Professional Profiles and Multidisciplinary Engineering Curriculum

Ing. Marla Constanza Barrera Botero, Universidad Nacional de Colombia

Systems Engineer from Universidad Distrital ”Francisco José de Caldas” and M.Sc. in System Engineering and Computer student from Universidad Nacional de Colombia.

Topics of interest: Semantic Web and Ontologies applied to representation and management of knowledge, Engineering Education and Innovation networks.

Prof. Oscar G. Duarte, Universidad Nacional de Colombia

Electrical Engineer by Universidad Nacional de Colombia in 1991. M.Sc. in Industrial Automation by Universidad Nacional de Colombia in 1997 Ph.D. in Informatics by Universidad de Granada in 2000

Professor of the Department of Electrical and Electronic Engineering of the Universidad Nacional de Colombia since 1994.

Academic Vicedean of the Faculty of Engineering of the Universidad Nacional de Colombia since 2012.

Ms. Carolina Sarmiento, Universidad Nacional de Colombia
Ing. Rene Alexander Soto Perez, Universidad Nacional de Colombia
Ing. Angélica Rosmery Ghisays, universidad nacional de Colombia

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Marla Constanza Barrera Botero
Oscar Germán Duarte Velasco
Carolina Sarmiento González
René Alexander Soto Pérez
Angélica Rosmery Ghisays Abril

Abstract

A professional profile is a set of knowledge and skills. We propose a methodology to define professional profiles giving a quantitative assessment of skills and knowledge associated with a multidisciplinary curriculum. This approach can be used to evaluate the curriculum flexibility, i.e., if the curriculum offers students diverse and flexible approaches and routes to learning. We describe a mathematical model that allows us to calculate the compliance level accomplished by a student with regard to one or more different profiles. Our proposal has been applied in the Department of Electrical Engineering from *Universidad Nacional de Colombia*.

Introduction

Professional profiles are a set of skills and knowledge that a professional (i.e. an engineer) has or should have. For multidisciplinary engineering programs, the definition of such professional profiles is difficult due to the inherent flexibility of those programs. Since we require flexibility in the curricula, the question is how this flexibility affects the professional profile of the students.

There is no specific methodology to define professional profiles in educational institutions and organizations. Usually, professional profile definitions try to satisfy current needs and expectations from the academy, organizations and society. Educational institutions propose professional profiles according to what industry, organizations and society expect from new professionals.

The way that professional profiles are currently established, involves common features (educational outcomes) that give us the basis to get to know the principal elements of a profile. These features can be classified in two major groups: *skills* and *knowledge*. In other words, a profile can be visualized as a set of skills and knowledge.

We have developed a methodology to evaluate professional profiles in the context of multidisciplinary engineering curriculum. We consider this methodology as a potential tool in educational institutions since it allows us to know if the curriculum fulfills the current expectations of the training of new professionals.

In the section titled "Professional Profiles", the definition of professional profile is given and two important concepts derived from this are suggested. Furthermore, the process of knowledge acquisition and representation of the sources of knowledge through ontologies is explained.

A mathematical model is submitted in the section titled "Mathematical Model" according to our profile definition. Our model was built using techniques taken from computational intelligence to propose a quantitative assessment of profiles. The impacts produced in the results when we select a kind of fuzzy implication and aggregation operator are also described.

Our methodology was applied at the Department of Electrical Engineering from *Universidad Nacional de Colombia*. A team of domain and human resources experts has helped us to build, test and evaluate the model. The application process is shown in the section titled "Application".

Finally, we present conclusions and future work regarding this project.

Professional Profiles

Despite professional profiles arise from current needs from the academy, organizations and society, there is no specific methodology that defines or determines them. Even though each of these have their own definition of professional profiles, the techniques used by each one have common objectives:

- To satisfy the current and future needs from society and organizations.
- To develop personal and communication skills, besides the knowledge and skills within specific domain.
- To reinforce leadership and teamwork abilities.[1–3]

There is no formal definition of 'professional profile' that is universally accepted. However, an explicit definition is: "Previous image of features, knowledge, skills, values and feelings that should have been developed for a student in her/his training process".[4]

According to the above definition, a professional profile is mainly based in the knowledge and skills expected by academy, society and organizations. For this reason, in our project we have defined that:

Def. 1. **Professional profile:** the set of skills and knowledge that a professional (i.e., an engineer) has or should have.

