7e45\\_405b\\_84e4\\_8a3b48aea914](http://emmc.info/emmo#EMMO_f67528f5_7e45_405b_84e4_8a3b48aea914)

**Relations:**

- `is_a item`

## time

**IRI:** [http://emmc.info/emmo#EMMO\\_bdc95950\\_1798\\_4619\\_b1f5\\_19e3155411e4](http://emmc.info/emmo#EMMO_bdc95950_1798_4619_b1f5_19e3155411e4)

**Relations:**

- `is_a substrate`
- `has_part only time`
- `is_part_of only time`

## interval

IRI: [http://emmc.info/emmo#EMMO\\_ac8e5770\\_cb05\\_4d82\\_ac83\\_93de968cdd8e](http://emmc.info/emmo#EMMO_ac8e5770_cb05_4d82_ac83_93de968cdd8e)

### Relations:

- is\_a time
- has\_part only interval
- is\_part\_of only interval
- equivalent\_to is\_projection\_of some spacetime

## instant

IRI: [http://emmc.info/emmo#EMMO\\_eeb837b9\\_3995\\_4805\\_8662\\_5c2a59aeb494](http://emmc.info/emmo#EMMO_eeb837b9_3995_4805_8662_5c2a59aeb494)

### Relations:

- is\_a time
- has\_part only instant
- is\_part\_of only instant
- equivalent\_to is\_time\_slice\_of some interval

## space

IRI: [http://emmc.info/emmo#EMMO\\_1ca51de7\\_6aa5\\_45d3\\_94ae\\_1df14d9aad5e](http://emmc.info/emmo#EMMO_1ca51de7_6aa5_45d3_94ae_1df14d9aad5e)

### Relations:

- is\_a substrate
- has\_part only space
- is\_part\_of only space

## line

IRI: [http://emmc.info/emmo#EMMO\\_13399199\\_cb46\\_4641\\_a951\\_cf032d5996ae](http://emmc.info/emmo#EMMO_13399199_cb46_4641_a951_cf032d5996ae)

### Relations:

- is\_a space
- has\_part only line
- is\_part\_of only line
- equivalent\_to is\_space\_slice\_of some surface

## volume

IRI: [http://emmc.info/emmo#EMMO\\_7152d8e4\\_7c94\\_4a67\\_87b9\\_6de9c021e1b5](http://emmc.info/emmo#EMMO_7152d8e4_7c94_4a67_87b9_6de9c021e1b5)

### Relations:

- is\_a space
- has\_part only volume
- is\_part\_of only volume
- equivalent\_to is\_time\_slice\_of some spacetime

## point

IRI: [http://emmc.info/emmo#EMMO\\_6a572193\\_effc\\_43a1\\_ab52\\_b2cec846b37e](http://emmc.info/emmo#EMMO_6a572193_effc_43a1_ab52_b2cec846b37e)

### Relations:

- is\_a space
- has\_part only point
- is\_part\_of only point
- equivalent\_to is\_space\_slice\_of some line

## surface

IRI: [http://emmc.info/emmo#EMMO\\_54dc7f83\\_6c93\\_4bec\\_a0ff\\_3ea96f6ce16a](http://emmc.info/emmo#EMMO_54dc7f83_6c93_4bec_a0ff_3ea96f6ce16a)

### Relations:

- is\_a space
- has\_part only surface
- is\_part\_of only surface
- equivalent\_to is\_space\_slice\_of some volume

## hybrid

IRI: [http://emmc.info/emmo#EMMO\\_718157a4\\_4580\\_4c59\\_815b\\_74ad3fdffca8](http://emmc.info/emmo#EMMO_718157a4_4580_4c59_815b_74ad3fdffca8)

### Relations:

- is\_a substrate

## world\_volume

IRI: [http://emmc.info/emmo#EMMO\\_a984ae65\\_ea32\\_44aa\\_9fab\\_c8493fe6d3e0](http://emmc.info/emmo#EMMO_a984ae65_ea32_44aa_9fab_c8493fe6d3e0)

### Relations:

- is\_a hybrid

## world\_line

IRI: [http://emmc.info/emmo#EMMO\\_fee4fbb6\\_03a4\\_4e09\\_8af1\\_de772829963b](http://emmc.info/emmo#EMMO_fee4fbb6_03a4_4e09_8af1_de772829963b)

### Relations:

- is\_a hybrid

## world\_sheet

IRI: [http://emmc.info/emmo#EMMO\\_2efbd83b\\_97c7\\_412a\\_805e\\_9866aa572885](http://emmc.info/emmo#EMMO_2efbd83b_97c7_412a_805e_9866aa572885)

### Relations:

- is\_a hybrid

## spacetime branch

The space and time that the real world manifest itself in (the Universe).

It has several important subclasses:

- **physical**: is declared to be `EquivalentTo`: `field` or `matter`
- **matter**: a subclass of `spacetime` that expresses some mass property
- **field**: a subclass of `spacetime` that can be perceived by the ontologist, but expresses no mass property
- **vacuum**: is a field that has no *elementary* parts
- **void**: a vacuum that has no *field* parts

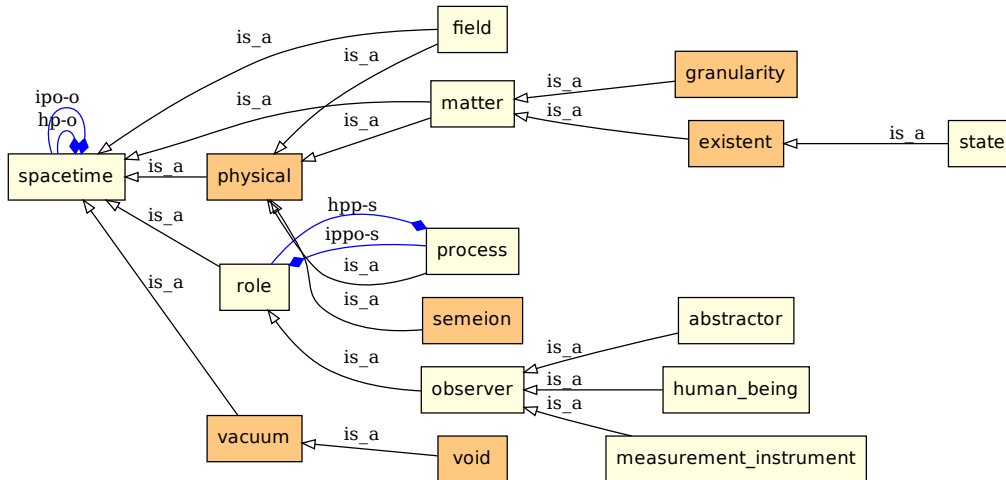


Figure 3.3: The spacetime branch.

## spacetime

**Comment:** The EMMO basic assumption is that the real world (the world outside us) manifests itself as a one spacetime entity, the Universe.

Some mereological parts (regions) of the Universe express peculiar properties that can be perceived by (they interact with) an interpreter/ontologist.

These mereological parts can be categorized in matter spacetimes or field spacetimes individuals.

‘physical’ class is the union of ‘field’ and ‘matter’ classes.

**IRI:** [http://emmc.info/emmo#EMMO\\_d82fd6c6\\_aebe\\_440f\\_9dd2\\_24a4eb3a417b](http://emmc.info/emmo#EMMO_d82fd6c6_aebe_440f_9dd2_24a4eb3a417b)

### Relations:

- `is_a` hybrid
- `has_part` only spacetime
- `is_part_of` only spacetime

## field

**Elucidation:** A distribution of energy in a spacetime in the form of e.g. gravitational wave, electromagnetic field...

**Comment:** A field can overlap other physicals.

**Comment:** A field is a continuum entity, without voids between its parts.

**IRI:** [http://emmc.info/emmo#EMMO\\_0d94fe70\\_010f\\_48e5\\_b3bf\\_c93593e20c54](http://emmc.info/emmo#EMMO_0d94fe70_010f_48e5_b3bf_c93593e20c54)

**Relations:**

- is\_a physical
- is\_a spacetime
- has\_part only field
- is\_part\_of only field

## matter

**Elucidation:** A spacetime that manifests the properties of matter (has mass).

**Comment:** A spacetime that is made of elementary entities.

(Atomic Mereology)

**Comment:** Matter includes also voids between sub granular entities.

e.g. the space between electrons and nucleus in an atom.

**Comment:** There are no particular criteria for matter instances structure, except that is made of some elementaries as fundamental parts and not only vacuum.

e.g. a spacetime that has spatial parts an atom and a cubic light year of vacuum exxtending for some time can be a matter instance.

**Comment:** While a field can have only field parts, a matter can have parts coming from all spacetime subclasses.

This is done in order to cover spatial gaps between granularity levels using the class vacuum.

This enables merging mereology and topology in a mereotopological description of matter.

e.g. An electron is a finite volume mass. The same holds for a nucleus. An atom is declared having a volume that is not only the sum of nucleus and electron volumes, but it's done according to interatomic potential criteria or wave function from Schroedinger equation. The space needed to fill the gap between parts and the whole is a direct part of the whole.

**Comment:** Matter is always 4D! There is no 3D representation of matter.

There can be a 3D slice of a matter but is no more matter: it's simply a 3D spatial region.

**IRI:** [http://emmc.info/emmo#EMMO\\_3769c91c\\_b851\\_44c5\\_8fca\\_50751dd81d0a](http://emmc.info/emmo#EMMO_3769c91c_b851_44c5_8fca_50751dd81d0a)

**Relations:**

- is\_a physical
- is\_a spacetime
- is\_a elementary or (has\_proper\_part some elementary)
- is\_part\_of only matter

## existent

**Elucidation:** A superclass that contains in a taxonomy all matter that can be classified in some way by the material ontologist.

**Comment:** A matter and non-existent entity is something not classifiable by common terms or definitions, i.e. an heterogeneous heap of elementaries, appearing and disappearing in time.

(we cannot do examples, because we should use a name and implicitly use a definition!)

**Comment:** An existent can be a state.

**Comment:** Existent is the most important class to be used for representing real changing things.

This class is used to represent the whole life of a complex but structured state-changing matter entity  
e.g. a car, a supersaturated gas with nucleating nanoparticles, an atom that becomes ionized and then recombines with an electron.

**Comment:** ex-sistere (latin): to stay (to persist through time) outside others of the same type (to be distinct from the rest).

**IRI:** [http://emmc.info/emmo#EMMO\\_52211e5e\\_d767\\_4812\\_845e\\_eb6b402c476a](http://emmc.info/emmo#EMMO_52211e5e_d767_4812_845e_eb6b402c476a)

**Relations:**

- is\_a **matter**
- equivalent\_to **state** or (has\_temporal\_direct\_part some **state**)

## role

**Comment:** Participants of a process are always parts of that particular process (i.e. they are spacetime). It means that is\_participant relation is subclass of is\_part\_of relation (e.g. you cannot participate to a party if you are not enclosed by the party room)

**IRI:** [http://emmc.info/emmo#EMMO\\_da6411c8\\_8551\\_487c\\_94ee\\_582ba2b8b748](http://emmc.info/emmo#EMMO_da6411c8_8551_487c_94ee_582ba2b8b748)

**Relations:**

- is\_a **spacetime**
- is\_proper\_part\_of some **process**

## observer

**IRI:** [http://emmc.info/emmo#EMMO\\_a39a6ebd\\_a450\\_4435\\_be98\\_19677c6873da](http://emmc.info/emmo#EMMO_a39a6ebd_a450_4435_be98_19677c6873da)

**Relations:**

- is\_a **role**

## abstractor

**IRI:** [http://emmc.info/emmo#EMMO\\_47a6ab67\\_e56d\\_4e9e\\_bfdd\\_e4377bae3edd](http://emmc.info/emmo#EMMO_47a6ab67_e56d_4e9e_bfdd_e4377bae3edd)

**Relations:**

- is\_a **observer**

## human\_being

**IRI:** [http://emmc.info/emmo#EMMO\\_4a47a644\\_330f\\_4346\\_bd7b\\_c007a233ef3e](http://emmc.info/emmo#EMMO_4a47a644_330f_4346_bd7b_c007a233ef3e)

**Relations:**

- is\_a **observer**

## measurement\_instrument

**IRI:** [http://emmc.info/emmo#EMMO\\_a60dff7b\\_7a27\\_4925\\_9c44\\_2d094cee14c0](http://emmc.info/emmo#EMMO_a60dff7b_7a27_4925_9c44_2d094cee14c0)

**Relations:**

- is\_a **observer**

## physical

**Elucidation:** The 4D domain upon which matter or field (e.g. electromagnetic, gravitational) exists.

**Comment:** A physical can be a field or matter or both (they are not disjoint).

A field is infinite divisible in terms of parthood. Matter however is granular up to the elementary level (atom, in mereological lexycon).

**Comment:** We perceive things only in space and time (3D + 1D), so the only place for physical entities is spacetime. There is no possible perception of a 3D thing, since perception is a process (unfolds in time).

**IRI:** [http://emmc.info/emmo#EMMO\\_c5ddfdbba\\_c074\\_4aa4\\_ad6b\\_1ac4942d300d](http://emmc.info/emmo#EMMO_c5ddfdbba_c074_4aa4_ad6b_1ac4942d300d)

**Relations:**

- is\_a **spacetime**
- equivalent\_to **field** or **matter**

## semeion

**Elucidation:** A physical that stays for:

- another specific physical through abstraction and representation processes involving only that specific physical (i.e. train miniature)
- an abstract that is not referred to a particular physical but is an abstraction based on other physicals (i.e. a fictional character, the design of a prototype, the plan of my future house)

**Comment:** “Semeion” means sign, and is a fundamental concept in semiotics.

**Comment:** The semeion is a way to reduce the complexity of a physical to a simple sign (“semeion” in greek).

**IRI:** [http://emmc.info/emmo#EMMO\\_b21a56ed\\_f969\\_4612\\_a6ec\\_cb7766f7f31d](http://emmc.info/emmo#EMMO_b21a56ed_f969_4612_a6ec_cb7766f7f31d)

**Relations:**

- is\_a **physical**
- equivalent\_to **is\_representation\_for** some **abstract**

## matter

**Elucidation:** A spacetime that manifests the properties of matter (has mass).

**Comment:** A spacetime that is made of elementary entities.

(Atomic Mereology)

**Comment:** Matter includes also voids between sub granular entities.

e.g. the space between electrons and nucleus in an atom.

