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On Using a Graphical Notation in Ontology Engineering

Prepared By
Rami Mohammad Awad Hodrob

Supervised By
Dr. Mustafa Jarrar

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استخدام الرسومات الدلالية في هندسة الانطولوجيا

Prepared By
Rami Mohammad Awad Hodrob

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The names and signatures of the examining committee members as follows:

1. Head of committee: Dr. Mustafa Jarrar Signature ....

2. Internal examiner: Dr. Wasel Ghanem Signature ....

3. External examiner: Dr. Mahmoud Saheb Signature ....

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Dedication

To my parents, to my family: Shatah, Mira, Mohammad, and Yahya Hodrob.
They taught me to always keep looking.

Rami Mohammad Hodrob

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List of Abbreviations

- ABox : Assertion Box
- ALC : Attribute Concept Description Language with Complements
- DIG : Description Logic Implementation Group
- DLs : Description Logics
- EER : Enhanced Entity Relationship
- IDE : Integrated Development Enhancement
- IRI : Internationalized Resource Identifier
- LOT : Lexical Object Type
- NGO : Non-Governmental Organization
- NIAM : Natural Language Information Analysis Method
- nRQL : new RacerPro Query Language
- ODM : Ontology Definition Metamodel
- OKBC : Open Knowledge Base Connectivity protocol
- OMG : Object Management Group
- ORM : Object Role Modeling
- ORM-ML : ORM Markup Language
- OWL : Web Ontology Language
- RBox : Role Box
- RDF : Resource Description Framework
- SPARQL : Simple Protocol and RDF Query Language
- TBox : Terminological Box
- UML : Unified Modeling Language
- UNA : Unique Name Assumption
- UoD : Universe of Discourse
- URI : Uniform Resource Identifier
- W3C : World Wide Web Consortium
- XML : Extensible Markup Language

Publications

1. Rami Hodrob, Mustafa Jarrar: Mapping ORM into OWL 2. In proceedings of the *International Conference on Intelligent Semantic Web – Applications and Services*. Pages 68-73. ACM ISBN 9781450304757. June 2010.

2. Mustafa Jarrar, Rami Hodrob, Anton Diek: An ORM-based Graphical Notation for Authoring OWL 2 Ontologies. *Data & Knowledge Engineering Journal*. *Elsevier*. (Submitted, December 2011).

Abstract

The enormous need for well engineered ontologies is growing rapidly, as the need for ontologies is increasing in many application areas such as data integration, the semantic web, knowledge engineering, enhanced information retrieval, etc. Due to the central role ontologies are playing, the World Wide Web Consortium (W3C) developed the Web Ontology Language (OWL) as a language to author ontologies. However, OWL, like many other similar ontology languages, does not provide a practical and methodological means for ontology engineering. In addition, one is required to understand the logical foundation underpinning OWL, which is very difficult for domain experts. For an ontology language to be easily understood by domain experts it must be close to the natural language they speak and the 'logic' they use. Also, it should have a graphical notation to enable simple and conceptual modeling. The expressive, methodological, and graphical capabilities of Object-Role Modeling (ORM) make it a good candidate for use in ontology engineering. The modeling approach (ORM) selected here is one of the richest graphical modelling approaches and the knowledge and practice of it is easy to be acquired at a short period of time. The second version of OWL (OWL 2) is a recommended web ontology language from W3C which contains the majority of the constructs to be used for building any needed ontology. Many reasoners such as RacerPro 2.0, Pellet, Hermit, Fact++ and others support reasoning ontologies represented in OWL 2 which is created using the description logic SROIQ (characterized by expressivity and decidability). In this research, we (i) map the most commonly used ORM constructs to OWL 2 using SROIQ Description Logic and, on the other hand, we (ii) extend the ORM notation to cover all OWL 2 constructs not currently covered by ORM. By doing so, we combine the strengths of both ORM and the W3C-recommended Web Ontology Language (OWL). This creates a framework that allows one to engineer OWL ontologies graphically using ORM.

المستخلص

نمت الحاجة بصورة كبيرة مؤخرا ل هندسة الانطولوجيا (علم ما هو موجود) في مجالات تطبيقية متعددة، ومن أهمها : تكامل البيانات، الشبكة الدلالية، هندسة المعرفة، وتعزيز استرجاع المعلومات. ونظرا للدور المهم الذي تلعبه الانطولوجيا، قام اتحاد W3C باستحداث لغة انطولوجيا الويب (OWL) كلغة تستخدم في هندسة الانطولوجيا. يعد الإصدار الثاني للغة الانطولوجيا OWL 2 من أغنى لغات بناء الانطولوجيا لاحتوائها على الغالبية العظمى من التراكيب التي تمكّن المستخدم من بناء الانطولوجيا المطلوبة،
بالإضافة إلى احتوائها على العديد من الميزات الجديدة، إلا أن لغة الانطولوجيا OWL 2 مثل لغات الانطولوجيا الأخرى لا توفر وسيلة عملية أو منهجية لهندسة الانطولوجيا، حيث يحتاج المستخدم لهذه اللغة في بناء الانطولوجيا، إلى فهم البنية الأساسية والمنطق الخاص بها وهو أمر ليس بالسهل. ولكي يتم فهم لغة الانطولوجيا من قبل مستخدمي هندسة الانطولوجيا يجب أن تكون هذه اللغة قريبة من اللغة الطبيعية التي يتحدثون بها أو "المنطق" الذي يستخدمونه وأيضا بحاجة لبيئة رسومية تتيح القيام ببناء الانطولوجيا بطريقة بسيطة. تعتبر القدرات التعبيرية والمنهجية، والإمكانات الرسومية لأداة النمذجة ORM من الأسباب التي رشحتها بشكل أساسي ليتم استخدامها في هندسة الانطولوجيا. كما أن أداة ORM التي اخترناها في هذه الأطروحة كطريقة عملية ومنهجية لبناء الانطولوجيا بلغة OWL2 تعتبر من أغنى الطرق ذي الرسومات الدلالية التي يتم فهمها وممارستها بسلاسة . قمنا في هذه الأطروحةبما يلي : (أ) تمثيل تراكيب ORM بلغة OWL 2 وذلك عن طريق استخدام لغة المنطق SROIQ (ب) نطوير ORM لتمثيل كامل لغة OWL 2، وبذلك جمعنا بين نقاط القوة الخاصة ب ORM ولغة OWL2 وهذا يخلق الإطار الذي يمكّن المستخدم من هندسة الانطولوجيا بلغة OWL 2 باستخدام الرسومات الدلالية الخاصة ب ORM المطورة.

Chapter One

Introduction

1.1 Introduction and Motivation

Ontology engineering is one of the major challenges that brought the attention of the research community in the last decade. This is especially due to the growing need for well-engineered ontologies [G98] for many application areas such as data integration, the semantic web, knowledge engineering, enhanced information retrieval and others [G98, BGME07, CW05, ZWL08, F03, F04, HS10, JMY99, VHS10, ZLW08]. Due to the central role ontologies play in realizing the vision of the semantic web [DFV03, FH11, LH07], the World Wide Web Consortium (W3C) developed the Web Ontology Language (OWL) among its semantic web technology stack, as a language to author ontologies for the semantic web. OWL is based on Description Logic. In particular, the older version of OWL is based on SHOIN [MLL06] description Logic while the newest version (OWL 2 [HKP+09]) is based on SROIQ. OWL is fully supported by many description logic reasoning tools such as Racer [HO01], Pellet [PP04], Hermit[1], Fact++ [TH06].

However, like other ontology languages, using OWL to engineer ontologies is a difficult task as it does not provide a practical and methodological means for ontology engineering. In addition, one is required to understand the logical foundation underpinning OWL, which is very difficult for domain experts. In fact, the limitations of OWL and other similar languages are not that they lack expressiveness or logical foundations, but their suitability for being used by subject matter experts. For an ontology language to be easily understood by domain

[1] http://web.comlab.ox.ac.uk/people/boris.motik/HermiT/

experts, it should at least meet the following two requirements [J05, J07b]: (i) it must be close to the natural language the experts speak and the ‘logic’ they use. (ii) The language should have a graphical notation to enable simple and conceptual modeling. What we mean by ‘graphical notation’ here is not merely *visualization* but a *graphical language* that allows for ontology construction using notations for concepts, relations, and axioms. In other words, such language should guide domain experts to think conceptually while building, modifying, and validating an ontology [GH08, COL08].

Object-Role Modeling (ORM) is a conceptual modeling approach that has been in use since the early 1970s in database modeling, and has recently become popular in ontology engineering [JDM03]. Its expressive, methodological and graphical capabilities make it indeed one of the best candidates for building ontologies. Specifically, what distinguish ORM as a conceptual modeling approach are its simplicity, intuitiveness, stability, and verbalization capabilities, among many others. ORM simplifies the modeling process by using natural language, intuitive diagrams, and examples, and by examining information in terms of simple elementary facts and expressing them in terms of objects and roles [H89, H01].

Compared to other graphical modeling notations such as EER or UML, ORM is a stable modeling notation and more expressive [JDM03, GH08]. This is due to the fact that ORM makes no use of attributes (i.e., attribute-free). All facts are represented in terms of concepts (object-types or value-types) playing roles [H04a]. This makes ORM not impacted by changes that cause attributes to be remodeled as object types or relationships. Also, one of ORM’s strongest features is its verbalization capabilities; ORM diagrams can be automatically verbalized into pseudo natural language [H04a] (See the example in section 3.1). The verbalization capability of ORM simplifies the communication with subject matter experts and allows them to better understand, validate, and build ORM diagrams. It is also important to note that ORM’s verbalization techniques have been adopted in the business rules community and have become an OMG standard.

For ORM to be used as an Ontology Engineering methodology, the underlying semantics of the notation must be formally specified (using logic). Mapping of ORM using First Order Logic was done comprehensively in [J07a]. In addition, because FOL is not decidable (does not enable automatic reasoning), ORM was formalized in [J07a, J07b] using less complex logic languages that allows for automatic reasoning, namely, DLR Description logic [J07a] and SHOIN/OWL description logic [HJ10, J07b]. This extensive work on the formalization of ORM has indeed played an important role in laying the foundation for using ORM in ontology engineering.

In order to fully establish ORM as a practical and methodological means for ontology engineering, we propose to combine the strengths of both ORM and the W3C-recommended Web Ontology Language (OWL 2) [HKP+09]. In short, we propose to map all ORM constructs to OWL 2 using SROIQ Description Logic and, on the other hand, extend the ORM notation to cover all OWL2 constructs not currently covered by ORM. By doing so, we exploit the advantages of both ORM as an intuitive graphical approach for conceptual modeling and OWL2 as a standard W3C-recommended language [BKMP09] for authoring ontologies. This creates a framework that allows one to author OWL 2 ontologies graphically using ORM.

In the extension part (extending ORM to completely represent OWL 2), each construct of OWL 2 is checked if it is mapped by ORM, if it is not a proposed ORM graphical notation is chosen to represent that of OWL 2 according to a surveyed evaluation process. The constructs of OWL 2 that are not covered by ORM and are used to extend ORM are Equivalent Classes, Disjoint Classes, Intersection of Class Expressions, Class Complement, Class Assertions, Individual Equality, Individual Inequality, positive object/data property assertion and negative object/data property assertion. In addition to these proposed notations, some of the constructs of OWL 2 are represented as non-notational expressions.

It is important to note here that the main purpose of this thesis is to develop an expressive and methodological graphical notation for OWL 2, which allows people to author OWL 2 ontologies graphically. This is presented in this thesis in two parts. In the first part, we investigate all ORM constructs by mapping/formalizing them into OWL 2 and its underpinning SROIQ Description Logic. Here ORM is used and not ORM 2 where ORM is the same as ORM 2 except that ORM 2 has modified shapes for graphical notations to occupy less space in modeling. Some new notations of ORM 2 are still not mature. ORM notations are less complicated than that of ORM 2, where here we concentrate in graphical notations that are more users friendly. In the second part, we investigate OWL 2 constructs that do not have equivalent graphical notations in ORM and develop ORM-inspired graphical notations for them. By doing so, we have developed an ORM-based graphical notation that expresses OWL 2 completely. Because of this, all of our work in this paper is based on the semantics of OWL 2 not on ORM's semantics as in [J07a, J07b]. That is, the semantics of some ORM constructs were altered to adapt them to the semantics of OWL 2.

1.2 Thesis Statement and Objectives

The aim of this research is to map between Object Role Modeling (ORM) and OWL 2 Web Ontology Language to enable one to use ORM as a graphical notation in ontology engineering. Acquiring the knowledge to build an ontology graphically using ORM can be accomplished with minimal effort and time. However, ORM as a graphical modeling approach is not supported by currently available reasoners. OWL 2 is the recommended language for authoring ontologies. However, using the OWL 2 syntax is rather complicated. So an innovative way to solve this problem is proposed by using ORM as interface for OWL2 for authoring ontologies. We map between ORM and OWL 2 and extend ORM for complete representation of OWL 2. The result of mapping enables one to build ontology graphically and check the correctness of the built ontology using an appropriate reasoner that supports OWL2.

The objectives of the thesis are as follows:

- Mapping from ORM into SROIQ Description Logic/OWL 2.
- Extending the notations of ORM to completely represent OWL 2.
- Evaluating the correctness of mapping (ORM into OWL2), using appropriate reasoning services such as instance checking.
- Evaluating the proposed ORM extension using a survey.
- Extending DogmaModeler (modeling tool) to hold the implementation of mapping between ORM and OWL 2.

1.3 Contributions

The original contributions of this thesis can be summarized as follows:

1. Contributes to the mapping of ORM into SROIQ/OWL 2. This mapping was done for each of the twenty nine constructs that forms the ORM notations. This mapping was carried out jointly and in a close cooperation with Anton Deik and Dr Mustafa Jarrar, and based on previous research published in [J07a] and [J07b].

2. Contributes to extending the ORM notation by introducing new graphical notations to cover OWL 2 constructs not currently covered by ORM. The extended ORM notation covers all constructs of OWL 2. This extension was carried out jointly and in a close cooperation with Anton Deik and Dr Mustafa Jarrar.

3. Evaluating the correctness of our mapping, where each mapped ORM construct was loaded as a complete OWL/XML file into RacerPro 2.0. Different reasoning methods like consistency, coherency and special instance checking were used to prove the correctness of our mapping.

4. Evaluating the new ORM extension by means of a survey conducted with more than 31 ORM experts and practitioners.

5. Implementation: We extended DogmaModeler (an ORM-based modeling tool [JM08]) to implement (a) our mapping (from ORM into OWL 2) and (b) the new ORM extension. Also, we have integrated the Hermit reasoning tool into DogmaModeler so that the correctness of the built ontology can be checked by methods of Logical reasoning.

The initial and primitive results of this research appeared first in [HJ10], and then it was revised, extended, evaluated, and implemented in an article submitted to Data and Knowledge Engineering Journal, Elsevier on December 2011.

1.4 Overview of the thesis

The thesis is divided into six chapters. The current chapter provides an introduction, aim and objectives for this research. Chapter two introduces and defines ORM, Description Logics, and OWL 2 in addition to providing a thorough review of related work. Chapter three discusses the mapping from ORM into OWL 2; it also describes definitions, requirements, and works of mapping. Chapter four includes extending ORM for complete representation of OWL 2. Chapter five evaluates the OWL 2 mappings of ORM in addition to our ORM extension. Chapter six describes the implementation of our work in DogmaModeler tool. Chapter seven concludes the work.

Chapter Two

Background and Related Work

2.1 Introduction

In this chapter, we shed the light on background and related work. For background we highlight three fundamental related topics, namely, Object-Role Modeling (ORM), Description Logics, and Ontology Web Language (OWL 2) that are briefly discussed in the following related subsections with an example on the Object-Role Modeling (ORM) approach. For related work we briefly discus two themes and compare them to our thesis work, one of these themes consider the problem of ontology modeling a problem of visualization and the other develop formal semantics (i.e., formalize) such as UML and EER.

2.2 Object Role Modeling (ORM)

Object Role Modeling (ORM) which was introduced in the mid of 1970s, is used to model, transform and query about business information in a fact-oriented context. All facts and rules can be verbalized in natural languages that are understood of interested users including unknowledgeable technical users. ORM is an attribute-free modeling language, unlike Entity Relationship (ER) modeling and Unified Modeling Language (UML) class diagramming, where ORM treats all elementary facts as relationships between objects making implemented structures of ORM irrelevant to business semantics. The fact that ORM is an attribute-free modeling tool maintains the semantic of modeled domain, enhances semantic stability and makes it easy for ORM structures (of grouping facts) to be verbalized.

In order to build a needed ontology we can graphically use ORM notations to implement the conceptual modeling techniques in a reasonable way [GH08, JDM03, CH05].

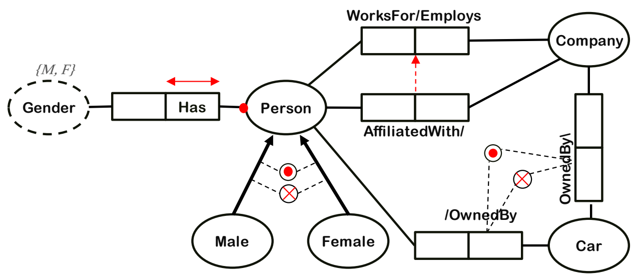
ORM is a conceptual modeling method that allows the semantics of a universe of discourse to be modeled at a highly conceptual level and in a graphical manner. As mentioned earlier, ORM has been used commercially for more than thirty years as a database modeling methodology and has been recently becoming popular not only for ontology engineering but also as a graphical notation in other areas such as modeling of business rules, XML schemes, data warehouses, requirements engineering, web forms, etc. ORM has an expressive and stable graphical notation. It supports not only n-ary relations and reification, but a fairly comprehensive treatment of many ‘practical’ and ‘standard’ business rules and constraint types such as mandatory, uniqueness, identity, exclusion, implications, frequency occurrences, subsetting, subtyping, equality, and many others [H89, H01, H04b, J07a, J07b].

ORM makes it easy to simplify the presented conceptual model using both natural language (via its verbalization capabilities) and graphical notations to present facts in their simple or elementary forms. In addition, ORM diagrams can be populated by examples to measure the correctness of the design [H01, H04b]. Practical use cases have shown that skills and know-how of using ORM can be acquired easily and in a short period of time even by non-IT specialists [J07a, JDM03]. Moreover, several modeling tools support ORM notation such as: Microsoft Visio ™, DogmaModeler, and Norma.

The example in Fig. 2.1.a below depicts a sample ORM diagram including several rules and constraints that ORM is capable of expressing graphically. Note the three basic constructs of ORM; object types, value types, and roles (forming relations).Object types are represented as solid-line ellipses, value types are presented as dashed-line ellipses and relations as rectangles, where one or more ORM roles for each ORM relation. For example, the relation (*WorksFor/Employs*) in Fig. 2.1.a is a binary relation (i.e., composed of two roles).

The preceding knowledge that underpinning ORM is NIAM (Natural Language Information Analysis Method) [H89]. NIAM was introduced in the early 70’s. An important reason under designing NIAM is to use natural language to declare the “semantics'” of a business application’s data. Fig. 2.1b shows the verbalization of the ORM rules presented graphically in

Fig. 2.1a. One of the most powerful features of ORM is its verbalization capability in which ORM diagrams can be automatically verbalized into pseudo natural sentences. In other words, all rules in a given ORM diagram can be translated into fixed syntax sentences [H01, JDM03, H04a, HC06 JKD06]. For example, the Mandatory constraint (•) between 'Person' and 'Has Gender' is verbalized by rule-1 in Fig.1b as "Each Person Has at least one Gender". Similarly, the role uniqueness constraint (↔) is verbalized by rule 2, Subtype (→) by rule 3, (⤒) by rule 6, (⊙) and (⊗) between subtypes by rules 4 and 5, and between roles by rules 7 and 8. The value constraint ({'M','F'} on Gender) is verbalized by rule 9. These verbalizations are generated automatically by the DogmaModeler tool through using verbalization templates parameterized over a given ORM diagram. DogmaModeler enables verbalization in 11 different human languages [JKD06]. The main purpose of this verbalization is to simplify the communication with non-IT specialists and to allow them to better validate and build ontology models.



1. Each Person Has at least one Gender. (Mandatory)
2. Each Person Has at most one Gender. (Role uniqueness)
3. Each Male is a Person. Each Female is a Person. (Subtype)
4. Each Person cannot be a Male and a Female at the same time. (Exclusive)
5. Each Person must be, at least, Male or Female. (Totality)
6. If a Person is AffiliatedWith a Company then this Person WorksFor that Company. (Subset)
7. Same Car cannot be OwnedBy by Person and OwnedBy a Company at the same time. (Exclusion)
8. Each Car should be OwnedBy by Person or OwnedBy a Company, or both. (Disjunctive Mandatory)
9. A Gender can only be one of {M,F}. (Value Constraint)

(a) (b)

Figure 2.1: Sample ORM Diagram along with the verbalization of its rules.

2.3 Description Logics (ALC, SHOIN and SROIQ)

Description logics [BCM+07] are a family of knowledge representation formalisms. Description logics are decidable fragments of first-order logic, associated with a set of automatic reasoning procedures [HST99]. The basic primitives of description logic are the notion of a concept and the notion of a relationship. Complex concept and relationship expressions can be built from atomic concepts and relationships. For example, one can define $HumanMother$ as $HumanMother \sqsubseteq Female \sqcap \exists HasChild.Person$. All DLs implies the open world assumption [NB02].

ALC [HST06] is simple description logic stands for Attributive Concept Language with Complements. Each feature of description logic has a letter assigned to it for example ALC is AL augmented with complements. ALC syntax is as follows, where $N_{C,}$ N_R and N_O are atomic concepts. The followings are concepts: $\top$, $\bot$ and every $A \in N_C$ (all atomic concepts are concepts). If C and D are concepts and R is a role (binary relation) then $C \sqcap D$, $C \sqcup D$, $\neg C$, $\forall R.C$, $\exists R.C$ are concepts.

We can use the constructs (primitives of the notations of concept and relationship) of ALC to represent the complex concept and relationship expressions. As an example the expression Person$\sqcap$ Doctor (Person and Doctor are atomic concepts) means persons that are also doctors. The expression Doctor $\sqcap$ $\forall$hasPatient.Person (hasPatient is an atomic role) means that doctors have only persons as patients.

For the semantic of ALC's we need the notation of interpretation $I = (\Delta^I, .^I)$, where Δ^I is the non empty set which is the domain of I and $.^I$ which is the interpretation function used to map every individual to an element $a^I \in \Delta^I$, every atomic concept A to a subset of Δ^I and every role name to a binary relation(subset of Δ^I x Δ^I). The following definitions represent the semantic of *ALC* constructs:

$$
\begin{array}{rcll}
\top^I & = & \Delta^I & \\
\bot^I & = & \emptyset & \\
(C\sqcap D)^I & = & C^I \cap D^I & \text{(intersection)} \\
(C\sqcup\text{-}D)^I & = & C^I \cup D^I & \text{(union)} \\
(\neg C)^I & = & \Delta^I \setminus C^I & \text{(complement)} \\
(\exists R.C)^I & = & \{x \in \Delta^I \mid y \in \Delta^I : \langle x,y\rangle \in R^I \text{ and } y \in C^I\} & \text{(exists restriction)} \\
(\forall R.C)^I & = & \{x \in \Delta^I \mid \langle x,y\rangle \in R^I \text{ implies } y \in C^I\} & \text{(universal restriction)}
\end{array}
$$

Figure 2.2: Semantic of *ALC*

SHOIN which is the base of Web Ontology Language (OWL) is expressive and decidable description logic. SHOIN equals (ALC extended with transitive roles(R_+)) + role hierarchy (H)($R \sqsubseteq S$) + nominals (O) ($C \equiv \{a,b,c\}$) + inverse (I)($S \sqsubseteq R^-$) + number restrictions (N).

SROIQ Description Logic [HST06] compromises both features of expressivity and decidability. SROIQ is an extension of SHOIN which is the underlying description logic of

OWL [BHH+04]. However, the rise of the Semantic Web increased the need for a more featured and expressive Description Logic to author ontologies. As a result of this increasing demand, SROIQ was introduced with many new features (especially regarding expressivity) which led to adopting SROIQ as the underpinning logic for OWL 2.

A Description Logic knowledge base is composed of two components: a TBox and an ABox. The TBox contains intensional knowledge in the form of a terminology. TBox is built through declarations that describe general properties of concepts. The ABox contains extensional knowledge which is also called assertional knowledge. It is knowledge that is specific to the individuals of the domain of discourse (knowledge specific to the instances) [BCM+07].

SROIQ syntax can be defined as follows. If C and D are concepts and R is a binary relation (also called role), then $(C \sqcap D)$, $(C \sqcup D)$, $(\neg C)$, $(\forall\, R.C)$, and $(\exists R.C)$ are also concepts. If R is simple (i.e., neither transitive nor has any transitive sub-relations), then $(\leq nR)$ and $(\geq nR)$ are also concepts, where n is a non-negative integer. For C and D (possibly complex) concepts, $C \sqsubseteq D$ is called general concept inclusion. SROIQ also allows hierarchy of roles ($R \sqsubseteq S$), transitivity of roles (R_{+}), and inverse of roles ($S \sqsubseteq R^{-}$). In addition, SROIQ allows everything SHOIN allows, in addition to the following [HST06]:

i) **Disjoint roles:** most description logics do not support disjoint roles and this makes them unbalanced. SROIQ is said to be balanced because it allows the expressivity of disjoint between roles. For example, the roles *brother* and *father* should be declared as being disjoint.

ii) **Reflexive, reflexive and antisymmetric roles:** these constraints are useful when using ABox to represent individuals. E.g., the role *loves* should be declared as being reflexive (one can love himself), and the role hasSibling should be declared as being irreflexive (one cannot be the sibling of himself).

iii) **Negated role assertion:** Although most Abox formalisms allow for only positive role assertions, SROIQ allows for negated roles assertions as well. For example, such statements can be found in a SROIQ Abox: $(Rami, Tony): \neg knows$, which means that Rami do not know Tony.

iv) **Role inclusion axioms:** these roles are of the form $R \circ S \sqsubseteq R$ and $S \circ R \sqsubseteq R$. For example, given the following two axioms (1) $owns \circ hasPart \sqsubseteq owns$, and (2) the fact that each car contains an engine $Car \sqsubseteq \exists hasPart.Engine$. This implies that an owner of a car is also an owner of an engine, i.e., the following subsumption is implied: $\exists owns.Car \sqsubseteq \exists owns.Engine$.

v) **Universal role** $\boldsymbol{U}$.

vi) **Local reflexivity** of the form $\exists R.Self$. For example, the following expresses the fact that somebody loves himself/herself: $\exists likes.Self$.

vii) SROIQ also provides what is referred to as ***Rbox*** which contains all statements concerning roles.

SROIQ (D) consists of ALC (description logic) + role chains = SR, SR + O (nominals(closed classes)), SRO+I(inverse roles), SROI+Q(qualified cardinality restrictions) and SROIQ+D(data types). Since SROIQ is an extension of ALC (introduced above) we will introduce the constructs of SROIQ not present in ALC through the following table that shows syntax and semantic of SROIQ description logic.

Table 2.1 : Syntax and Semantic of *SROIQ* other than *ALC*

	Name	Syntax	*Semantic*		Name	Syntax	*Semantic*
S R	Role chains	R o S $\sqsubseteq$ R	$\forall x\ \forall y\ (\exists z((R(x,z) \wedge S(z,y)) \rightarrow R(x,y)))$	*S R* + ***O***	Nominals	{a}	$\{a^I\}$
	Transitivity	R^*	$(R^I)^*$		Individual equality	a = b	$a^I = b^I$
	role hierarchies	R $\sqsubseteq$ S	$C^I \subseteq D^I$		Individual inequality	a ≠ b	$a^I \neq b^I$
SRO + ***I***							
inverse roles		R^-	$\{\langle x,y\rangle \mid \{\langle y,x\rangle \in R^I\}$				
SROI + ***Q***							
Qualified Number Restriction		$\geq n$ R.C	$\{x\in \Delta^I \mid \#\{y\in \Delta^I \mid \langle x,y\rangle \in R^I$ and $y \in C^I\}\geq n\}$				
		$\leq n$ R.C	$\{x\in \Delta^I \mid \#\{y\in \Delta^I \mid \langle x,y\rangle \in R^I$ and $y \in C^I\}\leq n\}$				
		$= n$ R.C	$\{x\in \Delta^I \mid \#\{y\in \Delta^I \mid \langle x,y\rangle \in R^I$ and $y \in C^I\}=n\}$				

2.4 OWL 2 Web Ontology Language

The W3C-recommended Web Ontology Language (OWL) [BHH+04] is a knowledge representation language [MMH04] used to publish and share ontologies on the Web, where this ontology language includes formally defined meanings. While the underpinning description logic of OWL is SHOIN, OWL 2[2] (the new version of OWL) is based on SROIQ description logic. Roughly speaking, one can often view OWL 2 as SROIQ written in other syntaxes (XML, RDF/XML, etc). Among OWL 2 basic constructs are: *Class* (corresponds to a 'concept' in SROIQ or called 'object-type' in ORM), *Property* (corresponds to a SROIQ 'relationship' or an ORM 'role'), and *Object* (corresponds to a SROIQ individual/assertion).

It is worth also noting here that OWL 2 is supported by several semantic reasoners such as RacerPro 2, Hermit, Pellet and Fact++[3].

As of October 27, 2009, OWL 2 has been set as a W3C recommended as a standard for ontology representation on the Web. Classes, properties, individuals, and data values are all supported by OWL 2 and stored semantically on the Web. OWL 2 ontologies are primary exchanged as RDF documents, where these ontologies can be used with information written in RDF. In addition to XML/RDF syntax which is used to serialize and exchange OWL 2 ontologies, functional syntax is used to determine the structure of OWL 2 and OWL/XML syntax is used as an XML serialization for better interoperability. OWL 2 elements are identified by Internationalized Resource Identifiers (IRIs). It extends OWL 1 which uses Uniform Resource Identifiers (URIs) [MGH+09, GW09]. Every IRI must be absolute to be published internationally. OWL 2 increases expressive language power for properties.

The following are some of the new features that distinguish OWL 2 from its OWL predecessor [GW09]:

i) Syntactic sugar

[2] www.w3.org/2009/pdf/REC-owl2-overview-20091027.pdf

[3] http://owl.man.ac.uk/factplusplus/

- DisjointUnion states that if we have the classes A, B and C then class A is the union of classes B or C and at the same time class B and C are disjoint to each other, where no individual can be an instance of class B and C at the same time.

- DisjointClasses states that if we have a set of classes' constraint by the construct DisjointClasses then these classes are disjoint to each another, where an individual of one class of the set cannot be an instance of the other classes of the set.

- NegativeObjectPropertyAssertion (also we have NegativeDataPropertyAssertion) states that a given individuals are not related to the intended object property.

ii) New constructs for properties

- Self restriction: ObjectHasSelf states that if we have an object property such as likes related to a class person then the individuals of this class are related to themselves by the object property likes.

- Property Qualified Cardinality Restrictions: ObjectMinCardinality, ObjectMaxCardinality, and ObjectExactCardinality; and respectively DataMinCardinality, DataMaxCardinality, and DataExactCardinality allow asserting minimum, maximum or exact qualified cardinality restrictions for object and data properties.

- Reflexive, Irreflexive, and Asymmetric Object Properties [MGH+09].

- Disjoint Properties states that if two or more object properties restricted by DisjointObjectProperties construct then these object properties are exclusive to each others. Also the same for data properties restricted by DisjointDataProperties construct.

- Property Chain Inclusion states that if we have two or more object properties chained by the construct ObjectPropertyChain in a SubObjectPropertyOf axiom then as a result we have a property that is the composition of several properties.

- Keys: HasKey allows defining keys for a given class.

iii) Simple metamodeling capabilities

- Punning: OWL 2 allows using the same term for both a class and an individual at the same time.

iv) Extended Annotations

- Annotations: the construct AnnotationAssertion is used to assert annotations for classes, properties and individuals.

- Axioms about annotation properties: (AnnotationPropertyDomain) and ranges (AnnotationPropertyRange) and participate in an annotation property hierarchy (SubAnnotationPropertyOf). These special axioms have no semantic meaning in the OWL 2 Direct Semantics, but carry the standard RDF semantics in the RDF-based Semantics (via their mapping to RDF vocabulary).

v) Declarations: The prior announcement for an entity such as a class is important for error catching where a declaration in OWL 2 for an entity such as class, datatype, object property, data property, annotation property, or individual indicates that an entity is part of the terminology of ontology.

vi) Top and Bottom Properties: In addition to top and bottom classes (owl:Thing and owl:Nothing), OWL 2 provides top and bottom object properties(owl:topObjectProperty, owl:bottomObjectProperty) and data properties (owl:topDataProperty, and owl:bottomDataProperty).

vii) IRIs: OWL 2 uses Internationalized Resource Identifiers (IRIs) for identifying the elements of ontologies and ontologies themselves in order to come over the language limitations of URIs [MPP09, SWM04] that were used in OWL 1.

2.5 Related Work

As discussed previously, our work revolves around establishing ORM as a practical and methodological means for ontology engineering by combining its strengths with those of the Web Ontology Language (OWL). There are several approaches and tools similar to our work, which aim to use graphical notations such as UML and EER for ontology modeling. Also, in particular, some of them aim to model OWL ontologies graphically. Some of these approaches and tools consider the problem of ontology modeling a problem of visualization, thus ignoring the underpinning semantics. However, some efforts exist to develop formal semantics (i.e., formalize) UML and EER. In this section, we discuss these efforts and compare them to our approach.

Many efforts exist to use UML or UML-based notations for graphical representation of ontologies. Cranefield *et al, in* [CHD+02], proposed using UML as an ontology visualization and editing tool. Although their goal is to visualize and edit ontologies, they did not consider the underpinning semantics. Their work does not also provide any type of mapping of the graphical notation (i.e., UML) into OWL. Brockmans *et al,* in [BVEL04], introduced a UML-based notation for the visualization of OWL ontologies by developing a UML profile. In such approach, OWL is visualized based on the UML profiles of the Ontology Definition Metamodel (ODM[4]). ODM defines a set of UML metamodels and profiles for the development of RDF and OWL. These UML profiles adapt UML notations to provide a suitable visual representation of RDF and OWL ontologies. This representation of ontologies using ODM enables one to only visualize the ontology but does not capture the semantics of it. This is due to the challenges of developing well-formed and usable UML models with equivalent semantics in OWL. However, in [KBB+09], Kendall *et al* presented some potential extensions to the UML profiles of ODM to address some of the requirements of OWL 2. It is important to note also that UML itself is a very basic notation; as will be demonstrated later, ORM is much more expressive as it allows 20 types of rules to be expressed graphically, while UML support only cardinality rules.

[4] http://www.omg.org/spec/ODM/1.0/

Many ontology editing tools are available such as Protégé[5], TopBraid[6], NeOn[7] and GrOWL[KWF07]. These tools are used to build and edit ontologies by enabling the creation of classes, object properties and various constraints. After building the needed ontology, it can be visualized graphically. However, such tools do not capture the ontology semantics. In our methodology, we build the ontology graphically using ORM notation which is then mapped into the equivalent OWL 2 constructs capturing the semantics of the ontology.

Protégé is an open source ontology editor for OWL and recently OWL 2. Protégé is built using Java and it is a framework for other project plug-ins. By using protégé you can build the needed ontology by using all the constructs of OWL 2 based in SROIQ (D) description logic. One can create classes, object properties, data object properties, class expressions, individuals and the relations between these concepts using the various constraints of OWL 2. But here we still talk about building the intended ontology in a tree-based hierarchy methodology (composed of classes, properties and individuals) and not in a graphical context representation, besides not gaining the big picture of modeling. Protégé provides two main techniques of modeling ontologies, one is Protégé-OWL[8] editor, and the other is Protégé-Frames editor, based on Open Knowledge Base Connectivity protocol (OKBC). The built ontology can be visualized in the shape of tree indicating the classes and the relations between them, but here we are talking about just displaying the built ontology in a graph representation and not capturing the semantic of built ontology. OntoViz which is a visualization plug-in included in Protégé and uses the library of GraphViz[9] to create an ontology in 2D graph. The built ontology is displayed in 2D graph showing the classes, their properties, role relations and instances. Indeed our work is in opposite context where we can build the needed ontology graphically using the extended ORM. The extended ORM includes all the needed OWL 2 constructs for building the intended ontology. Once the ontology is built graphically in an easy way with capturing the semantic of ontology, it is automatically formalized into OWL 2 using the DogmaModeler tool. This highlights our wok in enabling the building of ontology graphically and in an easy way in comparison with the wide used Protégé modeling tool.

[5] http://protege.stanford.edu/
[6] http://www.topquadrant.com/products/TB_Composer.html
[7] http://neon-toolkit.org
[8] http://protege.stanford.edu/publications/ontology_development/ ontology101.pdf
[9] http://graphViz.org

TopBraid is a commercial modeling tool for developing ontologism in semantic web context. TopBraid Composer is an RDF (Resource Description Framework) and OWL editor, where one can create the RDF/OWL files and query over them using SPARQL. By using the TopBraid editor you can create and edit the needed classes, object properties and various constraints. After creating ontology you can display the graph representation of it, similar to that of Protégé. As we said before our work is opposite where you can create an ontology graphically using the extended ORM and consequently you will have its semantic equivalent in OWL 2.

NeOn is an open source tool that provides an ontology engineering environment based on Eclipse Integrated Development Environment (IDE). It includes many plug-ins that support many ontology engineering activities and provides a means of visualizing the ontology as it is being built.

GrOWL [KWF07] is also a tool for visualizing and editing OWL ontologies with advanced browsing and navigation tools. Our approach enables one to graphically build the ontology using ORM notation with semantic capturing and this Ontology is automatically mapped into OWL and validated.

Mapping EER is done in [BCM+07] and UML is done in [BCG05]. Formalizing form EER and UML into DLR_{idf} description logic is done in these two works [BCM+07, BCG05]. Jarrar [J07a] implemented mapping from ORM to SHOIN/OWL description logic. SHOIN is chosen because of its ability of expressiveness and decidability. Each rule of ORM that is supported by SHOIN is mapped into SHOIN. Twenty two cases of ORM constructs are mapped, where the purpose is to use ORM as a technique and expressive notation for ontology engineering. Although mapping ORM into SHOIN is achieved in [J07b], but mapping ORM into OWL is not achieved. In our research, mapping between ORM and OWL 2 is achieved and is implemented automatically by DogmaModeler tool.

It is also worth noting that the ICOM tool was one of the first tools to enable automated reasoning with conceptual modeling. ICOM [FN00] is a conceptual modeling tool, which is used for knowledge representation by allowing one to design multiple extended ontologies. ICOM was first released in 2000 [FN00], but recently it has version 3 release [FFT10]. ICOM has reasoning capabilities. ICOM supports ontology modeling using a graphical notation that is a mix of UML and EER notations. ICOM[10] enables one to build ontologies using multiple ER or UML class diagrams with various inter and intra constraints. The class diagrams and constraints are formally translated into class-base logic. It can express EER and UML class diagrams enriched with various constrains, into classes and relations involved with expressions, representing various ontologies. ICOM is integrated with a description logic reasoning server that acts as a background inference engine to enable automatic reasoning.

ICOM does not express ORM, where our work express extended ORM for full representation of OWL 2, where ORM is friendlier for use than ER and UML and at the same time more rich with needed constrains for knowledge representation. ICOM represents ER or UML class diagrams into DIG for the purpose of reasoning, but not into OWL 2, where in our work we map extended ORM into OWL 2. The implementation of mapping is done using the extended DogmaModeler (extended to hold mapping between ORM and OWL 2). Once we build the needed ontology graphically using ORM under DogmaModeler tool. An OWL 2 file is automatically generated. We can reason about the generated OWL 2 file by using Hermit reasoned(integrated with DogmaModeler) that supports OWL 2.

Bārzdiņš et al. [BBC+10] proposed a hard extension of UML class diagrams to visualize OWL 2 in a dense way, but here we still talking about visualization method that not exactly capture the semantics of OWL 2. Here textual representation is still used to represent OWL 2 constructs in a graphical way like disjoint, equivalent and others, so here the representation of OWL 2 constructs is not graphically pure while our work semantically represents OWL 2 constructs with pure graphic notations. The proposed extension is implemented to visualize OWL 2 using a UML graphical editor called OWLGrEd. As we said, in our work we are talking about extending ORM to graphically represent the constructs of OWL 2 that are not

[10] www.inf.unibz.it/~franconi/icom/files/icommanual.pdf

represented by ORM, in order to be able to use ORM as an interface of OWL 2 in order to be able to build an ontology graphically in an easy way . This extension is implemented using the extended tool (DogmaModeler). Some of the extension that is done in [BBC+10] to represent uncovered OWL 2 constructs by UML is already included in ORM like equivalent and disjoint properties, in addition to the Boolean relations between class and class expression or even between class expressions themselves. OWL 2 is indicated by its expressive power of class expressions and at the same time ORM graphically do represent the relation between class and class expression, as also between class expressions themselves. Where ORM as a basis of concepts and relations between them in addition to the used constraints graphically represents the class expressions like denoting that a class A is a subclass of an expression of 'some values from' or 'all values from'. All these features indicate that ORM is a robust graphical tool as a fact oriented conceptual modeling tool and contains a rich set of constraints not covered in UML and ER.

Many other similar tools and frameworks which enable a text tree-based methodology for knowledge representation and not enabling graphical building of ontology are available such as, IBM Integrated Ontology Development Toolkit [IIODT[11]], SWOOP[12], DOME, and DERI[13] Ontology Management Environment among many others. Although all of these tools allow a graphical representation of the ontology, this representation is merely a visualization that ignores the underpinning semantics, in contrast to our proposed ORM ontology engineering paradigm.

The investigation of the ORM notation is done by formalizing it using both DLR_{idf} description logic [J07a, K07] and SHOIN description logic [HJ10, J07b]. The main purpose of this formalization/mapping was to enable automated reasoning on the formal properties of ORM diagrams, such as detecting constraint contradictions and implications. Thus, in this study of ORM, the native semantics of ORM were used which were expressed in DLR and SHOIN Description Logics. Anoher point we are concerning about SROIQ which is the logic underpinning OWL 2 that is decidable and supported by many reasoners and not DLR_{idf} as in

[11] http://www.alphaworks.ibm.com/tech/
[12] http://www.mindswap.org/2004/SWOOP/
[13] http://dome.sourceforge.net/

[K07]. In [BMST07] an attempt of mapping OWL into ORM/RIDL was done but it was not complete where not all ORM constructs were covered in this research as Ring constraints and role disjoitness; In addition the author did not rely in specified description logic and relied in OWL and not OWL 2 that includes new features where OWL 2 was not available at that time of research. However, in the mapping presented in this thesis, we have altered the native semantics of ORM to adapt it to that of OWL 2 (i.e., we have used the semantics of OWL 2 not of ORM). That is, we have expressed the semantics of OWL 2 graphically using the ORM notation, without employing the semantics of ORM. For example, ORM subtypes are proper subtypes. We say that B is a proper subtype of A if and only if the population of B is always a subset of the population of A, and $A \neq B$. This implies that the subtype relationship is acyclic; hence, loops are illegal in ORM. However, such loops according to the semantics of OWL 2 are allowed which means that the classes involved in the loop are equivalent. Furthermore, object types (i.e., classes) in ORM are mutually exclusive. That is, according to ORM semantics, it is not allowed for an object-type to be a subtype of two different object-types, unless these two supertypes have a common supertype. However, such a multiple inheritance is allowed according to the semantics of OWL 2.

Another important difference between ORM and OWL 2 semantics is that ORM adopts a close world assumption while OWL 2 adopts an open world assumption [NB02]. A closed world assumption states that any statement that is not known to be true or false is false. On the contrary, an open world assumption states that, unless the truth-value of a statement is explicitly determined, it is unknown. For instance, originally, ORM assumes that any two object types are disjoint, without the need to state it explicitly (closed world assumption). Here, we follow OWL 2's open world assumption where any two object types are not known whether they are disjoint or not, except if stated explicitly. The same applies, for example, to instances (assertions), where OWL 2 semantics states that any two instances are not considered different (unequal) or equal unless it is explicitly stated (open world assumption). In short, in this thesis, we don't present or follow ORM semantics, but rather use the ORM graphical notation to depict OWL 2 constructs using OWL 2 semantics.

Chapter Three

Mapping ORM into SROIQ/OWL 2

3.1 Introduction

Since we concentrate on the ability of expressivity and decidability for our mapping results (SROIQ achieves this ability [HST06]), we will use SROIQ Description Logic (which is the most common in ontology engineering and it is the language underpinning OWL 2) as a reference to map from ORM into OWL 2. First, we formally map the ORM construct into SROIQ Description Logic and then we represent this model in OWL 2. Our scope of conversion is every construct of ORM.

3.2 Use Case

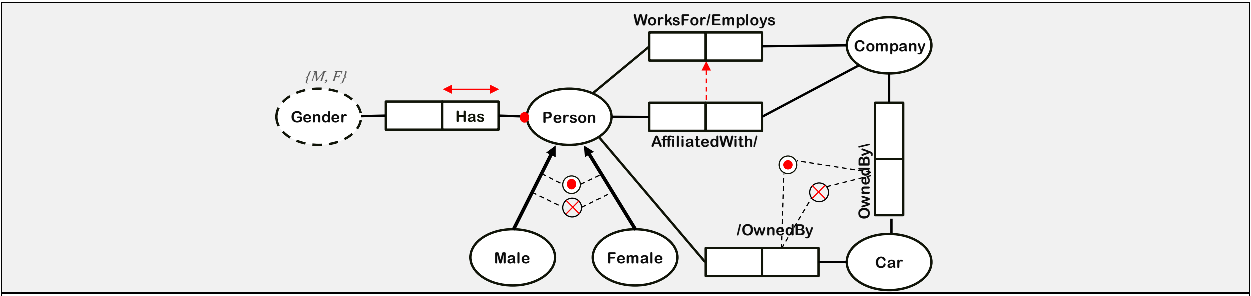
Before delving into the details of the mapping of ORM using SROIQ/OWL2, we first present a use case where we map the sample ORM diagram in Figure 2.1 into OWL2. Part of the mapping is depicted in Figures 3.1 through 3.3 along with a brief discussion. The full mapping using OWL/XML is provided in Appendix A-1.

The basic ORM constructs are mapped to OWL 2 as follows. An object/value type is mapped as a *Class* in OWL 2 whereas an ORM role is mapped as an *ObjectProperty/DataProperty*. Before mapping the ORM rules and constraints to OWL 2, one must first declare the object/value types and roles in OWL 2. Fig. 3.1 depicts the declarations of the object types *Person* and *Company* and the ORM relation *WorksFor/Employs* of Fig. 3.2.a. The complete declarations of the ORM diagram are provided in the Appendix.

```
<Declaration>
   <Class IRI="#Person"/>
</Declaration>

<Declaration>
   <Class IRI="#Company"/>
</Declaration>

<Declaration>
   <ObjectProperty IRI="#Employs"/>
</Declaration>

<Declaration>
   <ObjectProperty IRI="#WorksFor"/>
</Declaration>
```

Figure 3.1: OWL 2 declarations of Classes and Object Properties

The diagram in Fig. 3.2.a contains 9 rules which we map into SROIQ/OWL-2 in Fig. 3.2.b below. These rules are: *(1) Subsumption (subtype)*, *(2) Mandatory*, *(3) Role Uniqueness*, *(4) Total Constraint*, *(5) Exclusive Constraint*, *(6) Subset Constraint*, *(7) Disjunctive Mandatory (inclusive-or)*, *(8)Exclusion*, and *(9)Value Constraint*.



(a) The ORM diagram in Fig. 2.1.a

Subtype: Male $\sqsubseteq$ Person, Female $\sqsubseteq$ Person

```
<SubClassOf>
   <Class IRI="#Female"/>
   <Class IRI="#Person"/>
</SubClassOf>
<SubClassOf>
   <Class IRI="#Male"/>
   <Class IRI="#Person"/>
</SubClassOf>
```

Mandatory: Person $\sqsubseteq$ $\exists$HasGender.String

```
<EquivalentClasses>
   <Class IRI="#Person"/>
   <DataSomeValuesFrom>
     <DataProperty IRI="#HasGender"/>
     <Datatype abbreviatedIRI="xsd:string"/>
  </DataSomeValuesFrom>
</EquivalentClasses>
```

Role Uniqueness: Person $\sqsubseteq\leq$ 1HasGender.String

```
<EquivalentClasses>
  <Class IRI="#Person"/>
   <DataMaxCardinality cardinality="1">
    <DataProperty IRI="#HasGender"/>
    <Datatype abbreviatedIRI="xsd:string"/>
   </DataMaxCardinality>
 </EquivalentClasses>
```

Total and Exclusive Constraints: Person $\sqsubseteq$ Male Female,
Male $\sqcap$ Female $\equiv\bot$

```
<DisjointUnion>
  <Class IRI="#Person"/>
  <Class IRI="#Female"/>
  <Class IRI="#Male"/>
</DisjointUnion>
```

Subset: AffiliatedWith $\sqsubseteq$ WorksFor

```
<SubObjectPropertyOf>
   <ObjectProperty IRI="#AffiliatedWith"/>
   <ObjectProperty IRI="#WorksFor"/>
</SubObjectPropertyOf>
```

Disjunctive Mandatory:
Car $\sqsubseteq$ $\exists$OwnedBy.Person $\exists$OwnedBy.Company

```
<EquivalentClasses>
   <Class IRI="#Car"/>
   <ObjectUnionOf>
     <Class IRI="#OwnedByC.Company"/>
     <Class IRI="#OwnedByP.Person"/>
   </ObjectUnionOf>
</EquivalentClasses>
```

Exclusion: OwnedBy.Person $\sqsubseteq$ $\neg$ OwnedBy.Company

```
<EquivalentClasses>
   <Class IRI="#OwnedByC.Company"/>
   <ObjectComplementOf>
     <Class IRI="#OwnedByP.Person"/>
   </ObjectComplementOf>
</EquivalentClasses>
```

Value Constraint: Gender $\sqsubseteq$ STRING, Gender $\equiv$ {M, F}

```
<DataPropertyRange>
  <DataProperty IRI="#HasGender"/>
    <DataOneOf>
      <Literal datatypeIRI="&xsd;string"> M
</Literal>
      <Literal datatypeIRI="&xsd;string"> F
</Literal>
     </DataOneOf>
 </DataPropertyRange>
```

(b) The SROIQ/OWL 2 mapping of the ORM rules in (a)

Figure 3.2: The ORM diagram of Fig. 2.1.a and the mapping of its rules to SROIQ/OWL 2

Subsumption (subtype) is depicted as an arrow (→) in ORM. In our example, this arrow is seen in two places: between *Male* and *Person*, and between *Female* and *Person*. This means that all instances of *Male* (all males) form a subset of the population of *Person* (all persons). This is also true for the object-type *Female*. In OWL 2, *SubClassOf* construct is used to represent this rule (lines 1-8, Fig. 3.2.b).

Mandatory is depicted as a dot (•) on the line connecting *Person* object type with *hasGender* role. This constraint indicates that, in every interpretation of this schema, each instance of the object-type *Person* must have at least one *Gender*. This rule is mapped in OWL 2 in lines 9-15, Fig. 3.2.b.

Role Uniqueness is depicted by an arrow ↔ spanning along the role *hasGender*. In OWL 2, we map this rule as shown in lines 16-22 in Fig. 3.2.b. This constrains indicates that, in every interpretation of this schema, each instance of the object-type *Person* must have at most one *Gender*.

Total and Exclusive Constraints are depicted as (⊙) and (⊗) between the *Male* and *Female* subtypes. The Total Constraint means that the population of *Person* is exactly the union of the population of *Male* and *Female* subtypes. The exclusive constraint means that the intersection of the population of *Male* and *Female* is always empty. In our example, we use *DisjointUnion* OWL 2 construct (lines 23-27, Fig. 3.2.b) which expresses both Total and Exclusive constraints.

Subset Constraint is depicted in the ORM diagram in Fig. 3.2.a as an arrow (⇡) between the roles *AffiliatedWith* and *WorksFor*; which means that the role *AffiliatedWith* is a subset of role *WorksFor*. That is, all Persons who are *affiliated with* a Company must *work for* that company. This is written in SROIQ as: AffiliatedWith ⊑ WorksFor. Representation in OWL 2 is done using *SubObjectPropertyOf* (lines 28-31, Fig. 3.2.b)

Disjunctive Mandatory (inclusive-or), is depicted as (⊙) between two or more roles, illustrating that the disjunction of these roles is mandatory for members. In our example, each instance of object-type *Car* must be owned by at least a Person or a Company or both. This is written in SROIQ description logic as: $\text{Car} \sqsubseteq \exists \text{OwnedBy}.\text{Person} \sqcup \exists \text{OwnedBy}.\text{Company}$). This rule is mapped in OWL 2 in lines 32-38.

