PERSWADE-CORE: A Core Ontology for Communicating Socio-Environmental and Sustainability Science

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ABSTRACT The Centre on Persuasive Systems for Wise Adaptive Living (PERSWADE) aims at developing and applying persuasive technologies and system science for social innovation that can help humanity to move toward sustainable, wise, adaptive living. The PERSWADE collaborative knowledge base needs to be designed with the intent to bring together, enrich and logically relate heterogeneous content, such as datasets, scientific literature and any kind of multimedia and social content, to support a participatory approach and help to translate science into action. PERSWADE-CORE, the foundation ontology described in this paper, plays a critical role in this by providing the backbone semantic infrastructure to enable collaboration through efficient data and knowledge integration, sharing and reuse. It also serves the purpose of clarifying and explaining the goals, functions and operations of the Centre. Because of its purpose, PERSWADE-CORE has been designed to be easy-to-use and easy-to-adapt by allowing generic, as well as more specific, relationships among concepts. The PERSWADE approach prioritizes interoperability and relies on the Semantic Web infrastructure. Furthermore, its design is intrinsically aimed at collaborative environments in which ontologies are expected to evolve as a response to users' activity.

INDEX TERMS Ontology design, Semantic Web, persuasive systems, knowledge sharing, transdisciplinary, knowledge base, collaborative environment.

I. INTRODUCTION

The goal of the Centre on Persuasive Systems for Wise Adaptive Living (PERSWADE)[1] is *"to develop and apply persuasive technologies and system science for social innovation that can help humanity to move toward sustainable, wise, adaptive living*[1]*"*. Such a purpose is driven by our growing awareness that well-being and prosperity are very much dependent upon the Earth life-support system[1]. In many cases, *"by simply changing our behaviour, we can achieve more than all the technological progress can bring us*[1]*"*.

The centre brings together scholars from various disciplines to make science actionable, by developing advanced persuasive systems that deliver relevant and compelling information and knowledge that is relevant and understandable to inform decision making and public discourse. Such an intrinsically trans-disciplinary approach involving stakeholders and experts from different areas relies on effective and close collaborations among the core members as well as externally. That is the main reason for building a dynamic shared knowledge base that is expected to be further and progressively developed, consolidated, extended and enriched by the activities of the PERSWADE centre.

Collaborative knowledge base is a consolidated concept [1] which assumes collective knowledge to grow out of knowledge provided by individuals. A simplified model of the understanding of this concept within PERSWADE is presented in figure 1. The underlying idea is based on the capability to bring together, enrich and logically relate heterogeneous information, such as datasets, scientific literature and any kind of multimedia and social content. Communication becomes an absolute priority for PERSWADE. Beyond classical examples, for instance we may need to provide arguments against fake or manipulated news by presenting
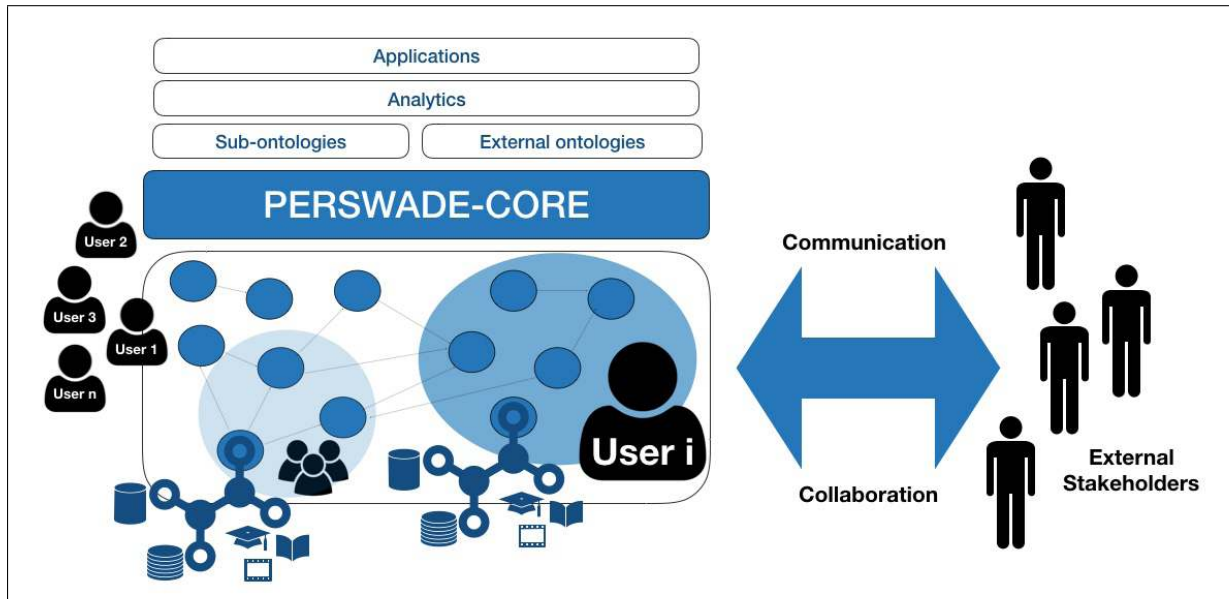

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[1]Centre on Persuasive Systems for Wise Adaptive Living (PERSWADE), https://www.uts.edu.au/PERSWADE - Accessed: 30 August 2018.

FIGURE 1. PERSWADE collaborative knowledge base concept.

scientific or factual evidence; or, on the contrary, we may need to demonstrate the lack of scientific evidence for a given claim.

All contributors maintain their individual perspectives on the system, meaning they establish, define and maintain their own knowledge bases; however, by sharing their knowledge bases (or parts of them), users intrinsically create collective perspective which results in collective knowledge. According to such a participatory approach, the knowledge base is continuously and dynamically evolving as a consequence of users' activity. Moreover, the knowledge base is assuming the Linked Data model [2]: it makes external content linked to some internal concept intrinsically part of the knowledge base.

Apart from an "internal" use as a research asset, the knowledge base has to facilitate the communication and the collaboration with external stakeholders by providing an unique portal to access and understand the knowledge and the technology developed within PERSWADE. The need for a "common language" becomes an absolute priority to support internal and broader external collaboration and communication which is critical in such a trans-disciplinary context as with PERSWADE. PERSWADE-CORE, the ontology described in this paper, plays a critical and central role in the previously mentioned system by providing the backbone semantic infrastructure. Although this ontology can be applied to a generic research centre, its design reflects the characteristics of PERSWADE where a trans-disciplinary approach meets the intrinsic need to interact, communicate and communicate with external stakeholders within a continuously evolving domain. Sub-ontologies are further accessed as domain ontologies from the different disciplines that converge in the PERSWADE domain. For instance, an ontology to describe indicators can be used to interchange data, as well

as to use and interpret such a data correctly. The description of purpose-specific ontologies is out of the scope of this paper that focuses uniquely on the core ontology.