Individual and Ideal Profiles

We use the word 'or' in the previous definition in order to include two different concepts that have been adopted in this project: *ideal profile*, a professional profile expected; and *individual profile*, a professional profile acquired. Formally, we propose the following definitions:

Def. 2. **Ideal profile**: the set of skills and knowledge that a student must achieve according to his/her expected future professional role. These expectations are defined by educational institutions, industry, organizations and society, and they are based on current requirements of each sector.

Def. 3. **Individual profile**: the actual set of skills and knowledge acquired and/or developed by a student during the professional training process.

Compliance Level

Compliance level is the measure that determines to what extend an *individual* profile satisfies one or more *ideal* profiles. It is a quantitative assessment of skills and knowledge associated to a curriculum. The section "Mathematical Model" describes the model that we have developed to quantify this measure.

Knowledge Acquisition for Profile Obtaining

Three sources of knowledge have been the basis to build the sets of Knowledge and Skills and generate the frame to get both individual and ideal profiles. Additionally, these sources are being used in a larger project whose objective is to represent the Electrical Engineering curriculum of *Universidad Nacional de Colombia* through ontologies.

The three sources of knowledge are:

- The Conceive, Design, Implement and Operate (CDIO) Syllabus.
- Technical knowledge.
- Electrical Engineering curriculum of *Universidad Nacional de Colombia*.

CDIO

CDIO is an initiative from the Massachusetts Institute of Technology (MIT) and other universities, whose goal is to integrate technical knowledge with some expected characteristics that a student should possess when he or she graduates from university. These features are based on needs from academy, industry and society, and they allow engineers to function in real engineering teams and to produce real products and systems.[5]

The CDIO initiative has created a new concept for undergraduate education based in the skills needed by the contemporary engineers and the appliance of an engineering problem solving paradigm. In this, two major tasks are involved:

- Developing and codifying a comprehensive understanding of the skills needed by the contemporary engineer.
- Developing new approaches to enable and enhance the learning of these skills.

A first outcome from this initiative was the CDIO Syllabus, a compendium of contemporary engineering knowledge, skills and attitudes that alumni, industry and academia desire in a future generation of young engineers. It consists of a template and an associate process, which can be used to capture the opinions of industry, alumni and faculty, and customize the Syllabus to a set of learning objectives appropriate for any specific undergraduate engineering program.[6]

The Department of Electrical and Electronic Engineering from *Universidad Nacional de Colombia* has adopted the CDIO methodology in their curricula since 2008, obtaining two outcomes:

- The CDIO Syllabus of the Electrical Engineering curriculum,[7] a set of 704 skills organized in four levels as suggested in the CDIO methodology.
- The selection of 11 major learning objectives, each one associated to one or more evaluation criteria for engineering programs according to ABET (*Accreditation Board of Engineering and Technology*).

Curriculum

The Agreement 033 of 2007 issued by the Superior Council of *Universidad Nacional de Colombia*, which defines the basic guidelines to student training through its curricular programs, provides two important concepts to this work: curriculum and multidisciplinary curricula.

Article 4 presents the definition of curriculum as: "a set of academic activities (...) organized by subjects gathered in train components that a student must take in order to achieve the training purposes from a curriculum program. A curriculum program may have several curricula".

Article 6 guarantees that all curriculum programs should be multidisciplinary when it establishes "(...) Interdisciplinarity is, in turn, an integration channel of the university community, since it promotes teamwork and relationships between its different departments as well as the relationships of other educational institutions with these".[8]

Resolution 181 of 2009 issued by the Faculty of Engineering Council, describes how Electrical Engineering curriculum must be adapted to the agreement 033, and presents the structure of the Electrical Engineering curriculum divided in components. Each component has one or more groups and each group has one or several courses.[9]

Technical Knowledge

Resolution 181 of 2009 presents a complete structure of Electrical Engineering curriculum. In this structure, the curriculum is divided into three components, which are: Fundamental component, Disciplinary Training or Professional component and Free Choice component.[9]

Technical knowledge representation was carried out by taking into account only the Disciplinary Training or Professional component, since this component contains the groups and courses that specify the training of the future Electrical Engineers.

In order to represent technical knowledge, the courses were organized into thematic contents. These, in turn, divide each course by topics organized in different levels.

