Europeean Materials Modelling Ontology

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European Materials Modelling Counsil (EMMC)

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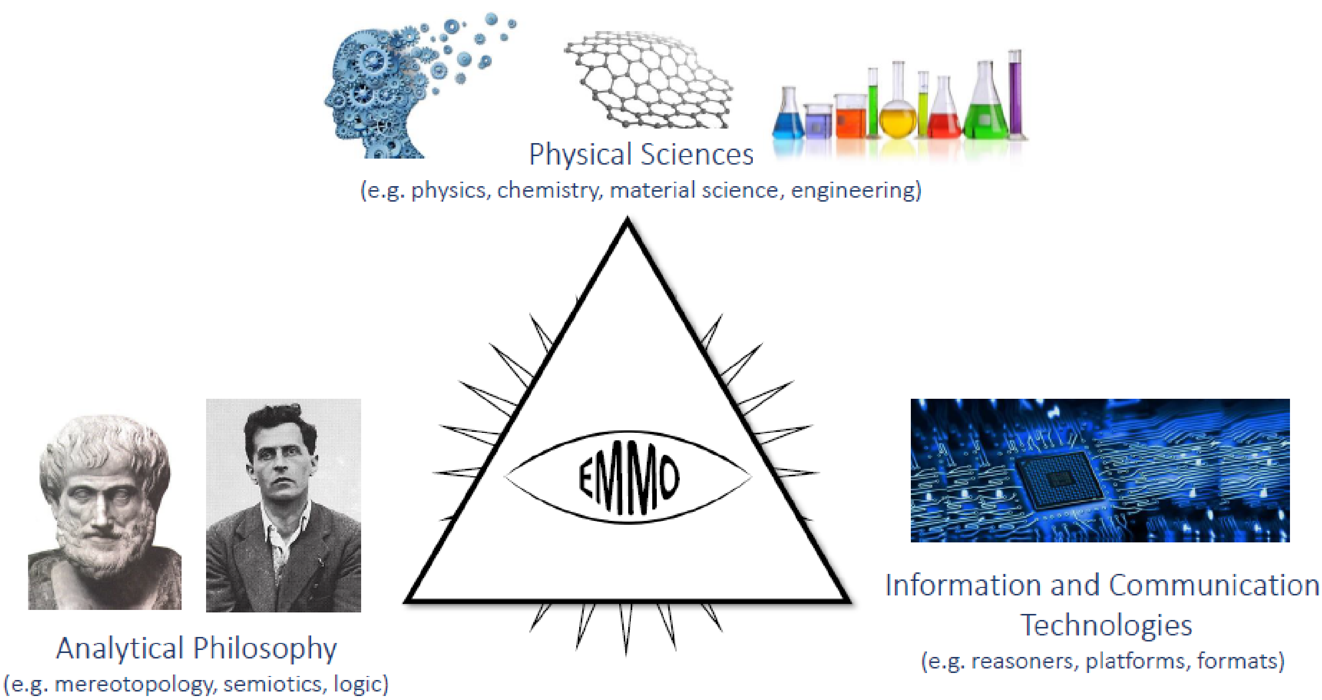

Abstract

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.

Keywords: EMMO, materials science, modelling, characterisation, materials, ontology

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Chapter 1

Introduction

EMMO is a multidisciplinary effort to develop a standard representational framework (the ontology) based on current materials modelling knowledge, including physical sciences, analytical philosophy and information and communication technologies. This 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.

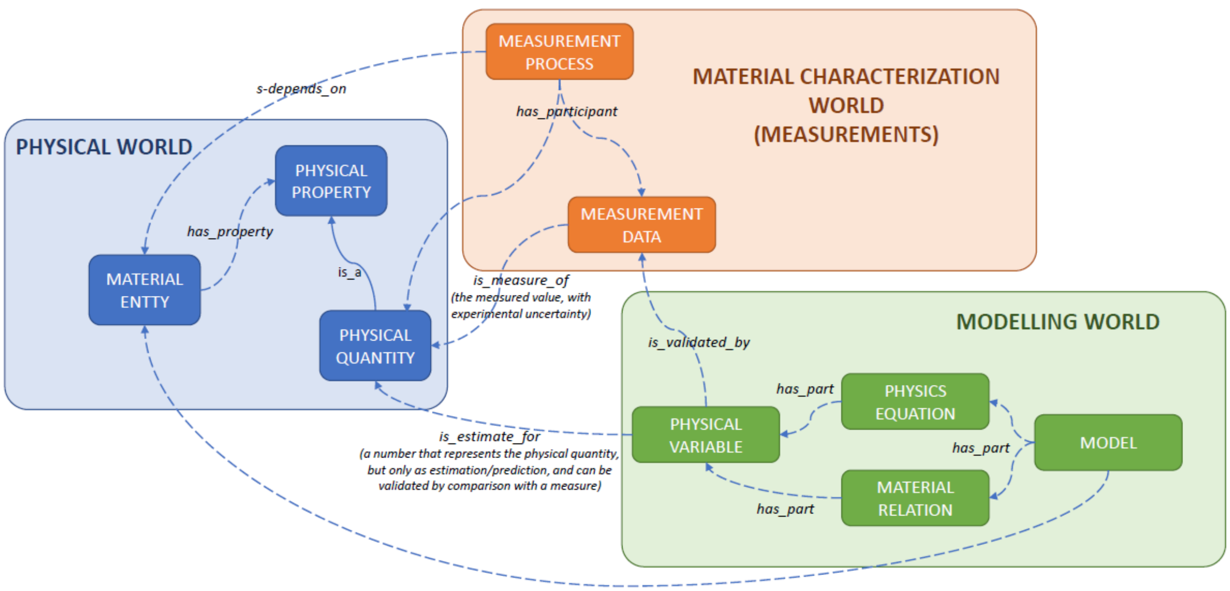

Figure 1.1: EMMO provides the connection between the physical world, materials characterisation world and materials modelling world.

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.

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
- the **properties** that is measured or modelled
- the **physics laws** that describes the material behaviour
- the **physical models** that approximate the physics laws

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

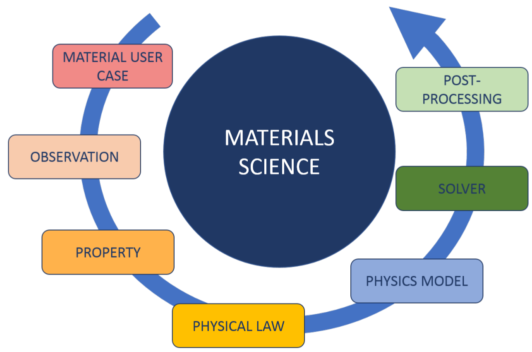

Figure 1.2: The aspects of materials modelling and characterisation covered by EMMO.

What is an ontology

In short, an ontology is a specification of a conceptualization. The word *ontology* has a long history in philosophy, in which it refers to the subject of existence. The so-called ontological argument for the existence of God was proposed by Anselm of Canterbury in 1078. He defined God as *"that than which nothing greater can be thought"*, and argued that *"if the greatest possible being exists in the mind, it must also exist in reality. If it only exists in the mind, then an even greater being must be possible – one which exists both in the mind and in reality"*. Even though this example has little to do with todays use of ontologies in computer science, it illustrates the basic idea; the ontology defines some basic premises (concepts and relations between them) from which it is possible 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 are for classifications. The figure shows a simple example of a taxonomy illustrating a categorisation of four classes into a hierarchy of more higher of levels of generality.

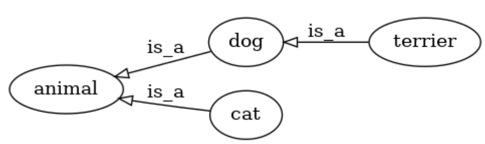

Figure 1.3: Example of a taxonomy.

In EMMO is the taxonomy a rooted directed acyclic graph (DAG). This is an 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 `quantitative_property` is for instance both `formed` and an `objective_property`. See appendix for the full EMMO taxonomy.

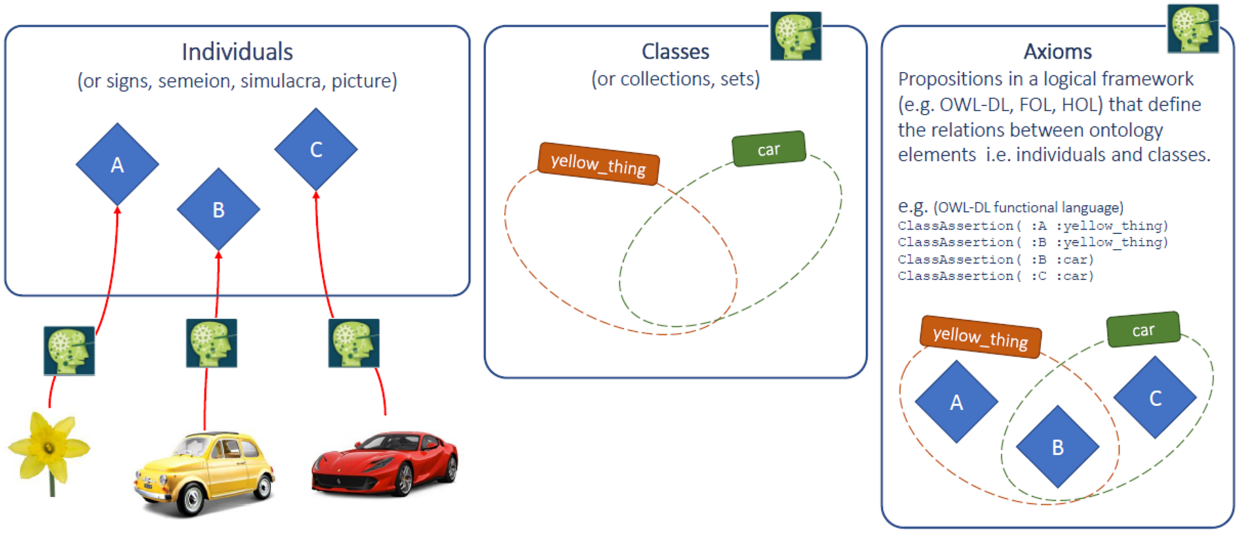

Figure 1.4: The primitive building blocks of EMMO.

