A Knowledge-based information system for managing research programs and value creation in a university environment

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ABSTRACT

We describe an integrated information *system* for managing knowledge generated from research and innovation activities in a university environment and for the creation of economic value from the resulting knowledge and innovations by using an action research methodology. The system uses a computer ontology for defining objects and provides both a corporate memory and a distribution vehicle for the knowledge and innovations invented by professors and graduate students. It comprises a set of interrelated subsystems that include scientific publications and innovations, graduate theses, professors, students, and research units. It generates statistics of research activities, a wide variety of reports and on line consultations as well as a search engine and data mining facilities for knowledge extraction. A version of the system has been operational for about a year and has been an important tool for creating wealth from the knowledge generated by the research activities.

Keywords

Corporate memory, Knowledge-based Systems, Ontologies

INTRODUCTION

Knowledge has become a strategic theme in modern society. The level of development and productivity of countries, the income per capita of their citizens and the population welfare are measured in terms of the level of investment in science and technology by the government of those nations. Generating knowledge is a necessity in modern economies, but the most important aspect is the economic value that can be created from the knowledge available in scientific databases and patent repositories. The economic value is often given by the number of technology-based companies, the number of jobs that require personnel with high-level training and skills, and the total revenue of those companies as a percentage of the Gross National Product. The universities of the XXI century play an important role as they become engines of economic development for the society (Etzkowitz and Leydesdorff, 1997).

Managing the knowledge generated by an organization and creating value from that knowledge poses important challenges for any organization. This is true of knowledge-based organizations such as research universities and technology-based corporations. *Knowledge Management* studies the processes around knowledge such as its creation, storage, distribution and use (Liebowitz, 2004). Scientific knowledge is generated mainly in research centers, institutes and academic departments of universities, companies and government-supported laboratories. This knowledge is accepted by the scientific community after a peer-review process and made public by its publication in journal articles, conference papers, technical reports, magazine articles and other means. On the other hand, the inventions and innovations are kept secret until an intellectual protection is obtained by means of a patent, a trade-mark, a distinctive sign, and industrial secret and other intellectual property mechanisms. The scientific productivity of an organization as well as of its researchers is commonly measured in terms of the quality of the journals in which they publish. This quality is frequently determined by the indexes and impact factor of the journal that depends on the number of cites made by articles in other journals. For the invention and innovating knowledge the measure is rather its economic impact that depends on licensing, spin-offs and other financial measures. Combining both types of knowledge seems to be a challenge for knowledge-based organizations.

In this research we focus on the management and value creation of scientific knowledge and innovation in an organization with an emphasis in university environments and in particular, the *Latin American* context. We propose and describe a knowledge-based information system that contains a corporate memory of research products, provides an account of research effectiveness and stimulates the value creation of the knowledge assets of the organization through spin-offs and entrepreneurial initiatives of faculty and students. The next section describes background and related work. Then we present the research methodology that follows an *action research* and *knowledge management* approach; next we explain the knowledge-based information system for research management and value creation; then we specify the publications system and depict its architecture, implementation, deployment and operation. Finally we analyze and compare the results and present conclusions and future work.

BACKGROUND AND RELATED WORK

The rankings of universities, graduate schools and colleges are used for attracting students as well as research grants. Research evaluation is an important component of those rankings that are calculated from weighted indicators that yield a general score. Typical indicators are the quality of journal articles and number of cites, the faculty awards, the formation of graduate students and researchers, research expenditure, and nowadays, the number of start-ups companies generated by the research and development activities of the professors and the students. Research evaluation has created the necessity for an information system that integrates data, information and knowledge for the calculation of these indicators for strategic planning, investment analysis and competitiveness. For instance, America's Best Graduate Schools (Zuckerman, 2004) is based on experts opinion about program quality and statistical indicators that measure the quality of school's faculty, research and students. The Lombardi Program on Measuring University Performance (Lombardi, Capaldi, Reeves, Craig, Gater and Rivers, 2003) considers in its rank Total Research, Federal Research, Endowments Assets, Annual Giving, Faculty Awards, National Academy Members, Doctorates Granted, Postdoctoral Appointees, and Median SAT Scores. Academic Ranking of World Universities[1] is based on several indicators of academic or research performance, including alumni and staff winning Nobel Prizes and Fields Medals, highly cited researchers, articles published in Nature and Science, articles in Science Citation Index-expanded and Social Science Citation Index, and academic performance with respect to the size of an institution.

Publications' indexing services provide valuable statistics about article and patent cites, abstracts and impact factors. Thomson's ISI Web of Science[2], for example, keeps proprietary databases of papers and patents published on a selected set of journals and conferences; articles and journals are ranked through an impact factor based on the number of cites. CiteSeer[3] (Giles, Bollacker, and Lawrence, 1998) and Google Scholar[4] provide this service for free obtaining their information through automatic web data extraction. Patents are available through public databases such as the US Trade Patent Office[5].

