ontocommons.eu

twitter.com/ontocommons

linkedin.com/company/ontocommons

# Report D2.5

# "MLOs Beta Release"

**Grant Agreement: 958371**

OntoCommons - Ontology-driven data documentation for Industry Commons, has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement no. 958371.

| | |
|---|---|
| Project Title | Ontology-driven data documentation for Industry Commons |
| Project Acronym | OntoCommons |
| Project Number | 958371 |
| Type of project | CSA - Coordination and support action |
| Topics | DT-NMBP-39-2020 - Towards Standardised Documentation of Data through taxonomies and ontologies (CSA) |
| Starting date of Project | 01 November 2020 |
| Duration of the project | 36 months |
| Website | www.ontocommons.eu |

# Report D2.5
# “MLOs Beta Release”

| | |
|---|---|
| **Work Package** | WP2 \| Top Reference Ontology |
| **Task** | T2.5 \| MLO Development/Harmonisation |
| **Lead author** | Arkopaul Sarkar (ENIT) |
| **Contributors** | Francesco Antonio Zaccarini (UNIBO), Emanuele Ghedini (UNIBO), Anne de Baas (GCL), Stefano Borgo (CNR), Claudio Masolo (CNR) |
| **Peer reviewers** | Hedi Karray (ENIT), Nadja Adamovic (TUWien) |
| **Version** | vfinal |
| **Date** | 10/05/2022 |

**Dissemination Level**

| | |
|---|---|
| X | PU: Public |
| | CO: Confidential, only for members of the consortium (including the Commission) |
| | EU-RES. Classified Information: RESTREINT UE (Commission Decision 2005/444/EC) |
| | EU-CON. Classified Information: CONFIDENTIEL UE (Commission Decision 2005/444/EC) |
| | EU-SEC. Classified Information: SECRET UE (Commission Decision 2005/444/EC) |

# Versioning History

| Revision | Date | Editors | Comments |
|---|---|---|---|
| 0.1 | 15/04/2022 | Arkopaul Sarkar | Creation of Deliverable Template |
| 0.2 | 01/05/2022 | Anne de Baas | Internal review conducted |
| 0.3 | 02/05/2022 | Arkopaul Sarkar | Compiled review comments |
| 0.4 | 03/05/2022 | Francesco Antonio Zaccarini | Added methodology |
| 0.5 | 06/05/2022 | Hedi Karray | Internal Review |
| 0.6 | 09/05/2022 | Arkopaul Sarkar | Final version created |
| vfinal | 10/05/2022 | Nadja Adamovic | Final Review, submission to EC |

# Glossary of terms

| Item | Description |
|---|---|
| MLO | Middle level ontology |
| TLO | Top level ontology |
| DLO | Domain level ontology |

# Keywords

Alignment; Data; Harmonization; Ontology; Standardisation

# Disclaimer

# Executive Summary

OntoCommons aims at working toward interoperability by means of harmonization with respect to upper-level ontologies and facilitating agreement in domain ontology development. As part of the effort of work package 2, an objective of OntoCommons is to provide alignments among existing MLOs from different TLO branches. This task needs to perform several activities, such as identification of existing MLOs and corresponding disciplines that are to be covered by the alignment effort, the definition of the expected level of alignment that is to be performed for the MLOs and finding gaps in the disciplines which may be filled with new MLO development. A beta version of the harmonized MLO is planned to be published in the 18th month of the project. This report associates the current development and describes the methodology, list of disciplines and MLOs considered and other technical details.

# Table of Contents



# List of Figures

# 1. Introduction

As part of the overall goals of work package 2 of the OntoCommons project, a foundation for middle-level cross-discipline interoperability will be achieved by Task 2.5. To accomplish the broad outcome of terminological alignments among MLOs from different TLO branches, this task needs to perform several activities, such as the identification of existing MLOs and corresponding disciplines that are to be covered by the alignment effort, the definition of the expected level of alignment that is to be performed for the MLOs and finding gaps in the disciplines which may be filled with new MLO development. A beta version of the harmonized MLO is planned to be published in the 18th month of the project. This report describes the current development and describes the methodology, list of disciplines and MLOs considered and other technical details.

Along with TRO development, in T2.4, MLO development also takes input from focused workshops and engagement with stakeholders. While the choice of TLO top-bottom considerations will precede the bottom-up approach due to the wide scope of TLO, the choice of MLOs to be included in the OCES will be done by prioritizing the bottom-up needs, as communicated in community feedback and demonstrators' needs, harmonising existing resources=? through ontology alignment and developing new ontologies when needed. The MLOs harmonized and developed will be tested through the duration of the project by the domain ontology developers who are direct exploiters of the MLOs and the MLOs will be validated by demonstrators. OntoCommons will standardise the documentation of the NMBP data and ontologize this.

# 2. Methodology

Task 2.5 aims to develop/harmonize the MLOs that will cover the NMBP domains of interest. The sub-tasks aimed at achieving that goal include:

- Identification of disciplines for which MLOs exist and domains for which new development is needed.
- Definition of the expected level of alignment between the MLOs (each MLO should be terminologically compatible with all TLOs, and semantically compatible with at least one TLO).
- Identification of disciplines for which new MLO development is needed together with partners.
- Harmonisation of existing MLOs, aimed at isolating common modules and establishing one or more core vocabularies, with a formal minimal characterisation based on OntoClean (Guarino & Welty, 2009) meta-properties plus further minimal constraints.
- Development of agreed vocabulary, taxonomies and ontologies to be included in the OCES.

This M18 report does not yet include the identification of disciplines for new MLO development as it will require more information on standardised domain vocabulary (T1.5) and ontology-related requirements and will be done after the second version of domain requirements (D3.5) are collected and published.

In the following sections, we first describe the characterisation of MLO, then the disciplines and existing MLOs considered and lastly, the methodology of harmonisation.

## 2.1 What is an MLO?

The main pillar of the OntoCommons EcoSystem (OES) is a hierarchy of networked ontologies of different levels of generality (from top-level to application level) for which multiple forms of interoperability will be provided. Whereas some recent works (ISO/IEC 21838-1:2021-Part 1, Top-level ontology survey from National Digital Twin) addressed the foundational topics and different ontological commitments concerning TLO development, no work of similar rigour is available for MLO development. We present an attempt to characterise the different levels of ontologies, e.g., TLO, MLO, and DLO formally.

Concerning Middle-Level Ontologies (MLOs), the OC proposal describes them as "primarily intended to extend those [TL-] concepts towards a specific discipline (e.g., manufacturing, materials science, chemistry) to provide a core shared vocabulary for lower-level modules. An MLO will provide a higher level of detail than a TLO, extending the taxonomical structure of the ontology more along on the horizontal dimension (i.e., sibling classes under the same superclass)."

A more articulated characterization of MLOs is provided in the context of the Common Core Ontologies (CCO)[1], a mid-level extension of the Basic Formal Ontology, where an MLO is considered an ontology that:

1. is designed to extend a top-level ontology and be extended by multiple domains and/or application ontologies;
2. only includes terms that are common across a variety of domains (the challenge is to adequately define "variety of domains");
3. includes terms that are used frequently, and do not contain terms that are much less common;
4. has a domain that can be expressed either as a single class or as a statement this class(es) should be at the root level of the ontology with the remainder of the content consisting of only those terms and relations relevant to characterizing entities of this type;
5. limits the depth of coverage by limiting the number of levels of subtypes to a predefined number (e.g., no more than three levels of subtypes should be included for any given term or relation). Rationale: going down a hierarchy means the terms are increasingly specific and therefore less "mid-level".

**Observations on CCO's characterisation of MLO:** Both the OC and the CCO descriptions stress the fact that MLOs are intended or designed to extend a TLO. However, in practice, several ontologies that intuitively match the majority of requirements for being a MLO do not explicitly refer to a TLO, see for instance the Core Vocabularies2 or the schema.org vocabulary. We may then distinguish two kinds of MLOs: (a) those that (explicitly or implicitly) presuppose a specific TLO, and (b) those which does not. In case (a), the TLO may be explicitly imported by the MLO and used to impose some constraints on ML concepts; otherwise, a specific TLO maybe just presupposed, in the sense that the MLO developers may implicitly refer to the TLO's terms while informally providing the meaning of the MLO primitives, without an explicit 'bridging' theory. In case (b), the MLO is usually addressed to a community of users who already agree on the shared meaning of the primitive concepts, and are mainly interested in the relationships among them, with special emphasis given to the taxonomic relationships. Of course, such shared meaning may not be obvious for agents that do not belong to the community. There is therefore the risk of a silos effect.

The constraints on the unicity of the top-concept (constraint 4 in the CCO description) and on the maximal taxonomical depth (constraint 5 in the CCO description) seem quite artificial and prescriptive to us. First, one needs to carefully characterize what a concept is to avoid, when several top-concepts exist, to just introduce the disjunction of these concepts. Furthermore, the Core Vocabularies mentioned above, for instance, do not have a single top-concept. Indeed, the taxonomical structure of concepts is not the main focus of these ontologies, they aim at introducing the main concepts necessary to describe some kinds of situations. Second, the depth of the taxonomy of an MLO strongly depends on the considered level of detail. Very subtle distinctions could require the introduction of 'intermediate' concepts that, intuitively, still belong to the ML.

**Broad observations:** While a Top-level ontology (TLO) is a domain-neutral ontology, built with a unified view of reality that can model a wide variety of concepts across many disciplines and domains, if not all (omnipresent), a Mid-Level Ontology (MLO) can be broadly described as a generalized set of terms that can

[1] See https://github.com/CommonCoreOntology/CommonCoreOntologies

[2] https://joinup.ec.europa.eu/collection/semantic-interoperability-community-semic/core-vocabularies

model one or many related domains (multi-presence). As the name suggests, MLO is developed by extending TLO terms downwards, i.e., going from more to less generality.

In contrast to TLO which generally have a single hierarchy (a single tree) MLO may contain multiple hierarchies (multiple trees with multiple root nodes). Each of these hierarchies may find its root node extending a concept in some TLO. Another important difference is that where terms from some TLO generalize at least some concepts in almost all domains, terms from some MLO may interest only some domains (Arp et al., 2015).

Multi-tier development of ontologies by creating an MLO that contains the common concepts and their relations found in DLO provides three benefits: 1) interoperability among domain level ontologies through common generalized terms as parent classes, and 2) sharing of existing domain level concepts, and 3) separation of concerns between domain level semantic and cross-domain semantic development.

The observations above need be formalised based on careful analysis of the MLOs most common characteristics. In the following, we look into the structure of the MLOs and their relationship with TLO and DLO. Next, we will consider philosophically drawn meta-properties of classes to draw more fine-grained characteristics.

**First, we need to formalize the notion of generalization. Generalization can be either defined in terms of the structure or the semantic of the ontologies.**

The elements in an ontology $O$ can be classified in the following intersecting groups:

$S_C$ is the set of all **classes**.

$S_I$ is the set of **inheritance** relationship, an ordered 2-tuples of elements from $S_C$, members of which are connected by *owl:SubClassOf* or *rdfs:subClassOf* property; $S_I = \{a \coloneqq (x, y) | x \in S_C, y \in S_C, x \neq y\}$.

$S_A$ is the set of **association** relationships, a labelled and ordered 2-tuples of elements from $S_C$, members of which connected by some object property; $S_A = \{a \coloneqq (x, y) | x \in S_C, y \in S_C\}$.

$S_S$ is the set of association **specialization** relationships, an ordered 2-tuples of elements from $S_C$ that connected by owl: *SubObjectPropertyOf* or *rdfs:subPropertyOf* relationship; $S_S = \{a \coloneqq (x, y) | x \in S_A, y \in S_A, x \neq y\}$.

We will denote $S_C(O)$, $S_I(O)$, $S_A(O), and\ S_S(O)$ as the set of all classes, inheritances, associations, and specializations belonging to ontology $O$.

**Frontier signatures:**

**Frontier inheritance**: Let $F_I(O) \subseteq S_I(O)$ and $L_I(O) \subseteq S_I(O)/F_I(O)$. $F_I(O)$ is called frontier inheritance of $O$ if and only if: $\forall (x, y) \in F_I(O), x \in S_C(O) \wedge y \notin S_C(O)$ and $\nexists (x, y) \in L_I(O), x \in S_C(O) \wedge y \notin S_C(O)$. Frontier inheritances of an ontology are those inheritances, for each of which has only the inherited class belongs to that ontology.

Caveat: Transitivity of *subclass* relationship is not assumed here.

**Frontier Association**: Let $F_A(O) \subseteq S_A(O)$ and $L_A(O) \subseteq S_A(O)/F_A(O)$. $F_A(O)$ is called frontier associations of $O$ if and only if: $\forall (x, y) \in F_A(O), \left(x \in S_C(O) \wedge y \notin S_C(O)\right) \vee \left(x \notin S_C(O) \wedge y \in S_C(O)\right)$ and $\nexists (x, y) \in L_A(O), \left(x \in S_C(O) \wedge y \notin S_C(O)\right) \vee \left(x \notin S_C(O) \wedge y \in S_C(O)\right)$. Frontier association of an ontology are those associations, for each of which has only one of the associated classes belongs to that ontology.

**Frontier Specialization**: Let $F_S(O) \subseteq S_S(O)$ and $L_S(O) \subseteq S_S(O)/F_S(O)$. $F_S(O)$ is called frontier specialization of $O$ if and only if: $\forall (x, y) \in F_S(O)$, $x \coloneqq (x_1, x_2)$, $y = (y_1, y_2)$; $(x_1 \in S_c(O) \vee x_2 \in S_c(O)) \wedge (y_1 \notin S_c(O) \vee y_2 \notin S_c(O))$ and $\nexists (x, y) \in L_S(O)$, $x \coloneqq (x_1, x_2)$, $y = (y_1, y_2)$; $(x_1 \in S_c(O) \wedge x_2 \in S_c(O)) \wedge (y_1 \notin S_c(O) \wedge y_2 \notin S_c(O))$ . Frontier specializations of an ontology are set of those specializations, for each of which only the specialized association, which also not in frontier association, belongs to the ontology.

$O_1$ is a **generalization** for $O_2$, denoted by $O_1 \subseteq \mathcal{G}(O_2)$, if and only if one of (1) and (2) or both holds and (3) always holds, i.e., some classes and some relationships in $O_1$ are inherited (specialized) from $O_2$ but no two concepts from these two ontologies are associated.

1) $\exists(x,y) \in F_I(O_2), y \in S_C(O_1)$
2) $\exists(x,y) \in F_S(O_2), y \in S_A(O_1)$
3) $\nexists(x,y) \in F_A(O_2), \left(x \in S_C(O_1) \land y \in S_C(O_2)\right) \lor \left(x \in S_C(O_2) \land y \in S_C(O_1)\right)$

(1) dictates that some classes in $O_2$ should inherit from $O_1$, (2) dictates that some association relationships in $O_2$ should be specialized from $O_1$, and (3) dictates that there should not be any association relationships between the classes of $O_1$and $O_2$.