**Comment:** There are no particular criteria for matter instances structure, except that is made of some elementaries as fundamental parts and not only vacuum.

e.g. a spacetime that has spatial parts an atom and a cubic light year of vacuum exxtending for some time can be a matter instance.

**Comment:** While a field can have only field parts, a matter can have parts coming from all spacetime subclasses.

This is done in order to cover spatial gaps between granularity levels using the class vacuum.

This enables merging mereology and topology in a mereotopological description of matter.

e.g. An electron is a finite volume mass. The same holds for a nucleus. An atom is declared having a volume that is not only the sum of nucleus and electron volumes, but it’s done according to interatomic potential criteria or wave



function from Schrodinger equation. The space needed to fill the gap between parts and the whole is a direct part of the whole.

**Comment:** Matter is always 4D! There is no 3D representation of matter.

There can be a 3D slice of a matter but is no more matter: it's simply a 3D spatial region.

**IRI:** [http://emmc.info/emmo#EMMO\\_3769c91c\\_b851\\_44c5\\_8fca\\_50751dd81d0a](http://emmc.info/emmo#EMMO_3769c91c_b851_44c5_8fca_50751dd81d0a)

**Relations:**

- is\_a **physical**
- is\_a **spacetime**
- is\_a **elementary** or (**has\_proper\_part** some **elementary**)
- is\_part\_of only **matter**

## existent

**Elucidation:** A superclass that contains in a taxonomy all matter that can be classified in some way by the material ontologist.

**Comment:** A matter and non-existent entity is something not classifiable by common terms or definitions, i.e. an heterogeneous heap of elementaries, appearing and disappearing in time.

(we cannot do examples, because we should use a name and implicitly use a definition!)

**Comment:** An existent can be a state.

**Comment:** Existent is the most important class to be used for representing real changing things.

This class is used to represent the whole life of a complex but structured state-changing matter entity

e.g. a car, a supersaturated gas with nucleating nanoparticles, an atom that becomes ionized and then recombines with an electron.

**Comment:** ex-sistere (latin): to stay (to persist through time) outside others of the same type (to be distinct from the rest).

**IRI:** [http://emmc.info/emmo#EMMO\\_52211e5e\\_d767\\_4812\\_845e\\_eb6b402c476a](http://emmc.info/emmo#EMMO_52211e5e_d767_4812_845e_eb6b402c476a)

**Relations:**

- is\_a **matter**
- equivalent\_to **state** or (**has\_temporal\_direct\_part** some **state**)

## field

**Elucidation:** A distribution of energy in a spacetime in the form of e.g. gravitational wave, electromagnetic field...

**Comment:** A field can overlap other physicals.

**Comment:** A field is a continuum entity, without voids between its parts.

**IRI:** [http://emmc.info/emmo#EMMO\\_0d94fe70\\_010f\\_48e5\\_b3bf\\_c93593e20c54](http://emmc.info/emmo#EMMO_0d94fe70_010f_48e5_b3bf_c93593e20c54)

**Relations:**

- is\_a **physical**
- is\_a **spacetime**
- has\_part only **field**
- is\_part\_of only **field**

## vacuum

**Elucidation:** A spacetime that has no elementary parts.

**IRI:** [http://emmc.info/emmo#EMMO\\_4d91b8d8\\_6df7\\_4b03\\_b648\\_cf7aef7284f0](http://emmc.info/emmo#EMMO_4d91b8d8_6df7_4b03_b648_cf7aef7284f0)

**Relations:**

- is\_a *spacetime*
- equivalent\_to *spacetime* and not (*has\_part* some *elementary*)

## void

**Elucidation:** A spacetime without matter or field.

**IRI:** [http://emmc.info/emmo#EMMO\\_29072ec4\\_ffcb\\_42fb\\_bdc7\\_26f05a2e9873](http://emmc.info/emmo#EMMO_29072ec4_ffcb_42fb_bdc7_26f05a2e9873)

**Relations:**

- is\_a *vacuum*
- equivalent\_to *vacuum* and not (*has\_proper\_part* some *field*)

## granularity branch

### granularity

**Elucidation:** A defined class which is the root of a taxonomy that categorizes states based on at least one object.

**Comment:** THE CLASSES UNDER GRANULARITY HAVE BEEN DEFINED ACCORDING TO THE MATERIAL ONTOLOGY PROVIDED UNDER THE OBJECT CLASS AS EXAMPLE!!!

**Comment:** The class containing all classes that define granularities of objects using direct parthood based definitions.

It's automatically populated based on the declarations of the primitive classes under object superclass.

**Comment:** “Granularity” stands for “matter with a particular granularity” .

Granularity is then defined as a superclass of defined subclasses that are defined as matter that is composed of specific types of objects (and vacuum) and whose partitions respect direct parthood criteria.

The granularity class (and its inherited classes) is useful since a reasoner can automatically puts the individuals defined by the user under a generic class that expresses clearly the types of its compositional parts.

Since most of physics based modelling tools are designed to describe systems made of a specific base-object (e.g. atoms, fluids, particles) the granularity classes can be directly linked to model types.

**IRI:** [http://emmc.info/emmo#EMMO\\_04955fb5\\_4912\\_4729\\_8a19\\_35276e380b43](http://emmc.info/emmo#EMMO_04955fb5_4912_4729_8a19_35276e380b43)

**Relations:**

- is\_a *matter*
- equivalent\_to *has\_spatial\_direct\_part* some *matter*

### atom\_based

**IRI:** [http://emmc.info/emmo-material#EMMO\\_5e6bc770\\_55ac\\_469a\\_84d7\\_8710d0d6ea51](http://emmc.info/emmo-material#EMMO_5e6bc770_55ac_469a_84d7_8710d0d6ea51)

**Relations:**

- is\_a *granularity*
- equivalent\_to *has\_spatial\_direct\_part* some *atom*

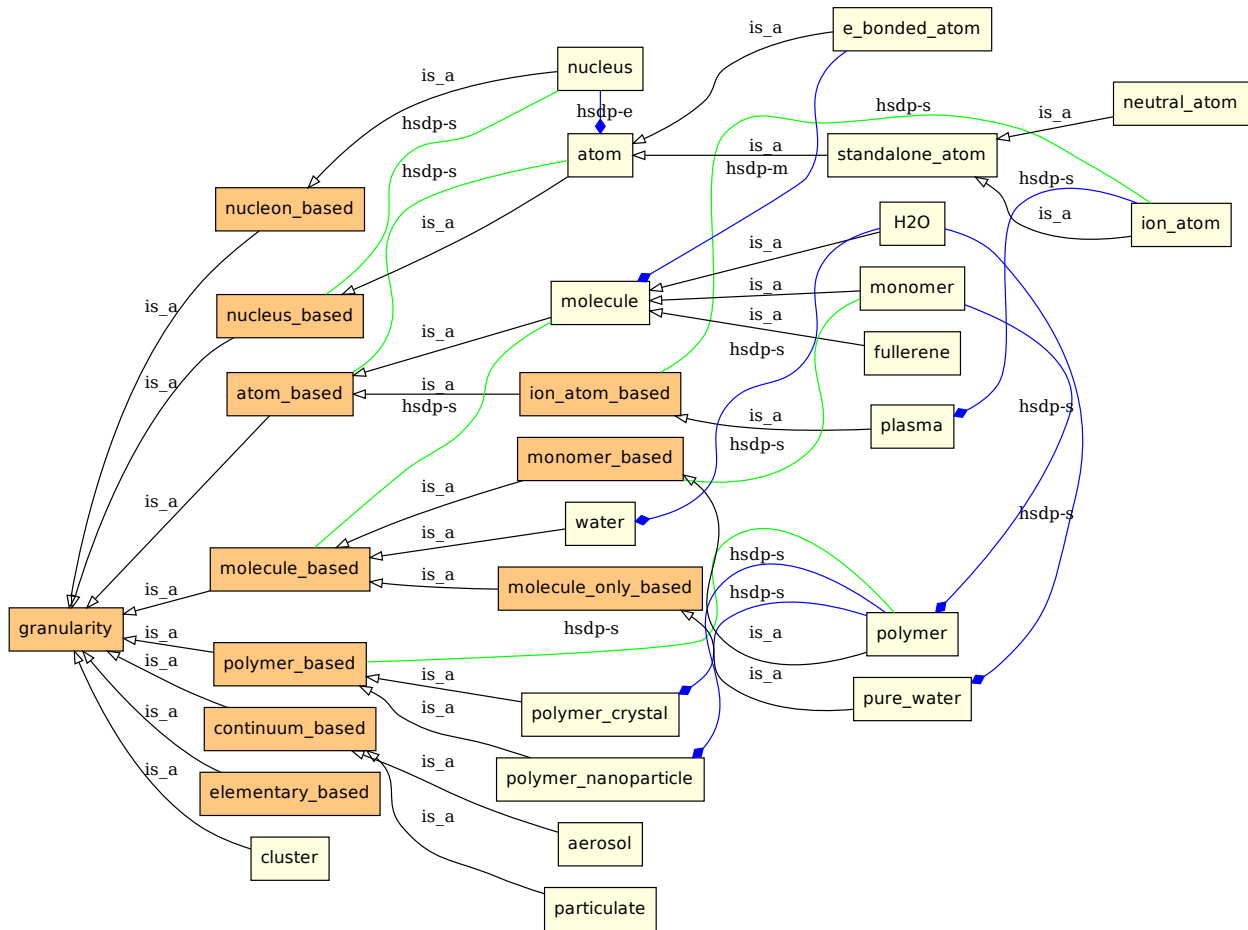


Figure 3.4: The granularity branch.

## ion\_atom\_based

IRI: [http://emmc.info/emmo-material#EMMO\\_23c0242f\\_d699\\_4e81\\_a07e\\_79738931ce57](http://emmc.info/emmo-material#EMMO_23c0242f_d699_4e81_a07e_79738931ce57)

### Relations:

- is\_a atom\_based
- equivalent\_to has\_spatial\_direct\_part some ion\_atom

## plasma

IRI: [http://emmc.info/emmo-material#EMMO\\_97d919ba\\_e7bc\\_4bed\\_8d17\\_55bad357dbb9](http://emmc.info/emmo-material#EMMO_97d919ba_e7bc_4bed_8d17_55bad357dbb9)

### Relations:

- is\_a fluid
- is\_a electron\_based
- is\_a ion\_atom\_based
- has\_spatial\_direct\_part some electron
- has\_spatial\_direct\_part some ion\_atom

## molecule

**Comment:** This definition states that this object is a non-periodic set of atoms or a set with a finite periodicity.

Removing an atom from the state will result in another type of atom\_based state.

e.g. you cannot remove H from H<sub>2</sub>O without changing the molecule type. However, you can remove a C from a nanotube. C<sub>60</sub> fullerene is a molecule, since it has a finite periodicity and is made of a well defined number of atoms. A C nanotube is not a molecule, since it has an infinite periodicity.

IRI: [http://emmc.info/emmo-material#EMMO\\_3397f270\\_dfc1\\_4500\\_8f6f\\_4d0d85ac5f71](http://emmc.info/emmo-material#EMMO_3397f270_dfc1_4500_8f6f_4d0d85ac5f71)

### Relations:

- is\_a mesoscopic
- is\_a electron\_based
- is\_a atom\_based
- has\_spatial\_direct\_part some electron
- has\_spatial\_direct\_part only (vacuum or electron or e\_bonded\_atom)
- has\_spatial\_direct\_part min e\_bonded\_atom

## monomer

IRI: [http://emmc.info/emmo-material#EMMO\\_076dda89\\_691f\\_4330\\_9a15\\_47cdc18ae388](http://emmc.info/emmo-material#EMMO_076dda89_691f_4330_9a15_47cdc18ae388)

### Relations:

- is\_a molecule

## H<sub>2</sub>O

IRI: [http://emmc.info/emmo-material#EMMO\\_7684509b\\_b4b3\\_425d\\_9a83\\_8042d89ca496](http://emmc.info/emmo-material#EMMO_7684509b_b4b3_425d_9a83_8042d89ca496)

### Relations:

- is\_a molecule

## fullerene

IRI: [http://emmc.info/emmo-material#EMMO\\_fc4acecf\\_b127\\_4a8d\\_a36d\\_b99cf9b4764c](http://emmc.info/emmo-material#EMMO_fc4acecf_b127_4a8d_a36d_b99cf9b4764c)

### Relations:

- is\_a [molecule](#)
- is\_a [nanoparticle](#)

## polymer\_based

IRI: [http://emmc.info/emmo-material#EMMO\\_77dc3bf8\\_f3b0\\_4ecb\\_9e4e\\_5ed236d8894a](http://emmc.info/emmo-material#EMMO_77dc3bf8_f3b0_4ecb_9e4e_5ed236d8894a)

### Relations:

- is\_a [granularity](#)
- equivalent\_to [has\\_spatial\\_direct\\_part](#) some [polymer](#)

## polymer\_nanoparticle

IRI: [http://emmc.info/emmo-material#EMMO\\_64334d8c\\_5a3d\\_4b6c\\_893f\\_99592a25b15e](http://emmc.info/emmo-material#EMMO_64334d8c_5a3d_4b6c_893f_99592a25b15e)

### Relations:

- is\_a [nanoparticle](#)
- is\_a [polymer\\_based](#)
- [has\\_spatial\\_direct\\_part](#) some [polymer](#)

## polymer\_crystal

IRI: [http://emmc.info/emmo-material#EMMO\\_aab61bb0\\_b232\\_42f3\\_bbf3\\_6bb1ac72ad71](http://emmc.info/emmo-material#EMMO_aab61bb0_b232_42f3_bbf3_6bb1ac72ad71)

### Relations:

- is\_a [crystal](#)
- is\_a [polymer\\_based](#)
- [has\\_spatial\\_direct\\_part](#) some [polymer](#)

## continuum\_based

IRI: [http://emmc.info/emmo-material#EMMO\\_995045d8\\_598e\\_4a5f\\_96a6\\_e1fba60d6a7a](http://emmc.info/emmo-material#EMMO_995045d8_598e_4a5f_96a6_e1fba60d6a7a)

### Relations:

- is\_a [granularity](#)
- equivalent\_to [has\\_spatial\\_direct\\_part](#) some [continuum](#)

## particulate

IRI: [http://emmc.info/emmo-material#EMMO\\_efe2b5e6\\_4524\\_4904\\_a60d\\_2931c790d8b0](http://emmc.info/emmo-material#EMMO_efe2b5e6_4524_4904_a60d_2931c790d8b0)

### Relations:

- is\_a [continuum\\_based](#)
- [has\\_spatial\\_direct\\_part](#) some [particle](#)