Exclusion, is represented as (⊗) between the roles it connects (in Fig. 3.a, it connects between the two *OwnedBy* roles of object-type *Car*). It means that each member of the population cannot play both roles constrained by exclusion. In the example, no car can be owned by a Person and a Company at the same time ($\text{OwnedBy}.\text{Person} \sqsubseteq \neg\, \text{OwnedBy}.\text{Company}$). Representation in OWL 2 is depicted in Fig 3.2.b (lines 39-44).

Value Constraint, is represented as {'M','F'} above the *Gender* dashed-line ellipse. This constraint indicates the possible set of values that the value type *Gender* can be populated with. Here, *Gender* can take any of the two STRING values: 'M' and 'F'. No other value is allowed. This constraint is mapped in OWL 2 in lines 45-51.

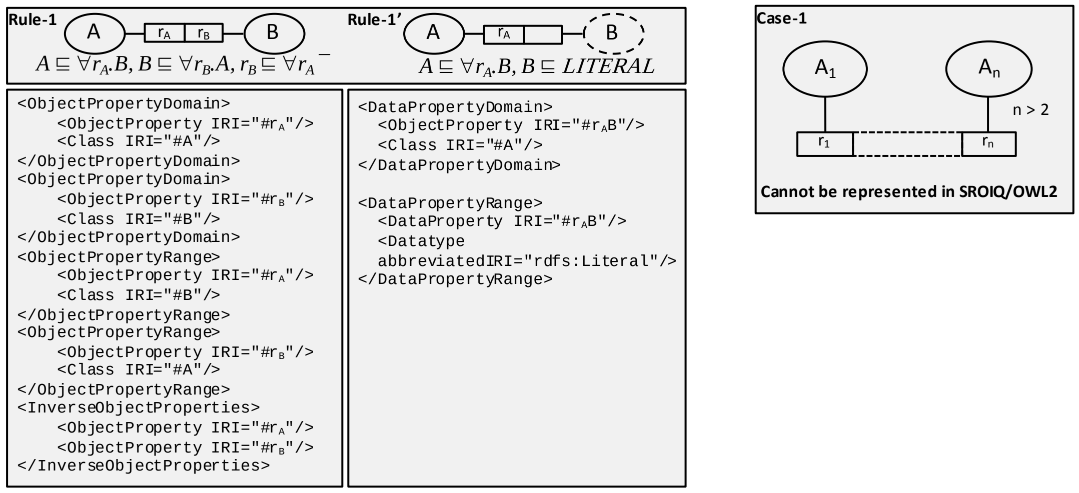
In the following subsections we thoroughly discuss the mappings of the ORM constructs into OWL 2 and its underpinning SROIQ Description Logic.

3.3 Object-Types and relations

3.3.1 Binary and N-ary relationships ($n \geq 1$):

ORM supports *n*-ary relationships, where $n \geq 1$. Each argument of a relationship in ORM is called a role. For example, consider the binary ORM relationship *WorksFor/Employs* in Fig. 3.2.a which has two roles, namely, *WorksFor* and *Employs*. However, SROIQ only supports binary relationships. Note that an ORM *role* is represented as a *relationship* in SROIQ. Thus, a binary ORM relationship is represented by two SROIQ relationships (that represent ORM roles) in addition to an inverse axiom to state that both SROIQ relationships are inverse to each other. Fig. 4.a (Rule-1) depicts a binary ORM relationship, its formalization into SROIQ, and its mapping into OWL 2. Fig. 3.3.b (Case-1) shows the general case of an ORM *n*-ary relationship, which cannot be represented in SROIQ/OWL 2. One can refer to [J07a] for the representation of Case-1 using DLR Description Logic. In this case, however, the n-*ary* relationship can be converted to binary relationships [H01] and then mapped into SROIQ/OWL 2.

The mapping of the binary ORM relation presented in Rule-1 represents the case where *A* and *B* (Fig. 3.3.a) are both object-types (equivalent to OWL 2 classes). However, in the case where either *A* or *B* are ORM value-types, the value-type is mapped into a “Literal” (the universal datatype) in OWL 2, or to any of its sub-datatypes. If, for example, *B* is a value-type, as depicted in Rule-1’, the ORM role r_A is mapped into an OWL 2 *DataProperty* with datatype “Literal”. Notice that this *DataProperty* is called r_AB; the concatenation of the names of both the ORM role (r_A) and the ORM value-type (B). Also note that we don’t need an additional inverse axiom, because in this case only one *DataProperty* is needed to represent the ORM relation between an object-type and a value-type.


Rule-1
A
r_A
r_B
B
$A \sqsubseteq \forall r_A.B, B \sqsubseteq \forall r_B.A, r_B \sqsubseteq \forall r_A^-$
Rule-1′
A
r_A
B
$A \sqsubseteq \forall r_A.B, B \sqsubseteq LITERAL$
Case-1
A_1
A_n
n > 2
r_1
r_n
Cannot be represented in SROIQ/OWL2

```
<ObjectPropertyDomain>
    <ObjectProperty IRI="#rA"/>
    <Class IRI="#A"/>
</ObjectPropertyDomain>
<ObjectPropertyDomain>
    <ObjectProperty IRI="#rB"/>
    <Class IRI="#B"/>
</ObjectPropertyDomain>
<ObjectPropertyRange>
    <ObjectProperty IRI="#rA"/>
    <Class IRI="#B"/>
</ObjectPropertyRange>
<ObjectPropertyRange>
    <ObjectProperty IRI="#rB"/>
    <Class IRI="#A"/>
</ObjectPropertyRange>
<InverseObjectProperties>
    <ObjectProperty IRI="#rA"/>
    <ObjectProperty IRI="#rB"/>
</InverseObjectProperties>
```

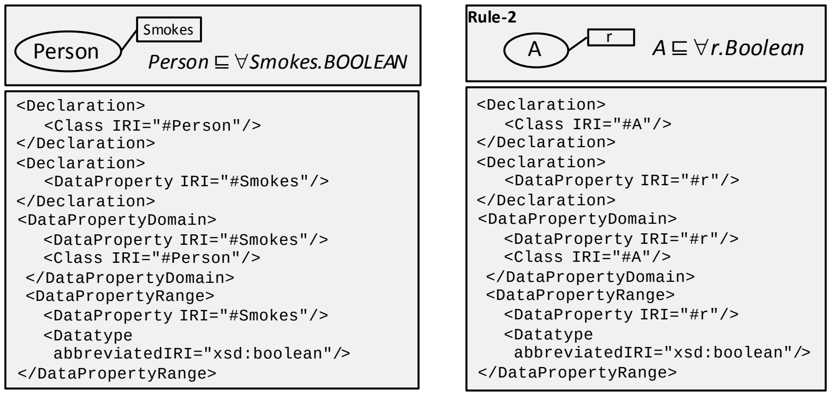
```
<DataPropertyDomain>
  <ObjectProperty IRI="#rAB"/>
  <Class IRI="#A"/>
</DataPropertyDomain>

<DataPropertyRange>
  <DataProperty IRI="#rAB"/>
  <Datatype
  abbreviatedIRI="rdfs:Literal"/>
</DataPropertyRange>
```

(a) (b)

Figure 3.3: Binary and N-ary relationship

3.3.2 Unary Relationship:

Although unary roles are allowed in ORM, they cannot be represented directly in SROIQ/OWL 2. The example below (Fig. 3.4.a) shows an ORM unary relationship which means that a person may smoke; or in FOL [J07b]: $\forall x\ (Smokes(x) \rightarrow Person(x))$. The population of this fact is either true or false. In order to map ORM unary roles into SROIQ/OWL 2, we introduce a new class called BOOLEAN, which takes one of two values: {TRUE, FALSE}. Each ORM unary fact is seen as a binary relationship in SROIQ/OWL 2, where the second concept is BOOLEAN. Rule-2 in Fig. 3.4.b presents the general case mapping of ORM unary fact types to SROIQ/OWL 2.


Person
Smokes
$Person \sqsubseteq \forall Smokes.BOOLEAN$
Rule-2
A
r
$A \sqsubseteq \forall r.Boolean$

```
<Declaration>
   <Class IRI="#Person"/>
</Declaration>
<Declaration>
   <DataProperty IRI="#Smokes"/>
</Declaration>
<DataPropertyDomain>
   <DataProperty IRI="#Smokes"/>
   <Class IRI="#Person"/>
 </DataPropertyDomain>
 <DataPropertyRange>
   <DataProperty IRI="#Smokes"/>
   <Datatype
    abbreviatedIRI="xsd:boolean"/>
</DataPropertyRange>
```

```
<Declaration>
   <Class IRI="#A"/>
</Declaration>
<Declaration>
   <DataProperty IRI="#r"/>
</Declaration>
<DataPropertyDomain>
   <DataProperty IRI="#r"/>
   <Class IRI="#A"/>
 </DataPropertyDomain>
 <DataPropertyRange>
   <DataProperty IRI="#r"/>
   <Datatype
    abbreviatedIRI="xsd:boolean"/>
</DataPropertyRange>
```

(a) (b)

Figure 3.4: Unary Relationship

3.4 Subtypes

ORM subtypes are proper subtypes. That is, as discussed earlier, we say that B is a proper subtype of A if and only if the population of B is always a subset of the population of A, and $A \neq B$, i.e., loops are illegal in ORM. However, because the focus of this thesis is to establish a graphical representation of OWL 2, we adopt the semantics of OWL 2, whose subtype relation, *SubClassOf*, is not a *proper* subtype (i.e., loops are allowed). Thus, for example, the axiom "Female is a Person" is written using OWL 2 semantics as: $Woman \sqsubseteq Person$, without the need to add the axiom ($Person \not\sqsubseteq Woman$), as opposed to following ORM semantics. Rule-3 presents the mapping of the general case of subtypes using SROIQ/OWL 2.

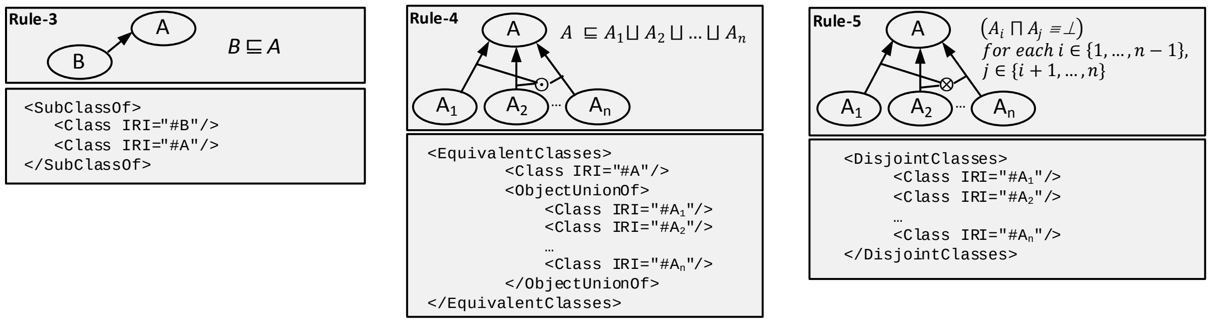
3.5 Total Constraint

Total constraint (⨀) in ORM is equivalent to *UnionOf* construct in OWL 2. This rule means that the population of the supertype is exactly the union of the population of all subtypes constrained by this rule. Rule-4 represents the formalization of the general case.

3.6 Exclusive Constraint

ORM exclusive constraint (⨂) is equivalent to *DisjointClasses* construct in OWL 2. It means that the population of the subtypes constraint by this rule is pairwise distinct, i.e., the intersection of the population of each pair of the subtypes must be empty. Rule-5 represents the formalization of the general case of the exclusive constraint.

Please note that in most of the examples and general case mappings in this thesis, the OWL 2 declarations are omitted due to space limitations.


Rule-3
A
B
$B \sqsubseteq A$
Rule-4
A
$A \sqsubseteq A_1 \sqcup A_2 \sqcup \ldots \sqcup A_n$
A_1
A_2
A_n
Rule-5
A
$(A_i \sqcap A_j \equiv \perp)$
$for\ each\ i \in \{1, \ldots, n-1\},$
$j \in \{i+1, \ldots, n\}$
A_1
A_2
A_n

```
<SubClassOf>
   <Class IRI="#B"/>
   <Class IRI="#A"/>
</SubClassOf>
```

```
<EquivalentClasses>
        <Class IRI="#A"/>
        <ObjectUnionOf>
            <Class IRI="#A1"/>
            <Class IRI="#A2"/>
            …
            <Class IRI="#An"/>
        </ObjectUnionOf>
</EquivalentClasses>
```

```
<DisjointClasses>
     <Class IRI="#A1"/>
     <Class IRI="#A2"/>
     …
     <Class IRI="#An"/>
</DisjointClasses>
```

(a) (b) (c)

Figure 3.5: Formalization of ORM Subtype, Total Constraint and Exclusive Constraint.

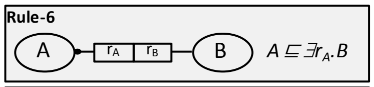
3.7 Mandatory Constraints

3.7.1 Role mandatory:

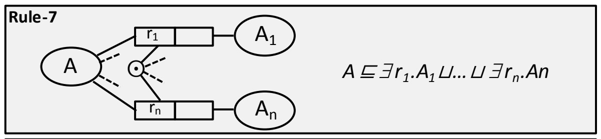
ORM’s Role mandatory constraint is depicted as a dot on the line connecting a role with an object type. Rule-6 of Fig. 3.6.a presents the general case formalization of this rule. Each instance of the object-type A must be related to at least one instance of object-type B by the relation r_A/r_B. In OWL 2, this rule is mapped using *ObjectSomeValuesFrom/ DataSomeValuesFrom* constructs as shown in Fig. 7.a. *ObjectSomeValuesFrom* is used when B is object-type, where as *DataSomeValuesFrom* is used when B is value-type. OWL 2 qualified minimum cardinality (*ObjectMinCardinality/DataMinCardinality)* construct can also be used to restrict the population of A to at least relate with one instance of B. However, the usage of *ObjectSomeValuesFrom/ DataSomeValuesFrom* is more elegant than *MinCardinality*.

3.7.2 Disjunctive Mandatory:

The Disjunctive Mandatory constraint is used to constrain a set of two or more roles connected to the same object type. It means that each instance of the object type’s population must play at least one of the constrained roles. In the general case presented in Fig. 3.6.b along with its formalization, each instance of object-type A must play at least one of the constrained roles: (r_1,…,r_n) related to the instances of classes A_1, … A_n respectively.



```
<EquivalentClasses>
  <Class IRI="#A"/>
  <ObjectSomeValuesFrom>
    <ObjectProperty IRI="#rA"/>
    <Class IRI="#B"/>
  </ObjectSomeValuesFrom>
</EquivalentClasses>
```


Rule-7
A
r1
rn
A1
An
$A \sqsubseteq \exists r_1.A_1 \sqcup ... \sqcup \exists r_n.An$

```
<EquivalentClasses>
  <Class IRI="#r1.A1"/>
  <ObjectSomeValuesFrom>
     <ObjectProperty IRI="#r1"/>
     <Class IRI="#A1"/>
  </ObjectSomeValuesFrom>
</EquivalentClasses>
    …
<EquivalentClasses>
  <Class IRI="#rn.An"/>
  <ObjectSomeValuesFrom>
     <ObjectProperty IRI="#rn"/>
     <Class IRI="#An"/>
  </ObjectSomeValuesFrom>
</EquivalentClasses>
```

```
<EquivalentClasses>
  <ObjectUnionOf>
     <Class IRI="#r1.A1"/>
     …
     <Class IRI="#rn.An"/>
  </ObjectUnionOf>
  <Class IRI="#A"/>
</EquivalentClasses>
```

(a) (b)

Figure 3.6: Mapping of ORM Mandatory Constraints

3.8 Uniqueness Constraints

One can distinguish between three types of Uniqueness Constraints in ORM, namely, role uniqueness, predicate uniqueness, and external uniqueness.

3.8.1 Role Uniqueness:

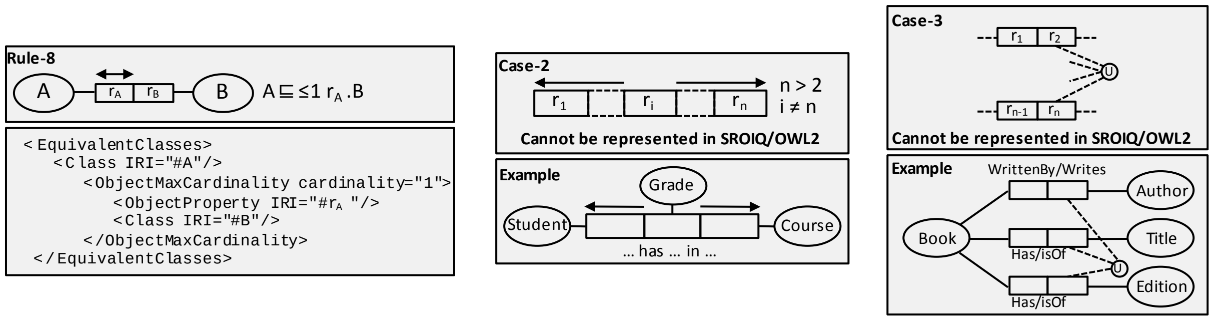
Role uniqueness is represented by an arrow spanning a single role in a binary relationship. Rule-8 of Fig. 3.7.a presents the general case mapping of this rule. This constraint means that each instance of an object-type A plays the relation r_A for at most one instance of B. Role uniqueness is mapped to OWL2 using qualified maximum cardinality (*ObjectMaxCardinality/DataMaxCardinality)* construct (restricted by '1').

3.8.2 Predicate Uniqueness:

This constraint is represented in ORM, as shown in Fig. 3.7.b, by an arrow spanning more than a role in an *n*-ary relationship. In the example shown in Fig. 3.7.b, in any instance of this relation, both *Student* and *Vehicle* must be unique together, i.e., functional dependency. Although this constraint can be represented using First Order Logic (FOL) and DLR_{idf} Description Logic [J07a, J07b], it cannot be represented using SROIQ/OWL 2.

3.8.3 External Uniqueness:

As shown in Fig. 3.7.c, ORM External Uniqueness constraint (denoted by 'U'), applies to roles from different relationships. The roles that participate in such a uniqueness constraint uniquely refer to an object-type. For example (Fig. 3.7.c), the combination of (Author, Title, Edition) must be unique, i.e., different values of (Author, Title, Edition) refer to different books. This constraint cannot be represented using SROIQ/OWL 2.



```
< EquivalentClasses>
   <Class IRI="#A"/>
      <ObjectMaxCardinality cardinality="1">
         <ObjectProperty IRI="#rA "/>
         <Class IRI="#B"/>
      </ObjectMaxCardinality>
 </EquivalentClasses>
```

(a) (b) (c)

Figure 3.7: Uniqueness Constraints

3.9 Frequency Constraints

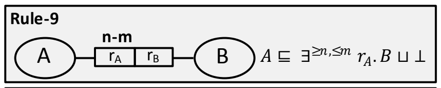
We distinguish between frequency constraints that span (1) a single role, which we call ‘Role Frequency’ constraints and (2) multiple roles, which we call ‘Multiple-Role Frequency’ constraints.

3.9.1 Role Frequency:

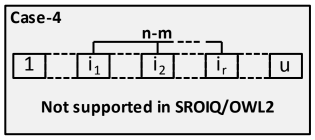
A frequency constraint (*min-max*) on a role is used to specify the number of occurrences that this role can be played by its object-type. Fig. 3.8.a depicts the general case formalization of this rule. This constraint means that role r_A is played by the object-type A for a number of occurrences between *n* and *m*. We map this constraint to OWL2 by using the qualified number restrictions of OWL 2 *ObjectMinCardinality/DataMinCardinality* and *ObjectMaxCardinality/DataMaxCardinality* constructs.

3.9.2 Multiple-Role Frequency:

A multiple-role frequency constraint spans more than one role (Figure 3.8.b). This constraint means that, in the population of the constraint relationship, the constraint roles must be played together by the related object-types for a number of occurrences between *n* and *m*. Multiple-role Frequency Constraint cannot be formalized in Description Logic [J07b] and OWL 2.



```
<ObjectPropertyRange>
  <ObjectProperty IRI="#rA"/>
  <ObjectMinCardinality cardinality="n">
    <ObjectProperty IRI="#rA"/>
    <Class IRI="#B"/>
  </ObjectMinCardinality>
</ObjectPropertyRange
<ObjectPropertyRange>
  <ObjectProperty IRI="#rA"/>
  <ObjectMaxCardinality cardinality="m">
     <ObjectProperty IRI="#rA"/>
     <Class IRI="#B"/>
  </ObjectMaxCardinality>
</ObjectPropertyRange>
```

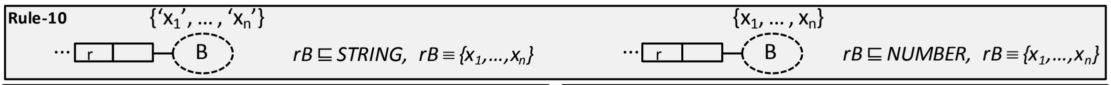


(a) (b)

Figure 3.8: Frequency Constraints

3.10 Value Constraint

The value constraint in ORM indicates the possible set of values (i.e., instances) that an object-type can be populated with. A value constraint on an object-type A is denoted as a set of values $\{x_1, x_2, \dots, x_n\}$ depicted near an object type. Value constraints can be declared only on ORM Lexical Object Types (LOT), which are depicted as dotted-line ellipses, and the values should be well-typed, i.e., their data types should be either *String* such as {'hi', '98', 'it'} or *Number* such as {3,4,5}. Notice that quotes are used to distinguish string values from number values. It is worth noting that OWL 2 supports many data types besides integer and string which is an advantage of OWL 2 over OWL 1 (which only supports integers and strings). OWL 2 *DataOneOf* construct is used to map the Value constraints (Fig. 3.9).


Rule-10
{'x1', ... , 'xn'}
r
B
$rB \sqsubseteq STRING,\ rB \equiv \{x_1,\dots,x_n\}$
{x1, ... , xn}
r
B
$rB \sqsubseteq NUMBER,\ rB \equiv \{x_1,\dots,x_n\}$

```
< DataPropertyRange>
  <DataProperty IRI="#rB"/>
    <DataOneOf>
      <Literal datatypeIRI="&xsd;string"> x1 </Literal>
      <Literal datatypeIRI="&xsd;string"> x2 </Literal>
          . . .
      <Literal datatypeIRI="&xsd;string"> xn </Literal>
    </DataOneOf>
 </DataPropertyRange>
```

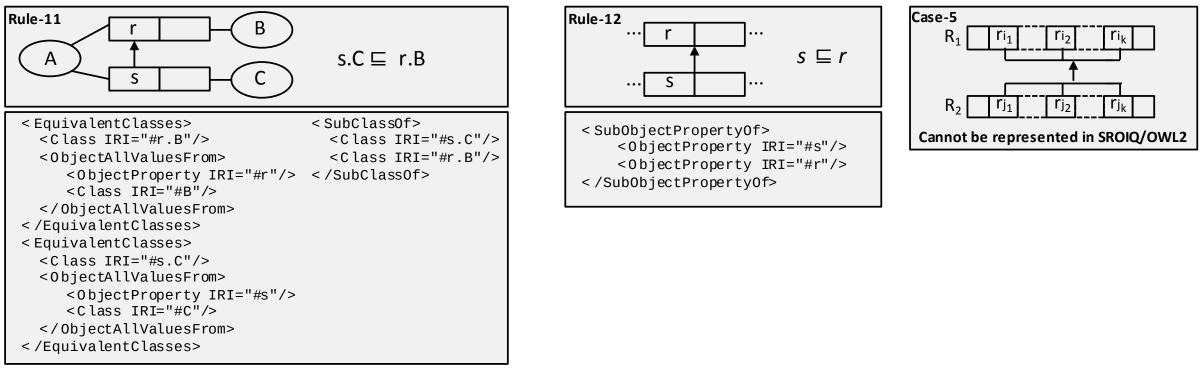
```
< DataPropertyRange>
  <DataProperty IRI="#rB"/>
    <DataOneOf>
      <Literal datatypeIRI="&xsd;int"> x1 </Literal>
      <Literal datatypeIRI="&xsd;int"> x2 </Literal>
          . . .
      <Literal datatypeIRI="&xsd;int"> xn </Literal>
    </DataOneOf>
 </DataPropertyRange>
```

Figure 3.9: Value Constraints

3.11 Subset Constraint

The subset constraint (→) between two roles is used to restrict the population of these roles so as one is a subset of the other. Fig. 3.10.a (Rule-11) depicts the general case mapping into SROIQ/OWL 2. It shows that all instances of A which plays the role*'s'* must also play the role *‘r’*. Rule-12 formalizes the case of subset constraint between two relations: the set of tuples of the subsuming relation is a subset of the tuples of the subsumed relation.

ORM also allows subset constraints between tuples of roles (not necessarily contiguous) as shown in case-5, where each *i*th and *j*th roles must have the same type. The population of the set of the *j*th roles is a subset of the population of the set of the *i*th roles. However, this last case cannot be represented in SROIQ/OWL 2.



```
< EquivalentClasses>
  <Class IRI="#r.B"/>
  <ObjectAllValuesFrom>
     <ObjectProperty IRI="#r"/>
     <Class IRI="#B"/>
  </ObjectAllValuesFrom>
< /EquivalentClasses>
< EquivalentClasses>
  <Class IRI="#s.C"/>
  <ObjectAllValuesFrom>
     <ObjectProperty IRI="#s"/>
     <Class IRI="#C"/>
  </ObjectAllValuesFrom>
< /EquivalentClasses>
```

```
< SubClassOf>
  <Class IRI="#s.C"/>
  <Class IRI="#r.B"/>
< /SubClassOf>
```

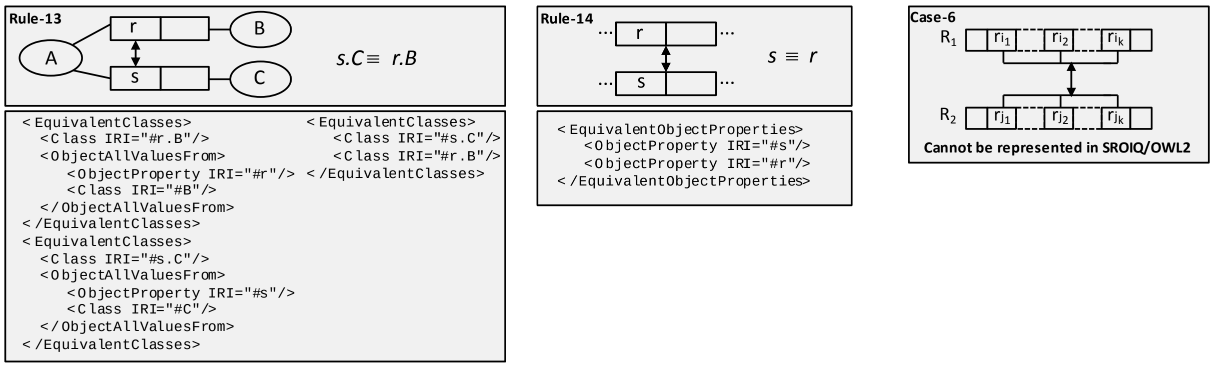
```
< SubObjectPropertyOf>
    <ObjectProperty IRI="#s"/>
    <ObjectProperty IRI="#r"/>
< /SubObjectPropertyOf>
```

(a) (b) (c)

Figure 3.10: Subset Constraints

3.12 Equality Constraint

Similar to the subset constraint, the equality constraint (↔) between roles and relations are mapped as shown in rules 13 and 14 (Fig. 3.11) respectively.



```
< EquivalentClasses>
  <Class IRI="#r.B"/>
  <ObjectAllValuesFrom>
     <ObjectProperty IRI="#r"/>
     <Class IRI="#B"/>
  </ObjectAllValuesFrom>
< /EquivalentClasses>
< EquivalentClasses>
  <Class IRI="#s.C"/>
  <ObjectAllValuesFrom>
     <ObjectProperty IRI="#s"/>
     <Class IRI="#C"/>
  </ObjectAllValuesFrom>
< /EquivalentClasses>
```

```
< EquivalentClasses>
    <Class IRI="#s.C"/>
    <Class IRI="#r.B"/>
< /EquivalentClasses>
```

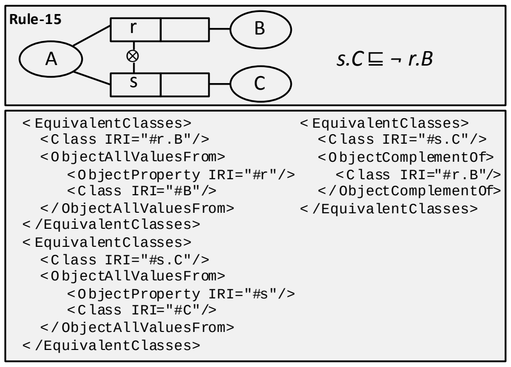
```
< EquivalentObjectProperties>
    <ObjectProperty IRI="#s"/>
    <ObjectProperty IRI="#r"/>
< /EquivalentObjectProperties>
```

(a) (b) (c)

Figure 3.11: Equality Constraints

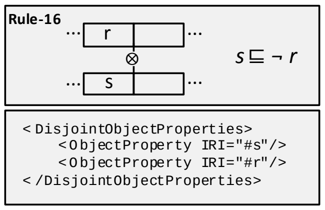
3.13 Exclusion Constraint

Similar to the subset and equality constraints, the exclusion constraint (⊗) between roles and relations are mapped as shown in rules 15 and 16 (Fig.3.15) respectively. OWL 2 construct (DisjointObjectProperty) is a new feature of OWL 2 which states that two roles are disjoint to each other (It is representation in SROIQ is “Dis(s,r)”).

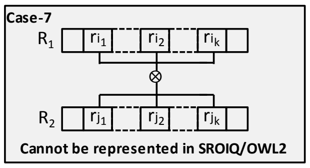


```
<EquivalentClasses>
  <Class IRI="#r.B"/>
  <ObjectAllValuesFrom>
     <ObjectProperty IRI="#r"/>
     <Class IRI="#B"/>
  </ObjectAllValuesFrom>
</EquivalentClasses>
<EquivalentClasses>
  <Class IRI="#s.C"/>
  <ObjectAllValuesFrom>
     <ObjectProperty IRI="#s"/>
     <Class IRI="#C"/>
  </ObjectAllValuesFrom>
</EquivalentClasses>
```

```
<EquivalentClasses>
  <Class IRI="#s.C"/>
  <ObjectComplementOf>
    <Class IRI="#r.B"/>
  </ObjectComplementOf>
</EquivalentClasses>
```



```
<DisjointObjectProperties>
    <ObjectProperty IRI="#s"/>
    <ObjectProperty IRI="#r"/>
</DisjointObjectProperties>
```



(a) (b) (c)

Figure 3.12: Exclusion Constraints

3.14 Ring Constraints

ORM allows ring constraints to be applied to a pair of roles (i.e., on binary relations) that are connected directly to the same object-type, or indirectly via super types. Six types of ring constraints are supported by ORM as illustrated in what follows.

OWL 2 supports Reflexive, Irreflexive, and Asymmetric object properties as a new feature in addition to Symmetric and Transitive that are supported by OWL 1.

3.14.1 Symmetric (sym):

This constraint states that if a relation holds in one direction, it also holds on the other. Fig. 3.13.a (Rule-17) depicts the general case formalization using SROIQ/OWL2.

3.14.2 Asymmetric (as):

Asymmetric constraint is the opposite of the symmetric constraint. If a relation holds in one direction, it cannot hold on the other. Fig. 3.13.b (Rule-18) depicts the general case formalization using SROIQ/OWL2.

3.14.3 Antisymmetric (ans):

The antisymmetric constraint is also an opposite of the symmetric constraint, but not exactly the same as asymmetric. The difference is that all asymmetric relations must be irreflexive, which is not the case for antisymmetric. Fig. 3.13.c (Case-8) shows an example of this constraint in addition to the general case formalization in SROIQ. Note that, up to our knowledge, this constraint cannot be expressed in OWL 2 because one cannot express role complement in OWL 2.

3.14.4 Irreflexive (ir)

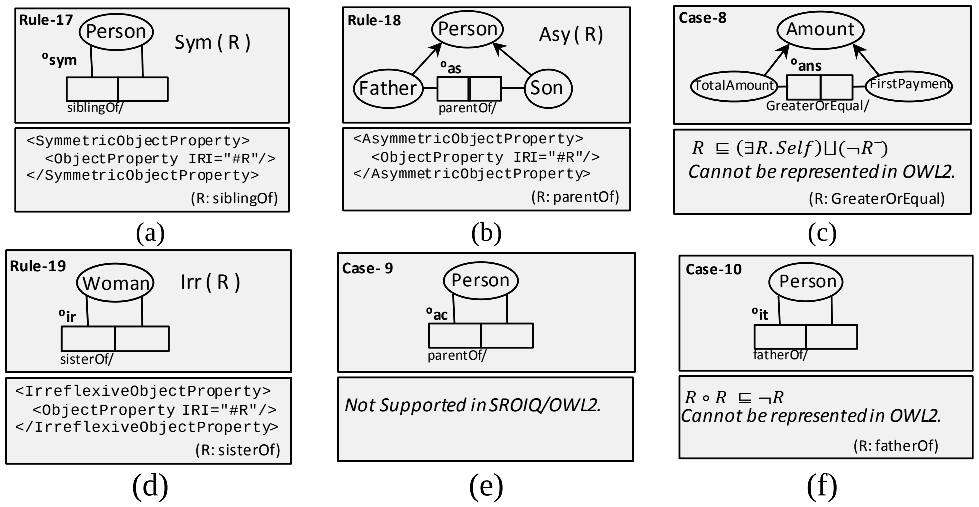
The Irreflexive ring constraint states that an object cannot participate in a relation with himself. For example a person cannot be the 'parent of' himself (cannot play the role of 'ParentOf' with himself). However, for example, one can love himself, i.e., the '*love*' relation is reflexive; a ring constraint supported by SROIQ/OWL but not by ORM. Fig. 3.13.d (Rule-19) depicts the general case formalization using SROIQ/OWL 2.

3.14.5 Acyclic (ac):

The acyclic constraint is a special case of the irreflexive constraint. For example, stating that the relation 'ParentOf' is acyclic means that a person cannot be directly (or indirectly through a chain) 'ParentOf' himself. In ORM, this constraint is preserved as a difficult constraint. "Because of their recursive nature, acyclic constraints maybe expensive or even impossible to enforce in some database systems"[J07a].Up to our knowledge, acyclicity with any depth on binary relations cannot be represented in SROIQ/OWL 2 (see Fig. 3.13.e).

3.14.6 Intransitive (it):

A relation R is intransitive over its population $iff\ \forall x, y, z\ [R(x, y) \land R(y, z) \rightarrow \neg R(x, z)]$. For example, if a Person X is FatherOf Person Y and Y is FatherOf Z, then it cannot be that X is FatherOF Z. See Fig. 3.13.f for the general case formalization in SROIQ. However, as in the case of the antisymmetric constraint, this constraint cannot be expressed in OWL2 because one cannot express role complement in OWL2.



```
<SymmetricObjectProperty>
  <ObjectProperty IRI="#R"/>
</SymmetricObjectProperty>
```
(R: siblingOf)

```
<AsymmetricObjectProperty>
  <ObjectProperty IRI="#R"/>
</AsymmetricObjectProperty>
```
(R: parentOf)

$R \sqsubseteq (\exists R.Self) \sqcup (\neg R^{-})$
Cannot be represented in OWL2.
(R: GreaterOrEqual)

```
<IrreflexiveObjectProperty>
  <ObjectProperty IRI="#R"/>
</IrreflexiveObjectProperty>
```
(R: sisterOf)

Not Supported in SROIQ/OWL2.

$R \circ R \sqsubseteq \neg R$
Cannot be represented in OWL2.
(R: fatherOf)

Figure 3.13: Ring Constraints

3.15 Objectified Relation

An objectified relation in ORM is a relation that is regarded as an object type, receives a new object-type name, and is depicted as a rectangle around the relation. In the example in Fig. 3.14.a, each (*Student*, *Vehicle*) enrollment is treated as an object-type that scores a *Grade*. In addition to this axiom, it is assumed that there must be a uniqueness constraint spanning all roles of the objectified relation, although it is not explicitly stated in the diagram. Objectified relations cannot be represented in SROIQ/OWL 2 as the additional uniqueness axiom cannot be represented in SROIQ/OWL 2. Refer to [J07a] for the representation of objectified relations in DLR description logic.

3.16 Syntatic Sugar for ORM/OWL 2

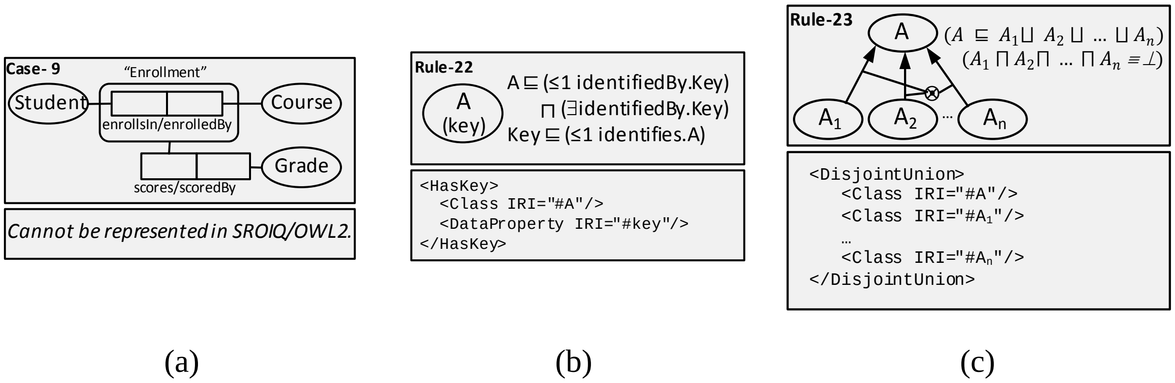
ORM and OWL 2 provide syntactic sugar formalization to ease the modeling of some constraints, such as identity, total and exclusive constraints which are illustrated below.

3.16.1 Identity Constraint:

This constraint determines the unique identifier of an object-type, and is usually specified inside the ellipse of the object-type (see Fig. 3.14.b). This constraint implies two constraints: role mandatory (section 4.5.1) and role uniqueness (section 4.6.1). This means that the object-type, specified as ‘key’ in Fig. 3.14.b, uniquely identifies the object-type A: i.e., it is mandatorily related to the object-type A and each instance of ‘key’ is related with at most one instance of A and each instance of A is related to at most one instance of ‘key’ . Although this constraint is not supported by SROIQ, it is mapped to OWL2 using the ‘*HasKey’* construct.

3.16.2 Total and Exclusive Constraints:

The Total and Exclusive constraints (section 3.5 and 3.6) often appear together in ORM. Instead of using two separate OWL2 constructs for their mappings (*ObjectUnionOf* and *DisjointClasses*), OWL2 provides one construct, namely, *DisjointUnion*, which fulfills both Total and Exclusive Constraints (Fig. 3.14.c).


Case- 9
“Enrollment”
Student
Course
enrollsIn/enrolledBy
Grade
scores/scoredBy
Cannot be represented in SROIQ/OWL2.
Rule-22
A (key)
A ⊑ (≤1 identifiedBy.Key) ⊓ (∃identifiedBy.Key)
Key ⊑ (≤1 identifies.A)
Rule-23
A
$(A \sqsubseteq A_1 \sqcup A_2 \sqcup \dots \sqcup A_n)$
$(A_1 \sqcap A_2 \sqcap \dots \sqcap A_n \equiv \bot)$
A_1
A_2
A_n
(a)
(b)
(c)

```
<HasKey>
  <Class IRI="#A"/>
  <DataProperty IRI="#key"/>
</HasKey>
```

```
<DisjointUnion>
   <Class IRI="#A"/>
   <Class IRI="#A1"/>
   …
   <Class IRI="#An"/>
</DisjointUnion>
```

Figure 3.14: (a) Objectified Relations, (b) Identity Constraint, (c) Total and Exclusive Constraints

Chapter Four

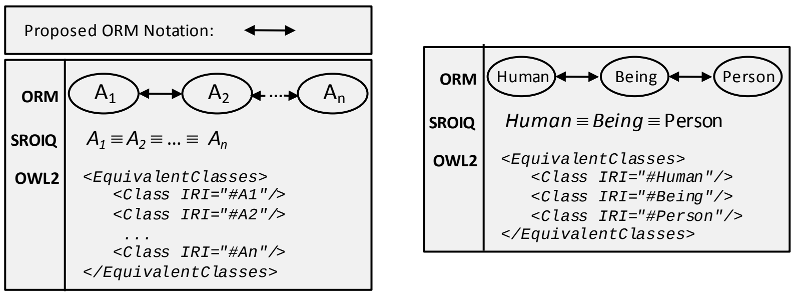
Extending ORM for Complete representation of OWL 2

4.1 Introduction

In chapter 3 of this thesis, we mapped all ORM constructs to SROIQ/OWL2. This allows one to build his/her ontology graphically using ORM and then map it automatically into OWL2. However, the current graphical notations of ORM are not sufficient to represent all OWL2 constructs (i.e., some OWL2 constructs cannot be represented graphically using ORM). In this section, we extend the ORM graphical notation to represent the eleven OWL2 constructs/expressions not covered currently by ORM. These OWL2 constructs are: (i) Equivalent Classes, (ii) Disjoint Classes, (iii) Intersection of Class Expressions, (iv) Class Complement, (v) Class Assertions, (vi) Individual Equality, (vii) Individual Inequality, (viii) Positive Object/Data Property Assertions, (ix) Negative Object/Data Property Assertions, (x) Reflexive, (xi) and Transitive. In addition we use already existing notations to represent Thing and Nothing Classes , and also Top and Bottom Object/Data Properties. Some of the OWL 2 expressions cannot be logically represented in a graphical format, so we use non-graphical notations for representing these OWL 2 expressions to completely cover OWL 2. The OWL 2 expressions that are not represented graphically and represented in non-notational expressions include (i) Datatypes, Facets, and Data Range Expressions, and (ii) Annotations. The graphical notations that we developed for representing the above mentioned eleven constructs in ORM were evaluated by means of a survey that included 31 practitioners in the field of ORM and OWL. After the evaluation process, final notations were chosen based on the results of the survey. In this way of complete representation of OWL 2 using ORM we can build an ontology graphically using ORM under the semantic of OWL 2. Using this mechanism we can combine both the simplicity of representing an ontology and the full functionality needed to check the correctness of the built ontology. The resulting OWL 2 ontology is supported by many sound and complete reasoners that can verify its correctness. Section 4.2 – 4.8 briefly discusses those eleven OWL2 constructs and our proposed graphical notations for their representation in ORM.

4.2 Equivalent Classes

An Equivalent Class constraint in SROIQ/OWL 2 states that all classes constrained by this rule are semantically equivalent to each other. This rule is expressed in OWL2 using the **EquivalentClasses** construct and in SROIQ description logic using the notation of '≡'. However, no notation is available in ORM for representing this construct, because ORM proposes that there is no need for equivalent objects within the same modeling case. However, because of the rapidly increasing usage of ontologies in data integration, the Equivalent Classes constraint is highly needed. The proposed notation for representing this constraint using ORM is shown in Fig. 4.1 along with a clarifying example. It's worth mentioning that this graphical notation was preferred by a (50%) of practitioners who participated in the evaluation survey.



$A_1 \equiv A_2 \equiv \ldots \equiv A_n$

```
<EquivalentClasses>
    <Class IRI="#A1"/>
    <Class IRI="#A2"/>
     ...
    <Class IRI="#An"/>
</EquivalentClasses>
```

$Human \equiv Being \equiv Person$

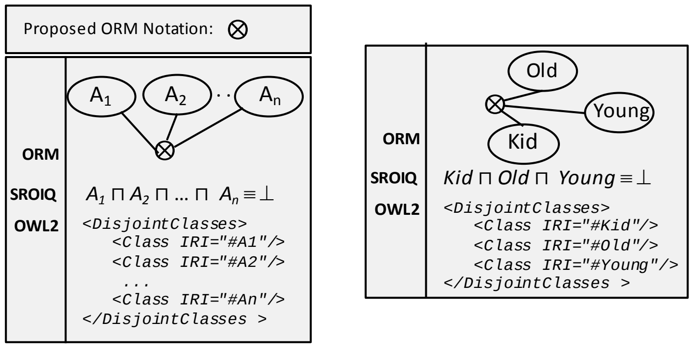
```
<EquivalentClasses>
    <Class IRI="#Human"/>
    <Class IRI="#Being"/>
    <Class IRI="#Person"/>
</EquivalentClasses>
```

(a) (b)

Figure 4.1: Equivalent Classes Constraint

4.3 Disjoint Classes

The population of all classes constrained by the Disjoint Classes constraint is pairwise distinct, i.e., the intersection of the population of each pair of the constrained classes must be empty. This rule exists in ORM. However, it is restricted to be used between subtypes that belong to the same supertype. As, in ORM, all objects within a modeling case are assumed to be disjoint with each other. This rule is expressed in OWL2 using the **DisjointClasses** construct. For representing this constraint in ORM, we propose to use the notation of (⊗), as shown in Fig. 4.2. It's worth mentioning that, from the three suggested graphical notations in the survey, this graphical notation was chosen by (64%) of practitioners who participated in the evaluation survey.



(a) SROIQ: $A_1 \sqcap A_2 \sqcap \ldots \sqcap A_n \equiv \bot$

```
<DisjointClasses>
   <Class IRI="#A1"/>
   <Class IRI="#A2"/>
    ...
   <Class IRI="#An"/>
</DisjointClasses >
```

(b) SROIQ: $Kid \sqcap Old \sqcap Young \equiv \bot$

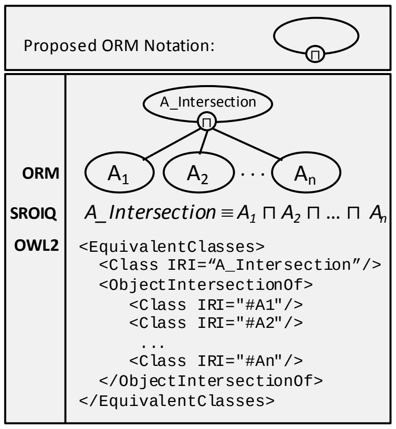
```
<DisjointClasses>
   <Class IRI="#Kid"/>
   <Class IRI="#Old"/>
   <Class IRI="#Young"/>
</DisjointClasses >
```

(a) (b)

Figure 4.2: Disjoint Classes Constraint

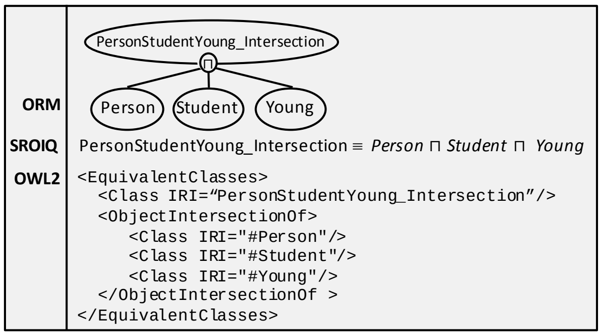
4.4 Intersection of Class Expressions

The intersection of classes A and B is all the individuals (instances) of A that are also instances of B but no other instances. This expression cannot be expressed currently in ORM. In OWL2, **ObjectIntersectionOf** expression is used to represent the intersection of classes, whereas the notation of '⊓' is used for the SROIQ representation, as shown in Fig. 19. In ORM, we propose to use the notation of '⊓' inside a bubble located on the edge of an ellipse (see Fig. 4.3). This bubble connects directly via lines to the classes to be intersected. Inside the ellipse, the name of the class equivalent to the intersection expression is assigned. Note that the intersection bubble can be connected directly to many classes: the classes which are being intersected. No other relations are allowed to be connected through the bubble. However, the ellipse (which represents the equivalent class of the intersection expression) can be connected via any relation to any other class.



$A\_Intersection \equiv A_1 \sqcap A_2 \sqcap \ldots \sqcap A_n$

```
<EquivalentClasses>
  <Class IRI="A_Intersection"/>
  <ObjectIntersectionOf>
     <Class IRI="#A1"/>
     <Class IRI="#A2"/>
      ...
     <Class IRI="#An"/>
  </ObjectIntersectionOf>
</EquivalentClasses>
```



$PersonStudentYoung\_Intersection \equiv Person \sqcap Student \sqcap Young$

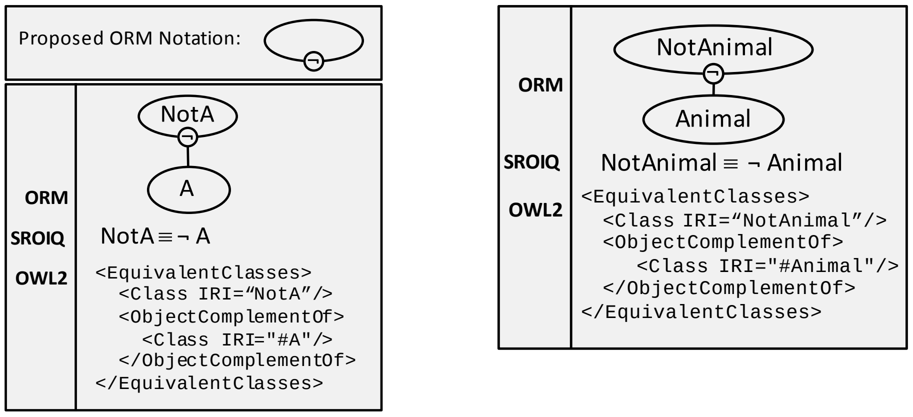
```
<EquivalentClasses>
  <Class IRI="PersonStudentYoung_Intersection"/>
  <ObjectIntersectionOf>
     <Class IRI="#Person"/>
     <Class IRI="#Student"/>
     <Class IRI="#Young"/>
  </ObjectIntersectionOf >
</EquivalentClasses>
```

(a) (b)

Figure 4.3: Intersection of Class Expressions

4.5 Class Complement

The complement of class *A* refers to the population of the Universe of Discourse (UoD) that is not of A (i.e., the instances outside of A). This expression cannot be expressed currently in ORM. In OWL2, **ObjectComplementOf** expression is used to represent class complement, whereas the notation of '¬' is used for the SROIQ representation, as shown in Fig. 4.4. In ORM, similar to the Intersection of Class Expressions discussed above, we propose to use the notation of '¬' inside a bubble located at the edge of an ellipse (see Fig. 4.4). This bubble connects directly via a line to the class to be complemented. Inside the ellipse, the name of the class equivalent to the complement expression is assigned. Note that the complement bubble can only be connected directly to one class: the class which is being complemented. No other relations are allowed to be connected through the bubble. However, the ellipse (which represents the equivalent class of the complement expression) can be connected via any relation to any other class.



```
<EquivalentClasses>
  <Class IRI=“NotA”/>
  <ObjectComplementOf>
    <Class IRI="#A"/>
  </ObjectComplementOf>
</EquivalentClasses>
```

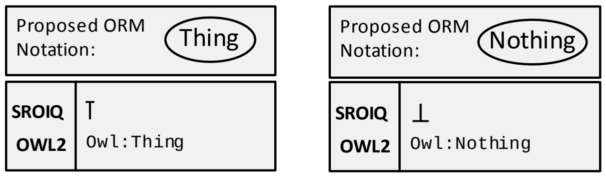
```
<EquivalentClasses>
  <Class IRI=“NotAnimal”/>
  <ObjectComplementOf>
     <Class IRI="#Animal"/>
  </ObjectComplementOf>
</EquivalentClasses>
```

(a) (b)

Figure 4.4: Class Complement

4.6 Universal and Empty Classes

Two classes in OWL 2 are predefined, namely, the classes “owl:Thing” and ”owl:Nothing”. “owl:Thing” is referred to as the Universal Class while “owl:Nothing” is called the Empty Class. The extension of class “owl:Thing” (i.e., its instances) is the set of all instances in the Universe of Discourse (UoD). Thus, all classes are subclasses (i.e., subtypes) of this universal class. On the other hand, the extension of class ”owl:Nothing“ is the empty set. Consequently, the empty class is a subclass of all classes. In SROIQ, the universal and empty classes correspond to the Top (⊤) and Bottom (⊥) concepts, respectively. These two predefined OWL 2 classes are not currently defined in the ORM notation. We propose to express these two classes using the regular ORM object-type notation as show in Fig. 4.5. Note that this proposed graphical representation was not evaluated in the survey because of its intuitiveness. That is, the representation of these two predefined OWL2 classes is no different than the representation of any other OWL2 class; all OWL2 classes are mapped in ORM as object-types.

