Elementary Multiperspective Material Ontology: Leveraging Perspectives via a Showcase of EMMO-Based Domain and Application Ontologies

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Abstract: The effectiveness of semantic technologies in ensuring interoperability is often hindered by the preference for internally developed knowledge bases and the presence of diverse conceptual frameworks and implementation choices. Foundational, upper-level ontologies based on FOL and OWL2-DL address interoperability and provide a robust foundation for domain and application ontologies. They emphasize logical rigor and expressiveness, aligning with the idea of shared ontologies for knowledge diffusion and reuse. In scientific and industrial contexts, a framework that accommodates scientific pluralism is essential. The Elementary Multiperspective Material Ontology (EMMO) meets this need, offering a rigorous yet pluralistic representation of knowledge through the mereocausal theory, focusing on parthood (mereology) and causation. EMMO's adaptable architecture includes discipline-specific modules, enabling the representation of items from multiple perspectives, such as viewing an image as both an 'Object' and 'Data'. This paper presents EMMO's perspectives, including the Reductionistic, Holistic, Persistence, Contrast, Structural and Semiotics perspectives. It then proceeds to showcase four recently-developed ontologies based on EMMO, one at the domain level (CHAMEO) and three at the application level (BTO, HPO and MAEO), taking advantage of EMMO's perspectives and therefore demonstrating its representational capabilities and versatility.

1 INTRODUCTION

The practical effectiveness of semantic technologies in supporting interoperability is hindered by the prevailing tendency to favor internally developed Knowledge bases, in an effort to exert greater control over proprietary data. Furthermore, different *conceptual frameworks* and *implementation choices* (related to trade-offs between expressiveness and computational efficiency Levesque and Brachman (1987)), exhibit varying degrees of suitability for specific domains of application and use-cases. In literature, it is a common practice to classify ontologies hierarchically based on the generality of the concepts they include, *i.e.* their domain of application. These "levels" have vague boundaries, but the presence of borderline cases does not undermine the practical utility of this classification criterion. By definition, a domain ontology focuses on concepts, properties, and relationships relevant to a specific area of knowledge or field of study. A domain ontology can either be a specialized module of an upper-level ontology or a standalone ontology targeting a specific domain (*e.g.* additive manufacturing, composite materials). On the other hand, an application ontology is an ontology en-

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gineered for a specific use or application focus, and whose scope is usually specified or driven through specific use cases (De Baas et al., 2023). Things are further complicated by the fact that domain and application ontologies tend to be highly context-specific and lean towards technologies, such as triplestores, that prioritize handling large volumes of instance data over supporting expressive knowledge frameworks, increasing the risk of mistakes in conceptualization.

Upper-level ontologies are usually axiomatized in expressive formal languages (such as FOL and OWL2-DL (W3C, 2012)) and can be considered the explicit expression of a precise worldview. These ontologies are commonly employed both to provide a foundation for domain and application ontologies and to address interoperability issues among different schemas Trojahn et al. (2021). They can be considered the true heirs of the original idea of employing a common ontology to enable knowledge sharing and reuse across different systems Gruber (1993), a notion more recently expressed by Guarino et al. (2009). Indeed, Gangemi et al. (2002) explored the use of formal ontologies in semantic web applications, highlighting the significance of logical rigor and expressiveness in ontology design. Remarkably, neuro-symbolic AI may soon enable the full exploitation of richly axiomatized ontologies in practical settings, addressing one of the core challenges deterring practitioners from employing upper-level, foundational ontologies, as exemplified by Lazzari et al. (2024) and discussed in Bouraoui et al. (2019).

Addressing the issues arising from the plurality of frameworks presents a significant challenge, particularly in scientific and industrial contexts. These contexts seem to demand a framework that is not only firmly rooted in the sciences but also accommodates scientific pluralism – recognizing that multiple interpretations or standards may exist for the same phenomena or processes. The Elementary Multiperspective Material Ontology (EMMO) [1], specifically, is an expression of the common tenets and general worldview central to the applied sciences. It aims to cater to both practical needs and theoretical desiderata of practitioners, striving to be both a standard representational framework for science and engineering and a versatile ontology for broader applications.