Knowledge Representation using Ontologies

The term *ontology* comes from philosophy, and has been adopted in the field of Computer Science with a slightly different meaning:

Def. 4. **Ontology:** a formal and explicit specification of a shared conceptualization.[10]

As an ontology is a formal description of concepts that describes a knowledge domain, it allows us to formally represent any kind of knowledge. The most important elements of an ontology are:

- Classes: they describe concepts in the domain. A class can have one or several subclasses that represent more specific concepts of the principal class.
- Individuals: they are particular objects from the class.
- Relationships: generally, they include class hierarchy, i.e., a class A is a subclass from B if each object from A is also included in B.
- Object and Data Properties: object properties connect pairs of individuals and data properties connect individuals with a data type.
- Restrictions and rules: they allow us to infer the represented knowledge.
- Functions and processes between classes.

Ontologies are tools of the artificial intelligence field that facilitate knowledge share and re-use. They interweave human and machine understanding; this property facilitates the process of ontologies performed among humans and/or machines. Ontologies have been used by several fields such knowledge engineering, natural-language processing, knowledge representation, intelligent information integration, cooperative information systems, information retrieval, electronic commerce and knowledge management.

The use of ontologies promises "a shared and common understanding of a domain that can be communicated between people and application systems".[11] Some of the important features of ontologies are the following:

- They allow to represent complex knowledge and complex knowledge relationships.
- They can be reused and shared for different applications.
- They allow to organize information hierarchically.
- They can contain heterogeneous information and data.
- They can be integrated with other ontologies and applications such as relational and semantic databases.
- They are portable.

These features provide ontologies a great potential to represent and manage knowledge. For this reason, the three sources of knowledge (CDIO, Curriculum and Technical Knowledge) with Regulation from Electrical Engineering curriculum, have been represented through ontologies.[12]

Mathematical Model

In the following subsections we describe our proposal of model in order to represent a professional profile and to calculate compliance levels. We use fuzzy implications and aggregation operators such as OWA, to find a level of compliance of an individual profile in regard to ideal profiles.

Profile Structure

In the section "Professional Profiles", we have defined that a profile is composed of a set of skills and a set of knowledge. Since these skills and knowledge can be nested, they can be represented by a tree. The depth and number of nodes are different for each tree.

Definition 1. Let S a set of nested Skills.

$$S = \{s_1, s_2, s_3, \ldots, s_n\}$$

S is the set of all nodes of tree shown in figure 1.

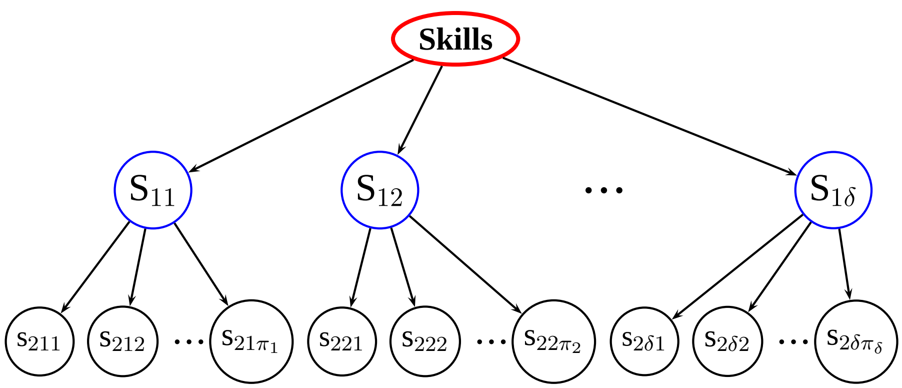

Figure 1: Skills Tree Structure

Definition 2. Let K a set of nested Knowledge.

$$K = \{k_1, k_2, k_3, \ldots, k_m\}$$

K is the set of all nodes of the tree shown in figure 2.

According with profile definition, we can represent a profile as a binary tree. A possible profile structure is shown in figure 3.

Both, the ideal and individual profiles, must have the same number of nodes and levels (depth).