$O_1$ is a **companion** for $O_2$, denoted by $O_1 \subseteq \mathcal{C}(O_2)$, if and only if all the following holds, i.e., some associations exist between concepts from these two ontologies.

1) $\nexists(x,y) \in F_I(O_2), y \in S_C(O_1)$
2) $\nexists(x,y) \in F_S(O_2), y \in S_A(O_1)$
3) $\exists(x,y) \in F_A(O_2), \left(x \in S_C(O_1) \land y \in S_C(O_2)\right) \lor \left(x \in S_C(O_2) \land y \in S_C(O_1)\right)$

**Generalization among TLO, MLO, and DLO.**

| ➔ | TLO | MLO | DLO |
|---|---|---|---|
| **TLO** | False | True | True |
| **MLO** | False | True | True |
| **DLO** | False | False | False |

**Companionship among TLO, MLO, and DLO.**

| ➔ | TLO | MLO | DLO |
|---|---|---|---|
| **TLO** | True | False | False |
| **MLO** | True | True | False |
| **DLO** | True | True | True |

1. A TLO cannot be generalized by another TLO, MLO, or DLO.
2. A TLO cannot be the companion of a MLO or a DLO but may be a companion of another TLO.
3. An MLO cannot be generalized by a DLO, but a can be generalized by a TLO or another MLO.
4. An MLO cannot be the companion of a TLO or a DLO but can be companion of another MLO.
5. A DLO cannot be the generalization of a TLO or MLO but may be generalized by another DLO.
6. A DLO cannot be companion of a TLO or MLO but maybe companion of another DLO.

**We can derive the necessary conditions for characterizing TLO, MLO, and DLO.**

For a network of ontologies $\mathcal{O} = \{O_1, O_2, O_3, \dots\}$:

1) There exists a **TLO** $O_T \in \mathcal{O}$ if and only if $\nexists o\ (o \in \mathcal{O}) \land \left(o = \mathcal{G}(O_T)\right)$ and $\forall o\ (o \in \mathcal{O}) \land \left(o = \mathcal{C}(O_T)\right) \rightarrow \nexists o'(o' \in \mathcal{O}) \land (o \neq o') \land \left(o' = \mathcal{G}(o)\right)$
   i.e., no ontology is generalization of $O_T$ and every companion ontology must not be generalized by another ontology in the network.

2) There exists a **DLO** $O_D \in \mathcal{O}$ if and only if $\nexists o\ (o \in \mathcal{O}) \wedge \big(O_D = \mathcal{G}(o)\big)$ and $\forall o\ (o \in \mathcal{O}) \wedge \big(o = \mathcal{C}(O_D)\big) \rightarrow \exists o'(o' \in \mathcal{O}) \wedge (o \neq o') \wedge \big(o' = \mathcal{G}(o)\big)$
i.e., there must exist some ontology that generalizes of $O_D$ and every companion ontology must have some other ontology as a generalization.
3) There exists an **MLO** $O_M \in \mathcal{O}$ if $\forall o\ (o \in \mathcal{O}) \wedge \big(o = \mathcal{G}(O_M)\big) \rightarrow \nexists o'(o' \in \mathcal{O}) \wedge (o \neq o') \wedge \big(o' = \mathcal{G}(o)\big)$. And does not satisfy any of the conditions in 1) and 2)

The formalization above points to a three-level stratification. However, ontologies in a network can be chosen by developers to be stratified in more than three levels. In a multi-level ontology network, we may easily identify the top and domain (bottom-most) level ontology, but the condition for MLO fails in case some ontology generalizing an MLO is not a TLO but another MLO at a higher level. To tackle this scenario, the following definition of MLO uses induction to define the strata.

Function ***ordinate*** ($\mathbb{O}$) denotes the level of stratification, which increases from the bottom-up. E.g., the ordinate of an ontology $o$ at the third level of stratification has $\mathbb{O}(o) = 3$. DLO has ordinate 0, considering them situated at the lowest level of stratification.

i) If $O_D$ is a DLO then $O_M^1$ is a first-ordinate MLO if $O_M^1 = \mathcal{G}(O_D) \wedge (\forall o\ o = \mathcal{C}(O_M^1) \rightarrow \mathbb{O}(o) \geq 1\ )$.
ii) If $O_M^1$ is a first-ordinate MLO then $O_M^2$is a second-ordinate MLO if $O_M^2 = \mathcal{G}(O_M^1) \wedge (\forall o\ o = \mathcal{C}(O_M^2) \rightarrow \mathbb{O}(o) \geq 2)$
iii) If $O_M^{n-1}$ is a (n-1)th-ordinate MLO then $O_M^n$is a nth-ordinate MLO if $O_M^n = \mathcal{G}(O_M^{n-1}) \wedge (\forall o\ o = \mathcal{C}(O_M^n) \rightarrow \mathbb{O}(o) \geq n)$

Now, we can redefine TLO based on the inductive definition of the MLO above as follows:

If $O_M^n$ is a nth-ordinate MLO then $O_M^n$ is a TLO if $\nexists o\ \big(o = \mathcal{G}(O_M^n)\big)$

The above conditions are not sufficient for defining TLO, MLO, and DLO because there is no guarantee that the network of ontologies represents a standard multi-tier ontology network. A careful modularization of an ontology describing only domain-level concepts may also satisfy the above conditions. Logical conditions only provide necessary conditions where for deriving sufficient conditions, we need to find semantic conditions.

In the following, we explore the possibility of formally representing some of the notions considered in the above characterizations to make more precise and sharable the TLO vs. MLO distinction. As we will see, we do not provide a complete and fully operational definition able to sharply separate TLOs from MLOs. On the one hand, the TLO vs. MLO distinction seems to have an intrinsically qualitative nature preventing a precise definition of what a TLO and an MLO are. On the other hand, the value of a sharp distinction in applicative and practical scenarios is not clear to us especially when one considers examples of MLOs like the ones mentioned before.

Given these considerations, we focus here on a series of dimensions (according to which ontologies can be classified and compared) that together can help to qualitatively understand if an ontology has more of a TL- or ML character.

**The nature of concepts**:

Following the informal descriptions in Sect. 1, one of the main aspects that characterize the TLOs is the high degree of generality of their concepts. A first possibility to characterize highly general concepts is to refer to the distinctions introduced in OntoClean (Guarino & Welty, 2009). To better understand this, let us recall some intuitions about the notions of rigidity and identity conditions in OntoClean (Guarino & Welty, 2009).

A concept is said to be rigid if it is essential to all its instances, i.e., if x is an instance of a rigid concept ϕ, x is necessarily an instance of ϕ (i.e., it cannot exist without being a ϕ). On the opposite side, one finds anti-rigid concepts, whose instances do not satisfy them necessarily, i.e., if x instantiates an anti-rigid concept ϕ, x can exist without being a ϕ. A common example of a rigid concept is Person: if x is an instance of Person, x must be an instance of Person in all possible scenarios. An example of anti-rigid concept is Student[3]. Examples of rigid concepts closer to industrial engineering are Cutting Machine, Pipe, Screw, etc. Examples of anti-rigid concepts are Technician, Manufacturing resource, etc.

Considering identity conditions, these are properties that allow distinguishing between the instances of a certain concept. Consider Person; assuming a biological perspective, one can tell that x and y are identical (i.e., they are the same person) if and only if they have the same DNA. Having the same DNA can be therefore taken as the property defining the identity condition of persons. From a practical modelling stance, it is however challenging to fix identity conditions. These are indeed commonly established with respect to modelling conventions, e.g., one may assume that having the same social security number defines the identity condition of persons; or having the same plaque defines the identity condition of cars. Reference to identity plays an important role in ontology design, because—according to OntoClean (Guarino & Welty, 2009)—concepts with incompatible identity conditions cannot be taxonomically related. Concepts with identity conditions are called sortals in OntoClean (Guarino & Welty, 2009).

With these notions, we can now come back to the characterization of TL- and MLOs. In general, TL-concepts can be seen as non-sortal, since they do not provide common identity conditions for their instances. Moreover, TL-concepts are usually also rigid[4]. Examples of non-sortal rigid concepts are Object, Amount of matter, Quality, Region, Feature, and Event, among others.

Vice versa, ML-concepts are usually sortal and they can comprise also non-rigid concepts, including so-called roles, which are assumed to be anti-rigid (e.g., Manufacturing Resource). However, a grey zone often exists, e.g., the bottom-concepts of a TLO could be sortal (e.g., Physical Object) and the top-concepts of an MLO could be non-sortal.

In the case of integrated ontologies which fuse into a single engineering artefact concept of different degrees of generality, the previous distinctions can be helpful to isolate a Top-Level layer where the bottom-concepts of the TL-layer coincide with the top-concepts of the ML-layer.

**The nature of the primitive relations:**

The informal description above highlights another important characteristic of TLOs, namely, to make available some basic relations that can be (re)used to characterize ML concepts and relations.

TLOs have then a foundational role which becomes usually evident by looking at the kind of primitive relations considered. TLOs usually adopt formal relations, i.e., following Husserl, relations that can be applied to all kinds of entities and can be studied and axiomatized independently of any specific domain. Examples of formal relations are: identity, dependence, parthood, connection, constitution, and location. From a technical perspective, formal relations are formally characterized (often in a modularizable way) starting from general theories (e.g., different kinds of orders or lattices) that are then specialized to capture the specificity of a given primitive. In contrast, MLOs often consider material relations (e.g., friendship or fatherhood) whose arguments are constrained to a specific domain and whose axiomatizations may become quite peculiar.

Interestingly, TLOs usually ground their main distinctions on formal relations. It follows that (i) differences and disagreements among TLOs can be established based on the axiomatizations of the adopted formal relations; and (ii) the characterization of TL-concepts in terms of formal relations offers another view on concept generality, i.e., general concepts are characterized only in terms of formal relations.

Covering: The generality of TLOs can be also intended in terms of covering, i.e., looking at how large is the intended domain of quantification, possibly including everything one may assume to have some kind of

[3] Recall that OntoClean is a methodology for ontological analysis constraining taxonomic relations based on formal principles. It does not however fix a conceptualization; e.g., the choice of modeling Person as rigid is user-dependent.

[4] More specifically, TL-concepts correspond to what OntoClean calls categories, i.e., non-sortal rigid concepts.

existential status. In this view, the top-concepts of a TLO cover a huge part of the existence and no other concept is assumed to subsume them, besides the universal concept of 'thing' or 'entity'5. A related way of characterizing TLOs relies on their models: TLOs are compatible with several interpretations, and they have a large number of models. Even though intuitively these two aspects seem quite precise and informative, a formal characterization of them is not trivial and their role in distinguishing TLOs from MLOs is not clear.

Let us assume that both TLOs and MLOs are first-order logical (FOL) theories. To characterize the aspects above discussed, some formal notions coming from model-theory are needed (they are summarized in the Appendix).

Let $T$ (a TLO) and $U$ (an MLO) be FOL-theories with signature $\Sigma(T)$ and $\Sigma(U)$, respectively, and let $\mathfrak{L}(T)$ and $\mathfrak{L}(U)$ be the sets of first-order sentences built from $\Sigma(T)$ and $\Sigma(U)$, respectively. Furthermore, to simplify the definitions, suppose that an MLO $U$ introduces at least a new unary predicate w.r.t the TLO $T$, thus $\Sigma(U) \setminus \Sigma(T) \neq \emptyset$.

We start by considering two standard relations between logical theories, **logical refinement** and **definitional extension**.

1. $U$ is a **logical refinement** of $T$ iff $U \vdash T$ ($\vdash$ is the logical consequence)[5].
2. $U$ is a **definitional extension** of $T$ if there exists a set of sentences $\Phi$ such that (i) for every predicate $P \in \Sigma(U) \setminus \Sigma(T)$, $\Phi$ includes a sentence of the form $\forall\bar{x}\big(P(\bar{x})\backslash ifif\,\phi(\bar{x})\big)$, where $\phi \in \mathfrak{L}(T)$; and (ii) $T \cup \Phi$ is a conservative extension of $T$ and is logically equivalent with $U$.

If $\Sigma(T) \subset \Sigma(U)$, logical refinement implies that $\mathfrak{Mod}(U)|_{\Sigma(T)} \subseteq \mathfrak{Mod}(T)$ where $\mathfrak{Mod}(U)|_{\Sigma(T)}$ is the class of the reducts of the structures in $\mathfrak{Mod}(U)$ to $\Sigma(T)$ (see Appendix). Logical refinement can then be used to capture the fact that TLOs have more models than MLOs, however, it requires $\Sigma(T) \subset \Sigma(U)$, i.e., it makes sense only when an MLO ($U$) explicitly imports all the concepts and relations of a TLO ($T$). The notion of definitional extension abstracts from the signatures $\Sigma(T)$ and $\Sigma(U)$ but it requires a TLO ($T$) to be enough to define all the concepts in an MLO ($U$). In general, this is quite implausible, MLOs are usually intended to extend TLOs with genuinely new concepts and relations.

The notion of definitional extension abstracts from the signatures $\Sigma(T)$ and $\Sigma(U)$ but it requires a TLO ($T$) to be enough to define all the concepts in an MLO ($U$). In general, this is quite implausible, MLOs are usually intended to extend TLOs with genuinely new concepts and relations.

To account for the fact that MLOs genuinely extend TLOs, we consider the notion of **extensional refinement** defined below.

$U$ is an **extensional refinement** of $T$ iff there exists a set of sentences $\Phi$ such that (i) for every unary predicate $P \in \Sigma(U) \setminus \Sigma(T)$, $\Phi$ includes a sentence of the form $\forall x\big(P(x) \rightarrow \phi(x)\big)$, where $\phi \in \mathfrak{L}(T)$; and (ii) $T \cup U \cup \Phi$ is consistent.

First note that, when $U$ is an extensional refinement of $T$, all the concepts of $U$ are extensionally subsumed by a logical combination of the concepts of $T$. This means that modulo the chosen set $\Phi$ of mappings, the concepts in $\Sigma(U)$ are (extensionally) more specific than the ones in $\Sigma(T)$ and then all the entities considered in $U$ are covered by $T$. Second, extensional refinement does not require any specific set-theoretical or cardinal relation between $\Sigma(U)$ and $\Sigma(T)$, in particular, it is possible that $\Sigma(U) \cap \Sigma(T) = \emptyset$.

Intuitively, the previous observations seem to capture the idea that TLOs cover MLOs. However, extensional refinement relationally characterizes ontologies, it establishes only if the concepts of an ontology are (extensionally) more specific than the concepts of another ontology. To define what a TLO is, one need then to 'quantify' on possible refinements, i.e., a TLO could be defined as an ontology that is not a strict extensional

[5] Warning. In the literature $U \vdash T$ is used to say that $U$ is more general than, it brings more information, than $T$.

refinement[6] of any other ontology, i.e., an ontology with a maximal (with respect to the existing ontologies) domain. This quantification on ontologies is quite critical—do we quantify on existent ontologies or on possible ontologies? —and does not exclude the possibility to have several TLOs with domains which are not included in one in the other.