A. RELATED WORK

At a conceptual level, there are at least three different kinds of ontologies that could be adopted here:

- *Collaboration ontology* that addresses specific environments such as service-oriented architecture [3] as well as defines generic collaboration processes [4]. Normally, the most relevant contribution of collaboration ontology is the definition of the collaboration process in itself.
- *Ontologies within collaborative environments* are, in general terms, valuable assets to properly design and manage knowledge [5]. They play a critical role in terms of data aggregation and reuse [6]. Requirements may vary significantly from case to case. For example, in [7] the authors propose an ontological approach to dynamically define, calculate and share fine-grained urban indicators [8]. Also, the RDF Data Cube Vocabulary[2] may be used to enable multi-dimensional data in the Semantic Web [9].
- *Domain ontologies and standard vocabularies* provide specific sets of concepts and properties within a given domain, as well as upper vocabularies [10] to interconnect the different domains.

Depending on the focus, purpose and scope of concrete applications, these ontologies may have a different impact on the target system. PERSWADE-CORE proposes a synthesis of the ontological approaches mentioned above as it (i) defines the key concepts to establish a collaborative

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[2]The RDF Data Cube Vocabulary, https://www.w3.org/TR/vocab-data-cube/. Accessed: 10 September 2018.

research environment, (ii) enables dynamic data integration, re-use and sharing and (iii) supports the inter-connection of different domains.

In practice, a number of vocabularies are currently available to describe aspects of research environments or academic institutions. For instance, AIISO[3] focuses on the description of the internal structure of academic institutions by providing a core set of concepts as an OWL ontology. Scholarly Ontology [11] describes scholarly practices by defining an ontology structured in multiple layers to address top concepts, inter-discipline concepts and discipline-specific extensions. This last contribution assumes a number of main concepts, including, among others, publications and projects. VIVO[4] is a tool for describing enriched and extended information about research and researchers; VIVO ontology [12] enables the integrated definition of scholarly works, research interests and organizational relationships. SPAR ontologies [13] provide support to describe bibliographic resources and their parts, citations of scholarly resources and even publishing work-flows. SWRC Ontology [14] aims at enabling research communities in the Semantic Web [9]. In [15], the authors explicitly address the problem of organizing and transferring new knowledge from an industrial research centre to the operational units.

The PERSWADE research centre proposes some structural features common to most research organisations. However, it also presents peculiarities due to its specific purpose and trans-disciplinary nature. For instance, the centre is internally structured in streams. Each stream is identified by the method adopted. So the participatory modelling stream prioritises research where the participatory component is relevant, while the conceptual model stream is focusing on conceptualizations. PERSWADE-CORE Ontology supports the description of real operations (e.g. relating a project to a stream or method) in a way that can be understood internally as well as externally. As extensively explained later on, the ontology backbone describes a relatively generic research centre, meaning that most concepts adopted are generic and may be used in a context different than PERSWADE. On the other hand, such a core set of concepts is integrated with additional concepts and attributes aimed at a more effective communication. For example, "aims and scope" is a short description, normally associated with a project, to briefly describe intent and extent to a broad audience. That is different from the generic description that is usually much shorter and may have a more generic content. According to our approach, the identity of the centre is defined by the population of the ontology, meaning the instances and their characterizations. Additionally, the ontological approach prioritises interoperability at a Semantic level. We consider this last aspect one of the key and critical issue for an effective knowledge management, collaboration and communication. Indeed, we have aligned internal

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3Academic Institution Internal Structure Ontology (AIISO), http://vocab.org/aiiso/. Last accessed: 22 July 2019.
4VIVO, http://vivoweb.org/. Last visited: 22 July 2019.

TABLE 1. External vocabularies currently linked to PERSWADE-CORE.

Vocabulary	Short	Prefix
Data Catalog Vocabulary	dcat	http://www.w3.org/ns/dcat#
vCard Ontology	vcard	http://www.w3.org/2006/vcard/ns#
FOAF Vocabulary	foaf	http://xmlns.com/foaf/0.1/
Dublin Core Metadata	dc	http://purl.org/dc/dcmitype/
AIISO Ontology	aiiso	http://purl.org/vocab/aiiso/schema#
Scholarly Ontology	so	-
SWRC Ontology	swrc	-

concepts with equivalent concepts from external vocabularies wherever possible. External vocabularies currently linked to our ontology are listed in table 1.

We believe none of the existing ontologies may meet all the requirements of our research centre. However, we consider extremely important to establish a common language based on existing vocabularies. Thus, we prefer an ad-hoc approach that assumes explicit linking to generic concepts and, therefore, the definition of an harmonised environment according to the Semantic Web philosophy [9].

An additional and probably key issue for our ontology is the fact that besides "only" describing scientific results we also have to communicate them properly and in context to a very heterogeneous audience. Indeed, it is well known that communicating research results outside the community that produced them is, generally speaking, a challenge. It becomes a much more serious challenge outside the scientific community, looking therefore at a non-scientific audience. Many examples could be reported. For instance, [16] discusses the challenges facing any effort to communicate science in social environments. Even narrowing on a single well defined discipline or issue (e.g. marine reserve science [17] or climate change [18]) doesn't solve the problem, which become even harder in presence of contextual factors (e.g. uncertainty [19]). We are aware that no single tool or asset, nor even the most sophisticated one, will allow alone an effective communication by itself. However, we believe that an ontological approach, if properly used, may be the backbone to dynamically define an effective language by providing a formal conceptualization of our domain. That is because the semantic interoperability model [20] working on the Web infrastructure (Semantic Web

B. METHODOLOGY AND APPROACH

PERSWADE-CORE strives to facilitate the collaboration among researchers and stakeholders via interoperability, by providing and effective and extensible support for knowledge specification, integration and reuse. The critical features and design principles underlying the ontology can be summarised as follows:

- *Easy to use*. Usability is a critical features in collaborative systems. Indeed, we have adopted an approach based on a few, well-known and largely accepted concepts (see section III-A for examples of how usability was prioritised).

