Using Visual Representation for Decision Support in Institutional Research Evaluation

Anastasios Tsolakidis, Cleo Sgouropoulou, Effie Papageorgiou, Olivier Terraz, and Georgios Miaoulis

Abstract. Higher Education Institutes worldwide are facing an increased demand to strengthen their capacities for research and innovation. This study introduces an ontology-based software system architecture that supports research policy evaluation processes and decision-making strategies, using visual analytics. A knowledge modeling technique drawing on multi criteria analysis and data visualisation is proposed. In addition, the paper presents a prototype built on Protegé, Pellet reasoner and Java Technologies, which is friendly to the user and capable of interactive synthesis of institutional decision support criteria. In this work we make a transition from knowledge to visual web-based decision support systems with different kinds of visualisations. The developed system enables research managers to evaluate key aspects of academic research activity in the context of specific policies and criteria, correlate strategic goals with research performance and make informed decisions on the establishment of research strategies.

Keywords: decision support system, university research, visual support system, evaluation, data visualization.

1 Introduction

The twenty-first century is expected as a period of high growth and major changes in Higher Education Institutions (HEIs) and their operation so as to be aligned

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D. Plemenos & G. Miaoulis (Eds.): Intelligent Computer Graphics 2012, SCI 441, pp. 41–57.
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with public sector financial management systems [1]. Modern institutions face specific challenges in order to incorporate governance and financial accountability regarding their research projects and goals. In addition, the importance of university research has been significantly promoted by the Lisbon Declaration in 2000. As a result, the evaluation of research activities in HEIs has become a core constituent of institutional management and a lot of evaluation systems have been developed in this direction [2].

The literature on evaluation systems is focused on the different methods that are used in order to assess research outputs [3][4][5][6], i.e. publications in combination with science metric indicators (e.g. the H-index), scientists' engagement in technology transfer activities such as patenting, spin-off firms, and research contracts [7].

Governments and HE agencies are implementing strategies to improve academic efficiency and ensure optimal utilization of resources [8]. Along with increasing necessity, there has been a shift in the thinking of the research policy in supporting university research activities. In our approach we implement a decision support system which can be described as a continuous process of collecting and analyzing data to compare how well a policy is being implemented among different choices for the purpose of a defined goal. Due to the complexity and the great number of different parameters that describe the field of research activities in HEIs we have created an ontology (owl) which consists of all the key concepts and their relationships. The benefit of the ontology is that the user and the system can communicate on a shared semantic basis as it provides common understanding of a domain. The aim of this paper is to develop an ontology based framework for the analysis and evaluation of the research eco system of a HE academic unit. The main concept of this framework is to provide research managers with the ability to make decisions on specific research aspects (e.g. analysis of researcher profiles based on science metrics) using data visualizations. In addition, the user can formulate and store decision rules (SWRL) in order to enrich the ontology. Our approach builds upon an Analytical Hierarchical model for supporting decision making and the Parallel Coordinators visualization technique that enables representation of options in an interactive way. Our system integrates functionality for the assessment of the faculty members of an academic unit with regard to their research publications and projects. Through our prototype the user is able to form composite criteria, set explicit weights for each of the indicators according to his priorities and get the corresponding representation. On this basis, the paper presents an example of research result and activity ranking for individual researchers or research groups.

The paper is structured as follows: Section 1 introduces the importance for Institutional Research Management in HE and outlines the followed approach. Section 2 provides a brief description and background on Decision Support Systems (DSS). Section 3 illustrates the developed ontology and Section 4 describes the specific methodology. Section 5 presents a concrete case study for an academic unit (Department of Informatics) of a Greek HEI and Section 6 discusses the implementation issues. Finally, results of applying the proposed framework for setting a specific decision support goal and future plan are described in Section 7.

2 Decision Support Systems in HEI

Higher Education Institutions are confronted with increasing pressures to improve the quality of education and management processes, in combination with their research activities. The decision-making process in HEIs should be planned and resolved in a comprehensive, reliable, and transparent manner [9].

Decision support systems are computer-based information systems that support decision-making activities A properly designed DSS is an interactive software-based system intended to help decision makers compile useful information from a combination of raw data to identify and solve problems and make decisions. Various academic DSSs have been proposed for handling issues, such as resource allocation [10][11][12], workload management [13], course scheduling, admission policy [14], advising [15] , and strategic planning [16].