There are international accreditation boards that measure the academic quality of universities such as the Southern Association of Colleges and Schools (SACS) and the Accreditation Board for Engineering Teaching (ABET). Also, the national councils for science and technology in various *Latin American* countries like Mexico (Consejo Nacional de Ciencia y Tecnología, CONACyT), Cuba (Ministerio de Educación Superior), Venezuela (Consejo Nacional de Investigaciones Científicas y Tecnológicas, CONICIT), Chile (Comisión Nacional de Investigación Científica y Tecnológica, CONICYT), Argentina (Comisión Nacional de Evaluación y Acreditación Universitaria, CONEAU) and Brazil (Coordinación y Perfeccionamiento del Personal de Nivel Superior, CAPES) evaluate the quality of the research and graduate programs and of its research professors. This creates the need for automated aids in managing the vast amount of data, information and knowledge generated by the research activities which is the main issue addressed in this research. In Mexico, CONACyT

[1] http://ed.sjtu.edu.cn/ranking.htm

[2] http://www.thomson.com/

[3] http://www.citeseer.org/

[4] http://scholar.google.com/

[5] http://www.uspto.gov/

uses an information system to record research products from researcher and graduate programs for evaluation and accreditation purposes. Other Latin American countries address the same issues.

RESEARCH METHODOLOGY

We use an *action research* methodology for analyzing the tasks accomplished by the information system described in this article (Reason and Bradbury, 2004). We also follow a *knowledge management methodology* for describing the processes and products of the information system. Action research is defined in various ways but the main idea is about the capacity of a group of people for analyzing and reflecting about their own activities. The following are classical definitions of action research: Kurt Lewin wrote in 1947 "Action Research is a three-step spiral process of (1) planning which involves reconnaissance; (2) taking actions; and (3) fact-finding about the results of the action"; Stephen Corey wrote in 1953 "Action Research is the process by which practitioners attempt to study their problems scientifically in order to guide, correct, and evaluate their decisions and actions". Finally, (Kemmis and McTaggart, 1988) suggest that "Action Research should have four cyclical phases: Planning – or definition of the problem and organization of research practices. Acting – or implementation. Observing – or action and collection of data: Observation, subsequent reflection and action. Reflecting- and developing revised action derived from what has been learned". The authors are responsible for the design and implementation of an information system for managing research programs at their university. They are also researchers in the field of knowledge and information systems. Thus, they have conducted a meta-level analysis and reflection of their own work by applying an action research methodology to their own work and have described the information system as a case study.

On the other hand, a knowledge management methodology has been applied as part of the research action project (Liebowitz and Beckman, 1998). The KM methodology comprises the following steps: *Identify, Collect, Select, Store, Share, Apply, Create and Sell*. Each of the processes summarized by these verbs are related to the creation of a corporate memory which stores and distributes information and knowledge that is relevant for business operation. They classify corporate memories according to the *capture* and *distribution* mechanisms that are used to build the memory; these mechanisms can be either *passive* or *active* procedures. *Passive capture* and *passive distribution* is just an archive called a *knowledge attic* which is consulted when needed. *Active capture* and *passive distribution* is a repository with automated capture facilities called a *knowledge sponge*. *Passive capture* and *active distribution* is called a *knowledge publisher* which has automatic distribution facilities to interested users. Finally, *active capture* and *active distribution* is a corporate memory called a *knowledge pump*. In this research we regard the knowledge-based information system for managing research programs and products as a *knowledge pump*.

A KNOWLEDGE-BASED SYSTEM FOR MANAGING RESEARCH PROGRAMS AND PRODUCTS

We describe a knowledge-based system for handling research programs and products. The system is regarded as a knowledge-based system because it handles a corporate memory for managing data, information and knowledge; it uses an ontology for identifying objects, and employs reasoning and data mining facilities for extracting useful patterns from databases. We describe each of these elements.

Corporate memory

The system is built around the concept of a *knowledge pump* corporate memory which gathers the research products generated by professors and students through the various research groups and academic programs at the university. The capturing of data and information is an active process done in the following way:

- The system receives information about professors, students and projects by means of an automated on-line interface to the Banner Enterprise Resource Planner (ERP) system that contains payroll, registry and accounting databases.
- The system inputs information fed by professors and students through a semi-automated user interface with pull-down menus. For instance, if the professor feeds in a journal article, the information attributes of that journal are automatically fetched from the journals database in the system.
- This database contains the main journals of the scientific disciplines as well as information about its impact factor and other attributes. The journals database is automatically updated when a new article is published in journal that is not yet in the database. Every new publication is audited to make sure it is correctly classified and all the relevant information has been fed in.

The distribution of information and knowledge is an active process done as follows:

- The system generates automatically predefined reports of publications of various types as well as statistics and indicators by professor, student, department, college, school, campus or university system. One of these reports includes the curriculum vitae (CV) of a faculty member. It also has the capacity for updating personal and departmental web pages.
- The system sends automatic notifications to a co-author of a paper when the author feeds in the paper into the system. It also sends professors automatic messages when a publication that is relevant to his/her research interests is uploaded

Ontology

Ontologies are a convention for identifying and naming elements from a field of study. Ontologies facilitate the communication among individuals of different disciplines as well as the human computer interaction (Uschold and Gruninger, 1996). The research elements of our system are classified according to the taxonomy shown in Figure 1 from which we define the ontology for defining terms in research processes, actors and products. This ontology is part of the corporate memory definitions in the system.