Primitive elements in EMMO

Individuals

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

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

Classes

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

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

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

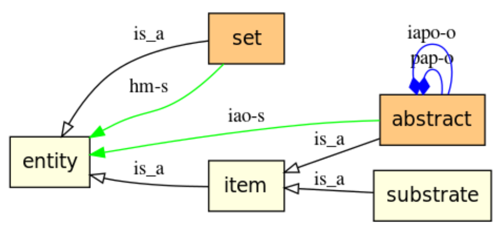

Figure 1.5: Example of the top-level entity branch showing some classes and relationships between them.

Axioms

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

The simplest form of a class axiom is a class description that just states the existence of the class and gives it 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:

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

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

Theoretical foundations

EMMO build upon several theoretical frameworks.

Semiotics

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

Set theory

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

Mereology

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

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

For further information, see Casati and Varzi "Parts and Places" (1999).

Topology

Topology is the study of geometrical properties and spatial (and time-wise) relations. It is introdused in combination with mereology (and therefore often referred to as **mereotopology**) via the `substrate` class, which represents the place in space and time in which every real world item exists. Substrates in EMMO are always topologically connedted in space and time.

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

Metrology

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

Description logic

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

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

OWL distinguishes six between types of class descriptions:

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

Except for the first, all of these refer to *defined classes*. The table below shows the notation in OWL, DL and the Manchester OWL syntax, all commonly used for the definitions. The Manchester syntax is used by Protege and is designed to not use DL symbols and to be easy and quick to read and write. Several other syntaxes exists for DL. An interesting example is the pure Python syntax proposed by Lamy (2017), which is used in the open source Owlready2 Python package.

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

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

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

Examples

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

Inclusion (`rdf:subclassOf`)

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

An employee is a person.

DL: `employee` *sqsubseteq* `person`

Manchester: `employee is_a person`

Enumeration (`owl:oneOf`)

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

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

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

Property restriction (`owl:someValuesFrom`)

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

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

Manchester: `mother equivalent_to woman and has_child some person`

Property restriction (`owl:allValuesFrom`)

All parents that only have daughters:

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

Manchester: `parents_with_only_daughters equivalent_to person and has_child only woman`

Property restriction (`owl:hasValue`)

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

All children of Mary:

DL: $\texttt{Marys\_children} \equiv \texttt{person} \sqcap \exists\texttt{has\_parent}.\{\texttt{Mary}\}$

Manchester: `Marys_children equivalent_to person and has_parent value Mary`

Property cardinality (`owl:cardinality`)

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

A person with one parent:

DL: $\texttt{half\_orphant} \equiv \texttt{person}$ and $=1\texttt{has\_parent.person}$

Manchester: `half_orphant equivalent_to person and has_parent exactly 1 person`

Intersection (`owl:intersectionOf`)

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

A man is a person that is male:

DL: $\texttt{man} \equiv \texttt{person} \sqcap \texttt{male}$

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: $\texttt{person} \equiv \texttt{man} \sqcup \texttt{woman}$

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: $\texttt{female} \equiv \neg\, \texttt{male}$

Manchester: `female equivalent_to not male`

EMMO Structure

EMMO is structures in a hierarchical set of modules covering all aspects materials modelling. The modules and their interdependencies are shows in the figure below. Each module correspond to a separate OWL file. The special module `emmo-all.owl` includes all of EMMO.

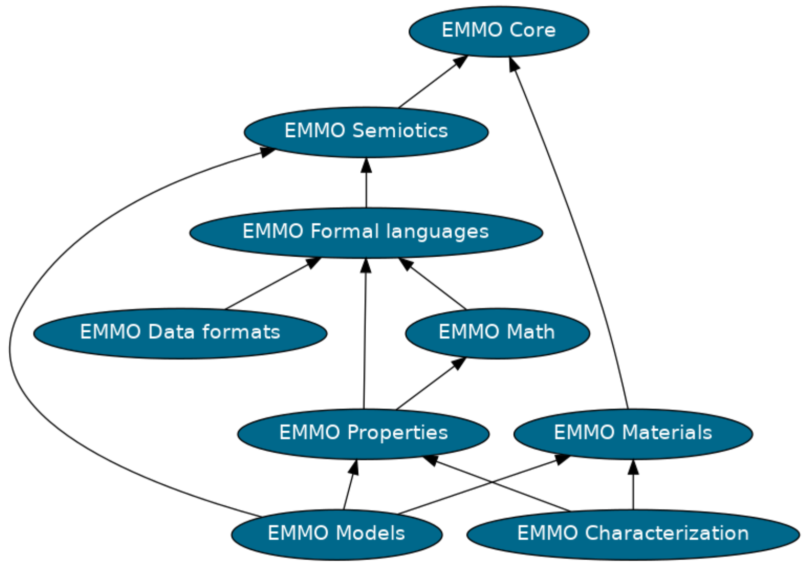

Figure 1.6: EMMO modules.

EMMO Core

EMMO core contains three levels as illustrated in the figure below.

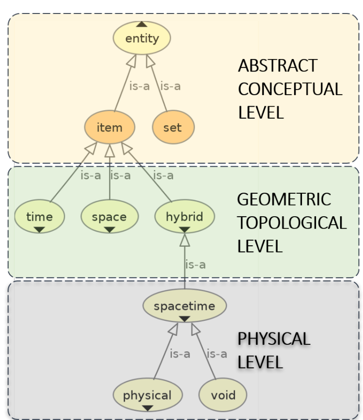

Figure 1.7: Toplevel structure of EMMO Core.

- **The abstract conceptual level** makes a clear separation between `set` (set theory) and `item` (mereotopology).
- **The geometric/topological level** contains the space (3D) and time (1D) in which all items unfolds.
- **The physical level** holds the 4D `spacetime` in which all real world entities exists. A `spacetime` that can be perceived by (interact with) the interpreater is a `physical`. If the `spacetime` entity is empty in terms of perception, it is a `void`.

EMMO defines a parthood hierachy under `physical` by introducing the following concepts (illustrated in the figure below):

- **`elementary`** is the fundamental, non-divisible constituent of entities
- **`state`** is a `physical`whose parts have a constant cardinality during its life time
- **`existent`** is a succession of states

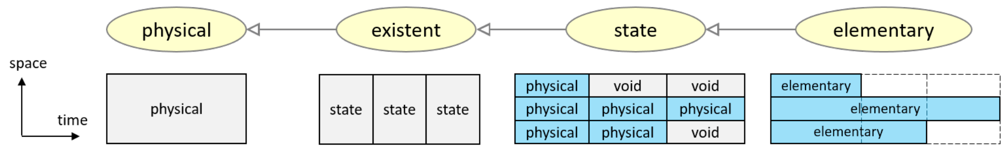

Figure 1.8: Parthood hierachy under `physical`.

Via the mereological direct parthood relation, EMMO can describe entities made of parts at different levels of granularity. 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.

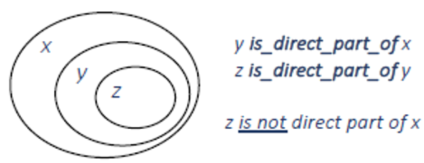

Figure 1.9: Direct parthood.

EMMO Materials

EMMO Material contains a first draft of a materials ontology. It relies on direct parthood to identify granularity levels. It is generic and flexible enough to represent both classical and quantum mechanical systems in a way that is compatible with different interpretations (e.g. the Copenhagen and De Broglie-Bohm interpretations of quantum mechanics) and levels of approximations (e.g. classical physics and Born-Oppenheimer approximation).

EMMO Semiotics

The semiotics module introduces three connected branches, `symbolic`, `semiosis` and `semiotic_role` in addition to the `has_sign`/`stands_for` family of relations.

Since the EMMO must represent models and properties (which are signs that stand for a physical entity), the semiotic process must be described also within the EMMO itself. The concepts of Peirce semiotics (interpreter, object, sign) are included in the semiotic branch, together with the semiosis process.

EMMO Formal languages

EMMO Data formats

EMMO Math

EMMO Properties

EMMO Models

EMMO Characterisation

How to read this document

Annotations

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

- **Elucidation** is a human readable explanation and 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. Even though the IRIs used in EMMO appears to be URLs, they currently do not point to any existing content. This might change in the future.
- **Relations** is a list of relations applying to the current class or relation. The relations for relations are special and will be elaborated on in the introduction to chapter [Relations]. Some of the listed relations are defined in the OWL sources, while other are inferred by the reasoner.

  The relations are using the Manchester OWL syntax introduced in section Description logic.

Graphs

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

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

Relation	UML arrow	UML concept
is-a		inheritance
disjoint_with		association
equivalent_to		association
encloses		aggregation
has_abstract_part		aggregation

Relation	UML arrow	UML concept
has_abstraction		aggregation
has_representation		aggregation
has_member		aggregation
has_property		aggregation

All relationships have a direction. In the graphical visualisations, the relationships are represented with an arrow pointing from the subject to the object. In order to reduce clutter and limit the size of the graphs, the relations are abbreviated according to the following table:

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

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

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

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

Chapter 2

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 call them *relations* here.

