

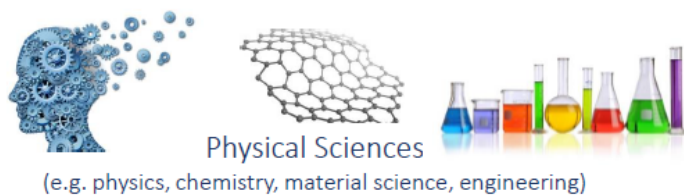
European Materials Modelling Ontology

VERSION 0.9.9

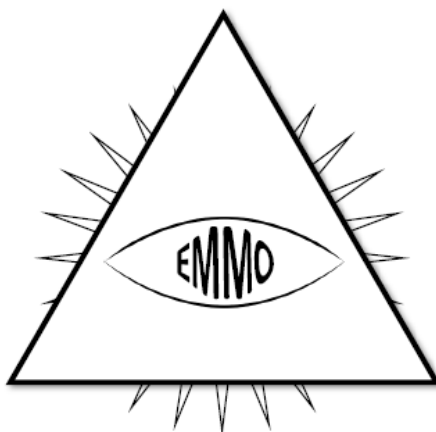
European Materials Modelling Council (EMMC)



January 26, 2020



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, modelling, characterisation, materials, ontology

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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 nature is illustrated by the figure on the title page. It provides the connection between the physical world, materials characterisation world and materials modelling world.

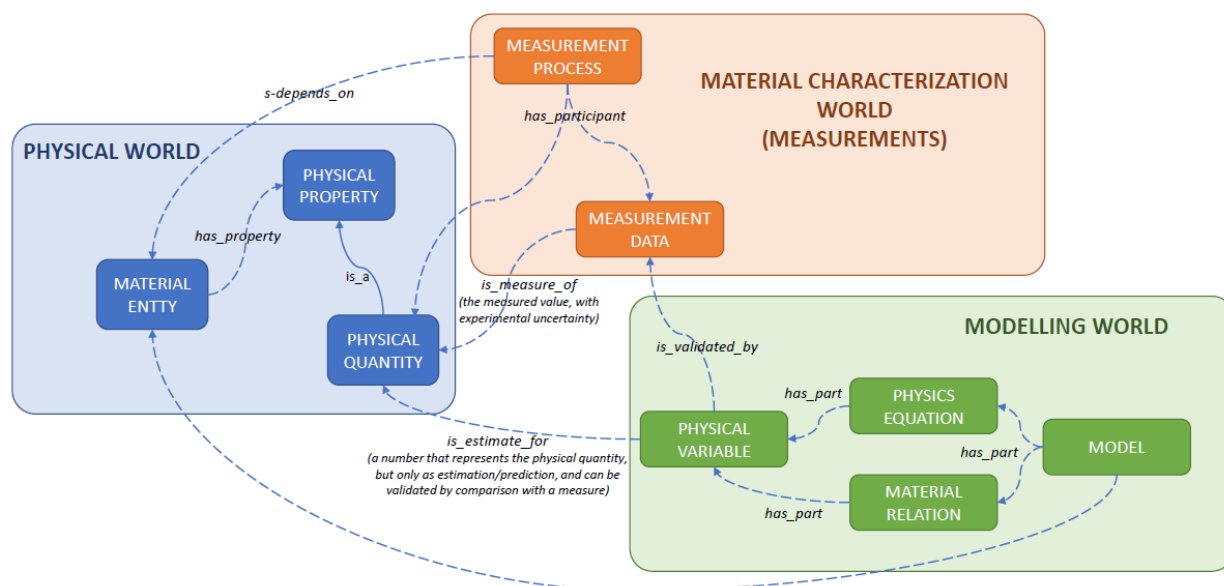


Figure 1.1: EMMO provides the connection between the physical world, materials characterisation world and materials modelling world.

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 than these foundations.

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 (characterisation)
- the **properties** that are measured or modelled
- the **physics laws** that describe 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

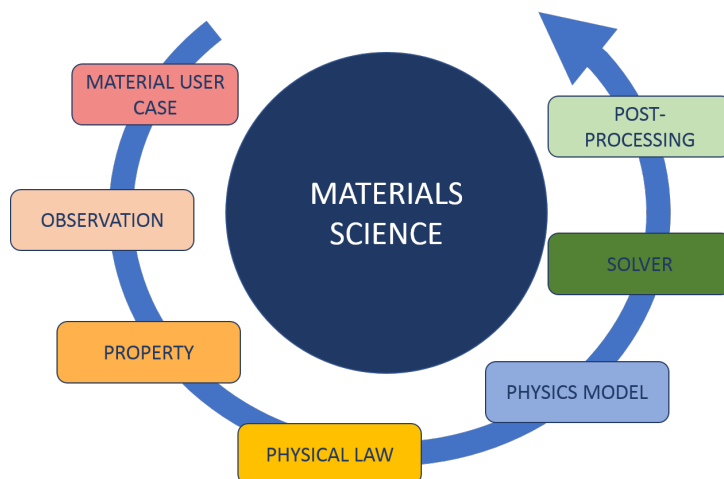


Figure 1.2: The aspects of materials modelling and characterisation covered by EMMO.

EMMO is released under the [Creative Commons license](#) and is available at emmo.info/. The OWL2-DL sources are available in RDF/XML format.

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 e.g. computer science, it illustrates the basic idea; the ontology defines some basic premises (concepts and relations between them) from which it is possible 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 is for the organisation of 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.

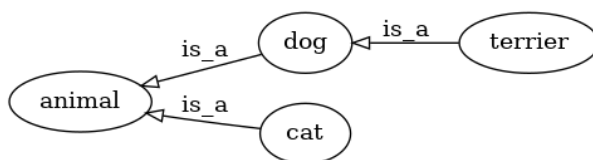


Figure 1.3: Example of a taxonomy.

In EMMO, the taxonomy is a rooted directed acyclic graph (DAG). This is important since many classification methods relies on this property, see e.g. [Valentini \(2014\)](#) and [Robison et al \(2015\)](#). Note, that EMMO is a DAG does not prevent some classes from having more than one parent. A `Variable` is for instance both a `Mathematical` and a `Symbol`. See [appendix](#) for the full EMMO taxonomy.

Primitive elements in EMMO

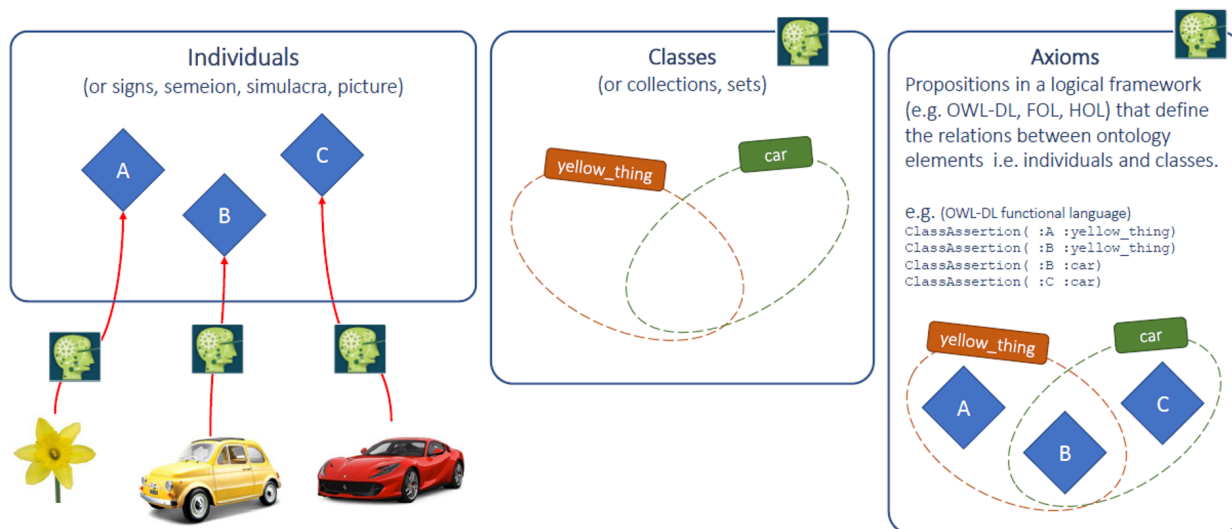


Figure 1.4: The primitive building blocks of EMMO.

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 possess attributes in form of axioms that are defined by the user (interpreter) upon declaration.

Classes

Classes represent 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, The root EMMO and a defined class (defined to be the disjoint union of *Item* and *Collection*).

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

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:

- *Subclass* (`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.
- *Equivalence* (`owl:equivalentClass`) allows one to say that a class description has exactly the same class extension (i.e. the individuals associated with the class) as another class description.
- *Disjointness* (`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.

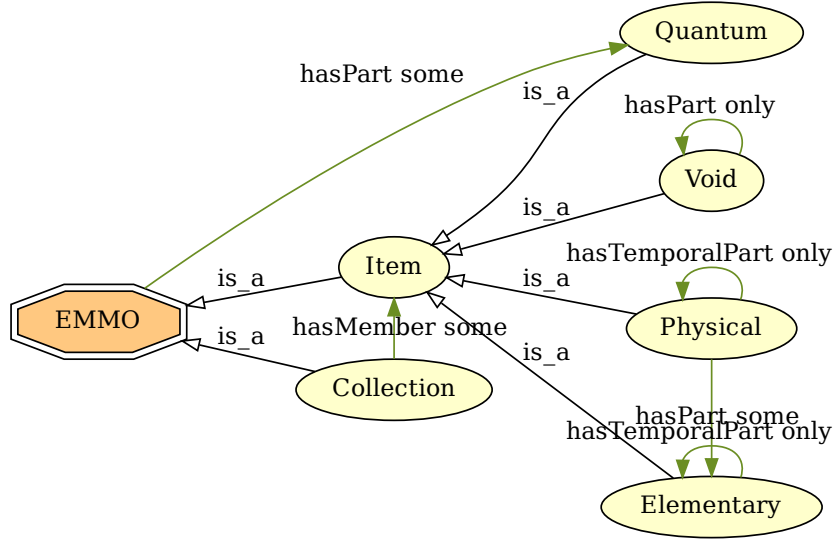


Figure 1.5: Example of the top-level entity branch showing some classes and relationships between them.

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 dicipline of formulating something that possibly can exist in a defined space and time in the real world.

Mereotopology

Mereotopology is the combination of **mereology** (science of parthood) and **topology** (mathematical study of the geometrical properties and conservation through deformations). It is introduced via the **Item** class and based on the **mereotopological** relations. Items in EMMO are always topologically connected in space and time. EMMO makes a strong distinction between membership and parthood relations. In contrast to collections, items can only have parts that are themselves items. For further information, see [Casati and Varzi “Parts and Places” \(1999\)](#).

Physics

EMMO is strongly based on physics, with the aim of being able to describe all aspects and all domains of physics, from quantum mechanics to continuum, engeneering, chemistry, etc. EMMO is compatible with both the De Broglie - Bohm and the Copenhagen interpretation of quantum mecancis (see [Physical](#) for more comments).

EMMO defines a physics-based parthood hierachy under **Physical** by introducing the following concepts (illustrated in the figure below):

- **Elementary** is the fundamental, non-divisible constituent of entities. In EMMO, elementaries are based on the standard model of physics.

- **State** is a **Physical** whose parts does not change during its life time (at the chosen level of granularity). This is consistent with a state within e.g. thermodynamics.
- **Existent** is a succession of states.

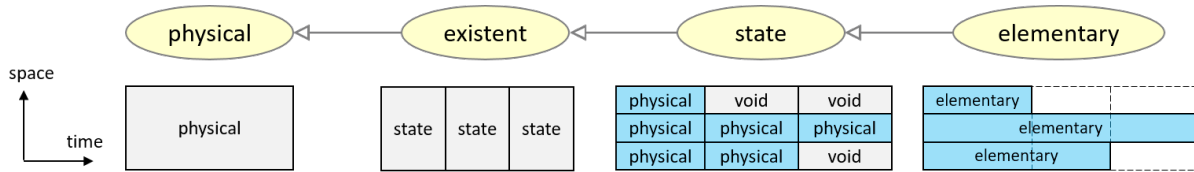


Figure 1.6: Parthood hierarchy under **Physical**.

Metrology

Metrology is the science of measurements. It introduces units and links 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 in turn is based on DL. This brings along 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 between six 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 exist for DL. An interesting example is the pure Python syntax proposed by [Lamy \(2017\)](#), which is used in the open source [Owlready2](#) Python package. The [Python API for EMMO](#) is also based on Owlready2.

Table 1.1: Notation for DL and Protege. A and B are classes, R is an active relation, S is an passive relation, a and b are individuals and n is a literal. Inspired by the [Great table of Description Logics](#).

DL	Manchester	Python + Owlready2	Read	Meaning
Constants				
\top		Thing	top	A special class with every individual as an instance
\perp		Nothing	bottom	The empty class
Axioms				
$A \doteq B$			A is defined to be equal to B	Class <i>definition</i>
$A \sqsubseteq B$	A subclass_of B	class A(B): ... issubclass(A, B)	all A are B	Class <i>inclusion</i> Test for <i>inclusion</i>

DL	Manchester	Python + Owlready2	Read	Meaning
$A \equiv B$	A equivalent_to B	A.equivalent_to.append(B) B in A.equivalent_to	A is equivalent to B	Class <i>equivalence</i> Test for equivalence
$a : A$	a is_a A	a = A() isinstance(a, A)	a is a A	Class <i>assertion</i> (<i>instantiation</i>) Test for instance of
$(a, b) : R$	a object property assertion b	a.R.append(b)	a is R-related to b	Property <i>assertion</i>
$(a, n) : R$	a data property assertion n	a.R.append(n)	a is R-related to n	Data <i>assertion</i>
Constructions				
$A \sqcap B$	A and B	A & B	A and B	Class <i>intersection</i> (<i>conjunction</i>)
$A \sqcup B$	A or B	A B	A or B	Class <i>union</i> (<i>disjunction</i>)
$\neg A$	not A	Not(A)	not A	Class <i>complement</i> (<i>negation</i>)
$\{a, b, \dots\}$	{a, b, ...}	OneOf([a, b, ...])	one of a, b, ...	Class <i>enumeration</i>
$S \equiv R^{-}$	S inverse_of R	Inverse(R) S.inverse == R	S is inverse of R	Property <i>inverse</i> Test for <i>inverse</i>
$\forall R.A$	R only A	R.only(A)	all A with R	<i>Universal restriction</i>
$\exists R.A$	R some A	R.some(A)	some A with R	<i>Existential restriction</i>
$= nR.A$	R exactly n A	R.exactly(n, A)		<i>Cardinality restriction</i>
$\leq nR.A$	R min n A	R.min(n, A)		<i>Minimum cardinality restriction</i>
$\geq nR.A$	R max n A	R.max(n, A)		<i>Maximum cardinality restriction</i>
$\exists R\{a\}$	R value a	R.value(a)		<i>Value restriction</i>
Decompositions				
$A \sqcup B \sqsubseteq \perp$	A disjoint with B	AllDisjoint([A, B]) B in A.disjoints()	A disjoint with B	Disjoint Test for disjointness
$\exists R.\top \sqsubseteq A$	R domain A	R.domain = [A]		Classes that the restriction applies to
$\top \sqsubseteq \forall R.B$	R range B	R.range = [B]		All classes that can be the value of the restriction

Examples

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

Equivalence (`owl:equivalentTo`)

Equivalence (\equiv) defines necessary and sufficient conditions.

Parent is equivalent to mother or father

DL: `parent \equiv mother \vee father`

Manchester: parent equivalent_to mother or father

Inclusion (rdf:subclassOf)

Inclusion (\sqsubseteq) defines necessary conditions.

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}

Existential 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

Universal restriction (owl:allValuesFrom)

All parents that only have daughters:

DL: parents_with_only_daughters \equiv person \sqcap \forall has_child.woman

Manchester: parents_with_only_daughters equivalent_to person and has_child only woman

Value 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: Marys_children \equiv person \sqcap \exists has_parent.{Mary}

Manchester: Marys_children equivalent_to person and has_parent value Mary

Property cardinality (owl:cardinality)

The owl:cardinality restrictions (\geq , \leq or \equiv) allow 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: half_orphant \equiv person and =1has_parent.person

Manchester: half_orphant equivalent_to person and has_parent exactly 1 person

Intersection (owl:intersectionOf)

Individuals of the intersection (\sqcap) of two classes, are simultaneously instances of both classes.

A man is a person that is male:

DL: man \equiv person \sqcap male

Manchester: man equivalent_to person and male

Union (`owl:unionOf`)

Individuals of the union (\sqcup) of two classes, are either instances of one or both classes.

A person is a man or woman:

DL: `person` \equiv `man` \sqcup `woman`

Manchester: `person` `equivalent_to` `man` or `woman`

Complement (`owl:complementOf`)

Individuals of the complement (\neg) of a class, are all individuals that are not member of the class.

Not a man:

DL: `female` \equiv \neg `male`

Manchester: `female` `equivalent_to` not `male`

The structure of EMMO

EMMO is structures in a hierarchical set of modules covering, expressed by specific ontology fragments, that extends from fundamental concepts to the application domains, following the dependency flow. The modules and their interdependencies are shows in the figure below. Each module correspond to a separate OWL file. The special module `emmo.owl` includes all of EMMO.

EMMO core groups

- **Base:** The [emmo-base](#) is the fundamental group of axioms that constitutes the philosophical foundation of the EMMO. Following a physicalistic/nominalistic perspective the EMMO defines real world objects as 4D objects that always extends in space and time (i.e. real world objects cannot be spaceless or timeless).