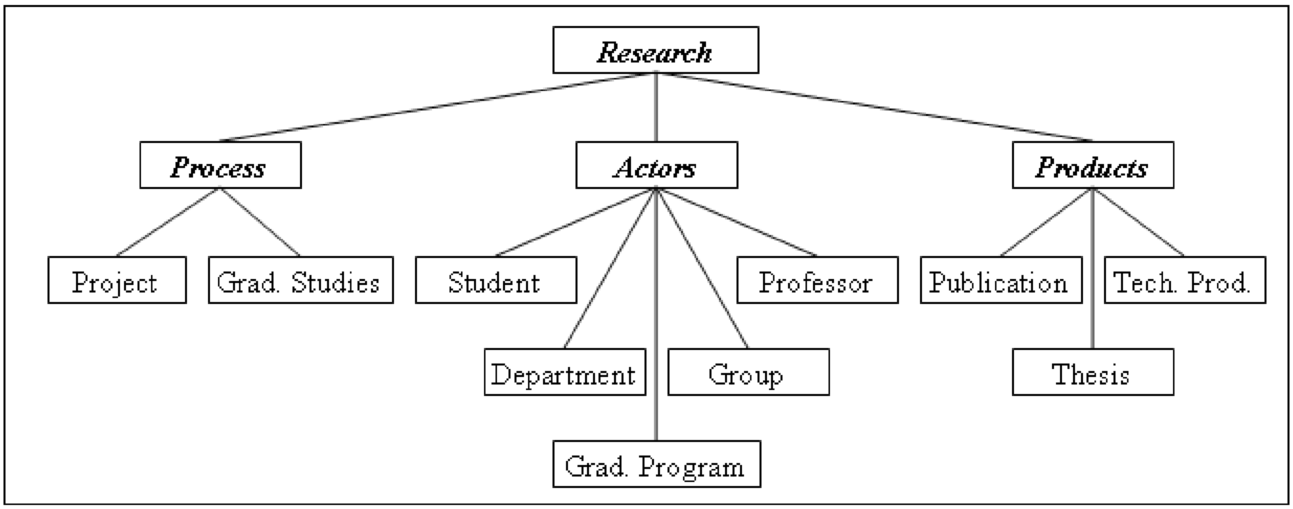


Figure 1. Research Entities Taxonomy

Modules and repositories

The information system is divided into modules that communicate among them through the repositories of the corporate memory. The following are the main modules and repositories:

- *Professors*, concentrates personal and academic information of professors and researchers. The CV is generated from the professors repository
- *Graduate Students*, keeps track of graduate students and generate statistics that measure efficiency of the various graduate programs
- *Projects*, registers and keeps track of research and consulting projects developed by the university for external parties such as companies and government
- *Graduate Programs*, provides a description of master and PhD programs offered by the university including external accreditations and rankings
- *Research Departments and Centers*, concentrates research information about centers and departments
- *Research Groups*, provides information about the research groups in a multidisciplinary manner
- *Publications*, contains the research products like journal and conference articles, patents, books, book chapters, technical reports, etc.
- *Theses*, stores the master and PhD theses published by graduate students and their professors.

Additionally, an administration module was developed, where permissions, catalogs and alerts are managed and configured.

This specification is shown in Figure 2.