The reference to models can be useful to extend the notions of definitional and **extensional refinement** to the cases where mappings between the concepts in the two ontologies are not first-order definable. In these cases, one can establish mappings (between the corresponding models) that are based on higher-order mathematical constructions. This kind of links has been used, for instance, to compare and connect point-based vs. interval-based theories of time where intervals can be reduced to a set of points and points to appropriate filters of intervals.

One can ground a qualitative distinction between TLOs and MLOs on the three dimensions of comparison discussed in Sect. 2:

– TLOs are ontologies that are not (cannot be) the extensional refinement of any other ontology and where the majority of concepts are rigid, non-sortal, and characterized in terms of formal relations.

– MLOs are ontologies that are (can be) an extensional refinement of one or several TLOs and where the majority of concepts are sortal and are characterized also by means of material relations.

These definitions make clearer and more formal the intuitive ideas of generality and covering, attributing to TLOs a high degree of both these aspects. However, first, it seems that MLOs and Domain-Level Ontologies (DLOs) need different dimensions than those in Sect. 2 to be consistently separated: both MLOs and DLOs are extensional refinements of TLOs and contain sortal concepts together with material relations, i.e., the proposed definitions seem mainly to distinguish TLOs from not-TLOs ontologies. A possible way out could consider MLOs as ontologies that extensionally refine TLOs without extensionally refining any other ontology. Vice versa DLOs extensionally refine both TLOs and non-TLOs ontologies. This characterization needs however to be further investigated.

Second, neither the notion of 'discipline' mentioned in the OC description of MLOs nor the one of 'domain' considered in the CCO description is captured by the present analysis. It is not clear to us if these notions must be addressed from an ontological perspective, e.g., by clarifying the ontological nature of domains and disciplines, or if a more practical characterization based on the agreement (among experts) on a set of ML concepts is enough. For instance, experts may agree that the concepts of measurement and system of measurement are cross-domain and yet do not belong to a TLO since limited to the scientific domains. Building on this idea, experts in several domains could agree on a list of concepts that they consider relevant to be in an MLO. These concepts must be relevant across several domains, but their coverage is limited to some areas. One can then use the notions introduced in Sect. 2.3 to establish the generality of other concepts/ontologies with respect to the agreed set of ML-concepts. From a practical viewpoint, some existing standards could be used as a starting point to detail a possible list of ML-concepts.

## 2.2 Disciplines and MLOs in scope

While deciding on the topics that OntoCommons MLOs should cover, both top-down and bottom-up approaches are considered.

*Bottom-up considerations*

In ONTOCOMMONS the desired MLO topics for the OCES are based on different sources, such as focus workshops, engagement with domain experts, existing MLOs, and domain requirements. Broadly, inputs are collected from both WP2 and WP3 activities. The target domains are derived from bottom-up inputs. Broadly, the OntoCommons project focuses on materials and manufacturing. However, specific domains to consider

[6] *U* is a strict extensional refinement of *T* if *U* is an extensional refinement of *T* but the vice versa does not hold.

have also been curated from the inputs from domain experts, both internal and external to the project, domain landscape analysis and demonstration use cases. Some of the sub-areas of materials and manufacturing are listed in deliverables D3.2 and D3.4.

*Top-down considerations*

We also apply top-down considerations. As an example of top-down influence, ISO/IEC 21838-1:2021 Part A listed the necessary topics for a TLO. As some of these topics are not addressed by existing TLOs, some of them e.g., cognition and intention, can be introduced at the MLO level.

*Content considerations*

Also, the MLO can extend domain-neutral topics from the TLO with more specificity to be closer to domains, e.g., different types of causality may be introduced in the MLO for serving the target domains.

Topics for MLO are carefully selected by balancing both top-down and bottom-up content considerations. The topics for our initial investigation include:

- Agent
- Unit of measure (quality, currency etc.)
- Clock and calendar system
- Events and processes
- GeoSpatial information
- Information entity (sign, symbols, language, document)
- Mathematical entities (model, parameter, variable, equation)
- Artefact (artefact taxonomy)
- Communication and social interaction (business transactions)
- Capability and skill
- Functions
- Roles, anti-rigid kinds,
- Engineering designs
- Materials Science

Some of the MLOs that are identified for consideration in the Materials and Manufacturing domains are:

| | |
|---|---|
| IOF-CORE | https://github.com/iofoundry/Core (private) |
| The IOF Core Ontology contains terms and concepts found to be common across multiple domains of industry and represents an OWL implementation of them. The ontology itself utilizes the Basic Formal Ontology or BFO as a philosophical foundation but also imports terms from various domain-independent or mid-level ontologies. The purpose of the ontology is to serve or is intended to serve as a core for IOF's domain-specific ontologies, with a goal being to ensure consistency and interoperability across the suite of ontologies the IOF publishes. | |
| Common Core Ontology (CCO) | https://github.com/CommonCoreOntology/CommonCoreOntologies |
| The Common Core Ontologies (CCO) comprise twelve ontologies that are designed to represent and integrate taxonomies of generic classes and relations across all domains of interest. CCO is a mid-level extension of Basic Formal Ontology (BFO), an upper-level ontology framework widely used to structure and integrate ontologies in the biomedical domain. The CCO provide semantics for concepts and | |

| | |
|---|---|
| relations that are used in most domains of interest. The utility of the CCO comes from preventing BFO-compliant domain-specific ontologies from needlessly duplicating common concepts or from forcing such ontologies to include concepts outside of their domain (e.g. organization in the Ontology of Biomedical Investigations). | |
| BWMD mid-level | https://gitlab.cc-asp.fraunhofer.de/EMI_datamanagement/bwmd_ontology#modularization-of-the-original-bwmd-ontology |
| The BWMD-Ontology was curated within the DMD4F-project. It was divided into two modules: 'mid' and 'domain'. The ontology IRI was changed and the IRI-naming convention was altered in order to incorporate iterative IDs, the former entity-IRI now is the 'label'. | |
| SUMO mid-level ontology | https://github.com/ontologyportal/sumo/blob/master/Mid-level-ontology.kif |
| This is the source file for the MILO (MId-Level Ontology), an ontology that is being developed as a bridge between the abstract content of the SUMO and the rich detail of the various domain ontologies. | |
| Allotrope Ontology | https://www.allotrope.org/ontologies |
| The Allotrope Foundation® Ontologies ("AFO") is a curated collection of defined terms prepared by Allotrope Foundation. The AFO is collectively licensed under the Creative Commons Attribution License (CC-BY). However, the collection includes terms that are from or based on third party sources, as identified in the release notes, as updated from time-to-time. Such individual terms may be subject to subject to other licenses specified by the source (e.g., terms from the CHMO or chemical methods ontology are also under the CC-BY, while terms based on Wikipedia entries are subject to CC BY-SA). | |

Some ontology networks for a specific domain level concern also include many MLO modules.

- Key Performance Indicator ontology (as part of BIMERR ontology)
- Digital Construction Ontology
- Data Collection Ontology
- iiRDS Ontology
- EVMPO (as part of VIMMP ontology)

Some other standardized ontologies could also be considered MLO as they capture ubiquitous topics, such as time, calendar, provenance, measurement etc.

| | |
|---|---|
| Organization ontology (ORG) | https://www.w3.org/TR/vocab-org/ |
| This ontology is designed to enable publication of information on organizations and organizational structures including governmental organizations. It is intended to provide a generic, reusable core ontology that can be extended or specialized for use in particular situations. | |
| Provenance Ontology (PROV-O) | https://www.w3.org/TR/prov-o/ |

| | |
|---|---|
| The PROV Ontology (PROV-O) defines the OWL2 Web Ontology Language encoding of the PROV Data Model [PROV-DM]. This document describes the set of classes, properties, and restrictions that constitute the PROV Ontology. This ontology specification provides the foundation to implement provenance applications in different domains that can represent, exchange, and integrate provenance information generated in different systems and under different contexts. Together with the PROV Access and Query [PROV-AQ] and PROV Data Model [PROV-DM], this document forms a framework for provenance information interchange in domain-specific Web-based applications. | |
| Time Ontology (OWL-Time) | https://www.w3.org/TR/vocab-org/ |
| The PROV Ontology (PROV-O) defines the OWL2 Web Ontology Language encoding of the PROV Data Model [PROV-DM]. This document describes the set of classes, properties, and restrictions that constitute the PROV Ontology. This ontology specification provides the foundation to implement provenance applications in different domains that can represent, exchange, and integrate provenance information generated in different systems and under different contexts. Together with the PROV Access and Query [PROV-AQ] and PROV Data Model [PROV-DM], this document forms a framework for provenance information interchange in domain-specific Web-based applications. | |
| Time Ontology (OWL-Time) | https://www.w3.org/TR/vocab-org/ |
| The PROV Ontology (PROV-O) defines the OWL2 Web Ontology Language encoding of the PROV Data Model [PROV-DM]. This document describes the set of classes, properties, and restrictions that constitute the PROV Ontology. This ontology specification provides the foundation to implement provenance applications in different domains that can represent, exchange, and integrate provenance information generated in different systems and under different contexts. Together with the PROV Access and Query [PROV-AQ] and PROV Data Model [PROV-DM], this document forms a framework for provenance information interchange in domain-specific Web-based applications. | |

Unit and measurements related ontologies:

- Unit Ontology (uo) (https://www.ebi.ac.uk/ols/ontologies/uo)
- Ontology of units of Measure (OM) (https://github.com/HajoRijgersberg/OM)
- Quantities and Units of Measure Ontology Standard (QUOMOS) (https://wiki.oasis-open.org/quomos/FrontPage)
- Quantity Unit Dimension Type (QUDT) (http://www.qudt.org/pages/HomePage.html)

## 2.3 MLO Harmonization workflow

When it comes to ontologies, alignment is the most important task to the end of achieving harmonisation. An alignment is a set of relationships aimed at drawing correspondences between different ontologies (which, in the case at hand, cover the same domains of interest or different parts of a manufacturing value chain employing the same cross-domain concepts). The OntoCommons Consortium proposed to achieve terminological alignment among the ontologies which will make up a portion of the ready-to-use Ontology Commons Eco System (OCES) while also setting up new agreed-upon standards for domains lacking coverage or without any widely adopted ontology.

The OntoCommons Consortium aims to achieve alignments among the ontologies in the top and middle layers with different levels of rigour. It is broadly proposed that OCES will have semantic alignment among the ontologies in the same TLO branch and terminological alignment among ontologies from different TLO branches. Alignment also needs to be performed vertically (lower to upper-level ontology, e.g., MLO to TLO) and horizontally (among ontologies at the same level of generality, e.g., MLO to MLO). In what follows, formal definitions of terminological and semantic alignments are provided:

A **Terminological alignment** between two ontologies is a set of mappings, each of which provides a correspondence between pairs of terms -employed by the two ontologies respectively- considered from a purely linguistic perspective, that is as terms. A complete set of mappings will be such that for every two terms t, t' (in a language $L$) belonging to the same synonymy graph $S$, the mapping $\sigma$ will preserve the connected components of the synonymy graph $S$, i.e. their synset[7]: $\forall t, t' \in L, S(t) = S(t') \Rightarrow S(\sigma(t)) = S(\sigma(t'))$ (Jérôme Euzenat, 2001). For example, 'car' & 'automobile' are synonyms possibly employed by different ontologies.

From the perspective of this project, terminological alignment proved to be extremely difficult to achieve due to a lack of elucidations for the terms in most of the existing ontology. It must be noted that the terminological mapping assumes that the concept that the term represents is the same as the dictionary meaning of the term. However, in most cases, the term carries a label, whose dictionary meaning does not convey the concept it represents, i.e., the original interpretation of the term for it is used by the developer. Such concept may only be found in the associated definition, either as formal axioms or natural language, and supporting texts as elucidation. In this sense, the terminological alignment demands that the mapping preserves the interpretation of the aligned terms. This consists of mapping signs to equivalent signs with respect to the expected interpretation of a reader (let Σ be the interpretation rules and $\Vdash^{i}$ the interpretation relation for person $i$, $\forall \delta, \forall i, j, r, \sum \Vdash^{i} \delta \Rightarrow \tau(r), \tau(\sum) \Vdash^{j} \tau(\delta)$). These aspects can be related to rhetoric (Rutledge et al., 2000) or pragmatics (i.e., properties not directly relevant to a compositional view of semantics but which interfere with sheer semantic interpretation) (Jérôme Euzenat, 2001).

A **Semantic alignment** between two ontologies is a set of mappings, each of which provides a correspondence between pairs of concepts -employed by the two ontologies respectively- such that the consequence of the set of axioms (using relations) used for modelling one of the two concepts is preserved over the mapping. For instance, let $r$ be a set of axioms and $\delta$ a logical consequence of $r$ ($r \vDash \delta$) in language L, then a semantic mapping $\tau$ is such that it will preserve all $r$'s theorems in a language L', i.e., $\forall \delta, r \vDash_{L} \delta \Rightarrow \tau(r) \vDash_{L'} \tau(\delta)$ (Jérôme Euzenat, 2001).

This type of alignment attempts to bypass more substantial differences in modelling the same domains of interest. The latter may be caused by the use of different axioms for defining (what are taken to be) the same concepts, or due to the presence of different concepts in the respective ontology networks. Putatively equivalent ontologies can be characterized by completely different axiomatizations. Intuitively, similar cases have well-known analogues: consider, for instance, different axiomatizations of geometry taking respectively points and spheres as primitives. There is a difference between Conceptualisation Mismatch, which concerns the differences between modelled concepts, and Explication Mismatch, which revolves around the way the relevant concepts are expressed (Jerome Euzenat & Shvaiko, 2007).

A plethora of different scenarios can then be distinguished depending on whether the alignments involve:

1. MLOs, TLOs, or DLOs, though the latter are not explicitly considered here given the task at hand,
2. pairs of ontologies at the same or different levels,

[7] In metadata a synonym ring, or synset, is a group of data elements that are considered semantically equivalent for the purposes of information retrieval.

3. ontologies previously aligned with other ontologies or not,

with further cases being distinguishable depending on:

3.1. the degree and form of the alignment, and

3.2. whether the ontologies currently being aligned are connected to the same, or different, ontologies. This last point is especially relevant when MLOs constructed via a top-down process starting from the same/different TLOs are considered.

Given the ultimate goal of the project, scalability is pivotal. Any activity leading to harmonization, alignments included, has to take into account non-negotiable pragmatical desiderata: specifically, the various particular alignments will have to be achievable in a pragmatically reasonable amount of time, given a pragmatically reasonable investment of resources. It is thus extremely desirable, to the point of being almost crucial for the success of the project, to engineer methodologies which make alignments progressively less resources-intensive. It is also extremely important to the end of usability, and in line with the aims of the project, to pursue strategies which improve conceptual clarity.