For this reason abstract objects, i.e. objects that does not extend in space and time, are forbidden in the EMMO. The role of abstract objects is fulfilled by semiotics objects, i.e. real world objects (e.g. symbols) that stand for other real world objects within a semiotic process.

The EMMO is also based on atomistic mereology applied to 4D. The EMMO calls it ‘quantum mereology’, since the atomic mereological object in the EMMO is a portion of spacetime at Planck level in time and space.

The [emmo-mereotopology](#) introduces the fundamental mereotopological concepts and their relations with the real world objects that they represent that lay the ground for all the subsequent ontology modules. The concept of topological connection is used to define the first distinction between ontology entities according to definition of self connectedness, by introducing the *item* and *collection* classes. Quantum mereology is represented by the *quantum* class. Connectivity is related to the concept of phisical causality.

The [emmo-4d](#) introduces the fundamental mereotopological relations used to distinguish between space and time dimensions.

The [emmo-physical](#) introduces the fundamental definitions in order to define the *physical* objects and the concept of *void* that plays a fundamental role in the description of multiscale objects and quantum systems. It also define the *elemetary* object that restricts mereological atomism in space, and refers to the concept of elementary particles coming from the Standard Model of Particles.

- **Perspectives:** For the EMMO, the only univocally defined real world objects are the *item* individual call **universe** that stands for the Universe and the *quantum* individuals. Every other real world object is a composition in time and space of *quantum* objects up to the most comprehensive object: the **universe**. These intermediate objects are not univocally defined, but their definition is provided according to some specific perspectives.

This is an expression of reductionism (i.e. objects are made of sub-objects) and epistemological pluralism (i.e. objects are always defined according to the perspective of an interpreter, or a class of interpreters).

The ontologies collected in the [emmo-perspectives](#) are different ways to represent the objects that populate the conceptual region between quantum and universe levels.

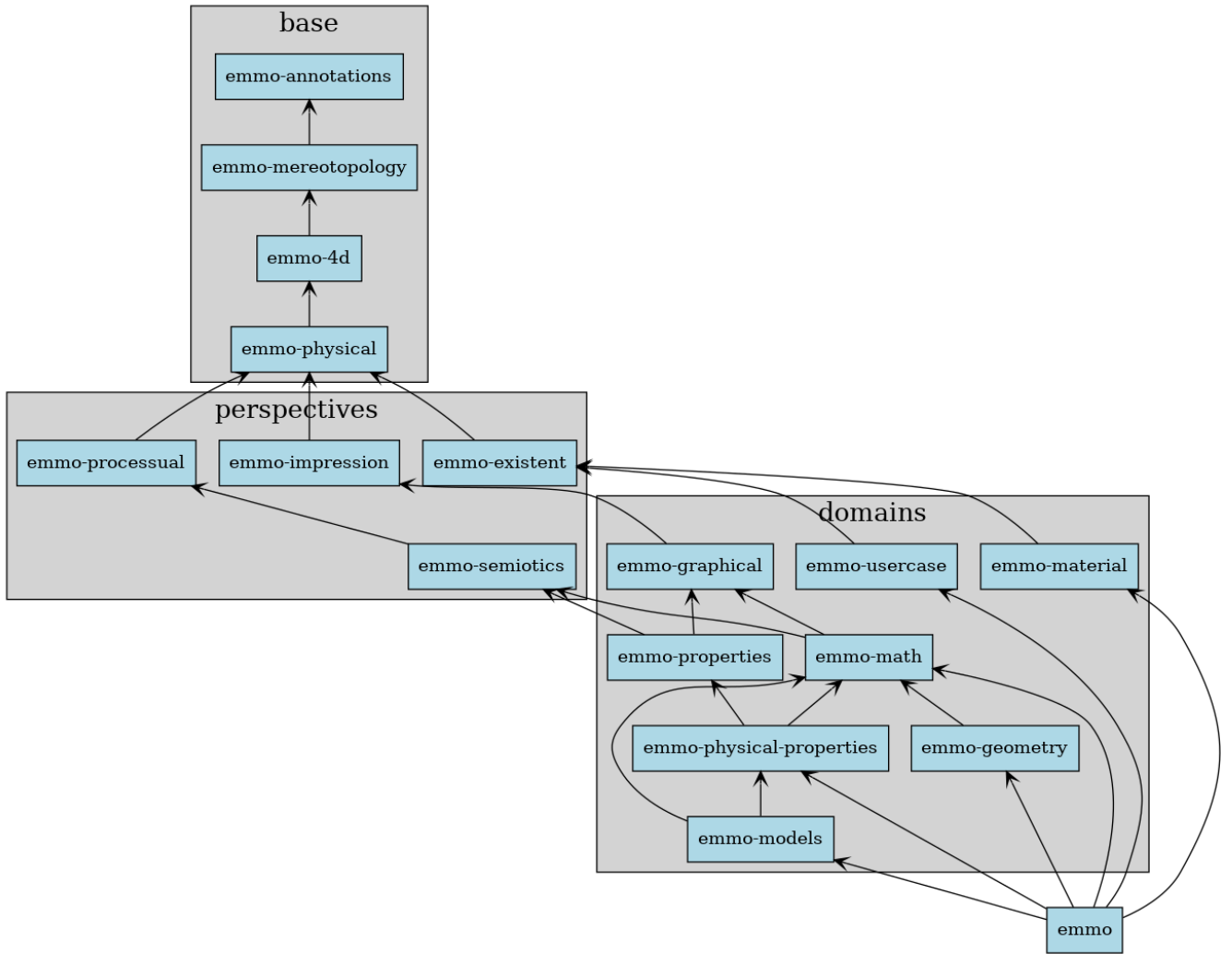


Figure 1.7: The hierarchy of EMMO modules and their interdependencies grouped into three groups; base, perspectives and domains.

The [emmo-existent](#) introduces the fundamental non-transitive parthood relations, called direct parthood, that provides a powerful granularity description of multi scale real world objects. The EMMO can in principle represents the **universe** as a direct rooted tree up to its quantum constituents.

The [emmo-impression](#) introduces the concept of real world objects that have a meaning for the EMMO user, by means of a recognizable pattern in space or time that impress the user. Under this class the EMMO categorize e.g. formal languages, pictures, geometry, mathematics, sounds. Impressions can be used in a semiotic process as signs.

The [emmo-processual](#) introduces the concept of real world objects that unfold in time in a way that has a meaning for the EMMO user, through the definition of the classes *process* and *participant*.

The [emmo-semiotics](#) introduces the concept of semiotic process that is used in the EMMO to represent e.g. models, formal languages, theories, information, properties.

- **Domains:** The domains ontologies act as roots for extending the EMMO under specific application domains. Up to now the EMMO includes graphical, geometry, material, mathematics, models, properties, physical properties and usecase.

Relations

All EMMO relations are subrelations of two roots relations: **mereotopological** and **semiotical**. The relation hierarchy extends more vertically (i.e. subrelations) than horizontally (i.e. sibling realtions), facilitating the categorization and inferencing of individual. See also the [EMMO Relations](#) chapter.

A unique feature in EMMO, is the introduction of *direct parthood*. As illustrated in the figure below, it is a mereological relation that lacks transitivity. This makes it possible to entities made of parts at different levels of granularity and to go between granularity levels in a well-defined manner. This is paramount for cross scale interoperability. Every material in EMMO is placed on a granularity level and the ontology gives information about the direct upper and direct lower level classes using the non-transitive direct parthood relations.

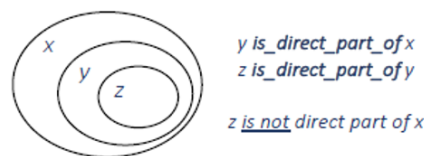


Figure 1.8: Direct parthood.

Annotations

All entities and relations in EMMO have some attributes, called *annotations*. In some cases, only the required *International Resource Identifier* (IRI) and *relations* are provided. However, descriptive annotations, like *elucidation* and *comment*, are planned to be added for all classes and relations. 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. In EMMO, the IRIs are now valid URLs pointing to the stable version of EMMO.
- **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 expressed using the Manchester OWL syntax introduced in section [Description logic](#).

Chapter 2

EMMO 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 only call them *relations*.

[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 OWL 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 **dog** is the subject, **is_a** the predicate and **animal** the object.

OWL distingues between *object properties*, that link classes or individuals to classes or individuals, and *data properties* that link individuals to data values. Since EMMO only deals with classes, we will only be discussing object properties. However, in actual simulation or characterisation applications build on EMMO, datatype properties will be important.

The characteristics of the different properties are 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 of **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 *y1* and *y2* such that the pairs (*x,y1*) and (*x,y2*) 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 instance of *P*, then we can infer that 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 **siblingOf** relation.
- **rdfs:domain** specifies which classes the property applies to. Or said differently, the valid values of the *subject* in a *subject-predicate-object* triplet.
- **rdfs:range** specifies the property extension, i.e. the valid values of the *object* in a *subject-predicate-object* triplet.

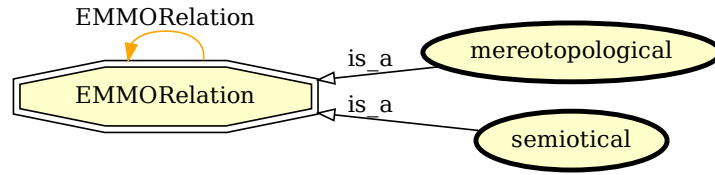


Figure 2.1: Top-level of the EMMO relation hierarchy.

Root of EMMO relations

EMMORelation

IRI: http://emmo.info/base/emmo-mereotopology.owl#EMMO_ec2472ae_cf4a_46a5_8555_1556f5a6c3c5

Relations:

- `is_a` owl:ObjectProperty
- `is_a` owl:SymmetricProperty
- `is_a` owl:TransitiveProperty
- `is_a` owl:topObjectProperty
- `inverse_of` **EMMORelation**
- `domain` **EMMO**
- `range` **EMMO**

Mereotopological branch

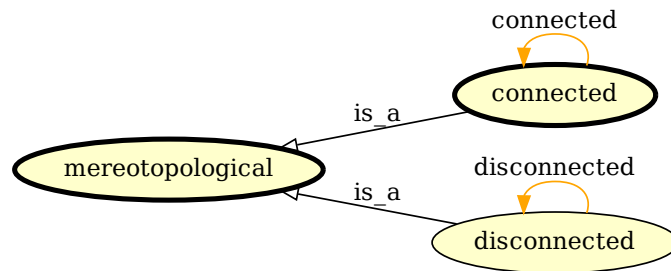


Figure 2.2: Mereotopological branch.

mereotopological

IRI: http://emmo.info/base/emmo-mereotopology.owl#EMMO_03212fd7_abfd_4828_9c8e_62c293052d4b

Comment: Mereotopology merges mereological and topological concepts and provides relations between wholes, parts, boundaries, etc.

Relations:

- `is_a` owl:ObjectProperty
- `is_a` **EMMORelation**
- `Inverse(emmo-mereotopology.EMMORelation)`

disconnected

IRI: http://emmo.info/base/emmo-mereotopology.owl#EMMO_517dfaf9_4970_41ac_81ee_d031627d2c7c

Relations:

- is_a owl:ObjectProperty
- is_a owl:SymmetricProperty
- is_a mereotopological
- Inverse(emmo-mereotopology.mereotopological)
- inverse_of disconnected

Connected branch

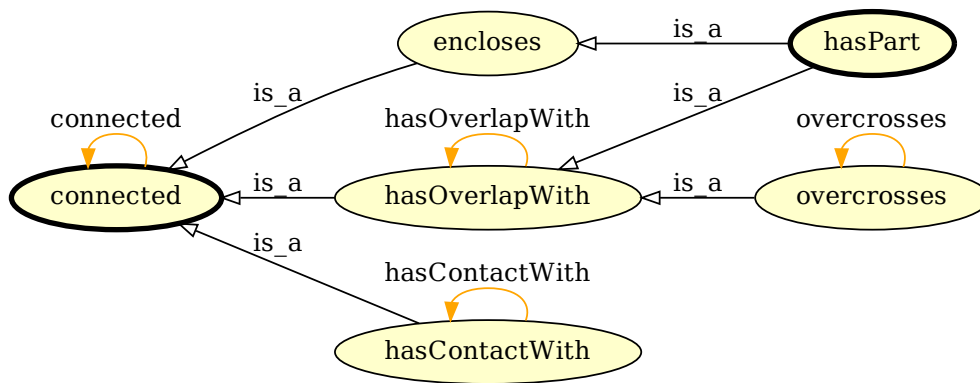


Figure 2.3: Connected branch.

connected

IRI: http://emmo.info/base/emmo-mereotopology.owl#EMMO_6703954e_34c4_4a15_a9e7_f313760ae1a8

Comment: Causality is a topological property between connected items.

Comment: Items being connected means that there is a topological contact or “interaction” between them.

Relations:

- is_a owl:ObjectProperty
- is_a owl:SymmetricProperty
- is_a mereotopological
- Inverse(emmo-mereotopology.mereotopological)
- inverse_of connected

encloses

IRI: http://emmo.info/base/emmo-mereotopology.owl#EMMO_8c898653_1118_4682_9bbf_6cc334d16a99

Comment: Enclosure is reflexive and transitive.

Seealso: is_enclosed_by

Relations:

- is_a owl:ObjectProperty
- is_a owl:TransitiveProperty

- is_a **connected**
- Inverse(emmo-mereotopology.connected)

hasContactWith

IRI: http://emmo.info/base/emmo-mereotopology.owl#EMMO_4d6504f1_c470_4ce9_b941_bbbebc9ab05d

Relations:

- is_a owl:ObjectProperty
- is_a owl:SymmetricProperty
- is_a **connected**
- Inverse(emmo-mereotopology.connected)
- inverse_of **hasContactWith**

hasOverlapWith

IRI: http://emmo.info/base/emmo-mereotopology.owl#EMMO_d893d373_b579_4867_841e_1c2b31a8d2c6

Relations:

- is_a owl:ObjectProperty
- is_a owl:SymmetricProperty
- is_a **connected**
- Inverse(emmo-mereotopology.connected)
- inverse_of **hasOverlapWith**

overcrosses

IRI: http://emmo.info/base/emmo-mereotopology.owl#EMMO_9cb984ca_48ad_4864_b09e_50d3fff19420

Relations:

- is_a owl:ObjectProperty
- is_a owl:SymmetricProperty
- is_a **hasOverlapWith**
- Inverse(emmo-mereotopology.hasOverlapWith)
- inverse_of **overcrosses**

Has Part branch

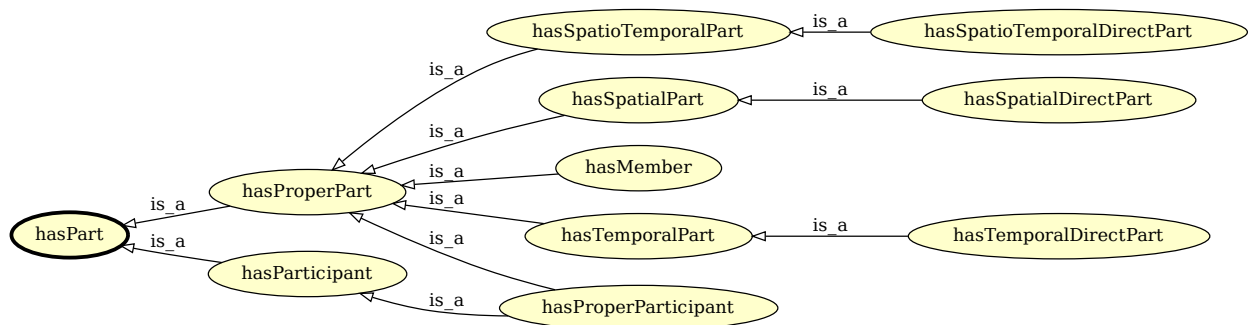


Figure 2.4: Has Part branch.

hasPart

IRI: http://emmo.info/base/emmo-mereotopology.owl#EMMO_17e27c22_37e1_468c_9dd7_95e137f73e7f

Relations:

- is_a owl:ObjectProperty
- is_a owl:TransitiveProperty
- is_a **encloses**
- is_a **hasOverlapWith**
- Inverse(emmo-mereotopology.hasOverlapWith)

hasParticipant

IRI: http://emmo.info/perspectives/emmo-processual.owl#EMMO_ae2d1a96_bfa1_409a_a7d2_03d69e8a125a

Elucidation: The relation between a process and an object participating to it.

Comment: Participation is a parthood relation: you must be part (and then be connected) of the process to contribute to it.

Comment: Participation is not under direct parthood since a process is not strictly related to reductionism, but it's a way to categorize temporal regions by the interpreters.

Relations:

- is_a owl:ObjectProperty
- is_a **hasPart**
- domain **Process**
- range **Participant**

hasProperPart

IRI: http://emmo.info/base/emmo-mereotopology.owl#EMMO_9380ab64_0363_4804_b13f_3a8a94119a76

Relations:

- is_a owl:ObjectProperty
- is_a owl:TransitiveProperty
- is_a **hasPart**

hasSpatialPart

IRI: http://emmo.info/base/emmo-4d.owl#EMMO_f68030be_94b8_4c61_a161_886468558054

Elucidation: A relation that isolates a proper part that extends itself in time within the lifetime of the whole, without covering the full spatial extension of the 4D whole (i.e. is not a temporal part).