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

In EMMO, are the subject and object classes or individuals (or data) while the predicate is a relation. An example of an relationship is the statement *dog is_a animal*. Here is `dog` the subject, `is_a` the predicate and `animal` the object. We distinguish between `active relations` where the subject is acting on the object and `passive relations` where the subject is acted on by the object.

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

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

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

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

- `owl:equivalentProperty` states that two properties have the same property extension.
- `owl:inverseOf` axioms relate active relations to their corresponding passive relations, and vice versa. The root relation `relation` is its own inverse.
- `owl:FunctionalProperty` is a property that can have only one (unique) value y for each instance x, i.e. there cannot be two distinct values 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 also instance of P, then we can infer the the pair (x,z) is also an instance of P.
- `owl:SymmetricProperty` states that if the pair (x,y) is an instance of P, then the pair (y,x) is also an instance of P.

  A popular example of a symmetric property is the `friend_of` relation.

emmo_relation branch

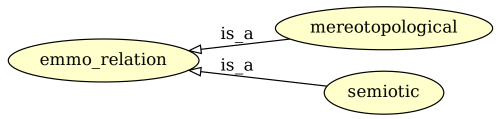

Figure 2.1: The emmo_relation branch.

emmo_relation

Elucidation: The sign that stand for the most generic EMMO relation.

IRI: http://emmc.info/emmo-core#EMMO_ec2472ae_cf4a_46a5_8555_1556f5a6c3c5

Relations:

- is_a owl:ObjectProperty
- is_a owl:topObjectProperty
- domain emmo
- range emmo

mereotopological branch

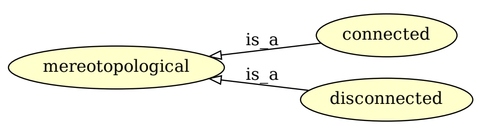

Figure 2.2: The mereotopological branch.

mereotopological

Elucidation: The generic EMMO mereotopological relation.

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

IRI: http://emmc.info/emmo-core#EMMO_03212fd7_abfd_4828_9c8e_62c293052d4b

Relations:

- is_a owl:ObjectProperty
- is_a emmo_relation

disconnected

Elucidation: The relation between two individuals that stand for real world topological disconnected objects.

IRI: http://emmc.info/emmo-core#EMMO_517dfaf9_4970_41ac_81ee_d031627d2c7c

Relations:

- is_a owl:ObjectProperty
- is_a owl:SymmetricProperty
- is_a mereotopological
- Inverse(emmo-core.mereotopological)

semiotic branch

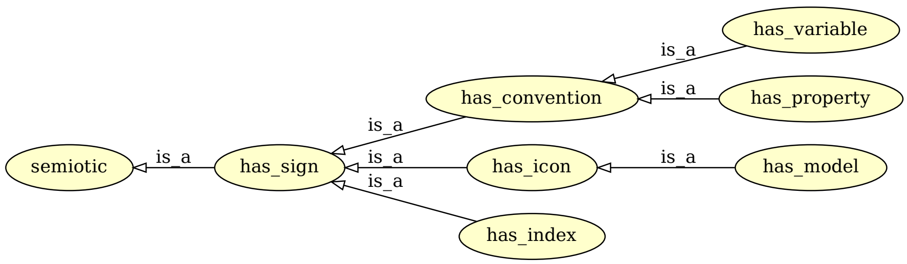

Figure 2.3: The semiotic branch.

semiotic

IRI: http://emmc.info/emmo-semiotics#EMMO_2337e25c_3c60_43fc_a8f9_b11a3f974291

Relations:

- is_a owl:ObjectProperty
- is_a emmo_relation

connected branch

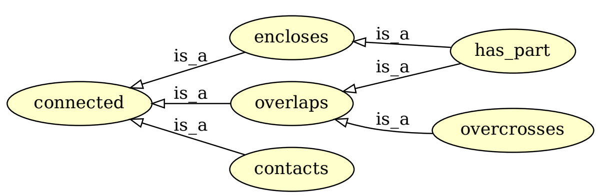

Figure 2.4: The connected branch.

connected

Definition: Definition: Cxy := x is connected with y

Axiom: 1) Cxx (x is always connected with itself (reflexivity)) Axiom: 2) Cxy->Cyx (if x is connected with y then y is connected with x (symmetry))

Elucidation: The relation between two individuals that stand for real world topological connected objects.

Comment: Causality is a topological property between connected items.

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

IRI: http://emmc.info/emmo-core#EMMO_6703954e_34c4_4a15_a9e7_f313760ae1a8

Relations:

- is_a owl:ObjectProperty
- is_a owl:SymmetricProperty
- is_a mereotopological
- Inverse(emmo-core.mereotopological)

encloses

IRI: http://emmc.info/emmo-core#EMMO_8c898653_1118_4682_9bbf_6cc334d16a99

Relations:

- is_a owl:ObjectProperty
- is_a owl:TransitiveProperty
- is_a connected
- Inverse(emmo-core.connected)

overlaps

Definition: Definition: Oxy <=> z(Pzx   Pzy)

x overlap with y means that there exists a z that is part of both x and y

IRI: http://emmc.info/emmo-core#EMMO_d893d373_b579_4867_841e_1c2b31a8d2c6

Relations:

- is_a owl:ObjectProperty
- is_a owl:SymmetricProperty
- is_a connected
- Inverse(emmo-core.connected)

overcrosses

IRI: http://emmc.info/emmo-core#EMMO_9cb984ca_48ad_4864_b09e_50d3fff19420

Relations:

- is_a owl:ObjectProperty
- is_a owl:SymmetricProperty
- is_a overlaps
- Inverse(emmo-core.overlaps)

contacts

IRI: http://emmc.info/emmo-core#EMMO_4d6504f1_c470_4ce9_b941_bbbebc9ab05d

Relations:

- is_a owl:ObjectProperty
- is_a owl:SymmetricProperty
- is_a connected
- Inverse(emmo-core.connected)

has_sign branch

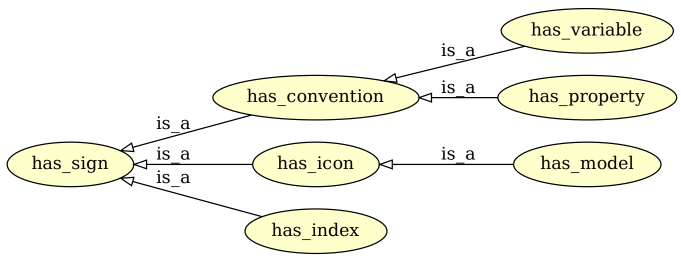

Figure 2.5: The has_sign branch.

has_sign

IRI: http://emmc.info/emmo-semiotics#EMMO_60577dea_9019_4537_ac41_80b0fb563d41

Relations:

- is_a owl:ObjectProperty
- is_a semiotic
- domain object
- range sign

has_convention

IRI: http://emmc.info/emmo-semiotics#EMMO_eb3518bf_f799_4f9e_8c3e_ce59af11453b

Relations:

- is_a owl:ObjectProperty
- is_a has_sign
- range conventional

has_variable

IRI: http://emmc.info/emmo-math#EMMO_3446e167_c576_49d6_846c_215bb8878a55

Relations:

- is_a owl:ObjectProperty
- is_a has_convention

has_property

IRI: http://emmc.info/emmo-properties#EMMO_e1097637_70d2_4895_973f_2396f04fa204

Relations:

- is_a owl:ObjectProperty
- is_a has_convention
- range property

has_icon

IRI: http://emmc.info/emmo-semiotics#EMMO_39c3815d_8cae_4c8f_b2ff_eeba24bec455

Relations:

- is_a owl:ObjectProperty
- is_a has_sign
- range icon

has_model

IRI: http://emmc.info/emmo-models#EMMO_24c71baf_6db6_48b9_86c8_8c70cf36db0c

Relations:

- is_a owl:ObjectProperty
- is_a has_icon

has_index

IRI: http://emmc.info/emmo-semiotics#EMMO_297999d6_c9e4_4262_9536_bd524d1c6e21

Relations:

- is_a owl:ObjectProperty
- is_a has_sign
- range index

has_part branch

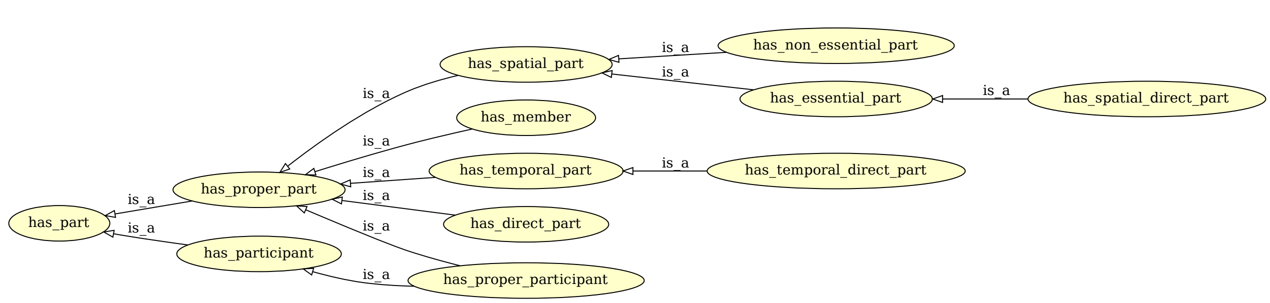

Figure 2.6: The has_part branch.

has_part

IRI: http://emmc.info/emmo-core#EMMO_17e27c22_37e1_468c_9dd7_95e137f73e7f

Relations:

- is_a owl:ObjectProperty
- is_a owl:TransitiveProperty
- is_a encloses
- is_a overlaps
- Inverse(emmo-core.overlaps)

has_proper_part

IRI: http://emmc.info/emmo-core#EMMO_9380ab64_0363_4804_b13f_3a8a94119a76

Relations:

- is_a owl:ObjectProperty
- is_a owl:TransitiveProperty
- is_a has_part

has_spatial_part

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

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

Relations:

- is_a owl:ObjectProperty
- is_a has_proper_part

has_non_essential_part

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

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

Relations:

- is_a owl:ObjectProperty
- is_a has_spatial_part

has_essential_part

Elucidation: A relation that isolates a proper part extending in time through all the lifetime of the whole.

