Jornada de Seguimiento de Proyectos en Tecnologías Software y Hardware

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(editores)

MINISTERIO
DE CIENCIA
Y TECNOLOGIA

II

Prólogo

Las convocatorias de proyectos del plan Nacional de Ciencia y Tecnología incluyen la obligación por parte de la Subdirección de Proyectos de Investigación de efectuar un seguimiento y evaluación de los resultados de cada proyecto subvencionado. Siguiendo el espíritu de esta norma, el Programa Nacional de Tecnologías de la Información y las Comunicaciones realiza periódicamente unas jornadas de Seguimiento de Proyectos que tienen como fin, tanto la mencionada evaluación, como la difusión de las actividades en esta área a otros científicos y al sector industrial.

La Jornada de Seguimiento de Proyectos en Tecnologías Software y Hardware pretende constituir un foro en el que se presente una selección de los proyectos financiados en los últimos años con cargo al Programa Nacional de Tecnologías de la Información y las Comunicaciones en temas relacionados con las tecnologías del software y del hardware. En paralelo a estas jornadas, se han organizado otras para el seguimiento de proyectos en Tecnologías de Radio, Comunicaciones y Telemática y otras en el campo de la Electrónica. Esta jornada es la tercera que se celebra de similares características: en los años 2000 y 2001 se organizaron en Valladolid y Almagro, respectivamente, coincidiendo con las Jornadas sobre Ingeniería del Software y Bases de Datos.

La Jornada se celebró en El Escorial (Madrid) el día 21 de Noviembre, como parte de los Encuentros en Tecnologías del Software, y contó con la colaboración del Comité Organizador de dicho evento. Deseamos agradecer su participación a los miembros de la Comisión Técnica que han constituido los dos paneles en que se ha organizado el seguimiento. Dicha Comisión estuvo compuesta por diferentes investigadores provenientes tanto del sector académico como industrial, incluyendo algunos miembros de otros países.

Noviembre 2002   Juan José Moreno Navarro
                                        Ernesto Pimentel Sánchez
                                           Programa Nacional de
                    Tecnologías de la Información y las Comunicaciones

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Organización

La Jornada de Seguimiento de Proyectos en Tecnología Software y Hardware ha sido organizada por el equipo de gestión del Programa Nacional de Tecnologías de la Información y las Comunicaciones (TIC) de la Subdirección General de Proyectos de Investigación del Ministerio de Ciencia y Tecnología, y ha contado con la colaboración del Comité Organizador de los Encuentros en Tecnologías del Software 2002.

Programa Nacional de Tecnologías de la Información y las Comunicaciones

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Ernesto Pimentel (Colaborador del Programa TIC)
José Ignacio Alonso (Colaborador del Programa TIC)
Carles Cané (Colaborador del Programa TIC)

Miembros de los paneles

Jean-Raymond Abrial (Consultor Independiente, Francia)
Ana Moreira (Universidad Nova de Lisboa, Portugal)
Fernando Orejas (Universidad Politécnica de Cataluña)
Isidro Ramos (Universidad Politécnica de Valencia)
Tomás Rodríguez (Eptron, S.A.)
Jorge de Teresa (INDRA)

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DOLMEN: Distributed Objects, Languages, Models and Environments
TIC2000-1673-C06

PROJECT COORDINATOR: Isidro Ramos Salavert, Polytechnic University of Valencia

SUB-PROJECTS

1. SIGLO, Polytechnic University of Valencia (TIC2000-1673-C06-01, PI: José H. Canós Cerdá)
2 SIRENrm, University of Murcia (TIC2000-1673-C06-02, PI: José Ambrosio Toval Álvarez)
3 MADEIRA,University of Seville (TIC 2000-1673-C06-03, PI: Jesús Torre Valderrama)
4 MEIGAS ,¡University of Granada (TIC 2000-1673-C06-04, PI: María J. Rodríguez Fórtiz)
5. MEDEO University of Castilla la Mancha (TIC 2000-1673-C06-05, PI: Mario Piattini)
6. AMIS, University of Valladolid (TIC 2000-1673-C06-05, PI: Miguel A. Laguna)

Abstract

The project aims to provide solutions to problems that arise in the development of global computing solutions of an entity, such as interoperability, evolution, reuse, scalability, distribution, etc., using the know-how in Software Engineering acquired in the last years by the participating groups. In particular, we will use the groups experience in the design, development and application of CASE tools for automatic code generation (model compilers) that provide most of the characteristics mentioned earlier.

The order of the problems has changed; but the **models** (object-oriented and very expressive), **languages** (formal, based in different formalisms) and **tools** generating either real code (OO-METHOD CASE) or prototypes (AFTER, ARCA, LUNA, OCA) have lead us to view business automation as a **continuous engineering** process in which such models, languages and tools can be applied just by changing the scale: from individual applications to workflows, from databases to global information systems, etc. We will work at two levels. First, at the **Global Information System level**, a workflow reference model with semantics defined in our formal languages will be used. Second, at the **individual application level**, new methods for requirements management and reuse will be developed. The metalevel will be visually supported in UML and formalized by means of high level design languages. Metrics will be applied to the models in order to ensure their quality.

1   Project Goals

The DOLMEN consortium is composed of six research groups belonging to spanish universities (see above). The overall goal of the project was to improve the quality of software artefacts, in a distributed, heterogeneous, and global world. The change of scale from standalone to distributed systems led to a change of scale in the problems to solve, too. Therefore, we focused our attention, first, in the problems related to the development of global business solutions, in which the organizational model provides the starting point for any further development. Second, we wanted to study the trends in the development of web applications, specifically in both methodological and

technological aspects. To go on this, the background of the participating groups played a curial role in the selection of the solutions: model compilers, formal methods, requirements engineering, software evolution, software quality and metrics, to name a few, have configured a project that, summing up efforts of all the partners, tried to solve several open software engineering problems.

At the Global Information System Level, we proposed to use *Workflow* as the enabling technology for the development of enterprise-wide solutions. Study of what practices of conventional software engineering are suitable to the development of workflow models, adapting them if needed.

At the application level, enforce good requirements engineering processes as the base for correct application development. Use UML as the modelling language, and give formal semantics to some of the UML's models in order to ensure good properties of the models. Furthermore, to use model compiler technology to produce industrial applications from formal requirement models in an automated way.

An enumeration of the initial goals of DOLMEN follows[1]:

- **Global Information System level**
    - Definition of a process model for the development of global information systems (1)
    - Study of techniques for the definition of workflow models, adapting and/or applying techniques used successfully in the development of conventional applications to the development of such models. (1)
    - Metamodelling as the way to deal with problems such as evolution, tuning, etc. of the workflow models (1, 4)
    - Automatic generation of workflow models in efficient environments (1, 5)
    - Workflow evolution and continuous improvement (1, 4, 5)
    - Use of data mining techniques to analyze workflow executions (1)
    - Integration of legacy systems and new applications (1)
    - Study of generic architectures for global information systems (1, 3)
- **Application level**
    - Construction of model compilers which, starting from models built using well accepted standard languages (specifically, UML), produce applications in industrial environments in an automated way. (1, 2, 3)
    - Formalization of UML models in order to have precise semantics enablig automatic generation of applications from UML models (2)
    - Software evolution (1, 4)
    - Definition of a reuse-based software process model. (2, 5)
    - Systematic software reuse: product lines, frameworks and assets evolution. (5)
    - Definition and use of reuse metrics (5, 6)
    - Software development processes with and for reuse (5)
    - Definition of web-based application development, focusing in the navigational aspects as a crucial issue. (3)
    - User interface modelling and development (1, 6, 3).

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[1] The numbers enclosed in parentheses alter each goal refer to the different DOLMEN partners involved in (as numbered in the paper's header)

2 Project's achievements

In this section we include a progress report of each of the DOLMEN sub-projects. Some of the achievements have been produced in cooperation of some partners, and can appear listed more than once in a different subsection.

2.1 SIGLO

SIGLO (Global Information Systems for Organizations) was intended to work at two levels, namely the Global Organization level and the Application level. In the following paragraphs, e¡we explain the main results obtained in each of them.

Global Information System level

We have used the workflow paradigm to cope with the development of enterprise-wide applications. We have defined a workflow reference metamodel, and a process model for the development of good workflow models. In this research, we have used techniques successfully applied in software engineering like Use Cases to obtain from them a workflow model in a semi-automatic way. WE also have used data warehousing techniques to analize execution logs and obtain information relevant for business process improvement. Finally, we have developed tools for creating workflow models from use cases. The work in this line is essentially finished as for September 2002.

We have also worked in workflow evolution, with some preliminary results. However, a detailed analysis of the literature has led us to abandon this line, and concentrate in the use of well known solutions to support software processes. Specifically, we are very interested in the use of ad-hoc workflows to support agile software development processes, as well as to obtain navigational models of hypermedia applications from workflow models. Both lines are very promising, and we hope to have results at mid term.

Application level

We have worked in validation and verification of OASIS formal specification by automatic prototyping. Also, model compiler technology is being used to obtain executable applications in industrial environmens like, e.g., Oracle™. Some prototypes have been developed to demonstrate the feasibility of the rapid prototyping approach to software development.

We have started to work in traceability. This is a very interesting topic that is becoming a key issue in the major software engineering conferences. In strong cooperation with researchers of the City University London, some preliminary results are being obtained and it is feasible they will be published during the project's third year.

Another interesting topic is software evolution and migration. Building on the results of the MENHIR project, we have studied the problems of data migration in the context of schema evolution, both in relational and object-oriented systems. This line has been very fruitful, and we have developed industrial systems in cooperation with our partner Consoft, as well as high number of publications.

Other topics of interest

In this section we outline other topics we have been working in, and can be dealt with from both the global system and the application levels.

OASIS as an Architecture Definition Language

We have started to study the ability of the OASIS language to describe software architectures. Specifically, we have used separation of concerns to extend the OASIS formal object model to become PRISMA, a model subsuming OASIS that is able to deal with both static and dynamic software architectures.

We will use the PRISMA model to develop a representation of the 5S model for Digital Libraries.

User interfaces

In cooperation with the members of the project MEDEO, we have worked in the definition of a method for the automatic generation of user interfaces starting from Use Case models and task analysis; we have also worked in the development of the associated tools.

Use of Ontologies to integrate heterogeneous information systems

We are exploring the use of ontologies as the paradigm for the integration of heterogeneous systems, mainly with the purpose of information retrieval in distributed contexts. Specifically, we have chosen the domain of automatic bibliography handling to apply our ideas. We are transforming BibWord, a bibliography management tool for Microsoft Word into a platform for unified, multi-processor bibliography services. We have contacted Michael Ley (University of Trier, Germany) to use the DB&Lp collection as one of the repositories to be integrated in our system. We expect to have consolidated results in the project's third year.

2.2 SIRENrm

SIRENrm (SImple REuse of requiremeNts and rigorous modeling) is made up of two main research lines: 1) Formalizing the UML metamodel and 2) Requirements Reuse.

UML formalization

Firstly, the UML, as the Software Engineering intuitive notation for Object-Oriented development, and Algebraic Specifications and the Maude executable language as the formal theory and tool, were chosen. Our main achievements related to this topic are:

- Class Diagram: Formalized Syntax and both static and dynamics Semantics, including associations, inheritance and most of the UML metamodel elements. Demonstrations of proofs concerning both semantics. Definition and formalization of a transformation algorithm to obtain all the derived associations from a given DC model.
- Study of metrics and their inclusion in the current formal UML models.
- Statechart: Formalized Syntax and static Semantics. Currently investigating approaches to deal with its dynamics semantics. Demonstrations of proofs concerning static semantics.
- Sequence Diagram: Formalized Syntax and static Semantics. Currently investigating approaches to deal with its semantics. Partial formalization of a transformation algorithm to obtain the collection of statecharts corresponding to a given set of related SDs.
- Integration of the SD with CD and Statecharts.
- Formalization of the OCL semiformal UML specification language and inclusion in RIVIERA.
- Running prototype of the CASE tool RIVIERA, currently providing UML model simulation features, connection with Maude and translation of the XMI Class Diagram representation to Maude and communication with the NSUML metamodel implementation.

Requirements Reuse

A new template for reusing requirements has been defined, based upon the IEEE-830-1998 standard. A requirements based process model, has been defined. Main results obtained up to now are (see sections 3-4 for specific results obtained):

- Definition of a reusable catalog containing generic security requirements, which conform to the Spanish Methodology on Risks Analysis and Management (MAGERIT) [4] and the Security Common Criteria [5].
- Definition of a reusable catalog containing generic personal data protection, which conform to the Spanish Constitutional Law 15/1999, (LOPD), the Spanish personal data privacy law.
- Integration of the two catalogs mentioned above, made operational.
- Definition of the SIREN process model, based upon requirements reuse

In both modules, we are working closely with other partners of the coordinated project, mainly those in UCLM.

2.3 MADEIRA

Separating the Navigational Aspect.

Our work tried to address navigation by means of the ideas proposed by researchers in the area of the advanced separation of concerns, crossing the gap between the design level described in methodologies and the implementation level. Moreover, we are using the proposed ideas in the area of the advanced separation of concerns.

After doing an exhaustive study about the available methodological propositions to develop global and web information systems, we concluded that the current propositions deal with the navigational aspect only in the last phases of the project life. They do not offer suitable techniques, models or process that let define the navigational aspect at the beginning of the project. So, we have defined NDT (Navigational Development Techniques), a methodological process, and also suitable models and techniques, which let treat the navigational aspect correctly in the first phases of the life cycle. NDT is oriented to be applied in global information systems in general, but it could also be apply in web information systems.

NDT is a proposition oriented to the process, because it describes what steps have to be made to specify, analyse and design the system navigation. But it is also oriented to the technique and the result, because it describes and presents techniques and models that must be used in each step and the structure of the product to obtain.

Nowadays, only the requirements capture workflow has been completely proposed and elaborated in NDT. Also, the propositions of this workflow have been applied in some real projects. Concretely, NDT requirements capture workflow has been applied in three real systems:

- The System to manage Grants to the Cultural Promotion, developed with Sadiel to the Consejería de Cultura.
- The System to manage Grants to the Development, developed with Sadiel to the Consejería de la Presidencia.
- The System to spread out The Andalusian Historic Patrimony Thesaurus via Internet developed to the Andalusian Historic Patrimony Institute.

Also, a tool case, named NDT-Tool, has been developed to help in this first workflow. NDT-Tool has been implemented with ORACLE and JAVA, and it offers a guide to applied the development process of NDT. Nowadays, this tool is being tested. In the future, the other workflows (analysis and design) will be included in NDT-Tool.

By another way, the Analysis workflow has been proposed. The development process and the techniques that must be applied have been defined. Nowadays, they are being applied to those real projects to evaluate the results.

Modeling and design of user interfaces

The goal of our work is, on one hand, to obtain a methodology for the systematic development of user interfaces and, on the other hand, to find a way to test the usability of the developed interfaces. First, we are doing a comparative analysis of the current state-of-the-art in user interface modeling methodologies in order to find the one that fits better for modeling user interaction in digital libraries. This methodology will later be integrated with the general methodology that will be proposed by our group.

We are also working towards the proposal of a way to test the usability of the developed user interfaces. Usability is a topic of great concern in digital library systems as one of the goals of these systems is to bring information to a great variety of users, most of them with little knowledge about computers. Our aim is to make as automatic as possible the measurement of the usability, avoiding the use of traditional empirical methods.

We are analyzing the features of the different users who work in the Instituto Andaluz de Patrimonio Histórico, the organization to which we are planning to apply our work. This way we can propose a model of the interface for each user. These models are pretended to be adaptive and evolve with the behavior of the users.

We are also developing MadeiraGUI, which has a radically new approach to creating user interfaces. The object oriented data model is connected directly with the user interface through MadeiraGUI. Using schema driven GUI design, the user interface can be generated directly from the data model.

The information in the object model is used to support the automatic generation of applications. This goes far beyond the functionality of Case systems or GUI builders. Case systems can't create GUIs directly from their models, and GUI builders know about user interfaces, but not about their connection to the object model. When the user interface is created with a conventional tool, the elements are not aware of the database. The code to get the data from the database to the screen and back must be programmed by hand. Very often the fields of a screen form correspond directly to members of objects in the database. However a screen as a whole does rarely correspond to a single object. Typically the fields of a form are selected from several related objects.

Extraction of Qualitative Knowledge from Databases

In order to extract qualitative information in user searches, we have defined a semiqualitative methodology in order to study the different behaviours of a system that evolves along the time. This approach is based on a transformation process, application of stochastic techniques, quantitative simulation, generation of a database, definition of a query/classification language, data mining, clustering and genetic algorithms of obtain the behaviour patterns of a system.

We have also defined a qualitative similarity index (QSI). This index is defined to compare time series stored into a database, taking into account the evolution of the values of the series. Our approach uses a similarity index defined by qualitative labels. Every label represents a rank of

values that we may consider similar, from a qualitative perspective. The proposed index is defined by means of the matching of qualitative labels.

We are studying the application of this index to the researches of Mario Piattini group. He is working trying to find a model to calculate the difficult of maintenance of an application based on the diagrams classes written in UML.

2.4 MEIGAS

The main objective of our project is the study of concepts, formalisms and methods to specify and implement the process of software evolution. Besides, our aim is applying the theoretical results to study the evolution of Decision Support Systems and Teaching support systems. We are also constructing a new version of prototype,a tool for evolution, to prove the developed theory. Finally, a study of the evolution of workflows is a common objective with the group of Valencia.

Theoretical research in evolution

The theoretical research is based on the results of the previous project MEDES (TIC97-0593-C05-04). In this sense, biological models of evolution have been applied to characterise and specify software evolution process. Besides, Anticipatory Systems theory has been adapted to model evolution in the structure and use of a system. The managing of the versions space has been studied, using the UML model to model it. Finally, the obtained models are being applied to commercial tools like WinWin which implement techniques of requirements elicitation.

The results of this research are: the Ph. Thesis of Jesus Torres Carbonell and several papers in national and international conferences]. Besides, a workshop on software evolution has been successfully organised by our group, and a group interested in software evolution is being created at national level.

Application of evolution to concrete environments

Several formalisms have been used to apply the evolution models: temporal logic, Petri nets, graph theory, semantic nets, ontologies, object oriented model and fuzzy logic. Besides, the concepts risen from the theoretical research and new concepts studied are being put in practice.

Two tasks were initially assigned to this module: the application to Decision Support Systems and the authoring systems for teaching. The second task has derived in two research lines: hypermedia systems and adaptive hypermedia. Besides, two new applications of evolution have raised: Co-operative software agents and Interactive Systems.

> **Hypermedia Systems**: SEM-HP model has been proposed as composed by Conceptual, Presentation and Navigation subsystems. System and Metasystem abstraction levels has been distinguished in this architecture with the objective of achieving a good separation of concerns both in the development and in the evolution processes.
> **Adaptive Hypermedia**: Based on SEM-HP model, the specification of its learning subsystem is being carried out. It implies the analysis of the reader knowledge observing its behaviour and taking into account his skills, education, age, ... The main objective that is being reached is the adaptation of the hypermedia while navigating. Several national and international groups are very interested in this research line.
> **Decision Support Systems(DSS):** Evolving techniques based on ontologies are being used to integrate the Information System and the Decision Support System. The study

takes into account changes in repository schema and rules, and automatic changes propagation. Object oriented model is being used.

Co-operative Software Agents: The theoretical model is being improved, adding the managing and of an agents hierarchy which co-operate to carry out more complex actions (transactions). A communication and co-operation pattern has been developed. Some formalisms as temporal logic is being used to model the evolution of the agents architecture and the complex actions definition. This new model could be extended and applied to the previous research lines.

Interactive Systems: A new model based in direct manipulation style has been defined. It specifies objects domains, images, relationships, gestures and manipulative processes. A language has also been created to be used by the developer during the specification. Temporal logic is being used to model the cinematic (user interaction) and the dynamic or evolution of the applications.

Development of Evolution tools

A prototype is being developed. Java language is being used to implement it. The prototype is a new version of another previous prototype. Initially, it tried to model the evolution of use cases, but it has been improved and its functionality amplified to model the evolution of DSS and hypermedia systems. This task is being developed before the date initially programed because it allows to prove the theoretical results which are being obtained in other modules.

The main contribution of the tool is the kernel which is useful to specify any kind of system using conceptual and semantical structures. It carries out automatic verification and change propagation. Besides, it implements the subsystems and the levels of SEM-HP model for Hypermedia Systems.

A person has been hired to implement the prototype and several members of the group are collaborating in its development.

The prototype is not fully completed and has not been presented yet.

Workflow evolution

We are working with Valencia Group in this subject. Up to now there are not published results

2.5 AMIS

Extension of Mecano model

We have advanced in the support of variability in the product line approach, combining the Mecano model and FORM (*Feature-Oriented Reuse Method*). The *feature*, key concept of domain engineering is supported by the functional descriptor of Mecano model. In the framework field, we have proposed formal concept analysis to assist the construction of frameworks.

Regarding evolution, we have obtained some results in the refactoring approach. In addition, a line of work in data base reengineering has been recently initiated. In addition to this work, specific results in inheritance hierarchies have been achieved:

In metrics line, several tools has been completed and applied to real situations. Finally, other possible applications of Mecano model have been explored:

Domain engineering

This module focuses the requirement assets and its role in Mecano model. A Ph. D. thesis (Oscar López) was initiated in coincidence with the DOLMEN project. The definition of a requirement meta-model and its mapping to Petri nets has been accomplished. Some preliminary advances in the task "Definition of requirement pattern" have also been obtained. We ave also built tools for requirements elicitation.

Reuse based Software Process

The pending work we are affording during this second year is essentially the definition of a general framework for the introduction of reuse in software process. We have published a first approximation to the problem and we are currently working in a complete solution. This process definition is completed with the construction or adaptation of a series of supporting tools. This work has being accomplished by technical personnel and last year students. The results at this moment include a requirement reuse tool and an API for insertion of assets and mecanos in a repository.

2.6 MEDEO
The global objective of subproject 6 of DOLMEN project is the introduction of systematic reuse in software engineering. It is subdivided in several modules with convergent objectives: extension of Mecano model (our coarse-grained reusable element) for considering product lines, frameworks or refactoring concepts; definition and experimental validation of Mecano metrics; requirement specific treatment in the model; and finally aspects of the software process related to reuse.
We have analysed the most important proposals about metrics for object-oriented models. A set of new metrics for class models have been defined. These metrics have been validated theoretically following the formal frameworks of axiomatic approaches and measurement theory approaches. We have also carried out several experiments in order to empirically validate the metrics, using traditional statistical analysis and more advanced knowledge discovery in databases and fuzzy techniques. At this moment we are defining metrics for dynamic models (e.g. state diagrams), following the same method.

We have also studied some metrics for object-oriented process, and the consequences of refactoring and patterns in object-oriented development.

User interface design

Different alternatives in the area of user interface design based on models have been revised. We have analyzed the expressiveness of the different models included in UML and their adaptation for modeling the user interface.

Security

We have defined a process model based on requirements reuse for defining security requirements. A methodology, which extends UML and UP, for designing secure information systems has been developed. This methodology proposes a language for expressing security constraints in UML class models and also specifies a set of transformation between the different stages of a database development life cycle.

3 Results Indicators

3.1 Summary of publications

Table 2 shows the number and type of the publications produced by the DOLMEN partners during the development of the project.

Type of pub.	SIGLO	SIRENrm	MADEIRA	MEIGAS	AMIS	MEDEO	TOTAL
Book or book chapter	1	4	3		2	3	13
Intl. Journal	5	3	4	1		3	16
Nat. journal			3			1	4
Intl. proceedings	16	8	12	15	14	29	94
Natl. proceedings	9	7	19	10	6	8	59
Tech. reports	1	4	2				7
PhD Theses	1	2		4		3	10
TOTAL	33	28	43	30	22	47	203

3.2 Results of the SIGLO Project

Staff training: two persons were hired for 6 months. Many students have participated supporting researchers in different tasks of the project.

Technology transfer: We have a strong cooperation with Consoft, a software development company who has sponsored part of our work in software evolution and migration, specifically by means of student grants. Our experience is very positive, though we weren't able to publish some of our results due to confidentiality issues.

Participation in international projects: During the development of DOLMEN, we have strengthened our relationship with several european consortia:

- Dr. J. H. Canós is the coordinator of the Valencia Core Node of NAME, a network of excellence in Agile Methods for Software Development. The main goal of this network is to define a research roadmap for Agile Methods in the next years. Moreover, Dr. Canós has joined the Program Committee of XP 2003, the major European forum on Agile Methods, where he also server as Workshop Chair.
- Dr. P. Letelier has been invited to join traceability network of excellence

Cooperation with other groups Our group keeps good relationships with several spanish, european and american research groups. An enumeration of these groups follows:

1. *Information and Communication Systems Group* at ETH Zurich (Switzerland), leaded by Prof. Dr. Gustavo Alonso. We have worked closely in the workflow management area, where the co-supervision with Dr. Canós is the most remarkable academic result.
2. *Department of Computer Science, State University of New York at Stony Brook.* Leaded by Prof. Dr. Michael Kifer, currently is hosting Dr. J. Á. Carsí for 6 motnhs statrting in September 2002.
3. *Digital Library Research Laboratory* del *Department of Comupter Science, Virginia Tech.* There is strong cooperation with this group, leaded by Prof. Dr. Edward A. Fox, especially in the framework of NDLTD (www.ndltd.org). Moreover, we are investigating how to represent the 5S odel for digital libraries in the OASIS framework.
4. *Department of Computing. School of Echonomics, City University London.* Dr. P. Letelier has been working for 5 months with Dr. George Spanoudakis and Dr. Andrea Zisman studying the consistency of UML models and requirements traceability..
5. *CERN* (Switzerland) Prof. J. Jaén has been working at CERN for 3 years in the European Data Grid Project.

3.3 Results of the SIRENrm Project

Staff training: 2 Phd; 4 term projects; 1 FPI grant (during the first year of the project).

Cooperation with other groups

Regarding UML formalization activities, we are cooperating with Dr. Jonathan Whittle, at NASA Ames Research. Some joint papers and two workshops co organization are results of this cooperation.

Concerning Requirements Reuse, we have established a cooperation with Dr. Ana Moreira, at Universidade Nova de Lisboa, aimed at exploring quality (non-functional) requirements management, applying results from the Aspect Oriented Programming realm. We are preparing a common application for the next call for bilateral cooperation projects, between Spain and Portugal.

3.4 Results of the MADEIRA Project

Cooperation with other groups

- Sevilla – UCLM OO development & testing
- Sevilla – U. of Granada regarding to e-comerce and evolving cycle life

3.5 Results of the MEIGAS Project

Staff training: A grant holder of the program FPI (from the MEC) is working in the project. Another person has also been contracted to work in the prototype

Cooperation with other groups

- Coordinated action with Sevilla University regarding to e-comerce and evolving cycle life.

- Coordinated action with the Psychology Department of the University of Granada to study adaptive hypermedia and learning systems.
- Collaboration with the Graphics group of the University of Granada regarding the evolution of graphical specifications.
- Collaboration with Mr. Dubois Group of Belgic to study software systems as anticipatory systems

3.6 Results of the AMIS Project

Staff training: 3 Ph. D. thesis in course of realization: Oscar López Villegas (date of finalization: end of 2002), Mª Esperanza Manso Martínez, Félix Prieto Arambillet.. 1 Ph. D. thesis recently initiated: Carmen Hernández Díez

 Technology transfer:

 We have carried on a series of experiences in collaboration with several organizations: Both in the *Junta de Castilla y León (C. Agricultura y Ganadería) and Cortes de Castilla y León,* a product line approach is currently assessed. Tecsidel, a software company, has facilitated access to some of its code libraries. A metrics study, an application of FCA tool and a refactoring proposal have been emitted.

3.7 Results of the MEDEO Project

Cooperation with other groups
- Professors Brito e Abreu (Portugal), Geert Poels (Belgium) and Houari Saharaoui (Canada): co-organization of the workshop "Quantitative Approaches in Object-Oriented Software Engineering (QAOOSE)", associated to the ECOOP Conference. Proceedings of the 2001 edition: *Brito e Abreu, F., Henderson-Sellers, B., Piattini, M., Poels, G. & Sahraoui, H.A. (2002). "Object-**Oriented Technology ECOOP 2001 Workshop Reader"***Lecture Notes in Computer Science Vol. 2323, Springer, Frohner, A. (ed.)174-183:*
- Professor Giovani Cantone: **"Experimental Software Engineering in Europe: Alining the contents", financiada por el** MURST (Ministero dell`Università e della Ricerca Científica e Tecnológica, Italy). Partners: Università degli Studi di Roma "Tor Vergata" (Giovanni Cantone), Università di Sannio de Benevento (Aniello Cimitile), Universitá di Bari (Giuseppe Visaggio), Dutch Open University (Fred Heemstra), Escuela Superior de Informática de Ciudad Real (Mario Piattini),
- Contact with the ISERN y ESERNET internacional networks on empirical software engineering..
- Relationship with iberoamerican universities (via the RITOS2 network funded by CYTED) Dr. Alejandra Cechich from Universidad del Comahue (Argentina) will work in quality of components.
- Cooperation with spanish groups: UCLM – Valencia: user interfaces; UCLM – Murcia: security and audit.; UCLM – Valladolid: metrics; UCLM – Sevilla: OO development & testing

4 References

The full list of publications generated in DOLMEN are available as an addendum to this document, than will be given to the committee at the evaluation session. Any interested person can obtain a copy upon request to the project coordinator, Prof. I. Ramos (iramos@dsic.upv.es).

Ariadne: método y herramienta para el diseño de aplicaciones hipermedia TIC2000-0402

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Abstract

This project is aimed at developing a hypermedia method, called Ariadne, that integrates six different design views (navigation, presentation, control, security, data and processes) and assumes a user-centred process with a view to gathering the features of this technology and produce usable applications. An automation tool,called AriadneTool, is being developed to support the modelling, documentation and prototype generation processes. This document reports the current status of the project.

Keywords: hypermedia; web engineering; data models; security

1 Project goals

Many organizations and companies are pushed to set up their web sites in a rush, so that they approach hypermedia development without a solid background on this technology. Hypermedia development poses very specific problems that do not appear in other software applications, such as the need for mechanisms to model sophisticated navigational structures, some of which can be ephemeral, interactive behaviors and multimedia compositions which have to be usable and harmonic at the same time. Although experience and modelling skills can be borrowed from existing design methods such as object oriented modelling, hypermedia developers need intellectual mechanisms to analyse and design using abstractions and design entities related to the hypermedia domain (e.g. nodes, links, anchors and synchronisms). Moreover, since the majority of hypermedia applications, and particularly those implemented as web environments, will be accessed by different users with different purposes, security becomes a key feature to be taken into account. Hypermedia methods should provide mechanisms to deal with all the features of any hyperdocument, including security, in an progressive and integrated way.

The main goal of this project is to define a hypermedia design methodology, called `Ariadne`, which among other features is supported by a tool, called `AriadneTool`, that automates a systematic and integrated process to develop hypermedia applications and systems. With this purpose the planning shown in Figure 1 was proposed.

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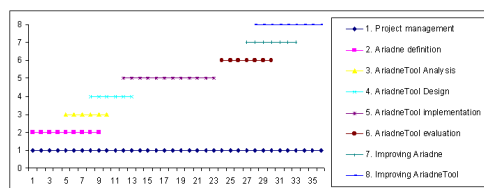
Figure 1: Project planning

2 Project status

At this moment the project results are as expected. The main modification, detected at the very beginning of the project, was concerning the development cycle of the tool. As `AriadneTool` is an interactive system, it was decided to assume a prototype-based process model, so that evaluation (phase number 6 in Figure 1) was performed as soon as a first prototype was available at the end of the first year, in order to detect possible interaction problems. In this way, the tool is being implemented using an iterative development process. In the next subsections the status of `Ariadne` and `AriadneTool` are described.

2.1 Study of existing hypermedia design methods

The first step before defining the methodology itself consisted of carrying out a survey of some methods for hypermedia modelling including HDM [11], RMM [13], OOHDM[17], WSDM [9], Autoweb[10], WebML[3] and OO-H method [12] to analyze their contributions as well as the requirements they did not cover. The study [16] revealed some weak points including: methods do not consider no-functional and usability characteristics nor validation and integrity rules that would help to determine the correctness, integrity and completeness of the design; reusing is design is complicated since even though navigation patterns are used, they are not related to the interface and the structure of the system nor to design components; most methods do not model contents in a separate way and do not take into account their multimedia nature, therefore different data views, time- and space-based constraints among contents cannot be specified; users are not taken into account like another type of element, so personalization issues are made by means of "cut-paste" technique; elements to specify security policies are not included; bottom-up design is not allowed and the evaluation stage is often forgotten.

2.2 The `Ariadne` design method

Taking into account the aforementioned study, the `Ariadne` design method has been fully developed and tested in the design of different hypermedia applications. The most relevant features of the `Ariadne` method are: integration of different design views; assumption of a user-centered design; and provision of general design products.

Integration of different design views

Modelling hypermedia applications and systems involves several complementary views (see Figure 2) that have to be considered in any development method [5].
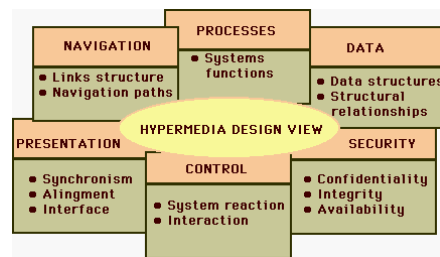
Figure 2: Design views for hypermedia systems

- *Navigation design* is a key task in hypermedia modelling since it deals with the most important and essential function in any hyperdocument. Selecting links is the basic navigation mechanism although navigation tools such as maps, active indexes, guided tours, marks, footprints and backtracking mechanisms are frequently used to try and overcome the disorientation problem

- *Presentation design* is an important part of multimedia design, since the way and rhythm used to deliver information determines the hyperdocument usefulness. Designers can define nodes templates placing types of contents, establish some commonalties in the presentation features of all the nodes treating a similar concept, divide the visualization space into different areas or define how contents are delivered making use of time- and space-based relationships [8].

- *Security design*. Hyperdocuments are usually envisaged as collaborative environments that make use of private nets or web servers in order to provide information access to different users. In such environments, security becomes a main concern, since both integrity and confidentiality of information have to be preserved. Security models are specified during the design stage to translate the rules will govern information access into clearances assigned to user roles. Detailed information on the products oriented towards modelling security constraints in `Ariadne` can be found in [7] [2].

- *Data design* methods describe the system in terms of data entities and structural relationships. Paradigms like entity-relationship, semantic and object-oriented modelling have been translated into the hypermedia field or used as the application structural schema in different works, such as [11, 13, 17, 3].

- *Process design* defines how the system works, not in terms of navigation, but in terms of other kind of no-navigation functions (e.g. information flow, databases access).

- *Control design* provides a behavioral specification describing how particular events affect to the system. Hypermedia systems are highly interactive and therefore, gathering the system reaction to particular events should be a relevant design concern.

Assumption of a user-centered design

Hypermedia applications are highly interactive and, therefore, the development process has to take into account the user needs and requirements. In order to promote a user-centered design, `Ariadne` proposes the process illustrated in figure 3, where the evaluation of prototypes plays a central role. The first phase, *Conceptual Design*, allows us to specify the system structure and function from an abstract point of view, for next performing a *Detailed Design* where the elements defined in the previous phase are specified in a more detailed way. Moreover, the *Evaluation* phase can be performed in parallel, what allows the method to be more iterative and generate an immediate feedback to improve the design according to the users opinions. *Validation and Integrity Rules* are not considered a phase, but a way to guarantee the completeness and integrity of the design. Moreover, each of the `Ariadne` phases gives place
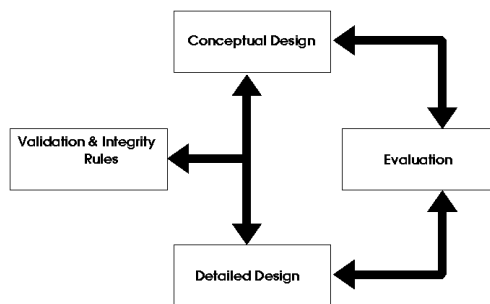
Figure 3: `Ariadne`: phases of the development process

to a number of design products whose notation is easy enough as to be discussed with the users representatives. The usability of the different design products is being constantly tested thanks to the use of an iterative development process as commented before.

Provision of general design products

The `Ariadne` Method is not oriented towards supporting a specific implementation technology but to offer general design products that can be translated to different implementation environments. With this purpose, we propose a conceptual framework consisting of a two-level hierarchical structure of design entities:

- Low-level entities represent basic components of hyperdocuments (e.g. nodes, contents, links, anchors, events, users and so on), for which the elements of the Labyrinth reference model are used [4, 8].

- High-level entities, are the products (e.g., Structural Diagram, Navigation Diagram, Users Diagram and so on) that will be discussed among the members of the development team and the user representatives to produce the most appropriate design [5].

Figure 4 summarizes the different products generated in each phase. More information concerning each product can be found in [6].

2.3 `AriadneTool`: automating hypermedia design

In order to develop `AriadneTool` the following requirements were considered:
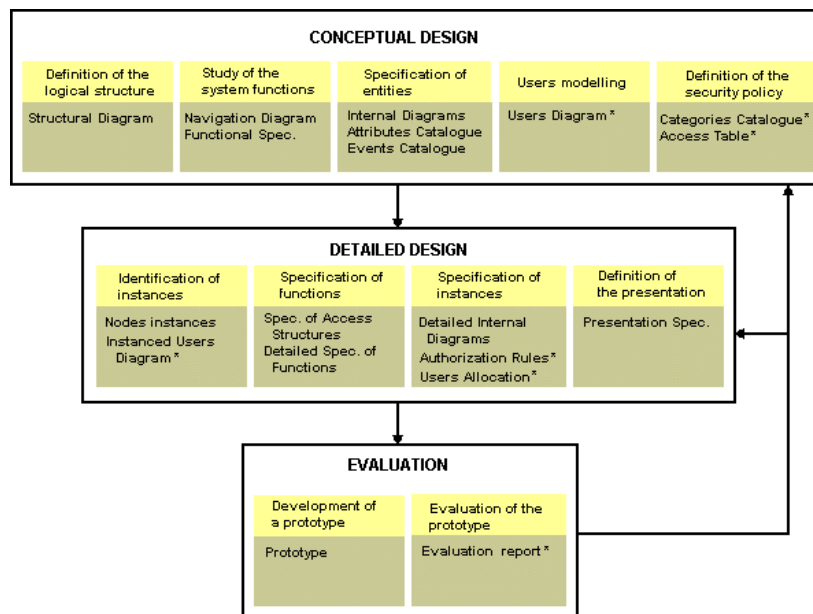
Figure 4: `Ariadne`: whole development process (phases, steps and products)

- Functional requirements: provision of tools to specify the `Ariadne` products (see fig. 4), inclusion of validation tools for each product and among products, generation of documentation, inclusion of a repository to held the elements in a consistent way.

- Non-Functional requirements: efficiency, flexibility, adaptability and modularity.

- Usability requirements: easiness to use and to learn.

The tool offers mechanisms to specify the different products of a project. In particular, it provides mechanisms to: (1) model the structural and navigational relationships among information elements; (2) place multimedia contents, events, attributes and anchors into the nodes; (3) align and synchronize such contents within the node representation area; (4) represent the kinds of users that will access the system; and (5) define the security policy of the application. On the other hand, it offers other functions for efficiently managing an `Ariadne` project, including checking the completeness and consistency of the project products, generating documentation about the project and assigning data to multimedia contents in order to generate dynamically XML+SMIL templates from which, using for example XSLT stylesheets, the web application can be automatically created. The main components to support such mechanisms are (see figure 5): (1) the *Front-End* that provides a perfect environment for elaborating the `Ariadne` Method products in a graphical way; (2) the *Validation and Verification Module* that holds the rules to validate and verify the completeness and correctness of the design, notifying any mistake or warning to the designer; (3) the *Dynamic Repository* that holds the components

of the front-end in dynamic memory, so that access is faster; and (4) the *Central Repository* that holds the components in a persistent way. `AriadneTool` is implemented using JDK1.4 what allows us to obtain an independent operation platform. The Validation and Verification Module is represented by DTD documents in which the rules defining well-formed design products are specified. Elements designed in the different products of the method are stored in the Central Repository by JAXB1.1 which allows an automatic two-way mapping between Java objects stored in the *Dynamic Repository* and final XML documents. We are building a module to translate our synchronization operations to SMIL specifications.

Figure 5: `AriadneTool` architecture

3 Results of the project

Three are the main kinds of results derived till now from the project: new research works and areas in the group; publications about the project results; and cooperation and contacts with other groups.

New research works and areas in the group. Several new research areas have arisen from the `Ariadne` project in our research group. Figure 6 shows the relationships of the project with other research initiatives.

MAZE is a meta-model that extends the model underlying `Ariadne` to deal with information imperfection in adaptive hypermedia systems. It's being developed as a Doctoral Thesis that is expected to be presented at the "Universidad Carlos III de Madrid" by the end of this year. Future works concerning MAZE include the integration of this model into `Ariadne` and `AriadneTool`.

MARAH is an Apache module implemented following the security model proposed in `Ariadne` in order to test the efficiency of supporting RBAC policies in a web server. It is developed as part of a project funded by "Comunidad de Madrid". This project finished but it is expected to continue including a module into `AriadneTool` to generate the configuration file required by MARAH to support RBAC web servers.

Figure 6: The project and its relation with other research works

The hypermedia patterns ontology is a Doctoral Thesis, that is being done at the group, whose goal is to conceptualize the different patterns that can be used in a hypermedia design and to classify them through an ontology with a view of offering some intelligent mechanism (such as CBR) to propose the best pattern for each design problem. The results of this work are expected to be related with `AriadneTool` in future versions.

The evaluation framework proposes a procedure to evaluate the usability of hypermedia applications as well as a number of criteria and parameters to collect data on usability. The framework has been used till now to assess educational hypermedia applications but it is expected to be generalized so that it can be integrated into the evaluation phase of `Ariadne`.