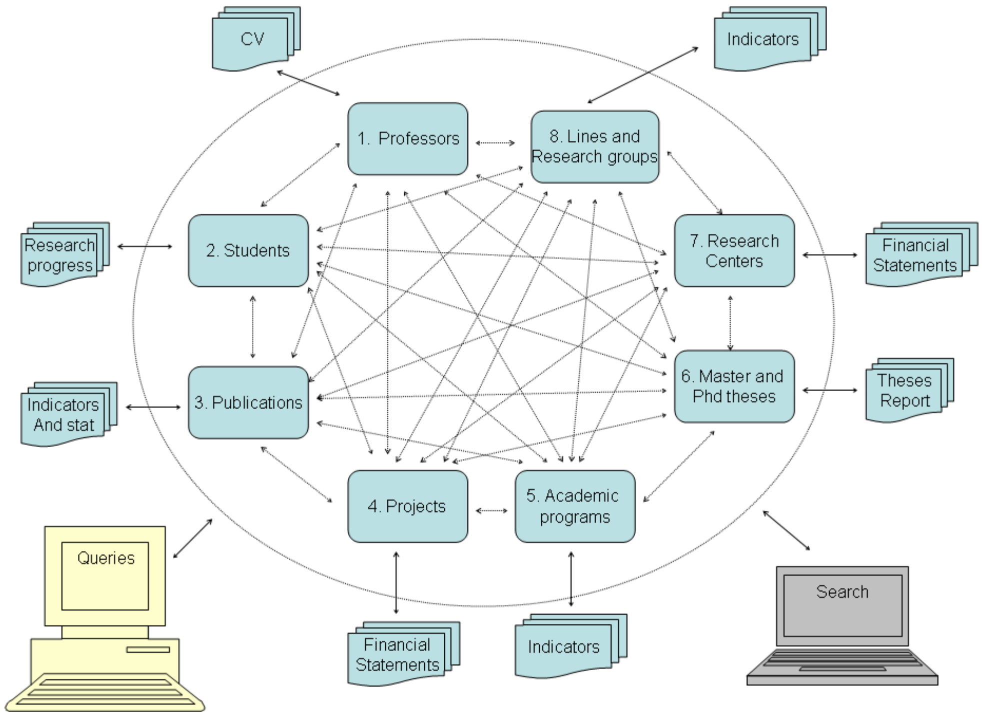


Figure 2. System specification: modules, relationships and reports

Data mining and reporting

Data, text and Web mining techniques are used in the system for extracting useful patterns and knowledge stored in the repositories and in the Web. Data mining is accomplished by using statistical and machine learning techniques that include cluster analysis, regression analysis, factor analysis and hypothesis testing as well as decision tree learning, Bayesian networks, neural networks, fuzzy logic, case-based reasoning and social network analysis (Berry and Linoff, 1997). A similar process can be done with internet sources assisted by tools that mine the web (Gottlob and Koch, 2004). The approach used for processing queries from Web sources is an adaptation of the *global-as-view* (Cali, Calvanese, De Giacomo and Lenzerini, 2003). Data and Web mining techniques are applied off-line to the system repositories; their implementation is at various stages of development within the system.

PUBLICATIONS MODULE

One of the most important modules in the system is the publications module. Information about publications represents a high volume of data and is a rich source for generating scientific information and knowledge for external users. This module is connected practically with every other module in the system.

Publications ontology

We revised existent taxonomies for classifying publications, such as the ones provided by *Latex*, indexing organizations, and national councils for science and technology. From these standards we designed a new taxonomy that serves the university objectives and meets the external requirements from accrediting and ranking organizations. Publications were classified at the top level as *refereed* and *not refereed*. Refereed publications are divided into *specialized* and *not specialized* publications whereas non-referred publications are divided into *books* and dissemination or diffusion papers. The taxonomy is shown in Figure 4.

The value associated to a publication depends on the type of publication. We identify scientific value as well as economic value. Journal articles are assigned the highest score. This depends on the prestige of the journal that is determined by its *impact factor*. The impact factor depends on the number of cites the articles receive from articles of other journals (Garfield, 1999). The accreditation of researchers, programs and universities as well as faculty awards strongly depend on this measure. On the other hand, the economic value of a publication such as a patent is dependent upon the royalties and revenues obtained as a result of the licensing of technologies and products developed around those inventions for commercial purposes. Universities in the XXI century face the challenge of making these two views of publications coexist in a sustainable way (Etzkowitz, 2001). In order to assure the correct classification of a professor's publications an auditing was conducted to avoid miss-classifying publications. An example is classifying a conference paper as a journal article.

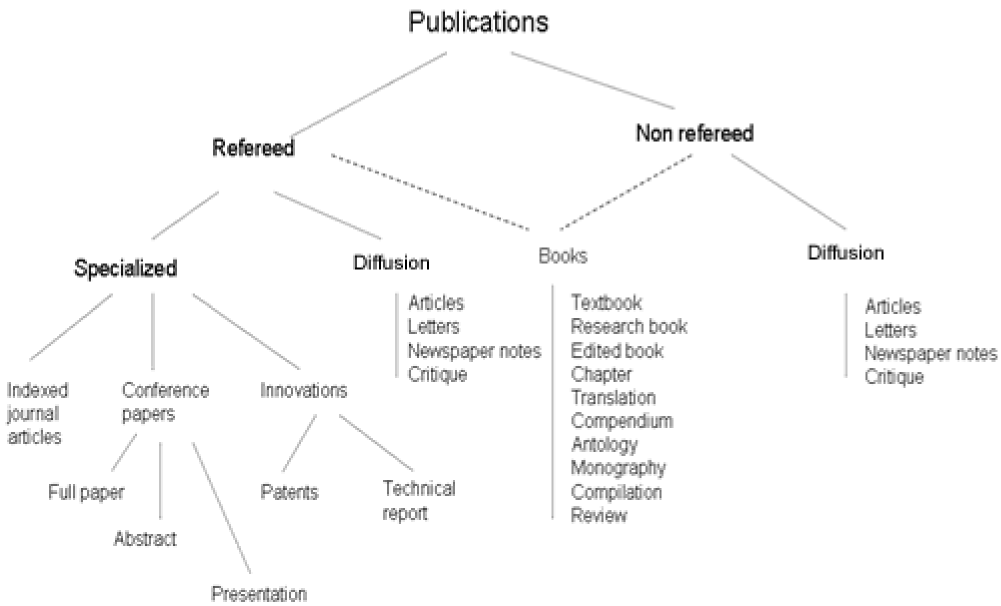


Figure 4. Publications Taxonomy

Publications Repository

The repositories are designed in terms of entities, attributes and relationships. The conceptual model is mapped into a relational database. This model is implemented through classes that serve as a gateway between schemas and data in order to register and recover information. Among the schemas represented are *Article*, *Book*, *Translated-Book*, *title, editorial, pages*, etc.[6]

User interfaces for capturing publications were designed for every type of publication and contain different attributes depending on the nature of the publication. They appear on the principal menu in order of importance; for example, *Journal Article* appears in first place, whereas *Program Committee Member* appears as part of *Support Activities*.

We consider relationships between the publications module and other modules or repositories. For instance, *Professors, Students*, *Projects* and *Research groups* are entities that keep a relation with the publications module. Association interfaces provide a way to search through the database in answering user queries.

