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IT Skills Ontology

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Abstract

With the advance of technology, the jobs in the Information Technology (IT) area have increased, contemplating more and more new skills. Nowadays, it constitutes a problem in the recruitment field once there is no standard for all of those IT skills. As a consequence of this lack, it became hard to understand/assess if a candidate is, or not, the right match for a specific job and also to describe the job itself.

The chosen approach for overcoming this problem was to create an ontology for IT Skills, which should identify, conceptualize, and relate all the skills and jobs in the IT domain. We performed a Systematic Literature Review to learn more about ontologies in the field of IT and the methodologies for their development and evaluation to help us constructing an ontology for IT skills. The development, demonstration, and evaluation of the IT Skills ontology were guided by the Design Science Research methodology and conducted in a professional environment, mainly in a company that is dedicated to recruiting IT professionals. Using the data from the Systematic Literature Review, it was chosen and applied the Methontology methodology for the development. In order to evaluate the developed ontology, three approaches were used: Competency Questions, Experts Assessment, and Talent Advocate Specialists Interviews.

Through the assessment of the IT Skills Ontology, it was possible to conclude that its application is useful and brings advantages to the specialists, by facilitating the curation process and by making it easier and faster, especially for less experienced IT recruiters.

Keywords

Ontology, Ontology Development, IT Skills, IT Skills Ontology, Ontology Evaluation, IT Recruitment

Resumo

Com o avanço da tecnologia, aumentaram também os empregos na área de Tecnologia da Informação (TI) bem como o aparecimento de novas skills. Atualmente, este aumento repentino e constante constitui um problema na área do recrutamento, uma vez que não existe um standard definido para todas essas novas skills de TI. Como consequência, tornou-se difícil entender/avaliar se um determinado candidato é o mais adequado para um dado trabalho e até mesmo descrever os requisitos dos próprios trabalhos.

Uma possível abordagem para dar respostas a esse problema é criar uma ontologia para skills de TI, que identifique, conceptualize e relacione as diferentes skills e as diferentes funções/trabalhos no domínio de TI. A fim de nos ajudar a construir e avaliar a ontologia foi realizada uma Systematic Literature Review. A Systematic Literature Review possibilitou-nos aprender mais sobre ontologias no campo da TI e as metodologias para seu desenvolvimento e avaliação, de forma a permitir uma escolha sólida das metodologias a utilizar para a construção e avaliação da ontologia de skills deTI. O desenvolvimento, demonstração e avaliação da ontologia de habilidades de TI foi guiado pela metodologia Design Science Research e realizado em ambiente profissional, integrado a uma empresa dedicada ao recrutamento na área de TI. Utilizando os dados da Revisão Sistemática da Literatura, optou-se por aplicar a metodologia Methontology para o desenvolvimento da ontologia e, para avaliar a ontologia desenvolvida, foram utilizadas três abordagens: Competency Questions, Avaliação com Experts e Entrevistas a Talent Advocate Specialists.

Através da avaliação da Ontologia de Skills IT, foi possível concluir que sua aplicação é útil e traz vantagens para os especialistas uma vez que ajuda no processo de curadoria, facilitando-o e tornando-o

mais rápido, principalmente para recrutadores de IT menos experientes.

Palavras Chave

Ontologia, Desenvolvimento de Ontologias, IT Skills, Ontologia de IT Skills, Avaliação de Ontologias, Recrutamento IT

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1

Introduction

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With the advance of the world and the appearance of new technologies, computer science conferred to the word ontology a different purpose compared to the philosophic one [8].

In the computer science field, an ontology is a graph structure to present knowledge capable of representing real world domain artifacts [9]. Ontologies are an essential part of Semantic Web and are even "considered as its backbone" [6]. They provide a formal way to represent knowledge [8], representing the relation between the different concepts in a way that both people and machine could understand/share it.

In that sense, ontology is a way to conceptualize, define and specify a certain domain in order to provide shared understanding about it [10]. It is possible to perceive ontologies as "thesauruses describing galaxies of concepts (stars) and features (planets) held together by semantic gravitation weighted by similarity or proximity"[1].

The computer science ontologies are used in different fields like biology [11], health [12], information management [13], semantic web [14], data science [15] among other fields, with the promise of performing a formal and complex representation of a domain of knowledge including the concepts, their definitions and all the relations between them [8] in a way that can decrease the information complexity and make it easier to understand.

Nowadays, with the web and technology present in all of everyone' routines the field of jobs and careers in Information Technology (IT) is expanding exponentially, which constitutes a problem because there is still no official standard for assessing and categorizing IT skills [16], containing the different skills, their relations and the jobs profiles in this field. This lack generates difficulties to perform a better match between the job's requirements and the candidate's skills. The recruitment process became a way more difficult for the companies that have problems on understanding the right candidates for the different types of job and describing the job requirements[2].

Different organizations are already trying to deal with this problem such as ESCO[3] (European Skills, Competences, Qualifications and Occupations) that already started to categorize and conceptualize the different jobs and careers and the correspondent skills to each one, and ESCoE (UK)[4] that made a taxonomy of the skills required for different jobs.

Both approaches (ESCO and EScoE) work like a taxonomy since they conceptualize and relate the skills hierarchically on the different jobs. Still, they do not relate the skills between themselves and don't identify and specify all the kind relations between the different jobs and skills.

The chosen approach to solve the lack of standards for assessing and categorizing IT skills is to design and develop a comprehensive ontology of IT skills. The choice of this approach was made because an ontology allows us to define, conceptualize, categorize the different skills of IT area and to

[1] https://caminao.blog/knowledge-architecture/ontologies-models
[2] https://www.4cornerresources.com/blog/the-challenges-of-it-recruiting-how-to-overcome-them
[3] https://ec.europa.eu/esco/portal/skill
[4] https://data-viz.nesta.org.uk/skills-taxonomy/index.html

relate all the concepts, genuinely representing the knowledge involved.

To chose the best methodology for the ontology's development and evaluation, we carried out a Systematic Literature Review (SLR) based on Kitchenham's Procedures for Performing Systematic Reviews [2] because, according to Kitchenham, it is a way of "identifying, evaluating and interpreting all available research relevant to a particular research question, or topic area, or phenomenon of interest". Our SLR approach identified the IT field related ontologies as well as the methodologies that were applied to their development and evaluation to help us finding the best methodology for constructing and evaluating the IT Skills ontology. To develop and evaluate the IT Skills ontology's project in an organized and consistent way, we followed the guidelines provided by the Design Science Research [1] methodology.

This project, the development, demonstration and evaluation of the ontology, was conducted on a professional environment, more specifically in a company that is dedicated to matching the best tech professionals to the right companies all around Europe. It was decided that, due to being the most valuable for the company context, the ontology developed would cover only the hard/technical skills related to the IT Development jobs (for example: Backend Developer, Frontend Developer, etc...). So, the data used for the construction of the ontology was real data, mostly from the company in which this project was inserted.To develop and evaluate the IT Skills ontology's project in an organized and consistent way, we followed the guidelines provided by the Design Science Research methodology.

The developed ontology was applied to the curation field, integrated in the recruitment process, of the company where the project was developed. Three approaches were used to evaluate our ontology: Competency Questions, Talent Advocate specialists Interviews and Experts Assessment.

1.1 Research Methodologies

In this Section, we exposed the two research methodologies that were used during the development of this master's thesis.

The SLR was made to understand which are the main areas of IT that the ontologies are used and which are the most applied methodologies for their development and evaluation.

The entire development process of this thesis was guided by the DSR methodology. This methodology aims to produce and evaluate an IT artifact, in this case the IT Skills Ontology, which supports the solution to an identified problem.

1.1.1 Design Science Research

For guiding this research, we used the Design Science Research (DSR) methodology. DSRM intends to provide guidelines to improve the research in Information Systems with the main objective of achieving

the understanding of a problem' domain and the creation and application of "new and innovative artifacts" [17] about it.

Peffers et al. [1] present a set of six steps for performing a DSR methodology, which are:

- **Problem Identification and Motivation** - identification and definition of the research problem and the importance/relevance of a solution for it;
- **Definition of the Objectives for a Solution** - identification of the objectives for the solution of the previously defined problem;
- **Design and Development** - identification of the models and methods for the creation of the desired solution, and development of the solution;
- **Demonstration** - application of the developed solution solving a particular case of the problem;
- **Evaluation** - observation and measurement the quality of the developed artifact as a solution for the problem;
- **Communication** - communication of the problem and its relevance, the artifact, and its importance and utility.

The phases of the DSRM described are represented in the Figure 1.1, specifying the work that we will develop in each one of the phases.

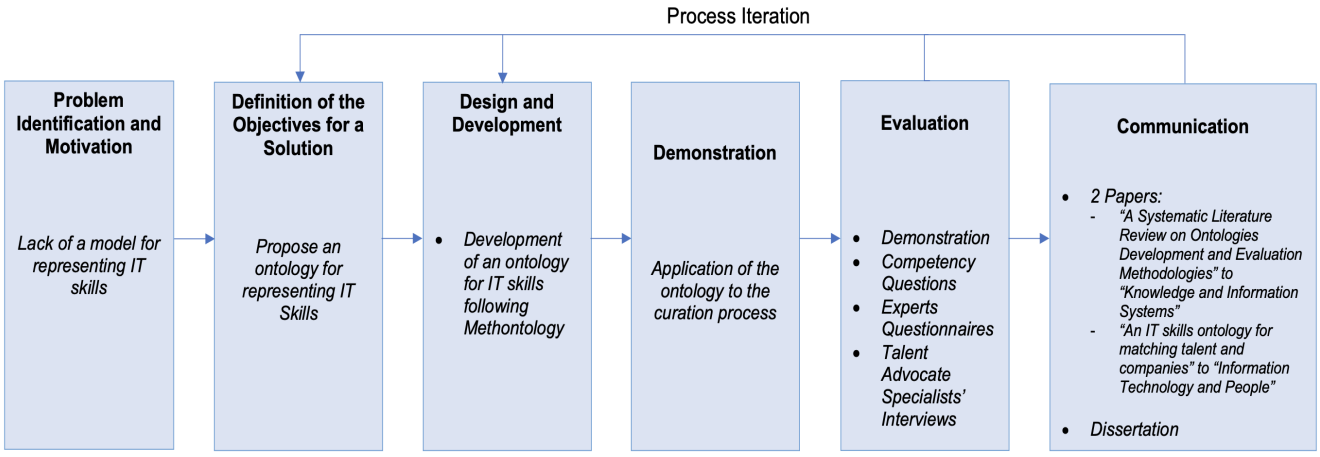

Figure 1.1: Phases of the Design Science Research process adapted from [1].

1.1.2 Systematic Literature Review

In this work we used an SLR. An SLR is a way to perform a literature review using a systematic manner that allows us to identify, analyze and interpret all available information regarding a specific area, topic or question, using a rigorous methodology [2], and to sum the existing work and information regarding it. By applying this systematic research methodology we can achieve results from a reliable and unbiased set.

We performed our SLR guided by Kitchenham's Procedures for Performing Systematic Reviews [2], which contains the following phases:

- **Planning:** This phase exposes the need to perform a systematic review that summarizes all information about a particular topic or area in an unbiased manner. The research questions, SLR objectives, exclusion and inclusion criteria are defined, and a review protocol must be written.
- **Conducting:** This phase applies the review protocol previously defined as a way to achieve studies that contain the information that will be the object of the review.
- **Reporting:** This phase intends to write and summarize the extracted information/data from the selected studies in order to achieve the results of the review.

The three phases of the SLR described above are represent in Figure 1.2, which specify the work that we did in each phase. SLR was our choice to perform this work once it is a trustworthy research methodology, which allowed us to summarize the existing works of development and evaluation of ontologies in IT with the respective methodologies that were used in each work, allowing us to get the answers to the proposed Research Questions.

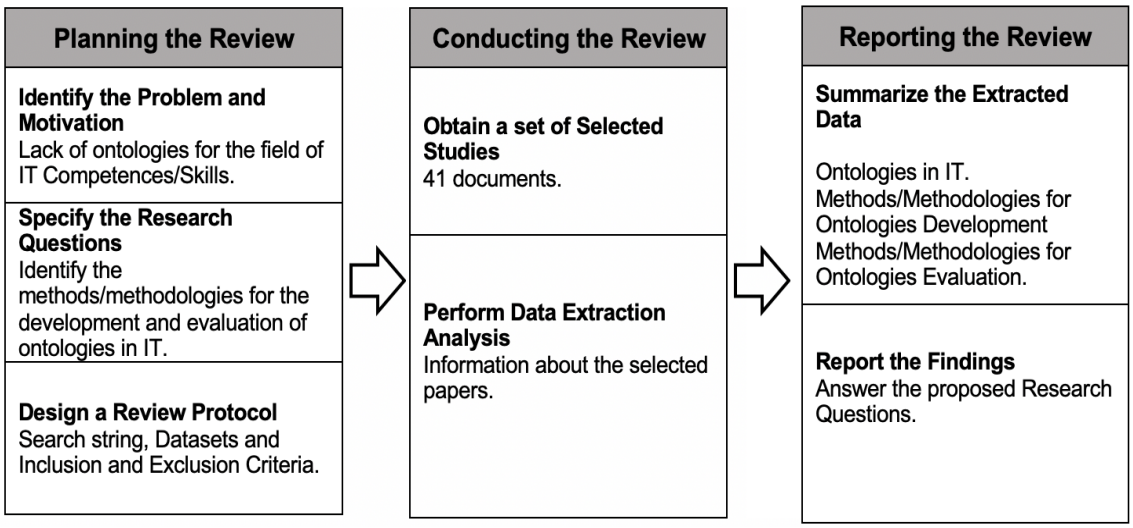

Figure 1.2: Phases of the Systematic Literature Review adapted from [2].

1.2 Document Structure

The remainder of the paper is structured as follows. Chapter 2 concerns the state of the art on Ontologies in Sections 2.1, 2.2 and 2.3, IT Skills in Section 2.4 and the work related to IT Skills Ontologies in Section 2.5.

Chapter 3 treats the Systematic Literature Review composed by the Planning phase (Section 3.1), the Conducting phase (Section 3.2), the Reporting phase (Section 3.3) and an analysis of the obtained results (Section 3.4).

In Chapter 4, the Research Problem of this master thesis is presented. After this, the IT Skills Ontology, our proposal to mitigate the defined problem, is developed following partially the Methontology methodology, in Chapter 5. Chapter 6 covers the Demonstration of the IT Skills Ontology, and its evaluation is performed in Chapter 7.

Chapter 8 exposes the conclusions of our research, our main limitations until now and our intentions for future work.

2

Theoretical Background

Contents

2.1 Ontology Definition

In the beginning, the word “ontology” was associated with philosophy. The philosophical approach of ontologies was based on a categorical analysis with the intent of categorize the reality, make an “inventory reality” [18]. More recently, in computer science, ontologies have followed the same principles that in philosophy but with a different purpose. Working as a technology, ontologies have the purpose of modeling a domain in order to make it readable and possibly reasoned by a software [18].

Ontologies perform an important role in knowledge representation and reasoning [19]. Over the years, many authors gave their definitions for ontologies, for example:

- “the term used to refer to the shared understanding of some domain of interest” according to Uschold and Gruninger [10];

- “a formal representation of the knowledge by a set of concepts within a domain and the relationships between those concepts” by Man [8];

- “a formal, explicit specification of a shared conceptualization as stated by” Studer et al. [20].

In our work, we follow a combination of the definition proposed by Man [8] and Uschold and Gruninger [10] because we believe that ontologies are a formal representation of a domain of interest through the definitions and relations between the concepts of that domain, as a way to achieve shared understanding.

2.2 Ontology Development

With the increasing use of ontologies in computer science, several methodologies have been proposed for their development. According to the literature, different surveys [21] [22] [23] on methodologies for the development of ontologies have exposed some common methodologies, namely:

- **Methontology** [24], which is a methodology for ontologies development, “is based on the IEEE standard criteria to design the life-cycle process ontology” [25]. It begins with “Planning” phase, that consists in defining the reasons to develop the ontology and their uses. After that, is performed the “Specification” phase that states the reason why the ontology is being built, what its intended applications are and who the end-users will be. The third phase is the “Knowledge Acquisition”, which is characterized by obtaining knowledge drawn from different sources. The following step is “Conceptualization”, where the domain of knowledge must be structured in order to achieve a conceptual model that describes the problem and its solution (relative to the domain vocabulary defined in the “Specification” stage). Follows the “Integration” phase and after that must be executed the “Implementation” of the ontology, which consists in codify/represent the ontology using a language. Finally, an “Evaluation” must be executed over the ontology.

- The **Enterprise Model Approach** [26] is a methodology that is divided into five stages. It starts by identifying the Purpose - the place where the questions such as "why the ontology is wanted. What it will be used for. And possible mechanisms for use" must be answered. Next, it defines the level of formality that the ontology will be developed. The next step concerns identifying the scope, where is defined the range of information that the ontology should cover. This step can be performed by using "motivating scenarios and informal competency questions" or by "brainstorming and trimming". The fourth stage is about "Building the Ontology" where the ontology is structured. The last phase is the formal evaluation of the ontology.

- Grüninger and Fox have suggested the **TOVE** development methodology [27], which is essentially divided into six phases. The first one, "motivating scenarios", is where the problem of an Enterprise is defined. The second step is, according to the previously defined motivation scenario, formulating informal competency questions (that will work as the evaluation of the requirements exposed in phase one). On the third is performed the terminology specification (in first-order logic) where the objects, attributes and relations formally specified. In the following step, formal competency questions are defined. Then, at the fifth phase, the axioms that specify the definition of terms and constraints on their interpretations are given in first-order logic, guided by the formal competency questions (defined in the fourth phase). The last phase concerns the "completeness theorems". It's performed an evaluation stage where the competency of the ontology is verified by defining the conditions where the solutions for the previously defined competency questions are complete.

- The **IDEF5** [28] is another ontology development method, which have continuous refinement during all the development. This method consists in the phases of "Organize and Define Project" in which is defined the purpose of the ontology, the scope and the level of detail, "Collect Data" in which implies exploiting and getting the information useful for the ontology development, "Analyze Data", "Develop Initial Ontology" in which a draft version of ontology is developed according to the information extracted from the sources and, at last, "Refine and Validate Ontology" in which the ontology is refined, tested and concluded.