- *Allowing generic as well as specific relationships*. As explained in detail in section III-B, the strategy to optimise the natural trade-off between usability and complexity is based on the possibility to define generic as well as specific relationships among concepts. A part of the inference mechanisms defined in the ontology are able to work also considering only generic relationships (see section III-C).
- *Inference and automatic reasoning to support intelligent systems* . The simple inference mechanisms provided are explicitly designed to integrate contributions from different users as a part of a unique ecosystem.
- *Application-oriented philosophy*. PERSWADE-CORE is not simply a domain ontology. It rather aims at supporting a number of target applications.
- *Domain-independent approach*. Although the ontology explicitly targets the PERSWADE domain, the underlying approach can be used within different domains (see section III-D).
- *Dynamic evolution of the knowledge base*. The knowledge base underpinned by PERSWADE-CORE is expected to dynamically evolve through contributions of the system's users. Therefore, the ontology has been designed to be easily extensible in all its parts, including Tbox and Abox [21].
- *Communication strategy based on the Semantic Web*. PERSWADE-CORE enables the PERSWADE knowledge base within the Semantic Web. It defines a strategy to communicate knowledge that takes advantage of the semantic interoperability model [20].
- *Prioritizing interoperability through Ontology alignment*. Additionally, internal concepts are aligned with external concepts belonging to other vocabularies.

The ontology presented in this paper is the result of two convergent processes following a top-down and a bottom-up approach respectively.

The former process reflects the preliminary activity that has been carried out mostly by the research centre director, who shaped and structured the centre according to its intent and extent. This phase played a critical role in terms of ontology design as we needed to clearly identify the peculiarities of the centre and define a dynamic vocabulary structure accordingly.

Additionally (bottom-up process), we have analysed the information shared by the different core members. Such information includes recent/ongoing research projects, Ph.D. projects, research grants, related publications, interviews by media. Part of this information is publicly available on the centre webpage. Such an analysis is not obvious because of the intrinsic multi-disciplinary focus. It allowed a further consolidation of the previous step, as well as the definition of a core set of concepts to describe our environment according to a very generic terminology suitable to the most. This information is constantly updated as new members come on board and new projects are started.

Finally, at a more technical level, we have optimised the vocabulary to be enabled within the Semantic Web [9].

C. STRUCTURE OF THE PAPER
The paper follows with an overview of PERSWADE-CORE (section II). Then, in section III, its implementation is briefly discussed by providing some details about the key components of the vocabulary. Finally, some examples of use in particular applications are proposed (section IV). As usual, the paper ends with conclusions.

II. ONTOLOGY OVERVIEW
The concept of the ontology is presented in figure 2. Our semantic structure may be ideally described in terms of Tbox and Abox [22], [23]. The former set of statements includes classes, properties, inference constructs and, eventually, inference rules; the latter is limited to individuals (ontology population).

- *Tbox*. This schema includes the main and most common concepts (classes) that normally define a collaborative research environment (e.g. a research centre) both with the main relationships (properties) that exist or that can be established among them. The PERSWADE-CORE's Tbox is characterised by its generalness as it refers to a completely generic collaborative research environment. The Tbox will be described in detail in section III-A and III-B.
- *Abox*. The characterisation of the domain is provided by the ontology population (section III-D). In this paper we only address most generic concepts such as research fields, methods and application. An extensive description of the current PERSWADE activities through the population of the ontology is out of the scope of the paper which rather focuses on the description of the ontology itself.

Looking holistically at the semantic structure, its main characteristic is the set of object properties that has been designed to allow a flexible use of the vocabulary. First of all, completely generic relationships among concepts can be established by using the properties *related_to* (see section III-B). Furthermore, even more specific relationships are designed to map a natural language and, indeed, can be used in multiple ways. In terms of structure, according to this open philosophy only a part of the object properties has a domain and a range as defined in RDFS.[5] For example, a research project, defined by the class *Research_Project*, and a research outcome (*Research_Outcome*) are explicitly related by the couple of inverse properties *outcome_of* and *delivers*. On the other hand, other properties specify only their domain or only the range. Details will be discussed later on in the paper.

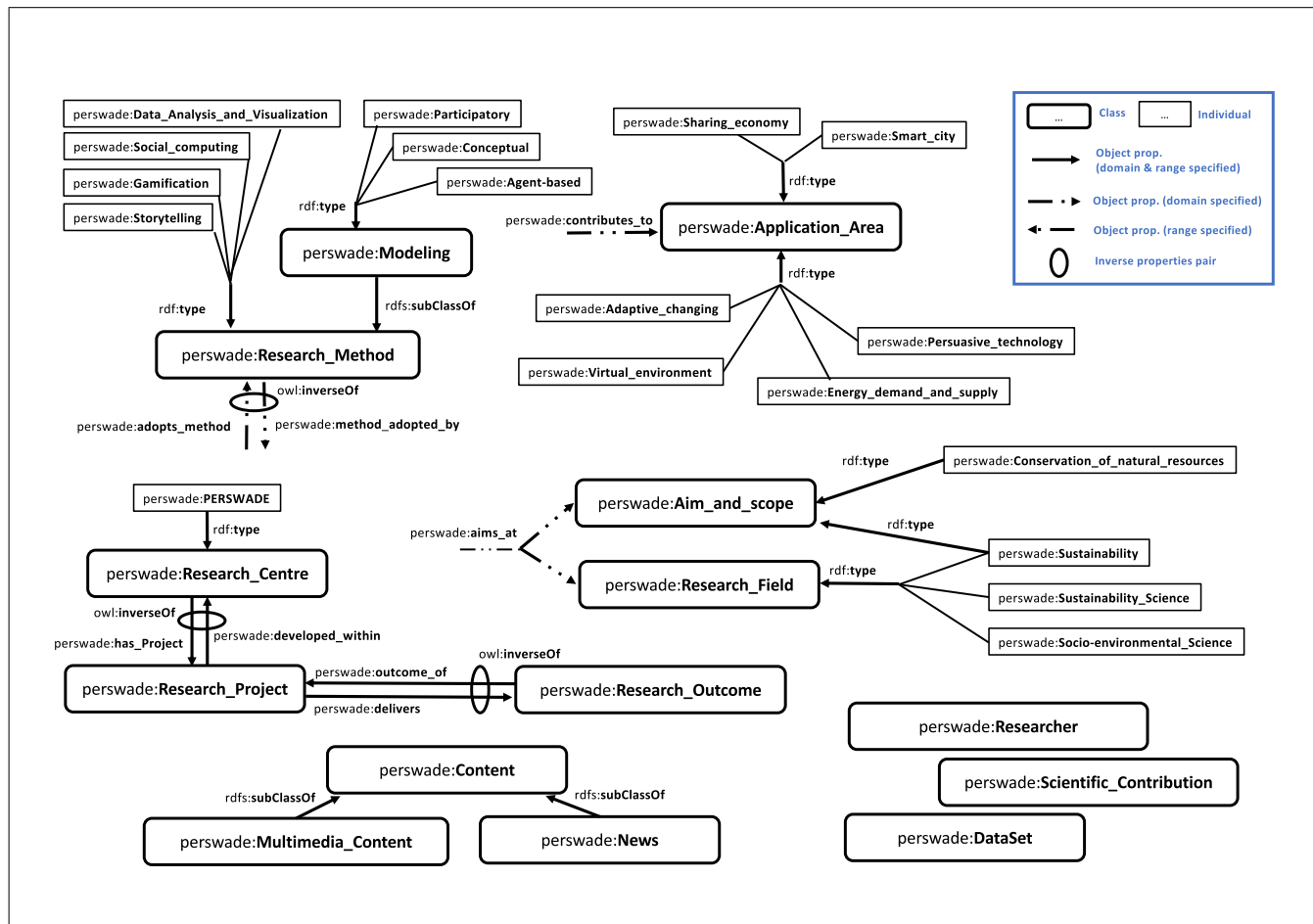[5]RDF Schema 1.1, https://www.w3.org/TR/rdf-schema/. Accessed: 10 September 2018