System Implementation, deployment and operation

Currently, the *publications module* and parts of the *professors, students*, *research centers* and *academic programs* modules are implemented and have been operational for about a year. A version of the system was developed using open source software like PHP and My-SQL. Additionally, development was improved with the use of the Model View Controller

[6] Nomenclature: Entities starts with capital letter meanwhile attributes don't. Underscore is not used in names.

(MVC) framework Mojavi[7] and the IWT library[8], which modularizes the Web page construction with the use of custom classes. The publications module was the first module implemented because of its importance and difficulty due to the lack of structure and the spreading of information over the university departments and centers. Figure 5 shows the system architecture. Using the Mojavi's framework, code was organized into modules including a system administration module. Authentication is done through the institution mail server, meaning that only users with a current mail account can log in. Roles, users and repositories are stored in a single My-SQL database.

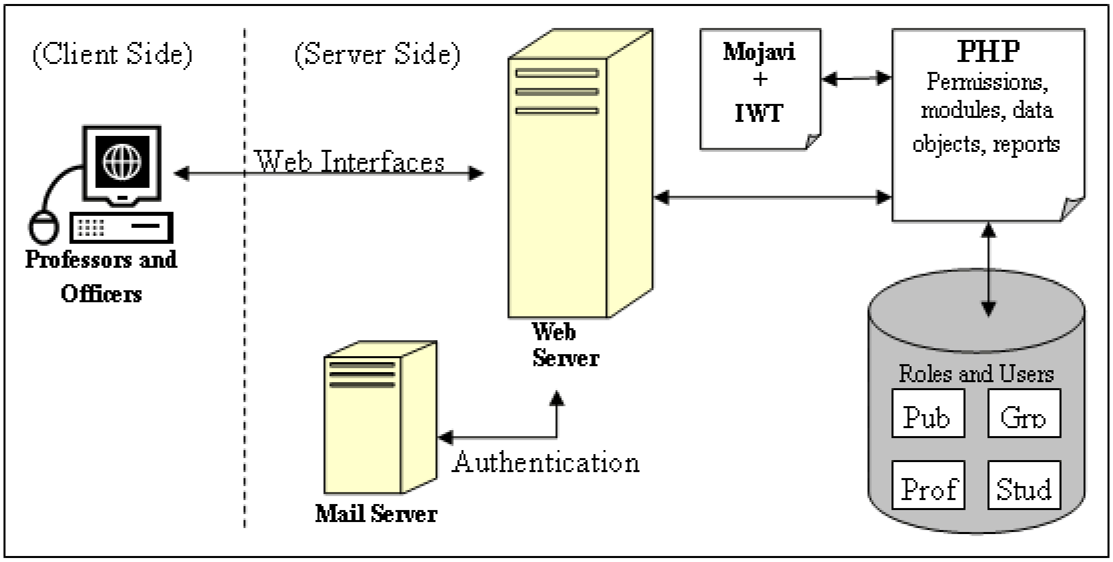


Figure 5. System Architecture

We developed a user interface for the publications module. For example, author association to a publication is made through a custom interface. Figure 6 shows the author association interface displayed over the *Journal Article* register screen.

Mojavi classes named *pagers* are used to generate detail reports for every publication type. Entity characteristics solicited in the report are passed to these classes as parameters. Report formatting is made in bibliographic style as can be seen in Figure 7. Icons shown in the right of every publication are used for editing or deleting purposes. Additional information is found at the left of every publication, for example the blue icon in the figure denotes association of a publication with a research group.