- Noy and McGuinness [29] proposed the **Ontology Development 101**, which is a methodology of ontology development that consists in the execution of seven steps. It starts by determining the domain and scope of the ontology using, for example, competency questions. After that, on step two it suggests to verify if it's possible to reuse existing ontologies because "almost always worth considering what someone else has done and checking if we can refine and extend existing sources for our particular domain and task". On step three the important terms in the ontology must be enumerated. The following step (step four) consists in defining the classes and the class hierarchy, using top-down, bottom-up, or mixed approaches (as proposed in the project of Uschold

et al. [10]). As the next step, the properties of each class (step five) and step the facets of the slots (step six) must be defined. The last step is the creation of the instances.

- **On-to-Know (OTK)** [30] for ontologies development is methodology composed by the phases of "Feasibility Study", which consists in determine the project feasibility (identifying the problem and the possible solutions), "Kickoff" where is performed a semi-formal description of the ontology, "Refinement" where the ontology is constructed and compared with what was previously defined, "Evaluation" of the ontology and "Application and Evolution" of the developed ontology.

- Goméz et al. [31] proposes a methodology called **NeOn**, which is a scenario-based methodology for ontology engineering that "does not prescribe a rigid workflow, but instead it suggests a variety of pathways for developing ontologies". It provides a list of nine scenarios to build ontologies with the respective activities.

Just as there are diverse methodologies for ontology development so do are different tools to help in the development process. According to the literature [32] [33], it was possible to find that some of the main tools used for ontology development and management are Protégé/Protégé 2000, OilEd, OntoLingua, Apollo, OntoEdit, RDFedt, WebOnto, WebODE, KAON, DOE (Differential Ontology Editor), ICOM, Medius Visual Ontology Modeler, LinKFactory Workbench and K-Infinity.

2.3 Ontology Evaluation

Ontologies Evaluation is a crucial to verify if the ontology developed meets the requirements and if it satisfies the objectives for which it was built. Ontology evaluation can be understood, according to Goméz-Pérez [34], as a "technical judgment of the content of the ontology with respect to a frame of reference during each phase and between phases of their life cycle" including ontology verification, which "refers to building the ontology correctly", and ontology validation, which "refers to whether the meaning of the ontology definitions really model the real world".

There are three main types of errors in ontologies and taxonomies namely inconsistency errors, incompleteness errors and redundancy errors [34]. The inconsistency errors includes the circularity, partition, and semantic ones, the incompleteness errors includes incomplete concept classification and omission of disjoint knowledge and the redundancy errors includes grammatical ones and identical formal definition of some classes/instances.

According to Hlomani et al. [5] ontology evaluation must focus on two main perspectives: Ontology Correctness and Ontology Quality. In Table 2.1 and Table 2.2 we present the metrics described for each of the perspectives [5] [6]:

Table 2.1: Ontology Correctness Metrics adapted from [5] and [6].

Ontology Correctness Metrics	Meaning
Accuracy	Declares if the knowledge present in an ontology is right.
Completeness	Evaluates whether ontology adequately covers the domain of interest.
Conciseness	Declare whether the ontology includes elements irrelevant to the domain to be covered.
Consistency	Relate that the ontology doesn't include or allow for any constraints.

Table 2.2: Ontology Quality Metrics adapted from [5] and [6].

Ontology Quality Metrics	Meaning
Computational Efficiency	Relates to the speed at which tools can work with the ontology.
Adaptability	Measures the ease of the ontology being used in different contexts and to anticipating its uses.
Clarity	Measures how effectively the ontology communicates the intended meaning of the defined terms.

Vrandecic [35] also included Organizational Fitness/Commercial Accessibility as an important metric to take into account during the ontology evaluation. Organizational Fitness/Commercial Accessibility concerns the fit of the ontology in the respective organization to be applied.

According to Cruz and Raad [6] the existing methods/techniques for ontology evaluation are:

- **Gold Standard** - This approaches consist in compare the developed ontology with a previously created reference ontology (a gold standard). This technique is a good one for evaluating metrics like accuracy, correctness and conciseness of an ontology.
- **Corpus-based** - This type of approach is similar to the "gold standard", but instead of comparing the developed ontology with a reference, it compares the ontology with a text corpus that considerably covers a given domain. As the "gold standard", this approach is a good one for evaluating metrics like accuracy, correctness and conciseness of an ontology.
- **Application/Task-based** - This approach is based on evaluating how well the ontology can perform a specific task or how effective it can be in the context of an application. This kind of approach is a good one for evaluating metrics like adaptability, computational efficiency and consistency of an ontology.
- **Criteria-based** - This type of techniques consists on evaluating how far an ontology comply with a specific criteria. This kind of approach is a good one for evaluating metrics like clarity, computational efficiency and consistency of an ontology.

Hlomani and Stacey [5], also reported some problems and difficulties with the evaluation of ontologies like the subjectivity of criteria, lack/subjectivity in thresholds and influences of subjectivity on the overall value of the measures/metrics. Already exists inductive approaches [5] to criteria selection based, for example, on competency questions [36], and deductive approaches to criteria selection that use metrics similar to software cohesion metrics have been defined to evaluate the different ontology elements.

2.4 Skills in Information Technology

The concept of skill is huge and vague. So, it is important to understand the what is, in fact, a skill and what types of skills exist in the IT field.

Francis Green mentioned an approach, named “PES” [37], for the definition of the concept of skill, not only for IT field but in general. “PES” is an acronym which contains the three key features that a personal quality needs to be a skill, which are:

- **Productive** - using skills at work are productive of value;
- **Expandable** - skills are enhanced by training and development;
- **Social** - because skills are socially determined.

All of these key features are dependent of the role and the field of works of each person.

Although there is an illusion that in the IT area, specifically, the only skills that matter is technical skills, soft skills also play a decisive role throughout a career in this field [38]. So it is possible to divide skills in two types, hard/technical skills and soft skills. The technical skills are the skills provident from technical knowledge or training that it is obtained and improved through education or professional work and soft skills are attributes and qualities that are reflected on each person behavior and personality.

Regarding technical skills, in the work of Kong et al. [39], the five main categories used to organize them were Programming Languages (ex. C/C++, Java and COBOL), Web Development (ex. SQL, HTML and JavaScript), Database (Oracle, SQL Server and DB2), Operating System and Environments (ex. Unix and Windows 95/98/2000) and Networking (ex. Windows NT and WAN/LAN). It was also found a soft skill, in this case, communication skill.

Laar et al. [40] carried out a SLR to understand, among other subjects, “which concepts are being used to describe the skills needed in a digital environment, go beyond mere technical use, and focus on 21st-century digital skills”. As a result of this study, it was concluded that the concepts are approaching skills related to knowledge or content, suggesting the approximation and mixing between technical skills and soft skills, although in job advertisements still prevail in technical ones.

The skills of IT professionals are, during the recruitment process, the key element in establishing the connection, or match, between a candidate and a job, where a perfect candidate-job combination includes the match between both soft and hard skills. Although, the majority of the job advertisements mainly focus on technical skills [41] mostly technical skills from different areas and types [39].

In this master thesis, we focused our work on hard skills, and we used the “PES” approach to check which of the found concepts can be classified as skills.

2.5 Related Work

In the literature, we found some valuable research regarding the development of ontologies for IT skills and others that used the IT skills ontologies as way to achieve a certain purpose.

Corrêa Leão et al. [42] developed a solution to face the difficulty of organizations "to attract, keep and manage talents". For this solution, the authors decided to develop an ontology about the competencies of IT professionals. They identified several possible scenarios to the use of the ontology and defined certain questions that, in the end, the ontology must able to answer. This ontology focus on the management of the IT professionals' competencies/skills for Human Resources in IT Organizations. In 2016, Gavrilova and Laird [43] developed a practical ontology for IT skills, also for a human resources knowledge management system. They start by building a glossary of IT Skills and Knowledge and develop the ontology over it. It was possible to observe that the general ontology developed includes different categories, with sub-categories of the IT application areas with different types of relations and more specific skills inside them.

With a quite different purpose, in 2013, Singto and Mingkhwan [16], have noticed that even there are a lot of different Careers in IT, these are not stored in an "hierarchical structure" which makes the search performance decrease. To solve this, the authors developed the IT Careers Ontology (ITCO) that is composed of three main parts: IT Career Category, IT Skill and IT Education. The IT Skill part is composed of different areas that aggregate different skills. In this paper is also proposed, semantic search using this ontology that revealed results linking IT skills to IT Careers.

More recently, in 2018, due to the increasing use of the online job search and talent procurement, Balachander and Moh [44] decided to use ontologies to find similarities between skills as a way to solve searching and matching problems associated with the e-recruitment. They calculate the scores between several skills using different approaches, and it was possible to relate that, comparing to human evaluated scores, the system has a better performance.

Khobreh et al. [45] also proposed an ontology, not for IT skills but for job knowledge in general. This ontology intends to identify people' lacks in the knowledge domain in relation to the required tasks for a specific role/type of job. It represents three main parts: Knowledge, Task and Competence. The Task and Competence are related as the Task requires Competence and the Competence enables Task. And the Knowledge is related to the Competence as the Knowledge qualify Competence and the Competence requires Knowledge.

Although there are few studies specifically related to IT skills ontologies, it is possible to verify the advantages of their uses by analyzing the above cases. Some problems with the studies that we analyzed are that they are quite general, and, because of that, they become incomplete. In some of the papers (e.g. [42]), the relationships between the skills themselves are not taken into account. As the IT area is constantly expanding some of the analyzed papers do not present some of the most recent IT skills.

3

Systematic Literature Review

Contents

3.1 Planning the Review

This Section corresponds to the first step of the SLR Methodology. We start by exposing our Motivation for this work, then the Objectives and correspondent Research Questions that we intend to answer with our research, and finally we present our Review Protocol.

3.1.1 Motivation

Ontologies are an important part of semantic web. The advantages of using ontologies are vast, and include enabling the sharing of knowledge, the reuse of knowledge, and the better engineering of knowledge-based systems with respect to acquisition, verification, and maintenance. The phases of development and evaluation are very important to achieve consistency and usefully on ontologies.

Ontologies are used in many different areas and there are several theoretical approaches for ontologies developing and evaluating. Henceforward, this work intends to get information regarding about the methodologies and methods used to develop ontologies specifically in IT field and about the methods or methodologies used to evaluate those ontologies.

3.1.2 Research Questions

This search intends to achieve the main objectives of understanding the fields of IT that use ontologies and the most used methodologies for those ontologies development and evaluation. So, in order to achieve these objectives we formulated the following research questions (RQ):

RQ1. Which are the main areas of IT (or related/applicable) where ontologies are used?

RQ2. Which are the main methods/methodologies to **develop** ontologies in IT?

RQ3. Which are the main methods/methodologies to **evaluate** ontologies in IT?

3.1.3 Review Protocol

The Review Protocol starts by the literature search, with the definition of the search string, which was used to do the search across the chosen datasets in order to retrieve the maximum number of studies that may achieve answers to the proposed research questions. The search string used to perform the search and the chosen datasets are listed below.

Search String: “Information Technology Ontology” AND [(“Methods for” OR “Methodologies for”) AND (“Ontology Development” OR “Ontology Evaluation”)].

Datasets: Science@Direct[1], IEEE Digital Library[2], Scopus[3], Springer Link[4].

[1] https://www.sciencedirect.com
[2] https://ieeexplore.ieee.org/Xplore/home.jsp
[3] https://www.scopus.com/home.uri
[4] https://link.springer.com

Table 3.1: Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
IT, IT related or IT applicable Ontology	Not IT, IT related or IT applicable Ontology
Application of Ontologies Development	Theoretical approach of Ontologies Development
Application of Ontologies Evaluation	Theoretical approach of Ontologies Evaluation
Application of methodologies for Ontologies Development	Theoretical approach of methodologies for Ontologies Development
Application of methodologies for Ontologies Evaluation	Theoretical approach of methodologies for Ontologies Evaluation
Application of methodologies for Ontologies Development or Evaluation	Theoretical approach of methodologies for Ontologies Development or Evaluation

Then, one must apply inclusion and exclusion criteria in order to filter the obtained papers. Our criteria for inclusion and exclusion is presented in Table 3.1.

Afterwards, the first set of papers is obtained. Then the abstracts must be screened in order to decide their relevance to the research. Finally, these papers are read in order to obtain the final selection of studies to perform the review. The review protocol is illustrated in Figure 3.1.

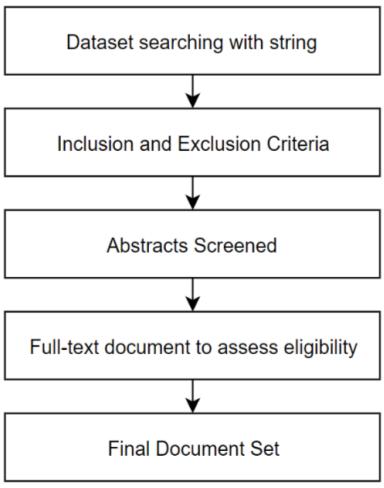

Figure 3.1: Review Protocol

3.2 Conducting

This Section concerns to the second phase of the SLR Methodology described in Section 1.1.2. We started by performing the search using the search query to the databases selected in the defined review protocol, and then we did the analysis to the extracted data.

3.2.1 Selection of Studies

After applying the search string in the datasets defined in the review protocol, 848 papers were found, and then, by excluding the duplicates and applying the inclusion and exclusion criteria to the title and abstract of each paper, 137 papers were selected.

Each one of the 137 papers was totally read, getting a total of 41 relevant studies for our research.

The Studies Selection, based on our inclusion/exclusion criteria, is represented in Figure 3.2.

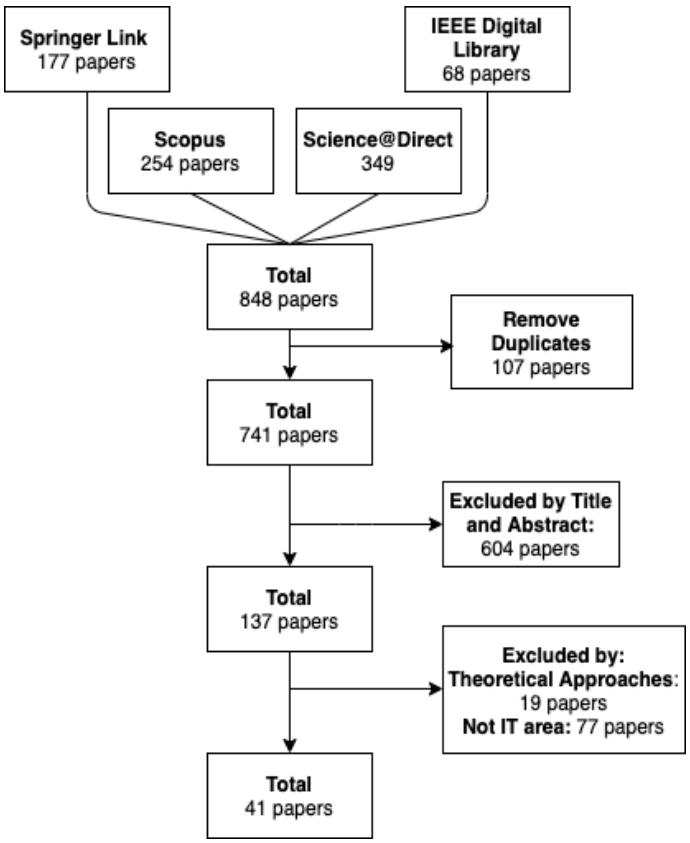

Figure 3.2: Studies Selection process.

3.2.2 Data Extraction Analysis

In this Section, we present the Data Extraction Analysis covering different parameters of the selected studies, such as their data sources, their distribution over the years and their type of publication.

As it is possible to notice in Figure 3.3, the majority of the selected papers was from Science@Direct, followed by IEEE Digital Library and, after that, Springer Link and Scopus with the same number of papers.

In Figure 3.4 it is possible to observe the distribution of the papers selected over the years and it was also possible to observe that 2018 is the year from which more papers were selected for this research.

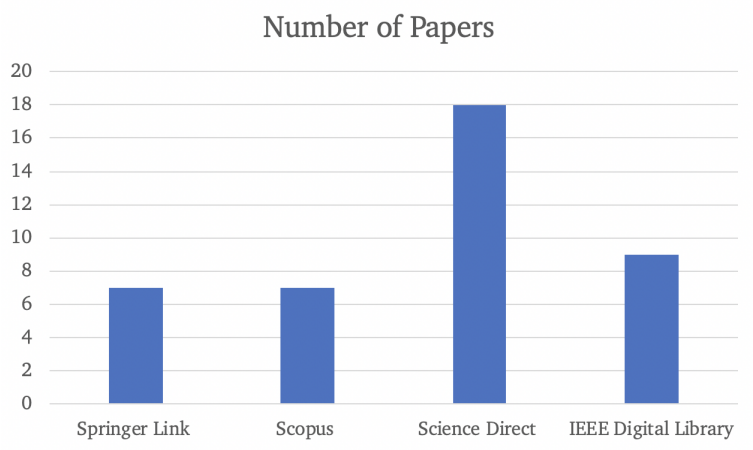

Figure 3.3: Data sources of the selected papers.

This might indicate that the ontologies are being more investigated and applied in the IT field.

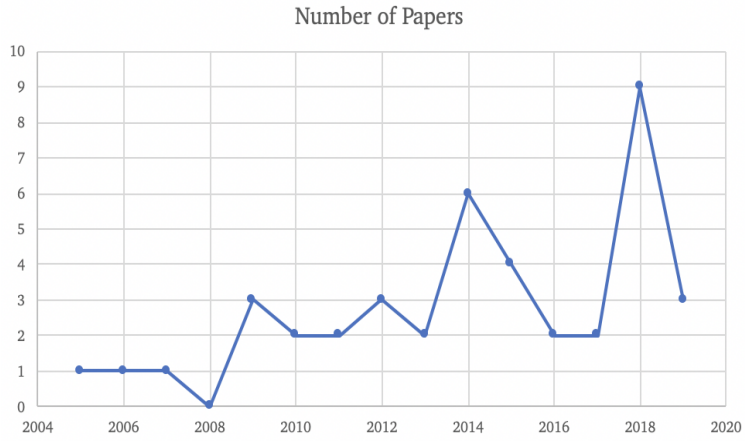

Figure 3.4: Distribution of the selected papers over the years.

The most common type of publication among selected papers is a Journal paper, around fifty five percent of papers. Papers from conferences (twenty four percent) and book chapters (twenty one percent) were also selected. This distribution is represented in Figure 3.5.

3.3 Reporting

This Section concerns to the last phase of the SLR. We divided the results of this work in three different topics: ontologies in IT, ontologies development and ontologies evaluation.

