# Europeean Materials Modelling Ontology

## Version 1.0.0

European Materials Modelling Counsil (EMMC)



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**Abstract**

EMMO is an ontology that is created by the Europeean 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.

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# Contents

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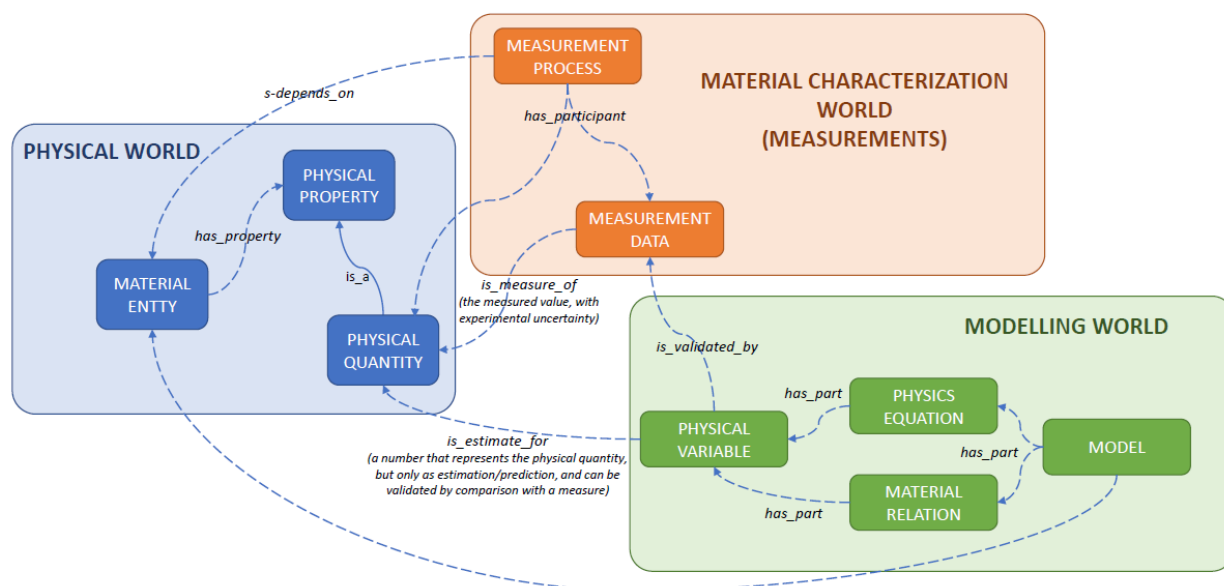


Figure 1.1: EMMO provides the connection between the physical world, materials characterisation world and materials modelling world.

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 percieves 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
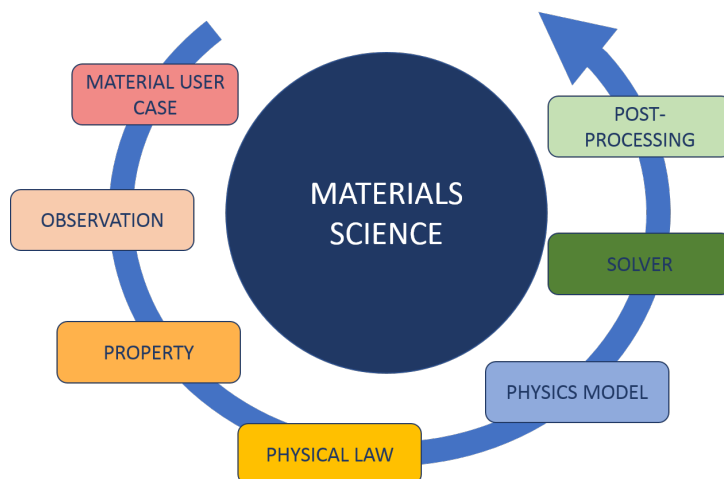- the **post processing** of experimental or simulated data

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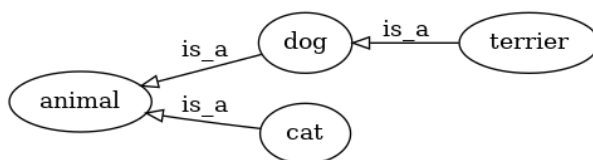
In EMMO, the taxonomy is a rooted directed acyclic graph (DAG). This is important since many classification methods relies on this property, see e.g. Valentini (2014) and Robison et al (2015). Note, that EMMO is a DAG does not prevent some classes from having more than one parent. A `Variable` is for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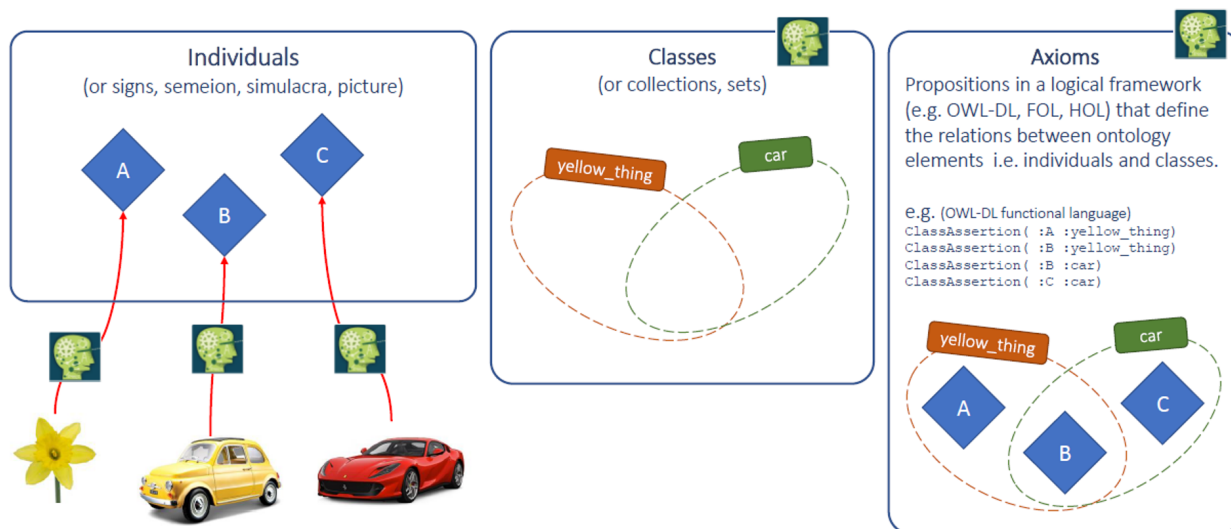
# Primitive elements in EMMO



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 an 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.