At its core, EMMO is built on a mereocausal theory, developed to support a rigorous yet pluralistic representation of scientific and industrial knowledge. This theory hinges on two formal relations, parthood (mereology) and causation, which provide clear extensional criteria of identity (Partridge et al., 2020) and set up the preconditions for the qualitative and quantitative representation of systems at different granularities, up to a high level of detail. More fine-grained, yet subjective, distinctions among entities are expressed by means of exploiting *perspectives*, a special feature of EMMO's architecture, designed to include a plurality of tools to categorize entities, as well as to support user-driven downward expansions. In fact, EMMO includes various discipline-specific modules, such as metrology and units (based on BIPM et al. (2012)), materials, and manufacturing (based on ISO and DIN standards). These modules ensure that EMMO can address specific domain needs while maintaining a high level of expressiveness and interoperability. For instance, it allows for the representation of an item from different perspectives, such as viewing an image both as an 'Object' resulting from an imaging process and as 'Data'.

This paper presents EMMO's perspectives and showcases a number of recently-developed domain and application ontologies that are based on EMMO and take advantage of its representational capabilities and perspectives. The paper is structured as follows: Section 2 describes EMMO's perspectives, including the Reductionistic, Holistic, Persistence, Contrast, Structural and Semiotics perspectives; Section 3 lists a selection of 4 ontologies (1 domain ontology and 3 application ontologies) based on EMMO, underlining their main characteristics and their usage of EMMO's perspectives; finally, Section 4 draws the conclusions.

2 PERSPECTIVES IN EMMO

EMMO includes and embraces a plurality of perspectives, representing real-world objects according to specific representational viewpoints. These perspectives allow for subjective categorization of entities above elementary particles and below the item 'Universe', each constituting a subclass of 'perspective'. This approach reflects pluralism in carving out portions of the world, according to different principles and in line with diverse interests. In EMMO, only entities described by the standard model of particle physics have univocal definitions and clear identity criteria: 'physical objects' are conceptualized as 'spatiotemporal objects composed of fundamental physical constituents', without referring to any subjective perspective. The different perspectives are pragmatically chosen to increase expressiveness and avoid the core limitations of reductionistic approaches. Figure 1 shows EMMO's perspectives, which are described in greater detail in the subsections below.

[1] Available at https://github.com/emmo-repo/EMMO/.

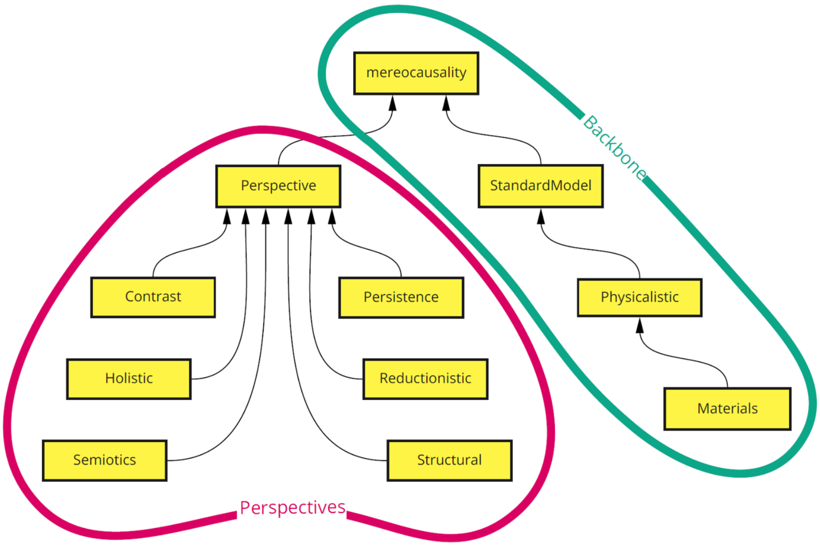

Figure 1: EMMO's architecture, with its backbone based on mereocausality and its implementation of physics, chemistry and materials, grounded in current natural science foundations (StandardModel). This core is complemented by modules incorporating various perspectives: Reductionistic (tiling of space and/or time), Holistic (whole/part or role), Persistence (process/object), Contrast (based on Floridi's work), Structural (typed mereological relations) and Semiotics (based on Peirce).