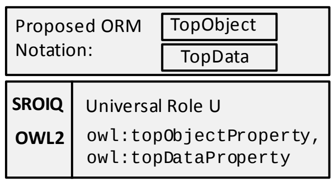


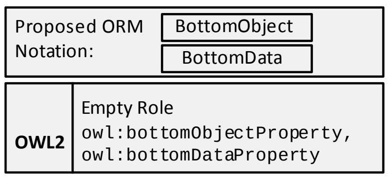
(a) (b)

Figure 4.5: Thing and Nothing Classes

4.7 Universal and Empty Object/Data Properties

OWL 2 provides two built-in object/data properties with predefined semantics: (i) `owl:topObjectProperty/` `owl:topDataProperty` (Universal Property), (ii) `owl:bottomObjectProperty/` `owl:bottomDataProperty` (Empty Property). The universal object property connects all possible pairs of object-type instances (individuals) while the universal data property connects all possible object-type instances (individuals) with all values (literals). On the contrary, the empty property neither connects any pair of object-type instances (individuals) nor connects any object-type instance (individual) with a value (literal). Unlike other variants of Description Logic, SROIQ does support Universal and Empty roles. These predefined OWL 2 properties are not currently defined in ORM. We propose to express these notations using the regular ORM role notation as show in Fig. 4.6. Note that this proposed graphical representation was not evaluated in the survey because of its intuitiveness. That is, the representation of these predefined OWL2 properties is no different than the representation of any other OWL2 property; all OWL2 properties are mapped as ORM roles.



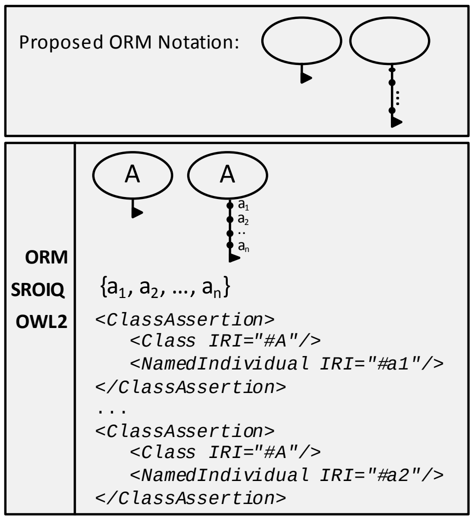


(a) (b)

Figure 4.6: Top and Bottom Object/Data Properties

4.8 Class Assertions

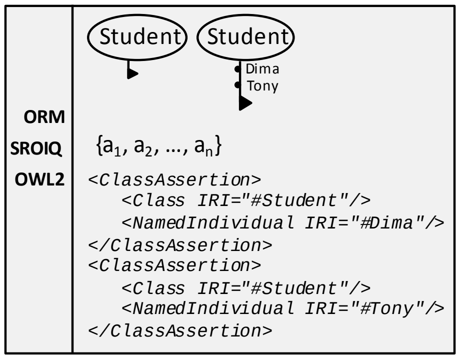
The **ClassAssertion** axiom of OWL2 allows one to state that an individual is an instance of a particular class [MPP09]. In SROIQ, this is done in the assertion component, i.e., the ABox which contains instantiations of the axioms specified in the TBox. In ORM, we propose to use the notation depicted in Fig. 4.7. This notation provides the user the flexibility to show/hide the instances of a particular class. In our implementation of this notation in DogmaModeler (discussed in chapter 6), clicking on the (▶) symbol at the bottom of the ellipse expands/collapses the set of instances. The user specifies how many instances he/she prefers to be shown.



$\{a_1, a_2, \ldots, a_n\}$

```
<ClassAssertion>
   <Class IRI="#A"/>
   <NamedIndividual IRI="#a1"/>
</ClassAssertion>
...
<ClassAssertion>
   <Class IRI="#A"/>
   <NamedIndividual IRI="#a2"/>
</ClassAssertion>
```

(a)



$\{a_1, a_2, \ldots, a_n\}$

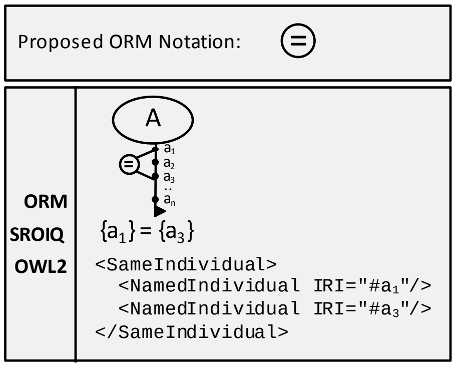
```
<ClassAssertion>
   <Class IRI="#Student"/>
   <NamedIndividual IRI="#Dima"/>
</ClassAssertion>
<ClassAssertion>
   <Class IRI="#Student"/>
   <NamedIndividual IRI="#Tony"/>
</ClassAssertion>
```

(b)

Figure 4.7: Class Assertions

4.9 Individual Equality

The OWL2 individual equality axiom **SameIndividual** states that all of the individuals constrained by this rule are equal to each other. In SROIQ, this axiom is expressed in the assertion component, i.e., the ABox, using the notation of '=' between individuals. In ORM, we propose to use the notation of (⊜) to express individual equality. This notation is used between class instances as shown in Fig. 4.8.



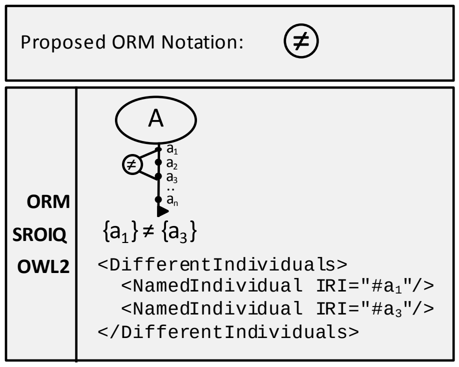
$\{a_1\} = \{a_3\}$

```
<SameIndividual>
  <NamedIndividual IRI="#a1"/>
  <NamedIndividual IRI="#a3"/>
</SameIndividual>
```

Figure 4.8: Individual Equality

4.10 Individual Inequality

The OWL 2 individual inequality axiom **DifferentIndividuals** states that all of the individuals constrained by this rule are different from each other. In SROIQ, this axiom is expressed in the assertion component, i.e., the ABox, using the notation of '$\neq$' between individuals. In ORM, we propose to use the notation of (≠) to express individual inequality. This notation is used between class instances as shown in Fig. 4.9.



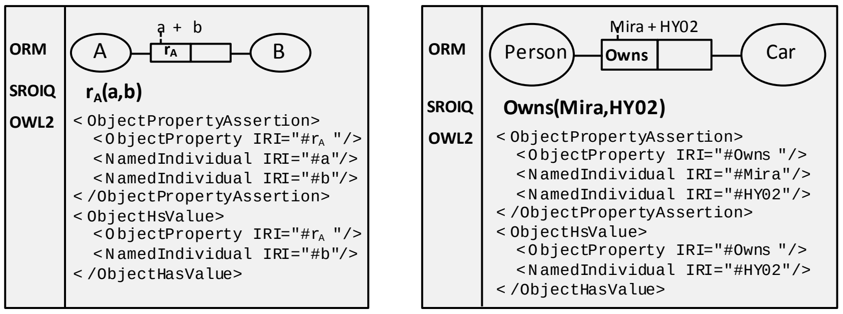
```
<DifferentIndividuals>
  <NamedIndividual IRI="#a1"/>
  <NamedIndividual IRI="#a3"/>
</DifferentIndividuals>
```

Figure 4.9: Individual Inequality

4.11 Property Assertions

4.11.1 Positive Object/Data Property Assertion

The OWL2 **Object/DataPropertyAssertion** states that the individuals or individuals and values constrained by this rule are related to each other by the specified object or data property. In SROIQ, this axiom is expressed in the assertion component, i.e., the RBox, using the notation of ‘+’ between individuals or individuals and values. In ORM, we propose to use the notation of (+) to express the relation between individuals. This notation is used between class instances that are related with each others as shown in Fig. 4.10.



```
< ObjectPropertyAssertion>
  <ObjectProperty IRI="#rA "/>
  <NamedIndividual IRI="#a"/>
  <NamedIndividual IRI="#b"/>
< /ObjectPropertyAssertion>
< ObjectHsValue>
  <ObjectProperty IRI="#rA "/>
  <NamedIndividual IRI="#b"/>
< /ObjectHasValue>
```

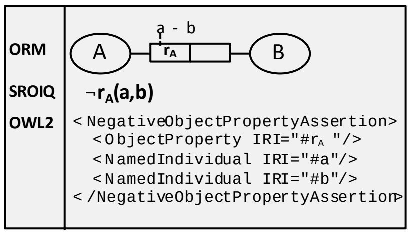
```
< ObjectPropertyAssertion>
  <ObjectProperty IRI="#Owns "/>
  <NamedIndividual IRI="#Mira"/>
  <NamedIndividual IRI="#HY02"/>
< /ObjectPropertyAssertion>
< ObjectHsValue>
  <ObjectProperty IRI="#Owns "/>
  <NamedIndividual IRI="#HY02"/>
< /ObjectHasValue>
```

(a) (b)

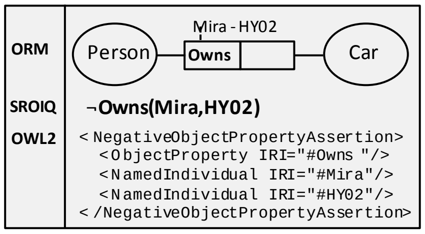
Figure 4.10: Positive Object Property Assertion

4.11.2 Negative Object/Data Property Assertion

The OWL2 **NegativeObject/DataPropertyAssertion** states that the individuals or individuals and values constrained by this rule are *not* related to each other by the specified object or data property. In SROIQ, this axiom is expressed in the assertion component, i.e., the RBox, using the notation of ‘-’ between individuals or individuals and values. In ORM, we propose to use the notation of (-) to express the relation between individuals. This notation is used between class instances that are *not* related with each others as shown in Fig. 4.11.



```
< NegativeObjectPropertyAssertion>
  <ObjectProperty IRI="#rA "/>
  <NamedIndividual IRI="#a"/>
  <NamedIndividual IRI="#b"/>
< /NegativeObjectPropertyAssertion>
```



```
< NegativeObjectPropertyAssertion>
  <ObjectProperty IRI="#Owns "/>
  <NamedIndividual IRI="#Mira"/>
  <NamedIndividual IRI="#HY02"/>
< /NegativeObjectPropertyAssertion>
```

(a) (b)

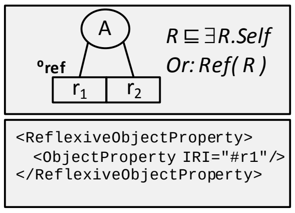
Figure 4.11: Negative Object Property Assertion

4.12 Reflexive (ref)

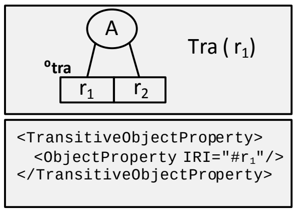
This constraint states that an object can participate in a relation with himself. For example, a ‘person’ can love himself (he can play the role of ‘loves’ with himself). Reflexive is not used in ORM, Where it can be an extension to ORM notations as we want to reflect the semantic of OWL 2 into ORM. Fig. 4.12.a depicts the general case extension of this constraint using ORM, where this notation is selected according to similar notations of ring constraints shown in Fig. 3.16.

4.13 Transitive (tra)

A relation R is transitive over its population $iff\ \forall x,y,z\ [R(x,y) \wedge R(y,z) \rightarrow\ R(x,z)]$. For example, if a Person X is FrindOf Person Y and Y is FriendOf Z, then X is FriendOf Z. Transitive does not exist in ORM, Where it can be an extension to ORM notations as we want to reflect the semantic of OWL 2 into ORM. Fig. 4.12.b depicts the general case extension of this constraint using ORM, where this notation is selected according to similar notations of ring constraints shown in Fig. 3.16.



```
<ReflexiveObjectProperty>
  <ObjectProperty IRI="#r1"/>
</ReflexiveObjectProperty>
```



```
<TransitiveObjectProperty>
  <ObjectProperty IRI="#r1"/>
</TransitiveObjectProperty>
```

(a) (b)

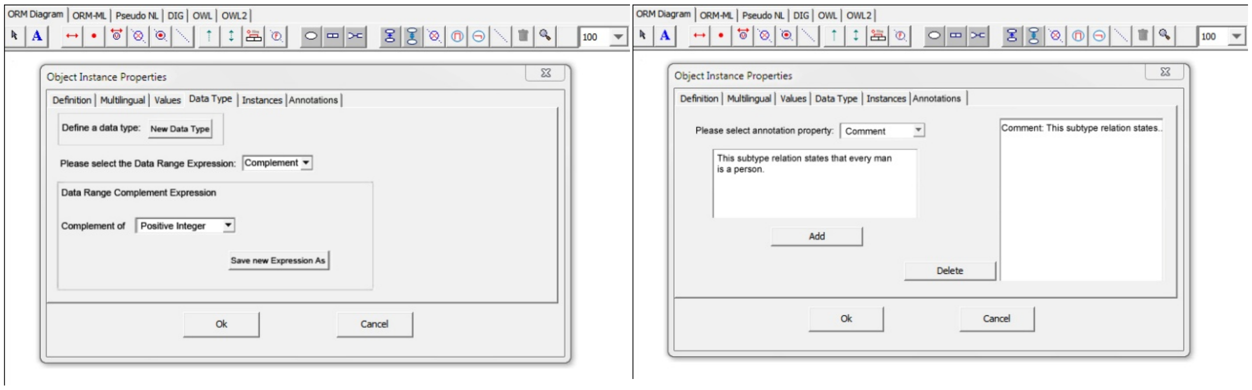
Figure 4.12: Extended Ring Constraints

4.14 Non Notational Expressions

In the previous subsections, we have introduced our proposed *graphical* extension of ORM. However, this extension does not cover all OWL 2 expressions graphically. The OWL 2 expressions not expressed graphically can be put into two categories; (i) Datatypes, Facets, and Data Range Expressions, and (ii) Annotations.

OWL 2 introduces many built in datatypes in addition to the "Number" and "String" datatypes defined in ORM, such as Real, Rational, Double, Float, Boolean, Binary, etc. In addition, it introduces the so-called "Facets", borrowed from XML Schema Datatypes, which are simply a group of restrictions used to specify new user-defined datatypes. For example, one can define a new datatype for a person's age, called *personage*, by constraining the datatype *Integer* to values between 0 and 150 (inclusive) using the *minInclusive* facet. Furthermore, OWL 2 supports advanced uses of datatypes, called Data Range Expressions, which include expressions similar to those used with OWL 2 Classes such as complement, union and intersection. For example, assuming we have already defined a datatype called *minorAge*, we can define the datatype *majorAge* by complementing the datatype *minorAge* and then intersecting it with the datatype *personAge*. All OWL 2 Datatypes, Facets, and Data Range Expressions are not expressed graphically. Instead, we introduce the "Datatypes Guided Editor" which aids the user in specifying datatypes and defining new datatypes and data range expressions. Fig. 4.13.a depicts a simplified Datatypes Guided Editor as implemented in our DogmaModeler tool.

The last category of our non-notational expressions is OWL2's "Annotations". In OWL 2, annotations are used to describe parts of the OWL 2 ontology or the ontology itself. For example, an annotation can be simply a human-readable comment on an axiom of an ontology. E.g., one can add the following comment on the subtype relation between Man and Person: "This subtype relation states that every man is a person". Other annotation properties include: Label, SeeAlso, VersionInfo, etc. Annotations can be specified using the "Annotations Guided Editor". Fig. 4.13.b depicts a snapshot of our implemented annotations editor part of DogmaModeler.



Define a data type:
Please select the Data Range Expression: Complement
Data Range Complement Expression
Complement of: Positive Integer

Please select annotation property: Comment
This subtype relation states that every man is a person.
Comment: This subtype relation states..

(a) (b)

Figure 4.13: The Datatypes and Annotations Guided Editors of DogmaModeler

An illustration of full representation for mapping OWL 2 into ORM is shown in Appendix B.

4.15 Use Case

One of the most important use cases of the extended ORM notation introduced above is the case of integration. Consider, for example, the case of ontology integration in Fig. 4.14. The figure depicts two sample ontologies expressed in ORM; the first ontology (Ontology-1) represents a part of the organization (non-natural person) ontology specifying, in particular, the *Company* and the *Local Government Unit* entities. The second ontology represents another part of the organization ontology, namely, the *Association* entity. Note that these two sample ontologies are based on the Palestinian Legal Person Ontology [DJF11] and thus are in harmony with the Palestinian law. However, what is depicted in Figure 4.14 is not a complete ontology and is only meant to be a sample demonstration of the usefulness of the newly proposed ORM notations.

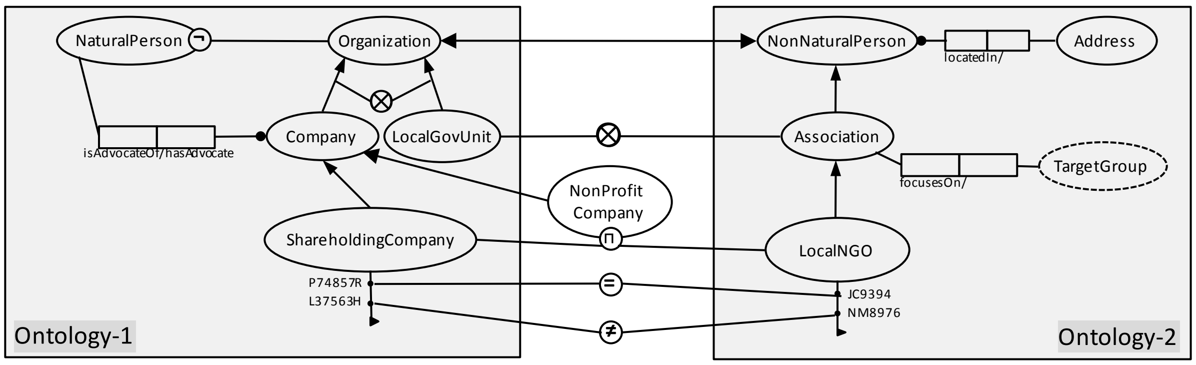


Figure 4.14: Use Case of the extended ORM notations.

Let us look at the usage of the new ORM notations in Ontology-1. In this ontology, the new notation is used in two places; (i) to express the class ‘Natural Person’ as the complement of the ‘Organization’ entity and (ii) to express two assertions of the ‘Shareholding Company’ entity. In Ontology-2, we also use class assertions to represent two ‘LocalNGO’ instances. For the purpose of integrating the two ontologies the following newly introduced notations are used:

i) *Equivalent Classes*, expressed as a double-headed arrow between ‘Organization’ and ‘Non-Natural Person’ entities, to express the fact that both entities are equivalent.

ii) *Disjoint Classes*, expressed using the notation of “⊗” between ‘LocalGovUnit’ and ‘Association’ to express the fact that both entities are disjoint.

iii) *Intersection of Class Expressions*, used to introduce a new entity, namely, the ‘Non Profit Company’ which includes all shareholding companies that are also registered as local NGOs. Note that, this type of companies does exist in Palestine; it includes private limited-liability companies that provide services to the society but whose profit is not allowed to be distributed among the partners.

iv) Individual Equality, expressed using the notation of (⊜) between the shareholding company (P74857R) and the Local NGO (JC9394). This means that the two identifiers refer to the same real-world entity. Notice the usage of the Individual Equality here for Entity Resolution/ Disambiguation: a much-used process to match different identifiers from different heterogeneous information systems that refer to the same entity.

v) Individual Inequality, expressed using the notation of (≠) and is used to state that the two instances constrained by this rule are not the same. In our example, this expression is also used for entity disambiguation by stating that that shareholding company (L37563H) and the local NGO (NM8976) refer to different real-world organizations.

The complete mapping of the ORM diagram in Fig. 4.14 into OWL2 is provided in Appendix A-2.

Chapter Five

Evaluation

5.1 Introduction

Evaluation is divided into two parts. For the first part of evaluation we discuss the evaluation of our work of mapping/formalizing ORM into OWL 2/SROIQ. In particular, we briefly discuss the means by which we evaluated our work and give some clarifying examples. For this evaluation, the last version (version 2) of RacerPro 2[14] was used as a description logic reasoning tool, especially because of its support of OWL 2. RacerPro provides an interface to query and reason about knowledge bases. A knowledge base in RacerPro consists of a T-Box and an A-Box. For each of the formalized ORM notations, its OWL 2 mapping was inserted into the RacerPro system in the T-Box of a Knowledge Base. After that, the knowledge base was populated with several A-Box assertions in ordered to perform various kinds of tests and queries over it.

For the second part, we evaluate our proposed ORM extension via a survey that was made to choose the most appropriate graphical notations. This survey involved practitioners in the fields of ORM and OWL 2.

5.2 Evaluation Process for mapping ORM into OWL 2

For each mapping work, tests were done to be sure of the correctness of the mapped OWL 2 construct. These tests include consistency, coherency, and instance checks in addition to

[14] http://www.racersystems.com/products/racerpro/users-guide-1-9-2-beta.pdf

several other checks depending on the individual construct to be tested. The consistency test checks whether the given Assertion Box is consistent with respect to the Terminology Box. An A-Box *A* is consistent with a T-Box *T iff* A-Box has a model *w.r.t.* T-Box. Otherwise, the A-Box is called inconsistent. Coherency (also called Satisfiability) can be divided into three tests: Concept Coherency, T-Box Coherency, and Ontology Coherency. Checking the satisfiability (coherency) of a concept *C* in a T-Box *T* means to check whether there exists a model *I* of *T* such that $C^I \neq \phi$. This is usually done by checking this concept for any possible contradictions in the T-Box. If the concept *C* is involved in a contradiction, this means that it cannot be satisfied. For the T-Box coherency; a T-Box *T* is said to be incoherent *iff* there exists an unsatisfiable concept in *T*. Similarly, an ontology *O* is incoherent *iff* its T-Box is incoherent. The Instance Retrieval test simply finds all individuals (instances) mentioned in an A-Box that are instances of a certain concept *C*. Different kinds of queries supported by the new query language (nRQL) of RacerPro 2.0 were used to retrieve the instances of classes within the needed ontology (instance checking) to check the correctness of the ontology and consequently the mapping itself. It is worth noting here that all A-Box tests and queries are written in nRQL (The New RacerPro Query Language), a query language for the RacerPro system that is capable of querying description logics, RDF(s), and OWL.

All possible cases of instance checking are taken into consideration to evaluate mapping correctness. In what follows, we illustrate the evaluation of mapping ORM into OWL 2 for each mapped construct.

5.2.1 Binary Relation (Rule 1):

A general case of Binary Relation is plotted and mapped into OWL 2 functional syntax (Fig. 5.1) consisting of two classes (objects) Person and Vehicle, and two relations Drives and DrivenBy. The instances that are inserted for classes Person and Vehicle are shown in Fig. 5.1. As an evaluation process, all possible cases of tests are taken into consideration to prove the correctness of the mapping as follows:

i) The domain of relation Drives which is expected to be class Person is checked and the right expected answer (Person) is obtained.

ii) The range of Drives which is expected to be class Vehicle is checked and the right expected answer (Vehicle) is obtained.

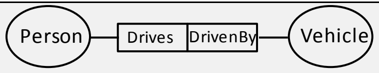
iii) Using the same way, the domain and range for relation DrivenBy which are expected to be Vehicle and Person respectively are checked and the right expected answers (Vehicle and Person) are obtained.

iv) The inverse of role Drives which is expected to be DrivenBy is checked and the right expected answer (DrivenBy) is obtained.

v) Instances of classes Person and Vehicle are retrieved and the right expected instances are obtained.

vi) Each instance of class Person which is related to the other instance of class Vehicle by the role Drives is retrieved and the right expected answer is obtained. The same is done for the role DrivenBy and the right expected answer is obtained. That was done to make sure that Drives is the inverse role of DrivenBy and vice versa.

All the preceding mentioned cases are shown in Figure 5.1.

OWL 2 Functional Syntax	**Checked Example**		

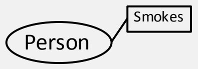
Declaration(NamedIndividual(:p11))
ClassAssertion(:Person :p11)
Declaration(NamedIndividual(:p12))
ClassAssertion(:Person :p12)
Declaration(NamedIndividual(:p13))
ClassAssertion(:Person :p13)
Declaration(NamedIndividual(:v11))
ClassAssertion(:Vehicle :v11)
Declaration(NamedIndividual(:v12))
ClassAssertion(:Vehicle :v12)
Declaration(NamedIndividual(:v13))
ClassAssertion(:Vehicle :v13)
	Type of Test	**nRQL query**	**Result**

	Domain	(role-domain |#Drives|)	:Person
		(role-domain |#DrivenBy|)	:Vehicle
	Range	(role-range |#Drives|)	:Vehicle
		(role-range |#DrivenBy|)	:Person
	Inverse	(role-inverse |#Drives|)	:DrivenBy
	Retrieve Person and Vehicle Instances	(retrieve(?x)(?x #Person))	:p13, :p12, :p11
		(retrieve(?x)(?x #Vehicle))	:v13, :v12,:v11
	Retrieve related Instances	(retrieve (?x ?y) (?x ?y #Drives))	(:p11, :v11),(:p12, :v12),(:p13, :v13)
		(retrieve(?x?y)(?x?y #DrivenBy))	(:v11, :p11),(:v12, :p12), (:v13, :p13)

Figure 5.1: Tests performed on OWL 2 mapping of ORM binary role notation (Rule 1)

5.2.2 Unary Relation (Rule 2):

An example (Figure 5.2) in OWL 2 is created to formalize the Unary Relation of ORM. The example contains a class named Person and a data property named smokes with Boolean range, then we asserted two instances for class Person related by data property smokes where one of these instances set to be true by assigning "1" to it and the other set to false by assigning "0" to it . When we retrieve the instances (Table 5.1) of property smokes, it gives us the population of class person which plays data property range of type Boolean.

OWL 2 Functional Syntax	**Checked Example**		

Declaration(Class(:Person))
Declaration(DataProperty(:smokes))
SubDataPropertyOf(:smokes owl:topDataProperty)
DataPropertyRange(:smokes xsd:boolean)
Declaration(NamedIndividual(:ahmad))
ClassAssertion(:Person :ahmad)
DataPropertyAssertion(:smokes :ahmad "1"^^xsd:boolean)
Declaration(NamedIndividual(:sahar))
ClassAssertion(:Person :sahar)
DataPropertyAssertion(:smokes :sahar "0"^^xsd:boolean)
DifferentIndividuals(:sahar :ahmad)
DataPropertyAssertion(:smokes :ahmad "1"^^xsd:boolean)
DataPropertyAssertion(:smokes :sahar "0"^^xsd:boolean)
	Type of Test	**nRQL query**	**Result**

	Retrieve Instances	(retrieve(?x(datatype-fillers(|#smokes|?x)))(?x (some |#smokes|)))	(((:ahmad) ((:datatype-fillers (:smokes)) (#T)))(((:sahar) ((:datatype-fillers (:smokes))(#T))))
	Consistency Check	(abox-consistent? file://unaryrelation.owl)	True

Figure 5.2: Tests performed on OWL 2 mapping of ORM unary role notation (Rule 2)

5.2.3 Subtype (Rule 3):

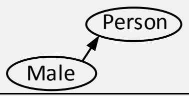
The OWL 2 file which is mapped from ORM is loaded into RacerPro 2.0. The file includes two classes Man and Person (where Man is a SubClass of Person) is created (Figure 5.3). Instances for both classes are inserted. Two types of tests were performed, namely, concept subsumption and instance retrieval. In short, the tests we have done on the subtype relation can be summarized as follows. After inserting the OWL 2 mapping of the ORM in Fig. 5.3 as a T-Box in a knowledge base, we entered a set of assertions into the A-Box. These assertions were: one assertion of the object-type *Person* (i.e., Mira) and two assertions of the object-type *Male* (Issa and Abbas). Two concept consumption tests were performed; the first to check whether the object-type *Male* subsumes *Person*, resulting in ‘True’, as expected. The second verified whether *Person* subsumes *Male*, resulting in Nil (False), also as expected. When we retrieved the instances of *Person*, all instances of *Male* (Issa and Ahmad) appeared in the result set in addition to the instance of *Person* (Mira); a result which we expected because of the subtype relation.

All possible cases for ontology checking are taken into consideration to evaluate mapping correctness as follows:

i) Concept subsumption is checked where class Person subsumes class Man and the expected result (which is true) is obtained. The inverse is done where does class Male subsumes class Person and the expected result (which is false) is obtained.

ii) The instances of class Person are retrieved and the expected results are the instances already asserted for class Person (super class) in addition to the instances of class Male (subclass). These results are obtained.

iii) The instances of class Male are retrieved and those are expected to be only the instances assigned to class Male and this result is obtained.

OWL 2 Functional Syntax	**Checked Example**		

SubClassOf(:Male :Person)
Declaration(NamedIndividual(:Issa))
Declaration(NamedIndividual(:ahmad))
Declaration(NamedIndividual(:Mira))
ClassAssertion(:Male :Issa)
ClassAssertion(:Male :Ahmad)
ClassAssertion(:Person :Mira)
	Type of Test	**nRQL query**	**Result**

	Concept Subsumption	?(concept-subsumes? |#Person| | #Male|)	True
		?(concept-subsumes?|#Male| | #Person|)	Nil (i.e., False)
	Retrieve Instances	?(retrieve(?x) (?x #Person))	Mira, Issa, Ahmad
		?(retrieve(?x) (?x #Male))	Issa, Ahmad

Figure 5.3: Tests performed on OWL 2 mapping of ORM subtype role notation (Rule 3)

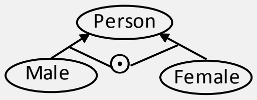
5.2.4 Total Constraint (Rule 4):

An example (Fig. 5.4) that contains class Person which is equivalent to class Man or Female is created. Instances for the three classes are asserted.
For Total Constraint, all possible cases (Fig. 5.4) are taken into consideration as follows:

i) Checking if class Person (super class) is equivalent to the union of classes Male and Female, and the expected result which is true is obtained.

ii) The instances of class Person are retrieved and those are expected to be the already assigned instances for Person in addition to instances of class Male or Female. The expected result is obtained.

iii) The instances of subclasses Male and Female are expected to be just the instances assigned to each class and the result is as expected.

OWL 2 Functional Syntax	Checked Example		

Declaration(Class(:Male))
Declaration(Class(:Person))
EquivalentClasses(:Person ObjectUnionOf(:Female :Male))
Declaration(Class(:Female))
Declaration(NamedIndividual(:ahmad))
ClassAssertion(:Male :ahmad)
Declaration(NamedIndividual(:issa))
ClassAssertion(:Person :issa)
Declaration(NamedIndividual(:wafa))
ClassAssertion(:Female :wafa)
	Type of Test	**nRQL query**	**Result**

	Concept-Equivalence	(concept-equivalent? |#Person|(or |#Male| |#Female|))	True
	Retrieve Instances	(retrieve(?x)(?x #Male))	(((:ahmad)))
		(retrieve(?x)(?x #Female))	(((:wafa)))
		(retrieve(?x)(?x #Person))	(((:issa))((:ahmad))((:wafa)))

Figure 5.4: Tests performed on OWL 2 mapping of ORM total constraint (Rule 4)

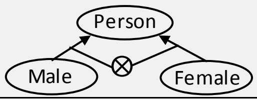
5.2.5 Exclusive Constraint (Rule 5):

An example (Figure 5.5) that contains classes Male and Female which are disjointed is created. The same instance is created for both classes. For Exclusive Constraint, the cases (Fig. 5.5) are :

i) Disjoint is checked between classes Male and Female and the result is true as expected true.

ii) The equivalence of class Person to the union of classes Male and Female is checked and the result is false as expected.

iii) The instance ahmad (as an example) is assigned to both classes Male and Female, where in this assignment the Abox consistency is violated to ensure that classes Male and Female are disjoint. The result is as expected inconsistent Abox.

OWL 2 Functional Syntax	Checked Example		

Declaration(Class(:Male))
Declaration(Class(:Female))
Declaration(Class(:Person))
SubClassOf(:Male :Person)
SubClassOf(:Female :Person)
DisjointClasses(:Male :Female)
Declaration(NamedIndividual(:ahmad))
ClassAssertion(:Male :ahmad)
ClassAssertion(:Female :ahmad)
Declaration(NamedIndividual(:wafa))
ClassAssertion(:Female :wafa)
	Type of Test	**nRQL query**	**Result**

	Concept-Disjoint	?(concept-disjoint? |#Male| |#Female|)	True
	Concept-Equivalence	?(concept-equivalent? |#Person|(or |#Male| |#Female|))	Nil
	Consistency Check	? (abox-consistent? file:// /disjointclasses.owl) (with assertions that <u>do not</u> violate the constraint)	True
		? (abox-consistent? file://disjointclasses.owl) (with assertions that <u>do</u> violate the constraint)	Nil

Figure 5.5: Tests performed on OWL 2 mapping of ORM exclusive constraint (Rule 5)

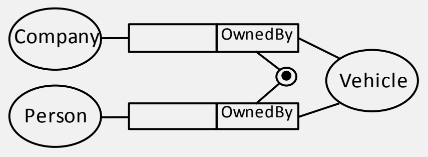
5.2.6 Role Mandatory (Rule 6):

To represent the ORM Role Mandatory constraint in OWL 2, we use the construct “ObjectSomeValuesFrom” that represents the extensional quantifier in SROIQ. Example of section 5.2.8 (Figure 5.7) includes the representation of Role Mandatory constraint. The relation “OwnedBy” is populated by relating the instances of class “Company” to that of class “Vehicle”. When checking the consistency of ABox, the result was that the ABox is consistent as the constraint Mandatory (represented by “ObjectSomeValuesFrom”) is achieved.

5.2.7 Disjunctive Mandatory (Rule 7):

An example (Figure 5.6) that contains the classes and relations of Rule 7. Instances (created to prove the correctness of formalization) are asserted and related by OwnedByC and OwnedByP roles. When we check the coherency of TBox and consistency of ABox using RacerPro 2.0, it gives us true for both checks. The result is as expected since the inserted instances comply with the restriction " Disjunctive Mandatory " resulted that each instance of object-type “A” must play at least one of the constrained roles.

OWL 2 Functional Syntax	Checked Example		

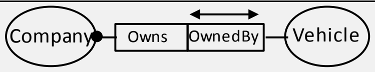
Declaration(Class(:OwnedBy.Company))
EquivalentClasses(:OwnedBy.Company
ObjectSomeValuesFrom(:OwnedByC :Company))
Declaration(Class(:OwnedBy.Person))
EquivalentClasses(:OwnedBy.Person
ObjectSomeValuesFrom(:OwnedByP :Person))
EquivalentClasses(:Vehicle
ObjectUnionOf(:OwnedBy.Company :OwnedBy.Person))
ObjectPropertyDomain(:OwnedByC :Vehicle)
ClassAssertion(:Company :jts.com)
ClassAssertion(:Person :mira)
ClassAssertion(:Vehicle :HYI30)
ObjectPropertyAssertion(:OwnedByP :HYI30 :mira)
ObjectPropertyAssertion(:OwnedByC :HYI30 :jts.com)
			

	Type of Test	**nRQL query**	**Result**
	Coherency Check	? (tbox-coherence? file://disjunctivemandatory.owl)	True
	Consistency Check	? (abox-consistent? file://disjunctivemandatory.owl)	True

Figure 5.6: Tests performed on OWL 2 mapping of ORM disjunctive mandatory constraint (Rule 7)

5.2.8 Role Uniqueness (Rule 8):

An example (Figure 5.7) contains classes Company and Vehicle which are related by the relation OwnedBy is created. The role OwnedBy is constrained Role Uniqueness. An Instance to prove the correctness of formalization is asserted and related by the relation OwnedBy. When we check the coherency of TBox and consistency of ABox using RacerPro 2.0, it gives us true for both checks. The result is as expected since the inserted instances comply with the restriction "max cardinality of 1" that constraints the role OwnedBy related to the class Vehicle to relate a one instance in the domain to maximum one instance in the range. But when we make an instance like “jts.com” in our example to be related to two instances “MAZ230” and “eng” by the object type property OwnedBy (restricted for the domain “Company” and the range “Vehicle” in our example). The restriction is achieved by using max cardinality of one. Relating one instance of the domain to two instances of the range by object type property “OwnedBy” violates the constraint max cardinality of one. The result is inconsistency of ABox. In the example mentioned above, we use the construct DifferentIndividuals to differentiate between the instances used semantically, where OWL 2 does not support Unique Name Assumption (UNA) [SWM04], which means that using different names for individuals does not mean that these individuals are different.

OWL 2 Functional Syntax	**Checked Example**		

Declaration(Class(:Vehicle))
Declaration(Class(:Vehicle))
EquivalentClasses(:Vehicle ObjectMaxCardinality(1 :OwnedBy :Company))
EquivalentClasses(:Company ObjectSomeValuesFrom(:Owns :Vehicle))
Declaration(ObjectProperty(:OwnedBy))
ObjectPropertyDomain(:OwnedBy :Vehicle)
ObjectPropertyRange(:OwnedBy :Company)
Declaration(NamedIndividual(:HYI30))
ClassAssertion(:Vehicle :HYI30)
Declaration(NamedIndividual(:MAZ230))
ClassAssertion(:Vehicle :MAZ230)
Declaration(NamedIndividual(:jts.com))
ClassAssertion(:Company :jts.com)
ObjectPropertyAssertion(:OwnedBy :HYI30 :bis.com)
DifferentIndividuals(:MAZ230 :HYI30)
DifferentIndividuals(:bis.com :HYI30)
DifferentIndividuals(:jts.com :MAZ230)
ObjectPropertyAssertion(:OwnedBy :HYI30 :jts.com)
ObjectPropertyAssertion(:OwnedBy :MAZ230 :jts.com)
	Type of Test	**nRQL query**	**Result**

	Consistency Check	? (abox-consistent? file:// uniqueness.owl) (with assertions that do not violate the constraint)	True
		? (abox-consistent? file://disjointclasses.owl) (with assertions that do violate the constraint)	Nill

Figure 5.7: Tests performed on OWL 2 mapping of ORM role uniqueness and mandatory constraints (Rule 5)

5.2.9 Role Frequency Constraints (Rule 9):

The same methodology is used as in (5.2.8) to evaluate the correctness of Role Frequency Constraints’ mapping. The example in the previous section is modified to represent this rule (Role Frequency Constraints), where this example contains classes “Company” and “Vehicle” related by the relation “Owns”. The role “Owns” is played by the object-type “Company” for a number of occurrences between 2 and 3. This is achieved by restricting “Owns” to play “Vehicle” between 2 and 3 occurrences using the qualified number restrictions of OWL 2 *ObjectMinCardinality* and *ObjectMaxCardinality* constructs. We instantiate “Company” with “ccs.com” and “Vehicle” with four different instances. Relating “ccs.com” with the four instances of “Vehicle” violating the restriction on object property “Owns”. When checking the consistency of ABox using Racer reasoned, the reasoned gives inconsistent ABox. This violating of used constraint and the result of inconsistency proves the correctness of using *owl:maxQualifiedCardinality* to map the max occurrence “m” of Role Frequency Constraints (ORM notation).

5.2.10 Value Constraint (Rule 10):

The same general format is used as in Fig. 3.9 to create a complete example which is loaded into RacerPro 2.0. The inserted values for data property range *rB* are X_1, X_2 and X_3. The cases (Fig 5.8) which are used to prove the correctness of Value Constraint formalizing are as follows:

i) The values of data property range are retrieved and the result is as expected.

ii) One of the assigned values for data type property range is retrieved and the result is true as expected.

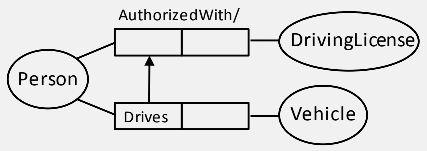
iii) A value which is not one of the assigned values for data type range is retrieved and the result is as expected. The result of retrieving this value is an error with a message "Undefined value" that assures that the values of data property range are only those values specified by *DataOneOf* construct.

Type of check	**nRQL query**	**Result**
Retrieve values	(retrieve(?x)(?x #rB))	(((:X3))((:X2)) ((:X1)))
Retrieve Check	(retrieve() (:X1 #rB))	True
	(retrieve() (:X4 #rB))	(:ERROR"Undefined value |#X4| in ABox |file://Value.owl|")

Figure 5.8: Cases of queries for checking value constraint correctness (Rule 10)

5.2.11 Subset Role (Rule 11):

An example (Figure 5.9) in OWL 2 that contains classes Person, Vehicle, DrivingLicense, AuthorizedWith.DrivingLicense and Drives.Vehicle, in addition to roles AuthorizedWith and Drives is created. Instances are inserted for classes Person, Vehicle, DrivingLicense. Also instances are inserted for object properties AuthorizedWith and Drives. All these insertions are made to apply instance checking to this ontology to prove the correctness of this ontology that represents the formalizing (formalizing subset role constraint of ORM using OWL 2).

OWL 2 Functional Syntax	**Checked Example**	 AuthorizedWith/ DrivingLicense Person Drives Vehicle	

Declaration(Class(:Drives.Vehicle))
EquivalentClasses(:Drives.Vehicle
ObjectSomeValuesFrom(:Drives :Vehicle))
SubClassOf(:drives.Person :owns.Person)
Declaration(Class(:AuthorizedWith.DrivingLicense))
EquivalentClasses(:AuthorizedWith.DrivingLicense
ObjectSomeValuesFrom(:AuthorizedWith
:DrivingLicense))
ObjectPropertyDomain(:Drives :Person)
ObjectPropertyRange(:Drives :Vehicle)
ObjectPropertyDomain(:AuthorizedWith :Person)
ObjectPropertyRange(:AuthorizedWith :DrivingLicense)
ClassAssertion(:Person :jawad)
ClassAssertion(:.Person :sahar)
ClassAssertion(:DrivingLicense :LC2011)
ClassAssertion(:Vehicle :HYI30)
ObjectPropertyAssertion(:AuthorizedWith :jawad :LC2011)
ObjectPropertyAssertion(:Drives :sahar :HYI30)
	Type of Test	**nRQL query**	**Result**

	Retrieve Instances	(retrieve(?x)(?x#Drives. Vehicle))	(:sahar)
		(retrieve(?x)(?x #AuthorizedWith.Drivi ngLicense))	((:jawad) (:sahar))

Figure 5.9: Tests performed on OWL 2 mapping of ORM role subset constraint (Rule 11)

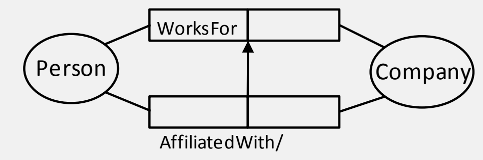
The cases for checking the correctness of formalizing as illustrated in Fig. 5.9 are:

i) The equivalent class Drives.Vehicle is checked to be a subset of equivalent class AuthorizedWith.DrivingLicense and the result is true as expected.

ii) The inserted instance sahar (as an example) to class Person is set to play role ‘Drives’ and it is checked if it also plays role ‘AuthorizedWith’ and the result is true as expected.

5.2.12 Subset Binary Role (Rule 12):

An example is created and loaded into RacerPro 2.0 by using its RacerPorter interface. The example includes classes Person and Car, in addition to object properties owns and drives where the role drives is a subset of the role owns. An instance named ahmad is asserted to class Person and plays the role drives for the instance honda200 of class Car and it is checked if it is at the same time plays the role owns and the result is true as expected (Fig. 5.10).

OWL 2 Functional Syntax	**Checked Example**		

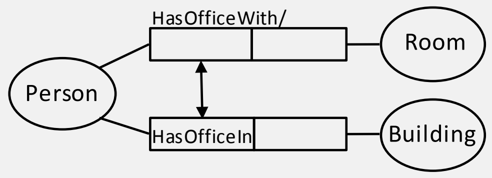
SubObjectPropertyOf(:AffiliatedWith :WorksFor)
SubObjectPropertyOf(:AffiliatedBy :Employes)
InverseObjectProperties(:WorksFor :Employes)
ObjectPropertyDomain(:WorksFor :Person)
ObjectPropertyRange(:ownedBy :Person)
InverseObjectProperties(:AffiliatedWith :AffiliatedBy)
ObjectPropertyDomain(:AffiliatedWith :Person)
ObjectPropertyRange(:WorksFor :Company)
ClassAssertion(:Person :ahmad)
ObjectPropertyAssertion(:WorksFor :ahmad :jts.com)
ClassAssertion(:Person :bassam)
ClassAssertion(:Company :jts.com)
ClassAssertion(:Company :bsi.com)
ObjectPropertyAssertion(:AffiliatedWith :bassam :bis.com)
	Type of Test	**nRQL query**	**Result**

	Retrieve Instances	(retrieve (?x ?y) (?x ?y #AffiliatedWith))	((:bassam) (:bis.com))
		(retrieve (?x ?y) (?x ?y #WorksFor))	(((:ahmad) (:jts.com)) ((:bassam) (:bis.com)))

Figure 5.10: Tests performed on OWL 2 mapping of ORM binary role constraint (Rule 12)

5.2.13 Equality Role (Rule 13):

An example (Figure 5.11) is created which demonstrates an equality between the equivalent classes expressions HasOfficeWith.Room and HasOfficeIn.Building and one instances are inserted for each equivalent class expression. After testing the instances of the two class expressions, each class expression contains both instances as a result of role equality.

OWL 2 Functional Syntax	**Checked Example**		

Declaration(Class(:HasOfficeWith.Room))
EquivalentClasses(:HasOfficeWith.Room ObjectSomeValuesFrom(:HasOfficeWith :Room))
Declaration(Class(:HasOfficeIn.Building))
EquivalentClasses(:HasOfficeIn.Building ObjectSomeValuesFrom(:HasOfficeIn :Building))
ObjectPropertyDomain(:HasOfficeWith :Person)
ObjectPropertyRange(:HasOfficeWith :Room)
ObjectPropertyDomain(:HasOfficeIn :Person)
ObjectPropertyRange(:HasOfficeIn :Building)
EquivalentClasses(:HasOfficeWith.Room :HasOfficeIn.Building)
ClassAssertion(:HasOfficeWith.Room :rajee)
ClassAssertion(:Person :rajee)
ClassAssertion(:Person :zaher)
ObjectPropertyAssertion(:HasOfficeWith :rajee :R101)
ObjectPropertyAssertion(:HasOfficeIn :zaher :IT)
ClassAssertion(:HasOfficeIn.Building :zaher)
	Type of Test	**nRQL query**	**Result**

	Retrieve Instances	(retrieve(?x)(?x #HasOfficeWith.Room))	((:rajee) (:zaher))
		(retrieve(?x)(?x #HasOfficeIn.Building))	((:rajee) (:zaher))

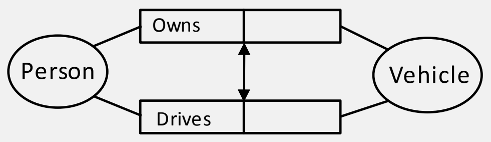
Figure 5.11: Tests performed on OWL 2 mapping of ORM equality role constraint (Rule 13)

5.2.14 Equality Binary Role (Rule 14):

An example (Fig. 5.12) is used for the purpose of mapping correctness. This example is written in OWL 2 functional syntax. The example includes classes Vehicle and Person, in addition to object properties Owns (inverse of OwnedBy) and Drives (inverse of DrivenBy) and these roles are set to be equivalent to each other. Instances for classes Person and Vehicle, which are related by drives relation, are inserted.
For this rule (Equality Binary Role), all possible cases (Fig. 5.12) are taken into consideration as follows:

i) The instances of class Person and their consequences of instances of class Vehicle, which are related by the role Owns, are retrieved and, as expected, they are the same as the instances of class Person and their consequences of class Vehicle playing the role Drives.

ii) The inverse case is done where the instances of class Vehicle and their consequences of instances for class Person related by the role drives and owns are retrieved and the result is as expected.

OWL 2 Functional Syntax	**Checked Example**		

InverseObjectProperties(:drivenBy :drives)
ObjectPropertyDomain(:drivenBy :Vehicle)
ObjectPropertyRange(:drivenBy :Person)
EquivalentObjectProperties(:drives :owns)
ObjectPropertyDomain(:drives :Person)
ObjectPropertyRange(:drives :Vehicle)
InverseObjectProperties(:owns :ownedBy)
ObjectPropertyDomain(:ownedBy :Vehicle)
ObjectPropertyRange(:ownedBy :Person)
ObjectPropertyDomain(:owns :Person)
ObjectPropertyRange(:owns :Vehicle)
ClassAssertion(:Person :ahmad)
ClassAssertion(:Vehicle :honda200)
ClassAssertion(:Vehicle :volvo100)
ClassAssertion(:Person :sahar)
ObjectPropertyAssertion(:drives :ahmad :honda200)
ObjectPropertyAssertion(:drives :sahar :volvo100)
	Type of Test	**nRQL query**	**Result**

	Retrieve Instances	(retrieve (?x ?y) (?x ?y #drives))	(((:ahmad) (:honda200)) ((:sahar) (:volvo100)))
		(retrieve (?x ?y) (?x ?y #owns))	(((:ahmad) (:honda200)) ((:sahar) (:volvo100)))
		(retrieve (?x ?y) (?x ?y #drivenBy))	(((:ahmad) (:honda200)) ((:sahar) (:volvo100)))
		(retrieve (?x ?y) (?x ?y #ownedBy))	(((:honda200) (:ahmad)) ((:volvo100) (:sahar)))

Figure 5.12: Tests performed on OWL 2 mapping of ORM equality binary role constraint (Rule 14)

5.2.15 Exclusion Role (Rule 15):

An example in OWL 2 that contains classes Vehicle, Company, Person, OwnedBy.Company and OwnedBy.Person, in addition to roles OwnedByC and OwnedByP. Instances are inserted for classes Vehicle, Company and Person. Also, instances are inserted for object properties OwnedByC and OwnedByP. All these insertions are made to apply instance checking to this ontology to prove the correctness of this ontology that represents the mapping (mapping Exclusive Role from ORM into OWL 2). For Exclusive Role the cases are:

i) The equivalent class OwnedBy.Company is checked to be equivalent to the complement of equivalent class OwnedBy.Person and the result is true as expected.

ii) Consistency check is performed without violating exclusion constraint and the result is as expected consistent Abox with Tbox.

iii) The inserted instance jts.com to class Company is set to play both roles OwnedByC and OwnedByp to vaiolate the exclusion constraint and the result Abox is expected to be inconsistent as a result of role exclusion and the result is as expected (inconsistent Abox).

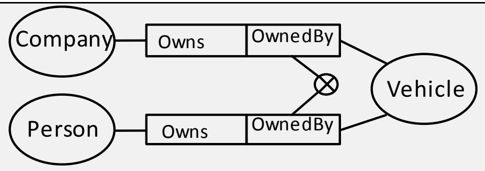
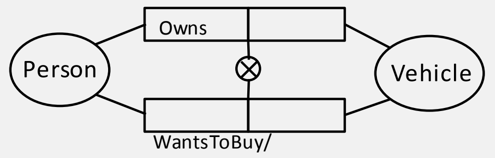
OWL 2 Functional Syntax	**Checked Example**	 Company Owns OwnedBy Person Owns OwnedBy Vehicle	
Declaration(Class(:OwnedBy.Company)) EquivalentClasses(:OwnedBy.Company ObjectComplementOf(:OwnedBy.Person)) EquivalentClasses(:OwnedBy.Company ObjectSomeValuesFrom(:OwnedByC :Company)) Declaration(Class(:OwnedBy.Person)) EquivalentClasses(:OwnedBy.Person ObjectSomeValuesFrom(:OwnedByP :Person)) ObjectPropertyDomain(:OwnedByC :Vehicle) ObjectPropertyDomain(:OwnedByP :Vehicle) ClassAssertion(:Person :mira) ClassAssertion(:Company :jts.com) ClassAssertion(:Vehicle :HYI30) ObjectPropertyAssertion(:OwnedByC :HYI30 :jts.com) ObjectPropertyAssertion(:OwnedByP :HYI30 :mira)	**Type of Test**	**nRQL query**	**Result**
	Concept-Equivalence	(concept-equivalent? |#OwnedBy.Company| (not |#OwnedBy.Person|))	True
	Consistency Check	? (abox-consistent? file:// exclusionrole.owl) (with assertions that do not violate the	True
		? (abox-consistent? file://exclusionrole.owl) (with assertions that do violate the constraint)	Nill

Figure 5.13: Tests performed on OWL 2 mapping of ORM exclusion role constraint (Rule 15)

5.2.16 Exclusion Binary Role (Rule 16):

An example is created and loaded into RacerPro 2.0 by using its RacerPorter interface. The example includes classes Person and Car, in addition to object properties owns and drives. An instance named ahmad is asserted to class Person and plays the role drives for the instance honda200 of class Car and at the same time this instance (ahmad) plays the role owns for the same instance honda200 of class Car. This assertion is expected to give inconsistency for Abox and this result is obtained as expected (inconsistent Abox). The result of inconsistency of ABox with TBox proves the mapping of Exclusion Binary Relation using OWL 2 construct (DisjointObjectProperties).