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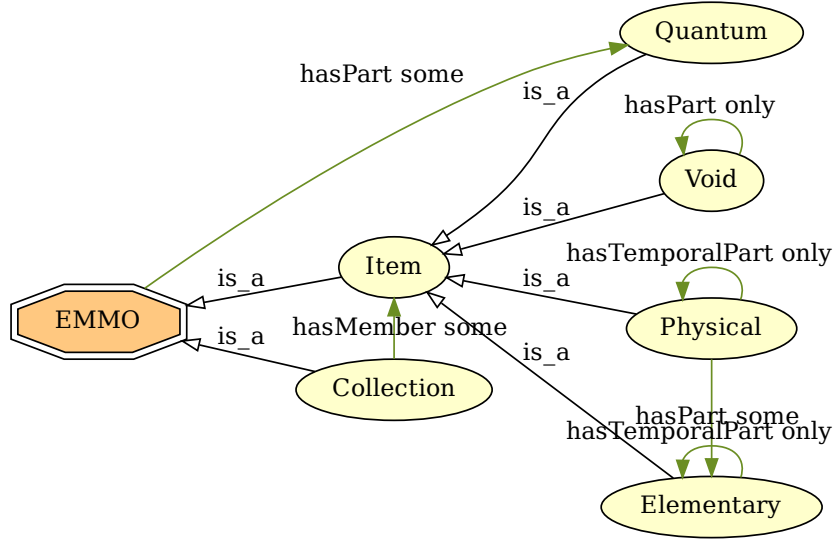
Figure 1.5: Example of the top-level entity branch showing some classes and relationships between them.

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 introdused 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 mecanics (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.
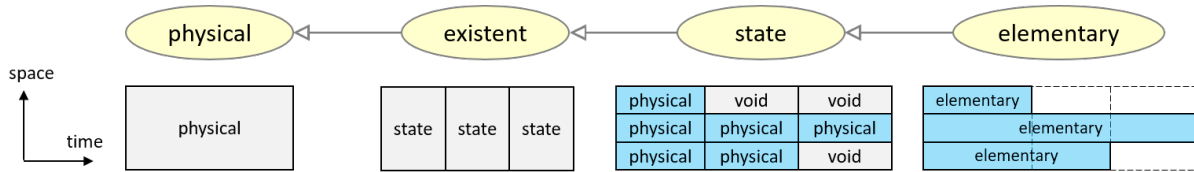
- **Existent** is a succession of states.



Figure 1.6: Parthood hierachy 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 |
| $\bot$ | | Nothing | bottom | The empty class |
| **Axioms** | | | | |
| $A \doteq B$ | | | A is defined to be equal to B | Class *definition* |
| $A \sqsubseteq B$ | A subclass_of B | class A(B): ... issubclass(A, B) | all A are B | Class *inclusion* Test for *inclusion* |

6

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

A person with one parent:

**DL:** `half_orphant` $\equiv$ `person` and $=1$`has_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 (⊔) of two classes, are either instances of one or both classes.

A person is a man or woman:

**DL:** `person ≡ man ⊔ woman`

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


**Complement (`owl:complementOf`)**

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

Not a man:

**DL:** `female ≡ ¬ 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.

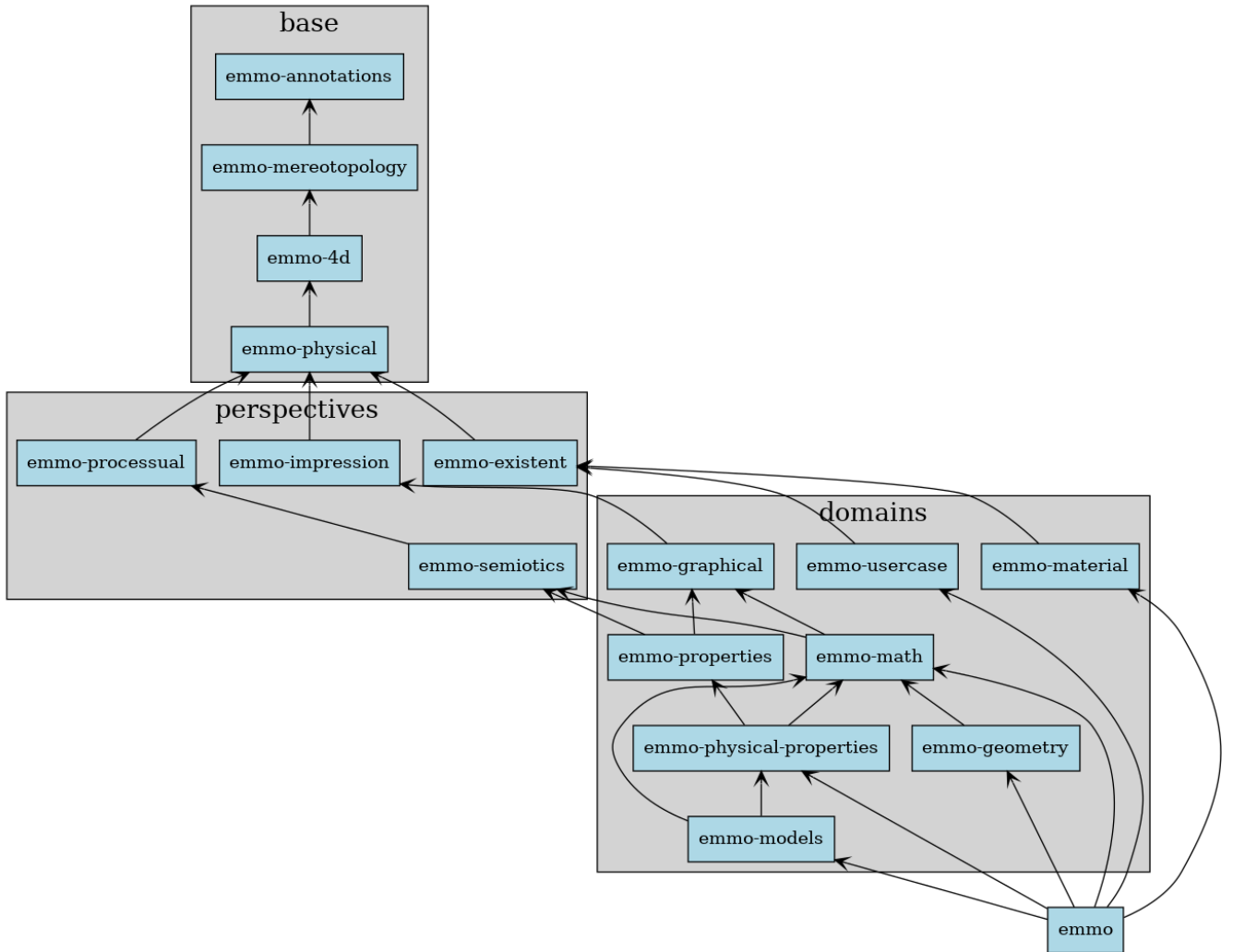Figure 1.7: The hierarchy of EMMO modules and their interdependencies grouped into three groups; base, perspectives and domains.

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-processsual 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 usercase.

## 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.
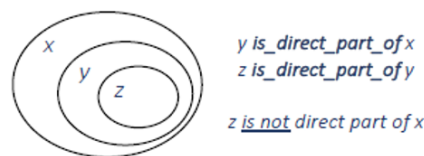


Figure 1.8: Direct parthood.