2.1 Reductionistic Perspective

The Reductionistic perspective offers a powerful granularity description of multi-scale entities, determined by the direct parthood relation (a non-transitive relation). Differently from the standard transitive notion of parthood employed in mereology, direct parthood makes it possible to individuate levels for the analysis of entities. Every macro-individual, including the Universe, can be iteratively tessellated down to elementary constituents, as it is most convenient for specific use cases. Tessellation based on spatial and temporal criteria can be especially salient in specific scenarios (*e.g.* temporal parts for the individuation of steps in a productive workflow).

2.2 Holistic Perspective

The Holistic perspective offers a tool to represent relations between entities whose categorization under specific types intrinsically depends on part-whole relations. The holistic class introduces important concepts such as 'role' and/or 'participant', used to describe the parts of a particular system or process, respectively. This enables the description of parts in terms of how they contribute to the whole, including functional aspects. This perspective allows for an analysis of entities in mereological relations without imposing a strict granularity, and is thus complementary to the reductionistic perspective.

2.3 Persistence Perspective

The Persistence perspective classifies entities according to how they persist in time Sider (2001) with respect to specific types under which they are categorized, allowing for a distinction between objects (for which a type is conserved through all temporal parts) and processes (for which it is not). This categorization method is deeply ingrained in common sense and entrenched in natural languages. The distinction primarily hinges on whether the emphasis is placed on the preservation of characteristics (indicative of objects) or patterns in the evolution (indicative of processes) of spatiotemporal regions, given a principle of salience. It also provides classes aimed to represent concepts similar to the ones of endurant/continuant and perdurant/occurrent, facilitating connections with other upper-level ontologies (*e.g.* BFO (Arp et al., 2015)), supporting interoperability.

2.4 Contrast Perspective

The Contrast perspective draws from Luciano Floridi's philosophy of information, given the idea that data can be broadly understood as distinctions that make a difference (Floridi, 2010). It encompasses various types of data (semantic, environmental...) and enhances EMMO's expressive power by allowing it to represent different forms of data and information.

2.5 Structural Perspective

The Structural perspective introduces formal tools for the analysis of parthonomic relations between entities of the same or different types. In practical scenarios, this perspective can be used, for instance, to distinguish between a car's base model and its accessories.

2.6 Semiotics Perspective

The Semiotics perspective takes inspiration from Peirce's theory of signs (Atkin, 2023) (and their triadic structure of object, sign-vehicle, and interpretant) and covers expressive needs that are usually dealt with by using abstract objects such as numbers, sets, and universals/tropes. This perspective encompasses all of the semantic and symbolic 'world', covering labeling, property attributions and abstractions. Compared to Peirce, in EMMO more emphasis is put on the role of interpreters and the underlying causal connections between the three 'prongs', making it possible to rigorously analyze observation and estimation, and to keep track of interpreters' possibly inconsistent attributions. This is especially useful in operative contexts where it is important to keep track of the gap between data and phenomena, to circumscribe disagreement (Bogen and Woodward, 1988). Not only does this perspective greatly enhance EMMO's expressive power, but it also affords mappings to ontologies that utilize qualities and/or properties.

3 SHOWCASE OF FOUR EMMO-BASED ONTOLOGIES

A number of domain and application ontologies revolving around EMMO that are part of its ecosystem have been developed so far and/or are currently under development. Here, one domain ontology and three application ontologies recently developed by this study's authors are listed and briefly showcased, underlining their alignment with EMMO and their exploitation of EMMO's expressiveness via the use of perspectives. A description of each ontology and specific details about their use of EMMO's perspectives are provided in the following subsections.