OWL 2 Functional Syntax	**Checked Example**		

InverseObjectProperties(:Owns :OwnedBy)
ObjectPropertyDomain(:Owns :Person)
ObjectPropertyRange(:Owns :Vehicle)
InverseObjectProperties(:WantsToBuy :BoughtBy)
ObjectPropertyDomain(:OwnedBy :Vehicle)
ObjectPropertyRange(:OwnedBy :Person)
ObjectPropertyDomain(:WantsToBuy :Person)
ObjectPropertyRange(:WantsToBuy :Vehicle)
ObjectPropertyDomain(:BoughtBy :Vehicle)
ObjectPropertyRange(:BoughtBy :Person)
DisjointObjectProperties(:Owns :WantsToBuy)
ClassAssertion(:Person :ahmad)
ClassAssertion(:Vehicle :honda200)
ObjectPropertyAssertion(:Owns :ahmad :honda200)
ObjectPropertyAssertion(:WantsToBuy :ahmad :honda200)
	Type of Test	**nRQL query**	**Result**

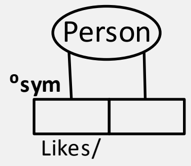
	Retrieve Instances	(retrieve (?x ?y) (?x ?y #Owns))	((:ahmad)(:honda200))
		(retrieve (?x ?y) (?x ?y #WantsToBuy))	((:ahmad) (:honda200
	Consistency Check	? (abox-consistent? file:// exclusionbinary.owl) (with assertions that <u>do not</u> violate the constraint)	True
		? (abox-consistent? file://exclusionbinary.owl) (with assertions that <u>do</u> violate the constraint)	Nill

Figure 5.14: Tests performed on OWL 2 mapping of ORM exclusion binary role constraint (Rule 16)

5.2.17 Symmetric Ring Constraint (Rule 17):

For Symmetric Ring Constraint, we assign an instance ahmad (Fig. 5.15) for the class Person that plays the role *Likes* for the instance issa, which is also assigned to class Person. We retrieve the instances related by the role likes and the result is as expected ahmad likes issa and issa likes ahmad and this achieves the symmetric constraint.

OWL 2 Functional Syntax	Checked Example		

Declaration(Class(:Person))
Declaration(ObjectProperty(:isLikedBy))
InverseObjectProperties(:isLikedBy :likes)
Declaration(ObjectProperty(:likes))
InverseObjectProperties(:isLikedBy :likes)
SymmetricObjectProperty(:likes)
ObjectPropertyDomain(:likes :Person)
ObjectPropertyRange(:likes :Person)
Declaration(NamedIndividual(:ahmad))
ClassAssertion(:Person :ahmad)
ObjectPropertyAssertion(:likes :ahmad :issa)
Declaration(NamedIndividual(:issa))
ClassAssertion(:Person :issa)
			

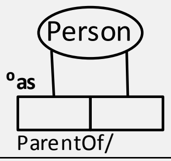
	Type of Test	**nRQL query**	**Result**
	Retrieve Instances	?(retrieve(?x?y)(?x?y #likes))	(((:ahmad) (:issa)) ((:issa) (:ahmad)))

Figure 5.15: Tests performed on OWL 2 mapping of ORM symmetric ring constraint (Rule 17)

5.2.18 Asymmetric Ring Constraint (Rule 18):

For Asymmetric Constraint, an instance ahmad is asserted for the class Person and plays the role *ParentOf* for an instance issa, and at the same time the symmetric relation is created where issa is made to play the role *ParentOf* for the instance ahmad (Fig. 5.16). When checking the consistency for the Abox, it is as expected inconsistent and this is true where the role ParentOf is defined as Asymmetric and as in the example ahmad is parent of issa, then issa cannot be parent of ahmad.

OWL 2 Functional Syntax	Checked Example		

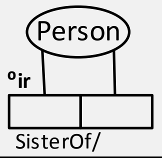
Declaration(Class(:Person))
Declaration(ObjectProperty(:SonOf))
InverseObjectProperties(:Son :ParentOf)
Declaration(ObjectProperty(:ParentOf))
AsymmetricObjectProperty(:ParentOf)
ObjectPropertyDomain(:ParentOf :Person)
ObjectPropertyRange(:ParentOf :Person)
Declaration(NamedIndividual(:ahmad))
ClassAssertion(:Person :ahmad)
ObjectPropertyAssertion(:ParentOf :ahmad :issa)
Declaration(NamedIndividual(:issa))
ClassAssertion(:Person :issa)
ObjectPropertyAssertion(:ParentOf :issa :ahmad)
			

	Type of Test	**nRQL query**	**Result**
	Retrieve Instances	?(retrieve(?x?y)(?x?y #ParentOf))	(((:ahmad) (:issa)) ((:issa) (:ahmad)))
	Consistency Check	? (abox-consistent? file:// asymmetric.owl) (with assertions that <u>do not</u> violate the constraint)	True
		? (abox-consistent? file://asymmetric.owl) (with assertions that <u>do</u> violate the constraint)	Nill

Figure 5.16: Tests performed on OWL 2 mapping of ORM asymmetric ring constraint (Rule 18)

5.2.19 Irreflexive Ring Constraint (Rule 19):

For Irreflexive Constraint, an instance mira of class Person is made to play the role *SisterOf* for instance maya which does not violate the irreflexive constraint and Abox is consistent. Also instance mira is set to play the role *SisterOf* for itself (Fig. 5.17). When checking the consistency for Abox, it gives us inconsistent Abox as expected, which is true since the role *SisterOf* is defined as irreflexive.

OWL 2 Functional Syntax	**Checked Example**		

Declaration(Class(:Person))
Declaration(ObjectProperty(:SisterOf))
InverseObjectProperties(:SisterOf : SisterOf)
Declaration(ObjectProperty(:SisterOf))
IrreflexiveObjectProperty(:SisterOf)
ObjectPropertyDomain(:likes :Person)
ObjectPropertyRange(:likes :Person)
Declaration(NamedIndividual(:mira))
ClassAssertion(:Person :maya)
Declaration(NamedIndividual(:maya))
ClassAssertion(:Person :maya)
ObjectPropertyAssertion(:SisterOf :mira :maya)
ObjectPropertyAssertion(:SisterOf :mira :mira)
	Type of Test	**nRQL query**	**Result**

	Retrieve Instances	?(retrieve(?x?y)(?x?y #SisterOf))	(((:mira) (:maya)) ((:mira) (:mira)))
	Consistency Check	? (abox-consistent? file:// irreflexive.owl) (with assertions that do not violate the constraint)	True
		? (abox-consistent? file://irreflexive.owl) (with assertions that do violate the constraint)	Nill

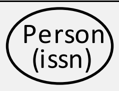
Figure 5.17: Tests performed on OWL 2 mapping of ORM irreflexive ring constraint (Rule 18)

5.2.20 Syntatic Sugar for ORM/OWL 2

5.2.20.1 Identity Constraint

An example in OWL 2 that contains a class named Person with a defined construct HasKey named issn is created (Fig. 5.18). Different instances ahmad and ayser are asserted for the class Person and populated by the data type property issn to the same instance 12345 of type integer. This population of the relation (issn) makes the ABox inconsistent with TBox. The inconsistency of ABox proves that the Haskey construct works as intended from the perspective of machine logic. Here we use Pellet 2.2.2[15] reasoner which supports OWL 2 and HasKey construct.

[15] http://clarkparsia.com/pellet/

OWL 2 Functional Syntax	Checked Example	 	

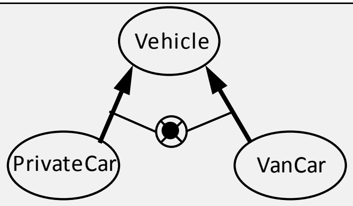
Declaration(Class(:Person))
Declaration(DataProperty(:issn))
Declaration(NamedIndividual(:ahmad))
ClassAssertion(:Person :ahmad)
DataPropertyAssertion(:issn :ahmad "12345"^^xsd:integer)
Declaration(NamedIndividual(:aysar))
ClassAssertion(:Person :aysar)
DataPropertyAssertion(:issn :aysar "12345"^^xsd:integer)
DifferentIndividuals(:aysar :ahmad)
DataPropertyAssertion(:issn :ahmad "12345"^^xsd:integer)
DataPropertyAssertion(:issn :aysar "12345"^^xsd:integer)
HasKey(:Person () (:issn))
	Type of	**nRQL query**	**Result**

	Consistensy Check	Pellet Consistency c:/ hasKey.owl) (with assertions that do not violate the constraint)	Yes
		Pellet Consistency c:/ hasKey.owl) (with assertions that do violate the constraint)	No

Figure 5.18: Tests performed on OWL 2 mapping of ORM identity constraint

5.2.20.2 Total and Exclusive Constraints

An example as shown in Figure 5.18, in OWL 2 is created. That contains a class named Vehicle as a super type and other two classes named PrivateCar and VanCar as a subtypes for the class Vehicle. This example is created to prove the correctness of disjoint union formalizing. When retrieving the instances of class Vehicle, it gives us the union of instances of subclasses PrivateCar and VanCar, and this achieves unionOf between subclasses. The instances are made different from each other where OWL 2 does not support unique name assumption. After asserting the same individual mercedes100 to class VanCar, where this instance is already asserted to class Private Car, this assertion violates the disjoitness between classes VanCar and PrivateCar. The result of checking the consistency of ABox is nil (ABox is inconsistent) and this result is as expected.

OWL 2 Functional Syntax	Checked Example	 	

DisjointUnion(:Vehicle :VanCar :PrivateCar)
Declaration(NamedIndividual(:bora100))
ClassAssertion(:Vehicle :bora100)
ClassAssertion(:VanCar :honda100)
ClassAssertion(:VanCar :mazda200)
ClassAssertion(:PrivateCar :mercedes100)
ClassAssertion(:PrivateCar :toyota200)
ClassAssertion(:VanCar : mercedes100)
DifferentIndividuals(:honda100 :bora100)
DifferentIndividuals(:mazda200 :bora100)
DifferentIndividuals(:mercedes100 :bora100)
DifferentIndividuals(:toyota200 :bora100)
DifferentIndividuals(:mazda200 :honda100)
DifferentIndividuals(:mercedes100 :honda100)
DifferentIndividuals(:toyota200 :honda100)
DifferentIndividuals(:mercedes100 :mazda200)
DifferentIndividuals(:toyota200 :mazda200)
	Type of Test	**nRQL query**	**Result**

	Retrieve Instances	(retrieve(?x) (?x #Vehicle))	(((:bora100)) ((:honda100)) ((:mazda200)) ((:mercedes100)) ((:toyota200)))
	Consistency Check	? (abox-consistent? file:// asymmetric.owl) (with assertions that do not violate the constraint)	True

DifferentIndividuals(:toyota200 :mercedes100)		? (abox-consistent? file://asymmetric.owl) (with assertions that do violate the constraint)	Nill

Figure 5.19: Tests performed on OWL 2 mapping of ORM total and exclusive constraints

Although the tests performed on the OWL 2 mappings of the ORM constructs cannot be theoretically complete, they cover most of the ground (i.e., they are comprehensive). In fact, in our tests we focused on using the boundary analysis techniques of software testing, where we tested boundary or limit conditions of the constraints. An example of such tests is the consistency check performed on the exclusive constraint as discussed in section 5.2.5. Note that the exclusive constraint means that the population of the subtypes constrained by this rule is pairwise distinct (i.e., no assertion can be the instance of two classes). The limit of this constraint can be simply checked by trying to violate the constraint and then checking the consistency of the A-Box. Consider, as another example, the role frequency constraint. Consider an object-type *A* that is restricted to play a role with 3-5 occurrences only (e.g., a teacher that is restricted to teach between 2-4 courses). Testing the limits of such constraint requires testing the minimum occurrence restriction (i.e., 2) in addition to the maximum occurrence restriction (i.e., 4).

5.3 Evaluation Process of extending ORM for Complete representation of OWL 2

Our work of extending the ORM notation to cover all OWL 2 constructs was evaluated by means of a survey. Each construct of the eleven additional constructs added to the ORM notation was represented by three different graphical notations after extensive analysis of the graphical notations currently used in ORM and the rationale behind them. The three new proposed notations were chosen to comply with the existing ORM graphical notations. The available choices for the graphical representation were then put in a form of a survey shown in appendix c. The survey was revised by two computer engineers working at the Palestinian e-government academy and the Ministry of Telecom and IT involved in the development of the Palestinian Interoperability Framework “Zinnar” who developed related ontologies in ORM, one of the master of computing students who works at the SINA institute at Birzeit university who studied object role modeling, description logic and web ontology language through some of the master courses and the supervisor of the this thesis who is an expert in ORM, description logics and OWL 2.

Workshops were held to explain the broader scope of the research, the motivation behind extending ORM, and the rationale behind each possible graphical representation. Thirty one ORM and OWL practitioners participated in the workshops and survey process, twenty one of these practitioners who conducted a workshop where master students of computing at Birzeit university who studied the course of knowledge engineering taught by Dr.Mustafa Jarrar. The workshop participants were at the end of the knowledge engineering course (the course was at fall 2011 semester) after they had studied object role modeling, description logics and web ontology language. The students participated in the workshop had developed several modeling cases and projects using object role modeling and web ontology language. Through the workshop an explanation for students about the objectives and related information of this thesis was conducted, also an explanation about the extending of ORM and the new proposed graphical notations was introduced, in addition to a clarification about each construct of OWL 2 and its three new proposed graphical notations. A discussion concerning the ORM extension was held by the thesis author, thesis supervisor and workshop students. At the end of workshop discussion these practitioners were asked to determine their preferred graphical representation for each construct (by filling the survey). Also the practitioners were asked to add a new proposed graphical notation other than the already three specified ones if they were willing to do so from their own perspective. The results of the survey were then analyzed and the final notations were determined with the highest percent of selection. Ten of the practitioners were conducted individually. Some of these ten survey fillers were practitioners in ORM who developed the stationers ORM modeling cases for the Palestinian e-government project, others were students of master of computing at Birzeit university who studied the course of knowledge engineering that includes related surveyed subjects.

5.3.1 Equivalent Classes:

Equivalent Classes as an OWL 2 construct means that two or more classes constrained with the construct Equivalent Classes are semantically equivalent to each other. In ORM there are no notations that implement the equivalence between two or more objects. The proposed notations to represent Equivalent Classes in ORM are shown in Figure 5.20; also the usage of using each proposed notation is shown in the same figure. Of the 31 knowledgeable persons surveyed, ten preferred notation (a), five preferred notation (b) and sixteen preferred notation (c). According to the survey result the graphical notation (c) was preferred by 16 of the 31 experts who participated in the evaluation survey (52%). So this graphical notation was used.

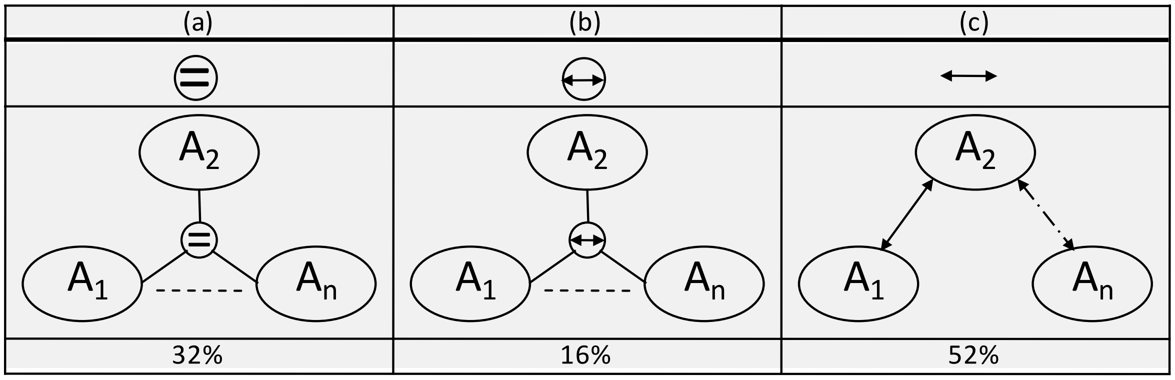


Figure 5.20 Surveyed notations and their percent results for ORM in their symbol and usage shapes to represent OWL 2 construct of Equivalent Classes

5.3.2 Disjoint Classes:

To represent Disjoint Classes construct of OWL 2 in ORM, three notations are suggested as shown in Figure 5.21 according to usually used symbols that logically indicate the semantic of disjoint, also the usage of using each proposed notation is shown in the same figure. Of 31 experts surveyed 20 preferred the ⊗ symbol to represent the Disjoint Classes construct, three preferred the symbol shown in (b) and eight preferred symbol (c). According to the survey result the graphical notation (a) was preferred by 20 of the 31 practitioners who participated in the evaluation survey (64%). So this graphical notation is used.

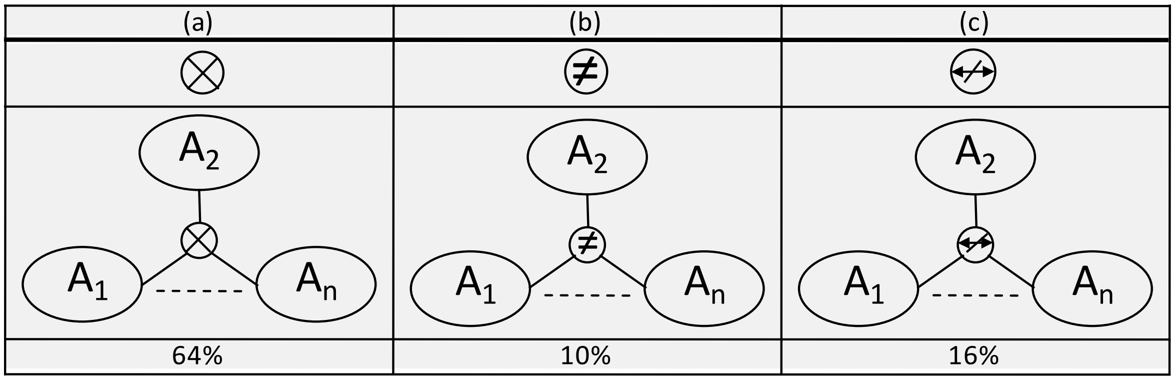


Figure 5.21 Surveyed notations and their percent results for ORM in their symbol and usage shapes to represent OWL 2 construct of Disjoint Classes

5.3.3 Intersection of Class Expressions

Intersection of classes construct of OWL 2 is an expression states that the intersection between classes contains the individuals that are members of each class belongs to intersected classes. ObjectIntersectionOf construct for classes is not represented in ORM. A symbol of intersection (⊓) is proposed to be used for representing the expression of classes' intersection in three different ways as shown in Fig. 5.22. As shown in Fig. 5.22, we represent anonymous class (class with no name) just to show that we have an expression of intersection of classes, which is virtually equivalent to the anonymous class. In implementation we do show the anonymous class graphically. The proposed graphic notation of the circle with the symbol ⊓ attached in different ways within the ellipse represents intersected equivalent class. This proposed graphical notation represents the expression of classes' intersection. The same thing in principle is applied for class complement. Of 31 practitioners surveyed four preferred notation (a), 18 preferred notation (b) and nine preferred notation (c). According to the survey result the graphical notation (b) was preferred by 18 of the 31 experts who participated in the evaluation survey (58%). So this graphical notation is used.

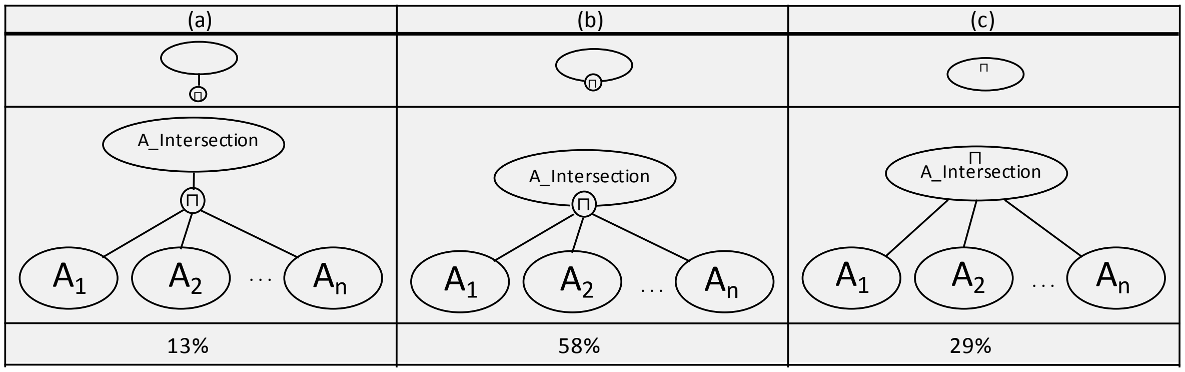


Figure 5.22 Surveyed notations and their percent results for ORM in their symbol and usage shapes to represent OWL 2 construct of Intersected Classes

5.3.4 Class Complement

The Complement of Class expression is not represented in ORM which states that the complement class contains all individuals that are not members of the intended class. The three notations that are proposed to represent the expression of class' complement are shown in Fig. 5.23. The symbol not (¬) is proposed to be used for representing the complement of class expression as shown in the Fig. 5.23 of 31 practitioners surveyed six preferred notation (a), 14 preferred notations (b) and eleven preferred notation (c). According to the survey result the graphical notation (b) was preferred by 14 of the 31 experts who participated in the evaluation survey (45%). So this graphical notation is used in the implementation.

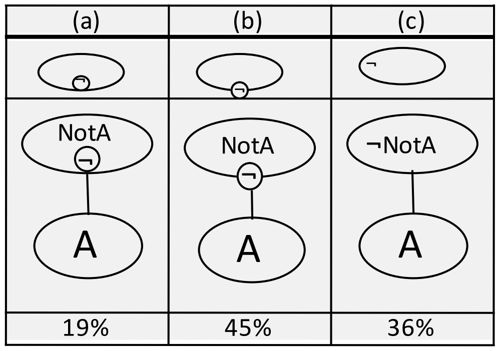
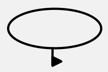
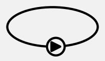
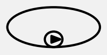
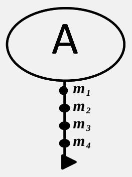
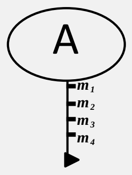
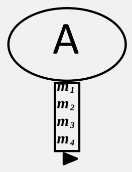


Figure 5.23 Surveyed notations and their percent results for ORM in their symbol and usage shapes to represent OWL 2 construct of Class Complement

5.3.5 Class Assertions

Class Assertions is not formally represented in ORM. The three notations that are proposed to represent class assertions are shown in Fig. 5.24.a. The symbol (▶) is proposed to be used to enable the class assertions as shown in Fig. 5.24. Of 31 practitioners surveyed nine preferred notation (a), four preferred notation (b) and fifteen preferred notation (c). According to the result of the survey the graphical notation (c) was preferred by 15 of the 31 practitioners who participated in the evaluation survey (48%). So this graphical notation is used in the implementation. Three proposed notations for the appearance of individuals are shown in Fig. 5.23.b. The graphical appearance of individuals is planned to be allowed for four of them, if there is more than four individuals they will be shown within separate window. Of 31 practitioners surveyed 17 preferred notation (a), eight preferred notation (b) and six preferred notation (c). According to the survey result the graphical notation (a) was preferred by 17 of the 31 experts who participated in the evaluation survey (55%).

(a)	(b)	(c)
		
48%	13%	39%

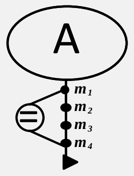
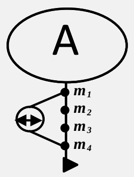
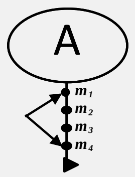
(a)	(b)	(c)
		
55%	26%	19%

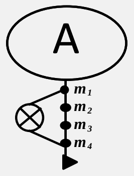
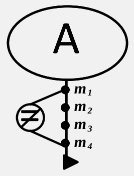
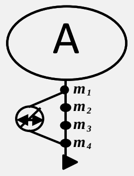
(a) (b)

Figure 5.24 Surveyed notations and their percent results for ORM to represent OWL 2 construct of Class Assertions

5.3.6 Individual Equality

Individual Equality states that if we have two instances or more that are related by Individual Equality (OWL 2 Construct), then these instances are the same. The three notations that are proposed to represent Individual Equality are shown in Fig. 5.25.a. Of 31 practitioners surveyed 24 preferred notation in (a), six preferred notation (b) and one preferred notations (c). According to the survey result the graphical notation (a) was preferred by 24 of the 31 experts who participated in the evaluation survey (77.5%). So this graphical notation is used in the implementation.

(a)	(b)	(c)
		
77.5%	19.5%	3%

(a)	(b)	(c)
		
19%	71%	10%

(a) (b)

Figure 5.25 Surveyed notations and their percent results for ORM to represent OWL 2 construct of (a) Individual Equality and (b) Individual Inequality

5.3.7 Individual Inequality

Individual Inequality states that if we have two instances or more that are related by Individual Inequality (OWL 2 Construct), then these instances are different from each other. The three notations that are proposed to represent Individual Inequality are shown in Fig. 5.25.b. Of 31 practitioners surveyed six preferred notation in (a), 22 preferred notations (b) and three preferred notation (c). According to the survey result of the graphical notation (b) was preferred by 22 of the 31 experts who participated in the evaluation survey (71%). So this graphical notation is used in the implementation.

5.3.8 Positive Object/Data Property Assertion

The three notations that are proposed to represent Positive Object Property Assertion are shown in Fig. 5.26. Of 31 practitioners surveyed 19 preferred notation in (a), eight preferred notation (b) and four preferred notation (c). According to the survey result the graphical notation (a) was preferred by 19 of the 31 practitioners who participated in the evaluation survey (61%). So this graphical notation is used in the implementation.

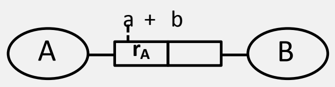
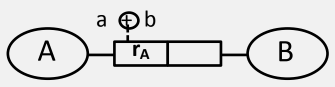
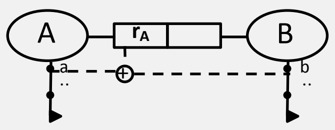
(a)	(b)	(c)
		
61%	26%	13%

Figure 5.26 Surveyed notations and their percent results for ORM to represent OWL 2 construct of Positive Object Property Assertion

5.3.9 Negative Object/Data Property Assertion

The three notations that are proposed to represent Negative Object Property Assertion are shown in Fig. 5.27. Of 31 experts surveyed 21 preferred notation in (a), seven preferred notation (b) and three preferred notation (c). According to the survey result the graphical notation (a) was preferred by 19 of the 31 practitioners who participated in the evaluation survey (68%). So this graphical notation is used in the implementation.

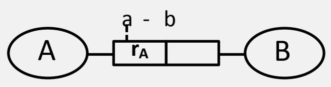
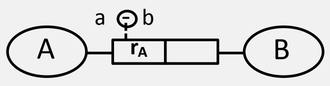
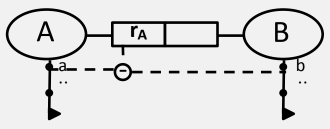
(a)	(b)	(c)
		
68%	23%	9%

Figure 5.27 Surveyed notations and their percent results for ORM to represent OWL 2 construct of Negative Object Property Assertion

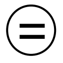
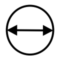
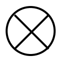
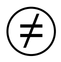
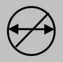
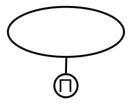
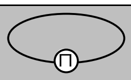
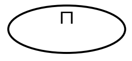
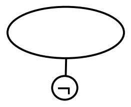
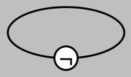
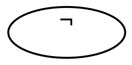
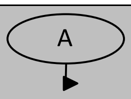
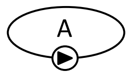
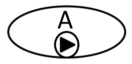
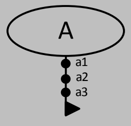
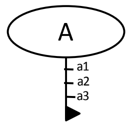
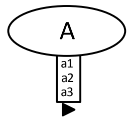
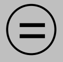
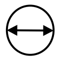
5.3.10 Reflexive Ring Constraint:

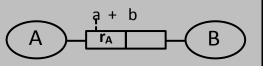
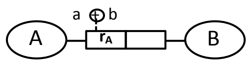
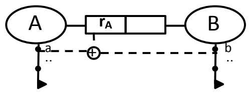
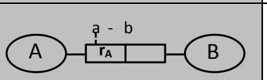
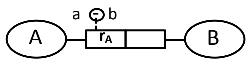
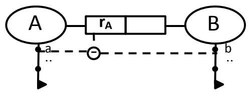
The notation for reflexive constraint is set as that for ring constraints using the word “ref” to indicate the reflexive constraint. This notation was not surveyed because we used exactly the same pattern used in ORM for ring constraints and so as for transitive constraint.

5.3.11 Transitive Ring Constraint:

The notation for reflexive constraint is set as that for ring constraints using the word “tra” to indicate the reflexive constraint.

Table 5.1 summarizes all the graphical representation choices and the results of the survey.

	Construct Name	**Representation (1)**	**Representation (2)**	**Representation (3)**
1	Equivalent Classes	 32%	 16%	52%
2	Disjoint Classes	 64%	 10%	 16%
3	Intersection of Class Expressions	 13%	 58%	 29%
4	Class Complement	 19%	 45%	 36%
5	Class Assertions (before)	 48%	 13%	 39%
	Class Assertions (after)	 55%	 26%	 19%
6	Individual Equality	 77.5%	 19.5%	3%

7	Individual Inequality	≠ 71%	↮ 10%	⊗ 19%
8	Positive Property Assertion	 61%	 26%	 13%
9	Negative Property Assertion	 68%	 23%	 9%

Chapter Six

Implementation of Mapping between ORM and OWL 2

6.1 Introduction

This chapter provides an overview of the extension of DogmaModeler tool to hold the mapping between ORM and OWL 2. DogmaModeler was developed as a modeling tool using the programming language Java within the integrated development environment Java Beans. DogmaModeler is used as a tool for ontology engineering, where it enables ontology builders to build ontologies that are characterized by both usability and reusability, and by easily using ORM graphical notations [JDM03]. DogmaModeler and its extension can be downloaded from[16]. Using the extended DogmaModeler, the person can graphically build an ontology using graphical representation of objects, relations and constraints on the user-interface for both building and editing the required ontology. The DogmaModeler tool will automatically create the equivalent OWL 2 file that represents the graphically-built ontology using ORM. The mapped OWL 2 file can be checked for correctness (like consistency and coherency checking) using the Hermit reasoner, which is integrated into DogmaModeler.

6.2 DogmaModeler

The work presented in this thesis is implemented as an extension to DogmaModeler. DogmaModeler is an ontology modeling tool based on ORM. DogmaModeler allows modeling, browsing, and managing ontologies. This tool allows one to build his Ontology

[16] http://www.jarrar.info/Dogmamodeler/

using the ORM paradigm and then validate his Ontology using integrated Description Logic reasoning services. In its original implementation, DogmaModeler supported the mapping of built ORM ontologies into three notations: ORM-ML (ORM Markup Language), Pseudo Natural Language, and DIG (Description Logic Interface). These mappings allow the ontology to be easily exchanged and understood by domain experts, accessed and processed automatically by application, and validated using Description Logic reasoning services. Originally, ORM diagrams built in DogmaModeler were mapped automatically to DIG; a description logic interface (XML-based language). The DIG mappings of the ORM models were then validated using a Description Logic reasoning server (such as Racer, Fact++, etc) which acted as a background reasoning engine.

In fact, DogmaModeler integrates reasoning services (such as Racer, Fact++, etc) as background reasoning engines. This allows one to validate his/her ontology, for any possible contradiction or inconsistency. The following is a brief description of the three mappings of ORM that DogmaModeler originally support:

(i) *ORM Markup Language (ORM-ML) [J05]*. It is an XML-based language to markup conceptual diagrams, thus allowing the ontology that is built in ORM to be accessed and processed at run-time of applications.

(ii) *Pseudo Natural Language.* Through utilizing ORM’s verbalization capabilities, DogmaModeler supports verbalization of ontologies into pseudo natural language, allowing for easy exchange and understanding of the ontologies by domain experts.

(iii) *Description Logic Interface (DIG).* It is an XML-based language supported by several description logic reasoners (such as Racer, Fact++, etc), which allows for the validation of ontologies built in ORM.

6.3 Extending DogmaModeler

Our implemented extension of DogmaModeler is twofold:

i) We implemented the OWL 2 mapping of ORM presented in this paper, such that the ORM diagrams currently built in DogmaModeler are automatically mapped to OWL 2 and then validated using the Hermit reasoning tool.

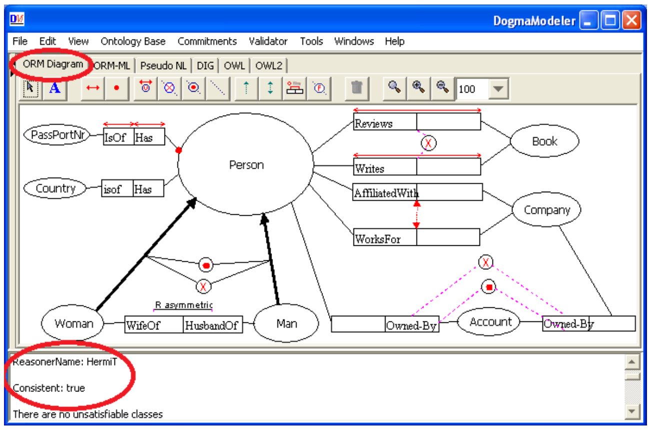
ii) We implemented our newly proposed ORM notations with its OWL 2 mapping.

By doing so, one can now build his OWL 2 ontology graphically using ORM and its mapping into OWL 2 is automatically generated and then validated using description logic reasoning. As we mentioned before the idea behind the implementation of our work is enabling ontology building by the intended person using the graphical oriented paradigm.

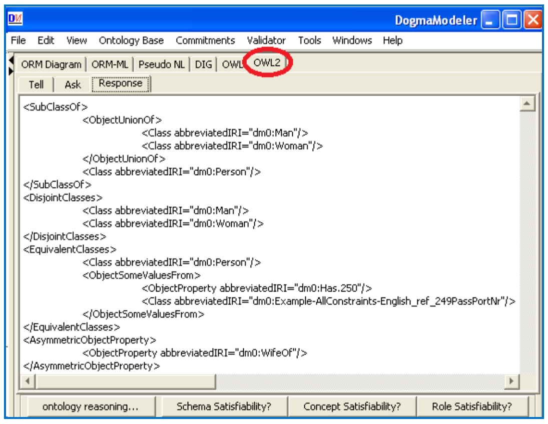
The DogmaModeler tool is now extended to become an environment for authoring OWL 2 ontologies graphically using ORM. That is, one now builds his OWL 2 ontology graphically using ORM and then DogmaModeler generates the OWL 2 code automatically. This code can then be validated easily using description logic reasoning via the integrated “HermIT” reasoning tool.

For the first part of implementation, we extend DogmaModeler to automatically map ORM into OWL 2 constructs depending on ORM markup language [DJM02, J05] (which is automatically generated according to equivalent ORM graphical notations). Figure 6.1.a shows a snapshot of DogmaModeler outputs, which illustrates an ORM graphical notation example with reasoning results indicating that the built example of ORM is consistent and there is no unsatisfiable concepts. Figure 6.1.b, shows the mapping result of OWL 2 for the example illustrated in Figure 6.1.a.

Fig. 6.2 depicts a modification for ORM diagram of Fig 6.1.a which is built using DogmaModeler. The first window (Fig. 6.2.a) shows the diagram and its validation (by means of logical reasoning) using the integrated HermIT reasoning server while the second window shows the OWL 2 mapping of the diagram. Note that the results of the reasoning state that the class ‘ownedBy.Company’ is unsatisfiable due to the contradiction between the exclusion and mandatory constraints.



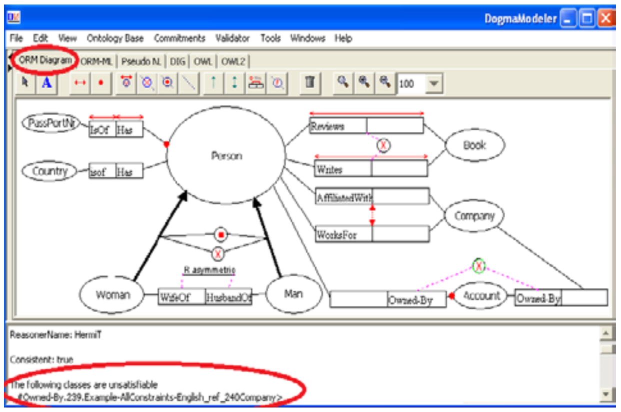
```
ReasonerName: HermiT

Consistent: true

There are no unsatisfiable classes
```



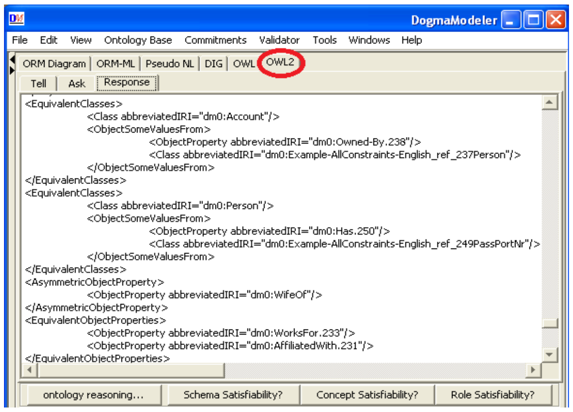
```
<SubClassOf>
		<ObjectUnionOf>
				<Class abbreviatedIRI="dm0:Man"/>
				<Class abbreviatedIRI="dm0:Woman"/>
		</ObjectUnionOf>
		<Class abbreviatedIRI="dm0:Person"/>
</SubClassOf>
<DisjointClasses>
		<Class abbreviatedIRI="dm0:Man"/>
		<Class abbreviatedIRI="dm0:Woman"/>
</DisjointClasses>
<EquivalentClasses>
		<Class abbreviatedIRI="dm0:Person"/>
		<ObjectSomeValuesFrom>
				<ObjectProperty abbreviatedIRI="dm0:Has.250"/>
				<Class abbreviatedIRI="dm0:Example-AllConstraints-English_ref_249PassPortNr"/>
		</ObjectSomeValuesFrom>
</EquivalentClasses>
<AsymmetricObjectProperty>
		<ObjectProperty abbreviatedIRI="dm0:WifeOf"/>
</AsymmetricObjectProperty>
```

(a) ORM built and validated in DogmaModeler (b) OWL 2 mapping of the ORM in (a)

Figure 6.1: A Snapshot of an ORM diagram built in DogmaModeler, its mapping to OWL 2, and its validation.



```
ReasonerName: HermiT

Consistent: true

The following classes are unsatisfiable
  #Owned-By.239.Example-AllConstraints-English_ref_240Company>
```



```
<EquivalentClasses>
		<Class abbreviatedIRI="dm0:Account"/>
		<ObjectSomeValuesFrom>
				<ObjectProperty abbreviatedIRI="dm0:Owned-By.238"/>
				<Class abbreviatedIRI="dm0:Example-AllConstraints-English_ref_237Person"/>
		</ObjectSomeValuesFrom>
</EquivalentClasses>
<EquivalentClasses>
		<Class abbreviatedIRI="dm0:Person"/>
		<ObjectSomeValuesFrom>
				<ObjectProperty abbreviatedIRI="dm0:Has.250"/>
				<Class abbreviatedIRI="dm0:Example-AllConstraints-English_ref_249PassPortNr"/>
		</ObjectSomeValuesFrom>
</EquivalentClasses>
<AsymmetricObjectProperty>
		<ObjectProperty abbreviatedIRI="dm0:WifeOf"/>
</AsymmetricObjectProperty>
<EquivalentObjectProperties>
		<ObjectProperty abbreviatedIRI="dm0:WorksFor.233"/>
		<ObjectProperty abbreviatedIRI="dm0:AffiliatedWith.231"/>
</EquivalentObjectProperties>
```

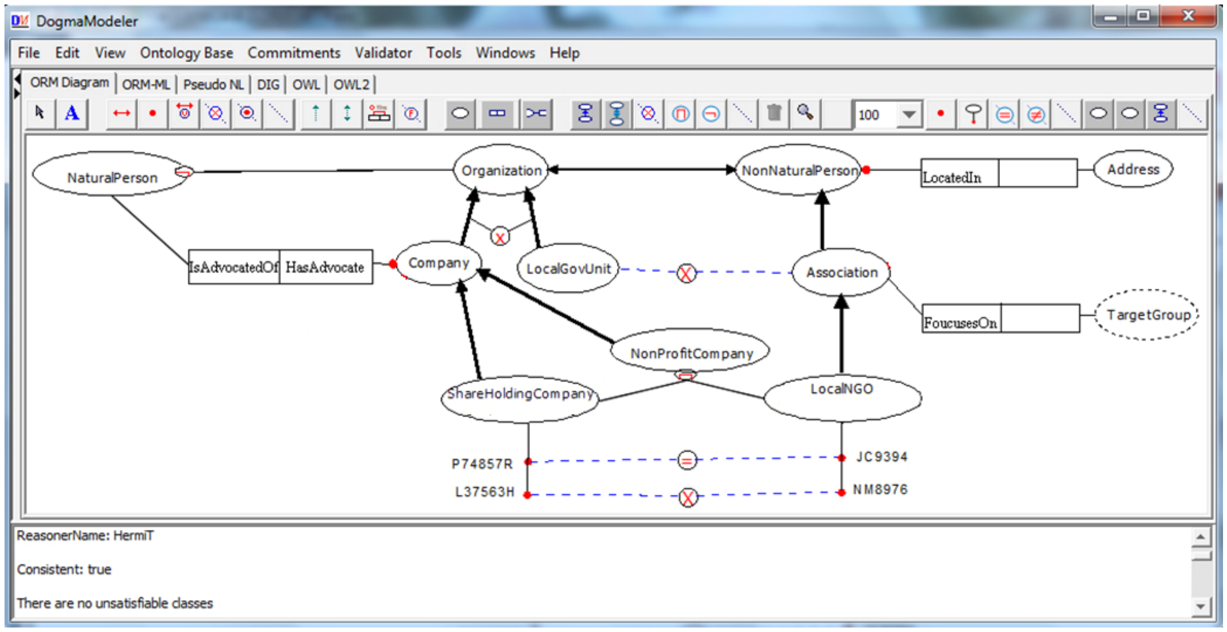
(a) ORM built and validated in DogmaModeler (b) OWL 2 mapping of the ORM in (a)

Figure 6.2: A Snapshot represent modified ORM diagram of Figure 6.1, built in DogmaModeler, its mapping to OWL 2, and its validation.

For the second part of implementation, that illustrates the extending of ORM notations to represent those of OWL 2 not represented by original ORM notations. We extended DogmaModeler by adding the new proposed ORM notations which are illustrate in chapter 4. These extended notations are integrated with the family of ORM notations holed by DogmaModeler with the full functionality of mapping. The mapping of these new proposed ORM notations is done to both ORM Markup Language and OWL 2. We proposed the new equivalent constructs for ORMML to hold the extended ORM notations, but here our significance concern is mapping the extended ORM notations into OWL 2 that is actually implemented.

As a result of implementation we are mainly concerned with enabling one to graphically build his/her ontology using extended ORM that fully represents of OWL 2. OWL 2 (recommended web ontology language from W3C) contains the majority of constructs to be used for building any needed ontology supported by many reasoners for checking the correctness of built ontology. This extension of ORM constructs is included in the extended DogmaModeler tool, which will enable one to build his ontology graphically without writing OWL 2 syntax and DogmaModeler will automatically convert this ontology to OWL 2 representation file. The resulting file of OWL 2 can be used easily for ontology modeling purposes. One can interactively model the needed ontology using DogmaModeler and after every graphical modeling step she/he will be fed back about his/her progress. The incremental ontology building can be checked continuously for correctness.

Fig. 6.3 shows the use case of Fig. 4.9 (section 4.15) built in DogmaModeler. The first window (Fig. 6.3) contains the ORM diagram. Note that this diagram contains our proposed extension of the ORM notation. The results of the validation using logical reasoning show that the ORM model is consistent and there are not unsatisfiable concepts. The second window (Fig. 6.5.a) shows the OWL mapping of the ORM diagram. Notice the mapping of the newly added ORM notations into OWL 2.



```
ReasonerName: HermiT
Consistent: true
There are no unsatisfiable classes
```

Figure 6.3: ORM use case of Figure 4.9 using DogmaModeler with new proposed ORM notations.

Fig. 6.4 shows another ORM example created using DogmaModeler. The figure depicts three sample ontologies for ministry of labor, health ministry and transportation ministry expressed in ORM; these sample ontologies are integrated with each other using some of the new proposed ORM notations illustrated below. Note that these three sample ontologies are proposed for Palestinian ministries. However, what is depicted in Figure 6.4 is not a complete ontology and is only meant to be a sample demonstration of the usefulness of the newly proposed ORM notations. Fig. 6.5.b shows the equivalent OWL 2 constructs (in OWL/XML syntax) of new proposed ORM notations that are illustrated in Fig. 6.4.

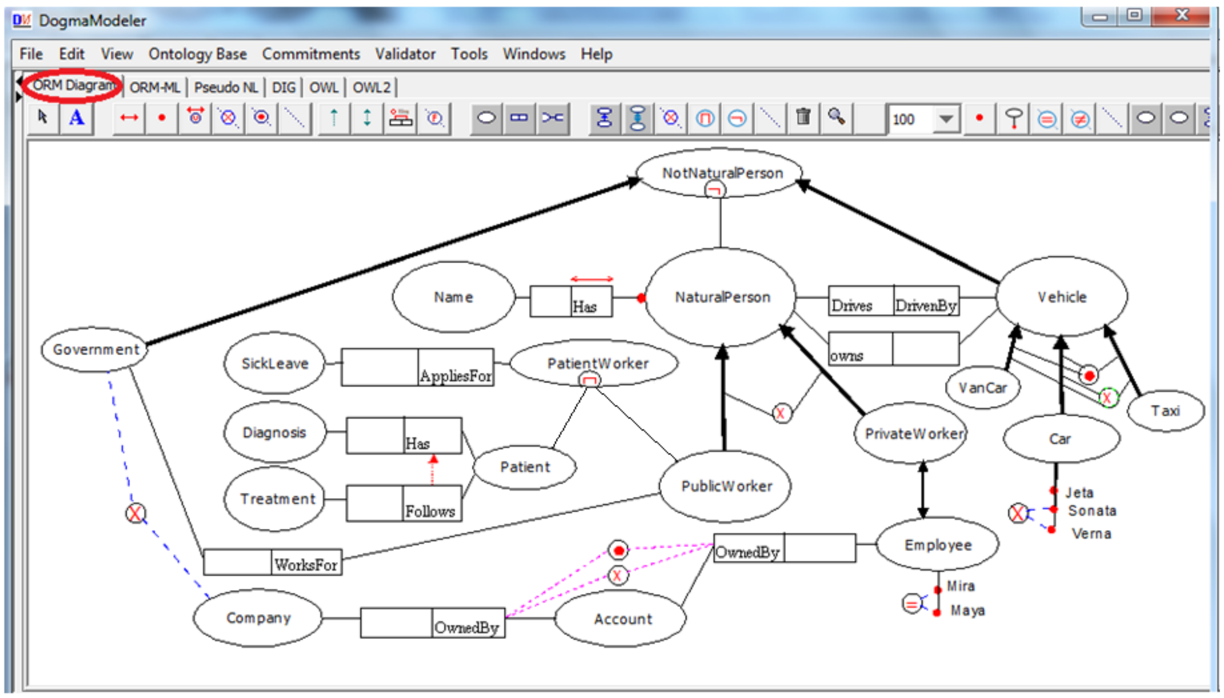


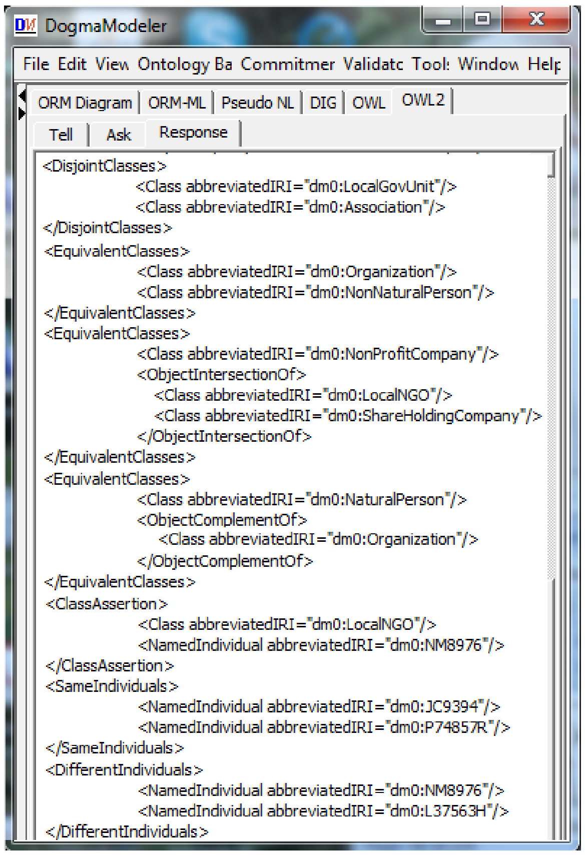
Figure 6.4: ORM example using DogmaModeler with new proposed ORM notations

Figure 6.4 contains new proposed ORM graphical notations. These notations are illustrated in what follows:

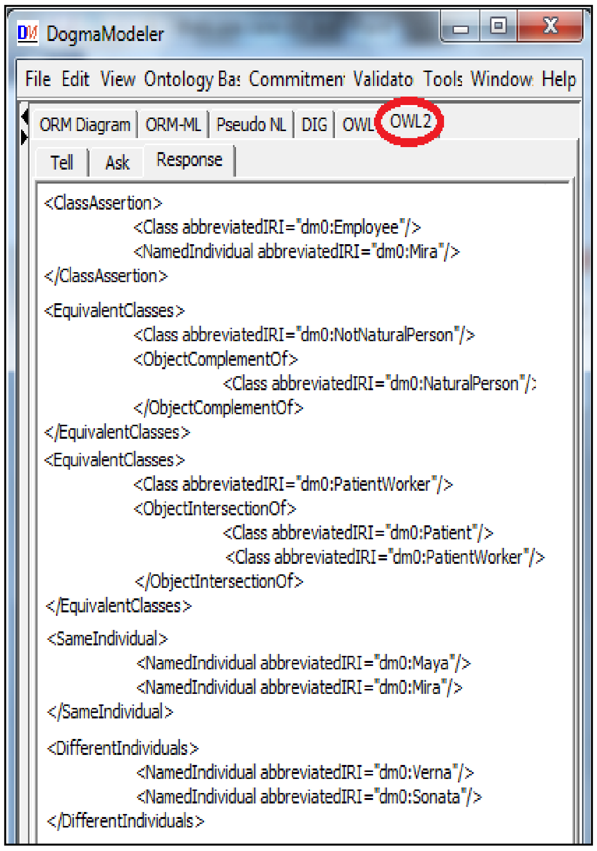
- Equivalent Classes is depicted as "↔" between the equivalent classes PrivateWorker and Employee.

- Disjoint Classes is depicted as "⊗" between the disjoint classes Government and Company.

- Intersection of Class Expressions is depicted as "⊓" between the intersected classes Patient and PublicWorker and the proposed equivalent class PatientWorker.
- Class Complement is depicted as "¬" connected to the intended class NaturalPerson and the proposed equivalent class NotNaturalPerson which is equivalent the complement of class NaturalPerson.
- Individual Equality is depicted as "⊜" between the same individuals Mira and Maya which are instances asserted as instances into the class Employee.
- Individual Inequality is depicted as "≠" between the different individuals Sonata and Verna.