## 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 clearification of the documented class or relation.
- **Example** clearifies the elucidation through an example. A class may have several examples, each addressing different aspects.
- **Comment** is a clearifying note complementing the definition and elucidation. A class may have several comments, each clearifying 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 propertyes 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 or `relation`. The `rdf:subPropertyOf` axioms forms a taxonomy-like tree for relations.

- `owl:equivalentProperty` states that two properties have the same property extension.

- `owl:inverseOf` axioms relate active relations to their corresponding passive relations, and vice versa. The root relation `relation` is its own inverse.

- `owl:FunctionalProperty` is a property that can have only one (unique) value y for each instance x, i.e. there cannot be two distinct values 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.
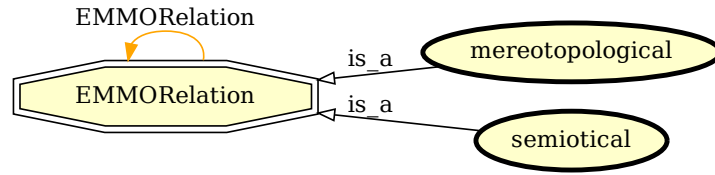
Figure 2.1: Top-level of the EMMO relation hierarchy.

# 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
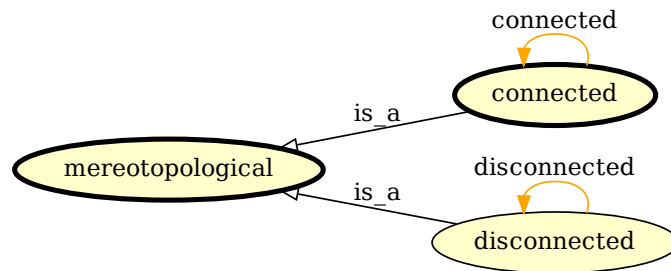


Figure 2.2: Mereotopological branch.

## 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
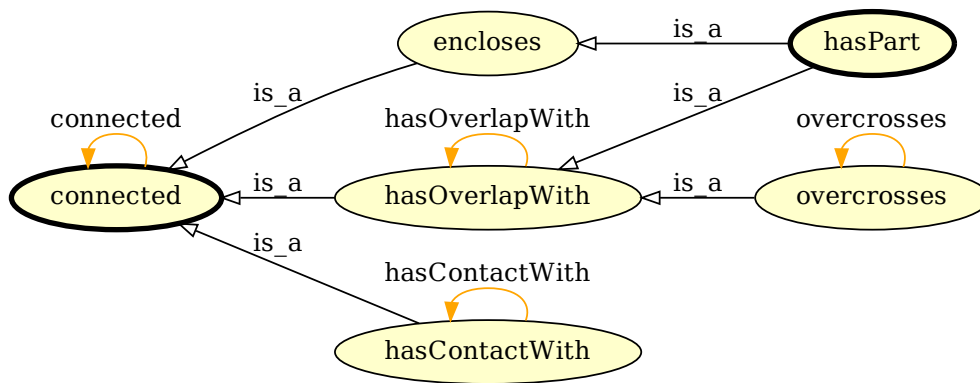


Figure 2.3: Connected branch.

## 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
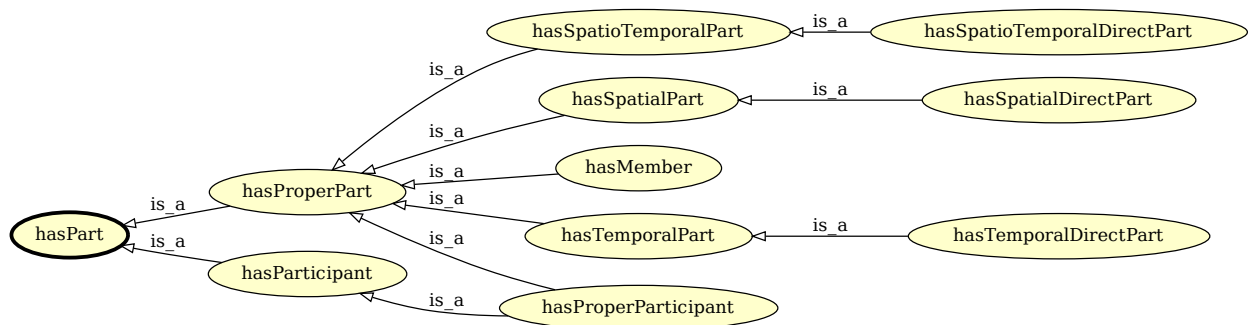


Figure 2.4: Has Part branch.

## hasPart

**IRI:** [http://emmo.info/base/emmo-mereotopology.owl#EMMO_17e27c22_37e1_468c_9dd7_95e137f73e7f](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](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](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](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](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
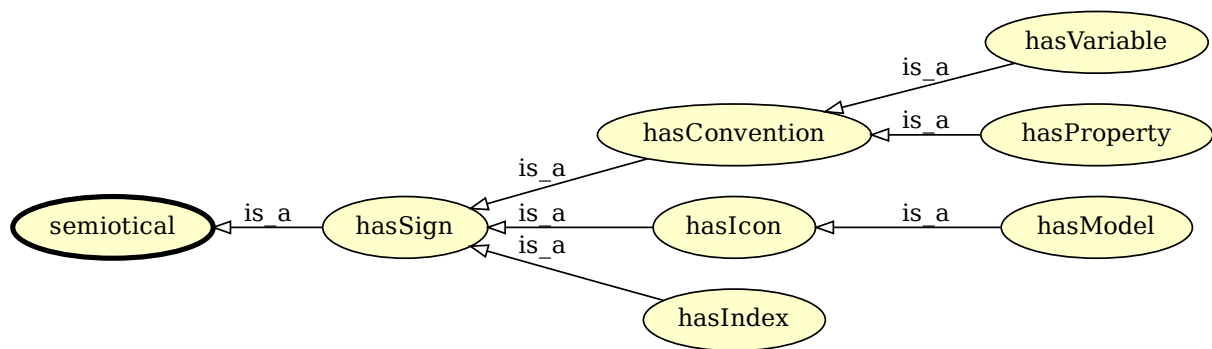


Figure 2.5: Semiotical branch.

## 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](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](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](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](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](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](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
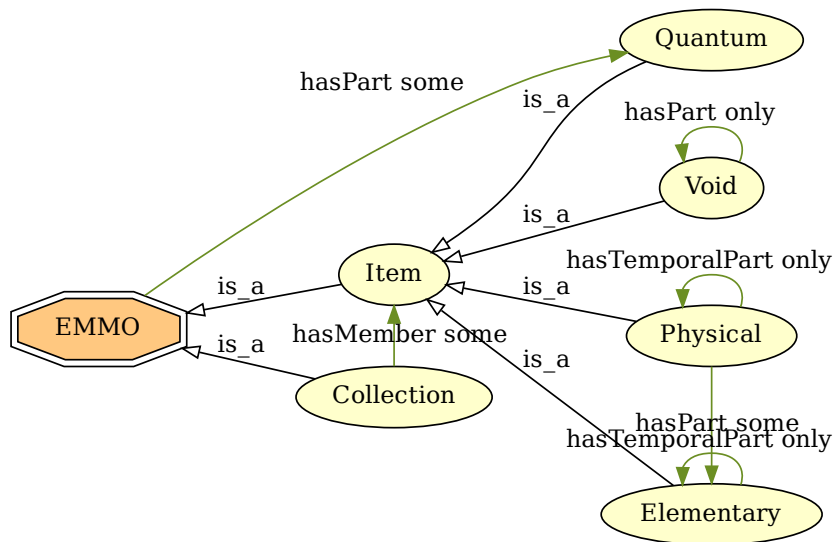


Figure 3.1: EMMO branch.