3.1 Domain Ontology: CHAMEO

The CHAracterization MEthodology Ontology (CHAMEO) (Del Nostro et al., 2022a,b) is a domain-level ontology designed to offer a harmonized and standardized representation of materials characterization methods and processes. The development of CHAMEO is grounded in the CHADA (CHAracterization DAta) document template, subject of a 2021 CEN Workshop Agreement (CWA 17815), which aims to provide a standard structure for documenting material characterization techniques. CHADA employs four key concepts to classify the steps of a characterization workflow: "User case" (information about the sample and testing environment), "Experiment" (characterization process including probe, signal, detector, noise, *etc.*), "Raw data" (output of the metrological process), and "Data processing" (analysis of the data to achieve the final shape). These concepts correspond to the sections of a CHADA document. While this document was easily interpretable by humans, it lacked structured data for retrieving information on characterization methodologies according to their various dimensions (*e.g.* material, probe, detector, properties). In order to address this limitation, CHADA was used as the foundation to build a more structured and shared knowledge base, leading to the creation of the CHAMEO ontology. CHAMEO models the common aspects of diverse characterization techniques by providing high-level, methodological definitions, facilitating the development of more specialized ontologies at a finer-grained application level. This capability is enhanced by the intrinsic modularity of its ontological design, positioning CHAMEO at the domain level of a larger ontological framework, with EMMO as its upper layer. As part of EMMO's framework, CHAMEO leverages EMMO's versatility in describing processes and data from multiple perspectives. This integration allows CHAMEO to model various aspects of characterization techniques comprehensively, using EMMO's multiperspective approach to enhance its descriptive capabilities. Consequently, CHAMEO is well-suited for modeling the shared aspects of characterization methodologies, providing a robust foundation for further ontology development and application-specific adaptations.

3.1.1 EMMO's Perspectives in CHAMEO

In CHAMEO[2], the `chameo:CharacterisationWorkflow` class models the overall characterization process as a subclass (further down in the hierarchy) of `emmo:Process` within the Persistence perspective. Characterization workflows consist of various methods, each contributing to the final characterization property. These methods are represented by the `chameo:CharacterisationMethod` class, which

[2]CHAMEO's names for classes and properties follow the Cambridge English naming convention, especially notable by the use of *s* instead of *z*, whereas this work complies with the Oxford University Press English convention.

is itself a subclass (further down in the hierarchy) of emmo:Process as well as emmo:Observation from the Semiotics perspective; each method is thus a process (Persistence), but also a part of the chameo:CharacterisationWorkflow (Holistic). Each chameo:CharacterisationMethod is divided into stages (subclass of emmo:Stage) capturing general steps common across different characterization techniques. For instance, the chameo:SpecimenPreparation stage refers to the preparation of a specimen, where the holder used is modeled as an emmo:Object (Persistence) and plays a role in the process (emmo:Role, Holistic). Specializations for specific techniques and temporal sequences are expressed through EMMO's hasTemporalCause property. The characterization system is modeled as a subclass of emmo:HolisticSystem (Holistic), which is the system used for characterization, built by assembling and adapting characterization components. Instances of chameo:CharacterisationInstrument, chameo:Probe, chameo:Detector, chameo:Holder and all of the possible devices that can be used to build a characterization system can be deemed a chameo:CharacterisationComponent (Persistence). The different types of data produced during the characterization process (*e.g.* chameo:CharacterisationData) are subclasses of emmo:EncodedData (Contrast perspective). The characterization properties are assigned meaning via a semiotic process (Semiotics perspective).