## aerosol

IRI: [http://emmc.info/emmo-material#EMMO\\_153ba20b\\_72b1\\_4b34\\_8b16\\_29ce5ecf5437](http://emmc.info/emmo-material#EMMO_153ba20b_72b1_4b34_8b16_29ce5ecf5437)

### Relations:

- is\_a suspension
- is\_a continuum\_based
- has\_spatial\_direct\_part some particle
- has\_spatial\_direct\_part some (molecule or atom)

## nucleon\_based

IRI: [http://emmc.info/emmo-material#EMMO\\_49d7e01f\\_59da\\_4391\\_82cd\\_bea33b856849](http://emmc.info/emmo-material#EMMO_49d7e01f_59da_4391_82cd_bea33b856849)

### Relations:

- is\_a granularity
- equivalent\_to has\_spatial\_direct\_part some nucleon

## nucleus

IRI: [http://emmc.info/emmo-material#EMMO\\_f835f4d4\\_c665\\_403d\\_ab25\\_dca5cc74be52](http://emmc.info/emmo-material#EMMO_f835f4d4_c665_403d_ab25_dca5cc74be52)

### Relations:

- is\_a subatomic
- is\_a nucleon\_based
- has\_spatial\_direct\_part some nucleon
- has\_spatial\_direct\_part only (vacuum or nucleon)
- has\_spatial\_direct\_part min proton

## nucleus\_based

IRI: [http://emmc.info/emmo-material#EMMO\\_8324a9a7\\_de25\\_4536\\_b7a4\\_30b5d2e1c8b7](http://emmc.info/emmo-material#EMMO_8324a9a7_de25_4536_b7a4_30b5d2e1c8b7)

### Relations:

- is\_a granularity
- equivalent\_to has\_spatial\_direct\_part some nucleus

## atom

IRI: [http://emmc.info/emmo-material#EMMO\\_eb77076b\\_a104\\_42ac\\_a065\\_798b2d2809ad](http://emmc.info/emmo-material#EMMO_eb77076b_a104_42ac_a065_798b2d2809ad)

### Relations:

- is\_a atomic
- is\_a nucleus\_based
- has\_spatial\_direct\_part only (vacuum or electron or nucleus)
- has\_spatial\_direct\_part exactly nucleus

## standalone\_atom

**Comment:** A standalone atom can be bonded with other atoms by intermolecular forces (i.e. dipole–dipole, London dispersion force, hydrogen bonding), since this bonds does not involve electron sharing.

IRI: [http://emmc.info/emmo-material#EMMO\\_2fd3f574\\_5e93\\_47fe\\_afca\\_ed80b0a21ab4](http://emmc.info/emmo-material#EMMO_2fd3f574_5e93_47fe_afca_ed80b0a21ab4)

## Relations:

- is\_a [electron\\_based](#)
- is\_a [atom](#)
- [has\\_spatial\\_direct\\_part](#) some [electron](#)

## neutral\_atom

IRI: [http://emmc.info/emmo-material#EMMO\\_4588526f\\_8553\\_4f4d\\_aa73\\_a483e88d599b](http://emmc.info/emmo-material#EMMO_4588526f_8553_4f4d_aa73_a483e88d599b)

## Relations:

- is\_a [standalone\\_atom](#)

## ion\_atom

**Comment:** The ion\_atom is the basic part of a pure ionic bonded compound i.e. without electron sharing,

IRI: [http://emmc.info/emmo-material#EMMO\\_db03061b\\_db31\\_4132\\_a47a\\_6a634846578b](http://emmc.info/emmo-material#EMMO_db03061b_db31_4132_a47a_6a634846578b)

## Relations:

- is\_a [standalone\\_atom](#)

## e\_bonded\_atom

**Comment:** A real bond between atoms is always something hybrid between covalent, metallic and ionic.

In general, metallic and ionic bonds have atoms sharing electrons.

**Comment:** The bond types that are covered by this definition are the strong electronic bonds: covalent, metallic and ionic.

IRI: [http://emmc.info/emmo-material#EMMO\\_8303a247\\_f9d9\\_4616\\_bdcf\\_f5cbd7b298e3](http://emmc.info/emmo-material#EMMO_8303a247_f9d9_4616_bdcf_f5cbd7b298e3)

## Relations:

- is\_a [atom](#)

## cluster

IRI: [http://emmc.info/emmo-material#EMMO\\_86e47a95\\_cc49\\_48f3\\_9f45\\_9ce2d114a819](http://emmc.info/emmo-material#EMMO_86e47a95_cc49_48f3_9f45_9ce2d114a819)

## Relations:

- is\_a [mesoscopic](#)
- is\_a [granularity](#)
- [has\\_spatial\\_direct\\_part](#) some ([molecule](#) or [atom](#))

## molecule\_based

IRI: [http://emmc.info/emmo-material#EMMO\\_4efc77eb\\_2d23\\_42a1\\_86c4\\_a94c93c2b052](http://emmc.info/emmo-material#EMMO_4efc77eb_2d23_42a1_86c4_a94c93c2b052)

## Relations:

- is\_a [granularity](#)
- [equivalent\\_to](#) [has\\_spatial\\_direct\\_part](#) some [molecule](#)

## molecule\_only\_based

IRI: [http://emmc.info/emmo-material#EMMO\\_7825135e\\_5e07\\_4bf3\\_9cfb\\_5b2e20cdcd20](http://emmc.info/emmo-material#EMMO_7825135e_5e07_4bf3_9cfb_5b2e20cdcd20)

### Relations:

- is\_a molecule\_based
- equivalent\_to (has\_spatial\_direct\_part some molecule) and (has\_spatial\_direct\_part only (vacuum or molecule))

## pure\_water

IRI: [http://emmc.info/emmo-material#EMMO\\_4307f559\\_d089\\_4393\\_9cd9\\_bee0efdab0f2](http://emmc.info/emmo-material#EMMO_4307f559_d089_4393_9cd9_bee0efdab0f2)

### Relations:

- is\_a liquid
- is\_a molecule\_only\_based
- has\_spatial\_direct\_part some H2O
- has\_spatial\_direct\_part only (vacuum or H2O)

## monomer\_based

IRI: [http://emmc.info/emmo-material#EMMO\\_cea2d620\\_987c\\_4f05\\_9d76\\_23ab91df0caa](http://emmc.info/emmo-material#EMMO_cea2d620_987c_4f05_9d76_23ab91df0caa)

### Relations:

- is\_a molecule\_based
- equivalent\_to has\_spatial\_direct\_part some monomer

## polymer

IRI: [http://emmc.info/emmo-material#EMMO\\_899521af\\_8847\\_4534\\_b726\\_c2cf3e49eee1](http://emmc.info/emmo-material#EMMO_899521af_8847_4534_b726_c2cf3e49eee1)

### Relations:

- is\_a mesoscopic
- is\_a monomer\_based
- has\_spatial\_direct\_part some monomer

## water

IRI: [http://emmc.info/emmo-material#EMMO\\_760461a5\\_4666\\_4d62\\_a180\\_c5042d7395f0](http://emmc.info/emmo-material#EMMO_760461a5_4666_4d62_a180_c5042d7395f0)

### Relations:

- is\_a liquid
- is\_a molecule\_based
- has\_spatial\_direct\_part some H2O

## elementary\_based branch

### elementary\_based

IRI: [http://emmc.info/emmo-material#EMMO\\_da8c23ce\\_9e39\\_4837\\_975a\\_cf652d73db47](http://emmc.info/emmo-material#EMMO_da8c23ce_9e39_4837_975a_cf652d73db47)

### Relations:



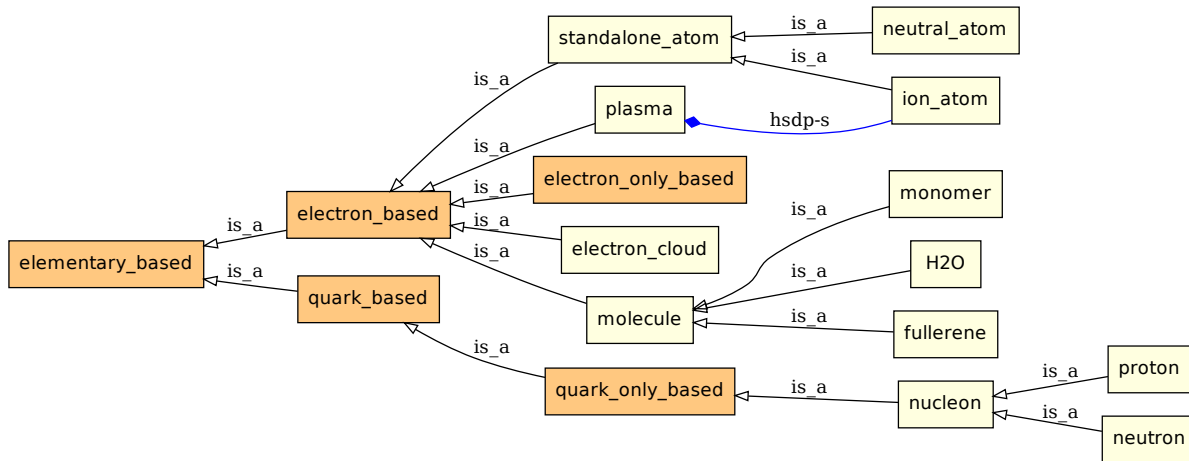


Figure 3.5: The elementary\_based branch.

- is\_a **granularity**
- equivalent\_to has\_spatial\_direct\_part some elementary

## electron\_based

IRI: [http://emmc.info/emmo-material#EMMO\\_9f54a0bf\\_3bfd\\_4303\\_b220\\_8d8b0503e6af](http://emmc.info/emmo-material#EMMO_9f54a0bf_3bfd_4303_b220_8d8b0503e6af)

### Relations:

- is\_a elementary\_based
- equivalent\_to has\_spatial\_direct\_part some electron

## standalone\_atom

**Comment:** A standalone atom can be bonded with other atoms by intermolecular forces (i.e. dipole–dipole, London dispersion force, hydrogen bonding), since this bonds does not involve electron sharing.

IRI: [http://emmc.info/emmo-material#EMMO\\_2fd3f574\\_5e93\\_47fe\\_afca\\_ed80b0a21ab4](http://emmc.info/emmo-material#EMMO_2fd3f574_5e93_47fe_afca_ed80b0a21ab4)

### Relations:

- is\_a electron\_based
- is\_a atom
- has\_spatial\_direct\_part some electron

## neutral\_atom

IRI: [http://emmc.info/emmo-material#EMMO\\_4588526f\\_8553\\_4f4d\\_aa73\\_a483e88d599b](http://emmc.info/emmo-material#EMMO_4588526f_8553_4f4d_aa73_a483e88d599b)

### Relations:

- is\_a standalone\_atom

## ion\_atom

**Comment:** The ion\_atom is the basic part of a pure ionic bonded compound i.e. without electron sharing,

**IRI:** [http://emmc.info/emmo-material#EMMO\\_db03061b\\_db31\\_4132\\_a47a\\_6a634846578b](http://emmc.info/emmo-material#EMMO_db03061b_db31_4132_a47a_6a634846578b)

**Relations:**

- is\_a standalone\_atom

## electron\_only\_based

**IRI:** [http://emmc.info/emmo-material#EMMO\\_55dc2a1f\\_e613\\_4d72\\_b458\\_e48b196565a6](http://emmc.info/emmo-material#EMMO_55dc2a1f_e613_4d72_b458_e48b196565a6)

**Relations:**

- is\_a electron\_based
- equivalent\_to (has\_spatial\_direct\_part some electron) and (has\_spatial\_direct\_part only (vacuum or electron))

## plasma

**IRI:** [http://emmc.info/emmo-material#EMMO\\_97d919ba\\_e7bc\\_4bed\\_8d17\\_55bad357dbb9](http://emmc.info/emmo-material#EMMO_97d919ba_e7bc_4bed_8d17_55bad357dbb9)

**Relations:**

- is\_a fluid
- is\_a electron\_based
- is\_a ion\_atom\_based
- has\_spatial\_direct\_part some electron
- has\_spatial\_direct\_part some ion\_atom

## electron\_cloud

**IRI:** [http://emmc.info/emmo-material#EMMO\\_1067b97a\\_84f8\\_4d22\\_8ace\\_b842b8ce355c](http://emmc.info/emmo-material#EMMO_1067b97a_84f8_4d22_8ace_b842b8ce355c)

**Relations:**

- is\_a subatomic
- is\_a electron\_based
- has\_spatial\_direct\_part some (vacuum and electron)

## molecule

**Comment:** This definition states that this object is a non-periodic set of atoms or a set with a finite periodicity.

Removing an atom from the state will result in another type of atom\_based state.

e.g. you cannot remove H from H<sub>2</sub>O without changing the molecule type. However, you can remove a C from a nanotube. C<sub>60</sub> fullerene is a molecule, since it has a finite periodicity and is made of a well defined number of atoms. A C nanotube is not a molecule, since it has an infinite periodicity.