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](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, exension 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](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](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 uncertainity 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](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
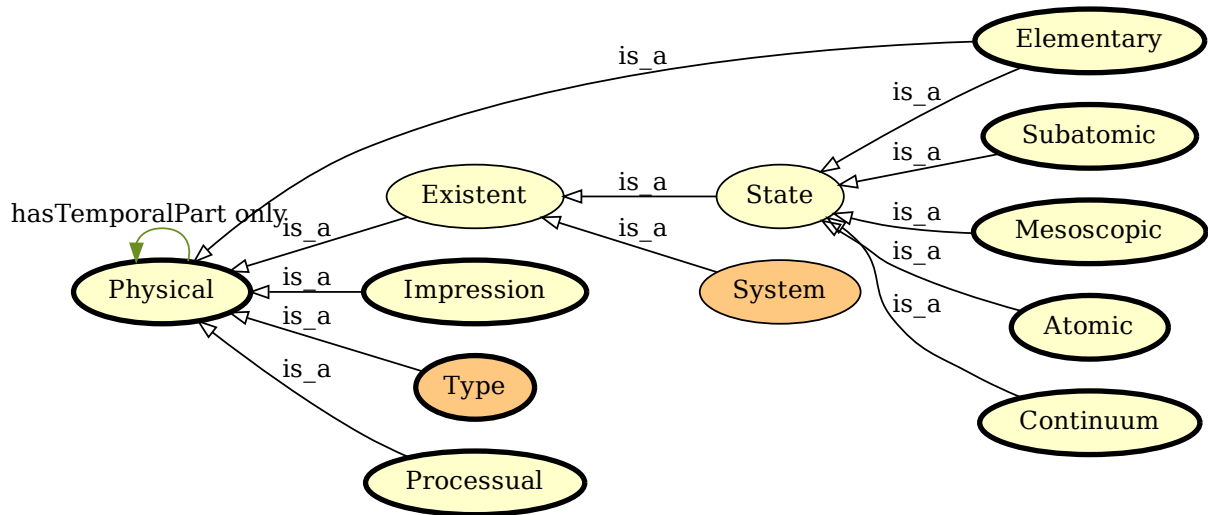


Figure 3.2: Physical branch.

## Physical

**IRI:** http://emmo.info/base/emmo-physical.owl#EMMO_c5ddfdba_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 analized 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 exists 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 Schroedinger 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 assumtpion 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 Schroedinger 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 sysyem are correlated) and described by a global wavefunction obtained solving the Schroedinger Equation.

Upon measurement, the wavefunction collapses to a combination of close eigenstates that provide information about bservables 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 Schroedinger equation based model whose Hamiltonian is calculated trough 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 immidiate next change.

**Example:** e.g. the existent in my glass is declared at t = t_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_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:**
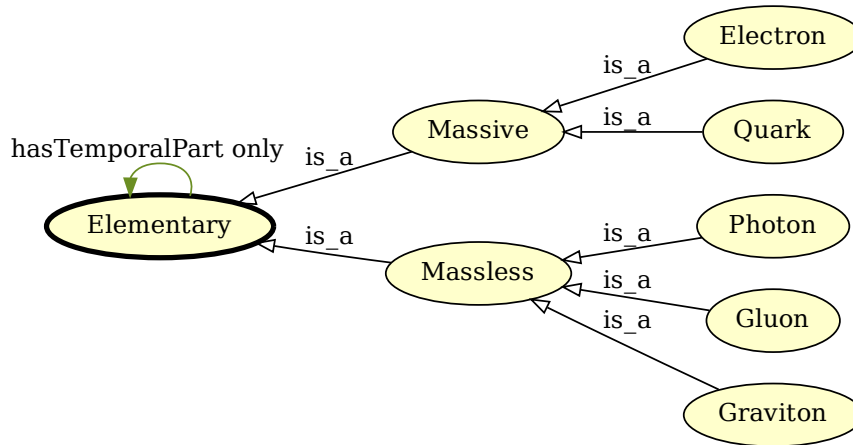
Figure 3.3: Elementary branch.

- 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
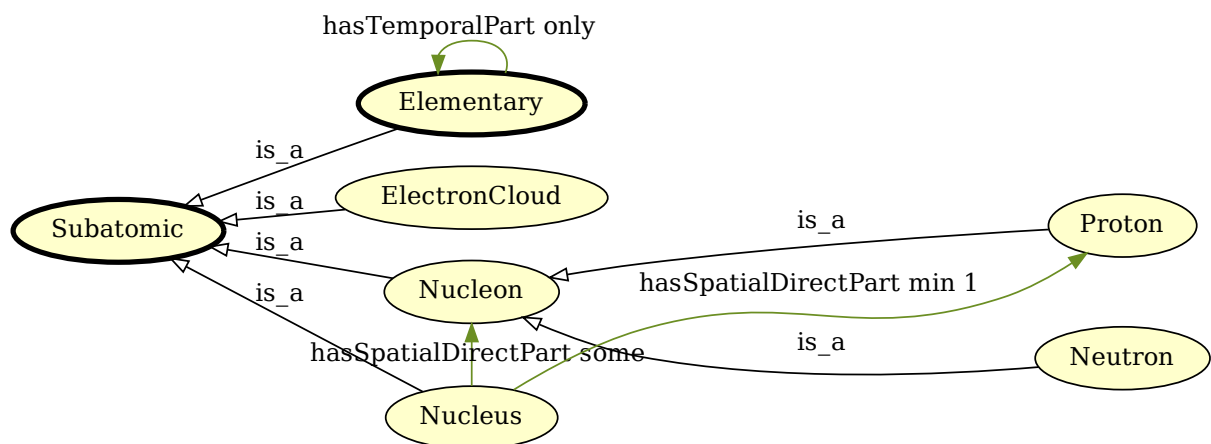


Figure 3.4: Subatomic branch.