FIGURE 2. Ontology overview.

III. IMPLEMENTATION

We have developed the ontology in OWL 2 DL[6] by using Protege[7] [24]. Table 1 reports the external vocabularies currently linked to PERSWADE-CORE. Our ontology is aligned with main concepts from the already mentioned *AIISO Ontology*, *Scholarly Ontology* and *SWRC Ontology*. *Data Catalog Vocabulary (DCAT)* is an RDF vocabulary from W3C designed to facilitate interoperability between data catalogues published on the Web.[8] *vCard Ontology* aims at describing people and organisations.[9] *FOAF Vocabulary* supports linking people and information using the Web.[10] *Dublin Core Metadata* provides a further set of key concepts to metadata.[11]

In the following subsections, we provide details on the ontology Tbox (classes and properties) as well as on the core Abox, meaning the population of the ontology without contributions from individual users.

A. CLASSES

The core set of classes composing the ontology (a subset is reported in table 2) aims at modelling a relatively generic research centre considering also PERSWADE peculiarities. It allows knowledge integration and management according to different perspectives, including a whole research centre, particular research projects, individual researchers and contributions, as well as the most common research characterisations (such as field, aim, scope and method).

Specific classes are designed to define dataset and, more generally, any kind of content that can be related to existing or new concepts through the provided vocabulary. From a methodological perspective, we have identified a number of concepts that are very generic and that all users are able to understand and use properly. This core ontology is expected to evolve and to be extended by users' contributions. Because of their generality and simplicity, the core set of classes is expected to be easily linked and logically connected to more specific vocabularies (e.g. to describe datasets or scientific

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[6]Web Ontology Language (OWL), https://www.w3.org/OWL/. Accessed: 22 August 2018.

[7]Protege - A free, open-source ontology editor and framework for building intelligent systems, https://protege.stanford.edu. Accessed: 22 August 2018.

[8]Data Catalog Vocabulary (DCAT), https://www.w3.org/TR/vocab-dcat/. Accessed: 3 September 2018.

[9]vCard Ontology - for describing People and Organizations, https://www.w3.org/TR/vcard-rdf/. Accessed: 3 September 2018.

[10]FOAF Vocabulary Specification 0.99, http://xmlns.com/foaf/spec/. Accessed: 3 September 2018.

[11]Dublin Core Metadata Initiative, http://dublincore.org. Accessed: 5 September 2018.
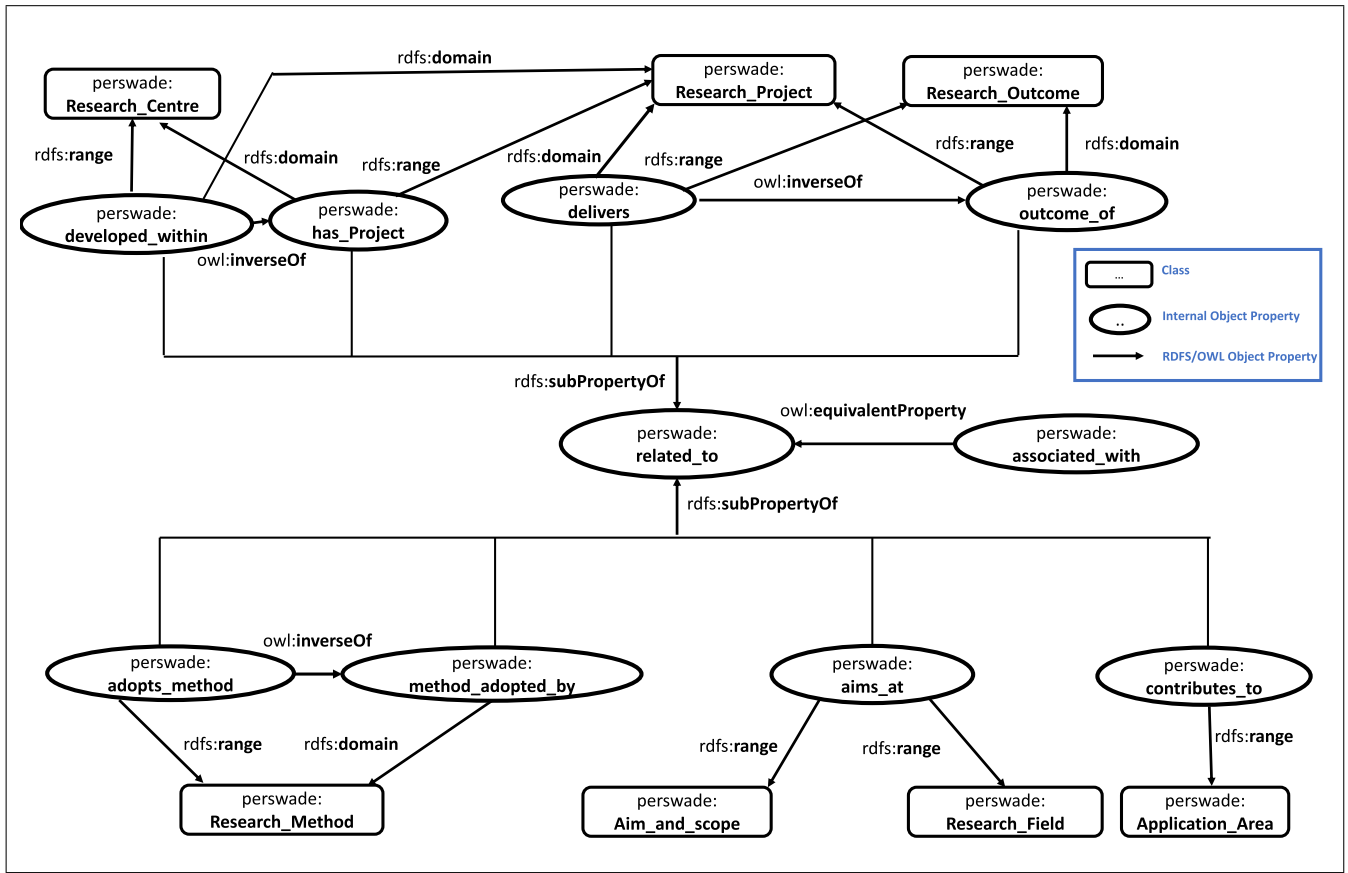
FIGURE 3. Object Property view.