In our system we attempt to deploy information visualization techniques into decision support methods. Information visualization is used to provide suitable methods and instruments to explore and depict data and information through graphical representation. Decision support is a process of reporting data in alternative ways for the purpose of attaining a goal. In the literature several methodologies have been deployed in this field as the trial and error methodology [17] which relies on the interaction between users and the visualization system to derive satisfactory results with minimum assistance from the computer. The design galleries methodology [18] is a data-centric approach that relies on limited knowledge of any underlying data model. In this approach the visualization system automatically selects parameters and generates a set of visualizations, from which users selects the most relevant and useful ones. This process is repeated until satisfactory visualizations are obtained. The information-assisted methodology extracts more abstract information from data (e.g., histogram [19], cluster [20] and topology [20]), and uses it to guide users in their interactive visualization process.

In this paper we propose a methodology for the evaluation of faculty members' research activities. The main difference of the proposed approach is that we have developed an ontology-based framework for the analysis and evaluation of the research system in a HEI academic unit. Our methodology has been integrated into a decision support system for the assessment of faculty members' activities of a university academic unit and we define the decision support rules using data visualisation.

Our main result is the support of the decision-making process by using data visualizations. In addition, the user formulates and stores decision rules (SWRL) in order to enrich the ontology with his rules. In addition, the user is able to form the composite criteria, set weights for each indicator according to his priorities and get the corresponding representation.

3 Research Ontology

An ontology provides an explicit conceptualization that describes the semantics of data. It consists of concepts, relationships and attributes. The ontology used in our application has been developed using Stanford's Protégé tool [22] and is expressed in RDF/OWL [23]. In order to represent the research activities we created an ontology based on Vivoweb [21]. Furthermore, we reconstructed and adapted the ontology so as to be aligned with the profile of a concrete academic unit (TEI of Athens, Department of Informatics).

The Research ontology consists of seven areas (concepts or entities or classes) which enable decision makers to perform evaluation, by attributing weights at each one level of the hierarchy through a cooperative judgment process and consistency index. These criteria areas are the following:

- Event
  (Research Events such as publications)
- Project
- Country
- Role
  (Project coordinator, Leader, Grant holder, Teacher, Presenter, Editor,...)
- Equipment
- Academic Degree
  (MSc, Phd,)
- Person
  (Faculty member, Scientific personnel, Student)

Figures 1 and 2 depict the proposed research evaluation ontology, which combines the terms of the research evaluation, as well as 'is-a' inherent relations of semantic linkages among all of those selected terms.

4 Methodology for DSS Using Ontologies

Our system launches an in-depth study of research activities with the aim to develop the appropriate Decision Support System. The tool which has been developed combines data mining and decision support with a modified ontology model. Our implementation was accomplished using an ontology which represents the faculty members' research profile in a HE academic unit by employing a multi-criteria decision support technique. Our ontology model has the possibility to be extended and integrated into Decision-Making systems. In our approach we use two models:

- The Visual Oriented Decision Support (VODS)
- The Analytical Hierarchical Process (AHP)

For both models our system encompasses the following stages (Figure 3).

Stage 1: Set up of the DSS goal
Stage 2: Dynamic synthesis of the evaluation criteria
Stage 3: Execution of the query using Sparql
Stage 4: Report generation
Stage 5: Data visualization
Stage 6: Storing of the evaluation criteria as rule