IRI: http://emmc.info/emmo-core#EMMO_42eef0b0_cc64_4380_b912_8cc37e87506c

Relations:

- is_a owl:ObjectProperty
- is_a owl:TransitiveProperty
- is_a has_spatial_part

has_spatial_direct_part

IRI: http://emmc.info/emmo-direct#EMMO_b2282816_b7a3_44c6_b2cb_3feff1ceb7fe

Relations:

- is_a owl:ObjectProperty
- is_a owl:InverseFunctionalProperty
- is_a owl:AsymmetricProperty
- is_a owl:IrreflexiveProperty
- is_a has_essential_part

has_member

IRI: http://emmc.info/emmo-core#EMMO_6b7276a4_4b9d_440a_b577_0277539c0fc4

Relations:

- is_a owl:ObjectProperty
- is_a owl:AsymmetricProperty
- is_a owl:IrreflexiveProperty
- is_a has_proper_part
- domain collection
- range item

has_temporal_part

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

IRI: http://emmc.info/emmo-core#EMMO_7afbed84_7593_4a23_bd88_9d9c6b04e8f6

Relations:

- is_a owl:ObjectProperty
- is_a owl:TransitiveProperty
- is_a has_proper_part

has_temporal_direct_part

IRI: http://emmc.info/emmo-direct#EMMO_65a2c5b8_e4d8_4a51_b2f8_e55effc0547d

Relations:

- is_a owl:ObjectProperty
- is_a owl:InverseFunctionalProperty
- is_a owl:AsymmetricProperty
- is_a owl:IrreflexiveProperty
- is_a has_temporal_part

has_direct_part

IRI: http://emmc.info/emmo-direct#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 has_proper_part

has_proper_participant

IRI: http://emmc.info/emmo-process#EMMO_c5aae418_1622_4d02_93c5_21159e28e6c1

Relations:

- is_a owl:ObjectProperty
- is_a has_proper_part
- is_a has_participant

has_participant

IRI: http://emmc.info/emmo-process#EMMO_ae2d1a96_bfa1_409a_a7d2_03d69e8a125a

Relations:

- is_a owl:ObjectProperty
- is_a has_part
- domain process
- range participant

has_proper_participant

IRI: http://emmc.info/emmo-process#EMMO_c5aae418_1622_4d02_93c5_21159e28e6c1

Relations:

- is_a owl:ObjectProperty
- is_a has_proper_part
- is_a has_participant

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

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 parthood (mereotopology).

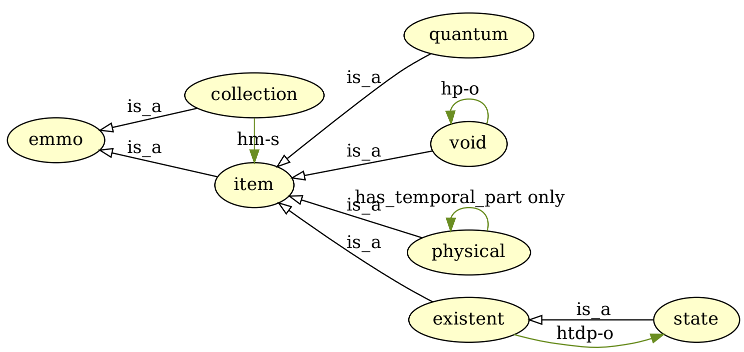

Figure 3.1: The emmo branch.

emmo

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 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).

A real world object is then a topological sub-region of the whole 4D manifold that describes our universe.

A universe sub-region is isolated and defined as a real world object by the ontologist, through a semiotic process that occurs on the meta-ontological level.

Mereotopology is the fundamental logical representation used to characterize the universe and to provide the definitions for the EMMO concepts.

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

Comment: In the EMMO we will refer to spacetime 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.

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

IRI: http://emmc.info/emmo-core#EMMO_802d3e92_8770_4f98_a289_ccaaab7fdddf

Relations:

- is_a owl:Thing

collection

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

Elucidation: The class representing the collection of all the individuals (signs) that represents a collection of ‘item’ individuals.

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

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

A ‘set’ cannot have as member another ‘set’. This relation is expressed instead by the subset relation, which is the OWL-DL built-in ‘is_a’ relation used to declare subclasses of ‘set’.

Comment: Since OWL-DL classes are intended as signs that stand for real world sets, we can consider the ‘set’ branch as a meta-ontological branch, since ‘item’ class and all its subclasses are then individuals of ‘set’.

It is also possible to define a relation ‘is_subset_of’ valid only between ‘set’ individuals that is equivalent to the OWL-DL built-in ‘is_a’ relation between classes in the ‘item’ branch.

However this is not done in the EMMO for the sake of simplicity and due to the limitation of the language.

Comment: The ‘set’ class can be used to declare individuals that stand for collections of parts that does not form a self-connected whole in mereotopological sense.

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

IRI: http://emmc.info/emmo-core#EMMO_2d2ecd97_067f_4d0e_950c_d746b7700a31

Relations:

- is_a emmo
- (has_member some item)

item

Elucidation: The class of individuals that stand for single real world self-connected objects.

Elucidation: The class that collects all the individuals that are member of a set (it's the most comprehensive set individual).

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).

The 'item' individuals stand for sub-regions of the 4D spacetime.

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.

Comment: The 'item' class and all its sub-classes are 'set' individuals.

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

IRI: http://emmc.info/emmo-core#EMMO_eb3a768e_d53e_4be9_a23b_0714833c36de

Relations:

- is_a emmo

quantum

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

Comment: A 'quantum' is the most fundamental subclass of 'item', since we consider it as the smallest 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 is a 4D real world object.

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

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

IRI: http://emmc.info/emmo-core#EMMO_3f9ae00e_810c_4518_aec2_7200e424cf68

Relations:

- is_a item

- (has_proper_part only owl:Nothing)

void

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

IRI: http://emmc.info/emmo-core#EMMO_29072ec4_ffcb_42fb_bdc7_26f05a2e9873

Relations:

- is_a item
- (has_part only void)

existent

Definition: 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 objects under a reductionistic perspective (i.e. objects come from the composition of sub-part objects).

‘existent’ class collects all individuals that stand for real world objects that can be structured in temporal sub-parts of constant mereological cardinality (i.e. number of parts) through the temporal direct parthood, that provides a way to axiomatize tassellation principles for a specific whole class, and non-transitivity 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: IMPORTANT: if we agree that every item can be partitioned in time into ‘state’-s with constant cardinality, then ‘existent’ is conincident with ‘item’.

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

IRI: http://emmc.info/emmo-direct#EMMO_52211e5e_d767_4812_845e_eb6b402c476a

Relations:

- is_a physical
- is_a item
- is_a state or (has_temporal_direct_part some state)
- (has_temporal_direct_part only state)

physical branch

physical

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.

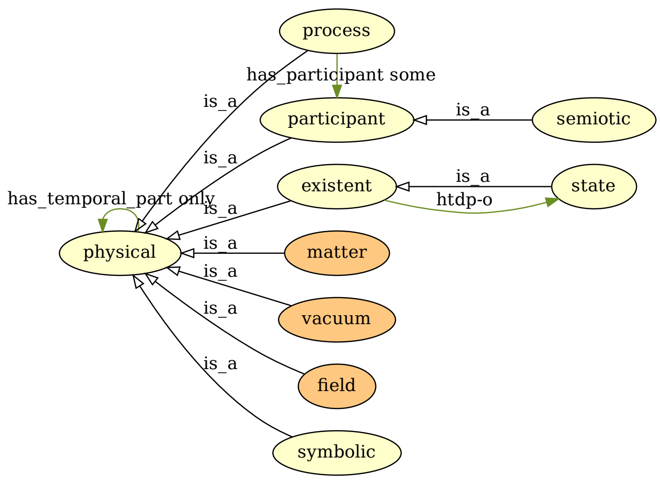

Figure 3.2: The physical branch.

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: 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

IRI: http://emmc.info/emmo-core#EMMO_c5ddfdba_c074_4aa4_ad6b_1ac4942d300d

Relations:

- is_a item
- is_a elementary or (has_proper_part some physical)
- (has_temporal_part only physical)

participant

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

Comment: If we allow a void region to play a role in a process, the 'participant' class must belong to 'item'.

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

IRI: http://emmc.info/emmo-process#EMMO_49804605_c0fe_4538_abda_f70ba1dc8a5d

Relations:

- is_a physical

semiotic

Elucidation: The class of semiotic elements used in 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'

IRI: http://emmc.info/emmo-semiotics#EMMO_b803f122_4acb_4064_9d71_c1e5fd091fc9

Relations:

- is_a participant
- (Inverse(emmo-process.has_proper_participant) some semiosis)
- equivalent_to interpreter or object or sign

object

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).