contributions). For example, the internal concept *DataSet* is logically equivalent, among others, to the well known *dcat:Dataset* from the Data Catalog Vocabulary (DCAT). This makes data linking and integration much easier (see section IV). The internal concept *Research_Centre* to specify research centres is a sub-class of the generic organization in the vCard ontology (*vcard:Organisation*). According to the same logic, a researcher (*Researcher*) is declared as a sub-class of an "Individual" in vCard (*vcard:Individual*)

The research field may play an important role. To address such a concept in the ontology, we provide the generic concept *Research_Field* to allow informal and fine-grained specifications of the research fields that are used like keywords. We also refer to formal classifications, such as the ANZSRC FOR classification.

B. PROPERTIES

According to the OWL model [25], PERSWADE-CORE includes a number of object properties to relate individuals with each other, data properties to characterise individuals by setting attributes value and annotation properties to provide associated meta-data to ontology components.

1) OBJECT PROPERTIES

An object property view of the ontology is proposed in figure 3. It reflects a philosophy of balancing between usability and complexity for the target applications.

Indeed, the ontology allows to establish completely generic relationships among individuals by adopting the object property *related_to* or the equivalent *associated_with*. These very abstracted mechanisms allow an intuitive but correct use of the ontology even for users that do not know any details about the ontology implementation. In the context of the provided schema, generic relations are really useful especially if considered in a multi-user collaborative environment. On the other hand, they provide a relatively limited support to automatic inference and reasoning. For example, a new scientific contribution C can be defined as a member of the class *Scientific_Contribution* and can be related to the unclassified concept C_x through a generic relationship. If the user does not explicitly specify what C_x actually is, this latter concept remains unclassified in the system since inference based uniquely on generic relationships presents certain limitations. Users that know the vocabulary are expected to define more specific relationships by adopting sub-properties. Those still define relatively generic relationships but, exactly as in a natural language, their concrete use defines the context and the focus of the statement. Recalling the previous example, if C is related to C_x by using *aims_at*, then C_x is automatically recognised as a *Research_field* and an *Aim_and_scope*. Based on the experience in common systems and tools, users are expected to increase progressively their familiarity with the vocabulary. A normal user should be

TABLE 2. Main classes.

Class	Sub-class of	Equivalent class	Description
Research_Centre	vcard:Organization / foaf:Organization	aiiso:Center / aiiso:Institute	Research centre.
Research_Project	foaf:Project / so:Activity	so:Project / swrc:Project	Class to specify generic research projects.
Aim_and_scope	-	-	Define aims and scope for a given research.
Application_Area	-	-	Possible application areas related to a research.
Content	-	so:InformationResource	Generic content.
Multimedia_Content	Content / so:InformationResource	-	A multimedia content.
News	Content / so:InformationResource	-	Referenceable news.
DataSet	so:InformationResource	dcat:Dataset / dc:Dataset / so:Dataset	Generic dataset.
Research_Field	-	so:Discipline	Research field.
Research_Method	-	so:Method	Research method.
Modeling	Research_Method	-	Modelling-based research approach.
Research_Outcome	-	-	Research outcome.
Researcher	vcard:Individual / foaf:Person / so:Actor	-	Individual researcher.
Scientific_Contribution	so:InformationResource	swrc:Publication	Scientific contribution.
FOR	-	-	Fields of Research (FOR) classification[a]
FOR_divison	FOR	-	FOR classifications by division[a]
FOR_group	FOR_division	-	FOR group[a]
FOR_field	FOR_group	-	FOR field[a]
Keyword	-	Research_Field	Keyword.

[a] Australian and New Zealand Standard Research Classification (ANZSRC), https://www.arc.gov.au/grants/grant-application/classification-codes-rfcd-seo-and-anzsic-codes. Accessed: 15 September 2018.

able to adopt the whole vocabulary, while an expert user should be able to extend it.

2) DATA PROPERTIES
The data property set provides a vocabulary to specify attributes for OWL individuals. A subset of the data properties included in the ontology is reported in table 3. In the context of the target environment, such a vocabulary is expected to be extended to provide specific characterizations. Looking at the current setup, the URLs to access external content may play a key role in practice. The ontology usually allows the association of a generic URL to an individual (*url*) as well as more specific identifiers such as DOI, access and source URL.

3) ANNOTATION PROPERTIES
Most common annotation properties are integrated with a specific set of properties aimed at providing information on the prescribed or suggested use of vocabulary's elements. The most commonly used ones are reported in table 3.

C. INFERRED CONCEPTS
A number of inferred concepts are defined by DL rules [25] as in table 4. Such rules are reported as in the Protege syntax. Their purpose is to provide a kind of filter to define "featured" concepts within the ontology. This simplifies querying. According to this logic, a "featured research centre" (*Featured_Research_Centre*) is defined as a research centre which is related to some research project. Likewise, a "featured content" (*Featured_DataSet*) is a Data set which is related to some of the PERSWADE-CORE key concepts such as a research field, method, outcome or project. In this way, featured data set may be identified by inference within the data space. Further concepts, including *Featured_Content*, *Featured_Scientific_Contribution*,

Featured_Research_Project and *Featured_Research_Outcome* are inferred according to the same philosophy.