DogmaModeler
File Edit View Ontology Ba Commitmer Validatc Tool: Window Help
ORM Diagram | ORM-ML | Pseudo NL | DIG | OWL | OWL2
Tell | Ask | Response

```
<DisjointClasses>
        <Class abbreviatedIRI="dm0:LocalGovUnit"/>
        <Class abbreviatedIRI="dm0:Association"/>
</DisjointClasses>
<EquivalentClasses>
        <Class abbreviatedIRI="dm0:Organization"/>
        <Class abbreviatedIRI="dm0:NonNaturalPerson"/>
</EquivalentClasses>
<EquivalentClasses>
        <Class abbreviatedIRI="dm0:NonProfitCompany"/>
        <ObjectIntersectionOf>
          <Class abbreviatedIRI="dm0:LocalNGO"/>
          <Class abbreviatedIRI="dm0:ShareHoldingCompany"/>
        </ObjectIntersectionOf>
</EquivalentClasses>
<EquivalentClasses>
        <Class abbreviatedIRI="dm0:NaturalPerson"/>
        <ObjectComplementOf>
          <Class abbreviatedIRI="dm0:Organization"/>
        </ObjectComplementOf>
</EquivalentClasses>
<ClassAssertion>
        <Class abbreviatedIRI="dm0:LocalNGO"/>
        <NamedIndividual abbreviatedIRI="dm0:NM8976"/>
</ClassAssertion>
<SameIndividuals>
        <NamedIndividual abbreviatedIRI="dm0:JC9394"/>
        <NamedIndividual abbreviatedIRI="dm0:P74857R"/>
</SameIndividuals>
<DifferentIndividuals>
        <NamedIndividual abbreviatedIRI="dm0:NM8976"/>
        <NamedIndividual abbreviatedIRI="dm0:L37563H"/>
</DifferentIndividuals>
```


DogmaModeler
File Edit View Ontology Bas Commitmen Validato Tools Window Help
ORM Diagram | ORM-ML | Pseudo NL | DIG | OWL | OWL2
Tell | Ask | Response

```
<ClassAssertion>
        <Class abbreviatedIRI="dm0:Employee"/>
        <NamedIndividual abbreviatedIRI="dm0:Mira"/>
</ClassAssertion>
<EquivalentClasses>
        <Class abbreviatedIRI="dm0:NotNaturalPerson"/>
        <ObjectComplementOf>
                <Class abbreviatedIRI="dm0:NaturalPerson"/:
        </ObjectComplementOf>
</EquivalentClasses>
<EquivalentClasses>
        <Class abbreviatedIRI="dm0:PatientWorker"/>
        <ObjectIntersectionOf>
                <Class abbreviatedIRI="dm0:Patient"/>
                <Class abbreviatedIRI="dm0:PatientWorker"/>
        </ObjectIntersectionOf>
</EquivalentClasses>
<SameIndividual>
        <NamedIndividual abbreviatedIRI="dm0:Maya"/>
        <NamedIndividual abbreviatedIRI="dm0:Mira"/>
</SameIndividual>
<DifferentIndividuals>
        <NamedIndividual abbreviatedIRI="dm0:Verna"/>
        <NamedIndividual abbreviatedIRI="dm0:Sonata"/>
</DifferentIndividuals>
```

Figure 6.5 OWL 2 constructs (in OWL/XML syntax) of new proposed ORM notations that are illustrated in (a) Figure 6.3 and (b) Figure 6.4.

Chapter Seven

Conclusion and Recommendations for Future Work

7.1 Conclusion

The ever increase of the need to develop various applications that depend on ontology pressures the need to build ontology without time and effort consuming. It is more easily for people to perform conceptual modeling graphically. OWL 2 which is the recommended Web Ontology Language needs proficiency and using it to build the needed ontology is time and effort consuming. It is worth to find a way to build ontology graphically and at the same time using OWL 2. ORM which is rich of graphical notations and characterized by high expressivity is used as a conceptual modeling tool in a graphical context.

The mapping and automation of this mapping between ORM and OWL 2 are the main theme of this thesis. We mapped nineteen (out of twenty nine) ORM constructs. The ORM constructs that depend on n-arity cannot be mapped into SROIQ/OWL 2 constructs according to the fact that OWL 2 supports only binary relations. Where these nineteen constructs represent the most commonly used constructs in ORM. At the same time, those constructs are supported by SROIQ Description Logic; which means that OWL 2 output we have mapped is characterized by its ability of decidability. Although the mapping from ORM into OWL 2 is done theoretically using SROIQ Description Logic, which leads to the verification of mapping correctness, we do evaluate this mapping (from ORM into OWL 2). The evaluation here which is done practically using RacerPro reasoner is done to assure practically the correctness of mapping. This evaluation of mapping from ORM into OWL 2 is done by examining each mapped construct as a complete OWL 2 file (the file is loaded into RacerPro 2.0 reasoner) using different reasoning services such as consistency, coherency and instance checking.

In the second part of this research, we extend ORM for complete representation of OWL 2 . We do proposed new notations of ORM to completely represent OWL 2 by ORM notations, in addition of using non-notational expressions. The proposed notations for extending ORM are selected according to an evaluation process. The evaluation process depends in a survey fulfilled by practitioners in both ORM and OWL.

DogmaModeler as a modeling tool based on ORM is extended to include the new proposed notations of ORM with the already existing notations that are mapped into OWL 2. As a result one can use ORM as an interface of OWL 2 to build him/her ontology graphically, where the built ontology is automatically mapped into OWL 2 using the extended DogmaModeler to perform this mapping (between ORM and OWL 2). Once the mapped OWL 2 file from extended ORM is generated, we can reason about the ontology represented in OWL 2 using Hermit reasoner that supports OWL 2 to check the correctness of the built ontology. It is important to note here that the extended ORM is not merely a graphical notation for the visualization of ontologies. It is a methodology that guides the ontology engineer to design and represent an ontology using the different constructs and rules it provides. ORM facilitates the process of engineering the ontology through its verbalization capabilities which allow the involvement of domain experts in the modeling process.

As a result of this thesis work we have developed an expressive and methodological graphical notation for OWL 2, which allows people to author OWL 2 ontologies graphically. To summarize, we develop our thesis work through two main phases : (i) mapping the graphical notations of ORM to SROIQ/OWL 2 following the semantics of OWL 2 (ii) extending the ORM graphical notation to cover all OWL 2 constructs not currently covered by ORM. OWL 2 is the W3C-recommended ontology language for authoring ontologies. However, it does not provide any methodological or graphical means to engineer ontologies. On the other hand, ORM is a graphical methodological notation used for conceptual modeling. By mapping between ORM and OWL 2, one can now engineer OWL 2 ontologies graphically using ORM and then map them automatically to OWL 2.

7.2 Recommendations for Future Work

Future directions of our research will involve extending DogmaModeler to allow user-friendly debugging and reasoning that helps the user find the cause of the problem and directions on how to solve it. Note that this is not an implementation issue; it rather needs theoretical research on reasoning problems. In addition, we plan to perform full mapping of ORM into SROIQ/OWL 2, by extending OWL 2 and the underpinning description logic to hold the uncovered notations of ORM. This will include investigating an extension of the SROIQ Description Logic and the development of a new reasoning engine to support complete reasoning of ORM.

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Appendices

Appendix A-1

```
<?xml version="1.0"?>
<Ontology xmlns="http://www.w3.org/../owl#"
xml:base="http://www.dogma.org/Ontology.owl"
xmlns:rdfs="http://www.w3.org/../rdf-schema#"
xmlns:xsd="http://www.w3.org/2001/XMLSchema#"
xmlns:rdf="http://www.w3.org/../22-rdf-syntax-ns#"
xmlns:xml=http://www.w3.org/../namespace

<Declaration>
   <Class IRI="#Car"/>
</Declaration>
<Declaration>
   <Class IRI="#Company"/>
</Declaration>
<Declaration>
   <Class IRI="#Female"/>
</Declaration>
<Declaration>
   <Class IRI="#Male"/>
</Declaration>
<Declaration>
   <Class IRI="#OwnedByC.Company"/>
</Declaration>
<Declaration>
   <Class IRI="#OwnedByP.Person"/>
</Declaration>
<Declaration>
   <Class IRI="#Person"/>
</Declaration>
<Declaration>
   <ObjectProperty IRI="#AffiliatedWith"/>
</Declaration>
<Declaration>
   <ObjectProperty IRI="#Employs"/>
</Declaration>
<Declaration>
   <ObjectProperty IRI="#OwnedByC"/>
</Declaration>
<Declaration>
   <ObjectProperty IRI="#OwnedByP"/>
</Declaration>
<Declaration>
   <ObjectProperty IRI="#WorksFor"/>
</Declaration>
<Declaration>
   <DataProperty IRI="#hasGender"/>
</Declaration>

<InverseObjectProperties>
   <ObjectProperty IRI="#Employs"/>
   <ObjectProperty IRI="#WorksFor"/>
</InverseObjectProperties>

<ObjectPropertyDomain>
   <ObjectProperty IRI="#AffiliatedWith"/>
   <Class IRI="#Person"/>
</ObjectPropertyDomain>


<ObjectProperty IRI="#OwnedByC"/>
   <Class IRI="#Car"/>
 </ObjectPropertyDomain>
 <ObjectPropertyDomain>

 <ObjectPropertyDomain>
    <ObjectProperty IRI="#OwnedByP"/>
    <Class IRI="#Car"/>
 </ObjectPropertyDomain>

 <ObjectPropertyDomain>
    <ObjectProperty IRI="#WorksFor"/>
    <Class IRI="#Person"/>
 </ObjectPropertyDomain>

 <ObjectPropertyRange>
    <ObjectProperty IRI="#AffiliatedWith"/>
    <Class IRI="#Company"/>
 </ObjectPropertyRange>

 <ObjectPropertyRange>
    <ObjectProperty IRI="#OwnedByC"/>
    <Class IRI="#Company"/>
 </ObjectPropertyRange>

 <ObjectPropertyRange>
    <ObjectProperty IRI="#OwnedByP"/>
    <Class IRI="#Person"/>
 </ObjectPropertyRange>

 <ObjectPropertyRange>
    <ObjectProperty IRI="#WorksFor"/>
    <Class IRI="#Company"/>
 </ObjectPropertyRange>

 <EquivalentClasses>
    <Class IRI="#OwnedByC.Company"/>
    <ObjectSomeValuesFrom>
      <ObjectProperty IRI="#OwnedByC"/>
      <Class IRI="#Company"/>
    </ObjectSomeValuesFrom>
 </EquivalentClasses>

 <EquivalentClasses>
    <Class IRI="#OwnedByP.Person"/>
    <ObjectSomeValuesFrom>
      <ObjectProperty IRI="#OwnedByP"/>
      <Class IRI="#Person"/>
    </ObjectSomeValuesFrom>
 </EquivalentClasses>

 <EquivalentClasses>
    <Class IRI="#Car"/>
    <ObjectUnionOf>
      <Class IRI="#OwnedByC.Company"/>
      <Class IRI="#OwnedByP.Person"/>
    </ObjectUnionOf>
 </EquivalentClasses>

 <EquivalentClasses>
    <Class IRI="#OwnedByC.Company"/>
   <ObjectComplementOf>
     <Class IRI="#OwnedByP.Person"/>
   </ObjectComplementOf>
</EquivalentClasses>

<EquivalentClasses>
   <Class IRI="#Person"/>
   <DataSomeValuesFrom>
     <DataProperty IRI="#hasGender"/>
     <Datatype abbreviatedIRI="xsd:string"/>
   </DataSomeValuesFrom>
</EquivalentClasses>

<SubClassOf>
   <Class IRI="#Female"/>
   <Class IRI="#Person"/>
</SubClassOf>

<SubClassOf>
   <Class IRI="#Male"/>
   <Class IRI="#Person"/>
</SubClassOf>

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   <Class IRI="#Person"/>
   <Class IRI="#Female"/>
   <Class IRI="#Male"/>
</DisjointUnion>
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   <ObjectProperty IRI="#WorksFor"/>
   <ObjectProperty IRI="#AffiliatedWith"/>
</SubObjectPropertyOf>

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   <DataMaxCardinality cardinality="1">
    <DataProperty IRI="#HasGender"/>
    <Datatype abbreviatedIRI="xsd:string"/>
   </DataMaxCardinality>
</EquivalentClasses>

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   <DataProperty IRI="#HasGender"/>
   <Class IRI="#Person"/>
</DataPropertyDomain>

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  <DataProperty IRI="#HasGender"/>
    <DataOneOf>
      <Literal datatypeIRI="&xsd;string"> M </Literal>
      <Literal datatypeIRI="&xsd;string"> F </Literal>
     </DataOneOf>
 </DataPropertyRange>

</Ontology>
```

Figure A-1. A maped OWL 2 (OWL/XML) for ORM schema of Figure 2.1

Appendix A-2

```
<?xml version="1.0"?>
<Ontology xmlns="http://www.w3.org/../owl#"
xml:base="http://www.dogma.org/Ontology.owl"
xmlns:rdfs="http://www.w3.org/../rdf-schema#"
xmlns:xsd="http://www.w3.org/2001/XMLSchema#"
xmlns:rdf="http://www.w3.org/../22-rdf-syntax-ns#"
xmlns:xml=http://www.w3.org/../namespace
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   <Class abbreviatedIRI="dm0:LocalGovUnit"/>
</Declaration>
<Declaration>
   <Class abbreviatedIRI="dm0:Organization"/>
</Declaration>
<Declaration>
   <Class abbreviatedIRI="dm0:Company"/>
</Declaration>
<Declaration>
   <Class abbreviatedIRI="dm0:Association"/>
</Declaration>
<Declaration>
   <Class abbreviatedIRI="dm0:TargetGroup"/>
</Declaration>
<Declaration>
   <Class abbreviatedIRI="dm0:LocalNGO"/>
</Declaration>
<Declaration>
   <Class abbreviatedIRI="dm0:Address"/>
</Declaration>
<Declaration>
<Class abbreviatedIRI="dm0:ShareHoldingCompany"/>
</Declaration>
<Declaration>
   <Class abbreviatedIRI="dm0:NonNaturalPerson"/>
</Declaration>
<Declaration>
   <Class abbreviatedIRI="dm0:NonProfitCompany"/>
</Declaration>

<SubClassOf>
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   <Class abbreviatedIRI="dm0:Organization"/>
</SubClassOf>

<SubClassOf>
   <Class abbreviatedIRI="dm0:Company"/>
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   <Class abbreviatedIRI="dm0:ShareHoldingCompany"/>
   <Class abbreviatedIRI="dm0:Company"/>
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<SubClassOf>
   <Class abbreviatedIRI="dm0:Association"/>
   <Class abbreviatedIRI="dm0:NonNaturalPerson"/>
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<SubClassOf>
   <Class abbreviatedIRI="dm0:LocalNGO"/>
   <Class abbreviatedIRI="dm0:Association"/>
</SubClassOf>

<SubClassOf>
   <Class abbreviatedIRI="dm0:NonProfitCompany"/>
   <Class abbreviatedIRI="dm0:Company"/>
</SubClassOf>

<EquivalentClasses>
   <Class abbreviatedIRI="dm0:Organization"/>
   <Class abbreviatedIRI="dm0:NonNaturalPerson"/>
</EquivalentClasses>

<DisjointClasses>
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   <Class abbreviatedIRI="dm0:Association"/>
</DisjointClasses>

<EquivalentClasses>
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   <ObjectIntersectionOf>
    <Class abbreviatedIRI="dm0:LocalNGO"/>
    <Class abbreviatedIRI="dm0:ShareHoldingCompany"/>
   </ObjectIntersectionOf>
</EquivalentClasses>

<EquivalentClasses>
   <Class abbreviatedIRI="dm0:NaturalPerson"/>
   <ObjectComplementOf>
    <Class abbreviatedIRI="dm0:Organization"/>
   </ObjectComplementOf>
</EquivalentClasses>

<Declaration>
   <DataProperty abbreviatedIRI="dm0:FocusesOnTargetGroup"/>
</Declaration>

<DataPropertyDomain>
   <DataProperty abbreviatedIRI="dm0:FocusesOnTargetGroup"/>
   <Class abbreviatedIRI="dm0:Association"/>
   </ObjectPropertyDomain>
   <DataPropertyRange>
      <ObjectProperty abbreviatedIRI="dm0:FocusesOnTargetGroup"/>
      <Datatype abbreviatedIRI="xsd:string"/>
</DataPropertyRange>

<Declaration>
   <ObjectProperty abbreviatedIRI="dm0:LocatedIn"/>
</Declaration>
<Declaration>
   <ObjectProperty abbreviatedIRI="dm0:LocatedInInverse"/>
</Declaration>

<InverseObjectProperties>
   <ObjectProperty abbreviatedIRI="dm0:LocatedIn"/>
   <ObjectProperty abbreviatedIRI="dm0:LocatedInInverse"/>
</InverseObjectProperties>

<ObjectPropertyDomain>
   <ObjectProperty abbreviatedIRI="dm0:LocatedIn"/>
   <Class abbreviatedIRI="dm0:NonNaturalPerson"/>
</ObjectPropertyDomain>

<ObjectPropertyDomain>
   <ObjectProperty abbreviatedIRI="dm0:LocatedInInverse"/>
   <Class abbreviatedIRI="dm0:Address"/>
</ObjectPropertyDomain>

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<ObjectPropertyRange>
   <ObjectProperty abbreviatedIRI="dm0:LocatedInInverse"/>
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</ObjectPropertyRange>

<Declaration>
   <ObjectProperty abbreviatedIRI="dm0:IsAdvocatedOf"/>
</Declaration>
<Declaration>
   <ObjectProperty abbreviatedIRI="dm0:HasAdvocate"/>
</Declaration>

<InverseObjectProperties>
   <ObjectProperty abbreviatedIRI="dm0:IsAdvocatedOf"/>
   <ObjectProperty abbreviatedIRI="dm0:HasAdvocate"/>
</InverseObjectProperties>

<ObjectPropertyDomain>
   <ObjectProperty abbreviatedIRI="dm0:IsAdvocatedOf"/>
   <Class abbreviatedIRI="dm0:NaturalPerson"/>
</ObjectPropertyDomain>

   <ObjectPropertyDomain>
   <ObjectProperty abbreviatedIRI="dm0:HasAdvocate"/>
   <Class abbreviatedIRI="dm0:Company"/>
</ObjectPropertyDomain>

<ObjectPropertyRange>
   <ObjectProperty abbreviatedIRI="dm0:IsAdvocatedOf"/>
   <Class abbreviatedIRI="dm0:Company"/>
</ObjectPropertyRange>

<ObjectPropertyRange>
   <ObjectProperty abbreviatedIRI="dm0:HasAdvocate"/>
   <Class abbreviatedIRI="dm0:NaturalPerson"/>
</ObjectPropertyRange>

<DisjointClasses>
   <Class abbreviatedIRI="dm0:LocalGovUnit"/>
   <Class abbreviatedIRI="dm0:Company"/>
</DisjointClasses>

<EquivalentClasses>
   <Class abbreviatedIRI="dm0:Company"/>
    <ObjectSomeValuesFrom>
     <ObjectProperty abbreviatedIRI="dm0:HasAdvocate"/>
   abbreviatedIRI="dm0:NaturalPerson"/>
   </ObjectSomeValuesFrom>
</EquivalentClasses>

<EquivalentClasses>
   <Class abbreviatedIRI="dm0:NonNaturalPerson"/>
    <ObjectSomeValuesFrom>
     <ObjectProperty abbreviatedIRI="dm0:LocatedIn"/>
    <Class abbreviatedIRI="dm0:Address"/>
   </ObjectSomeValuesFrom>
</EquivalentClasses>

</Ontology>
```
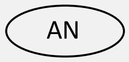
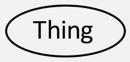
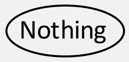
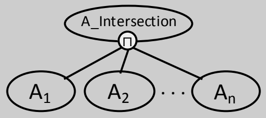
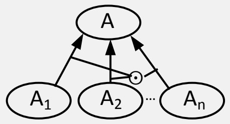
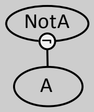
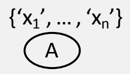
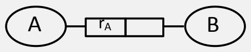
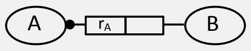
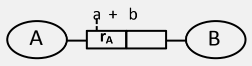
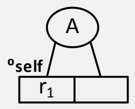
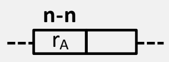
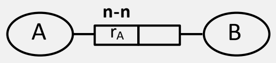
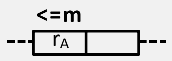
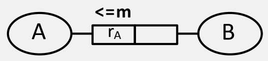
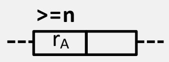
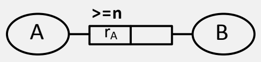
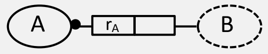
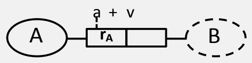
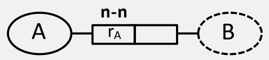
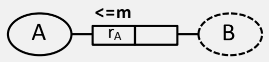
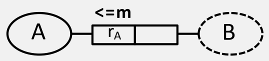
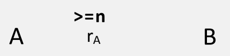
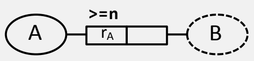
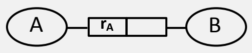
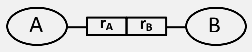
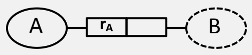

Figure A-2. A complete mapping of ORM into OWL 2 (OWL/XML) for ORM schema (Use Case) that shows the new proposed notations of Figure 4.14

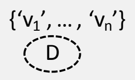
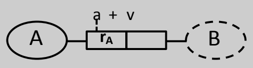
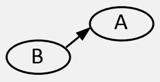
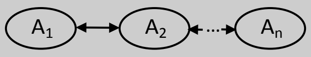
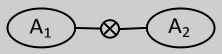
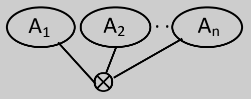
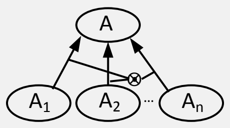
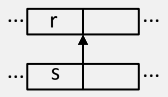
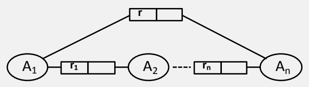
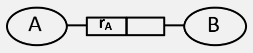
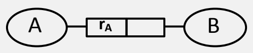
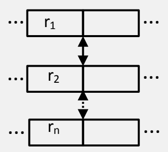
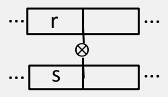
Appendix B

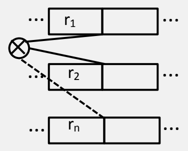
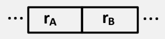
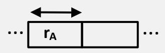
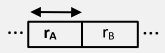
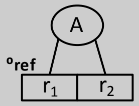
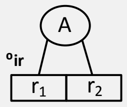
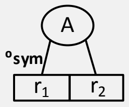
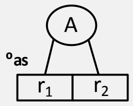
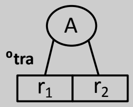
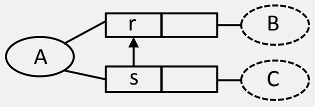
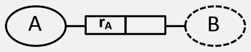
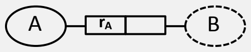
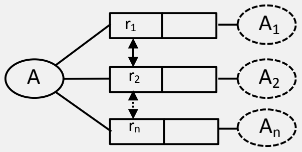
Table B. Summary of mapping for OWL 2 constructs and axioms into ORM. All constructs and axioms of OWL 2 are listed according to the quick reference of OWL 2 (www.w3.org/TR/owl2-quick-reference/)

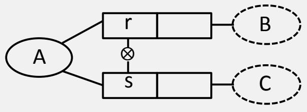
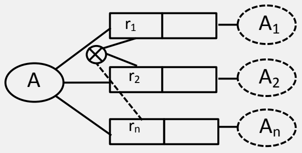
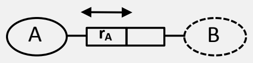
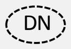
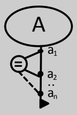
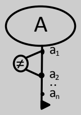
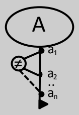
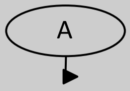
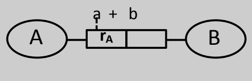
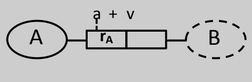
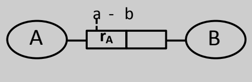
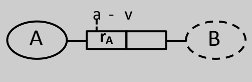
	OWL 2 Feature	Functional Syntax	RDF Syntax	ORM Notation
1	**Class Expressions**			
1.1	**Predefined and Named Classes**			
1.1.1	named class	AN	AN	
1.1.2	universal class	owl:Thing	owl:Thing	
1.1.3	empty class	owl:Nothing	owl:Nothing	
1.2	**Boolean Connectives and Enumeration of Individuals**			
1.2.1	Intersection	ObjectIntersectionOf(A_1 … A_n)	_:x rdf:type owl:Class. _:x owl:intersectionOf (A_1 … A_n).	
1.2.2	Union	ObjectUnionOf(A_1 … A_n)	_:x rdf:type owl:Class. _:x owl:unionOf (A_1 … A_n).	
1.2.3	Complement	ObjectComplementOf(A)	_:x rdf:type owl:Class. _:x owl:complementOf A.	
1.2.4	Enumeration	ObjectOneOf(x_1 … x_n)	_:x rdf:type owl:Class. _:x owl:oneOf (x_1 … x_n).	
1.3	**Object Property Restrictions**			
1.3.1	Universal	ObjectAllValuesFrom(r_A B)	_:x rdf:type owl:Restriction. _:x owl:onProperty r_A. _:x owl:allValuesFrom B	
1.3.2	Exsistential	ObjectSomeValuesFrom(r_A B)	_:x rdf:type owl:Restriction. _:x owl:onProperty r_A. _:x owl:someValuesFrom B	

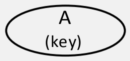
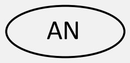
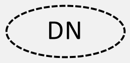
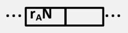
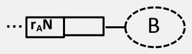
1.3.3	Individual value	ObjectHasValue(r_A b)	_:x rdf:type owl:Restriction. _:x owl:onProperty r_A. _:x owl:hasValue b.	
1.3.4	Local reflexivity	ObjectHasSelf(r_1)	_:x rdf:type owl:Restriction. _:x owl:onProperty r_1. _:x owl:hasSelf "true"^^xsd:boolean.	
1.3.5	exact cardinality	ObjectExactCardinality(n r_A)	_:x rdf:type owl:Restriction. _:x owl:onProperty r_A. _:x owl:cardinality n.	
1.3.6	qualified exact cardinality	ObjectExactCardinality(n r_A B)	_:x rdf:type owl:Restriction. _:x owl:onProperty r_A. _:x owl:qualifiedCardinality n. _:x owl:onClass B.	
1.3.7	maximum cardinality	ObjectMaxCardinality(m r_A)	_:x rdf:type owl:Restriction. _:x owl:onProperty P. _:x owl:maxCardinality n	
1.3.8	qualified maximum cardinality	ObjectMaxCardinality(m r_A B)	_:x rdf:type owl:Restriction. _:x owl:onProperty r_A. _:x owl:maxQualifiedCardinality n. _:x owl:onClass B.	
1.3.9	minimum cardinality	ObjectMinCardinality(n r_A)	_:x rdf:type owl:Restriction. _:x owl:onProperty r_A. _:x owl:minCardinality n.	
1.3.10	qualified minimum cardinality	ObjectMinCardinality(n r_A B)	_:x rdf:type owl:Restriction. _:x owl:onProperty r_A. _:x owl:minQualifiedCardinality n. _:x owl:onClass B.	
1.4	**Data Property Restrictions**			
1.4.1	Universal	DataAllValuesFrom(r_A.B D)	_:x rdf:type owl:Restriction. _:x owl:onProperty r_A.B. _:x owl:allValuesFrom D.	A r_A B
1.4.2	Existential	DataSomeValuesFrom(r_A.B D)	_:x rdf:type owl:Restriction. _:x owl:onProperty r_A.B. _:x owl:someValuesFrom D.	
1.4.3	literal value	DataHasValue(r_A.B v)	_:x rdf:type owl:Restriction. _:x owl:onProperty r_A.B. _:x owl:hasValue v.	
1.4.4	exact cardinality	DataExactCardinality(n r_A.B)	_:x rdf:type owl:Restriction. _:x owl:onProperty r_A.B. _:x owl:cardinality n.	
1.4.5	qualified exact cardinality	DataExactCardinality(n r_A.B D)	_:x rdf:type owl:Restriction. _:x owl:onProperty r_A.B. _:x owl:qualifiedCardinality n. _:x owl:onDataRange D.	A n-n r_A B
1.4.6	maximum cardinality	DataMaxCardinality(m r_A.B)	_:x rdf:type owl:Restriction. _:x owl:onProperty r_A.B. _:x owl:maxCardinality m.	
1.4.7	qualified maximum cardinality	DataMaxCardinality(m r_A.B D)	_:x rdf:type owl:Restriction. _:x owl:onProperty r_A.B. _:x owl:maxQualifiedCardinality m. _:x owl:onDataRange D.	

1.4.8	minimum cardinality	DataMinCardinality(n r_A.B)	_:x rdf:type owl:Restriction. _:x owl:onProperty r_A.B. _:x owl:minCardinality n.	
1.4.9	qualified minimum cardinality	DataMinCardinality(n r_A.B D)	_:x rdf:type owl:Restriction. _:x owl:onProperty r_A.B. _:x owl:minQualifiedCardinality n. _:x owl:onDataRange D.	
1.5	**Restrictions Using n-ary Data Range**			
1.5.1	n-ary universal	DataAllValuesFrom(r_1 … r_n D^n)	_:x rdf:type owl:Restriction. _:x owl:onProperties (r_1 … r_n). _:x owl:allValuesFrom D^n.	Non-notational Expression
1.5.2	n-ary existential	DataSomeValuesFrom(r_1 … r_n D^n)	_:x rdf:type owl:Restriction. _:x owl:onProperties (r_1 … r_n). _:x owl:someValuesFrom D^n.	Non-notational Expression
2	**Properties**			
2.1	**Object Property Expressions**			
2.1.1	Named object property	r_A	r_A	
2.1.2	universal object property	owl:topObjectProperty	owl:topObjectProperty	$\boxed{\text{TopObject}}$
2.1.3	empty object property	owl:bottomObjectProperty	owl:bottomObjectProperty	$\boxed{\text{BottomObject}}$
2.1.4	inverse property	ObjectInverseOf(r_B)	_:x owl:inverseOf r_B	
2.2	**Data Property Expressions**			
2.2.1	named data property	r_A.B	r_A.B	
2.2.2	universal data property	owl:topDataProperty	owl:topDataProperty	$\boxed{\text{TopData}}$
2.2.3	empty data property	owl:bottomDataProperty	owl:bottomDataProperty	$\boxed{\text{BottomData}}$
3	**Individuals & Literals**			
3.1	Named individual	a	a	● a
3.2	anonymous individual	_:a	_:a	● _:a
3.3	literal (datatype value)	"abc"^^DN	"abc"^^DN	Non-notational Expression
4	**Data Ranges**			
4.1	**Data Range Expressions**			
4.1.1	named datatype	DN	DN	Non-notational Expression
4.1.2	data range complement	DataComplementOf(D)	_:x rdf:type rdfs:Datatype. _:x owl:datatypeComplementOf D.	
4.1.3	data range intersection	DataIntersectionOf(D_1…D_n)	_:x rdf:type rdfs:Datatype. _:x owl:intersectionOf (D_1…D_n).	
4.1.4	data range union	DataUnionOf(D_1…D_n)	_:x rdf:type rdfs:Datatype.	

			_:x owl:unionOf (D_1…D_n).	
4.1.5	literal enumeration	DataOneOf(v_1 … v_n)	_:x rdf:type rdfs:Datatype. _:x owl:oneOf (v_1 … v_n).	
4.1.6	datatype restriction	DatatypeRestriction(DN f_1 v_1 … f_n v_n)	_:x rdf:type rdfs:Datatype. _:x owl:onDatatype DN. _:x owl:withRestrictions (_:x_1 ... _:x_n). _:x_j f_j v_j. j=1…n	 Set by the properties
5	**Axioms**			
5.1	**Class Expression Axioms**			
5.1.1	Subclass	SubClassOf(B A)	B rdfs:subClassOf A.	
5.1.2	equivalent classes	EquivalentClasses(A_1 … A_n)	A_j owl:equivalentClass A_{j+1}. j=1…n-1	
5.1.3	disjoint classes	DisjointClasses(A_1 A_2)	A_1 owl:disjointWith A_2.	
5.1.4	pairwise disjoint classes	DisjointClasses(A_1 … A_n)	_:x rdf:type owl:AllDisjointClasses. _:x owl:members (A_1 … A_n).	
5.1.5	disjoint union	DisjointUnionOf(A A_1 … A_n)	A owl:disjointUnionOf (A_1 … A_n).	
5.2	**Object Property Axioms**			
5.2.1	subproperty	SubObjectPropertyOf(s r)	s rdfs:subPropertyOf r	
5.2.2	property chain inclusion	SubObjectPropertyOf(ObjectPropertyChain(P_1 … P_n) P)	P owl:propertyChainAxiom (P_1 … P_n).	
5.2.3	property domain	ObjectPropertyDomain(r_A A)	r_A rdfs:domain A.	
5.2.4	property range	ObjectPropertyRange(r_A B)	r_A rdfs:range B.	
5.2.5	equivalent properties	EquivalentObjectProperties(r_1 … r_n)	r_j owl:equivalentProperty r_{j+1}. j=1…n-1	
5.2.6	disjoint properties	DisjointObjectProperties(s r)	s owl:propertyDisjointWith r.	

5.2.7	pairwise disjoint properties	DisjointObjectProperties(r_1 … r_n)	_:x rdf:type owl:AllDisjointProperties. _:x owl:members (r_1 … r_n).	
5.2.8	inverse properties	InverseObjectProperties(r_A r_B)	r_A owl:inverseOf r_B.	
5.2.9	functional property	FunctionalObjectProperty(r_A)	r_A rdf:type owl:FunctionalProperty.	
5.2.10	inverse functional property	InverseFunctionalObjectProperty(r_A)	r_A rdf:type owl:InverseFunctionalProperty.	
5.2.11	reflexive property	ReflexiveObjectProperty(r_1)	r_1 rdf:type owl:ReflexiveProperty.	
5.2.12	irreflexive property	IrreflexiveObjectProperty(r_1)	r_1 rdf:type owl:IrreflexiveProperty.	
5.2.13	symmetric property	SymmetricObjectProperty(r_1)	r_1 rdf:type owl:SymmetricProperty.	
5.2.14	asymmetric property	AsymmetricObjectProperty(r_1)	r_1 rdf:type owl:AsymmetricProperty.	
5.2.15	transitive property	TransitiveObjectProperty(r_1)	r_1 rdf:type owl:TransitiveProperty.	
5.3	**Data Property Axioms**			
5.3.1	subproperty	SubDataPropertyOf(sC rB)	sC rdfs:subPropertyOf rB.	
5.3.2	property domain	DataPropertyDomain(r_AB A)	r_AB rdfs:domain A.	
5.3.3	property range	DataPropertyRange(r_AB D)	r_AB rdfs:range D.	
5.3.4	equivalent properties	EquivalentDataProperties(r_1A_1 … r_nA_n)	r_j owl:equivalentProperty r_{j+1}. j=1…n-1	

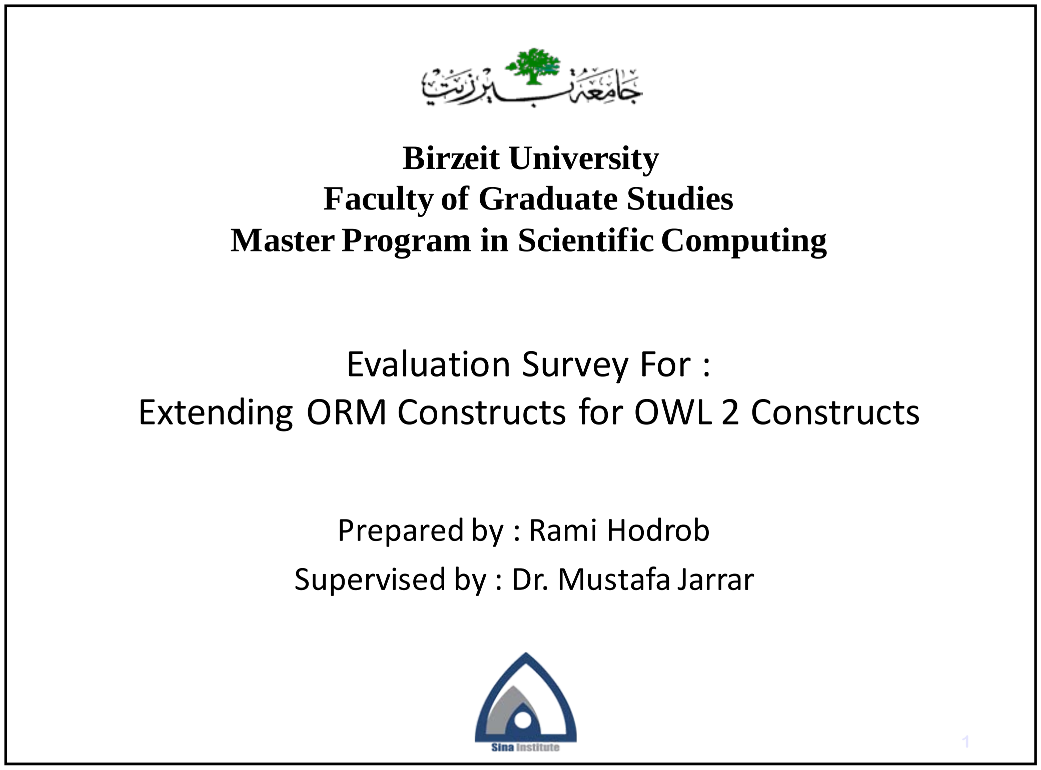
5.3.5	disjoint properties	DisjointDataProperties(sC rB)	sC owl:propertyDisjointWith rB.	
5.3.6	pairwise disjoint properties	DisjointDataProperties(r_1A_1 … r_nA_n)	_:x rdf:type owl:AllDisjointProperties. _:x owl:members (r_1A_1 … r_nA_n).	
5.3.7	functional property	FunctionalDataProperty(r_A)	r_A rdf:type owl:FunctionalProperty.	
5.4	**Datatype Definitions**			
5.4.1	datatype definition	DatatypeDefinition(DN D)	DN owl:equivalentClass D.	 Set by the properties of datatype
5.5	**Assertions**			
5.5.1	individual equality	SameIndividual(a_1 … a_n)	a_j owl:sameAs a_{j+1}. j=1…n-1	
5.5.2	individual inequality	DifferentIndividuals(a_1 a_2)	a_1 owl:differentFrom a_2.	
5.5.3	pairwise individual inequality	DifferentIndividuals(a_1 … a_n)	_:x rdf:type owl:AllDifferent. _:x owl:members (a_1 … a_n).	
5.5.4	class assertion	ClassAssertion(C a)	a rdf:type C.	
5.5.5	positive object property assertion	ObjectPropertyAssertion(r_A a b)	_:x rdf:type owl:PropertyAssertion. _:x owl:sourceIndividual a. _:x owl:assertionProperty r_A. _:x owl:targetIndividual b.	
5.5.6	positive data property assertion	DataPropertyAssertion(r_A.B a v)	_:x rdf:type owl:PropertyAssertion. _:x owl:sourceIndividual a. _:x owl:assertionProperty r_A.B. _:x owl:targetValue v.	
5.5.7	negative object property assertion	NegativeObjectPropertyAssertion(r_A a b)	_:x rdf:type owl:NegativePropertyAssertion. _:x owl:sourceIndividual a. _:x owl:assertionProperty r_A. _:x owl:targetIndividual b.	
5.5.8	negative data property assertion	NegativeDataPropertyAssertion(r_AB a v)	_:x rdf:type owl:NegativePropertyAssertion. _:x owl:sourceIndividual a. _:x owl:assertionProperty r_AB. _:x owl:targetValue v.	

5.6	**Keys**			
5.6.1	Key	HasKey(A () (key))	C owl:hasKey (key).	
6	**Declarations**			
6.1	class	Declaration(Class(AN))	AN rdf:type owl:Class.	
6.2	datatype	Declaration(Datatype(DN))	DN rdf:type rdfs:Datatype.	
6.3	object property	Declaration(ObjectProperty(r_AN))	r_AN rdf:type owl:ObjectProperty.	
6.4	data property	Declaration(DataProperty(r_ANB))	r_ANB rdf:type owl:DatatypeProperty.	
6.5	annotation property	Declaration(AnnotationProperty(ANT))	ANT rdf:type owl:AnnotationProperty.	Non-notational Expression
6.6	named individual	Declaration(NamedIndividual(a))	a rdf:type owl:NamedIndividual.	● a

* AN is a class name. A, B and C are class expressions. r and s are object property expressions. DN is a datatype name. D is a datatype. rB is a data property expression. a is an individual. _:a is an anonymous individual. _:x is a blank node. v is a literal. n is a non negative integer. $(x_1...x_n)$ are RDF List.

Appendix C

The following Survey was designed to evaluate extending ORM notations for representation of uncovered OWL 2 constructs by ORM. This survey was filled by 31 practitioners in ORM and OWL. Three notations for each OWL 2 construct were proposed. Each notation with the highest percentage selection is chosen to represent the intended OWL 2 construct.

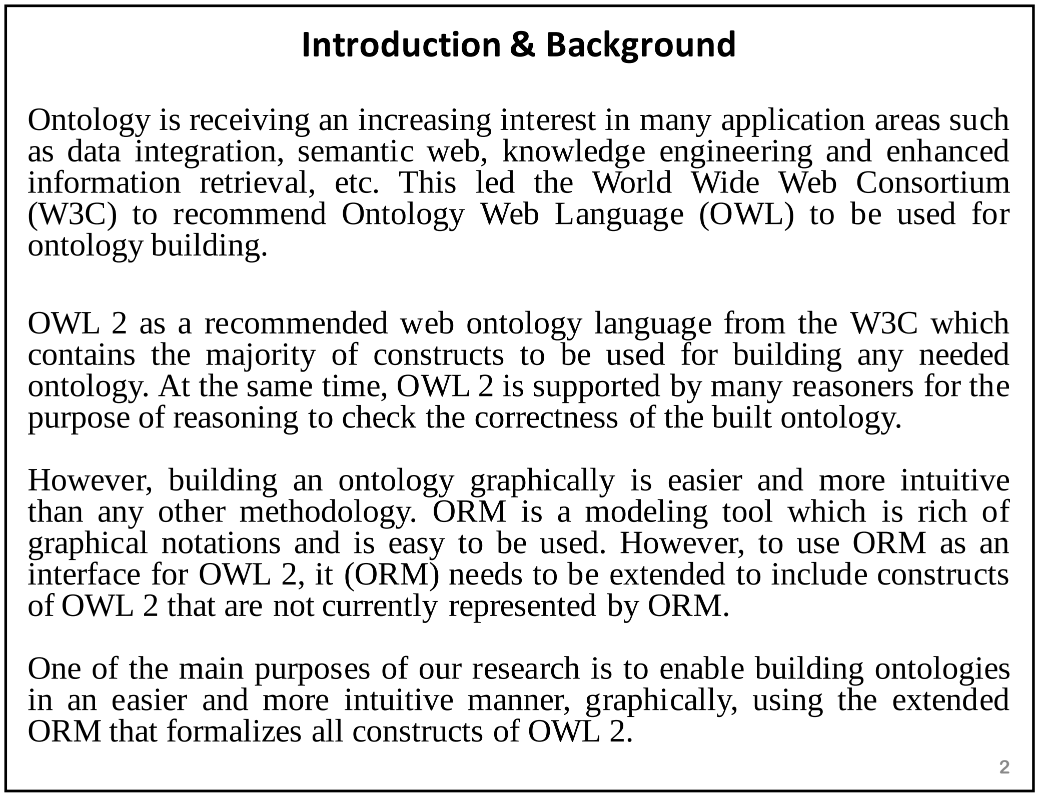


Birzeit University
Faculty of Graduate Studies
Master Program in Scientific Computing

Evaluation Survey For :
Extending ORM Constructs for OWL 2 Constructs

Prepared by : Rami Hodrob
Supervised by : Dr. Mustafa Jarrar

1



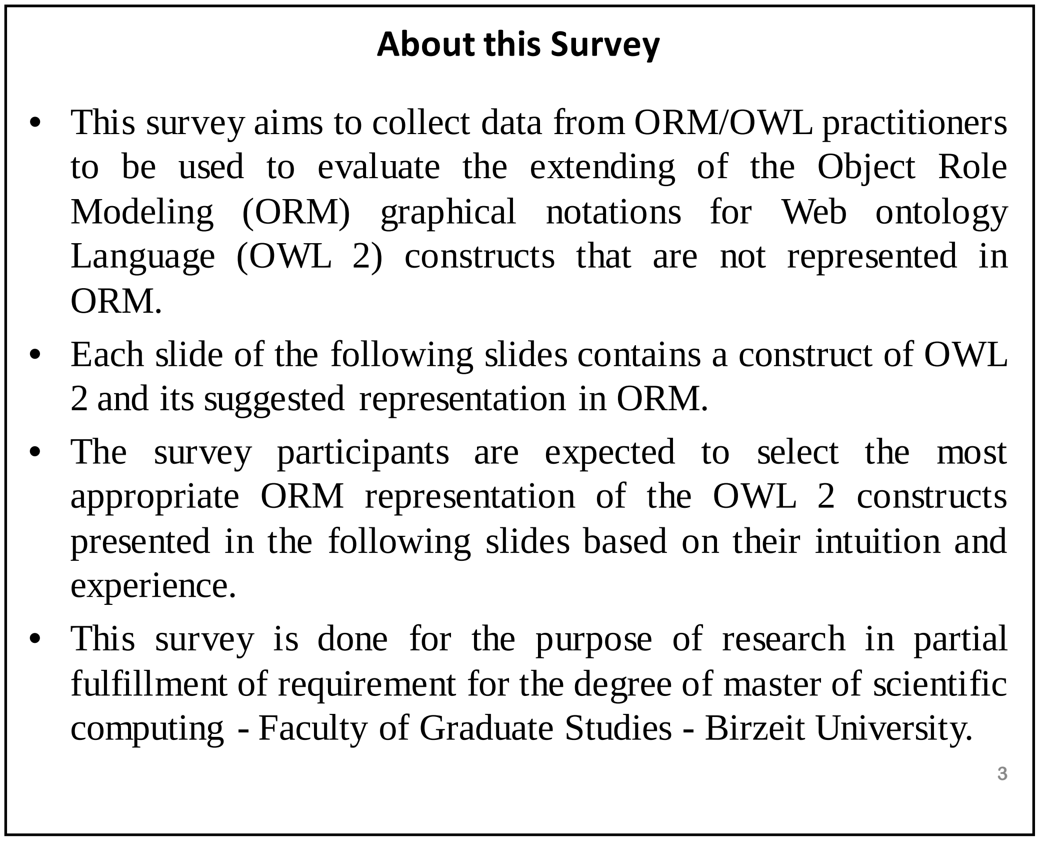
Introduction & Background

Ontology is receiving an increasing interest in many application areas such as data integration, semantic web, knowledge engineering and enhanced information retrieval, etc. This led the World Wide Web Consortium (W3C) to recommend Ontology Web Language (OWL) to be used for ontology building.

OWL 2 as a recommended web ontology language from the W3C which contains the majority of constructs to be used for building any needed ontology. At the same time, OWL 2 is supported by many reasoners for the purpose of reasoning to check the correctness of the built ontology.

However, building an ontology graphically is easier and more intuitive than any other methodology. ORM is a modeling tool which is rich of graphical notations and is easy to be used. However, to use ORM as an interface for OWL 2, it (ORM) needs to be extended to include constructs of OWL 2 that are not currently represented by ORM.

One of the main purposes of our research is to enable building ontologies in an easier and more intuitive manner, graphically, using the extended ORM that formalizes all constructs of OWL 2.

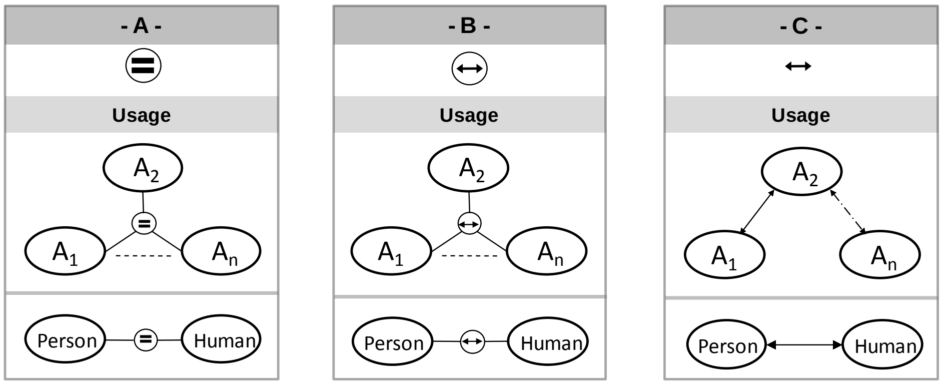


About this Survey

- This survey aims to collect data from ORM/OWL practitioners to be used to evaluate the extending of the Object Role Modeling (ORM) graphical notations for Web ontology Language (OWL 2) constructs that are not represented in ORM.
- Each slide of the following slides contains a construct of OWL 2 and its suggested representation in ORM.
- The survey participants are expected to select the most appropriate ORM representation of the OWL 2 constructs presented in the following slides based on their intuition and experience.
- This survey is done for the purpose of research in partial fulfillment of requirement for the degree of master of scientific computing - Faculty of Graduate Studies - Birzeit University.

OWL2 Construct: Equivalent Classes

If you want to say that class A_1, class A_2, and class A_n are **equivalent** to each other, which notation you prefer?
Your preference is: ____

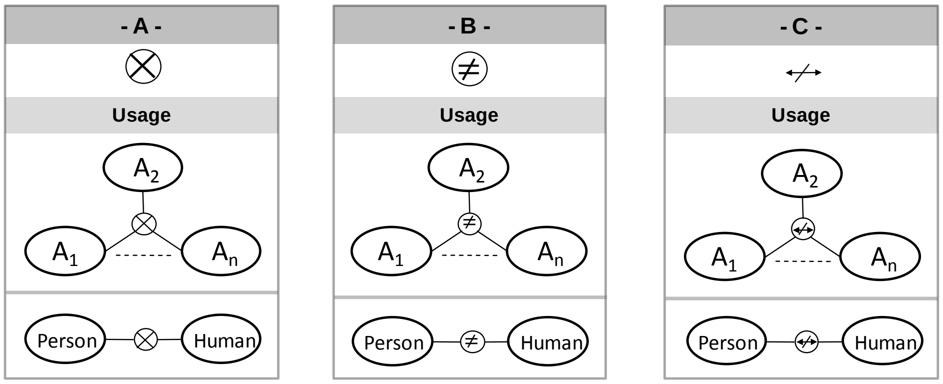


Comments:

4

OWL2 Construct: Disjoint Classes

If you want to say that class A_1, class A_2, and class A_n are **disjoint** (i.e., NOT equivalent to each other), which notation you prefer?
Your preference is: ____



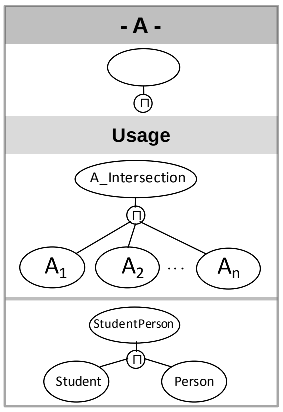
Comments:

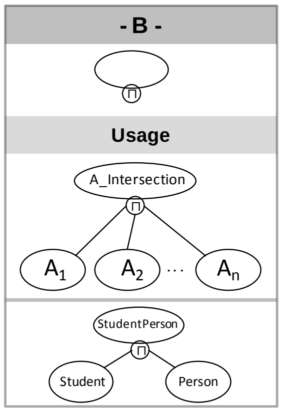
5

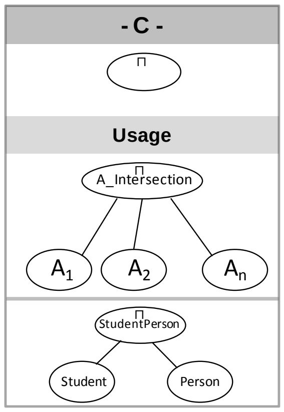
OWL2 Construct: Intersection of Classes

If you want to say that class A is result of the **intersection** of class A_1, class A_2, and class A_n, which notation you prefer?

Your preference is: ____





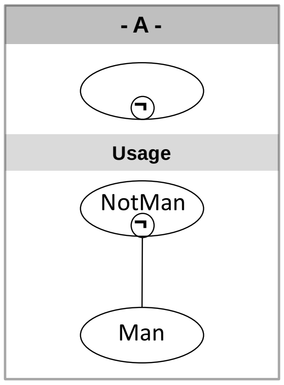


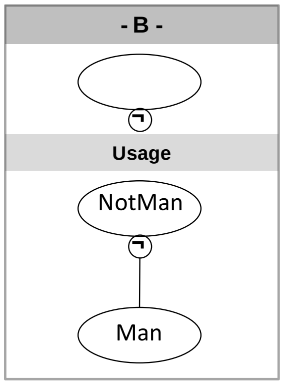
Comments:

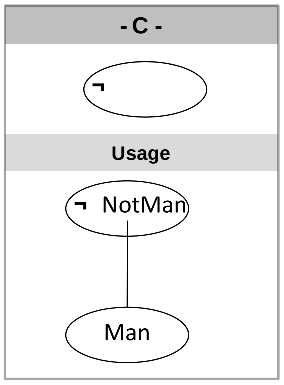
OWL2 Construct: Class Complement

If you want to represent the complement of class A, which notation you prefer?