Relations:

- is_a owl:ObjectProperty
- is_a owl:TransitiveProperty
- is_a **hasProperPart**
- domain **Item**
- range **Item**

hasSpatioTemporalPart

IRI: http://emmo.info/base/emmo-4d.owl#EMMO_6e046dd0_9634_4013_b2b1_9cc468087c83

Elucidation: A relation that isolates a proper part that extends itself in time through a portion of the lifetime whole.

Relations:

- is_a owl:ObjectProperty
- is_a owl:TransitiveProperty
- is_a **hasProperPart**
- domain **Item**
- range **Item**

hasTemporalPart

IRI: http://emmo.info/base/emmo-mereotopology.owl#EMMO_7afbed84_7593_4a23_bd88_9d9c6b04e8f6

Elucidation: A relation that isolate a proper part that covers the total spatial extension of a whole within a time interval.

Relations:

- is_a owl:ObjectProperty
- is_a owl:TransitiveProperty
- is_a **hasProperPart**
- domain **Item**
- range **Item**

hasProperParticipant

IRI: http://emmo.info/perspectives/emmo-processual.owl#EMMO_c5aae418_1622_4d02_93c5_21159e28e6c1

Relations:

- is_a owl:ObjectProperty
- is_a **hasProperPart**
- is_a **hasParticipant**

hasMember

IRI: http://emmo.info/base/emmo-mereotopology.owl#EMMO_6b7276a4_4b9d_440a_b577_0277539c0fc4

Relations:

- is_a owl:ObjectProperty
- is_a owl:AsymmetricProperty
- is_a owl:IrreflexiveProperty
- is_a **hasProperPart**
- domain **Collection**
- range **Item**

hasSpatialDirectPart

IRI: http://emmo.info/perspectives/emmo-existent.owl#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 **hasSpatialPart**
- domain **Existent**
- range **Existent**

hasSpatioTemporalDirectPart

IRI: http://emmo.info/perspectives/emmo-existent.owl#EMMO_a50d920d_1ee3_4668_9a73_5d80a1c6fe15

Relations:

- is_a owl:ObjectProperty
- is_a owl:InverseFunctionalProperty
- is_a owl:AsymmetricProperty
- is_a owl:IrreflexiveProperty
- is_a **hasSpatioTemporalPart**
- domain **Existent**
- range **Existent**

hasTemporalDirectPart

IRI: http://emmo.info/perspectives/emmo-existent.owl#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 **hasTemporalPart**
- domain **Existent**
- range **State**

Semiotical branch

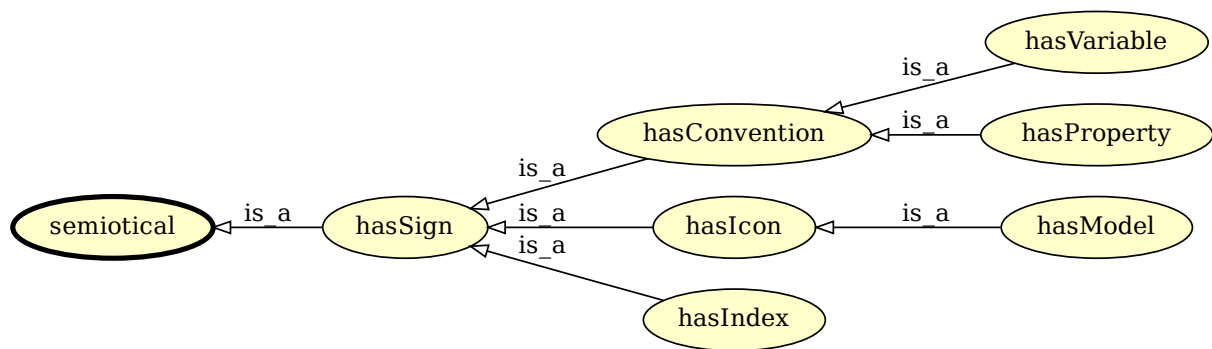


Figure 2.5: Semiotical branch.

semiotical

IRI: http://emmo.info/perspectives/emmo-semiotics.owl#EMMO_2337e25c_3c60_43fc_a8f9_b11a3f974291

Elucidation: The generic EMMO semiotical relation.

Relations:

- is_a owl:ObjectProperty
- is_a **EMMORelation**
- Inverse(emmo-mereotopology.EMMORelation)

hasSign

IRI: http://emmo.info/perspectives/emmo-semiotics.owl#EMMO_60577dea_9019_4537_ac41_80b0fb563d41

Relations:

- is_a owl:ObjectProperty
- is_a **semiotical**
- domain **Object**
- range **Sign**

hasConvention

IRI: http://emmo.info/perspectives/emmo-semiotics.owl#EMMO_eb3518bf_f799_4f9e_8c3e_ce59af11453b

Relations:

- is_a owl:ObjectProperty
- is_a **hasSign**
- range **Conventional**

hasIcon

IRI: http://emmo.info/perspectives/emmo-semiotics.owl#EMMO_39c3815d_8cae_4c8f_b2ff_eeba24bec455

Relations:

- is_a owl:ObjectProperty
- is_a **hasSign**
- range **Icon**

hasIndex

IRI: http://emmo.info/perspectives/emmo-semiotics.owl#EMMO_297999d6_c9e4_4262_9536_bd524d1c6e21

Relations:

- is_a owl:ObjectProperty
- is_a **hasSign**
- range **Index**

hasModel

IRI: http://emmo.info/domains/emmo-models.owl#EMMO_24c71baf_6db6_48b9_86c8_8c70cf36db0c

Relations:

- is_a owl:ObjectProperty
- is_a **hasIcon**

hasProperty

IRI: http://emmo.info/domains/emmo-properties.owl#EMMO_e1097637_70d2_4895_973f_2396f04fa204

Relations:

- is_a owl:ObjectProperty
- is_a **hasConvention**
- range **Property**

hasVariable

IRI: http://emmo.info/domains/emmo-math.owl#EMMO_3446e167_c576_49d6_846c_215bb8878a55

Relations:

- is_a owl:ObjectProperty
- is_a **hasConvention**
- domain **Number**
- range **Variable**

Chapter 3

EMMO Classes

emmo 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.

EMMO branch

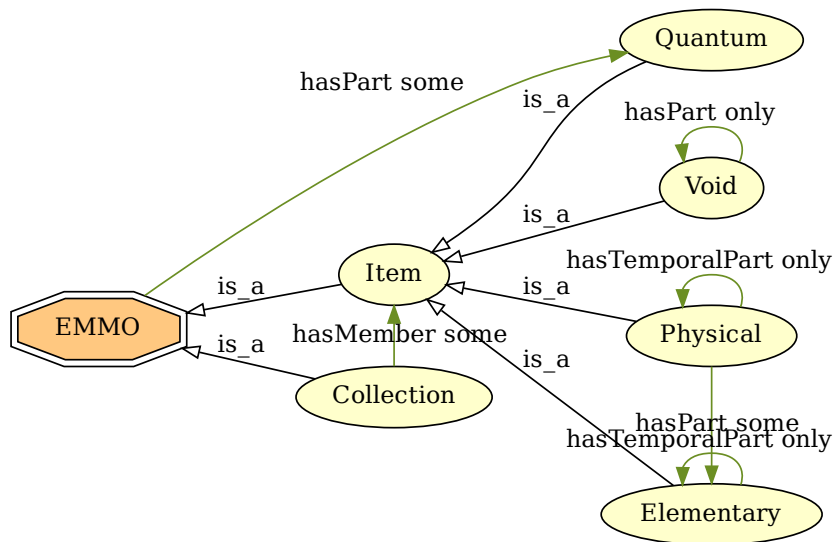


Figure 3.1: EMMO branch.

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

collection is the class representing the collection of all the individuals (signs) that represents a collection of non-connected real world objects.

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 mereotopology.

EMMO

IRI: http://emmo.info/base/emmo-mereotopology.owl#EMMO_802d3e92_8770_4f98_a289_ccaaab7fdddf

Elucidation: The class representing the collection of all the individuals declared in this ontology that stand for real world objects.

Comment: ‘emmo’ is the disjoint union of ‘item’ and ‘collection’ (covering axiom).

The union implies that ‘emmo’ individuals can only be ‘item’ individuals (standing for self-connected real world objects) or ‘collection’ individuals (standing for a collection of disconnected items).

Disjointness means that a ‘collection’ individual cannot be an ‘item’ individual and viceversa, meaning that a real world object cannot be self-connected and non-self connected at the same time.

Comment: For the EMMO the whole universe is represented at meta-ontological level (i.e. the representational level that includes the ontologist, the ontology and the universe) as a 4D path-connected topological manifold (i.e. the spacetime).

Mereotopology is the fundamental logical representation used to characterize the universe and to provide the definitions for the EMMO concepts at interpreter’s level.

A real world object is then a 4D topological sub-region of the universe.

A universe sub-region is isolated and defined as a real world object by the ontologist. Then, through a semiotic process that occurs at the meta-ontological level (i.e. outside the ontology). an ontology entity (e.g. an OWL individual) is assigned to represent that real world object.

The fundamental distinction between real world objects, upon which the EMMO is based, is self-connectedness: a real world object can be self-connected xor not self-connected.

Comment: In the EMMO we will refer to the universe as a Minkowski space, restricting the ontology to special relativity only. However, extension to general relativity, will adding more complexity, should not change the overall approach.

Comment: Parthood relations does not change dimensionality of an ‘emmo’ individual, i.e. every part of a real world object always retains its 4D dimensionality.

The smallest part is a ‘quantum’, that has no proper parts.

It follows that, for the EMMO, real world objects of dimensionality lower than 4D do not exist (e.g. surfaces, lines).

Relations:

- is_a owl:Thing
- (hasPart some Quantum)
- equivalent_to (Inverse(emmo-mereotopology.hasPart) value Universe)
- disjoint_union_of Collection, Item

Collection

IRI: http://emmo.info/base/emmo-mereotopology.owl#EMMO_2d2ecd97_067f_4d0e_950c_d746b7700a31

Elucidation: The class of all individuals that stands for a real world not self-connected object.

Comment: A ‘collection’ individual is a sign that stands for a non-self-connected real world object.

A ‘collection’ individual is related to each ‘item’ individuals of the collection (i.e. the members) through the membership relation.

An ‘item’ individual stands for a real world self-connected object which can be represented as a whole made of connected parts (e.g. a car made of components).

Comment: Formally, ‘collection’ is axiomatized as the class of individuals that ‘has_member’ some ‘item’.

A ‘collection’ cannot have as member another ‘collection’.

Comment: From Latin collectio, from colligere ‘gather together’.

Comment: e.g. the collection of users of a particular software, the collection of atoms that have been part of that just dissociated molecule, or even the collection of atoms that are part of a molecule considered as single individual non-connected objects and not as a mereotopological self-connected fusion.

Relations:

- is_a EMMO
- (hasMember some Item)

Item

IRI: http://emmo.info/base/emmo-mereotopology.owl#EMMO_eb3a768e_d53e_4be9_a23b_0714833c36de

Comment: A real world object is self-connected if any two parts that make up the whole are connected to each other (here the concept of connection is primitive).

Alternatively, using the primitive path-connectivity concept we can define a self-connected real world object as an object for which each couple of points is path-connected.

Comment: An ‘item’ individual stands for a real world self-connected object which can be represented as a whole made of connected parts (e.g. a car made of components).

In the EMMO, connectivity is the topological foundation of causality.

All physical systems, i.e. systems whose behaviour is explained by physics laws, are always represented by ‘item’-s.

Members of a ‘collection’ lack of causality connection, i.e. they do not constitute a physical system as a whole.

Comment: From Latin item, “likewise, just so, moreover”.

Relations:

- is_a **EMMO**
- disjoint_union_of **Void**, **Physical**

Individuals:

- **Universe**

Quantum

IRI: http://emmo.info/base/emmo-mereotopology.owl#EMMO_3f9ae00e_810c_4518_aec2_7200e424cf68

Elucidation: An ‘emmo’ that can’t be further divided in time nor in space.

Example: For a physics based ontology, like the EMMO, the ‘quantum’ can stand for the smallest identifiable portion of spacetime defined by the Planck limit in length (1.616e-35 m) and time (5.39e-44 s).

For a manpower management ontology, a ‘quantum’ can stand for an hour (time) of a worker (space) activity.

Comment: A ‘quantum’ is the most fundamental subclass of ‘item’, since we consider it as the smallest possible self-connected 4D real world object.

The quantum concept recalls the fact that there is lower epistemological limit to our knowledge of the universe, related to the uncertainty principle.

Comment: A ‘quantum’ stands for a 4D real world object.

Comment: A quantum is the EMMO mereological 4D a-tomic entity.

To avoid confusion with the concept of atom coming from physics, we will use the expression quantum mereology, instead of a-tomistic mereology.

Comment: From Latin quantum (plural quanta) “as much as, so much as;”, introduced in physics directly from Latin by Max Planck, 1900.

Relations:

- is_a **Item**
- (**hasProperPart** only owl:Nothing)

Void

IRI: http://emmo.info/base/emmo-physical.owl#EMMO_29072ec4_ffcb_42fb_bdc7_26f05a2e9873

Elucidation: A ‘item’ that has no ‘physical’ parts.

Comment: From Latin vacuus, “empty”.

Relations:

- is_a **Item**
- (hasPart only **Void**)

Physical branch

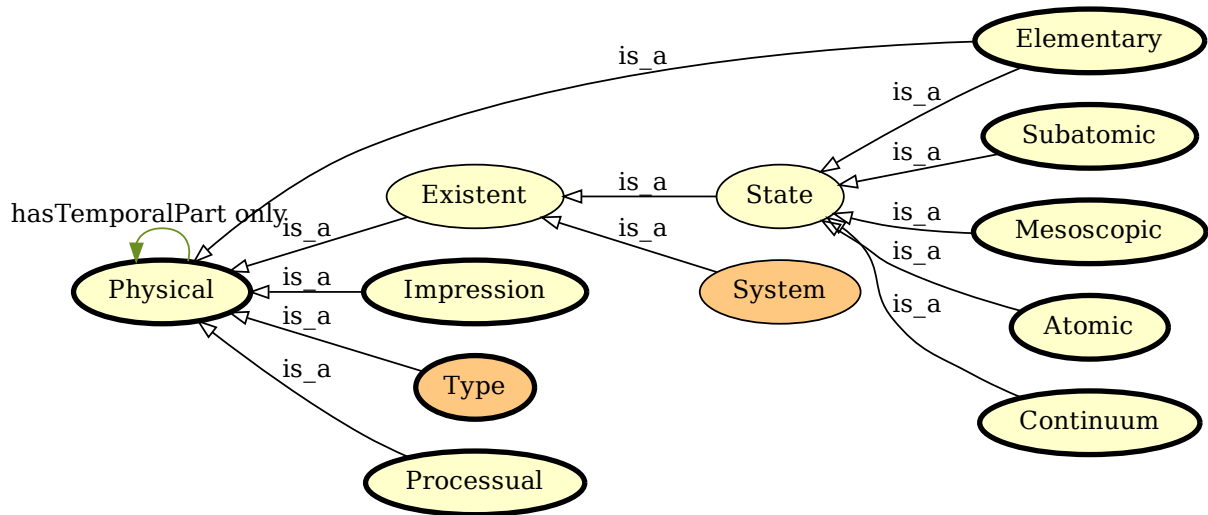


Figure 3.2: Physical branch.

Physical

IRI: http://emmo.info/base/emmo-physical.owl#EMMO_c5ddfdbba_c074_4aa4_ad6b_1ac4942d300d

Elucidation: A ‘item’ that is an ‘elementary’ or has some ‘elementary’ as proper parts and whose temporal proper parts are only ‘physical’-s (i.e. it can be perceived without interruptions in time).

Comment: A ‘physical’ is the class that contains all the individuals that stand for real world objects that interact physically with the interpreter.

Perception is a subcategory of interaction.

A physical must be perceived through physical interaction by the ontologist. Then the ontologist can declare an individual standing for the physical object just perceived.

Comment: A ‘physical’ must include at least an ‘elementary’ part, but can also include void parts.

A ‘physical’ may include as part also the ‘void’ surrounding or enclosed by its ‘physical’ sub parts.

There are no particular criteria for ‘physical’-s structure, except that is made of some ‘elementary’-s as proper parts and not only ‘void’.

This is done in order to: a) take into account the quantum nature of physical systems, in which the actual position of sub-components (e.g. electrons in an atom) is not known except for its probability distribution function (according to the Copenhagen interpretation.) b) take into account the fact that large entities (e.g. devices, cars, materials) have some void into them.

e.g. a ‘spacetime’ that has spatial parts an atom and a cubic light year of ‘void’ extending for some time can be a ‘physical’ individual.

Comment: A ‘physical’ with dimensions other than 4D cannot exist, following the restriction of the parent ‘emmo’ class.

It follows from the fact that perception is always a process (e.g. it unfolds in time).

e.g. you always have an aperture time when you take a picture or measure a property. Instantaneous perceptions are idealizations (abstractions) or a very small time measurement.

Comment: From Latin *physica* “study of nature” (and Ancient Greek *φυσικός*, “natural”).

Here the word relates to things perceived through the senses as opposed to the mind; tangible or concrete.

Comment: In the EMMO there are no relations such as ‘occupies_space’, since ‘physical’-s are themselves the 4D region.

Comment: The EMMO can be used to represent real world entities as ‘physical’-s that are easy to connect to classical or quantum mechanical based models.

Classical mechanics poses no representational issues, for the EMMO: the 4D representation of ‘physical’-s is consistent with classical physics systems.

However, the representation of ‘physical’-s that are typically analyzed through quantum mechanics (e.g. molecules, atoms, clusters), is not straightforward.