Furthermore, it is mandatory to use -and, even more, reuse- all the various resources available. Given the vast number of different scenarios which the project is addressing (some of which were outlined above), this last point suggests the implementation of a plurality of strategies, taking into account the differences in starting points to ensure that no resource is left unused.

A core problem in the alignment of existing MLOs concerns the unavailability of sufficient axioms, supporting documentation, or contextual information to analyse the original intended meaning of the terms, completely understand the rationale of the framework, and comprehend the underlying background assumptions, of any kind they might be. It is also often difficult to set up active collaborations with the teams which have developed -or are doing maintenance to MLOs; moreover, the benefits of active collaborations might be nullified, or even out-weighted, by the inherent difficulties in managing a vast number of collaborations, thus endangering scalability. Finally, the harmonisation process ought to be considered holistically: the alignment strategies should also aim, in general, at providing (reusable) tools to ensure standardisation and promote understanding between the involved stakeholders.

The three following strategies -with their respective workflows- are a first concrete attempt at suggesting a pluralistic methodology for the harmonisation subtask here considered. Some reasons to pursue a pluralistic (yet interlinked and complementary) methodology are the following: the OntoCommons Project is charting unexplored territories in ontology-harmonisation and strategy-diversification reduces the risk of not achieving the goals; the possibility of comparing the empirical results of the different strategies -in overlapping cases in which they are not employed synergistically- will provide data for further refinements, improving the overall results in two different ways; finally, it will be possible to implement strategies heavily reliant on other aspects of the OntoCommons Project (e.g. WP2 and WP3 activities) without slowing down the progress of the specific task, respecting the project's schedule and milestones (see the second strategy). The list above is not meant to be exhaustive.

### 2.3.1 *Sketch of the first strategy and workflow outline:*

The first two strategies are heavily reliant on mappings among the TLOs (T2.4) which make up the core of the OCES. The first strategy is to create a vertical alignment between an MLO and a TLO part of the TRO which is considered to be most appropriate in light of first recognition. The alignment between the MLO and other TLOs is then achieved via the mappings among TLOs. Pairs of MLOs aligned with a given TLO should then be more easily aligned, though this point needs further investigation and won't be developed here. The first strategy is especially useful when there is an already existing alignment between an MLO and a TLO, or -even better- the MLO was built top-down starting from one of the TLOs parts of the TRO; nonetheless, it might be possible to employ this strategy to good results even in other scenarios. The vertical alignment between MLO and TLO ontologies is thus either produced, or manually checked and evaluated, by the OntoCommons

Consortium, depending on the circumstances, and the resulting alignments are integrated with the OCES on the back of the mappings among TLOs. Thus, a single alignment connects an MLO to all the TLOs making up the TRO for which there is a TLO-TLO mapping. The steps for the strategy are presented in Figure 1.

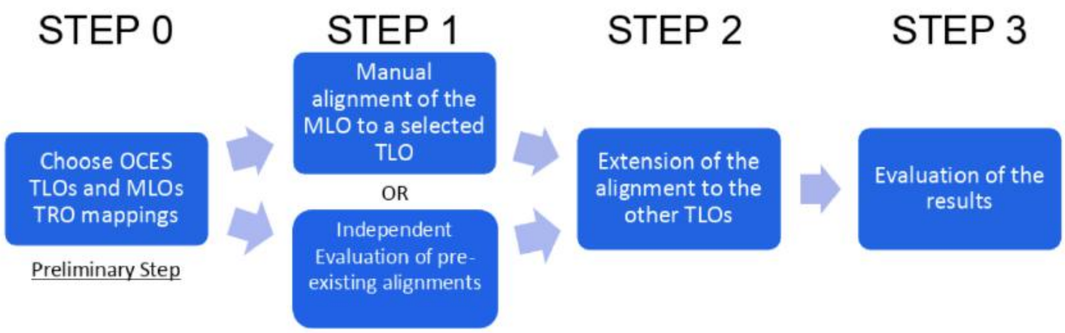


*Figure 1: Flowchart of strategy 1*

**Step 0 (preliminary step):** Selection of the TLOs which will make up the core of the OCES; production of partial mappings among them; selection of 1 MLO and 1 TLO (which is part of the TRO).

**Step 1a (circumstantial step):** Production of a manual alignment between the target MLO and the target TLO (given a previous heuristic recognition to end of determining the best candidate for a connection), making use of the various tools at the ontologists' disposal.

OR

**Step 1b (circumstantial step)**: Independent evaluation of the pre-existing alignments between the target ontologies. **Step 2**: Extension of the alignments to another TLO part of the TRO by means of TLO-TLO mappings

Step 2 can be iterated until all the branches of the TRO are connected with the given MLO.

**Step 3**: Independent evaluation of the resulting alignments to check their appropriateness.

During the testing phase, step 3 will involve comparison with golden standards, that is, previously-done manual alignments.

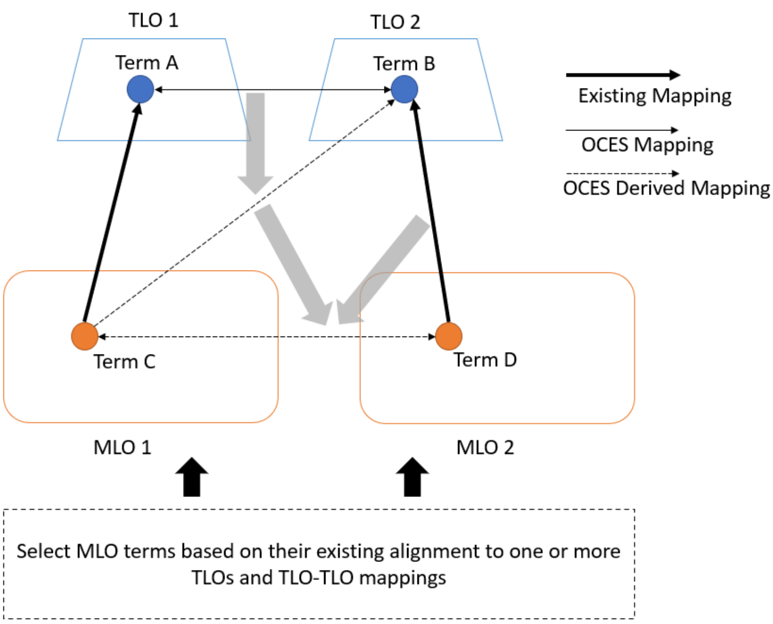


*Figure 2: Example of MLO to MLO and MLO to TLO mapping using strategy 1.*

Arguably, this strategy should be able to support semantic alignments. It should be noted that this strategy makes full use of the mappings developed in T2.4 as shown in Figure 2. The difficulties and intricacies involved in the production of MLO-TLO alignments are not addressed directly in this strategy: notably, the issue is circumvented in the "best use-cases" outlined above, leading to significantly reduced investments of resources. However, as a result of that, the particular re-used MLO-TLO alignments might be grounded on different standards and methodologies. There might also be interoperability issues arising due to the characteristics of the mappings among TLOs, yet that is a matter left for future investigation. As it was pointed out, this strategy can also be considered the first step in MLO-MLO alignments, ensuring that different MLOs fall under the same TRO branch and thus recovering one of TLOs' advantages (as acknowledged by the relevant literature), that is simplifying the alignment of subsumed MLOs; however, it is not clear -at the current stage- to what degree TLOs retain the capability of facilitating alignments when the outlined procedure is employed. A test of this strategy will soon be conducted to evaluate its practical efficacy, at least in a vacuum.

### 2.3.2 *Sketch of the second strategy and workflow outline:*

The second strategy is the most ambitious, aiming to achieve conceptual alignments capable of supporting semantic alignments, and being at the same time the strategy which enjoys the most general applicability, at least when existing ontologies are concerned. As such, only the very first steps (Phase 1) will be covered in what follows, namely, the ones leading from preliminary horizontal alignments among similar concepts underlying certain terms with pragmatically salient characteristics, to the establishment of OntoCommons Artificial ML Concepts. Phase 1's aim is the creation of salient links among existing MLOs, focusing on core concepts, and the establishment of families of MLO-concepts aligned to TLOs.

In general, this second strategy attempts to reconcile pragmatic constraints and theoretical needs conducive to the circumvention of operability issues which might arise from reliance on superficial links. The approach is entirely bottom-up and respectful of MLO's developer's specific skills, yet it is hinged on pragmatic fit rather than match, holistic, and, thus, EcoSystem-dependent/bound. Ultimately, whether this approach is feasible -and to what degree-, and whether it is adequate to the end of achieving the desired results, can be settled only via empirical testing. Still, it should be noted that the strategy can be downscaled in a number of ways, depending on the quantity, and quality, of the desired alignments, and other predefined parameters. In what follows, a comment will be provided for each of the core steps making up the workflow as shown in Figure 3.

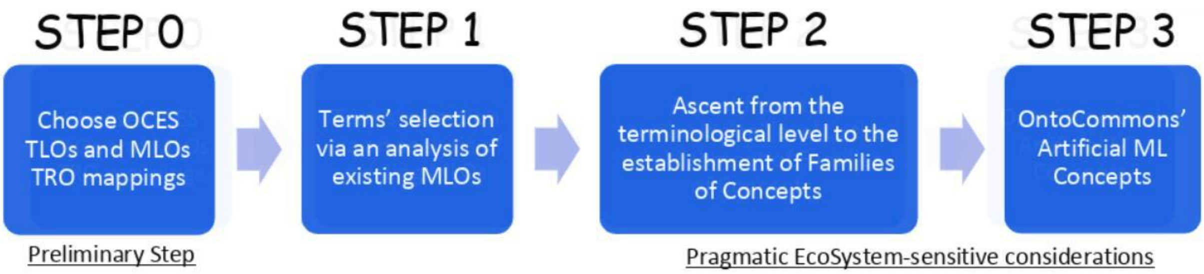


*Figure 3: Flowchart of strategy 2*

**Step 0 (preliminary step):** Selection of the TLOs which will make up the core of the EcoSystem; production of partial mappings among them; selection of the MLOs which will become the EcoSystem's first denizens.

**Step 1**: Selection of the target terms, by means of e.g., a statistical analysis of terms' frequency of occurrence in the selected MLOs, a network/topological analysis of the latter to the end of weighting the first results, and a final selection of the candidates via manual screening.

Despite being opaque with respect to the underlying concepts, terms/(linguistic-)labels de facto employed by MLOs are a good starting point, especially considering pragmatic constraints. The approach is set up in a way which can benefit from intra-MLO webs of relations to simplify further alignments pertaining to future phases not discussed in this brief outline: frequently occurring terms/labels allow for more inter-MLOs comparisons; the weighting procedure's role is conducive to the screening of a-specific terms which would not necessarily provide meaningful connections capable of supporting further alignment phases. While in some cases (e.g., when small datasets are involved) it might be preferable to move directly to the final manual selection, avoiding automatic pre-screening, a well-defined procedure will ensure standardisation, in line with the aims of the project.

**Step 2**: Ascent from terms-equivalence to the establishment of families of concepts, guided by pragmatic EcoSystem-sensitive considerations. Step 2 involves the following sub-steps: (Step 2.1) holistic analysis of the (intended) concepts underlying the target terms in the context of their respective (ML-)ontologies, with a focus on possible vertical links with TLOs; (Step 2.2) documentation of the results by means of templates for existing concepts developed by the OntoCommons Consortium specifically to that end; (Step 2.3) comparison of the analysed concepts underlying a specific term among the targets; (Step 2.4) establishment of families of concepts, with a focus on vertical network compatibility and by means of approximation.

Substeps 2.1 to 2.3 come down to conceptual analysis and documentation of the latter. The intended meaning underlying the terms -as they are employed in their respective ontologies- is investigated taking into account all the direct, and indirect, sources of information available, from actual use cases to the mathematical properties of the relevant part of the ontology analysed as a graph. A holistic procedure is made necessary by the opaqueness of terms, and the fact that the explicit documentation usually under-determinates the intended meaning. The procedure would greatly benefit from direct collaboration with both domain experts and the target ontologies' stakeholders, but scalability requires compromises, and direct contact is sometimes impossible to achieve: still, an ontological analysis done by the sole ontologists may result in increased risks of incorrect characterisations.

In Substep 2.4 terms are grouped together based on the preliminary results of the analysis (their similarities). However, a major role is played by constraints determined by tentative alignments to the TRO, given the mappings among TLOs, and -optionally, depending on parametrization- on the tentative alignments (again, to the TRO) of other related ontology nodes, to preserve consistency. The resulting families of concepts are thus heavily dependent on the OCES in its entirety, and, specifically, on the TLOs. The groupings are ultimately pragmatic, favouring the establishment of interconnections over actual conceptual similarity, to a degree. Then again, it ought to be remembered that differences in the alignments to TLOs are, at the very least, indicative of differences among concepts, given the roles commonly attributed to TLOs in the literature.

**Step 3**: Establishment of a schematic intermediary between existing MLOs and the TRO proceeding upward. Step 3 involves the following sub-steps: (Step 3.1) bottom-up construction of "Artificial Concepts" with new identifiers for the established families (classes) of concepts, or -given a different perspective- their prototypical abstraction; (Step 3.2) concepts' cataloguing by means of templates for "new" concepts developed by the OntoCommons Consortium specifically to that end; documentation by means of aggregation of the templates for existing concepts & external resources.

Step 3 finalizes step 2. The established families of concepts are treated as "new" artificial concepts and properly documented for future re-use. It should be noted that being bottom-up aggregations, the resulting concepts are not new; the documentation procedure will thus make sure to respect the original concepts when external domain resources are added to improve conceptual clarity. The aggregation of the templates relative to the single concepts making up the family will further ensure that, besides adding to the final documentation available, reusing the work of ML ontologists and respect their domain knowledge.

Shortlisted concepts are analysed to characterise them based on background knowledge, different domain level interpretations, and standardised definitions. A standard template is used to capture the analysis. The template is given in Appendix B.

**Beyond Phase 1**: Implementation of OntoCommons' Artificial ML Concepts in the alignment process (for other MLO-concepts) and to spread connections both in particular MLO-networks and in the entire OCES.

The artificial concepts together make up the foundations of a schematic intermediary between MLOs and the TRO, facilitating and spreading in-framework connections, improving conceptual clarity through re-documentation, and simplifying further expansions of the OCES, despite being rigidly dependent on the original OCES members at a certain version.