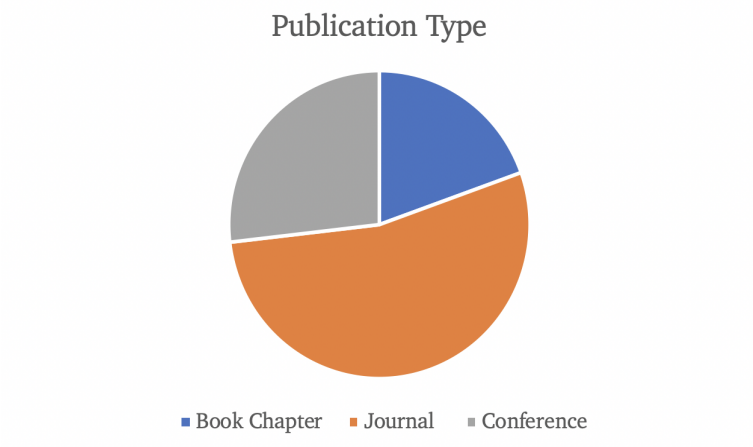

Figure 3.5: Publication Type of the selected papers.

3.3.1 Ontologies in Information Technology

With the increasing use of ontologies in computer science, several ontologies have been proposed for the IT area. In this Section we analyze some of those ontologies.

It is possible to perceive by the analysis of the documents, and as represented in Table A.1, that ontologies act in the main areas of Web Development, Software Development and Security, also having in areas such as Cloud Computing, Game Development, and Project Management.

As we can see, ontologies are widely used in web development. E-learning courses, for example, can benefit from the use of ontologies, since according to Panagiotopoulos et al. [46] "one of the most important tasks in the process of designing educational material for distance learning is the representation and modeling of the cognitive domain to which the material refers" and the ontologies have the capability of doing it, representing knowledge of certain domain of interest. The cases proposed by Yun et al. [47] and Lee et al. [48] are examples of application of ontologies in the learning field, to model ways of learning, using domain ontologies to represent, respectively, C Programming and Java Programming. The C Programming ontology, which is profitable for an E-learning course, will work like a "conceptual course-ware structure" that will work to streamline and facilitate teaching while it will allow students to define their ways in order to mentally organize the domain vision for learning C Programming. The Java Learning Object Ontology (JLOO) is a reusable and shareable ontology that works like a guide in e-learning environments and helps teachers to perform the best and more adequate schooling process.

Other examples of the applications of ontologies in Web Development are, for example, the case of the Dynanamic Ontology created for E-trading exposed by Anithakumari, et al. [49] or the work of Albarghothi et al. [50], which consists in the development of an approach to the Arabic ontology, for Dubai e-government customer services, in order to represent the information present Arabic Web pages in a more structured and easy way to analyse.

Software Engineering has the pretensions to “find higher abstraction levels and ways to reuse software” [51] as a way to improve performance and the and quality of programs. Ontologies can be a powerful tool in achieve this goal. We can note its applications in projects such as the ones proposed by Pakdeetrakulwong [25] and Pico-Valencia2019 et al. [52]. In [25] has been developed an ontology based on the Rational Unified Process (RUP). The development of this ontology was useful because, due to their inference capabilities (using reasoners), it allowed workers to access valuable software project information, to reuse software components and improving software development information retrieval “which is lacking in traditional software applications”.

In [52] proposed an ontology that describes the domain of HAC (Human-Agent Collectives) to achieve an shared understanding between heterogeneous HAC systems in order to allow their integration, these ontologies are also beneficial because they help make inferences that lead to recommending preventive and corrective control actions.

Since ontologies contain knowledge related to the particular domain they represent, they can transmit that knowledge and act as an aid to Decision Support engines. Currently, Decision Support Systems have successfully took advantage of the use of ontologies in some phases of their decision making [53]. There are some ontologies used to improve Decision Support Systems, like the case of the one proposed by Miah et al. [54] with EUEDE (End-User Enabled Design Environment) for dairy farm management which uses a problem ontology in the creation of specific decision systems, dependent on circumstances, to end-user factors or the one suggest by Delir Haghighi et al. [55] with the DO4MG (Domain Ontology for Mass Gatherings), which intends to resolve terminology inconsistencies and conflicts and to increase efficiency in communication between medical emergency personnel.

The e-community is concerned about the security of the web because since web applications assumed a strong presence in the quotidian of almost everybody, the threats to those have increased putting many organizations security in risk [56]. The ontologies in this field have been used for works such as defining the security domain, improving the detection of attacks and identifying types of attacks and vulnerabilities [57].

Some examples of those applications of ontologies in the security are the Ontology for Attack Detection from Razzaq et al. [56] that exhibited an ontology used to improve the detection of attacks on web applications, the Vulnerability Ontology from Shenbagam et al. [58], the Security Ontology proposed by Tsoumas et al. [59] and the Security Ontology for Security Requirements Elicitation from Souag et al. [60]. The Vulnerability Ontology uses inferences from the query of the user and predict, classify and suggest means of prevention for web application attacks. The Security Ontology for Security Requirements Elicitation regards an Ontology for Information Systems Security Requirements elicitation and analysis that intends to help requirements engineers to achieve a more effectively incidents report and to take advantage of re-usability of the information present in ontology about a certain domain.

Another field in IT that often uses ontologies is Project Management that takes advantage of features such as reusability and shared conceptualization and agreement to provides internal consistency. For example, Diamantini et al. [61] suggested an ontology, named TeamOnto, was used to represent project teams in collaborative KDD (Knowledge Discovery in Databases) domain. This ontology, in the domain of KDD projects, contemplates team capacities and computational resources in order to give the necessary information to the team while executing the project. In 2009, Sarantis et al. [62] created the electronic Government Transformation Project Management (eGTPM) ontology, which aims to achieve interoperability, shared agreement and understanding within the project stakeholders during the project management as well as reuse of knowledge; so the projects can be understood correctly and well executed.

Games have adopted a more and more present role in society in the lasts decades and started to use ontologies to their improvement. Like the Video Game Ontology (VGO) proposed by Parkkila et al. [63] which intends to enable the interoperability between different games. Through game modeling, using VGO, is possible to connect different games content and players allowing the creation of new and interesting players experiences.

In 2011, Tang et al. [64] developed an ontology for documenting serious Game design called Game Content Model (GCM). This ontology models the game design construction and provides game designers help to perform the design of computer games or document specification of game design formally.

We can observe from the results of research that the main characteristics that lead to the development of ontologies in the area of IT are their capability to organize/model knowledge, the ability to allow inferences, and the advantage of achieving an shared agreement that is essential for processes of integration.

3.3.2 Ontologies Development Methodologies

Although there are many proposed methodologies for the ontologies development as discussed, in the area of IT, according to the research carried out, few methodologies are used. It is possible to observe in Appendix A, according to the chosen documents, that the methodologies more used for ontology development were, Methontology, Ontology Development 101 and NeOn. Most of the papers have opted for combinations (mixes) between different methodologies, and a considerable number had proposed their own for the development of the ontology.

The Methontology is widely used in ontologies development due to “its domain-independent characteristics” [65] and because it is “the most well-known methodology for ontology development” [25]. According to our research, this methodology was chosen for projects as the development of an ontology for Rational Unified Process Software Development [25], the development of a Cloud SLA Ontology (CSLAOnto) [65], the development of an ontology for emergency notification systems accessibility

(SEMA4A) [66], the development urban density ontology used in a framework in order to eliminating data heterogeneity for urban analytics in the project of Chen et al. [67], the development of an ontology for design of active fall protection systems by Guo et al. [68] and the development of an ontology for Attack Detection within the security of a web application in the ontology proposed by Razzaq et al. [56].

The Ontology Development 101 [29] is a set of seven steps proposed by Noy and McGuiness for the development of an ontology, it is very used because it is "the best starting point" [64] for those that just started to develop ontologies. From our research this methodology was used for the development of projects like the development of an ontology for documenting serious game design in the work of Tang et al. [64], the development of ONT4HAC, which is an ontology for Human-Agent Collectives proposed by Pico-Valencia et al. [52] and the development of an ontology for the patent system to integrate information from the patent and court case domains by Taduri et al. [69].

The NeOn methodology, proposed by Goméz-Pérez et al. [31], is a very different methodology compared to the one previously presented because it not only provides the steps for developing the ontology but also includes a glossary, a group composed by nine scenarios, two ontology network life cycle models and, finally, different guidelines. This methodology was used, according to our research, in the work of Dibley et al. [70] with the development of an ontology framework for intelligent sensor-based building monitoring taking advantage of reusing existent resources, in the development of the Job-Know ontology [45] that represents and relates task and knowledge domains where the choice of scenarios was made according to the needs of the ontology and in the development of an ontology for a platform-as-a-service semantically interoperable marketplace [71] where was possible to reuse existing vocabularies/models.

In the development of RecOnto [72], an ontology to model recommender systems and its components, the methodology chosen was the one used for OntoAdapt development. This methodology is inspired in Ontology Development 101. It starts by identifying the feasibility of the study. After that, there are four more stages. First, the "Kick-off" where must be defined the domain and scope of the ontology as well as the competency questions and the important terms. In this phase is also studied the reuse of other ontologies. In the second stage, "Refinement", the information must be structured in an ontology structure. The third stage is the "Evaluation" of the ontology. And, at last, the "Maintenance" of the ontology.

It is interesting to notice that the majority of the papers opted for mixed methodologies for the ontologies development. The combination of different methodologies of ontology development usually combines one of the most used like Methontology, NeOn and Ontology Development 101 with another one. For example the cases of the work of Diamantini et al. [61] that applied a combination between Methontology and OTK Methodology using also quality requirements additionally and the work of Pereira et al. [73] that chose Ontology Development 101 is using it in an interesting way, conjugated with the

Design Science approach.

It is also possible to notice that different tools were used for ontology development in the selected papers, as it is represented in Figure 3.6. The most used tool for ontologies development present in our research is Protégé, which might be related to the fact that Protégé is the most common and well-known tool for ontologies development [50]. It also has reasoners and visualisation tools that might be useful in the ontology development and evaluation process.

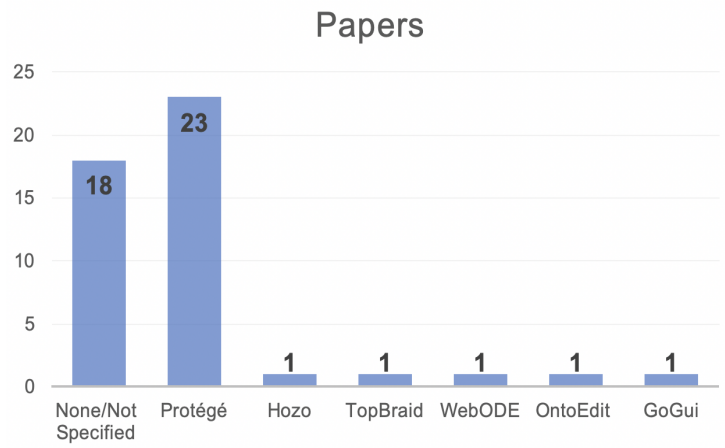

Figure 3.6: Tools used on ontologies development from the selected papers.

3.3.3 Ontologies Evaluation

There are several techniques and approaches for assessing the quality of ontologies. In this research, we found that in the different ontologies proposed in the chosen papers, the evaluation methods are quite different, not following a standard as it is possible to verify in Appendix B. It is also possible to notice that in the evaluation of several cases are used more than one evaluation techniques and around twenty-seven percent of the papers collected don't evaluate or don't specify the methodology used to evaluate the ontology developed.

One of the approaches which were verified to be more used is the "Application-based/ Task-based" evaluation. Around thirty seven percent of the papers analysed used this approach, testing the ontology developed by using it in an application or to perform tasks. Some examples of this are the evaluation of the projects of Delir Haghighi et al. [55], Da Silva Serapião Leal et al. [74] and Bassiliades et al. [71]. In the work of Delir Haghighi et al. [55] the ontology (DOGMA) was incorporated in a Decision Support System component in order to verify its work dealing with complexity and inconsistency of decisions in medical emergency management. In a different manner, the ontology proposed by Da Silva Serapião Leal et al. [74] developed is instantiated and applied for performing "interoperability assessment" in the ambit of a real case study based on an IT service provider in Luxembourg. The ontology PaaSPort [71]

is evaluated through its interaction with the recommendation and persistence layers.

The “Criteria-based” approach was applied to about nineteen percent of the papers selected from our research. This approach is applied using very different techniques because the evaluated criteria differ according to the authors. We can verify it, for example, between the evaluations performed by Leal et al. [74] and Delir Haghighi et al. [55] to evaluate criteria of each ontology developed. In the work of Souag et al. [60] the criteria chosen for evaluation was the Completeness (comparing to others ontologies), the Validity (using SWRL questions) and the Usability (performed with users), but in the one proposed by Delir Haghighi et al. [55] more criteria have been evaluated like Clarity, Consistency/Coherence, Conciseness, Expandability/Extendibility, Correctness, Completeness, Minimal Ontological Commitment and Coverage.

A technique which is very used, in around twenty percent of the papers, is the use of “Competency Questions”. This type of approach consists of elaborating a set of questions which the ontology be able to answer correctly. Projects of ontologies like the one exposed by Rao et al. [75] and the one exposed by Dibley et al. [70] are an example of this type of evaluation. The use of queries in evaluation of the ontologies is also a quite common practice which is evidenced in our papers. This queries, for example, SPARQL queries can be use applying query performance tests [71] or used as a “translation” of Competency Questions as way to check the Validity of the ontology [76].

About twenty percent of the authors appealed to the knowledge of experts in the domain to validate their ontologies. This kind of evaluation is useful because it allows to validate/evaluate the quality of the ontology content using the knowledge of the expert as benchmark. I can be performed in different ways as for example like asking experts for suggestions and advices [71] or “Expert assessment” approach proposed used in the work of Fathalla et al. [77].

OntoClean is methodology for “validating the ontological adequacy of taxonomic relationships” [77]. It is widely used when it comes to ontology evaluation. In our research, this methodology was performed, for example, in projects like the one elaborated by Shenbagam et al. [58] to remove inconsistency and incompleteness and used for verification and validation of the ontological model in the ontology of Razzaq et al. [56].

Around twenty-one percent of the papers used tools for helping in the evaluation process. The referred tools for ontologies development were:

- OntoCheck: is a plugin from Protégé that “checks certain properties of an active OWL ontology and allows for amendments in the areas of metadata analysis and naming convention” [78].
- W3C RDF/XML Validator: “is an online service for checking and visualizing your RDF documents” [79].
- Vapour: “is a linked Data Validator in the form of a scripting approach to debug content.” [79].

- OOPS! (OntOlogy Pitfall Scanner!): “is a tool for detecting pitfalls in ontologies and targeted at newcomers and domain experts unfamiliar with description logics and ontology implementation languages.” [80].

In the evaluation of the U ontology [81] it is used an interesting and different evaluation approach. This approach intends to analyse aspects as Vocabulary, Syntax, Structure, Semantics, Representation and Context. This methodology is different than the other because instead of the others that evaluate ontologies as a way to understand if the ontology is good, this one intends to know “if an ontology is bad, and if so, in which way”.

3.4 Lessons Learned

In this Section we summed up and analysed the relevant information extracted from our SLR.

Based on our selected papers, it was possible to notice that ontologies are widely used on IT, namely in the Web and Software development field, for example but there is a lack of ontologies for the area of recruitment/e-recruitment in IT or IT skills/competencies. The ontologies had revealed themselves useful for representing knowledge in web technologies, such as e-learning courses, for representing the domains of interest, organizing them and facilitating its understanding, both the functioning of the courses and their contents. In software engineering, ontologies are used as a benefit since they have the ability to allow and facilitate, with the help of reasoners, the reuse of software components, making software development more efficient. A very common use of ontologies in IT is in decision support engines, since they represent a certain domain, it is useful to use this knowledge to help in situations that can be premeditated or deduced. The ontologies are also used in IT fields such as security, project management and games development.

It is interesting to notice that about twenty percent of the papers opted for mixed methodologies, were they conjugate one of the most used methodologies (Methontology, Ontology Development 101 and NeOn) with another less used, to complement it. The most used methodologies for ontologies development are the Methontology, Ontology Development 101 and NeOn. One possible explanation of the wide use Methontology is that this methodology is the most documented one, the most well known methodology for ontologies development [25], and, according to the selected papers, is used in diverse fields of IT.

In about twenty percent of the papers, belonging mostly to the web area, the authors proposed their own methodology for the ontology development. The most of the methodologies for ontologies development proposed on the papers followed the general principles of the main methodologies already defined (Methontology, Ontology Development 101 and NeOn) and its complemented for other less known methodologies or slightly changed/adapted by the author.

The most used tool for ontologies development is Protégé. It should be noted that in the selected papers, many tools for the development of ontologies were not exposed. In addition to Protégé, five more tools were referenced, each one only once and without much detail. This much use of Protégé may be due to its ease of use and the possibility of using plugins that complement it and which it is possible to take advantage of.

One interesting aspect about the ontologies evaluation methodologies is that it is very common to be applied more than one type of evaluation for ontology. The most used way of evaluation ontologies was the Application/Task-based, because it works like the demonstration of the ontology utility in real world situations and contexts. Other methodologies quite used for ontologies evaluation are Criteria-based, Competency Questions and validation from the domain experts.

There were also mentioned some evaluation tools for ontologies. The most used ones were OntoCheck, a Protégé's plugin, and OOPS! (OntOlogy Pitfall Scanner!), a web-based tool for detecting potential pitfalls that could lead to modelling errors.

4

Research Problem

According to the DSR methodology, this Chapter corresponds to the "Identification of the Problem and Motivation" step.

Nowadays, with the digital transformation, IT is performing an important role in people's daily lives and as a consequence of this strong presence of IT, the demand of companies for professionals in this area has increased.

It was possible to understand that the process of recruitment of IT professionals is growing faster[1]. IT is a big area, full of different subareas, which require different skills and competences inside it and, due to that, it is not simple to find the right person for the right job [82]. The professionals of IT have a lot of different profiles and do not fit in every role, so this recruitment process needs to be performed very carefully, paying attention and assessing the different skills that the person has. It is important to understand the skills prerequisites of job to find the right candidate to execute it and improve job performance [45].