3.2 Application Ontology: Battery Testing Ontology (BTO)

The Battery Testing Ontology (BTO) (Nostro et al., 2024) is a standardized and flexible framework for representing knowledge in the areas of battery testing and quality control. BTO's purpose is to model a range of electrical battery cell tests, such as impedance spectroscopy (monitoring current and voltage over time), self-discharge (current over time), and high-voltage tests (voltage over time). BTO can specify the necessary hardware for measuring specific battery cell properties, like the quality of the separator layer in a high-voltage test. It references electrical measurement data (voltage, current, time) and incorporates details about the mechanical fixturing of the battery cell to the test hardware and the electrical calibration procedures. In high-voltage separator tests, BTO can specify what hardware is suitable for testing a particular battery separator to achieve a specific accuracy. It also allows users to verify if their test hardware and voltage specifications can measure certain battery samples (*e.g.* separator layers with different thicknesses), considering the maximum test voltage and required accuracy. Therefore, BTO assists in designing high-voltage separator test experiments by combining separator requirements (*e.g.* thicker separators need a higher maximum test voltage), hardware specifications (*e.g.* the tester's voltage specifications), and the required measurement accuracy. BTO operates at the application level of EMMO's ecosystem of ontologies. BTO aligns closely with EMMO and CHAMEO, the latter providing common domain concepts for characterization methods and experiments. Additionally, BTO is connected and aligned with other EMMO-based domain ontologies, including the Battery Domain Ontology (BDO)[3] and the Electrochemistry Domain Ontology (EDO)[4].

3.2.1 EMMO's Perspectives in BTO

In BTO, the battery testing process is modeled as a bto:BatteryCharacterizationMethod that is made up of a number of potential steps, or tasks, namely bto:BatterySamplePreparation, bto:CalibrationForBatteryCharacterization and bto:BatteryMeasurementProcess. Each of these four classes is a subclass of a CHAMEO class, *i.e.* chameo: CharacterisationMethod, chameo:SamplePreparation, chameo: CalibrationProcess and chameo: CharacterisationMeasurementProcess, respectively. Therefore, given what has been discussed in 3.1.1, bto:BatteryCharacterizationMethod is also a subclass of emmo:Process as well as emmo:Observation (Semiotics perspective), whereas each task is also a subclass of emmo:Process (Persistence), and at the same time a part of the overall battery characterization method (Holistic). Furthermore, the ambient in which a testing takes place is modeled as a bto:BatteryCharacterization Environment, which is a subclass of chameo: Characterisation Environment, which in turn is a emmo:SemioticObject (Semiotics); each characteristic of the ambient is modeled as a bto:CharacterizationEnvironmentProperty, which is an emmo:Property, which in turn is an emmo:Sign from the Semiotics perspective; and the hardware used for the battery testing is modeled as a bto:BatteryCharacterization Hardware, which is a subclass of chameo:CharacterisationInstrument (Persistence perspective). The data resulting from a battery

[3]https://github.com/emmo-repo/domain-battery.

[4]https://github.com/emmo-repo/domain-electrochemistry.

testing experiment, *i.e.* `bto:TraceData`, are modeled as a subclass of `chameo:CharacterisationData`, which is a subclass of `emmo:EncodedData` and thus takes advantage of EMMO's Contrast perspective.

3.3 Application Ontology: Hyperdimensional Polymer Ontology (HPO)

The Hyperdimensional Polymer Ontology (HPO) is designed to capture the staggering diversity of polymeric materials and their applications, with a particular focus on their manufacturing aspects. HPO has been developed primarily to describe the manufacturing process of carbon-fiber-reinforced polymers and includes a rich taxonomy of materials, processes and properties for this application. The terms used to label the main classes are taken from a glossary for polymers and composite materials compiled from the Compendium of Chemical Terminology (IUPAC) and specialized journals.