### 2.3.3 *Sketch of the third strategy and workflow outline:*

The third strategy is hinged on conceptual engineering and proceeds top-down from TLOs to MLOs, in the form of an extension of the TRO; nonetheless, the strategy is grounded on a preliminary analysis of stakeholders' demands and desiderata, conducted in the context of OntoCommons' activities, and specifically those related to D2.5 and D3.4. The strategy consists of the engineering of well-documented, and ontology-neutral, core "Bridge-Concepts", which are then connected to the TLOs which make up the TRO and come to constitute an extension of the latter, which is accessible, and directly usable, by domain experts. The concepts themselves are defined by referring to golden standards, state-of-the-art publications, and well-known and pervasively employed domain resources, also taking into account the actual usage of possibly related concepts in existing MLOs given tentative pre-emptive alignments. An elucidation and an extensive commentary are provided with both for the definition itself, its relation with domain resources, and each of the alignments to the TLOs. The concepts are developed around explicit, and understandable, traits and the most relevant ambiguities which might affect categorization are explicitly addressed, with ontology usage in mind. Once created and aligned with TLOs, the Bridge-Concepts can be employed to align the entirety of the OCES with a concept belonging to a given MLO at once.

These Bridge-Concepts will also aid users in better understanding TLOs, and in choosing a single TLO for a certain task if they so desire. They can also be considered well-defined desiderata, if not normative requirements, for new ontologies developed specifically in the context of the OntoCommons Project, thus covering that aspect of the harmonisation task.

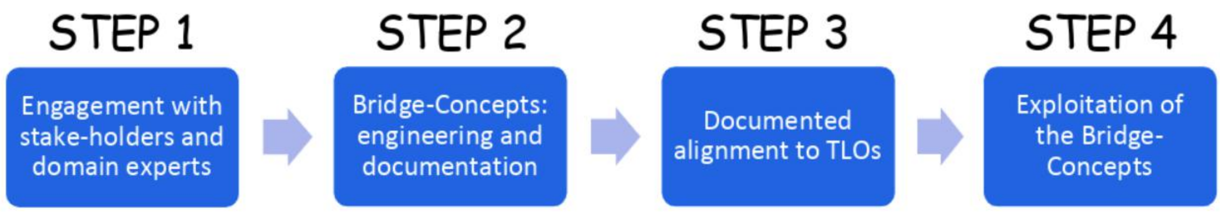


*Figure 4: Flowchart of strategy 3*

**Step 1**: Definition of a set of functional and non-functional requirements based on the needs of demonstrators and stakeholders' (including domain experts') inputs -from inside and outside the OntoCommons project- by means of a thorough analysis of group meetings, workshop and surveys (e.g. competency questions).

**Step 2**: Engineering of domain-expert-friendly and ontology-neutral Bridge-Concepts (which give content to the requirements) taking into account golden standards, domain resources, and actual usage in existing (ML) ontologies; production of extensive documentation by means of standard templates developed to that end by the OntoCommons Consortium.

**Step 3**: Manual alignment of the Bridge-Concepts to TLOs, and documentation of the alignment process.

**Step 4**: Exploitation of bridge concepts to the end of aligning the entirety of the TRO with a selected MLO at once, or as a normative requirement for the creation of new ontologies to be added to the OCES.

Engineering domain-expert-friendly and ontology-neutral concepts are no easy task, requiring both background knowledge on conceptual engineering, domain knowledge at different levels of interpretation, and case-by-case research of the relevant literature for golden standards and the most pervasive resources' definitions, to ensure immediateness and intuitiveness for domain experts and ontologists, while at the same time improving the usability for non-experts and reducing, the risk of meaning/conceptual shift, and thus, of short-term obsoleteness. Even in this case, collaboration with domain experts greatly improves the resulting Bridge-Concepts; and differently in strategy 2, scalability issues are less prominent, given the top-down approach.

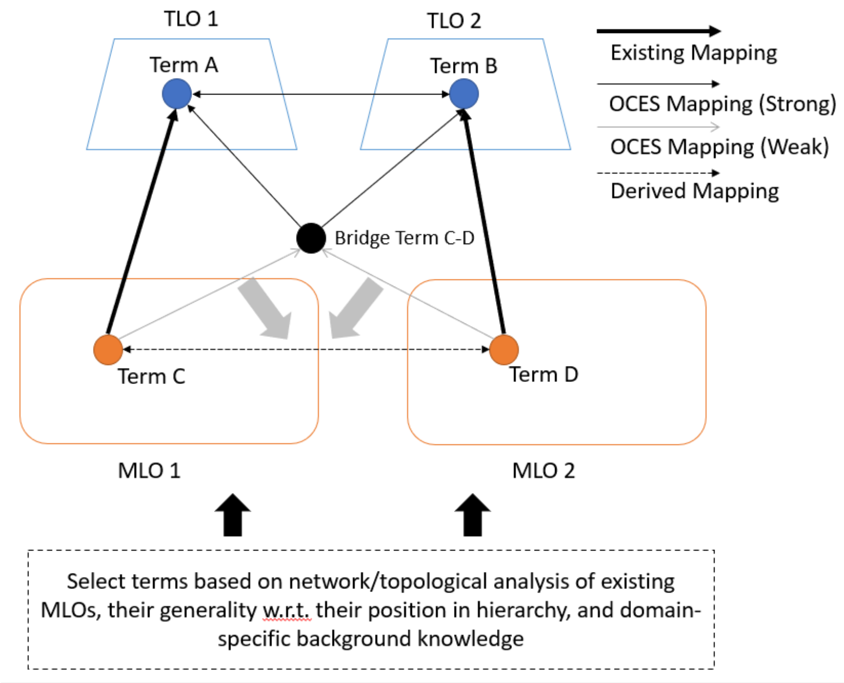


*Figure 5: Example of MLO to MLO and MLO to TLO mapping using strategy 2.*

**Synergies and complementarity:** the three strategies outlined above are entirely standalone, and tailored to specific scenarios. As such, they can be considered complementary, and employed case-by-case to make use of all the resources available. That said, there are apparent synergies among the strategies, and it might be possible to employ them together to greater effect. For instance, bottom-up Artificial Concepts, and top-down Bridge-Concepts together might come to constitute a strongly interlinked and versatile MRO; the requirements determined by the third strategy for new OCES ontologies will greatly improve standardisation, making the second one much easier across iterations. The first strategy offers elements reusable by the second one, and so on and so forth. Given the focus on reusability, the strategies might be pursued in parallel, without a corresponding increase in workload, though the actual advantages can only be determined in practice.

# 3. Result

For the development of the Beta version of the MLO, we adopt the third strategy due to its suitability in the current situation. In the following, we justify such a choice.

Although the first strategy makes full use of the TRO and may provide an opportunity to automate as most of the mappings are derived from the TLO-TLO mappings in TRO, this strategy relies on the existing mappings between MLO and TLO and considers that such mappings exist and correctly done. Many existing MLOs, that are not aligned to a TLO, cannot be accommodated by this strategy. Furthermore, it is noted from our observation that existing MLOs often have questionable mappings to the existing TLOs. On the other end, both the second and third strategy used the bottom-up approach to select the terms which will be considered for the alignment and creates intermediate terms (called the family of concept for the second strategy and bridge term for the third strategy) for similar concepts from existing MLOs under consideration. However, the second strategy relies on the MLOs original elucidation to group the concepts. The primary difficulty in this method is the lack of elucidations available in the existing MLOs which is described in Section 2.3. Moreover, any change committed in the MLOs may require a change in the family of concept affiliation of certain MLO terms. Therefore, the second strategy poses many risks as such changes then completely jeopardise the upward mapping to every TLO. The third strategy however addresses both of these concerns in some ways: first, the bridge terms are characterised from the top-down without any commitment to existing MLO. Therefore, the elucidation of these bridge concepts is neutral and independent of any change in the MLO also. While OCES provides a tentative mapping of the bridge terms to existing MLO terms, the original developers of these MLOs may come forward and change the mapping according to their conceptualisation without affecting the bridge terms to the TLOs.

For all artefacts produced to be part of this task will be stored in the GitHub repository: https://github.com/OntoCommons/OntologyFramework.

A list of potential MLO terms grouped under topics along with concept elucidations and ontology mappings will be available in this public GitHub repository. Potential MLO terms for several MLO topics along with definitions are produced. The list is provided in Appendix A.

Next, the elucidations of shortlisted bridge terms are documented in a separate document for each term. These documents are also stored in the GitHub repository. In the beta version, 15 terms are shortlisted as listed below:

- Industrial Process
- Physical Quantity
- Property
- System
- Agent
- Document
- Material Device
- Function
- Service
- Resource
- Commercial Product
- Atom
- Physical Field
- Physical Matter
- Structure
- Scale

In Appendix C, we provide the concept and mapping elucidations for “Atom" in the prescribed template as an example. The content of the template can be expressed using more flexible formats (e.g. XML, JSON) and documented within the RDFS version as shown by the term “Atom”.

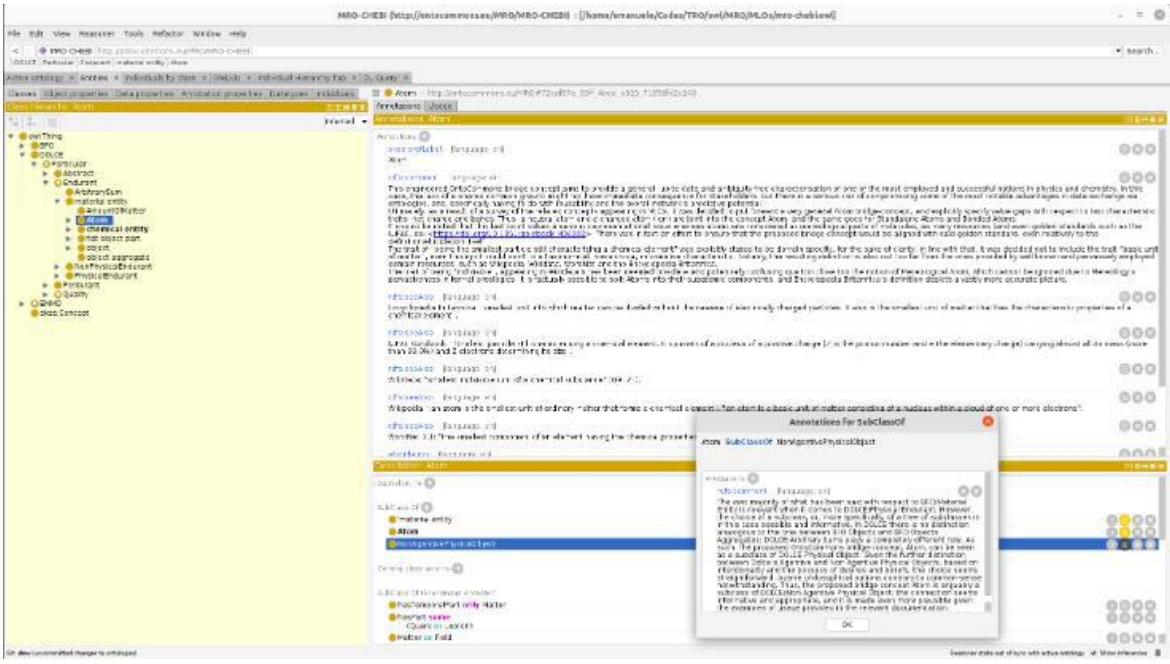

*Figure 6: Protégé screenshot of MRO*

An example of the Atom concept acting as a bridge between the DOLCE/BFO/EMMO TLOs is shown in Figure 7(a). The user can target the Atom concept while building or aligning it's MLO/DLO/ALO that will provide a gate toward one or more TLO according to its needs. This bridge term may then be aligned to the existing MLO term, e.g., “CHEBI atom” as shown in Figure 7(b).

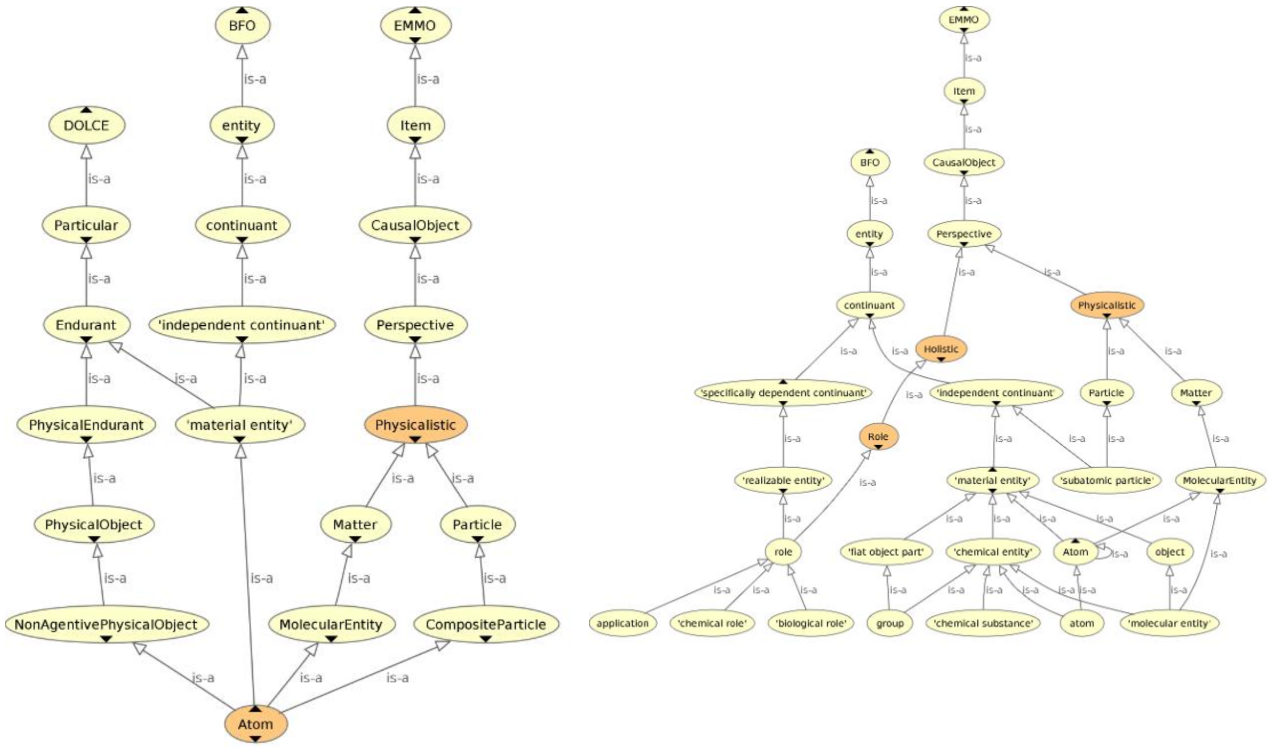


*Figure 7: (a) Bridge term “Atom” aligned to BFO, DOLCE, and EMMO, (b) CHEBI atom aligned to bridge term and TLOs*

The GitHub repository will have multiple ontology modules to provide a flexible import structure, as shown in Figure 8. While the OntoCommons modules contain mappings and ontologies which are part of the OntoCommons ecosystem, the empty import nodes provide options to the user to selectively choose modules that are suitable for their requirement. The TRO import node may contain all/some of the TLOs from the TLO node and pairwise mappings between them from the META node. The Concepts module will contain the bridge terms along with mapping to every TLO. Together with the TRO, the MRO module contains the TLOs, pairwise mapping between TLOs and vertical mapping from MLO terms to the TLOs. Separate ontology specific modules will be used to provide weak mapping to every existing MLO, e.g., the CHEBI mapping module contains the mapping between CHEBI concepts to MRO concepts.