In many different companies, the old recruitment techniques cannot totally satisfy this need anymore, so a lot of companies started to adhere to new ones, such as e-recruitment. E-recruitment process intends to find the match between the professional talents and the jobs in a faster and more efficiently way comparing to the one performed by human experts by hand. To allow this kind of applications of e-recruitment to work with its full potential and efficiency, is needed to incorporate the knowledge of the experts in the systems in way to make it scalable and currently there is no standard for conceptualize and categorize the skills of the professionals in IT field in order to achieve make possible to transmit the knowledge of the human experts to the systems.

With the absence of a way of organize and categorize the skills in IT, the e-recruitment is time consuming and less efficient, leading sometimes to unsuccessful hirings due to incompatibilities of the professional with the role to perform or the company itself (for example constraints of location, language or internal environment). Not having an hierarchical and well-defined structure for IT Skills the specification, search and match between the right job and the right candidate do not "acquire satisfactory search results" [16].

In the particular case of this project, which was conducted in a professional environment - in a company that provides a candidate-driven tech career marketplace, it was possible to notice that there are some phases of the recruitment process that are conducted by people that are not IT professionals. These professionals do not have the same knowledge and insights as the IT professionals about the IT skills domain, reinforcing the need for having structured information about the skills used in the different the IT fields.

So, in summary, we can conclude that the problem for this research is that **there is a lack of a coherent and comprehensive approach for conceptualizing, categorizing and relating skills of**

[1] https://economics.ubc.ca/news/2018/the-future-of-jobs-is-in-i-t-ubc-economist-studies-rise-of-information-technology/#.XgVWvNb7RQI

the professionals in IT field, namely in IT recruitment, **that helps matching the right candidate to the right job**.

5

Development

Contents

5.1 Overview

This chapter describes the objectives of the solution and explain in detail our proposal.

5.1.1 Objectives

The main objectives related to the creation of the IT skills ontology is to help the recruitment process, facilitating the correspondence between a candidate and a company being able to be used in different scenarios across the process.

5.1.2 Description

In this research we proposed to develop an ontology for IT skills. As we noticed, from the previously made research (Chapter 2), there are just a few approaches that propose an ontology for IT skills. Also, these approaches are outdated and have lack important concepts.

In order to develop the proposed ontology we partially followed the Methontology approach. The choice of this development methodology was made because it is one of the most "well-known" [25] methodologies for ontology development, it is compatible with the use of Protegé tool [3] and, as it was concluded in our SLR (Chapter 3), it is widely used in IT area.

According to the Methontology [24], before we start performing the development itself, it should be performed a "Planification" activity. One should define which tasks should be performed, how they should be executed, and which are the resources required to perform such tasks. Therefore we identified the main following tasks for our ontology development:

- Find the main areas of work in IT and skills of IT;
- Find definitions for the founded concepts;
- Relate the concepts between each other.

In order to create and develop our proposed ontologies, we chose the Protégé tool since it is. Moreover, according to Corcho et al. [3], it allows us to follow the Methontology methodology.

The ontology development activities following Methontology, described in Chapter 2.2, are presented in Figure 5.1.

The "Specification" activity is about defining the reasons why the ontology is being built, which is, in this case, to solve the problem relate in Chapter 4.

The "Conceptualization" activity intends to find the majority of the concepts and information about the IT skills domain, constructing a conceptual model. In our development we did not perform the "Formalization" activity, which is not mandatory, because we used Protégé to carry out the "Implementation"

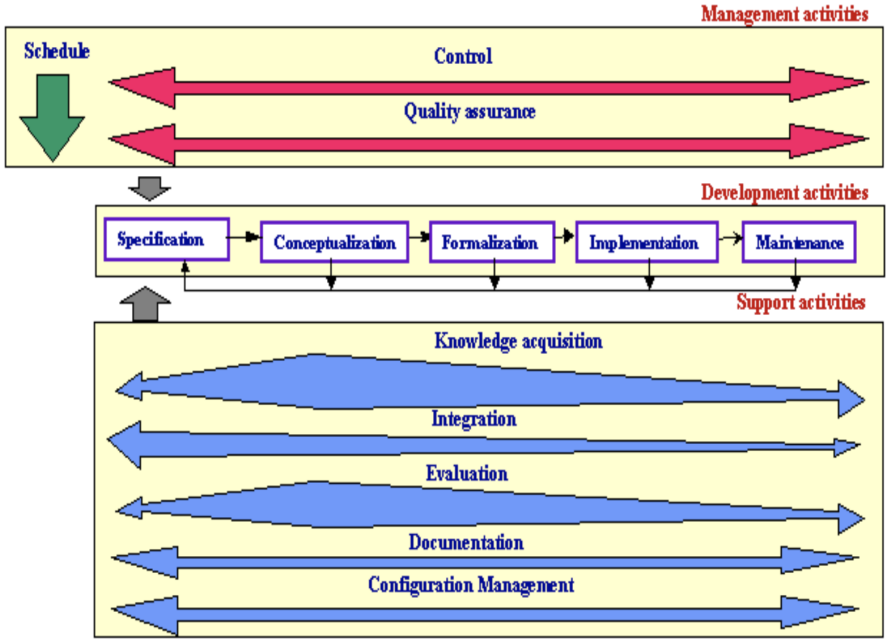

Figure 5.1: Activities in the ontology development proposed by Methontology [3].

activity, so it allowed us to automatically implement the conceptual model developed, in OWL (Ontology Web Language).

As represented in Figure 5.1, the "Management" and "Support" were be implemented in parallel to the whole development process. Throughout the ontology development process, feedback was requested from experts in the field as a way of providing guidelines and allowing us to evaluate the concepts and relationships that were being established.

5.2 Specification

The "Specification" activity has the purpose of defining the reason why the ontology is being built and the problem it intends to solve. As it was exposed in Chapter 4, the problem of this research is the **lack of a coherent and comprehensive approach for conceptualizing, categorizing and relating skills of the professionals in IT field**, which causes difficulties in recruitment processes and on job/candidate matching.

In this research we develop an ontology for IT skills that is used to help in recruitment processes. It was decided that only technical skills, regarding IT Development, such as programming languages (Java, Ruby, etc.), software tools (PostegreSQL, MongoDB, etc.), frameworks (Ruby on Rails, React.js, etc.) and libraries (SciPy, NumPy, etc.) would be considered in this ontology and, consequently, the jobs in which technical skills are decisive. Although soft skills are also relevant to the standardization of jobs

and profiles of IT professionals, these were out of the scope of this research since they are much more subjective.

5.3 Conceptualization

"Conceptualization" aims to acquire knowledge, so it was in this activity that we found the majority of the concepts and information on the IT Skills domain, building, according to this collected knowledge, a conceptual model. Conceptualization activity, from Methontology, is divided in eleven activities, as represented in Table 5.1.

Table 5.1: Conceptualization activities adapted from [3]

Task	Description
Task 1	Build glossary of terms
Task 2	Build concept taxonomies
Task 3	Build ad hoc binary relations diagrams
Task 4	Build concept dictionary
Task 5	Describe ad hoc relations
Task 6	Describe instances attributes
Task 7	Describe class attributes
Task 8	Describe constants
Task 9	Describe formal axioms
Task 10	Describe rules
Task 11	Describe instances

In the first task, we developed a glossary containing all the relevant terms for the IT Skills Ontology with the respective Type and Description. Most of the skills were extracted from the IT recruiting company's database and complemented with the main terms founded on the leading e-recruitment websites, as represented in Figure 5.2.

In order to guarantee the consistency of the extracted skills, we only added to the glossary those that, being technical skills, fulfill all the requirements of the PES approach [37]. An excerpt of our glossary of terms is represented on Table 5.2.

After the glossary of terms is concluded we build, we should create, as stated on the second Task, the concept taxonomies obtaining a concept hierarchy. We decided to divide the concepts in two main categories:

- IT Skills - abilities, knowledge and talents regarding to the use, development, architecture and management of technology.
- IT Job Areas - main job areas in the IT field.

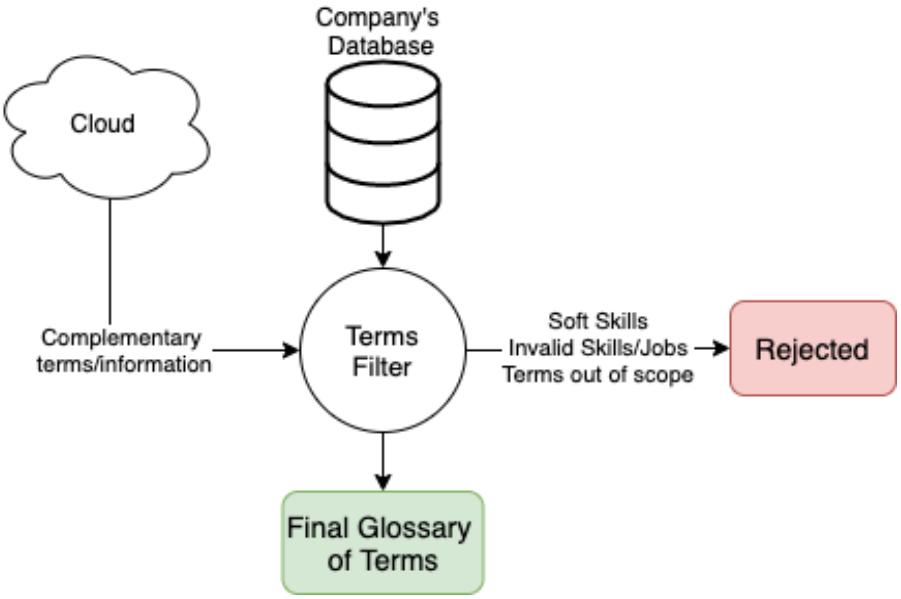

Figure 5.2: Terms extraction and filtering.

Table 5.2: A sample of the glossary of terms of the IT Skills ontology.

Term name	Description	Type
IT Development	IT Development is the job of building and creating software and applications, including writing, debugging and executing software.	Concept
Fronted Development	Frontend Development is the job of developing the front end of a website, which is the part that users interact with	Concept
Data Engineering	Data Engineering is the job of transforming the data into a useful format for analysis.	Concept
version	The version of a certain Programming Language, Framework, Library, or Engine instance.	Instance Attribute
Libraries	A Library is a collection of implementations of behavior, written in a certain Programming Language, that has a well-defined interface by which the behavior is invoked.	Concept
Programming Languages	A Programming Language is a formal language, which comprises a set of instructions for a computer that produce various kinds of output.	Concept
Frameworks	A Framework is a collection of Libraries and Tools, written in a certain Programming Language, in support of writing a particular class of applications.	Concept

The IT Skills concept is divided in Engines, Programming Languages, Libraries, Frameworks and Work Methodologies and its taxonomy is represented in Figure 5.3.

The IT Job Areas concept is divided on IT Design, IT Development and IT Infrastructure, as represented in Figure 5.4. This work was focused on the IT Development field.

In the third task we expose the relations between the different concepts. The relations between the different job areas of IT Development and the different types IT Skills are represented in Figure 5.5. The different relations between the IT skills themselves are represented in Figure 5.6.

The fourth task, consists in developing a dictionary of concepts, which describes the terms of the IT Skills ontology from the glossary of terms, containing all the domain concepts, their relations, their

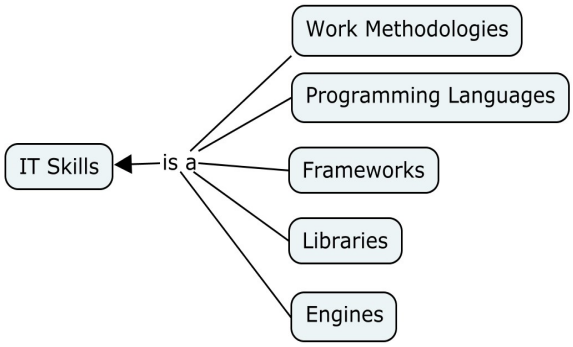

Figure 5.3: Taxonomy of IT Skills.

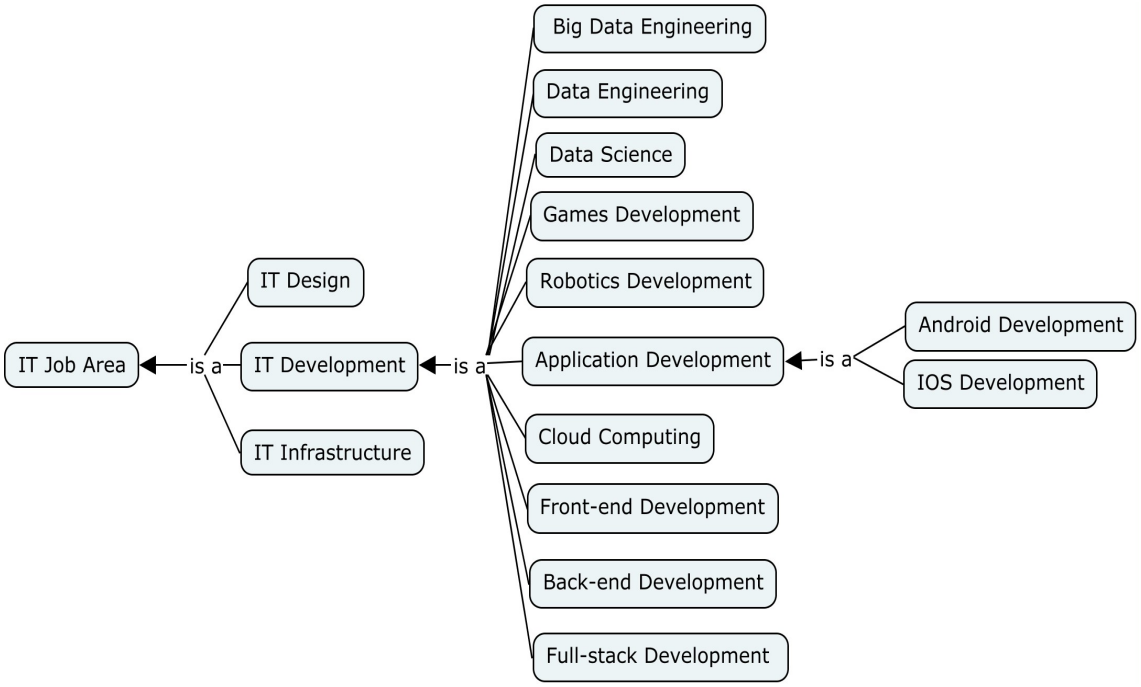

Figure 5.4: Taxonomy of IT Job Areas.

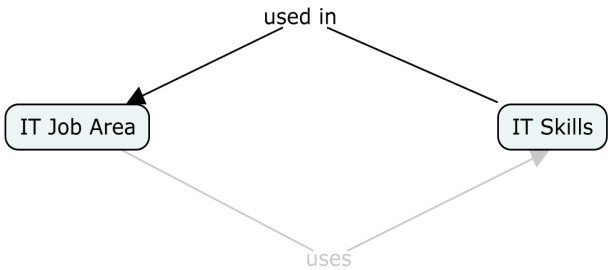

Figure 5.5: Relations between IT Development and IT Skills.

instances, and their class and instance attributes. This activity was performed with the help of the Protégé ontology editor.

The Table 5.3 concerns the fifth task of the Conceptualization phase, describing the ad hoc relations

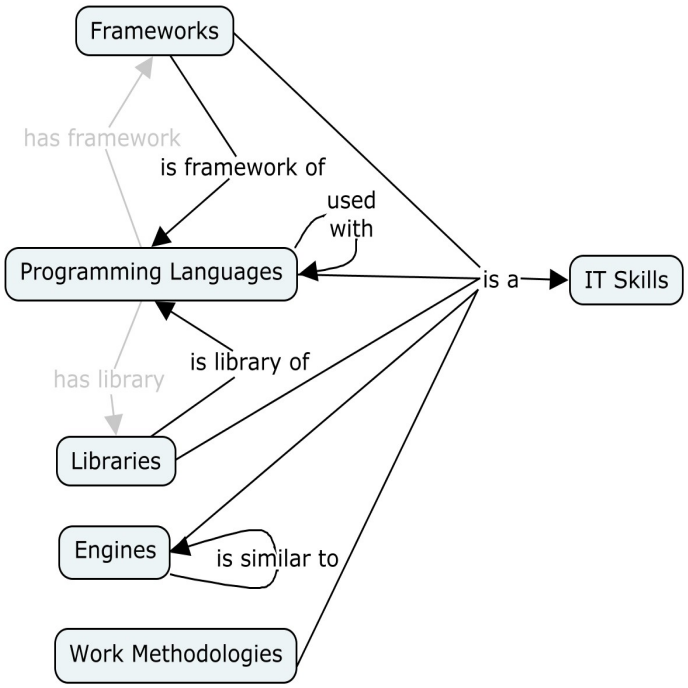

Figure 5.6: Relations between the IT Skills.

of the ontology. For each ad hoc binary relation, its name, the source and target concepts, its cardinality, and its inverse relation is specified.

Table 5.3: Description of ad hoc relations of the IT Skills Ontology.

Relation Name	Source Concept	Source Cardinality	Target Concept	Inverse Relation
is framework of	Frameworks	N	Programming Languages	has framework
has framework	Programming Languages	N	Frameworks	is framework of
is library of	Libraries	N	Programming Languages	has library
has library	Programming Languages	N	Libraries	is library of
used with	Programming Languages	N	Programming Languages	used with
similar to	Engines	N	Engines	similar to
uses	IT Development	N	IT Skills	used in
used in	IT Skills	N	IT Development	uses

The relations of Specialization are represented by superclasses. For example, Frontend Development is a particular kind of IT Development, so the IT Development is the superclass of Frontend Development.

The relations regarding the uses of IT Skills by IT Developers, like using a certain framework, library, engine or programming language, work as Used By relationships, once it represents the use of the different types of skills by the different IT professional roles.

The relations of being a framework/library of a certain programming language work as Serving relationships because they represent the ability of that an element provides its functionality to another

element.

The “Used with” relations, between two programming languages, is used as an Influence relationship, it represents that an element affects the implementation of another element. The “similar to” relation works as an Association relationship, and it means that a certain Engine/tool have the same or similar functionalities that another one.

In the sixth task, the instance attributes already on the concept dictionary are described in detail in an attribute table. Table 5.4 shows an excerpt of the instance attribute table of the IT Skills ontology.

Table 5.4: Description of the instance attributes.

Instance Attribute Name	Concept Name	Value Type	Value Range	Cardinality
Name	IT Skills	String	–	(1,1)
Version	IT Skills	Integer	1...	(1, 1)
Experience	IT Jobs	Integer	1...	(1, 1)

The seventh and eighth tasks were not performed since they are not applicable in the scope of the IT Skills ontology as class attributes or constants were not used.