**IRI:** [http://emmc.info/emmo-material#EMMO\\_3397f270\\_df1\\_4500\\_8f6f\\_4d0d85ac5f71](http://emmc.info/emmo-material#EMMO_3397f270_df1_4500_8f6f_4d0d85ac5f71)

**Relations:**

- is\_a mesoscopic
- is\_a electron\_based
- is\_a atom\_based
- has\_spatial\_direct\_part some electron

- `has_spatial_direct_part` only (vacuum or electron or `e_bonded_atom`)
- `has_spatial_direct_part` min `e_bonded_atom`

## monomer

IRI: [http://emmc.info/emmo-material#EMMO\\_076dda89\\_691f\\_4330\\_9a15\\_47cdc18ae388](http://emmc.info/emmo-material#EMMO_076dda89_691f_4330_9a15_47cdc18ae388)

### Relations:

- is\_a `molecule`

## H2O

IRI: [http://emmc.info/emmo-material#EMMO\\_7684509b\\_b4b3\\_425d\\_9a83\\_8042d89ca496](http://emmc.info/emmo-material#EMMO_7684509b_b4b3_425d_9a83_8042d89ca496)

### Relations:

- is\_a `molecule`

## fullerene

IRI: [http://emmc.info/emmo-material#EMMO\\_fc4acecf\\_b127\\_4a8d\\_a36d\\_b99cf9b4764c](http://emmc.info/emmo-material#EMMO_fc4acecf_b127_4a8d_a36d_b99cf9b4764c)

### Relations:

- is\_a `molecule`
- is\_a `nanoparticle`

## quark\_based

IRI: [http://emmc.info/emmo-material#EMMO\\_3d559699\\_c023\\_44ab\\_a1f8\\_c8d081f87c58](http://emmc.info/emmo-material#EMMO_3d559699_c023_44ab_a1f8_c8d081f87c58)

### Relations:

- is\_a `elementary_based`
- `equivalent_to` `has_spatial_direct_part` some `quark`

## quark\_only\_based

IRI: [http://emmc.info/emmo-material#EMMO\\_d2a955db\\_996e\\_4ac8\\_b373\\_01ec1084f972](http://emmc.info/emmo-material#EMMO_d2a955db_996e_4ac8_b373_01ec1084f972)

### Relations:

- is\_a `quark_based`
- `equivalent_to` (`has_spatial_direct_part` some `quark`) and (`has_spatial_direct_part` only (vacuum or `quark`))

## nucleon

IRI: [http://emmc.info/emmo-material#EMMO\\_50781fd9\\_a9e4\\_46ad\\_b7be\\_4500371d188d](http://emmc.info/emmo-material#EMMO_50781fd9_a9e4_46ad_b7be_4500371d188d)

### Relations:

- is\_a `subatomic`
- is\_a `quark_only_based`

## proton

IRI: [http://emmc.info/emmo-material#EMMO\\_8f87e700\\_99a8\\_4427\\_8ffb\\_e493de05c217](http://emmc.info/emmo-material#EMMO_8f87e700_99a8_4427_8ffb_e493de05c217)

### Relations:

- is\_a nucleon
- has\_spatial\_direct\_part some quark
- has\_spatial\_direct\_part only (vacuum or quark)

## neutron

IRI: [http://emmc.info/emmo-material#EMMO\\_df808271\\_df91\\_4f27\\_ba59\\_fa423c51896c](http://emmc.info/emmo-material#EMMO_df808271_df91_4f27_ba59_fa423c51896c)

### Relations:

- is\_a nucleon
- has\_spatial\_direct\_part some quark
- has\_spatial\_direct\_part only (vacuum or quark)

## state branch

### state

**Elucidation:** A matter whose direct parts are all matter or vacuum direct spatial parts.

(it follows from matter definition that it must have only matter as temporal parts)

**Comment:** A state is a finite thickness slice in time of a physical.

**Comment:** Direct partitioning is not unique. It depends on the choice of object types to be used as direct parts.

A state can always be direct partitioned in elementary objects and vacuum.

e.g. the water in my glass can be seen as a single object without declaring direct parts, or as made of H<sub>2</sub>O molecules direct parts.

**Comment:** The definition of states implies that its direct parts are not gained or lost during its temporal extension (they exist from the left to the right side of the time interval), so that the granularity of a state is well defined.

This does not mean that there cannot be a change in the parts of a state's direct part during its lifetime. It means only that this change must not affect the existence of the direct part itself.

e.g. the existent in my glass is declared at  $t = t_{\text{start}}$  as made of two direct parts: the ice and the water. It will continue to exist as state as long as the ice is completely melted at  $t = t_{\text{end}}$ . The new state will be completely made of water. Between  $t_{\text{start}}$  and  $t_{\text{end}}$  there is an exchange of molecules between the ice and the water, but this does not affect the existence of the two states.

If we partition the existent in my glass as ice surrounded by several molecules (we do not use the object water as direct part) then the appearance of a molecule coming from the ice will cause a state to end and another state to begin.

**Comment:** The usefulness of state is that it makes it possible to describe the evolution in time of an existent in terms of series of states that can take into account the disappearance or appearance of parts within an entity. A state is a recognizable granularity level of matter, in the sense that its direct parts do not appear or disappear within its lifetime as it can be for a generic existent.

**Comment:** "state" stands for "matter in a particular configurational state" and is defined as having spatial direct parts that persists (do not change) throughout the lifetime of the whole: the state.

There is no change in granularity or cardinality of parts within a state.

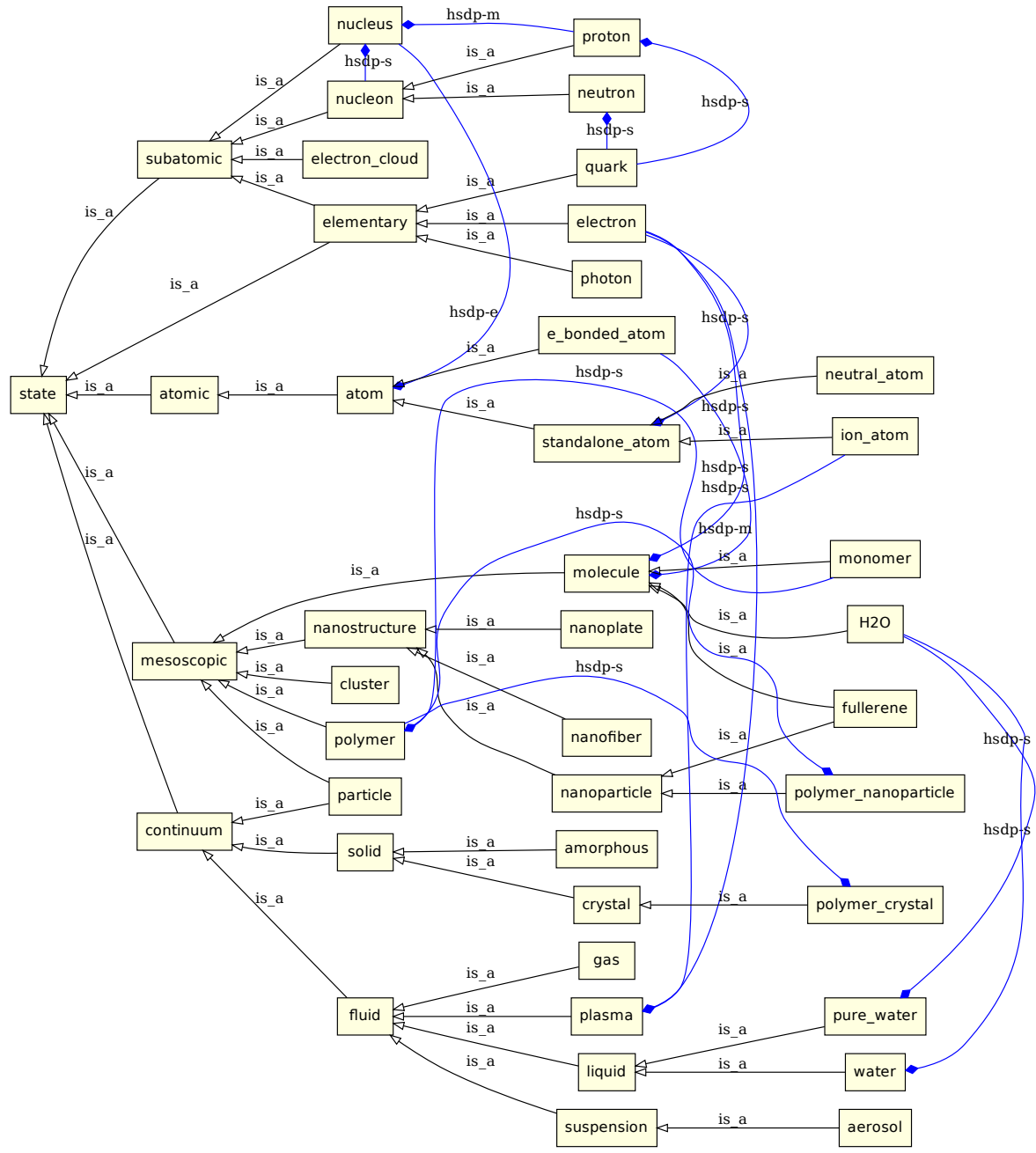


Figure 3.6: The state branch.

The use of spatial direct parthood in state definition means that a state cannot overlap in space another state  
A spatial direct part of a state can only be matter or vacuum.

**IRI:** [http://emmc.info/emmo#EMMO\\_36c79456\\_e29c\\_400d\\_8bd3\\_0eedddb82652](http://emmc.info/emmo#EMMO_36c79456_e29c_400d_8bd3_0eedddb82652)

**Relations:**

- is\_a **existent**
- is\_a **elementary** or (**has\_spatial\_direct\_part** some **matter**)

## elementary

**Elucidation:** The basic constituent of matter, that can be proper partitioned only in time.

**IRI:** [http://emmc.info/emmo#EMMO\\_0f795e3e\\_c602\\_4577\\_9a43\\_d5a231aa1360](http://emmc.info/emmo#EMMO_0f795e3e_c602_4577_9a43_d5a231aa1360)

**Relations:**

- is\_a **subatomic**
- is\_a **state**
- **has\_spatial\_proper\_part** only owl:Nothing

## photon

**IRI:** [http://emmc.info/emmo-material#EMMO\\_25f8b804\\_9a0b\\_4387\\_a3e7\\_b35bce5365ee](http://emmc.info/emmo-material#EMMO_25f8b804_9a0b_4387_a3e7_b35bce5365ee)

**Relations:**

- is\_a **elementary**

## quark

**IRI:** [http://emmc.info/emmo-material#EMMO\\_72d53756\\_7fb1\\_46ed\\_980f\\_83f47efbe105](http://emmc.info/emmo-material#EMMO_72d53756_7fb1_46ed_980f_83f47efbe105)

**Relations:**

- is\_a **elementary**

## electron

**IRI:** [http://emmc.info/emmo-material#EMMO\\_8043d3c6\\_a4c1\\_4089\\_ba34\\_9744e28e5b3d](http://emmc.info/emmo-material#EMMO_8043d3c6_a4c1_4089_ba34_9744e28e5b3d)

**Relations:**

- is\_a **elementary**

## mesoscopic

**IRI:** [http://emmc.info/emmo-material#EMMO\\_174cf221\\_9d16\\_427c\\_abea\\_e217a948969b](http://emmc.info/emmo-material#EMMO_174cf221_9d16_427c_abea_e217a948969b)

**Relations:**

- is\_a **state**

## molecule

**Comment:** This definition states that this object is a non-periodic set of atoms or a set with a finite periodicity.

Removing an atom from the state will result in another type of atom\_based state.

e.g. you cannot remove H from H<sub>2</sub>O without changing the molecule type. However, you can remove a C from a nanotube. C<sub>60</sub> fullerene is a molecule, since it has a finite periodicity and is made of a well defined number of atoms. A C nanotube is not a molecule, since it has an infinite periodicity.

**IRI:** [http://emmc.info/emmo-material#EMMO\\_3397f270\\_dfc1\\_4500\\_8f6f\\_4d0d85ac5f71](http://emmc.info/emmo-material#EMMO_3397f270_dfc1_4500_8f6f_4d0d85ac5f71)

### Relations:

- is\_a mesoscopic
- is\_a electron\_based
- is\_a atom\_based
- has\_spatial\_direct\_part some electron
- has\_spatial\_direct\_part only (vacuum or electron or e\_bonded\_atom)
- has\_spatial\_direct\_part min e\_bonded\_atom

## monomer

**IRI:** [http://emmc.info/emmo-material#EMMO\\_076dda89\\_691f\\_4330\\_9a15\\_47cdc18ae388](http://emmc.info/emmo-material#EMMO_076dda89_691f_4330_9a15_47cdc18ae388)

### Relations:

- is\_a molecule

## H<sub>2</sub>O

**IRI:** [http://emmc.info/emmo-material#EMMO\\_7684509b\\_b4b3\\_425d\\_9a83\\_8042d89ca496](http://emmc.info/emmo-material#EMMO_7684509b_b4b3_425d_9a83_8042d89ca496)

### Relations:

- is\_a molecule

## fullerene

**IRI:** [http://emmc.info/emmo-material#EMMO\\_fc4acecf\\_b127\\_4a8d\\_a36d\\_b99cf9b4764c](http://emmc.info/emmo-material#EMMO_fc4acecf_b127_4a8d_a36d_b99cf9b4764c)

### Relations:

- is\_a molecule
- is\_a nanoparticle

## particle

**Comment:** Solid or liquid particles suspended in a fluid medium.

**IRI:** [http://emmc.info/emmo-material#EMMO\\_47bc4df0\\_291e\\_436a\\_bf3d\\_d69cb9c8af8f](http://emmc.info/emmo-material#EMMO_47bc4df0_291e_436a_bf3d_d69cb9c8af8f)

### Relations:

- is\_a mesoscopic
- is\_a continuum
- is\_a liquid or solid

## nanostructure

IRI: [http://emmc.info/emmo-material#EMMO\\_6f26d928\\_6131\\_4e8e\\_8161\\_35eadb429285](http://emmc.info/emmo-material#EMMO_6f26d928_6131_4e8e_8161_35eadb429285)

### Relations:

- is\_a mesoscopic

## nanoparticle

IRI: [http://emmc.info/emmo-material#EMMO\\_5e4b8f8a\\_3f5b\\_485d\\_8561\\_9f0dcf05ec50](http://emmc.info/emmo-material#EMMO_5e4b8f8a_3f5b_485d_8561_9f0dcf05ec50)

### Relations:

- is\_a nanostructure

## polymer\_\_nanoparticle

IRI: [http://emmc.info/emmo-material#EMMO\\_64334d8c\\_5a3d\\_4b6c\\_893f\\_99592a25b15e](http://emmc.info/emmo-material#EMMO_64334d8c_5a3d_4b6c_893f_99592a25b15e)

### Relations:

- is\_a nanoparticle
- is\_a polymer\_based
- has\_spatial\_direct\_part some polymer

## fullerene

IRI: [http://emmc.info/emmo-material#EMMO\\_fc4acecf\\_b127\\_4a8d\\_a36d\\_b99cf9b4764c](http://emmc.info/emmo-material#EMMO_fc4acecf_b127_4a8d_a36d_b99cf9b4764c)

### Relations:

- is\_a molecule
- is\_a nanoparticle

## nanofiber

IRI: [http://emmc.info/emmo-material#EMMO\\_688c27d3\\_1a3d\\_4204\\_b814\\_073321d51ae4](http://emmc.info/emmo-material#EMMO_688c27d3_1a3d_4204_b814_073321d51ae4)

### Relations:

- is\_a nanostructure

## nanoplate

IRI: [http://emmc.info/emmo-material#EMMO\\_ee54b49e\\_81ce\\_4e6c\\_8674\\_7c6b00492089](http://emmc.info/emmo-material#EMMO_ee54b49e_81ce_4e6c_8674_7c6b00492089)

### Relations:

- is\_a nanostructure

## cluster

IRI: [http://emmc.info/emmo-material#EMMO\\_86e47a95\\_cc49\\_48f3\\_9f45\\_9ce2d114a819](http://emmc.info/emmo-material#EMMO_86e47a95_cc49_48f3_9f45_9ce2d114a819)

### Relations:

- is\_a mesoscopic



- `is_a` `granularity`
- `has_spatial_direct_part` some (molecule or atom)

## polymer

**IRI:** [http://emmc.info/emmo-material#EMMO\\_899521af\\_8847\\_4534\\_b726\\_c2cf3e49eee1](http://emmc.info/emmo-material#EMMO_899521af_8847_4534_b726_c2cf3e49eee1)

### Relations:

- `is_a` `mesoscopic`
- `is_a` `monomer_based`
- `has_spatial_direct_part` some monomer

## atomic

**IRI:** [http://emmc.info/emmo-material#EMMO\\_5c4aff3c\\_c30c\\_4507\\_86d5\\_b4df41eb9f2f](http://emmc.info/emmo-material#EMMO_5c4aff3c_c30c_4507_86d5_b4df41eb9f2f)

### Relations:

- `is_a` `state`

## atom

**IRI:** [http://emmc.info/emmo-material#EMMO\\_eb77076b\\_a104\\_42ac\\_a065\\_798b2d2809ad](http://emmc.info/emmo-material#EMMO_eb77076b_a104_42ac_a065_798b2d2809ad)

### Relations:

- `is_a` `atomic`
- `is_a` `nucleus_based`
- `has_spatial_direct_part` only (vacuum or electron or nucleus)
- `has_spatial_direct_part` exactly nucleus

## standalone\_atom

**Comment:** A standalone atom can be bonded with other atoms by intermolecular forces (i.e. dipole–dipole, London dispersion force, hydrogen bonding), since this bonds does not involve electron sharing.