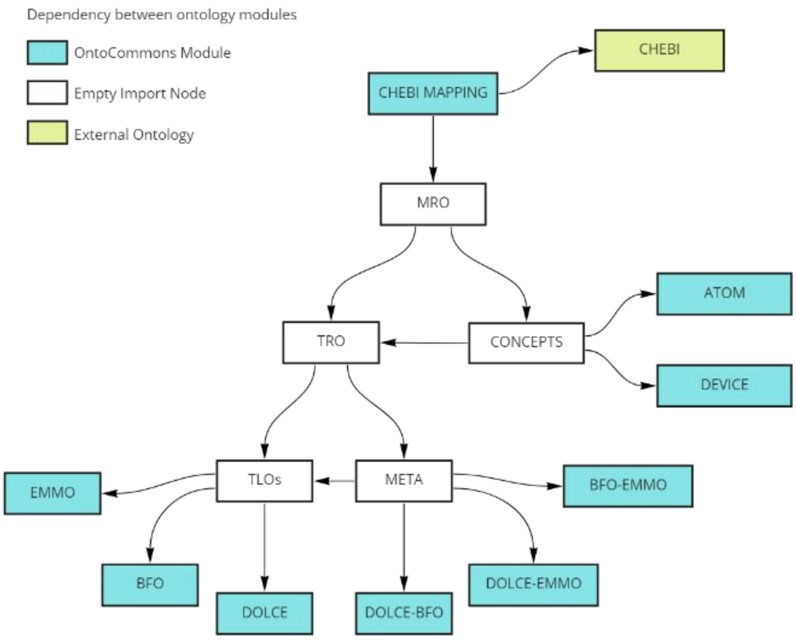


*Figure 8: MRO ontology module among the OCES ontology network*

# 4. Conclusions

This report summarizes the effort invested in MLO harmonisation in the first 18th month of the project. The effort mainly consists of characterisation of MLO, landscape survey for existing MLOs and relevant topics, and methodology for MLO harmonisation. The initial list of terms and preliminary alignment is also initiated and under development.

Section 2.1 presents the MLO characterisation based on structural analysis. Section 2.2 presents the MLO disciplines and a list of existing MLOs considered for this effort. Section 2.3 presents three alternative harmonisation workflows. Currently, the third strategy is adopted due to practical reasons but it is also on our agenda to experiment with the other strategies to compare their advantages and shortcomings. We will present such a report in the final version of the MLO harmonisation report.

In Section 3, an overview of the ongoing work is presented. This consists of a glossary of terms and their definitions, and the initial set of artificial terms which will be aligned to TLOs as a bridge between TLOs and existing MLOs. Each term is analysed for its background knowledge as well as an overarching definition, which are documented in the template proposed in Section 2.3.

In the coming months, the harmonisation will be implemented in the ontology artefacts as prescribed in Section 3. These artefacts will be available in the designated GitHub repository.

# 5. References

Arp, R., Smith, B., & Spear, A. D. (2015). Kinds of Ontologies and the Role of Taxonomies. In *Building Ontologies With Basic Formal Ontology* (Issue June 2017, pp. 1–13). The MIT Press. https://doi.org/10.7551/mitpress/9780262527811.001.0001

Euzenat, Jérôme. (2001). Towards a principled approach to semantic interoperability. In *Proc. IJCAI 2001 workshop on ontology and information sharing* (pp. 19–25). https://hal.inria.fr/hal-00822909/

Euzenat, Jerome, & Shvaiko, P. (2007). *Ontology Matching*. Springer Berlin Heidelberg. http://www.springerlink.com/index/10.1007/978-3-540-49612-0

Guarino, N., & Welty, C. A. (2009). An Overview of OntoClean. In *Handbook on Ontologies* (pp. 201–220). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-540-92673-3_9

Rutledge, L., Davis, J., van Ossenbruggen, J., & Hardman, L. (2000). Inter-dimensional Hypermedia Communicative Devices for Rhetorical Structure. *Multimedia Modeling*, 89–105. https://doi.org/10.1142/9789812791993_0007

# 6. Appendix I

## 6.1 Commercial agent

| **Term** | **Definitions** | **Hyponyms** |
|---|---|---|
| Contractor | A Role that inheres in an Agent or Group of Agents who enters into a Contract to provide materials or labor to perform a service or complete a task. (CCO)<br>A person or organization that contracts to provide the goods, services or engineering and construction works covered by the contract (ISO 10845-5:2011) | |
| Customer/buyer* | organization or person that receives a product (ISO 16426:2002) | |
| End-user | person who, or organization that, actually uses a product (ISO 26871:2020), that ultimately uses the service delivered (ISO 20539:2019) | |
| Supplier | organization or person that provides a product (ISO 15388:2012) | |
| Vendor | one who sells and/or delivers equipment and/or engineering services (ISO 35101:2017) | |
| Service Provider | An organization that contracts to provide one or more service instances to a customer. (ISO/IEC/IEEE 8802) | |
| Seller* | Person who aims to hand over voluntarily or in response to a demand, a good, service and/or right to another Person and in return receives an acceptable equivalent value, usually in money, for the good, service and/or right provided (ISO/IEC 15944-1) | |
| Manufacturer | natural or legal person with responsibility for the design, manufacture, packaging and labelling of a device before it is placed on the market under his own name, regardless of whether these operations are carried out by that person himself or on his behalf by a third party (ISO 7396-2:2007) | |

## 6.2 Organizational agent

| | | |
|---|---|---|
| Operator* | person or organization having responsibility for the operation of the equipment (ISO 21789:2009) | |
| Employee* | Individual who is, according to national law or practices, employed by the organization (ISO 30414:2018) | |
| Crew | A Group of Persons that bear Roles realized by the operation of the specified Vehicle.(CCO) | |

| | | |
|---|---|---|
| Manager* | entities that provide functionalities of filtering, accessing, storing, editing, updating and securing (ISO/IEC 21000-22:2019) | |
| Designer* | party who defines and specifies a component (3.6), a sub-assembly (3.5) or an assembly (3.4) (ISO/TS 21619:2018) | |
| Surveyor | (narrow) Person entrusted with the carrying-out of one or more of the different measuring operations in the building process. (ISO 4463-1:1989) | |
| Planner | | |
| Scheduler | Computer program, usually part of an operating system, that schedules, initiates, and terminates jobs (ISO/IEC/IEEE 24765:2017) | |
| Stakeholder* | person or organization (3.1) that can affect, be affected by, or perceive itself to be affected by a decision or activity (ISO 44001:2017)<br>An agent that has a stake on the execution of the activities but does not (necessarily) itself execute them. (DiCon) | |
| Instructor | person performing training (ISO 22876:2021) | |
| Expert | person who is an expert in a particular domain, area or topic (ISO/IEC 27034-3:2018) | |

| | | |
|---|---|---|
| Company | A legal entity established for commercial purposes (DiCon)<br>owner, operator, or license or duty holder of the authorized work (ISO 35101:2017) | |
| Organization/ Institution* | A Group of Agents which can be the bearer of roles, has members, and has a set of organization rules. (CCO)<br>An organized group of people with a particular purpose involved in the process. (DiCon)<br>company, corporation, firm, enterprise, authority or institution, person or persons or part or combination thereof, whether incorporated or not, public or private, that has its own functions and administration(ISO 30000:2009) | |
| Consortium/ Network | (Broad) A Group of Agents that are connected in dyadic relations by similar personal or career interests, activities, backgrounds, or real-life connections.(CCO) | |

# 7. Process and Events

## 7.1 Communication and exchanges

| | | |
|---|---|---|
| Communicating* | An Intentional Act in which some Information Content Entity is transferred from some Agent to Another. (CCO) | recording, reporting, |

| | | |
|---|---|---|
| | Communicating is transferring information from one material entity to another. This can be by way of a material or energy connecting the entity or by transporting the material bearing the information between the locations. (Allotrope) | commanding, indicating, broadcasting |
| Transacting* | (narrow) An Act of Artifact Employment in which some Agent uses some Financial Instrument.(CCO) | contracting, supplying, buying/purchasing, selling, renting, ordering |
| Service* | (narrow) service (3.1.17) that is designed to support interoperable machine-to-machine interaction over a network (ISO/IEC 19763-7:2015) | webservice, API |

## 7.2 Cognitive process

| | | |
|---|---|---|
| Planning* | activities concerned with the specification of a plan (ISO/IEC/IEEE 24748-5:2017)<br>An Intentional Act that involves making a Plan to achieve some specified Objective. (CCO)<br>A process of creating or modifying a plan specification. (Allotrope) | |
| Analyzing | (narrow) A planned process with the objective to produce information about the material entity that is the evaluand, by physically examining it or its proxies. (Allotrope) | |
| Observing* | Observation is the active acquisition of information from a primary source. In living beings, observation employs the senses. (Allotrope)<br>An Intentional Act of acquiring information from a source via the use of one or more senses.(CCO) | |
| Specifying/* denoting/ prescribing/ referencing/ describing | Referencing is the process of mentioning or referring to an entity by using a denotation of the entity. (Allotrope)<br>Denoting is a process that assigns a symbol to an entity in order to reference it. (Allotrope)<br>Describing is a process by which an account of some relevant characteristics, qualities or events of an entity are given or presented. (Allotrope)<br>Specifying is a process that produces an information object which describes constraints or objectives on characteristics like qualities, functions, dispositions, facets of continuants or processes. (Allotrope) | |
| Identifying | Identifying is recognizing an entity by some criteria and assigning an identifier to the entity. (Allotrope) | |

| | | |
|---|---|---|
| Modelling* | construction of abstract representations in the course of design, for example to represent the logical structure of software applications before coding (ISO/TS 13972:2015) | |
| Deciding | Deciding is making a choice from a set of alternatives. (Allotrope)<br>The cognitive process of concluding (BWMD) | |

## 7.3 Material handling process

| | | |
|---|---|---|
| Transforming* (material) | (broad) A Process in which some independent continuant endures and 1) one or more of the dependent entities it bears increase or decrease in intensity, 2) the entity begins to bear some dependent entity or 3) the entity ceases to bear some dependent entity. (CCO)<br>A process that affects the physical qualities of materials or creates, destroys or converts materials. (Allotrope) | adding/joining/ coupling, subtracting/ cutting/removing, modifying/ synthesizing/ converting, mixing/ Combining |
| Transporting* (material) | (broad) A Natural Process in which a Continuant changes its Location or Spatial Orientation over some Temporal Interval. (CCO)<br>Transporting is channeling by shifting, or conveying, a material from one place to another. (Allotrope) | delivering, driving, transporting, sailing |
| Storing* (material) | Storing material is the storing of material. (Allotrope) | |
| Maintaining* (artifact) | Combination of all technical and associated administrative actions intended to retain an item at/or restore it to a state in which it can perform its required function (ISO 17665-1:2006) | |
| Sorting* (material) | Sorting is the dividing of material by an ordering criterion. (Allotrope) | |
| Packaging (material) | Packing is the process of transferring an object into a container as a densely packed phase. (Allotrope) | |
| Recycling (material) | (narrow) processing of plastics waste materials for the original purpose or for other purposes, excluding energy recovery (ISO 15270:2008) | |

## 7.4 Other process

| | | |
|---|---|---|
| Energetic Process | A process where an agent affects energy flowing in and out of a system or affecting the energetic state of materials. (Allotrope) | |
| Business Process* | partially ordered, often nested, set of enterprise (3.4) activities that can be executed to achieve some desired result in pursuit | Marketing, Budgeting, |

| | | |
|---|---|---|
| | of a specified objective of an enterprise or a part of an enterprise (ISO 15704:2019) | Accounting, Sales, Supply-chain, Customer service |
| Experimenting* | An experiment is a planned process that has the goal of verifying, falsifying, or establishing the validity of a hypothesis. (Allotrope) | Testing |
| Simulating* | use of a similar or equivalent system to imitate a real system, so that it behaves like or appears to be the real system (ISO 16781:2021) | VIMMP(OSMO) |
| Measuring* | Measuring is observing a property of an entity called a quantity, that has a magnitude that can be expressed as a number and a reference to another entity, and obtaining one or more quantity values for it. The observed entity is a quality or a disposition for a continuant, for a process it is a process property such as duration. [Allotrope] | |
| Computational Process* | (narrow) A calculation is a process by which a data transformation technique that involves problem solving for numbers or quantities is performed. [Allotrope] | Ordering/ranking, Counting, calculating, optimizing, estimating, solving, deriving, integrating |
| Achieving/ Accomplishing/ Satisfying* | A process boundary based on some physical characteristics at the start or end of some process changing these characteristics. [Allotrope] | |
| Controlling* | Controlling is changing or regulating a flow in its magnitude. (NIST, Allotrope) | managing, starting, stopping, monitoring, regulating, repeating |

## 7.5 Information entity

| | | |
|---|---|---|
| Measurement* | A Descriptive Information Content Entity that describes the extent, dimensions, quantity, or quality of an Entity relative to some standard.(CCO)<br>A measurement datum is an information content entity that is a recording of the output of a measurement such as produced by a device. (IAO) | Deviation, count, interval, ratio, probability, fuzzy, reference system, geospatial measurements, time measurements |
| Name | A Designative Information Content Entity that consists of a string of characters that designates an entity within a specified cultural or social namespace and which is typically a word or | Country name, element name, |

| | | |
|---|---|---|
| | phrase in a natural language that has an accepted cultural or social significance. (CCO) | chemical symbol, colour name |
| Identifier* | A Designative Information Content Entity that consists of a string of characters that designates an entity within a specified namespace or context, is not a Designative Name, may be automatically or randomly generated, and typically has no pre-existing cultural or social significance. (CCO)<br>Any kind of identifier, which is used to identify any kind of entity (BWMD)<br>(narrow) A serial number is an information content entity which is a unique sequence of characters borne by part of manufactured product or its packaging that is assigned to each individual in some class of products, and so can serve as a way to identify an individual product within the class. Serial numbers can be encoded in a variety of other information objects, such as bar codes, numerals, or patterns of dots. (IAO)<br>An identifier is a name that identifies (that is, labels the identity of) either a unique object or a unique class of objects, where the "object" or class may be an idea, physical [countable] object (or class thereof), or physical [uncountable] substance (or class thereof). (Allotrope) | Version, colour code |
| Specification* | A specification is a proposition about the intended purpose or design of an entity. [Allotrope]<br>An Information Content Entity that consists of a set of propositions or images (as in the case of a blueprint) that prescribe some Entity. (CCO)<br>(narrow)Plan specification is a directive information entity with action specifications and objective specifications as parts that, when concretized, is realized in a process in which the bearer tries to achieve the objectives by taking the actions specified. (IAO) | Conditional specification, Objective specification, Process specification, Plan specification, Algorithm specification, Software specification, Language specification, Route specification, Design specification |
| Format* | A Descriptive Information Content Entity that describes a set of standards for organizing and understanding data of the specified type or domain. (CCO)<br>(narrow) Any kind of specific data format, e.g. file types like .txt, .xls, .png, .pdf, … (BWMD)<br>A data format specification is the information content borne by the document published defining the specification.(IAO) | File type |

| | | |
|---|---|---|
| Document* | A file with a specific file format (BWMD)<br>A collection of information content entities intended to be understood together as a whole (IAO)(Allotrope) | report, article, webpage, form, spreadsheet |
| Document part/Facet/Field* | An information content entity that is part of a document. (IAO)<br>A facet is a partial information that contains an aspect of some information content entity or parts of it when participating in some process. The facet abstracts of the concrete representation of this aspect of information. [Allotrope] | title, abstract, caption, reference |
| Dataset | Some kind of field data (tables, columns, matrices...) (BWMD)<br>Represents a collection of observations, possibly organized into various slices, conforming to some common dimensional structure. (Allotrope) | array, table, data cube |
| Figure/Image | An information content entity consisting of a two dimensional arrangement of information content entities such that the arrangement itself is about something. [IAO]<br>Any kind of figure in a report, publication, book or an image file (.png, tiff, .jpg...) (BWMD) | Logo, icon, plot, diagram |