In the ninth task, the formal axioms are described with properties such as name, natural language description, the first-order-logic expression of the axiom, and other components that axiom refers to. In IT Skills ontology, this axioms were described with Protégé tool. For example, the axioms for disjoint classes of programming languages, represented as shown in Figure 5.7, or the equivalent class axioms represented in Figure 5.8.

```
<owl:Class rdf:about="http://www.semanticweb.org/beatriztoscano/
ontologies/2019/9/untitled-ontology-20#JavaScript">
    <rdfs:subClassOf rdf:resource="http://www.semanticweb.org/beatriztoscano/
    ontologies/2019/9/untitled-ontology-20#Programming_Languages"/>
    </rdfs:subClassOf>
    <owl:disjointWith rdf:resource="http://www.semanticweb.org/beatriztoscano/
    ontologies/2019/9/untitled-ontology-20#Julia"/>
    <owl:disjointWith rdf:resource="http://www.semanticweb.org/beatriztoscano/
    ontologies/2019/9/untitled-ontology-20#Karel"/>
    <owl:disjointWith rdf:resource="http://www.semanticweb.org/beatriztoscano/
    ontologies/2019/9/untitled-ontology-20#Kotlin"/>
                        ...
    <owl:disjointWith rdf:resource="http://www.semanticweb.org/beatriztoscano/
    ontologies/2019/9/untitled-ontology-20#C++"/>
    <owl:disjointWith rdf:resource="http://www.semanticweb.org/beatriztoscano/
    ontologies/2019/9/untitled-ontology-20#Embedded_C++"/>
</owl:Class>
```

Figure 5.7: Excerpt of the JavaScript’s disjoint classes.

```
<owl:Class rdf:about="http://www.semanticweb.org/beatriztoscano/ontologies/2019/9/untitled-ontology-20#Backend">
    <owl:equivalentClass>
        <owl:Class>
            <owl:intersectionOf rdf:parseType="Collection">
                <rdf:Description rdf:about="http://www.semanticweb.org/beatriztoscano/
                ontologies/2019/9/untitled-ontology-20#IT_Development"/>
                <owl:Restriction>
                    <owl:onProperty rdf:resource="http://www.semanticweb.org/beatriztoscano/
                    ontologies/2019/9/untitled-ontology-20#uses"/>
                    <owl:someValuesFrom>
                        <owl:Class>
                            <owl:intersectionOf rdf:parseType="Collection">
                                <rdf:Description rdf:about="http://www.semanticweb.org/beatriztoscano/
                                ontologies/2019/9/untitled-ontology-20#IT_Skills"/>
                                <owl:Restriction>
                                    <owl:onProperty rdf:resource="http://www.semanticweb.org/beatriztoscano/
                                    ontologies/2019/9/untitled-ontology-20#isFromArea"/>
                                    <owl:someValuesFrom rdf:resource="http://www.semanticweb.org/beatriztoscano/
                                    ontologies/2019/9/untitled-ontology-20#Backend"/>
                                </owl:Restriction>
                            </owl:intersectionOf>
                        </owl:Class>
                    </owl:someValuesFrom>
                </owl:Restriction>
            </owl:intersectionOf>
        </owl:Class>
    </owl:equivalentClass>
</owl:Class>
```

Figure 5.8: Backend's equivalent class axioms.

The tenth task is about describing rules. This task was performed using the Protégé tool, which allow us to define the logical rules to be applied over the ontology. The defined rules tend to classify and take advantage of the use of inference in the ontology, working together with a reasoner. When running the reasoner, the rules and ontology are "compiled" in order to classify and infer according to what has been defined. Figure 5.9 is an example of two inference rules, the first one infers that if a Candidate uses a certain Framework, then he also uses the skill to which the framework belongs and the second rule one classifies as Android Developer any Candidate that uses both Kotlin and Java.

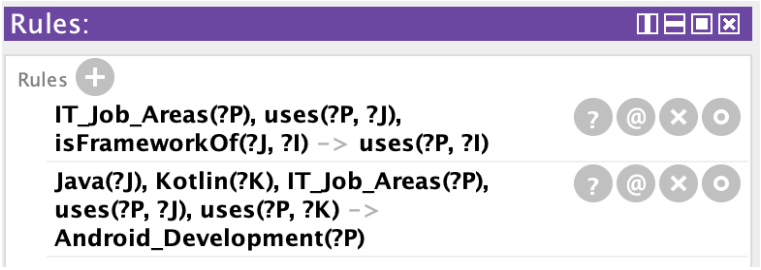

Figure 5.9: Example of inference rules.

To verify the application of the defined inference rule we ran the Pellet reasoner on the Protégé Tool. It was possible to notice that the "Android Developer" category, in yellow, was associated to Candidate X (Figure 5.11), since he uses both Kotlin and Java, and the use of the JS (JavaScript) skill was also associated since React (React.js) is a framework of JS (JavaScript). Figure 5.10 presents the Candidate X instance before the reasoner execution and Figure 5.11 presents the Candidate X instance after the reasoner execution.

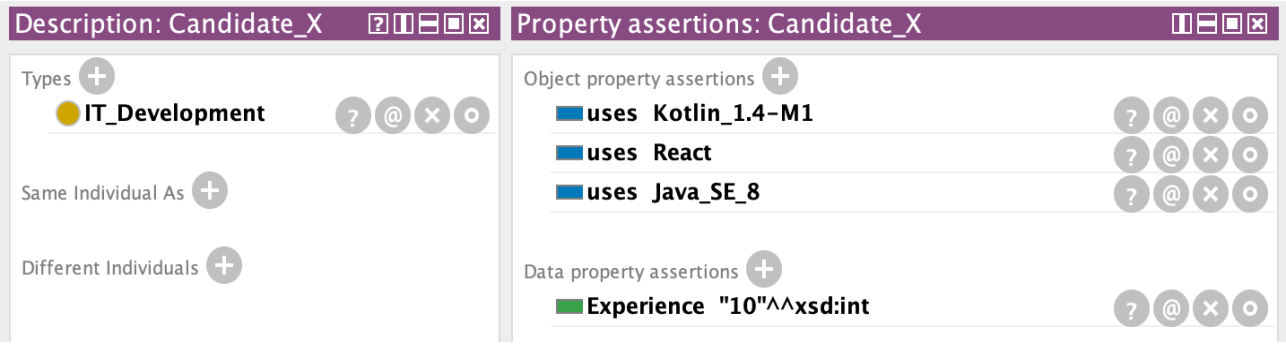

Figure 5.10: Example of the Candidate X instance before the reasoner's execution.

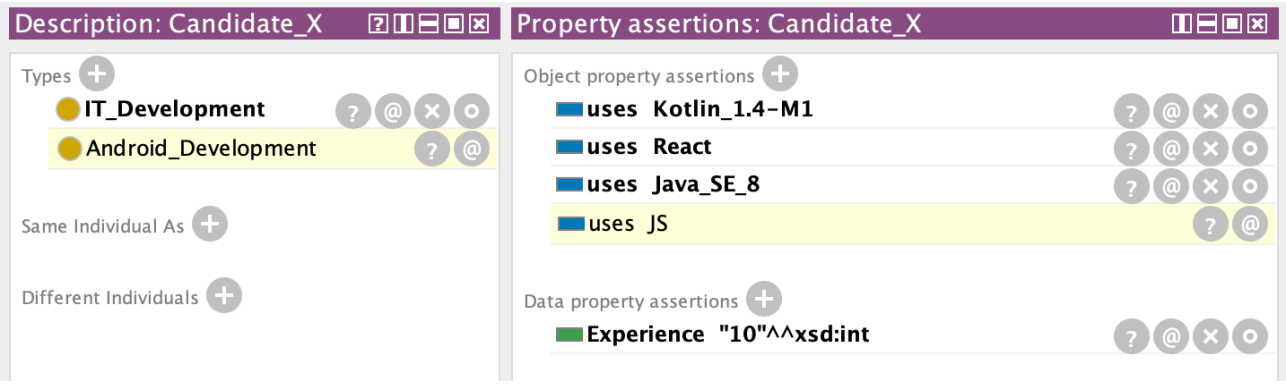

Figure 5.11: Example of the Candidate X instance after the reasoner's execution.

Once the all the concepts, attributes, and relations are established we can defined the relevant instances (eleventh task). Table 5.5 is an example of instances of the IT Skills Ontology containing its name, the name of the concept it belongs to, and, if it is applicable, its attribute values.

Table 5.5: Description of the instance.

Instance Name	Concept Name	Attribute	Value
Java SE 8	Java	Version	8
Java SE 13	Java	Version	13
JS	JavaScript	Version	4
css	CSS	Version	2
Html	HTMLs	Version	3
React	React.js	Version	6

It is important to notice that in our development we did not perform the "Formalization" and the "Implementation" activities, once Protégé allowed us to automatically implement the conceptual model developed, in OWL (Ontology Web Language).

At the end of the execution of all these development steps proposed by Methontology we obtained the final IT Skills Ontology (presented in Figure 5.12).

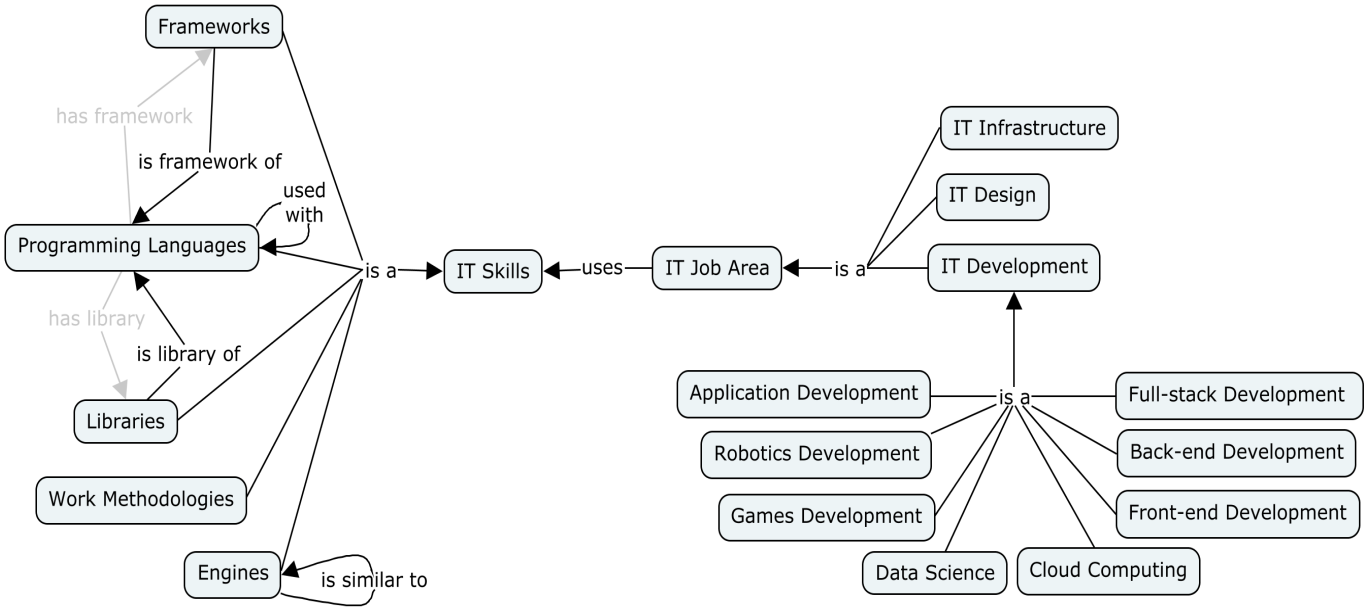

Figure 5.12: IT Skills Ontology's high level model.

6

Demonstration

Contents

This Chapter concerns the fourth phase/step of the DSR methodology. Therefore, we demonstrated the usability of the IT Skills Ontology in a specific context of the recruitment process, the curation process. It is used as a suggestion engine that provides help to users/Talent Advocate Specialists in order to enrich the knowledge in the skills domain, transmitting information and connections about the different skills presented when comparing particular candidate-job pairs.

6.1 Context

This master's thesis was applied in a professional environment, integrated in a company that is dedicated to matching the best tech professionals to the right companies all around Europe.

In order to provide a better understanding of the context in which the proposed ontology is going to be applied, Figure 6.1 tries to represent the current recruitment flow.

Through the company's online recruitment platform, the potential candidates are able to search the different jobs available and choose to apply for those jobs that match their interests. The recruitment process begins when a candidate applies for a certain job. These applications are then sent to specialists in order to be curated by the company's talent specialists. However, is always up to the employer to select the applications he wants to analyze, and among these he chooses the candidates he wants to reject and the ones he wants to hire.

To demonstrate the application of the developed ontology on the recruitment process, we had several possible scenario options:

- Apply the IT skills ontology to improve the search engine of jobs;
- Apply the IT skills ontology to improve the search engine of candidates;
- Apply the IT skills ontology to the candidate sign up/update providing skills suggestion;
- Apply the IT skills ontology to the candidate profile validation;
- Apply the IT skills ontology to provide smarter market insights based on the most wanted/used skills in the different areas;
- Apply the IT skills ontology to the posting jobs providing skills suggestion;
- Apply the IT skills ontology to the posting jobs validation;
- Apply the IT skills ontology to improve the search engine of candidates;
- Apply the IT skills ontology to improve the curation process.

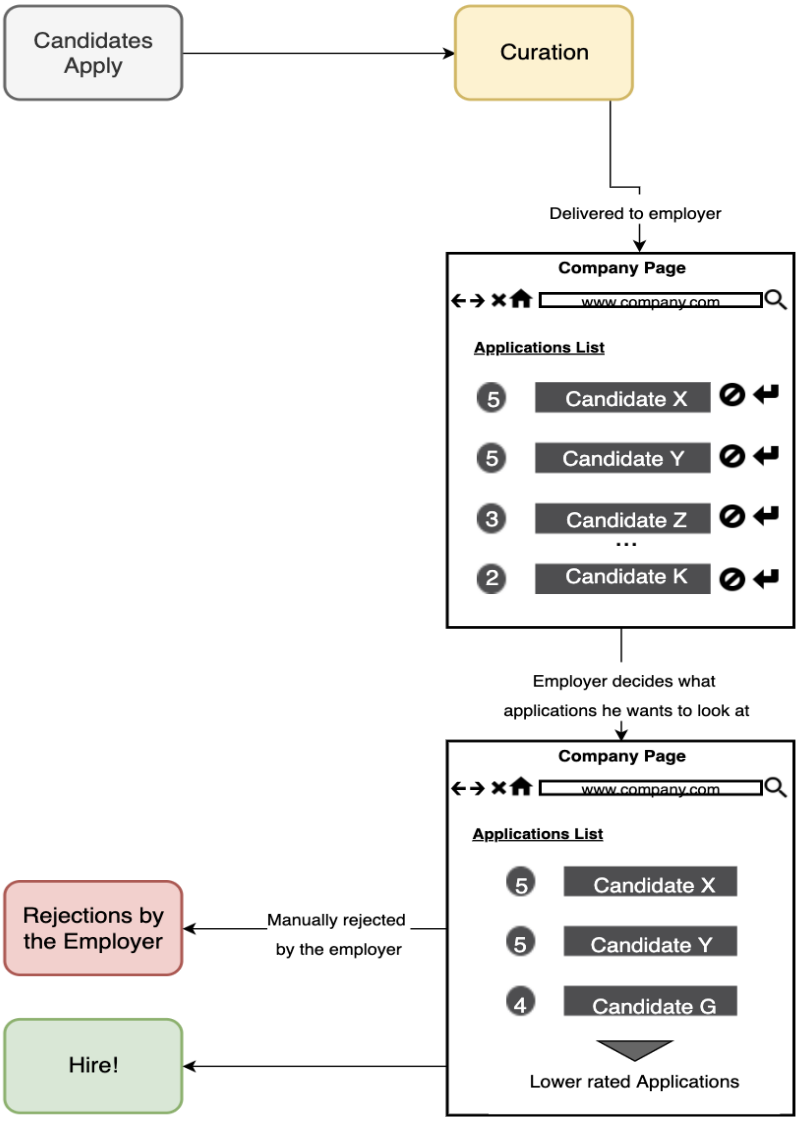

Figure 6.1: Company recruitment process.

Due to time constraints, we decided to apply the ontology to the curation scenario since this is the one that provides more value to the company.

Curation is an initial pre-screening process that ranks and creates an abstract for applications. It takes place before the application is delivered to the employer and is manually performed by a curator that has the help of some pre-defined algorithms for the different dimensions. The outcome is not a badge of fit or to make upfront rejections. It is just a way to help employers streamline the hiring process.

Ranking applications with the overall rate of 1-5 should only be interpreted as a suggestion to employers: start reviewing the 5-star applications and leave the 1 star for last. As said, the candidates are

evaluated according to different dimensions.

Multidimensional Curation merely breaks the overall rate into several dimensions of evaluation and rates them independently. Another goal is to standardize, providing the curators with a better way to maintain the consistency in their work.

One problem that the curation faces is the fact that the information is not always accurate since, sometimes, it varies from source to source, and do not follow a certain standard. Also, when filling the skills field, the candidate sometimes does not introduce all the skills that are aware of (more often, the more common skills such as Windows or Linux are neglected). Therefore, it is sometimes very difficult to provide a match score between the application of the candidate and job position.

Finally, and since this field is constantly evolving, a new set of IT skills (frameworks, libraries, tools, programming languages, etc.) surges almost every day, making the curation of the application very difficult. In that way, some mistakes happen because the specialist may not be able to match a skill that is present in the profile of the candidate and in the job requirements since in spite of being the same, they are presented in very different manners.