## 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](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](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](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](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](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](http://emmo.info/domains/emmo-material.owl#EMMO_5c4aff3c_c30c_4507_86d5_b4df41eb9f2f)
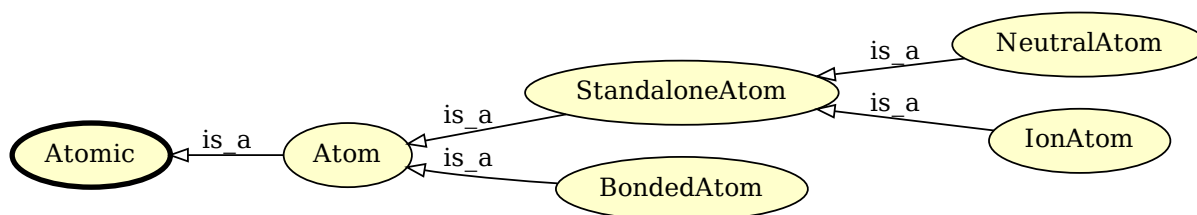
**Relations:**

- 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 electonic 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 eclectron 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
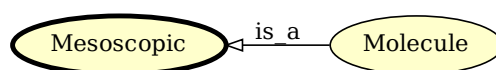
Figure 3.6: Mesoscopic branch.

## 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:** H20, 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 redundand 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 H20 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
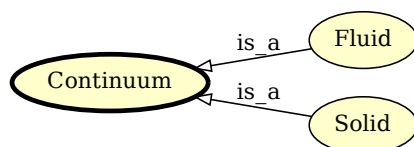


Figure 3.7: Continuum branch.

## 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 [#/m3] x dV [m3] >> 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
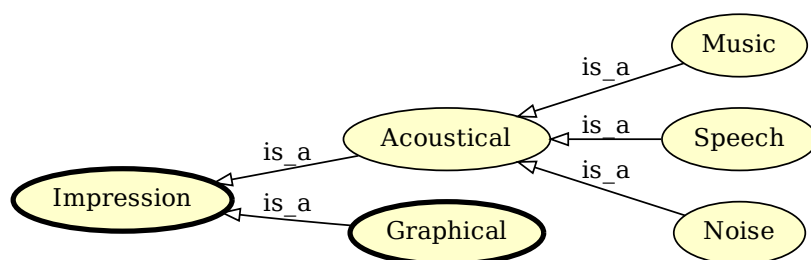


Figure 3.8: Impression branch.

## 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 <span style="color:red">Impression</span>

## 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 <span style="color:red">Acoustical</span>

## Noise

**IRI:** http://emmo.info/domains/emmo-acoustical.owl#EMMO_91756568__8655__4060__8937__a1a906dad8c1

**Relations:**

- is_a <span style="color:red">Acoustical</span>

## Speech

**IRI:** http://emmo.info/domains/emmo-acoustical.owl#EMMO_660ef3b0__6692__4c51__8f69__763c7817b2e1

**Relations:**

- is_a <span style="color:red">Acoustical</span>

# Graphical branch
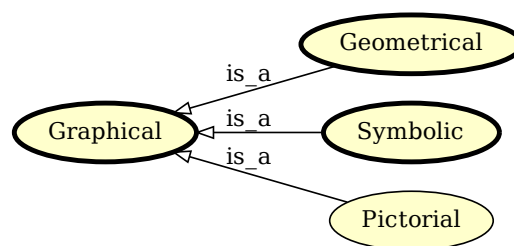


Figure 3.9: Graphical branch.

## 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
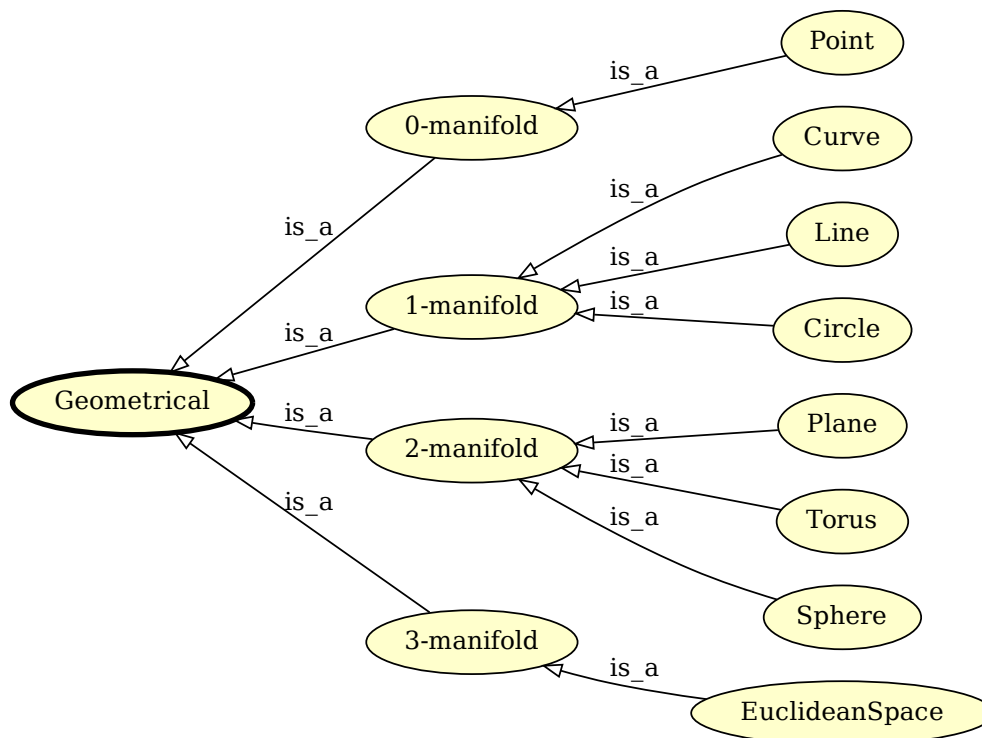


Figure 3.10: Geometrical branch.