Publications about the project results. Publications related to the project outcomes include:

- Modelling principles and requirements: [14, 1, 16]

- `Ariadne` method: [14, 1, 6, 18, 2]

- `AriadneTool`: [15]

Cooperation and contacts with other groups. Finally, some research groups have shown interest both in the method and the tool, including: Universidad de Granada, Universidad Politécnica de Valencia (UPV-DATSI), Universidad de Castilla la Mancha, University of Strathclyde (Scotland), CWI (The Netherlands).

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SOFIA: Software Fiable de Alta Calidad[*]
TIC2000-1632

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Abstract

Nowadays, modern applications need for the development of reliable and high quality programs. However, existing tools, and languages do not always allow for a methodology improving reliability and quality in software development process. From our point of view, a reasonable solution comes from the use of formal methods and declarative technology in all the steps of software development. The idea is not new and the main drawback to be adopted by software developers is the lack of practical tools. Our thesis is that declarative technologies (declarative languages design principles, implementation issues, declarative modelling, etc.) can play a significant role in this process.

In particular, we propose a number of languages and tools for this purpose that cover:

- An object oriented specification system, called Slam-sl, combining a high expressiveness with the possibility of generating code automatically. This allow to a fully automatization of the **I**terative **R**apid **P**rototyping **P**rocess (IRPP). The SLAM system incorporates an advanced development environment including, among other features, code generation from Slam-sl specifications, reasonably efficient and easy to read useful for prototyping and for debugging.

- Improvement of the expressiveness and efficiency of the implementation for existing declarative languages like Prolog (by incorporating negation) and Curry (a functional-logic language). In particular we will extensively exploit the use of advanced program analysis techniques.

Keywords: Formal Methods, Requirement Engineering, Declarative Languages, Software Reliability.

1 Project goals

The general goal of the project is to propose and to develop a number of languages and tools for high quality and reliable software development based on declarative technology. This goal is divided into several subgoals:

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1.1 SLAM: Software development from specifications.

The main idea is to offer an environment for the development of software from formal specifications. The IRPP methodology is based on the use of prototypes. However, the main goal of prototypes is usually limited to requirement validation, while they are usually expensive and the final application is developed from scratch. Our idea is to develop a complete system, called SLAM, that can generate readable and enough efficient code from specifications.

The most important part of the system is the specification language, called Slam-sl. Slam-sl is an object oriented specification language and its most novel feature is that is designed as a trade-off between the high expressiveness of the underlying logic and the possibility of an efficient compilation. Slam-sl formulae, that extend logical formulae, are used to specify a function by means of a precondition (condition to apply the function with success), a postcondition (that relates input arguments and the result), and the *solution* (an effective method to compute the result). A key concept is the direct operational interpretation of *quantifiers* (extending usual logic quantifiers). Quantifiers allow the expressiveness of logic while the basis for their efficient implementation are the characterization of the collection classes (in the sense of object orientation) that can be traversed and the method to do it. By using program transformation techniques it is possible to obtain code in a high level programming language (object oriented preferably like Java or C++, although Slam-sl is language independent) that is efficient and *readable*, i.e. it can be modified by the user.

The SLAM development environment includes advanced facilities. Among others, it allows defining specification elements in a convenient and friendly way. This means that the specification language has no concrete syntax but the environment allows completing the specification by using selections, menus, keys, etc. Even more, the language is not (directly) stored as a text source file, instead XML format is used. The environment allows to compile the specification to obtain object oriented imperative code that is acceptable efficient and easy to read by the programmer. This feature allows a complete automating of the IRPP. The user can either modify the original specification (i.e. to obtain a new prototype) so generating code again or optimize the final code (operational prototype).

In this case the main advantage is that additionally to the executable code a debugging code is generated. This code (that could be generated in a declarative language like Prolog or Curry [26]) can be linked conveniently with the program providing declarative debugging (by means of assertions) of the modified code. Notice that the system can work even in the presence of partial specifications.

The main tasks associated to this subgoals are:

- Design of the specification language.

- Development of the Slam-sl compiler.

- Design and implementation of the debugging facilities. As we have mentioned, we can use a declarative language as the target language. In the case of using Curry we need a reliable and efficient implementation of it. In the case of using Prolog we need an effective and efficient support for negation. In both cases, this goal is strongly connected with the next goal on *Declarative languages expressiveness and implementation*.

- Declarative reflection. One of the most advanced and useful characteristics incorporated into Slam-sl is *reflection*. Reflection is the ability of a language for meta-programming,

i.e. to reason about the own elements of the language. Now, reflection is considered a key feature for component based systems and it is present in languages like Maude, Java, or C#. We will only sketch them in a simplified manner. In Slam-sl it is possible to dynamically inspect and manipulate classes, objects, methods, and other language elements.

- Development of additional SLAM environment features.

- Development of real world applications by using SLAM. In a first step we will use some semi-academic examples in order to compare the expressiveness of Slam with other specification languages (Z, VDM, Maude, B, ...). In a second step we plan to apply Slam to some already developed applications with the enterprise Eliop S.A. in order to compare the quality of the automatically generated code with the manually produced code. In particular we plan to use a railway stations control application.

1.2 Declarative languages expressiveness and implementation

1.2.1 Functional-logic languages.

The language Curry is an international project to define and develop a functional-logic language that can be used by all the researchers of the area. Our group is taking part in the Curry project activities from the beginning. One of our contributions was the development of the first implementation of Curry by providing a translator from Curry to Prolog called Sloth. Although it is not an ideal implementation it is very useful for testing new ideas, languages elements, optimizations, etc. The improvement of the Sloth system is part of the goals of the project. The other main goal in this topic is the development of global analysis techniques for improving the efficiency of any implementation. Notice that the structure of a functional-logic program gives many opportunities for analyses. One of the most promising one is demand analysis (an extension of backwards strictness analysis) that we proposed some years ago. Now, we are interesting in the formal definition and the proving of properties of the analysis and its application to Curry. We are also interested on the sequentiallity properties of Slam and how it can be improved with the use of global analysis. All these techniques can improve the efficiency of an implementation in a significant way.

1.2.2 Negation in Logic Programming

Knowledge representation based applications are a natural area for logic programming. However, this kind of applications requires a more complete set of capabilities than those offered by conventional Prolog compilers. As the knowledge about any subject contains positive as well as negative information, the possibility to include negation in goals is crucial for knowledge representation.

For these reasons, the research community on negation in Logic Programming has made a lot of efforts to propose different ways to understand and incorporate negation into logic programming languages. Most of the interesting proposals rely on semantics, and a considerable amount of papers in logic programming conferences is devoted to these subjects. Surprisingly, only a small subset of these ideas has arrived to the field on implementation and has produced modifications to Prolog compilers. In fact, the negation capabilities incorporated by current

Prolog compilers are rather limited: The (unsound) negation as failure rule, the sound (but incomplete) delay technique of the language Gödel, or Nu-Prolog, and the constructive negation of Eclipse, which was announced in earlier versions but has been removed from recent releases.

Our goal is to design the steps needed to extend a conventional Prolog compiler with a negation subsystem. Notice that this allows us to keep the very advanced Prolog current implementations based on WAM technology as well as to reuse thousands of Prolog lines.

Our idea is to combine and implement some existing techniques to make some negation techniques useful for practical application. There are two requirements for the techniques to be used: they need to fulfil Clark's Closed Word Assumption (CWA) by program completion and Kunen's 3-valued semantics. They must also be "constructive", i.e. the program execution need to search for the values that make false a negated goal. One can argue that Chan's constructive negation [25] fulfils both points, but it is quite difficult to implement and expensive in terms of execution resources. Therefore, our idea is to try to use the simplest (and cheapest) technique as possible in any particular case. To help on this distinction, we need to use some tests to characterize the situation. To avoid the execution of these tests during the execution of the program, the results of a global analysis of the source code are used. The program analyses includes groundness detection, elimination of delays, and the determination of the finiteness of the number of solutions. All these analyses are incorporated in the CIAO system, a freeware extension of Sicstus Prolog, which will be used as the testbed for our implementation.

The techniques we are planning to implement and use are:

- Negation as failure when the groundness analysis succeess or the delay elimination analysis provides an adequate program transformation.

- The finite version of constructive negation (that need to be implemented, but it is easier than the full version) when the finiteness analysis ensures a finite number of solutions.

- Intensional negation [24]. In this case we propose to reformulate it in terms of Herbrand constraints. Then we need to provide an implementation of universal quantification.

- Full constructive negation. This is the hardest step because there is no existing implementation of such this technique.

2 Level of Success

In this section we simply describe the current state of the project. In general, many of the goals have been fulfilled in a very high degree.

2.1 Functional Logic Languages

- We have formalized and specified in a detailed manner a formal framework and the analysis algorithms by means of *partial predicates* [2]. Partial predicates allow to define the properties to be analyzed in the same languages to analyze (Curry). Partial predicates can be composed either functionally or by means of usual operators, that, again, can be defined in the same language.

- We have also studied [2] several analysis algorithms and domains: demand analysis, Wadler's four points domain, etc.

- The sequentiality problem of Curry has been solved by using the information of program analyzers.

- The Sloth compiler for Curry has been improved.

- The implementation of demand analysis has been started in order to improve the Sloth code generation.

2.2 Prolog Negation

In this topic we have obtained almost all the initial goals.

- The implementation of all the auxiliary techniques (except constructive negation) has been completed and a prototype has been incorporated into the Ciao system [10].

- A strategy for implementing negation by the mentioned techniques guided by the information of the analyzers has been defined, implemented and tested [5].

- The implementation of constructive negation has been designed and a preliminary implementation has been tested [6].

- We have applied Multiagent Systems Engineering (MaSE) methodology to design our negation approach [1], and, we have also studied new applications of our negation to other areas, specially, fuzzy logic programming [4, 8]. In particular, a Ciao Prolog library for using fuzzy clauses has been developed [7, 9] (in co-operation with other research groups).

2.3 Specification languages and automatic code generation

- The Slam specification language is fully defined (up to additional extensions) [19, 23].

- The declarative reflection features of the language has been defined [16, 14]. Furthermore, they have been applied to model some desing properties, like design patterns formalization [13, 17, 18]. beginning

- We have a complete implementation of the syntactic analyzer for the language. It includes the type checker and a generator of the XML internal representation of Slam programs.

- We have a preliminar prototype of the development environment that allows for specification edition.

- The translation scheme from algebraic types into imperative types has been defined [12, 15]. The formal translation of Slam expressions into imperative code (f.i. loops for quantifiers) has been also established [15]. Therefore, the Java code generator is almost finished. The assertion generator has been tested by interfacing Java with Prolog [11].

- Some preliminar results for a Slam semantics based on a specific logic.

3 Results

3.1 Personnel and PhD Thesis

The project has favoured the research activity of 3 young researchers of the group. There is one thesis completed during the project [20], and two additional ones in preparation [21, 22]. Another researcher was contracted by the project.

3.2 Publications

We have published 13 international conference and workshop papers, 3 spanish conference papers, and 2 journal papers [8, 14]. There are also 3 submitted papers to other journals. A full list of related publications can be found in the reference list. There is also an invited talk to an international conference [23] as well as many invited talks to several events and Summer Courses by the project coordinator (Summer Course of Universidad Complutense de Madrid, El Escorial, July 2001; Summer Course of UNED, Avila , July 2001, July 2002; Main lecture, graduate ceremony, Escuela de Informática, Universidad de Castilla-La Mancha, May 2001, 20th Anniversary Facultad de Informática, Universidad Politécnica de Valencia (pannel), Jornadas Técnicas de Red Iris, Pamplona, October 2001,Jornadas sobre Micro@Nanotecnologías, San Sebastian, June 2002).

3.3 Collaborations

The research team has a strong relationship with other groups in the form of joint projects, stays, visits, etc.: M. Hanus, Kiel University, Alan Mycroft, Cambridge Computer Lab, Luis Moniz Pereira, Universidade Nova de Lisboa, etc.

On the other hand the team is part of a IST Expression of Interest of the VI Programme Framework with title *Network of Excellence on Reliable, Rigorous and High Quality Software Development* with the following partners: Jean-Raymond Abrial (Consultant, Marseille - F), Juan Bicarregui (Rutherford-Appleton Laboratory - UK), David Crocker (Escher Technologies Ltd - UK), Anthony Filkenstein (University College London - UK), Cliff Jones (University of Newcastle upon Tyne - UK), Thierry Lecomte (ClearSy - F), Dino Mandrioli (Politecnico di Milano - I), Ana Moreira (Universidad Nova de Lisboa - P), Axel van Lamsweerde (Université Catholique de Louvain - B), Holger Schlingloff (FHG-FIRST - D).

3.4 Industrial co-operation

The enterprise ELIOP S.A. was originally included in the proposal as EPO (promoter/observer entity). Although the Slam system was not ready, the methodology and techniques underlining Slam were used for the development of a control system for railway stations. This application is going to be used for testing Slam.

Now we have a common project with the enterprise SoftWCare for the development of a system for validation of critical applications where the Slam experience will be used.

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HERMES, Hemerotecas electrónicas: Recuperación multilingüe y extracción semántica TIC2000-0335-C03

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Abstract

The main goal of the HERMES project is to explore computational linguistics techniques in order to evaluate their potential for accessing information contained in multilingual collections of documents, either static or dynamic. We aim to provide fully evaluated and scalable search prototypes to help users searching both a stable news repository and a set of dynamic online news servers. For this, Human Language Technologies in English, Spanish, Catalan and Basque are being developed in order to optimize their use in such Information Access applications. Results obtained so far are given and open challenges are described.

Keywords: Human language technologies, cross-lingual information retrieval

1   Goals and work plan of the project

The main goal of the HERMES project is to explore computational linguistics techniques in order to evaluate their potential for improving multilingual information retrieval, providing accurate responses to users requests. Our approach considers the design and building of resources and techniques in four languages, namely Spanish, Catalan, Basque and English, to process multilingual textual information available in a variety of electronic repositories such as digital libraries, Internet or Intranets sites. To reach this goal, both basic and applied research are needed. Firstly, algorithms to deal with multilingual information are required; some are known for one language and need to be adapted to other languages and for this, corpora are required. Others are open problems and the work to be done will contribute to the state of the art. Secondly, from the application point of view, the tools implemented need to be efficient and reusable, in order to explore better ways of indexing, searching and accessing multilingual information in real scenarios, as well as to offer more functionalities such as summarization. Furthermore, resources and tools should comply and contribute to international efforts in standardization and evaluation. Two applications are foreseen: (1) An environment to consult a

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large virtual library in four languages (2) A search engine for news-on-line from a variety of Internet newspapers sites. Both applications raise at least two challenges: going beyond information retrieval techniques based on matching search terms, and linking documents and queries in an independent way of their source language.

The following set of intermediate, more concrete objectives, outlines the task structure of the work plan:

a) Improve and/or propose new word sense disambiguation techniques (task 3)

b) Develop robust techniques to process a document in any of the 4 languages to perform: Language identification, multiword and term recognition, entity recognition and co-reference resolution. (task 3)

c) Develop new algorithms, to be used as components in the applications, to perform clustering and summarization of documents (task 4)

d) Create robust techniques to map a query in one language in any of the other languages (task 4)

e) Define interactive cross-lingual information retrieval tasks, including as proof of concept linguistic techniques. Propose an evaluation framework. (task 5)

f) Design and implement two applications, to show the performance with different requirements: closed vs. open collections, on-line/off line,…(task 5)

g) Create, refine, and compile the linguistic resources needed for the above objectives (task 2).

The project structures these objectives in four tasks, plus coordination (task 1), each one organized in subtasks, as detailed in the technical annex. The duration of the project is from January 2001 to December 2003. Relevant aspects of each task are described in the next section.

2 Approach, work done and future directions

Task 2: Document Collections, Resources and Evaluation Criteria

For any sophisticated NLP application such as this project goals, it is necessary to rely on robust, wide-coverage language resources, which includes lexical databases, corpora, and linguistic processors. Additionally, it is necessary to evaluate the coverage and performance of all these resources. Task 2 deals with the creation, updating and adaptation of new and existing resources for NLP processing. The task is organized in three subtasks:collection creation and international evaluation campaigns (this last listed in section3), 2.2 resources adaptation and 2.3 evaluation.

Regarding **subtask 2.1** (collection creation), the building and compiling stage have been completed, and all the corpora and document collections required in the project have been acquired. Nevertheless, useful corpora will continue being compiled. The collection includes: a) a Spanish-Catalan parallel corpus from *El Periódico* online newspaper. A webbot collects every day the bilingual edition of this newspaper. The data is cleaned, converted to XML, paragraph-aligned and stored, b) a Spanish-Basque parallel corpus from the official gazette of the Basque Country. The data is cleaned, converted to XML, paragraph-aligned and stored, c) a Spanish-Catalan-English

comparable corpus from *EFE* news agency. All *EFE* news from 2000 in these three languages has been standardized through XML annotation. The marks include date, author, topic, etc, d) a Basque corpus from *Egunkaria* newspaper from 2000. It has been standardized through the same XML annotation. These collections have been used in text categorization experiments, and constitutes a valuable resource for cross-lingual Information Retrieval experiments (see task 4) e) Basque and Spanish corpora hand annotated with Named Entities (see task 3.2) Additionally, several specific actions have been undertaken: A 100,000 word Spanish corpus has been annotated manually with PoS tags, in order to train, tune and evaluate taggers and lemmatizers with high fiability. Also, a 800,000 word subset of *EFE* Spanish corpus has been annotated with Named Entities (see task 3.2), enabling the training and evaluation of NE recognisers and Classifiers for Spanish.

Task 2.2 consists of adapting existing resources to the current project, and has two main threads. **(1)WordNet enrichment**- on the one hand, the WN-Domain labels developed by (Magnini and Cavaglia, 2001) for WordNet, have been ported to EuroWordNet, enabling its use in Spanish, Catalan and Basque. The use of WN Domains is a useful information source in tasks such as text categorization and word sense disambiguation. Basque EuroWordNet is being extended and revised. Nominal synsets are under thorough revision to ensure the presence of basic lexical items and senses. On the other hand, procedures for hierarchy mapping (Daudé et al., 2001) have been developed, and applied to different WN versions, providing accurate version independence to WN-based applications and resources. The mapping procedures have also been applied to multilingual hierarchy mapping between Spanish dictionary-acquired taxonomies and WN. Currently, prototypes are available for the following areas: a) Example acquisition system. Occurrences of EuroWordNet concepts are automatically acquired from online texts, b) Topic signatures. EuroWordNet synsets are enriched with characteristic term vectors (Agirre et al., 2001), c) Relation acquisition. Derivation and syntagmatic synset relations are acquired from machine-readable dictionaries (Agirre at al., 2002a), d) Selectional restrictions. English verbs are enriched with selectional restrictions (Agirre and Martínez, 2002), e) Synset clustering based on topic signatures, f) WordNet enrichment using Internet directories (Santamaria et al., 2001). Currently up to a 30% coverage, g) Automatic creation of a phrase bilingual Spanish-English dictionary from comparable corpora and alignment algorithms. Currently more than 2 million phrases of two and three words have been collected. These prototypes should be definitive and operative to enrich all EWN concepts before the end of 2002.

 (2)Linguistic Processors adaptation- this is mainly an engineering task, which aims to ease the integration of analysers and resources for all languages involved in the project. The proposed architecture is a distributed system based on a CORBA layer, which makes each component independent of the others. In this sense, two XML DTDs have been defined for the corpus storage and analyser outputs. The document-oriented off-line DTD is used to annotate corpus that will be accessed through the IR/QA techniques, and contains information about document attributes (date, author, category), structure (title, paragraphs), and Named Entities appearing in the text. The query-oriented on-line DTD defines the output of the basic distributed Linguistic Processor modules, and encodes information about morphology, part-of-speech, and Named-Entity recognition. Following these DTDs, processors have been embedded into CORBA objects, which can be accessed from any remote machine, following the architecture proposed in (Carreras and Padró, 2002). In addition, a C++ recoding of the slower Perl modules is currently being undertaken in order to speed up the system, which is a critical issue, especially on the on-line processors, since they will be used from the IR/QA end-user applications. Additionally, the robustness and customisation of the Basque processors have been improved (Alegría et al., 2002).

Task 2.3 Deals with the evaluation of the project components at different levels: At the linguistic processor level, the evaluation is performed through usual precision/recall scores, according to each specific processor. At application level, a more general evaluation is required, including user viewpoint evaluation. This implies the evaluation of tasks, for which standard test sets -such as those of CLEF- may be used. In addition, a document (Amigó, 2002) has been issued stating project evaluation criteria and protocols, both to the specific resource level and to the application level.

Task 3: Advanced techniques for language processing

In this task we have joint efforts to produce state-of-the-art systems in the following areas: a) Word sense disambiguation, b) Language identification, c) Recognition and classification of Named Entities and terms and d) Co-reference resolution

Word Sense Disambiguation- in this area all UPV/EHU, UPC and UNED teams have reputable experience. There are two main classes of systems for WSD: (1) *Supervised systems*: they need tagged material to train, where tagging is usually performed by hand. There is only enough training material for a handful of words in Spanish, English and Basque. In the case of English there is training material for most words, but the amount of examples per word is not enough to train accurate systems. (2) *Unsupervised systems*: do not need hand-tagged texts. They are usually based in information in dictionaries and co-occurrence data from large corpora. The first objective of Hermes was to be able to evaluate the different systems produced by each of the teams on common grounds. All systems took part in the SENSEVAL competition (where UPV/EHU organized the Basque task and UPC and UNED jointly organized the Spanish task). The results allowed us to take the following conclusions:

- English all-words: UNED presented the best performing unsupervised system, but systems trained on available corpora obtained better results. This means that there is room left for improvement on this area. (Fernández-Amorós et al., 2001)
- English lexical-sample: the three teams presented systems that performed in top 10, proving that Hermes will be able to provide state-of-the art supervised WSD systems. In particular, UPCs system proved the best of all three (Escudero et al., 2001).
- Basque lexical-sample: the UPV/EHU supervised algorithm used for English was successfully ported to Basque, adapting the features to the idiosyncrasies of Basque (Agirre and Martinez, 2001).

All in all, when sufficient hand-tagged data are available, supervised systems outperform the rest. This means that a moderately precise WSD system (70%) could be made available for English. The next objectives for Hermes involve increasing the accuracy of such an English system (in order to be useful in IR/IE tasks) and adapting the algorithms to the rest of the Hermes languages. The project is currently exploring the following areas: a) Obtaining more tagged training material, e.g. using an example-extraction system based on information in WordNet. This will allow for more accurate systems primarily for English. All UNED, UPV/EHU and UPC are testing the validity of this approach. b) Using vast amounts of untagged training material and semi-supervised machine learning algorithms (UPC).

Language identification- a system capable of recognizing text in Basque, English, Catalan and Spanish was successfully developed, and is currently available for Hermes participants.

Recognition and classification of Named Entities and terms- the UPC team has developed a framework to perform wide-coverage Spanish Named Entity Recognition, which is described in (Arévalo et al., 2002). First, a linguistic description of the typology of Named Entities is proposed. Following this definition architecture of sequential processes is defined for addressing the recognition and classification of *strong* (or simple) named entities and *weak* (or complex) named entities. On the one hand, strong entities are treated in an inference scheme combining several classifiers (based on the AdaBoost learning algorithm) learnt on the basis of very simple attributes requiring non tagged corpora complemented with external information sources (a list of trigger words and a gazetteer)(Carreras et al 2002b). This part of the system has participated in the Shared Task competition organized by the ACL's Special Interest Group on Natural Language Learning during the annual CoNLL workshop, achieving the first position both in Spanish and Dutch languages (Carreras et al., 2002a). On the other hand, the recognition of weak named entities is approached through a context free grammar for recognizing syntactic patterns, which is currently being improved and fully tested-first results in (Arévalo et al., 2002).

Co-reference resolution- the UPC group is currently developing a module for performing co-reference resolution. The architecture of the system is aimed to be language independent. The system is rule-based and its performance is controlled by three rule-sets: i) a rule set for detecting units that could be considered anaphoric descriptions (basically anaphoric pronouns), ii) a rule-set constraining the nominal phrases candidates to co-refer with such anaphoric units, and iii) a rule-set defining preferences between the candidates accepted by the second rule-set. The system follows basically (Palomar et al., 2001) for detecting co-referents of pronouns in Spanish texts. The original system has been adapted to the characteristics of the parser used within Hermes. The system is currently being implemented for Spanish. In the next future it will be tuned to Catalan and English.

Task 4: Advanced techniques for IR/IE: Document Classification, Clustering and Linking

Task 4 involves three subtasks: Document classification, clustering and linking (4.1), Automatic summarisation (4.2) and, Query expansion/translation and conceptual indexing (4.3).
Regarding **Document classification** (or categorisation) several actions have been undertaken. On the one hand text classifiers for the 4 languages involved in the project (Basque, Catalan, English, and Spanish) have been developed using a unified set of categories: the standard IPTC first level 17 categories for news agencies. In doing so, several aspects have been studied: (1) a comparison between several Machine Learning algorithms for performing the task. Specifically, we have tried Bayesian classifiers and SNoW -sparse network of linear Winnow classifiers- for categorising Basque documents, and AdaBoost and Support Vector Machines for dealing with Catalan, English, and Spanish. The overall results are over 80% (F1 measure), which can be considered state-of-the-art, and the best performing algorithm is SNoW for Basque and SVM (with a slight advantage over AdaBoost) for the other languages. (2) We also addressed the problem of collecting a labelled corpus for training the systems. For Catalan, English, and Spanish we used the *EFE* collection of news agency documents (year 2000), which are labelled with internal category codes. We developed an *n* to *m* automatic mapping between *EFE* categories to the IPTC categorization scheme in order to automatically obtain training documents. The Basque collection is extracted from the *Egunkaria* newspaper, categorized according to the newspaper sections. Mappings to the IPTC categories plus

a booststrapping step (with human supervision) have been performed in order to obtain training examples for all categories. (3) Alternatives for the representation of documents: from the common bag of words (plus stemming and stop-words removal) to the coding of entities, and statistically based n-grams of words. For Basque, lemmatisation has proved to be very important, while the representation of documents using only nouns lead to very good results (Arregi and Fernández, 2002). (4) A knowledge-based text classification system based on the domain-labels of the nouns appearing in the documents has been developed. Linking the domains through EuroWordNet and having again a mapping between domain labels and IPTC categories, we obtained a language independent non-supervised classification system valid for the four languages of the project. This system is now under evaluation in order to see if it is competitive with the supervised machine learning systems. One issue under consideration is to test the effect of the automatic mappings between category schemes on the accuracy of the resulting systems. Another clear challenge for the future research is the combination of both approaches for text classification.

 The clustering subtask deals with the problem of identifying sets of thematically related documents (e.g., a set of documents, in one or many languages, referring to the same new/event). Since these sets or categories are not defined in advance, this is a task of unsupervised learning (usually referred to as clustering). The list of research topics in which we have been working up to the present include:

- Development of a survey on similarity metrics for dealing with text (Rodriguez, 2002)
- Experimenting with several distance measures between documents, which take into account different levels of granularity between document components (paragraph, summary, document, etc.). This topic is especially relevant also for the document summarization task and for establishing the links between parts of documents. Several experiments are being carried out in order to try different clustering algorithms with several metrics using a mid-size document collection (about 16,000 documents per language). The clustering algorithms used are freely available implementations. The clustering is performed on monolingual and multilingual collections of documents.
- The problem of measuring the quality of clustering systems is very important since the non-supervised nature of the task does not allow defining "accuracy"-like measures on the resulting clusters. The quality of the clusters generated depends on many factors, which can be partially automatically measured (granularity/density/intersection degree of clusters, etc.) but always requires some manual intervention in order to assess the real utility. We have worked on defining some measures of direct and indirect utility measures of the results.

 The work performed on similarity metrics and clustering is the basis for addressing the linking of documents at a level of document, paragraph, and entities involved in the documents. We plan to achieve a first prototype by the end of the year.

Automatic Summarization- the final goal of this task is to develop a multilingual summarization system. The first step performed was an extensive study of the state of the art in automated text summarization. This resulted in a document proposing three complementary classifications and a comprehensive file for analysing summarization systems (Alonso et al., 2002). Among all the existing possibilities, two complementary summarization strategies were chosen: 1) detecting lexical chains on texts, based on the work of (Barzilay, 1997), and 2) exploiting rhetorical structure of the texts, based on the work of (Marcu, 1997). The reasons to choose these two lines of research were the following: (a) They rely on general linguistic properties of texts, providing for flexibility and scalability, which are one of the main shortcomings of systems that exploit genre- or domain-dependent features of texts. (b) They can be easily adapted to other languages and to other kinds of

summarization, such as multilingual summarization. (c) They exploit properties of texts that are highly informative but that can be treated with shallow NLP techniques, namely, morphological analysis and chunking. (d) They are complementary, since they both exploit discourse properties of text, but from a different perspective: lexical and structural.

Two prototypes of indicative, extractive summarization systems for Spanish have been developed:

- A system based on lexical chains (Fuentes and Rodriguez, 2002) that selects the most informative fragments for including in the summary. The system uses lexical chains as primary source for ranking segments of the text. It also uses co-reference chains and named-entity chains. The system aims to be language independent provided we could access the required knowledge sources, basically the corresponding WordNets.
- A system based on the rhetorical structure of texts. It detects discourse markers in text and exploits the information in a discourse marker lexicon to obtain shallow discourse structure. Up to the moment, this system only performs sentence and paragraph-level summarization.

 The performance of these systems has been evaluated to assess further improvements. The lexical chain system has been tested with a gold standard built from a corpus of Spanish agency news using the evaluation software MEADeval (http://perun.si.umich.edu/clair/meadeval). Its results were compared with two baselines: the lead method (i.e., extracting a number of paragraphs, starting on the first one, until the desired length, given the compression rate is achieved) and SweSum an available system (http://www.nada.kth.se/~xmartin/swesum/) allowing summarization of Spanish texts. As for the rhetorical structure system, only the discourse segmentation module has been evaluated (Alonso and Castellón, 2001). Both evaluations show competitive results and they are especially valuable to indicate future improvements. In addition, these two summarization systems have been combined to achieve an improved representation of discourse that should correspondingly improve the quality of the resulting summary. Evaluation of this combination (Alonso and Fuentes, 2002) shows that there is a qualitative (selection of text fragments) and quantitative (degree of compression) improvement on the performance of both systems when they are combined. Future improvements on the lexical chain system concern Named Entity chains, which could be improved with more accurate recognition and classification of Named Entities, for example, by using gazetteers. Additionally, Named Entities could be linked to EuroWordNet, which would relate these two kinds of information directly. Concerning co-reference chains, extended co-reference mechanisms (e.g., definite descriptions) should be taken into account to improve the performance of the system. Also developing more complex forms of chain merging could be a promising direction. The rhetorical structure system should be improved by enhancing the quantity of discourse markers in the discourse marker lexicon and the information associated to them. To address the first, bootstrapping techniques have been used. As for the second problem, we plan to obtain discourse schemata that span over high-level textual units by multiple sequence alignment techniques. A parallel line of research is on cross-language summarization for foreign-language document selection. This kind of summaries only make sense in the context of foreign-language document retrieval, and hence it is described in detail in task 5 (search applications).

Query Expansion/Translation and Conceptual Indexing- these techniques can only be evaluated in the context of Cross-Language Information Retrieval engines. For the sake of readability, we describe both the techniques and their evaluation in next section.

Task 5: Multilingual Information Access Applications

The driving force of the HERMES project is the idea that Language Engineering techniques and resources may help bridging the gap between the classic "Document Retrieval" model and the broader "Multilingual Information Access" paradigm. Traditionally, Information Retrieval has been understood as a fully automatic process that inputs a query (a statement of user needs) and a text collection, and outputs a (ranked) set of documents, which are relevant to the query. A perfect IR engine would retrieve only relevant documents (perfect precision) and all relevant documents (perfect recall). This model made many implicit assumptions: that the text collection and the user needs are static, that both query and documents are written in the same language; that the user is familiar with the terminology used in the documents; that information needs are optimally satisfied with documents (rather than information itself), etc. The advent of Internet and the so-called *Information Society* has quickly driven this paradigm into obsolescence. The term "Multilingual Information Access" refers to the broader –and now realistic- challenge of helping users to browse, search, retrieve, recognize and ultimately use information (rather than documents) from distributed, dynamic and heterogeneous sources of multimedia and multilingual hyperlinked information objects. Relevant research topics include Multilingual IR, Multimedia (video, speech, image) retrieval, Interactive Retrieval, Question & Answer systems, Digital Libraries, Internet crawlers and search engines, etc. The HERMES project focuses in the problem of accessing information contained in multilingual collections of documents, either static (news repository) or dynamic (searching online news sources). The user profile can vary along three main features: (1) Native language, and degree of familiarity with each of the other languages in the collection. (2) Degree of familiarity with the contents and the terminology of the collection. (3) Specificity of the information need, from very fuzzy (mostly navigation) to very concrete (focused search of specific information items). The ultimate goal of HERMES is providing fully evaluated and scalable search prototypes to help such users searching both a stable news repository and a set of dynamic online news servers. The companion goal, described in previous sections, is leveraging Human Language Technologies in English, Spanish, Catalan and Basque in order to optimise their use in such Information Access applications. We have currently accomplished the following tasks towards the final HERMES prototypes:

- Qualitative evaluation of Word Sense Disambiguation Strategies in Concept-based multilingual retrieval.
- Development and evaluation of a prototype, "Website Term Browser" that uses morphosyntactic information to provide a "phrase-browsing" multilingual search feature for users with reading abilities in most languages of the collection.
- Development of the first HERMES prototype, that incorporates morphosyntactic analysis, named entity recognition, summarization, paragraph-based searches and clustering in a single search interface.
- Development and comparative evaluation of search strategies for unknown languages, including a cross-language summarization technique to assist document selection and a query formulation and refinement strategy based in user assisted monolingual phrase selection combined with automatic phrase translation.

In the remainder of this Section we summarize the results obtained in each of these stages.

Word Sense Disambiguation and Concept-based multilingual retrieval- the possibility of using a language-independent inventory of concepts (the EuroWordNet InterLingual Index) as indexing space for all documents in all languages seemed a very attractive option to the HERMES consortium, for a variety of reasons: (a) Compared to other Cross-Language IR (CLIR) strategies

(essentially, query translation into the document languages), having a unique indexing space avoids the problem of merging ranked lists from individual languages, a problem that is yet unresolved in CLIR. (b) It scales better than query (or document) translation for a growing number of languages. (c) It uses WSD to solve directly some traditional problems of keyword-based retrieval (identification of synonym terms, identification of different senses of a word, etc.). (d) It permits using the conceptual relations in EuroWordNet for query expansion (broader and narrower terms, part-of relations, etc). Two main reasons, however, led to provisionally discarding this approach: (1) Word Sense Disambiguation techniques have not yet reached a sufficient degree of maturity for such an ambitious approach. On the one hand, supervised techniques are not yet scalable, in the absence of large-scale training corpora. On the other hand, unsupervised techniques are still far from being accurate enough for indexing purposes. While the HERMES unsupervised WSD systems were the best both in the lexical sample and in the all-words SENSEVAL tasks (see task 3), the recall obtained was essentially similar to a pick-first-sense strategy. (2) The qualitative evaluation of the concept indexing approach showed that there is a friction between multiword indexing units for monolingual and cross-language retrieval. Multiword expressions (either being units in the conceptual indexing or not) are not adequate for monolingual retrieval, where it is better to index all its components. This has been thoroughly tested for agglutinative languages (German and Dutch in particular) in the framework of CLEF evaluations. However, phrasal expressions are much better than individual words for translation. Conceptual indexing suffers from this problem of different granularities for different searches: if a multi-word expression is not in EuroWordNet, it will not be translated adequately into other languages; and if it is present in EuroWordNet, it will be translated properly but it will not produce good monolingual results in each individual language searched. This problem derives from understanding indexing and translating as one single task. We have, therefore, looked for alternative uses of lexical processing in multilingual search applications, with a remarkable success, as detailed below.

Development and evaluation of a Multilingual Phrase-Browsing Search Approach- as mentioned above, multiwords and, more generally, phrasal expressions are not adequate indexing units for automatic retrieval because they are too restrictive, hiding their components as partial matching units between text and query. Phrases extracted from the collection can be, however, extremely useful in interactive searches, because they provide an alternative, information-oriented perspective of the contents of the collection. This is known as the "phrase-browsing" approach to interactive retrieval. The UNED group has extended the phrase-browsing paradigm to a multilingual phrase-browsing paradigm (Peñas 2002). The main idea is to exploit the two potential benefits of phrases: as a rich source of information for interactive searching, on one hand, and for accurate lexical expansion and translation, on the other. This approach solves the problem of the conceptual indexing approach: phrases are not used for indexing (but for interactive refinement of the query), but they are used for translation (where they provide enough context for accurate translation) and expansion (again offering enough context to expand only with relevant terms). The result is the WebSite Term Browser, a multilingual phrase-browsing search engine that unifies expansion and translation of the query terms as a single process. WTB has two main components: at indexing time, efficient morphosyntactic analysis is used to recognize all noun phrases in the documents, and an index from phrases to documents is built in addition to the classical index from words into documents. An index from words to phrases completes the indexing process. At searching time, the system expands every word in the query using semantic relations in EuroWordNet, including synonyms and cross-language equivalents in all document languages. This process, initially very noisy, is used to select phrases in the collection containing a maximal number

of query-related terms; this restriction eliminates most noise. Phrases are organized conceptually and shown to the user as an alternative way of accessing the information in the collection. The evaluation of WTB was done comparing the utility of phrasal information to the ranked document lists provided by Google, which is currently one of the best Internet search engines. A search interface for the UNED domain (with approximately 50000 docs.) was designed to make this comparison. Given a user query, this interface outputs both the results of Google and the phrases retrieved by the WTB software. The user could then select a document or a phrase matching his information needs. The search interface was offered as a service of the UNED educative portal, and all searching sessions were logged for analysis. The study of the first 2000 non empty queries revealed that choosing a phrase after the initial query was even more frequent than choosing a document retrieved by Google, indicating the potential value of the approach (Peñas et al 2001).

First HERMES prototype- the success of the multilingual phrase browsing approach led to a continuation in the first HERMES prototype, which incorporates lexical resources (EuroWordNet), extends phrase recognition with detection of named entities and events, provides document and paragraph searching facilities based in all that language annotations, and provides room for summarization, and clustering. Rather than simple document retrieval, this interface provides sophisticated access to the information contained in relevant subsets of the collection being searched. In this first prototype, a search begins with an initial short query containing some keyword terms. The system filters the contents of the collection, retrieving documents that contain the query terms. From such set of documents, the systems extracts and displays information about persons, locations, events, etc., related to the query. The user can then refine his information need by selecting and combining such pieces of information. The system allows, for instance, selecting all actions taken by Arafat in relation to Israel in a particular time frame. Finally, the system displays the results of this information request. The user may select to view documents or paragraphs related to his query:

- If the documents view is selected, there is a range of options to examine them. The first prototype includes the possibility of a) clustering them according to their IPTC category, which is automatically assigned, b) viewing summaries of individual documents, and c) viewing classified entities within individual documents.
- If users prefer to view relevant paragraphs, they can chose to list them grouped by subjects, actions or objects. Once a paragraph is selected, the system shows it with the same options than documents, but also with the option of saving the paragraph in a table that plays the role of a clipboard where user can build a cross-document summary.

Hence this first prototype integrates morphological analysis, parsing, named entity recognition and summarization techniques. The next prototypes will also include the possibility of viewing documents according to their similarity (clustering), together with a multi-document summary of contents of the cluster. Multilinguality is not yet incorporated into this prototype; we believe that multilingual information access challenges are of a very specific nature, and should be thoroughly tested in isolation before incorporating them into a single search interface. According to this philosophy, we have designed and evaluated some information access strategies for unknown languages that we describe below.

Foreign-Language Search Assistance- Cross-Language Information Retrieval is stated as the problem of, given a query in some source language, being able to identify relevant documents

written in some (different) target languages. Over the last 6 years, this problem has received a growing attention from the Information Retrieval and Language Engineering research communities, and there exists now well-founded techniques to solve it and well-established comparative evaluation methodologies. As mentioned before, the UNED group is involved in the organization of an annual comparative evaluation of CLIR systems in European Languages. This problem is, however, only one of the challenges of the multilingual information access problem. For instance, if we type a Spanish query and receive a ranked list of Chinese documents, how can we recognized which of them are really relevant for our purposes? How can we refine our query taking these results into account? How can we use the information contained in documents we cannot read? These are problems that have not received enough attention from the research community yet. The default assumptions for a Cross-Language search engine are that a) commercial Machine Translations systems can be used to translate documents into the native language of the user, and b) document selection and query refinement can be done using such translations. In order to challenge such (untested) assumptions, the UNED team designed and organized, together with the University of Maryland, a common evaluation framework, called iCLEF, for the comparative study of user interaction issues in Cross-Language IR.The first evaluation campaign took place in 2001 (Oard and Gonzalo 2002), and it was devoted to document selection mechanisms: Is Machine Translation the only option available? Can it be substituted for simpler and faster methods without degradation of relevance judgements? Are there even better alternatives than Machine Translation?