Your preference is: ____





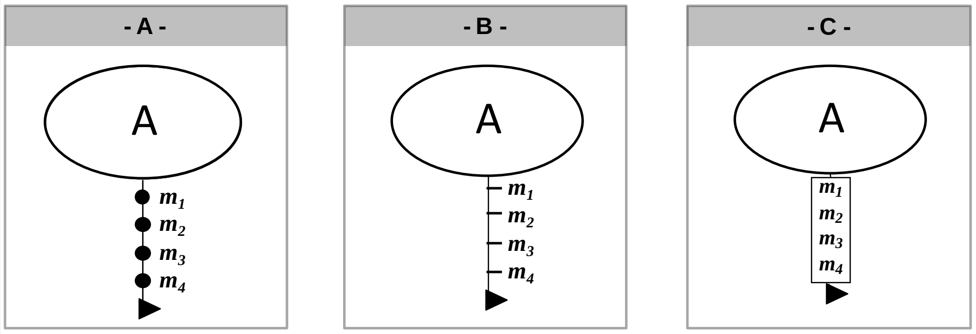


Comments:

OWL2 Construct: Class Assertions

If you want to say the m1, m2, m9 are instances of Man, which notation of the following you prefer?

Your preference is: ____



This means that the class contains four instances as a maximum number to be shown and we can click on icon ▶ and assert or visualize the needed instances for the class Man.

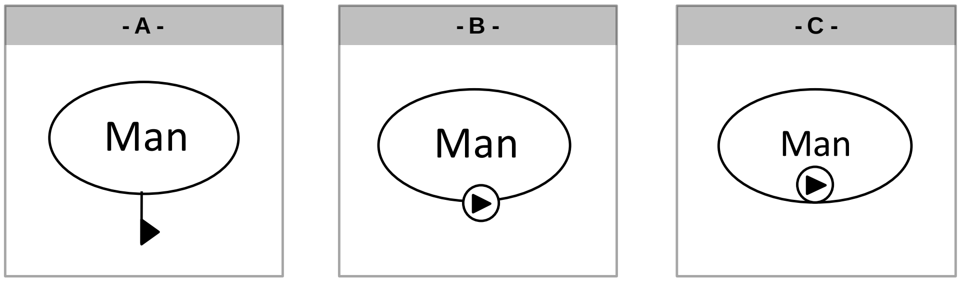
Comments:

9

OWL2 Construct: Class Assertions

If you want to **assert** an individual (a) to be a member of the population of class Man, which notation you prefer?

Your preference is: ____



The user can click on icon ▶ and assert or visualize the instances for the class Man.

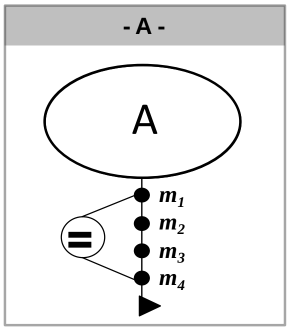
Comments:

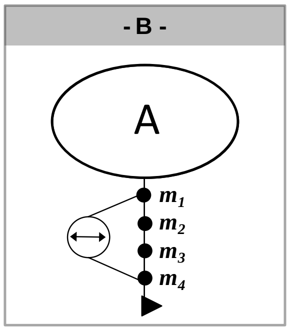
8

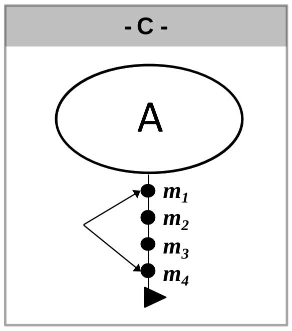
OWL2 Construct: Individual Equality

If you want to say that instance m2 is same as instance m3, which notation of the following you prefer?

Your preference is: ____







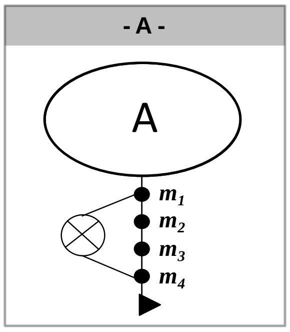
Comments:

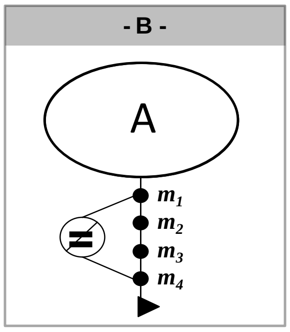
10

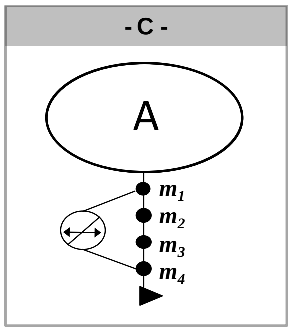
OWL2 Construct: Individual Inequality

If you want to say that instance m2 is different from instance m3, which notation of the following you prefer?

Your preference is: ____







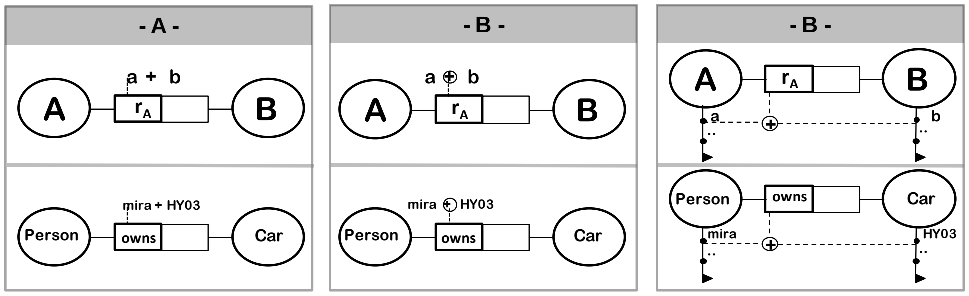
Comments:

11

OWL2 Construct: Positive Object Property Assertion

If you want to say that an instance a of class A ,is related to an instance b of class B, by the role (object property) r_A, which notation you prefer?

Your preference is: ____



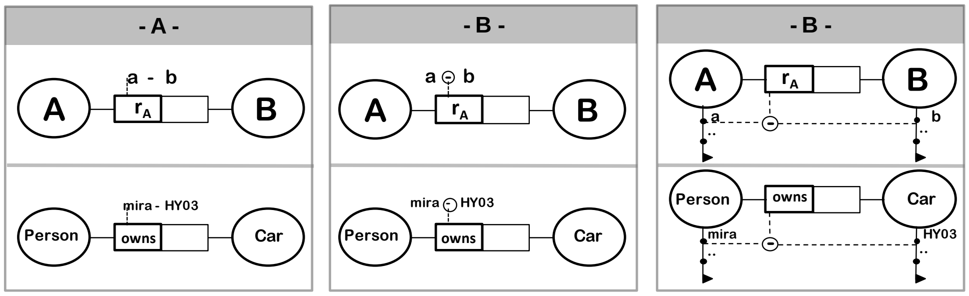
Comments:

12

OWL2 Construct: Negative Object Property Assertion

If you want to say that an instance a of class A ,is **not** related to an instance b of class B, by the role (object property) r_A, which notation you prefer?

Your preference is: ____



Comments:

13

Publications

The followings are the two articles which were conducted for this research. The first paper includes the initial and primitive results of mapping ORM into OWL 2, appeared first in [HJ10]. The second article includes revising, extending, evaluating, and implementing of mapping between ORM and OWL 2 to enable authoring an ontology graphically and was submitted to Data and Knowledge Engineering Journal, Elsevier.

Mapping ORM into OWL 2

Rami Hodrob
Arab American University, Jenin, Palestine
Birzeit University, Palestine
rhodrob@aauj.edu

Mustafa Jarrar
Birzeit University, Palestine
mjarrar@birzeit.edu

Abstract: The goal of this article is to map between Object Role Modeling (ORM) and Ontology Web Language 2 (OWL 2 DL). This mapping allows one to graphically develop his/her ontology using the ORM notation, while the ORM is automatically translated into OWL 2 DL. We map the most commonly used rules of ORM into OWL 2 DL which have the ability of decidability. DogmaModeler is extended to perform automatically this mapping (ORM into OWL 2 DL). Mapping technique is assessed using desirable reasoning methodology which depends on RacerPro2 reasoner .

Keywords: Ontology, Object Role Modeling, Web Ontology Language 2 (OWL 2 DL), SHOIN Description Logic.

1. Introduction and Motivation

Ontology is receiving an increasing interest in many application areas such as data integration, semantic web, knowledge engineering and enhanced information retrieval, etc [5]. This led World Wide Web Consortium (W3C) to recommend Ontology Web Language (Owl) [14]. It is difficult for IT people to build an ontology .At the other hand building ontology is time consuming. One who builds ontology needs good knowledge in formal logic.
Building an ontology using graphical notation tool is easier than other available techniques, even for non-IT specialists such as Object Role Modeling (ORM). ORM is a conceptual modeling language used in ontology engineering [13]. It encompasses a group of constraints that can comprehensively represent an ontology using rich graphical notation [7,8]. On the other hand, OWL 2 DL [16] is relatively a non user friendly language to be used by even IT specialists.
In our research, we map between ORM and OWL 2 DL. In this way (mapping) we exploit the benefits of both ORM and OWL 2. The benefits of ORM are i) it is true conceptual modeling independent of application; ii) it is a very user-friendly methodology; iii) it is more expressive than other techniques such as ER and UML [11,2,6]; iv) it is easy to reason about [10]; v) it is used in ontology standards and for expressing business rules [1]. In the other hand the benefits of OWL 2 are i) it is the recommended ontology web language [17]; ii) it is used to publish and share ontologies on the Web semantically; iii) it is used to construct a structure to share information standards for both human and machine consumption; iv) Automatic reasoning can be done against ontologies represented in OWL 2 to check consistency and coherency of these ontologies.

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That is a good motivation to combine ORM and OWL 2. This way we can build our ontology in ORM which is very close to natural language and easy to understand and use. In other words, we can build a system that uses ORM as interface for OWL 2.
We extend DogmaModeler [4] tool to implement our mapping (ORM into OWL 2) work. Another goal for the mapping is to extend ORM to represent notations that are not supported in ORM and available in OWL 2 like equivalent classes, data types, transitive closure, intersection and union between relations.
As a related work, the mapping from ORM to SHOIN/OWL description logic has been implemented [11]. SHOIN is chosen to compromise both its ability of expressiveness and decidability.
Each rule of ORM which is supported by SHOIN is mapped to SHOIN. Twenty two cases of ORM constructs are mapped. The purpose of this research [11] also is to use ORM as a technique and expressive notation for ontology engineering. Although in this research [11] mapping ORM into SHOIN is achieved, but mapping ORM into OWL is not achieved, where in our research mapping ORM into OWL 2 DL is achieved and is implemented automatically. Some other related work to our ontology modeling considered using UML as front-end to visualize and edit ontologies [2] without semantics as we do in our work, in addition the mentioned related work does not map to OWL 2 DL or even to OWL 1.
The rest of the paper is structured as follows. Section 2 briefly describes ORM background. Section 3 describes OWL 2 DL. Section 4 describes the mapping between ORM and OWL 2. Section 5 implements the mapping. Section 6 evaluates the mapping, and finally Section 7 concludes our work and states future work.

2. ORM Background

ORM is a fact-oriented modeling methodology independent from implementation-oriented procedures. This independence leads to a satisfactory modeling process [11]. ORM makes it easy to simplify the representative schema using either natural language or graphical notations to represent facts in their simple or elementary shapes. In addition, we can populate the diagrams by examples to measure the correctness of the design [7,8]. We have several tools based on ORM like Microsoft's Visio Modeler™, DogmaModeler and Norma. The knowledge of using ORM can be acquired easily and in a short period of time from non-IT specialists [11,13].
ORM can be fairly used to adopt the conceptual modeling techniques for building the needed ontology [6,13]. By using a graphical notation of ORM, we can express and treat many rules like mandatory, uniqueness, identity, exclusion, implications, frequency occurrences, subsetting, subtyping, equality, and others [7]. Many rules of ORM and their graphic representations are explained (see section 4).

3. OWL 2 DL

Ontology Web Language (OWL) is a knowledge representation language [20] used to publish and share ontologies on the Web and is endorsed by the W3C Consortium.
OWL 2 Web Ontology Language, is an ontology language for the semantic web (extended of OWL 1, empowered by new features and supported by several semantic reasoners such as RacerPro 2 and FaCT++). This ontology language includes formally defined meaning. On 27 October 2009, OWL 2 was recommended by W3C Consortium as a standard of ontology representation on the Web [17].Classes, properties, individuals, and data values are provided by OWL 2 and stored semantically on the WEB. OWL 2 ontologies are primary exchanged as RDF documents, where these ontologies can be used with information written in RDF. OWL 2 elements are identified by Internationalized Resource Identifiers (IRIs). It extends OWL 1 which uses Uniform Resource Identifiers (URIs) [16,20]. Every IRI must be absolute to be published internationally. OWL 2 increases expressive language power for properties.
The new features of OWL 2 are i) syntactic sugar to make some statements easier. ii) new constructs that increase expressivity. iii) extended support for datatypes; iv) simple metamodeling capabilities; v) extended annotation capabilities. OWL 2 is serialized by XML to structurally specify it.

4. Mapping between ORM and OWL 2

Since we concentrate on the ability of expressivity and decidability for our mapping results(SHOIN achieves this Ability [11]), we will use SHOIN Description Logic (which is the most common in ontology engineering [11]) as a reference to map from ORM into OWL 2 DL. First, we formally formalize the ORM construct into SHOIN Description Logic and then we represent this model in OWL 2. Our scope of conversion is every construct of ORM .

4.1 Use Case

In order to recognize the ORM graphical notations, and Mapping between ORM, SHOIN and OWL 2 refer to Figure 1, and the explanation that follows.

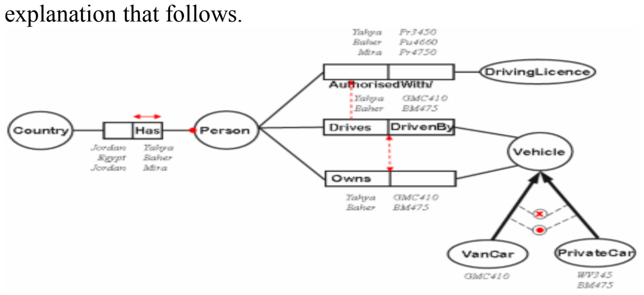


Figure 1. Example of an ORM Schema

In Figure 1, object-types are represented as ellipses, and relations as rectangles, where one or more role form each ORM relation. Binary relation (*Drives/DrivenBy*) in SHOIN is as *(Person* $\sqsubseteq$ $\forall$*Drives.Vehicle, Vehicle* $\sqsubseteq$ $\forall$*DrivenBy.Person, DrivenBy* $\sqsubseteq$ *Drives*$^{-}$*)*. This relation is represented in OWL 2 DL as shown in the OWL/XML syntax below. Object-type in ORM is declared as Class (*Person* and *Vehicle)* construct in OWL 2. Each role of the relation in ORM is declared as objectProperty (*Drives* and *DrivenBy)* construct in OWL 2.

```
<Declaration>
<Class IRI="#Person"/>
…<
Declaration>
<ObjectPropertyIRI="#DrivenBy"/>
</Declaration>
<InverseObjectProperties>
<ObjectProperty IRI="#DrivenBy"/>
<ObjectProperty IRI="#Drives"/>
</InverseObjectProperties>
<ObjectPropertyDomain>
<ObjectProperty IRI="#Drives"/>
<Class IRI="#Person"/>
</ObjectPropertyDomain>
<ObjectPropertyRange>
<ObjectProperty IRI="#Drives"/>
<Class IRI="#Vehicle"/>
</ObjectPropertyRange>
```

In the following we explain each rule in ORM, its formalization in SHOIN and its representation in OWL 2 (rules represented in figure 1):

a. *Subsumption* is represented in SHOIN as (*VanCar* $\sqsubseteq$ *Vehicle, PrivateCar* $\sqsubseteq$ *Vehicle*). In OWL 2 subClassOf construct is used to represent this rule as

```
<SubClassOf>
    <Class IRI="#PrivateCar"/>
    <Class IRI="#Vehicle"/>
</SubClassOf>
<SubClassOf>
    <Class IRI="#VanCar"/>
    <Class IRI="#Vehicle"/>
 </SubClassOf>
```

b. *Mandatory* is depicted as a dot • on the line. In SHOIN is (*Person* $\sqsubseteq$ $\exists$*Has.Country*). In OWL 2 ObjectSomeValuesFrom construct which is equivalent to the extensional quantifier($\exists$) is used to represent Mandatory in ORM which is more elegant than using minCardinality construct to restrict the population of Person to at least have one Country as

```
<ObjectPropertyRange>
   <ObjectProperty IRI="#Has"/>
     <ObjectSomeValuesFrom>
       <ObjectProperty abbreviatedIRI="owl:topObjectProperty"/>
       <Class IRI="#Country"/>
      </ObjectSomeValuesFrom>
 </ObjectPropertyRange>
```

c. *Total constraint* is depicted as a dot (•) between the two subtypes. In SHOIN it is (*Vehicle* $\sqsubseteq$*VanCartPrivateCar*).OWL2, ObjectUnionOf construct is used to represent this rule.

d. *Exclusive Constraint* is depicted as ⊗ between the two subtypes. In SHOIN it is (*VanCar* $\sqcap$ *PrivateCar* $\equiv\perp$). In OWL 2 DisjointClasses expressions is used. We use DisjointUnion construct to map both Total Constraint and Exclusive as

```
</DisjointUnion>
    <Class IRI="#Vehicle"/>
    <Class IRI="#PrivateCar"/>
    <Class IRI="#VanCar"/>
</DisjointUnion>
```

e. *Subset Constraint* is depicted as an arrow → between the roles *Drives* and *AuthorizedWith*; which means that the object role Drives is a subset of object role AuthorizedWith. *(Drives.Vehicle*$\sqsubseteq$*AuthorizedWith.DrivingLicence*). In OWL 2, to represent this rule we consider Drives. Person as a class using equivelentClass construct in OWL2. This construct is subClassOf the equivelantClass (AuthorizedWith.Person) as shown below

```
<EquivalentClasses>
<Class IRI="#AutorizedWith.Person"/>
```

```
<ObjectAllValuesFrom>
<ObjectProperty IRI="#AuthorizedWith"/>
<Class IRI="#Person"/>
</ObjectAllValuesFrom>
</EquivalentClasses>
<EquivalentClasses>
<Class IRI="#Drives.Person"/>
<ObjectAllValuesFrom>
<ObjectProperty IRI="#Drives"/>
<Class IRI="#Person"/>
</ObjectAllValuesFrom>
</EquivalentClasses>
<SubClassOf>
<Class IRI="#Drives.Person"/>
<Class IRI="#AutorizedWith.Person>
</SubClassOf>
```

f. *EqualityConstraint* is depicted as a double-headed arrow↔ (*Owns≡Drives*). Representation in OWL 2 is done using EquivalentObjectProperties as

```
        <EquivalentObjectProperties>
            <ObjectProperty IRI="#Drives"/>
            <ObjectProperty IRI="#Owns"/>
         </EquivalentObjectProperties>
```

g. *Role uniqueness* is depicted by an arrow ↔ spanning along single role of binary relation. In SHOIN ($Person \sqsubseteq \leq 1 Has.Country$). In OWL 2 we use FunctionalObjectProperty (range is exactly one (for domain population of property)) which is more elegant than using maxCardinality (restricted by integer 1) construct. It is represented as

```
           <FunctionalObjectProperty>
               <ObjectProperty IRI="#Has"/>
        </FunctionalObjectProperty>
```

Verbalization of ORM rules

ORM diagrams can be read easily by domain experts, and rules can be automatically verbalized into pseudo natural language sentences as the following:

- Each Person Has at least one Country. *(Mandatory)*
- Each Vehicle can not be a VanCar and a PrivateCar at the same time. *(Exclusive)*
- Each Vehicle must be, at least, VanCar or PrivateCar. *(Totality)*
- If a Person Drives a Vehicle then that Person AuthorizedWith a DrivingLicence. *(Subset)*
- If a Person Owns a Vehicle this Person is also Drives that Vehicle, and vice versa. *(Equality)*
- Each Person must Has at most one Country. *(External uniqueness)*

This verbalization simplifies the communication with non-IT specialists and allows them to better recognize, validate, or build ORM diagrams.

A complete list of ORM rules and mapping work in general cases is explained in the following.

4.2 Object-Types and relations:

4.2.1 Unary relationship

See the first column in Table 1.

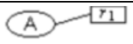
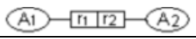
4.2.2 Binary relationship

The mapping is as stated in the example in section 4.1 (general case is shown in Table 1 right side).

4.2.3 N-ary relationships where n>2

It is not considered (not supported by SHOIN).

Table 1. Relationships (Unary and Binary) are represented in ORM, SHOIN and OWL 2 DL

ORM		
SHOIN	$A \sqsubseteq \forall r1.Bolean$	$A1 \sqsubseteq \forall r1.A2,\ A2 \sqsubseteq \forall r2.A1,\ r2 \sqsubseteq \forall r1^{-}$
OWL 2	<Declaration> <Class IRI="#A"/> </Declaration> <Declaration> <DataProperty IRI="#r1"/> </Declaration> <SubDataPropertyOf> <DataProperty IRI="#r1"/> <DataProperty abbreviatedIRI="owl:topDataProperty"/> </SubDataPropertyOf> <DataPropertyDomain> <DataProperty IRI="#r1"/> <Class IRI="#A"/> </DataPropertyDomain> <DataPropertyRange> <DataProperty IRI="#r1"/> <Datatype abbreviatedIRI="xsd:boolean"/> </DataPropertyRange> …	<InverseObjectProperties> <ObjectProperty IRI="#r2"/> <ObjectProperty IRI="#r1"/> </InverseObjectProperties> <ObjectPropertyDomain> <ObjectProperty IRI="#r1"/> <Class IRI="#A1"/> </ObjectPropertyDomain> <ObjectPropertyDomain> <ObjectProperty IRI="#r2"/> <Class IRI="#A2"/> </ObjectPropertyDomain> <ObjectPropertyRange> <ObjectProperty IRI="#r1"/> <Class IRI="#A2"/> </ObjectPropertyRange> <ObjectPropertyRange> <ObjectProperty IRI="#r2"/> <Class IRI="#A1"/> </ObjectPropertyRange> …

4.3 Subtypes

ORM uses proper subtype [8,11]. See the example in section 4.1 and Table 2 (first column).

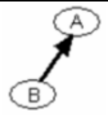
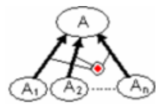
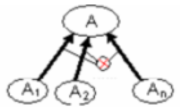
4.4 Total constraint

General case of mapping is shown in Table 2 (middle column).

4.5 Exclusive constraint

The general case of mapping is in Table 2 (last column).

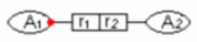
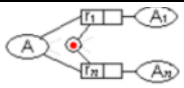
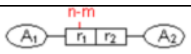
Table 2. Subtype, Total Constraint and Exclusive Constraint (declaration of classes is not included)

ORM			
SHOIN	*B* ⊑ *A*	*A* v A1 t A2 … t An	*(Ai* u *Aj* ≡ *⊥) for each i*∊*{1…n-1},j*∊*{i+1…n}*
OWL 2	… <SubClassOf> <Class IRI="#B"/> <Class IRI="#A"/> </SubClassOf> …	<SubClassOf> <ObjectUnionOf> <Class IRI="#A1"/> <Class IRI="#An"/> </ObjectUnionOf> <Class IRI="#A"/> </SubClassOf>	… <DisjointClasses> <Class IRI="#A1"/> <Class IRI="#A2"/> … <Class IRI="#An"/> </DisjointClasses>

4.6 Mandatory Constraints
4.6.1 Role mandatory
The mapping is as stated in the example in section 4.1 (see the first column in Table 3).

4.6.2 Disjunctive Mandatory
The disjunctive mandatory constraint is as stated in middle column of table 3, means that each instance of object-type A must play the role of at least one of the constraints role r1….rn. The representation of this in OWL2 is shown in Table 3 (middle column).

Table 3 Mandatory Constraints and Role Frequency Constraint (Classes and ObjectProperties are not declared)

ORM			
SHOIN	*A1* ⊑ ∃*r1.A2*	*A* v ∃*r1.A1* … t ∃*rn.An*	*A1* v ≥ n, ≤ *m r1.A2* t ⊥
OWL 2	</ObjectPropertyRange> <ObjectPropertyRange> <ObjectProperty IRI="#r1"/> <ObjectSomeValuesFrom> <ObjectProperty IRI="#r1"/> <Class IRI="#A2"/> </ObjectSomeValuesFrom> </ObjectPropertyRange>	<ObjectPropertyRange> <ObjectProperty IRI="#r1"/> <ObjectSomeValuesFrom> <ObjectProperty IRI="#r1"/> <Class IRI="#A1"/> </ObjectSomeValuesFrom> </ObjectPropertyRange> …	<ObjectPropertyRange> <ObjectProperty IRI="#r1"/> <ObjectMinCardinality cardinality="n"> <ObjectProperty IRI="#r1"/> <Class IRI="#A2"/> </ObjectMinCardinality> … <ObjectMaxCardinality cardinality="m"> …

4.7 Role Uniqueness
Refer to Subsection 4.1.

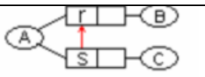
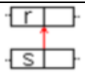
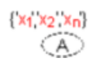
4.8 Frequency Constraints
4.8.1 Role Frequency Constraint
Role Frequency in ORM means that role r1 is played by the object A2 number of occurrences (see Table 3 last column).

4.8.2 Multiple-role Frequency Constraint
Can not be formalized in description logic [4] and so it is not considered in OWL 2.

4.9 Value Constraints
The value constraint in ORM points to the possible set of values that an object-type can be populated with (Table 4 last column).

4.10 Subset Constraints
Stated in the example in section 4.1 (Table 4 (first two columns)).

Table 4 Subset Constraint (Role and Binary) and Value Constraint (String Type)

ORM			
SHOIN	*s.C* ⊑ *r.B*	*s* ⊑ *r*	*A1* ⊑ *STRING* *A* ≡ *{x1,…,xn}*

OWL 2	<EquivalentClasses>
	  <Class IRI="#r.A"/>
	  <ObjectAllValuesFrom>
	      <ObjectProperty IRI="#r"/>
	   <Class IRI="#A"/>
	  </ObjectAllValuesFrom>
	</EquivalentClasses>
	 <EquivalentClasses>
	 <Class IRI="#s.A"/>
	  <ObjectAllValuesFrom>
	      <ObjectProperty IRI="#s"/>
	      <Class IRI="#A"/>
	 </ObjectAllValuesFrom>
	  </EquivalentClasses>
	<SubClassOf>
	    <Class IRI="#s.A"/>
	    <Class IRI="#r.A"/>
	  </SubClassOf>
		…
		  <SubObjectPropertyOf>
		     <ObjectProperty IRI="#s"/>
		     <ObjectProperty IRI="#r"/>
		</SubObjectPropertyOf>
		…
			<EquivalentClasses>
			    <Class IRI="#A"/>
			    <DataAllValuesFrom>
			      <DataProperty
			abbreviatedIRI="owl:topDataProperty"/>
			      <Datatype abbreviatedIRI="xsd:string"/>
			    </DataAllValuesFrom>
			  </EquivalentClasses>
			<EquivalentClasses>
			    <Class IRI="#A"/>
			    <ObjectOneOf>
			      <NamedIndividual IRI="#X1"/>
			      …
			      <NamedIndividual IRI="#Xn"/>
			    </ObjectOneOf>
			  </EquivalentClasses>

4.11 Equality Constraint

It is similar to subset constraint. In OWL 2, we use (EquivalentObjectProperties) construct to represent it.

4.12 Exclusion Constraint

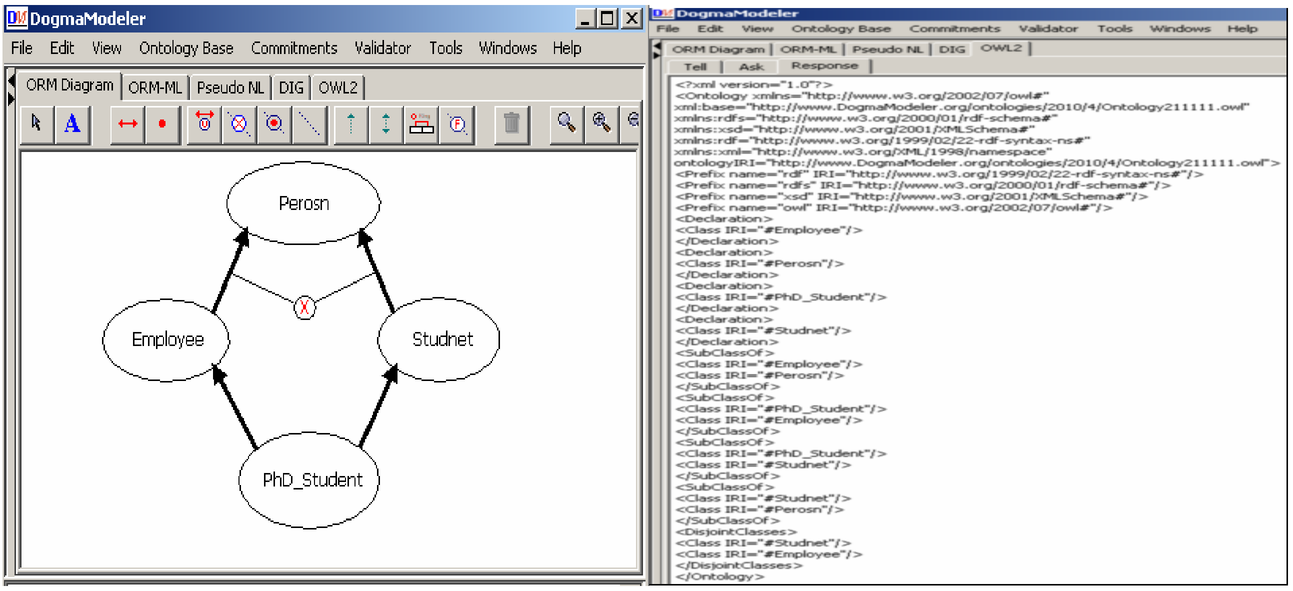
It is similar to subset constraint. In OWL 2, we use (DisjointObjectProperties) construct to represent it.

4.13 Ring Constraints

OWL 2 supports Reflexive, Irreflexive, and Asymmetric object properties as new features in addition to Symmetric and Transitive that are supported by OWL 1 (equivalent constructs are used in ORM).

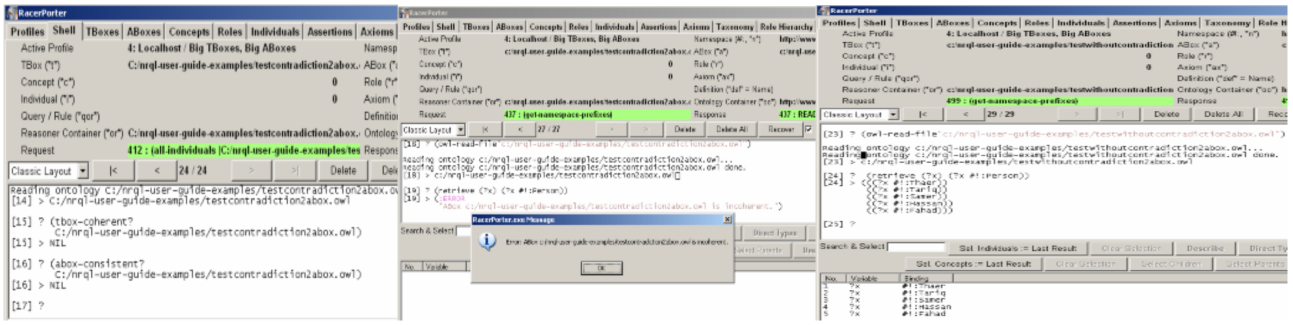
5. Implementation

We implement our mapping using DogmaModeler. DogmaModeler is a modeling tool used to represent and reason for ontology and other related applications based on ORM. We have extend DogmaModeler (Java is used as a programming language for coding) to automatically map ORM into OWL 2 DL constructs depending on ORM markup language [3,12] (which is automatically generated according to equivalent ORM graphical notations). Figure 2 shows a snap shot of DogmaModeler outputs, where the left screen shows the ORM graphical notation containing subtypes and exclusive constraint. The right screen shows a complete OWL 2 file output that represents the ORM graphical notation.


DogmaModeler
File Edit View Ontology Base Commitments Validator Tools Windows Help
ORM Diagram ORM-ML Pseudo NL DIG OWL2
Perosn
Employee
Studnet
PhD_Student
DogmaModeler
File Edit View Ontology Base Commitments Validator Tools Windows Help
ORM Diagram ORM-ML Pseudo NL DIG OWL2
Tell Ask Response

```
<?xml version="1.0"?>
<Ontology xmlns="http://www.w3.org/2002/07/owl#"
xml:base="http://www.DogmaModeler.org/ontologies/2010/4/Ontology211111.owl"
xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
xmlns:xsd="http://www.w3.org/2001/XMLSchema#"
xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
xmlns:xml="http://www.w3.org/XML/1998/namespace"
ontologyIRI="http://www.DogmaModeler.org/ontologies/2010/4/Ontology211111.owl">
<Prefix name="rdf" IRI="http://www.w3.org/1999/02/22-rdf-syntax-ns#"/>
<Prefix name="rdfs" IRI="http://www.w3.org/2000/01/rdf-schema#"/>
<Prefix name="xsd" IRI="http://www.w3.org/2001/XMLSchema#"/>
<Prefix name="owl" IRI="http://www.w3.org/2002/07/owl#"/>
<Declaration>
<Class IRI="#Employee"/>
</Declaration>
<Declaration>
<Class IRI="#Perosn"/>
</Declaration>
<Declaration>
<Class IRI="#PhD_Student"/>
</Declaration>
<Declaration>
<Class IRI="#Studnet"/>
</Declaration>
<SubClassOf>
<Class IRI="#Employee"/>
<Class IRI="#Perosn"/>
</SubClassOf>
<SubClassOf>
<Class IRI="#PhD_Student"/>
<Class IRI="#Employee"/>
</SubClassOf>
<SubClassOf>
<Class IRI="#PhD_Student"/>
<Class IRI="#Studnet"/>
</SubClassOf>
<SubClassOf>
<Class IRI="#Studnet"/>
<Class IRI="#Perosn"/>
</SubClassOf>
<DisjointClasses>
<Class IRI="#Studnet"/>
<Class IRI="#Employee"/>
</DisjointClasses>
</Ontology>
```

Figure 2. Implemented example using DogmaModeler (ORM graphical notation and OWL 2 DL).


RacerPorter
Profiles | Shell | TBoxes | ABoxes | Concepts | Roles | Individuals | Assertions | Axioms | Taxonomy | Role Hierarchy
Classic Layout
Delete
Delete All
Recover
OK
Search & Select
Sel. Individuals := Last Result
Sel. Concepts := Last Result
Clear Selection
Describe
Direct Types
Select Children
Select Parents

Active Profile 4: Localhost / Big TBoxes, Big ABoxes
TBox ("t") C:/nrql-user-guide-examples/testcontradiction2abox.
Concept ("c") 0
Individual ("i") 0
Query / Rule ("qor")
Reasoner Container ("or") C:/nrql-user-guide-examples/testcontradiction2abox.
Request 412 : (all-individuals |C:/nrql-user-guide-examples/tes
24 / 24

```
Reading ontology C:/nrql-user-guide-examples/testcontradiction2abox.ow
[14] > C:/nrql-user-guide-examples/testcontradiction2abox.owl

[15] ? (tbox-coherent?
        C:/nrql-user-guide-examples/testcontradiction2abox.owl)
[15] > NIL

[16] ? (abox-consistent?
        C:/nrql-user-guide-examples/testcontradiction2abox.owl)
[16] > NIL

[17] ?
```

Request 437 : (get-namespace-prefixes)
27 / 27

```
[18] ? (owl-read-file "c:/nrql-user-guide-examples/testcontradiction2abox.owl")

Reading ontology c:/nrql-user-guide-examples/testcontradiction2abox.owl...
Reading ontology c:/nrql-user-guide-examples/testcontradiction2abox.owl done.
[18] > c:/nrql-user-guide-examples/testcontradiction2abox.owl

[19] ? (retrieve (?x) (?x #!:Person))
[19] > (:ERROR
        "ABox c:/nrql-user-guide-examples/testcontradiction2abox.owl is incoherent.")
```

RacerPorter.exe Message

Error: ABox c:/nrql-user-guide-examples/testcontradiction2abox.owl is incoherent.

TBox ("t") c:/nrql-user-guide-examples/testwithoutcontradiction
Reasoner Container ("or") c:/nrql-user-guide-examples/testwithoutcontradiction
Request 499 : (get-namespace-prefixes)
29 / 29

```
[23] ? (owl-read-file "c:/nrql-user-guide-examples/testwithoutcontradiction2abox.owl")

Reading ontology c:/nrql-user-guide-examples/testwithoutcontradiction2abox.owl...
Reading ontology c:/nrql-user-guide-examples/testwithoutcontradiction2abox.owl done.
[23] > c:/nrql-user-guide-examples/testwithoutcontradiction2abox.owl

[24] ?  (retrieve (?x) (?x #!:Person))
[24] > (((?x #!:Thaer))
        ((?x #!:Tariq))
        ((?x #!:Samer))
        ((?x #!:Hassan))
        ((?x #!:Fahad)))

[25] ?
```

No.	Variable	Binding
1	?x	#!:Thaer
2	?x	#!:Tariq
3	?x	#!:Samer
4	?x	#!:Hassan
5	?x	#!:Fahad

Figure 3. RacerPro 2 outputs for consistent, coherent, and instance retrieval checks.

6. Evaluation

For the evaluation part, every construct of OWL 2 mapped from ORM is loaded as a complete file to the RacerPro 2 [18] that supports OWL 2. We have many checks (such as consistency and coherent checks) concerning reasoning techniques [15] used to validate the ontology represented in OWL 2. RacerPro 2 checks the coherence of TBos. If it is coherent, it will give t (which means true). If not, it will give NIL. Another check done by RacerPro is the consistency of ABox to check if it is as a model consistent with TBox. If so, the reasoner will give t (true). Another way of reasoning using RacerPro2 is creating queries using the New RacerPro Query Language-nRQL[19], by populating the TBox of knowledge base. Then, we check the consistency of knowledge base. We load the OWL 2 file (shown in Figure 2 left side) into the RacerPro 2. When we check the coherence of TBox, it gives us NIL (see Figure 3 left side) because of the contradiction between Exclusive constraint and PhDStudent subtype Class. When we insert individuals into the knowledge base for classes Student, Employee and PhD_Student, and checked the consistency of ABox with TBox, it gives us NIL because of the contradiction mentioned above. After populating the classes Student, Employee and PhD Student and applying nRQL for individual retrieval, RacerPro 2 gives us that the knowledge base was incoherent and there is no valid model for the class Person (Fig 3 middle screen). Where we exclude the exclusive constraint and check the consistency of ABox, it gives us a valid model for Person, and ABox is consistent (see figure 3 right side) with the TBox (axioms represented in OWL 2 (see figure 2 right side)). This output of check (instance retrieval) proves the correctness of mapping Exclusive construct of ORM (represented in graphical notation (figure 2 left side) into OWL 2 construct (DisjointClasses which is represented in Figure 2 right side).

7. Conclusion and Future Work

The mapping and automation of this mapping from ORM into OWL 2 are the main theme of this paper. We do map twenty two (out of twenty nine) ORM constructs. Where these 22 constructs represent the most commonly used constructs in ORM. At the same time, those constructs are supported by SHOIN Description Logic; which means the OWL 2 output we have mapped characterized by its ability of decidability. Through the evaluation process, we illustrated the correctness of our mapping. The importance is not in the mapping itself, but in the outcome because of the existence of a large number of applications that depend on it. OWL 2 new features inspired the mapping of some ORM constructs that were not supported by OWL 1 such as DisjointUnion, Ring Constraints (Reflexive, Irreflexive, and Asymmetric Object Properties) and others.
Some of the OWL 2 constructs are not supported by ORM such as equivalent class, etc. We plan to work on that in the future.

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An ORM-based Graphical Notation for Authoring OWL 2 Ontologies

Mustafa Jarrar[a], Rami Hodrob[b1], Anton Deik[a]

[a]*Faculty of Information Technology, Birzeit University,*
P.O.Box 14, Birzeit, West Bank, Palestine
`mjarrar@birzeit.edu, anton.deik@gmail.com`

[b]*Faculty of Engineering and Information Technology, Arab American University - Jenin,*
P.O.Box 240, Jenin, West Bank, Palestine
`rhodrob@aauj.edu`

Abstract
The immense need for well engineered ontologies is growing rapidly, as the need for ontologies is increasing in many application areas such as data integration, the semantic web, knowledge engineering, enhanced information retrieval, among others. Due to the central role ontologies are playing, the World Wide Web Consortium (W3C) developed the Web Ontology Language (OWL) as a language to author ontologies. Although OWL is a great specification language like many other ontology languages, it focuses on "how" rather than "what" to represent. That is, it does not provide methodological means for ontology engineering. One in fact is required to understand the logical foundation underpinning OWL to build an ontology, which makes it difficult for domain experts to get involved in ontology building, or at least, in the review and validation phases. For an ontology language to be easily understood by domain experts it must be close to the natural language they speak and the 'logic' they use. Also, it should have a graphical notation to enable simple and conceptual modeling. The expressive, methodological, and graphical capabilities of Object-Role Modeling (ORM), which is a conceptual modeling language, make it a good candidate for use in ontology engineering. In this paper, we (i) map all ORM constructs to OWL 2 using SROIQ Description Logic and, on the other hand, we (ii) extend the ORM notation to cover all OWL 2 constructs not currently covered by ORM. By doing so, we combine the strengths of both ORM and the W3C-recommended OWL 2 Web Ontology Language. This creates a framework that allows one to author and engineer OWL 2 ontologies graphically using ORM.

Keywords: Ontologies; Conceptual Modeling; Semantic Web; Object Role Modeling (ORM); OWL 2 Web Ontology Language; Description Logic.

1 Introduction and Motivation

Ontology engineering is one of the major challenges that brought the attention of the research community in the last decade. This is especially due to the growing need for well-engineered ontologies for many application areas such as data integration, the semantic web, knowledge engineering, enhanced information retrieval, among others. Due to the central role ontologies play in realizing the vision of the semantic web, the World Wide Web Consortium (W3C) developed the Web Ontology Language (OWL) among its semantic web technology stack, as a language to author ontologies for the semantic web. OWL is based on Description Logic. In particular, the older version of OWL is based on SHOIN description Logic while the newest version (OWL 2) is based on SROIQ.

However, like other ontology languages, using OWL to engineer ontologies is a difficult task as it does not provide a practical and methodological means for ontology engineering. In addition, one is required to understand the logical foundation underpinning OWL, which is very difficult for domain experts. In fact, the limitations of OWL and other similar languages are not that they lack expressiveness or logical foundations, but their suitability for being used by subject matter experts. For an ontology language to be easily understood by domain experts, it should at least meet the following two requirements [1] : (i) It must be close to the natural language the experts speak and the 'logic' they use. (ii) The language should have a graphical notation to enable simple and conceptual modeling. What we mean by 'graphical notation' here is not merely *visualization* but a *graphical language* that allows for ontology

[1] Rami Hodrob is also a Master's Student of Computing at Birzeit University, where the research was conducted.

construction using notations for concepts, relations, and rules. In other words, such language should guide domain experts to think conceptually while building, modifying, and validating an ontology.

Object-Role Modeling (ORM) is a conceptual modeling approach that has been in use since the early 1970s in database modeling, and has recently become popular in ontology engineering. Its expressive, methodological and graphical capabilities make it indeed one of the best candidates for building ontologies. Specifically, what distinguish ORM as a conceptual modeling approach are its simplicity, intuitiveness, stability, and verbalization capabilities, among many others. ORM simplifies the modeling process by using natural language, intuitive diagrams, and examples, and by examining information in terms of simple elementary facts and expressing them in terms of objects and roles [2].

Compared to other graphical modeling notations such as Entity Relationship (ER) or the Unified Modeling Language (UML), ORM is a stable modeling notation. This is due to the fact that ORM makes no use of attributes (i.e., attribute-free). All facts are represented in terms of concepts (object-types or value-types) playing roles [2]. This makes ORM not impacted by changes that cause attributes to be remodeled as object-types or relationships. Also, one of ORM's strongest features is its verbalization capabilities; ORM diagrams can be automatically verbalized into pseudo natural language (see the example in section 3.1). The verbalization capability of ORM simplifies the communication with subject matter experts and allows them to better understand, validate, and build ORM diagrams. It is also important to note that ORM's verbalization techniques have been adopted in the business rules community and have become an Object Management Group (OMG) standard.

For ORM to be used as an Ontology Engineering methodology, the underlying semantics of the notation must be formally specified (using logic). Formalization of ORM using First Order Logic was done comprehensively by Halpin in [2, 3]. In addition, because FOL is not decidable (does not enable automatic reasoning), ORM was formalized in previous work [1, 4, 5] using less complex logic languages that allows for automatic reasoning, namely, DLR_{idf} Description logic [5] and SHOIN/OWL description logic [1, 4]. This extensive work on the formalization of ORM has indeed played an important role in laying the foundation for using ORM in ontology engineering.

In order to fully establish ORM as a practical and methodological means for ontology engineering, we propose to combine the strengths of both ORM and the W3C-recommended OWL 2 Web Ontology Language. In short, we propose to map all ORM constructs to OWL 2 using SROIQ Description Logic and, on the other hand, extend the ORM notation to cover *all* OWL 2 constructs not currently covered by ORM. By doing so, we exploit the advantages of both ORM as an intuitive graphical approach for conceptual modeling and OWL 2 as a standard W3C-recommended language for authoring ontologies. This creates a framework that allows one to author OWL 2 ontologies graphically using ORM. The original contributions of this paper can be summarized as follows:

(i) The mapping of ORM to OWL 2 and its formalization using SROIQ Description Logic that underpins OWL 2. This mapping is presented in this paper in 19 rules.
(ii) Extending the ORM notation by introducing new ORM-inspired graphical notations to cover all OWL 2 constructs not currently covered by ORM.
(iii) Evaluating our mapping/formalization by loading the OWL 2 mapping of every ORM construct into RacerPro 2.0 reasoner. Different reasoning methods like consistency, coherency and special instance checking were used to validate the correctness of our mapping/formalization.
(iv) Evaluating our new ORM extension by means of a survey conducted with more than 30 ORM practitioners.
(v) Implementation: We have extended DogmaModeler (an ORM-based ontology modeling tool) to implement (a) our mapping (generating OWL 2 from ORM diagrams) and (b) the new ORM extension. Also, we have integrated the Hermit reasoning tool into DogmaModeler so that the correctness of the built ontology can be checked by methods of logical reasoning.

It is important to note here that the main purpose of this paper is to develop an expressive and methodological graphical notation for OWL 2, which allows people to author OWL 2 ontologies graphically. This is presented in this paper in two parts. In the first part, we investigate all ORM constructs by mapping/formalizing them into OWL 2 and its underpinning SROIQ Description Logic. In the second part, we investigate OWL 2 constructs that do not have equivalent graphical notations in ORM and develop ORM-inspired graphical notations for them. By doing so, we have developed an ORM-based graphical notation that expresses OWL 2 *completely*. Because of this, all of our work in this paper is based on the semantics of OWL 2 not on ORM's semantics as we have done in previous work [1, 4, 5], where our focus was rather on ORM itself. That is, in this paper the semantics of some ORM constructs are altered to adapt them to the semantics of OWL 2. A more detailed discussion on this issue is provided in section 2.

The remainder of this paper is organized as follows. In section 2, we discuss related work. Section 3 provides background information about ORM, SROIQ Description Logic, and OWL 2. In section 4, we provide the mapping of ORM to OWL 2 using SROIQ Description Logic in addition to the evaluation of the mapping. Section 5 discusses the extension of ORM graphical notation for a complete representation of OWL 2. In the same section, we also briefly summarize the evaluation of the newly proposed ORM extension. Section 6 presents the implementation of our work as an extension to DogmaModeler. Section 7 concludes our discussion and provides directions for future work.

2 Related Work

As discussed previously, our work revolves around establishing ORM as a practical and methodological means for ontology engineering by combining its strengths with those of the OWL 2 Web Ontology Language. There are several approaches and tools similar to our work, which aim to use graphical notations such as UML and ER for ontology modeling. Also, in particular, some of them aim to model OWL ontologies graphically. Some of these approaches and tools consider the problem of ontology modeling a problem of visualization, thus ignoring the underpinning semantics. However, some efforts exist to develop formal semantics (i.e., formalize) UML and ER. In this section, we briefly discuss these efforts and compare them to our approach.

Many efforts exist to use UML or UML-based notations for graphical representation of ontologies. Kogut *et al,* in [6], propose using UML as an ontology visualization and editing tool. Although their goal is to visualize and edit ontologies, they did not consider the underpinning semantics. Their work does not also provide any type of mapping of the graphical notation (i.e., UML) into OWL. Brockmans *et al,* in [7], introduced a UML-based notation for the visualization of OWL ontologies by developing a UML profile. In such approach, OWL is visualized based on the UML profiles of the Ontology Definition Metamodel (ODM). ODM defines a set of UML metamodels and profiles for the development of RDF and OWL. These UML profiles adapt UML notations to provide a suitable visual representation of RDF and OWL ontologies. This representation of ontologies using ODM enables one to only visualize the ontology but does not capture its semantics. This is due to the challenges of developing well-formed and usable UML models with equivalent semantics in OWL [8]. However, in [9], Kendall *et al* presented some potential extensions to the UML profiles of ODM to address some of the requirements of OWL 2. It is important to also note that UML itself is a very basic notation; as will be demonstrated later, ORM is much more expressive as it allows for at least 19 types of rules to be expressed graphically, while UML supports only types of cardinality rules [2].

Many ontology editing tools are available such as TopBraid[2], Protégé [10], NeOn [11], and GrOWL [8]. These tools are used to author ontologies by enabling the creation of classes, object properties and various constraints. TopBraid is a commercial modeling tool for developing ontologies for the semantic web, where one can compose and edit RDF (Resource Description Framework) and OWL. On the other hand, Protégé is a free, open source ontology editor based on Java. It allows the user to build and edit OWL and RDF ontologies in addition to visualizing classes, properties, and rules. NeOn is an open source tool that provides an ontology engineering environment based on Eclipse Integrated Development Environment (IDE). It includes many plug-ins that support many ontology engineering activities and provides a means for visualizing the ontology as it is being built. GrOWL is also a tool for visualizing and editing OWL ontologies with advanced browsing and navigation tools. Many other similar tools and frameworks are available such as, IBM Integrated Ontology Development Toolkit [12], SWOOP [13], and DERI Ontology Management Environment (DOME)[3] among many others. Although all of these tools allow a graphical

[2] http://www.topquadrant.com/products/TB_Composer.html
[3] http://dome.sourceforge.net/

representation of the ontology, this representation is merely a visualization (i.e., not authoring) that ignores the underpinning semantics, in contrast to our proposed ORM ontology engineering paradigm.

We have found the most decent work in formalizing UML in [14] and ER in [15]. These two formalization efforts have studied the First Order Logic (FOL) semantics of UML and ER and mapped them into DLR_{ifd} Description Logic. It is worth noting here that the ICOM tool was one of the first tools to enable automated reasoning with conceptual modeling. ICOM [16] supports ontology modeling using a graphical notation that is a mix of UML and ER notations. ICOM is integrated with a description logic reasoning server that acts as a background inference engine to enable automatic reasoning. This automatic reasoning is done by mapping the graphical notations into DIG Description Logic Interface. In our methodology, we use ORM as a graphical and methodological approach to engineer and model ontologies while automated reasoning is performed by mapping the ontology to the W3C-recommended OWL 2 Web Ontology Language.

In previous work [1, 4, 5], we have investigated the ORM notation by formalizing it using both DLR_{idf} description logic [5] and SHOIN description logic [1, 4]. The main purpose of this formalization was to enable automated reasoning on the formal properties of ORM diagrams, such as detecting constraint contradictions and implications. Thus, in our study of ORM, we used the native semantics of ORM and expressed them in DLR_{idf} and SHOIN Description Logics. However, in the mapping/formalization performed in this paper, we have altered the native semantics of ORM to adapt them to those of OWL 2 (i.e., we have used the semantics of OWL 2 not of ORM). In other words, we have expressed the semantics of OWL 2 graphically using the ORM notation, without employing the semantics of ORM. For example, ORM subtypes are proper subtypes. We say that B is a proper subtype of A if and only if the population of B is always a subset of the population of A, and $A \neq B$. This implies that the subtype relationship is acyclic; hence, loops are illegal in ORM. However, such loops, according to the semantics of OWL 2, are allowed, which means that the classes involved in the loop are equivalent. Another example is that, according to ORM semantics, it is not allowed for an object-type to be a subtype of two different object-types, unless these two supertypes have a common supertype. However, such a multiple inheritance is allowed according to the semantics of OWL 2.