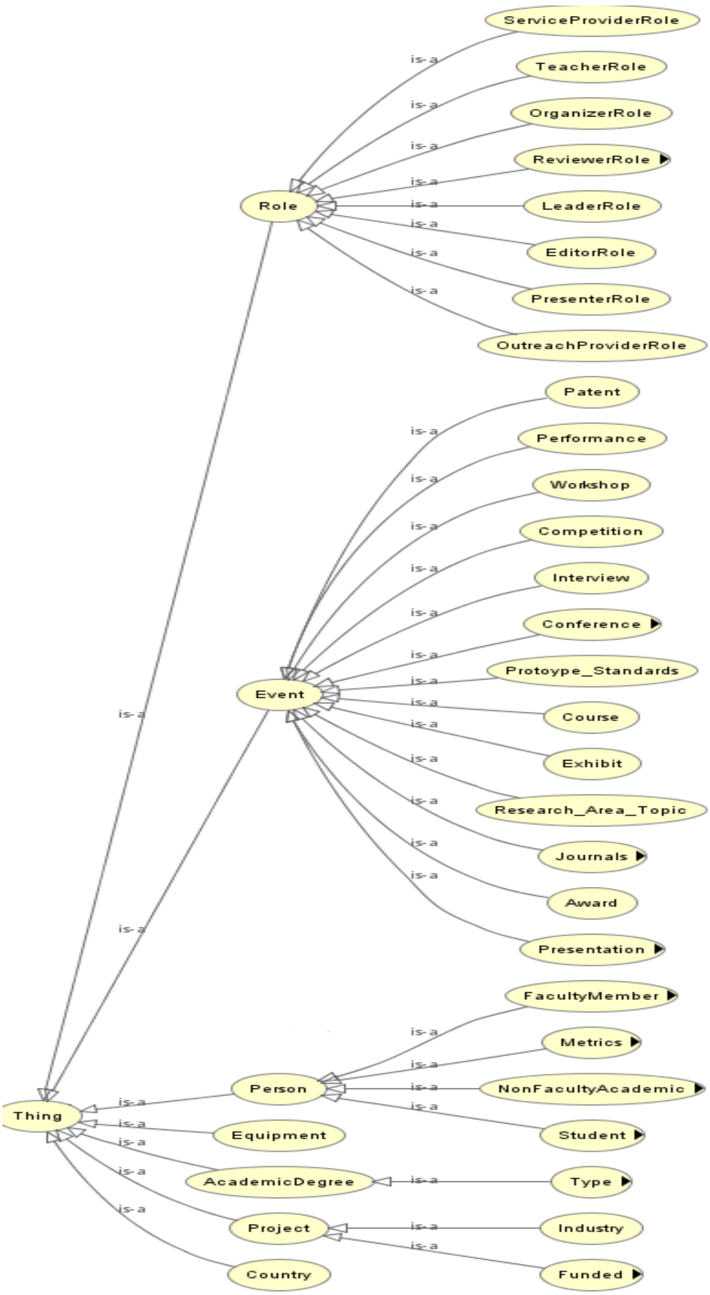


Fig. 1 Research Evaluation Ontology

Fig. 2 Research Evaluation Ontology describing Person-Project

Our prototype implements knowledge-driven query formulation using drag and drop methods for SPARQL generation. Users are guided in formatting the query using the ontology which has been built in owl format depending on the visualization form that he has selected. Queries translated into SPARQL are sent to the server and the results are presented to user in different visualization interfaces [24]: We use a tree representation for AHP and an interactive parallel coordinator diagram for VODS. Well defined formulated decision support criteria may be stored in the system in order to enrich the ontology with new rules.

Our objective is to allow users to define their queries by using a domain model expressed in owl and then store these criteria as rules in the ontology using the SWRL. This functionality is considered of high importance due to the fact that usually resources are shared and the decision makers need to get quick and accurate decisions.

In Figure 4 we illustrate how the user can choose either to use predefined criteria or to build new ones. Pre-defined criteria encompass SWRL rules which have been implemented using the Pellet Rule Engine which takes one set of input data, applies the rules and base facts to perform the decision task and return the results to the user. On the other hand, the user could form a query using the classes and the associations of the ontology. The application has been developed using J2EE technologies and the Pellet Reasoner.

Pellet is the first sound and complete OWL-DL reasoner with extensive support for reasoning with individuals (including nominal support and conjunctive query), user-defined datatypes, and debugging support for ontologies [26].