At the UNED group, we devised a cross-language summarization technique based on noun-phrase alignment using comparable corpora (López-Ostenero et al. 2002a). The idea is to extract noun phrases as in previous HERMES prototypes, and align them using only bilingual dictionaries and statistical evidence from related corpora (in our case, news in different languages from the same time frame). The result is not readable as a summary in its classical sense (cf. previous section on summarization), but it can be enough for indicating whether a document is relevant for a query or not, and it can be read much faster than a full Machine Translation of the document. The evaluation of such cross-language summaries was done using the common iCLEF methodology over four topics in Spanish, the English CLEF news collection, 32 Spanish users and 128 searching sessions. The official iCLEF results stated that cross-language summaries allowed for relevance judgement with almost the same precision than Systran Professional 3.0, and with a 51% improvement in recall, because users judged documents faster with phrase-based summaries. Compared to other iCLEF results, the UNED strategy was the only one to overperform, even to match, MT results. The second evaluation campaign took place in 2002 (Gonzalo and Oard 2002), and it was devoted to study support mechanisms for interactive query formulation and refinement. While other groups studied user-assisted term translation (via inverse dictionaries, translation definitions, etc), at UNED we hypothesized that user assisted term translation would demand a high cognitive load from the user. As an alternative, we tried to assist the user to select relevant phrases from his query, and then let the system perform automatic translation of the queries using the aligned phrases resource already built the previous year. Using phrase-based summaries to explore the document contents, the users could easily add new phrases to the query, which again would be translated without user intervention. In the official iCLEF measure, our strategy performed 65% better (combined precision/recall measure) than a strategy based on user assisted term selection (López-Ostenero et al., 2002b). To complete the picture, the Maryland group checked that user-assisted translation is better than blind translation; overall, the UNED strategy is one of the most promising ones. Both results from the two iCLEF evaluation campaigns will be crucial for the design of the next HERMES prototype, where all search facilities will be enhanced

with multilingual abilities. The future HERMES prototype should offer different searching facilities according to the knowledge of the languages involved. Users with active, passive or no knowledge of some of the target languages should receive very different types of search assistance. The Website Term Browser can be a good model for high or moderately multilingual users, while the iCLEF UNED prototypes could be a model to assist monolingual users.

Multilingual Online News Meta-searcher prototype- the second HERMES application is designed to facilitate access to online news rather than stable repositories. The first prototype is already active and is able to accept queries in any of the four HERMES languages translate them into all languages and query the online searchers of *ABC*, *El País*, *El Mundo* (Spanish), *Avui* (Catalan), *Egunkaria* (Basque) and *Washington Post* (English). Most of the effort on this initial prototype has been done on the meta-search aspects of the server, and thus the cross-language mapping is still fairly simple and experimental. Three ways of cross-language expansion have been currently devised: a) just building a query with all possible translations for all possible query terms, b) all terms, but structured in a Boolean query; translations for a single term are grouped with OR operators, and translations for different terms with AND operators; c) lookup of the bilingual dictionary of phrases described above as a first translation resource, and resort to bilingual dictionary for the rest of terms.

3 HERMES results and activities in the international research community

Publications- total number of papers published: 65, where 2 are HERMES technical reports, 13 in collections indexed by ISI JCR, 17 published in major CL events (ACL, COLING, LREC), 1 in ACM collection, 13 in international and 10 in national Conferences with referees, 7 in national journals and 2 in international journals. 2 PhD Thesis have been presented, one in UPC and the other in UNED. The full list is available at the project web site. http://terral.lsi.uned.es/hermes/ **Resources** built, with public distribution: Spanish CLEF collection and evaluation suites (free for participants and for a small fee through ELDA), Basque and Spanish SENSEVAL evaluation suites (available through the official site (http://www.itri.brighton.ac.uk/events/senseval/). Eurowordnet-HERMES (a lexical database including the 4 languages). **Relationships with other research groups involving PhD** students -the UNED group has established collaboration with Prof. A.Kilgariff, belonging to ITRI (Brighton University) on SENSEVAL resources and evaluation. The PhD student I.Chugur has carried out a 3-month stage in 2001 carrying out a study of sense similarity (Chugur et al., 2002). The PhD student E.Amigó has participated in a summer school organized by ELSNET with a grant from the organization. The UPC group has established collaboration with the *Cognitive Computation Group* (*Department of Computer Science, University of Illinois at Urbana-Champaign, http://l2r.cs.uiuc.edu/~cogcomp*) headed by Prof. Dan Roth, on the topic of the application of automatic learning methods to natural languages processing. These techniques have been applied to entity recognition and shallow parsing. The PhD student Xavier Carreras has carried out a stage in this group at the beginning of 2002. The UPV group: the PhD Mikel Lersundi has carried out a 3 month stage in Maryland University, under the supervision of Prof. Bonnie Dorr, on the topic of analysing the semantic interpretation of prepositions and suffix in Basque, Spanish and English. This work contributes to task 2.2, the extraction of lexical semantics

relations from dictionary definitions. The PhD student David Martínez will spend three months in John Hopkins University with Prof. David Yarowsky on the topic of *bootstrapping* for disambiguation purposes.

Partnership and Collaborations

In a variety of dimensions the research groups have strong links with international research groups, through EU funded projects, the co-organization of international campaigns, such as the **SENSEVAL** and **CLEF** competitions, the participation on excellence networks, or the co-organization of workshops. Next we mention some of them. (1) **CLEF**- IST Programme of the European Union (project no. IST-2000-31002). http://clef.iei.pi.cnr.it:2002/Scientific coordinator: ISTI-CNR Istituto di Elaborazione dell'Informazione, Consiglio Nazionale delle Ricerche, Pisa, UNED is partner and co organizer with the University of Maryland of the interactive iCLEF 2001 and 2002 interactive task (http://terral.lsi.uned.es/iCLEF). Task definition, guidelines, testbed development, and task coordination. See (Gonzalo and Oard, 2002). (2) **MEANING***: Developing Multilingual Web-scale Language Technologies* (IST-2001-34460), coordinated by Germán Rigau, also involved as researcher in HERMES. Both projects share topics related to WordNet (T2.2) y and WSD (T3.1). (3) **ELSNET**- European Network on Excellence in Human Languages Technologies. UNED and UPC groups belong to this network. http://www.elsnet.org/ (4) **RITOS2**, - UNED group is involved in the NLP group and is organizing a workshop on the topic *Multilingual Information Access and Natural Language Processing*, in the next Iberoamerican conference on artificial intelligence IBERAMIA 2002 to be held in Sevilla. http://sensei.lsi.uned.es/iberamia-mlia/ (4) The ISCA (International Speech Communication Association) **Special Interest Group on Speech and Language Technology for Minority Languages.** UPV/EHU belongs to this special interest group. http://193.2.100.60/SALTMIL/

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RICOTERM: An information retrieval system with terminological control TIC2000-1191

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Abstract

Most automatic information retrieval systems are based on strategies of formal character chains detection, complemented with the statistical analysis of text properties. These systems have some constraints because they do not use the semantic and pragmatic information associated to these chains and their context of use.
Main objective of RICOTERM project is to design an information retrieval (IR) system, capable to improve present systems using the terminological control. This control will be achieved with the grammatical, semantic and pragmatic information associated to the units or occurrences that transfer the specialised knowledge. The system will be also improved with the discourse control, drawn from the information concerning intention, communicative purposes, and implicits in a text. The methodology used combines a tool for natural language processing, which includes structural mark-up, morphological and syntactic analysis, disambiguation, and a terminology extraction system based on formal patterns and lexical ontologies. Ground criteria will be refined by standards for the identification and mark-up of semantic and pragmatic elements within a restricted domain.
For this reason, we will refine and update some of the tools used by our group members and to create new linguistic resources to describe linguistics patterns in specialized discourse for designing strategies for a future RI prototype. In this sense, a knowledge bank is building about genomics domain, which includes textual corpus, ontology, documental & factographic data base and terminological data base, in English, Spanish and Catalan.

Keywords:

Linguistic Engineering (LE)
Information Retrieval (IR)
Natural Language Processing (NLP)
Combination of strategies from statistics, cognitive sciences and linguistics
Terminology extraction towards users

1   Objectives

In the current Information Society, one of the most urgent necessities is the automatic processing of large amount of data with results adequated to the users' information needs. The increase of written production and the telematic access to these information sources through Internet have let us know that, in order to have effective searchings, the information retrieval systems need to be improved in the following aspects:

? Avoiding the high percentage of generated noise by means of a greater content filter.
? Allowing the personalised access to the information by means of a greater filter of the users' information needs.

The research in information retrieval (IR) includes the development of applications for document tasks, artificial intelligence projects and knowledge management.. The information retrieval (IR) tools are search engines, summary generators, terminology extractors, automatic indexers and document thesaurus creators. One of the most interesting centres of the information retrieval investigation is the construction of interrogation interfaces in natural language (oral and written) of textual data banks for the direct information management by the users.

The computational resources to process the natural language such as the morphologic and syntactic analysers, the linguistic based or stochastic based disambiguators or the lexical ontologies can be also used in IR systems to improve the searching results and the information classification.

The tool and strategy combination for the IR is very important to the managerial sector devoted to the organisation of the knowledge management in big corporations such as hospital management, administrative management, emergency service management or big file management.

Most of the Information Retrieval (IR) Systems that are now working (Berry y Browne, 1999; Chowdhury, 1999; Kowalski, 1997; Frakes y Baeza-Yates, 1992), are based on the analisis of textual statistics properties, the relevant use of simple index terms and the algorithms whose efficiency, is only proved for few languages, specially for the English language. Examples of such algorithms are the *inverse document frequency* (IDF) estimation applied by almost all index engines of document data bases and most of the search engines in Internet. Although there are other algorithms, all of them deal about variations on the application of the following basic process (Berry y Brown, 1999; Frakes y Baeza-Yates, 1992; Salton, 1989): (1) Simple character chain determination as term index candidates, (2) Deletion of empty words, (3) Reduction of inflections of the same term or lema to a stem term, (4) Assignment, to each term of each document, of a weight resulting from the estimation of its local frequency, that is to say in each document with its global frequency, (5) Assignment, as index terms to each document of the terms whose weight overcomes certain threshold.

Besides the previous paradigm, there are other automatic index models based on co-occurrence statistics estimations, but empirically, such systems repeatedly show low contributions. Another example of algorithms for IR is the vectorial system based on matrixes. However, such algorithms only use character chains instead of concepts as indexing elements. Lastly, there is a very promising path called *latent semantic indexing* (Berry y Browne, 1999; Letsche y Berry, 1997; Deeerwester et al., 1990), but it has been

just tried out in real conditions, that is, with great document collections and only for the English language and the basic entry of continuous information keep on being the presence or absence of character chains in the document.

To sum up, as these IR systems neither disambiguate the textual information nor use linguistic indicators, their efficiency is always limited because they never cross the term meanings and as a consequence they never reach an indexing based on concepts but only based on character chains. The limitations of the automatic IR systems have only overcome to date by means of using intellectual procedures (manual and expensive) of analysis and document indexing with the help of terminological control tools and document languages such as thesaurus.

In this project, the first hypothesis is that the application of the analysis instruments, disambiguation and document tagging that belong to the terminology and the computational linguistics can be applied to the development of IR systems that overcome the limitations previously mentioned. The second hypothesis is that any analysis and document indexing systems increase their efficiency if it is taken into account that the specialised fields produce regularities and behavioural laws different from the non specific and general fields. For example, it does not mean the same to study automatic indexing system for texts that come from written newspapers (paradigm of general field) than for documents about biology, medicine, economics, law, or environment (paradigm of specialised field). Besides, in real life, the intellectual or automatic indexing systems whether they applied themselves systematically on specialised collections or the users wish to apply their searchings to specialised collections. For example, whether we are considering the indexing in data bases of science and technology (in this case, it deals about indexing specialised documents in a knowledge branch) or we are indexing the users' information needs who even if they do their searchings in general fields such as WWW, they move themselves in a specific thematic domain. We think that if linguistic indicators and marks present in the documents and the association patterns that the links create among the documents of the same field of specialisation were combined, we could increase in a marvellous way the efficiency of the IR systems in the WWW with an extraordinary benefit for the citizens of the future information society.

Thus, the project has planned diverse sequential objectives:

1. The evaluation of the existing IR systems. To do that, it has been stablished parameters of analysis of a selected inventory of search engines, document data bases and indexing engines.
2. The creation of a knowledge bank about human genome of modular configuration: textual corpora, ontology, document and factographic data base and terminological data base. These linguistic resources offer us information about the discursive and lexical use of a specialised field, that allow us to suggest discursive and linguistic strategies in order to detect information. The integration of diverse bank modules will

be done by means of a search engine created adhoc so that it could query the diverse data formats.

3. The refinement of the resources and tools of processing of natural language available in the research group (computational dictionary, automatic term-extractor, automatic neology detector, dictionary administrator, disambiguation rules, improving of the corpus morphosyntactic tagging, etc.).

4. The proposal of linguistic strategies based on the specialised discourse analysis and the analysis of the genomic terminology for the previous design of an IR system which it is expected to develop in a prototype way in further stages.

2 Success of the project

Waiting for the third term, our main goals have been organised in working teams and some of the partial results are the following.

Materials processing and applications development

In the knowledge bank about human genome, we have finished the building of the multilingual textual corpus (English, Spanish and Catalan). Data has been processed (SGML structural mark-up and linguistic processing with linguistic and stochastic disambiguation). In this sense, we have also built the documental and factographic database which is continuously updated with relevant data.

At present, we are developing the ontology about human genome and its corresponding terminological database using the terminology management system called OntoTerm, based upon the Mikrokosmos ontology. Moreover, we are working in the development of a search engine that will interrelate different data contained in the knowledge bank. Both the bank and the search engine will be accessible from a web site which is now under construction.

IR systems evaluation

We have already selected those IR systems that will be analysed and evaluated. It is also completed the final protocol of analysis which will be used for each type of system analysed. The evaluation criteria and the working protocol constitute a methodology of analysis and evaluation of IR systems which could be reused for other analysis.

All the analysis have been done and, in this moment, the working team meets weekly in order to revise data for publication (see section 3 about publications).

Evaluation of ontology management tools

The paper about the comparative evaluation on ontology management systems is already published (see section 3). In this working process we have tested the ontology management system called ONTOTERM (©Antonio Moreno, Universidad de Málaga), for which a usage manual has been written (see section 3).

Terminology extraction

As a result of one of the Ph.D Dissertation included in the project, Jorge Vivaldi has developed the term extractor called YATE. At present, the term extractor is been adapted to the human genome domain and, at the same time, he is developing a user interface.

Corpus mark-up, towards a semantic mark-up and text mapping

We have developed a program for the domain indications retrieval in the lexicographical applications which will be used in the semiautomatic mark-up of textual corpora. Moreover, the Ph.D Dissertation carried on by Judit Feliu (foreseen for the final period of the project) proposes an application for the conceptual relations retrieval in texts. This approach will also provide some semantic information appearing in specialised texts which will be reused for semantic mark-up.

In the text mapping domain, Raul Araya is developing a doctoral research work about the possibility to generate the map of the information contained in a specialised text. Thus, we have been working in the analysis of the ISO standards about topic maps and Cristofòl Rovira has built an on-line tool for the conceptual maps edition.

3 Results Indicators

3.1. Doctoral Thesis

Jorge VIVALDI PALATRESI, *Extracción de candidatos a término mediante combinación de estrategias heterogéneas*
PhD in Computer Science at the Universitat Politècnica de Catalunya; Department Llenguatges i Sistemes Informàtics. Directors: M. Teresa Cabré (Universitat Pompeu Fabra) and Horacio Rodríguez Hontoria (Universitat Politècnica de Catalunya). Date: June, 2001

Cristòfol ROVIRA FONTANALS, *El disseny de navegació i l'organització de continguts en l'hipertext per a l'ensenyament-aprenentatge*
PhD in Teaching Sciences at the Universitat de Barcelona; Department of Educational Theory and History. Directors: Lluís Codina Bonilla (Universitat Pompeu Fabra) and Miguel Angel Aguareles Anoro (Universitat de Barcelona). Date: December, 2001

Other Doctorate Thesis in process:
Carles Tebé Soriano, about terminological data bases
Adelaida Delgado, about XML
Judit Feliu Cortès, about semantic relations and ontologies

Other Doctorate research in process:
Raul Araya, about topic maps and knowledge representation.
Gabriel Quiroz, about large terminological phrase structures.

3.2. Some Publications

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A Model for the Application of Intelligent Virtual Environments to Education TIC2000-1346

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Abstract

The objective of the project is the definition of a model for the application of intelligent virtual environments in education and training. This implies:·The definition of a generic model for intelligent learning environments based on the use of virtual environments; The definition of an open and flexible software architecture, based on components, to support the generic model of a learning environment; The design and implementation of a prototype authoring tool that simplifies the development of learning environments based on the generic model. The authoring tool will be based on the defined architecture; The definition of a set of methodological recommendations for the development of learning environments based on the use of virtual environments. This methodology will propose a set of steps for the design of the environment according to the generic model, and its implementation with the help of the authoring tool.

Keywords: Intelligent Tutoring System, Virtual Environment, Intelligent Virtual Training Environment, Co-operative agent architecture, Co-operative design of software

1   Goals of the Project

The general goal of this project is the definition of a model for the application of virtual intelligent environments to education and training. In the following sections this general goal will be decomposed into a more detailed set of goals.

GOAL 1: GENERIC MODEL

The definition of a generic model of intelligent system for education and training based on the use of virtual environments. The approach that we have followed to achieve this goal is the adaptation of the current standard architecture of Intelligent Tutoring Systems (ITS), considering that an Intelligent Virtual Training Environment (IVTE) is a specific kind of ITS. The four components of an ITS need to be analysed and specialised for this kind of system.

-         SUB-GOAL 1.1: Specialisation of the Tutoring Module. The objective is the design of a tutoring strategy that is able to determine in every moment which is the most important thing to do in order to improve and facilitate the student's learning process. Our approach is to use IVTEs as supervised learning environments where the student will be able to explore the environment, query

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the supervisor and rehearse operations and procedures. The tutoring module will act as an intelligent supervisor, answering the questions of the student and evaluating their progress. It will intervene when the student is disoriented or their performance gets too far from the learning objectives. Our objective is to design a tutoring strategy that is powerful and at the same time is modular, structured, configurable, flexible and adaptable so that it can be easily reused in multiple IVTEs without extensive changes. This tutoring strategy will be embodied into a virtual tutor, that is a three-dimensional humanoid model guided by an autonomous agent. Thus the student will be able to dialogue with the tutor, observe it and imitate it.

-       SUB-GOAL 1.2: Specialisation of the Student Model. The objective is the design of a modelling strategy that is able to formulate hypothesis about the student's knowledge and their personal features (learning speed, attention degree, etc.). This model will guide the decisions of the tutoring strategy. Our long term goal is the design of a cognitive diagnosis method (inference of the state of the student's knowledge from their behaviour) that is able to exhibit a non-monotonic reasoning, that is, able to create hypothesis, reason from those hypothesis and retract the conclusions derived from the hypothesis when they are proved to be wrong. It should also be a configurable and flexible modelling strategy that is applicable to a great variety of systems.

-       SUB-GOAL 1.3: Specialisation of the Expert Module. The objective is to propose a representation formalism specially oriented towards the kind of knowledge that is most appropriate to be teached by using a virtual environment. The formalism should consider the three-dimensional structure of the environment, the objects and inhabitants contained in it, the possible interactions with the environment and their direct and indirect effects, the goals that can be pursued by the student and the way they should behave to reach those goals, etc. It has to be an executable model, that is, able to act directly upon the environment, and it should be as independent as it is possible from the language used to build the environment (VRML, Direct3D, WorldToolkit, OpenGL, etc.).

-       SUB-GOAL 1.4: Specialisation of the Communication Module. The objective is to design a human-machine interaction approach that is appropriate for this kind of systems. Specially interesting is the study of the importance that the immersion feeling has on the efficiency and performance of the learning environment. In non-immersive environments, different interface approaches will be analysed, such as GUI-based and voice-based interfaces, to determine their advantages and disadvantages for a natural interaction.

GOAL 2: OPEN AND FLEXIBLE ARCHITECTURE

The definition of an open and flexible architecture, based on components, to provide support for the generic model (goal 1). Considering the generic model described in goal 1, the objective was to identify and design a set of reusable and adaptable components that implement the fundamental aspects of the model. We took as a starting point the results of a previous research project, funded by the CICYT between 1996 and 1999, titled "A Model Based on Co-operative Agents for Intelligent Tutoring Systems with Instructional Planning". This project defined an architecture of co-operative agents for ITS, and now we plan to adapt this architecture for the special needs of IVTEs. Communication and co-operation between agents in the original architecture was performed through a common data structure similar to a blackboard.

The interest in component-based approaches to the development of educational software has been increasing during the last years. Even a working group in IEEE, the IEEE Learning Technology Standards Committee (LTSC) (http://ltsc.ieee.org/) has been created with the goal to develop standards, recommendations and guides for software components, tools, technologies, and design methods to facilitate the development, deployment, maintenance and interoperation of systems for education and training.

This goal implies two sub-goals:

- SUB-GOAL 2.1: Adaptation of the base architecture and high-level definition of the necessary agents, describing their external interface and their role in the co-operation..
- SUB-GOAL 2.2: Low-level design of each agent, describing their structure, services and realisation of those services.

GOAL 3: AUTHORING TOOL

The design and implementation of a prototype authoring tool that facilitates the development of learning environments based on the generic model (goal 1), upon the infrastructure provided by the defined architecture (goal 2). The way to make the two previous objectives useful in practice and not just a scientific curiosity is to develop an authoring tool that encapsulates the co-operative agents architectures, implements the fundamental components of the generic model and allows the user to develop new IVTEs quite easily through the adaptation, configuration and adjustment of the existing components, without having to program the new system from scratch. In the duration of the project the goal is to develop a prototype that demonstrates the feasibility of the proposed approach. There are not many authoring tools today that support the development of ITSs. In fact, the few tools that exist are laboratory prototypes and most of them require knowledge of programming from the user.

This goal implies three sub-goals:

- SUB-GOAL 3.1: Implementation of the agents.
- SUB-GOAL 3.2: Development of an authoring interface that is easy to use, intuitive and makes the author feel comfortable exploring different possibilities.
- SUB-GOAL 3.3: Integration and testing.

GOAL 4: EXPERIMENTAL INTELLIGENT VIRTUAL TRAINING ENVIRONMENT

The design and implementation of an experimental virtual environment for training, making use of the authoring tool (goal 3), in order to validate and evaluate the tool and the model. The feedback obtained from this task will allow as to refine and improve the model and the tool.

This goal implies three sub-goals:

- SUB-GOAL 4.1: Development of the experimental IVTE.
- SUB-GOAL 4.2: Evaluation of the tool, considering aspects such as functional correctness and easiness of use.
- SUB-GOAL 4.3:. Evaluation of the model, considering aspects such as agent expressiveness, flexibility and trade-off between intelligence and development effort.

GOAL 5: METHODOLOGICAL RECOMMENDATIONS

The definition of methodological recommendations for the development of training systems based on the use of virtual environments. A methodology for the development of this kind of systems should propose a set of steps to be followed in the design of a new system (according to the defined model) and its implementation (using the authoring tool). A holistic approach to the development of IVTEs requires a study of the methodological aspects in this kind of projects, apart from scientific and technological considerations. A set of models, an architecture and even an authoring tool can be useless if we do not have a framework in which these components fit. A methodology should guide and simplify the work of anyone interested in the development of an IVTE, and it minimises the risks of the project.

This goal implies two sub-goals:

- SUB-GOAL 5.1: Definition of the phases in the development process and life cycle of an IVTE; definition of the activities to be executed in each phase and the products to be constructed.
- SUB-GOAL 5.2: Methodological recommendations for the execution of certain activities.

The scientific area in which this project is included is a quite immature one yet. Therefore, we couldn't think just in the development of an authoring tool, because any development tool should be based on and give support to a methodology, and a methodology, in turn, should be founded upon a set of well-defined modelling and design techniques. Nowadays there are neither well-defined and widely accepted techniques nor methodologies for the development of intelligent learning environments based on the use of three-dimensional virtual scenarios. It becomes necessary, then, the creation of new models that provide support for a rational and systematic use of this kind of technologies. Given this immature state of the technology, the expected final products will be prototype tools that will allow researchers and developers to experiment and drive useful conclusions.

METHODOLOGICAL APPROACH

The work in this project was organised in five stages, almost sequential but with some overlapping:

·   SCIENTIFIC RESEARCH: The first year of the project has been devoted to scientific research activities, with the aim to develop valid models for IVTEs, making a strong emphasis on the flexibility, power and easy configuration of the proposed solutions.

·   SCIENTIFIC AND TECHNOLOGICAL ADAPTATION: The first half of the second year has been devoted to the adaptation of results from previous projects for the kind of systems considered in this project. This includes the adaptation of the co-operative agents architecture.

·   DEVELOPMENT OF TECHNOLOGIES: At half of the project duration, we started to develop concrete tools to facilitate the implementation and practical evaluation of the results obtained in the two previous stages.

·   EXPERIMENTATION: The last year of the project will be devoted mainly to experimentation, including the development of an example system, with the developed tools.

·   INTROSPECTION AND EVALUATION: In parallel to the experimentation stage, a set of evaluation reports will be produced analysing the proposed solutions and the tools that implement them. We will reflect on the obtained results and will generate recommendations and lessons learned to be used in our future research and development.

DESCRIPTION OF THE TASKS

Six tasks have been planned for this project, decomposed into 13 subtasks. The ordering and time programming of these tasks can be seen on the table 1.

TASK T1: Definition of a generic model for IVTEs. Devoted to satisfy goal 1 of the project.

TASK T2: Definition of an open and flexible architecture based on components. Devoted to satisfy goal 2 of the project.

TASK T3: Design and implementation of a prototype authoring tool. Satisfies goal 3 of the project.

TASK T4: Development of an experimental IVTE. Satisfies goal 4 of the project.

TASK T5: Methodological recommendations for the development of IVTEs. Satisfies goal 5 of the project.

TASK T6: Project management.

	YEAR 1	YEAR 2	YEAR 3
T1			
T2			
T3			
T4			
T5			
T6			

Table 1. Project Plan

2 Evaluation of the Project Success

At the time of writing this report, the project has gone through its first year and eight months. One year and four months still remain.

Generally speaking we can say that the success of the project must be considered high, because it is giving us the opportunity to formalise and integrate several research lines in which we have been working for years. We are having to deal with interesting technological and design challenges, and we are making progress towards establishing a powerful foundation for the development of IVTEs. The goals of the project are being achieved, we are obtaining interesting results, both theoretically and in practice, and we are working in the construction of a tool that we hope will be very useful for the future development of IVTEs.

Several models have been defined for the different components of the Intelligent Tutoring System, thus satisfying the goal 1 of the project. However, we cannot consider task T1 as finished because we are still implementing the models in the authoring tool and this implementation is making us revise and improve the models. Moreover, the study of the impact of the immersion degree on the learning success is planned for the third year of the project. For this study, several devices have been acquired:

- 1 HMD V6 for the visualisation of the virtual environment
- 1 CyberGlove with 18 sensors for the interaction with the virtual environment
- 1 position tracking system Flock of Birds, including an SRT emitter with a radius of 2 meters, and 2 reception units, for tracking the position and orientation of the user within the virtual environment.

We have already developed a library of classes that encapsulate the management of these kinds of devices. They will allow the designer of the ITVE to easily integrate the devices in the desired system.

From task T1 we can highlight the work performed with respect to the student modelling. An exhaustive study has been done of the different solutions that have been proposed for non-monotonic cognitive diagnosis and user modelling, and we have found significant limitations in the current approaches. That lead us to open a research line in this area that we expect will produce a doctoral dissertation by one of the project researchers, Julia Clemente.

Regarding the tutoring module, we decided to embody the tutoring capability into an intelligent virtual agent (IVA) that will inhabit the virtual environment together with the students. We will also provide the possibility of substituting one or more of the students by IVAs, in order to facilitate the learning of co-operative procedures. Recognizing the need to make these IVAs as believable as it is possible for the success of the learning process, another research line was opened with the goal of defining a perceptual model for IVAs that was strongly inspired by the human perceptual system. This research line has produced another doctoral dissertation by Pilar Herrero, that will be presented in a few months. The proposed model is currently being implemented and evaluated.

The need of believability lead us to open another research line with the goal of defining a cognitive model and architecture for IVAs that incorporates emotion and personality aspects. This kind of cognitive model is essential in some IVTEs that require from the IVAs a behaviour guided by psychological aspects, as it happens, for instance, in combat simulation and training environments. This research line is being lead by Ricardo Imbert, and we already have the design of an internal modelling system for IVAs that takes into account personality traits and moods. We are currently implementing this model and we will continue to investigate how to provide IVAs with the capability of inferring the emotional state or personal features of other IVAs in order to be able to adjust their behaviour.

With respect to task T3, there is some delay with respect to the plan, mainly because the implementation of the authoring tool has required the combination of a very diverse set of technologies and we had some difficulties in trying to integrate the different components. Those problems have currently been solved, and we already have some prototypes of some of the subsystems of the tool. We have a prototype of the runtime environment, that is, the system that will execute the IVTE that has been created. This is the system with which the student will interact. This prototype runtime environment implements some of the agents that have been identified in task T2; represents the student with an avatar; provides the student with the capability of visualising and interacting with the environment both through conventional interfaces (monitor, keyboard and mouse) or through virtual reality devices (HMD, data glove and tracking system). The communication module, that is, the subsystem that deals with the 3D models and animations, and with the graphical user interface, is implemented in C++ and OpenGL. The agents have been implemented in Java, using the FIPA-OS platform to manage the inter-agent communication. This is a platform compliant to the FIPA standard. The system has been designed as a distributed application, and the support for distribution has been implemented in Corba.

We also have a prototype of the authoring environment that implements the collaborative design approach proposed by Marco Villalobos in his doctoral dissertation. This dissertation will be presented in a few months. We are currently in the process of instantiating this tool for the process model for the development of virtual environments defined by María Isabel Sánchez in her doctoral dissertation, presented in 2001. We are also integrating a variety of collaboration tools in this subsystem.

We can say that the methodological aspect of the project has been one of the most satisfactory, because it has produced unexpectedly significant results. Task T5, that was planned for the third year, was in fact initiated from the beginning of the project. The initial aim of this task was just the recollection and documentation of lessons learned and methodological recommendations derived from our previous experience in the development of this kind of systems. However, this goal acquired more importance during the first year of the project, and our work in this area has produced one of the most significant results of the project, the definition of a process model for the development of virtual environments that has been presented as a doctoral dissertation. The authoring tool will support and automate the implementation of the proposed process model.

3 Results Indicators

EDUCATION AND TRAINING
Two kinds of people are receiving education and training through this project:
- Ph.D. Students: The following 8 people are Ph.D. students participating in the project: Julia Clemente Párraga, Ricardo Imbert Paredes , Pilar Herrero Martín, Jaime Ramírez Rodríguez, María Isabel Sánchez Segura, Gonzalo Méndez Pozo, Oswaldo Vélez Langs, Marco Villalobos Abarca

The first five are members of the research team and professors at the UPM, UC3M and UAH. Julia Clemente, Ricardo Imbert and Pilar Herrero's research lines are directly related to this project. Jaime Ramírez and María Isabel Sánchez have obtained their doctoral degree during the project, being the doctoral dissertation of María Isabel Sánchez a direct result of this project. Gonzalo Méndez holds a FPU grant from the Spanish Ministry of Science and Education. Oswaldo Vélez has been contracted through this project as Research Assistant and he is in his second year of doctoral studies. Marco Villalobos, finally, is a professor coming from the Universidad of Tarapacá,

Chile, and he holds a grant from his university for his doctoral studies. The areas of research of the last three students are also directly related to this project.

- Undergraduate students: several students are collaborating in the low level design and implementation tasks of the project: José Manuel Alonso Castro, Víctor Manuel Corrales Gallego, Miguel Angel Chou Bravo, Miguel García Arribas, Mónica García Garcelán, Bruno Hermida Portales, Raúl Rodríguez Juárez, Moisés Tavira Manjón

DOCTORAL DISSERTATIONS

One doctoral dissertation has been presented that is directly derived from this project:

- María Isabel Sánchez Segura; Methodological Approach to the Development of Virtual Environments (Aproximación Metodológica a la Construcción de Entornos Virtuales); Apto Cum Laude, December 2001

Five other doctoral dissertations are being elaborated under this project (ordered by degree of completion):

- Marco Villalobos Abarca; A Model Based on a Co-operative Multi-disciplinary Approach for the Development of Educational Software

- Pilar Herrero Martín; Perceptual Model for Intelligent Virtual Agents

- Ricardo Imbert Paredes; Cognitive Model and Architecture for Intelligent Virtual Agents Based on Fuzzy Logic and Genetic Algorithms – Application to the Optimization of Social Behaviours

- Julia Clemente Párraga; A Non-monotonic Cognitive Diagnosis Method for Student Modelling in Intelligent Tutoring Systems

- Gonzalo Méndez Pozo; Un Modelo Basado en un Enfoque Cooperativo Multidisciplinario para Desarrollar Software Educativo

PUBLICATIONS

Up to this moment, 11 papers have been accepted in journals and conferences, containing results derived directly or indirectly from our work in this project (see references [1] to [11]). The papers [3] and [10] are global overviews of the ideas that underlie this project. Papers [4], [9] and [2] present the results related to the perception model for intelligent virtual agents to be applied to the virtual supervisor. Paper [8] deals with the internal modelling of the intelligent virtual agent. Papers [5], [6] and [1] describe the collaborative design model to be used for the development of IVTEs. This model should be instantiated with the methodology that has been proposed for the development of virtual environments and that is described in papers [7] and [11]. There are 2 contributions to journals and 8 contributions to conferences.

PROJECTS

The researchers of this project are currently working in another project that has a direct relationship with MAEVIF. The project is called VRIMOR Virtual Reality for Inspection, Maintenance, Operation, and Repair of Nuclear Power Plant. VRIMOR is a shared cost project running for two years having commenced in February 2001. The aim of the project is to combine environmental scanning technologies with human modelling and radiological dose estimating tools and to deliver an intuitive and cost-effective system for use by operators involved with human interventions in radiologically controlled areas. The main intersection with MAEVIF is in the human-machine interaction aspect, since one of the main goals of this project is to investigate on alternative interfaces to facilitate the use of the simulation tool (which is based on a three-dimensional virtual environment) for users that are not experts in using computers. VRIMOR, however, is not a tool for training, but for design and planning.

The UPM's team has a strong relationship with one of the partners in VRIMOR, namely Tecnatom, dating back from 1998. We have developed several systems for them, in the nuclear power plant application area, based on virtual environments, and some of them for training. This previous experiences have inspired us for the MAEVIF project and we hope that the results obtained in MAEVIF will be applied in future collaborations with Tecnatom. We are currently helping them to elaborate a strategic plan for investment in virtual reality related projects.

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AMEVA: Desarrollo Formal de Sistemas Basados en Agentes Móviles y Evaluación de Rendimientos
TIC2000–0701–C02

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Abstract

The widespread use of new technologies has caused the exponential growth of services available over Internet. Mobile agents have recently been introduced as a distributed programming technique to develop and deploy such services. We propose the use of formal methods to model this kind of services so that they can be analyzed, proved correct, and guaranteed to have a good performance.

We will mainly use for our illustrative examples the language Mobile Maude which is currently being defined. But we will not stop there, because one of the main goals of this project is to contribute to the development of the language, as well as the definition of a methodology for the design and implementation of computational systems based on mobile agents. In particular, we will focus our attention in modelling workflow systems, and business-to-business and client-to-business applications.

The other main goal of our project is the definition of an algebraic language based on stochastic processes allowing the design of distributed systems. We propose to carry out their performance evaluation by applying well known techniques and algorithms.

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1 Main objectives of the project

The main objectives of the project can be grouped according to the two main tasks of the project: AGMOV, which corresponds to the study of formal methods for the design of mobile agent based systems, and ERSD, which corresponds to the study of formal techniques which simplify the study of the performance of distributed systems.

1.1 AGMOV: Mobile agents based systems

The fast irruption of Internet in the world of Informatics has made that a novel way of programming appeared and expanded in a very fast way. We are talking about systems based on mobile agents, where both distributed programming and object-oriented programming have been generalized and combined. Agents generalize objects, while Internet is the support for a broad concept of distributed programming. But if the modelling and development of correct distributed systems is already a rather difficult task, when mobility comes to scene, things are even more difficult, since new properties, such as security or use of non-reliable networks have to be taken into account. Therefore, we need to use some adequate formalisms and methodologies to design and reason about mobile systems. These formalisms have to be designed on the basis of existing formalisms for both distributed programming and object-oriented programming.

1.1.1 Modelling languages for mobile agents based systems

Our first field of inspiration is that of *process algebras*. There we can find two important contributions on the subject: the *pi-calculus* and the *ambient calculus*. Although both of them have been extensively studied, due to the difficulty of the subject there is yet a lot of interesting work to do.

There are several topics in which we are working in our project: first we have the definition of satisfactory abstract semantics, mainly *testing* and *bisimulation* semantics which will be adequate to support the main characteristics of mobility. Then we plan to work on the field of types, by means of which we can define and check in a very elegant way most of the properties related with security. Finally, the use of mobile logics to specify and prove properties of those systems is also a very attractive subject.

1.1.2 Maude and Mobile Maude

Even if the formalisms based on process algebras will support the first steps of our work, we want to apply the developed techniques and results in the framework of a broad spectrum multiparadigm language, as *Maude*. Maude is a declarative language whose semantics is formally supported, by means of *rewriting logic*. As a consequence, one can formally prove properties of the corresponding programs. Besides, the language supports in a clean way both object-oriented programming and concurrent programming, thus becoming a perfect candidate to be extended, by providing the adequate primitives, to get a mobile version of the language, where we can define and reason about properties of mobile agents based systems.

Since it is already available a first proposal for the definition of such an extension, we want to contribute to its development, by detecting and incorporating those new facilities which will contribute to get a satisfactory language. This will be our starting point for the definition of

a methodology to develop correct and secure mobile agents based systems. Therefore we plan to develop a full proposal, including both syntactic and semantic aspects. Besides, we want to contribute to the implementation of part of the elements of the new language, and specially we are interested on the development of a collection of illustrative examples which will prove the adequacy of our model to solve the task described above.

1.1.3 Advanced services supported by Internet

The abstract description of our objectives could mislead one to think that the main goals to are mainly theoretical. This is not true at all. If we want to develop a formal model for the design and study of mobile agents based systems, it is just to really be able to develop real applications, solving many practical problems in the world of mobile programming. We have chosen workflow systems, and in particular *electronic commerce* and *business-to-business* systems as the testing bed for the applicability of our approach.

We will also study the models that nowadays are mostly used for the design of that kind of systems, which are *UML* and *Java*. In the first case, we will try to formalize some of the languages which are included in the methodology, in order to be able to apply them in a more systematic way, and finally to transform them in the adequate way to include them in our proposal. Concerning Java, we want to use that language as support for some of our developments, in order to get prototypes which could be directly executed under real conditions in Internet.

1.2 ERSD: Performance evaluation of distributed systems

In the last two decades there has been an intensive research in the field of distributed systems and their underlying principles. Obviously, time aspects are important in the analysis of distributed systems, particularly in the study of the performance evaluation of those systems. However, timed descriptions are not enough to specify the behavior of those systems whenever some of their actions may occur with a certain probability, like fault tolerance systems or communication protocols. In such a case, the corresponding information about those *probabilities* has also to be included in the specification of the system.

Formal models of concurrency are the adequate tool for the specification and analysis of distributed systems. Among them, we have process algebras and Petri nets. We have already talked about process algebras, which due to its algebraic character are intrinsically modular, and allow the proof of properties by means of deductive mechanisms. Instead, Petri nets have a graphical nature, which makes them easily interpretable. Besides, there are several available tools, which allow us to analyze the behavior of the described systems.

We are very interested in the relationship between both formalisms, since by combining them we can get the advantages of each of the them. So, for a typical software designer it will be easier to handle a language based on process algebras, as they are closer to usual programming languages, while the corresponding translation into a Petri net will usually be easier to analyze, since for it we have many techniques and tools which are not available for algebraic models.

Therefore, the main goal of this task of the project is the definition of a language based on a stochastic process algebra, allowing the definition of distributed systems whose performance could be easily established and checked. Once again, we are not just looking for a theoretical

proposal, but instead we look for a tool which facilitates the development of real systems whose performance can be evaluated under the basis of its definition, that is, in a totally static way.

Once we have the desired modelling language, we will apply to it the known techniques for performance evaluation. Thus, we will study algorithms based on the exploration of the state graph of the systems, trying to reduce it as much as possible, in order to get more efficient algorithms. It is clear that this subject is strongly related with that of model checking. Since we are also interested on its study for the case of ambient logics, we will try to discover any more concrete relationship by means of which we could cross fertilize these two fields.

There are two application fields in which we are particularly interested. First we have *fault tolerant communication protocols*, where we will have to combine both the computation of the probability with which any fault appears, with the performance evaluation of the system for any possible state corresponding to each possible fault. Besides, these systems represent an attractive challenge, because of the need to get a satisfactory balance between efficiency and correctness, since the price that must be paid to obtain a safe system is the *extra* overload represented by the additional mechanisms that must be included in the system, in order to guarantee the correct operation of the system, even in the presence of some failures.

The second field of application corresponds to multimedia systems which are more and more ubiquitous in modern computer systems. In this case, we will consider systems supported by Internet whose bottlenecks will correspond to the transmission times for large amounts of data, such as those corresponding to sound and image representation.

Finally, we would like to put together the two main goals of the project, thus getting a framework for the performance evaluation of mobile agents based systems. But obviously, this cannot be done until we have separately studied in detail the two subjects of the project.

2 Objectives already fulfilled

Several important tasks are still in an intermediate state, and therefore the corresponding results are still partial, specially if we are talking about already published results which had to be finished several months ago. Even so, we have already got an appreciable number of publications which will be described in this section, and later summarized in the following section of this report.

2.1 Tasks A1 and A2: Mobile agents and modelling of systems

2.1.1 Maude and Rewriting Logic

Regarding the specification and modelling of systems in Maude, which will make easier the development of other systems using Mobile Maude, we have studied in [VPM01] the good capabilities of Maude for modelling and validating commercial communication protocols like the IEEE 1394 serial multimedia bus standard (*Firewire*). There we presented three descriptions, at different abstract levels, of the tree identify protocols of that standard. The descriptions were given using the object-oriented specifications of Maude. Particularly, the time aspects of the protocol were considered. Then, we proved the correctness of the protocol in two steps. First, the descriptions were validated by an exhaustive exploration of all the possible reachable states, from any initial configuration of a network, proving that in each case a single leader is chosen. Then, we presented a formal proof that shows that all the desirable properties of the

protocol are always fulfilled, provided that the network is connected and acyclic. A full version of the paper, where also some additional results are presented is going to appear as [VPM02].