The important difference between ORM and OWL 2 semantics is that ORM adopts a closed world assumption while OWL 2 follows an open world assumption. A closed world assumption states that any statement that is not known to be true or false is false. On the contrary, an open world assumption states that, unless the truth-value of a statement is explicitly determined, it is unknown. For instance, originally, ORM assumes that any two object-types are disjoint, without the need to state it explicitly (closed world assumption). Here, we follow OWL 2's open world assumption where any two object-types are not known whether they are disjoint or not, except if stated explicitly. The same applies, for example, to instances (assertions), where OWL 2 semantics states that any two instances are not considered different (unequal) or equal unless it is explicitly stated (open world assumption). In short, in this paper, we don't present or follow ORM semantics, but rather use the ORM graphical notation to depict OWL 2 constructs using OWL 2 semantics.

3 Background

In this section, we shed the light on three fundamental related topics that are important to be introduced before delving into the details of our work, namely, Object-Role Modeling (ORM), SROIQ Description Logic, and OWL 2 Web Ontology Language. The following subsections provide a brief discussion on the topics with a clarifying example on the Object-Role Modeling approach (ORM).

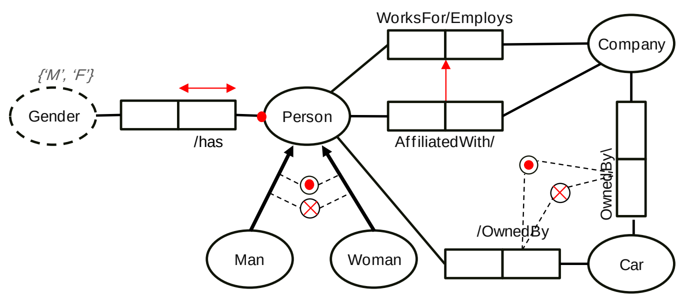
3.1 Object-Role Modeling (ORM)

ORM is a conceptual modeling approach that allows the semantics of a Universe of Discourse (UoD) to be modeled at a highly conceptual level and in a graphical manner. As mentioned earlier, ORM has been used commercially for more than thirty years as a database modeling methodology and has been recently becoming popular not only for ontology engineering but also as a graphical notation in other areas such as modeling of business rules, XML schemes, data warehouses, requirements engineering, web forms, among others. ORM has an expressive and stable graphical notation. It supports not only *n*-ary relations and reification, but also provides a fairly comprehensive treatment of many 'practical' and 'standard' business rules and constraint types such as mandatory, uniqueness, identity, exclusion, frequency occurrences, subsetting, subtyping, equality, and many others [17].

ORM makes it easy to simplify the presented conceptual model using both natural language (via its verbalization capabilities) and graphical notations to present facts in their simple or elementary forms. In addition, ORM diagrams can be populated by examples to measure the correctness of the design [2]. Practical use cases have shown that skills and know-how of using ORM can be acquired easily and in a short period of time even by non-IT specialists[5, 18]. Moreover, several modeling tools support ORM notation such as: Microsoft Visio, DogmaModeler, and Norma.

The example in Fig. 1.a below depicts a sample ORM diagram including several rules and constraints that ORM is capable of expressing graphically. Note the three basic constructs of ORM; object-types, value-types, and roles (forming relations). Object-types are represented as solid-line ellipses, value-types are presented as dashed-line ellipses and relations as rectangles, where one or more ORM roles form each ORM relation. For example, the relation (*WorksFor/Employs*) in Fig. 1.a is a binary relation (i.e., composed of the two roles: *WorksFor* and *Employs*).

Fig. 1b shows the verbalization of the ORM rules presented graphically in Fig. 1a. One of the most powerful features of ORM is its verbalization capability in which ORM diagrams can be automatically verbalized into pseudo natural sentences. In other words, all rules in a given ORM diagram can be translated into fixed syntax sentences [5, 19]. For example, the Mandatory constraint (•) between 'Person' and 'hasGender' is verbalized by rule-1 in Fig.1b as "Each Person Has at least one Gender". Similarly, the role uniqueness constraint (↔) is verbalized by rule 2, Subtype (→) by rule 3, subset (↑) by rule 6, (⊙) and (⊗) between subtypes by rules 4 and 5, and between roles by rules 7 and 8. The value constraint ({'M','F'} on Gender) is verbalized by rule 9. These verbalizations are generated automatically by our DogmaModeler tool through using verbalization templates parameterized over a given ORM diagram. For more discussion on ORM verbalization, we encourage the reader to refer to [19], which shows how DogmaModeler enables verbalization in 11 different human languages. The main purpose of this verbalization is to simplify the communication with non-IT specialists and to allow them to better validate and build ontology models.



(a)

1. Each Person Has at least one Gender. (Mandatory)
2. Each Person Has at most one Gender. (Role uniqueness)
3. Each Man is a Person. Each Woman is a Person. (Subtype)
4. Each Person cannot be a Man and a Woman at the same time. (Exclusive)
5. Each Person must be, at least, Man or Woman. (Totality)
6. If a Person is AffiliatedWith a Company then this Person WorksFor that Company. (Subset)
7. Same Car cannot be OwnedBy by Person and OwnedBy a Company at the same time. (Exclusion)
8. Each Car should be OwnedBy by Person or OwnedBy a Company, or both. (Disjunctive Mandatory)
9. A Gender can only be one of {M,F}. (Value Constraint)

(b)

Figure 1: Sample ORM Diagram along with the verbalization of its rules.

3.2 SROIQ Description Logic

Description logics are a family of knowledge representation formalisms. Description logics are decidable fragments of first-order logic, associated with a set of automatic reasoning procedures. The basic primitives of a description logic are the notion of a concept and the notion of a relationship. Complex concept and relationship expressions can be built from atomic concepts and relationships. For example, one can define $HumanMother$ as $HumanMother \sqsubseteq Female \sqcap \exists HasChild.Person$. The expressiveness of a description logic is characterized by the set of constructors it offers.

SROIQ Description Logic compromises both features of expressivity and decidability. SROIQ is an extension of SHOIN which is the underlying description logic of OWL-DL. However, the rise of the Semantic Web increased the need for a more featured and expressive Description Logic to author ontologies. As a result of this increasing demand, SROIQ was introduced with many new features (especially regarding expressivity) which led to adopting SROIQ as the underpinning logic for OWL 2.

A Description Logic knowledge base is composed of two components: a TBox and an ABox. The TBox contains intensional knowledge in the form of a terminology and is built through declarations that describe general properties of concepts. The ABox contains extensional knowledge which is also called assertional knowledge. It is knowledge that is specific to the individuals of the domain of discourse (knowledge specific to the instances) [15].

SROIQ syntax can be defined as follows. If C and D are concepts and R is a binary relation (also called role), then ($C \sqcap D$), ($C \sqcup D$), ($\neg C$), ($\forall R.C$), and ($\exists R.C$) are also concepts. If R is simple (i.e., neither transitive nor has any transitive sub-relations), then ($\leq nR$) and ($\geq nR$) are also concepts, where n is a non-negative integer. For C and D (possibly complex) concepts, $C \sqsubseteq D$ is called general concept inclusion. SROIQ also allows hierarchy of roles ($R \sqsubseteq S$), transitivity of roles (R_+), and inverse of roles ($S \sqsubseteq R^-$). In fact, SROIQ allows everything SHOIN allows, in addition to the following [20]:

i) **Disjoint roles:** most description logics do not support disjoint roles and this makes them unbalanced. SROIQ is said to be balanced because it allows the expressivity of disjoint between roles. For example, the roles *brother* and *father* should be declared as being disjoint.
ii) **Reflexive, irreflexive and antisymmetric roles:** these constraints are useful when using ABox to represent individuals. E.g., the role *loves* should be declared as being reflexive (one can love himself), and the role hasSibling should be declared as being irreflexive (one cannot be the sibling of himself).
iii) **Negated role assertion:** Although most Abox formalisms allow for only positive role assertions, SROIQ allows for negated roles assertions as well. For example, such statements can be found in a SROIQ Abox: $(Rami, Tony): \neg knows$, which means that Rami does not know Tony.
iv) **Role inclusion axioms:** these roles are of the form $R \circ S \sqsubseteq R$ and $S \circ R \sqsubseteq R$. For example, given the following two axiom (1) $owns \circ hasPart \sqsubseteq owns$, and (2) the fact that each car contains an engine $Car \sqsubseteq \exists hasPart.Engine$. This implies that an owner of a car is also an owner of an engine, i.e., the following subsumption is implied: $\exists owns.Car \sqsubseteq \exists owns.Engine$.
v) **Universal role $\boldsymbol{U}$.**
vi) **Local reflexivity** of the form $\exists R.Self$. For example, the following expresses the fact that somebody loves himself/herself: $\exists likes.Self$.
vii) SROIQ also provides what is referred to as ***Rbox*** which contains all statements concerning roles.

3.3 OWL 2 Web Ontology Language

The W3C-recommended OWL Web Ontology Language is a knowledge representation language used to publish and share ontologies on the web. While the underpinning description logic of OWL is SHOIN, OWL 2 (the new version of OWL) is based on SROIQ description logic. Roughly speaking, one can often view OWL 2 as SROIQ description logic written in other syntaxes such as XML, RDF/XML, etc. Among OWL 2 basic constructs are: *Class* (corresponds to a 'concept' in SROIQ and called 'object-type' in ORM), *Property* (corresponds to a SROIQ 'relationship' or an ORM 'role'), and *Object* (corresponds to an individual/assertion). It is also worth mentioning here that OWL 2 is supported by several semantic reasoners such as RacerPro 2, Hermit, Pellet and FaCT++. The following is a summarization of the new additional features that distinguish OWL 2 from its OWL predecessor, as put by the World Wide Web Consortium (W3C):

(i) Syntactic sugar to make some statements easier to express.
(ii) New constructs that increase expressivity.
(iii) Extended support for datatypes.
(iv) Simple metamodeling capabilities.
(v) Extended annotation capabilities.

4 Mapping ORM to SROIQ/OWL 2

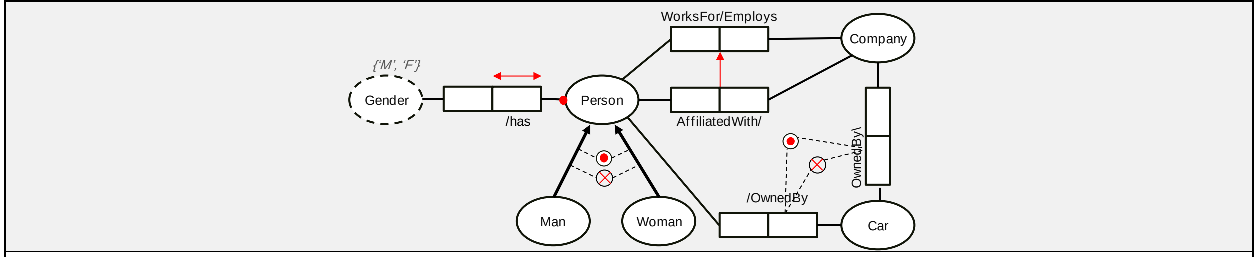
In this section, we present the formalization of all ORM constructs using SROIQ description logic and their mappings to OWL 2. Before delving into the details of the formalization/mapping, we first present a use case where we map the sample ORM diagram in Fig. 1.a into OWL 2. The diagram is repeated in Fig. 3 along with a part of its SROIQ/OWL 2 mapping. The complete OWL 2 mapping is provided in Appendix A.

The basic ORM constructs are mapped to OWL 2 as follows. An object-type is mapped as a *Class* in OWL 2 whereas an ORM role is mapped as an *ObjectProperty/DataProperty*. Before mapping the ORM rules and constraints to OWL 2, one must first declare the object-types and roles in OWL 2. Fig. 2 depicts the declarations of the object-types *Person* and *Company* and the ORM relation *WorksFor/Employs* of Fig. 3.a. The complete declarations of the ORM diagram are provided in Appendix A.

```
<Declaration>                      <Declaration>
   <Class IRI="#Person"/>             <ObjectProperty IRI="#Employs"/>
</Declaration>                     </Declaration>
<Declaration>                      <Declaration>
   <Class IRI="#Company"/>            <ObjectProperty IRI="#WorksFor"/>
</Declaration>                     </Declaration>
```

Figure 2: OWL 2 declarations of Classes and Object Properties

The diagram in Fig. 3.a contains 9 rules which we map into SROIQ/OWL 2 in Fig. 3.b below. These rules are: *(1) Subsumption (subtype), (2) Mandatory, (3) Role Uniqueness, (4) Total Constraint, (5) Exclusive Constraint, (6) Subset Constraint, (7) Disjunctive Mandatory (inclusive-or), (8)Exclusion*, and *(9)Value Constraint*.



(a) The ORM diagram in Fig. 1.a

Subtype: Man $\sqsubseteq$ Person, Woman $\sqsubseteq$ Person

```
<SubClassOf>
   <Class IRI="#Woman"/>
   <Class IRI="#Person"/>
</SubClassOf>
<SubClassOf>
   <Class IRI="#Man"/>
   <Class IRI="#Person"/>
</SubClassOf>
```

Mandatory: Person $\sqsubseteq$ $\exists$Has. Gender

```
<EquivalentClasses>
   <Class IRI="#Person"/>
   <DataSomeValuesFrom>
     <DataProperty IRI="#hasGender"/>
     <Datatype abbreviatedIRI="xsd:string"/>
  </DataSomeValuesFrom>
</EquivalentClasses>
```

Role Uniqueness: Person $\sqsubseteq \leq$ 1Has. Gender

```
<EquivalentClasses>
  <Class IRI="#Person"/>
  <DataMaxCardinality cardinality="1">
    <DataProperty IRI="#hasGender"/>
    <Datatype abbreviatedIRI="xsd:string"/>
  </DataMaxCardinality>
</EquivalentClasses>
```

Total and Exclusive Constraints: Person $\sqsubseteq$ Man Woman,
Man $\sqcap$ Woman $\equiv \bot$

```
<DisjointUnion>
  <Class IRI="#Person"/>
  <Class IRI="#Woman"/>
  <Class IRI="#Man"/>
</DisjointUnion>
```

Subset: AffiliatedWith $\sqsubseteq$ WorksFor

```
<SubObjectPropertyOf>
   <ObjectProperty IRI="#AffiliatedWith"/>
   <ObjectProperty IRI="#WorksFor"/>
</SubObjectPropertyOf>
```

Disjunctive Mandatory: Car $\sqsubseteq$ $\exists$OwnedBy. Person $\sqcup$ $\exists$OwnedBy. Company

```
<EquivalentClasses>
   <Class IRI="#OwnedByC.Company"/>
   <ObjectSomeValuesFrom>
     <ObjectProperty IRI="#OwnedByC"/>
     <Class IRI="#Company"/>
   </ObjectSomeValuesFrom>
</EquivalentClasses>
<EquivalentClasses>
   <Class IRI="#OwnedByP.Person"/>
   <ObjectSomeValuesFrom>
     <ObjectProperty IRI="#OwnedByP"/>
     <Class IRI="#Person"/>
   </ObjectSomeValuesFrom>
</EquivalentClasses>

<EquivalentClasses>
   <Class IRI="#Car"/>
   <ObjectUnionOf>
     <Class IRI="#OwnedByC.Company"/>
     <Class IRI="#OwnedByP.Person"/>
   </ObjectUnionOf>
</EquivalentClasses>
```

Exclusion: OwnedBy. Person $\sqsubseteq$ $\neg$ OwnedBy. Company

```
<EquivalentClasses>
   <Class IRI="#OwnedByC.Company"/>
   <ObjectAllValuesFrom>
     <ObjectProperty IRI="#OwnedByC"/>
     <Class IRI="#Company"/>
   </ObjectAllValuesFrom>
</EquivalentClasses>

<EquivalentClasses>
   <Class IRI="#OwnedByP.Person"/>
   <ObjectAllValuesFrom>
     <ObjectProperty IRI="#OwnedByP"/>
     <Class IRI="#Person"/>
   </ObjectAllValuesFrom>
</EquivalentClasses>

<EquivalentClasses>
   <Class IRI="#OwnedByC.Company"/>
   <ObjectComplementOf>
     <Class IRI="#OwnedByP.Person"/>
   </ObjectComplementOf>
</EquivalentClasses>
```

Value Constraint: Gender $\sqsubseteq$ STRING, Gender $\equiv$ {M, F}

```
<DataPropertyRange>
 <DataProperty IRI="#hasGender"/>
  <DataOneOf>
   <Literal datatypeIRI="&xsd;string"> M </Literal>
   <Literal datatypeIRI="&xsd;string"> F </Literal>
  </DataOneOf>
</DataPropertyRange>
```

(b) The SROIQ/OWL 2 mapping of the ORM rules in (a)

Figure 3: The ORM diagram of Fig. 1.a and the mapping of its rules to SROIQ/OWL 2

Subsumption (subtype) is depicted as an arrow (→) in ORM. In our example, this arrow is seen in two places: between *Man* and *Person*, and between *Woman* and *Person*. This means that all instances of *Man* (all males) form a subset of the population of *Person* (all persons). This is also true for the object-type *Woman.* In OWL 2, *SubClassOf* construct is used to represent this rule (lines 1-8, Fig. 3.b).

Mandatory is depicted as a dot (•) on the line connecting *Person* object-type with *hasGender* role. This constraint indicates that, in every interpretation of this schema, each instance of the object-type *Person* must have at least one *Gender*. This rule is mapped in OWL 2 in lines 9-15, Fig. 3.b.

Role Uniqueness is depicted by an arrow ↔ spanning along the role *hasGender*. In OWL 2, we map this rule as shown in lines 16-22 in Fig. 3.b. This constrains indicates that, in every interpretation of this schema, each instance of the object-type *Person* must have at most one *Gender*.

Total and Exclusive Constraints are depicted as (⊙) and (⊗) between the *Man* and *Woman* subtypes. The Total Constraint means that the population of *Person* is exactly the union of the populations of *Man* and *Woman* subtypes. The exclusive constraint means that the intersection of the populations of *Man* and *Woman* is always empty. In our example, we use *DisjointUnion* OWL 2 construct (lines 23-27, Fig. 3.b) which expresses both Total and Exclusive constraints.

Subset Constraint is depicted in the ORM diagram in Fig. 3.a as an arrow (↑) between the roles *AffiliatedWith* and *WorksFor*; which means that the role *AffiliatedWith* is a subset of role *WorksFor*. That is, all Persons who are *affiliated with* a Company must *work for* that company. This is written in SROIQ as: $\mathrm{AffiliatedWith} \sqsubseteq \mathrm{WorksFor}$. Representation in OWL 2 is done using *SubObjectPropertyOf* (lines 28-31, Fig. 3.b)

Disjunctive Mandatory (inclusive-or), is depicted as (⊙) between two or more roles, illustrating that the disjunction of these roles is mandatory for members. In our example, each instance of object-type *Car* must be owned by at least a Person or a Company or both. This is written in SROIQ description logic as: $\mathrm{Car} \sqsubseteq \exists \mathrm{OwnedBy.Person} \sqcup \exists \mathrm{OwnedBy.Company}$). This rule is mapped in OWL 2 in lines 32-53.

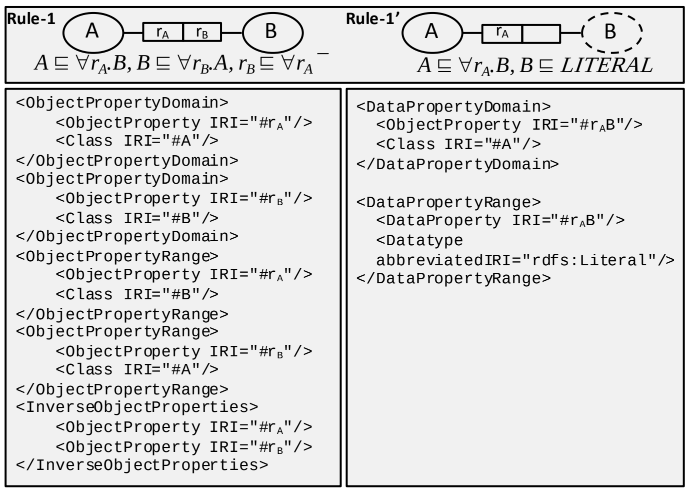
Exclusion, is represented as (⊗) between the roles it connects (in Fig. 3.a, it connects between the two '*OwnedBy*' roles of object-type *Car*). It means that each member of the population cannot play both roles constrained by exclusion. In the example, no car can be owned by a Person and a Company at the same time ($\mathrm{OwnedBy.Person} \sqsubseteq \neg \mathrm{OwnedBy.Company}$). Representation in OWL 2 is depicted in Fig 3.b (lines 54-75).

Value Constraint, is represented as {'M','F'} above the *Gender* dashed-line ellipse. This constraint indicates the possible set of values that the value-type *Gender* can be populated with. Here, *Gender* can take any of the two STRING values: 'M' and 'F'. No other value is allowed. This constraint is mapped in OWL 2 in lines 76-82.

4.1 Roles and Relationships

4.1.1 Binary and N-ary relationships

ORM supports *n*-ary relationships, where $n \geq 1$. Each argument of a relationship in ORM is called a role. For example, consider the binary ORM relationship *WorksFor/Employs* in Fig. 3.a which has two roles, namely, *WorksFor* and *Employs*. However, SROIQ only supports binary relationships. Note that an ORM *role* is called a *relationship* in SROIQ. Thus, a binary ORM relationship is represented by two SROIQ relationships (represent ORM roles) in addition to an inverse axiom to state that both SROIQ relationships are inverse to each other. The same is true for the OWL 2 mapping except that each ORM role is mapped into an OWL 2 *ObjectProperty*. Fig. 4.a (Rule-1) depicts a binary ORM relationship, its formalization into SROIQ, and its mapping into OWL 2. Fig. 4.b (Case-1) shows the general case of an ORM *n*-ary relationship, which cannot be represented in SROIQ/OWL 2. One can refer to [5] for the representation of Case-1 using DLR$_{idf}$ Description Logic. In this case, however, the n-*ary* relationship can be converted to binary relationships and then mapped into SROIQ/OWL 2.

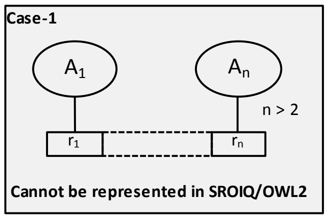

Rule-1
A
r_A
r_B
B
$A \sqsubseteq \forall r_A.B, B \sqsubseteq \forall r_B.A, r_B \sqsubseteq \forall r_A^{-}$
Rule-1'
A
r_A
B
$A \sqsubseteq \forall r_A.B, B \sqsubseteq LITERAL$

```
<ObjectPropertyDomain>
    <ObjectProperty IRI="#rA"/>
    <Class IRI="#A"/>
</ObjectPropertyDomain>
<ObjectPropertyDomain>
    <ObjectProperty IRI="#rB"/>
    <Class IRI="#B"/>
</ObjectPropertyDomain>
<ObjectPropertyRange>
    <ObjectProperty IRI="#rA"/>
    <Class IRI="#B"/>
</ObjectPropertyRange>
<ObjectPropertyRange>
    <ObjectProperty IRI="#rB"/>
    <Class IRI="#A"/>
</ObjectPropertyRange>
<InverseObjectProperties>
    <ObjectProperty IRI="#rA"/>
    <ObjectProperty IRI="#rB"/>
</InverseObjectProperties>
```

```
<DataPropertyDomain>
  <ObjectProperty IRI="#rAB"/>
  <Class IRI="#A"/>
</DataPropertyDomain>

<DataPropertyRange>
  <DataProperty IRI="#rAB"/>
  <Datatype
  abbreviatedIRI="rdfs:Literal"/>
</DataPropertyRange>
```

(a)



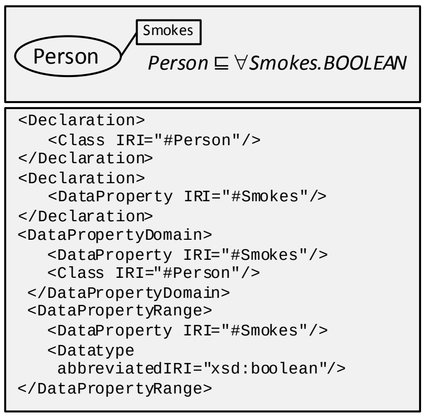
(b)

Figure 4: Binary and N-ary relationships

The mapping of the binary ORM relation presented in Rule-1 represents the case where *A* and *B* (Fig. 4.a) are both object-types (equivalent to OWL 2 classes). However, in the case where either *A* or *B* are ORM value-types, the value-type is mapped into a "Literal" (the universal datatype) in OWL 2, or to any of its sub-datatypes. If, for example, *B* is a value-type, as depicted in Rule-1', the ORM role r_A is mapped into an OWL 2 *DataProperty* with datatype "Literal". Notice that this *DataProperty* is called r_AB; the concatenation of the names of both the ORM role (r_A) and the ORM value-type (B). Also note that we don't need an additional inverse axiom, because in this case only one *DataProperty* is needed to represent the ORM relation between an object-type and a value-type.

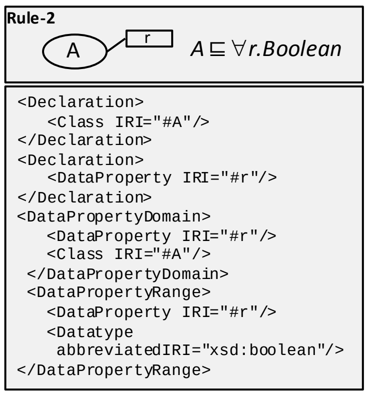
4.1.2 Unary Relationship

Although unary roles are allowed in ORM, they cannot be represented directly in SROIQ/OWL 2. The example below (Fig. 5.a) shows an ORM unary relationship that means that a person may smoke; or in FOL [3]: $\forall x\ (Smokes(x) \rightarrow Person(x))$. The population of this fact is either true or false. In order to map ORM unary roles into SROIQ/OWL 2, we introduce a new class called BOOLEAN, which takes one of two values: {TRUE, FALSE}. Each ORM unary fact is seen as a binary relationship in SROIQ/OWL 2, where the second concept is BOOLEAN. Rule-2 in Fig. 5.b presents the general case mapping of ORM unary fact types to SROIQ/OWL 2.



```
<Declaration>
   <Class IRI="#Person"/>
</Declaration>
<Declaration>
   <DataProperty IRI="#Smokes"/>
</Declaration>
<DataPropertyDomain>
   <DataProperty IRI="#Smokes"/>
   <Class IRI="#Person"/>
 </DataPropertyDomain>
 <DataPropertyRange>
   <DataProperty IRI="#Smokes"/>
   <Datatype
    abbreviatedIRI="xsd:boolean"/>
</DataPropertyRange>
```

(a)



```
<Declaration>
   <Class IRI="#A"/>
</Declaration>
<Declaration>
   <DataProperty IRI="#r"/>
</Declaration>
<DataPropertyDomain>
   <DataProperty IRI="#r"/>
   <Class IRI="#A"/>
 </DataPropertyDomain>
 <DataPropertyRange>
   <DataProperty IRI="#r"/>
   <Datatype
    abbreviatedIRI="xsd:boolean"/>
</DataPropertyRange>
```

(b)

Figure 5: Unary Relationship

4.2 Subtypes

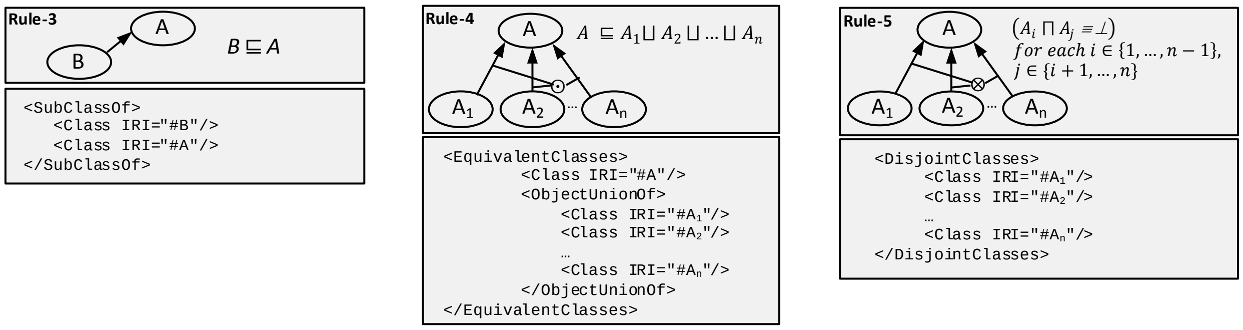
ORM subtypes are proper subtypes. That is, as discussed earlier, we say that B is a proper subtype of A if and only if the population of B is always a subset of the population of A, and $A \neq B$, i.e., loops are illegal in ORM. However, because the focus of this paper is to establish a graphical representation of OWL 2, we adopt the semantics of OWL 2, whose subtype relation, *SubClassOf*, is not a *proper* subtype (i.e., loops are allowed). Thus, for example, the axiom "Woman is a Person" is written using OWL 2 semantics as: $Woman \sqsubseteq Person$, without the need to add the axiom ($Person \not\sqsubseteq Woman$), as opposed to following ORM semantics. Rule-3 presents the mapping of the general case of subtypes using SROIQ/OWL 2.

4.3 Total constraint

Total constraint (⊙) in ORM is equivalent to *UnionOf* construct in OWL 2. This rule means that the population of the supertype is exactly the union of the population of all subtypes constrained by this rule. Rule-4 represents the formalization of the general case.

4.4 Exclusive constraint

ORM exclusive constraint (⊗) is equivalent to *DisjointClasses* construct in OWL 2. It means that the population of the subtypes constrained by this rule is pairwise distinct, i.e., the intersection of the population of each pair of the subtypes must be empty. Rule-5 represents the formalization of the general case of the exclusive constraint.
Please note that in most of the examples and general case mappings in this paper, the OWL 2 declarations are omitted due to space limitations.


Rule-3
A
B
$B \sqsubseteq A$
Rule-4
A
$A \sqsubseteq A_1 \sqcup A_2 \sqcup \ldots \sqcup A_n$
A_1
A_2
…
A_n
Rule-5
A
$(A_i \sqcap A_j \equiv \bot)$
$for\ each\ i \in \{1, \ldots, n-1\}$,
$j \in \{i+1, \ldots, n\}$
A_1
A_2
…
A_n

```
<SubClassOf>
   <Class IRI="#B"/>
   <Class IRI="#A"/>
</SubClassOf>
```

```
<EquivalentClasses>
        <Class IRI="#A"/>
        <ObjectUnionOf>
            <Class IRI="#A1"/>
            <Class IRI="#A2"/>
            …
            <Class IRI="#An"/>
        </ObjectUnionOf>
</EquivalentClasses>
```

```
<DisjointClasses>
     <Class IRI="#A1"/>
     <Class IRI="#A2"/>
     …
     <Class IRI="#An"/>
</DisjointClasses>
```

(a) (b) (c)

Figure 6: Formalization of ORM Subtype, Total Constraint and Exclusive Constraint.

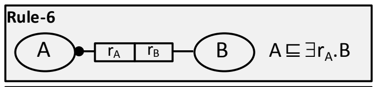
4.5 Mandatory Constraints

4.5.1 Role mandatory

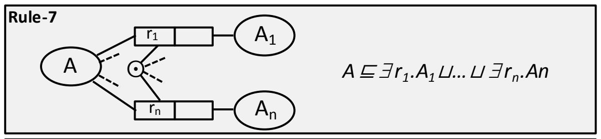
ORM's Role mandatory constraint is depicted as a dot on the line connecting a role with an object-type. Rule-6 of Fig. 7.a presents the general case formalization of this rule. Each instance of the object-type A must be related to at least one instance of object-type B by the relation r_A/r_B. In OWL 2, this rule is mapped using *ObjectSomeValuesFrom/ DataSomeValuesFrom* constructs as shown in Fig. 7.a. *ObjectSomeValuesFrom* is used when B is an object-type, whereas *DataSomeValuesFrom* is used when B is a value-type. OWL 2 *MinCardinality* construct can also be used to restrict the population of A to at least relate with one instance of B. However, the usage of *ObjectSomeValuesFrom/ DataSomeValuesFrom* is more elegant than *MinCardinality*.

4.5.2 Disjunctive Mandatory

The Disjunctive Mandatory constraint in ORM is used to constrain a set of two or more roles connected to the same object-type. It means that each instance of the object-type must play at least one of the constrained roles. In the general case presented in Fig. 7.b along with its formalization, each instance of object-type A must play at least one of the constrained roles: (r_1,…,r_n).



```
<EquivalentClasses>
  <Class IRI="#A"/>
  <ObjectSomeValuesFrom>
    <ObjectProperty IRI="#rA"/>
    <Class IRI="#B"/>
  </ObjectSomeValuesFrom>
</EquivalentClasses>
```


Rule-7
A
r_1
A_1
r_n
A_n
$A \sqsubseteq \exists r_1.A_1 \sqcup \ldots \sqcup \exists r_n.An$

```
<EquivalentClasses>                          <EquivalentClasses>
  <Class IRI="#r1.A1"/>                        <ObjectUnionOf>
  <ObjectSomeValuesFrom>                          <Class IRI="#r1.A1"/>
     <ObjectProperty IRI="#r1"/>                  …
     <Class IRI="#A1"/>                           <Class IRI="#rn.An"/>
  </ObjectSomeValuesFrom>                      </ObjectUnionOf>
</EquivalentClasses>                           <Class IRI="#A"/>
    …                                        </EquivalentClasses>
<EquivalentClasses>
  <Class IRI="#rn.An"/>
  <ObjectSomeValuesFrom>
     <ObjectProperty IRI="#rn"/>
     <Class IRI="#An"/>
  </ObjectSomeValuesFrom>
</EquivalentClasses>
```

(a) (b)

Figure 7: Formalization of ORM Mandatory Constraints

4.6 Uniqueness Constraints

One can distinguish between three types of Uniqueness Constraints in ORM, namely, role uniqueness, predicate uniqueness, and external uniqueness.

4.6.1 Role Uniqueness

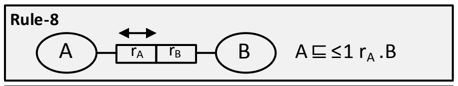
Role uniqueness is represented by an arrow spanning a single role in a binary relationship. Rule-8 of Fig. 8.a presents the general case formalization of this rule. This constraint means that each instance of an object-type A plays the role r_A with at most one instance of B. Role uniqueness is mapped to OWL 2 using the *MaxCardinality* construct, restricted by ‘1’.

4.6.2 Predicate Uniqueness

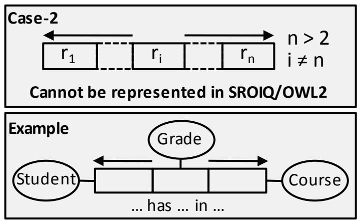
This constraint is represented in ORM, as shown in Fig. 8.b, by an arrow spanning more than a role in an *n*-ary relationship. In the example shown in Fig. 8.b, in any instance of this relation, both *Student* and *Course* must be unique together, i.e., functional dependency. Although this constraint can be represented using First Order Logic (FOL) [3] and DLR_{idf} Description Logic [5], it cannot be represented using SROIQ/OWL 2.

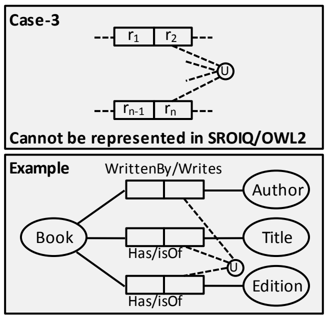
4.6.3 External Uniqueness

As shown in Fig. 8.c, ORM External Uniqueness constraint (denoted by ‘U’), applies to roles from different relationships. The roles that participate in such a uniqueness constraint uniquely refer to an object-type. For example (Fig. 8.c), the combination of (Author, Title, Edition) must be unique, i.e., different values of (Author, Title, Edition) refer to different books. This constraint cannot be represented using SROIQ/OWL 2.



```
<EquivalentClasses>
   <Class IRI="#A"/>
      <ObjectMaxCardinality cardinality="1">
         <ObjectProperty IRI="#rA "/>
         <Class IRI="#B"/>
      </ObjectMaxCardinality>
 </EquivalentClasses>
```





(a) (b) (c)

Figure 8: Uniqueness Constraints

4.7 Frequency Constraints

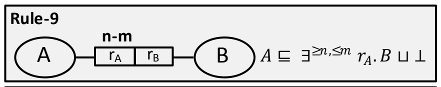
We distinguish between a frequency constraint that spans (1) a single role, which we call ‘Role Frequency’ constraint and (2) multiple roles, called ‘Multiple-Role Frequency’ constraint.

4.7.1 Role Frequency Constraint

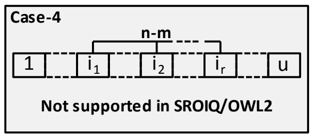
A frequency constraint (*min-max*) on a role is used to specify the number of occurrences that this role can be played by its object-type. Fig. 9.a depicts the general case formalization of this rule. This constraint means that role r_A is played by the object-type A for a number of occurrences between *n* and *m*. We map this constraint to OWL 2 by using *MinCardinality* and *MaxCardinality* constructs.

4.7.2 Multiple-Role Frequency Constraint

A multiple-role frequency constraint spans more than one role (Fig. 9.b). This constraint means that, in the population of the constrained relationship, the constrained roles must be played together by the related object-types for a number of occurrences between *n* and *m*. Multiple-role frequency constraint cannot be formalized in Description Logic and OWL 2 [1].



```
<ObjectPropertyRange>
  <ObjectProperty IRI="#rA"/>
  <ObjectMinCardinality cardinality="n">
    <ObjectProperty IRI="#rA"/>
    <Class IRI="#B"/>
  </ObjectMinCardinality>
</ObjectPropertyRange
<ObjectPropertyRange>
  <ObjectProperty IRI="#rA"/>
  <ObjectMaxCardinality cardinality="m">
     <ObjectProperty IRI="#rA"/>
     <Class IRI="#B"/>
  </ObjectMaxCardinality>
</ObjectPropertyRange>
```

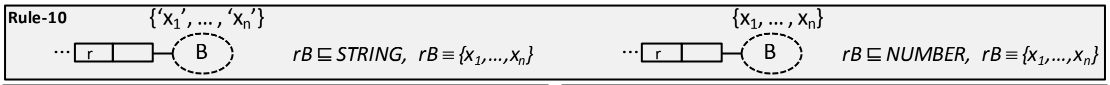


(a) (b)

Figure 9: Frequency Constraints

4.8 Value Constraint

The value constraint in ORM indicates the possible set of values (i.e., instances) that a value-type can be populated with. A value constraint on a value-type *A* is denoted as a set of values $\{s_1, s_2, \ldots, s_n\}$ depicted near a value-type. Value constraints can be declared only on ORM value-types, which are depicted as dotted-line ellipses, and the values should be well-typed, i.e., their data types should be either *String* such as {'hi', '98', 'it'} or *Number* such as {3,4,5}. Notice that quotes are used to distinguish string values from number values. It is worth noting that OWL 2 supports many data types besides integer and string; an advantage of OWL 2 over OWL (which only supports integers and strings). OWL 2 enumeration class *DataOneOf* is used to map the value constraints (Fig. 10).


Rule-10
{'x1', ... , 'xn'}
r
B
$rB \sqsubseteq STRING,\ rB \equiv \{x_1,\ldots,x_n\}$
{x1, ... , xn}
r
B
$rB \sqsubseteq NUMBER,\ rB \equiv \{x_1,\ldots,x_n\}$

```
<DataPropertyRange>
  <DataProperty IRI="#rB"/>
    <DataOneOf>
      <Literal datatypeIRI="&xsd;string"> x1 </Literal>
      <Literal datatypeIRI="&xsd;string"> x2 </Literal>
          . . .
      <Literal datatypeIRI="&xsd;string"> xn </Literal>
     </DataOneOf>
 </DataPropertyRange>
```

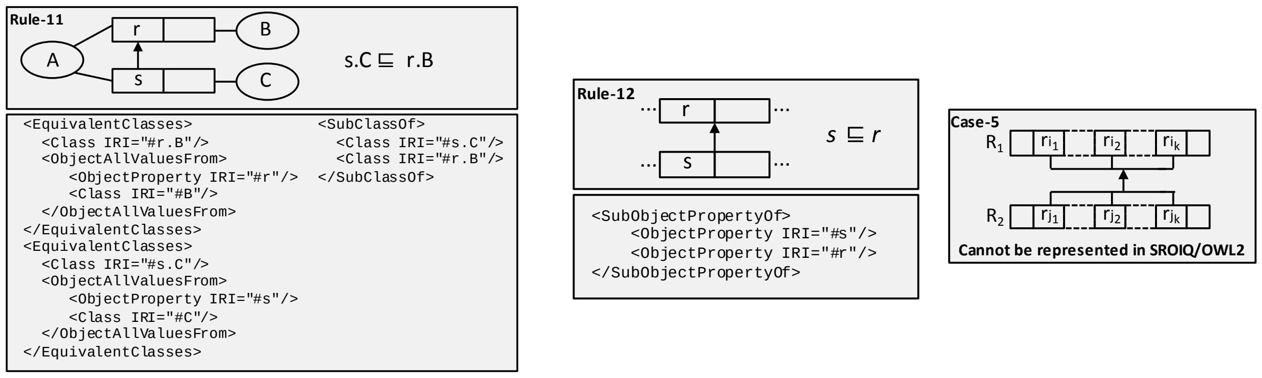
```
<DataPropertyRange>
  <DataProperty IRI="#rB"/>
    <DataOneOf>
      <Literal datatypeIRI="&xsd;int"> x1 </Literal>
      <Literal datatypeIRI="&xsd;int"> x2 </Literal>
          . . .
      <Literal datatypeIRI="&xsd;int"> xn </Literal>
     </DataOneOf>
 </DataPropertyRange>
```

Figure 10: Value Constraints

4.9 Subset Constraint

The subset constraint (→) between two roles is used to restrict the population of these roles so as one is a subset of the other. Fig. 11.a (Rule-11) depicts the general case mapping into SROIQ/OWL 2. It shows that all instances of A, which plays the role*'s'*, must also play the role *'r'*. Rule-12 formalizes the case of subset constraint between two ORM relations: the set of tuples of the subsuming relation is a subset of the tuples of the subsumed relation.

ORM also allows subset constraints between tuples of roles (not necessarily contiguous) as shown in case-5, where each i^{th} and j^{th} roles must have the same type. The population of the set of the j^{th} roles is a subset of the population of the set of the i^{th} roles. However, this last case cannot be represented in SROIQ/OWL 2.



```
<EquivalentClasses>
  <Class IRI="#r.B"/>
  <ObjectAllValuesFrom>
     <ObjectProperty IRI="#r"/>
     <Class IRI="#B"/>
  </ObjectAllValuesFrom>
</EquivalentClasses>
<EquivalentClasses>
  <Class IRI="#s.C"/>
  <ObjectAllValuesFrom>
     <ObjectProperty IRI="#s"/>
     <Class IRI="#C"/>
  </ObjectAllValuesFrom>
</EquivalentClasses>
```

```
<SubClassOf>
  <Class IRI="#s.C"/>
  <Class IRI="#r.B"/>
</SubClassOf>
```

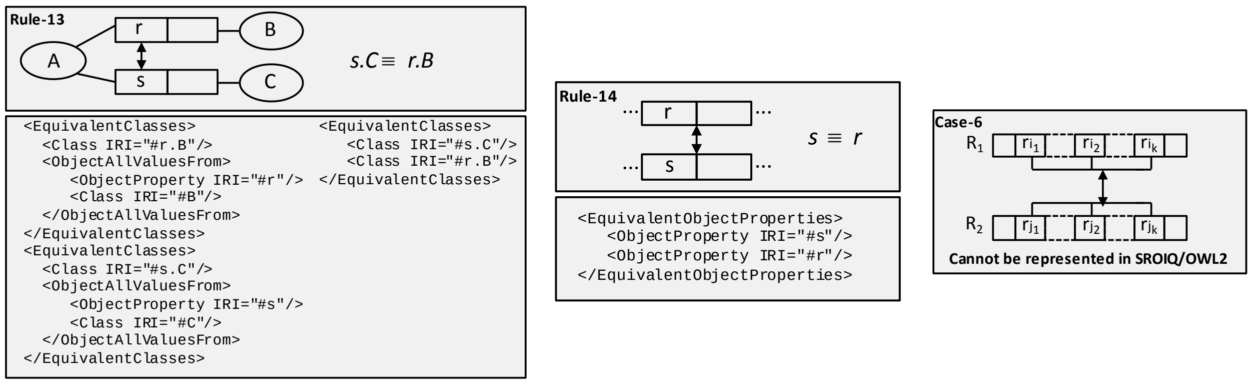
```
<SubObjectPropertyOf>
    <ObjectProperty IRI="#s"/>
    <ObjectProperty IRI="#r"/>
</SubObjectPropertyOf>
```

(a) (b) (c)

Figure 11: Subset Constraint

4.10 Equality Constraint

Similar to the subset constraint, the equality constraint (↔) between roles and relations are mapped as shown in rules 13 and 14, respectively.



```
<EquivalentClasses>
  <Class IRI="#r.B"/>
  <ObjectAllValuesFrom>
     <ObjectProperty IRI="#r"/>
     <Class IRI="#B"/>
  </ObjectAllValuesFrom>
</EquivalentClasses>
<EquivalentClasses>
  <Class IRI="#s.C"/>
  <ObjectAllValuesFrom>
     <ObjectProperty IRI="#s"/>
     <Class IRI="#C"/>
  </ObjectAllValuesFrom>
</EquivalentClasses>
```

```
<EquivalentClasses>
   <Class IRI="#s.C"/>
   <Class IRI="#r.B"/>
</EquivalentClasses>
```

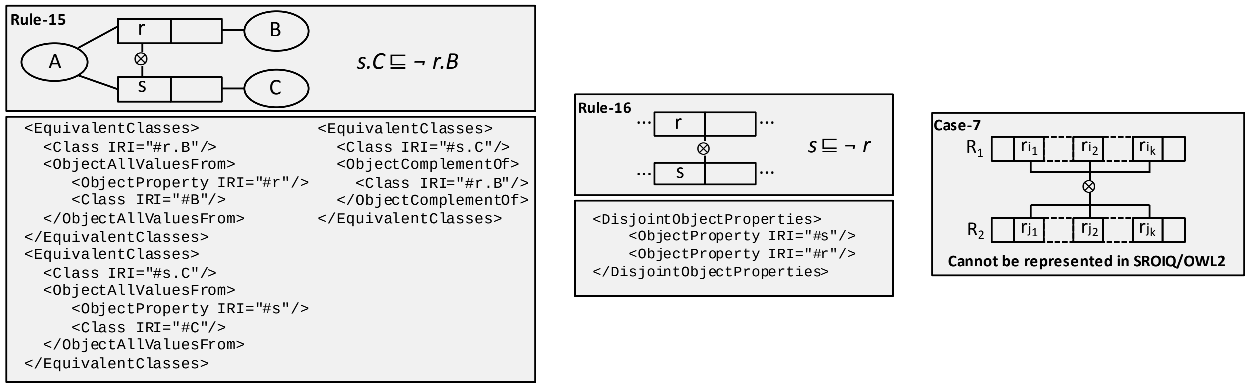
```
<EquivalentObjectProperties>
   <ObjectProperty IRI="#s"/>
   <ObjectProperty IRI="#r"/>
</EquivalentObjectProperties>
```

(a) (b) (c)

Figure 12: Equality Constraint

4.11 Exclusion Constraint

Similar to the subset and equality constraints, the exclusion constraint (⊗) between roles and relations are mapped as shown in rules 15 and 16, respectively.



```
<EquivalentClasses>
  <Class IRI="#r.B"/>
  <ObjectAllValuesFrom>
     <ObjectProperty IRI="#r"/>
     <Class IRI="#B"/>
  </ObjectAllValuesFrom>
</EquivalentClasses>
<EquivalentClasses>
  <Class IRI="#s.C"/>
  <ObjectAllValuesFrom>
     <ObjectProperty IRI="#s"/>
     <Class IRI="#C"/>
  </ObjectAllValuesFrom>
</EquivalentClasses>
```

```
<EquivalentClasses>
  <Class IRI="#s.C"/>
  <ObjectComplementOf>
    <Class IRI="#r.B"/>
  </ObjectComplementOf>
</EquivalentClasses>
```

```
<DisjointObjectProperties>
    <ObjectProperty IRI="#s"/>
    <ObjectProperty IRI="#r"/>
</DisjointObjectProperties>
```

(a) (b) (c)

Figure 13: Exclusion Constraint

4.12 Ring Constraints

ORM allows ring constraints to be applied to a pair of roles (i.e., on binary relations) that are connected directly to the same object-type, or indirectly via super types. Six types of ring constraints are supported by ORM.

4.12.1 Symmetric (sym)

This constraint states that if a relation holds in one direction, it also holds on the other, e.g., ‘siblingOf’ and ‘colleagueOf’. Fig. 14.a (Rule-17) depicts the general case formalization using SROIQ/OWL 2.

4.12.2 Asymmetric (as)

Asymmetric constraint is the opposite of the symmetric constraint. If a relation holds in one direction, it cannot hold on the other, e.g., ‘wifeOf’ and ‘parentOf’. Fig. 14.b (Rule-18) depicts the general case formalization using SROIQ/OWL 2.

4.12.3 Antisymmetric (ans)

The antisymmetric constraint is also an opposite of the symmetric constraint, but not exactly the same as asymmetric. The difference is that all asymmetric relations must be irreflexive, which is not the case for antisymmetric. Fig. 14.c shows an example of this constraint in addition to the general case formalization in SROIQ. Up to our knowledge, this constraint cannot be expressed in OWL 2 because one cannot express role complement in OWL 2.

4.12.4 Irreflexive (ir)

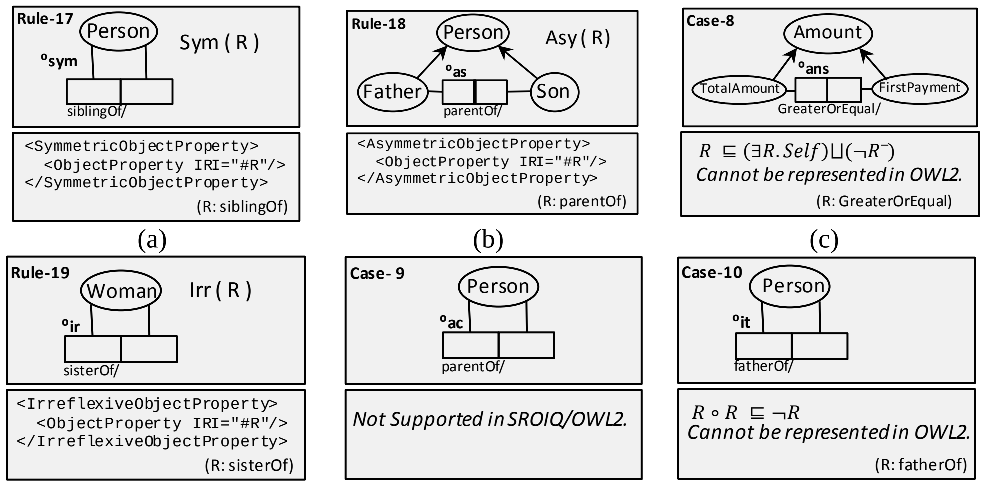
The Irreflexive ring constraint states that an object cannot participate in a relation with himself. For example, a person cannot be the ‘parent of’ himself (i.e., cannot play the role of ‘ParentOf’ with himself). However, for instance, one can love himself, i.e., the ‘*love’* relation is reflexive: a ring constraint supported by SROIQ/OWL 2 but not by ORM (see section 5.8). Fig. 14.d (Rule-19) depicts the general case formalization using SROIQ/OWL 2.

4.12.5 Acyclic (ac)

The acyclic constraint is a special case of the irreflexive constraint. For example, stating that the relation ‘ParentOf’ is acyclic means that a person cannot be directly (or indirectly through a chain) ‘ParentOf’ himself. In ORM, this constraint is preserved as a difficult constraint. “Because of their recursive nature, acyclic constraints maybe expensive or even impossible to enforce in some database systems” [2]. Up to our knowledge, acyclicity with any depth on binary relations cannot be represented in SROIQ/OWL 2 (see Fig. 14.e).

4.12.6 Intransitive (it)

A relation R is intransitive over its population $iff\ \forall x,y,z\ [R(x,y) \wedge R(y,z) \rightarrow \backsim R(x,z)]$. For example, if a Person *X* is FatherOf Person *Y* and *Y* is FatherOf *Z*, then it cannot be that *X* is FatherOF *Z*. See Fig. 14.f for the general case formalization in SROIQ. However, as in the case of the antisymmetric constraint, this constraint cannot be expressed in OWL 2 because one cannot express role complement in OWL 2.



```
<SymmetricObjectProperty>
   <ObjectProperty IRI="#R"/>
</SymmetricObjectProperty>
```
(R: siblingOf)

(a)

```
<AsymmetricObjectProperty>
   <ObjectProperty IRI="#R"/>
</AsymmetricObjectProperty>
```
(R: parentOf)

(b)

$R \sqsubseteq (\exists R.Self) \sqcup (\neg R^{-})$
Cannot be represented in OWL2.
(R: GreaterOrEqual)

(c)

```
<IrreflexiveObjectProperty>
   <ObjectProperty IRI="#R"/>
</IrreflexiveObjectProperty>
```
(R: sisterOf)

(d)

Not Supported in SROIQ/OWL2.