## 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](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](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](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](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](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](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](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.
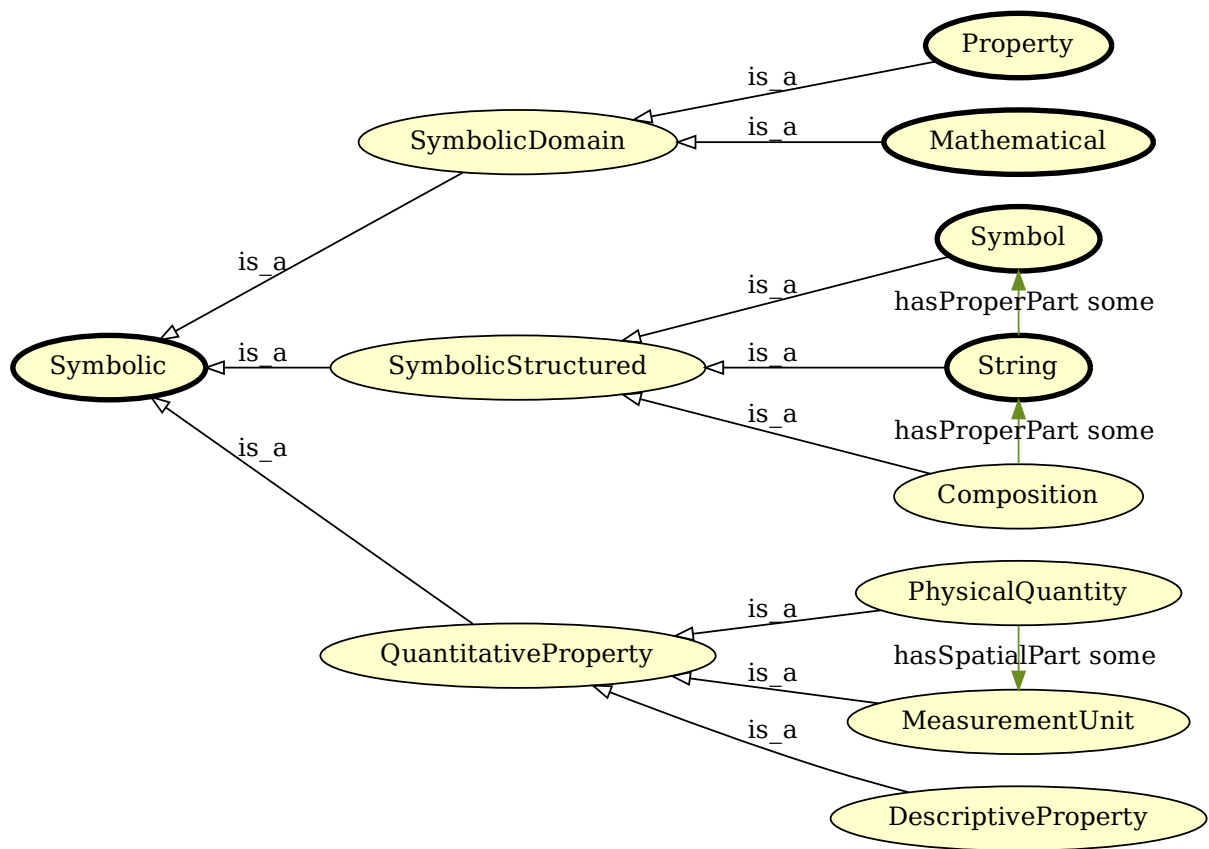
**Relations:**

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 propertiy'-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
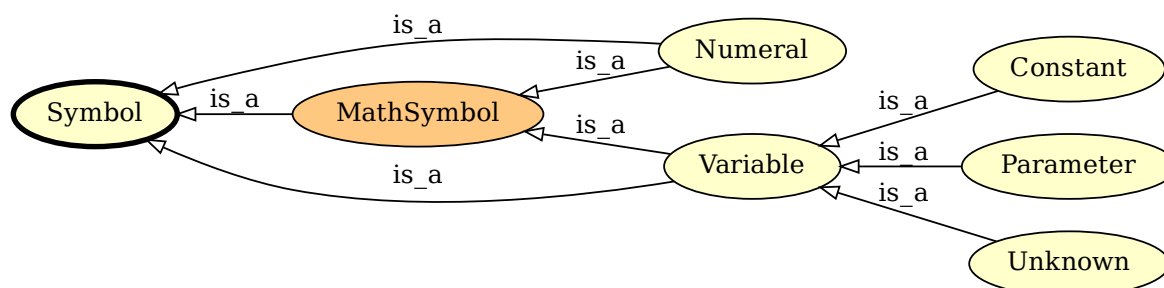


Figure 3.12: Symbol branch.

**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 'varaible' 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
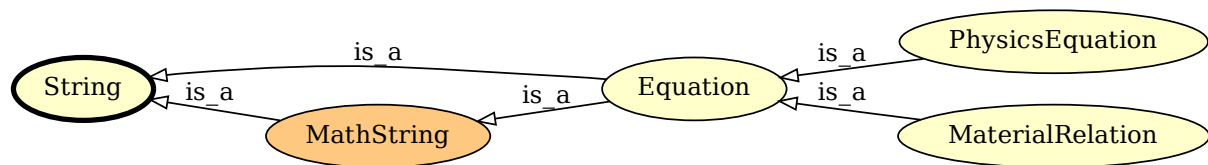


Figure 3.13: String branch.

## 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

43

## Equation

**IRI:** [http://emmo.info/domains/emmo-math.owl#EMMO_e56ee3eb_7609_4ae1_8bed_51974f0960a6](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(v0, v1, …, vn) = g(v0, v1, …, vn)

where f is the left hand and g the right hand side expressions and v0, v1, …, vn 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](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](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)
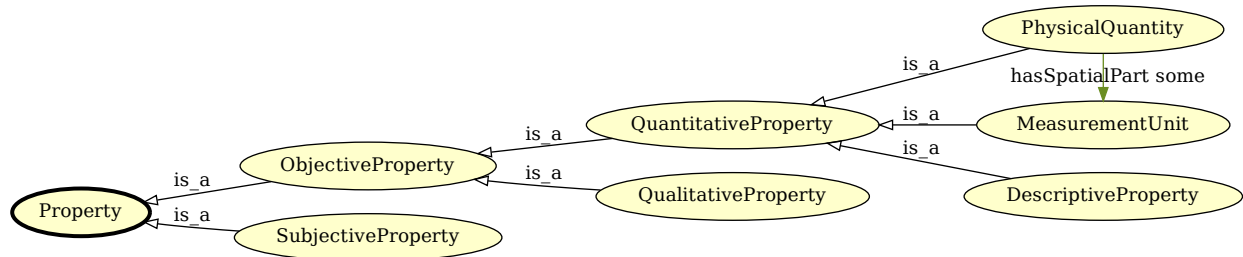- (Inverse(emmo-semiotics.hasIcon) some PhysicalPhenomenon)

# 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 be 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 existance that has no intersection with us and we can say nothing about it).

Perception/observation of a real wolrd 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_2a888cdf_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 propertiy'-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
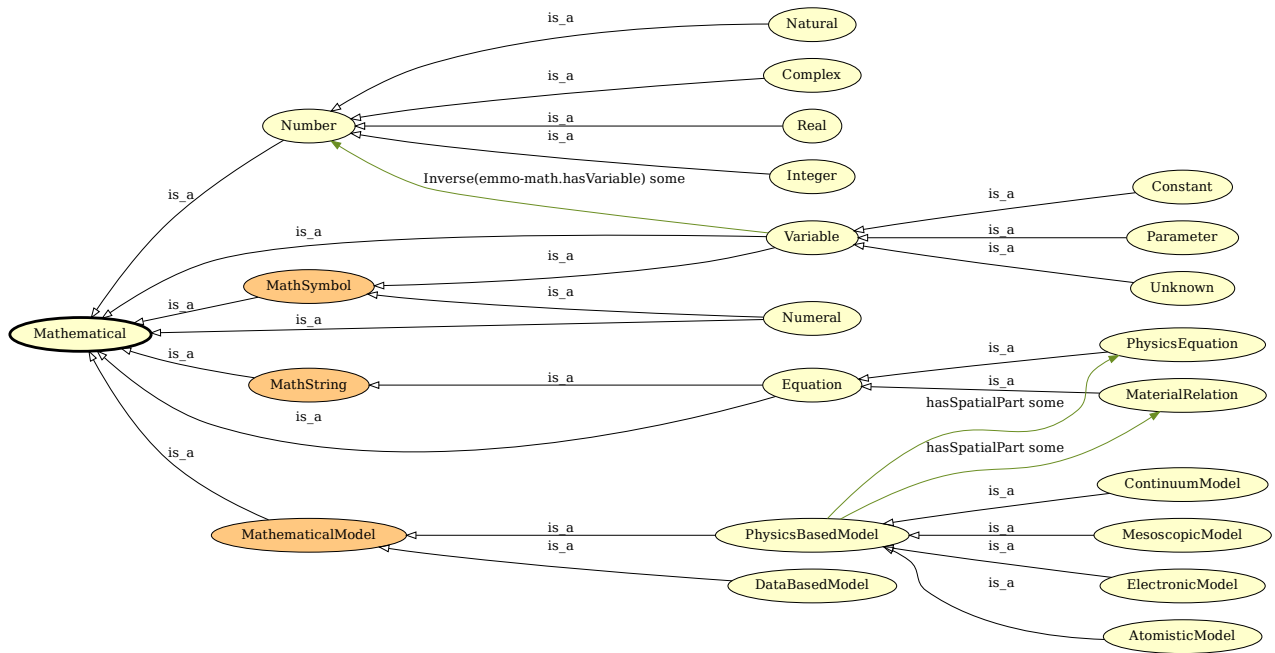
Figure 3.15: Mathematical branch.