IRI: http://emmc.info/emmo-semiotics#EMMO_6f5af708_f825_4feb_a0d1_a8d813d3022b

Relations:

- is_a semiotic
- equivalent_to (has_sign some sign)

interpreter

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

IRI: http://emmc.info/emmo-semiotics#EMMO_0527413c_b286_4e9c_b2d0_03fb2a038dee

Relations:

- is_a semiotic
- (has_spatial_part some interpretant)

observer

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.

IRI: http://emmc.info/emmo-properties#EMMO_1b52ee70_121e_4d8d_8419_3f97cd0bd89c

Relations:

- is_a interpreter

measurement_instrument

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

Relations:

- is_a observer

existent

Definition: 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 objects under a reductionistic perspective (i.e. objects come from the composition of sub-part objects).

'existent' class collects all individuals that stand for real world objects that can be structured in temporal sub-parts of constant mereological cardinality (i.e. number of parts) through the temporal direct parthood, that provides a way to axiomatize tassellation principles for a specific whole class, and non-transitivity 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: IMPORTANT: if we agree that every item can be partitioned in time into 'state'-s with constant cardinality, then 'existent' is conincident with 'item'.

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

IRI: http://emmc.info/emmo-direct#EMMO_52211e5e_d767_4812_845e_eb6b402c476a

Relations:

- is_a physical
- is_a item
- is_a state or (has_temporal_direct_part some state)
- (has_temporal_direct_part only state)

vacuum

IRI: http://emmc.info/emmo-material#EMMO_3c218fbe_60c9_4597_8bcf_41eb1773af1f

Relations:

- is_a physical

- equivalent_to physical and not (has_part some massive)

field

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

IRI: http://emmc.info/emmo-material#EMMO_70dac51e_bddd_48c2_8a98_7d8395e91fc2

Relations:

- is_a physical
- equivalent_to (has_part some massless)

process branch

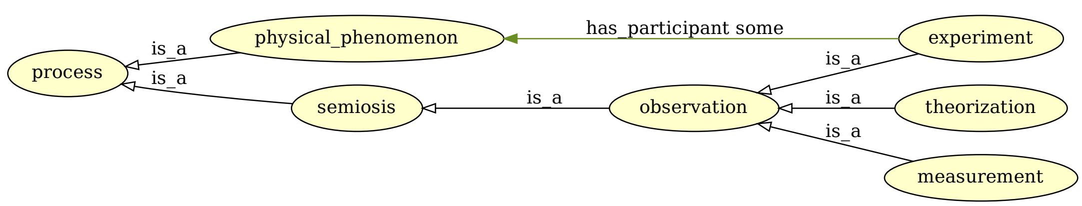

Figure 3.3: The process branch.

process

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

Following the common definition of process, every 'physical' is 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 interpreter.

Elucidation: A 'process' is always a 'physical', since a 'void' does not have elements that evolves in time.

However, 'void' parts inside a 'process' can be a 'participant'.

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

IRI: http://emmc.info/emmo-process#EMMO_43e9a05d_98af_41b4_92f6_00f79a09bfce

Relations:

- is_a physical
- (has_participant some participant)

physical_phenomenon

IRI: http://emmc.info/emmo-models#EMMO_314d0bd5_67ed_437e_a609_36d46147cea7

Relations:

- is_a process

semiosis

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

IRI: http://emmc.info/emmo-semiotics#EMMO_008fd3b2_4013_451f_8827_52bceab11841

Relations:

- is_a process
- (has_participant some interpreter)
- (has_proper_participant some object)
- (has_proper_participant some sign)

observation

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.

IRI: http://emmc.info/emmo-properties#EMMO_10a5fd39_06aa_4648_9e70_f962a9cb2069

Relations:

- is_a semiosis
- (has_participant some observer)

experiment

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

IRI: http://emmc.info/emmo-models#EMMO_22522299_4091_4d1f_82a2_3890492df6db

Relations:

- is_a observation
- (has_participant some physical_phenomenon)

theorization

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

IRI: http://emmc.info/emmo-models#EMMO_6c739b1a_a774_4416_bb31_1961486fa9ed

Relations:

- is_a observation

measurement

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

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

Relations:

- is_a observation
- (has_participant some measurement_instrument)

semiotic branch

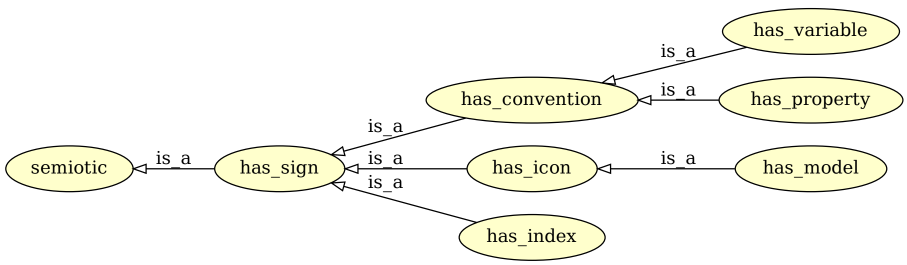

Figure 3.4: The semiotic branch.

semiotic

IRI: http://emmc.info/emmo-semiotics#EMMO_2337e25c_3c60_43fc_a8f9_b11a3f974291

Relations:

- is_a owl:ObjectProperty
- is_a emmo_relation

has_sign

IRI: http://emmc.info/emmo-semiotics#EMMO_60577dea_9019_4537_ac41_80b0fb563d41

Relations:

- is_a owl:ObjectProperty
- is_a semiotic
- domain object
- range sign

has_convention

IRI: http://emmc.info/emmo-semiotics#EMMO_eb3518bf_f799_4f9e_8c3e_ce59af11453b

Relations:

- is_a owl:ObjectProperty
- is_a has_sign

- range conventional

has_variable

IRI: http://emmc.info/emmo-math#EMMO_3446e167_c576_49d6_846c_215bb8878a55

Relations:

- is_a owl:ObjectProperty
- is_a has_convention

has_property

IRI: http://emmc.info/emmo-properties#EMMO_e1097637_70d2_4895_973f_2396f04fa204

Relations:

- is_a owl:ObjectProperty
- is_a has_convention
- range property

has_icon

IRI: http://emmc.info/emmo-semiotics#EMMO_39c3815d_8cae_4c8f_b2ff_eeba24bec455

Relations:

- is_a owl:ObjectProperty
- is_a has_sign
- range icon

has_model

IRI: http://emmc.info/emmo-models#EMMO_24c71baf_6db6_48b9_86c8_8c70cf36db0c

Relations:

- is_a owl:ObjectProperty
- is_a has_icon

has_index

IRI: http://emmc.info/emmo-semiotics#EMMO_297999d6_c9e4_4262_9536_bd524d1c6e21

Relations:

- is_a owl:ObjectProperty
- is_a has_sign
- range index

state branch

state

Elucidation: A 'physical' 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.

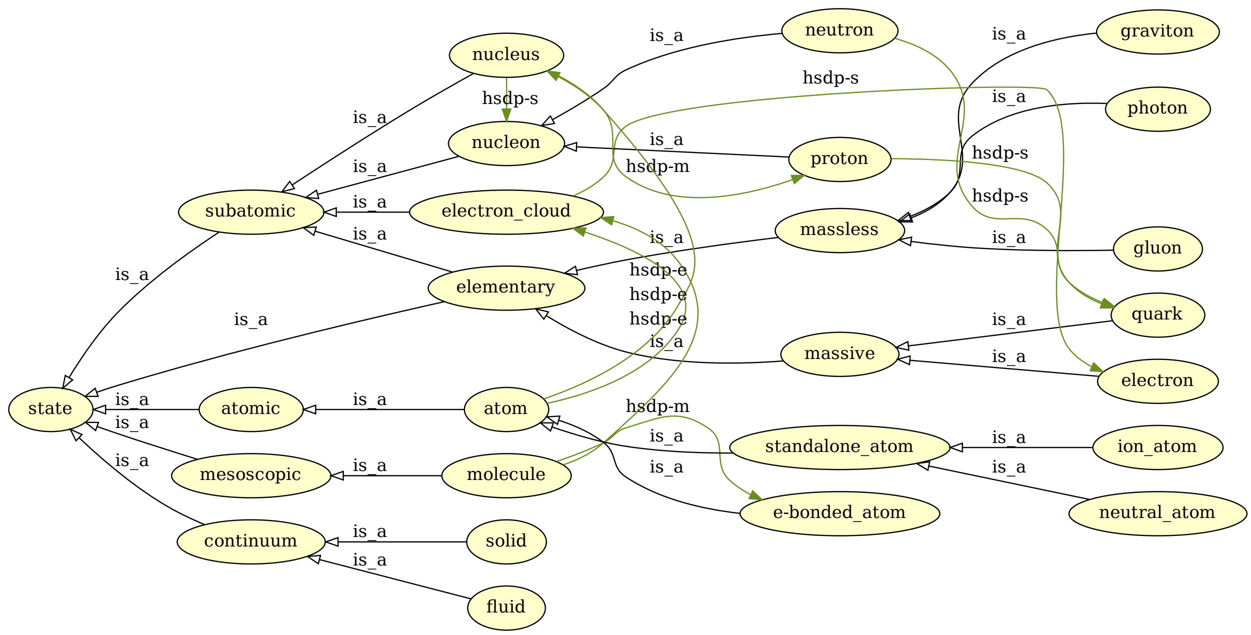

Figure 3.5: The state branch.