We have also studied the good properties of rewriting logic and Maude as an executable semantic framework. In [VMO02] we have described in detail how to bridge the gap between theory and practice, giving an implementation of the CCS operational semantics in Maude, where transitions become rewrites and inference rules become conditional rewrite rules which also apply rewriting into the conditions, as made possible by the new features in Maude 2.0. We have implemented both the usual transition semantics and the weak transition semantics where internal actions are not observed, and on top of them we have also implemented the Hennessy-Milner modal logic for describing processes. We have compared this implementation with a previous one, seeing that the new one is much more satisfactory.

The techniques used in this work have been applied in [BVS01] and [Ver02], to get a formal tool for *Full LOTOS* based on the representation of its symbolic semantics, where any specification without restrictions in their data types can be executed. The reflective feature of rewriting logic and the metalanguage capabilities of Maude made it possible to implement the whole tool within the same semantic framework, thus integrating the basic LOTOS operational semantics and ACT ONE specifications, getting a complete environment including parsing, pretty printing, and input/output processing of LOTOS specifications. We have obtained a formal tool which can be used by anyone, just knowing the source language, without knowing at all the concrete implementation, and where the semantics representation is made at such a high level, that it can be understood and modified just knowing how an operational semantics is defined.

2.1.2 Microeconomics techniques for the control of mobile agents

When we looked for some new fields of application of mobile agents, we found some new trends which have produced several interesting results already published, after a very short time working on them.

The first of these trends consists in the application of some Microeconomics concepts to the field of agents. These concepts have been used to endow mobile agents with negotiation skills, so that they can reach *good* deals when negotiating with other agents. The mechanism guarantees that agents preserve their independence, but they will never hamper any possible exchange that does not worsen its own state. As a consequence, we obtain an optimal distribution of resources that cannot be improved by any agent without worsening some other. Such an equilibrium is called *Pareto equilibrium* in the Microeconomics Theory terminology.

The first work which exploited these ideas was [NR01]. In this paper, the agents have the ability to exchange their available resources, and each of them is looking for the resources it needs to perform each own task. This is just the situation in any scheduling system such as an operating system. The model has been extended in [NR02], where time issues have also been taken into account. Another difference with the previous work is that now we use *Extended finite state machines* instead of process algebras as the underlying semantic model. Besides, we introduce a formal framework to properly compare different resource exchange policies.

2.2   Task A3: Internet advanced services

2.2.1   The Semantic Web

We have found that an interesting field for the application of our techniques is the *Semantic Web*. *RDF* (Resource Description Framework) looks like the first step to build the Semantic Web vision. Our long-term goal is to have a sound way to verify and validate the semantic web interactions that applications and agents may develop in a distributed environment. The first step for reaching this goal is to provide a semantic support for RDF itself. Based on this formal support, we could analyze the properties of the developed systems, as well as define and apply correct transformations. In [BL*02a] and [BL*02b] we have provided the desired semantic support, by means of a translation of RDF documents into object-oriented modules in Maude. This translation provides a semantics for RDF documents and allows programs managing them to be expressed in the same formalism, since Maude specifications are executable. Moreover, thanks to the reflective features of Maude, this translation can be implemented in Maude itself, by means of a function that receives as input an RDF document and returns the corresponding object-oriented module.

2.2.2   Electronic commerce

Another field where Microeconomics concepts have been successfully applied is *electronic commerce*. In [LN*02a] an *electronic barter* environment was presented. Each customer was represented by an agent, which was able to exchange goods with other agents inside a market. The markets are structured in a hierarchical form according to geographical issues. The idea underlying this architecture is to minimize shipping costs. With the aim of improving the overall commerce, markets have the ability to represent its customer agents in higher order markets. Besides, an exchange algorithm was given which guaranteed that final distributions were indeed (Pareto) equilibria from a global point of view. This work has been extended in [LNRR03], where transaction and shipping costs were included in the system, and their influence on exchanges was studied. In particular, it was studied the global impact of these costs on final equilibria, as they biased the exchange process.

2.2.3   Tutoring systems

Another field of application is that of remote tutoring systems. In [LN*02c] a web tutor to teach Haskell was presented. In this system, some agents gather students' performance statistics. This knowledge is used to adapt the behavior of the system accordingly, trying to improve the teaching given to each student. The work was continued in [LN*02b] where the Haskell course is extended to get a medium-size collaborative project.

Since in a collaborative environment the improvement of the skills of each student critically depends on the kind of mates he has, in our system some real students have been substituted by agents, which become virtual students. Each student does not know his mates, which implies that he does not know, in particular, if some of his colleagues are virtual indeed. Besides, both agents and real students may provide wrong code so that the rest of the team has to care not only about their own code but also about the code of the whole group. The agents dynamically adapt themselves depending on their partners which seems to be the best way to improve the collaborative skills of all the students.

2.2.4 Describing the behavior of Internet users

Many research areas related to Internet (resource discovery, intelligent browsing and navigation, data search and retrieval, ...) are developing agents and adaptive systems whose main target is to help the user to manage the large quantity of information available through Internet. A detailed knowledge of users behavior when navigating or using services provided by Internet is a vital component for many of these agents and systems. Up to now, Internet user behavior traces are mainly collected at the servers or proxies, but studying the behavior at the server-side we only get a partial vision of the user. Instead, in [GP02] we have introduced a distributed cross-platform, lightweight tool, called `Ergotracer`, that gathers in detail the behavior of a user navigating the web.

2.3 Task B: Mobile Maude

As indicated in the description of the project, before working in depth on the formal definition of our version of the language Mobile Maude, we wanted to develop a wide gallery of complete examples, by means of which we could illustrate the power of the most important features of the language.

In [DV02] we implement an ambitious wide area application. The subject of the application is a reviewing system to support the selection of submitted papers to a conference, going from its announcement to the edition of the proceedings. The specification of the system was proposed by Cardelli as a challenge example to demonstrate the usability and good properties of any wide area language.

In [BL*02b] we have used the previously commented translation of RDF into Maude, by developing an application related to *e-commerce*, where a buyer agent visits several sellers which give him the information about their printers in RDF. The buyer keeps the price of the cheapest printer. Mobile Maude has also been successfully used to develop the application.

Finally, in [Pita02] we see how to define using the modal logic VLRL spatial properties of systems specified with Mobile Maude. The approach is more general, and could be applied to any specification using rewriting logic where any notion of locality has been defined, where abstract localities are defined by certain mechanisms to divide the state of a process into a collection of components.

2.4 Task C: Performance evaluation of distributed systems

Before studying performance evaluation and the stochastic algebras that are needed to specify the systems whose performance we want to evaluate, we need a strong knowledge of the two factors of time and probabilities that influence the performance of a system.

2.4.1 Languages for the specification of distributed systems

The paper [Núñ02], presents the main results of the Ph.D.Thesis of the author about probabilistic process algebras, including the extension of the classical testing theory by de Nicola & Hennessy. The suitable probabilistic extension of the notion of acceptance sets was used to develop an alternative characterization of the probabilistic testing semantics. A fully abstract denotational semantics was developed, by using a probabilistic extension of acceptance trees. Finally, a sound a complete axiomatization of the testing semantics was also presented.

We have also introduced the language called TPAL (Timed-Probabilistic Algebraic Language), whose operational semantics has been defined in [PVCC01]. There we have also defined a high level semantics, based on a model of dynamic state graphs, which have some similarities with timed automata. Currently we are working on the implementation of the language, by means of a tool also called TPAL, which can be found at *http://www.info-ab.uclm.es/fmc/tpaltool.htm*. The tool includes several interesting features, such as the creation and edition of projects, which allow to break down the specification of complex systems into several components; the translation of TPAL specifications into dynamic state graphs, and the reduction algorithms for them; and the translation into timed-arc Petri nets, whose execution can be visualized.

Since the combination of probabilities and time makes the systems rather complicated to be analyzed, we have devoted recent work to the development of several partial models, which are just probabilistic or timed. So, in [CCV*02] we have defined the language PNAL, which is an algebraic language which integrates three choice operators, namely, a classic external choice, a probabilistic choice and an internal choice. In [CCVP01] and [CCVL01] we considered a restricted version of PNAL (without recursion), defining both a testing semantics and a denotational semantics, and also the corresponding proof system for it. Finally, in [CCV*02] we get the complete algebraic theory for the full language, including the recursive definition of processes.

2.5 Translation into timed-arc Petri nets

As a first step in the relationship between stochastic process algebras and stochastic Petri nets, we started studying the timed case. In particular, we were interested in timed extensions of PBC (Petri Box Calculus), which is a process algebra with a simple denotational semantics based on Petri nets. Therefore, it can be considered as an appropiate bridge between the two worlds we want to relate. In [MF01] we have presented our proposal for such an extension, which we have proved to have better properties than a previous proposal by M. Koutney. Currently, we are revising our proposal to include time-outs and related mechanisms.

We have defined in [VPC02] a translation of TPAL specifications into a timed model of Petri nets, the so called *Timed-arc Petri nets* (TAPNs), which we had thoroughly studied in the past.

To conclude this section we mention our efforts to get a new extension of PBC, which includes the operators of the Ambient Calculus. In order to get the corresponding denotational semantics based on Petri nets, we have first to introduce the corresponding class of *Mobile Petri nets*. Although this is still work in progress, a preliminary proposal is already available as [FF02].

2.6 Stochastic algebras and performance evaluation

First, in [LN01] a testing semantics for a model of stochastic processes is presented. The possibility of defining the duration of actions by means of random variables dramatically increases the expressive power of a language. Unfortunately, it is not always clear how the semantics of these languages is defined. By means of our model we solve the problem, including the case of non-Markovian random variables which were not allowed in previous approaches to the subject.

A great effort of integration with other research lines was performed in [LNR02b], where a new methodology to generate concurrent implementations of systems specified using a stochastic process algebra was developed. We get executable implementations which can be used as early prototypes. Using these implementations we can measure the performance of the original specification.

The work in Albacete on stochastic algebraic models is focused on the definition of the language ROSA [PCV*01], which has some similarities with the language EMPA by Bernardo and Gorrieri, but there are also some important differences, such as the inclusion of three choice operators (as in PNAL), and the removal of some syntactic restrictions. For instance, in EMPA one of the actions involved in a synchronization must be always passive. This makes difficult to model a synchronization between two actions which have both a positive duration. An important problem of EMPA is that higher priority actions always prevent the execution of lower priority ones. In ROSA we have removed these problems, since the value of the parameter λ associated with every action does not limit the possibility to synchronize on it.

2.7 Translation into stochastic Petri nets

We are also working on a translation of a stochastic algebraic language into *stochastic Petri nets* (SPNs). By using this translation the software designer will be able to specify the behavior of a distributed system using a (modular) algebraic language, which can be automatically translated into the corresponding SPN. Then we could use the existing tools supporting SPNs for the analysis of properties and performance evaluation of the system.

As a first step we considered a stochastic extension of PBC (sPBC), without passive actions, for which we have defined in [MVF01] an operational semantics and a denotational semantics. A revised version of this paper appeared as [MVFC01].

Recently we have discovered that under this semantics we cannot obtain a satisfactory equivalence relation. Currently we are working on a second version of the language, where we have a slightly different definition of the synchronization operator, by means of which we expect to solve our previous technical problems. Although the work is still in progress, in [MVCP02] we are going to present our first results on the subject.

2.8 Performance evaluation

To show the application of our model for performance evaluation we have specified and analyzed a well known video encoder algorithm (MPEG-2). Following the proposed approach, we have obtained a Timed-arc Petri net, whose performance has been analyzed using our tool TPAL. An interesting conclusion of this analysis is that the performance of the encoding process can be dramatically improved just by introducing some minor changes on the encoder. Several versions of this work have been published in [VP*02a, VP*02b, VP*02c].

3 Some numbers on the results of the project

Since the main subject of the project, was quite new for us, we did not expect too many results until the conclusion of the project. However, even when the second year of the project has not

still finished, we are surprised but happy to present such a long list of publications, most of them already published in very high quality forums.

3.1 Subproject 01 : UCM - Madrid

Papers	2 International journals: Formal Aspects, JLAP. 13 International conferences with externally published proceedings: 8 LNCS (Concur, 3 Forte, Petri Nets, . . .), LNAI, 2 IEEE, ACM, Kluwer. 2 International conference with electronically published proceedings: 2 ENTCS 1 Poster on an international conference. 2 National conferences
Ph.D. Theses	Up to 4 Ph. D. Theses are really close to be finished, and are expected to be presented along next year (J. Alberto Verdejo, Isabel Pita, Natalia López, Olga Marroquín). 3 other Ph. D. Theses are in progress (Miguel Palomino, Ismael Rodríguez, Carlos Gregorio).
Collaborations with some other groups.	First we have to recall the collaboration with the members of the working group of this subproject who do not belong to our University: F. Durán at the Universidad de Málaga, J. Salvachúa and T. Robles at the Departamento de Ingeniería Telemática of the UPM, and specially J. Meseguer, now at University of Illinois at Urbana-Champaign. As indicated in the project proposal, the inclusion of J. Meseguer in our group is a way to formalize a very long and fruitful collaboration between him and several members of our group. Currently M. Palomino is enjoying a stay at Urbana, where he is working under the advice of Meseguer. Besides, we have established new collaborations with the groups of R. Gorrieri in Pisa and A. Cavalli in Paris. Finally, we plan to organize FORTE 2004 in Madrid and Toledo, and WRLA 2004 in Barcelona.

3.2 Subproject 02 : UCLM - Albacete

Papers	2 International journals : Inf. Proc. Letters, JLAP. 3 International Conferences with externally published Proceedings: LNCS (Petri Nets), 2 IEEE (PNPM, Asia- Pacific). 1 International conference with electronically published Proceedings: ENTCS 3 other international conferences: 2 UK Performance, . . . 3 National conferences
Ph.D. Theses	Diego Cazorla López: *PNAL: An Algebraic Model for Probabilistic and Nondeterministic Processes.* Departamento de Informática, Universidad de Castilla-La Mancha. 2 Ph. D. Theses are really close to be finished, and are expected to be presented along next year (Juán José Pardo, Fernando López Pelayo). 2 other Ph. D. Theses are in progress (Antonio Bueno, Hermenegilda Macià) Research formation of two other members of the research group.

Collaboration with other groups.

Group on *Semantics and Theory of Computation, and Design and Implementation of Distributed Systems*, directed by Prof. Dr. Kim Larsen, at BRICS (Basic Research in Computer Science), Computer Science Department of University of Aarhus and Aalborgh University. One of the members of our group has been working there for a period of 6 months.

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Automated Reasoning and Heuristic Planning TIC2000-0539

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Abstract

The goal of the project on automated reasoning and heuristic planning, started at the UAM in 2000, is to develop new analytical and practical techniques in these two subareas of AI, hoping to benefit from synergistic effects. Planning is seen as a useful testebed for automated reasoning techniques, as well as an area where automated reasoning can help make significant progress. The driving force behind this approach, which is not in itself novel, is the use of generic reasoning algorithms with declarative representations.

The specific goals of the project are as follows:

- In automated reasoning, we focus on inference methods based on ordered and kernel resolution; on polynomial time simplification methods that can be used during search in propositional satisfiability and constraint satisfaction; and on the development of new tractable classes for both kinds of reasoning approaches.

- In planning, the focus is in modelling and benchmarking. In modelling, the declarative specification of planning knowledge is crucial, and several representation languages (SAT, CSP, CLP, Answer sets) are considered, from the point of view of expresivity as well as suitability for efficient reasoning. Linked to this is the use of planning as benchmark domain for automated reasoning techniques such as those described above.

Keywords: Automated reasoning, resolution theorem proving, automated planning, heuristic planning.

1 Project goals

The generic goals spelled out above in automated reasoning and declarative planning were detailed in the project's proposal as follows:

1. Development, analysis and experimental evaluation of inference techniques based on ordered and kernel resolution [dV99, BG01]:

   (a) Development of automated reasoning software for ordered and kernel resolution.

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(b) Experimental evaluation of ordered and kernel resolution for classical reasoning, including knowledge compilation (see e.g. [CD97, dV94, dV99, DM02]).

(c) Theoretical and experimental extensions of kernel resolution to non-classical forms of reasoning, such as assumption-based reasoning ([Mar00] for a survey).

2. Development and evaluation of polynomial time simplification methods for preprocessing or for use during search.

3. Heuristic planning:

(a) Modelling of specific planning domains with heuristic knowledge for action selection.

(b) Analysis of various representation formalisms for planning knowledge from the point of expressivity.

(c) Experimental evaluation of the effect of the form and content of various representations in planning efficiency.

2 Degree of success

We next review the degree of success achieved in the various goals.

2.1 Ordered and kernel resolution

Most subgoals have been achieved in this area. For objective 1.1, we have developed software for ordered and kernel resolution, implementing the methods introduced by the principal investigator (AdV) in [dV99] using both a trie-based and a very novel ZBDD-based implementation, in collaboration with Laurent Simon, from the Laboratoire de Recherche Informatique of the University opf Paris-South. The first implementation is currently in use by researchers from Stanford Univeristy (Sheila McIlraith) in the context of successors to the High Performance Knowledge Bases (HPKB) Initiative funded by DARPA. The experimental evaluation of both implementations (objective 1.2) for forms of classical and non-classical reasoning (objetive 1.3) yielded excellent results, such as computing as many as 10^{70} clauses in a very short time for some problems in consequence-finding. These results were published in the major AI conference [SdV01]. Additional theoretical results, which complement those of [dV00c, dV00a], will soon appear in the major AI journal [dV02], and other work on applications of kernel resolution to knowledge compilation is as yet unpublished [dVS02], where we show that knowledge compilation can be scaled up to larger problems than before, and can result in an order of magnitude improvement in query answering performance. In this sense, objective 1 is basically achieved, and new opportunities arise in the application of kernel resolution for high performance knowledge bases in the work of [MA01].

2.2 Polynomial simplification methods

For goal 2, the question of whether more powerful simplification techniques than those typically used in SAT solvers can be made time-effective is still open, a subject of work in progress. On the other hand, in the relationship between polynomial time simplification and tractable SAT classes, our current results go beyond the goals that we initially set for the project.

Specifically, we have developed new polynomial time simplification techniques [dV01], based on our previous work on reasoning with binary clauses [dV00b]. During this year, we have worked on the topic of detection of binary clauses in a state-of-the-art SAT solver, zchaff [MMZ$^+$01], which turned out to be more difficult than we expected from the point of view of efficient implementation. The next step is to implement and compare simplification techniques such as those developed by [ZS02, GR02, vG02] which extend our previous work on 2SAT [dV00b], as well as our own extensions. On the other hand, we are working on new tractable classes for the SAT problem, which extend previously known tractable classes yet can be used for simplification during search; and on extensions of these tractability results to multivalued logics such as the many-valued CNFs of [MAB$^+$02].

2.3 Planning

In the area of planning, we have developed a language for the declarative formalization of strategies for action selection and compared it to other approaches to heuristic planning in terms of their capacity for controlling the search process and their effectiveness for solving planning problems. This includes comparison with temporal logic formalisms [BK00] and an extension to answer set planning (goals 3.1-3.3). A paper describing the approach has been accepted for publication in the major AI journal [Sie02b]. In addition, we have developed formal declarative models of non-linear planning [Sie02a], and their application to the blocks-world. A novel line of research is that of "grounded models" [Sie01, SS02], a conceptualization of the semantics of sensor-based concepts which could prove important to the development of autonomous planning robots.

The overall goal in this area is that of developing general representation techniques for general purpose automated reasoners and planners. In addition to work on situation calculus languages and answer set planning, we are investigating SAT and CSP based formulations. The latter currently appear most promising, and we are developing libraries of constraint satisfaction algorithms which, in preliminary results, achieve large performance gains with respect to other CSP-based planners [vBC99, DK00].

3 Indicators of results

3.1 Publications

The project has so far resulted in the following publications:

[dV01] Alvaro del Val. Simplifying binary propositional theories into connected components twice as fast. In *LPAR'01, Proceedings of the Eigth International Conference on Logic for Programming, Artificial Intelligence and Reasoning*. LNCS, Springer-Verlag, 2001.

[dV02] Alvaro del Val. First order LUB approximations: Characterization and algorithms. *Artificial Intelligence*, 2002. Accepted for publication.

[SdV01] Laurent Simon and Alvaro del Val. Efficient consequence-finding. In *IJCAI'01, Proceedings of the Seventeenth International Joint Conference on Artificial Intelligence*, pages 359–365. Morgan Kaufmann, 2001.

[Sie01a] Josefina Sierra. Grounded models. In *AAAI Spring Symposium on Learning Grounded Representations*, 2001.

[Sie01b] Josefina Sierra. Grounded models as a basis for intuitive reasoning. In *IJCAI'01, Proceedings of the Seventeenth International Joint Conference on Artificial Intelligence*, pages 401–406. Morgan Kaufmann, 2001.

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[Sie02a] Josefina Sierra. Declarative formalization of reasoning strategies: A case study of heuristic non-linear planning. *Annals of Mathematics and Artificial Intelligence*, 2002. Accepted for publication.

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[SS02] Josefina Sierra-Santibáñez. Grounded models as a basis for intuitive and deductive reasoning: the acquisition of logical categories. In *ECAI'02, Europeran Conference on Artificial Intelligence*, 2002.

Además, los siguientes artículos están en preparación:

dV02b: Alvaro del Val. Kernel resolution for consequence-finding

dvS02: Alvaro del Val and Laurent Simon. Knowledge compilation: Scaling up.

3.2 Personnel

The project is currently training 4 persons, including two Ph.D. students, for research. Among the two Ph.D. stdudents, one is working on his thesis on automated selection of heuristics and propagators in constraint satisfaction based on dynamic information about search progress, and the other one is in his first year in the Ph.D. working on constraint satisfaction algorithms. In addition, a Polish student will be coming in the second semester of this year to work on tractable SAT classes.

3.3 Collaborations

We can cite the following informal collaborations related to the project.

- Sheila McIlraith, Stanford University. A student of hers is using the software we developed for kernel resolution; and the connections of kernel resolution with their work on HPKBs and on the theorem prover SNARK, developed at SRI, have already been mentioned. A visit by the principal researcher to Stanford is planned for next quarter to discuss further collaborations.

- Laurent Simon, LRI, Universite de Paris-Sud. Collaboration on kernel resolution and knowledge compilation, yielding one published paper and an unpublished manuscript.

- Felip Manya, Universitat de Lleida. Informal collaboration on tractable classes for many-valued CNFs.

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Parallel and Reactive Functional Programming: Technology and Applications TIC2000-0738

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Abstract

Parallel and concurrent functional programming is nowadays an area of intensive research. It offers the possibility of developing parallel algorithms for multicomputer architectures using much less effort and getting a lower error rate than their counterparts written in imperative languages, such as Java or C++. In recent years several parallel functional languages incorporating parallelism in different ways have been developed. Some of them are GpH (Glagow parallel Haskell), PMLS (Parallel ML with Skeletons), Erlang, Concurrent Haskell, and Eden.

Eden is a parallel extension of the lazy functional language Haskell. A preliminary implementation of Eden has been developed by our group, in cooperation with the computer science department of the Philipps University of Marburg (Germany). The Eden compiler is currently based in version ghc-3.xx of the Glasgow Haskell Compiler. This research was done in the framework of a German-Spanish 'Acción Integrada' (HA 142B/962, HA 1996-0147, HA 1997-0107) from 1996 to 1998, and supported by the programs 'Tecnologías de la Información y las Comunicaciones' (TIC97-0672) and 'Comunidad Autónoma de Madrid' (06T/033/96). These projects spanned from 1996 to 2000.

The aim of the current project is to make the language a practical and competitive tool. For this reason, first we intend to apply Eden to several problems coming from different environments and to evaluate its performance in such applications. Strongly connected to these objectives is to improve and enlarge the development tools, so that the language can become a useful instrument in scientific and industrial environments, both national and international ones.

Keywords: functional programming, concurrent programming, parallel programming, performance caracterization, simulation, semantics.

1 Project Objectives

Project objectives fall into three categories:

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Language application This includes all activities related to writing programs in Eden, developing an appropriate methodology to do it, reasoning about the programs, detecting which problem domains are interesting for Eden and developing programs which can be run in an architecture independent way.

Language evaluation Its aim is to evaluate the performance of Eden in different applications and architectures and to compare this performance to that of related languages.

Tools improvement It includes supporting the Eden compiler in different architectures, upgrading it to the new versions of the underlying Haskell compiler and adding new features and optimizations to the compiler and related tools.

The detailed objectives falling into the first category, as described in the original project proposal, were the following:

A1 Developing of a **benchmark suite**. This will comprise a variety of parallel programs aimed, on the one hand at developing a programming methodology for Eden, and on the other hand at evaluating its performance.

A2 Developing a library of **skeletons** aimed at facilitating the task of programming parallel applications. A skeleton is a library function setting up a concrete process topology to solve a family of related problems. Using a skeleton is similar to using any other higher-order function.

A3 Developing a **methodology** for using the language. This should include practical as well as semantical aspects. In particular, attention will be paid to reasoning and verification issues, including how to prove deadlock absence.

A4 Application of the language to different domain areas. In the proposal, two such areas were identified: computational algebra problems and computer architecture problems.

The detailed objectives falling into the second category were the following:

E1 Running the benchmark suite in three different architectures: a Spark-SUN-Solaris shared memory multiprocessor with 4 processors, a X86-Linux Beowulf cluster with 64 processors, and a Mips-SGI-Irix NUMA multiprocessor with 54 processors. Obtaining absolute and relative speedups of the benchmarks in these architectures.

E2 Comparing Eden expressiveness and performance with other related languages. In the proposal, only GpH (*Glasgow parallel Haskell*, [30]) was explicitly mentioned.

Finally, the detailed objectives falling into the last category were the following:

T1 Upgrading the compiler and related tools to the latest version of the underlying Haskell Compiler GHC [25]. This is now GHC-5.xx.

T2 Porting the compiler (first the current version, and then the upgraded version) to the three architectures mentioned above.

T3 Developing **analyses** and **transformations** in the compiler to either improve the performance or to guarantee the correctness of the generated code. Three analyses were explicitly mentioned in the proposal: non-determinism analysis, duplication analysis and productivity analysis. The first and the third ones are related to correctness, and the second one is related to efficiency.

T4 Completing the Eden **simulator** *Paradise* [3] with new outputs. The simulator is a tool derived from the compiler which is able to run an Eden program in a controlled environment simulating a parallel machine with any number of processors. The tool provides detailed graphics about the execution, allowing the programmer to detect the bottlenecks of the parallel algorithm. The new foreseen outputs were duplication and speculation graphics. The first one is aimed at measuring the amount of work duplicated in several processors and the second one the amount of work not needed for the final result of the algorithm.

2 Degree of success achieved by the project

The project is now finishing its second year. Most of the objectives described in the previous section has been already achieved. Others are in course of development and a few ones have been abandoned. A detailed account follows. We provide a subsection for each group of objectives and use the identifiers provided above (e.g. objective A1, E2, etc.).

2.1 Language application

Objectives A1 and A2 have been completely reached. The benchmark suite includes a large variety of algorithms with different parallel properties. There are data parallel, task parallel and systolic parallel algorithms. There are some with regular parallelism such as matrix multiplication, ray tracing or conjugate gradient algorithms, and some other with irregular parallelism such as mandelbrot sets, Karatsuba integer multiplication, the traveling salesman problem or exact linear systems solving by using the chinese remainder method.

The skeleton library is one of the most important achievements of the project. In the beginning with did not think that skeletons were to play such an important role in the language. Now we are convinced that using the skeletons library is the easiest and safest way of building parallel applications in Eden. Programming with skeletons also fulfills part of objective A3, since it is the recommended and preferred way of programming in Eden. We have developed skeletons for *parallel map*, *map and reduce*, *divide and conquer*, *iterative method* and several process topologies such as pipelines, meshes, torus and rings. Most of the benchmark programs have been built on top of the skeleton library.

Objective A3 has been almost completely achieved. Apart from the skeleton aspect, we have devoted much effort to the two following issues:

Development of a formal semantics A complete operational semantics for Eden programs has been developed. By establishing a set of small step transition rules, the semantics formally specifies the allowed behaviours for the programs. A denotational semantics for a subset of Eden not including streams and non-determinism has also been developed. A complete denotational semantics is on the way.

Development of verification methods We have developed an annotated type system based on Hughes and Pareto *sized types* [9, 14, 15] to prove deadlock absence and termination of Eden programs. For the moment the method can only be manually applied and we have applied it to proving the correctness of some of our skeletons. With a rather big effort a type checker could be built to automatically do the proofs. Even in this case the annotated types should be provided by the programmer. So, we are not considering investing effort in building the type checker.

Objective A4 is under development. In 2002 we have devoted some effort to forming a consortium to set up a european *Network of Excellence* in parallel symbolic computation. The aim is to put together groups from the parallel functional programming field and groups from the computational algebra field. The functional groups are interested in applying our languages to useful computational intensive tasks, and the algebra groups are interested in having their algorithms running faster with a low effort investment. The consortium consists now of 23 european groups (see our page `http://www-circa.dcs.st-and.ac.uk/FP6.html`) and in June 2002 we prepared an *Expression of Interest* which was submitted to the EU Committee for *Framework VI* research program.

In the meantime, our group is starting to build an interface between our language Eden and the Maple library in order to be able to parallelize some algorithms of the Algebra Department of Universidad Complutense de Madrid. This task is foreseen to run during the whole 2003.

2.2 Language evaluation

Objective E1 has been achieved with respect to spark-Solaris and x86-Linux architectures. Architecture Mips-Irix is still pending until we have a compiler available for it (see objective T2 below).

Objective E2 has been completely reached. During 2001 we conducted exhaustive experiments on three related languages: Eden, GpH and PMLS [28]. The first two are extensions of the lazy language Haskell while the third is an extension with skeletons of the eager language ML. We programmed three typical parallel algorithms for matrix multiplication, ray tracing and exact linear systems solving in the three languages and run them on a Beowulf cluster. Eden results were very good, specially compared to GpH. The main reason is that the programmer in Eden has a better control over the number and the placement of the parallel threads. In GpH these issues are under the control of the runtime system. With respect to PMLS, Eden is more expressive as the only available skeletons in the latter are parallel `map` and parallel `fold`. For instance, a matrix multiplication by using Gentlemen's algorithm [1] needing a torus topology, cannot be programmed in PMLS.

2.3 Tools improvement

Objective T1 is almost finished. Eden's runtime system (RTS) is responsibility of the german group at Marburg and the new version of GHC differs from the previous versions mainly in this part, so the upgrading effort is being mainly conducted by the german group. They have at this moment an unstable Eden RTS for ghc-5.xx and we expect to run actual programs at the end of this year. The simulator should also be upgraded to the new RTS and this is our responsibility, but we have to wait until the upgrading of the compiler is completed as most

of the code is shared by both RTSs. In fact, there are no separated files for compiler's RTS and for simulator's RTS. Files are the same but just compiled with different flags. This is the normal procedure in all the RTSs related to GHC.

Objective T2 is our responsibility. The porting of the Eden compiler to the Mips-Irix platform has been just completed. It should be noted that GHC was not previously supported for this platform, so the big part of the job has been first to port the GHC compiler. It consists of 80.000 Haskell lines and about 50.000 additional C lines. The main difficulties have been related to the version of the gcc C compiler required by GHC 3.xx which was not compatible with the Irix 6.xx of our Mips machine. In addition, the Eden compiler needs the PVM library whose version in this machine seems to be compatible with Irix but not with the code generated by gcc. Up to now we have been able to successfully compile Eden programs and to run them in one processor but not to run them in configurations with more than one processor. We have also started to port the (unstable) new version of the Eden compiler to the mips machine. We have the hope that this version (once it is stable) will present less porting problems than the old one because the gcc compiler required by GHC 5.xx is more modern and so compatible both with Irix 6.xx and with PVM.

Objective T3 has also been completed. We developed some transformations in the GHC compiler to eagerly evaluate some Eden expressions (Eden introduces eagerness in some points where Haskell is lazy) and a simple *bypassing* analysis to avoid creating redundant threads. This was done prior to this project and published elsewhere [11, 13]. During these two years we have developed and implemented a *non-determinism* analysis to detect deterministic expressions even when the non-deterministic Eden process `merge` is used. This is a very useful predefined process which merges a set of input lists into a single list. The output list is created by immediately copying to the output list a value appearing at any of the input lists. So, the output list depends on the speed at which the input lists are generated. Detecting deterministic expressions is important as many transformations inside the GHC compiler assume that equational reasoning is guaranteed. This is not true when non-determinism is present.

Productivity is another name for deadlock absence. Instead of developing an analysis for this problem, we have developed a verification method to be manually applied. This has been reported in objective A3. Converting the method into an automatic analysis will require much programming effort and the annotation of programs by the programmer anyway. So, we are glad with the solution provided.

Duplication analysis has been abandoned. We found this analysis very difficult. A closely related problem, update avoidance analysis has produced lot of research papers and still it has not been satisfactorily solved (As a result, GHC includes since 1993 a very primitive form of update analysis). On the other hand, in our benchmarks we have not found duplication of work to be a problem. If it were in the future, we consider a better approach to complete our simulator with measurements for duplication.

Objective T4 is still pending. We would rather prefer to wait until the Eden compiler has been upgraded. As it has been explained in objective T1, the simulator *Paradise* consists of just a different RTS for the Eden compiler, so it is better to have first a stable version of the parallel RTS.

3 Results indicators

During 2001 and 2002, the group has produced 17 publications related to the project and 4 more related to other areas of functional programming. Two Ph.D. thesis and one 3rd cycle research work have been presented. One more Ph.D. thesis is about to finish. Appart from the latter, there are two more people doing their Ph.D. studies within the group. Cooperation with Philipps University at Marburg (Germany) has continued during these years. A Spanish-British Accion Integrada has been running during 2001 and part of 2002, funding a cooperation with the scottish group in the universities of St. Andrews and Heriot-Watt responsible for language GpH. A new cooperation has started with this and other european groups to launch a Network of Excellence in symbolic computation in the context of the EU VI Framework Program. A detailed account of these results follows.

3.1 Language application and evaluation

A first work on skeletons in Eden was presented at the conference IFL 2000 (*Implementation of Functional Languages*) and it was afterwards selected for publication by Springer [10]. The bulk of the work on skeletons was first presented to HLPP 2001 (*Workshop on High-level Parallel Programming and Applications*) [16] and then to PPDP 2001 (*Principles and Practice of Declarative Programming*) whose proceedings were published by ACM [17]. A spanish version of this work was the subject of an invited conference in the *XI Summer School on Informatics* taking place at Albacete (Spain) in the summer of 2001 [18]. A long account of all the work on the subject was published by invitation as a chapter of a special Springer book on skeletons and patterns edited by F. Rabhi and S. Gorlatch [12].

The comparison work reported in Section 2.2 was done in the framework of the mentioned Accion Integrada and sent for publication to the journal *Higher-Order and Symbolic Computation* in January 2002 [2]. We are still waiting for the referees decision.

The work on skeletons and the language comparison results were the kernel of Fernando Rubio's Ph.D. thesis presented and approved with the maximum mark on November 2001 [26].

3.2 Analysis, semantics and methodology

Two non-determinism analyses were developed in the beginning and published by Springer in early 2001 [22]. These were not completely satisfactory: the less expensive one lacked precision and the precise one had exponential cost in the worst case. We developed an intermediate one, both in precision and cost, by using a *widening* technique in the computation of fixpoints. This was the one finally implemented. It was presented at IFL 2001 and selected for publication by Springer [23]. An account of the three analyses was presented at the spanish conference PROLE 2001 [21].

The verification method reported in objective A3 was also presented at IFL 2001 and selected for publication [24]. The analysis and verification work was the subject of Clara Segura's Ph.D. thesis presented on November 2001 and approved with the highest mark [29].

Eden's operational semantics was first published in 2000 [4]. A refinement of it was first presented to the national workshop *IX Jornadas de Concurrencia* [5], then to CMPP 2002 (*Constructive Methods for Parallel Programming*) [8], where it was selected for publication in the journal *Parallel Processing Letters*, and then to *X Jornadas de Concurrencia* [7]. A first

account of the denotational semantics was presented at SFP 2001 [6]. The work on semantics is the subject of Mercedes Hidalgo's Ph.D. thesis now in course on finalization.

Finally, three more methodological works were respectively presented at the conferences SFP 2001 [20], LCR 2002 [27] and IDPT 2002 [19]. The first two are related to building new skeletons and the third one is a continuation of [24]. It presents a verification method based on predicates.

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Development of distributed geographic information catalog services, oriented toward the web and based on open standards: Effective steps toward a National Geographic Information Infrastructure
TIC-2000-1568-C03

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Abstract

This work describes a three-year collaborative project to create the technology underpinnings of a Spain National Spatial Data Infrastructure, its objectives, the work currently in progress and the strategy defined for transferring results to the entities which will collaborate with it. This project began at the end of year 2.000 and it is being developed by researches from three Spanish Universities (Polytechnic University of Madrid, University Jaume I and University of Zaragoza). The main objectives of this project include the demonstration of the benefits for geographic data providers and customers in having access to services created around the concept of a national SDI. This will be done by creating the basic technology for a set of services specified using OpenGIS Consortium standards as starting point. These services will be tested during 2.002 in a pilot project which includes three nodes (one in each University) offering the basic functionality. This functionality will be developed around a geographic catalog. During this pilot project, efforts for capturing metadata and geographic data will be focused, contrasted and tested by the providers of a restricted set of users (providers and customers) who has the task of testing the initial prototypes and operational versions trying to identify problems and malfunctions and to find new functionality to be incorporated. It is very important to create a set of metadata enough for testing search services with valid results. This pilot project will be used, as well, as a tool to convince public entities about the technological, social and economical viability of a national SDI.

Keywords: OpenGIS, CORBA, Java, Catalogs, Catalog Services, Metadata, Geographic Information, GIS, Internet, Map Servers, Interoperability, Distributed Objects, National Geographic Information Infrastructure, Open Standards, Data Bases, Data discovery/recovery, Natural language

1   Project objectives

The main objective of this project is to leverage recently developed geographic information processing standards and technologies, as well as developments in web services and related fields within the wider Internet community, to create and demonstrate the viability of software components which can contribute to a nascent Spatial (Geographic) Data Infrastructure in Spain. Key among these components is a spatial data catalog service, which allows data providers –

traditionally from the private sector—to both organize and publish their spatial data holdings. This goal of helping "unlock Public Sector Information" coincides with the title of a recently published E.U. Green Paper (DG-INFSOC), and thus with the desires of the EU. Organization of data holdings under the SDI concept helps data providers reduce duplicated data creation and processing, while controlled publication of key reference data allows them to better serve users, from partner organizations (i.e. Ministry to Ministry) to the general public, as well as give a boost to the economy[1]. Currently individual institutions implement taylor-made information systems which may serve their internal needs, but certainly have not be designed with network-based data sharing and maintenance in mind. Recent SDI standards, both technical and political (rules and guidelines for best practice), allow for both internal optimization and external interoperability of these information systems. This project exercises (implements) several of the technical standards underpinning the SDI concept, and is producing demonstrations which can serve (and have served) politicians in Spain who are contemplating the construction of a Spatial Data Infrastructure in Spain, following those already created in the USA, Australia and several European nations such as Netherlands, UK and Finland. In the process, a long list of collaborators, from the students and researchers at the 3 collaborating universities, to government officials and private companies are gaining valuable pratctical competence in the new technologies (and policy decisions) involved in making SDI a reality.

In this project the following concrete subobjectives have been proposed and are being implemented:

- Subobjective 1: **Technology Watch** activities, following the progress of standards activies in several related fields, especially with regard to the 3 main technology components of an SDI: metadata creation and maintenance; catalog services; and web map services. The fact that members of the research team are intimately involved in many of these standardization efforts allows for early and priveledged access to draft documents, providing an advantage over the general public which would normally only learn of interesting developments *a posteriori*. This allows the research group to work proactively.

- Subobjective 2: **Implement components** for metadata creation and publication, using on-line catalog services.
    - To maximize interoperability the metadata model proposed by ISO/TC211 (Technical Committee on Geographic Information), also adopted as version 4.0 of the OpenGIS Abstract Specification volume 11, is being supported. This model has been the result of a fusion of metadata models from the USA (Federal Geographic Data Committee), Europe (CEN) and Australasia (ANZLIC) as well as the digital library community (Dublin Core group).
    - Creation of Catalog Services also follows accepted international standards of these two organiszations, specifically version 4.0 or greater of the OpenGIS Catalog Interface Implementation Specification.
    - As additional value to the project, natural language interaction and reasoning techniques are being applied to the catalog searching and retrieval components.

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[1] Economic gains due to SDI-like data sharing initiatives have been demonstrated by government agencies in nations such as the USA, Netherlands and UK.

- Subobjective 3: **Creation of web services** to deliver geographic information, especially web map servers.
  - o Several implementations of the OpenGIS Web Map Server Interface Specification v1.0 or greater will be undertaken, to demonstrate how multiple servers running on heterogenous platforms can peacefully coexist and collaborate to provide the user a seamless view of multiple overlayed datasets to his/her web browser. The WMS interfaces assure that data views (bitmaps) are delivered upon demand, and connection via OGC Catalog services greatly improves the ability to first identify what is available on-line to be retrieved and viewed.
- Subobjective 4: **Pilot project** demonstrating viability of standards-based SDI components.
  - o The client and server components developed by the research group are to be tested in a network pilot setting, utilizing University of Zaragoza as a principal node. There most all issue of hardware/software compatibility, configuration and testing will take place, whereas the universities Politécnica of Madrid and Jaume I of Castellón will be secondary testing nodes within the prototype SDI.
  - o The research group aims to exploit the pilot testing to become a reference at national and European level, as experts in designing and implementing open solutions for building and sustaining SDIs.
  - o Because public and private sector "buy-in" (collaboration) is essential, the research group will strive to involve a healthy subset of these organizations and will attempt to obtain and make publicly available as much relevant reference data as is possible.