D. CORE POPULATION
The core population of the ontology, understood like the initial specification of the PERSWADE domain, is reported in table 5. It includes, among others, a number of research fields, methods and application areas. In this version of the ontology, the population is limited to very generic concepts of general interest. We are not including fine grained and more specific data such as information on ongoing projects, researchers and outcomes, which are to be addressed separately. The collaborative approach in building the knowledge base will be evident especially in the population of the ontology, which is expected to reflect the activities of PERSWADE and, eventually, the activities of external actors.

IV. VALIDATION AND EXAMPLES OF USE
One of the most logical consequences of our design approach (see Section I-B) is the intrinsic ability to provide a formal description of all the information available about PERSWADE and its activity. As the ontological approach is absolutely not prescriptive, each aspect may be addressed in a different way depending on the information available and can be semantically enriched by internal or external linking.

Such description is in a machine-processable format which automatically enables our environment in the Semantic Web and, therefore, potentially worldwide according to the Linked Data model [2].

In this section we provide some simple examples of use. We refer to typical examples to link external data to the ontology [50] and to define research projects. Additionally, we provide more complex examples that include some extension of the vocabulary different from simple population (e.g. intuitive definition of new classes).

TABLE 3. Subset of data and annotation properties.

Property	Domain/Range	Sub-property of	Equivalent property (external)	Description
Data Property				
description	- / xsd:string	-	-	As in common understanding.
address	- / xsd:string	-	vcard:extended_address	As in common understanding.
city	- / xsd:string	-	vcard:locality	As in common understanding.
country	- / xsd:string	-	vcard:country_name	As in common understanding.
acronym	- / xsd:string	-	-	As in common understanding.
name	- / xsd:string	-	-	As in common understanding.
period	-	-	-	Time-period specified in a free format.
reference	- / xsd:string	-	-	As in common understanding.
url	- / xsd:anyURI	-	-	Generic URL.
access_url	- / xsd:anyURI	url	-	URL adopted to access a given resource.
source_url	- / xsd:anyURI	url	-	URL of a source of information
DOI	- / xsd:anyURI	url	-	Digital Object Identifier (DOI)[b]
year	-	-	-	As in common understanding.
title	- / xsd:string	-	-	As in common understanding.
funder	foaf:Project / xsd:string	-	-	Entity that funds a project.
Annotation Property				
usage	-	-	-	Annotation on ideal usage.
usageNote	-	usage	-	Note on the ideal usage.
recommendedUse	-	usage	-	Note on the recommended use.

[b] The DOI System, https://www.doi.org. Accessed: 30 August 2018.

TABLE 4. Inferred concepts.

Inferred Concept	DL Rule
Featured_Research_Centre	Research_Centre AND (related_to SOME Research_Project)
Featured_Content	Content AND ((related_to SOME Aim_and_scope) OR (related_to SOME Application_Area) OR (related_to SOME Research_Field) OR (related_to SOME Research_Method) OR (related_to SOME Research_Outcome) OR (related_to SOME Research_Project) OR (related_to SOME Researcher) OR (related_to SOME Research_Centre))
Featured_Scientific_Contribution	Scientific_Contribution AND ((related_to SOME Aim_and_scope) OR (related_to SOME Application_Area) OR (related_to SOME Research_Field) OR (related_to SOME Research_Method) OR (related_to SOME Research_Outcome) OR (related_to SOME Research_Project) OR (related_to SOME Researcher) OR (related_to SOME Research_Centre))
Featured_DataSet	DataSet AND ((related_to SOME Aim_and_scope) OR (related_to SOME Application_Area) OR (related_to SOME Research_Field) OR (related_to SOME Research_Method) OR (related_to SOME Research_Outcome) OR (related_to SOME Research_Project) OR (related_to SOME Researcher) OR (related_to SOME Research_Centre))
Featured_Research_Project	Research_Project AND ((related_to SOME Aim_and_scope) OR (related_to SOME Application_Area) OR (related_to SOME Research_Field) OR (related_to SOME Research_Method) OR (related_to SOME Research_Outcome) OR (related_to SOME Researcher) OR (related_to SOME Research_Centre))
Featured_Research_Outcome	Research_Outcome AND ((related_to SOME Aim_and_scope) OR (related_to SOME Application_Area) OR (related_to SOME Research_Field) OR (related_to SOME Research_Method) OR (related_to SOME Research_Project) OR (related_to SOME Researcher) OR (related_to SOME Research_Centre))

The use in practice of the ontology may be very simple, either within generic knowledge-based systems and more specific expert systems, if interfaces suitable for target users are provided. For example, our current browsing interface prototype (fig. 4) relies on SPARQL,[12] a formal query language, rather than on a natural language (future work). Therefore, it is understood for experts only.

A. POPULATING THE ONTOLOGY

In order to provide a direct and intuitive understanding of the use of the Ontology in practice, three common examples of population are reported below.

1) LINKING EXTERNAL DATASETS

An external data set can be linked to PERSWADE-CORE in two different ways (fig. 5). If the external data set is described according to an external vocabulary already linked to PERSWADE, then the data set descriptor is automatically linked (fig. 5, top). Else, the external data set can be simply declared as a member of the internal class *DataSet* (fig. 5, bottom). For instance, the Australian Government[13] includes in most open data sets a descriptor that uses DCAT. In PERSWADE-CORE, the concept *DataSet* is declared as equivalent to the correspondent concept in DCAT (*dcat:Dataset*) through the following statement:

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[12]SPARQL 1.1 Query Language, https://www.w3.org/TR/sparql11-query/. Last accessed: 12 August 2019.

[13]data.gov.au, https://data.gov.au. Accessed: 10 September 2018.

TABLE 5. Individuals (core population).

Individual	Member of	Description/Reference
PERSWADE	Research_Centre	Centre on Persuasive Systems for Wise Adaptive Living (PERSWADE)
Adaptive_changing	Research_Area	[26]
Agent-based_Modeling	Modeling	[27], [28]
Conceptual_Modeling	Modeling	[29]
Conservation_of_natural_resources	Aims_and_scope	[30]
Data_Analysis	Research_Method	[31]
Data_Visualisation	Research_Method	[32]
Energy_demand_and_supply	Application_Area	[33]
Gamification	Research_Method	[34]
Participatory_Modeling	Modeling	[35]
Persuasive_Technology	Application_Area	[36]
Sharing_economy	Application_Area	[37]
Smart_City	Application_Area	[38], [39]
Social_Computing	Research_Method	[40]
Socio-environmental_Science	Research_Field	[41]
StoryTelling	Research_Method	[42]
Sustainability	Research_Field, Aims_and_scope	[43]
Sustainability_Science	Research_Field	[44]
Transition_to_future	Application_Area	[45]
Virtual_environment	Application_Area	[46]
Green_Logistics	Application_Area	[47]
Green_Economy	Application_Area	[48]
ParticipatoryModelling_Tools	Scientific_Contribution	[49]

```
perswade:DataSet
        rdf:type owl:Class;
        owl:equivalentClass dcat:Dataset;
        ...
        perswade:usageNote "Generic dataset".
```

Therefore, all descriptors from the Australian Government repository that have a descriptor in RDF may be registered automatically without need of explicit linking.