- 1) De Broglie - Bohm interpretation The most simple approach is to rely on Bohmian mechanics, in which each particle is supposed to exist in a specific position between measurements (hidden variables approach), while its trajectory is calculated using a Guiding Equation based on a quantum field calculated with the Schrodinger Equation.

While this approach is really easy to implement in an ontology, since each entity has its own well defined 4D region, its mathematical representation failed to receive large consensus due to the difficulties to include relativistic effects, to be extended to subnuclear scale and the strong non-locality assumption of the quantum field.

Nevertheless, the Bohmian mechanics is a numerical approach that is used in electronic models to reduce the computational effort of the solution of Schrodinger Equation.

In practice, an EMMO user can declare a ‘physical’ individual that stand for the whole quantum system to be described, and at the same time all sub-parts individuals can be declared, having them a well defined position in time, according to De Broglie - Bohm interpretation. The Hamiltonian can be calculated by considering the sub-part individuals.

‘physical’-s are then made of ‘physical’ parts and ‘void’ parts that stand for the space between ‘physical’-s (e.g. the void between electrons and nucleus in an atom).

- 2) Copenhagen interpretation In this interpretation the properties (e.g. energy level, position, spin) of a particle are not defined in the interval between two measurements and the quantum system is entangled (i.e. properties of particles in the system are correlated) and described by a global wavefunction obtained solving the Schrodinger Equation.

Upon measurement, the wavefunction collapses to a combination of close eigenstates that provide information about observables of the system components (e.g. position, energy).

The EMMO can be used to represent ‘physical’-s that can be related to Copenhagen based models. In practice, the user should follow these steps:

- a) define the quantum system as a ‘physical’ individual (e.g. an H2 molecule) under a specific class (e.g. ‘h2_molecule’). This individual is the whole.
- b) define the axioms of the class that describe how many sub-parts are expected for the whole and their class types (e.g. ‘h2_molecule’ has axioms ‘has_proper_part exactly 2 electron’ and ‘has_proper_part exactly 2 nucleus’)
- c) the user can now connect the whole to a Schrodinger equation based model whose Hamiltonian is calculated through the information coming only from the axioms. No individuals are declared for the subparts!
- d) a measurement done on the quantum system that provides information on the sub-part observables is interpreted as wavefunction collapse and leads to the end of the whole and the declaration of the sub-parts individuals which can be themselves other quantum systems

e.g. if the outer electron of the H2 molecule interacts with another entity defining its state, then the whole that stands for the entangled H2 molecule becomes a ‘physical’ made of an electron individual, a quantum system made of one electron and two nuclei and the void between them.

e.g. in the Born-Oppenheimer approximation the user represent the atom by un-entangling nucleus and electronic cloud. The un-entanglement comes in the form of declaration of individual as parts.

e.g. the double slit experiment can be represent in the EMMO as: a) before the slit: a ‘physical’ that extend in space and has parts ‘electron’ and ‘void’, called ‘single_electron_wave_function’. ‘electron’ and ‘void’ are only in the axioms and not decalred individuals. b) during slit passage: a ‘physical’ made of one declared individual, the ‘electron’. c) after the slit: again ‘single_electron_wave_function’ d) upon collision with the detector: ‘physical’ made of one declared individual, the ‘electron’.

Comment: The purpose of the ‘physical’ branch is to provide a representation of the real world objects, while the models used to explain or predict the behaviour of the real world objects lay under the ‘semiotic’ branch.

More than one model can be connected to the same ‘physical’.

e.g. Navier-Stokes or Euler equation applied to the same fluid

Relations:

- is_a **Item**
- (hasPart some **Elementary**)
- (hasTemporalPart only **Physical**)

Existent

IRI: http://emmo.info/perspectives/emmo-existent.owl#EMMO_52211e5e_d767_4812_845e_eb6b402c476a

Elucidation: A ‘item’ which is a ‘state’ or made only of ‘state’ temporal direct parts.

Comment: ‘existent’ is the most important class to be used for representing real world physical objects under a reductionistic (i.e. objects come from the composition of sub-part objects) and epistemological pluralistic (i.e. objects definitions are interpreter dependent) perspectives .

‘existent’ class collects all individuals that stand for real world physical objects that can be structured in well defined temporal sub-parts called states through the temporal direct parthood.

This class provides a granularity hierarchy in time, that provides a way to axiomatize tessellation principles for a specific whole with a non-transitivity relation that helps to retain the granularity levels.

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).

Relations:

- is_a **Physical**
- is_a **State** or (hasTemporalDirectPart some **State**)

State

IRI: http://emmo.info/perspectives/emmo-existent.owl#EMMO_36c79456_e29c_400d_8bd3_0eedddb82652

Elucidation: An ‘existent’ whose spatial direct parts extends from one change in spatial direct part cardinality (i.e. the number of spatial direct parts) to the immediate next change.

Example: 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 exists as state as long as the ice is completely melt at $t = t_{\text{end}}$. The new state will be completely made of water. Between t_{start} and t_{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: Direct partitions declaration is a choice of the ontology developer that choses the classes to be used as direct parts, according to its own world view.

A ‘state’ can always be direct partitioned in ‘elementary’-s and ‘void’ or ‘physical’.

e.g. the water in my glass can be seen as a single object without declaring direct parts, or as made of H₂O molecules direct parts.

Comment: The definition of ‘state’ implies that its spatial direct parts (i.e. ‘physicals’) 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 constant.

This does not mean that there cannot be a change in the internal structure of the ‘state’ direct parts. It means only that this change must not affect the existence of the direct part itself.

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

Also, the ‘state’ must cover all the time interval between two successive cardinality changes.

The use of spatial direct parthood in ‘state’ definition means that a ‘state’ cannot overlap in space another ‘state’.

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 ‘state’-s that can take into account the disappearance or appearance of parts within a ‘physical’.

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

The use of spatial direct parthood in state definition means that a state cannot overlap in space another state that is direct part of the same whole.

Relations:

- is_a **Existent**
- is_a **Elementary** or (hasSpatialDirectPart some **Existent**)

System

IRI: http://emmo.info/domains/emmo-usercase.owl#EMMO_e775e341_5687_4d45_b50c_379b098a8c26

Relations:

- is_a **Engineered**
- is_a **Existent**
- equivalent_to (hasSpatialDirectPart some **Component**)

Elementary branch

Elementary

IRI: http://emmo.info/base/emmo-physical.owl#EMMO_0f795e3e_c602_4577_9a43_d5a231aa1360

Elucidation: The basic constituent of ‘item’-s that can be proper partitioned only in time up to quantum level.

Comment: According to mereology, this should be call ‘a-tomistic’ in the strict etimological sense of the word (from greek, a-tomos: un-divisible).

Mereology based on such items is called atomistic mereology.

However, in order not to confuse the lexicon between mereology and physics (in which an atom is a divisible physical entity) we prefer to call it ‘elementary’, recalling the concept of elementary particle coming from the standard particles model.

Comment: While a ‘quantum’ is a-tomistic in time and space, an ‘elementary’ is a-tomistic only in space, recalling the concept of elementary particle.

Relations:

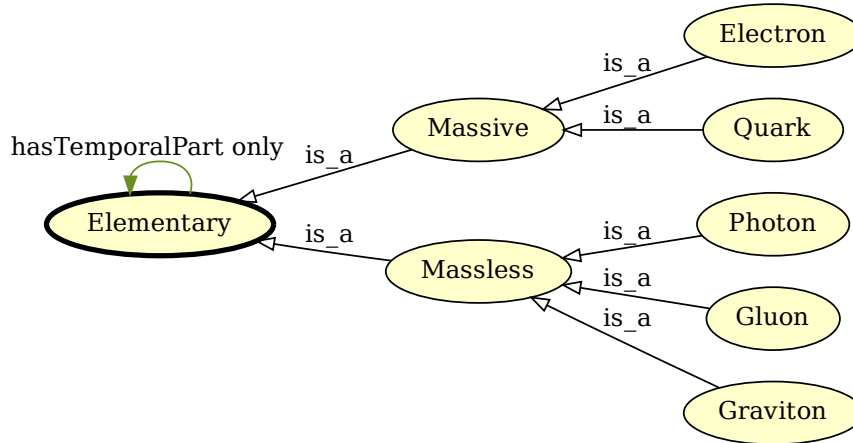


Figure 3.3: Elementary branch.

- is_a Subatomic
- is_a State
- is_a Physical
- is_a Item
- (hasSpatialPart only owl:Nothing)
- (hasTemporalPart only Elementary)
- disjoint_union_of Massive, Massless

Massive

IRI: http://emmo.info/domains/emmo-material.owl#EMMO_385b8f6e_43ac_4596_ad76_ac322c68b7ca

Relations:

- is_a Elementary
- disjoint_union_of Quark, Electron

Massless

IRI: http://emmo.info/domains/emmo-material.owl#EMMO_e5488299_8dab_4ebb_900a_26d2abed8396

Relations:

- is_a Elementary
- disjoint_union_of Photon, Gluon, Graviton

Electron

IRI: http://emmo.info/domains/emmo-material.owl#EMMO_8043d3c6_a4c1_4089_ba34_9744e28e5b3d

Relations:

- is_a Massive

Gluon

IRI: http://emmo.info/domains/emmo-material.owl#EMMO_7db59e56_f68b_48b7_ae99_891c35ae5c3b

Relations:

- is_a **Massless**

Graviton

IRI: http://emmo.info/domains/emmo-material.owl#EMMO_eb3c61f0_3983_4346_a0c6_e7f6b90a67a8

Relations:

- is_a **Massless**

Photon

IRI: http://emmo.info/domains/emmo-material.owl#EMMO_25f8b804_9a0b_4387_a3e7_b35bce5365ee

Relations:

- is_a **Massless**

Quark

IRI: http://emmo.info/domains/emmo-material.owl#EMMO_72d53756_7fb1_46ed_980f_83f47efbe105

Relations:

- is_a **Massive**

Subatomic branch

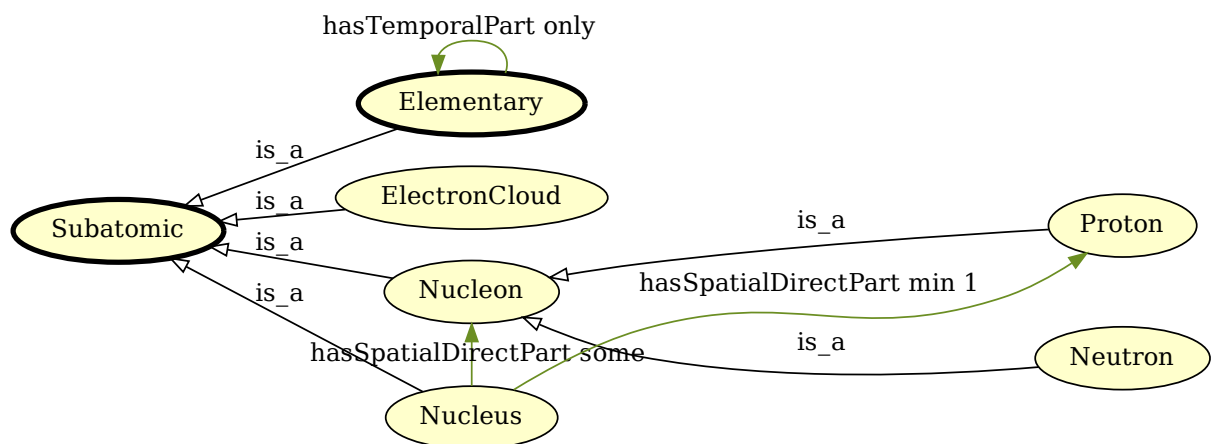


Figure 3.4: Subatomic branch.

Subatomic

IRI: http://emmo.info/domains/emmo-material.owl#EMMO_7d66bde4_b68d_41cc_b5fc_6fd98c5e2ff0

Relations:

- is_a **State**

ElectronCloud

IRI: http://emmo.info/domains/emmo-material.owl#EMMO_1067b97a_84f8_4d22_8ace_b842b8ce355c

Elucidation: A ‘spacetime’ that stands for a quantum system made of electrons.

Relations:

- is_a **Subatomic**
- (hasSpatialDirectPart some **Electron**)

Nucleon

IRI: http://emmo.info/domains/emmo-material.owl#EMMO_50781fd9_a9e4_46ad_b7be_4500371d188d

Relations:

- is_a **Subatomic**
- disjoint_union_of **Proton**, **Neutron**

Nucleus

IRI: http://emmo.info/domains/emmo-material.owl#EMMO_f835f4d4_c665_403d_ab25_dca5cc74be52

Relations:

- is_a **Subatomic**
- (hasSpatialDirectPart some **Nucleon**)
- (hasSpatialDirectPart min 1 **Proton**)

Neutron

IRI: http://emmo.info/domains/emmo-material.owl#EMMO_df808271_df91_4f27_ba59_fa423c51896c

Relations:

- is_a **Nucleon**
- (hasSpatialDirectPart some **Quark**)

Proton

IRI: http://emmo.info/domains/emmo-material.owl#EMMO_8f87e700_99a8_4427_8ffb_e493de05c217

Relations:

- is_a **Nucleon**
- (hasSpatialDirectPart some **Quark**)

Atomic branch

Atomic

IRI: http://emmo.info/domains/emmo-material.owl#EMMO_5c4aff3c_c30c_4507_86d5_b4df41eb9f2f

Relations:

- is_a **State**

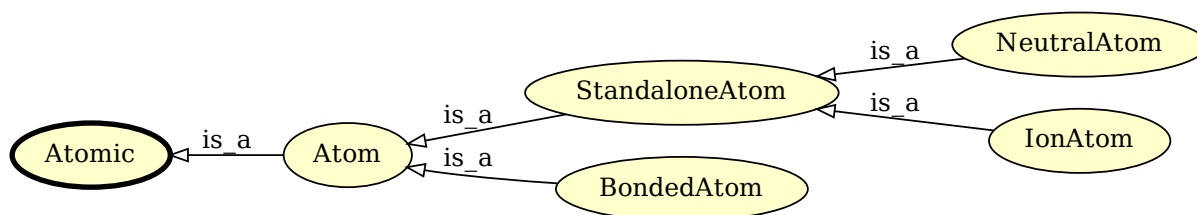


Figure 3.5: Atomic branch.

Atom

IRI: http://emmo.info/domains/emmo-material.owl#EMMO_eb77076b_a104_42ac_a065_798b2d2809ad

Elucidation: A standalone atom has direct part one ‘nucleus’ and one ‘electron_cloud’.

An O ‘atom’ within an O₂ ‘molecule’ is an ‘e-bonded_atom’.

In this material branch, H atom is a particular case, with respect to higher atomic number atoms, since as soon as it shares its electron it has no nucleus entangled electron cloud.

We cannot say that H₂ molecule has direct part two H atoms, but has direct part two H nucleus.

Comment: An ‘atom’ is a ‘nucleus’ surrounded by an ‘electron_cloud’, i.e. a quantum system made of one or more bounded electrons.

Relations:

- is_a **Atomic**
- (hasSpatialDirectPart exactly 1 **ElectronCloud**)
- (hasSpatialDirectPart exactly 1 **Nucleus**)

BondedAtom

IRI: http://emmo.info/domains/emmo-material.owl#EMMO_8303a247_f9d9_4616_bdcd_f5cbd7b298e3

Elucidation: An bonded atom that shares at least one electron to the atom-based entity of which is part of.

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.

Comment: This class can be used to represent molecules as simplified quantum systems, in which outer molecule shared electrons are un-entangled with the inner shells of the atoms composing the molecule.

Relations:

- is_a **Atom**

StandaloneAtom

IRI: http://emmo.info/domains/emmo-material.owl#EMMO_2fd3f574_5e93_47fe_afca_ed80b0a21ab4

Elucidation: An atom that does not share electrons with other atoms.

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.

Relations:

- is_a **Atom**
- disjoint_union_of **NeutralAtom**, **IonAtom**

IonAtom

IRI: http://emmo.info/domains/emmo-material.owl#EMMO_db03061b_db31_4132_a47a_6a634846578b

Elucidation: A standalone atom with an unbalanced number of electrons with respect to its atomic number.

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

Relations:

- is_a **StandaloneAtom**

NeutralAtom

IRI: http://emmo.info/domains/emmo-material.owl#EMMO_4588526f_8553_4f4d_aa73_a483e88d599b

Elucidation: A standalone atom that has no net charge.

Relations:

- is_a **StandaloneAtom**

Mesoscopic branch

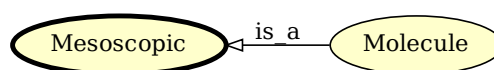


Figure 3.6: Mesoscopic branch.

Mesoscopic

IRI: http://emmo.info/domains/emmo-material.owl#EMMO_174cf221_9d16_427c_abea_e217a948969b

Relations:

- is_a **State**

Molecule

IRI: http://emmo.info/domains/emmo-material.owl#EMMO_3397f270_dfc1_4500_8f6f_4d0d85ac5f71

Elucidation: An atom_based state defined by an exact number of e-bonded atomic species and an electron cloud made of the shared electrons.

Example: H₂O, C₆H₁₂O₆, CH₄

Comment: An entity is called essential if removing one direct part will lead to a change in entity class.

An entity is called redundant if removing one direct part will not lead to a change in entity class.

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 H₂O without changing the molecule type (essential). However, you can remove a C from a nanotube (redundant). C₆₀ fullerene is a molecule, since it has a finite periodicity and is made of

a well defined number of atoms (essential). A C nanotube is not a molecule, since it has an infinite periodicity (redundant).