- Subobjective 5: **Product definition** to assist institutions and businesses in adopting SDI technology.
  - o The project will identify suitable products to be plugged into the SDI framework. This indentification process may be done in an objective manner using as a guide the international standards which have been adopted wholly or partially by each product.
  - o Three types of organization can benefit from this categorization of products:
    1. Spatial data providers (ex. national mapping agency) who need to catalog and publish data;
    2. Institutions wishing to establish local or regional nodes for the interchange of spatial data;
    3. Third party collborators or brokers who would facilitate data retrieval.

  - o Identification of possible e-Commerce solutions to assist with the sales/payment for data acquired.

- Subobjective 6: **Promotion and dissemination**.
  - o Dissemination of project results and general publication of best practice information is a key part of helping establish a SDI. This includes participation at relevant conferences and seminars, creation of a project web portal with news items and hyperlinks to important information, and targeted visits to potential collaborator institutions.
  - o Aside from the (anonymous) web portal, the research group also strives to create an umbrella identity for itself, as a consortium of reference within Spain, dedicated to the development and uptake of SDI technology.

- Subobjective 7: **Coordination of subprojects**.
  - o This is a global subobjective which seeks to coordinate the three subprojects and to eliminate, where possible, duplication of effort and to assure the project meets its stated goals.

The work to achieve the previously mentioned objectives is structured into nine activities according to the following time table:

Activity	First year	Second year	Third year
1. Project coordination and management			
2. Metadata support and improve			
3. Catalog creation			
4. Internet services components			
5. Node creation			
6. Pilot project			
7. Interoperability and portability study			
8. Product analysis			
9. Promotion and dissemination.			

2 Measures of project success

2.1 Participation in Standardization processes

One of the main objectives of this project is to become representatives in the process of development of standards related to geographic data and metadata. It is considered interesting because this is one way to transfer research results to the industrial community and, on the other hand, this provides the possibility to gain first-hand access to key information, while standards are being formulated. (Without this inside access academic institutions are often caught constantly behind the wave…)

The participation of researchers from this project in national and international standardization processes can be summarized as following:
- The teams of the University of Zaragoza and the University Jaume I are members of the OpenGIS Consortium (hereafter **OGC**), and international organization with 230+ members from industry (Sun, Oracle, Siemens, etc.), public sector (JRC, Ordnance Survey UK, US Census, etc.) and academic institutions. Additionally, a princupal investigator from this project has been working with this consortium as external consultant and (during a sabbatical visit to USA 2000-2001) coordination of the OpenGIS documentation committee. Additionally project representatives have worked for the European section of this organization (OpenGIS Europe Ltd) as subcontractor.
- Participation in the Technical Committee CTN148 from AENOR (Spanish National Normalization Agency). This committee has it focus in digital cartography and geographic

information in general, and is in turn the national body representing Spain in CEN, ISO and other international standards bodies.

- Participation in the expert committee for the redefinition/migration of the UNE 148001 EXP MIGRA (Spanish standard for geographical data and metadata) as an ISO profile.
- Working as editors and experts in the CEN/ISSS Metadata/Dublin Core Workshop (MMI-DC) Project Team: improving discovery of geographic information in cross-domain searching. 2002. The work in this workshop is focused in the definition of a semantic and operational crosswalk between ISO geographic metadata standard and Dublin Core. This work is financed by CEN/ISSS – Comitée Européen de Normalisation/Information Society Standarization System (European Union).
- Members of the Architectures and Standards Working Group of INSPIRE (a European Union initiative for the development of the European spatial data infrastructure).
- Members of the Spanish National Council for Geographic Information expert committee. This is the entity which has began to work for the development of the Spanish spatial data infrastructure; chaired by national mapping agency (IGN) subdirector.

This presence is completed by participating in national and international associations :

- Spanish Association for Geographic Information Systems (Asociación Española de Sistemas de Información Geográfica - AESIG). Members of the executive committee since 1997.
- European Umbrella Organization for Geographic Information (EUROGI, Unión Europea, DG-XIII).
- Association of Geographic Information Labs. in Europe (AGILE). Members of the executive committee (AGILE Council) and annual conference Scientific Programme Committee chair.

The work in this area has been satisfactory and should continue for the foeseeable future. The current situation of our teams give us the possibility of be considered as experts in future initiatives.

2.2   Scientific and technological results

The research work undertaken in this project became reality as a set of procedures, knowledge relations and software components. Most of these results where presented at the 6th Global Spatial Data Infrastructure (GSDI) conference (Sept 2002, Budapest) as a part of the workshop "Standards in Action", by invitation of Douglas Nebert (U.S. FGDC/ISO/GSDI technical chair). The main results are summarized below.

Metadata creation tool and metadata improvements

One of the main components developed is a tool for cataloguing geographic metadata. This is a user-friendly tool that allows users to create metadata according to one of the following standards:

- ISO/TC 211 (Draft International Standard ISO/DIS 19115, September 2001)
- Content Standard for Digital Geospatial Metadata (FGDC-STD-001-1998)
- Dublin Core applied to geographic information.

The current version of this tool is version 3. It is being used by the Spanish Cadastral Agency, Spanish Ministry of Environment (Ebro River Basin and Nature Data Bank), Andalusia Cartographic Institute (Junta of Andalusia) and Xunta of Galicia (Environment Department).

Perhaps one of the main problems we have found is the need to demonstrate to and educate data providers on the necessity of having established, standards-based processes for metadata creation. A tool is not enough; it is necessary to develop training material for teaching users in the creation processes. Some ideas from the work-flow area are being studied in order to manage this problem from this point of view.

Besides typical software tool features (different database servers, access control, license control, friendly GUI, etc), the main component of this tool is a set of *metadata-crosswalks* developed with XML technology that allow the easy transformation of metadata from one standard to other. These *crosswalks* have been built by the definition of semantic and operational bridges among the these standards. Additionally, crosswalks to MIGRA (Spanish standard for geographical data and metadata) from ISO, FGDC and Dublin Core have been developed but they currently are not being used in the metadata creation tool.

Other work related to improving the metadata craetion task is under way. One task is related with the concept of *metadata aggregation*. Working in metadata creation, we have identified problems related with the joining of metadata in order to create higher levels of abstraction of the geographic information. There is a PhD thesis in progress which offers an important contribution to the solution of this kind of problem. This thesis will be completed in 2003.
Additionally, there are other research works in progress, related with semantic interoperability through knowledge organization and classification. This work is in its initial steps, but there are initial results that have been presented in conference papers.

Data access components

Several components are under development for accessing geographic data (for visualization or use). Currently, we have a component that implements the OGC Styled Layer Descriptor (Draft Candidate Implementation Specification, version 0.7.0, 7 Feb. 2001). Additionally, the latest version of our Web map server is in compliance with the OGC Web Map Service Interface Specification (version 1.1.0, June 2001) and the consortium has also implemented open source Web Map Servers, at two nodes of the nascent pilot project. Finally, there is a server that implements the OGC Web Feature Server Implementation Specification (version 0.0.14, 17 Oct. 2001) and two additional WFSs (commercial and open source) will be implmented before the end of 2002 as part of collaboration in OGC's Conformance and Interoperability Testing Exercise (CITE). We have also implemented standard Web clients that can access to these components, or any other which supports the OGC specifications.

Metadata catalogs

Another basic component that has been developed is metadata catalog services. The work of this project is based on two types of metadata catalogs: geographic metadata catalogs and Web service catalogs.

Currently, there is a geographic metadata catalog in use. This is a component that offers the necessary services for cataloguing geographic metadata and for searching and presenting results. (An example natural language query illustrating what a user would search for, might be: "Find me satellite images with little cloud cover, of between 01July and 31August2000, and overlay on them road maps in GDF format, for the following geographic extension <user defines with the mouse a rectangle on a map of Europe>").

The catalog service implements the OGC Catalog Interface Implementation Specification (WWW profile, version 1.1, March 28, 2001). This is the first implementation of this particular profile of OGC standard in the world (OpenGIS has no notice of other implementations) and we are currently awaiting the creation of the OGC conformance test.

As an initial test of client-server interoperability based on the use of published standards –what this project is attempting to demonstrate should be the route toward creating an open SDI in Spain-- the catalog service server running at Univ Zaragoza was accessed using a catalog service client application (Java) developed by a student at Univ. Jaume I. These two components were developed entirely in isolation, each following OGC specifications documents, and then were "blindly" joined with only minor tuning at the client end, to form a fully operational client-server catalog query system. This test may be considered a first stage in the pilot project described below.

The service mentioned follows traditional digital library technology standards. Additionally, we have an implementation of a (stateless) Web Service catalog following the OGC Web Services Stateless Catalog Profile (was Web Registry Service, version: 0.06, 29 August 2001). This catalog is used for coordinating and linking GIS (web) services such as catalogs, Web map server, etc. and is experimental.

Both catalogs are being used in the development of some of the local and regional data infrastructure projects in which we are participating.

The main work we are doing in this area at this moment is related with the conceptual base for linking services, and the architecture of these mechanisms.

Pilot project
As a test bed, and to demonstrate the components necessary for an eventual Spanish National Spatial Data Infrastructure, we are building a set of Internet services with the technology described above. At this moment, there is an initial node in the University of Zaragoza (with access restricted to people from the project) with geographic metadata catalog service and Web map services. Next step will be to extend this node and to create two other server nodes at the Polytechnic University of Madrid and in the University Jaume I, all related through service links based on service catalogs. Components developed are also being used in projects to create specific software products and regional data infrastructures.

Through this pilot project and other projects where the components are being deployed, we are making a detail analysis of the functionality required for the development of spatial data infrastructures. This analysis process must be associated with the necessary abstraction in order to be able to propose new architectural models, and the adaptation of existing ones to the GIS context.

2.3   Promotion and dissemination

Certainly one of the more critical objectives of this project is the promotion and dissemination of the ideas, standards and philosophies that define and sustain the concept of a Spatial Data Infrastructure. Initially the GIS community in Spain was skeptical due to the lack of information

on how this infrastructure could be implemented following open standards. Fortunately, there have been some important changes since this project began.

The INfrastructure for SPatial InfoRmation in Europe (INSPIRE) is a European Union initiative (sponsored by DG-Environment, Joint Research Centre, and Eurostat) that aims at making available relevant, harmonised and quality geographic information for the purpose of formulation, implementation, monitoring and evaluation of Community policy-making. In practice, this initiative is going to create a legal framework to guide every EU member state in creating its own national data infrastructure, according with a set of standards, processes and directives.

INSPIRE has attracted people's attention, and therefore has been extremely useful for us in our work of promoting open SDI concepts, because at this moment we are able to present an European Union initiative that directly supports our arguments. Additionally, because we are participating directly in INSPIRE, we have first-hand information.

In this context, we have made a series of presentations to organisations and companies. The most relevant ones are:
- 9/6/2001 – Presentation at the Ebro River Basin office (Zaragoza). The audience was integrated by people from different departments of the Ebro River Basin, Aragon Government and Geologic-Technological Institute.
- 5/3/2002 – First Workshop on Spatial Data Infrastructures (Madrid). The audience was integrated by people from the Spanish National Geographic Institute (IGN), National Center for Geographic Information (CNIG), Xunta of Galicia (Environment Department), Community of Madrid (Environment Department), Catalonian Cartographic Institute and some departments from de Spanish Ministry of Environment.
- 1/4/2002 – Presentation at the Xunta of Galicia Environment Department office (Santiago de Compostela). The audience was integrated by people from different departments of the Xunta of Galicia.
- 5/9/2002 – Presentation at the Spanish National Geographic Institute office (Madrid). The audience was integrated by people from the Spanish National Geographic Institute (IGN), National Center for Geographic Information (CNIG).
- 24/10/2002 – Presentation at the Aragon Government Computer Science Department office (Zaragoza). The audience was integrated by people from different departments of the Aragon Government.
- 25/10/2002 – Presentation at the La Rioja Government Environment Department office (Logroño). The audience was integrated by people from different departments of the La Rioja Government.

As a consequence of our work in promotion and dissemination, we are participating in all major initiatives launched in Spain for the development of spatial data infrastructures:
- We are working with the Spanish National Council for Geographic Information, the Spanish National Geographic Institute (IGN) and the National Center for Geographic Information (CNIG) to create some components as the initial kernel for the future Spanish National Data Infrastructure. Kickoff scheduled for December 2002.
- We are working with several departments of the Spanish Ministry of Environment, especially with the Nature Data Bank and Ebro River Basin.

- Creation of the Catalonian Spatial Data Infrastructure (IDEC). We are working together with the Catalonian Cartographic Institute (which has the responsibility for its creation) as technological consultant and with software components.
- Creation of the Galicia Spatial Data Infrastructure. We are working together with the Xunta of Galicia Department of Environment (which has the responsibility of its creation) as technological consultant and with software components.
- We are also working with several departments of the Aragon Government (Agriculture, Environment, Miner) in order to assist them to develop tools that could be integrated into de Aragon Spatial Data Infrastructure.
- We are advising the Andalusia Cartographic Institute (Junta of Andalusia) in the process of geographic metadata creation. They are also using our metadata cataloguing tool.
- The team has recently received a small project funding to create a pilot regional environmental SDI for the agricultural area "Plana de Castellón", allowing environmental researchers to share and access data on-line.

Currently, we have a very good position in Spain, and our opinions are being taken into account at European level. We should continue work in this same line in order to become the reference research team in Spain in the field of Spatial Data Infrastructures.

2.4   Team consolidation

When this project was proposed, the intention of the researchers from the three universities was to begin collaboration in order to create a R&D team with some sort of critical mass. Several initiatives in this direction have been implemented during the first two years of the project. Perhaps the most relevant ones are the following:

- Celebration of the First Symposium of the Spanish Spatial Data Infrastructure (Zaragoza, Feb.15-16, 2002). This was a two-day meeting, restricted to people from the three universities, that served to create inter-personal relations among the research groups of the three universities.
- Creation of a consortium with a single identity, denominated "*TeIDE Consortium" (Tecnologias para Infraestructuras de Datos Espaciales)*, to facilitate joint participation in projects related with spatial data infrastructures. Snce TeIDE was established all public presentations have been made under this name instead of individual institutions.
- Coauthoring and publication of papers and reports by researchers from the three universities in collaboration (see 3.2).

3 Result indicators

This section provides an enumeration of the different result indicators.

3.1 Teaching

Two doctoral courses are now offered in relation to the SDI concepts stemming from this CICYT project: at the Polytechnic University of Madrid denominated *Spatial Data Infrastructures.*, and at Univ. Jaume I a course officially titled "3D GIS" has evolved beginning in 2001 to now cover web services and SDI topics.

Additionally, an elective course for Topographic and Cartographic Technician Engineers at the Polytechnic University of Madrid denominated *Introduction to Spatial Data Infrastructures* has been created, and the undergraduate course "GIS" at Univ. Jaume I (5-year Engineering degree in Computer Science) now contains a good deal of SDI material.

Currently, there are three PhD students at the University Jaume I and eight more at the University of Zaragoza, working in areas directly related with this project. Two of these students will present their PhD thesis next year, and another one was presented in September 2002 (Dolores María Llidó Escrivá).

Additionally, so far about 20 final projects for engineering students (Computer Science) have been developed in areas directly or indirectly related with this project.

3.2 Professional publications

The following list of professional papers presents results directly related with this project (see bibliography for full references):

Journals and book chapters:

[1], [2], [3], [4], [5], [6], [7], [8], [9], [10], [11], [12], [13], [14], [15], [16], [17], [18], [19], [20], [21], [22], 23] and [55].

Conference contributions

[24], [25], [26], [27], [28], [29], [30], [31], [32], [33], [34], [35], [36], [37], [38], [39], [40], [41], [42], [43], [44], [45], [46], [47], [48], [49], [50], [51], [52], [53] and [54].

3.3 Projects

As a consequence of this project, we have been in the position to participate in the following projects related with the same research area:

European Union:
- GETIS: Geoprocessing networks in a European Territorial Information Study (IST-1999-14146). 2001-2003
- PreANVIL: Interoperability Observatory (1999-2001). Joint Research Centre (JRC), Space Applications Institute, EU.
- CEN/ISSS Metadata/Dublin Core Workshop (MMI-DC) Project Team: improving discovery of geographic information in cross-domain searching. CEN/ISSS – Comitée Européen de Normalisation/Information Society Standarization System. 2002-2003.
- ACE-GIS : Adaptable and Composable E-commerce and Geographic Information Services. *Information Society Technologies* (IST-2001-37724), June 2002 – November 2004.

National Level:

- Advanced Territorial Information Public Services Development and Implantation. Evolution of SITNA to provide open interoperable internet services and electronic commerce capabilities on territorial information. Ministerio de Ciencia y Tecnología, project Profit FIT-150400-2001-20
- Integration of Location based services and OpenGIS standard compliant GIS capabilities into the CRM Vantive system "Field Service" component to access internet. Ministerio de Ciencia y Tecnología (PROFIT FIT-070000-2000-0827)
- Terrestial transport fleet control and tracking service centre with internet access. Ministerio de Ciencia y Tecnología (50% FEDER funding, objective 2 area). Project P4, reference: TIC2000-0048-P4-02

Regional Level:

- Project cofinancing: Internet oriented and open standard based services development for distributed geographic information catalogs. Effective steps toward the Spain National Geographic Information Infrastructure. Gobierno de Aragón, CONSI+D, project P089/2001
- Information technologies and Pyrenees territorial environment network. Gobierno de Aragón, Departamento de Educación y Ciencia. (Projects for the development and consolidation of thematic networks in the Pyrenees Working Community. Aragon, Navarre and Aquitaine regions)
- Implementation of an Environmental SDI: Pilot study for supporting Groundwater Research. Fundación Castellón-Bancaixa (local bank R+D funding). 2003-2005.

Technological transfer contracts:

- Geographical information visualization system to olive plot characteristics recognition. Diputación General de Aragón, Departamento de Agricultura. From: 2000, to: 2001

- Plot raster images georeferentiation and georectification. Diputación General de Aragón, Departamento de Agricultura. From: 2000, to: 2001
- Technological assistance to a location based service demonstration prototype development on the CRM Vantive Field Service module, I phase. From: 2001 to: 2001
- Development of a computing tool to the management and diffusion of the technical and administrative information of the Dirección General de Energía y Minas. Diputación General de Aragón, Dirección General de Energía y Minas. From: April-2001, to: Dec-2001
- Functional analysis and migration processes design for the water point inventory geospatial and tabular data to an Oracle database. Confederación Hidrográfica del Ebro. From: feb-2001, to: Dec-2001
- Architectural patterns establishment and GUI design for the IPA information system infrastructure. Confederación Hidrográfica del Ebro. From: Feb-2001, to: Dec-2001
- Previous study for an Environmental Information Structuring and Storage System development. Xunta de Galicia, Conselleria de Medio Ambiente. From: ene-2002, to: jul-2002
- Development of the Galician Environmental and Geographical Information Network. Xunta de Galicia, Conselleria de Medio Ambiente. From: jun-2002, to: Dec-2002
- Map georeferenciaton and visualization adaptation. Diputación General de Aragón, Departamento de Agricultura. From: mar-2002, to: jul-2002
- Improvement and increase of the water point inventory system query component functionality. Confederación Hidrográfica del Ebro. From: Jan-2002, to: Dec-2002
- Water point inventory system infrastructure implementation. Confederación Hidrográfica del Ebro. From: Jan-2002, to: Dec-2002
- WMS client development to the managing and combining of geographic data arriving from several predefined servers. Institut Cartogràfic de Catalunya – Generalitat de Catalunya. From: Oct-2002, to: Nov-2002

3.4   National and international cooperation with other R&D groups

In addition to the three project partners, along the duration of the project we have been in cooperation with several R&D groups at different levels of implication. Cooperation with groups of the University of La Rioja and University Carlos III has made a notable contribution to the research and to the project itself. Further cooperation has been established with R&D groups mainly derived from our membership in AGILE (Association of GIS Laboratories in Europe) emphasizing the University of Münster (Germany) where we have one of our PhD students as visiting scholar, and two of their students visiting Univ Jaume I; the Technical University of Vienna (Austria) and Luleà University of Technology (Sweden) where we have maintained cooperation in several EU projects and some papers, and the University of Bremen trying to establish collaboration for multilingual catalogue technology interchange.

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CAPDIS: High Performance Computing and Communication via Internet and Intranets: Experiences and Pilots TIC2000-1165-C02

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Abstract

This article describes the results of the CAPDIS project. In this project, an architecture for the access to high performance computing systems through intranet or Internet and an architecture for high-performance distributed components have been developed. A cluster of PCs has been set-up and four test case applications have been developed: an image diagnosis system that works on a corporative hospital intranet, an application for high-quality graphics on electronic commerce applications and two applications for assembly and haptic recognition of components on a distributed environment. The outcome of the project has been 4 prototypes, 1 doctoral thesis, 5 European projects and 14 publications.
Keywords: HPCN, Parallel Computing, CORBA, Distributed Systems, Haptics.

1 Project Objectives

The development of the high performance computing (HPC) systems based on standard PC clusters has led to the availability of affordable multiprocessor systems. Although PC clusters are widespread beyond academia or large companies, the popularisation of this kind of systems is still under its possibilities, mainly due to the problems on the integration of these systems on corporate networks, as www or database servers do. The objective of this project has been to advance on the development of effective base or infrastructure software (usually called middleware) that could ease the adaptation of a software application (or a package combining several of them) to work on a distributed environment, focusing on applications with HPC requirements. The project has been aimed at the development of HPC services through out Internet and corporate intranets or extranets. In this way it is possible to provide affordable HPC services from any location. On top of this system, several pilot projects have been developed to be used as demonstrators for the promotion of results, mainly on the industry.

2 Background

Middleware emerged as a result of evolution of computer architectures in response to business needs. In the 70's and 80's systems were running on mainframes accessed through terminals. The

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emergence of client servers divided the business logic (i.e. the application) into two, one part residing in the client end and the other part together with the database in the server end. Communication between these parts is done through a network (normally using TCP/IP). This architecture utilises PC's as clients and allows servers to be located where convenient. Next step was the use of a distributed architecture with a middleware layer supporting distributed applications. This allowed a more flexible design as they can rely on basic IT services (such as naming and security) being available in the middleware. These 3-tier distributed environments evolved as a solution to support complex transactions of large business enterprises.

The emergence of the Internet has brought a new set of concepts and tools to distribution of computing power. One can view the Internet as a huge distributed computing environment. It can also be deployed by enterprises both to restructure their internal computing resources with web-based approaches (intranet) and to communicate with the outside world (extranet). Wireless technologies have added further complexity and freedom of choice to enterprises to structure their distributed computing environments. The Internet approach enables the networking of enterprises. Instead of the 3-tier architecture we now have an n-tier architecture.

Distributed architectures and common IT services go hand in hand with objects and object orientation. Today the main industrial consortia working in distributed architectures and common IT services is the Object Management Group (OMG). OMG comprises today all major computer and software vendors. It is a joint venture to define a fully object based architecture. It has published the Common Object Request Broker Architecture (CORBA) based on the Object Request Broker (ORB) and a set of common IT services.

With the success of web servers, web browsers and Java as a programming language, Sun's J2EE has become also a de facto standard platform for building distributed web-based environments. Integration of OMG- and Java-based applications is today a standard feature with the extension of the ORB towards the Internet through the Internet Interoperability Protocol (IIOP) and the Remote Method Invocation protocol (RMI) at the J2EE side.

The W3 consortium has been instrumental in developing standards and solutions for the Internet environment. The steps from SGML through HTML to XML are one such example. Today XML is finding many uses in integrating data and enterprise functions. Simple Object Access Protocol (SOAP) is another example of how XML can be used to transfer function between applications.

These developments can also be viewed as generation shifts. The 1st generation approach was the original OMG and Microsoft DCOM solutions. The Internet created a need for the 2nd generation with access mechanisms to and from Internet, e.g. the IIOP extension of the CORBA architecture. The further proliferation and quick take-up of the Internet produced the 3rd generation with XML and SOAP as means to provide tighter integration in widely distributed environments, e.g. the .Net product line of Microsoft. The next step may be agent based environments, e.g. Genie.

Parallel Distributed Applications

The technologies mentioned above have been very successful and their design and development have been biased towards mainstream computing. However, their utilisation can be cumbersome in other more specific scenarios such as technical computing. For instance, parallel computing is not considered, and therefore combining distributed and parallel technologies can be a major difficulty.

An important part when deploying a distributed application is migration, since in most cases there are already existing applications and an existing infrastructure. The task is to add new applications to this infrastructure or to replace existing ones with new or better applications or both. In addition, it is often desirable to continue to make use of the databases that store valuable data even

though the actual applications will be replaced. This is called encapsulation of legacy systems. In the case of legacy systems which include parallel programs, this task is far from being trivial.

At the moment of writing this document, the final Data Parallel CORBA Specification [1] has been adopted, although implementations which support it are yet to come. This specification is very welcome after a long period of emptiness and it acknowledges the need of such technology. However, it is rather specific for a certain kind of applications and requires rewriting virtually all the application's code in order to leverage legacy codes.

Previous to this standardization effort, there have been several attempts from academia to bridge both distributed and parallel computing worlds. Some examples are PARDIS, TENT, COBRA, COVISE, PaCO, PADICO and other projects, some of which are still actively developed. Research in programming models for Grid Computing is related to some of these projects. In this work, the authors explore this issue by testing design concepts and strategies directly on real applications.

High Performance Cluster

Clusters of computers based on commodity components have become a widely accepted platform for running parallel applications due to its price/performance ratio. Although the difficulty of installation and administration is still its main drawback, currently available software tools (either commercial or public domain) have improved the situation considerably.

A PC cluster has been set-up during the project. This system is composed of twelve IBM xSeries 330 SMP severs, mounted on a Netfinity Rack. Each node comprises

- Two Pentium III 866 MHz processors with 256 KB cache.
- 512 MB 133 MHz RAM.
- 9,1 GB Hot-swap Ultra 160 SCSI Hard disk.
- Integrated double port Ethernet 10/100 adapter.
- Ethernet Gigabit adapter.

Two interconnection networks are implemented in the system, a FastEthernet one for administration and a Gigabit Ethernet one for parallel application communication. The operating system is Red Hat Linux 7.1, with multiprocessor support kernel (2.4.2-2). As a reference for the computational power, the system reaches 11 Gflops (sustained) with HPL benchmark (High Performance Linpack) using 24 processes for a problem size of 25000.

3 Architecture of the System

Actually, three different architectures have been developed to deal with three different scenarios:
- Intranet-based approach, assuming that a high bandwidth connection is available and the network is private with authenticated access. Real-time interaction is supported.
- Client-server Internet approach, in which computational power is accessed via an Internet server.
- Collaborative Internet approach, in which the main focus is co-operation and distributed access.

Architecture of the Intranet-based approach

The architecture of the system is shown on Figure 1. Parallel computers are available through a server node. This server node is part of the high-speed network binding the nodes of the parallel computer and is the only point accessible from the external client applications. These applications

can be run on heterogeneous computers with few resources and connected to the corporate intranet via narrow bandwidth networks (such as Fast Ethernet).
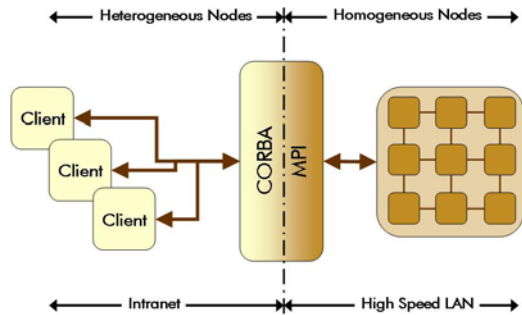
Figure 1: Architecture of the intranet approach.
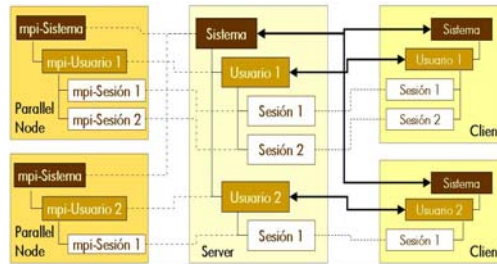
Figure 2: Hierarchy of the components.

The following objectives have been approached:

- Portability and multi-platform support is ensured by the use of CORBA protocols for the connectivity of client applications. The use of MPI for the internal communication of parallel computing nodes also guarantees portability to a wide range of platforms.
- Efficiency is obtained by the clear separation between high-speed LAN, where homogeneous nodes communicate through MPI and the intranet area where heterogeneous nodes execute objects remotely through CORBA.
- Robustness is obtained by the use of fault tolerance scheduling on the server system. Multi-server systems are also supported.
- Scalability is obtained by the use of clusters of computers as the parallel computing system.

The implementation of the system implies two types of components:

- Remote-callable CORBA objects. Pure CORBA objects that provide methods that can be directly executed remotely on the clients with the usual marshalling process.
- Remote-referencing objects. Main concern of parallel computing is data distribution. In order to avoid the redistribution of data that would strongly penalize the performance, remote-referencing virtual objects have been set-up. These objects implement methods that can be executed through remote-callable CORBA objects.

The hierarchy of the components that interact on the system is depicted in Figure 2. The core of the system is a component called `System`. It manages all the users and assigns the resources of the parallel computer to the different users taking into account load balancing, availability and user profiles. It also provides means for Logon and Logoff and management of the MPI processes.

Each user that binds to the system creates an instance of the `User` component. Each user negotiates with the `System` component the allocation of resources and it is the container for the different problems (sessions). Component `Session` is a reference to the object that comprises all the parallel methods that solve the problem to be implemented. All the actions should be executed through the `User` component. As an example, Figure 3 shows a sequence of sample commands for the creation of a session and the execution of a parallel method on it.

```
System SystemObject(CreationData)
User UserObject = SystemObject->logonUser(UserData, Resources)
Session SessionObject = UserObject->CreateSession(SessionData)
UserObject->DoAction(SessionObject, ActionParameters)
ActionResult Result = UserObject->GetResult(SessionObject)
UserObject->CloseSession(SessionObject)
UserObject->logoffUser()
```

Figure 3: Sample sequence of commands.

Architecture of the Internet-based approach

In the case of accessing computing power via Internet, the main focus is on providing a friendly user interface for a high-end computing capacity which is providing fast computational response transparently to the user. The proposed architecture uses a web interface in the same way as other so-called portal computing initiatives.

Figure 4 shows a scheme of the architecture particularized to the rendering service for e-commerce described in the next section. The client accesses the system via Internet with a standard browser. From his point of view, the system looks much like a conventional virtual store, with many tools for searching and browsing the catalogue. The main parts of the system are the following:

- The web server and the electronic commerce system installed in it. This virtual store has an up-to-date catalogue of products and might be also connected to the company's back-office. The virtual store also contains the room design tool, from which the user issues the requests for computationally intensive image generation.
- The computational server in charge of generating the realistic picture that will be shown to the user. It can be a cluster of PC's.

The request for the generation of an image is made in the room planner by means of a *submit* button. This button activates a program that is executed in the web server via the Common Gateway Interface (CGI). This is a very small program that transfers the request to the parallel server. Once the image is generated, the CGI program will display it in the client's browser.

The CGI program does not contact the computational server directly. Instead, the request is routed via an intermediate agent: a CORBA service. This additional element is included in order to add flexibility to the system. The rendering service will be able to receive several request for renders, either from the same web server or from different web servers. Also, it will be able to route these requests to one or several computational servers, allowing for sophisticated scheduling policies.

In the simplest case, there will be only one computational server, as shown in the figure. The CORBA service will launch the requests, one at a time, for example via a queueing system.
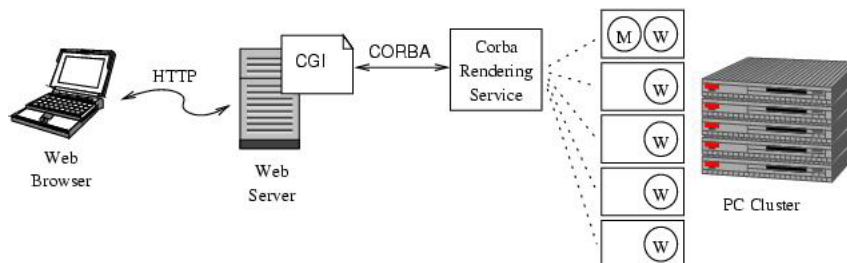
Figure 4: Architecture of the e-commerce rendering service.

Architecture of the collaborative approach

The architecture used in the development of the Assembly Simulation and Haptic Environment is shown in Figure 5. The geometric kernel (DATum) is the central repository of active geometric data. Maverik is the visualization tool. Integration of Maverik and DATum permits the native representations and algorithms of the geometric kernel directly within the framework for interaction provided by Maverik.
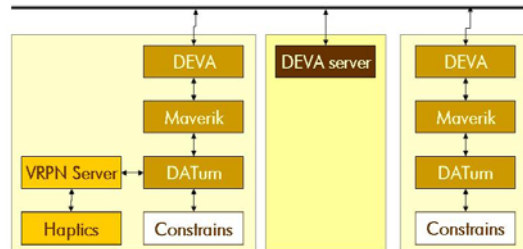
Figure 5: Architecture of collaborative tools.

This approach allows an extremely close coupling between an existing CAD modelling system and a VR kernel, gaining the capabilities of each system whilst avoiding the performance/flexibility losses of exporting an intermediate formats between these components. Distribution is handled by integration between Maverik and the distribution system - Deva. It uses techniques within Deva to maintain a smooth presentation of interaction in the face of communications latencies. The Deva system provides a networked multi-user and multi-environment layer on top of Maverik.

Based on this architecture, two different applications have been developed:

- Assembly Simulation. The constraints and assembly sequences are handled by this module integrated within DATum.
- Haptic Environment. It has been created by the integration of a haptic commercial device (PHANToM – Sensable Devices Inc. [2]) and the geometric kernel DATum. The integration within the distributed environment has been done through VRPN.

DATum [3] has been developed by LABEIN. Maverik and DEVA [4] have been developed at University of Manchester. VRPN has been developed at University of North Carolina-UNC [5].

4 Test Case Applications

The architecture and software tools developed in the project have led to the development of four pilot applications that show clearly the advantages of accessing parallel resources from computers connected to an intranet or the Internet. The applications are applied to four different industrial sectors and are described in the following sections.

Medical Imaging Application

A multi-user, multi-computer, multi-threaded parallel computing software library for standard image processing tools, such as 3D segmentation, 3D projection and multiplanar reconstruction has been developed. This software library runs on a parallel server that provides computing power to any standard computer. The software library is completed with a client tool running under MS Windows operating systems that connects via CORBA to the parallel server. The system is scalable and easily upgradeable. It comprises 3 main elements:

- A Server, acting as a the bridge among the client applications and the parallel computing server.

- A Parallel Computing System, which comprises a variable number of multiprocessor computers and performs the computing-demand operations.
- A client, which is the visible part of the system. It is an application that runs on a separate PC interacting with the server.

These elements are illustrated in figure 6 and described next in detail.
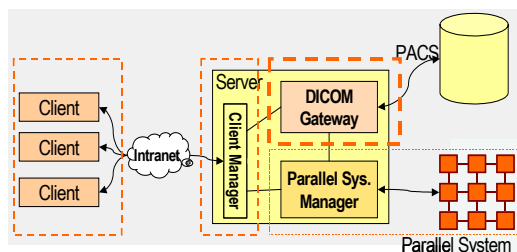
Figure 6: Structure of the medical imaging application.

Components: The Server. The server manages the parallel computing system controlling the processes and associating processes to users. User connects to the system through the client application, which interacts exclusively with the server. The server manages users, fetches studies, transmits the orders to the parallel server and returns the results to the user client. All the communication with the user applications is performed using CORBA protocol. Interaction with the image repository is performed through DICOM protocol and communication among parallel processes is performed by means of MPI. CORBA is used for providing a communication independently of the platform (thus enabling clients from any operative system). DICOM is used for ensuring compatibility with image providers. Finally, since communication with the cluster should be efficient, MPI is used.

Components: The Parallel Computing System. The parallel server implements a structure of components that store and process the information required in image diagnosis. The system holds a set of users, who can open a set of studies from the same or different patients. Each study stores a set of images, segmentations and projections.

Segmentation can be performed by using voxel-based methods, such as Region Growing or Thresholding in 3D or by contour extraction methods, such as snakes or deformable models. Voxel-based Region Growing segmentation is optimised by using 3D spans to maximise cache impact and it is implemented on a block distributed parallel computed fashion. The architecture is designed to be easily upgraded. New segmentation engines can be implemented to work on the top of the distributed volume. Segmentation can deal with up to 6 different simultaneous tissues that can modify the behaviour of the segmentation operations.

Figure 7: Two images using the system of the project.

Projection is provided by means of different projection engines. Projection object can be either a 2D projection (a multiplanar projection) or a 3D projection. A 3D projection can be obtained by

using any of the two projection methods (Ray casting and Splatting), any of the two tracing methods (perspective or orthogonal), any of the two interpolation functions (linear and tri-linear) and any of the two projection functions (Maximum Intensity Projection or MIP and Surface Shading). In this way, new projection methods do not have to implement the same projection functions or interpolation methods. All the methods are implemented in parallel. Ray casting uses a replicated volume and distributed cyclically the different rays among the processes. Splatting distributes the volume in a block-overlapped fashion. MIP uses a threshold for improving contrast.

Components: The Client. The architecture manages several simultaneous users. A user is a client application that communicates with the server. The client application is the visible part of the system. The current client application is implemented under Ms-Windows, although different version can be integrated with a single server due to the use of CORBA protocols.

The client user provides a user-friendly environment for fetching studies, presenting different images, computing segmentations, 3D projections or multiplanar projections. The application does not require large user requirements. Moreover, studies are not downloaded on the local client, but stored on the parallel server. Images are presented only under demand and at different resolutions. In this way, communication overhead is minimised. Low-cost processing (such as 2D filters, 2D measuring,...) are performed locally. 3D computations are performed on the server.

Electronic Commerce Application

The second pilot is an e-commerce tool that extends the conventional online store with a new section called room planner, a web application which is embedded in the virtual store. It allows the specification of the geometry of the room, placement of the objects and selection of the point of view. Then a realistic picture of the scene can be obtained. This functionality is very suitable for the furniture and ceramics sectors. In order to generate the images a parallel radiosity illumination algorithm has been implemented, which can be used in low-cost platforms such as a cluster of PCs, so that these technologies are affordable also for SMEs.

The main new functionality added in the system is the possibility of creating virtual environments by means of a room planner, an intuitive and easy-to-use tool which enables the customer to easily design a virtual ambient and then request the generation of a realistic picture of the scene.

The room planner is an applet which is embedded in a traditional electronic commerce store. The user can design the layout of the room and then place some elements in it. These elements are either products selected from the store's catalogue or auxiliary elements such as doors, lights... In the case of ceramics, the customer can also design the pattern of tiles covering the floor and walls.

Once the user is satisfied with the design of the room, it is possible to request a high quality synthetic image from a certain viewpoint. This is carried out by the radiosity code. Figure 7 shows an example of a generated image and its corresponding room layout.

The fact of using the radiosity method within an electronic commerce application has two important implications which are not present in other situations. First of all, the response time is critical in this kind of application. Turnaround time must be kept below 1 or 2 minutes because otherwise the user will soon give up using the system. Due to the computational complexity of the radiosity calculations, parallel computing must be used to achieve this short response time. The parallel job involves a number of processes organized in a manager-worker scheme and it achieves very high parallel efficiency (more than 95% for up to 24 processors). This computing kernel is accessed via the architecture described in the previous section. This access must be ubiquitous and transparent to the user, very much in the spirit of modern grid computing systems.
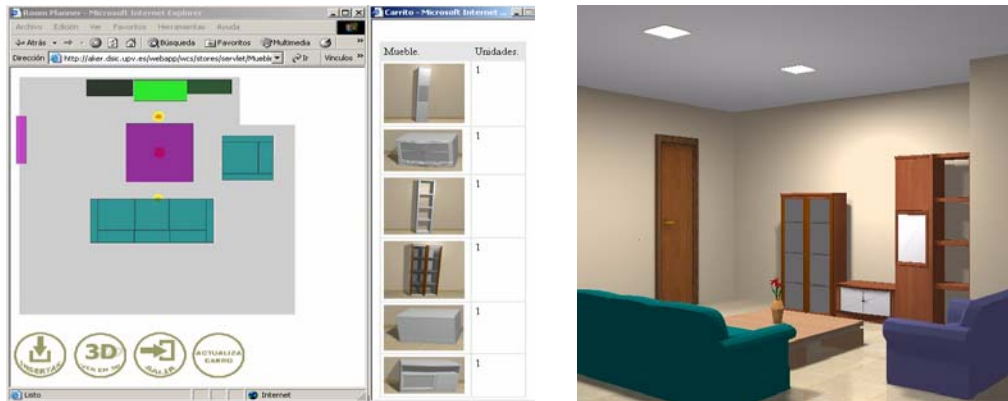
Figure 8: Room planner (on the left) and image generated by the system (on the right).

Assembly Simulation Application

This application is intended for virtual prototyping based on a VR kernel (Maverik) specialised for highly interactive applications, where frame-rate is one of the key criteria. Since optimisations are critical for maintaining the frame-rate, there is a significant benefit in using native data, as high level information is retained and can be used. Moreover, similar optimisation techniques can be used for collision and constraint detection.

Constraint and assembly sequence operations are handled by the Constraint Simulator of Datum. It introduces constraints to the virtual world application and provides a means to specify and remove constraints through direct manipulation. It combines direct manipulation techniques, collision detection, and constraint management and a novel sensor based constraint recognition and deletion techniques within a unified framework.. Since the constraints maintain the relationships and provide initial solutions to them, this technique can be used for precise object positioning. The novel aspect of the system is that it provides a facility to carry out assembly/disassembly with minimal user interaction through automatic assembly/disassembly techniques. This takes this area of virtual prototyping a step forward from the other systems, that only allow assembly operations through menu interaction or snapping through approximate collisions.