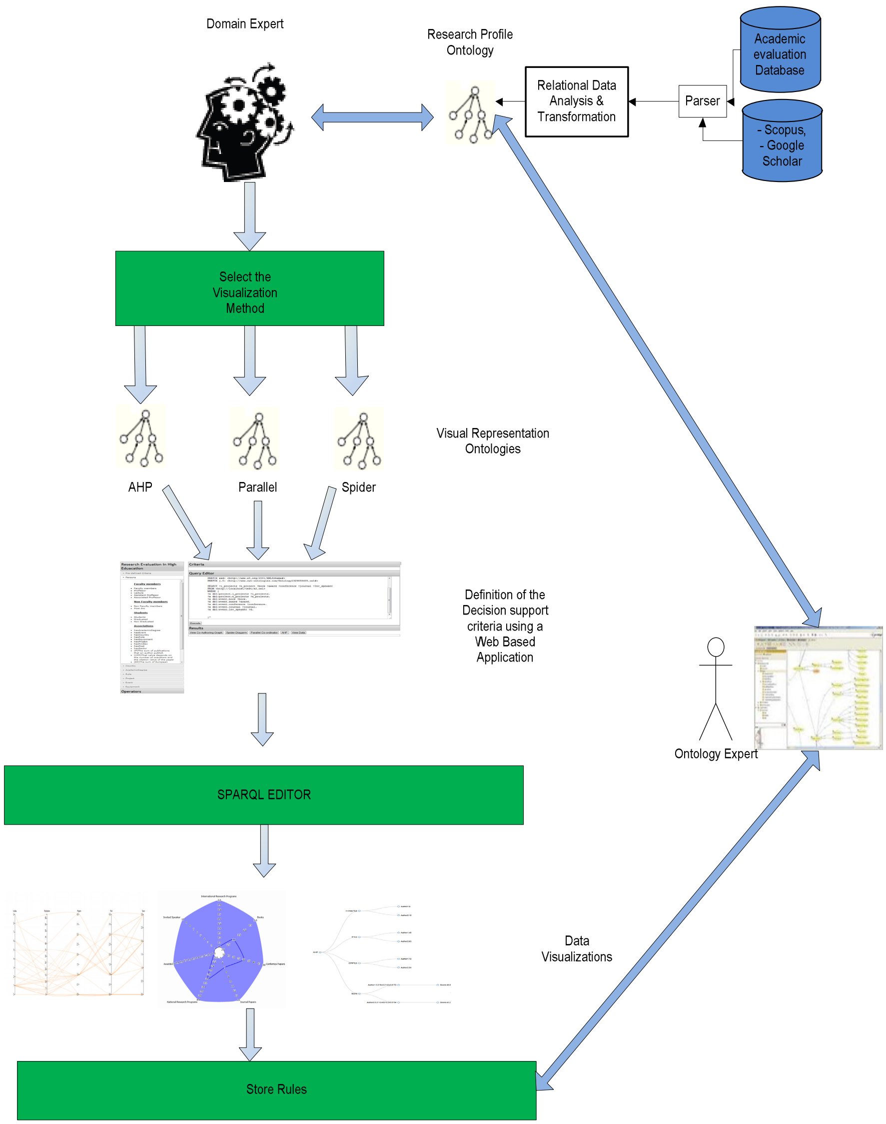


Fig. 3 DSS Web based Application

5 Case Study

The case study conducted is based on information and data from a Greek Higher Technological Educational Institution [6], obtained through our prototype software system which supports the overall process using data visualization. Papers and their citation were collected from the Quality Assurance Unit (QAU) of the Institute, Web of Science, Scopus and Google scholar, for the time period between 2006 and 2009. Faculty members' research areas were retrieved from their publications. Subsequently, their publications were classified across 233 subject areas also known as JSC from Thomson-Reuters. The Department of Informatics is divided into 3 sectors:

1. Sector of computer programming
2. Sector of information systems and applications
3. Sector of computer systems and networks

Table 1 Evaluation data for 2006-2009

No. of papers	233
No. of Authors	25
No. of Citations	276
No. of Research Areas	28
No. of Projects	51
Sectors	1. Sector of computer programming
	2.Sector of information systems and applications
	3. Sector of computer systems and networks
Faculty post	1.Proffesor
	2. Assistant Professor
	3. Associate Professor
	4. Lecture

6 DSS System Implementation

6.1 Visual Oriented Decision Support

One of the most common research evaluation criteria is to provide the most qualified researcher among the faculty members. Using our system the user is given the ability to apply a set of criteria depending on his objectives, e.g. in order to answer the above question a composite criterion could be formed, consisting of the relations *hashindex* (which is an index that attempts to measure both the productivity and impact of the published work of a scientist), *hasProject* (the sum of the research papers), *P* (the sum of publications that an author publish), *hasSector* (the sector that he belongs) and *hasPost* (the faculty post).

In order to form the query the user should drag the fields from the left frame and drop them to the criteria frame. Figure 4 shows a corresponding instance of our application. At the left frame the user could view all the classes of the ontology, the corresponding associations and operations. The users are allowed to use only one area of criteria (e.g person) the union of them and the existing operators.

After formulating the composite criteria, the user may evaluate the performance on those criteria in order to take the appropriate decisions. The user may interactively set the efficiency criteria for the corresponding data and get visual comparative results for the faculty members that fall within a given value range.