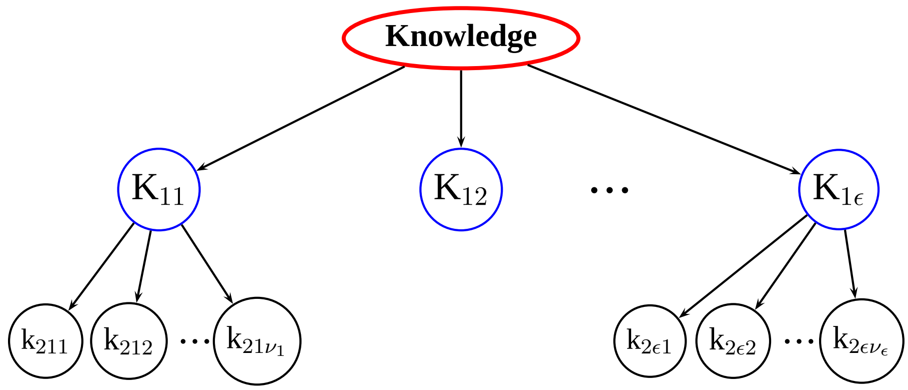

Figure 2: Knowledge Tree Structure

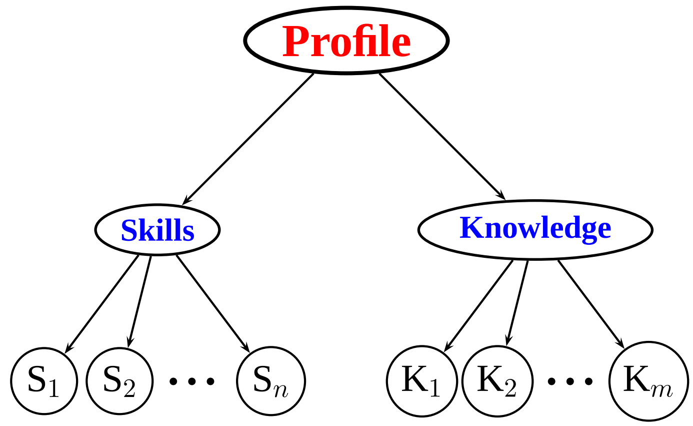

Figure 3: Profile Structure

Definition 3. There is a function that assigns a numeric value to each element of the skills and knowledge trees called *Competence Function*.

$$\mu_i(h_i) : S \longrightarrow [0,1]$$
$$\sigma_i(c_i) : K \longrightarrow [0,1]$$

Fuzzy Implications

In order to find the compliance level, it is necessary to establish a kind of relationship between an individual profile and an ideal profile. For this, we propose to set up these relationships through fuzzy implications.

When applying fuzzy implications we can obtain the grade of membership of a set in regard to another set; in our case, the grade of membership of an individual profile with respect to an ideal profile. We assimilate those grades as truth values that are in the interval [0,1]. Relationships are represented through rules *"if ... then"*; thus, truth values can be calculated with some T-norms or S-norms, as these kind of relationships $(p \rightarrow q)$ can be represented in terms of $\wedge$ and $\vee$, respectively.[13]

In this work, we use some fuzzy implications in order to find the values of the compliance level of a common node from both trees, individual profile and ideal profile. This process is made from leaf nodes to single root node, obtaining a new tree called *Compliance Level Tree*, as shown in figure 4.

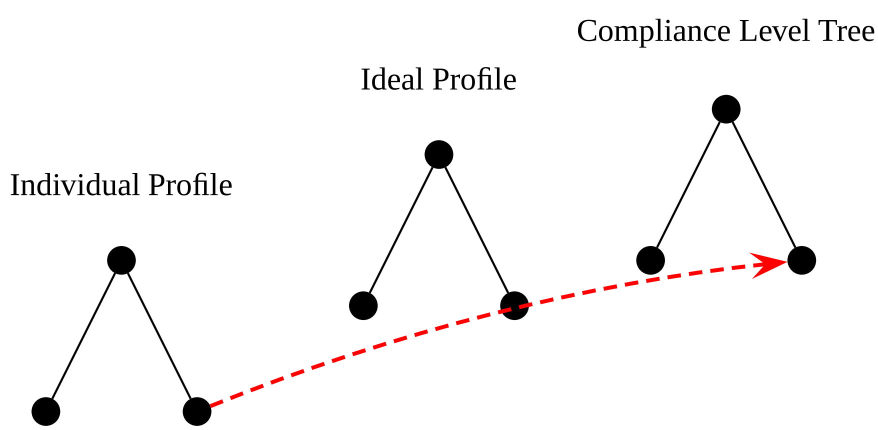

Figure 4: Relationships between Tree Profiles

Aggregation Operators

Through aggregation operators we can find a single numeric value that allows to know the compliance level that a student has with respect to one or some ideal profiles. This value shows the compliance level of an individual profile regarding an ideal profile.