Deva has a client/server architecture. Deva manages the connecting and disconnecting of the clients to the server. The programming model used by Deva is one of creating 'objects' in the server. The system then automatically manages the distribution of these objects to the client processes. Applications that control these objects work as if there were only a single copy of the object in the system, with the consistency being managed 'invisibly' by the system. Deva can interface directly to Maverik classes. It is therefore a simple task to get Deva to send a message to an object asking it to update itself, given a set of parameters which form part of the message.

Different methods for implementing these tasks can be used, again
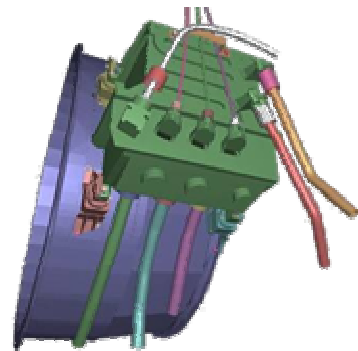
Figure 9: Assembly Simulation.

capitalising on knowledge of the application and the task. Deva provides mechanisms, but does not dictate how things must be done. For example, the Deva server can send a message to each client asking to update the position of an assembly process, representing a particular object which is moving by a user through the environment. The methods associated with the assembly class in Maverik already contain code to detect the assembly relationship (through the integration with DATum and the Constraint Manager), and these local methods control the movement of the object that is being assembled. Here, Deva and Maverik have an 'agreed' interface to the assembly class; Deva treats the object as a single entity with certain 'high-level' functions and Maverik deals with the details of smoothly rendering the animation of these functions for each user.

Figure 9 shows an aeronautic assembly provided by SENER. It has been used as test case to check the utilities of the application. The Assembly Simulation has been able to detect an assembly problem that was not discovered during the design phase in a traditional CAD system.

Haptic Sensor Application

The integration of a haptic interface with a geometric kernel like DATum allows the user to interact with the 3D designs in a new and more realistic way than the traditional systems. The user can not only view the objects designed in the CAD system, but also interact with them: touching, grasping and moving them by the virtual space detecting the possible collisions with other objects.
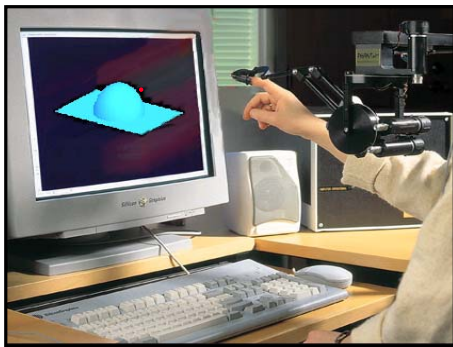
Figure 10: Work session with the haptic virtual environment.

Figure 10 shows a work session with the new haptic environment. The user inserts his/her finger in the thimble of the device PHANToM and moves it along the virtual space, being able to interact with the objects visualised on the screen and listen audio signs (for example to indicate a collision). In addition to the object, a point that represents the position of the user's finger is visualised. The objects that can be manipulated with the haptic environment can be solid or surface models and be defined by conics (lines, circles and ellipses), quadrics (planes, cylinders, cones, spheres) or more complex geometries like b_splines curves and surfaces.

Figure 11 shows the strategy followed for the integration of all the tools involved in the building of the CAPDIS haptic virtual environment and the haptic utilities that have been developed:

1. The user loads the 3D model.
2. The PHANToM device is activated.
3. PHANToM detects the movement of the user's finger and gets its new position.
4. *DAT*um receives the new position, analyses it according to the utility that is being used and calculates the force that has to be sent to the user.
5. PHANToM replicates the calculated force on the user's fingertip.
6. Go to step 3.
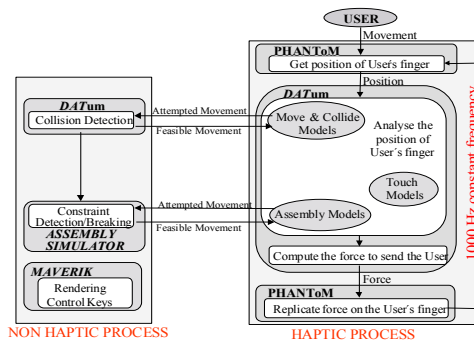
Figure 11:. Haptic Virtual Environment architecture.

In the project, a new server class vrpn_Tracker_Phantom (derived from vrpn_Tracker class) and a new client class vrpn_Tracker_Phantom_Remote (derived from vrpn_Tracker_Remote class) have been created in order to manipulate the PHANToM device remotely. The client process controls the geometric data and the relationships among the models (collisions, assemblies…), so this allows working with more complex geometries. The server process is the responsible of the communication with PHANToM (get the position and send the corresponding force). It has to run on the NT machine connected to the PHANToM device, while the client process runs on a UNIX or NT machine. This architecture is shown in Figure 12. The workload of a command is divided in the following way:

- On the server there are 2 processes. The haptic process gets the position of the user and sends the corresponding force. The other process is the responsible of the communication with the client.

- On the client there are also 2 processes. One analyses the point received from the server to calculate the force and the other responsible of the rendering.
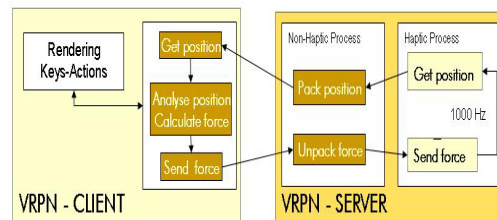
Figure 12: Client – Server Processes.

The methods of vrpn_Tracker_Phantom class that runs in the server process enable to reset, initialise or shutdown the PHANToM device and the haptic process, send the position of PHANToM to client process and the state of Phantom switch and receive the force and the required information for the command from the client process. The methods of vrpn_Tracker_Phantom_Remote class that runs in the client process enable to send the flag to server process to finish the command, receive the position of PHANToM from server process and the state of Phantom switch and send the force and the required information for the command.

5 Success Indicators

The project has been very successful, mainly in terms of technology transfer and publications. It has opened several research lines and enabled the cooperation with several national and international groups.

The work carried out during this project has led to the development of one Doctoral Thesis "Sistemas Distribuidos de Componentes de Altas Prestaciones Orientados a Objetos para el Diagnóstico por Imagen".

A list of publications performed due to the work developed during the project is the following:

- "DISCIR: An Architecture for High Performance Distributed and Component-oriented Image Diagnosis Applications", CARS, Paris, June 2002.
- "Reconstrucción 3D en Paralelo de Imágenes Médicas de Gran Dimensión con Almacenamiento Comprimido", CASEIB, October 2001.
- "DISCIR: Una Arquitectura para la Implementación de Aplicaciones de Diagnóstico por Imagen Distribuidas y Paralelas Orientadas a Componentes", CASEIB, October 2001.
- "Altas Prestaciones en el Post-procesado Digital", 1er Simposium en Imagen Digital en Radiología y su Entorno, Valencia, June 2002.
- "A Parallel Rendering Algorithm Based on Hierarchical Radiosity", VECPAR, Porto June 2002.

- "High Performance Virtual Reality Distributed Electronic Commerce: Application for the Furniture and Ceramics Industries", Information Visualisation Symposium, London, May 2002.
- "Comercio Electrónico con Visualización Integrada de Ambientes Virtuales: Aplicación a la Cerámica y el Mueble", Congreso Nacional de Comercio Electrónico Aplicado, Valencia, 2002.
- "Creating a Distributed Virtual Prototyping Environment for Concurrent Engineering", EUROIMAGE ICAV3D, Mykonos, Greece, May 2001.
- "Distributed Virtual Prototyping". VR World Congress, Barcelona June 2001.
- "Haptic Virtual Environment". VR World Congress, Barcelona June 2001.
- "TT and CAx Technologies used for the Product Development", RAPID Manufacturing Seminar at the IWB Institute in Augsburg, Germany, October 2001.
- "DIVIPRO Sketch". SIGGRAPH, San Antonio USA, July 2002.
- "DVIPRO paper". EGVE (Eurographics Workshop on Virtual Environments), 2002.
- Haptic Applications. CIDAT-ONCE Conference, Madrid September 2002.

Technology Transfer

The e-commerce solution was showcased at 2 industrial fairs and 2 workshops organised by industrial associations.

The Assembly Simulation Application has been installed at SENER premises and tested with a real industrial test case. SENER is an engineering company working in several industrial sectors such as aeronautic, automotive, naval, civil engineering, … The test case used was from the aeronautic field. The designers of SENER were able to detect an assembly error that was not discovered with the design process using a traditional 3D CAD system.

The Haptic Environment (in the single user version) is being used by ONCE (Spanish Blind Association). Several applications have been developed for the blind people such as games and mobility training (inside a building or in a city).

The work developed in this project has been linked to these European projects:

- IST-1999-20778, "DISMEDI: Distributed Medical Imaging, A New Component for Advanced PACS", Nov 2000 to April 2002.
- IST-2001-37354, "TT@MED: Technology Transfer in Medicine", July 2002 to Dec 2003.
- IST-1999-20785, "VRE-Commerce: Virtual High Performance Virtual Reality Distributed Electronic Commerce: Application for the Furniture and Ceramics Industries", Oct 2000 to March 2002.
- IST-1999-11421, "DIVIPRO: Distributed Virtual Prototyping" Jan 2000 to May 2002.
- IST-2000-26151, "GRAB: Computer Graphic Access for Blind People through a Haptic Virtual Environment", Jan 2001 to Dec 2003.

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Diseño e Implementación de Algoritmos de procesado de señal de altas prestaciones para Reconocimiento de voz en Condiciones ambientales Adversas (DIARCA): TIC99-0960

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Abstract:

The Recognition of Spoken Commands finds important application fields in avionics, car communications and control, manufacturing, handicap-aids, etc. One of the key aspects of this technique for its successful use is the reliability of the recognition interface. Speech enhancement techniques may be used to strengthen the reliability of speech recognition. The techniques suggested in the present proposal for speech enhancement combine adaptive time-domain noise cancellation and spectral subtraction with selective speaker detection using beamforming. The proposal foresees the performance evaluation of this system on two different computing platforms. The first one is a low-cost high-performance monoprocessor embedded system with applications in domotic control. The second one is a distributed system in which a network of client stations may request specific computing services to an specialized DSP server to process recorded speech traces. This second possibility is aimed to be applied in *cokctail-party effect* environments. The proposal is intended to evaluate the use of such platform in commercial building security systems.

Keywords: Noise-Robust Speech Recognition, Adaptive Filtering, Beamforming, Voice-Controlled Interfaces, DSP Platforms

1. Objectives:

The general objective consisted in setting up a system to detect speech in noise under robust conditions using speech enhancement and beamforming is to be defined, together with the best computing platforms to support such system, with application in security systems and domotic control using voice. This was divided into the following specific objectives:

Objective O.1.: Determination of the best-suited algorithmic techniques for speech enhancement and recognition based on hybrid noise cancellation.

Objective O.2.: Design and construction of a negative beamforming array. Determination of special selectivity and ability for speaker tracking.

Objective O.3.: Specification and set up of a speech enhancement and recognition system on a DSP platform for domotic applications.

Objective O.4.: Specification and set up of a system for speech enhancement and recognition on a distributed system of audio-processing stations for security, teleconferencing and multiple-party applications.

- **Workplan**

It may be seen in the Gantt diagram shown below. The time scale is given in months.

Task/Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
T.1.1	F	F	F	F	F	F	F	F																												
T.1.2	F	F	F	F																																
T.1.3									F	F	F	F	F	F																						

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[**] Email: juancar@uex.es

Task	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
T.1.4														F	F	F	F	F	F																
T.2.1	O	O	O	O	O	O	O	O	O	O	O																								
T.2.2							F	F	F	F	F	F																							
T.2.3																		F	F	F	F	F	F	F	F										
T.3.1																		F	F																
T.3.2																				F	F	F	F	F	F										
T.3.3																									F	F	F	F	F	F	F	P	P	P	
T.3.4																																			P
T.4.1		F	F	F	F	F																													
T.4.2							F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F													
T.4.3																				F	F	F	F	F	F										
T.4.4																									F	F	F								

Legend:
F: Task Fulfilled: Completed, objectives met.
O: Task Over-fulfilled: Carried beyond expected limits.
P: Pending: Not yet fulfilled.
A: Abandoned: Insurmountable difficulties found.

- **List of Tasks:**

O.1. Hybrid Speech Enhancement System.
- T.1.1. Hybrid speech enhancement algorithms.
- T.1.2. Recording instrumentation set-up.
- T.1.3. Speech Enhancement using real recordings.
- T.1.4. Hybrid Speech Recognition System set-up.

O.2. Design and construction of a negative beamforming array.
- T.2.1. Study and specification of negative beamforming algorithms.
- T.2.2. Simulation of the complete speech enhancement system.
- T.2.3. Validation of the complete speech enhancement system.

O.3. Speech enhancement and recognition system on a monoprocessor DSP platform.
- T.3.1. Determination of the computational complexity of speech enh. and rec. algorithms.
- T.3.2. Versioning of the algorithms to DSP code.
- T.3.3. Real time evaluations of the complete system.
- T.3.4. Generation of specifications for a commercial platform.

O.4.: Distributed system for speech enhancement and recognition.
- T.4.1. Specification and design of the distributed system platform.
- T.4.2. Adapting the *microkernel* on the complete distributed system.
- T.4.3. Adapting speech enhancement and recognition algorithms to the distributed DSP platform.
- T.4.4. Evaluation of the performance of the complete system.

2. Level of success achieved within the project life.

- **General comments.**

The project has been carried out at a regular and constant pace. Its state of development is well aligned with the preliminary plan. Practically all the tasks have been carried out to their expected completion[1], some of them having been pushed forward more than expected. Many different techniques have been investigated since the early stages of the project in the domain of frequency and time. De-correlation algorithms have proven very fruitful, and source separation is very efficient, results having been published and found high acceptance among the scientific community. The still open matter on this topic is DOA (Direction of Arrival) determination. The research group has introduced Higher Order Statistics

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[1] The small deviations produced are conveniently described in the appendix to this document.

and Independent Component Analysis to overcome this problem, with very promising results yet to be published. On the other hand, the efficiency of the hybrid speech enhancement methods developed within the project have proven to be quite high, improving recognition rates well above what was initially expected, showing better results that the usual ones reported in the state of the art. These results are explained in 0, and constitute a major achievement of the project, being still pending of full publication.

- **Fulfillments.**

Establishing the precise behavior of the FODB system.

This structure finds its roots in a simpler structure published by Elko in 1996 4.[1] under the name of *First Order Differential Microphone*, reporting it to have been successfully used in spatial filtering. It was of most importance to know the precise behavior of the system to be used as a source separation device. Two-sensor arrays present important advantages over multiple-sensor arrays, as are their simplicity, lower computational complexity, lower costs, etc. Nevertheless, their angular selectivity is much worse as far as positive lobes are concerned. The way to use them is to take advantage of their negative lobe, which is very selective, and can be easily controlled by a *steering parameter*. This would be done through three conceptually simple steps: Steer the negative lobe towards the source to be separated from the background, this would give as output the complementary set of sources to the one considered; Invert the resulting signal; Add it with the general signal estimated from the signals arriving to the array. This would result in an estimation of the desired source. This scheme, conceptually simple, had to be extended more carefully, as the additions and inversions could not be done in the strict sense due to mis-adjustments both in phase and in amplitude. Therefore, an optimal estimation in terms of least mean square optimization techniques or others similar had to be established. The results brought important implications in DOA detection, and opened the path for the continuation of the research explained in the next section.

Establishing the Theory for Speech Enhancement using Negative Beamforming by FODB's.
  ➤ **Frequency-Domain optimal steering.**

The cornerstone in Speech Enhancement using the *FODB* is based on exploiting the spatial ability of this subsystem to separate sources ones from the others. This ability had to be checked prior to establishing the conditions under which the *FODB* had to be steered. For such, simulation experiments were conducted. These experiments yelded a set of criteria which can be used to determine the best arrival angles for combinations of sinusoidal sources.
  ➤ **Time-Domain optimal steering.**

It was important to obtain a possible estimation of the best arrival angles directly from the input signals without sweeping the whole angular span. To evaluate the steering factor it will only be necessary to use the correlations of the input signals, channel by channel, not requiring the *a priori* operation of the *NBF's*. The application of this methodology will require the estimation of several correlations on short-time windows.

Completing the scheme of FODB and Adaptive Lattice-Ladder structures for Speech Enhancement.
  ➤ **Detecting reverberation.**

The before exposed techniques work well when reverberation is not present or is present in small amounts. If the level of reverberation grows up, the situation worsens, and the number of false detections may increase. In such a case other techniques have been devised, these being one-step ahead in the process of accurate angular detection. To control the effects of reverberation in this respect the use of *Joint-Process Estimation* has been proposed here, based on a lattice-ladder filter 4.[5] algorithm.
  ➤ **DOA (direction of arrival) Estimation.**

One of the most important problems yet to be solved at this point, is that of source presence from the analysis of the resulting signals statistics. To check the viability and performance of the methods described pure sinusoidal tones at different frequencies have been used to calibrate the processing through simulation. The coefficient of Kurtosis is a very efficient and selective indicator of the presence of
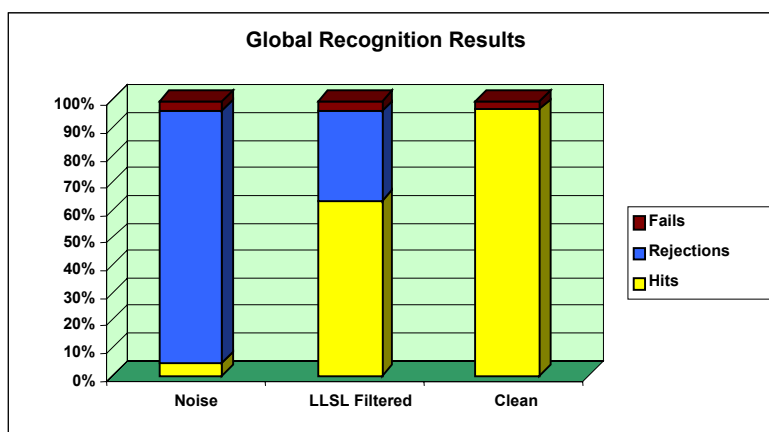
sources from evaluating their DOA's. The ratio between the energies of the dependent and orthogonal components of the input signal can also be used as a good DOA estimator.

Completing the scheme of FODB and Spectral Subtraction for Speech Enhancement.
Another technique to efficiently implement source separation is *Spectral Subtraction*. The process is rather elaborated, and was set up essentially during the lifetime of the project IVORY 4.[2], and re-adapted for its application in DIARCA. It constitutes the main body of the Ph.D. Thesis of Rafael Martínez Olalla (0). Spectral subtraction is essentially a power-spectra domain technique, based on evaluating the power spectra of the two signals to be subtracted and equalizing them accordingly with a certain criterion, subtracting the power spectra, applying a given estimation of the phase and reconstructing the time domain signal. Although the methodology needs still some refinements, a clear separation between sources has been achieved when combined with FODB. The effects are rather noticeable when listening to enhanced records. Intelligibility and naturalness are very well preserved.

Completing the Noise Robust Isolated Speech Recognizer and estimating the performance improvements offered by this technique.
The impact of speech enhancement on speech recognition working as a whole system was explored. For such, in the Ph.D. thesis of Rafael Martínez Olalla a complete study was carried out, its global results being reproduced here. The figure below gives the percent of Hits and Fails and Rejections for noisy, partially-enhanced and completely enhanced speech using the methodology developed in the project in Isolated Word Recognition. The success of speech recognition relies on its ability to work under current common life conditions, noise being present in these scenarios for different reasons, and in different forms. One of the steps to be covered to improve recognition rates must be speech enhancement.

Comparison of the overall results obtained for: noisy speech (left), *lattice-ladder* enhanced speech (center), and completely enhanced speech (right). The percentage of false recognitions keeps stable over the three groups. The number of rejections reduces to zero for completely enhanced speech.

Estimation of Computational Costs using monoprocessor DSP implementations.
In this field the possibilities for the implementation of the designed algorithms in real time on a specific DSP architecture were evaluated. The target architecture is the ADSP-21161N processor. The computational complexity of the system, measured in real experiments, is given in the table below:

Module	Execution time per frame of 128 samples (cycles)	% of real time
Data acquisition	7,168	0.62%
Band filtering	214,452	18.47%
DOA estimation	537,600	46.31%
Active-source list update	4,284	0.37%
FFT on active sources (5)	25,530	2.20%
Averaging noisy sources (5)	141,945	12.23%
Spectral subtraction (5)	98,543	8.49%
IFFT on active sources (5)	25,835	2.23%
Output of enhanced sources (5)	7,260	0.63%
Total	1,062,617	91.53%

Specification and set up of the Speech Enhancement and Recognition structure on a Distributed System of low cost workstations.

The activity described in the present section is entirely related with *Objective O.4. Distributed system for speech enhancement and recognition*, and has been carried by the team work in Universidad de Extremadura, under the coordination of Dr. Juan Carlos Díaz Martín, working in close contact with the Project Head, Pedro Gómez Vilda, and Agustín Álvarez Marquina. These are some of the concepts developed, which may be seen expanded in the appendix to this report: The target system, The Service DIARCA (Principles of design), The client DIARCA (design principles), The preliminary prototype as a cluster of PC's, The client DIARCA: implementation aspects, The service DIARCA (implementation aspects).

- **Difficulties found and actions to overcome them.**

The implementation of the system on a DSP multicomputer has shown to be the one most conflictive among the objectives. The target DSP processor, the TMSC44 was overcome by its successors from the family C6000, which has implied a great push forward in the use of DSP systems with the introduction of the platform DSK (developer starter kit) meaning the definitive drop out of the C44 in favour of the C6000. Another aspect of the project which has not been afforded following the initial proposal has been the configuration of the nucleus MiThOS as a POSIX compliant operating system for multicomputers. Its source code, monolithic and complex in excess has revealed itself as intractable for the purposes of modification and migration to other platforms different from the original one. As a consequence a specific implementation following the specifications POSIX had to be carried out. The result is PONNHI 4.[3], a DSP core POSIX compliant. The methodology has been divided into two steps. First of all PONNHI has been developed as a user library on Linux. Secondly, PONNHI has been migrated to the architecture DSP C6000 on DSK. This work has been presented in the congress Texas Instruments Developers Conference, held at Houston (Texas) in August 2002 (0). The system consists of a PCI carrier board with four C6000 nodes within a reasonable budget 4.[4]. The work left to be finished is to migrate PONNHI on this platform. The largest difficulty expected is the communications protocol. Concurrently with these tasks the recoding of the DIARCA algorithms on the C6000 architecture has been successfully finished.

3. Indices of results.

- **Milestone table and its fulfillment.**

Milestone	Type	Date	Fulfilled
H.1.1. Hybrid Models for Speech Enhancement.	C-C++ Code	End of month 8	yes
H.1.2. *Array* of microphones	Subsystem	End of month 4	yes
H.1.3. Simulator of the Enhancement System.	C-C++ Code	End of month 14	yes
H.1.4. Evaluation of the speech enhancement system.	Report 4.[8], publications	End of month 20	yes
H.2.1. Beamforming modeling	Matlab and C-C++ code	End of month 12	yes
H.2.2. Simulator of the tracking and enhancement system.	Matlab and C-C++ code	End of month 18	yes
H.2.3. Evaluation of the tracking and enhancement system.	Report 4.[8], publications	End of month 26	yes
H.3.1. Evaluation of the computational complexity of the enhancement and tracking system.	Report 4.[8], publications	End of month 19	yes
H.3.2. Version of the tracking and enhancement system for ADSP21160M	Code	End of month 26	yes[2]
H.3.3. Performance evaluation of the tracking and enhancement system.	Report 4.[8]	End of project	no
H.3.4. Specifications for a commercially aplicable system.	Report 4.[8]	End of project	no
H.4.1. Distributed system platform.	Node network	End of month 5	yes
H.4.2. Adaptation of the *microkernel* MiThOS.	Code	End of month 20	yes[3]

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[2] The code has been developed for the ADSP-21161N (a low cost evolution of the processor in the proposal).

| H.4.3. Version of the enhancement and tracking system for C44 | Code | End of month 26 | yes[4] |
| H.4.4. Evaluation of the enhancement and tracking system on the distributed platform | Report 4.[8] | End of month 29 | partially[5] |

- **Personnel instructed and trained.**

List of researchers under training enrolled at the project from the beginning:

Name	Status
Bernal Bermúdez, Jesús	Ph. D. Finished 1QY2000
Bobadilla Sancho, Jesús	Ph. D. Finished 3QY1999
Díaz Pérez, Francisco	Ph. D. Finished 2QY1999
García Alcántara, Vicente	Ph. D. Pending
García Zapata, Juan Luis	Ph. D. Pending.
Godino Llorente, Juan Ignacio	Ph. D. Finished 2QY2002
Hombrados López, Miguel Ángel	Ph. D. Finished 3QY2000
Martínez de Icaya Gómez, Elvira	Ph. D. Pending.
Martínez Olalla, Rafael	Ph. D. Finished 3QY2002
Rodríguez García, José María	Ph. D. Pending
Rubio Sánchez, Manuel	Ph. D. Pending

- **Ph. D. Theses finished.**

TITLE: Contribution to parametric extraction in robust speech recognition based on the application of knowledge from Acoustic Phonetics. **AUTHOR**: D. Agustín Alvarez Marquina. **UNIVERSITY**: Politécnica de Madrid. **CENTER**: Facultad de Informática. **DATE**: 4Q1999**.**

TITLE: Methodology for the visualisation of formants based on Fourier Transfor and its use in the spectral study of the Acoustic Phonetics of the Spanish Language. **AUTHOR**: D. Jesús Bernal Bermúdez. **UNIVERSITY**: Politécnica de Madrid. **CENTER**: Facultad de Informática. **DATE**: 1Q2000.

TITLE: Characterisation of the Dynamic Profiles of the sounds in Spanish using Adaptive Representations. **AUTHOR**: Miguel Angel Hombrados López. **UNIVERSITY**: Politécnica de Madrid. **CENTER**: Facultad de Informática. **DATE**: 3Q2000.

TITLE: Hybrid System for Noise Cancellation in Speech Signals based on Adaptive Filtering and Spectral Subtraction. **AUTHOR**: Rafael Martínez Olalla. **UNIVERSITY**: Politécnica de Madrid. **CENTER**: Facultad de Informática. **DATE**: 3Q2002.

TITLE: Strategies for the Automatic Detection of Larynx Pathologies from the Speech Record. **AUTHOR**: Juan Ignacio Godino Llorente. **UNIVERSITY**: Politécnica de Madrid. **CENTER**: Facultad de Informática. **DATE**: 3Q2002.

- **Publications.**

Articles directly related with the objectives of the project

P.1. Gómez, P., Martínez, R., Álvarez, A., Rodellar, V., Title: El Proyecto IVORY: Reconocimiento de Voz Robusto al Ruido, Investigación y Ciencia, Volume: Enero Pages, initial: 38 final: 39 Date: 2000, ISSN: 0210136X

P.2. Gómez, P., Álvarez, A., Martínez, R., Nieto, V., and Rodellar, V., Speech Enhancement through Binaural Negative Filtering, Proceedings of the X European Signal Processing Conference, EUSIPCO'2000, Volume: I Pages, initial: 187 final: 190 Date: 2000, ISBN: 952-15-0444-7

P.3. Gómez, P., Álvarez, A., Martínez, R., Nieto, V., Rodellar, V., Frequency-Domain Steering for Negative Beamformers in Speech Enhancement and Directional Source Separation, Proceedings of the IEEE Int. Symposium on Circuits and Systems, ISCAS'01, Volume: II Pages, initial: 289 final: 292 Date: 2001, ISBN: 0-7803-6687-5

P.4. Martínez, R., Álvarez, A., Gómez, P., Nieto, V., Rodellar, V., Combination of Adaptive Filtering and Spectral Subtraction for Noise Removal, Proceedings of the IEEE Int. Symposium on Circuits and Systems, ISCAS'01, Volume: II Pages, initial: 793 final: 796 Date: 2001, ISBN: 0-7803-6687-5

P.5. Álvarez, A., Gómez, P., Martínez, R., Rodellar, V., Combination of Negative Beamforming and Nonlinear Spectral Subtraction for Speech Enhancement and Source Tracking, Proceedings of IEEE-EURASIP Workshop on Nonlinear Signal and Image Processing, NSIP 2001, Volume: Pages, initial: final: Date: 2001.

P.6. Álvarez, A., Gómez, P., Martínez, R., Nieto, V., A Simple Two-Microphone Array Devoted to Speech Enhancement and Source Tracking, Proceedings of the 5th WSES International Conference on Circuits, Systems, Communications and Computers (CSCC 2001), Volume: Pages, initial: 128 final: 132 Date: 2001, ISBN: 960-8052-37-8.

P.7. Álvarez, A., Gómez, P., Martínez, R., Nieto, V., Rodellar, V., Speech Enhancement and Source Separation based on Binaural Negative Beamforming, Proceedings of the EUROSPEECH'01, Volume: Pages, initial: 2615 final: 2618 Date: 2001, ISBN: 87-90834-10-0 ISSN: 1018-4074.

P.8. Gómez, P., Álvarez, A., Nieto, V., Rodellar, V., Martínez, R., Multiple source separation in the frequency domain using Negative Beamforming, Proceedings of the EUROSPEECH'01, Pages, initial: 2619 final: 2622 Date: 2001, ISBN: 87-

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[3] The system MíThOS has revealed itself as intractable. Instead an implementation on C6000 has been carried out under the name PONNHI (see *Difficulties found and actions to overcome them*).

[4] See the same sections referred in the previous footnote.

[5] The definitive enhancement and tracking system has not been decided yet.

90834-10-0 ISSN: 1018-4074.

P.9. **Álvarez, A., Martínez, R., Gómez, P., Nieto, V., A Speech Enhancement System Based on Binaural Microphone Array. ADSP 21161N Digital Signal Processor Implementation Details, Proceedings of the SHARC International DSP Conference 2001, Pages, initial: 40 final: 44 Date: 2001, ISBN: 0-916550-25-7.**

P.10. **Díaz, J. C., Rodríguez, J. M., García, J. L., Gómez, P., Title: Robust Voice Recognition as a Distributed Service, Proceedings of the 8th IEEE International Conference on Emerging Technologies and Factory Automation, Pages, initial: 571 final: 575 Date: 2001, ISBN: 0-7803-7241-7.**

P.11. **Díaz Martín, J.C., García Zapata, Rodríguez García, J.M, J.J., Álvarez Salgado, J.F., Espada Bueno, P., Gómez Vilda, P., Scalable Distributed Voice Recognition Via Cluster Computing, Proceedings of the Simposium en Informática y Comunicaciones, Pages, initial: 163 final: 171 Date: 2001, ISBN: 84-931933-8-0.**

P.12. **Gómez, P., Álvarez, A., Martínez, R., Nieto, V., Rodellar, V., Time-Domain Steering of a Differential Beamformer for Speech Enhancement and Source Separation, Proceedings of the 6th International Conference on Signal Processing, Volume: I Pages, initial: 338 final: 341 Date: 2002, IEEE Press, Published in Beijing, China, ISBN: 0-7803-7488-6.**

P.13. **Álvarez, A., Gómez, P., Nieto, V., Martínez, R., Rodellar, V., Speech Enhancement and Source Separation supported by Negative Beamforming Filtering, Proceedings of the 6th International Conference on Signal Processing, Volume: I Pages, initial: 342 final: 345 Date: 2002, IEEE Press, Beijing, China, ISBN: 0-7803-7488-6.**

P.14. **Rodríguez, J.M., Rico, J.A., Álvarez, J.M., Díaz Martín, J.C., PONNHI. Una nueva arquitectura microkernel Pthreads en espacio de usuario, XIII Jornadas de Paralelismo, Pages, initial: 217 final: 222 Date: 2002, Universitat de Lleida, Lleida, Spain, ISBN: 84-8409-159-7.**

P.15. **Álvarez, J.M., Díaz Martín, J.C., Rodríguez García, J.M., Extendiendo Minix a Arquitecturas SMP, XIII Jornadas de Paralelismo, Pages, initial: 239 final: 244 Date: 2002, Universitat de Lleida, Lleida, Spain, ISBN: 84-8409-159-7.**

P.16. **Díaz, F., Rubio, M., Gómez, P., Nieto, V., Rodellar, V., Using Hidden Markov Models in segmentation of speaker-independent connected-digit corpus, Proc. of the WSEAS 2002 Multiconference, Pages, initial: 2591 final: 2595 Date: 2002, WSEAS Press, Puebla, Mexico.**

Contributions to Conferences

Díaz Martín, J.C. *et al*, "Distributing voice processing over DSP multicomputers. The role of POSIX 1003.13", Simposio Español de Informática Distribuida, Ourense 25-26-27 de Septiembre, 2000. **http://www.ei.uvigo.es/seid2000/**

Díaz Martín, J.C., Irala Veloso, and Rodríguez García, J.M., "Building predictable remote speech recognition services", Third European DSP Education and Research Conference. Paris. 20th & 21st September 2000. Texas Instruments Literature Number SSQC00.

Díaz Martín, J.C., Irala Veloso, I. y Rodríguez García, J.M*., "ViTReOS: Hacia la portabilidad de las aplicaciones paralelas DSP"*, XI Jornadas de Paralelismo, 11-13 de septiembre, 2000, Universidad de Granada, España.

Martínez, R., Álvarez, A., Gómez, P., Nieto, V., and Rodellar, V., "Noise-Robust speech processing based on adaptive and spectral cancellation techniques", Actas de las I Jornadas en Tecnología del Habla, Sevilla, Noviembre de 2000.

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Martínez, R., Álvarez, A., Nieto, V., Rodellar, V., Gómez, P., "Noise Cancellation in Speech: Combination of Time and Spectral Domain Techniques", Proceedings of the Seventh International Workshop on Acoustic Echo and Noise Control, Darmstadt University of Technology, Darmstadt, Alemania, 10-13 de Septiembre, 2001, pp. 179-182.

Álvarez, A., Martínez, R., Gómez, P., Nieto, V., "A Speech Enhancement System based on Negative Beamforming and Spectral Subtraction", Proceedings of the Seventh International Workshop on Acoustic Echo and Noise Control, Darmstadt University of Technology, Darmstadt, Alemania, 10-13 de Septiembre, 2001, pp. 219-222.

Rodríguez García, J.M., Rico Gallego, J.A., and García Zapata, J.L. and Díaz Martín, J.C., "PONNHI: An Implementation of Pthreads Standard For C6000 Architecture", Texas Instruments Developer Conference, **www.ti.com**, Westin Galleria Hotel, Houston, Texas, USA , August, 6-8, 2002.

Gómez, P., Álvarez, A., Martínez, R., Nieto, V., Rodellar, V., " Optimal Steering of a Differential Beamformer for Speech Enhancement", XI European Signal Processing Conference EUSIPCO 2002, Toulouse, Francia, 3-6 septiembre de 2002, Vol. III, pp. 233-236.

- **Patents**

Inventors (by signature): Gómez, P., Martínez, R., Álvarez, A.
Title: Reconocedor de Palabras Aisladas Robusto al Ruido
Appl. Nº: **86.486**   Country: **Spain**   Date: **1Q2000**
Owner: Universidad Politécnica de Madrid

- **Technology Transfer**

Title of the contract: Design and implementation of high performance speech processing algorithms under adverse environmental conditions
Company: Centre Suisse d'Electronique et de Microtechnique (CSEM)
Contributor: Universidad Politécnica de Madrid
Responsible researcher: **Pedro Gómez Vilda**
Number of researchers: **6**

- **Collaboration with national and international groups**

The following is a list of some of the groups and institutions with which the project keeps some degree of relationship:

➢ Servicio de Otorrinolaringología del Hospital Príncipe de Asturias from Universidad de Alcalá de Henares. Spain. Basic ORL and physiopathological knowledge.

➢ Department of Electronic Engineering, Universidad Politécnica de Madrid. Spain. Speech Processing. Computer Platforms and Telematic Implantation.

➢ Dept. of Logopedics and Phoniatrics, Karolinska Institute, Huddinge University Hospital, Stockholm, Sweden. Basic ORL and physiopathological knowledge.

➢ Vrije Universiteit Medisch Centrum (VUMC), Amsterdam, The Netherlands. Basic ORL and physiopathological knowledge.

➢ ORL Unit, Katholieke Universiteit Leuven (KUL), Belgium. Basic ORL and physiopathological knowledge.

➢ Visual Tools S. A., Spain. SME devoted to video capture, processing, transmission and storage and other Internet applications.

➢ Institute of Computer Science, Technical University of Lodz, Lodz, Poland. Neural Networks for Pattern Classification.

➢ Department of Language and Speech, University of Nijmegen, The Netherlands. Speech Processing.

➢ Departamento de Arquitectura y Tecnología de Computadores, Universidad de Granada, Granada, Spain. SP: Neural Networks for Source Separation and Pattern Classification.

➢ Department of Electronics and Communications, Faculty of Engineering, Universitá degli Studi di Firenze, Florence, Italy.

➢ Departamento de Señales y Comunicaciones, Universidad de Las Palmas de Gran Canaria, Las Palmas de Gran Canaria. Spain.

➢ Department of Biomedical Informatics, Central Laboratory of Biomedical Engineering, Bulgarian Academy of Sciences, Sofia, Bulgaria. Feature Extraction and Pattern Classification - Applications to Voice Analysis.

➢ Department of Computer Science, School of Sciences, University of Salford, Salford, United Kingdom.

➢ The group is integrated in the Thematic Network of Speech Technologies in Spain, a group composed by more than 40 groups working in Speech Processing and Recognition (www.rthabla.org).

- **Side benefits in speech processing for pathology detection using JPE and NN's.**

Through 0several of the algorithms developed in the project may be applied for the estimation of biomechanical parameters from the glottal wave, with use in the early detection of larynx cancer from the speech trace. In this sense a proposal issued to the Plan Nacional de Investigación Científica, Desarrollo e Innovación Tecnológica in the call of 2002 has been approved for funding to extend these techniques to such applications field. The same idea has been adapted for an expression of interest to the EC call for EoI's last June, and has been published on the CORDIS website 4.[7] under the acronym ESCASPRA. The EoI has attracted the interest of many groups from different countries up to now, and will be reformulated as an Integrated Project for the next call of FP6.

4. General References.

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[5] Haykin, S., *Adaptive Filter Theory*, Prentice-Hall, Englewood Cliffs, N. J., 1996.

[6] Hyvärinen, A., Karhunen, J., Oja, E., *Independent Component Analysis*, John Wiley, New York, 2001.

[7] http://eoi.cordis.lu/search_form.cfm

[8] Gómez, P., *Fundamentals of Negative Beamforming*, Internal Report, Departamento de Arquitectura y Tecnología de Sistemas Informáticos, Facultad de Informática, Universidad Politécnica de Madrid, Campus de Montegancedo s/n, 28660 Boadilla del Monte, Madrid, Spain. Last version: 1.6, May 2002.

Multimodal User Interfaces: Active Environments. TIC2000-0464

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Abstract

In this paper we report the work done in the various research areas that are involved in the development of an Active Environment. These are the design and implementation of a software integration architecture to support the heterogeneous interaction of software agents; the design and implementation of a hardware architecture that supports the software architecture (an integrated domotics and TCP/IP network); the design and implementation of a natural language dialogue system, sensitive to user context; and the design an implementation of a user-task analyser agent based on computer vision.

Keywords: Active Environments, Intelligent Environments, Multimodal User Interfaces, Domotics, Autonomous Agents

1 Short description of the project

The goal of the InterAct project is the development of the necessary technology to implement Active Environments, in which human/computer interaction is carried out in a natural and context-sensitive way. An example of Active Environment is a home in which the user may interact with the different appliances and other devices (lights, phone, TV, music, etc.) in natural language. The interaction will be multimodal and sensitive to the context: who occupies each room, what are their preferences, what are their current tasks, etc.

In order to achieve this goal, the InterAct project (TIC2000-0464) proposes to focus in the following areas:

- Design and implementation of a software integration architecture to support the heterogeneous interaction of software agents.
- Design and implementation of a hardware architecture that supports the software architecture (an integrated domotics and TCP/IP network).
- Design and implementation of a natural language dialogue system, sensitive to user context.
- Design an implementation of a user-task analyser agent based on computer vision.