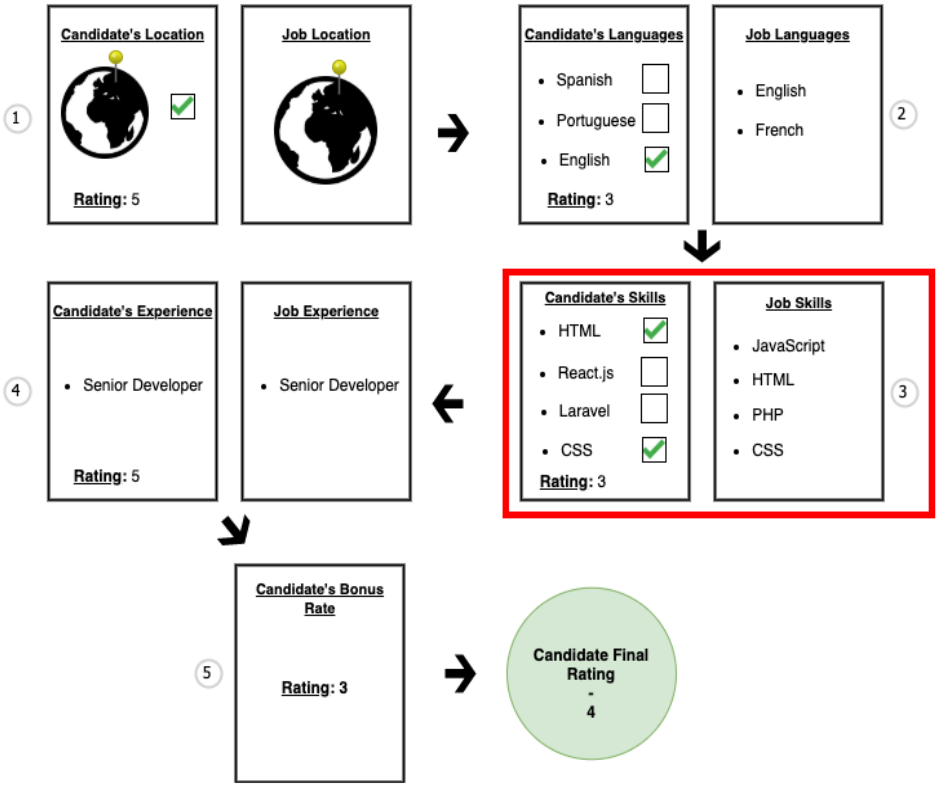

Figure 6.2: Curation process, including the dimensions: Location (1), Language (2), Skills (3), Experience (4) and Bonus (5).

To apply our ontology with the enterprise platform, we exported the ontology in order to make its

data available to be consulted on MongoDB platform, which is an object-oriented, simple, dynamic, and scalable NoSQL database, as represented in the Figure 6.3.

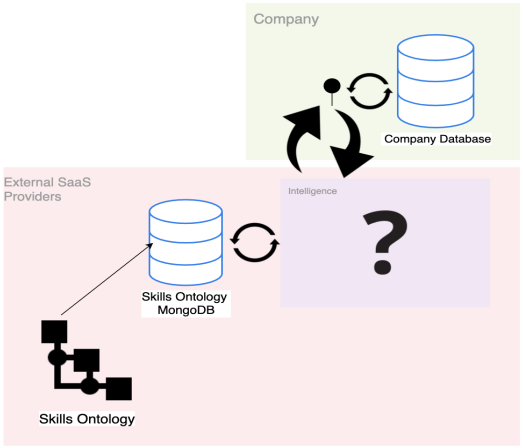

Figure 6.3: Application of the Ontology on the company platform.

6.2 IT Skills Ontology Application

To demonstrate the use of ontology we applied it to the curation process. The application of ontology in the curation process consists on a field, called “Skills Report”, on the platform used by Talent Advocate Specialists to assess the combination of a job and a candidate. This “Skills Report” field consists of a suggestion engine that transmits information about the relationships, direct or indirect, between the skills required in the jobs and the skills of the candidates. Some examples of the “Skills Report” in the curation process application are presented in Figures 6.4, 6.5 and 6.6.

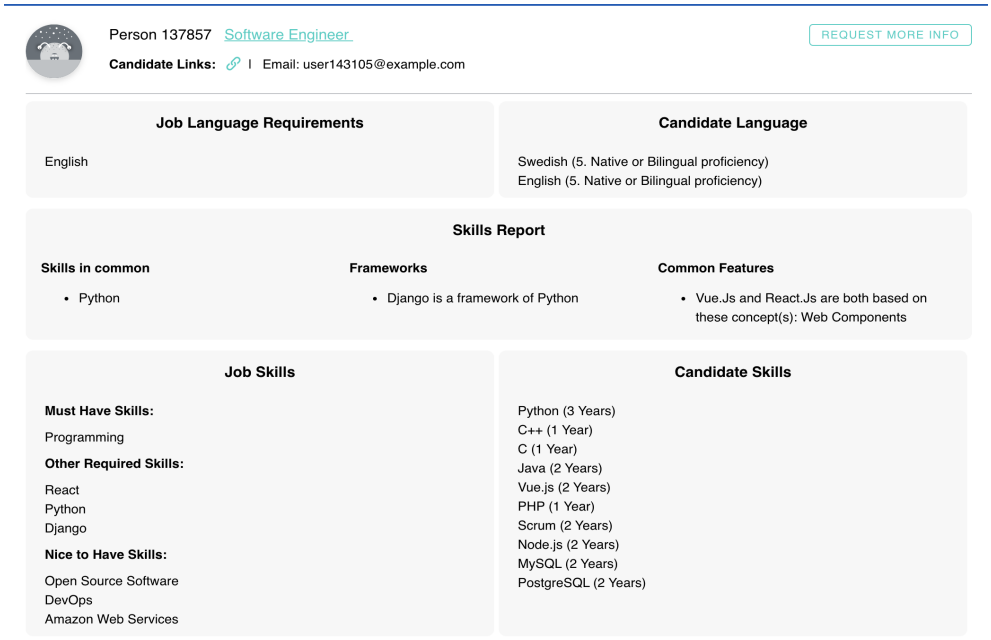

Figure 6.4: Skills Report example.

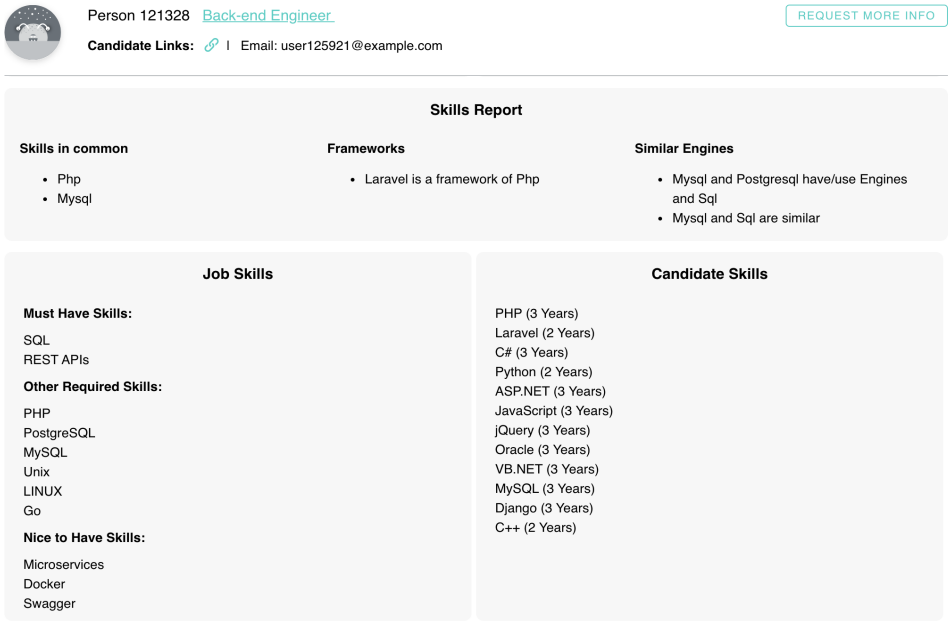

Figure 6.5: Skills Report example.

The demonstration of the use of the ontology in a given context can be considered an “early evaluation activity” [7] by “illustrating that the artifact works in practice”, achieving its Goal. It provides the validation that the artifact fulfills its objective, working correctly. The Skills Report is being used in a real context, being displayed on the platform used by the Talent Advocate Specialists to perform their work.

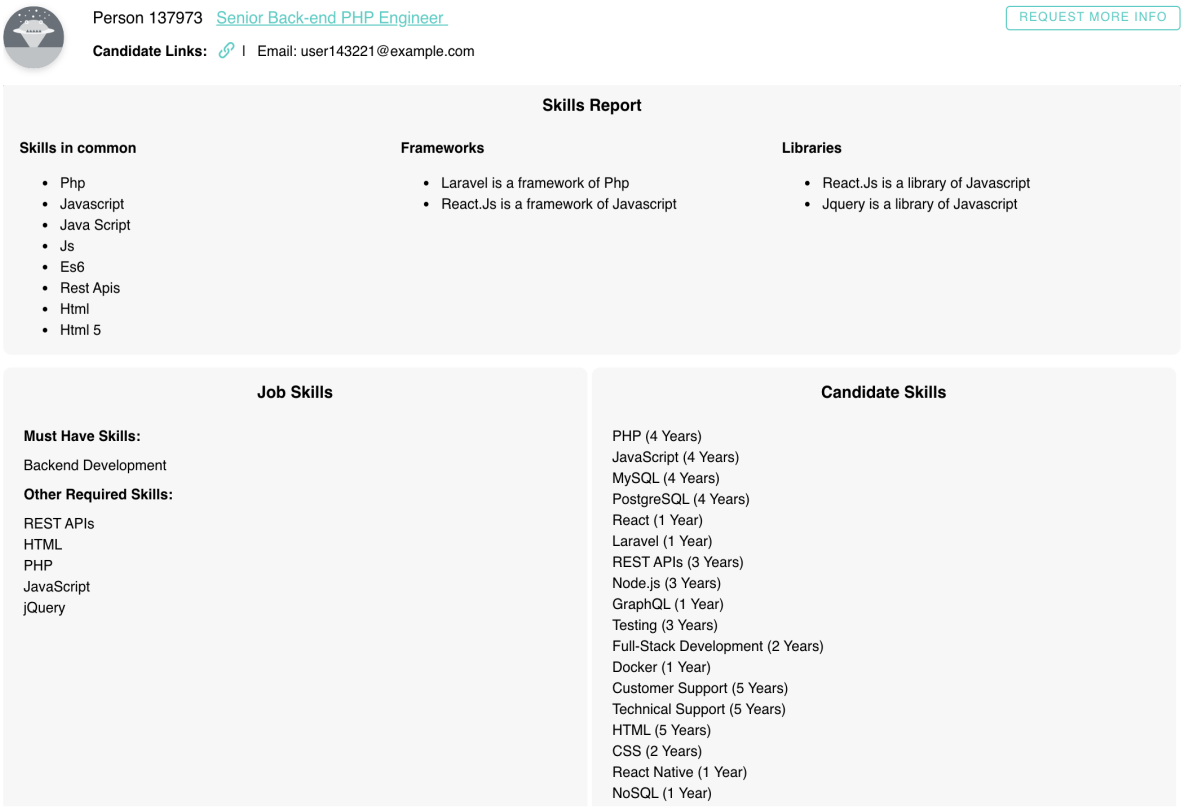

Figure 6.6: Skills Report example.

7

Evaluation

Contents

This Chapter corresponds to the evaluation phase of DSR methodology and presents the three approaches used to evaluate the IT Skills Ontology.

According to Pries-Heje et al. [4], the evaluation of an Information System artifact, as represented at Figure 7.1, can be performed before the artifact construction, called “ex ante” perspective, or after the construction of the artifact, named “ex post” perspective.

This evaluation can be classified in two distinct forms: naturalistic or artificial. The naturalistic approach consists in evaluating thee artifact in a real-life environment and the artificial approach is about laboratory experiments, field experiments, simulations, criteria-based analysis, theoretical arguments, and mathematical proofs.

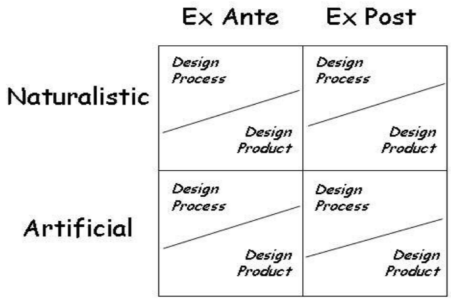

Figure 7.1: Strategic DSR evaluation framework from [4]

As it is presented in Figure 7.2, in our work we performed three approaches for evaluation:

- **Competency Questions** - by applying this approach, we developed a set of questions that our artifact must be able to answer correctly. This evaluation also works as a way to check the artifact validity.
- **Experts Evaluation** - in this approach, we made a questionnaire to Experts in the IT field using their opinion to evaluate the IT Skills ontology.
- **Talent Advocate Specialists Interviews/task-based Evaluation** - in this approach, we applied ontology to the curation process, as done in the demonstration, and we evaluated the artifact based on the users’ experience through interviews.

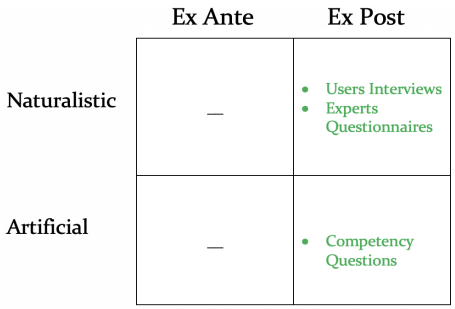

Figure 7.2: Our approach for artifact evaluation adapted from [4].

7.1 Competency Questions Evaluation

Competency Questions (CQ) are, as demonstrated by the SLR previously executed a very common type of ontology evaluation because they work as the validation that the ontology meets its requirements.

The ontology must have enough relations and axioms to be able to answer the competency questions. After developing the ontology, a set of eleven CQ was applied to the ontology. The CQ and their answers are represented in Table 7.1.

Table 7.1: Competency questions answered by the IT Skills Ontology.

	Competency Question	**Answer**	**Correct?**
CQ1	*Which are the engines used by Frontend developers?*	Akka, Altera, Blockchain Testnet, Chrome Devtools, Codepen, Coldfusion, Creative Tim, Drupal, ... , Workbox	Yes
CQ2	*Which are the programming languages used by Frontend developers?*	Cobol, CSS, Elm, Forth, HTML, JavaScript, TypeScript, Web Assembly	Yes
CQ3	*Which are the frameworks used by Frontend developers?*	Angular, Backbone.js, Bootstrap, Bulma, ... , Vue.js, Yaml, Slim.js	Yes
CQ4	*Which are the programming languages used by both Frontend and Backend developers?*	Cobol, JavaScript	Yes
CQ5	*Which are the frameworks of JavaScript?*	Angular, Aurelia, Bounce.js, Ext.js, Mocha.js, ... , Nest.js, React.js, Vue.js	Yes
CQ6	*Which are the JavaScript frameworks used by Frontend developers?*	Ext.js, Jasmine, Mercury, Meteor, React.js, Svelte, Vue.js, Slim.js	Yes
CQ7	*Which library of python is used in Data Science?*	Keras, Matplotlib, NLTK, Numpy, Pandas, Scikit Learn, Seaborn, Spacy	Yes
CQ8	*Is Laravel a framework?*	Yes	Yes
CQ9	*Laravel is framework of which programming language?*	PHP	Yes
CQ10	*In which jobs can we use Ruby on Rails?*	Bakend and Full Stack	Yes
CQ11	*What engines are similar to MongoDB?*	Redis, OrientDB, Aerospike, ArangoDB, CouchDB, Cassandra, Amazon DynamoDB	Yes

CQs should cover as much of the ontology as possible in order to provide answers regarding as many different concepts as possible. As it is very important that the QCs cover as much of the ontology's domain as possible in Table 7.2 are represented the areas/concepts of the ontology that the previous CQs cover. Were considered the four IT Jobs (Frontend, Backend, Full Stack andData Science) randomly,

once the ontology behavior is the same for all the jobs in the IT Development area.

Table 7.2: Competency questions by the different field of the IT Skills Ontology.

	IT Jobs					IT Skills			
	Frontend	**Backend**	**Full Stack**	**...**	**Data Science**	**Programming Languages**	**Frameworks**	**Libraries**	**Engines**
CQ1	X								X
CQ2	X					X			
CQ3	X						X		
CQ4	X	X				X			
CQ5						X	X		
CQ6	X						X		
CQ7					X			X	
CQ8							X		
CQ9						X	X		
CQ10		X	X				X		
CQ11									X

According to the CQs made to ontology, it was verified that the ontology answered correctly to all the questions in the different fields of concepts, which makes possible to notice that the ontology meets the requirements and achieves objectives defined at the beginning of the development.

7.2 Experts Evaluation

As stated in Methontology, there was a parallel assessment throughout the development activities of ontology, consisting on feedbacks provided by Experts in the field of jobs and IT recruitment.

In order to assess the final result, a questionnaire (presented in Appendix C) about the usefulness of the information present in the ontology, its consistency with the company, namely in the recruitment process, and its efficacy, was made to a group of Experts in the field of IT recruitment, including two Senior Developers, one Scrum Master/Senior Developer and two Product Owners workers in this field.

To evaluate the achievement of this research purpose, similarly to that carried out in the Section 7.3 we selected the following criteria proposed by Prat et al. [7]. The criteria that we considered most appropriate to evaluate our artifact in this context is presented in Table 7.3. In this evaluation, we decided not to cover the completeness criteria, once this criteria was previously assessed by the Experts during the development activities.

Table 7.3: Hierarchy of criteria for IS artifact evaluation, excerpt from Prat [7].

Dimension	Criteria	Sub-Criteria	Description
Goal	Efficacy	-	The degree to which the artifact produces its desired effect.
Environment	Consistency with Organization	Utility	Measures the quality of the artifact in practical use.
		Fits with organization	Characterizes the alignment of the IS artifact with its organizational environment.

To assess each previously selected criterion, a set of questions regarding the exposed information from the ontology were asked. We followed a semi-structured questionnaire since we had open-ended questions and rating questions in order to extract as much of the questionnaire as possible and make it

more dynamic. The open questions allows interviewees to expose more information, including feelings, opinions and understanding of each topic and the rating scale questions raise quantitative judgements about the subject. The rating questions follow the 5-point Likert scale. The minimum value (1) represents ”Very hard” or ”Not useful” and the maximum one (5) represents ”Very easy” or ”Very useful”.

The achievement of the ontology goal can be assessed by its **efficacy**, the understanding regarding the achievement of the effect/consequences that we intended. In order to assess the efficacy of the ontology, Experts were asked whether it helps or facilitates the recruitment process. The answers given by the respondents were unanimous, considering that the ontology produces the desired effect, with twenty percent of respondents finding that ontology was moderately effective, another twenty percent considered it effective, and sixty percent considered that it very effective. It was pointed out that ontology was an asset and an aid to the shortening process as intended since it allows the transmission and inference of relevant information, avoiding human errors, namely in the curation process, once the Talent Advocate Specialists are mostly non-tech professionals.