2) LINKING SCIENTIFIC CONTRIBUTIONS AND ON-LINE CONTENT

External scientific contributions and on-line content can be linked by using a very similar mechanism (fig. 6 and 7).

The most reasonable way to establish such a link would be to use the content url as the ID for the external content. However, from our experience in collaborative systems, users often prefer to adopt other IDs such as a formal or informal title.

We have tried to re-propose also this linking philosophy by providing a number of data properties to specific URLs when they are not used as IDs.

For example the individual *ParticipatoryModeling_Tools* is defined as follows:

```
perswade:ParticipatoryModeling_Tools
 rdf:type owl:NamedIndividual,
        perswade:Scientific_Contribution;
perswade:related_to
perswade:Participatory_Modeling;
perswade:DOI "...".
```

It is defined as a scientific contribution. Its DOI is specified by the corresponding property (*DOI*). Finally, it can be related in a generic way (*related_to*) to the method *Participatory_Modeling*.

3) DEFINING A RESEARCH PROJECT

The research project "Knowledge Graphs in the UTS Data Arena" is defined as a member of the internal class *Research_Project*. It can be related to a given research centre by using the internal property *developed_within* as well as the research method can be specified through the internal property *adopts_method*. Likewise, the other internal properties may be used to further characterise the project and to set the value of its attributes (e.g. title, year or period, funder). The sample code is reported below:

```
perswade:KG_DataArena
 rdf:type owl:NamedIndividual,
        perswade:Research_Project;
perswade:adopts_method
perswade:Data_Visualization;
perswade:developed_within
perswade:PERSWADE;
perswade:title "Knowledge Graphs ...";
perswade:year 2018.
```

B. EXTENDING THE ONTOLOGY

There is a potentially infinite range of possible extension for the ontology. We focus on two very common cases that we expect to continuously happen in response to the centre evolution.

In general, the ontology extension process follows a semi-supervised approach, meaning that any user may propose extensions that are visible and effective in their own data space; such extensions become part of the shared vocabulary (visible and usable by everyone) only after a validation by an expert who acts as a super user for such a purpose.

1) EXTENDING THE TAXONOMY BY ADDING INDEPENDENT CLASSES

Let's define a number of application areas, i.e. Health, Food and Water. We don't need any extension of the ontology for
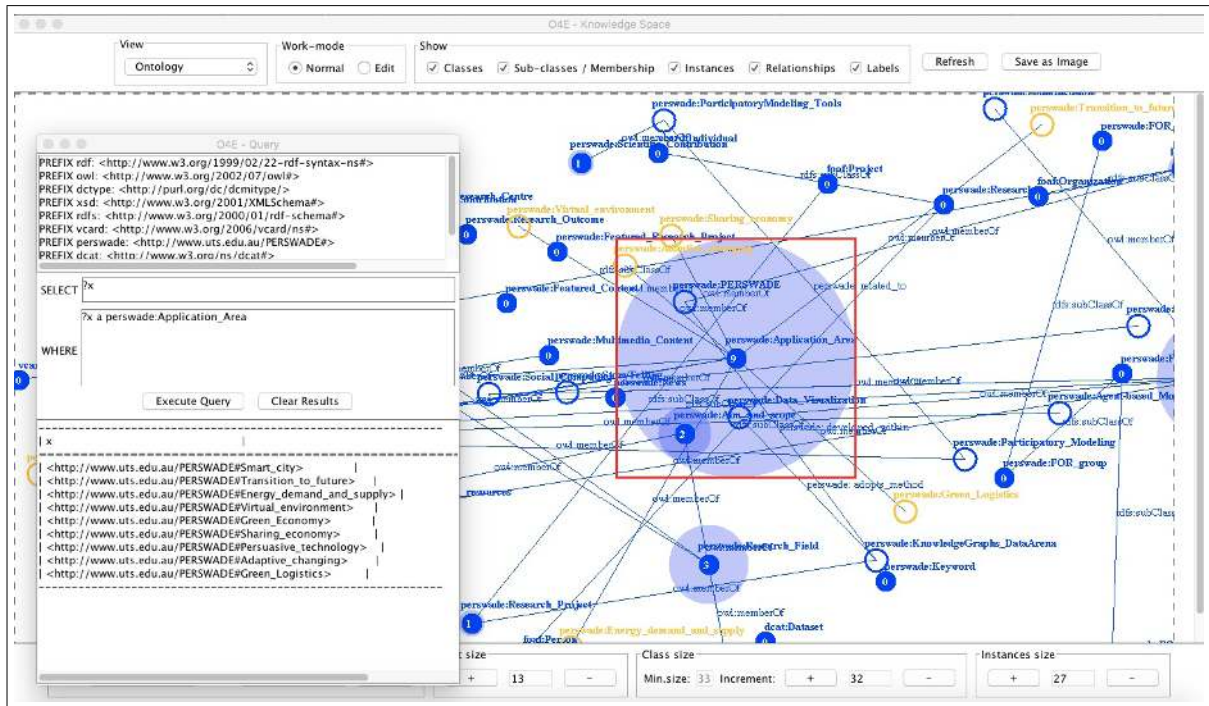
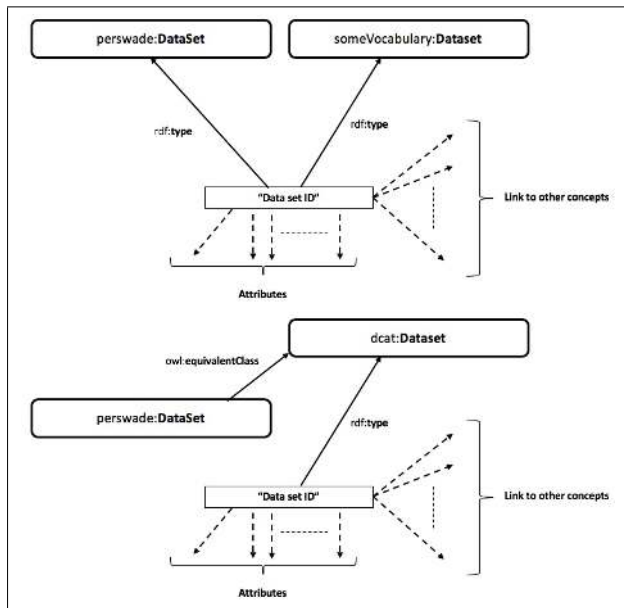**FIGURE 4.** Browsing interface prototype (for experts).