The work in these areas was scheduled as follows:

Tasks	2001	2002	2003
T1:Sensor infraestr. analysis and design.	x x│ │ │ │ │ │ │ │ │ │	│ │ │ │ │ │ │ │ │ │ │ │	│ │ │ │ │ │ │ │ │ │ │ │
T2:Sensor infraestr. instalation & maintenance	│ │x x x x x x x x x	x x x x x x x x x x x x	x x x x x x x x x x x x
T3:Sw architecture analysis and design.	x x x x x x x x x x x x	│ │ │ │ │ │ │ │ │ │ │ │	│ │ │ │ │ │ │ │ │ │ │ │
T4: Sw architecture implementation	│ │ │ │ │ │x x x x x x	x x x x x x x x x x x x	x x x x x x│ │ │ │ │ │
T5:Domotics bus requirements analysis	x x x│ │ │ │ │ │ │ │ │	│ │ │ │ │ │ │ │ │ │ │ │	│ │ │ │ │ │ │ │ │ │ │ │
T6: Domotics infraestr. design.	│ │ │x x x x x x│ │ │	│ │ │ │ │ │ │ │ │ │ │ │	│ │ │ │ │ │ │ │ │ │ │ │
T7: Domotics infraestr. implementation	│ │ │ │ │ │ │ │ │x x x	x x x x x x x x x x x x	x x x x x x│ │ │ │ │ │
T8: Domotics infraestr. integration	│ │ │ │ │ │ │ │ │ │ │ │	│ │x x x x x x x x x x	x x x x x x x x x x x x
T9:Voice recognition tests in domotic environment	x x x x x x│ │ │ │ │ │	│ │ │ │ │ │ │ │ │ │ │ │	│ │ │ │ │ │ │ │ │ │ │ │
T10:Natural lang. dialogue agent analysis & design	x x x x x x x x x xx x x	│ │ │ │ │ │ │ │ │ │ │ │	│ │ │ │ │ │ │ │ │ │ │ │
T11: Natural lang. dialogue agent implem. & integr.	│ │ │ │ │ │x x x x x x	x x x x x x x x x x x x	x x x x x x x x x x│ │
T12:Artif. Vision tests in domotic environment	x x x│ │ │ │ │ │ │ │ │	│ │ │ │ │ │ │ │ │ │ │ │	│ │ │ │ │ │ │ │ │ │ │ │
T13:Artificial vision agent analysis & design	│ │ │x x x x x x│ │ │	│ │ │ │ │ │ │ │ │ │ │ │	│ │ │ │ │ │ │ │ │ │ │ │
T14: Artificial vision agent implement. & integrat.	│ │ │ │ │ │x x x x x x	x x x x x x x x x x x x	x x x x x x x x x x x x│
T15:Dissemination activities	│ │ │x x x x x x x x x	x x x x x x x x x x x x	x x x x x x x x x x x x
T16:Conclusion	│ │ │ │ │ │ │ │ │ │ │ │	│ │ │ │ │ │ │ │ │ │ │ │	│ │ │ │ │ │ │ │ │ │ │ │x

2 Current status of the project

Software integration architecture

The work in task T3 has been completed, and work in task T4 is in an advanced status. After an initial version of the blackboard using the Context Toolkit software, from the Georgia Institute of Technology, we have currently implemented a second version of the software integration architecture developing our own technology.

The InterAct project proposes a "context" layer as the glue to achieve the required synergy among pervasive computing devices in order to constitute a smart environment. In agreement with other works such as [1], we believe that a global "world model", although implemented in a distributed way, is the best approach to achieve complex interactions among devices in order to provide pro-active services to the user.

The context layer provides:
1. a single interface that abstracts from the communication details of the various physical devices;
2. a unified model where the world is represented.

The context layer implementation lies on a global data structure, called blackboard [2]. This blackboard is a model of the world, where all the prominent information related to the environment (including the users) is stored. The blackboard also holds a representation of the flow of information among the physical devices (microphones, speakers, cameras, displays, etc.).

Information from the blackboard is used by pervasive devices to understand the context and to adapt to it. For example, the number of persons in the room, the task they are performing and the status of several physical devices (lights, heating, video/audio displays) are represented in the context layer, and are used by the natural language dialogue-management agent.

Context may be defined as the state of the environment in a given time. In context-aware environments, the same user action produces different consequences depending on context. Our environment is composed by a heterogeneous set of pervasive computing elements, structural elements, and people. These elements include from mobile devices to rooms. Each of them is called an entity. An entity has a context piece associated that contributes to create the whole environment context. Thus, the state of the environment emerges from the particular state of all the environment entities.

Each context fragment can be represented as a set of properties, where a property is name-value pair. Property values may be directly measured from the environment or may be deduced from other property values. For example, a property could be the number of persons inside a room, and it could be computed analysing the images captured by a video camera. The environment context is the aggregation of the directly measured properties and the deduced properties.

A context information source is any computational entity that contributes to build the context environment. Context information sources of very different kinds can be found within a smart environment. Sources may be very close to the physical world or may be linked to a virtual world. The former set is composed by all kind of devices that interact to the physical world directly, such as sensors, switches, appliances, screens, microphones, speakers, etc. The latter set brings together all kind of purely computational components, such as dialogue managers, intelligent agents, etc.

A tree structure has been chosen to exchange context information. Components (agents) that query the blackboard are answered using context trees, which reflect context modification. A context tree is a partial representation of the whole blackboard graph. It is a data structure composed by a root and a set of nodes. This tree allows a hierarchical organisation of a set of entities, properties and parameters, where each of them corresponds to a node of the tree. Each context tree provides information about the state of the internal entity and its hierarchical relationship in the blackboard.

This structure allows organising the context information using several abstraction levels. The deepest nodes represent more concrete properties, while the upper nodes in the hierarchy may reflect structural relationships among components. A context tree is a snapshot of the state of some part of the environment. There are multiple partial context trees that represent the state of parts of the environment, and they can be dynamically generated.

All the nodes that belong to the blackboard graph have one or more node identifiers (nid): several naming mechanisms are provided in order to reference an entity, property or parameter:

1. All nodes can be univocally located starting the nid with the entity numerical identifier. The numerical identifier of properties and parameters can be substituted directly by its name. For example, the status (on/off) of a lamp with identifier 901 may be obtained by means of the nid: /id/901/props/status.

2. Using a predefined hierarchy: a string identifies each hierarchy. This is used when the numerical identifier is unknown. The hierarchy defines the initial node, and how to go through the graph. Eg: /roomdevice/lab407/lamp_2/props/status. Each application can define its own hierarchycal view of the world.
3. Using the type of the entity as the guiding hierarchy. Eg: /people/dave/props/mail.

In addition, wildcards can be used to substitute one or several tokens that constitute a nid. This allows that several nodes can be referenced at the same time. Eg: /roomdevices/lab407/* references all the devices in lab407..

Context information is published in a central repository accessible to the whole system, following the classical blackboard paradigm [3]. Each blackboard manages a part of the context environment, and is represented by a context tree. It provides standard procedures to request or modify node values, and to subscribe to context changes. Context agents could easily access the properties at context tree nodes in a transparent way : the nature of the source for such values is concealed. For example, one property of the context of a room may be the number of persons that are present. Several sources may be used to deduce such information. However, a single final value of the property is produced, and all the other devices and computational entities in the smart environment may use this information independently of the nature of the source.

For example, if somebody enters a previously empty smart room, the vision agent may signal this event by changing a value of a blackboard node. A context-aware agent may be subscribed to this node and check the value of another node that indicates the current environment luminosity. If it is too dark, then the agent finally changes the node value that increases the intensity of the lights. The physical layer component then reacts making the lights to adjust to the required new state.

Blackboard designers are provided with a tool that supports blackboard development. A blackboard is fully determined by its context tree. The context tree defines which properties are relevant, how they can be accessed, and what organisation has been chosen. A compiler has been developed for this purpose. It produces a blackboard implementation from a context tree described by a set of XML files; one for every set of entities of the same type. A set of entities is defined by a tree composed of properties, parameters and their initial values, and the related entities.

Hardware architecture

The work in tasks T1, T5, and T6 has been completed. Work in tasks T2, T7 and T8 has been started, and is in proper status of development. The hardware interaction infrastructure of the domotic environment, including sensors, actuators, displays, microphones, speakers, etc., has been selected and deployed.

The installed devices can be divided in three categories:
- Home automation: composed of several independent systems: an automatic lock used to control the physical access, photoelectric sensors that inform when someone enters the room, a smart card system that identifies users when accessing the room, and several EIB devices, such as room lights, switching devices, an alphanumeric display, etc.

- Audio-Video information: includes a TV set, two hi-fi speakers, a DVD, and several flat monitors that may be used alternatively as output devices for video information or as computer interfaces. An IP video camera provides context information about the activity in the room.
- Voice interaction: wireless microphones provide user free-movements.

A working prototype of a smart environment has been implemented. The prototype consists in a room equipped as the living room of a typical house, and an adjacent room equipped as an office (see Figure 1).

Figure 1. Snapshot of the Interact Environment

In this prototype we are using two physical networks. For the connection of sensors (presence, temperature, luminosity, etc.) and actuators (switches, engine controllers, etc.) we utilise the European bus EIB [http://www.eiba.com]. This bus tries to set a standard within the European Union for home automation. For the video/audio information flow (microphones, cameras, etc.), we are using an Ethernet network (both terrestrial and radio) that connects all the different devices. Each device can be connected to either network (or both), depending on its nature, and has access to the context blackboard through them. The access to the physical layer is harmonised through the Interact-DDM layer.

Interact-DDM is based on the standard agent – manager interaction defined on Internet management standards and SNMP protocol. All the system devices and operations are defined on a Management Information Base, MIB.

Basic system structure is presented on Figure 2. Devices and agents are connected to a Local Area Network, that is the communications backbone for all the domotic space. Depending on the location or specific characteristics of each device, an agent manages a single device or a group of devices. In the case of EIB bus, for example, each EIB segment is managed by a single agent, which interacts with all the devices attached to the segment. On the system, the agent and all the devices that are under its control are called an Area. Each area has its own IP Address.

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The Central Point of Control (CPC) is the manager application. It interacts with the agents to query or modify the status of the devices. CPC can be used to control the devices by itself, or as gateway by Intelligent User Interface Applications to link to the real world.

The managed objects of an area are contained in the Interact MIB. The structure of the MIB is common for all the agents on the system, independently of the devices that are attached to it. This is possible due to a parametric definition of the devices under management.
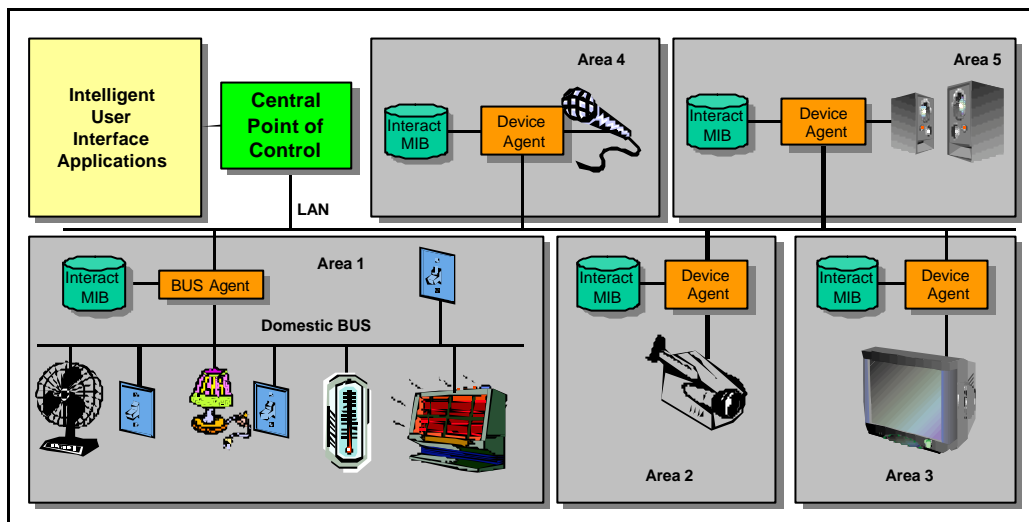
Figure 2: Interact-DDM layer

The domestic environment control applications have some special requirements that have to be considered while designing the general architecture of the management system. The device definition in the MIB is done in a parametric way, as a set of attributes. Each MIB attribute is associated to a specific characteristic of the device. CPC can read or write MIB attributes to modify the status or the behaviour of the device. To have the maximum flexibility on the device definition, the system allows multiple attributes for each. Complex devices, as, for example, hi-fi, can be defined with a single device description with multiple attributes (left speaker volume, right speaker volume, tone…).

The CPC interacts with the devices in two ways:
- Ordinary operations can be done by polling / setting the devices, to know or to modify their current status. This is the case where a user's interaction is the trigger that starts the change on the device. This operation mode can be solved by the normal polling mechanism provided by SNMP commands GET and SET.
- Specific actions must be triggered by user interactions to the devices. When a user operates a sensor device, for example, a switch, the device has to inform CPC of this situation. It receives the signal, informs the blackboard, and user interface applications generate the suitable reaction, which could be to switch on a lamp, the TV or a music device. Normal polling

mechanisms are not valid for this operation mode. Instead, notifications are the most proper method to proceed, implemented by using SNMP Traps.

It is important to note that intensive data communications between devices is performed in a peer-to-peer way. The CPC is never involved in these communications. It will be only responsible for the network management. It sets up devices for data transmission, starts and stops the data streaming, and monitors the communication.

Context agents: the dialogue agent

Work in tasks T9, T10 and T11 is proceeding as scheduled. We have developed a first prototype of a dialogue management system that allows the user to interact and to control the environment making utterances in natural language, using intensively the context blackboard. Dialogue implementation is based on various dialogue modules that are independent from each other, each dialogue module managing just a specific subject. There is a dialogue manager that decides the dialogue subject in which the system is involved in each moment.

Most of the items specified on the blackboard have or may have a related specific dialogue. Dialogues take advantage of the information concerning to the item or any other contextual data stored on the blackboard. They interact with the blackboard on the same way as any other device does. Using the blackboard services, a dialogue can gather or set information at runtime. This information is used to improve the dialogue performance or to change the state of the environment as a consequence of a user utterance.

Having contextual information stored and easily accessible in a blackboard is a key advantage for the development of dialogues. The developer knows in advance which information is available to support the dialogue, and the context information may also help the recognizer to lower significantly the chances of misrecognition.

We are also currently experimenting the possibility of automatic dialogue generation based on the information gathered from the blackboard. Dialogues are based on templates, in a way similar to Schank's scripts [4]. New templates can be created or old templates modified, even at runtime, using the information stored on the blackboard.

Context agents: the movement detection agent

In relation with tasks T12, T13 and T14 we have implemented a second intelligent agent that provides context information for the use of other modules: the "movement detection agent". This agent records constantly the room, searching for any kind of movements. Based on the idea of frame-to-frame differences (time derivative), this agent implements an adaptive algorithm witch subtracts the background from every frame, then applying an edge enhancement in order to obtain information about movement. One of the requirements was to achieve a low computational cost, so that it could be eventually embedded in a stand-alone computing-empowered video camera, connected to the rest of the environment via the blackboard. Resulting images are treated as a number averaging the values over all image pixels, and then this number identifies the frame. If this number changes excessively, it means that have had movement in the scene. This way, we obtain local movement detection, and it's possible to locate the movement along the room. To be adapted

to no-movement image variations, the "movement detection agent" implements and integral-accumulative formula, which smoothes the variation of the number assigned to each square.

The findings of this agent are an important context information, which is stored in the blackboard and can be subsequently used by other agents. In this fashion, any agent can know the spatial situation of any object in movement inside the room. Several operation parameters of the movement detection agent are represented in the blackboard: by changing them any interested agent can tune the sensibility of the movement detection depending on the intended use.

3 Results and publications

Three PhD students are currently working towards their PhD on their work in this project:
- Antonio Martinez (that is involved with the hardware architecture).
- Pablo Haya (that is involved in the software architecture)
- Germán Montoro (that is involved in the natural language dialogue manager).

During the first two years of the project, several dissemination activities have been performed, to communicate the initial results of the project:
- We are holding a monthly seminar on the project, which is open to any interested researcher in the area.
- We are participating regularly in the activities organised by the Spanish Association for person/computer interaction (AIPO), that include regular research seminars on person/computer interaction (that are held in various universities), and one annual scientific conference.
- The (initial) results of the project have been presented and/or published in various fora:
    - Alamán, X., P. Haya, G. Montoro, 'ODISEA: Hacia un entorno inteligente basado en un interfaz en lenguaje natural', I Meeting on Language Engineering, Sevilla, 6-10 de Noviembre de 2000.
    - Xavier Alamán, Pablo Haya and Germán Montoro. 2001. 'El proyecto InterAct: Una arquitectura de pizarra para la implementación de Entornos Activos'. International Conference on Human-Computer Interaction (Interaction 2001). Salamanca. 16-18 May.
    - Pablo Haya, Xavier Alamán and Germán Montoro. 2001. 'A Comparative Study of Communication Infrastructures for the Implementation of Ubiquitous Computing'. Upgrade Vol 2, num. 5, Octubre 2001.
    - Pablo Haya, Xavier Alamán and Germán Montoro. 2001. 'Un estudio comparativo de infraestructuras de comunicación para la implementación de Computación Ubicua', dentro de la monografía sobre computación ubicua publicada en Novática, Vol 153, Octubre 2001, págs. 35-39.
    - Pablo Haya, 'Arquitecturas para el desarrollo de Entornos Inteligentes'. Trabajo de investigación del segundo año de doctorado. Universidad Autónoma de Madrid. 2001.
    - I.Gonzalez, F.J. Gomez y J. Martinez. "Labomat-Web. Recursos reconfigurables en remoto vía Web". JCRA2001 Jornadas sobre computación reconfigurable y aplicaciones. Alicante. Sept 2001.

- R.Cabello, I.Gonzalez, F.J. Gomez y J. Martinez. "A Web Laboratory for a Basic Electronics Course" World conference of the WWW and Internet . WebNet 2001. Orlando USA. Oct 2001.
- I.Gonzalez, F.J. Gomez y J. Martinez. "A HW-SW Codesign case study: Implementing a cryptographic algorithm in a Reconfigurable platform". Proceedings DCIS'01, XIV Design of Circuits and Integrated Systems Conference. Oporto, Portugal. Nov 2001

- We have maintained a close relationship with Siemens, which is one of the main suppliers of EIB solutions in Europe, and has its Spanish headquarters close to our University.
- On November 2001, the architecture to control domotic devices used was presented by some researches of the Interact project in a European meeting in the Bordeaux University. The goal of the meeting was to prepare a proposal to the EU Socrates Program. The main objective of the proposed project eMerge "educational network structure for dissemination of real laboratory experiments to support engineering education" is to develop an educational structure that will permit the dissemination of real laboratory experiments to support engineering and science education throughout Europe. To achieve this goal, the project propose to establish a network consisting of several European educational institutions that develop, provide and use laboratory experiments via the Internet. The control of the remote devices in the laboratory is a main aspect in the development of the project. One of the solutions proposed is closely related with the architecture developed in the Interact Project. The project with reference 100671-CP-1-2002-1-FR-MINERVA-M was approved by the European commission and it started on October 1, 2002. The approved budget of the project is 804814, being the community grant the 50% of the global amount. Seven European institutions of six countries are involved in the project, being the Universidad Autonoma of Madrid one of the partners.
- Other members of the scientific community, inside and outside the department, have been in contact with the project. Future collaborations are to be expected. Among others, some researchers from the Instituto de Robótica Industrial have been contacted.
- In June 2002 we have collaborated to a summer course of the Universidad Autonoma de Madrid, that included a seminar on Active Environments.

4 References

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INTFORCLI: Desarrollo de un sistema de integración de registros clínicos distribuidos basado en el prestándar de arquitectura de historia clínica informatizada CEN/TC251 ENV13606 bajo CORBA
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Abstract

Everyday, more and more, the healthcare sector requires the exchange of healthcare information between professionals from different disciplines and institutions. To support co-operative work among health professionals and institutions it is necessary to share healthcare information about patients in a meaningful way. But, nowadays, in most hospitals the heath data is distributed across several heterogeneous and autonomous information systems whose interconnection is difficult to achieve. Integration of such system may bring about many advantages such as consistent patient health records or interdepartmental workflow. In this project it was intended to develop a generic and scalable integration system of distributed healthcare records. The system allows healthcare professional to access in a unified, transparent and easy way to the healthcare information scattered across several heterogeneous, autonomous information systems. The European pre-standard ENV 13606 from CEN is used as canonical model for the representation of healthcare information, in such a way, that healthcare professionals can access patient information stored in heterogeneous autonomous information systems through a set of customised formal aggregates of health data based on the healthcare record architecture ENV13606 from CEN/TC251.

Keywords: electronic healthcare records, heterogeneous distributed health information systems, integration, hospital information systems.

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1 Project Objectives

Integration is still central for health information systems. Most modern hospitals have computerised records. However, these systems are usually proprietary and often only serve one specific department within the hospital. Hospitals can have dozens of individual systems that do not interoperate with each other. A patient's health information profile can be spread out over a number of disparate systems, making it difficult for clinicians to capture a complete clinical history of a patient. Everyday more, patients' health is not longer the sole responsibility of a single health professional, but rather is shifting to a shared-care approach. This new situation requires a high level of interoperability and data sharing among professionals and institutions which crucially depends on the ability to exchange information about patients while preserving its original meaning. Under this context this project has sought:

- To define a methodology and to implement a generic and open solution to sharing Electronic Healthcare Records over enterprise-wide networks based on CORBA. The computer system should let healthcare professionals retrieve the patient data they need on-line and present the data in an integrated common way. The emphasis will be on facilitating data sharing between professionals via the computer system, rather than on integrating the specialist systems that supply or use the data.
- To use as reference model for representing extracts of Electronic Healthcare Records (EHCR) the European pre-standard of Electronic Healthcare Record Architecture (EHCRA) ENV13606[1][2][3][4] from CEN/TC251 (Technical Committee 251 of the European Committee for Standardisation) which is responsible for developing the relevant standards for the health sector. The reason is simple, the Electronic Healthcare Record (EHCR) is on the way and anyone starting a project to integrate Health Information Systems at this time, should consider the implications of the EHCR and whether their integration strategy will be compatible with and support the emerging EHCR.
- To enable users to define and populate with existing data their own aggregates of health data according to ENV13606. The classes and attributes defined by ENV13606 provide a flexible model for existing clinical data from which sophisticated healthcare records models and messages can be constructed to fulfil the needs of individual users.
- To validate the prototype in a real clinical setting.

The project duration is two years and it will be completed by 30th December 2002. A medium-sized regional hospital, Lluis Alcanyís of Xàtiva (Valencian Community) has been used as trial site. Data relevant to the surgery department has been integrated, this has required to access data from 5 different departmental information system ranging from admission to pathological anatomy.

The working group consists of 17 professionals from different disciplines and institutions: The Technical University of Valencia, Valencian regional health authorities, medical staff and computer services department personnel from Lluis Alcanys Hospital (Xàtiva) and Doctor Pesset Hospital (Valencia) and a health software company Novasoft S.A. A key element of the project has been the participation of clinical professionals in the proactive validation of the system and related technical innovations.

2 Level of success achieved up to date

2.1. Introduction and motivation

The complexity and great variety of healthcare actions and protocols, the diversity of organisations not only regarding structure or size but also political, economical or cultural aspects and the preferences of health professionals' groups makes it very difficult to develop a single computer system that could effectively serve the information needs of an entire hospital. As a result, most hospitals have developed their information systems on a department-oriented basis. In the absence of this information, tests may be repeated or prior findings ignored, and in emergency care lifesaving information may be unavailable. Briefly, what is required is that everyone involved in the delivery of healthcare to a patient should be able to access all the relevant patient's healthcare information. Unfortunately, data sharing is often hindered by the fact that the data are distributed among several autonomous and heterogeneous (database) systems.

Any integration solution has to define a way to represent the patients' specific health data in such a way that their original meaning is preserved through faithful preservation of content and context. EHCRA Standardisation is vital if the clinical information is to be transferred outside the organisation/department where it was created. Much work has been done in the field of EHCRA standardisation, in particular, CEN/TC251 has developed a pre-standard known as ENV13606. Basically, an EHCR architecture is an information model or framework for the construction of electronic healthcare records. It models the generic features necessary in any EHCR in order that the record may be communicable, complete, a useful and effective ethic-legal record of care, and may retain integrity across systems, countries, and time. An architecture does not either prescribe or dictate what should be store in a healthcare records and nor does it prescribe or dictates how any electronic healthcare record system should be implemented. The EHCR architecture used in this project is the European pre-standard ENV13606. This architecture is divided up into four parts each of them addressing a particular technical aspect: structure, domain, distribution rules and messaging. Two consequences of the use of ENV13606 are:

- The reference model should conform to the ENV13606 European pre-standard. This means that we should take this pre-standard as a minimum starting point for the design of the information model.
- We are also concerned with the organisation of the electronic health record presented to users, thus information may only be exchanged by element that are valid extract of an electronic healthcare record as defined by ENV13606.

2.2. Objectives already achieved

The project is about to finish, and we consider that, all the objectives have been accomplished. Currently, a stable version of a prototype is being tested in a real clinical setting (Hospital Lluis Alcanyís of Xàtiva). We have only change in part one of our original objective, we have discarded the use of CORBA as middleware for the communication and exchange of data between systems.

We have coincided with the development of SOAP, this protocol suits perfectly to our needs: use of XML and to accomplish the requirement that between-organisation communications needs to be facilitated, ideally using the same technological approach as for intra-organisational communication. We think that this transition is easier with SOAP.

2.3. Main difficulties encountered during the project and proposed solutions

The main difficulty encountered during the project has been the use of ENV13606 in an integration project such as the one described here. The three main reasons are the big gap between the generality of the constructs defined by pre-standard and the specificity of the departmental information systems to be integrated, the complexity of the pre-standard itself (ENV13606 is a document of more than 450 pages, as example 25 pages are used just to describe the DTD for the provide EHCR message) and how to publish the health data held by the existing relational database management systems as XML document compliant with ENV13606.

The components of ENV13606 have been defined at a high level of abstraction to provide a flexible model capable of representing any entry in a healthcare record, independently of the healthcare institution, speciality or professional. Thus, the ENV13606 classes can be easily extended to represent terms or concepts from the medical domain (e.g. GP Record, inpatient stay, discharge report, transfer, demographics, blood pressure, protein S level, etc.). This representation leads to a set of new classes which extend (specialise) the ones defined in ENV13606, we call them archetypes. Archetypes are formal structural constraint models based on a reference model, in our case ENV13606. They ought to be designed by domain specialist to represent a formalisation of a particular information structures used in the filed of interest. For instance, a discharge report can be defined by using the ENV13606 construct "Composition OCC" which contains other terms (which are themselves represented by an ENV13606 construct) such as patient details, diagnosis, comments, medication, etc. These sub-terms may be themselves based on others and so on. The data items are at the lowest level of the hierarchy and therefore are the basic blocks to construct other components. Examples of data items are patient's name, main diagnosis code (drawn from an international classification of diseases), discharge date, discharge reason, etc. This allows a high level of reutilization, already defined archetypes may be used to build new ones.

Archetypes are the core of our integration solution, their purpose is to make public the information content in the underlying databases and, at the same time, to hide technical details (heterogeneity) of the data repositories. They constitute a semantic layer over the underlying databases associating them with domain specific semantics, thus true integration is performed at a meta-level instead of at data level. One of the main advantages of this approach is that it allows each hospital unit or service to define its own view of the medical record.

Sharing of archetypes within health systems would enable data from different systems to be understood at the level of the knowledge concepts of the archetypes, rather than just at the data level. The main consequences of archetypes are: domain specialists (rather than IT professionals) can define formal models of clinical concepts, information systems can be developed based only on the reference mode and deployed while archetypes are used post-deployment, so it is difficult that

the system becomes out of date; knowledge-level interoperability is possible if systems can share archetypes and finally powerful querying is possible.

Since the health data resides on the underlying databases, there should be defined some kind of mapping information relating archetypes to databases schemas. It is important to remark that it is not only necessary to retrieve pure clinical information but also any available context information in order to safeguard the original meaning of data. ENV13606 describes which context information must accompany any piece of health information. For exchange clinical data, relational data held by component databases needs to be mapped to XML. The mapping is not a trivial task, because the two data models differ significantly. Relational data is flat, normalised into many relations, and its schema is often proprietary. By contrast, XML data is nested, unnormalised, and its schema is public, as proposed by ENV13606. Publishing XML data involves joining tables, selecting and projecting the data that needs to be exported, mapping the relational table and attributes names into XML element and attribute names, creating XML hierarchies, and possibly processing values.

Views are used as a tool for providing abstraction in interfacing between legacy data (relational data) and ENV13606 data (hierarchical data). We want to use the views for instantiating archetypes to produce extract of electronic healthcare records. To achieve this, views should provide mappings between the extracts of EHCR and the underlying database schemas. The mapping is done by linking archetype attributes to relation attributes. The archetype designer defines a set of values correspondences between archetype attributes and column of tables. From this set of correspondences the system generates a candidate query [5] that will allow the population of EHCR extract from data stored in the underlying databases. Furthermore, the query facilitates the structuring of the final XML document. When generating a candidate query for an archetype some issues have been considered:

- We are trying to generate extracts of electronic healthcare records; therefore not all the information held by the data repositories is relevant. Typically, we are only interested in data for which we can determine the patient they are about.
- The existing relationships among the data, typically expressed by foreign keys, must be kept.
- We must not lose information.
- The query should facilitate the generation of XML documents.

2.4. Scientific-technical results

- A valid methodology for publishing legacy health data as a XML document compliant with the European pre-standard of EHCRA ENV13606 from the European Committee for Standardisation.

- Development in Java and validation of a prototype of a computer system that lets health professionals retrieve, from the underlying health data repositories, the patient data that they need on-line and present back the health data as a XML document according to the European pre-standard ENV13606. Basically, the system manages a "virtual" electronic health record

which is assembled "on the fly" from data held in multiple (database) systems. Some of the most important modules are:

- **The metadata server is** the module that is in charge of managing the system metadata. It manages a database (implemented by using an object oriented database, ObjectStore for Java) which contains the archetypes definition and their relationships, the underlying databases schemas, the archetypes-schemas mappings, information about the location of patients' social-demographic data, general information about the underlying databases and network addresses.

- Visual tools to assist in the management of metadata:

    - The archetype editor facilitates the edition of archetypes (it allows the creation of new ones from scratch or the reuse of existing ones), validates their correctness, allows the classification into groups in order to ease the search, the definition of mappings with the component databases schemas and finally it controls the versioning (all prior versions are kept for legal reasons).

    - The schemata manager allows the automatic retrieval of schemas from the underlying databases, enrich the schema by defining new inter-database dependencies, define where the social-demographic data about patients are located in order to allow the matching of patient identifiers and define which data from the underlying database are shared.

- **The Patient Identification service allows the identification of identical patients across different system when there is not a universal patient ID.** This task is quite important, maintaining a correct, non-duplicative list of patients is difficult enough even for a single practice. However, a high-quality patient identification service is an absolute requirement if data is to be shared when a single patient visits more than one practice in the hospital. For this purpose, a set of social-demographic attributes is used. The search begins by matching the supplied attributes. If none is found (for instance due to spelling mistakes), the condition is weakened and all the patients that match in a random part of the supplied attributes are selected, a variant of the Levenstein distance algorithm is used to select and sort the most similar ones. Finally, the users select the correct one and the matched patient IDs are stored in a cache database to be reused later on.

- The Electronic Patient Record Server is the core of the whole system. It is layered between the client applications and the data repositories. This server retrieves, by request, all the relevant patient information wherever it is located and presents back the information in a uniform way to the user applications. User applications request to the EPR service healthcare information about a particular patient as one or more instances of any archetype defined in the data dictionary. The EPR service obtains the definition and mappings of the requested archetype from the metadata manager. Afterwards, it builds and populates the extracts of EHCR and presents it back to the user as a XML document in compliance with the DTD that specifies a valid provide-EHCR message.

3 Indicators of results

Publications

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Ferrer Ivars, R., Casanova, J.C., Romero, R.. Aplicación de la tecnología de repositorio de datos clínicos en hospitales. VII Congreso Nacional de Documentación Médica, 56-51 (2001).

PhD.

José A. Maldonado. Diseño de una metodología para la interconexión de sistemas de información sanitarios: Aplicación a hospitales de la Comunidad Valenciana (to be defended next year).

Collaboration with other groups

BET (Bioengineering, Electronics and Telemedicine group) from the Technical University of Valencia: application of EHCRA standards in Telemedicine.

Participation in the research network INBIOMED: Plataforma de almacenamiento, integración y análisis de datos clínicos, genéticos, epidemiológicos e imágenes orientada a la investigación sobre patologías. The network comprises thirteen groups from eleven different research centers. The total number of researchers is 100.

Participation in a research network for the investigation of health services based on telemedicine. The network comprises fourteen research groups, nine of them from the Spanish National Health System.

A request of a European project is under preparation, this project will be led by Francisco del Pozo, university professor of Technical School of Telecommunication Engineering of Madrid. The aim of this project will be the investigation of generic methodologies for the implementation of telemedice services using ENV13606.

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Intelligent environments for health care mobile applications
TIC2000-0399-C02

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Abstract

The development of wireless broadband communication systems and mobile computers (hand-held computers, subnotebooks, PDA's, smartphones) allows the user to access the information infrastructure of an organization from an increasing number of different contexts. These technological changes suggest for a rethinking of several of the classical concepts used in computer science until now, such as human-computer interfaces, mobility, portability, etc. This project is focused on several aspects related to human-machine interfaces in mobile computation. The project will have a user-centered approach, and one of its main objectives will be to evaluate the developed technologies in realistic environments, specially (but not exclusively) those related to health care.

Keywords: Computer Vision, Intelligent Interfaces, Biometric Systems, Medical Imaging, Mobile Systems, Interactivity.

1 Project Objectives

The main objective of the project is to develop an intelligent environment composed of:

1. A set of mobile devices (hand-held PCs, subnotebooks, PDA's) to allow access to medical information from everywhere at every time, in a user-friendly and natural way.

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2. A set of tools and applications, adapted to different scenarios, including telepresence and telediagnosis tools for medical information visualization and analysis, paper-based interfaces (and visual object recognition in complex environments) for accessing information from mobile computers and XML data repositories.

3. A pilot installed in a real environment.

The distinctive features of our approach can be summed up in the following points:

1. The use of biometric systems to authorize the access of a given user to devices, data and applications. Facial recognition is a natural option when considering applications that require the non collaborative identification of a person. Moreover, these methods are non obstrusive, passive and do not restrict the user movements.

2. The use of advanced user interfaces for improving the interactivity of the system. The integration of digital information (sounds, speech, text, images, video, xml pages etc.) and real environments opens new expectations in many applications where the coupling between user perception and computer interface can not be defined by the classical desktop metaphor. The perception of reality can be enhanced making connection between these worlds. Visual recognition is a candidate to implement this connection.

3. The use of computer aided decision tools, based on image analysis capabilities, for telediagnosis and telepresence. Medical staff performing daily ward rounds or visits to patients are usually far from a desktop PC. So, doctors do not adopt a fluid workflow (i.e. current system are paper based, time consuming and not readily accessible). Doctors and nurses working with home patients have an even greater difficulty managing and accessing up to date information specific to the patient they are seeing, as currently it is impossible to access the HIS via a patient's home. Wireless technologies and mobile devices can be a solution to this problem, but they must provide the needed functionalities. This line of research will explore the feasibility of developing computer aided decision tools in traumatology and cardiology mobile environments.

This project is a collaborative work, involving the "Ambient Intelligence" and "Medical Imaging" groups from the Computer Vision Center (Universitat Autònoma de Barcelona) and the "Computer Vision Group" of the Dept. of Electronics and Computation (Universidad de Santiago de Compostela). The first group is responsible for developing the following technologies: biometrics, paper-based interfaces, mobile environment and applications related to cardiology. The group from Santiago de Compostela is developing a visualization and analysis tool for a traumatology application.

2 Project Achievements

In this section the most important achievements of the project are described.

2.1 Face detection and recognition in non controlled environments

The project has developed a working face recognition prototype that recognizes people's identity in non controlled environments. The system comprises a "face detection" module that

is able to detect several faces in an image at real time (15 frames per second). This module is based on advanced learning techniques that used the "boosting" procedure in a set of binary classifiers. The face recognition module is based on a new non parametric technique for discriminant analysis, NDA, which has been developed in the context of this project.
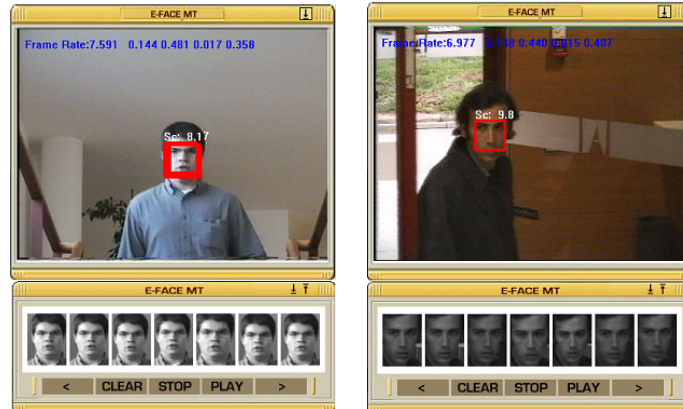
Figure 1: A face recognition system has been tested in the CVC environment.

We have performed a large scale test of the prototype in the CVC building. The test involved the CVC personnel (about 60 people) during one month. Final results show that the system is able to recognize people with high precision (96% success) despite the changing environmental variables (lighting in the building at different times of the day, changes in people appearance, etc.)

2.2   Tangible interfaces: augmented paper

Paper is a technology that will continue to be the ideal choice for certain activities. Emphasis has to be put on the development of technologies which better integrate this paper use with coexisting digital technologies. VisualTag is a prototype system that links, using visual recognition methods, tagged physical objects (paper stickers) to remote digital information. The system has been designed to work on mobile terminals equipped with low cost cameras and wireless Internet access.

In order to test the feasibility of the system and to show its potential, we have developed two working prototypes.

The first one is based on a PDA (with a digital CMOS camera), and the application is directed to read visual tags attached to "touristic artifacts" (maps, brochures, etc.) The systems links (using wireless communications) that "artifacts" to virtual information stored in a XML repository located in a remote server, to be visualized in the PDA screen.

The second prototype, InfoTag, has been developed for e-learning purposes. This systems allows the connection of digital information (notes, videos, etc.) to physical textbooks via a WebCam. In this way, physical resources for learning can be augmented with multimedia information at a low cognitive cost for the student. This system has been tested by several Master students at the UAB.

Figure 2: InfoTag is a demonstration prototype that uses a paper interface for learning purposes.
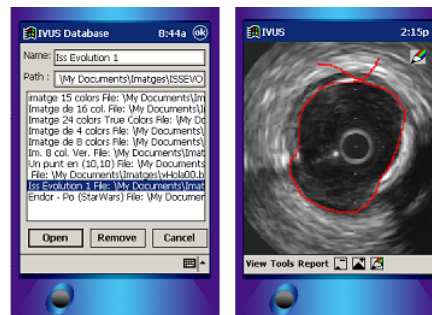
Figure 3: Medical information can be accessed from different devices using wireless communications.

2.3 Mobile application development in health care environments

In order to design an infrastructure for the mobile environment, we have explored two lines of research: the use of a open source P2P development platform (JXTA) and the development of medical applications for PDA's.

JXTA technology is a set of open-source, generalized peer-to-peer protocols that allow any connected device on the network from cell phone to PDA from PC to server to communicate and collaborate in a peer-to-peer manner. The JXTA platform standardizes the manner in which peers (a) Discover each other, (b) Advertise network resources, (c) Communicate with each other, and (d) Cooperate with each other to form secure peer groups.

We have developed a set of "demonstrators" of this technology related to medical information sharing, to demonstrate the feasibility of the approach and its potential applications. A direct result of this work was the presentation (finally, not successful) to the UE of an European project, MedXChange, involving seven international groups, and leaded by the CVC.

Regarding the developement of medical applications, there are two lines of research:

1. **Cardiology.** The growing appreciation of the pathophysiological and prognostic importance of arterial morphology has led to the realization that angiograms are inherently
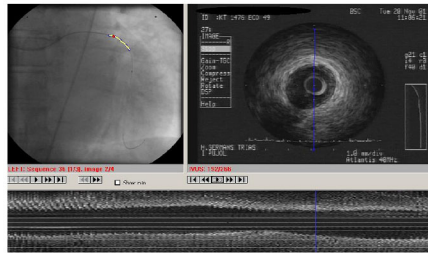
Figure 4: Fusion of angiograms and intravascular ultrasound images.

limited in determining the distribution and extension of coronary wall disease. By Intravascular Ultrasound images physicians have a picture of the composition of vessel in detail. However, observing an intravascular ultrasound stack of images, it is difficult to figure out the image position and extension with regard to the vessel parts and ramifications, and misclassification or misdiagnosis of lesions is possible.

We have developed a complete PDA application for cardiology that allows physicians to visualize and analyze IVUS images and angiographies. This work has two parts: the development of computer vision techniques in order to fuse the information from angiograms and intravascular ultrasound images defining the correspondence of every ultrasound image with a corresponding point of the vessel in the angiograms, and the development of a client-server application that allows physician to access this information from a PDA.

2. **Traumatology**. In this field the work has focused on the development of new visualization and analysis techniques to be used for CT images. The most important achievements are related to the development of new methods in the filed of *deformable models*, and the development of new visualization techniques that allow a multiresolution representation of CT images. These techniques will converge in the development of a mobile application to visualize and analyze 3D data.

3 Project Results

3.1 PhD and Master Students

The project has involved in its activities several Master and PhD students:

- M.Bressan. *Independent Modes of Variation in Point Distribution Models*, Master Thesis, September 2001.

- D.Guillamet. *Reconeixement d'Objectes en Entorns poc controlats mitjançant mètodes estadístics*, Master Thesis, September 2001.

- D.Rotger. *Multimodal Registration of Intravascular Ultrasound Images and Angiography*, Master Thesis, September 2002.

- PhD Students (estimated date for completing the degree): C.Cañero (2002), M.Bressan (2003), D.Guillamet (2003), D.Masip (2004), D.Rotger (2004), R.Dosil (2004), V.Leborán (2004).

3.2   Publications

Project activities have produced a large set of scientific publications (see the bibliography section): 1 book chapter, 10 publications in journals indexed in the SCI (Science Citation Index), 4 papers in books indexed in the SCI (LNCS), 7 publications in major international conferences (IEEE ICPR, IEEE CVPR, CAIP, IWVF, IEEE ICIP), and 11 publications in sectorial conferences.

3.3   Technology Transfer Activities

The project has been the origin of the following contacts with technology providers and users:

- *Hospital Germans Trias i Pujol de Badalona, (Departamento de Hemodinámica)* that is collaborating as a tipical end user, Its main interest is the development of image analysis techniques and decision tools for IntraVascular Ultrasound Images (IVUS). Several of the application have been tested in this Hospital.

- *Centre Hospitalari Unitat Coronària de Manresa.* This hospital has installed a wireless LAN that is being used for testing developed applications.

- *Institut Cartogràfic de Catalunya*, who has signed an agreement in order to use some of the pattern recognition techniqes that have been developed in this project to classify satelite and aerial images in order to build use maps.