The parallel coordinator visualization method provides the extraction of that knowledge. Parallel coordinate plots were introduced by Inselberg [29] for some recent work) and also discussed by Wegman [30], who proposed applying them in data analysis. They enable the display of multi-dimensional data in two-dimensional space. Each dimension is represented by a vertical axis (hence the name — all axes are parallel to each other) and values for a particular case are linked by lines. There must be some loss of information but this can be partly counteracted by varying the order of the axes. Different orders give different views of the multi-dimensional space. Interactivity is valuable for reordering the axes flexibly and fast. Interaction is also valuable for dealing with the dense mass of lines produced by large data sets. Being able to select subgroups of cases, highlight the selected lines, switch between different subgroups, all assist in interpreting the otherwise intricate displays which arise.

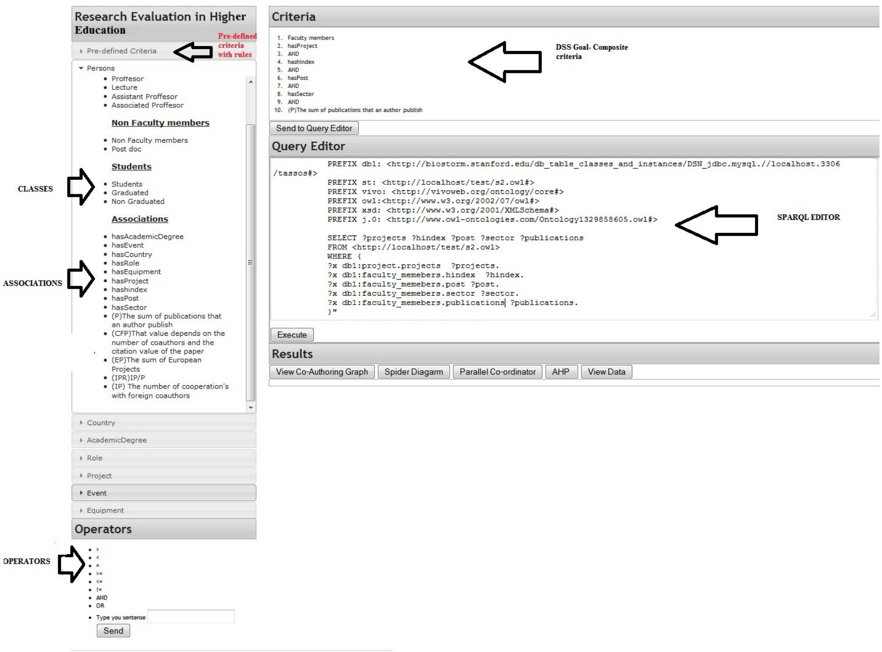
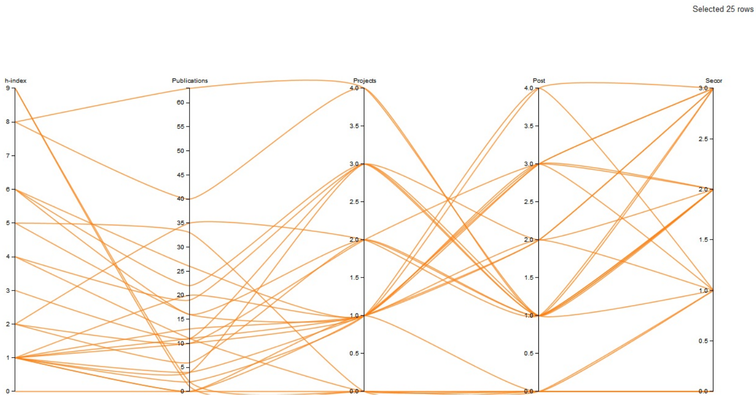


Fig. 4 The web-based DSS Application

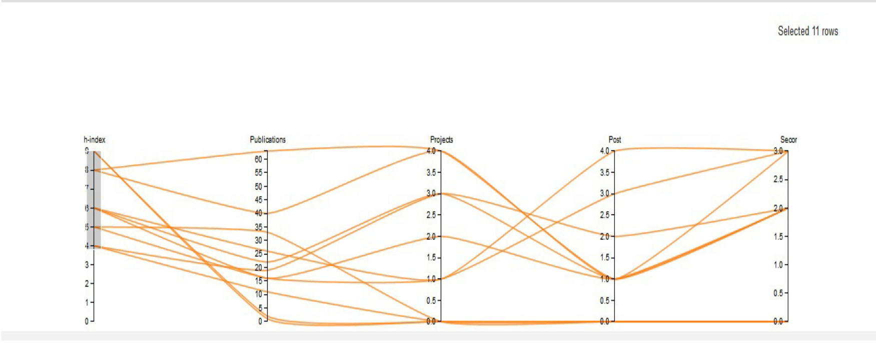
In Figure 5 we can see the parallel coordinator visualization which represents all the evaluated sectors with the faculty members. Using this representation the user has the ability to set manually filters and select only those data that have values at specific desired ranges. So in Figure 5 the user can see all the 25 authors of the department. Figure 6 shows the application results of the h- index criteria and specifically the authors with h-index among 4 and 9.