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 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.

IRI: http://emmc.info/emmo-direct#EMMO_36c79456_e29c_400d_8bd3_0eedddb82652

Relations:

- is_a existent
- is_a quantum or (has_spatial_direct_part some existent)

elementary

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

Comment: 'elementary' is by definition the most simple example of 'state'.

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.

IRI: http://emmc.info/emmo-core#EMMO_0f795e3e_c602_4577_9a43_d5a231aa1360

Relations:

- is_a subatomic
- is_a state
- is_a quantum or (has_temporal_part only elementary)

massive

IRI: http://emmc.info/emmo-material#EMMO_385b8f6e_43ac_4596_ad76_ac322c68b7ca

Relations:

- is_a elementary

electron

IRI: http://emmc.info/emmo-material#EMMO_8043d3c6_a4c1_4089_ba34_9744e28e5b3d

Relations:

- is_a massive

quark

IRI: http://emmc.info/emmo-material#EMMO_72d53756_7fb1_46ed_980f_83f47efbe105

Relations:

- is_a massive

massless

IRI: http://emmc.info/emmo-material#EMMO_e5488299_8dab_4ebb_900a_26d2abed8396

Relations:

- is_a elementary

photon

IRI: http://emmc.info/emmo-material#EMMO_25f8b804_9a0b_4387_a3e7_b35bce5365ee

Relations:

- is_a massless

gluon

IRI: http://emmc.info/emmo-material#EMMO_7db59e56_f68b_48b7_ae99_891c35ae5c3b

Relations:

- is_a massless

graviton

IRI: http://emmc.info/emmo-material#EMMO_eb3c61f0_3983_4346_a0c6_e7f6b90a67a8

Relations:

- is_a massless

subatomic

IRI: http://emmc.info/emmo-material#EMMO_7d66bde4_b68d_41cc_b5fc_6fd98c5e2ff0

Relations:

- is_a state

elementary

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

Comment: 'elementary' is by definition the most simple example of 'state'.

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.

IRI: http://emmc.info/emmo-core#EMMO_0f795e3e_c602_4577_9a43_d5a231aa1360

Relations:

- is_a subatomic
- is_a state

- is_a quantum or (has_temporal_part only elementary)

massive

IRI: http://emmc.info/emmo-material#EMMO_385b8f6e_43ac_4596_ad76_ac322c68b7ca

Relations:

- is_a elementary

electron

IRI: http://emmc.info/emmo-material#EMMO_8043d3c6_a4c1_4089_ba34_9744e28e5b3d

Relations:

- is_a massive

quark

IRI: http://emmc.info/emmo-material#EMMO_72d53756_7fb1_46ed_980f_83f47efbe105

Relations:

- is_a massive

massless

IRI: http://emmc.info/emmo-material#EMMO_e5488299_8dab_4ebb_900a_26d2abed8396

Relations:

- is_a elementary

photon

IRI: http://emmc.info/emmo-material#EMMO_25f8b804_9a0b_4387_a3e7_b35bce5365ee

Relations:

- is_a massless

gluon

IRI: http://emmc.info/emmo-material#EMMO_7db59e56_f68b_48b7_ae99_891c35ae5c3b

Relations:

- is_a massless

graviton

IRI: http://emmc.info/emmo-material#EMMO_eb3c61f0_3983_4346_a0c6_e7f6b90a67a8

Relations:

- is_a massless

electron_cloud

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

IRI: http://emmc.info/emmo-material#EMMO_1067b97a_84f8_4d22_8ace_b842b8ce355c

Relations:

- is_a matter
- is_a subatomic
- (has_spatial_direct_part some electron)

nucleon

IRI: http://emmc.info/emmo-material#EMMO_50781fd9_a9e4_46ad_b7be_4500371d188d

Relations:

- is_a matter
- is_a subatomic

proton

IRI: http://emmc.info/emmo-material#EMMO_8f87e700_99a8_4427_8ffb_e493de05c217

Relations:

- is_a nucleon
- (has_spatial_direct_part some quark)

neutron

IRI: http://emmc.info/emmo-material#EMMO_df808271_df91_4f27_ba59_fa423c51896c

Relations:

- is_a nucleon
- (has_spatial_direct_part some quark)

nucleus

IRI: http://emmc.info/emmo-material#EMMO_f835f4d4_c665_403d_ab25_dca5cc74be52

Relations:

- is_a matter
- is_a subatomic
- (has_spatial_direct_part some nucleon)
- (has_spatial_direct_part min 1 proton)

mesoscopic

IRI: http://emmc.info/emmo-material#EMMO_174cf221_9d16_427c_abea_e217a948969b

Relations:

- is_a state

molecule

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).

IRI: http://emmc.info/emmo-material#EMMO_3397f270_dfc1_4500_8f6f_4d0d85ac5f71

Relations:

- is_a mesoscopic
- is_a matter
- (has_spatial_direct_part min 2 e-bonded_atom)
- (has_spatial_direct_part exactly 1 electron_cloud)

atomic

IRI: http://emmc.info/emmo-material#EMMO_5c4aff3c_c30c_4507_86d5_b4df41eb9f2f

Relations:

- is_a state

atom

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

Example: 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.

IRI: http://emmc.info/emmo-material#EMMO_eb77076b_a104_42ac_a065_798b2d2809ad

Relations:

- is_a matter
- is_a atomic
- (has_spatial_direct_part exactly 1 electron_cloud)
- (has_spatial_direct_part exactly 1 nucleus)

standalone_atom

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.

IRI: http://emmc.info/emmo-material#EMMO_2fd3f574_5e93_47fe_afca_ed80b0a21ab4

Relations:

- is_a atom

neutral_atom

Elucidation: A standalone atom that has no net charge.

IRI: http://emmc.info/emmo-material#EMMO_4588526f_8553_4f4d_aa73_a483e88d599b

Relations:

- is_a standalone_atom

ion_atom

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,

IRI: http://emmc.info/emmo-material#EMMO_db03061b_db31_4132_a47a_6a634846578b

Relations:

- is_a standalone_atom

e-bonded_atom

Elucidation: An electronic 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.

IRI: http://emmc.info/emmo-material#EMMO_8303a247_f9d9_4616_bdcd_f5cbd7b298e3

Relations:

- is_a atom

continuum

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.

IRI: http://emmc.info/emmo-material#EMMO_8b0923ab_b500_477b_9ce9_8b3a3e4dc4f2

Relations:

- is_a state

fluid

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

Example: Gas, liquid, plasma,

IRI: http://emmc.info/emmo-material#EMMO_87ac88ff_8379_4f5a_8c7b_424a8fff1ee8

Relations:

- is_a continuum

solid

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

IRI: http://emmc.info/emmo-material#EMMO_a2b006f2_bbfd_4dba_bcaa_3fca20cd6be1

Relations:

- is_a continuum

matter branch

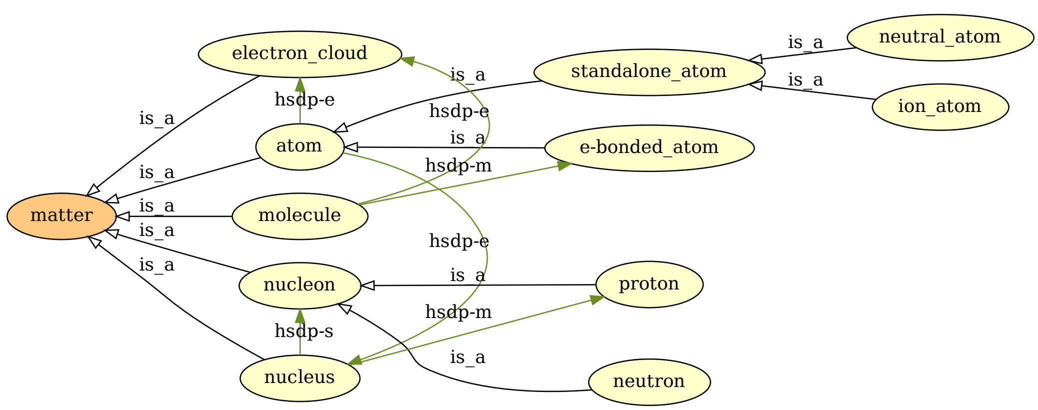

Figure 3.6: The matter branch.

matter

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

IRI: http://emmc.info/emmo-material#EMMO_5b2222df_4da6_442f_8244_96e9e45887d1

Relations:

- is_a physical
- equivalent_to (has_part some massive)

electron_cloud

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

IRI: http://emmc.info/emmo-material#EMMO_1067b97a_84f8_4d22_8ace_b842b8ce355c

Relations:

- is_a matter
- is_a subatomic
- (has_spatial_direct_part some electron)

atom

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

Example: 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.

IRI: http://emmc.info/emmo-material#EMMO_eb77076b_a104_42ac_a065_798b2d2809ad

Relations:

- is_a matter
- is_a atomic
- (has_spatial_direct_part exactly 1 electron_cloud)
- (has_spatial_direct_part exactly 1 nucleus)

standalone_atom

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.

IRI: http://emmc.info/emmo-material#EMMO_2fd3f574_5e93_47fe_afca_ed80b0a21ab4

Relations:

- is_a atom

neutral_atom

Elucidation: A standalone atom that has no net charge.

IRI: http://emmc.info/emmo-material#EMMO_4588526f_8553_4f4d_aa73_a483e88d599b

Relations:

- is_a standalone_atom

ion_atom

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,

IRI: http://emmc.info/emmo-material#EMMO_db03061b_db31_4132_a47a_6a634846578b

Relations:

- is_a standalone_atom

e-bonded_atom

Elucidation: An electronic 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.