[7] Mojavi: http://www.mojavi.org/

[8] EnsiTech: http://www.ensitech.com/, http://idem.sourceforge.net/

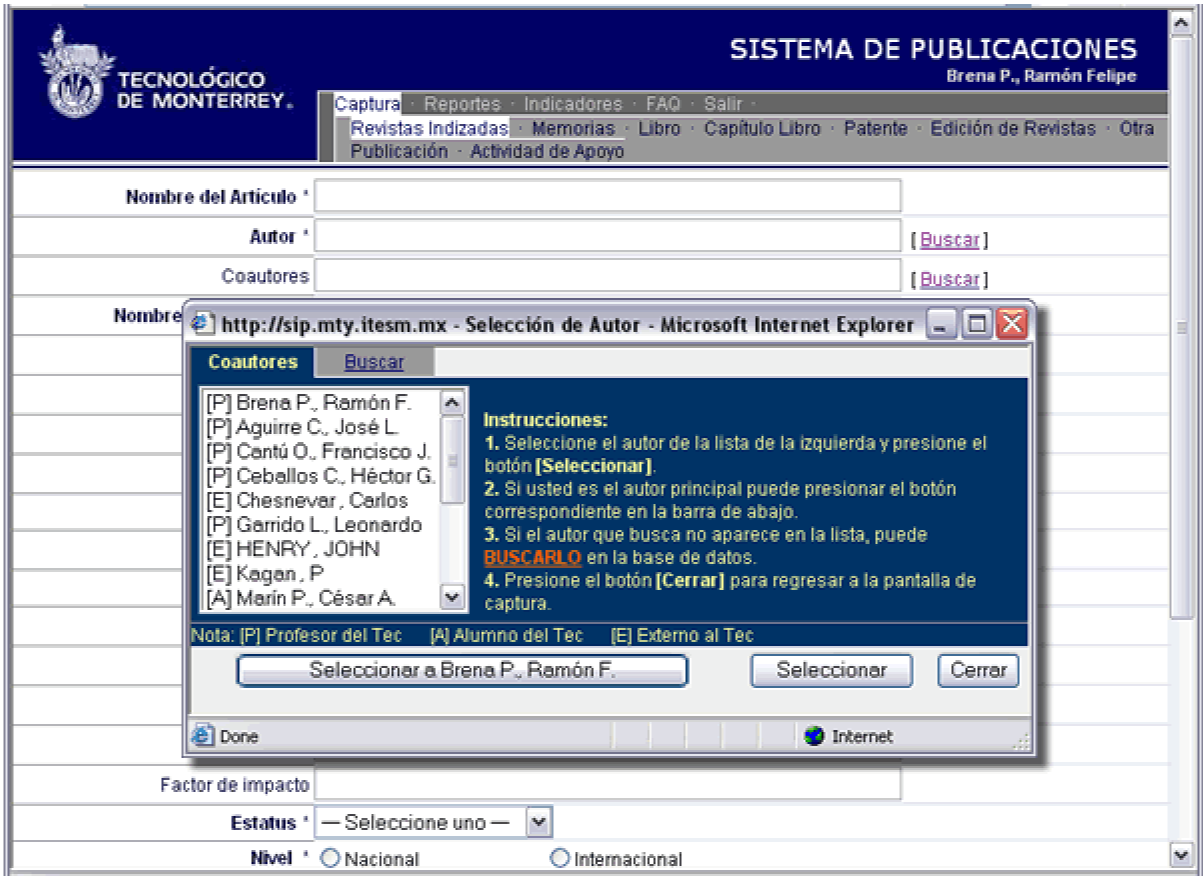


Figure 6. Author association interface

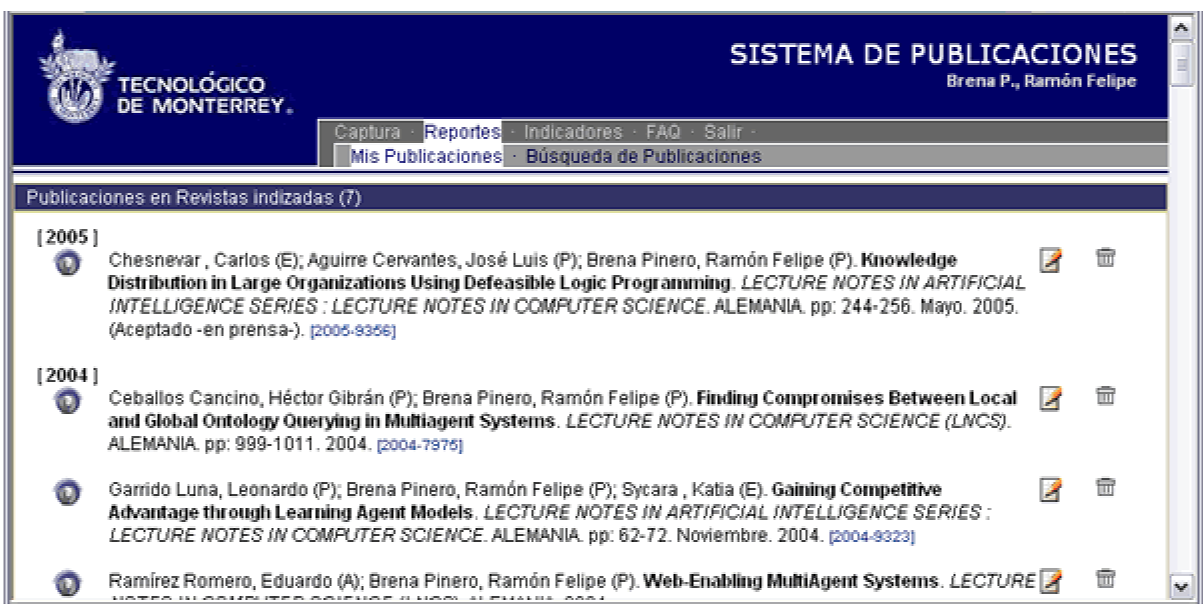


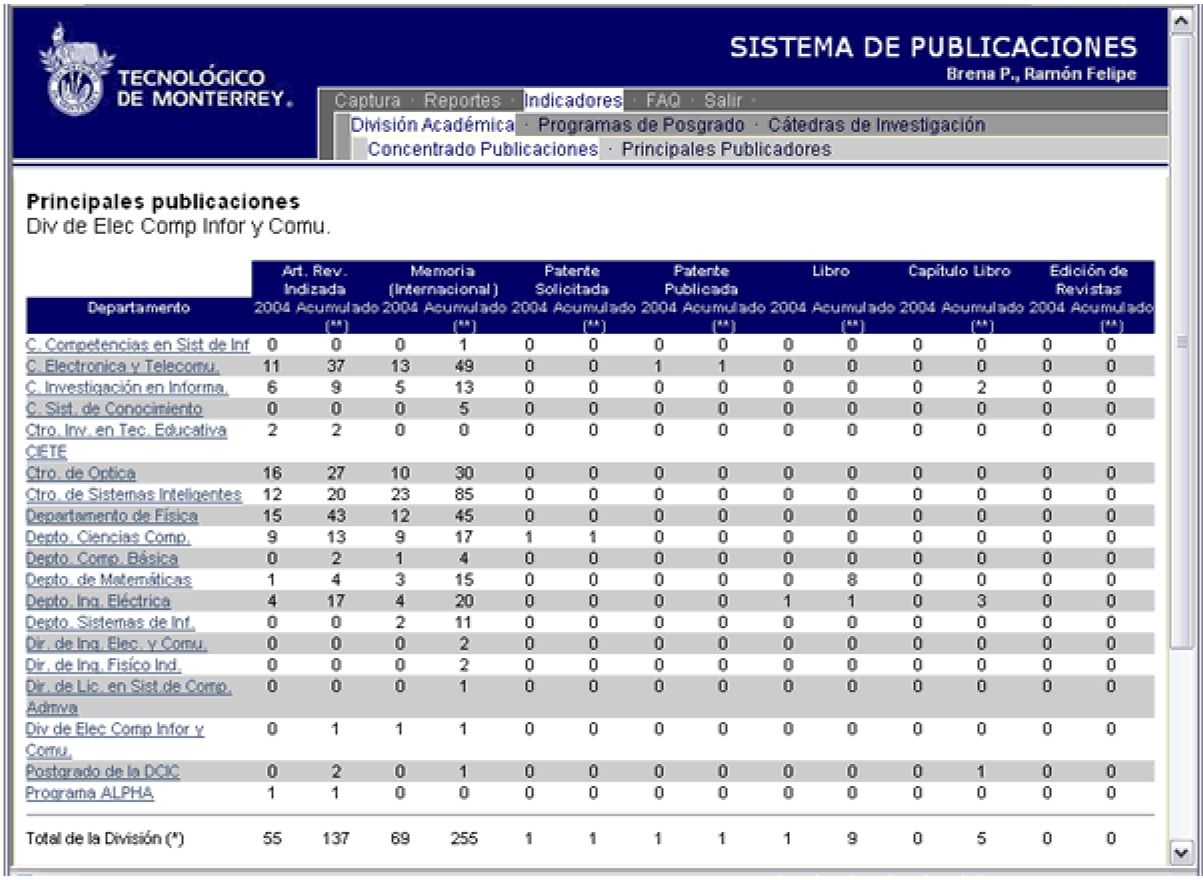
Figure 7. Publications Listing

Indicators are generated in a more elaborated way that listing reports. Two main considerations in their design were (1) generating reports according to the taxonomy categories and (2) the ability to drill down and roll up the information. First, dimensions were defined according to the hierarchy of concepts over which it is possible to navigate; for example, in an organizational report the dimension is given by Campus => School => Department => Person. Then SQL templates were defined in which scope, publication type and detail level are passed as parameters to a function that builds the query. Results are given in a standard format letting build matrixes that conform the indicator report. There is a PHP template that formats the results and creates links for navigation throughout reports. An example of an indicator report is shown in Figure 8.

Data, text and Web mining is done off-line using a machine learning environment developed by the authors and their students (Gutierrez et al, 2002; Frydman et al, 2004; Ceballos et al, 2004; Rios and Cantu, 2003; Carrillo et al, 2004; Robles et al, 2005; Cantu et al, 2005). Computer files are generated by the system and fed into the machine learning environment for knowledge extraction. Machine learning techniques include the following:

- Decision tree learning: includes the rules C4.5, GINI, CHAID
- Statistical learning: Cluster, regression, factor analysis, analysis of variance and hypotheses testing
- Bayesian learning: Bayesian classifiers, Bayesian networks, Dynamic Bayesian networks, Hidden Markov Models
- Connectionist learning: feed-forward neural networks
- Other learning techniques: fuzzy reasoning, genetic and evolutionary algorithms, simulated annealing, nearest neighbor, association rules, case-based reasoning

Patterns found using these techniques regarding students include student behavior in curriculum enrollment, heuristics for assigning students to projects, student graduation on time, etc. Similar patterns have been found for faculty members, projects, research groups, graduate programs, etc.



Principales publicaciones
Div de Elec Comp Infor y Comu.