The fundamental interaction technique in parallel coordinator browsers is the brushing [27]. It may be used so as to select a set of polylines and zoom into them. In our example we have selected to view only the researchers who have h-index value among 4 and 9 and make pair wise comparison in order to observe the current situation or select the most suitable according to the specified criteria. For example, in figure 6 we can see there are 11 members who have h-index within the specified range.



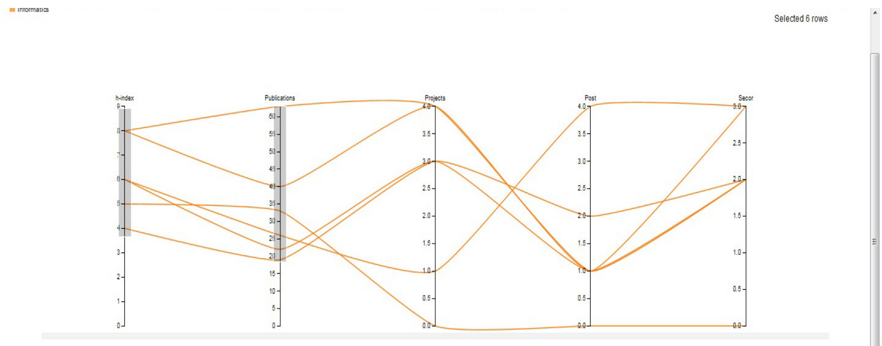
name	group	h-index	Publicati...	Projects	Post	Secor
12	Informatics	8	63	4	1	2
17	Informatics	2	35	2	1	3
23	Informatics	6	26	1	4	3
18	Informatics	8	40	4	1	3
14	Informatics	4	19	3	2	2
10	Informatics	6	16	2	1	2
58	Informatics	5	33	0	0	0
5	Informatics	1	20	1	3	1
3	Informatics	1	11	1	2	1
11	Informatics	6	22	3	1	2
15	Informatics	2	10	2	3	2
21	Informatics	5	16	1	3	3
16	Informatics	1	10	1	3	2
20	Informatics	1	13	1	2	3
13	Informatics	3	11	3	1	2
33	Informatics	4	11	0	0	0
9	Informatics	2	6	2	1	2
19	Informatics	1	4	1	2	3
8	Informatics	1	2	1	4	1
26	Informatics	9	1	0	0	0
27	Informatics	9	2	0	0	0
4	Informatics	1	0	1	0	1
22	Informatics	1	0	1	3	3
2	Informatics	0	0	0	0	1
1	Informatics	1	4	3	1	1

Fig. 5 Parallel coordinator for all the faculty members without any criteria



name	group	h-index	Publicati...	Projects	Post	Secor
12	Informatics	8	63	4	1	2
23	Informatics	6	26	1	4	3
18	Informatics	8	40	4	1	3
14	Informatics	4	19	3	2	2
10	Informatics	6	16	2	1	2
58	Informatics	5	33	0	0	0
11	Informatics	6	22	3	1	2
21	Informatics	5	16	1	3	3
33	Informatics	4	11	0	0	0

Fig. 6 Show all the faculty members with h-index value besides 4-9



name	group	h-index	Publicati...	Projects	Post	Secor
12	Informatics	8	63	4	1	2
23	Informatics	6	26	1	4	3
18	Informatics	8	40	4	1	3
14	Informatics	4	19	3	2	2
58	Informatics	5	33	0	0	0
11	Informatics	6	22	3	1	2

Fig. 7 Show all the faculty members with h-index value besides 4-9 and have publications mare than 19

Figure 7 shows the search results of the criterion that concern the number of publications and, specifically, the authors who produce more than 19 publications. In the same way, at this step the user could set as filter to view only the researchers who have taken part in more than 3 projects. Using this kind of visualizations, the user has the ability to set priorities by selecting the range of values for the examined sectors. So the user defines the priorities by observing the overall quality of all the faculty members. We thought that it is of high importance for a decision maker to get decisions in that way, because at any time he could change the ranges of the values or the order of the filters so as to get different results and different decisions. Furthermore, if we extend the experiment to take into consideration all HEI faculty members and use the thematic areas as the examined sectors, we can view the trend of the publication by observing where the most lines cross the axe of these criteria.