**IRI:** [http://emmc.info/emmo-material#EMMO\\_2fd3f574\\_5e93\\_47fe\\_afca\\_ed80b0a21ab4](http://emmc.info/emmo-material#EMMO_2fd3f574_5e93_47fe_afca_ed80b0a21ab4)

### Relations:

- `is_a` `electron_based`
- `is_a` `atom`
- `has_spatial_direct_part` some electron

## neutral\_atom

**IRI:** [http://emmc.info/emmo-material#EMMO\\_4588526f\\_8553\\_4f4d\\_aa73\\_a483e88d599b](http://emmc.info/emmo-material#EMMO_4588526f_8553_4f4d_aa73_a483e88d599b)

### Relations:

- `is_a` `standalone_atom`

## ion\_atom

**Comment:** The ion\_atom is the basic part of a pure ionic bonded compound i.e. without electron sharing,

**IRI:** [http://emmc.info/emmo-material#EMMO\\_db03061b\\_db31\\_4132\\_a47a\\_6a634846578b](http://emmc.info/emmo-material#EMMO_db03061b_db31_4132_a47a_6a634846578b)

**Relations:**

- is\_a standalone\_atom

## e\_bonded\_atom

**Comment:** A real bond between atoms is always something hybrid between covalent, metallic and ionic.

In general, metallic and ionic bonds have atoms sharing electrons.

**Comment:** The bond types that are covered by this definition are the strong electronic bonds: covalent, metallic and ionic.

**IRI:** [http://emmc.info/emmo-material#EMMO\\_8303a247\\_f9d9\\_4616\\_bdcd\\_f5cbd7b298e3](http://emmc.info/emmo-material#EMMO_8303a247_f9d9_4616_bdcd_f5cbd7b298e3)

**Relations:**

- is\_a atom

## subatomic

**IRI:** [http://emmc.info/emmo-material#EMMO\\_7d66bde4\\_b68d\\_41cc\\_b5fc\\_6fd98c5e2ff0](http://emmc.info/emmo-material#EMMO_7d66bde4_b68d_41cc_b5fc_6fd98c5e2ff0)

**Relations:**

- is\_a state

## electron\_cloud

**IRI:** [http://emmc.info/emmo-material#EMMO\\_1067b97a\\_84f8\\_4d22\\_8ace\\_b842b8ce355c](http://emmc.info/emmo-material#EMMO_1067b97a_84f8_4d22_8ace_b842b8ce355c)

**Relations:**

- is\_a subatomic
- is\_a electron\_based
- has\_spatial\_direct\_part some (vacuum and electron)

## nucleus

**IRI:** [http://emmc.info/emmo-material#EMMO\\_f835f4d4\\_c665\\_403d\\_ab25\\_dca5cc74be52](http://emmc.info/emmo-material#EMMO_f835f4d4_c665_403d_ab25_dca5cc74be52)

**Relations:**

- is\_a subatomic
- is\_a nucleon\_based
- has\_spatial\_direct\_part some nucleon
- has\_spatial\_direct\_part only (vacuum or nucleon)
- has\_spatial\_direct\_part min proton

## nucleon

**IRI:** [http://emmc.info/emmo-material#EMMO\\_50781fd9\\_a9e4\\_46ad\\_b7be\\_4500371d188d](http://emmc.info/emmo-material#EMMO_50781fd9_a9e4_46ad_b7be_4500371d188d)

**Relations:**

- is\_a [subatomic](#)
- is\_a [quark\\_only\\_based](#)

## proton

**IRI:** [http://emmc.info/emmo-material#EMMO\\_8f87e700\\_99a8\\_4427\\_8ffb\\_e493de05c217](http://emmc.info/emmo-material#EMMO_8f87e700_99a8_4427_8ffb_e493de05c217)

**Relations:**

- is\_a [nucleon](#)
- has\_spatial\_direct\_part some [quark](#)
- has\_spatial\_direct\_part only (vacuum or [quark](#))

## neutron

**IRI:** [http://emmc.info/emmo-material#EMMO\\_df808271\\_df91\\_4f27\\_ba59\\_fa423c51896c](http://emmc.info/emmo-material#EMMO_df808271_df91_4f27_ba59_fa423c51896c)

**Relations:**

- is\_a [nucleon](#)
- has\_spatial\_direct\_part some [quark](#)
- has\_spatial\_direct\_part only (vacuum or [quark](#))

## elementary

**Elucidation:** The basic constituent of matter, that can be proper partitioned only in time.

**IRI:** [http://emmc.info/emmo#EMMO\\_0f795e3e\\_c602\\_4577\\_9a43\\_d5a231aa1360](http://emmc.info/emmo#EMMO_0f795e3e_c602_4577_9a43_d5a231aa1360)

**Relations:**

- is\_a [subatomic](#)
- is\_a [state](#)
- has\_spatial\_proper\_part only owl:Nothing

## photon

**IRI:** [http://emmc.info/emmo-material#EMMO\\_25f8b804\\_9a0b\\_4387\\_a3e7\\_b35bce5365ee](http://emmc.info/emmo-material#EMMO_25f8b804_9a0b_4387_a3e7_b35bce5365ee)

**Relations:**

- is\_a [elementary](#)

## quark

**IRI:** [http://emmc.info/emmo-material#EMMO\\_72d53756\\_7fb1\\_46ed\\_980f\\_83f47efbe105](http://emmc.info/emmo-material#EMMO_72d53756_7fb1_46ed_980f_83f47efbe105)

**Relations:**

- is\_a [elementary](#)

## electron

**IRI:** [http://emmc.info/emmo-material#EMMO\\_8043d3c6\\_a4c1\\_4089\\_ba34\\_9744e28e5b3d](http://emmc.info/emmo-material#EMMO_8043d3c6_a4c1_4089_ba34_9744e28e5b3d)

**Relations:**

- is\_a elementary

## continuum

**Comment:** A continuum is made of a sufficient number of parts that it continues to exist as a continuum individual even after the loss of one of them i.e. a continuum is a redundant.

**Comment:** A continuum is not necessarily small (i.e. composed by the minimum amount of parts to fulfill the definition).

A single continuum individual can be the whole fluid in a pipe.

**Comment:** A continuum is the bearer of properties that are generated by the interactions of parts such as viscosity and thermal or electrical conductivity.

**IRI:** [http://emmc.info/emmo-material#EMMO\\_8b0923ab\\_b500\\_477b\\_9ce9\\_8b3a3e4dc4f2](http://emmc.info/emmo-material#EMMO_8b0923ab_b500_477b_9ce9_8b3a3e4dc4f2)

**Relations:**

- is\_a state

## fluid

**IRI:** [http://emmc.info/emmo-material#EMMO\\_87ac88ff\\_8379\\_4f5a\\_8c7b\\_424a8fff1ee8](http://emmc.info/emmo-material#EMMO_87ac88ff_8379_4f5a_8c7b_424a8fff1ee8)

**Relations:**

- is\_a continuum

## liquid

**IRI:** [http://emmc.info/emmo-material#EMMO\\_94b1c62a\\_f17b\\_4a68\\_b546\\_9c113192dd95](http://emmc.info/emmo-material#EMMO_94b1c62a_f17b_4a68_b546_9c113192dd95)

**Relations:**

- is\_a fluid

## pure\_water

**IRI:** [http://emmc.info/emmo-material#EMMO\\_4307f559\\_d089\\_4393\\_9cd9\\_bee0efdab0f2](http://emmc.info/emmo-material#EMMO_4307f559_d089_4393_9cd9_bee0efdab0f2)

**Relations:**

- is\_a liquid
- is\_a molecule\_only\_based
- has\_spatial\_direct\_part some H2O
- has\_spatial\_direct\_part only (vacuum or H2O)

## water

IRI: [http://emmc.info/emmo-material#EMMO\\_760461a5\\_4666\\_4d62\\_a180\\_c5042d7395f0](http://emmc.info/emmo-material#EMMO_760461a5_4666_4d62_a180_c5042d7395f0)

### Relations:

- is\_a liquid
- is\_a molecule\_based
- has\_spatial\_direct\_part some H2O

## plasma

IRI: [http://emmc.info/emmo-material#EMMO\\_97d919ba\\_e7bc\\_4bed\\_8d17\\_55bad357dbb9](http://emmc.info/emmo-material#EMMO_97d919ba_e7bc_4bed_8d17_55bad357dbb9)

### Relations:

- is\_a fluid
- is\_a electron\_based
- is\_a ion\_atom\_based
- has\_spatial\_direct\_part some electron
- has\_spatial\_direct\_part some ion\_atom

## suspension

IRI: [http://emmc.info/emmo-material#EMMO\\_b32d894b\\_9330\\_4ba0\\_a786\\_ef9ad1bbb46a](http://emmc.info/emmo-material#EMMO_b32d894b_9330_4ba0_a786_ef9ad1bbb46a)

### Relations:

- is\_a fluid

## aerosol

IRI: [http://emmc.info/emmo-material#EMMO\\_153ba20b\\_72b1\\_4b34\\_8b16\\_29ce5ecf5437](http://emmc.info/emmo-material#EMMO_153ba20b_72b1_4b34_8b16_29ce5ecf5437)

### Relations:

- is\_a suspension
- is\_a continuum\_based
- has\_spatial\_direct\_part some particle
- has\_spatial\_direct\_part some (molecule or atom)

## gas

IRI: [http://emmc.info/emmo-material#EMMO\\_e0bd02f0\\_99ed\\_4789\\_8981\\_8bcaf520f5b8](http://emmc.info/emmo-material#EMMO_e0bd02f0_99ed_4789_8981_8bcaf520f5b8)

### Relations:

- is\_a fluid

## solid

IRI: [http://emmc.info/emmo-material#EMMO\\_a2b006f2\\_bbfd\\_4dba\\_bcaa\\_3fca20cd6be1](http://emmc.info/emmo-material#EMMO_a2b006f2_bbfd_4dba_bcaa_3fca20cd6be1)

### Relations:

- is\_a continuum

## crystal

IRI: [http://emmc.info/emmo-material#EMMO\\_43e08b91\\_52e1\\_45e4\\_baf7\\_eea2e05b9da3](http://emmc.info/emmo-material#EMMO_43e08b91_52e1_45e4_baf7_eea2e05b9da3)

Relations:

- is\_a solid

## polymer\_crystal

IRI: [http://emmc.info/emmo-material#EMMO\\_aab61bb0\\_b232\\_42f3\\_bbf3\\_6bb1ac72ad71](http://emmc.info/emmo-material#EMMO_aab61bb0_b232_42f3_bbf3_6bb1ac72ad71)

Relations:

- is\_a crystal
- is\_a polymer\_based
- has\_spatial\_direct\_part some polymer

## amorphous

IRI: [http://emmc.info/emmo-material#EMMO\\_530cc355\\_84f0\\_45c0\\_ac79\\_7b075e313e96](http://emmc.info/emmo-material#EMMO_530cc355_84f0_45c0_ac79_7b075e313e96)

Relations:

- is\_a solid

## particle

Comment: Solid or liquid particles suspended in a fluid medium.

IRI: [http://emmc.info/emmo-material#EMMO\\_47bc4df0\\_291e\\_436a\\_bf3d\\_d69cb9c8af8f](http://emmc.info/emmo-material#EMMO_47bc4df0_291e_436a_bf3d_d69cb9c8af8f)

Relations:

- is\_a mesoscopic
- is\_a continuum
- is\_a liquid or solid

## process branch

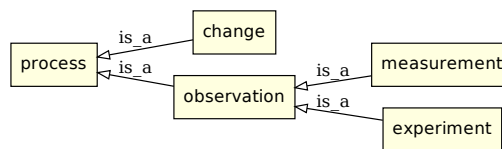


Figure 3.7: The process branch.

## process

**Elucidation:** A temporal part of a physical that identifies a particular type of evolution in time.

**Comment:** A process is easily defined as a temporal part of a physical that is categorized in a primitive process subclass according to what type of process we want to represent.

Strictly speaking, every physical is a process since it always has a time dimension, but in the EMMO we restrict the meaning of 'process' to physicals whose evolution in time have a particular meaning for the material ontologist. i.e. a process is not only something that unfolds in time, but something happening that has a meaning for the interpreter.

**Comment:** A 'process' individual is easily defined as a temporal part of a physical that is categorized in a primitive process subclass according to what type of process we want to represent.

Strictly speaking, every physical is a 'process' since it always has a time dimension, but here we restrict the meaning of 'process' to physicals whose evolution in time have a meaning for the material ontologist.