Relations:

- is_a Mesoscopic
- (hasSpatialDirectPart min 2 BondedAtom)
- (hasSpatialDirectPart exactly 1 ElectronCloud)

Continuum branch

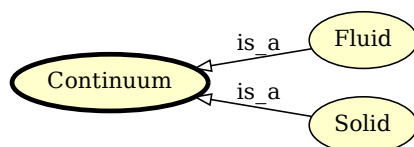


Figure 3.7: Continuum branch.

Continuum

IRI: http://emmo.info/domains/emmo-material.owl#EMMO_8b0923ab_b500_477b_9ce9_8b3a3e4dc4f2

Elucidation: A state that is a collection of sufficiently large number of other parts such that: - it is the bearer of qualities that can exists only by the fact that it is a sum of parts - the smallest partition dV of the state volume in which we are interested in, contains enough parts to be statistically consistent: $n [\#/m^3] \times dV [m^3] \gg 1$

Comment: A continuum is made of a sufficient number of parts that it continues to exists as 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 sates 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.

Relations:

- is_a State

Fluid

IRI: http://emmo.info/domains/emmo-material.owl#EMMO_87ac88ff_8379_4f5a_8c7b_424a8fff1ee8

Elucidation: A continuum that has no fixed shape and yields easily to external pressure.

Example: Gas, liquid, plasma,

Relations:

- is_a Continuum

Solid

IRI: http://emmo.info/domains/emmo-material.owl#EMMO_a2b006f2_bbfd_4dba_bcaa_3fca20cd6be1

Elucidation: A continuum characterized by structural rigidity and resistance to changes of shape or volume, that retains its shape and density when not confined.

Relations:

- is_a **Continuum**

Impression branch

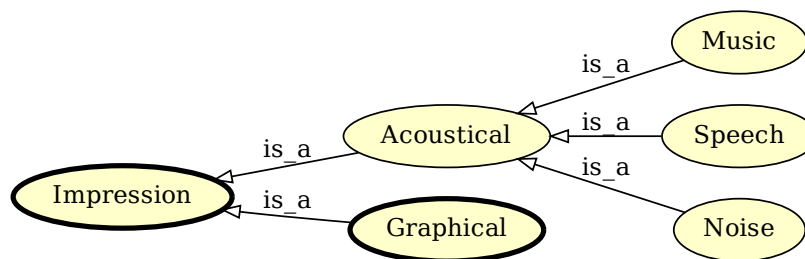


Figure 3.8: Impression branch.

Impression

IRI: http://emmo.info/perspectives/emmo-impression.owl#EMMO_649bf97b_4397_4005_90d9_219755d92e34

Elucidation: A ‘physical’ which stands for a real world object that stimulate a perception (e.g. a mental impression) to an interpreter.

Example: A line scratched on a surface. A sound. A smell. The word ‘cat’ and the sound of the word ‘cat’ (the first one is graphical and the second acoustical).

Comment: From Latin impressionem: “a pressing into, onset, attack,” figuratively “a perception, mental impression”.

Literally “a pressing into” from Latin imprimere “press into or upon”.

Comment: This class is the most general superclass that represents real world objects that can stand for something else in a semiotic process (acting as ‘signs’).

An impression is not necessarily a ‘sign’ (e.g. a line sketched on a blackboard is a recognizable ‘impression’ but it may stand for nothing).

Relations:

- is_a **Physical**

Acoustical

IRI: http://emmo.info/domains/emmo-acoustical.owl#EMMO_4b3afb22_27cf_4ce3_88bc_492bfccb546b

Elucidation: An ‘impression’ which stands for a real world object whose spatiotemporal pattern makes it identifiable by an observer as a sound.

Comment: ‘acoustical’ refers to the perception mechanism of the observer that can occur through a microphone, a ear.

Relations:

- is_a **Impression**

Music

IRI: http://emmo.info/domains/emmo-acoustical.owl#EMMO_0d69f94a_f4fa_49d9_bf90_ace770eeab02

Elucidation: A ‘acoustical’ that can be categorized as music by the ontologist.

Comment: A music score is not a ‘music’ individual.

A music score is a ‘graphical’ that can stand for a ‘music’ (or vice versa) since it comes through a different perception mechanism.

The ‘music’ individual is the sound itself as produced and delivered by a source in the form of sound wave through a medium.

Relations:

- is_a **Acoustical**

Noise

IRI: http://emmo.info/domains/emmo-acoustical.owl#EMMO_91756568_8655_4060_8937_a1a906dad8c1

Relations:

- is_a **Acoustical**

Speech

IRI: http://emmo.info/domains/emmo-acoustical.owl#EMMO_660ef3b0_6692_4c51_8f69_763c7817b2e1

Relations:

- is_a **Acoustical**

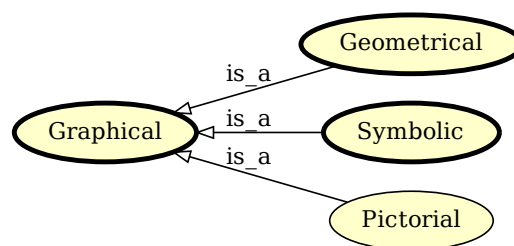
Graphical branch

Figure 3.9: Graphical branch.

Graphical

IRI: http://emmo.info/domains/emmo-graphical.owl#EMMO_c74da218_9147_4f03_92d1_8894abca55f3

Elucidation: An ‘impression’ which stands for a real world object whose spatial configuration shows a pattern identifiable by an observer.

Example: ‘graphical’ objects include writings, pictures, sketches ...

Comment: From the Ancient Greek γραφή (graphḗ) which means drawing, painting, writing, a writing, description, and from γράφω (gráphō) which means scratch, carve.

Relations:

- is_a **Impression**

Pictorial

IRI: http://emmo.info/domains/emmo-graphical.owl#EMMO_1da53c06_9577_4008_8652_272fa3b62be7

Elucidation: A ‘graphical’ that stands for a real world object that shows a recognizable pictorial pattern without being necessarily associated to a symbolic language.

Example: A drawing of a cat. A circle on a paper sheet. The Mona Lisa.

Relations:

- is_a **Graphical**

Geometrical branch

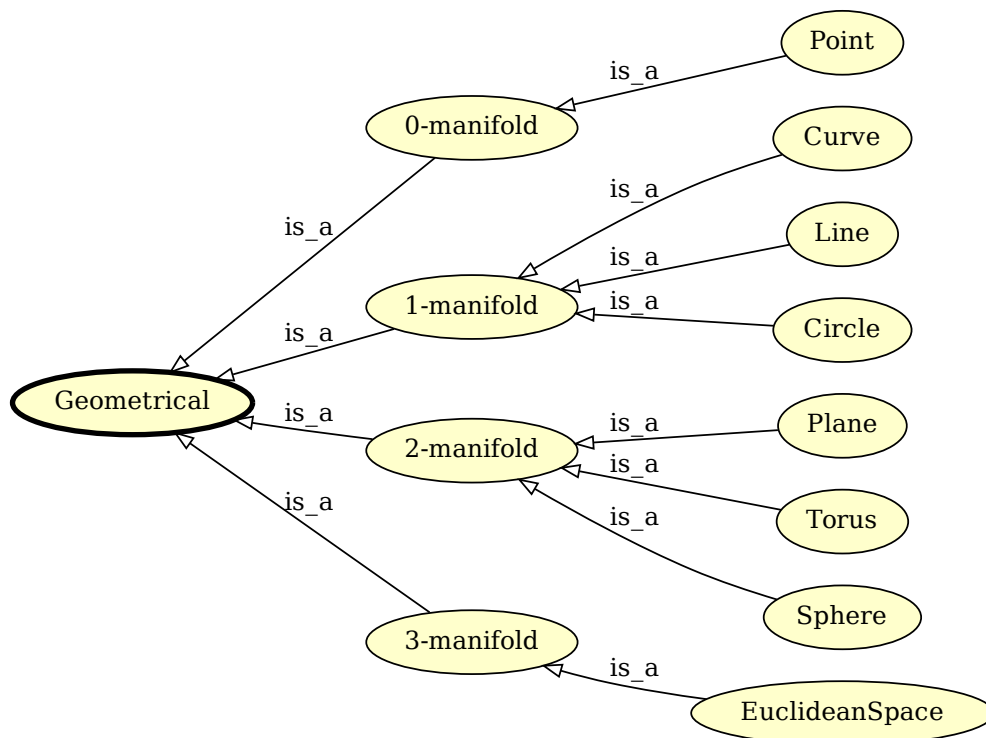


Figure 3.10: Geometrical branch.

Geometrical

IRI: http://emmo.info/domains/emmo-geometry.owl#EMMO_b5957cef_a287_442d_a3ce_fd39f20ba1cd

Elucidation: A ‘graphical’ aimed to represent a geometrical concept.

Comment: A ‘geometrical’ stands for real world objects that express a geometrical concept.

This can be achieved in many different ways. For example, a line can be expressed by: a) an equation like $y=mx+q$, which is both an ‘equation’ and a ‘geometrical’ b) a line drawn with a pencil on a paper, which is simply a ‘graphical’ object c) a set of axioms, when the properties of a line are inferred by the interpreter reading them, that are both ‘graphical’ and also ‘formula’

The case a) is a geometrical and mathematical, b) is geometrical and pictorial, while c) is geometrical and a composition of idiomatic strings.

Relations:

- is_a Graphical

0-manifold

IRI: http://emmo.info/domains/emmo-geometry.owl#EMMO_0ab0485c_9e5b_4257_a679_90a2dfba5c7c

Relations:

- is_a Geometrical

1-manifold

IRI: http://emmo.info/domains/emmo-geometry.owl#EMMO_0c576e13_4ee7_4f3d_bfe9_1614243df018

Relations:

- is_a Geometrical

2-manifold

IRI: http://emmo.info/domains/emmo-geometry.owl#EMMO_9268958f_7f54_48ab_a693_febe2645892b

Relations:

- is_a Geometrical

3-manifold

IRI: http://emmo.info/domains/emmo-geometry.owl#EMMO_46f0f8df_4dc6_418f_8036_10427a3a288e

Relations:

- is_a Geometrical

Circle

IRI: http://emmo.info/domains/emmo-geometry.owl#EMMO_b2a234a8_579a_422c_9305_b8f7e72c76cd

Relations:

- is_a 1-manifold

Curve

IRI: http://emmo.info/domains/emmo-geometry.owl#EMMO_0ef4ff4a_5458_4f2a_b51f_4689d472a3f2

Relations:

- is_a 1-manifold

EuclideanSpace

IRI: http://emmo.info/domains/emmo-geometry.owl#EMMO_5f278af9_8593_4e27_a717_ccc9e07a0ddf

Relations:

- is_a 3-manifold

Line

IRI: http://emmo.info/domains/emmo-geometry.owl#EMMO_3e309118_e8b7_4021_80f4_642d2df65d94

Relations:

- is_a 1-manifold

Plane

IRI: http://emmo.info/domains/emmo-geometry.owl#EMMO_25f5ca8e_8f7f_44d8_a392_bd3fe8894458

Relations:

- is_a 2-manifold

Point

IRI: http://emmo.info/domains/emmo-geometry.owl#EMMO_39362460_2a97_4367_8f93_0418c2ac9a08

Relations:

- is_a 0-manifold

Sphere

IRI: http://emmo.info/domains/emmo-geometry.owl#EMMO_d7bf784a_db94_4dd9_861c_54f262846fbf

Relations:

- is_a 2-manifold

Torus

IRI: http://emmo.info/domains/emmo-geometry.owl#EMMO_86060335_31c2_4820_b433_27c64aea0366

Relations:

- is_a 2-manifold

Symbolic branch

Symbolic

IRI: http://emmo.info/domains/emmo-graphical.owl#EMMO_057e7d57_aff0_49de_911a_8861d85cef40

Elucidation: An ‘graphical’ that stands for a symbolic object, i.e. a token or a string of tokens from a specific alphabet.

Example: fe780 emmo !5*a cat

Comment: A ‘symbol’ or a composition of ‘symbol’-s not necessarily respecting syntactic rules.

Relations:

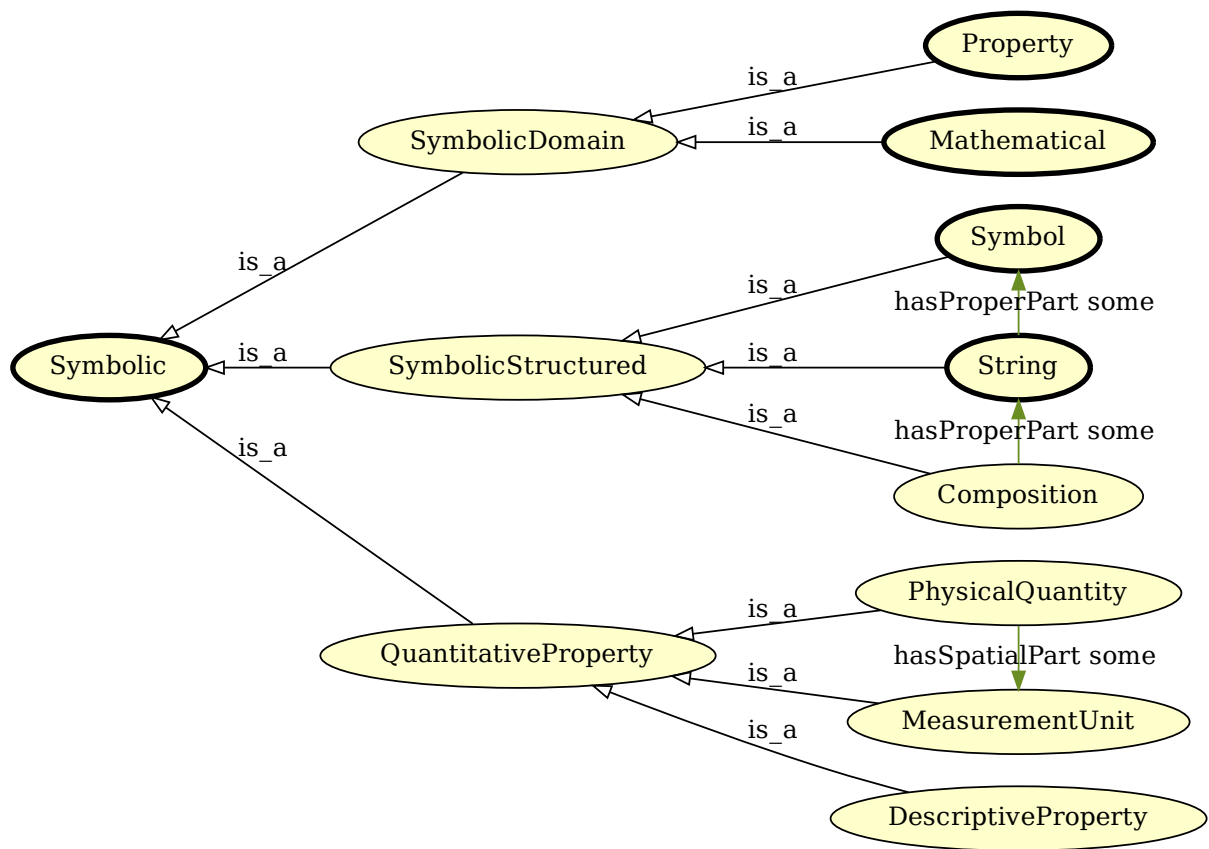


Figure 3.11: Symbolic branch.

- is_a Graphical
- is_a Symbol or (hasSpatialPart some Symbol)

SymbolicDomain

IRI: http://emmo.info/domains/emmo-graphical.owl#EMMO_0733a7f0_5ddd_4390_b94b_dfd52fe457f7

Relations:

- is_a Symbolic

SymbolicStructured

IRI: http://emmo.info/domains/emmo-graphical.owl#EMMO_b0b624ef_f126_4805_bfb6_86e2041a6e4c

Relations:

- is_a Symbolic

Composition

IRI: http://emmo.info/domains/emmo-graphical.owl#EMMO_2c1ceb4c_8b09_4374_91ec_98497b245a22

Relations:

- is_a SymbolicStructured
- (hasProperPart some String)

QuantitativeProperty

IRI: http://emmo.info/domains/emmo-physical-properties.owl#EMMO_dd4a7f3e_ef56_466c_ac1a_d2716b5f87ec

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

Relations:

- is_a ObjectiveProperty
- is_a Symbolic

DescriptiveProperty

IRI: http://emmo.info/domains/emmo-physical-properties.owl#EMMO_c46f091c_0420_4c1a_af30_0a2c8ebcf7d7

Relations:

- is_a QuantitativeProperty

MeasurementUnit

IRI: http://emmo.info/domains/emmo-physical-properties.owl#EMMO_b081b346_7279_46ef_9a3d_2c088fcd79f4

Elucidation: A ‘quantitative_property’ that stands for the standard reference magnitude of a specific class of measurement processes, defined and adopted by convention or by law.

Quantitative measurement results are expressed as a multiple of the ‘measurement_unit’.

Relations:

- is_a QuantitativeProperty

PhysicalQuantity

IRI: http://emmo.info/domains/emmo-physical-properties.owl#EMMO_02c0621e_a527_4790_8a0f_2bb51973c819

Elucidation: A “symbolic” entity that is made of a ‘number’ and a ‘measurement_unit’.

By definition it also stands for the result of a measurement process, and so it is also a ‘sign’.

Comment: Measured or simulated ‘physical property’-s are always defined by a physical law, connected to a physical entity through a model perspective and measurement is done according to the same model.