For example, in our case study we have 5 axes (h-index, Publications, Projects, Post and Sector) the values of these axes depend on the values that each of the members gets with regard to the specified criterion: the min value for the publications among the members is 0 and the max value is 63. In addition, we can see that author with id 12, who belongs at the Department of Informatics, has h-index 8, 63 publications, has participate in 4 projects his post is 1, meaning that he is a Professor and he belongs to the "Information Systems and Applications" sector of the Department.

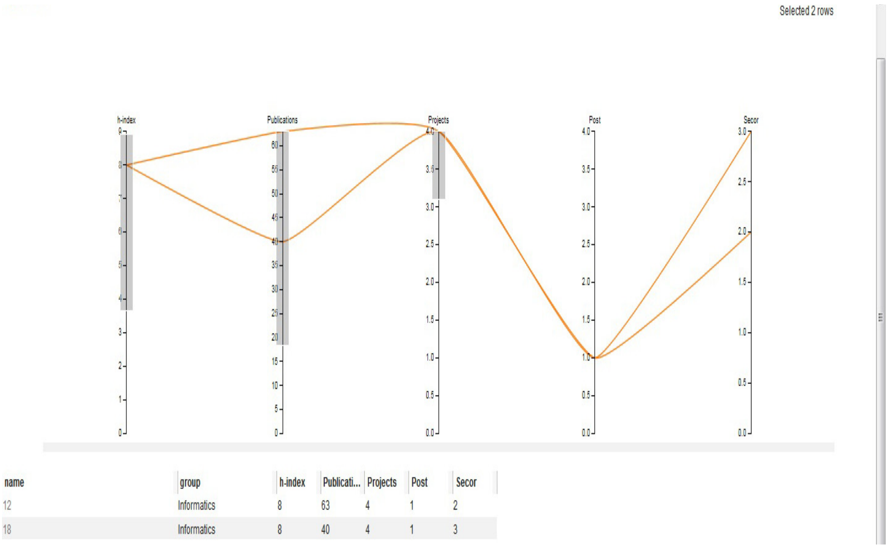


Fig. 8 Show all the faculty members with h-index value besides 4-9, publications more than 19 and have participate in more than 3 projects

So in our example, the user initially sets the criteria and subsequently gets figure based results in order to answer the question "Who is the most qualified researcher". Using the parallel coordinator, he sets the ranges to examined sectors for that decision support goal. During the process of parallel coordinators, the user may submit the criteria with their ranges to the administrator, in order to enrich the ontology with that rule and be available for future use. Table 2 depicts the rule corresponding to the aforementioned question.

Table 2 DSS Rule

DSS goal	Rule
Who is the most qualified researcher	Person(?p) ∧hashindex(?p,?hindex)∧swrlb:greaterThan(?hindex,4) ∧hasPublications(?p,?publication)∧swrlb:greaterThan(?publication,19) ∧hasProject(?p,?project)∧swrlb:greaterThan(?project,3) →sqwrl:select(?p)

The types of queries that our system supports are:

- Linear
  e.g. "Find all the authors with their publications "
- Filtering
  e.g. "Find all the authors who have more than 10 publications"
- Structured
  e.g. "Find all the authors and the corresponding co-authors".

6.2 Analytical Hierarchical Process

At this kind of representation we simulate the Analytical Hierarchical model [28] with the interactive tree diagram in order to answer the question "Who is the most qualified researcher" in a different way. Here the user can set weights to the examined sectors and get the corresponding scores for the authors. The analytical hierarchical method consists of the following stages:

> *Stage 1*: Set up the hierarchy, which means that the user selects a sample from the left frame and defines the evaluation criteria. In Figure 9 we can see an instance of our application where the user has selected only two researchers to evaluate and to compare them on the basis of the number of publications (Productivity), the value of h-index and the citation values of the papers (CFP).
>
> *Stage 2*: Set the priorities-weights at these criteria. In figure 9 the user has set the weights as follows:
>
> h-index * 0.2
> Productivity * 0.2
> CFP * 0.5
>
> *Stage 3*: Calculation of the overall weights. As we can see in our example (table 3) the scores of the members (authors) are the following.
>
> Author1= 46.8
> Author2= 43.2
>
> *Stage 4*: The last phase is the corresponding representation using a tree diagram.