Participants of a process are always parts of that particular process (i.e. they are spacetime). It means that is\_participant relation is subclass of is\_part\_of relation (e.g. you cannot participate to a party if you are not enclosed by the party room)

**IRI:** [http://emmc.info/emmo#EMMO\\_1703b6d9\\_b780\\_4c61\\_a75b\\_5f0cd39323e3](http://emmc.info/emmo#EMMO_1703b6d9_b780_4c61_a75b_5f0cd39323e3)

### Relations:

- is\_a physical
- has\_proper\_part some role

## change

**Elucidation:** A process that include the transition of a physical from a state to another (i.e. a discontinuity of parts)

**Comment:** A change is by definition not a property change but a granularity change.

**IRI:** [http://emmc.info/emmo#EMMO\\_2f79e5bc\\_5591\\_4996\\_8e35\\_4ff43f82daf7](http://emmc.info/emmo#EMMO_2f79e5bc_5591_4996_8e35_4ff43f82daf7)

### Relations:

- is\_a process

## observation

**Elucidation:** A process that involves an observer that perceive another physical by interacting with them.

**IRI:** [http://emmc.info/emmo#EMMO\\_ba7562e1\\_1416\\_4020\\_aed0\\_b6acd151de3e](http://emmc.info/emmo#EMMO_ba7562e1_1416_4020_aed0_b6acd151de3e)

### Relations:

- is\_a process
- has\_part some observer

## measurement

**Elucidation:** An observation that results in a quantitative comparison of a physical property with a standard reference.

**IRI:** [http://emmc.info/emmo#EMMO\\_0bd22df9\\_081a\\_4258\\_bf00\\_5ef31c51f883](http://emmc.info/emmo#EMMO_0bd22df9_081a_4258_bf00_5ef31c51f883)

### Relations:

- is\_a observation
- has\_proper\_part some measurement\_instrument

## experiment

**Elucidation:** A process that is aimed to replicate a physical phenomena in a controlled environment.

**IRI:** [http://emmc.info/emmo#EMMO\\_f24d4542\\_ccf1\\_4cb7\\_8225\\_01aa73fea9d2](http://emmc.info/emmo#EMMO_f24d4542_ccf1_4cb7_8225_01aa73fea9d2)

**Relations:**

- is\_a **observation**

## abstract branch

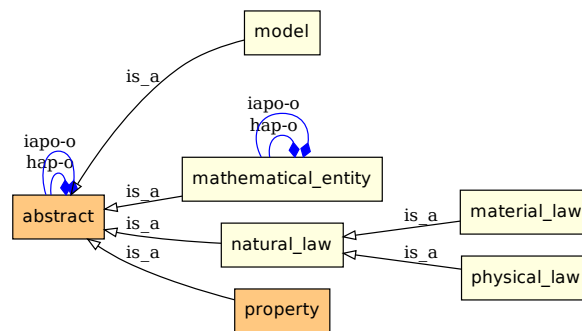


Figure 3.8: The abstract branch.

## abstract

**Elucidation:** Items representing the internal pictures that one (or more) being makes of some external entities.

**Comment:** An abstract is an abstraction provided by an observer, and are observer dependent.

An abstraction can come from a single being or from a group of being seen as a single being.

e.g. my\_democracy is the abstraction of democracy that I have. chinese\_democracy is the idea of democracy that Chinese have.

**Comment:** Individuals that fall under this class are not categories (i.e. they are not instantiable).

An abstract individual is created to express a particular abstraction coming from e.g. a single being or a group of beings.

Abstract individuals must be represented by at least one physical entity. A physical entity that represents an abstract object is called semeion (i.e. symbol).

A semeion S “stands” for the entity E that has been abstracted by the abstract A.

e.g. E is abstracted by A. A is represented by S. S stands for E. (this is related to the discipline of semiotics)

More than one abstract can refer to the same entity.

**Comment:** Rigorously speaking, an abstract is only a useful intermediate concept to connect an entity to its semeion.

According to a rigorous nominalistic view, an abstract exists only as long as it is represented by some physical semeion (i.e. a book, a mind).



If all the representations of a particular abstract are gone, the information is completely lost (e.g. the second book on poetry of Aristotle is lost since there are no more copies, a wedding in the XI century is lost since there are no people with a memory picture of that, nor a writing or document log).

**IRI:** [http://emmc.info/emmo#EMMO\\_c170a738\\_51ec\\_4983\\_8cc9\\_0e03dfa63c73](http://emmc.info/emmo#EMMO_c170a738_51ec_4983_8cc9_0e03dfa63c73)

**Relations:**

- `is_a` `item`
- `has_abstract_part` only `abstract`
- `is_abstract_part_of` only `abstract`
- `equivalent_to` `has_representation` some `semeion`
- `equivalent_to` `is_abstraction_of` some `entity`

## natural\_law

**IRI:** [http://emmc.info/emmo#EMMO\\_c2e4665b\\_66e5\\_419c\\_ad7c\\_4cdd7c5ea456](http://emmc.info/emmo#EMMO_c2e4665b_66e5_419c_ad7c_4cdd7c5ea456)

**Relations:**

- `is_a` `abstract`
- `is_abstraction_of` some `experiment`

## material\_law

**IRI:** [http://emmc.info/emmo#EMMO\\_be756ec4\\_e173\\_48ea\\_b907\\_fc966902be12](http://emmc.info/emmo#EMMO_be756ec4_e173_48ea_b907_fc966902be12)

**Relations:**

- `is_a` `natural_law`

## physical\_law

**IRI:** [http://emmc.info/emmo#EMMO\\_fe949e3e\\_557e\\_4244\\_918f\\_fee18b103eed](http://emmc.info/emmo#EMMO_fe949e3e_557e_4244_918f_fee18b103eed)

**Relations:**

- `is_a` `natural_law`

## mathematical\_entity branch

### mathematical\_entity

**Elucidation:** A class that collects other subclasses that represents the fundamental elements of mathematical expressions.

**IRI:** [http://emmc.info/emmo#EMMO\\_dd758354\\_7a63\\_4fe7\\_ac92\\_46d3e03dfbf5](http://emmc.info/emmo#EMMO_dd758354_7a63_4fe7_ac92_46d3e03dfbf5)

**Relations:**

- `is_a` `abstract`
- `has_abstract_part` only `mathematical_entity`
- `is_abstract_part_of` only `mathematical_entity`

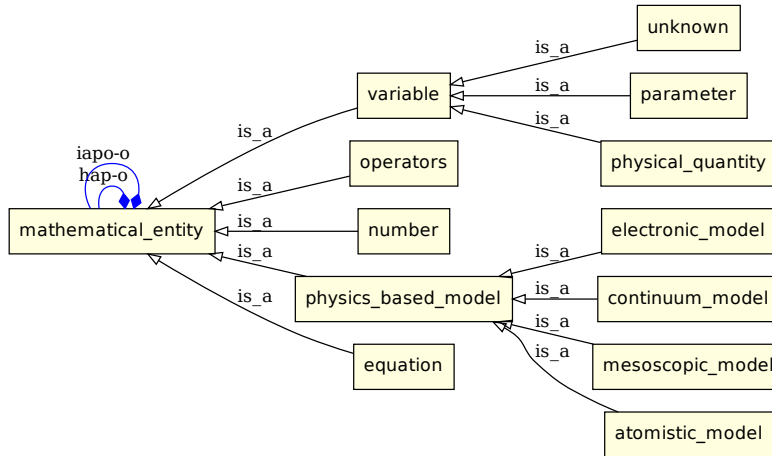


Figure 3.9: The mathematical\_entity branch.

## variable

**Elucidation:** A variable is a symbol that denotes a mathematical object, which could be e.g. a number, a vector, a matrix.

**IRI:** [http://emmc.info/emmo#EMMO\\_24516667\\_7969\\_453f\\_8a84\\_ba2239d69190](http://emmc.info/emmo#EMMO_24516667_7969_453f_8a84_ba2239d69190)

**Relations:**

- is\_a [mathematical\\_entity](#)

## unknown

**Elucidation:** The dependent variable for which an equation has been written.

**Example:** Velocity, for the Navier-Stokes equation.

**IRI:** [http://emmc.info/emmo#EMMO\\_48423f91\\_dd4a\\_445a\\_ac75\\_472066d9f416](http://emmc.info/emmo#EMMO_48423f91_dd4a_445a_ac75_472066d9f416)

**Relations:**

- is\_a [variable](#)

## parameter

**Elucidation:** A variable whose value is know or assumed to be known

**Example:** Viscosity, the total energy of the system given by an Hamiltonian, the force between two atoms.

**IRI:** [http://emmc.info/emmo#EMMO\\_961bda97\\_5825\\_45d8\\_9fc6\\_c6bdc4bfefe3](http://emmc.info/emmo#EMMO_961bda97_5825_45d8_9fc6_c6bdc4bfefe3)

**Relations:**

- is\_a [variable](#)

## physical\_quantity

**Elucidation:** A physical quantity is a physical property of a phenomenon, body, or continuum\_object, that can be quantified by measurement.

**IRI:** [http://emmc.info/emmo#EMMO\\_a1f1d799\\_5399\\_486c\\_88bc\\_623ac38ce8ac](http://emmc.info/emmo#EMMO_a1f1d799_5399_486c_88bc_623ac38ce8ac)

**Relations:**

- is\_a variable

## operators

**IRI:** [http://emmc.info/emmo#EMMO\\_9a88bc5f\\_50a1\\_45bc\\_b62b\\_6f025a19b5f1](http://emmc.info/emmo#EMMO_9a88bc5f_50a1_45bc_b62b_6f025a19b5f1)

**Relations:**

- is\_a mathematical\_entity

## number

**IRI:** [http://emmc.info/emmo#EMMO\\_cbe881a3\\_2e4a\\_44ca\\_81e3\\_038cdeb57e2c](http://emmc.info/emmo#EMMO_cbe881a3_2e4a_44ca_81e3_038cdeb57e2c)

**Relations:**

- is\_a mathematical\_entity

## physics\_based\_model

**Elucidation:** A solvable set of one Physics Equation and one or more Materials Relations.

**IRI:** [http://emmc.info/emmo#EMMO\\_1977f035\\_7220\\_4306\\_82b7\\_948cb782b288](http://emmc.info/emmo#EMMO_1977f035_7220_4306_82b7_948cb782b288)

**Relations:**

- is\_a model
- is\_a mathematical\_entity
- has\_abstract\_part some material\_relation
- has\_abstract\_part some physics\_equation

## electronic\_model

**IRI:** [http://emmc.info/emmo#EMMO\\_0975e80f\\_2e4f\\_4d94\\_afb2\\_90b2e492165f](http://emmc.info/emmo#EMMO_0975e80f_2e4f_4d94_afb2_90b2e492165f)

**Relations:**

- is\_a physics\_based\_model

## continuum\_model

**IRI:** [http://emmc.info/emmo#EMMO\\_1c22976c\\_5fe5\\_47a2\\_b88a\\_70fd5d0e41d0](http://emmc.info/emmo#EMMO_1c22976c_5fe5_47a2_b88a_70fd5d0e41d0)

**Relations:**

- is\_a physics\_based\_model

## mesoscopic\_model

IRI: [http://emmc.info/emmo#EMMO\\_9e923a71\\_321f\\_419c\\_a6c0\\_62cf2839f4f6](http://emmc.info/emmo#EMMO_9e923a71_321f_419c_a6c0_62cf2839f4f6)

Relations:

- is\_a [physics\\_based\\_model](#)

## atomistic\_model

IRI: [http://emmc.info/emmo#EMMO\\_d458195e\\_566c\\_44d0\\_8b6b\\_8c86dc7eb92f](http://emmc.info/emmo#EMMO_d458195e_566c_44d0_8b6b_8c86dc7eb92f)

Relations:

- is\_a [physics\\_based\\_model](#)

## equation branch

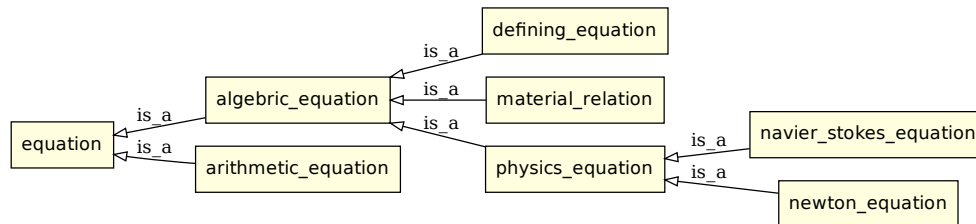


Figure 3.10: The equation branch.

## equation

**Elucidation:** A mathematical expression that puts in relation some variables and that can always be represented as  $f(v_0, v_1, \dots, v_n) = 0$

where  $f$  is the expression and  $v_0, v_1, \dots, v_n$  are the variables.

IRI: [http://emmc.info/emmo#EMMO\\_3fb0306b\\_0206\\_43f6\\_a42e\\_ddbf9e1bb0fd](http://emmc.info/emmo#EMMO_3fb0306b_0206_43f6_a42e_ddbf9e1bb0fd)

Relations:

- is\_a [mathematical\\_entity](#)
- has\_abstract\_part some (variable or operators)
- has\_abstract\_part only (variable or operators)

## algebraic\_equation

**Elucidation:** An equation that has parts operators, numbers and variables.

IRI: [http://emmc.info/emmo#EMMO\\_4a8bba7a\\_01c7\\_4f75\\_a7e4\\_e457342bbeab](http://emmc.info/emmo#EMMO_4a8bba7a_01c7_4f75_a7e4_e457342bbeab)

Relations:

- is\_a [equation](#)

## defining\_equation

**Elucidation:** An equation that define a new variable in terms of other base variables.

**Example:** The definition of velocity as  $v = dx/dt$ .

The definition of density as mass/volume.

**IRI:** [http://emmc.info/emmo#EMMO\\_5f721fac\\_a2bd\\_4085\\_961a\\_26daa168ef58](http://emmc.info/emmo#EMMO_5f721fac_a2bd_4085_961a_26daa168ef58)

**Relations:**

- is\_a [algebraic\\_equation](#)

## material\_relation

**Elucidation:** An ‘equation’ that is a representation of a physical assumption specific to a material, and provides an expression for a ‘physics\_quantity’ (the dependent variable) as function of other variables, physics\_quantity or data (independent variables).

**Example:** The Lennard-Jones potential.

A force field.

An Hamiltonian.

**Comment:** A material\_relation can e.g. return a predefined number, return a database query, be an equation that depends on other physics\_quantities.