The fundamental requirement of HPO is to describe materials as different as composite materials, energy materials and biomaterials. The EMMO backbone, based on the classification of real-world objects based on physical sciences, is exploited here by defining polymers as subclasses of `emmo:PolymericMaterial`, `emmo:ManufacturedMaterial`, or `emmo:NaturalMaterial`, plus additional restrictions to make further distinctions. Indeed, polymeric materials can be classified in many different ways, depending on the characteristics relevant to a specific application. For example, polymeric materials can be distinguished based on their chemical composition (`hpo:HomoPolymer` vs. `hpo:CoPolymer`), structure (`hpo:BranchedPolymer`, `hpo:CrosslinkedPolymer`, or `hpo:LinearPolymer`), or mechanical behavior. Another aspect covered by HPO is the description of the manufacturing process of composite materials, which includes the tools used (mixers, molds, covers), the processes (impregnation, molding, curing), and of course, any other material used (prepregs, thinners, fillers, catalysts).

3.3.1 EMMO's Perspectives in HPO

The classification of polymers by categories is based on multiple inheritance, obtained by declaring a class as a subclass of disconnected classes. For example, an organic semiconductor polymer such as P3HT can be classified as a `hpo:HomoPolymer` based on the chemical composition, a `hpo:CouplingPolymer` based on the polymerization mechanism, as well as a `hpo:LinearPolymer` based on the chemical structure. To achieve this expressivity, HPO uses the multiperspective character of EMMO to enrich the generic concept of `emmo:PolymericMaterial` with predicates increasing its specificity. For instance, the Contrast perspective provides the `emmo:ChemicalComposition` class that accommodates the classes `hpo:HomoPolymer` and `hpo:CoPolymer`, whereas the concept of `emmo:Behaviour` in the Persistence perspective is used to classify polymers based on their mechanical properties. The Semiotics perspective has a taxonomy of measured physical properties (under the `emmo:PhysicalQuantity` class) used to classify specific physical observables characterizing the manufacturing process, *e.g.* the `hpo:PrepregGlassTransitionTemperature` and `hpo:DegassingStepDuration`. The manufacturing aspects of the fabrication of polymers and composite materials are also covered in the Persistence perspective, with classes like `hpo:ShapingAndCuring` being part of the `emmo:Manufacturing` class, and `hpo:PrePreg` and `hpo:ResinMixer` belonging to the `emmo:ManufacturedProduct` family.

3.4 Application Ontology: MarketPlace Agent and Expert Ontology (MAEO)

The MarketPlace Agent and Expert Ontology (MAEO) (Del Nostro et al., 2023; Goldbeck and Toti, 2021)[5] is designed to model experts, expertise, and the broader community of knowledge providers and seekers within the domain of Materials Modeling, and was developed as part of the "MarketPlace" European project, meant to create an online platform as a central hub for connecting scientific and industrial stakeholders with their own expertise. MAEO supports this platform by providing a structured framework to represent and manage the necessary information as an application ontology of EMMO's ecosystem. It aligns with other ontologies, including Friend-Of-A-Friend (FOAF) (Brickley and Miller, 2014) and five EMMO-based domain ontologies, *i.e.* the Open Innovation Environment (OIE) ontologies[6], for classifying materials, models, manufacturing processes, characterization methods and software products. Designed to meet the needs of the MarketPlace project's stakeholders, MAEO leverages the expressive power and standardization efforts of EMMO, ensuring interoperability and promoting consistency and integration

[5] https://github.com/emmo-repo/MAEO-Ontology.

[6] https://github.com/emmo-repo/OIE-Ontologies/.

Table 1: Selection of EMMO-based ontologies: CHAMEO, BTO, HPO, MAEO. For each ontology, its acronym, the URI with which it is accessible, its GitHub repository and the perspectives used from EMMO are reported.

EMMO-based ontologies				
Acronym	**URI**	**GitHub repository**	**EMMO's perspectives**	**FAIR score**
CHAMEO	https://w3id.org/emmo/domain/characterisation-methodology/chameo	https://github.com/emmo-repo/domain-characterisation-methodology	Holistic, Persistence, Contrast, Semiotics	100%
BTO	http://w3id.org/emmo-bto/bto	https://github.com/emmo-repo/battery-testing-ontology	Holistic, Persistence, Contrast, Semiotics	100%
HPO	http://w3id.org/emmo-hpo/hpo	https://github.com/emmo-repo/hyperdimensional-polymer-ontology	Persistence, Contrast, Semiotics	100%
MAEO	http://w3id.org/emmo-maeo/maeo	https://github.com/emmo-repo/MAEO-Ontology	Holistic, Persistence, Semiotics	100%

across various domains within Materials Modeling.