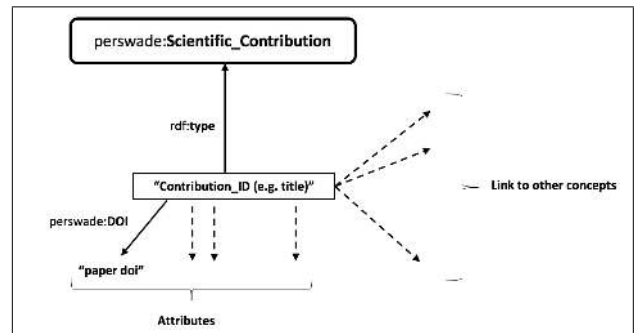**FIGURE 5.** Linking an external data set.

FIGURE 6. Linking and characterising a scientific paper.

However, the new application areas are macro-areas that we want to classify as domains within our data space. Additionally, we consider them as priorities. As the concept of domain and priority are not currently part of the ontology, they may be added by creating two new classes (fig. 8) as follows:

```
perswade:Domain rdf:type owl:Class.
perswade:Priority rdf:type owl:Class.
perswade:Health rdf:type owl:NamedIndividual,
                        perswade:
                        Application_Area,
                        perswade:Domain,
                        perswade:Priority.
perswade:Food rdf:type owl:NamedIndividual,
                        perswade:
                        Application_Area,
                        perswade:Domain,
                        perswade:Priority.
perswade:Water rdf:type owl:NamedIndividual,
                        perswade:
                        Application_Area,
                        perswade:Domain,
                        perswade:Priority.
```

such a purpose. We just need to create instances of the existing class *perswade:Application_Area* (Figure 8) by adding the following OWL statements:

```
perswade:Health rdf:type owl:NamedIndividual,
                        perswade:
                        Application_Area.
perswade:Food rdf:type owl:NamedIndividual,
                        perswade:
                        Application_Area.
perswade:Water rdf:type owl:NamedIndividual,
                        perswade:
                        Application_Area.
```
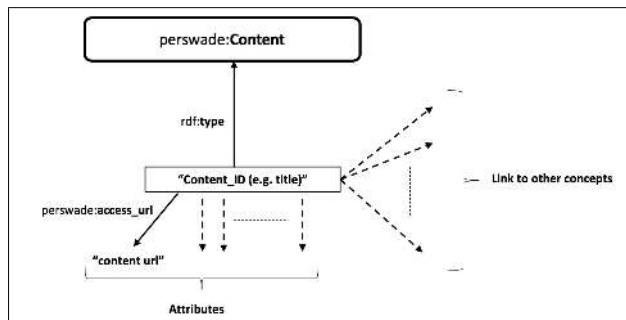
FIGURE 7. Linking and characterising an on-line content.
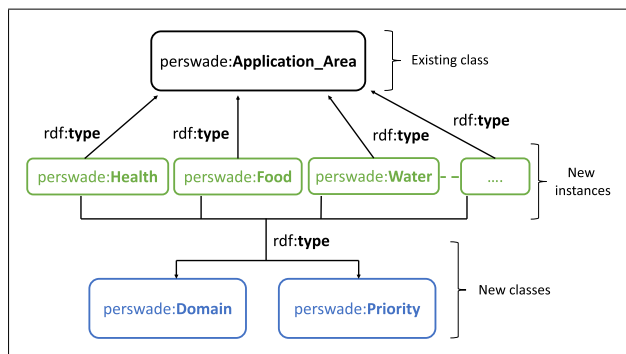

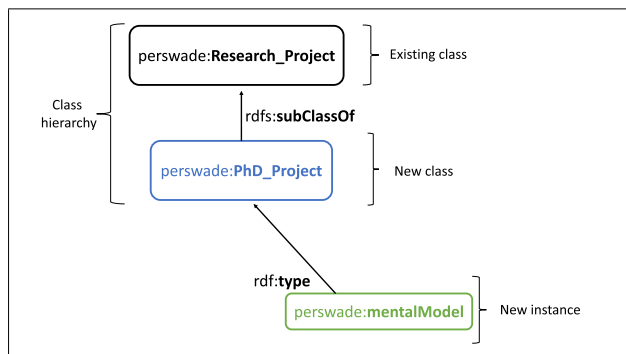**FIGURE 8.** Ontology extension by adding two independent classes.

FIGURE 9. Ontology extension by adding a class which is a subclass of an existent one.

2) ADDING CLASSES RELATED TO EXISTING ONES

In this second example (fig. 9), we define another new concept, the PhD project. We want it to be a subclass of the most generic research project currently in the vocabulary. Such a scenario is implemented by the following OWL statements:

```
perswade:PhD_Project
        rdf:type owl:Class;
        rdfs:subClassOf
        perswade:Research_Project.

perswade:mentalModel
        rdf:type owl:NamedIndividual,
                perswade:PhD_Project.
```

V. CONCLUSIONS AND FUTURE WORK

PERSWADE is a recently established research centre which belongs to an intrinsically trans-disciplinary research field that involves researchers and specialists from different areas

of expertise. The Centre also strives to produce "actionable" science, meaning that it works in close contact with stakeholders and partners from industry, business, governmental and non-governmental organizations. In order to enable an effective collaboration in this heterogeneous context, the centre is looking at a knowledge base designed to actively support collaboration through efficient data and knowledge integration, sharing and reuse. The ontological approach enables dynamic linking of datasets and of any other kind of content by logical association to the main concepts of the ontology. More advanced capabilities in terms of analytics can be built on top of the fundamental data layer developed upon semantic technologies.

PERSWADE-CORE is the foundation ontology for the PERSWADE knowledge base. It has been explicitly designed to support collaborative environments in which ontologies are expected to evolve in response to users' activity (extensibility). Therefore, the ontology has been designed to be easily extensible in all its parts, including Tbox and Abox. The most relevant aspects of the ontology (version 1.0) are described in the paper both with concrete examples of use.

Future work will be mostly focused on the integration of this core ontology with a number of sub-ontologies which will address, in a more fine grained way, the key aspects of the PERSWADE domain. Further versions of the ontology will reflect its evolution and extensions.

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