IRI: http://emmc.info/emmo-material#EMMO_8303a247_f9d9_4616_bdcd_f5cbd7b298e3

Relations:

- is_a atom

molecule

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).

IRI: http://emmc.info/emmo-material#EMMO_3397f270_dfc1_4500_8f6f_4d0d85ac5f71

Relations:

- is_a mesoscopic
- is_a matter
- (has_spatial_direct_part min 2 e-bonded_atom)
- (has_spatial_direct_part exactly 1 electron_cloud)

nucleon

IRI: http://emmc.info/emmo-material#EMMO_50781fd9_a9e4_46ad_b7be_4500371d188d

Relations:

- is_a matter
- is_a subatomic

proton

IRI: http://emmc.info/emmo-material#EMMO_8f87e700_99a8_4427_8ffb_e493de05c217

Relations:

- is_a nucleon
- (has_spatial_direct_part some quark)

neutron

IRI: http://emmc.info/emmo-material#EMMO_df808271_df91_4f27_ba59_fa423c51896c

Relations:

- is_a nucleon
- (has_spatial_direct_part some quark)

nucleus

IRI: http://emmc.info/emmo-material#EMMO_f835f4d4_c665_403d_ab25_dca5cc74be52

Relations:

- is_a matter
- is_a subatomic
- (has_spatial_direct_part some nucleon)
- (has_spatial_direct_part min 1 proton)

sign branch

sign

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.

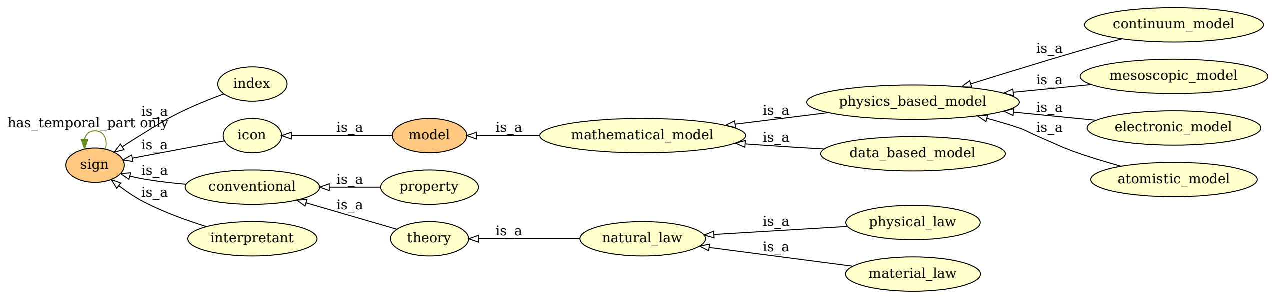

Figure 3.7: The sign branch.

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 continguity - 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.

IRI: http://emmc.info/emmo-semiotics#EMMO_b21a56ed_f969_4612_a6ec_cb7766f7f31d

Relations:

- is_a semiotic
- (has_temporal_part only sign)
- equivalent_to index or conventional or icon

index

Elucidation: A 'sign' that stands for an 'objectì due to causal contiguity.

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

My facial expression stands for my emotional status.

IRI: http://emmc.info/emmo-semiotics#EMMO_0cd58641_824c_4851_907f_f4c3be76630c

Relations:

- is_a sign

icon

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]

IRI: http://emmc.info/emmo-semiotics#EMMO_d7788d1a_020d_4c78_85a1_13563fcec168

Relations:

- is_a sign

model

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.

IRI: http://emmc.info/emmo-models#EMMO_939483b1_0148_43d1_8b35_851d2cd5d939

Relations:

- is_a icon
- equivalent_to (Inverse(emmo-models.has_model) some physical)

mathematical_model

IRI: http://emmc.info/emmo-models#EMMO_f7ed665b_c2e1_42bc_889b_6b42ed3a36f0

Relations:

- is_a mathematical
- is_a model

physics_based_model

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

IRI: http://emmc.info/emmo-models#EMMO_b29fd350_39aa_4af7_9459_3faa0544cba6

Relations:

- is_a mathematical_model
- (has_spatial_part some physics_equation)
- (has_spatial_part some material_relation)

continuum_model

IRI: http://emmc.info/emmo-models#EMMO_4456a5d2_16a6_4ee1_9a8e_5c75956b28ea

Relations:

- is_a physics_based_model

mesoscopic_model

IRI: http://emmc.info/emmo-models#EMMO_53935db0_af45_4426_b9e9_244a0d77db00

Relations:

- is_a physics_based_model

electronic_model

IRI: http://emmc.info/emmo-models#EMMO_6eca09be_17e9_445e_abc9_000aa61b7a11

Relations:

- is_a physics_based_model

atomistic_model

IRI: http://emmc.info/emmo-models#EMMO_84cadc45_6758_46f2_ba2a_5ead65c70213

Relations:

- is_a physics_based_model

data_based_model

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

IRI: http://emmc.info/emmo-models#EMMO_a4b14b83_9392_4a5f_a2e8_b2b58793f59b

Relations:

- is_a mathematical_model

conventional

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.

IRI: http://emmc.info/emmo-semiotics#EMMO_35d2e130_6e01_41ed_94f7_00b333d46cf9

Relations:

- is_a sign

theory

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

IRI: http://emmc.info/emmo-models#EMMO_8d2d9374_ef3a_47e6_8595_6bc208e07519

Relations:

- is_a conventional

natural_law

IRI: http://emmc.info/emmo-models#EMMO_db9a009e_f097_43f5_9520_6cbc07e7610b

Relations:

- is_a theory

physical_law

IRI: http://emmc.info/emmo-models#EMMO_9c32fd69_f480_4130_83b3_fb25d9face14

Relations:

- is_a natural_law

material_law

IRI: http://emmc.info/emmo-models#EMMO_f19ff3b4_6bfe_4c41_a2b2_9affd39c140b

Relations:

- is_a natural_law

interpretant

IRI: http://emmc.info/emmo-semiotics#EMMO_054af807_85cd_4a13_8eba_119dfdaaf38b

Relations:

- is_a sign

symbolic branch

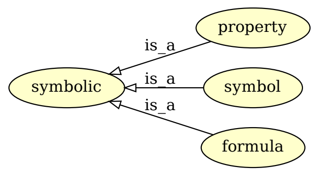

Figure 3.8: The symbolic branch.

symbolic

Elucidation: A 'symbol' or a composition of 'symbol'-s.

Example: fe@è0 emmo !5*a cat

Comment: In formal languages it is called a string of symbols.

IRI: http://emmc.info/emmo-semiotics#EMMO_057e7d57_aff0_49de_911a_8861d85cef40

Relations:

- is_a physical
- is_a symbol or (has_spatial_part some symbol)

symbol branch

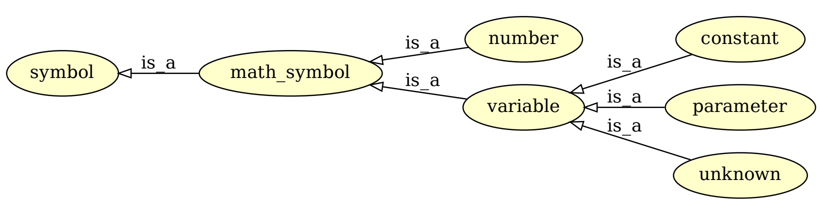

Figure 3.9: The symbol branch.

symbol

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 is the mark.

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

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.

IRI: http://emmc.info/emmo-semiotics#EMMO_a1083d0a_c1fb_471f_8e20_a98f881ad527

Relations:

- is_a symbolic

math_symbol

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

IRI: http://emmc.info/emmo-math#EMMO_031d61af_6405_41de_8880_df2f85a53383

Relations:

- is_a symbol
- (has_spatial_part only not mathematical)

number

IRI: http://emmc.info/emmo-math#EMMO_1a663927_3b68_4618_acd3_a8aa0d406329

Relations:

- is_a math_symbol

variable

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

IRI: http://emmc.info/emmo-math#EMMO_1eed0732_e3f1_4b2c_a9c4_b4e75eeb5895

Relations:

- is_a math_symbol

constant

Elucidation: A 'varaible' that stand for a well known constant.

Comment: pi = 3.14

IRI: http://emmc.info/emmo-math#EMMO_ae15fb4f_8e4d_41de_a0f9_3997f89ba6a2

Relations:

- is_a variable

parameter

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

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

IRI: http://emmc.info/emmo-math#EMMO_d1d436e7_72fc_49cd_863b_7bfb4ba5276a

Relations:

- is_a variable

unknown

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

Example: Velocity, for the Navier-Stokes equation.

IRI: http://emmc.info/emmo-math#EMMO_fe7e56ce_118b_4243_9aad_20eb9f4f31f6

Relations:

- is_a variable

formula branch

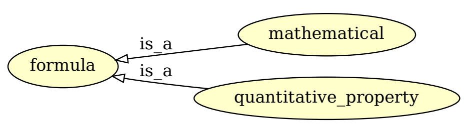

Figure 3.10: The formula branch.

formula

Elucidation: A composition of 'symbol'-s respecting a specific language syntactic rules (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.