Definition 4. An OWA operator of dimensions n is a mapping $F : \mathbb{R}^n \rightarrow \mathbb{R}$, such that:

$$F(a_1, a_2, \cdots, a_n) = \sum_{j=1}^{n} w_j b_j$$

where b_j is the jth largest of the a_i, and the w_j are weights, satisfying: $w_j \in [0, 1]$ and $\sum_{j=1}^{n} = 1$.[14]

OWA operator provides a class of averaging operators parametrized by the weighting vector. This property gives us three classes of OWA operators:

1. *Maximum*. Where $w_1 = 1$ and $w_j = 0$ for $j \neq 1$ here $F(a_1, a_2, \cdots a_n) = Max_i[a_i]$.
2. *Minimum*. Where $w_n = 1$ and $w_j = 0$ for $j \neq n$ here $F(a_1, a_2, \cdots a_n) = Min_i[a_i]$.
3. *Simple Average*. Where $w_n = 1/n$ here $F(a_1, a_2, \cdots a_n) = (1/n) \sum_{i=1}^{n} a_i$.[15]

A fourth class is derived when w_j for all j has a random value and the values to w_n are defined through various methods to find the weights.

Some of these methods imply:

- Using learning algorithms with a set of training data, associating values and trying to assign the weights according to values from training data.
- An exponential class of OWA operators. This is seen as a simple relationship between *orness degree* and a parameter that determines the OWA weights.[16]

The orness degree determines how flexible (or strict) is the result on OWA operator and it is represented as α. When $\alpha \to 1$, OWA operator trends to maximum (or) and when $\alpha \to 0$, OWA operator trends to minimum (and).

Figure 5 shows the aggregation information process over the compliance level tree, which obtains the compliance level value from an individual profile with respect to an ideal profile.

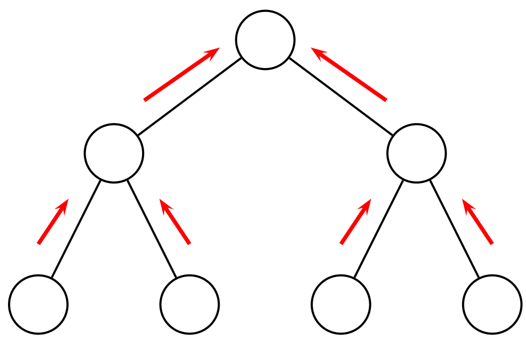

Figure 5: Aggregation Information Process

Choosing Fuzzy Implications and Aggregation Operators

In the section "Fuzzy Implications", we were referring to the use of fuzzy implications in order to find the compliance level tree. The selection of a type of fuzzy implication determines the results expected for our model. In our case, we found that Gödel and Goguel implications were closer than other fuzzy implications tested.

Similarly, the choosing of an aggregation operator defines how flexible or strict the compliance level of an individual profile must be in regard to ideal profiles. In this case, we found the following:

Impact of α parameter on flexibility level in compliance level can be seen in figure 6.

Operator	Result
Maximum (or $\alpha = 1$)	Most strict
OWA when $\alpha \rightarrow 1$	Strict
Simple Average	Middle
OWA when $\alpha \rightarrow 0$	Flexible
Minimum (or $\alpha = 0$)	Most flexible