- 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_d780abffbdfa

**Relations:**

- is_a Number

## MathString

**IRI:** [http://emmo.info/domains/emmo-math.owl#EMMO_2c03c212_742d_4699_9956_d182735009dc](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](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](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(v0, v1, …, vn) = g(v0, v1, …, vn)

where f is the left hand and g the right hand side expressions and v0, v1, …, vn 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](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](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](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](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](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_84cadc45_6758_46f2_ba2a_5ead65c70213](http://emmo.info/domains/emmo-models.owl#EMMO_84cadc45_6758_46f2_ba2a_5ead65c70213)

**Relations:**

- is_a PhysicsBasedModel

## ContinuumModel

**IRI:** [http://emmo.info/domains/emmo-models.owl#EMMO_4456a5d2_16a6_4ee1_9a8e_5c75956b28ea](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](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](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](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](http://emmo.info/domains/emmo-math.owl#EMMO_ae15fb4f_8e4d_41de_a0f9_3997f89ba6a2)

**Elucidation:** A 'varaible' 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](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

## 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)

## 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:**
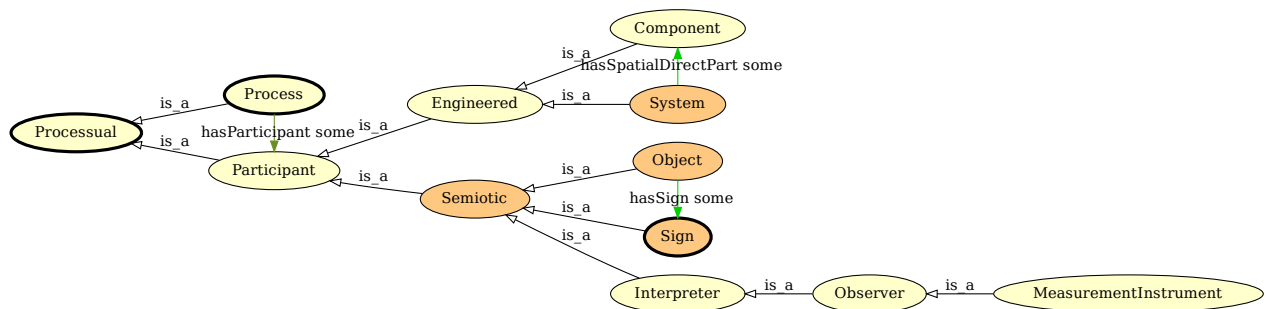
- is_a Variable

# Processual branch



Figure 3.16: Processual branch.

## Processual

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

**Elucidation:** A 'physical' that stands for a real world object related to or involving the study of processes rather than discrete events.

**Relations:**

- is_a Physical

## Participant

**IRI:** [http://emmo.info/perspectives/emmo-processual.owl#EMMO_49804605_c0fe_4538_abda_f70ba1dc8a5d](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](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 manufacturedfor 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](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](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 exists 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 become and '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
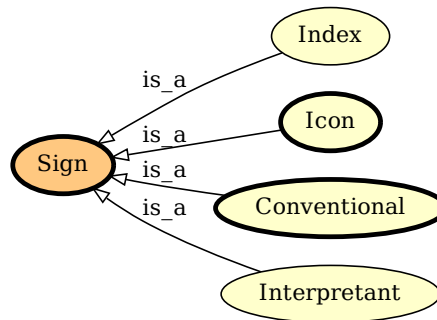
**Relations:**

- 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 'objectì due to causal continguity.

**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
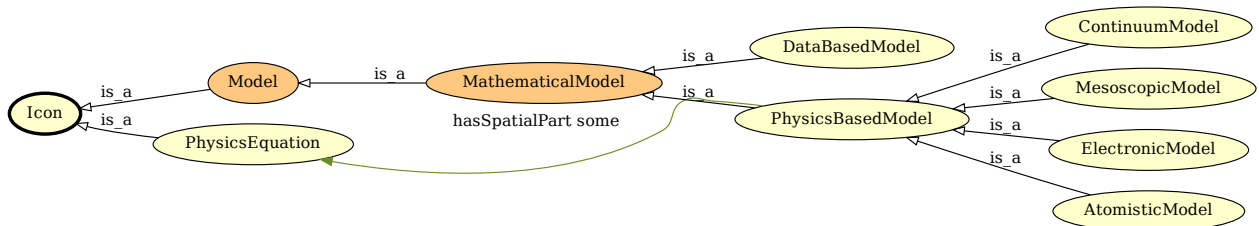
**Relations:**

- 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_84cadc45_6758_46f2_ba2a_5ead65c70213

**Relations:**

- is_a PhysicsBasedModel

## ContinuumModel

**IRI:** [http://emmo.info/domains/emmo-models.owl#EMMO_4456a5d2_16a6_4ee1_9a8e_5c75956b28ea](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](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](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](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](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.
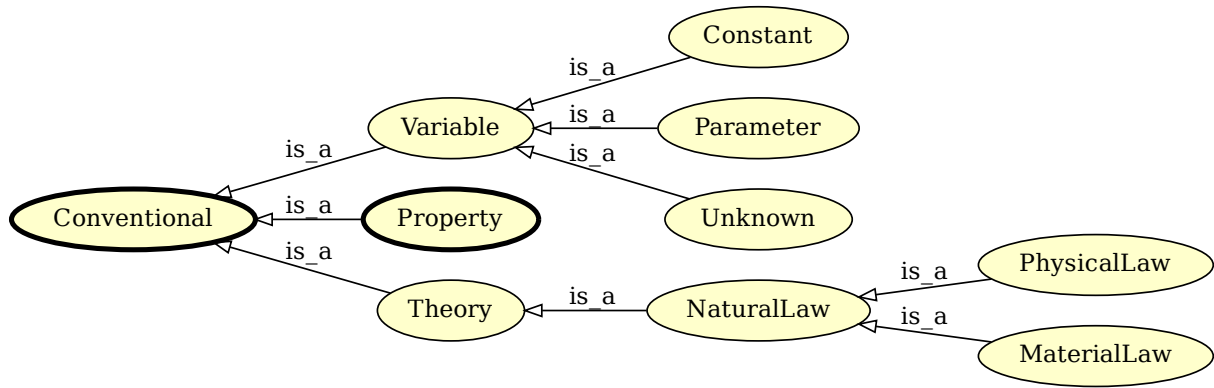
**Relations:**