**IRI:** [http://emmc.info/emmo#EMMO\\_89b0dade\\_3620\\_4879\\_9c1d\\_24ca8f7c7318](http://emmc.info/emmo#EMMO_89b0dade_3620_4879_9c1d_24ca8f7c7318)

**Relations:**

- is\_a [algebraic\\_equation](#)
- is\_abstraction\_of some [material\\_law](#)

## physics\_equation

**Elucidation:** An equation that create an abstraction of a physical law by mathematically defining the relations between physics\_quantities.

**Example:** The Newton’s equation of motion.

The Schrodinger equation.

The Navier-Stokes equation.

**IRI:** [http://emmc.info/emmo#EMMO\\_bad895e3\\_2adc\\_4aba\\_ad6e\\_ddbd110ee70d](http://emmc.info/emmo#EMMO_bad895e3_2adc_4aba_ad6e_ddbd110ee70d)

**Relations:**

- is\_a [algebraic\\_equation](#)
- is\_abstraction\_of some [physical\\_law](#)

## navier\_stokes\_equation

**IRI:** [http://emmc.info/emmo#EMMO\\_14032d4f\\_b0c2\\_43c9\\_b6ea\\_4e42b200c00e](http://emmc.info/emmo#EMMO_14032d4f_b0c2_43c9_b6ea_4e42b200c00e)

**Relations:**

- is\_a [physics\\_equation](#)

## newton\_equation

IRI: [http://emmc.info/emmo#EMMO\\_c73a42fd\\_3f6f\\_40b9\\_ad21\\_8ec2aa356bd6](http://emmc.info/emmo#EMMO_c73a42fd_3f6f_40b9_ad21_8ec2aa356bd6)

Relations:

- is\_a [physics\\_equation](#)

## arithmetic\_equation

Elucidation: An equation that has parts only operators and numbers.

IRI: [http://emmc.info/emmo#EMMO\\_70345bb9\\_783e\\_4b8b\\_9a20\\_0072eabec3fd](http://emmc.info/emmo#EMMO_70345bb9_783e_4b8b_9a20_0072eabec3fd)

Relations:

- is\_a [equation](#)

## model branch

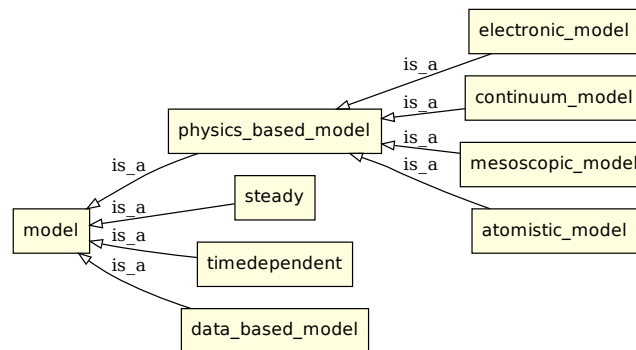


Figure 3.11: The model branch.

## model

Comment: A model can be an abstraction for simple entities (e.g. an atom, a field) or a more complex existent.

IRI: [http://emmc.info/emmo#EMMO\\_75bfd283\\_ff56\\_4a97\\_b05e\\_a3ea15d5e0a8](http://emmc.info/emmo#EMMO_75bfd283_ff56_4a97_b05e_a3ea15d5e0a8)

Relations:

- is\_a [abstract](#)

## physics\_based\_model

Elucidation: A solvable set of one Physics Equation and one or more Materials Relations.

IRI: [http://emmc.info/emmo#EMMO\\_1977f035\\_7220\\_4306\\_82b7\\_948cb782b288](http://emmc.info/emmo#EMMO_1977f035_7220_4306_82b7_948cb782b288)

Relations:

- is\_a [model](#)
- is\_a [mathematical\\_entity](#)

- `has_abstract_part` some `material_relation`
- `has_abstract_part` some `physics_equation`

## electronic\_model

IRI: [http://emmc.info/emmo#EMMO\\_0975e80f\\_2e4f\\_4d94\\_afb2\\_90b2e492165f](http://emmc.info/emmo#EMMO_0975e80f_2e4f_4d94_afb2_90b2e492165f)

Relations:

- `is_a` `physics_based_model`

## continuum\_model

IRI: [http://emmc.info/emmo#EMMO\\_1c22976c\\_5fe5\\_47a2\\_b88a\\_70fd5d0e41d0](http://emmc.info/emmo#EMMO_1c22976c_5fe5_47a2_b88a_70fd5d0e41d0)

Relations:

- `is_a` `physics_based_model`

## mesoscopic\_model

IRI: [http://emmc.info/emmo#EMMO\\_9e923a71\\_321f\\_419c\\_a6c0\\_62cf2839f4f6](http://emmc.info/emmo#EMMO_9e923a71_321f_419c_a6c0_62cf2839f4f6)

Relations:

- `is_a` `physics_based_model`

## atomistic\_model

IRI: [http://emmc.info/emmo#EMMO\\_d458195e\\_566c\\_44d0\\_8b6b\\_8c86dc7eb92f](http://emmc.info/emmo#EMMO_d458195e_566c_44d0_8b6b_8c86dc7eb92f)

Relations:

- `is_a` `physics_based_model`

## steady

IRI: [http://emmc.info/emmo#EMMO\\_57bb483f\\_45b8\\_449f\\_993e\\_98e7eef45ccc](http://emmc.info/emmo#EMMO_57bb483f_45b8_449f_993e_98e7eef45ccc)

Relations:

- `is_a` `model`

## timedependent

IRI: [http://emmc.info/emmo#EMMO\\_959daaf6\\_e074\\_46d7\\_b05e\\_867d7fc9ce55](http://emmc.info/emmo#EMMO_959daaf6_e074_46d7_b05e_867d7fc9ce55)

Relations:

- `is_a` `model`

## data\_based\_model

**Elucidation:** A computational model that uses data to create new insight into the behaviour of a system.

**IRI:** [http://emmc.info/emmo#EMMO\\_9d41ad75\\_6bcb\\_4a3d\\_985b\\_5f7d0c13f3c3](http://emmc.info/emmo#EMMO_9d41ad75_6bcb_4a3d_985b_5f7d0c13f3c3)

**Relations:**

- is\_a model

## property branch

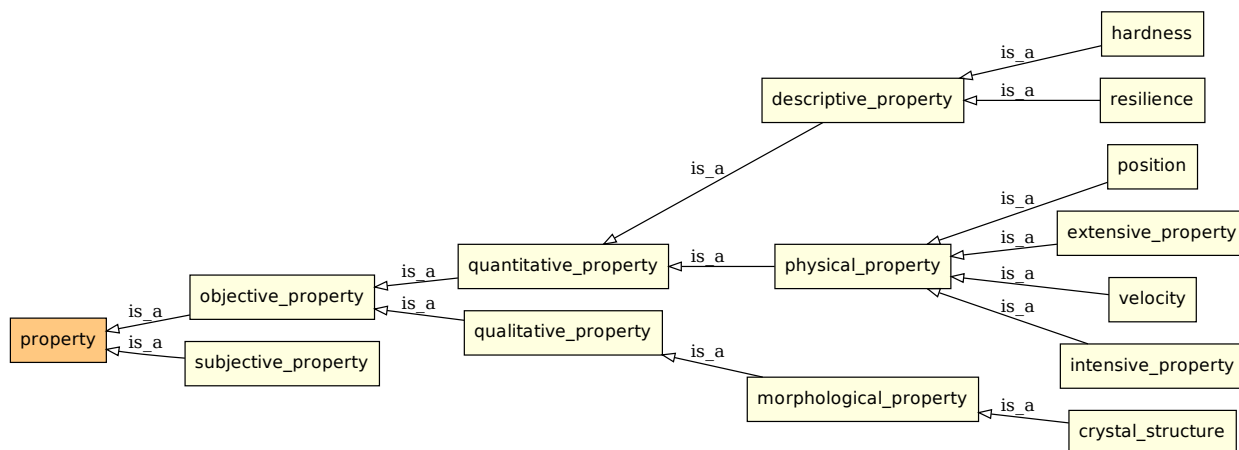


Figure 3.12: The property branch.

## property

**Elucidation:** A property is an abstraction of a process that catch the ability of an entity to be perceived.

The observation process (e.g. a look, a photo shot, a measurement) is performed by an observer (e.g. you, a camera, an instrument) through a specific perception mechanism (e.g. retina impression, CMOS excitation, piezoelectric sensor activation) and involves an observed entity.

The observed entity has the property that is the abstraction of that specific observation process.

Property subclasses are specializations that depend on the type of observation processes.

**Example:** Hardness is a subclass of properties.

Vickers hardness is a subclass of hardness that involves the procedures and instruments defined by the standard hardness test.

**Example:** Let's define the class 'color' as the subclass of the properties that involve photon emission and an electromagnetic radiation sensible observer.

An individual C of this class 'color' can be defined by declaring the process individual (e.g. daylight illumination) and the observer (e.g. my eyes)

Stating that an entity E has property C, we mean that it can be observed by such setup of process + observer (i.e. observed by my eyes under daylight).

This definition can be generalized by using a generic human eye, so that the observer can be a generic human.



More than one entity can have the same property.

This can be used in material characterization, to define exactly the type of measurement done, including the instrument type.

**Comment:** An abstract entity has no properties, according to this definition of property.

**Comment:** We know physical entity through observation/perception.

If we cannot perceive an entity then it does not exist (or it exists on a plane of existence that has no intersection with us and we can say nothing about it).

Perception/observation of an entity occurs when the entity stimulates an observer in a peculiar way through a well defined channel.

For this reason each property is related to a specific observation process which involves a specific observer with its own perception mechanisms.

e.g. the property 'color' is related to a process that involves emission or interaction of photon and an observer who can perceive electromagnetic radiation in the visible frequency range.

**IRI:** [http://emmc.info/emmo#EMMO\\_a6876b60\\_21b9\\_48cf\\_beed\\_b9ae7c8f5c98](http://emmc.info/emmo#EMMO_a6876b60_21b9_48cf_beed_b9ae7c8f5c98)

**Relations:**

- is\_a abstract
- is\_abstraction\_of some observation
- equivalent\_to is\_property\_for some physical

## objective\_\_property

**Elucidation:** A property that is univocally determined by each observer, and that can be used to describe a state of a physical system.

**IRI:** [http://emmc.info/emmo#EMMO\\_2b2c3291\\_452f\\_449f\\_b251\\_2146957f6d0a](http://emmc.info/emmo#EMMO_2b2c3291_452f_449f_b251_2146957f6d0a)

**Relations:**

- is\_a property

## quantitative\_\_property

**Elucidation:** A property that can be quantified with respect to a standardized reference physical instance (e.g. the prototype meter bar, the kg prototype) through a measurement process.

**IRI:** [http://emmc.info/emmo#EMMO\\_6fb6e842\\_1563\\_4e32\\_9dee\\_05e9791d69d2](http://emmc.info/emmo#EMMO_6fb6e842_1563_4e32_9dee_05e9791d69d2)

**Relations:**

- is\_a objective\_\_property
- is\_abstraction\_of some measurement

## descriptive\_\_property

**IRI:** [http://emmc.info/emmo#EMMO\\_3a27eb87\\_2611\\_40e6\\_847b\\_8f0520a6f9c2](http://emmc.info/emmo#EMMO_3a27eb87_2611_40e6_847b_8f0520a6f9c2)

**Relations:**

- is\_a quantitative\_\_property

## hardness

IRI: [http://emmc.info/emmo#EMMO\\_90c47cd1\\_2f71\\_4e6a\\_80ba\\_c5bddf8a7b83](http://emmc.info/emmo#EMMO_90c47cd1_2f71_4e6a_80ba_c5bddf8a7b83)

### Relations:

- is\_a [descriptive\\_property](#)

## resilience

IRI: [http://emmc.info/emmo#EMMO\\_fa61355d\\_448b\\_44c8\\_8fe8\\_996a25713fea](http://emmc.info/emmo#EMMO_fa61355d_448b_44c8_8fe8_996a25713fea)

### Relations:

- is\_a [descriptive\\_property](#)

## physical\_property

IRI: [http://emmc.info/emmo#EMMO\\_f4222422\\_8b07\\_47ca\\_a9d0\\_3e462b12fa34](http://emmc.info/emmo#EMMO_f4222422_8b07_47ca_a9d0_3e462b12fa34)

### Relations:

- is\_a [quantitative\\_property](#)

## position

IRI: [http://emmc.info/emmo#EMMO\\_09111718\\_0e36\\_4099\\_9f77\\_db0f34c3d1be](http://emmc.info/emmo#EMMO_09111718_0e36_4099_9f77_db0f34c3d1be)

### Relations:

- is\_a [physical\\_property](#)

## velocity

IRI: [http://emmc.info/emmo#EMMO\\_8e4871b7\\_33c3\\_4d2f\\_8310\\_8c849b46ed05](http://emmc.info/emmo#EMMO_8e4871b7_33c3_4d2f_8310_8c849b46ed05)

### Relations:

- is\_a [physical\\_property](#)

## qualitative\_property

IRI: [http://emmc.info/emmo#EMMO\\_e4ae8d15\\_cdd3\\_4ae3\\_8744\\_d008480453df](http://emmc.info/emmo#EMMO_e4ae8d15_cdd3_4ae3_8744_d008480453df)

### Relations:

- is\_a [objective\\_property](#)

## morphological\_property

IRI: [http://emmc.info/emmo#EMMO\\_86613c01\\_e996\\_4ecb\\_a6e5\\_7e52e145c6ed](http://emmc.info/emmo#EMMO_86613c01_e996_4ecb_a6e5_7e52e145c6ed)

### Relations:

- is\_a [qualitative\\_property](#)

## crystal\_structure

IRI: [http://emmc.info/emmo#EMMO\\_74768e3c\\_d687\\_401f\\_a4a0\\_f6d2a1f9ad53](http://emmc.info/emmo#EMMO_74768e3c_d687_401f_a4a0_f6d2a1f9ad53)

Relations:

- is\_a [morphological\\_property](#)

## subjective\_property

**Elucidation:** A property that cannot be univocally determined and is observer-dependent.

**Comment:** The beauty of that girl. The style of your clothing.

IRI: [http://emmc.info/emmo#EMMO\\_687e549d\\_5974\\_4f84\\_b4c6\\_7011719b303e](http://emmc.info/emmo#EMMO_687e549d_5974_4f84_b4c6_7011719b303e)

Relations:

- is\_a [property](#)

## extensive\_property branch

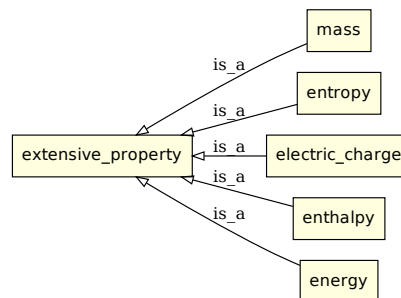


Figure 3.13: The extensive\_property branch.