## 7.6 Object and Artifact

| | | |
|---|---|---|
| Chamber/ Storage* | Container: An Artifact that is designed to contain (wholly or partially) some material entity. (CCO)<br>Container: A device that has the function to contain material. [Allotrope] (AFO)<br>Storage space: secured area where general goods and/or data centre (3.1.8) goods to be used in the premises and data centre are stored. (ISO/IEC 22237-1:2021) | |
| Mount/ Support/ Stand | | |
| Instrument/ Device** | Device: A device is an artifact that is designed to perform a function primarily by means of its mechanical or electrical nature. [Allotrope] (AFO)<br>Device: An object made or adapted for a particular purpose, such as a piece of mechanical or electronic equipment, and used in the operation of a building (DiCo) | |
| Machine (mechanical, electrical)* | material artifact that has a mechanical system as part. (IOF-Core)<br>Is a mechanical system designed expressly to perform a specific task, such as the forming of material or the transference and transformation of motion, force or energy. (ISO 22096:2007) | |
| Machine tool* | Machine element: An Artifact that is designed to be an elementary component of some Machine. (CCO) | |

| | | |
|---|---|---|
| Vehicle * | An Artifact that is designed to facilitate the movement of material entities from one location to another by conveying them there. (CCO)<br>An equipment for transporting shipments. The vehicle also moves from origin to the target of the transportation activity. Examples are trucks or forklifts. (DiCo) | |
| Engine* | An Artifact that is designed to convert one form of energy into mechanical energy. (CCO) | |
| Turbine | Turbine steam engine: A Steam Engine that is designed to extract thermal energy from pressurized steam and use it to do mechanical work on a rotating output shaft. (CCO)<br>Gas turbine: An Internal Combustion Engine that has a rotating compressor and a turbine and is designed to operate utilizing continuous Combustion to produce Thrust, either directly via exhaust or indirectly via a prop. (CCO) | |
| Pump* | A Fluid Control Artifact that is designed to impart motion to a portion of fluid to transport it within a system through the use of mechanical action. (CCO) | |
| Machine (electronics) (computer, server, hard disk, mobile phone etc.) | A computer is a general-purpose device that can be programmed to carry out a set of arithmetic or logical operations automatically. Since a sequence of operations can be readily changed, the computer can solve more than one kind of problem. [Wikipedia] (AFO)<br>Electronic component: An Artifact that consists of a basic discrete device or physical entity in an electronic system that is used to affect electrons or their associated fields. (CCO) | |
| Tool* | Tool: An Artifact that is designed to assist in the performance of manual or mechanical work and not to be consumed in that process. (CCO)<br>Tool: material artifact used by some person, or when added as a part of some machine, enables or improves some function or capability realized in actions of a certain kind. (IOF-Core) | |
| Controller* | A device that has the function to control some quality or process. [Allotrope] (AFO) | |
| Transducer (actuator, sensor/detector, antenna)* | Transducer: An Artifact that is designed to convert one form of energy to another. (CCO)<br>Sensor: A Transducer that is designed to convert incoming energy into a output signal which reliably corresponds to changes in that energy. (CCO)<br>Detector: Any piece of apparatus used to detect an analyte. [CHMO] (AFO) | |
| Measuring instrument * | Measurement device: A device that measures some aspect of reality, such as a quality or the profile of a process. [Allotrope] (AFO) | |

| | | |
|---|---|---|
| | Measurement: Represents the measured value made over a property. It is also linked to the unit of measure in which the value is expressed and the timestamp of the measurement. (Bimerr) | |
| Material handling devices* | Crane: An equipment for moving objects. The crane remains stationary during the movement and usually there is a difference in altitude in the origin and target location of the object movement. (DiCo) | conveyor, forklift, pallet, crane |
| Fluid handling equipment | Stirrer: A stirrer is a mixing device used for stirring something. [Allotrope] (AFO) | pump, pipe, stirrer |
| Sound generating device | Speaker: An auditory apparatus that converts an electronic signal into an acoustic signal. (ISO/IEC TR 18053:2000) | speaker |
| Lighting device | Lighting system: An Artifact that is designed to emit light within some area. (CCO)<br>Display: A display is a device or element of an instrument serving to represent information. [Allotrope] (AFO) | electric bulb, led, laser, display |
| Optical device | Optical device: An optical device is a device that creates, manipulates, or measures electromagnetic radiation. [Wikipedia] (AFO)<br>Optical instrument: An Artifact that is designed to process light waves. (CCO)<br>Optical Camera: A Camera that is designed to form and record an image generated from visible light. (CCO) | camera, microscope |
| Power generating device/ Energy source | Power source: An Artifact that is designed to supply power to some other Artifact. (CCO) | turbine, heater |
| Equipment/Appliance * | Piece of equipment =def. material artifact that has some function, that if realized, is realized in some planned process. (IOF-Core)<br>Equipment: Some kind of equipment, e.g. which is used in research or production systems. (BWMD)<br>Equipment: Machinery and tools used in construction activities. Equipment do not have a capability to operate activities by itself automatically. (DiCo)<br>Equipment Mount: A Machine Element that is designed to support an Artifact. (CCO) | |
| Gadget | | |
| Peripheral/Accessory | | |

| | | |
|---|---|---|
| Structures* | Structural support artifact function: An Artifact Function that is realized by an Artifact providing physical support to another object. (CCO) | Building, Dam |
| Facility* | Facility: An Artifact that is designed as a building or campus dedicated to some specific purpose. (CCO) | |
| System ** | System role: A Role that inheres in an entity in virtue of it being an arrangement of parts or elements that together exhibit behaviour or meaning that the individual constituents do not. (CCO) | |
| Resource ** | Resource: A Continuant that is owned by, in the possession of, or is otherwise controlled by an Agent such that it could be used by that Agent. (CCO) | |
| Component ** | Component role: A Role that inheres in an entity having a discrete structure in virtue of that entity being part of a system considered at a particular level of analysis. (CCO)<br>Component: Some kind of component (BWMD) | |
| Printed Medium* | Book: An Information Bearing Artifact that is designed to bear some specific Information Content Entity by means of ink, paper, parchment, or other materials fastened together to hinge at one side. (CCO) | book, barcode, receipt, ticket, photograph |

## 7.7 Quality (characteristics, attributes) and hidden qualities

| | | |
|---|---|---|
| Mechanical properties/ Physical properties** | A physical quality that inheres in an bearer by virtue of how that bearer behaves when subjected to forces or displacements and the effect of their bodies on their environment. (Allotrope)<br>Any kind of mechanical quantity or property (BWMD) | hardness, elasticity, frictional coefficient, viscosity, weight, force, power |
| Acoustical properties | Property that inheres in an independent continuant having to do with sound or hearing. (Allotrope) | absorption coefficient, propagation coefficient |
| Chemical properties | A chemical substance quality is a quality that inheres in some portion of chemical substance. [Allotrope]<br>(narrow) A molecular quality is a chemical quality which inheres in a molecular entity, a single molecule, atom, ion, radical etc. [Allotrope]<br>(broad) Any kind of structural quantity or descriptor to (quantitatively) describe the internal or external structure of an object. (BWMD) | acidity, concentration, molality, structure |

| | | |
|---|---|---|
| Electrical properties | (broad) A physical quality that inheres in an bearer by virtue of how that bearer interacts with electromagnetic radiation. (Allotrope) | capacitance, conductivity |
| Magnetic properties | broad) A physical quality that inheres in an bearer by virtue of how that bearer interacts with electromagnetic radiation. (Allotrope) | permeability, curie temperature, diamagnetism |
| Optical properties | An EM radiation quality in which the EM radiation is within the fiat range of the spectrum visible deemed to be light.(Allotrope) | luminosity, reflectivity |
| Thermal properties | A physical quality that inheres in a bearer by virtue of its material properties pertaining to temperature. (Allotrope) | boiling point, melting point, temperature |
| Thermodynamic properties | Thermodynamic properties are defined as characteristic features of a system, capable of specifying the system's state. (Wiki) | mass, density, entropy, fugacity, pressure, energy |
| Shape properties* | A Quality that inheres in a bearer in virtue of the ratios between dimensions of external features of that bearer. (CCO) | round, flat, sharp, thin |
| Size properties* | A Quality that inheres in a bearer in virtue of the bearer's extension in one or more dimensions. (CCO) | length, breadth, height, perimeter, circumference, angle, distance, volume |
| Numerical properties | (narrow) A Quality that inheres in a bearer in virtue of the total, aggregate or sum of a number of discrete items or material the entity contains as parts. (CCO) | count, ratio, percentage, fraction, occupancy |
| Configuration ** | A specific combination of qualities that the bearer realizes at some time. (Allotrope) | system configuration, device configuration |

## 7.8 Mathematical entities

| | | |
|---|---|---|
| Objective | | |
| Problem | | |
| Function | | |
| Parameter | | |
| Variable | | |
| Argument | | |
| Equation | | |
| Algorithm | | |

| | | |
|---|---|---|
| Collection | | set, bag, sequence, tuple, array, matrix |
| Constant | | |
| Formula/ Equation | | |
| Constraint | | |

## 7.9 3D design and virtual reality

| | | |
|---|---|---|
| Axis/Frame of reference | | |
| Point | | |
| Curve | | |
| Surface | | |
| Solid/ Volume(3D) | | |
| Boundary | | Loop, Shell |
| Form feature/ Shape feature | | Hole, Pocket, Slot, Boss, Knurl |
| Dimension | | |
| Tolerance | | |

## 7.10 Space and time:

- Interval algebra
  - precedes (and its inverse)
  - Meets (and its inverse)
  - Overlaps (and its inverse)
  - Finished by (and its inverse)
  - Contains (and its inverse)
  - Starts (and its inverse)
  - Equals
- Topology
  - Proper part of

- Overlaps
- Underlaps
- Sum
- Product
- Unrestricted fusion
- Unique fusion
- Atomicity

- Mereotopology
  - Closure
  - Boundary
  - Interior
  - Tangent
  - Region connection calculus (RCC8) relationships

## 7.11 Other relations

- Thematic roles
  - participate as an agent
  - participate as an instrument
  - participate as a cause
  - participate as a patient
  - participate as a beneficiary
  - participate as a purpose
  - participate as a result
  - participate as a reason
  - participate as a theme

## 7.12 Consideration for future:

- Unit system
- Finite state machine
- Situation calculus

# 8. Appendix II

## NEW CONCEPT NAME

*(use the preferred label, or IRI name, provided in the first table as title)*

**General Concept Info:**

| | |
|---|---|
| **IRI:** | *Suggested entity new IRI.* |
| **OWL Type:** | *Class\|ObjectProperty\|Individual.* |
| **Concept Elucidation:** | *Natural language definition of the concept (elucidation).<br>Here the concept that we want to introduce is expressed as precisely as possible, making references to knowledge domain resources, including instance and usage examples when relevant.* |
| **Labels:** | *Labels used to address the concept, ordered as:<br>i) preferred (one) (the label to primarily used to shortly refer to the concept)<br>ii) alternative (multiple) (labels that are commonly used to address the concept in practice, even if they are used with narrower of wider sense)<br>iii) deprecated (multiple) (labels that are misleading with respect to the concept, because of misuse, ambiguity or too wide meaning).* |

**Knowledge Domain Resources:**

| | |
|---|---|
| **Related Domain Resources:** | *Existing domain resources (e.g. standards, books, articles, dictionaries) that defines or are related to the concept (provide reference to the resource and quote the relevant informational content).<br>More than one resource can be reported.<br>These resources are aimed to support the choice of the above concept choice and elucidation.* |
| **Comments:** | *Explain the motivations behind the concept definition with reference to the domain resources, underlying similarities and differences.* |

**Alignments To Existing Ontologies:**

| | |
|---|---|
| **Target Ontology:** | *Existing IRI of the ontology that will express the concept according to its logical framework (concept alignment).* |
| **Related Ontology Entities:** | *List of terms and IRIs of the Target Ontology entities that are relevant for the concept (documentation is supposed to be accessible through the target ontology).* |

OntoCommons - Ontology-driven data documentation for Industry Commons, has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement no. 958371.

| | |
|---|---|
| **Mapping Elucidation:** | *Natural language description of the mapping choice and motivations.* |
| **Semantic Relation Level:** | *The level of semantic relationship between the Concept and the Target Ontology entities:*<br>• *Equivalence (strong mapping) (e.g. owl:equivalentClass, owl:equivalentProperty)*<br>• *Strong Hierarchical (e.g. rdfs:subClassOf, rdfs:subPropertyOf)*<br>• *Weak Hierarchical (e.g. skos:narrower, skos:broader)*<br>• *Similarity (e.g. skos:related).* |
| **Mapping Axioms:** | *Proposed mapping axiom (or axioms) between the Concept entity and the Target Ontology entities in a OWL2 compliant syntax (e.g. Turtle, Manchester, RDF/XML, Functional-Style, OWL/XML).* |

# 9. Appendix III

## ONTOCOMMONS BRIDGE-CONCEPT

## ATOM

**GENERAL CONCEPT INFO:**

| | |
|---|---|
| **IRI:** | *Suggested entity new IRI.* |
| **OWL Type:** | *Class* |
| **Concept Elucidation:** | An atom is a nucleus surrounded by an electron cloud. The nucleus consists of electrically positive protons and electrically neutral neutrons, and carries almost all of the atom's mass; the electron cloud is a quantum system made of one or more bounded electrons, and is pivotal in determining the atom's size and properties. It is the smallest system that has the characteristic properties of a chemical elements and, as such, it is often employed as a unit in the domain of chemistry. Atoms can either be standalone or bonded; they can have an unbalanced number of electrons with respect to their atomic number (the latter being determined by the number of protons in the nucleus) or have a net electric charge.<br><br>Domain: Natural sciences - Physics / Chemistry. |
| **Labels:** | *Labels used to address the concept, ordered as:*<br>*skos:prefLabel: Atom*<br>*skos:altLabel: Atom (Broad)*<br>*skos:hiddenLabel: Chemical Element; Neutral-or-Ion Atom; Standalone-or-Bonded Atom* |