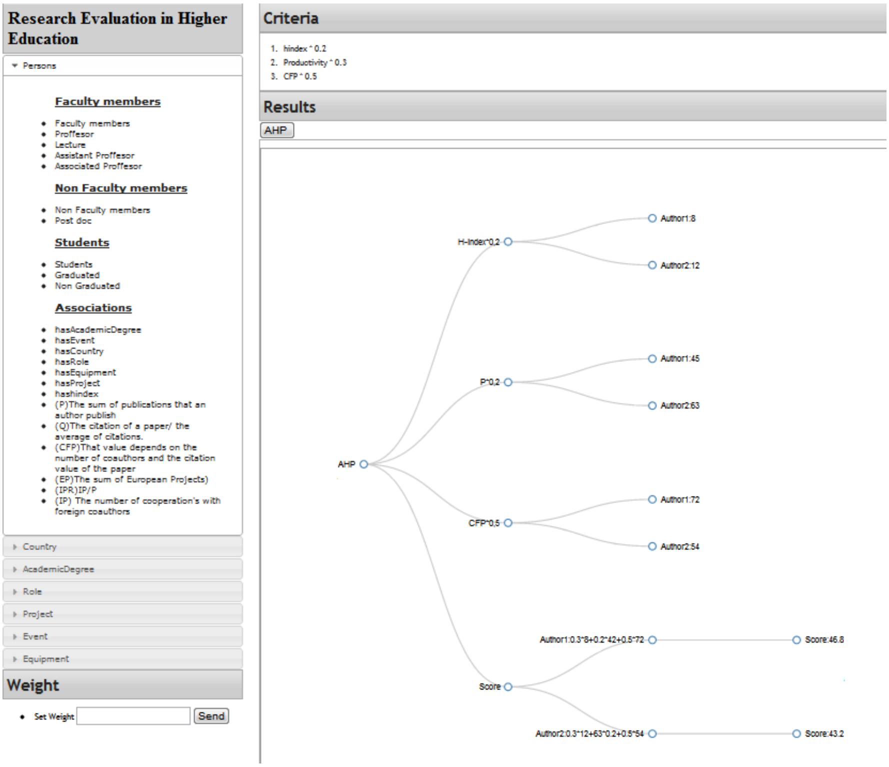


Fig. 9 Analytical Hierarchical model

Table 3 AHP Calculations

Weights for Author 1 8*0.2+45*0.2+72*0.5=46.8
Weights for Author 2 12*0.2+63*0.2+*0.5=43.2
AHP Ranking 1. Author2 =46.8 **2.** Author1=43.2

Table 4 DSS Rule

DSS goal	**Rule**
Who is the most qualified researcher	Person(?p) ∧hashindex(?p,?hindex)∧swrlb:multiply(?sum1,0.2,?hindex) ∧hasPublications(?p,?publication) ∧swrlb:multiply(?sum2, 0.2,?publication) ∧hasCFP(?p,?cfp∧swrlb:multiply(?sum3, 0.5,?cfp) ∧swrlb:add(?add1, ?sum1, ?sum2) ∧ swrlb:add(?add, ?sum3, ?add1) →Valuation_Average(?p, ?add)

The user could also store the rule (Table 3) which answers the same question in a different way and using different predicates.

7 Conclusion – Future Work

In our approach we present the methodology and the architecture of an evaluation decision support system for a HEI academic unit. The application field of the described methodology has been a Greek Higher Education academic unit of the technological sector, which has already applied conventional academic evaluation processes. The developed software system is a web application that supports an ontology based decision support using composite indicators through a model that links the decisions with corresponding visualizations. The proposed framework is illustrated by evaluating research activities through a biblio metric - science metric analysis of faculty members. The results are provided through "visual multi-criteria analysis" which enable the user to get the results for the validation of the hypothesis of institutional research policy. The three most significant functions of the system are (a) the possibility of hypothesis-based investigation for composite research fields; (b) the possibility of direct and interactive visualization of sensitivity analysis results for the characteristics of the systems entities such as research staff and publications, projected according to "what if" development scenarios of the given research policy choices; (c) rule definitions using data visualizations.

Future work falls under the prospective to improve the main functionalities of the system. In addition, we will have the opportunity to enhance the system evaluation in a more systematic way, by broader sets of data (included several departments) and by engaging a number of decision makers in the field.

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