- 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](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](http://emmo.info/domains/emmo-math.owl#EMMO_ae15fb4f_8e4d_41de_a0f9_3997f89ba6a2)

**Elucidation:** A 'varaible' 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](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](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](http://emmo.info/domains/emmo-material.owl#EMMO_508e84f6_5081_4a9b_80b4_0b7830718b37)

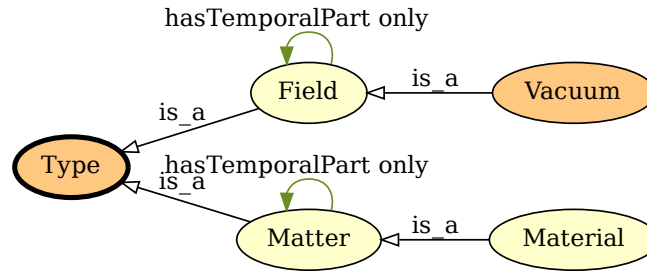**Relations:**

- 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](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](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](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](http://emmo.info/domains/emmo-material.owl#EMMO_3c218fbe_60c9_4597_8bcf_41eb1773af1f)

**Relations:**

- is_a Field
- equivalent_to Field and not Matter
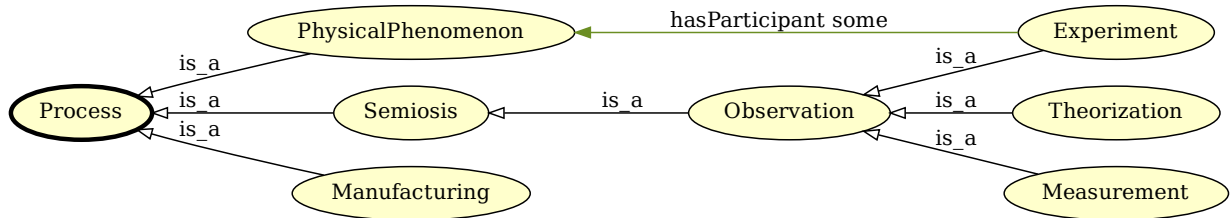
# Process branch



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 complec 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](http://emmo.info/base/emmo-mereotopology.owl#EMMO_08cb807c_e626_447b_863f_e2835540e918)

**Relations:**

- is_a Item

# Chapter 5

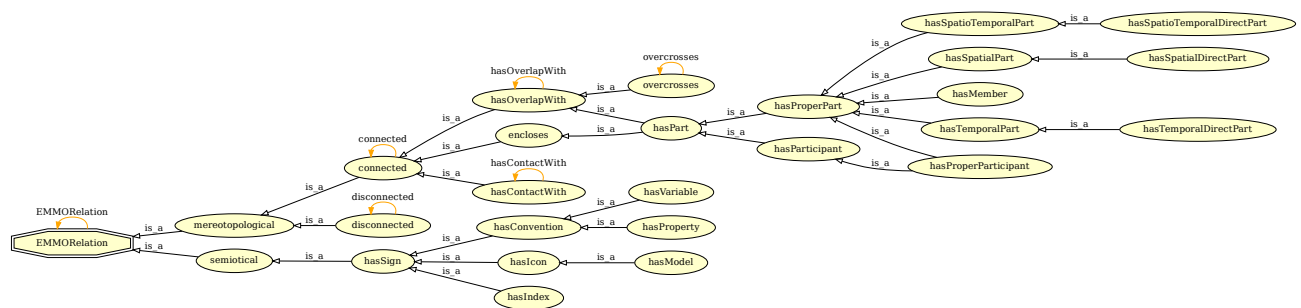# Appendix

## The complete taxonomy of EMMO relations



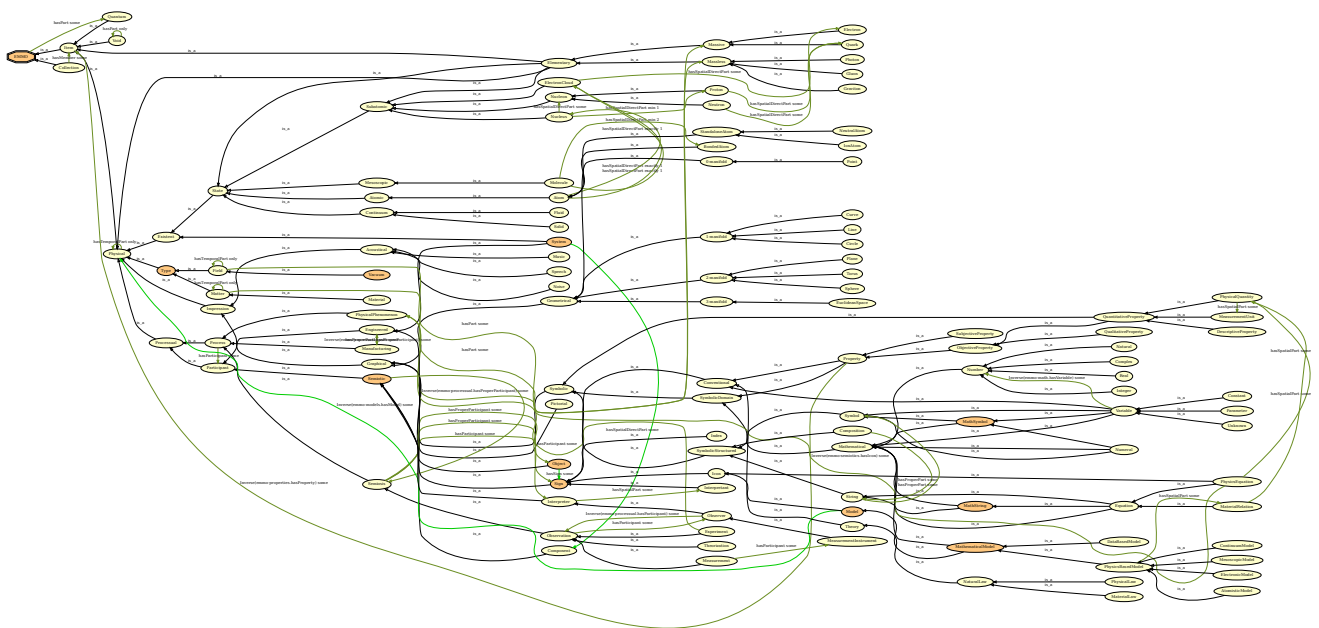Figure 5.1: The complete taxonomy of EMMO relations.

## The complete taxonomy of EMMO classes



Figure 5.2: The complete taxonomy of EMMO classes.