It was also mentioned that the process of using the ontology in the recruitment process is still at an early stage, working only as a suggestion engine, and this use may be automated, in the future, in order to calculate a score between a job and a candidate, which allows reaching two essential points for the business, expertise and scalability.

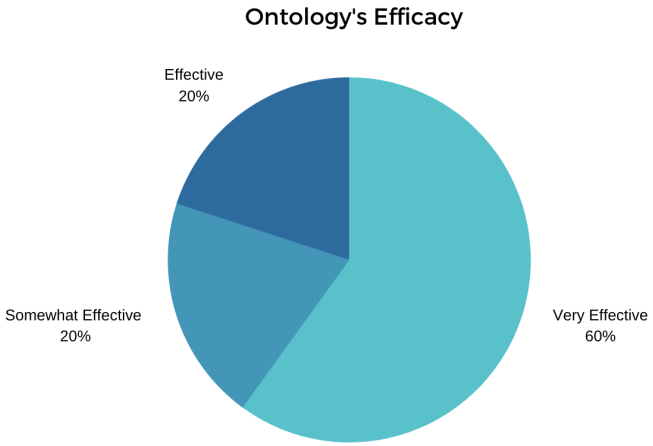

Figure 7.3: Ontoloy’s Efficacy, according to the Experts.

“The environment of IS artifacts comprises people, organization, and technology” [7]. Since this project was performed in a professional environment, it is very important to guarantee and assess its fit and its consistency with the organization. The ontology was applied to the recruitment process, in the curation stage, but it has many other scenarios where it can be used by the organization. Regarding the **utility** of ontology and its application, in this case in the curation process, the classification of Experts in the field was uniform, since twenty percent classified it as being moderately useful and eighty

percent as being very useful. This classification was based on the fact that ontology, if it continues to be updated, allows Talent Advocate Specialists to help and reduce their errors by transmitting relevant information regarding the technologies used in IT, which are constantly evolving. It was also emphasized that ontology is useful because it maps and lists very interesting concepts.

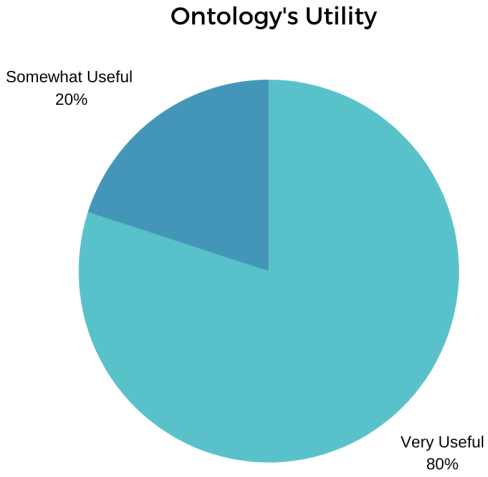

Figure 7.4: Ontoloy's Utility, according to the Experts.

Regarding the alignment of the ontology with its organizational environment, **its fit with the organization**, twenty percent of the surveyed Experts considered that it was aligned, and eighty percent considered that it was very aligned. The use of ontology was considered important and aligned with the organizational environment because it is becoming humanly impossible to follow the understanding and the relationships between the different skills in the IT area since they are becoming so diverse and dynamic, and to aggravate the constant evolution of IT skills, a large part of the workers involved in the recruitment process, namely in curation, are not IT professionals. It was added that although the ontology is aligned with the context of the company, there is always room to improve and complete the ontology more and more with new concepts and new categories that arise.

In order to also assess the limitations and future steps of using the IT skills ontology, we asked Experts about their vision of what could be improved and how they would see the evolution of this artifact. A limitation of ontology is its maintenance and updating, which is currently performed manually, as pointed out by one of the Experts who suggested the inclusion of machine learning elements to make sure that the knowledge base does not become obsolete. It is also important to perform cleanups and uniformazations steps to guarantee that the information is correct, in order to correct classifications and relationships that may not be correct, as has already happened. The creation of "ideal profiles" for a certain job position based on the ontology's information, which could also be useful and facilitate the recruitment process, was also mentioned. The inclusion of other types of skills on the ontology besides hard skills, such as cognitive and personality skills, would open the range of jobs and allow to improve

Figure 7.5: Ontoloy's fit with the organization, according to the Experts.

the match. In addition, it was reinforced by the Experts that, as mentioned in Chapter 6, there are more scenarios in which the ontology will be applied and from which it can be taken advantage of. It is also intended to provide guidance based on the company's database and knowledge on the world in order to understand how a talent skills report to other skills and what's the talent effort to learn new skills and how those skills can contribute to their career; so the ontology could contain not only relationships between skills but also with they're meaning for job positions and career management.

In addition to the evaluated criteria, it was also possible to extract, during the surveys, some interesting quotes about the respondents opinion regarding the IT Skills Ontology, such as:

- "We can infer a lot of relevant information just from using it and spread knowledge much more easily"
- "In my opinion the information presented in the ontology can really help the curators since it provides valuable information that will decrease the number of errors. Since the tech world is evolving fast, it's normal that humans are not aware of every new technology/language. Therefore, a system like this, if it is constantly updated, will be very useful."
- "As it is, it's merely a tool that provides more information to the curation. Therefore, in can help avoid human errors. However, I believe that its full potential will only be seen when we can automatize some parts of the process - i.e, that the ontology not only provide information but will also be able of providing a match score between the candidate's skills and the company's requirements."
- "The recruitment process in a specialized environment has a lot of relations that most HR departments and most recruitment professionals aren't really aware. This simplifies the process and prevents the exclusion of potentially great candidates."

- “It is very important to properly assess skill fit, as skills are getting so diverse and dynamic, it is becoming humanly impossible to be up-to-date with every trend, let alone being an expert...”
- “The ideal recruitment process would have an expert in both HR and tech, in the are of expertise the job requires. Nowadays, recruitment processes are far from ideal - typically being managed by HR staff, far away from the idiosyncrasies of tech - and are already extremely costly. Knowing how to use these ontologies in real-world scenarios has an incredible potential to address both problems: expertise and scalability.”
- “We have already identified a dozen of use cases where these Ontologies can help the organization.These use cases will definitely be part of our short-term roadmap. We want to be able to infer: if a candidate has given subset of skills, we can infer he also has other skills that are not yet formalized. We want to be able to guide: given our database and knowledge on the world, we want to understand how a talent skills relate to other skills and what’s the talent effort to learn new skills and how those skills can contribute to their career. For all of these to work, this Ontologies have to start growing by themselves. They have to evolve by learning from our database. Become enriched, not only with skill relations, but also with they’re meaning for job positions and career management. Another area Ontologies should address is to go beyond tech skills. Soft skills also relate to hard skills. How does that happen? What is the impact it has on talent career and job success?”

7.3 Talent Advocate Specialists Interviews

The curators, or Talent Advocate Specialists, interviews is a type of task-based evaluation since they are based on the application of the ontology in real life context, more specifically in a professional environment. We had defined nine possible scenarios, exposed in Chapter 6. Due to time constraints, we decided to start with the curation scenario since this is the one that provides more value to the company.

A total of eight Talent Advocate Specialists were interviewed, representing about 90% of the company’s curation team. The surveyed users, the Talent Advocate Specialists, had been using/consulting the information provided by the ontology, the Skills Report (represented in Chapter 6), for about two weeks, so it was possible for them to evaluate and have a consistent opinion about its use.

To evaluate the achievement of this research purpose, and validate if the objectives were accomplished, we selected the following criteria proposed by Prat et al. [7]. The criteria that we considered most appropriate to evaluate our artifact in this context is presented in Table 7.4.

To assess the criteria presented in Table 7.4, a set of questions regarding the exposed information from the ontology were asked, these questions are presented in Table 7.5.

Table 7.4: Hierarchy of criteria for IS artifact evaluation, excerpt from Prat [7].

Dimension	Criteria	Sub-Criteria	Description
Goal	Efficacy	-	The degree to which the artifact produces its desired effect.
Environment	Consistency with people	Utility	Measures the quality of the artifact in practical use.
		Understandability	Ease of use.
	Consistency with Organization	Utility	Measures the quality of the artifact in practical use.
		Fits with organization	Characterizes the alignment of the IS artifact with its organizational environment.
Structure	Completeness	-	Characterizes if the artifact has all the necessary/appropriate parts.

We followed a semi-structured interview based on open-ended questions, in order to extract as much of the interview as possible, making it more informal. The open questions allowed interviewees to expose more information, including feelings, opinions and understanding of each topic.

Table 7.5

Dimension	Metrics	Questions
Goal	——	- Did the Skills Report increased/facilitated the understanding about the skills match?
Environment	- Candidate ratings change - Average response time - New information - Work suitability - Misunderstanding	- Was it easy to understand the information presented? - What do you think the information in the Skills Report is referring to? - Unaware of the information provided by the Skills Report, what rating would you give the candidate? And taking into account the information provided by the Skills Report, would you change the rating given before? - Was any of the information provided already known to you? If so, which one(s)? - Did you consider the presented information useful for your work? - Did the Skills Report increased/facilitated the understanding about the skills match? - Did you think that the suggestions/information presented were in line with the scope of your work/company purpose?
Structure	- Missing information	- Is there more information that you considered needed/relevant and was not contemplated on the given suggestions?

The purpose of applying the ontology is to facilitate the recruitment process, in this particular case, by helping curation. In order to check if this purpose was being achieved, the ontology's **efficacy**, Talent Advocate Specialists were asked if, using the application of ontology, their task of assessing the match of skills between a job and a candidate was easier. The general answer to this question was unanimous that the Skills Report made it easier to assess the skills match between the job and the candidate. However, depending on the respondents, this help could be greater or lesser. It was noted that the Talent Advocate Specialists who are/were IT development workers considered that the information provided by Skills Report is less helpful to the curation process than the specialists who have never worked in IT development area, which considered this same information very helpful. Given the obtained answers, it was possible to state that the goal was achieved, the application of ontology in the curation process was effective since it produced the intended result.

One of the most important aspects of using the ontology in a real life context is its **utility**, which is essential in a DSR, especially when applied in a professional environment, with an associated business value. To assess the usefulness of the ontology, we used three different ways.

The first one was to ask directly the Talent Advocate Specialists' opinion about the utility of Skills Report in their work. In line with what happened in the effectiveness assessment of the Skills Report, all respondents considered that the skills report was useful although it is considered more useful for non-IT development workers and less experienced specialists. This difference in the utility of the Skills Report is supported, according to the respondents, by the fact that it provides less unknown information for more experienced Talent Advocate Specialists or who have been IT development workers than for less experienced ones, to whom it transmits a greater amount of unknown information. This discrepancy was expected, since the most experienced respondents have a deeper knowledge of the domain represented in the ontology. It was concluded, from the users' answers, that the ontology is, in fact, a useful artifact, although it is more useful for users that have less experience in the IT field.

The second way used to validate the utility of the ontology was by exposing an example of a curation (presented in Appendix D, Figure C.1), with the Skills Report field containing and indirect relation between skills. It was asked the respondents what score they would give to the candidate of the example and if this score would change if the Skills Report did not exist. For most respondents, except only one from all respondents, the rating given to the candidate, with the Skills Report view, would change for a more suitable rating. This change could be direct in the classification of the skills profile or in the form of a Bonus rating, depending on the interviewee specialist, but would always means an addition to the skills classification score of the candidate. According to the respondents' reasons for the changes in the given rating, it was justified that these changes on candidate's classification reflected the transmission of new and useful knowledge by the Skills Report, making it possible to proceed with a more detailed curation. The canditate's rating change, with and without the Skills Report, is proof that the application of the ontology is useful, as it provides Talent Advocate Specialists knowledge that allows them to make a different assessment, not only taking into account direct matches between skills but also other types of correlations.

The last way to evaluate the utility of the ontology's application was to notice, during the informal conversation, if they mentioned a change in the time spent in the curantion process. More than half of the Talent Advocate Specialists mentioned, during the interview, changes in the time spent during the curation. Approximately 37.5% of the respondents noted that the curation time had decreased, due to having, in a concise way, in the Skills Report information that they would otherwise have to look for. About 25% of the respondents, corresponding to two Talent Advocate Specialists, reported that the time increased, since, as the amount of information increased, the evaluation had to be more detailed, obtaining in the end a higher quality curation. It wasn't possible to conclude the utility of the ontology

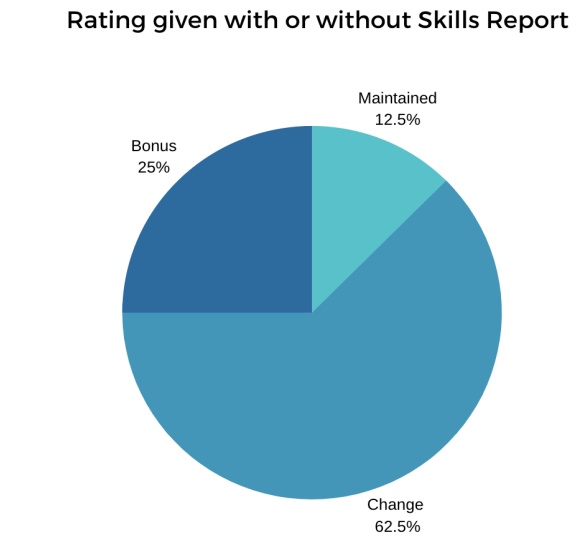

Figure 7.6: Rating changes with or without Skills report.

in terms of time variation, once the interviewees opinions about it are very different. A common point among the different respondents is that the use of the Skills Report, whether increasing or decreasing or maintaining the same time, allows greater confidence in the execution of the curation and produces results with higher quality.

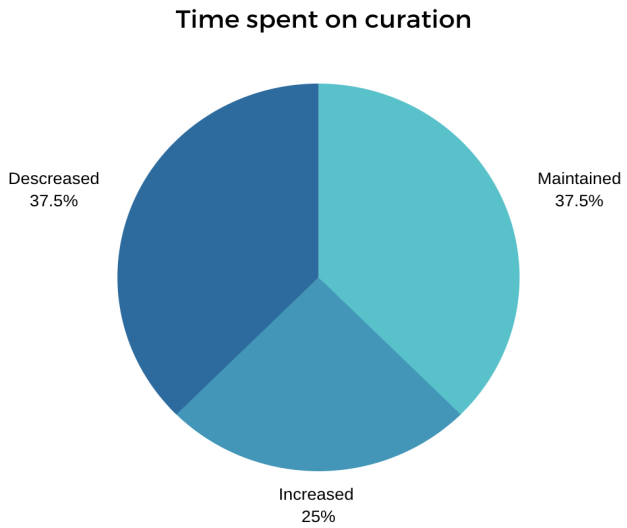

Figure 7.7: Time spent on curation process using the Skills Report.

To assess the **understanding** of the information provided by the ontology, two examples (presented in Appendix D) of the Skills Report were exposed to each respondent, and they were asked to respond with the information transmitted in each one. All respondents answered correctly, understanding the

information exposed in the correct way, which allowed us to conclude that the application of ontology has content that is easy to understand by users.

Since this artifact was developed and used in a business environment, it is important to check if it is suitable for people's work and has value for the company, its **fit with the organization**. In order to assess the fit of the information provided by the ontology in the organizational context, we asked the Talent Advocate Specialists if they considered that this information is in accordance with the work and objectives of the company. The response from the Talent Advocate Specialists was very positive, considering that the information given by the ontology to the Talent Advocate Specialists is not only aligned with the objectives of the company but can be expanded and transmitted in many more areas of the recruitment process.

According to the experience of the Talent Advocate Specialists and their use of the Skills Report, they were asked whether they had felt or noticed that there was relevant information that was not included in the Skills Report, in order to evaluate the ontology's **completeness**. Regarding profiles based on technical skills in the IT area, namely IT development, the respondents' response was common, that in most of the cases there was no relevant information that was not included in the Skills Report. However, it was conveyed by the majority of the interviewed Talent Advocate Specialists that they want more information on less common areas of IT, as well as the insertion of more abstract concepts (eg. Model-View-Controller (MVC), Model-View-View-Model (MVVM), etc.) and soft skills on the ontology.

In addition to the evaluated criteria, it was also possible to extract, during the interviews, some interesting quotes (Table 7.6) about the Skills Report in the recruitment process.

Table 7.6: Quotes from the interviews.

Interviewee	Quotes from the interviews
1	"The use of the Skills Report is very good and useful. It makes it easier to achieve the skills assessment, especially for new/less common technologies. Perhaps this information, if expanded to other areas of recruitment, allows a better requirements definition for the jobs and a higher specification for the candidates profiles." "It would be an advantage to include soft skills in the Skills Report, since for now the only way to deduced them is by reading the candidate's curriculum."
2	"I find the Skills Report useful for the curation process. During our work, when we want to evaluate the match between the skills of a candidate and the skills needed for a job we look for direct relationships, for example, if the job asks for "Python" we will look for "Python" in the candidate's curriculum. With this tool, indirect relationships are exposed, which facilitate and transmit information that otherwise would not occur to us or we would have to spend some time researching get it. With this provided information, we are able to easily understand and infer connections between the skills requested in the job and those of the candidate."
3	"An advantage of using the Skills Report is that it allows us to understand relationships between the different skills that we would otherwise have to spend more time researching."
4	"One of the things I think this information is good for is that it conveys more security and confidence in the quality of the curation." "It facilitates curation because it allows us to make assumptions from the simple relationships that are presented."
5	"The addition of information makes it possible to reduce human errors in curation."
6	"It would be good to give access to this type of information to those responsible for the preparation and publication of job descriptions, so that it is possible to clarify and clarify the skills sought in them."
7	"My world is not technology. These tips and information help a lot because they directly convey information that is not obvious to me." "Something that I think is not working perfectly is the elaboration of job requirements. Often the requirements are very vague and unclear and we end up having to read their descriptions to understand what is really required and the necessary skills. I think the Skills Report could help with that job specification."
8	"Although I already have some experience, I think that for new people in curation these tips are very good and can help a lot, at least they would have helped me when I started working in this field. Thee provided information work as a help and a learning experience." "In spite of considering the Skills Report a great help, I think that extending it to soft skills and less technical profiles would be a good bet."

7.4 Evaluation Analysis

Taking into consideration all the steps carried out, we would like to highlight that, in general, the implementation of the ontology can be considered a successful initiative.

Concerning the coverage of the ontology regarding the IT Skills domain, through the CQs, we could verify that it accomplished the defined requirements since it gave correct answers to all the questions about the IT Skills and jobs domain. It has been shown that the questions made had a good coverage over the different concepts of the ontology.