Systems of units suggests that this is the correct approach, since except for the fundamental units (length, time, charge) every other unit is derived by mathematical relations between these fundamental units, implying a physical laws or definitions.

Relations:

- is_a **QuantitativeProperty**
- (hasSpatialPart some **Numeral**)
- (hasSpatialPart some **MeasurementUnit**)

Symbol branch

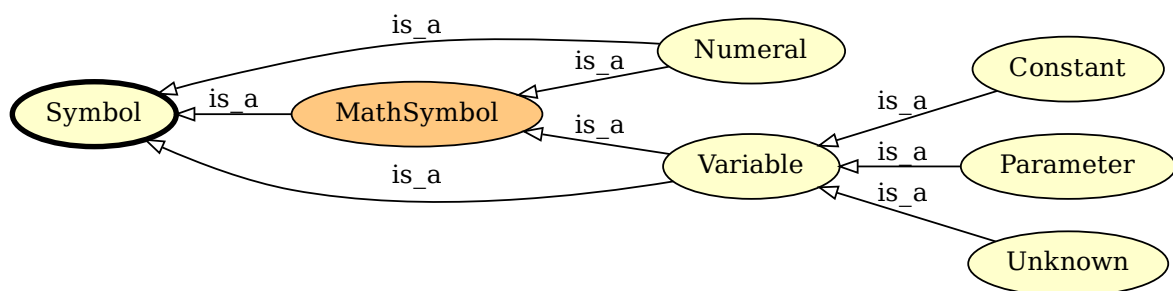


Figure 3.12: Symbol branch.

Symbol

IRI: http://emmo.info/domains/emmo-graphical.owl#EMMO_a1083d0a_c1fb_471f_8e20_a98f881ad527

Elucidation: The class of individuals that stand for an elementary mark of a specific symbolic code (alphabet).

Example: The class of letter “A” is the symbol as idea and the letter A that you see on the screen is the mark.

Comment: Subclasses of ‘symbol’ are alphabets, in formal languages terminology.

A ‘symbol’ is atomic for that alphabet, i.e. it has no parts that are symbols for the same alphabet.

e.g. a math symbol is not made of other math symbols

Comment: Symbols of a formal language need not be symbols of anything. For instance there are logical constants which do not refer to any idea, but rather serve as a form of punctuation in the language (e.g. parentheses).

Symbols of a formal language must be capable of being specified without any reference to any interpretation of them. (Wikipedia)

Comment: The class is the idea of the symbol, while the individual of that class stands for a specific mark (or token) of that idea.

Relations:

- is_a **SymbolicStructured**

MathSymbol

IRI: http://emmo.info/domains/emmo-math.owl#EMMO_031d61af_6405_41de_8880_df2f85a53383

Elucidation: A ‘symbol’ that is part of standard mathematical formalism.

Relations:

- is_a **Symbol**
- is_a **Mathematical**
- (hasProperPart only not **Mathematical**)
- equivalent_to **Symbol** and **Mathematical**

Numeral

IRI: http://emmo.info/domains/emmo-math.owl#EMMO_1a663927_3b68_4618_acd3_a8aa0d406329

Example: 0 3 7

Relations:

- is_a **MathSymbol**
- is_a **Symbol**
- is_a **Mathematical**

Variable

IRI: http://emmo.info/domains/emmo-math.owl#EMMO_1eed0732_e3f1_4b2c_a9c4_b4e75eeb5895

Elucidation: A ‘variable’ is a ‘symbol’ that stands for a numerical defined ‘mathematical’ entity like e.g. a number, a vector, a matrix.

Relations:

- is_a **MathSymbol**
- is_a **Conventional**
- is_a **Symbol**
- is_a **Mathematical**
- (Inverse(emmo-math.hasVariable) some **Number**)

Constant

IRI: http://emmo.info/domains/emmo-math.owl#EMMO_ae15fb4f_8e4d_41de_a0f9_3997f89ba6a2

Elucidation: A ‘variable’ that stand for a well known constant.

Comment: $\pi = 3.14$

Relations:

- is_a **Variable**

Parameter

IRI: http://emmo.info/domains/emmo-math.owl#EMMO_d1d436e7_72fc_49cd_863b_7bfb4ba5276a

Example: viscosity in the Navier-Stokes equation

Comment: A ‘variable’ whose value is assumed to be known independently from the equation, but whose value is not explicitated in the equation.

Relations:

- is_a Variable

Unknown

IRI: http://emmo.info/domains/emmo-math.owl#EMMO_fe7e56ce_118b_4243_9aad_20eb9f4f31f6

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

Example: Velocity, for the Navier-Stokes equation.

Relations:

- is_a Variable

String branch

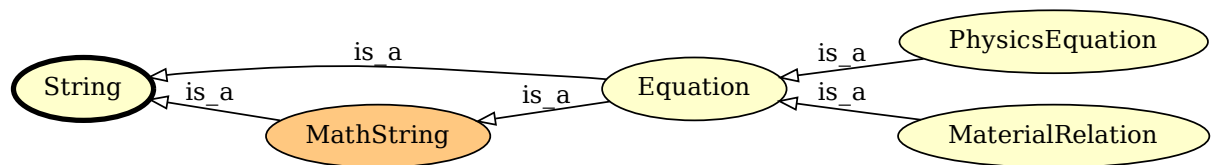


Figure 3.13: String branch.

String

IRI: http://emmo.info/domains/emmo-graphical.owl#EMMO_50ea1ec5_f157_41b0_b46b_a9032f17ca10

Elucidation: A composition of more than one ‘symbol’-s respecting a specific language syntactic rules (a well-formed formula).

Example: The word “cat” considered as a collection of ‘symbol’-s respecting the rules of english language.

In this example the ‘symbolic’ entity “cat” is not related to the real cat, but it is only a word (like it would be to an italian person that ignores the meaning of this english word).

If an ‘interpreter’ skilled in english language is involved in a ‘semiotic’ process with this word, that “cat” became also a ‘sign’ i.e. it became for the ‘interpreter’ a representation for a real cat.

Comment: In formal languages the terms word or well-formed formula are used with the same meaning.

Relations:

- is_a SymbolicStructured
- (hasProperPart some Symbol)

MathString

IRI: http://emmo.info/domains/emmo-math.owl#EMMO_2c03c212_742d_4699_9956_d182735009dc

Relations:

- is_a String
- is_a Mathematical
- equivalent_to String and Mathematical

Equation

IRI: http://emmo.info/domains/emmo-math.owl#EMMO_e56ee3eb_7609_4ae1_8bed_51974f0960a6

Comment: The class of ‘mathematical’-s that stand for a statement between two mathematical expressions that puts in relation some variables and that can always be represented as:

$$f(v_0, v_1, \dots, v_n) = g(v_0, v_1, \dots, v_n)$$

where f is the left hand and g the right hand side expressions and v_0, v_1, \dots, v_n are the variables.

e.g.

$$x^2 + 3x = 5x$$

$$dv/dt = a$$

$$\sin(x) = y$$

Relations:

- is_a **MathString**
- is_a **String**
- is_a **Mathematical**
- (hasSpatialPart some **Variable**)

MaterialRelation

IRI: http://emmo.info/domains/emmo-models.owl#EMMO_e5438930_04e7_4d42_ade5_3700d4a52ab7

Elucidation: An ‘equation’ that stands for 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.

Relations:

- is_a **Equation**
- (hasSpatialPart some **PhysicalQuantity**)

PhysicsEquation

IRI: http://emmo.info/domains/emmo-models.owl#EMMO_27c5d8c6_8af7_4d63_beb1_ec37cd8b3fa3

Elucidation: An ‘equation’ that stands for a ‘physical_law’ by mathematically defining the relations between physics_quantities.

Comment: The Newton’s equation of motion.

The Schrodinger equation.

The Navier-Stokes equation.

Relations:

- is_a **Equation**
- is_a **Icon**
- (hasSpatialPart some **PhysicalQuantity**)
- (Inverse(emmo-semiotics.hasIcon) some **PhysicalPhenomenon**)

Property branch

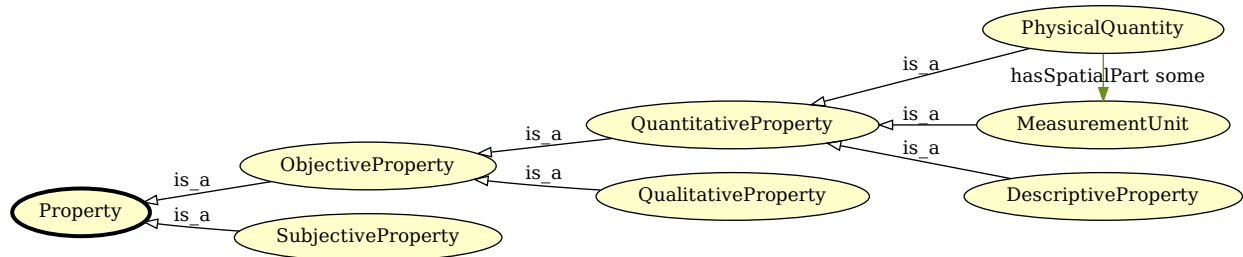


Figure 3.14: Property branch.

Property

IRI: http://emmo.info/domains/emmo-properties.owl#EMMO_b7bcff25_ffc3_474e_9ab5_01b1664bd4ba

Elucidation: A ‘sign’ that stands for an ‘object’ that the ‘interpreter’ perceived through a well defined ‘observation’ process.

(a property is always a partial representation of an ‘object’ since it reflects the ‘object’ capability to be part of a specific ‘observation’ process)

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 ‘colour’ as the subclass of the properties that involve photon emission and an electromagnetic radiation sensible observer.

An individual C of this class ‘colour’ 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.

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

Comment: We know real world entities through observation/perception.

A non-perceivable real world entity 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 a real world entity occurs when the entity stimulate an observer in a peculiar way through a well defined perception channel.

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

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.

An observation is a semiotic process, since it stimulate an interpretant within the interpreter who can communicate the perception result to other interpreters through a sign which is the property.

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

e.g. the property ‘colour’ 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.

Properties usually relies on symbolic systems (e.g. for colour it can be palette or RGB).

Relations:

- is_a **SymbolicDomain**
- is_a **Conventional**
- (Inverse(emmo-properties.hasProperty) some **Item**)
- disjoint_union_of **SubjectiveProperty**, **ObjectiveProperty**

ObjectiveProperty

IRI: http://emmo.info/domains/emmo-properties.owl#EMMO_2a88cdf_ec4a_4ec5_af1c_0343372fc978

Elucidation: A ‘property’ that is determined by each ‘observer’ following a well defined ‘observation’ procedure through a specific perception channel.

Comment: The word objective does not mean that each observation will provide the same results. It means that the observation followed a well defined procedure.

Relations:

- is_a **Property**

SubjectiveProperty

IRI: http://emmo.info/domains/emmo-properties.owl#EMMO_251cfb4f_5c75_4778_91ed_6c8395212fd8

Elucidation: A ‘property’ that cannot be univocally determined and depends on an agent (e.g. a human individual, a community) acting as black-box.

Example: The beauty of that girl. The style of your clothing.

Comment: The word subjective means that a non-well defined or an unknown procedure is used for the definition of the property.

This happens due to e.g. the complexity of the object, the lack of a underlying model for the representation of the object, the non-well specified meaning of the property symbols.

A ‘subjective_property’ cannot be used to univocally compare ‘object’-s.

e.g. you cannot evaluate the beauty of a person on objective basis.

Relations:

- is_a **Property**

QualitativeProperty

IRI: http://emmo.info/domains/emmo-physical-properties.owl#EMMO_909415d1_7c43_4d5e_bbeb_7e1910159f66

Elucidation: An ‘objective_property’ that cannot be quantified.

Example: CFC is a ‘sign’ that stands for the fact that the morphology of atoms composing the microstructure of an entity is predominantly Cubic Face Centered

Relations:

- is_a **ObjectiveProperty**

QuantitativeProperty

IRI: http://emmo.info/domains/emmo-physical-properties.owl#EMMO_dd4a7f3e_ef56_466c_ac1a_d2716b5f87ec

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

Relations:

- is_a **ObjectiveProperty**
- is_a **Symbolic**

DescriptiveProperty

IRI: http://emmo.info/domains/emmo-physical-properties.owl#EMMO_c46f091c_0420_4c1a_af30_0a2c8ebcf7d7

Relations:

- is_a **QuantitativeProperty**

MeasurementUnit

IRI: http://emmo.info/domains/emmo-physical-properties.owl#EMMO_b081b346_7279_46ef_9a3d_2c088fcd79f4

Elucidation: A ‘quantitative_property’ that stands for the standard reference magnitude of a specific class of measurement processes, defined and adopted by convention or by law.

Quantitative measurement results are expressed as a multiple of the ‘measurement_unit’.

Relations:

- is_a **QuantitativeProperty**

PhysicalQuantity

IRI: http://emmo.info/domains/emmo-physical-properties.owl#EMMO_02c0621e_a527_4790_8a0f_2bb51973c819

Elucidation: A “symbolic” entity that is made of a ‘number’ and a ‘measurement_unit’.

By definition it also stands for the result of a measurement process, and so it is also a ‘sign’.

Comment: Measured or simulated ‘physical property’-s are always defined by a physical law, connected to a physical entity through a model perspective and measurement is done according to the same model.

Systems of units suggests that this is the correct approach, since except for the fundamental units (length, time, charge) every other unit is derived by mathematical relations between these fundamental units, implying a physical laws or definitions.

Relations:

- is_a **QuantitativeProperty**
- (hasSpatialPart some **Numeral**)
- (hasSpatialPart some **MeasurementUnit**)

Mathematical branch

Mathematical

IRI: http://emmo.info/domains/emmo-math.owl#EMMO_54ee6b5e_5261_44a8_86eb_5717e7fdb9d0

Comment: The class of general mathematical symbolic objects.

Relations:

- is_a **SymbolicDomain**

Number

IRI: http://emmo.info/domains/emmo-math.owl#EMMO_21f56795_ee72_4858_b571_11cfaa59c1a8

Relations:

- is_a **Mathematical**

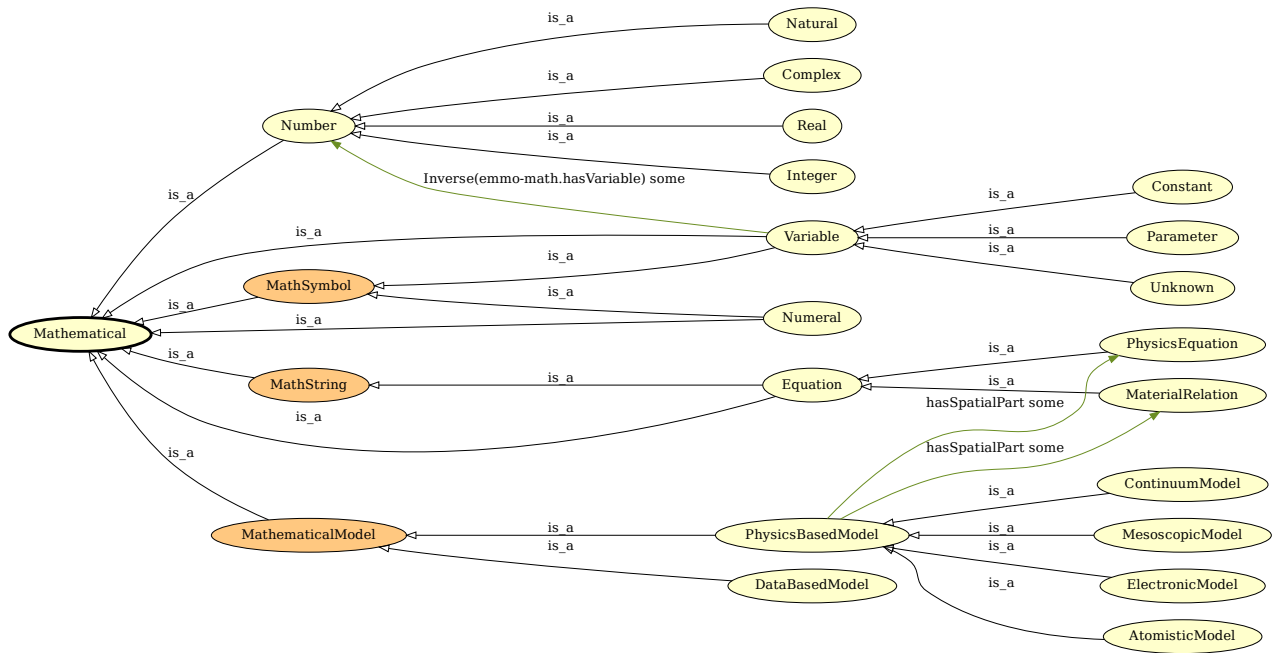


Figure 3.15: Mathematical branch.

- `is_a` **Numeral** or (`hasSpatialPart` some **Numeral**)

Complex

IRI: http://emmo.info/domains/emmo-math.owl#EMMO_ba24b317_6fdd_4c64_a168_cc85a9869e44

Relations:

- `is_a` **Number**

Integer

IRI: http://emmo.info/domains/emmo-math.owl#EMMO_f8bd64d5_5d3e_4ad4_a46e_c30714fecb7f

Relations:

- `is_a` **Number**

Natural

IRI: http://emmo.info/domains/emmo-math.owl#EMMO_b9db54a5_2a6c_4764_8141_9f7579fe5ad8

Relations:

- `is_a` **Number**

Real

IRI: http://emmo.info/domains/emmo-math.owl#EMMO_c22f0989_1be2_4a34_9bb8_d780abffbdafa

Relations:

- `is_a` **Number**

MathString

IRI: http://emmo.info/domains/emmo-math.owl#EMMO_2c03c212_742d_4699_9956_d182735009dc

Relations:

- is_a **String**
- is_a **Mathematical**
- equivalent_to **String** and **Mathematical**

MathSymbol

IRI: http://emmo.info/domains/emmo-math.owl#EMMO_031d61af_6405_41de_8880_df2f85a53383

Elucidation: A ‘symbol’ that is part of standard mathematical formalism.