(e)

$R \circ R \sqsubseteq \neg R$
Cannot be represented in OWL2.
(R: fatherOf)

(f)

Figure 14: Ring Constraints

4.13 Objectified Relations

An objectified relation in ORM is a relation that is regarded as an object-type, receives a new object-type name, and is depicted as a rectangle around the relation. In the example in Fig. 15, each (*Student*, *Course*) enrollment is treated as an object-type that scores a *Grade*. In addition to this axiom, it is assumed that there must be a uniqueness constraint spanning all roles of the objectified relation, although it is not explicitly stated in the diagram. Objectified relations cannot be represented in SROIQ/OWL 2 as the additional uniqueness axiom cannot be represented in SROIQ/OWL 2. Refer to [5] for the representation of objectified relations in DLR_{idf} description logic.

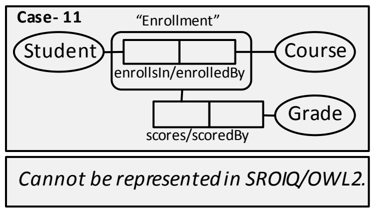


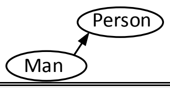
Figure 15: Objectified Relations

4.14 Evaluation

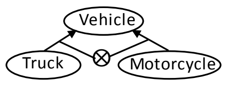
In the previous subsections, we have presented all ORM constructs and their mappings into SROIQ/OWL 2. In section 5, we extend the ORM graphical notation to represent the other OWL 2 constructs that are not originally supported in ORM. However before presenting these new notations, we discuss the evaluation of our mappings of ORM into SROIQ/OWL 2. In particular, we briefly discuss the means by which we evaluated our work and give some clarifying examples. For this evaluation, the last version (version 2) of RacerPro was used as a description logic reasoning tool, especially because of its support of OWL 2 and its user-friendly interface. RacerPro provides an interface to query and reason about knowledge bases. A knowledge base in RacerPro consists of a T-Box and an A-Box. For each of the formalized ORM notations, its OWL 2 mapping was inserted into the RacerPro system in the T-Box of a Knowledge Base. After that, the knowledge base was populated with several A-Box assertions in ordered to perform various kinds of tests and queries over it. These tests include consistency, coherency, and instance retrieval, in addition to several other tests depending on the individual construct to be tested.

The consistency test checks whether the given A-Box is consistent with respect to the T-Box (i.e., A-Box Consistency). An A-Box *A* is consistent with a T-Box *T iff* it has a model *w.r.t. T*. Otherwise, the A-Box is called inconsistent. Coherency (also called Satisfiability) can be divided into: Concept Coherency and T-Box Coherency. Checking the satisfiability (coherency) of a concept *C* in a T-Box *T* means to check whether there exists a model *I* of *T* such that $C^I \neq \phi$. This is usually done by checking this concept for any possible contradictions in the T-Box. If the concept *C* is involved in a contradiction, this means that it cannot be satisfied, i.e., cannot be instantiated. For the T-Box coherency; a T-Box *T* is said to be incoherent *iff* there exists an unsatisfiable concept in *T*. The Instance Retrieval test simply finds all individuals (instances) mentioned in an A-Box that are instances of a certain concept *C*.

As an example, Fig. 16 depicts parts of the tests performed on the mappings of the ORM subtype relation and exclusive constraint, as a demonstration of the type of tests performed. The complete evaluation including all the tests performed on each construct mapping can be found in the report [21].

Checked Example		
Type of Test	**nRQL query**	**Result**
Concept subsumption	?(concept-subsumes? |#Person| | #Man|)	True
	?(concept-subsumes?|#Man| | #Person|)	Nil (i.e., False)
Retrieve instances	?(retrieve(?x) (?x #Person))	Mira, Issa, Abbas
	?(retrieve(?x) (?x #Man))	Issa, Abbas

(a) Tests performed on ORM subtype relation

Checked Example		
Type of Test	**nRQL query**	**Result**
Concept-disjoint	?(concept-disjoint? | #Truck | | # Motorcycle|)	True
Concept-equivalence	?(concept-equivalent? | #Vehicle| (or |#Truck| | #Motorcycle|))	Nil
Consistency check	? (abox-consistent? file:// /disjointclasses.owl) (with assertions that <u>do not</u> violate the constraint)	True
	? (abox-consistent? file:// /disjointclasses.owl) (with assertions that <u>do</u> violate the constraint)	Nil

(b) Tests performed on ORM exclusive constraint

Figure 16: A sample demonstration of the tests performed on our mapped ORM constructs

In the example in Fig. 16.a, two types of tests were performed, namely, concept subsumption and instance retrieval. In short, the tests we have done on the subtype relation can be summarized as follows. After inserting the OWL 2 mapping of the ORM in Fig. 16.a as a T-Box in a knowledge base, we entered a set of assertions into the A-Box. These assertions were: one assertion of the object-type *Person* (i.e., Mira) and two assertions of the object-type *Man* (Issa and Abbas). Two concept consumption tests were performed; the first to check whether the object-type *Man* subsumes *Person*, resulting in 'True', as expected. The second verified whether *Person* subsumes *Man*, resulting in Nil (False), also as expected. When we retrieved the instances of *Person*, all instances of *Man* (Issa and Abbas) appeared in the result set in addition to the instance of *Person* (Mira); a result which we expected because of the subtype relation. It is worth noting here that all A-Box tests and queries were written in nRQL (The New RacerPro Query Language), a query language for the RacerPro system that is capable of querying description logics, RDF(s), and OWL.

In the example in Fig. 16.b, three types of tests were performed; concept disjoint, concept equivalence, and consistency check. The first test (concept disjoint) simply verifies that the object-types *Motorcycle* and *Truck* are indeed disjoint. The concept equivalence test checks whether the object-type *Vehicle* is equivalent to the union of *Vehicle* and *Motorcycle*; a rule not implied by the disjoint constraint and thus resulted in *Nil* (False), as expected. In the third test, we checked the consistency of the A-Box with respect to our OWL 2 mapping. At first, two instances of *Motorcycle* object-type were inserted in the A-Box: a Kawasaki motorcycle and Harley-Davidson motorcycle. For the *Truck* class, one instance was inserted, namely, the Iveco Trakker. Checking the consistency of this A-Box resulted in 'True' because there was no any violation of the exclusive constraint. On the other hand, when the Kawasaki motorcycle instance was also declared as an instance of Truck (in addition of being an instance of Motorcycle), the consistency test resulted in *Nil*, because the exclusive constraint was violated. This method of checking the mapped ORM constraints by inserting assertions that violate the constraints has been used with all constructs to test whether the constraints indeed 'detect' the violations.

Although the tests performed on the OWL 2 mappings of the ORM constructs *cannot be theoretically complete*, they cover most of the ground (i.e., they are comprehensive). The main goal of this evaluation is to ensure that our mappings are precisely supported by description logic reasoners as intended. In fact, in our tests we focused on using the *boundary analysis techniques* known in software testing, where we tested boundary or limit conditions of the constraints. An example of such tests is the consistency check performed on the exclusive constraint as discussed above (Fig. 16.b). Note that the exclusive constraint means that the population of the subtypes constrained by this rule is pairwise distinct (i.e., no assertion can be the instance of two classes). The boundary of this constraint can be simply checked by trying to violate the constraint and then checking the consistency of the A-Box, as described above. Consider, as another example, the role frequency constraint. Consider an object-type *A* that is restricted to play a role with 3-5 occurrences only (e.g., a teacher that is restricted to teach between 3-5 courses). Testing the limits of such constraint requires testing the minimum occurrence restriction (i.e., 3) in addition to the maximum occurrence restriction (i.e., 5). For more details about all tests performed on the mappings of the ORM constructs, we encourage the reader to refer to the report [21].

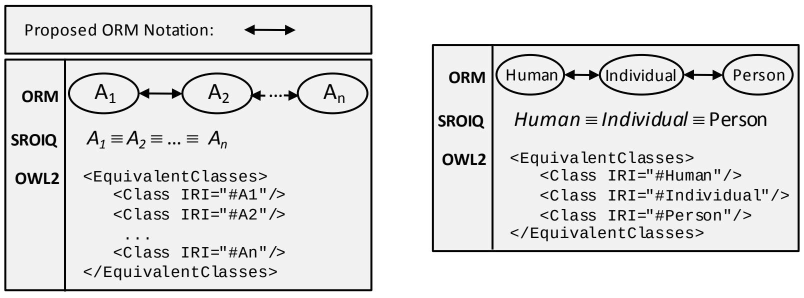
5 Extending ORM graphical notation for complete representation of OWL 2

In section 4 of this paper, we mapped all ORM constructs to SROIQ/OWL 2. This allows one to build his/her ontology graphically using ORM and then generate/map it automatically into OWL 2. However, the current graphical notations of ORM are not sufficient to represent all OWL 2 constructs (i.e., some OWL 2 constructs cannot be represented graphically using ORM). In this section, we extend the ORM graphical notation to represent the OWL 2 constructs not currently covered by ORM. The OWL 2 constructs we represent graphically are: Equivalent Classes, Disjoint Classes, Intersection of Class Expressions, Class Complement, Universal and Empty Classes, Universal and Empty Properties, Transitive Constraint, Reflexive Constraint, Class Assertions, Individual Equality, and Individual Inequality. Other OWL 2 expressions, in specific those which deal with assertion expressions, data types, and annotations, are all represented as *'Non-notational Expressions'*. That is, they are not represented using the ORM graphical notation. Instead they are expressed using specialized guided editors (see section 5.12).

In order to appreciate the importance of our ORM extension, the reader is advised to glimpse the use case in Fig. 29 (section 5.13) taken from the real-world case of the Palestinian government ontology, before delving into the details of the extension. The ORM-inspired graphical notations that we have developed for representing the OWL 2 construct graphically were evaluated by means of a survey that included 31 practitioners in the field of ORM and OWL. After the evaluation process, final notations were chosen based on the results of the survey. Section 5.1–5.11 briefly discusses our proposed graphical notations.

5.1 Equivalent Classes

An Equivalent Class constraint in SROIQ/OWL 2 states that all classes constrained by this rule are semantically equivalent to each other. This rule is expressed in OWL 2 using the `EquivalentClasses` construct and in SROIQ description logic using the notation of '≡'. No notation is available in ORM for representing this construct, because ORM proposes that there is no need for equivalent objects within the same modeling case. However, because of the rapidly increasing usage of ontologies in data integration, the Equivalent Classes constraint is highly needed. The proposed notation for representing this constraint using ORM is shown in Fig. 16 along with a clarifying example. It's worth mentioning here that this graphical notation was preferred by 16 of the 31 practitioners who participated in the evaluation survey (52%).


Proposed ORM Notation:
ORM
SROIQ
OWL2
A_1
A_2
A_n
$A_1 \equiv A_2 \equiv \ldots \equiv A_n$
Human
Individual
Person
$Human \equiv Individual \equiv Person$

```
<EquivalentClasses>
   <Class IRI="#A1"/>
   <Class IRI="#A2"/>
    ...
   <Class IRI="#An"/>
</EquivalentClasses>
```

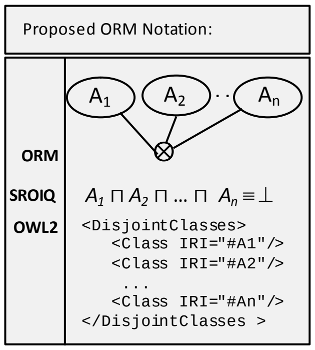
```
<EquivalentClasses>
   <Class IRI="#Human"/>
   <Class IRI="#Individual"/>
   <Class IRI="#Person"/>
</EquivalentClasses>
```

(a) (b)

Figure 16: Equivalent Classes Constraint

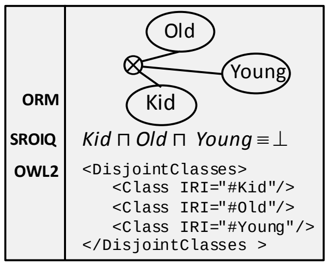
5.2 Disjoint Classes

The population of all classes constrained by the Disjoint Classes constraint is pairwise distinct, i.e., the intersection of the population of each pair of the constrained classes must be empty. This rule exists in ORM. However, it is restricted to be used between subtypes that belong to the same supertype. As, in ORM, all objects within a modeling case are assumed to be disjoint with each other. This rule is expressed in OWL 2 using the `DisjointClasses` construct. For representing this constraint in ORM, we propose to use the notation of (⊗), as shown in Fig. 17. It's worth mentioning that, from the three suggested graphical notations in the survey, this graphical notation was chosen by 20 of the 30 practitioners who participated in the evaluation survey (64%).



$A_1 \sqcap A_2 \sqcap \ldots \sqcap A_n \equiv \bot$

```
<DisjointClasses>
   <Class IRI="#A1"/>
   <Class IRI="#A2"/>
    ...
   <Class IRI="#An"/>
</DisjointClasses >
```



$Kid \sqcap Old \sqcap Young \equiv \bot$

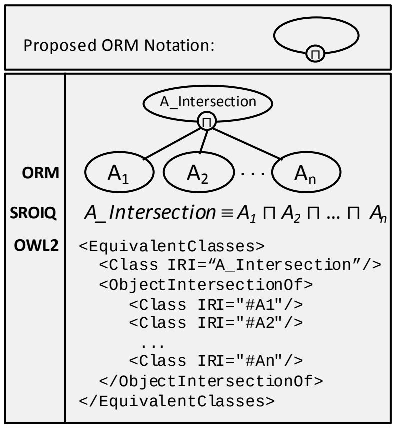
```
<DisjointClasses>
   <Class IRI="#Kid"/>
   <Class IRI="#Old"/>
   <Class IRI="#Young"/>
</DisjointClasses >
```

(a) (b)

Figure 17: Disjoint Classes Constraint

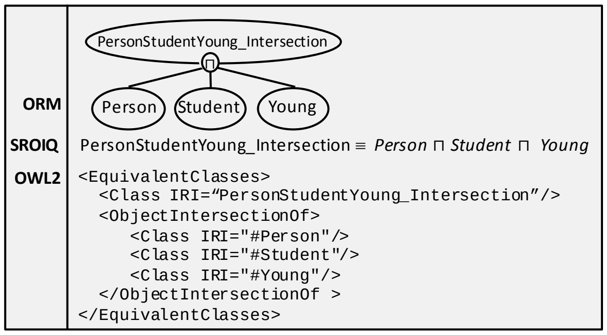
5.3 Intersection of Class Expressions

The intersection of classes A and B is all the individuals (instances) of A that are also instances of B but no other instances. This expression cannot be expressed currently in ORM. In OWL 2, `ObjectIntersectionOf` expression is used to represent the intersection of classes, whereas the notation of '⊓' is used for the SROIQ representation, as shown in Fig. 18. In ORM, we propose to use the notation of '⊓' inside a bubble located at the edge of an ellipse (see Fig. 18). This bubble connects directly via lines to the classes to be intersected. Inside the ellipse, the name of the class equivalent to the intersection expression is assigned. Note that the intersection bubble can be connected directly to many classes: the classes which are being intersected. No other relations are allowed to be connected through the bubble. However, the ellipse (which represents the equivalent class of the intersection expression) can be connected via any relation to any other class.



$A\_Intersection \equiv A_1 \sqcap A_2 \sqcap \ldots \sqcap A_n$

```
<EquivalentClasses>
  <Class IRI="A_Intersection"/>
  <ObjectIntersectionOf>
     <Class IRI="#A1"/>
     <Class IRI="#A2"/>
       ...
     <Class IRI="#An"/>
  </ObjectIntersectionOf>
</EquivalentClasses>
```



PersonStudentYoung_Intersection ≡ $Person \sqcap Student \sqcap Young$

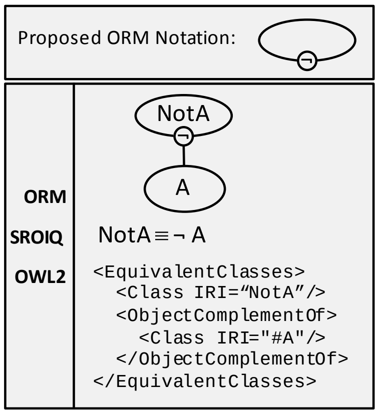
```
<EquivalentClasses>
  <Class IRI="PersonStudentYoung_Intersection"/>
  <ObjectIntersectionOf>
     <Class IRI="#Person"/>
     <Class IRI="#Student"/>
     <Class IRI="#Young"/>
  </ObjectIntersectionOf >
</EquivalentClasses>
```

(a) (b)

Figure 18: Intersection of Class Expressions

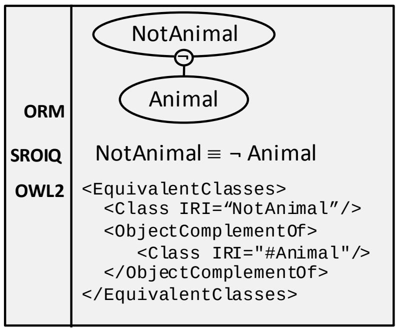
5.4 Class Complement

The complement of class *A* refers to the population of the Universe of Discourse (UoD) that is not of A (i.e., the instances outside of A). This expression cannot be expressed currently in ORM. In OWL 2, `ObjectComplementOf` expression is used to represent class complement, whereas the notation of '¬' is used for the SROIQ representation, as shown in Fig. 19. In ORM, similar to the Intersection of Class Expressions discussed above, we propose to use the notation of '¬' inside a bubble located at the edge of an ellipse (see Fig. 19). This bubble connects directly via a line to the class to be complemented. Inside the ellipse, the name of the class equivalent to the complement expression is assigned. Note that the complement bubble can only be connected directly to one class: the class which is being complemented. No other relations are allowed to be connected through the bubble. However, the ellipse (which represents the equivalent class of the complement expression) can be connected via any relation to any other class.



```
<EquivalentClasses>
  <Class IRI="NotA"/>
  <ObjectComplementOf>
    <Class IRI="#A"/>
  </ObjectComplementOf>
</EquivalentClasses>
```

(a)



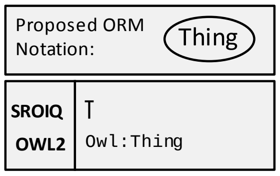
```
<EquivalentClasses>
  <Class IRI="NotAnimal"/>
  <ObjectComplementOf>
     <Class IRI="#Animal"/>
  </ObjectComplementOf>
</EquivalentClasses>
```

(b)

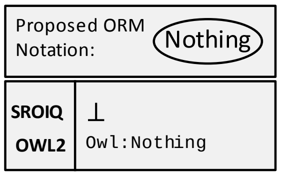
Figure 19: Class Complement

5.5 Universal and Empty Classes

Two classes in OWL 2 are predefined, namely, the classes `owl:Thing` and `owl:Nothing`. Class `owl:Thing` is referred to as the Universal Class while `owl:Nothing` is called the Empty Class. The extension of class `owl:Thing` (i.e., its instances) is the set of all instances in the Universe of Discourse (UoD). Thus, all classes are subclasses (i.e., subtypes) of this universal class. On the other hand, the extension of class `owl:Nothing` is the empty set. Consequently, the empty class is a subclass of all classes. In SROIQ, the universal and empty classes correspond to the Top (⊤) and Bottom (⊥) concepts, respectively. These two predefined OWL 2 classes are not currently defined in the ORM notation. We propose to express these two classes using the regular ORM object-type notation as show in Fig. 20. Our proposed representation of these two predefined OWL 2 classes is no different than the representation of any other OWL 2 class; all OWL 2 classes are mapped in ORM as object-types.



(a)

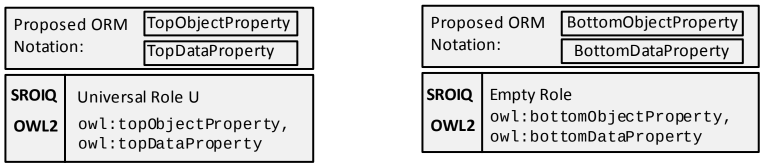


(b)

Figure 20: Universal and Empty Classes

5.6 Universal and Empty Properties

OWL 2 provides two built-in object/data properties with predefined semantics: (i) `owl:topObjectProperty/ owl:topDataProperty` (Universal Property), (ii) `owl:bottomObjectProperty/ owl:bottomDataProperty` (Empty Property). The universal object property connects all possible pairs of object-type instances (individuals) while the universal data property connects all possible object-type instances (individuals) with all values (literals). On the contrary, the empty property neither connects any pair of object-type instances (individuals) nor connects any object-type instance (individual) with a value (literal). Unlike other variants of Description Logic, SROIQ does support Universal and Empty roles. These predefined OWL 2 properties are not currently defined in ORM. We propose to express these notations using the regular ORM role notation as show in Fig. 21. Note that our proposed representation of these predefined OWL 2 properties is no different than the representation of any other OWL 2 property; all OWL 2 properties are mapped as ORM roles.



```
owl:topObjectProperty,
owl:topDataProperty
```

```
owl:bottomObjectProperty,
owl:bottomDataProperty
```

(a) (b)

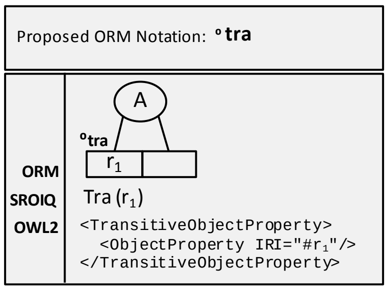
Figure 21: Universal and Empty Object/Data Properties

5.7 Transitive Constraint

A relation R is transitive over its population $iff\ \forall x,y,z\ [R(x,y) \wedge R(y,z) \rightarrow\ R(x,z)]$. For example, if a Person X is the ancestor of Person Y and Y is the ancestor of Z, then it implies that X is the ancestor Z. Although ORM supports the intransitive ring constraint, it does not support the transitive constraint. As this constraint is a ring constraint, we propose to express it graphically following exactly the same graphical representation of ORM's native ring constraints (Fig. 22).

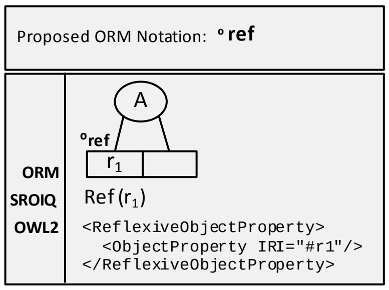
5.8 Reflexive Constraint

The reflexive constraint is a ring constraint that states that all objects participate in a relation with themselves via the constraint relation. For example, stating that the relation 'knows' is reflexive means that every person knows himself/herself. Because ORM currently does not support this constraint, we propose to express it graphically as shown in Fig. 23, following exactly the same representation of ORM's native ring constraints.



```
<TransitiveObjectProperty>
  <ObjectProperty IRI="#r1"/>
</TransitiveObjectProperty>
```

Figure 22: Transitive Constraint

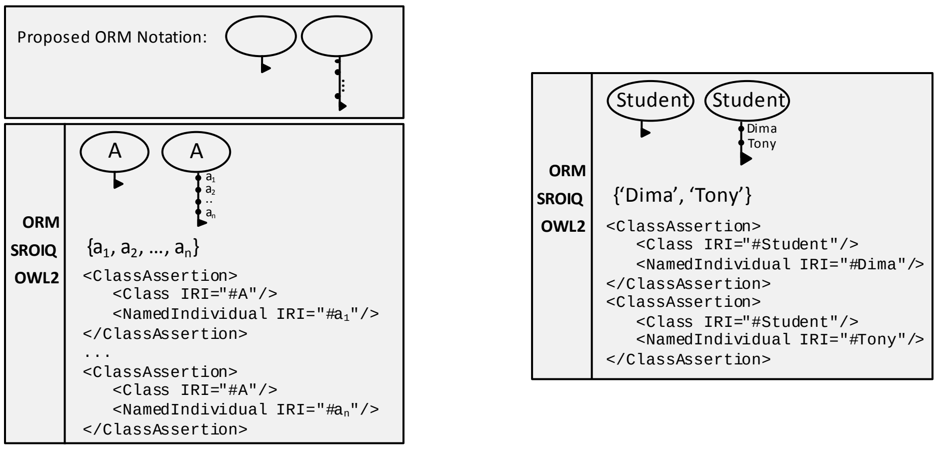


```
<ReflexiveObjectProperty>
  <ObjectProperty IRI="#r1"/>
</ReflexiveObjectProperty>
```

Figure 23: Reflexive Constraint

5.9 Class Assertions

The `ClassAssertion` axiom of OWL 2 allows one to state that an individual is an instance of a particular class. In SROIQ, this is done in the assertion component, i.e., the A-Box which contains instantiations of the axioms specified in the T-Box. In ORM, we propose to use the notation depicted in Fig. 24. This notation provides the user the flexibility to show/hide the instances of a particular class. In our implementation of this notation in DogmaModeler (discussed in section 6), clicking on the (►) symbol at the bottom of the ellipse expands/collapses the set of instances. The user specifies how many instances he/she prefers to be shown. If the number of instances is more than that specified by the user, they are shown in a separate view.



$\{a_1, a_2, \ldots, a_n\}$

```
<ClassAssertion>
   <Class IRI="#A"/>
   <NamedIndividual IRI="#a1"/>
</ClassAssertion>
...
<ClassAssertion>
   <Class IRI="#A"/>
   <NamedIndividual IRI="#an"/>
</ClassAssertion>
```

{'Dima', 'Tony'}

```
<ClassAssertion>
   <Class IRI="#Student"/>
   <NamedIndividual IRI="#Dima"/>
</ClassAssertion>
<ClassAssertion>
   <Class IRI="#Student"/>
   <NamedIndividual IRI="#Tony"/>
</ClassAssertion>
```

(a) (b)

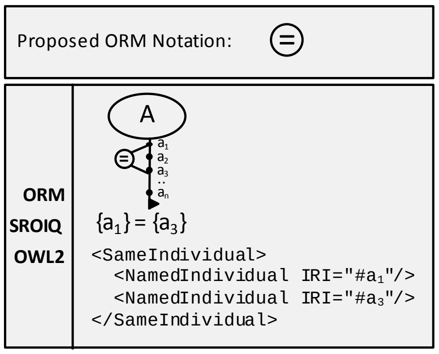
Figure 24: Class Assertions

5.10 Individual Equality

The OWL 2 individual equality axiom `SameIndividual` states that all of the individuals constrained by this rule are equal to each other. In SROIQ, this axiom is expressed in the assertion component, i.e., the A-Box, using the notation of '=' between individuals. In ORM, we propose to use the notation of (⊜) to express individual equality. This notation is used between class instances as shown in Fig. 25.

5.11 Individual Inequality

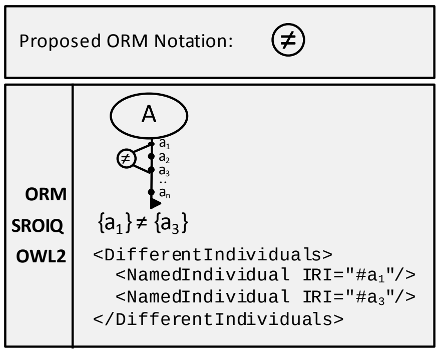
The OWL 2 individual inequality axiom `DifferentIndividuals` states that all of the individuals constrained by this rule are different from each other. In SROIQ, this axiom is expressed in the assertion component, i.e., the A-Box, using the notation of '≠' between individuals. In ORM, we propose to use the notation of (≠⃝) to express individual inequality. This notation is used between class instances as shown in Fig. 26.



$\{a_1\} = \{a_3\}$

```
<SameIndividual>
  <NamedIndividual IRI="#a1"/>
  <NamedIndividual IRI="#a3"/>
</SameIndividual>
```

Figure 25: Individual Equality



$\{a_1\} \neq \{a_3\}$

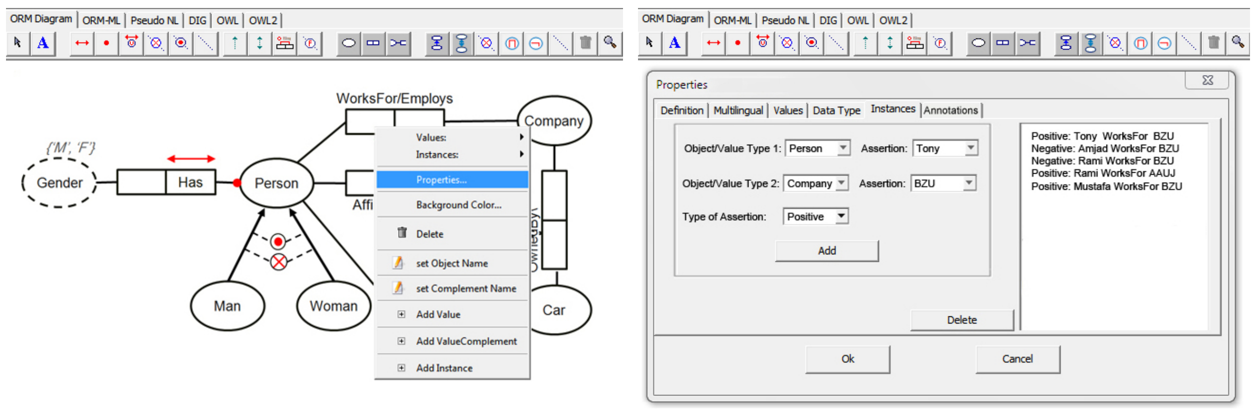
```
<DifferentIndividuals>
  <NamedIndividual IRI="#a1"/>
  <NamedIndividual IRI="#a3"/>
</DifferentIndividuals>
```

Figure 26: Individual Inequality

5.12 Non Notational Expressions

In the previous subsections, we have introduced our proposed *graphical* extension of ORM. However, this extension does not cover all OWL 2 expressions graphically. The OWL 2 expressions not expressed graphically can be put into three categories; (i) Assertions, (ii) Datatypes, Facets, and Data Range Expressions, and (iii) Annotations.

Of the OWL 2 assertion expressions, we have introduced a graphical notation to the following: Class Assertions, Individual Equality, and Individual Inequality. However, no graphical representation was introduced to the *Positive Object/Data Property Assertion*, or the *Negative Object/Data Properly Assertion*. A positive property assertion states that an individual (instance) is connected to another individual or value through a specific property. On the contrary, a negative property assertion states that an individual (instance) is not connected to another individual or value through a specific property. No graphical representation was introduced to these expressions because expressing positive/negative property assertions graphically may hinder the readability of the ORM diagram. Furthermore, these assertion expressions are not encountered frequently in practice. Thus, we introduce the "Assertions Guided Editor", which is specialized in representing these assertion expressions. Fig. 27 below depicts snapshots of our Assertions Guided Editor as implemented in the DogmaModeler tool. For instance, to add positive/negative property assertions to the relation *WorksFor/Employs*, one right-clicks this ORM relation, selects *Properties*, and then chooses the *Instances* tab which opens the assertions editor (Fig. 27.b).



Object/Value Type 1: Person Assertion: Tony

Object/Value Type 2: Company Assertion: BZU

Type of Assertion: Positive

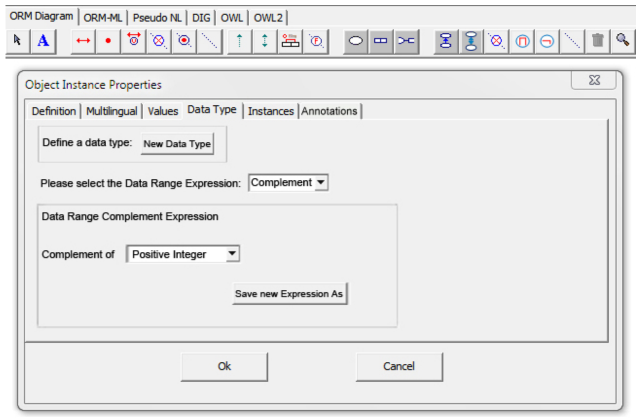
Positive: Tony WorksFor BZU
Negative: Amjad WorksFor BZU
Negative: Rami WorksFor BZU
Positive: Rami WorksFor AAUJ
Positive: Mustafa WorksFor BZU

(a) (b)

Figure 27: Assertions Guided Editor of DogmaModeler

OWL 2 introduces many built in datatypes in addition to the "Number" and "String" datatypes defined in ORM, such as Real, Rational, Double, Float, Boolean, Binary, etc. In addition, it introduces the so-called "Facets", borrowed from the XML Schema Datatypes, which are simply a group of restrictions used to specify new user-defined datatypes. For example, one can define a new datatype for a person's age, called *personAge*, by constraining the datatype *Integer* to values between 0 and 150 (inclusive) using the *minInclusive* facet. Furthermore, OWL 2 supports advanced uses of datatypes, called Data Range Expressions, which include expressions similar to those used with OWL 2 Classes such as complement, union and intersection. For example, assuming we have already defined a datatype called *minorAge*, we can define the datatype *majorAge* by complementing the datatype *minorAge* and then intersecting it with the datatype *personAge*. All OWL 2 Datatypes, Facets, and Data Range Expressions are not expressed graphically. Instead, we introduce the "Datatypes Guided Editor" which aids the user in specifying datatypes and defining new datatypes and data range expressions. Fig. 28.a depicts a simplified Datatypes Guided Editor as implemented in our DogmaModeler tool.

The last category of our non-notational expressions is OWL2's "Annotations". In OWL 2, annotations are used to describe parts of the OWL 2 ontology or the ontology itself. For example, an annotation can be simply a human-readable comment on an axiom of an ontology. E.g., one can add the following comment on the subtype relation between Man and Person: "This subtype relation states that every man is a person". Other annotation properties include: Label, SeeAlso, VersionInfo, etc. Annotations can be specified using the "Annotations Guided Editor". Fig. 28.b depicts a snapshot of our implemented annotations editor in DogmaModeler.



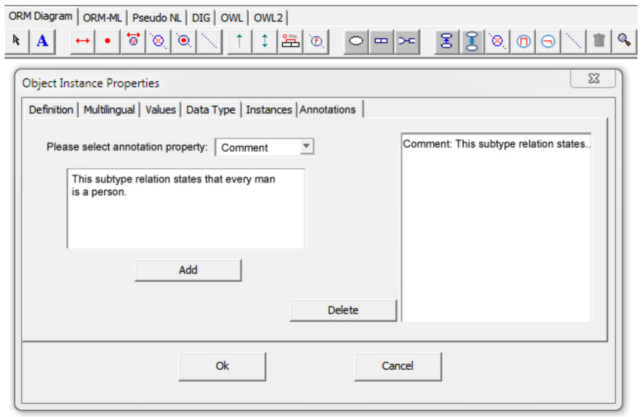
Define a data type:

Please select the Data Range Expression: Complement

Data Range Complement Expression

Complement of Positive Integer

(a) Datatypes Guided Editor



Please select annotation property: Comment

This subtype relation states that every man is a person.

Comment: This subtype relation states..

(b) Annotations Guided Editor

Figure 28: The Datatypes and Annotations Guided Editors of DogmaModeler

5.13 Use Case

One of the most important use cases of the extended ORM notation introduced above is the case of integration. Consider, for example, the case of ontology integration in Fig. 29. The figure depicts two sample ontologies expressed in ORM; the first ontology (Ontology-1) represents a part of the organization (non-natural person) ontology specifying, in particular, the *Company* and the *Local Government Unit* entities. The second ontology represents another part of the organization ontology, namely, the *Association* entity. Note that these two sample ontologies are based on the Palestinian Legal Person Ontology [22] and thus are in harmony with the Palestinian law. However, what is depicted in Fig. 29 is not a complete ontology and is only meant to be a sample demonstration of the usefulness of the newly proposed ORM notations.

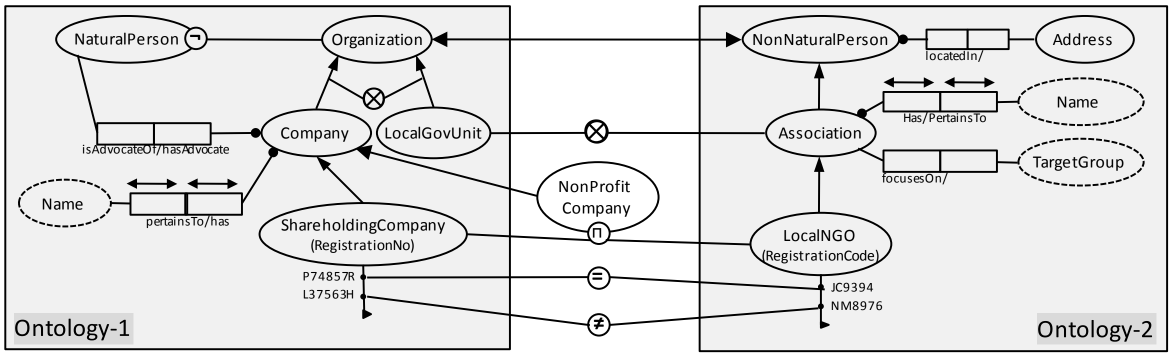


Figure 29: Use Case of the extended ORM notation.

Let us look at the usage of the new ORM notations in Ontology-1. In this ontology, the new notations are used in two places; (i) to express the class 'Natural Person' as the complement of the 'Organization' entity and (ii) to express two assertions of the 'Shareholding Company' entity. In Ontology-2, we also use class assertions to represent two 'LocalNGO' instances. For the purpose of integrating the two ontologies the following newly introduced notations are used:

(i) *Equivalent Classes*, expressed as a double-headed arrow between 'Organization' and 'Non-Natural Person' entities, to express the fact that both entities are equivalent.

(ii) *Disjoint Classes*, expressed using the notation of '⊗' between 'LocalGovUnit' and 'Association' to express the fact that both entities are disjoint.

(iii) *Intersection of Class Expressions*, used to introduce a new entity, namely, the 'Non Profit Company' which includes all shareholding companies that are also registered as local NGOs. Note that this type of companies does exist in Palestine; it includes private limited-liability shareholding companies that provide services to the society but whose profit is not allowed to be distributed among the partners.

(iv) *Individual Equality*, expressed using the notation of (⊜) between the shareholding company (P74857R) and the Local NGO (JC9394). This means that the two identifiers refer to the same real-world entity. Notice the usage of the Individual Equality here for Entity Resolution/ Disambiguation: a much-used process to match different identifiers from different heterogeneous information systems that refer to the same entity.

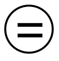
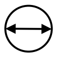
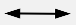
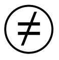
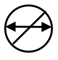
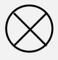
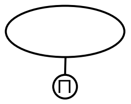
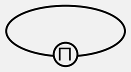
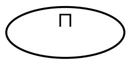
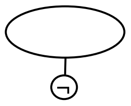
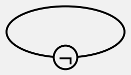
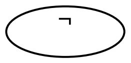
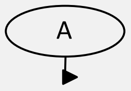
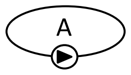
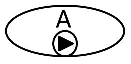
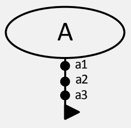
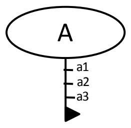
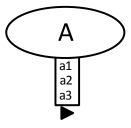
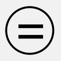
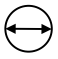
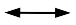
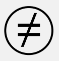
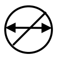
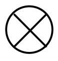
(v) *Individual Inequality*, expressed using the notation of (≠) and is used to state that the two instances constrained by this rule are not the same. In our example, this expression is used for entity disambiguation by stating that that shareholding company (L37563H) and the local NGO (NM8976) refer to different real-world organizations.

5.14 Evaluation

Our work of extending the ORM notation to cover the OWL 2 constructs not currently covered by ORM was evaluated by means of a survey. This survey was performed on 7 of the 11 newly proposed graphical notations, namely, Equivalent Classes, Disjoint Classes, Intersection of Class Expressions, Class Complement, Class Assertions, Individual Equality, and Individual Inequality. The four graphical notations not evaluated in this survey are: Universal and Empty Classes, Universal and Empty Properties, Transitive Constraint, and Reflexive Constraint. The Universal and Empty Classes and Properties of OWL 2 (sections 5.5 and 5.6) were represented graphically using exactly the same ORM notations for classes and roles. This is due to the fact that an OWL 2 class is equivalent to an ORM object-type and an OWL 2 property is equivalent to an ORM role. The same is true for both the transitive and reflexive constraints (sections 5.7 and 5.8). Because both constraints can be seen as part of ORM's ring constraints, they are expressed graphically using exactly the same graphical representation of ORM's ring constraints. Due to that, the four graphical notations mentioned above were not considered in our evaluation process.

Each construct of the seven constructs under evaluation has been represented by three different graphical notations after extensive analysis of the graphical notations currently used in ORM and the rationale behind them; so to follow the same intuitiveness of ORM. The available choices for the graphical representation were then put in a form of a survey, with several illustrative examples. Two workshops were held to explain the broader scope of the research, the motivation behind extending ORM, and the rationale behind each possible graphical representation. Thirty one ORM and OWL practitioners participated in the workshops (most of them are master students and e-government engineers) and were asked to determine their preferred graphical representation for each construct (by filling the survey). The results of the survey were then analyzed and the final notations were determined. Table 1 summarizes all the graphical representation choices and the results of the survey. The reader may refer to the report [21] for more details about the survey.

Table 1: Results of the evaluation survey of the ORM extension

	Construct Name	Representation (1)	Representation (2)	Representation (3)
1	Equivalent Classes	 32%	 16%	 52%
2	Disjoint Classes	 10%	 26%	 64%
3	Intersection of Class Expressions	 13%	 58%	 29%
4	Class Complement	 19%	 45%	 36%
5	Class Assertions (before)	 48%	 13%	 39%
	Class Assertions (after)	 55%	 26%	 19%
6	Individual Equality	 77.5%	 19.5%	 3%
7	Individual Inequality	 71%	 10%	 19%

6 Implementation: DogmaModeler Tool

The work presented in this paper is implemented as an extension to DogmaModeler. DogmaModeler was introduced in previous work [17, 18] as a tool that allows modeling, browsing, and managing ontologies. The tool uses ORM as a graphical notation for modeling ontologies. In its original implementation, DogmaModeler supported the mapping of built ORM ontologies into three notations: ORM-ML (ORM Markup Language), Pseudo Natural Language, and DIG (Description Logic Interface). These mappings allow the ontology to be easily exchanged and understood by domain experts, accessed and processed automatically by application, and validated using Description Logic reasoning services. In fact, DogmaModeler integrates reasoning services as background reasoning engines. This allows one to validate his/her ontology for any possible contradiction or inconsistency. The following is a brief description of the three mappings of ORM that DogmaModeler originally supported:

(i) *ORM Markup Language (ORM-ML).* It is an XML-based language introduced in [17, 18], used to markup conceptual diagrams, thus allowing the ontology that is built in ORM to be accessed and processed at run-time of applications.

(ii) *Pseudo Natural Language.* Through utilizing ORM's verbalization capabilities, DogmaModeler supports verbalization of ontologies into pseudo natural language, allowing for easy exchange and understanding of the ontologies by domain experts.

(iii) *Description Logic Interface (DIG).* It is an XML-based language supported by several description logic reasoners (such as Racer, FaCT++, etc), which allows for the validation of ontologies built in ORM.

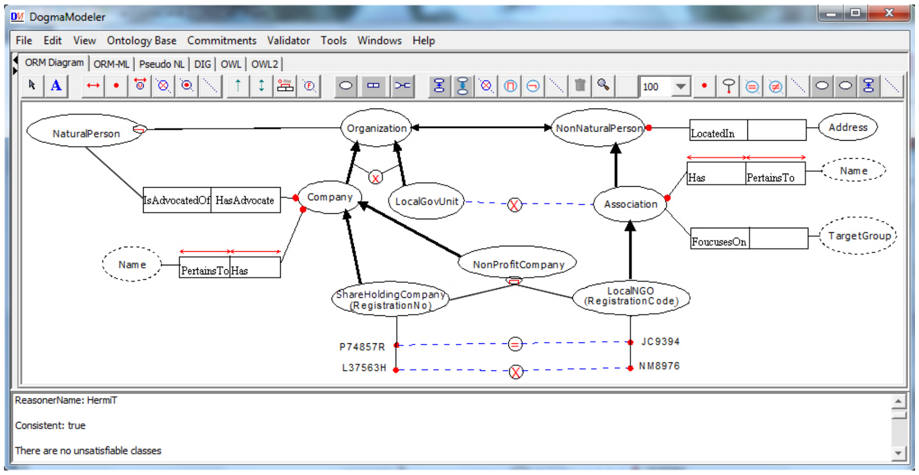
Our implemented extension of DogmaModeler is twofold:

(i) We implemented the OWL 2 mapping of ORM presented in this paper, such that the ORM diagrams built in DogmaModeler are automatically mapped to OWL 2 and then validated using the "HermIT" reasoning tool. "HermIT" was chosen because of its easy integration into DogmaModeler and its support of OWL 2.

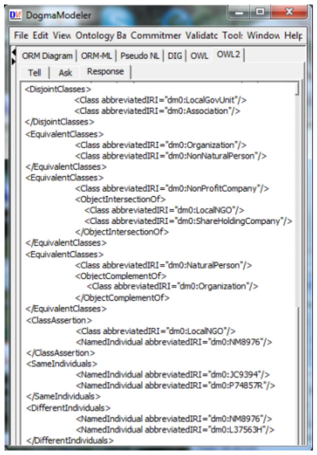
(ii) We implemented our newly proposed ORM extension with its OWL 2 mapping, in addition to the guided editors of the non-notational expressions.

The DogmaModeler tool is now extended to become an environment for authoring OWL 2 ontologies graphically using ORM. That is, one now builds his OWL 2 ontology graphically using ORM and then DogmaModeler generates the OWL 2 code automatically. This code can then be validated easily using description logic reasoning via the integrated "HermIT" reasoning tool.

Fig. 30 shows the use case of Fig. 29 built in DogmaModeler. The first window (Fig. 30.a) contains the ORM diagram. Note that this diagram contains our proposed extension of the ORM notation. The results of the validation using logical reasoning show that the ORM model is consistent and there are not unsatisfiable concepts. The second window (Fig. 30.b) shows the OWL 2 mapping of the ORM diagram.



```
ReasonerName: HermiT
Consistent: true
There are no unsatisfiable classes
```


DogmaModeler
File Edit View Ontology Ba Commitmer Validatc Tool: Window Help
ORM Diagram | ORM-ML | Pseudo NL | DIG | OWL | OWL2
Tell | Ask | Response

```
<DisjointClasses>
        <Class abbreviatedIRI="dm0:LocalGovUnit"/>
        <Class abbreviatedIRI="dm0:Association"/>
</DisjointClasses>
<EquivalentClasses>
        <Class abbreviatedIRI="dm0:Organization"/>
        <Class abbreviatedIRI="dm0:NonNaturalPerson"/>
</EquivalentClasses>
<EquivalentClasses>
        <Class abbreviatedIRI="dm0:NonProfitCompany"/>
        <ObjectIntersectionOf>
          <Class abbreviatedIRI="dm0:LocalNGO"/>
          <Class abbreviatedIRI="dm0:ShareHoldingCompany"/>
        </ObjectIntersectionOf>
</EquivalentClasses>
<EquivalentClasses>
        <Class abbreviatedIRI="dm0:NaturalPerson"/>
        <ObjectComplementOf>
          <Class abbreviatedIRI="dm0:Organization"/>
        </ObjectComplementOf>
</EquivalentClasses>
<ClassAssertion>
        <Class abbreviatedIRI="dm0:LocalNGO"/>
        <NamedIndividual abbreviatedIRI="dm0:NM8976"/>
</ClassAssertion>
<SameIndividuals>
        <NamedIndividual abbreviatedIRI="dm0:JC9394"/>
        <NamedIndividual abbreviatedIRI="dm0:P74857R"/>
</SameIndividuals>
<DifferentIndividuals>
        <NamedIndividual abbreviatedIRI="dm0:NM8976"/>
        <NamedIndividual abbreviatedIRI="dm0:L37563H"/>
</DifferentIndividuals>
```

(a) ORM built and validated in DogmaModeler

(b) OWL 2 mapping of the ORM in (a)

Figure 30: An ORM diagram containing notations of the proposed ORM extension, built in DogmaModeler.

7 Conclusion and Future Work

In this paper, we have developed an expressive and methodological graphical notation for OWL 2, which allows people to author OWL 2 ontologies graphically. This was done in two steps: (i) mapping the graphical notations of ORM to SROIQ/OWL 2 following the semantics of OWL 2 (ii) extending the ORM graphical notation to cover all OWL 2 constructs not currently covered by ORM. OWL 2 is the W3C-recommended ontology language for authoring ontologies. However, it does not provide any methodological or graphical means to engineer ontologies. On the other hand, ORM is a graphical methodological notation used for conceptual modeling. By mapping ORM to OWL 2 and extending ORM to cover all OWL 2 constructs, one can now author OWL 2 ontologies graphically using ORM and then map them automatically to OWL 2.

The work presented in this paper was evaluated as follows. The mapping of ORM into SROIQ/OWL 2 was evaluated using the RacerPro 2.0 description logic reasoner; for every ORM construct, its OWL 2 mapping was inserted into the RacerPro system and various kinds of tests were performed on it. On the other hand, our proposed extension of the ORM notation was evaluated by means of a survey that included more than 30 practitioners in the field of ORM and OWL.

Our work of developing an expressive and methodological graphical notation for OWL 2 was implemented in the DogmaModeler tool. This allows one to engineer OWL 2 ontologies graphically using ORM and then DogmaModeler maps them automatically to their equivalent OWL 2 code. It is important to note here that ORM is not merely a graphical notation for the visualization of ontologies. It is a methodology that guides the ontology engineer to design and represent an ontology using the different constructs and rules it provides. ORM facilitates the process of engineering the ontology through its verbalization capabilities which allow the involvement of domain experts in the modeling process.

Future directions of our research will involve extending our DogmaModeler to allow user-friendly debugging and reasoning. Currently, DogmaModeler uses the “HermIT” reasoning engine which only tells whether the ontology is satisfiable and consistent or not. Thus, it is important to also provide debugging features that helps the user find the cause of the problem and directions on how to solve it. Note that this is not an implementation issue; it rather needs theoretical research on reasoning problems. In addition, our future work will involve building a reasoning service that checks the consistency of RDF datasets (as A-Box) with the built ontology. Also, we will extend our DogmaModeler verbalizer to include the extended ORM notation. This will include multilingual verbalization into 11 languages. Furthermore, we plan to extend DogmaModeler with the import feature of OWL 2 to allow the modularization of ontologies.

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Dr. Mustafa Jarrar is an associate professor of Computer Science at Birzeit University, in Palestine, since 2009. Before that (2007-2009), he was an Experienced Marie Curie Fellow at the University of Cyprus, and was (1999-2007) a Senior Research Scientist at STARLab, Vrije Universiteit Brussel in Belgium, where he completed his Master's (2000) and PhD (early 2005). Jarrar published more than 80 articles and refereed reports. He chaired 15 international events and workshops and is PC members of more than 90 conferences and journals. Jarrar served/is serving as a coordinator and project leader of many national and EU projects (TEMPUS and Framework Programs) including SIERA, Pal-Gov, GovSeer, ArabicOntology, KnowledgeWeb, OntoWeb, Innovanet, among others. Jarrar has co-founded the Ontology Outreach Advisory, and is a full member of the IFIP2.6 on Database Semantics, the IFIP2.12 on Web Semantics, the IEEE Learning Standards Committee, and the CEN/ISSS ICT Skills.

Rami Hodrob is a lecturer of Information Technology at the Arab American University-Jenin (AAUJ), since 2003, where he also works as a researcher at the Information and Communication Technology Development Center. Between 2003 and 2007, he had also worked as a part-time instructor of Computer Science at Al-Quds Open University. Hodrob has completed his Bachelor Degree in Electronic Engineering from Yarmouk University, Jordan and holds a Master’s Degree in Business Administration, from An-Najah National University, Palestine. He is currently a Master’s student of Computing at Birzeit University and is also part of Sina Institute where he conducts research in the fields of Ontology and the Semantic Web. Hodrob has published several refereed articles and has participated in several international conferences.

Anton Deik has worked as a junior researcher at Sina Institute at Birzeit University, Palestine, where he completed his Bachelor degree in Computer Systems Engineering. Since 2009, he has been conducting research in the fields of Semantic Web, Ontology Engineering, Graph Databases, Interoperability, and Data Integration. In Sina Institute, Deik has been involved in several projects including: SIERA (EU FP7), PalGov (EU TEMPUS), ArabicOntology, and MashQL. Deik had also worked as an Interoperability Engineer at the Palestinian Ministry of Telecom and IT (2010-2011), where he was involved in the development of the Palestinian Interoperability Framework “Zinnar”. Deik has published several refereed articles and has been involved in several international conferences. Currently, Deik is serving as a volunteer on board of the Logos Hope Ship.