Diverse criteria were evaluated over Experts questionnaires and Talent Advocate Specialists' interviews. According to the specialists, the proposed ontology is effective since it achieves its goal by making the recruitment process easier and faster in terms of curation.

We have also verified that the information provided by the ontology is easy to understand and that the ontology is a useful artifact for the curation process. Although, according to the most of the users, its application is more useful in less common areas of IT Jobs or for Talent Advocate Specialists with less experience.

It was also referred by specialists that it would be useful to use the ontology for other parts of the

recruitment process, namely in the construction of jobs descriptions and requirements.

8

Conclusion

Contents

In this research, two research methodologies were used: DSR and SRL. We started by identifying the research problem, which is the lack of a coherent and comprehensive approach for conceptualizing, categorizing and relating skills of the professionals in IT field that helps matching the right candidate to the right job, namely in IT recruitment. In order to mitigate this problem we decided to develop an IT skills ontology, with the objective of helping the recruitment process, facilitating the correspondence between jobs and candidates.

Before starting the development of the IT Skills ontology, we carried out an SLR with the objective of identifying the IT-related areas in which the ontologies are used and the methodologies that are applied for their development and evaluation. The SRL allowed us to make a consistent choice of the approaches used for the development and evaluation of the ontology.

The ontology's development, demonstration and evaluation was carried out in a professional environment, integrated in a company, which is dedicated to matching the best tech professionals to the right companies. The ontology's development process was guided by the Methontology methodology, using data from the company and complemented with the data from other recruitment sources.

The proposed ontology was applied to 1 out of 11 scenarios identified, the curation of all the candidates' use case, a real professional scenario, which belongs to the recruitment process, since this is the scenario that provides more value to the company.

In order to evaluate our artifact, we used three different approaches. Firstly, we evaluated it using some CQ, which has the objective of verifying if the ontology fulfills its objectives, covering a large part of its domain. Secondly, questionnaires were made to Experts in the field in question. Finally, semi-structured interviews were carried out with the Talent Advocate team responsible for the curation of the candidates.

With the evaluation performed on the ontology, we verified that the goal of this artifact was achieved. Through the use of the application of the ontology in the context of recruitment, it was possible to conclude that the information related to the IT Skills' domain transmitted to curators is useful for them and helps them to be aligned with their work, obtaining better curations, especially for less experienced professionals or when skills and jobs are less common.

8.1 Contributions

With this research we hope to had helped to mitigate not only the research problem presented, but also to encourage new research so that the field of IT recruitment and IT Skills is increasingly studied, explored and improved, using the theoretical bases for obtain practical benefits for the professional world.

With the work carried out in this master's thesis, we contributed by obtaining (1) the lessons and learning resulting from the SLR about ontologies related to IT, as well as the main methodologies for its

development and evaluation and (2) an ontology for IT Skills, which brings together the main hard skills and the jobs that use them in the IT area.

Through the use of the application of ontology in the context of recruitment, it was possible to conclude that the information related to this domain that is transmitted to Talent Advocate Specialists is useful and helps them to be aligned with their work, helping to obtain better curations especially for less experienced professionals or when skills and jobs are less common.

8.2 Limitations

During the different phases of our work, we were faced with some challenges, such as:

- Lack of theoretical support about skills, more specifically IT skills;
- Lack of theoretical support on ontologies of skills, there are several ontologies in the IT area but few talk about skills, and those that do are not well detailed;
- Although there are numerous scientific papers that use Methontology for the development of ontologies, the stages of application of this methodology are not well specified and exemplified in the most recent the papers. It is possible to observe this application in greater detail and more documented in older papers;
- There were many titles for the same job, it was necessary to standardize these titles, taking into account the number of occurrences;
- During the concepts filtering, sometimes it was not clear what type of competences/technologies could be considered skill, since it is an vague concept.

It was also possible to verify that there are some limitations regarding the developed work. Some of these limitations were:

- The IT Skills Ontology only covers the main jobs in the IT field and the respective hard skills;
- The IT Skills Ontology does not contain soft skills;
- The IT Skills Ontology does not cover the level of expertise/experience of the skills;
- It was only possible to apply the ontology in one of eleven possible scenarios;
- The maintenance and updating of the ontology is essentially performed manually.

8.3 Communication

The last phase of the DSR methodology, is the communication of the results to the scientific community.

Therefore, two papers were submitted to the scientific community: “A Systematic Literature Review on Ontologies Development and Evaluation Methodologies” to “Knowledge and Information Systems” journal (Q1) and “An IT skills ontology for matching talent and companies” to “Information Technology and People” (Q1) journal. Both papers are currently awaiting results.

The paper “A Systematic Literature Review on Ontologies Development and Evaluation Methodologies” contains the SRL carried out during the development of this master’s thesis and the paper “An IT skills ontology for matching talent and companies” addresses the development, demonstration and evaluation of the Skills IT ontology.

8.4 Future Work

We are currently working on adding levels of expertise to ontology. The Expertise Level concept could be divided on three concepts, Junior, Mid-level and Senior, as presented in Figure 8.1. The Junior is the least experienced in a given domain, followed by the Mid-level with a medium experience, and finally the Senior, which is the most experienced and have a deeper knowledge.

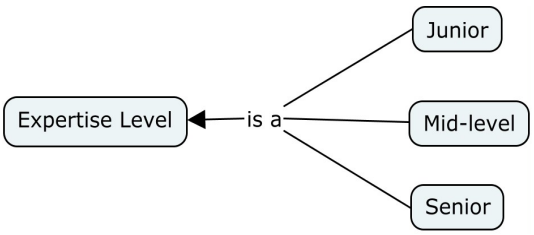

Figure 8.1: Taxonomy of Expertise Levels.

Figure 8.2 is an example of an inference rule that could be used to classify as Senior any Candidate that has more than 8 years of experience.

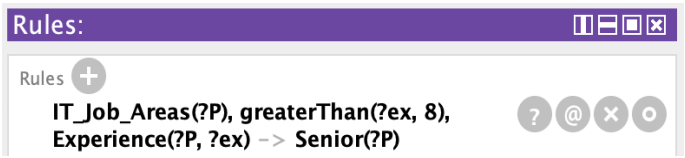

Figure 8.2: Inference rule for Senior workers.

To verify the application of the defined inference rule we ran the Pellet reasoner on the Protégé Tool. It was possible to notice that the ”Senior” category, in yellow, was associated to Candidate X (Figure 8.3).

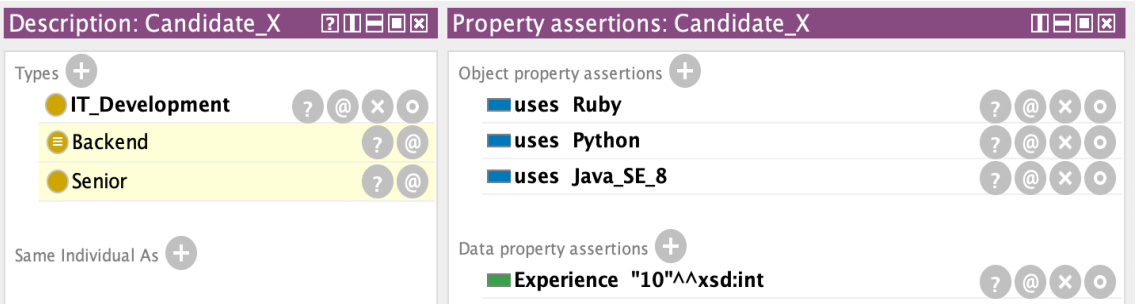

Figure 8.3: Reasoning results.

It is important to note that the inference to Backend that occurred in Candidate X is due to the axiom of equivalent classes shown in Figure 5.8.

As mentioned in several parts of this work, this project was developed in a professional environment and its application is being used in the company's curation process, as shown in Chapter 6. During interviews with Talent Advocate Specialists and questionnaires to Experts, we realized that some future steps would be desirable, both from a useful and professional point of view and from a scientific point of view, such as:

- Apply the IT skills the ontology to the posting jobs providing skills suggestion and help define job requirements so that they are clearer and more specific, since this is the aspect most criticized by Talent Advocate Specialists;
- Apply the IT skills ontology to the posting jobs validation;
- Apply the IT skills ontology to improve the search engine of jobs;
- Apply the IT skills ontology to improve the search engine of candidates;
- Apply the IT skills ontology to the candidate sign up/update providing skills suggestion;
- Apply the IT skills ontology to the candidate profile validation;
- Apply the IT skills ontology to provide smarter market insights based on the most wanted/used skills in the different areas;
- Add to the ontology more knowledge about less common skills and less technical areas;
- Introduce soft skills concepts in ontology;
- Align machine learning techniques with ontology so that it is more dynamic.

It is also important to ensure the maintenance and updating of the ontology, so that it continues to be useful and to transmit enriching information.

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Appendix A

Table A.1: Ontology Development Methodologies and IT Areas.

IT Area/ Methodology of Development	None or Not Specified	Mixed Methodologies	Proposed their own	Methontology	Ontology Development 101	NeOn	Model-Based System Engineering approach	Methodology from OntoAdapt in [83]	Inspirational, Synthetic and Collaborative Approach	TOVE	Automatic Creation
Web Development		[76]	[84], [47], [48], [49], [46]					[72]			[50]
Software Development		[85]		[25]	[52]	[70]					
Security	[58]	[59], [60]		[56]							
Cloud Computing				[65]		[71]					
Games			[63]		[64]						
Project Management		[61]	[62]								
Decision Support		[54], [86]	[55]								
Applications	[81]										
Artificial Intelligence	[87]										
Concept Development		[73]									
Data Mining		[88]									
Data Processing				[67]							
Automation Systems	[52]										
Information Retrieval					[69]						
IT Infrastructure	[89]									[75]	
Job Knowledge						[45]					
Knowledge-Based Systems				[68]							
Semantic Publishing			[90]								
Systems Interoperability				[66]			[74]				
Semantic Data Integration									[91]		

B

Appendix B

Table B.1: Ontology Development and Evaluation Methodologies.

Evaluation/ Methodology of Development	None or Not Specified	Mixed Methodologies	Proposed their own	Methontology	Ontology Development 101	NeOn	Model-Based System Engineering approach	Methodology from OntoAdapt in cite{Abech2016}	Inspirational, Synthetic and Collaborative Approach	TOVE	Automatic Creation
None or Not Specified		[61], [86], [54]	[48], [49]	[67]	[64], [69], [52]	[45]		[72]			
Application-based	[87], [89]	[76], [88]	[84], [63], [47], [55]	[65], [68]		[70], [71]	[74]		[91]	[75]	
Criteria-based	[89]	[60], [73]	[55]	[56], [68], [66]							[66]
Experts Opinion		[59], [73]	[90], [62], [46], [77]	[65]		[71]					
OntoClean	[58]		[77]	[56]							
Competency Questions		[85], [76], [73]	[63], [77]			[71], [70]				[75]	
Queries			[84]			[71]					
OOPS!		[76]	[84], [63]								
Vapour			[63]								
Reasoners				[25], [66]							
OntoCheck	[78]										
Methodology from [92]	[81]										

C

Experts Questionnaire

Ontology - Experts Feedback/Evaluation

Write a short comment/feedback in which you answer the following questions regarding the IT Skills Ontology.

*Obrigatório

Do you consider that the information presented in the ontology is useful? *

A sua resposta

How do you evaluate the ontology utility? *

	1	2	3	4	5	
Not useful	○	○	○	○	○	Very useful

Do you think that this type of relationship and categorization provided by the ontology is properly applicable to the recruitment process and appropriate to the company's business environment? *

A sua resposta

How appropriate do you consider the ontology to the context of recruitment? *

	1	2	3	4	5	
Not appropriate	○	○	○	○	○	Very appropriate

Do you think that the ontology can help recruitment process, facilitating the correspondence between a candidate and a company? *

A sua resposta

How much do you think ontology can help in the match process between a candidate and a company? *

	1	2	3	4	5	
Does'nt help	○	○	○	○	○	Helps a lot

How do you think ontology can be improved and what could be the next steps? *

A sua resposta

D

Talent Advocate Specialists Interviews - Skills Report's Examples

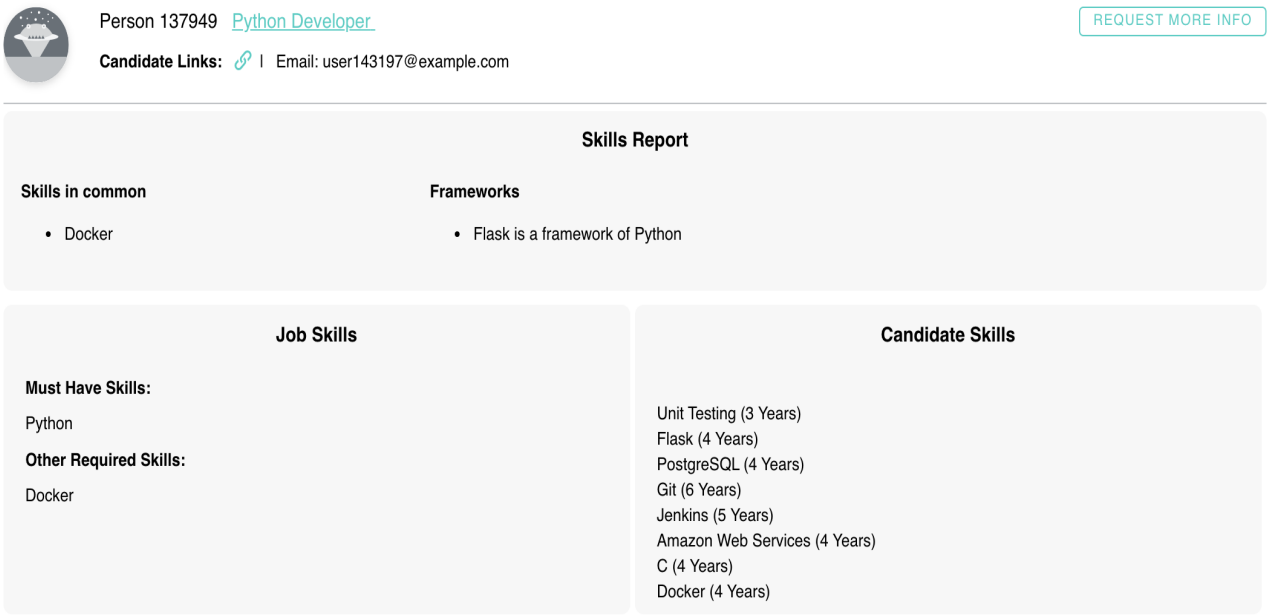

Figure D.1: “Skills Report’s print, used for curators interviews.”

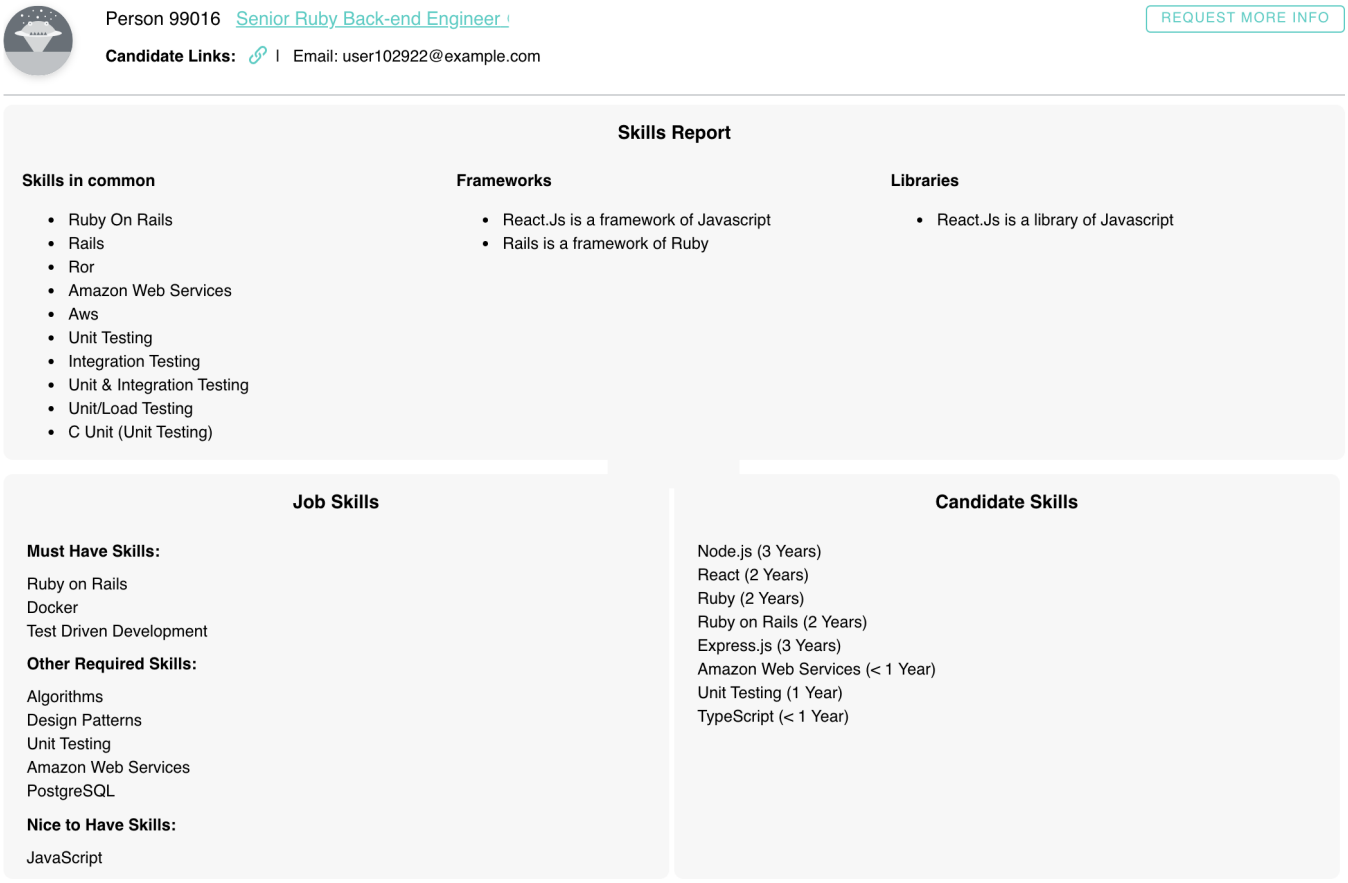

Figure D.2: “Skills Report’s print, used for curators interviews.”