Relations:

- is_a **Symbol**
- is_a **Mathematical**
- (hasProperPart only not **Mathematical**)
- equivalent_to **Symbol** and **Mathematical**

Equation

IRI: http://emmo.info/domains/emmo-math.owl#EMMO_e56ee3eb_7609_4ae1_8bed_51974f0960a6

Comment: The class of ‘mathematical’-s that stand for a statement between two mathematical expressions that puts in relation some variables and that can always be represented as:

$$f(v_0, v_1, \dots, v_n) = g(v_0, v_1, \dots, v_n)$$

where f is the left hand and g the right hand side expressions and v₀, v₁, ..., v_n are the variables.

e.g.

$$x^2 + 3x = 5x$$

$$dv/dt = a$$

$$\sin(x) = y$$

Relations:

- is_a **MathString**
- is_a **String**
- is_a **Mathematical**
- (hasSpatialPart some **Variable**)

Numeral

IRI: http://emmo.info/domains/emmo-math.owl#EMMO_1a663927_3b68_4618_acd3_a8aa0d406329

Example: 0 3 7

Relations:

- is_a **MathSymbol**
- is_a **Symbol**
- is_a **Mathematical**

MaterialRelation

IRI: http://emmo.info/domains/emmo-models.owl#EMMO_e5438930_04e7_4d42_ade5_3700d4a52ab7

Elucidation: An ‘equation’ that stands for 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.

Relations:

- is_a **Equation**
- (hasSpatialPart some **PhysicalQuantity**)

MathematicalModel

IRI: http://emmo.info/domains/emmo-models.owl#EMMO_f7ed665b_c2e1_42bc_889b_6b42ed3a36f0

Relations:

- is_a **Mathematical**
- is_a **Model**
- equivalent_to **Mathematical** and **Model**

DataBasedModel

IRI: http://emmo.info/domains/emmo-models.owl#EMMO_a4b14b83_9392_4a5f_a2e8_b2b58793f59b

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

Relations:

- is_a **MathematicalModel**

PhysicsBasedModel

IRI: http://emmo.info/domains/emmo-models.owl#EMMO_b29fd350_39aa_4af7_9459_3faa0544cba6

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

Relations:

- is_a **MathematicalModel**
- (hasSpatialPart some **PhysicsEquation**)
- (hasSpatialPart some **MaterialRelation**)

AtomisticModel

IRI: http://emmo.info/domains/emmo-models.owl#EMMO_84cad45_6758_46f2_ba2a_5ead65c70213

Relations:

- is_a **PhysicsBasedModel**

ContinuumModel

IRI: http://emmo.info/domains/emmo-models.owl#EMMO_4456a5d2_16a6_4ee1_9a8e_5c75956b28ea

Relations:

- is_a **PhysicsBasedModel**

ElectronicModel

IRI: http://emmo.info/domains/emmo-models.owl#EMMO_6eca09be_17e9_445e_abc9_000aa61b7a11

Relations:

- is_a **PhysicsBasedModel**

MesoscopicModel

IRI: http://emmo.info/domains/emmo-models.owl#EMMO_53935db0_af45_4426_b9e9_244a0d77db00

Relations:

- is_a **PhysicsBasedModel**

Variable

IRI: http://emmo.info/domains/emmo-math.owl#EMMO_1eed0732_e3f1_4b2c_a9c4_b4e75eeb5895

Elucidation: A ‘variable’ is a ‘symbol’ that stands for a numerical defined ‘mathematical’ entity like e.g. a number, a vector, a matrix.

Relations:

- is_a **MathSymbol**
- is_a **Conventional**
- is_a **Symbol**
- is_a **Mathematical**
- (Inverse(emmo-math.hasVariable) some **Number**)

Constant

IRI: http://emmo.info/domains/emmo-math.owl#EMMO_ae15fb4f_8e4d_41de_a0f9_3997f89ba6a2

Elucidation: A ‘variable’ that stand for a well known constant.

Comment: $\pi = 3.14$

Relations:

- is_a **Variable**

Parameter

IRI: http://emmo.info/domains/emmo-math.owl#EMMO_d1d436e7_72fc_49cd_863b_7bfb4ba5276a

Example: viscosity in the Navier-Stokes equation

Comment: A ‘variable’ whose value is assumed to be known independently from the equation, but whose value is not explicitated in the equation.

Relations:

- is_a **Variable**

IRI: http://emmo.info/domains/emmo-models.owl#EMMO_27c5d8c6_8af7_4d63_beb1_ec37cd8b3fa3

Comment: The Newton's equation of motion.

The Navier-Stokes equation.

- is_a Equation
- is_a Icon
- (hasSpatialPart some PhysicalQuantity)
- (Inverse(emmo-semiotics.hasIcon) some PhysicalPhenomenon)

IRI: http://emmo.info/domains/emmo-math.owl#EMMO_fe7e56ce_118b_4243_9aad_20eb9f4f31f6

Example: Velocity, for the Navier-Stokes equation.

- is_a Variable

```

graph TD
    Processual([Processual]) -- is a --> Process([Process])
    Processual -- is a --> Participant([Participant])
    Process -- hasParticipant some --> Participant
    Participant -- is a --> Engineered([Engineered])
    Participant -- is a --> Semiotic([Semiotic])
    Engineered -- is a --> Component([Component])
    Engineered -- is a --> System([System])
    Component -- hasSpatialDirectPart some --> System
    System -- is a --> Object([Object])
    Object -- hasSign some --> Sign([Sign])
    Sign -- is a --> Interpreter([Interpreter])
    Interpreter -- is a --> Observer([Observer])
    Observer -- is a --> MeasurementInstrument([MeasurementInstrument])
  
```

Processual

IRI: http://emmo.info/perspectives/emmo-processual.owl#EMMO_0277f24a_ea7f_4917_81b7_fb0406c8fc62

Relations:

- is a **Physical**

Participant

IRI: http://emmo.info/perspectives/emmo-processual.owl#EMMO_49804605_c0fe_4538_abda_f70ba1dc8a5d

Elucidation: A portion of a ‘process’ that participates to the ‘process’ with a specific role.

Comment: In the EMMO the relation of participation to a process falls under mereotopology.

Relations:

- is_a **Processual**

Engineered

IRI: http://emmo.info/domains/emmo-usercase.owl#EMMO_86ca9b93_1183_4b65_81b8_c0fcd3bba5ad

Elucidation: A ‘physical’ that stands for a real world object that has been manufactured for a particular purpose.

Comment: While the ‘state’ branch describes single simple entities (e.g. atoms, molecules, nanoparticles), the ‘engineered_entity’ branch describe entities that show some level of complexity/heterogeneity in their composition, and are made for a specific use.

Classes in this branch are primitive.

e.g. car, tire, composite material.

Relations:

- is_a **Participant**
- (Inverse(emmo-processual.hasProperParticipant) some **Manufacturing**)

Semiotic

IRI: http://emmo.info/perspectives/emmo-semiotics.owl#EMMO_b803f122_4acb_4064_9d71_c1e5fd091fc9

Elucidation: The class of individuals that stands for semiotic objects, i.e. objects that take part on a semiotic process.

Comment: Semiotic subclasse are defined using Peirce’s semiotic theory.

“Namely, a sign is something, A, which brings something, B, its interpretant sign determined or created by it, into the same sort of correspondence with something, C, its object, as that in which itself stands to C.” (Peirce 1902, NEM 4, 20-21).

The triadic elements: - ‘sign’: the sign A (e.g. a name) - ‘interpretant’: the sign B as the effects of the sign A on the interpreter (e.g. the mental concept of what a name means) - ‘object’: the object C (e.g. the entity to which the sign A and B refer to)

This class includes also the ‘interpeter’ i.e. the entity that connects the ‘sign’ to the ‘object’

Relations:

- is_a **Participant**
- (Inverse(emmo-processual.hasProperParticipant) some **Semiosis**)
- equivalent_to **Interpreter** or **Object** or **Sign**

Component

IRI: http://emmo.info/domains/emmo-usercase.owl#EMMO_494b372c_cfdf_47d3_a4de_5e037c540de8

Relations:

- is_a **Engineered**

Interpreter

IRI: http://emmo.info/perspectives/emmo-semiotics.owl#EMMO_0527413c_b286_4e9c_b2d0_03fb2a038dee

Elucidation: The entity (or agent, or observer, or cognitive entity) who connects ‘sign’, ‘interpretant’ and ‘object’.

Relations:

- is_a **Semiotic**
- (hasSpatialPart some **Interpretant**)

Object

IRI: http://emmo.info/perspectives/emmo-semiotics.owl#EMMO_6f5af708_f825_4feb_a0d1_a8d813d3022b

Elucidation: The object, in Peirce semiotics.

Comment: Here is assumed that the concept of ‘object’ is always relative to a ‘semiotic’ process. An ‘object’ does not exist per se, but it’s always part of an interpretation.

The EMMO relies on strong reductionism, i.e. everything real is a formless collection of elementary particles: we give a meaning to real world entities only by giving them boundaries and defining them using ‘sign’-s.

In this way the ‘sign’-ed entity becomes an ‘object’, and the ‘object’ is the basic entity needed in order to apply a logical formalism to the real world entities (i.e. we can speak of it through its sign, and use logics on it through its sign).

Relations:

- is_a **Semiotic**
- equivalent_to (hasSign some **Sign**)

Observer

IRI: http://emmo.info/domains/emmo-properties.owl#EMMO_1b52ee70_121e_4d8d_8419_3f97cd0bd89c

Elucidation: An ‘interpreter’ that perceives another ‘entity’ (the ‘object’) through a specific perception mechanism and produces a ‘property’ (the ‘sign’) that stands for the result of that particular perception.

Relations:

- is_a **Interpreter**
- (Inverse(emmo-processual.hasParticipant) some **Observation**)

System

IRI: http://emmo.info/domains/emmo-usercase.owl#EMMO_e775e341_5687_4d45_b50c_379b098a8c26

Relations:

- is_a **Engineered**
- is_a **Existent**
- equivalent_to (hasSpatialDirectPart some **Component**)

MeasurementInstrument

IRI: http://emmo.info/domains/emmo-physical-properties.owl#EMMO_f2d5d3ad_2e00_417f_8849_686f3988d929

Relations:

- is_a **Observer**

Sign branch

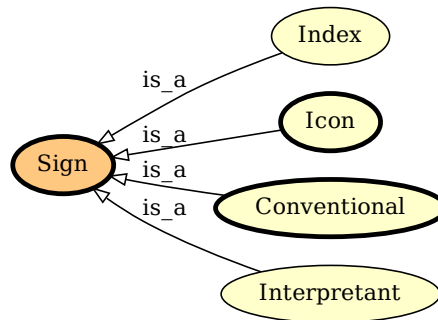


Figure 3.17: Sign branch.

Sign

IRI: http://emmo.info/perspectives/emmo-semiotics.owl#EMMO_b21a56ed_f969_4612_a6ec_cb7766f7f31d

Elucidation: An ‘spacetime’ that is used as sign (“semeion” in greek) that stands for another ‘spacetime’ through an semiotic process.

Example: A novel is made of chapters, paragraphs, sentences, words and characters (in a direct parthood mereological hierarchy).

Each of them are ‘sign’-s.

A character can be the a-tomistic ‘sign’ for the class of texts.

The horizontal segment in the character “A” is direct part of “A” but it is not a ‘sign’ itself.

For plain text we can propose the ASCII symbols, for math the fundamental math symbols.

Comment: A ‘sign’ can have temporal-direct-parts which are ‘sign’ themselves.

A ‘sign’ usually have ‘sign’ spatial direct parts only up to a certain elementary semiotic level, in which the part is only a ‘physical’ and no more a ‘sign’ (i.e. it stands for nothing). This elementary semiotic level is peculiar to each particular system of signs (e.g. text, painting).

Just like an ‘elementary’ in the ‘physical’ branch, each ‘sign’ branch should have an a-tomistic mereological part.

Comment: According to Peirce, ‘sign’ includes three subcategories: - symbols: that stand for an object through convention - indeces: that stand for an object due to causal contiguity - icon: that stand for an object due to similitudes e.g. in shape or composition

Comment: In a 4D ontology one could question if a ‘sign’ should be defined as a spatial direct part of a ‘semiosis’ i.e. a proper part of a ‘semiosis’ during all its existence.

e.g. one can say that an unread text is not a ‘sign’: it was a ‘sign’ during the ‘semiosis’ process in which it was written, but after that it is something else, until somebody read it again.

However, this is not the case for an ontology, since declaring an individual under the ‘sign’ class (a semiosis outside the EMMO, a meta-semiosis) is equivalent to say that for the ontologist (an interpreter outside the EMMO, a meta-interpreter) the real entity (an object outside the EMMO, a meta-object) is a ‘sign’.

So the ‘semiosis’ process within the EMMO is about how other ‘interpreter’-s deal with the ‘sign’-s here declared.

Comment: It can be defined as the semiotic branch of the EMMO.

‘sign’ subclasses categorize the type of signs that are used to create representations/models of the real world entities.

Relations:

- is_a **Semiotic**
- equivalent_to **Index** or **Conventional** or **Icon**

Index

IRI: http://emmo.info/perspectives/emmo-semiotics.owl#EMMO_0cd58641_824c_4851_907f_f4c3be76630c

Elucidation: A ‘sign’ that stands for an ‘object’ due to causal contingency.

Example: Smoke stands for a combustion process (a fire).

My facial expression stands for my emotional status.

Relations:

- is_a **Sign**

Interpretant

IRI: http://emmo.info/perspectives/emmo-semiotics.owl#EMMO_054af807_85cd_4a13_8eba_119dfdaaf38b

Relations:

- is_a **Sign**

Icon branch

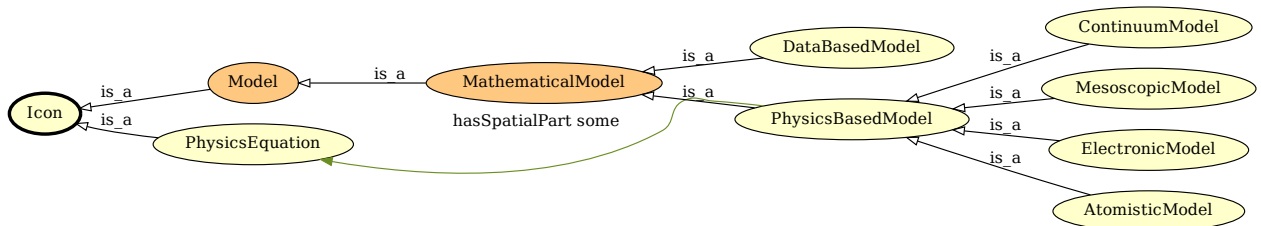


Figure 3.18: Icon branch.

Icon

IRI: http://emmo.info/perspectives/emmo-semiotics.owl#EMMO_d7788d1a_020d_4c78_85a1_13563fcec168

Elucidation: A ‘sign’ that stands for an ‘object’ by resembling or imitating it, in shape or by sharing a similar logical structure.

Example: A picture that reproduces the aspect of a person.

An equation that reproduces the logical connection of the properties of a physical entity.

Comment: Three subtypes of icon are possible:

- (a) the image, which depends on a simple quality (e.g. picture)
- (b) the diagram, whose internal relations, mainly dyadic or so taken, represent by analogy the relations in something (e.g. math formula, geometric flowchart)
- (c) the metaphor, which represents the representative character of a sign by representing a parallelism in something else

[Wikipedia]

Relations:

- is_a **Sign**

Model

IRI: http://emmo.info/domains/emmo-models.owl#EMMO_939483b1_0148_43d1_8b35_851d2cd5d939

Elucidation: A ‘sign’ that not only stands for a ‘physical’ or a ‘process’, but it is also a simplified representation, aimed to assist calculations for its description or for predictions of its behaviour.

A ‘model’ represents a ‘physical’ or a ‘process’ by direct similitude (e.g. small scale replica) or by capturing in a logical framework the relations between its properties (e.g. mathematical model).

Comment: A ‘model’ prediction is always a prediction of the properties of an entity, since an entity is known by an interpreter only through perception.