Table 1: Comparing class of Aggregation Operators

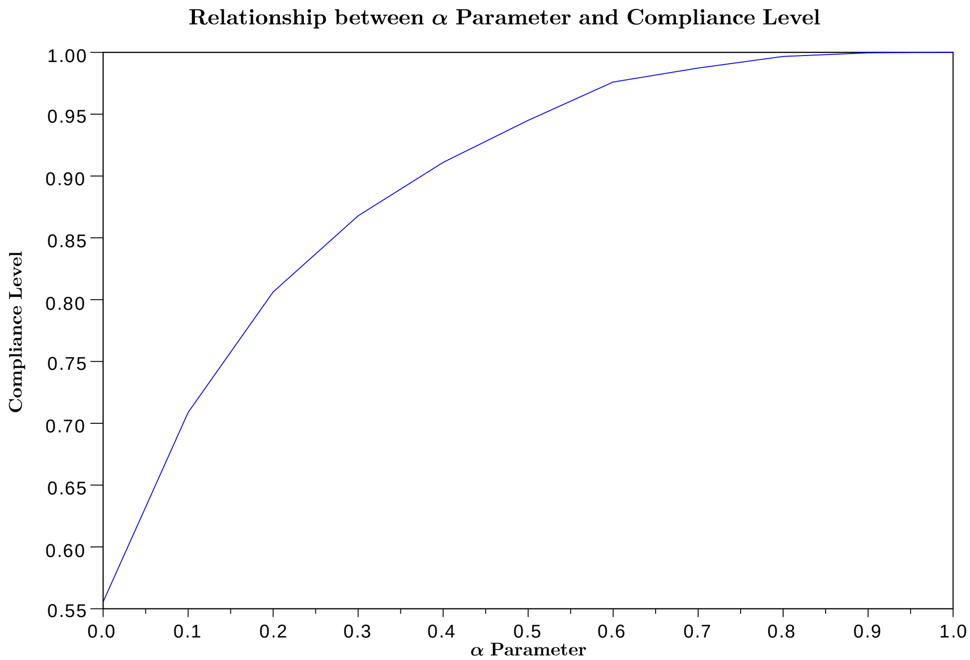

Figure 6: Behaviour of Compliance Level with respect to α Parameter

Application

In the section "Knowledge Acquisition for Profile Obtaining", we have mentioned that three sources of knowledge are the basis to build the general frame of a profile. These three sources of knowledge are part of a major project to represent curricula through ontologies. Within this project, four ontologies have been built in order to represent the Electrical Engineering Undergraduate Curriculum from *Universidad Nacional de Colombia*. Figure 7 shows structure of the ontologies integration.

The CDIO Syllabus represented in *Skills* ontology has provided the set of skills. In our case, we have taken into account the first two levels of skills.

The *Knowledge* ontology contains the representation of technical knowledge described in "Technical Knowledge", and this way of representation through ontologies has been the outcome from

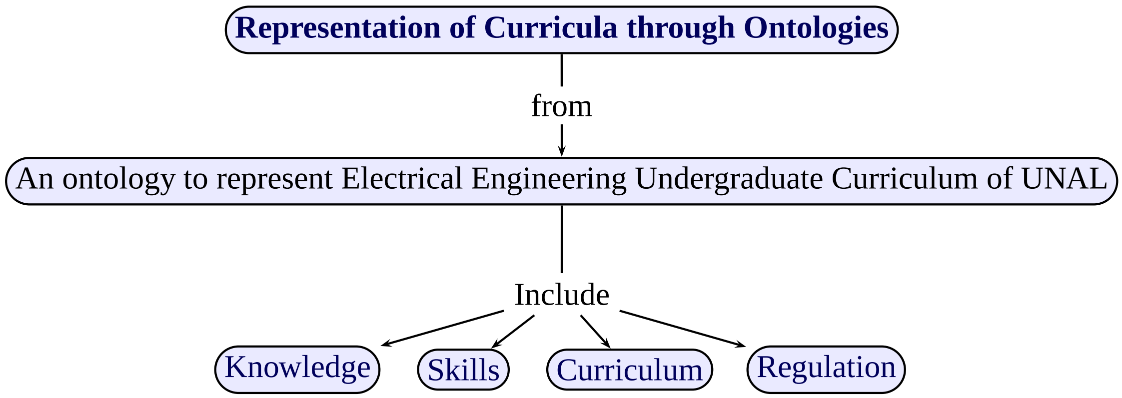

Figure 7: Representation of Electrical Engineering Undergraduate Curriculum through Ontologies[12]

two researches.[17,18] Similarly to the set of skills, knowledge is also organized in levels and this gives us the set of knowledge.

We have chosen two profiles defined by a group of experts by the Department of Electrical Engineering from *Universidad Nacional de Colombia*. These profiles are: *Power distribution systems* and *Industry applications*.

From the *Curriculum* ontology we extracted the set of courses. We define an *impact matrix* (a table) for every professional profile. That matrix relates skills and knowledge with courses. In every cell of the matrix there is a numeric value in the interval $[0, 1]$ that reflects the expected impact that a course would have on an specific student's skill or knowledge. The values has been estimated by the same group of experts.

Notice that every row of the matrix represents a skill or knowledge that belongs to the last level (a leaf node in the tree). In order to find the values of the higher levels where there are no designated values, we apply a kind of OWA operator that has been explained in "Aggregation Operators".