3.4.1 EMMO's Perspectives in MAEO

In MAEO, an agent, *i.e.* a person or an entity that is able to operate on the MarketPlace platform, (a concept grouping knowledge providers and knowledge seekers, including human experts, laboratories, teams and organizations) is modeled as a `experts:MarketPlaceAgent`, which is a subclass of `emmo:Participant` that is seen as both an object from the Persistence perspective and a participant in a process from the Holistic perspective. Knowledge providers possess a range of properties, divided into two main categories, subjective properties and objective properties. A subjective property is inherently non-well-defined and cannot be unambiguously determined; it relies on an agent acting as a "black box" for its definition. In MAEO, the expertise of knowledge providers is considered a subjective property because it cannot be objectively defined and requires validation by an agent, such as a certification authority or employer. Conversely, an objective property can be determined through a well-defined procedure and observed via a specific perception mechanism, making it measurable. In MAEO, objective properties include information about a knowledge provider that can be clearly and objectively identified, such as personal details (*e.g.* address), professional details (current and past employments), certifications acquired, contractual details, and affiliations to organizations or companies. These two concepts are modeled as `expert:ExpertSubjectiveProperty` and `expert:ExpertObjectiveProperty`, respectively, defined as subclasses of `emmo:Property`, which is a subclass of `emmo:Sign`, *i.e.* something that stands for an object through, for instance, a convention, thus embracing EMMO's Semiotics perspective.

3.5 FAIR Score and Technical Details

All of the ontologies described above have been tested for pitfalls and issues via the OOPS tool (Poveda-Villalón et al., 2014)[7], and no pitfalls were detected[8] Furthermore, the ontologies' compliance with the FAIR principles (Findability, Accessibility, Interoperability, Reusability) has been verified via the FOOPS! tool (Garijo et al., 2021)[9], and all of them have obtained a perfect score of 100%. The four ontologies' prefixes are stored in the prefix.cc repository[10] and have their corresponding entry in the Linked Open Vocabulary (LOV)[11] registry; the ontologies' files are stored in a corresponding GitHub repository. Table 1 shows a summary of the four ontologies; for each ontology, its acronym, the URI with which it is accessible, its GitHub repository, the perspectives from EMMO used and its FAIR score are reported.

4 CONCLUSIONS

This work has emphasized EMMO's role in defining a comprehensive framework to meet the needs of scientific and industrial contexts, accommodating scientific pluralism. EMMO's foundation in mereocausal theory allows for a rigorous yet pluralistic representation of knowledge, with a focus on fundamental relations such as parthood and causation. EMMO's architecture, notable for its modularity and adaptability, includes discipline-specific modules that ensure high expressiveness and interoperability. These modules enable the representation of items from various perspectives, enhancing the ontology's versatility. By

[7] https://oops.linkeddata.es/index.jsp.

[8] OOPS needs the direct URL of the ontology as input.

[9] https://foops.linkeddata.es/FAIR_validator.html.

[10] https://prefix.cc.

[11] https://lov.linkeddata.es/dataset/lov.

leveraging EMMO's representational capabilities and perspectives, this work has shown how four recently-developed domain and application ontologies, *i.e.* CHAMEO, BTO, HPO and MAEO, tackle different application scenarios. EMMO offers an adaptable framework for developing highly expressive domain and application ontologies. By defining foundational classes and properties and tracing them back to fundamental axioms of parthood, causation, persistence and semiotics, EMMO ensures a comprehensive knowledge representation, crucial for the advancement of both semantic web technologies and neuro-symbolic AI, and paves the way for improved interoperability across diverse scientific and industrial domains.

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