Relations:

- is_a **Icon**
- equivalent_to (Inverse(emmo-models.hasModel) some **Physical**)

MathematicalModel

IRI: http://emmo.info/domains/emmo-models.owl#EMMO_f7ed665b_c2e1_42bc_889b_6b42ed3a36f0

Relations:

- is_a **Mathematical**
- is_a **Model**
- equivalent_to **Mathematical** and **Model**

DataBasedModel

IRI: http://emmo.info/domains/emmo-models.owl#EMMO_a4b14b83_9392_4a5f_a2e8_b2b58793f59b

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

Relations:

- is_a **MathematicalModel**

PhysicsBasedModel

IRI: http://emmo.info/domains/emmo-models.owl#EMMO_b29fd350_39aa_4af7_9459_3faa0544cba6

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

Relations:

- is_a **MathematicalModel**
- (hasSpatialPart some **PhysicsEquation**)
- (hasSpatialPart some **MaterialRelation**)

AtomisticModel

IRI: http://emmo.info/domains/emmo-models.owl#EMMO_84cad45_6758_46f2_ba2a_5ead65c70213

Relations:

- is_a **PhysicsBasedModel**

ContinuumModel

IRI: http://emmo.info/domains/emmo-models.owl#EMMO_4456a5d2_16a6_4ee1_9a8e_5c75956b28ea

Relations:

- is_a **PhysicsBasedModel**

ElectronicModel

IRI: http://emmo.info/domains/emmo-models.owl#EMMO_6eca09be_17e9_445e_abc9_000aa61b7a11

Relations:

- is_a **PhysicsBasedModel**

MesoscopicModel

IRI: http://emmo.info/domains/emmo-models.owl#EMMO_53935db0_af45_4426_b9e9_244a0d77db00

Relations:

- is_a **PhysicsBasedModel**

PhysicsEquation

IRI: http://emmo.info/domains/emmo-models.owl#EMMO_27c5d8c6_8af7_4d63_beb1_ec37cd8b3fa3

Elucidation: An ‘equation’ that stands for a ‘physical_law’ by mathematically defining the relations between physics_quantities.

Comment: The Newton’s equation of motion.

The Schrodinger equation.

The Navier-Stokes equation.

Relations:

- is_a **Equation**
- is_a **Icon**
- (hasSpatialPart some **PhysicalQuantity**)
- (Inverse(emmo-semiotics.hasIcon) some **PhysicalPhenomenon**)

Conventional branch

Conventional

IRI: http://emmo.info/perspectives/emmo-semiotics.owl#EMMO_35d2e130_6e01_41ed_94f7_00b333d46cf9

Elucidation: A ‘sign’ that stand for an ‘object’ through convention, norm or habit, without any resemblance to it.

Comment: In Peirce semiotics this kind of sign category is called symbol. However, since symbol is also used in formal languages, the name is changed in conventional.

Relations:

- is_a **Sign**

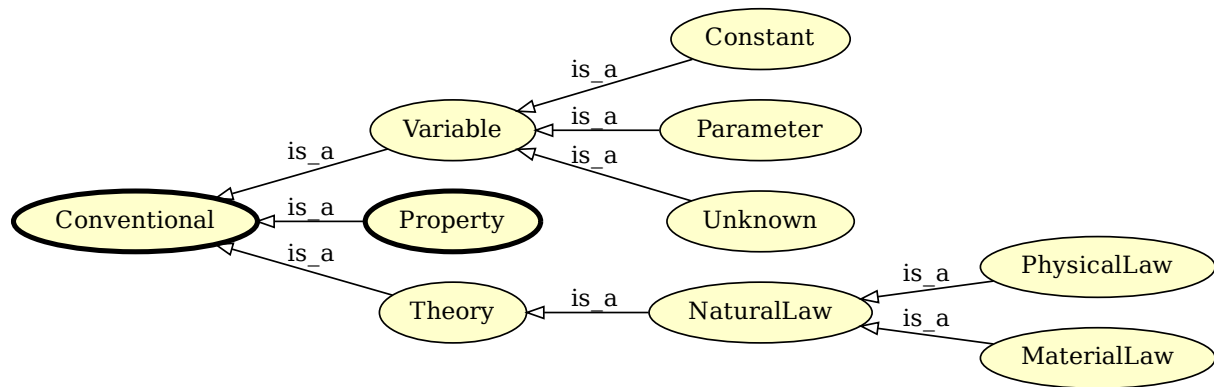


Figure 3.19: Conventional branch.

Theory

IRI: http://emmo.info/domains/emmo-models.owl#EMMO_8d2d9374_ef3a_47e6_8595_6bc208e07519

Elucidation: A ‘conventional’ that stand for a ‘physical’.

Comment: The ‘theory’ is e.g. a proposition, a book or a paper whose sub-symbols suggest in the mind of the interpreter an interpretant structure that can represent a ‘physical’.

It is not an ‘icon’ (like a math equation), because it has no common resemblance or logical structure with the ‘physical’.

In Peirce semiotics: legisign-symbol-argument

Relations:

- is_a **Conventional**

NaturalLaw

IRI: http://emmo.info/domains/emmo-models.owl#EMMO_db9a009e_f097_43f5_9520_6cbc07e7610b

Relations:

- is_a **Theory**

MaterialLaw

IRI: http://emmo.info/domains/emmo-models.owl#EMMO_f19ff3b4_6bfe_4c41_a2b2_9affd39c140b

Relations:

- is_a **NaturalLaw**

PhysicalLaw

IRI: http://emmo.info/domains/emmo-models.owl#EMMO_9c32fd69_f480_4130_83b3_fb25d9face14

Relations:

- is_a **NaturalLaw**

Variable

IRI: http://emmo.info/domains/emmo-math.owl#EMMO_1eed0732_e3f1_4b2c_a9c4_b4e75eeb5895

Elucidation: A ‘variable’ is a ‘symbol’ that stands for a numerical defined ‘mathematical’ entity like e.g. a number, a vector, a matrix.

Relations:

- is_a **MathSymbol**
- is_a **Conventional**
- is_a **Symbol**
- is_a **Mathematical**
- (Inverse(emmo-math.hasVariable) some **Number**)

Constant

IRI: http://emmo.info/domains/emmo-math.owl#EMMO_ae15fb4f_8e4d_41de_a0f9_3997f89ba6a2

Elucidation: A ‘variable’ that stand for a well known constant.

Comment: $\pi = 3.14$

Relations:

- is_a **Variable**

Parameter

IRI: http://emmo.info/domains/emmo-math.owl#EMMO_d1d436e7_72fc_49cd_863b_7bfb4ba5276a

Example: viscosity in the Navier-Stokes equation

Comment: A ‘variable’ whose value is assumed to be known independently from the equation, but whose value is not explicitated in the equation.

Relations:

- is_a **Variable**

Unknown

IRI: http://emmo.info/domains/emmo-math.owl#EMMO_fe7e56ce_118b_4243_9aad_20eb9f4f31f6

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

Example: Velocity, for the Navier-Stokes equation.

Relations:

- is_a **Variable**

Type branch

Type

IRI: http://emmo.info/domains/emmo-material.owl#EMMO_508e84f6_5081_4a9b_80b4_0b7830718b37

Relations:

- is_a **Physical**
- equivalent_to **Matter** or **Field**

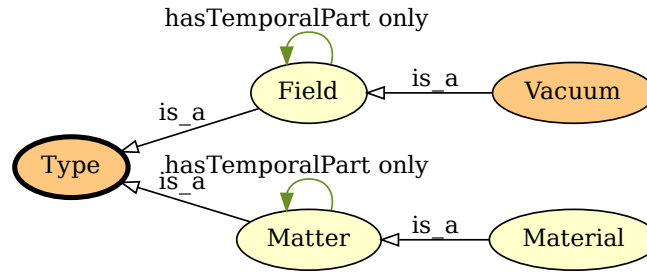


Figure 3.20: Type branch.

Field

IRI: http://emmo.info/domains/emmo-material.owl#EMMO_70dac51e_bddd_48c2_8a98_7d8395e91fc2

Elucidation: A ‘physical’ with ‘massless’ parts that are mediators of interactions.

Comment: The concepts of matter and field for classical physics, upon which we can categorize physical entities, are replaced in quantum physics by the more general concepts of quantum field.

Here the class ‘field’ refers to the quantum field of massless bosonic particles (i.e. photons, gluons), while the class ‘matter’ refers to the quantum field of massive fermionic or bosonic particles (e.g. quarks, electrons).

Relations:

- is_a **Type**
- (hasPart some **Massless**)
- (hasTemporalPart only **Field**)

Matter

IRI: http://emmo.info/domains/emmo-material.owl#EMMO_5b2222df_4da6_442f_8244_96e9e45887d1

Elucidation: A ‘physical’ that possesses some ‘massive’ parts.

Relations:

- is_a **Type**
- (hasPart some **Massive**)
- (hasTemporalPart only **Matter**)

Material

IRI: http://emmo.info/domains/emmo-material.owl#EMMO_4207e895_8b83_4318_996a_72cfb32acd94

Elucidation: An ‘existent’ that stands for a real world object that represents an amount of a physical substance (or mixture of substances) that constitute (is part of) a more comprehensive real world object.

Comment: The definition states that a ‘material’ is a portion of a real world object, being that a full functional device or component, or a sample made of that material (or the sample itself).

Relations:

- is_a **Matter**

Vacuum

IRI: http://emmo.info/domains/emmo-material.owl#EMMO_3c218fbe_60c9_4597_8bcf_41eb1773af1f

Relations:

- is_a **Field**
- equivalent_to **Field** and not **Matter**

Process branch

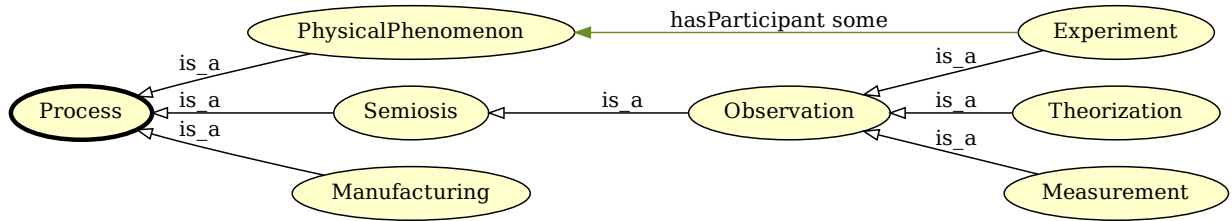


Figure 3.21: Process branch.

Process

IRI: http://emmo.info/perspectives/emmo-processual.owl#EMMO_43e9a05d_98af_41b4_92f6_00f79a09bfce

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

Comment: A ‘process’ is always a ‘physical’, since a ‘void’ does not have elements that evolves in time.

Comment: A ‘process’ is defined as a temporal part of a ‘physical’ that is categorized according to an EMMO user that recognizes a particular type of evolution in time of the real world object.

Following the common definition of process, every ‘physical’ should be a process, since every 4D object always has a time dimension.

However, in the EMMO we restrict the meaning of the word process to ‘physical’-s whose evolution in time have a particular meaning for the ontologist.

i.e. a ‘process’ is not only something that unfolds in time (which is automatically represented in a 4D ontology), but something happening that has a meaning for the ontologist.

Relations:

- is_a **Processual**
- (hasParticipant some **Participant**)

Manufacturing

IRI: http://emmo.info/domains/emmo-usercase.owl#EMMO_a4d66059_5dd3_4b90_b4cb_10960559441b

Relations:

- is_a **Process**
- (hasProperParticipant some **Engineered**)

PhysicalPhenomenon

IRI: http://emmo.info/domains/emmo-models.owl#EMMO_314d0bd5_67ed_437e_a609_36d46147cea7

Elucidation: A ‘process’ that is recognized by physical sciences and is catogrized accordingly.

Comment: While every ‘process’ in the EMMO involves physical objects, this class is devoted to represent real world objects that express a phenomena relevant for the ontologist.

Relations:

- is_a **Process**

Semiosis

IRI: http://emmo.info/perspectives/emmo-semiotics.owl#EMMO_008fd3b2_4013_451f_8827_52bceab11841

Elucidation: A ‘process’, that has participant an ‘interpreter’, that is aimed to produce a ‘sign’ representing another participant, the ‘interpreted’.

Example: Me looking a cat and saying loud: “Cat!” -> the semiosis process

me -> interpreter cat -> object (in Peirce semiotics) the cat perceived by my mind -> interpretant “Cat!” -> sign, the produced sign

Relations:

- is_a **Process**
- (hasParticipant some **Interpreter**)
- (hasProperParticipant some **Object**)
- (hasProperParticipant some **Sign**)

Observation

IRI: http://emmo.info/domains/emmo-properties.owl#EMMO_10a5fd39_06aa_4648_9e70_f962a9cb2069

Elucidation: A ‘semiosis’ that involves an ‘observer’ that perceives another ‘entity’ (the ‘object’) through a specific perception mechanism and produces a ‘property’ (the ‘sign’) that stands for the result of that particular perception.

Relations:

- is_a **Semiosis**
- (hasParticipant some **Observer**)
- (hasParticipant some **Property**)

Experiment

IRI: http://emmo.info/domains/emmo-models.owl#EMMO_22522299_4091_4d1f_82a2_3890492df6db

Elucidation: An experiment is a process that is intended to replicate a physical phenomenon in a controlled environment.

Relations:

- is_a **Observation**
- (hasParticipant some **PhysicalPhenomenon**)

Measurement

IRI: http://emmo.info/domains/emmo-physical-properties.owl#EMMO_463bcfda_867b_41d9_a967_211d4d437cfb

Elucidation: An ‘observation’ that results in a quantitative comparison of a ‘property’ of an ‘object’ with a standard reference.

Relations:

- is_a **Observation**
- (hasParticipant some **MeasurementInstrument**)

Theorization

IRI: http://emmo.info/domains/emmo-models.owl#EMMO_6c739b1a_a774_4416_bb31_1961486fa9ed

Elucidation: The ‘semiosis’ process of interpreting a ‘physical’ and provide a complex sign, ‘theory’ that stands for it and explain it to another interpreter.

Relations:

- is_a **Observation**

Chapter 4

Individuals

Universe

IRI: http://emmo.info/base/emmo-mereotopology.owl#EMMO_08cb807c_e626_447b_863f_e2835540e918

Relations:

- is_a **Item**

Chapter 5

Appendix

The complete taxonomy of EMMO relations

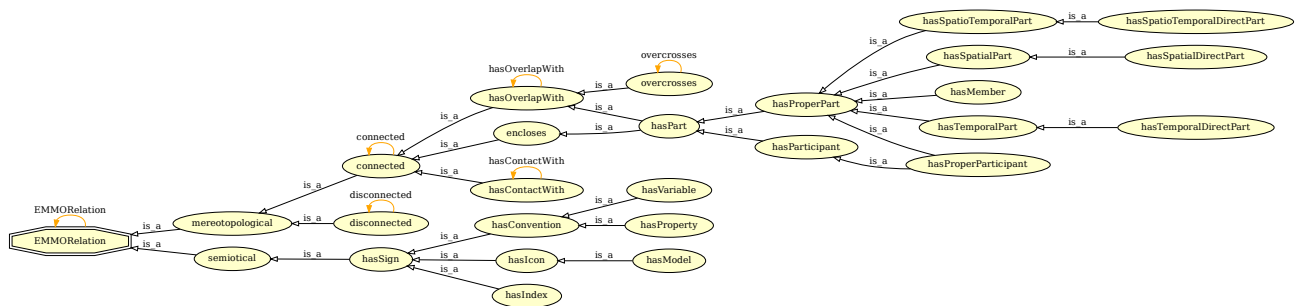


Figure 5.1: The complete taxonomy of EMMO relations.

The complete taxonomy of EMMO classes

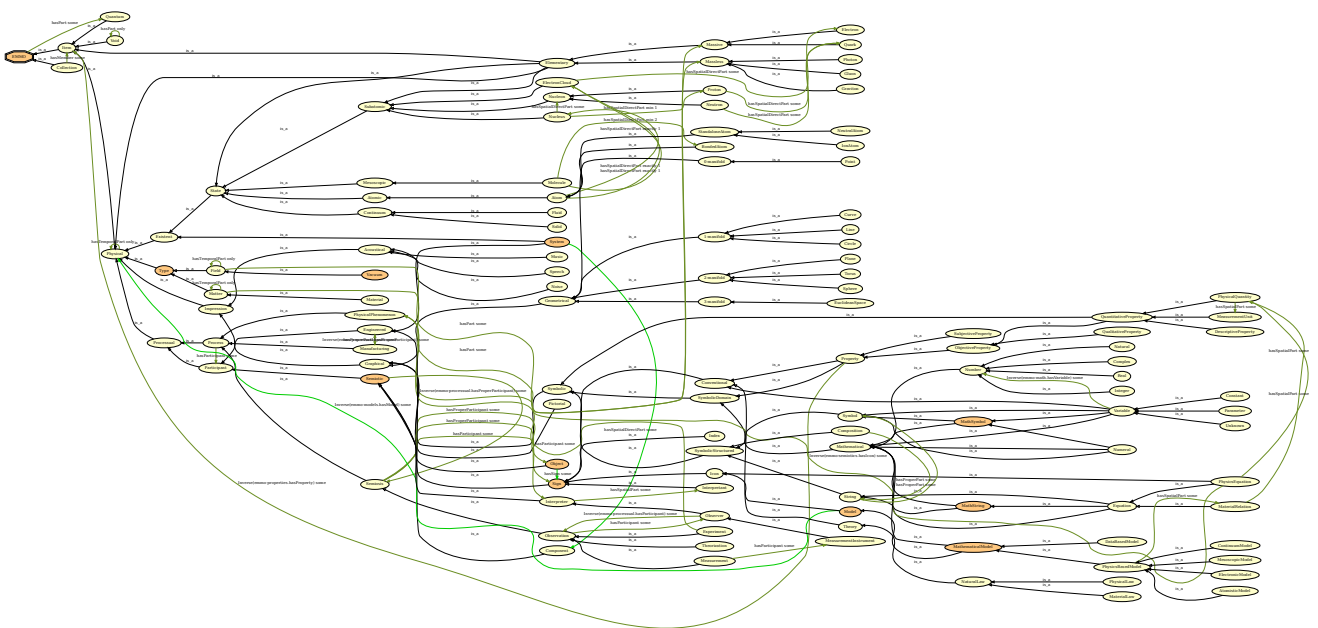


Figure 5.2: The complete taxonomy of EMMO classes.