Departamento	Art. Rev. Indizada 2004	Art. Rev. Indizada Acumulado (**)	Memoria (Internacional) 2004	Memoria (Internacional) Acumulado (**)	Patente Solicitada 2004	Patente Solicitada Acumulado (**)	Patente Publicada 2004	Patente Publicada Acumulado (**)	Libro 2004	Libro Acumulado (**)	Capítulo Libro 2004	Capítulo Libro Acumulado (**)	Edición de Revistas 2004	Edición de Revistas Acumulado (**)
C. Competencias en Sist de Inf	0	0	0	1	0	0	0	0	0	0	0	0	0	0
C. Electronica y Telecomu.	11	37	13	49	0	0	1	1	0	0	0	0	0	0
C. Investigación en Informa.	6	9	5	13	0	0	0	0	0	0	0	2	0	0
C. Sist. de Conocimiento	0	0	0	5	0	0	0	0	0	0	0	0	0	0
Ctro. Inv. en Tec. Educativa CIETE	2	2	0	0	0	0	0	0	0	0	0	0	0	0
Ctro. de Optica	16	27	10	30	0	0	0	0	0	0	0	0	0	0
Ctro. de Sistemas Inteligentes	12	20	23	85	0	0	0	0	0	0	0	0	0	0
Departamento de Física	15	43	12	45	0	0	0	0	0	0	0	0	0	0
Depto. Ciencias Comp.	9	13	9	17	1	1	0	0	0	0	0	0	0	0
Depto. Comp. Básica	0	2	1	4	0	0	0	0	0	0	0	0	0	0
Depto. de Matemáticas	1	4	3	15	0	0	0	0	0	8	0	0	0	0
Depto. Ing. Eléctrica	4	17	4	20	0	0	0	0	1	1	0	3	0	0
Depto. Sistemas de Inf.	0	0	2	11	0	0	0	0	0	0	0	0	0	0
Dir. de Ing. Elec. y Comu.	0	0	0	2	0	0	0	0	0	0	0	0	0	0
Dir. de Ing. Fisíco Ind.	0	0	0	2	0	0	0	0	0	0	0	0	0	0
Dir. de Lic. en Sist.de Comp. Admva	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Div de Elec Comp Infor y Comu.	0	1	1	1	0	0	0	0	0	0	0	0	0	0
Postgrado de la DCIC	0	2	0	1	0	0	0	0	0	0	0	1	0	0
Programa ALPHA	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Total de la División (*)	55	137	69	255	1	1	1	1	1	9	0	5	0	0

Figure 8. Indicator Example

ANALYSIS OF RESULTS

There are multiple advantages that have already been obtained by documenting the research products in a corporate memory and reflecting about the benefits that result from such knowledge assets. Among those benefits are the awareness about the importance of publishing scientific results and keeping track of their impact in the scientific community, as well as the relevance of developing intellectual property practices on research products and its economic impact measured in terms of patents, technology licensing, spin-off companies, equity sharing and royalty income. The knowledge-based information system for managing research product and value creation described in this paper has been a useful means for implementing a *knowledge pump* corporate memory that has proved useful in gathering research products as well as in the distribution of the knowledge generated by the research activities. Researchers are now conscious about what are the important journals and conferences in their disciplines and are teaching and encouraging their students to write their theses and projects results in scientific papers that are peer-reviewed and criticized during conference oral presentations. Professors from technological disciplines are also filing patents from their innovations and teaching their students to do so. Research centers and departments have access to historical reports that show statistics about their scientific productivity and main weaknesses. Graduate programs and schools are using the indicators and reports generated by the system to obtain accreditations from scientific societies, accreditation boards as well as governmental and international funding agencies. Students and professors are starting spin-off companies that commercialize products designed as a result of their research and innovation activities utilizing the support and infrastructure provided by the entrepreneurial program on Campus. At the university level there is useful information provided by the system that indicate what are the research areas with more publications, who are the researchers with the highest productivity, what are the journals and conferences in which researchers publish the most, what is the proportion of papers written jointly by professors and students, what theses produce published papers, what publications are obtained from research grants, what graduate programs are generating scientific papers, and similar questions. Another benefic of *the system* is the awareness that external entities will have about the university research and innovation capabilities. Among these entities are companies and corporations that demand research services, funding agencies and prospectus students that look for challenging research projects and research environments.

The Latin American benefits of such a system are particularly important because promotes the emergence of technology-based companies and the development of knowledge-based economies in the LA countries. This is relevant since most of the LA economies depend on low-cost labor and the exploitation of minerals, petrol, woods, fruits and vegetables, cattle and other natural resources. The use of a system like this is not different from what is done in other parts of the world since the countries face similar problems due to the globalization phenomena. However, the LA universities that follow approaches similar to the ones described in this paper are better off in contributing to their local economies. The *system* has been operational for almost a year and has proved very valuable in all these aspects

Related and future work

Many companies and government agencies have developed corporate memories and knowledge management systems to handle their knowledge assets (Liebowitz and Beckman, 1998; Liebowitz, 2004). Among those companies are General Electric, Monsanto, Buckman Laboratories, Skandia, Blue Cross, Federal Express, KPMG and many others. On the other hand, there are various companies like Thompson Scientific, Google, Elsevier, Springer-Verlag and other publishers that sell information in data bases of scientific publications as their core business. However, to the best of our knowledge, *the system* described in this paper is one of the first integrated solutions developed for a university environment that is currently operational. The *system* is still under development and will be fully operational in about a year with data mining facilities integrated on-line in an institutional research web portal through *Web Services*.

CONCLUSION

We described an integrated information *system* for managing the knowledge generated from research and innovation activities in a university environment and in particular, the LA context. We have followed an *action research* methodology for reflecting about the processes and products generated by research groups and graduate programs as well as the economic value associated to such knowledge assets. We have followed a *knowledge management* methodology for developing a *knowledge pump* corporate memory for storage and distribution of research knowledge assets. Being operational for about a year, this system has already proved its usefulness in creating an awareness and consciousness about the importance of publishing scientific results of research activities and measuring its relevance in terms of both its scientific impact and the creation of wealth.

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