IRI: http://emmc.info/emmo-semiotics#EMMO_50ea1ec5_f157_41b0_b46b_a9032f17ca10

Relations:

- is_a symbolic

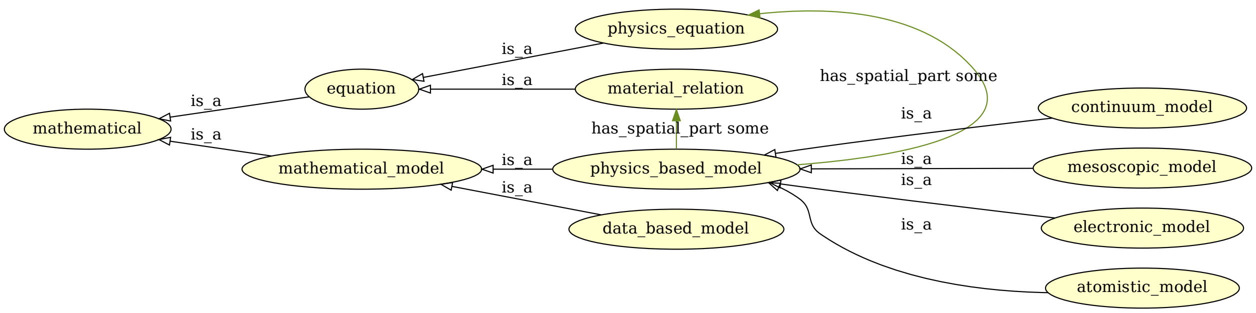

Figure 3.11: The mathematical branch.

mathematical branch

mathematical

Comment: The class of general mathematical symbols.

IRI: http://emmc.info/emmo-math#EMMO_54ee6b5e_5261_44a8_86eb_5717e7fdb9d0

Relations:

- is_a formula

equation

Comment: The class of 'mathematical'-s that stand for a mathematical expression 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

IRI: http://emmc.info/emmo-math#EMMO_e56ee3eb_7609_4ae1_8bed_51974f0960a6

Relations:

- is_a mathematical
- (has_spatial_part some variable)

physics_equation

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.

IRI: http://emmc.info/emmo-models#EMMO_27c5d8c6_8af7_4d63_beb1_ec37cd8b3fa3

Relations:

- is_a equation
- (has_spatial_part some physical_quantity)

material_relation

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.

IRI: http://emmc.info/emmo-models#EMMO_e5438930_04e7_4d42_ade5_3700d4a52ab7

Relations:

- is_a equation
- (has_spatial_part some physical_quantity)

mathematical_model

IRI: http://emmc.info/emmo-models#EMMO_f7ed665b_c2e1_42bc_889b_6b42ed3a36f0

Relations:

- is_a mathematical
- is_a model

physics_based_model

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

IRI: http://emmc.info/emmo-models#EMMO_b29fd350_39aa_4af7_9459_3faa0544cba6

Relations:

- is_a mathematical_model
- (has_spatial_part some physics_equation)
- (has_spatial_part some material_relation)

continuum_model

IRI: http://emmc.info/emmo-models#EMMO_4456a5d2_16a6_4ee1_9a8e_5c75956b28ea

Relations:

- is_a physics_based_model

mesoscopic_model

IRI: http://emmc.info/emmo-models#EMMO_53935db0_af45_4426_b9e9_244a0d77db00

Relations:

- is_a physics_based_model

electronic_model

IRI: http://emmc.info/emmo-models#EMMO_6eca09be_17e9_445e_abc9_000aa61b7a11

Relations:

- is_a physics_based_model

atomistic_model

IRI: http://emmc.info/emmo-models#EMMO_84cadc45_6758_46f2_ba2a_5ead65c70213

Relations:

- is_a physics_based_model

data_based_model

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

IRI: http://emmc.info/emmo-models#EMMO_a4b14b83_9392_4a5f_a2e8_b2b58793f59b

Relations:

- is_a mathematical_model

quantitative_property branch

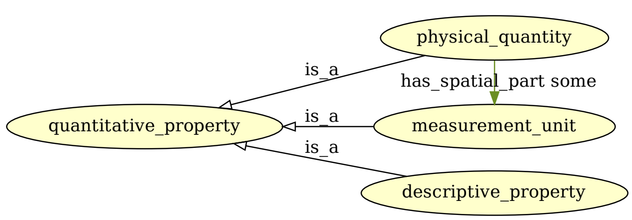

Figure 3.12: The quantitative_property branch.

quantitative_property

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

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

Relations:

- is_a objective_property
- is_a formula

physical_quantity

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.

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

Relations:

- is_a quantitative_property
- (has_spatial_part some number)
- (has_spatial_part some measurement_unit)

measurement_unit

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’.

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

Relations:

- is_a quantitative_property

descriptive_property

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

Relations:

- is_a quantitative_property

property branch

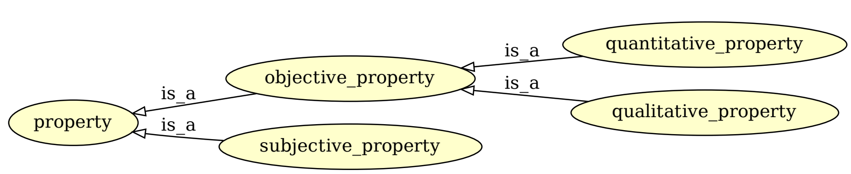

Figure 3.13: The property branch.

property

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).

IRI: http://emmc.info/emmo-properties#EMMO_b7bcff25_ffc3_474e_9ab5_01b1664bd4ba

Relations:

- is_a symbolic
- is_a conventional
- (Inverse(emmo-properties.has_property) some emmo)

objective_property

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.

IRI: http://emmc.info/emmo-properties#EMMO_2a888cdf_ec4a_4ec5_af1c_0343372fc978

Relations:

- is_a property

qualitative_property

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

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

Relations:

- is_a objective_property

subjective_property

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.

IRI: http://emmc.info/emmo-properties#EMMO_251cfb4f_5c75_4778_91ed_6c8395212fd8

Relations:

- is_a property

Chapter 4

Appendix

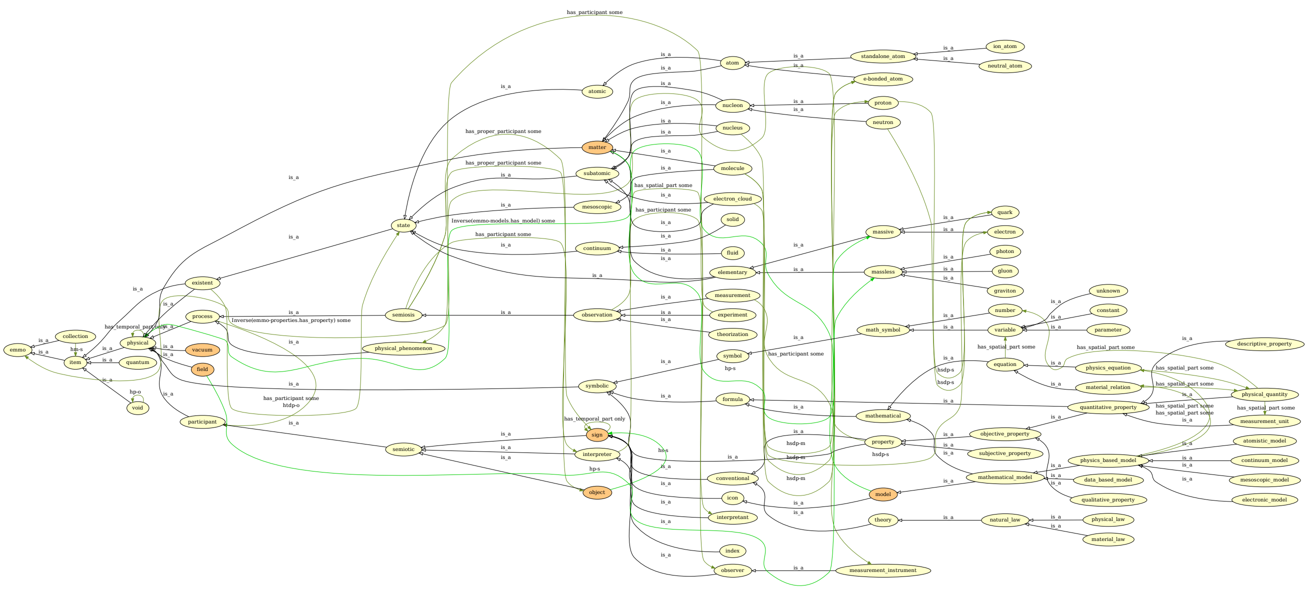

Figure 4.1: The complete EMMO taxonomy.

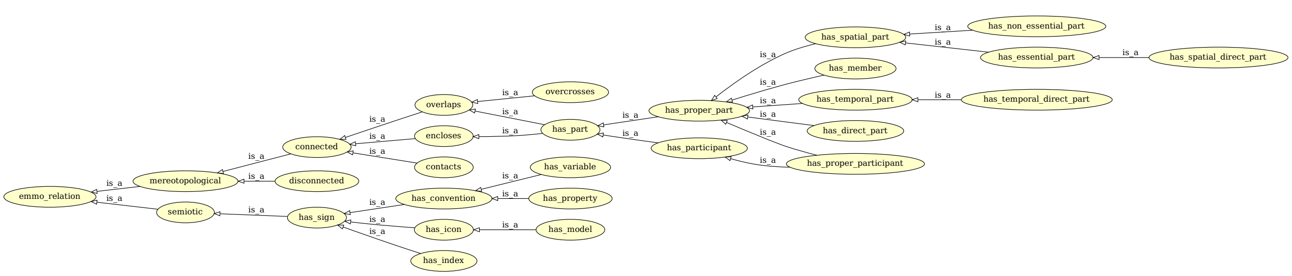

Figure 4.2: EMMO relations.