The impact matrices are the basis to create an individual profile. We use them in conjunction with the student's academic record to estimate the student's skills and knowledge acquired. In order to do this, we multiply the values of the impact matrices for a performance factor (and again in the interval $[0, 1]$) that is proportional to the grade that the student obtained in every course.

Once we have established the relationship between skills or knowledge and the level of performance of a student, we need to assign a single value for each skill or each knowledge. For this reason, we propose to use OWA operators in each row from each matrix.

Ideal profiles have also been obtained from a group of experts. They have provided us two *profile matrices* that link skills and knowledge sets with the two ideal profiles, where each cell contains numeric value in the interval $[0, 1]$.

In order to find the compliance level of an individual profile with respect to ideal profiles, we apply

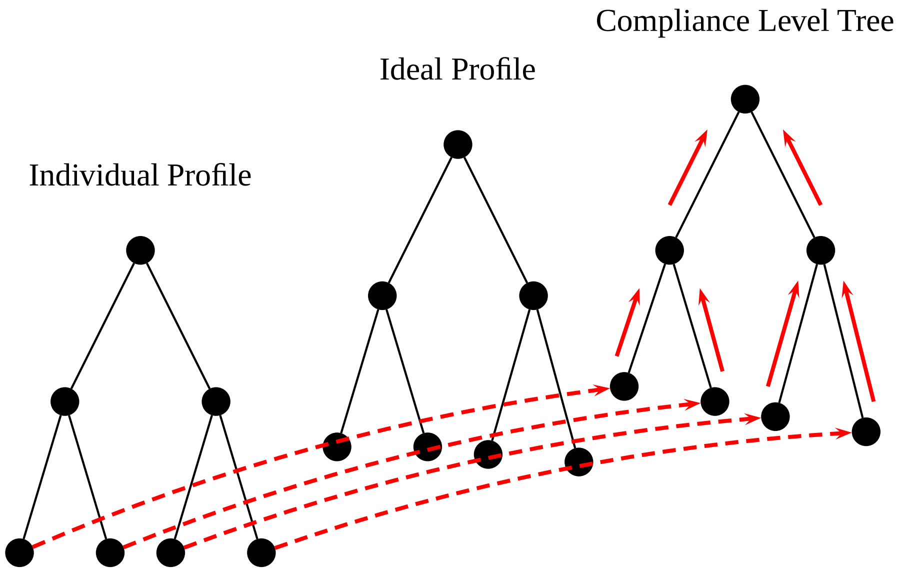

Figure 8: Information flow through the trees.

fuzzy implications to get the compliance level tree described in “Fuzzy Implications”. This gives us the level of compliance obtained by a student in each one of the skills and knowledges.

With OWA operators it is possible to calculate the compliance level of an individual profile in regard to one o more ideal profiles as an only numeric value in the interval $[0, 1]$, as it has been described in “Aggregation Operators”.

In order to test and evaluate the proposed methodology, a software prototype has been implemented. The main purpose of this software prototype is to facilitate the evaluation of the model by experts in the domain of knowledge in Electrical Engineering, i.e., teachers, Electrical Engineers and human resources experts.

Using the web application, a user can select a student, one, several or all ideal profiles, fuzzy implications and OWA operators (and an α parameter if required). The user can view the compliance level value and the compliance level tree (see figure 8).

We have used the RUP methodology of software design. This prototype is a Web application that has been implemented in PHP language and is based on a MySQL database. The database has nine tables with information about the sets of skills and knowledge, students, courses of curriculum and ideal profiles related with the Department of Electrical Engineering from *Universidad Nacional de Colombia*. In addition to this, the database records the information regarding compliance levels of individual profiles.

Conclusion and Future Work

A methodology to define professional profiles (ideal and individual) has been proposed. The mathematical foundations of the methodology have been presented. Some sensitivity analysis of the parameters involved have been conducted.

More experimentation is needed in order to adjust the methodology. Analysis of real cases is required. This will be carried out during the next months.

The potential of the methodology is broad: for example, it can be used in program assessment tasks since it is possible to measure if the expectations from organizations and society are being fulfilled. From another perspective, it can be used for students as an information tool about their individual learning processes.

Currently, our methodology is the basis of a project whose goal is to recommend learning pathways for students in the Electrical Engineering curriculum of *Universidad Nacional de Colombia*.

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