**KNOWLEDGE DOMAIN RESOURCES:**

| | |
|---|---|
| **Related Domain Resources:** | -*Wikipedia:* "an atom is the smallest unit of ordinary matter that forms a chemical element"; "an atom is a basic unit of matter consisting of a nucleus within a cloud of one or more electrons".<br>-*Encyclopedia Britannica:* "smallest unit into which matter can be divided without the release of electrically charged particles. It also is the smallest unit of matter that has the characteristic properties of a chemical element".<br>-*WordNet 3.1:* "the smallest component of an element having the chemical properties of the element".<br>-*WikiData:* "smallest indivisible unit of a chemical substance" (Q9121). |

OntoCommons - Ontology-driven data documentation for Industry Commons, has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement no. 958371.

| | |
|---|---|
| | -IUPAC Goldbook: “Smallest particle still characterising a chemical element. It consists of a nucleus of a positive charge (Z is the proton number and e the elementary charge) carrying almost all its mass (more than 99.9%) and Z electrons determining its size”. |
| **Comments:** | *This engineered OntoCommons bridge-concept aims to provide a general, up-to-date and ambiguity-free characterisation of one of the most employed and successful notions in physics and chemistry. In this case, the lack of a shared common ground might not have immediate consequence for stakeholders, but there is a serious risk of compromising some of the most notable advantages in data exchange via ontologies, and, specifically having to do with reusability and the overall network’s predictive potential. Ultimately, as a result of a survey of the related concepts appearing in MLOs, it was decided to put forward a very general Atom bridge-concept, and explicitly specify value gaps with respect to two characteristic traits: net charge and bonds. Thus, a neutral atom and a charged atom (ion) are joint into the concept Atom, and the same goes for Standalone Atoms and Bonded Atoms. It should be noted that this last point solves a serious representational issue whereas atoms are considered as mereological parts of molecules, as many resources (and even golden standards such as the IUPAC, do: <https://doi.org/10.1351/goldbook.M04002>. There was in fact an effort to ensure that the proposed bridge-concept would be aligned with said golden standard, even relatively to the definition/elucidation itself. The trait of “being the smallest particle still characterising a chemical element” was explicitly stated to be domain specific, for the sake of clarity: in line with that, it was decided not to include the trait “basic unit of matter”, even though it could point to a taxonomical, hierarchical, informative characteristic. Notably, the resulting definition is also not too far from the ones provided by well known and pervasively employed domain resources, such as Wikipedia, Wikidata, WordNet and the Encyclopedia Britannica. The trait of being “indivisible”, appearing in Wikidata’s has been deemed obsolete and potentially confusing qua too close too the notion of Mereological Atom, which cannot be ignored due to Mereology’s pervasiveness in formal ontologies. It is factually possible to split Atoms into their subatomic components, and Encyclopedia Britannica’s definition depicts a vastly more accurate picture.* |

**ALIGNMENTS TO EXISTING ONTOLOGIES:** *(1: VERTICAL, TLOS; 2: HORIZONTAL, MLOS)*

**1: VERTICAL ALIGNMENTS**

**BFO**

| | |
|---|---|
| **Target Ontology:** | *<http://purl.obolibrary.org/obo/bfo.owl>* |
| **Related Ontology Entities:** | *Material Entity: <http://purl.obolibrary.org/obo/BFO_0000040>* |
| **Mapping Elucidation:** | *Given BFO’s internal organization, there do not seem to be many options beside BFO:Material Entity for an alignment. In general, as far as BFO’s distinctions are concerned, Atoms do not seem to be vastly different from moderate-sized specimens of dry goods such as tables and bricks. Arguably, the real question concerns whether the proposed OntoCommons bridge-concept, Atom, is a subclass of BFO:Object, BFO:Object Aggregate, or BFO:Fiat Object (which is arguably the rightful categorisation for a restriction of Atom via the bonded trait); however the classes are not mutually disjoint as the relevant BFO universals are not rigid, so the questions is, to a degree, meaningless. In fact, the possibility of the relevant individuals of migrating among the classes seems especially appropriate in this specific scenario.* |

| | |
|---|---|
| | *There do not seem to be reasons to consider a different alignment, and the examples of usage appear to be pertinent. Despite the intuitive gap between Material Entities and Atoms, the connection seems informative and appropriate: in fact, it is pivotal to be wary of intuitions which might derive from unrelated considerations pertaining to concepts' prototypes and scale. Finally, it is worth considering whether such an alignment is conductive to an appropriate representation of electron clouds, but -it could be argued- that would be putting the cart before the horse.* |
| **Semantic Relation Level:** | *The level of semantic relationship between the Concept and the Target Ontology entities:*<br>*rdfs:subClassOf* |
| **Mapping Axioms:** | *TBD* |

**DOLCE**

| | |
|---|---|
| **Target Ontology:** | *<http://www.loa.istc.cnr.it/dolce/dolce-owl/DOLCEbasic>* |
| **Related Ontology Entities:** | *NonAgentivePhysicalObject: <http://www.loa.istc.cnr.it/dolce/dolce-owl/DOLCEbasic#NonAgentivePhysicalObject>* |
| **Mapping Elucidation:** | *The vast majority of what has been said with respect to BFO:Material Entity is relevant when it comes to DOLCE:Physical Endurant. However, the choice of a subclass, or, more specifically, of a tree of subclasses is in this case possible and informative. In DOLCE there is no distinction analogous to the one between BFO:Objects and BFO:Objects Aggregates; DOLCE:Arbitrary Sums plays a completely different role. As such, the proposed OntoCommons bridge-concept, Atom, can be seen as a subclass of DOLCE:Physical Object. Given the further distinction between Dolce's Agentive and Non Agentive Physical Objects, based on intentionality and the possess of desires and beliefs, the choice seems straightforward, bizarre philosophical options contrary to common-sense notwithstanding. Thus, the proposed bridge-concept Atom is arguably a subclass of DOLCE:Non Agentive Physical Object; the connection seems informative and appropriate, and it is made even more plausible given the examples of usage provided in the relevant documentation.* |
| **Semantic Relation Level:** | *The level of semantic relationship between the Concept and the Target Ontology entities:*<br>*rdfs:subClassOf* |
| **Mapping Axioms:** | *TBD* |

**EMMO**

| | |
|---|---|
| **Target Ontology:** | *<http://emmo.info/emmo>* |
| **Related Ontology Entities:** | *Atom: <http://emmo.info/emmo#EMMO_eb77076b_a104_42ac_a065_798b2d2809ad>* |
| **Mapping Elucidation:** | *EMMO:Atom appears to be the perfect candidate for an alignment based on class equivalence with the proposed OntoCommons bridge-concept, Atom. The tentative connection is supported by the relevant documentation, which makes explicit relevant value gaps by means of subclasses. There do not seem to be reasons to consider other* |

| | |
|---|---|
| | *alignments, and, in this case, even the problems involving the eventual in-framework representation of electron clouds can be dismissed.* |
| **Semantic Relation Level:** | *The level of semantic relationship between the Concept and the Target Ontology entities:*<br><br>*rdfs:equivalentClass* |
| **Mapping Axioms:** | *TBD* |

**2: Horizontal Alignments**

**BWMD**

| | |
|---|---|
| **Target Ontology:** | *<https://www.materials.fraunhofer.de/ontologies/BWMD_ontology/mid>* |
| **Related Ontology Entities:** | *Atom:*<br>*<https://www.materials.fraunhofer.de/ontologies/BWMD_ontology/mid#BWMD_00131>* |
| **Mapping Elucidation:** | *The prima facie obvious candidate for a connection is BWMD:Atom. The alignment is based on the assumption that the relevant Wikipedia page (in German), and specifically the version which was consulted by BWMD's developers, is consistent with its English analogue as of 24/04/22, given what has been said above in the comment to the elucidation of the OntoCommons bridge-concept, Atom. In support of this alignment, it should also be noted that BWMD is based on BFO, and BWMD:Atom is a subclass of BWMD/BFO:Object and of BWMD/BFO:Material Entity, consistently with the relative proposed alignment. Moreover, there do not seem to be other candidates worth considering, nor evidence against a semantic relationship of class equivalence. However there could, and should, be doubts concerning how literally "any kind of atom as described by https://de.wikipedia.org/wiki/Atom" should be interpreted: the referenced article appears to be covering the historical background of the notion up to Leucippus. Common-sense leads us to think that that is unintended.* |
| **Semantic Relation Level:** | *The level of semantic relationship between the Concept and the Target Ontology entities:*<br><br>*rdfs:equivalentClass* |
| **Mapping Axioms:** | *TBD* |

**Domain Mechanical Testing (EMMO-MECH-TEST)**

| | |
|---|---|
| **Target Ontology:** | *<http://emmo.info/emmo/domain/mechanical-testing>* |
| **Related Ontology Entities:** | *Atom:*<br>*<http://emmo.info/emmo/middle/materials#EMMO_eb77076b_a104_42ac_a065_798b2d2809ad>* |
| **Mapping Elucidation:** | *The Domain Mechanical Testing ontology EMMO-MECH-TEST is based on EMMO; as such what has been said above can be applied mutatis mutandis in this case. Given the proposed semantic link, the absence of better candidates should come as no surprise. However, it should be noted that EMMO-MECH-TEST is based on an outdated version of EMMO. Nonetheless, there are no significant differences compromising the* |

| | |
|---|---|
| | *alignment, or modifying the semantic relationship between the proposed OntoCommons bridge-concept, Atom, and EMMO-MECH-TEST's Atom.* |
| **Semantic Relation Level:** | *The level of semantic relationship between the Concept and the Target Ontology entities:*<br>*rdfs:equivalentClass* |
| **Mapping Axioms:** | *TBD* |

# RELATED EXISTING CONCEPTS

## TLOs

# MATERIAL ENTITY (BFO)

**GENERAL CONCEPT INFO:**

| | |
|---|---|
| **IRI:** | *<http://purl.obolibrary.org/obo/BFO_0000040>* |
| **OWL Type:** | *Class* |
| **Concept Elucidation:** | *A material entity is an independent continuant that at all times at which it exists has some portion of matter as continuant part.*<br><br>*Examples of Usage:* a human being, the undetached arm of a human being, an aggregate of human beings. |
| **Labels:** | Material Entity |

**KNOWLEDGE DOMAIN RESOURCES:**

| | |
|---|---|
| **Related Domain Resources:** | *Building Ontologies with BFO:* "material entity is an independent continuant that has some portion of matter as part. It is thus an independent continuant that is spatially extended in three dimensions, and that continues to exist through some interval of time, however short.". |

# NON AGENTIVE PHYSICAL OBJECT (DOLCE)

**GENERAL CONCEPT INFO:**

| | |
|---|---|
| **IRI:** | *<http://www.loa.istc.cnr.it/dolce/dolce-owl/DOLCEbasic#NonAgentivePhysicalObject>* |
| **OWL Type:** | *Class* |
| **Concept Elucidation:** | A Non-Agentive Physical Object is a physical object to which intentions, believes and desires are not ascribed.<br><br>*Examples of Usage:* a pebble, a house, a computer, a human body. |
| **Labels:** | *NonAgentivePhysicalObject* |

**Knowledge Domain Resources:**

| | |
|---|---|
| **Related Domain Resources:** | *Dolce D18:* "within Physical Objects, a special place have those those to which we ascribe intentions, beliefs, and desires. These are called Agentive, as opposite to Non-agentive. Intentionality is understood here as the capability of heading for/dealing with objects or states of the world26. This is an important area of ontological investigation we haven't properly explored yet, so our suggestions are really very preliminary". |

## ATOM (EMMO)

**General Concept Info:**

| | |
|---|---|
| **IRI:** | *<http://emmo.info/emmo#EMMO_eb77076b_a104_42ac_a065_798b2d2809ad>* |
| **OWL Type:** | *Class* |
| **Concept Elucidation:** | An 'atom' is a 'nucleus' surrounded by an 'electron_cloud', i.e. a quantum system made of one or more bounded electrons. |
| **Labels:** | *Atom* |

**Knowledge Domain Resources:**

| | |
|---|---|
| **Related Domain Resources:** | *European Materials Modelling Ontology v. 1.0.0 alpha 2:* "Bonded Atom: an Atom that shares at least one electron to the atom-based entity of which is part of. A real bond between atoms is always something hybrid between covalent, metallic and ionic. In general, metallic and ionic bonds have atoms sharing electrons. The bond types that are covered by this definition are the strong electonic bonds: covalent, metallic and ionic. 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"; "Standalone Atom: an atom that does not share electrons with other atoms. 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"; "Neutral Atom: A standalone atom that has no net charge"; "Ion Atom: standalone atom with an unbalanced number of electrons with respect to its atomic number". |

# MLOs

## ATOM (BWMD)

**General Concept Info:**

| | |
|---|---|
| **IRI:** | *<https://www.materials.fraunhofer.de/ontologies/BWMD_ontology/mid#BWMD_00131>* |
| **OWL Type:** | *Class* |
| **Concept Elucidation:** | Any kind of atom as described by https://de.wikipedia.org/wiki/Atom |

| | |
|---|---|
| **Labels:** | Atom |

**KNOWLEDGE DOMAIN RESOURCES:**

| | |
|---|---|
| **Related Domain Resources:** | *<https://de.wikipedia.org/wiki/Atom>* |

## ATOM (EMMO-MECH-TEST)

**GENERAL CONCEPT INFO:**

| | |
|---|---|
| **IRI:** | *<http://emmo.info/emmo/middle/materials#EMMO_eb77076b_a104_42ac_a065_798b2d2809ad>* |
| **OWL Type:** | *Class* |
| **Concept Elucidation:** | An 'atom' is a 'nucleus' surrounded by an 'electron_cloud', i.e. a quantum system made of one or more bounded electrons. 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. |
| **Labels:** | Atom |

**KNOWLEDGE DOMAIN RESOURCES:**

| | |
|---|---|
| **Related Domain Resources:** | *European Materials Modelling Ontology v. 1.0.0 alpha 2:* “Bonded Atom: an Atom that shares at least one electron to the atom-based entity of which is part of. A real bond between atoms is always something hybrid between covalent, metallic and ionic. In general, metallic and ionic bonds have atoms sharing electrons. The bond types that are covered by this definition are the strong electonic bonds: covalent, metallic and ionic. 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”; “Standalone Atom: an atom that does not share electrons with other atoms. 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”; “Neutral Atom: A standalone atom that has no net charge”; “Ion Atom: standalone atom with an unbalanced number of electrons with respect to its atomic number”. |