## extensive\_property

IRI: [http://emmc.info/emmo#EMMO\\_3b27ce04\\_e759\\_433f\\_b53c\\_23525181ecca](http://emmc.info/emmo#EMMO_3b27ce04_e759_433f_b53c_23525181ecca)

Relations:

- is\_a [physical\\_property](#)

## mass

IRI: [http://emmc.info/emmo#EMMO\\_0fad9a8\\_aea1\\_4a59\\_a302\\_0bdbae59061f](http://emmc.info/emmo#EMMO_0fad9a8_aea1_4a59_a302_0bdbae59061f)

Relations:

- is\_a [extensive\\_property](#)

## entropy

IRI: [http://emmc.info/emmo#EMMO\\_51c697ae\\_0d4f\\_4666\\_ba3b\\_aafa8e3b2c81](http://emmc.info/emmo#EMMO_51c697ae_0d4f_4666_ba3b_aafa8e3b2c81)

### Relations:

- is\_a [extensive\\_property](#)

## electric\_charge

IRI: [http://emmc.info/emmo#EMMO\\_aacfd909\\_5297\\_4c10\\_81d1\\_6d8b0c89a88c](http://emmc.info/emmo#EMMO_aacfd909_5297_4c10_81d1_6d8b0c89a88c)

### Relations:

- is\_a [extensive\\_property](#)

## enthalpy

IRI: [http://emmc.info/emmo#EMMO\\_e9ecb2c2\\_a125\\_42f4\\_acee\\_0642ffbdaca7](http://emmc.info/emmo#EMMO_e9ecb2c2_a125_42f4_acee_0642ffbdaca7)

### Relations:

- is\_a [extensive\\_property](#)

## energy

IRI: [http://emmc.info/emmo#EMMO\\_ff917773\\_2c22\\_43ba\\_8f3d\\_c057d6c6a32d](http://emmc.info/emmo#EMMO_ff917773_2c22_43ba_8f3d_c057d6c6a32d)

### Relations:

- is\_a [extensive\\_property](#)

## intensive\_\_property branch

### intensive\_\_property

IRI: [http://emmc.info/emmo#EMMO\\_e1e330cb\\_d0c6\\_485c\\_8624\\_6f0d62db8ce1](http://emmc.info/emmo#EMMO_e1e330cb_d0c6_485c_8624_6f0d62db8ce1)

### Relations:

- is\_a [physical\\_property](#)

### thermal\_\_conductivity

IRI: [http://emmc.info/emmo#EMMO\\_133735a3\\_c6ab\\_46f7\\_8d69\\_fc11eccc9f](http://emmc.info/emmo#EMMO_133735a3_c6ab_46f7_8d69_fc11eccc9f)

### Relations:

- is\_a [intensive\\_property](#)

### electrical\_\_conductivity

IRI: [http://emmc.info/emmo#EMMO\\_15865d0d\\_9423\\_4692\\_be1d\\_cf6a7a48dce7](http://emmc.info/emmo#EMMO_15865d0d_9423_4692_be1d_cf6a7a48dce7)

### Relations:

- is\_a [intensive\\_property](#)

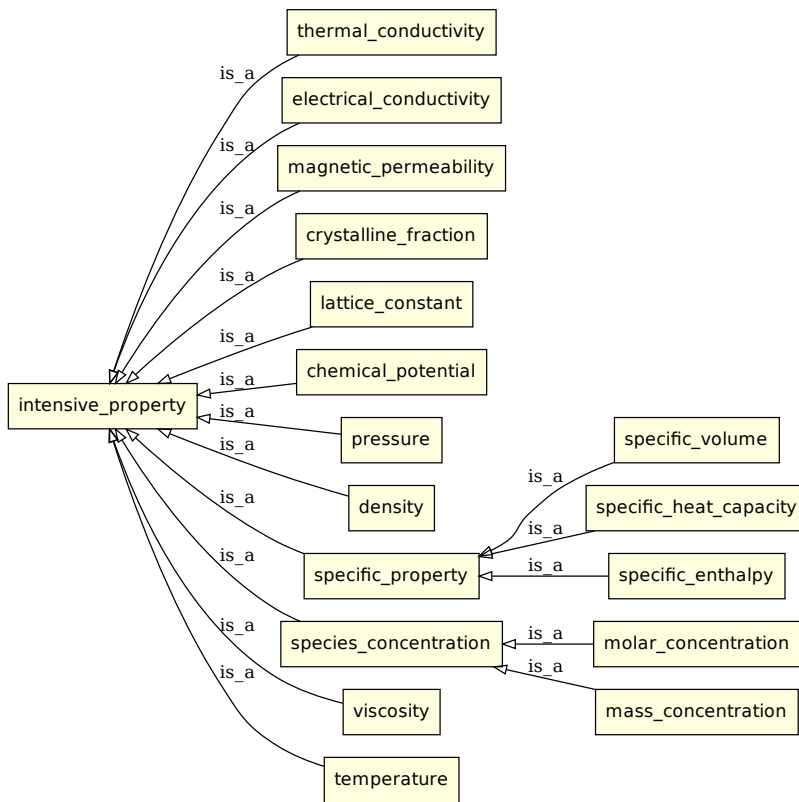


Figure 3.14: The intensive\_property branch.

## magnetic\_permeability

IRI: [http://emmc.info/emmo#EMMO\\_1999ee31\\_39d6\\_49d6\\_ba5a\\_fc7c75f2c495](http://emmc.info/emmo#EMMO_1999ee31_39d6_49d6_ba5a_fc7c75f2c495)

### Relations:

- is\_a [intensive\\_property](#)

## crystalline\_fraction

IRI: [http://emmc.info/emmo#EMMO\\_3042c107\\_5dc3\\_4264\\_9b64\\_d5ff081f3f27](http://emmc.info/emmo#EMMO_3042c107_5dc3_4264_9b64_d5ff081f3f27)

### Relations:

- is\_a [intensive\\_property](#)

## lattice\_constant

IRI: [http://emmc.info/emmo#EMMO\\_3acc8796\\_7874\\_40aa\\_82b7\\_ae634aad69b0](http://emmc.info/emmo#EMMO_3acc8796_7874_40aa_82b7_ae634aad69b0)

### Relations:

- is\_a [intensive\\_property](#)

## chemical\_potential

IRI: [http://emmc.info/emmo#EMMO\\_459f2072\\_572d\\_463a\\_8865\\_4308d159b0d4](http://emmc.info/emmo#EMMO_459f2072_572d_463a_8865_4308d159b0d4)

### Relations:

- is\_a [intensive\\_property](#)

## pressure

IRI: [http://emmc.info/emmo#EMMO\\_4f10b764\\_7451\\_41c0\\_896e\\_001e78f1a15c](http://emmc.info/emmo#EMMO_4f10b764_7451_41c0_896e_001e78f1a15c)

### Relations:

- is\_a [intensive\\_property](#)

## density

IRI: [http://emmc.info/emmo#EMMO\\_bfca1d4c\\_d54a\\_4a2b\\_be76\\_db04e7a5e7f3](http://emmc.info/emmo#EMMO_bfca1d4c_d54a_4a2b_be76_db04e7a5e7f3)

### Relations:

- is\_a [intensive\\_property](#)

## specific\_property

IRI: [http://emmc.info/emmo#EMMO\\_d3d3a586\\_8a94\\_4cb0\\_ab58\\_8bf744628fda](http://emmc.info/emmo#EMMO_d3d3a586_8a94_4cb0_ab58_8bf744628fda)

### Relations:

- is\_a [intensive\\_property](#)

## specific\_volume

IRI: [http://emmc.info/emmo#EMMO\\_0ac4e80a\\_5dee\\_480c\\_aad3\\_a793ce1c3bd7](http://emmc.info/emmo#EMMO_0ac4e80a_5dee_480c_aad3_a793ce1c3bd7)

### Relations:

- is\_a [specific\\_property](#)

## specific\_heat\_capacity

IRI: [http://emmc.info/emmo#EMMO\\_10ca69fa\\_1e33\\_4f09\\_86c8\\_5502dc2079ab](http://emmc.info/emmo#EMMO_10ca69fa_1e33_4f09_86c8_5502dc2079ab)

### Relations:

- is\_a [specific\\_property](#)

## specific\_enthalpy

IRI: [http://emmc.info/emmo#EMMO\\_aa2b4aa5\\_cfb0\\_48eb\\_9afe\\_be30a6453245](http://emmc.info/emmo#EMMO_aa2b4aa5_cfb0_48eb_9afe_be30a6453245)

### Relations:

- is\_a [specific\\_property](#)

## species\_concentration

IRI: [http://emmc.info/emmo#EMMO\\_e537b57b\\_077b\\_4706\\_98fe\\_a8db7a7e26bd](http://emmc.info/emmo#EMMO_e537b57b_077b_4706_98fe_a8db7a7e26bd)

### Relations:

- is\_a [intensive\\_property](#)

## molar\_concentration

IRI: [http://emmc.info/emmo#EMMO\\_1770adbc\\_1de4\\_4eaf\\_a841\\_e4ec12e56dd1](http://emmc.info/emmo#EMMO_1770adbc_1de4_4eaf_a841_e4ec12e56dd1)

### Relations:

- is\_a [species\\_concentration](#)

## mass\_concentration

IRI: [http://emmc.info/emmo#EMMO\\_5e05e440\\_2165\\_4e12\\_8cdf\\_58add59fcdfb](http://emmc.info/emmo#EMMO_5e05e440_2165_4e12_8cdf_58add59fcdfb)

### Relations:

- is\_a [species\\_concentration](#)

## viscosity

IRI: [http://emmc.info/emmo#EMMO\\_eecf7dcf\\_dabc\\_441f\\_b09c\\_69286bd0dd94](http://emmc.info/emmo#EMMO_eecf7dcf_dabc_441f_b09c_69286bd0dd94)

### Relations:

- is\_a [intensive\\_property](#)

**temperature**

**IRI:** [http://emmc.info/emmo#EMMO\\_fefab665\\_aee5\\_4d63\\_9e4a\\_43f3e64a518c](http://emmc.info/emmo#EMMO_fefab665_aee5_4d63_9e4a_43f3e64a518c)

**Relations:**

- is\_a *intensive\_property*



## Chapter 4

# Appendix

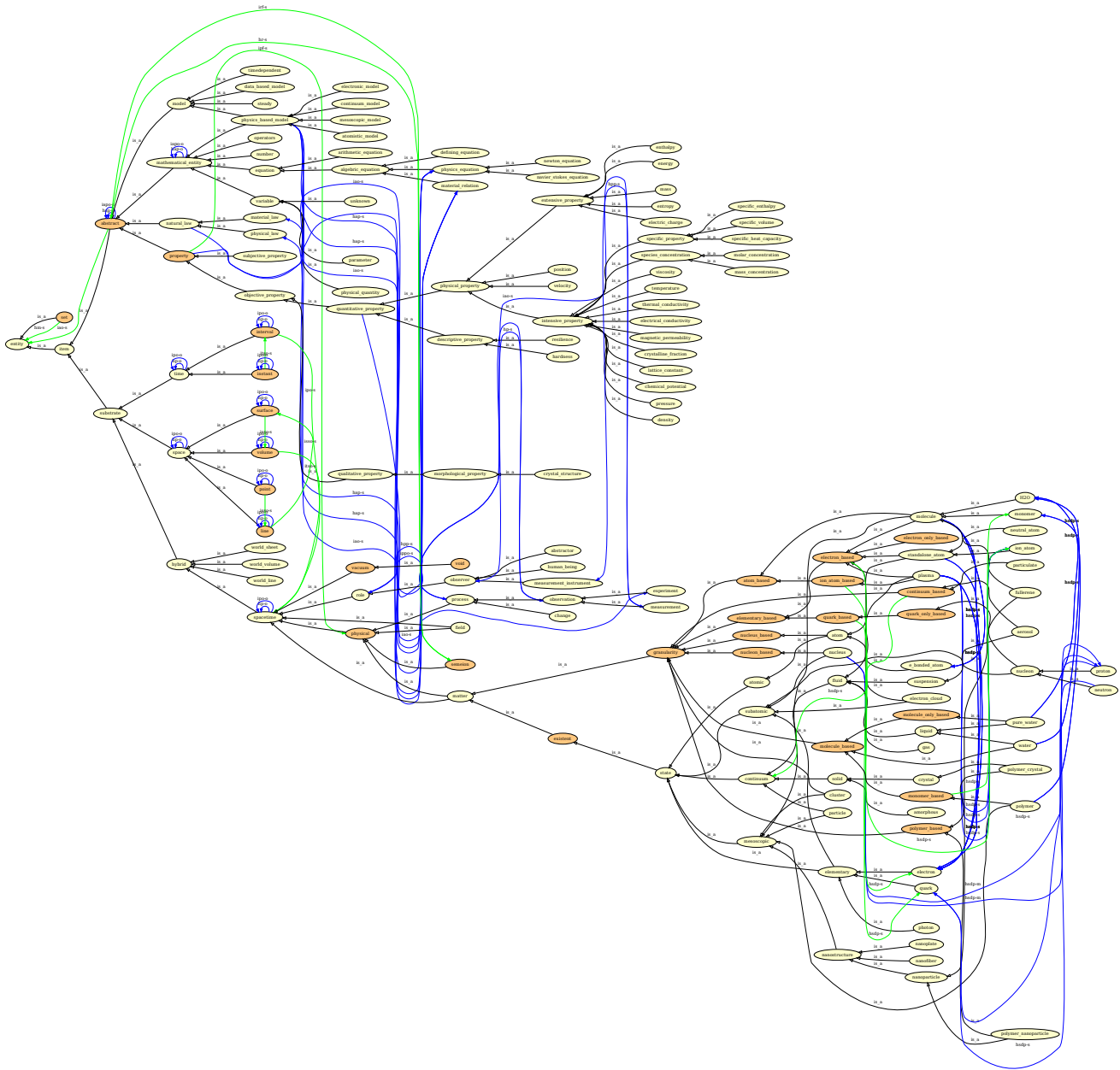


Figure 4.1: The full entity branch of EMMO including all relations between subbranches.