- *Siemens*, who has been crucial in supporting the connection of our applications to different imaging aquipment (angiography).

- *Boston Sci.*, who has signed an agreement and financed a complementary research grant in order to test our techniques in its IVUS machines.

- *la Caixa*, one of the most important saving banks in Spain, has signed an agreement to test the biometric system in its main building for security purposes.

- *Mossos d'Esquadra* (police of the Generalitat de Catalunya), who has evaluated the use of our biometric system in its daily activitites.

- *Servicio de Radiología del Policlínico Vigo SA, POVISA, de Vigo* is evaluating the use of developed software (image analysis techniques) for analysing NMR images.

- *Servicio de Radioterapia del Complejo Hospitalario Universitario de Santiago de Compostela* is evaluating the use of automatic segmentation tools for 3D external radiotherapy processes and IMRT.

- *Siemens Terapia* has been contacted in order to define a common interest goal, related to the development of software tools for automatic segmentation and image registration in radiotherapy.
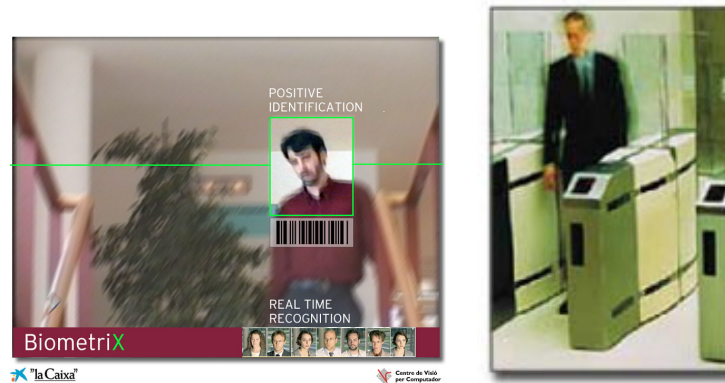
Figure 5: The system developed for "la Caixa" is able to detect and recognize faces in real time. The considered testing environment is an access area located in la Caixa main building.

3.4 Collaborations

- Person/group: Baback Moghaddam, MERL Cambridge Research, Research Scientist, Ph.D., Massachusetts Institute of Technology, 1997. Topic: Factorized Local Appearance Models. Participating members: D.Guillamet (PhD student), J.Vitrià (Inv.Principal del proyecto). Results: David Guillamet and Baback Moghaddam, "Joint Distribution of Local Image Features for Appearance Modeling", IAPR Workshop on Machine Vision Applications, December 11-13, 2002, Nara-ken New Public Hall, Nara, Japan.

- Person/group: Aapo Hyvärinen, Academy Research Fellow, Neural Networks Research Centre, Helsinki University of Technology. Topic: Independent Component Analisis and facial recognition. Participating members: : M.Bressan (PhD student), J.Vitrià.

- Person/group: Bernt Schiele. Assistant Professor of Computer Science at ETH Zurich. Topic: Non-negative Matriz Factorization for object recognition. Participating members: D.Guillamet (PhD student), J.Vitrià. Results: D.Guillamet, B.Schiele,J.Vitrià. Analyzing Non-Negative Matrix Factorization for Image Classification. *ICPR 2002*.

- Person/group: Raimund Leitner, R&D Optical Sensors and Imaging, CTR Carinthian Tech Research AG, Austria. Topic: Object recognition using "what and where" information. Participating members: : J.Vitrià.

- Person/group: Beating Heart Excellence Network (BHEN). Topic: We participate in the proposal of a Network of Excellence about "Dynamic Cardiac Imaging And Modelling To Improve Early Stage Diagnosis And Therapy Of Cardio-Vascular Diseases", under the 6th Framework Program of the EU. Participating members: J.Vitrià, P.Radeva.

- Person/group: Network of Excellence on Computer Vision and Image Analysis (NetCVIA). Topic: We participate in the proposal of a Network of Excellence under the 6th Framework Program of the EU. Participating members: J.Vitrià, P.Radeva.

- Person/group: We were the scientific leaders of the project "Share4Care: A new data-sharing platform for healthcare applications", presented to the 5th Framework Program of the EU, which was mainly based on the results of this project. Finally, th eproject was not successful. Participating groups:

  - CEFRIEL- Centro per la Ricerca e la Formazione in Ingegneria dell'Informazione , Italia, (www.cefriel.it)
  - CVC - Centre de Visió per Computador (www.cvc.uab.es)
  - The Biomedical Engineering and Telemedicine Group (GBT) - Universidad Politécnica de Madrid.
  - ITACA - Institute of Applications of Advanced Information and Communication Technologies (Universidad Politécnica de Valencia).
  - HUGTIP - Hospital Universitari "Germans Trias i Pujol" - Badalona, Spain.
  - SCS - ServicioCanario de la Salud (www.gobiernodecanarias.org/sanidad/scs/)
  - FCR-CARDIO - IRCCS Ospedale San Raffaele of Milano, Italia (cardiac surgery unit)

  Participating members: J.Vitrià, P.Radeva.

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Virtual Reality and Deformable Models used for Simulation and Diagnosis of Cardiopaties TIC2000-1009

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Abstract

This project pretends to be a first step towards the construction of interactive virtual models of the (left ventricle of the) human beating heart. These models are built form patient data and attempt to accurately reflect the patient's ailments. These models will let the physicians extract more information from tests they already preform today, and also analyze them for surgery planning or educational purposes.

We are forced to make simplifications. Within this projectg we intend to deal exclussively with SPECT and g-SPECT models. From these we will construct a hybrid model of the external and internal surfaces of the ventricle, plus a volume model of the muscle's blood perfusion, based on an irregular tetrahedral mesh. This tetrahedral mesh will also be used to model physical properties of the muscle for the interaction in the virtual environment.

Both a traditional renderer on a screen and a VR representation on a Workbench developed by our team under project TIC-98-0586-C03-01 will be developed. The VR representation will incorporate interaction with a haptic device simulating a scalpel and helping in the interaction.

The results of the project will also be clinically validated by the Medical Doctors in the research team. We shall strive to achieve the best presentations possible for the tools applicability in both clinical research and practice.

Keywords: Virtual Reality, Haptic Interaction, Applications to Medicine

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1 Objectives

The core objectives in this project were:

1. Definition of the geometric model

2. Construction of the model from SPECT data

3. Presentation and interaction

4. Interactive deformations

5. Validation

Detailed descriptions and scheduling are available in the original project proposal.

At present, we have suffered delays in the third and fourth of these objectives because of the unexpected lengthening of the acquisition of hardware linked to these. More specifically, early on in the projects development, a new manufacturer of the kind of haptic devices needed was identified. Their product offered several advantages to our project in different areas, including robustness, precission, stiffness and ease of integration softwarewise. For these reasons we moved forward to acquire one of these devices, but their lack of a representative in Spain together with the iontricacies of the legal procedures necessary for such an acquisition resulted in over a year's delay. The device is now under way and we expect it to be installed in our lab before the end of the month. We further expect to be able to invest extra effort in this area to make up for at least part of the time lost.

2 Degree of success

So far the project has obtained different methods([1], [2]) to aid and improve the segmentation of SPECT data (see Figure 1), which are afflicted of poor resolution and noise. These methods have been integrated (although work continues in their improvement) in a simple platform with a common user interface, so that they can be tested by Physicians. Figure 2 shows a screen shot of this application.

These segmentation routines yield triangular meshes that are fed into our special purpose on-the-fly tetrahedrizer to construct the basis for our hybrid model (see Figure 3, which shows different stages of the process for illustration purposes only; in actual excecution the whole process is completed automatically and at interactive rates).

On a different front, methods to perform accelerated (albeit approximated) computations of forces and deformations for the haptic interface are under development (see [3]).

The 3D presentation on the Workbench has been delayed in view of the unavailability of the haptic device, but will be readily available when the haptic robot is installed. Instead, we are now concentrating on dynamic aspects of the model, where we have encountered unexpected difficulties in tackling the problems of correspondences (model matching). This is complicated furhter by the combination of low resolution and repeatability of our datasets, and also by their noise, intrinsic to the method of data-gathering. Nonetheless we expect to have results that are at least sufficient to perform the basic necessary matching tasks by the end of the project. Algorithms not included in the original objectives to match different models (like stress vs. rest studies) are being worked upon.
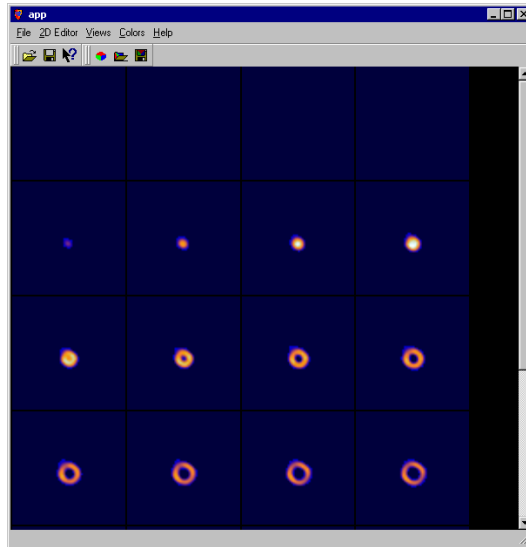
Figure 1: ROI-segmented SPECT data
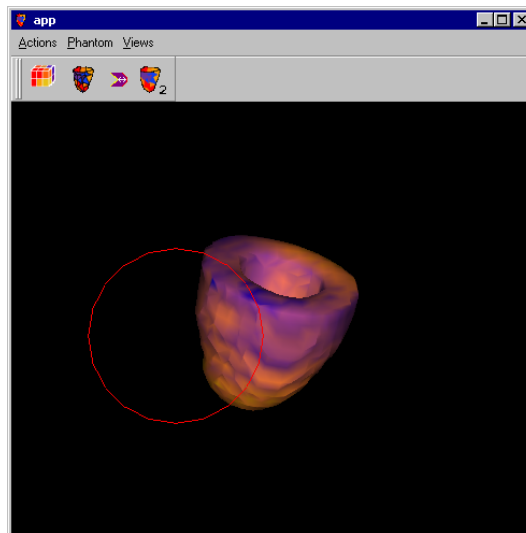
Figure 2: Sample of the testbed application
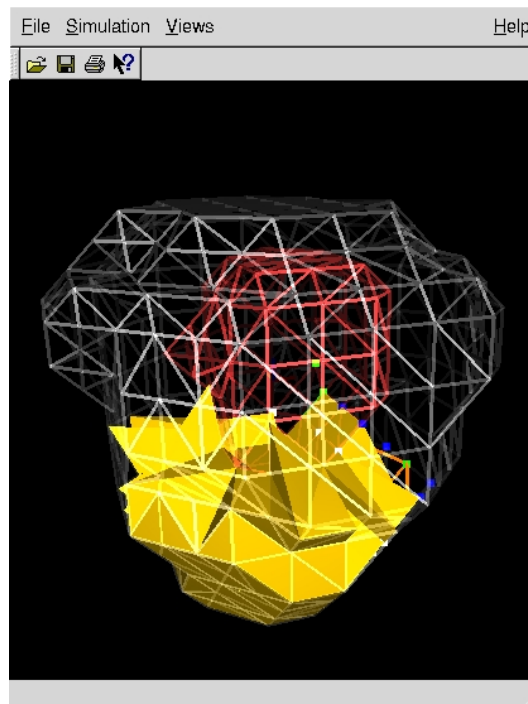
Figure 3: Different stages of the tetrahedrization

3   Performance indicators

The Bibliography section lists the international publications produced so far within this project. Notice must be taken that this project is poresently only at 61% of its planned duration, and publications linked to the project are naturally expected to be larger in number towards its end.

Currently three PhD. thesis are under way within the project. The students involved are Óscar García, Gonzalo Mero, and Lyudmila Rodríguez. A fourth student (Daniel Marín) may be starting work towards his thesis within the scope of the project in the near future.

The prototype of the 2D application mentioned in the project is currently being used in the Nuclear Medicine division of the Hospitals de Vall Hebron, in Barcelona, to compare its results and validate them based on a large clinical database.

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A Surveillance and Security System based on Computer Vision
TIC2000-0382

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Abstract

The goal of this project is to develop a general security and surveillance platform based on Computer Vision techniques. This platform consists of three components: The first module uses OCR techniques, and is addressed to the automatic reading of identity cards in order to register the access of people in a particular place. The second module, oriented to people identification using physical appearance descriptions, allows the automatic extraction of descriptive features based on phisiognomical and clothes combinations from images of people. These features can be associated to the personal data extracted in the previous module, being stored together into a database, and in order to make queries in terms of appearance descriptions to the identification of people in the building. Finally, the third module should allow the detection of troubled situations in the building, using sequences of images acquired by the set of surveillance cameras. This involves object tracking and action recognition tasks. The whole system should control all the people present inside the building, the recognition of conflictive actions like crowds, vandalism, etc. and the identification of the actors involved in such actions by means of queries based on appearance descriptions in the database. Since these queries could be done by a human operator, should be formulated in terms of features such as hair color, clothes combination, color and texture, height, etc. The system has been designed in a modular way. Each module can be seen as an independent product and could be integrated in other host applications. Thus, there are different companies involved in this project which are interested on taking advantage of some of the modules proposed in this project, using them in their particular environments.
Keywords: Computer Vision, Security, Surveillance, OCR, Pattern Recognition, Texture and Color, Tracking, Action recognition.

1 Project Goals

The objective of this project was the development of a platform of security and general surveillance based in Computer Vision techniques. This platform was designed divided in three components:

- **Check-in:** Daylife activity often requires people to be identified by showing their identity card or passport to security staff of particular installations. Examples are: checking-in in a

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hotel or an airport; identity validation in a Casino, an industry or an official building; renting a car, etc. In such situations, a human operator is supposed to type the personal data of the customer in order it to be registered into a database. Typing is a tedious and slow task, specially in crowded places. In addition it involves edit errors that may generate duplicates and wrong data in the database. The field of document analysis currently offers a sound technical background that can be used to develop robust and easy-to-use data capture interfaces to automatize the above task. The main goal of this part of the project was to develop a system to recognize the textual information of identity cards, passports or drive licenses. The goal was to design and develop algorithms able to tolerate the variability among documents from different countries and formats. Such variability depends on factors as background texture or colour combinations, text font, layout etc. Thus, two major tasks were stated: first, a document classification module, and secondly an Optical Character Recognition (OCR) module designed to cope with the particularities of textual fields of documents.

▪ **Appearance description and browsing (physiognomy):** Basically it is an access module for retrieving by content into databases of images. The fundamental objective is to make queries in databases that contain people's images formulated in terms of a description of the appearance. The answer to the queries should be the set of images in those that people that coincide with the description appear and, in case of having the personal data (extracted in the check-in module), the record containing such identificative data. Since queries should be made by human observers, the descriptive characteristics that should be recognized in the images should be based on physiognomic aspects such as hair color, glasses, beard, color and/or texture of the dress, tie, etc. The identification of people in terms of such characteristics represents a complementary and innovative
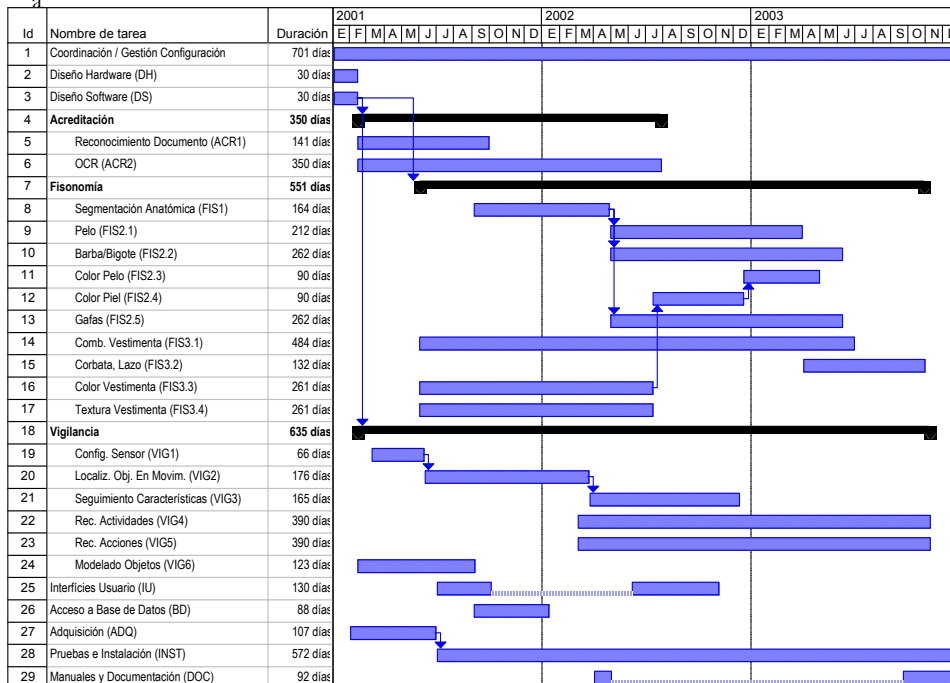
Figure 1. Project plan.

classical ones based on biometric aspects as face recognition. Actually, this part of the project solves an image database browsing problem, i.e. retrieving images from a database according to queries formulated in terms of symbolic descriptors.

- **Surveillance:** This module allows, firstly, the tracking of people inside the visual field provided by a camera of surveillance and, secondly, the detection of suspicious actions. Depending on the environment in which the system is running, for suspicious action we can understand the detention of an individual, a mass, an abrupt acceleration of the movement, etc.

Although the three subsystems can be considered in an independent way, the complete system should allow the control of all the present individuals in a certain building, the identification of conflicting actions (masses, vandal acts, etc.) and the identification of participant people in these actions starting from consultations for appearance in the database. The planning of the project tasks is presented in Fig. 1.

2 Level of success reached in the project

2.1 Check-in subsystem

The foreseen goals proposed for this subsystem were fulfilled in the first year of the project. From the scientific-technological point of view, two major parts should be highlighted:

Document classification. Documents are classified combining several features: size, background colour and texture, and structural configuration of text. After detecting the bounding box of the document using a Hough-based approach, its size is a fast feature that allows a pre-classification among a set of document classes. For document models with similar size (e.g. passports, and different versions of id cards of the same country) we have used a colour classification algorithm. We use the opposite color histogram as invariant feature. The dimensionality of the opposite color histogram is reduced using a PCA algorithm. An input document is classified by projecting it into the above subspace and computing the Mahalanobis distance to the document models. Finally, the third criterion that is used to classify an input document is the structure of text lines. Not only does this third criterion allows to classify the document but also to identify for each textual field the information that it contains (name, address, id number, date, etc.) according to the models. This process is formulated in terms of a consistent labeling approach where given a candidate text region, its corresponding label, i.e. which information field it belongs to, is assigned by a mapping from a set of model regions to the candidate ones according to their structural configuration. Once they are detected in the input document, text regions are organized in an attributed graph structure and the correspondence against models is performed by looking for a subgraph isomorphism between the graph representing the input document and the graph representing the model.

OCR engine. We have designed an OCR engine that combines by a voting strategy classical OCR techniques. Currently, the OCR combines approaches based on the statistical distribution of points and structural techniques. In the first family of techniques, characters are classified following a zoning technique. Zoning divides the frame containing the character into zones and uses as features the densities of points in the different regions. We also perform a statistical background analysis of characters. Particularly, characteristic-loci techniques are used to take as features the

number of times the vertical and horizontal vectors intersect line segments for every white point in the background of the character. A more comprehensive review of such techniques can be found in [10,12]. Finally, a third technique is used to analyze the structural features of characters represented by a set of characteristic points distributed along its skeleton. The method is based in the Point Distribution Model (PDM) defined by Cootes et al. [3]. Using a PDM, a model character is represented by a vector of characteristic points along its skeleton and a set of local deformations that map the representative shape to the other instances within the same class.

2.2 People description and browsing subsystem

Images of people entering a building are processed while they are checking-in. Textual descriptors based on people appearance are extracted from these images. This information is saved in a global database where the security personnel of the building can make queries. This might be useful if they can see in a camera inside the building someone who is causing problems, and they want the information that identifies this person. Here is where our module acquires importance, because in our database there is information about the appearance of the people who have entered the building and that has been automatically extracted. With this purpose, the system allows the user to make queries formulated in terms of textual descriptors, to retrieve those images from the database agreeing with the descriptors. Queries are formulated in terms of shape, colour, texture and structural properties of clothes that people is wearing. For example, a query may be "someone who wears glasses, tie, and blue jacket". The system will automatically build an appearance feature vector from an image acquired while people is checking-in in front of the desk.

Retrieving images from large databases using image content as a key is a largely studied problem in Computer Vision. Two major approaches can be stated. First, similarity retrieval consists in looking for images in a database using a reference image as query. The second approach concerns browsing applications and consists in retrieving images by pictorial content, i.e. using symbolic descriptors as indices. Concerning to features used as the basis to formulate queries, usually early visual primitives such as color and texture are used. Sometimes, structure of objects in the image is also important. A number of works combine low level visual cues as color and texture with higher level information as structure (e.g. [6,9,15]). Our work follows this approach. Queries are formulated in terms of textual descriptors like 'we are looking for a man in a red shirt' that are compared with descriptions stored in the database that were previously extracted from the input images.

Describing people by computational descriptors involves two steps. First, people is segmented in the image using a statistical model of the scene background. Afterwards, the different descriptors are modeled in terms of color, texture, region structure and shape. Let us further describe that.

People detection and segmentation. This step aims to separate people (foreground) from the rest of the scene (background). Given a sequence of images acquired at the same scenario, $I=\{I_1, I_2, …, I_n\}$, the goal of a background subtraction method is to label the image pixels into: (i) regions where the underlying scenario is visible (background), and (ii) regions where the scenario is being occluded (foreground), that in our application it is related to people. The proposed background subtraction method [11] assumes that all the background points will present a chromatic stability all over the background image regions, which is always represented by a diagonal model (i.e, this model is able to represent small illuminant variations that can occur along time).

Some previous works [3,19] broach this problem in a statistical way. These methods usually take a set of background (where the whole scenario is visible) reference images $B=\{B_1, B_2, \ldots, B_m\}$. These images are used to estimate the probability density function (PDF) that an image pixel belongs to background. The PDF applied in these methods encompass in the same model the variations of the background pixels due to illumination changes and acquisition noise. The application of these methods to our problem produces an over-relaxed background model, where slight changes on illumination produce the undesirable effect of increasing the number of possible foreground values being classified as background. To avoid this problem, the method applied in this work [11], splits the above methodology into two steps: (i) A statistically robust estimation of the global linear transformation that adjusts the image to a noise free reference background image. (ii) a statistical noise model that allows us to decide if the differences between the pixel values of a corrected image and those of the reference background model are expected for a background pixel. Assuming zero mean gaussian noise, the reference background image $M(x,y)$ is then constructed averaging a set of background images $B_1(x,y), \ldots, B_l(x,y)$. Notice that both the reference image, as well as the background images used to compute it, are updated each time the elements of the scenario are rearranged. More details of our approach can be read in [18].

Color and Texture description. Surface properties are essential visual cues for visual descriptions. Computational representations of color are easy to build due to the inherent simplicity of color vision in humans where three-dimensional spaces are enough, problems arise when color constancy abilities of human vision are intended on computational systems. In this sense, we are working on normalized representations of color that present invariant properties to illuminant and sensor changes [16]. Moreover, we have done a statistical approach for color naming. Structure of color naming. Spaces have been modeled by a Sigmoid-Gaussian model giving the membership functions of color coordinates to a given color category [1]. Learning steps are based on psychophysical data compiled from different experiments under different illuminants. On the other hand, general texture representations are not agreed, neither in psychology nor in computer vision. Hence, research in texture representation is still focusing on finding the essential perceptual dimensions of any natural texture. To this goal, we have proposed a texture description based on its decomposition on subtexture components that can be perceptually explained [13]. This can take us to a global and non-ambiguous texture representation with perceptual properties. Such a space can provide meaningful dimensions, that can allow to retrieve textures based on textural queries.

Clothes classification in terms of region structure. Color is an early visual primitive that is used as a coarse indexing cue to retrieve images from the database. This would allow to look for people wearing clothes of a certain color. In a finer indexing mechanism we look for region structure in the image. With this purpose, once pixels have been color labeled, they are hierarchically clustered in order to describe the image in terms of a region relational structure. The segmentation of these regions is formulated in terms of color and texture homogeneity. This relational description of images in terms of regions labeled by basic color terms would allow to convert textual description queries to a bi-level indexing formulation, namely, color and structure for browsing images agreeing with the description.

Image regions are organized in a relational graph structure. At this point we have a set of segmented regions organized in a graph. A graph clustering algorithm is then applied by iteratively merging neighboring regions. Informally speaking the region growing process can be described as a

graph contraction iterative procedure such that, at each iteration, two neighboring regions (graph nodes) are merged according to a similarity criterion formulated in terms of color similarity and the significance of image contours between regions. When images are encoded using a spatial information on regions, indexing is well performed using approaches based on 2D-strings for pictorial description [8]. Shearer et al. [14] recently proposed a variation formulated in terms of inexact isomorphism detection between region graphs representing two images. Our method is inspired by that one. Thus, the clothing configuration models are formulated in terms of ideal position of regions and the corresponding region graph. More details of our approach can be seen in [2,17]

Extracting shape-characterized descriptors. Some features describing people are particularly defined by its shape. Glasses and ties are two examples of that. We have developed preliminary approaches based on shape detection and classification to extract such features. First, image contours are extracted using a Canny operator. Afterwards, Principal Component Analysis and Generalized Hough Transform are the techniques that have inspired our method. This part of the work is still in progress.

2.3 Surveillance subsystem

From the technical point of view, an automatic system of video surveillance includes tasks such as localization of objects, visual tracking, classification of objects and recognition of activities and human actions. The localization implies the detection of the objects of interest in the scene. These objects have to be classified according to their type as for example people or cars. Once located, the module of visual tracking takes charge of maintaining its trajectories along the time. Finally, the modules of recognition of activities and actions is concerned of carrying out a symbolic description of what is happening in the scene. Let us further describe the main contributions of this project in the subtasks of the visual tracking and the recognition of activities and human actions [7].

Tracking. Many proposals for the generation of tracking models are based on lineal models of shapes, and some restrictions that define the values of the parameters that the models generate. We have focused this part of the project in the generation of models in an automatic way. Given a training sequence, the lineal models are determined using classical models, and the restrictions associated to the model are modeled using a mixture of gaussians. Next we use this model to generate a collection of a lineal model of the possible shapes of the human body when carrying out the action of walking, but of low dimension, where each one comes restricted by a gaussian model. This group of models represents the learning group better, reducing the computational cost

Recognition of Activities. Recently, computer vision research has been highly interested in the analysis of image sequences. When sequences involve humans, this task becomes challenging: human behavior analysis is still an open problem in which several issues need to be considered. We are interested in describing structured behaviors of an articulated agent in terms of its attitude and body motion, in contrast to analyze solely the location and velocity parameters of a single object. Gymnastic or yoga exercises, but also running, jumping, bending or walking provide examples. A taxonomy has been defined in order to discuss about a classification of human behavior in terms of knowledge: a proper definition of the concept of human action as a sequence of human postures, each human posture is represented using a 2D human body model (stick figure) which is described in terms of polar coordinates in order to avoid non-linearities when the posture varies strongly.

Subsequently, we present a human action model, the *aSpace*, based on a Point Distribution Model (PDM) [3]. This mathematical tool provides a compact (few parameters describe the posture), accurate (the postures which are plausible to appear in any performance of an action are included in the model) and specific (those postures which are not presented in the action are excluded in the model) representation for human actions [5]. Several sequences of actions are used to compare the *aSpace*. Two applications have been developed in order to validate our action model: recognition and synthesis of actions.

3   Indicators of results

Personnel in formation. Currently, there are 6 PhD students whose research subject is related to the goals of this project. In addition, a master student and an undergraduate student (formation grant) are hired by the personnel budget of the project.

Publications. In the last two years, this is the summary of publications in relation with the project:

> Papers in journals: 3
> Chapter in books: 4
> Papers in national conference proceedings: 8
> Papers in international conference proceedings: 15
> PhD dissertations: 4
> Master thesis: 3
> Technical reports: 2

Technological transfer. Recently, a company called ICAR Vision Systems has been created to transfer the exploitation of the Identity Card Reading System and the first version of the system for browsing people from image databases in terms of physiognomy descriptors. In addition, these systems are in use in the building of Inverama S.A. that is one of the sponsors of the project.

Collaborations with other groups. Researchers involved with the project are collaborating with the following groups:

> Prof. H. Nagel, Institut für Algorithmen und Kognitive Systeme, Karlsruhe University (Germany). *Subject:* people modeling and tracking.

> Prof. G. Finlayson, University of East Anglia, Norwich, UK. *Subject:* color modeling.

> Prof Manjunath. Department of Electrical and Computer Engineering Image Processing and Vision Research Lab. University of California, Santa Barbara. *Subject:* Towards the description of textures based on subtexture components.

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Three-dimensional modeling and simulation of the coronary arteries. MOTRICO project. TIC2000-1635-C04

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Abstract

Presently, cardiovascular diseases are the first cause of death in Spain among people from 75 and the second one among people between 15 and 74.

The MOTRICO project plans the creation of an advanced environment that will offer computer assistance to cardiac therapy and diagnosis. It will be useful in the hemodynamics units of those hospitals that have the possibility of working with the instrumental techniques of Angiography and Intravascular Ultrasound.

Keywords: Atherosclerosis, Restenosis, Aorta, Intravascular Ultrasound, Solid Mechanic, Computational Fluid Dynamic, Finite Element.

1 Project goals

From the medical images (obtained using Angiography and Intravascular UltraSound techniques - IVUS-) of segments selected from the coronary tree, the three dimensional geometry of the area will be reconstructed and the distribution of forces and deformations will be calculated both at blood-wall interaction (shear stress) and at the walls of the arteries.

Moreover, the project seeks the validation of the hypothesis that relates these stresses - fundamentally the shear ones- with the development of the atherosclerosis and restenosis postangioplastia and the application of the developed model to humans and animals. In humans, a model of patients with accelerated atheroesclerosis (situation after cardiac post-transplant) and a model of restenosis after stent implantation will be studied. In both cases the relation between biophysical factors and the development of atheroma and/or restenosis will be analysed. In animals, the same model will be applied to obtain a temporal profile of the restenosis after stents

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implant and to study the influence of the biophysical factors in the different restenosis phases: reendotelization (1 week), proliferation (1 month) and arterial remodelling (three months).

The procedure to obtain the biophysical factors that is proposed in this project is based on the application of simulation techniques to blood circulation inside the arteries, using Computational Fluid Dynamics methods. From the point of view of fluid mechanics, blood can be considered as a fluid with a viscosity that basically depends on the number of red corpuscles present, since they can be considered as semisolid particles. The problem will be initially solved as if it were stationary, taking afterwards into account the pulsating character of the flux of blood (transitory effects) and evaluating the effects drifted from the non-newtonian behaviour of the fluid.

The simulation of the proposed phenomenon is extremely complex, because it comprises not only fluid dynamics but also disciplines such as the ones related to the following problems:

The behaviour of the biological soft tissues, that may undergo big deformations and displacements. Therefore, it will be necessary to develop constitutive models of the material that will justify the use of non-linear models (hyperelastic models, reologic behaviours, two-phase matched models, etc.)

The contact between the fluid and the solid. This development will be divided into two phases. In the first one a fluid mechanics calculus with rigid walls will be done. Later, the structural behaviour under the previously calculated actions will be studied. Next phase will consist in the development of a model wholly coupled between the blood and the deformable walls.

External variables influence, such as temperature, etc.

To make all the previous aims possible, it is necessary the construction of a geometric three-dimensional model of the anatomic zone under study. The proposed environment will allow the generation of the model from the sequence of IVUS images and angiographies and the possibility of obtaining quantitative volumetric measurements. To fulfil these goals, several problems related to Computer Vision and Computer Graphics have to be solved.

It is fundamental for the system to be accepted to have a friendly user interface. Therefore, it will be developed within an interactive environment offering an intelligent and intuitive human computer interaction. Due to the characteristics of the work, interactive visualisation of 3D data using virtual and augmented reality techniques will be one of the most important elements of the project.

In order to obtain an "almost commercial" operative prototype the software development process will follow the Software Engineering Guide of the European Spatial Agency.

Due to the multidisciplinary character of the project, a work team made from groups with proven experience in each of the disciplines required to develop the project has been assembled.

These groups are:

- MEDTEC S. A., empresa interesada en los resultados del proyecto.

- Unidad de Hemodinámica y Cardiología Intervencionista. Grupo del Hospital Clínico de San Carlos de Madrid.

- Unidad de Hemodinámica y Cardiología Intervencionista del Hospital de Badalona.

- Grupo de Informática Gráfica Avanzada de la Universidad de Zaragoza. En este grupo participa también personal de la Universidad Pública de Navarra.

- El grupo de Biomecánica de la División de Mecánica Estructural de la Universidad de Zaragoza.

- Grupo de Mecánica de Medios Continuos de la Universidad Politécnica de Madrid.

- Grupo de Mecánica de Fluidos de la Universidad Politécnica de Madrid.

- Centro de Visión por Computador de la Universidad Autónoma de Barcelona.

2 Success range in the project

The goal of this research has been to develop a comprehensive framework to enable the conduct of computational vascular hemodynamics research. The prototype system in development will provide a set of tools to solve clinically relevant blood flow problems and test hypotheses regarding hemodynamic factors in vascular adaptation and disease.

The laboratory orchestrate the interactions between an object modeler, finite element mesh generator, multiphysics finite element parallel solver, and scientific visualizer. The result is a four step process for solving vascular blood flow problems:

1. Model Construction.
A geometric model of the vascular zones is created. These range from idealized straight, curved, and branched vessels to complex multibranched, patient-specific models.
2. Mesh Generation.
The continuous geometric model is discretized into a finite element mesh.
3. Finite Element Solution
The solution to blood flow problems is computed with appropriate behaviour of the difference artery material models.
4. Visualization and Information Extraction
A qualitative view of the flow field is obtained through contour and vector slices, streamlines, isosurfaces, and particle release methods.

2.1 Model construction:

2.1.1. Idealized vessels

We studied the coronary artery left anterior descending (LAD), with variable diameter of [3.1×10^{-3} m 2.0×10^{-3} m] and a length of 7×10^{-2}. Thickness media layer 0.3×10^{-3} m, thickness intima layer 0.1×10^{-3} , thickness adventitia layer null.

There are two idealized LAD without and with atherosclerotic plaque with differences thickness.
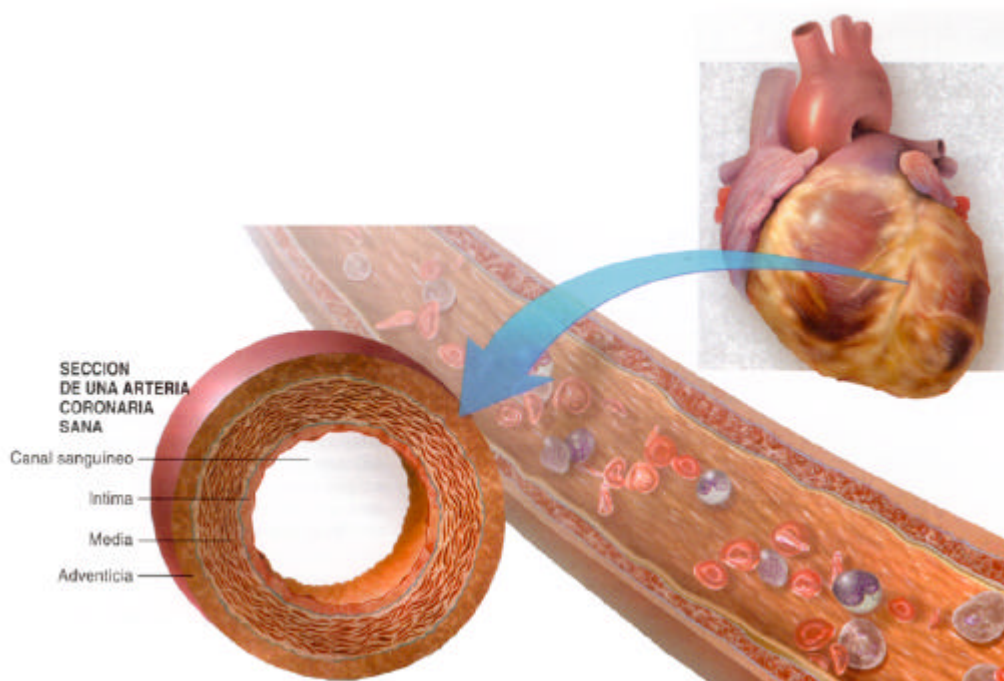
Figure 1. Coronary artery left anterior descending (LAD) healthy.

2.1.2. Patient vessels

The reconstruction of a geometric three-dimensional model of the anatomic zone under study, is obtained from the sequence of IVUS images and angiographies and opens possibility of obtaining quantitative volumetric measurements.

The procedural methods applied are:

Problem 1: Image filtering and enhancement are of high interest in order to extract vessel structures.
Answer 1: Among the several PDE based techniques, curvature flow appears to be highly reliable for strongly noisy images.

Problem 2: Ivus segmentation of the arterial lumen via a regularized curvature flow
Answer 2: In this part of the project, the parametric algorithm developed is based on the distinct dynamical behaviour among the different structures of a vessel. Tissue follows a periodic rotation produced by the heart beat. Blood presents a chaotic movement. The final surface, prone to be incomplete due to dark areas produced by the guide wire and side branches, is interpolated using active contours.

Problem 3: Texture IVUS analysis
Observing IVUS images it can be seen that they are composed of textured objects. The problem of texture analysis is necessary to solve the complete segmentation of the vessels.
Answer 3: In this part of the project it is proposed a new deformable model defined in a statistic framework to segment structures in IVUS images. It performs a supervised learning of local appearance of the textured objects and constructs a feature space using a set of co-occurrence matrix measures. Linear Discriminate Analysis allows to obtain an optimal reduced feature space where a mixture model is applied to construct a likelihood map. The active model is deformed on a regularized version of the likelihood map in order to segment objects characterized by the same texture pattern.

Problem 4: Predictive (un)distortion model and 3D reconstruction by Biplane Snakes
An important part of the project is concerning with the 3D reconstruction of coronary vessel centerlines and with how distortion of X-ray angiographic images affects it.
Answer 4: The effect can be reduced by integrating a predictive model of (un)distortion into the biplane snakes formulation for 3D reconstruction. The distortion can be accurately modelled using a polynomial for each view.

Problem 5: Multimodal registration of intravascular ultrasound images and angiography.
The aim of this part of the project was to develop a computer vision technique to fuse the information from angiograms and IVUS images defining the correspondence of every IVUS image with the point of the vessel in the angiograms by making a 3D reconstruction of the IVUS catheter path from its projection in the angiography and placing there the IVUS data.
Answer 5: The implemented approach for fusing both cardiovascular image modalities (angiograms and IVUS data) has been extensively validated.
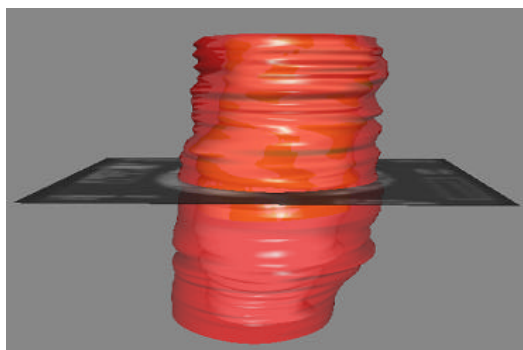
Figure 2. Reconstruction of vessel
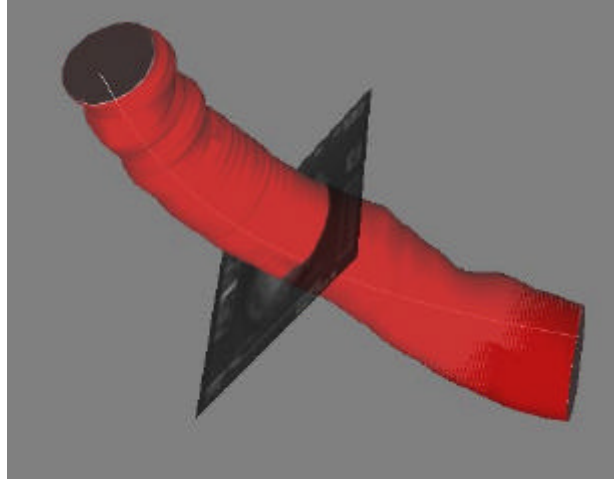
Figure 3. 3D reconstructed vessel and IVUS images can be displayed to the physicians to analyze better IVUS information through the whole vessel

2.2 Mesh Generation.

Problem 1: Strategies for mesh generation
In recognition of the fact that one of the most difficult aspects of using computational techniques to solve partial differential equations is the generation of the discretization. For complex problems, such as blood flow in multi-branched arterial system like the Coronary Arteries, this is especially difficult and precludes the use of simple "structured" mesh generation.
Answer 1: Mesh generation environment
The mesh generation tool used generates surface and volume meshes for solid model-based geometries; these meshes are used for finite element analysis applications. It is specifically designed to create all-quadrilateral and hexahedral meshes. A combination of techniques including hole, paving, sweeping, smoothing.

Problem 2: Meshes generated
Answer 2: Meshes idealized without and with atherosclerotic plaque and both of them without branches for:
- Intima
- Media
- Adventitia
- Blood flow(inner artery)
- Atherosclerotic plaque
- Thrombo

2.3 Finite Element Solution

Problem 1: Description of arterial material
To simulate the mechanical behaviour of the differences arterial walls it is necessary to build a model of the constitutive behaviour.
Answer 1: In this part of the project has been developed new deformable model defined as a hyperelastic isotropic material. Also has been developed a non linear hexahedral finite element.
Extensive results of the tests illustrate the usefulness of the present approach.
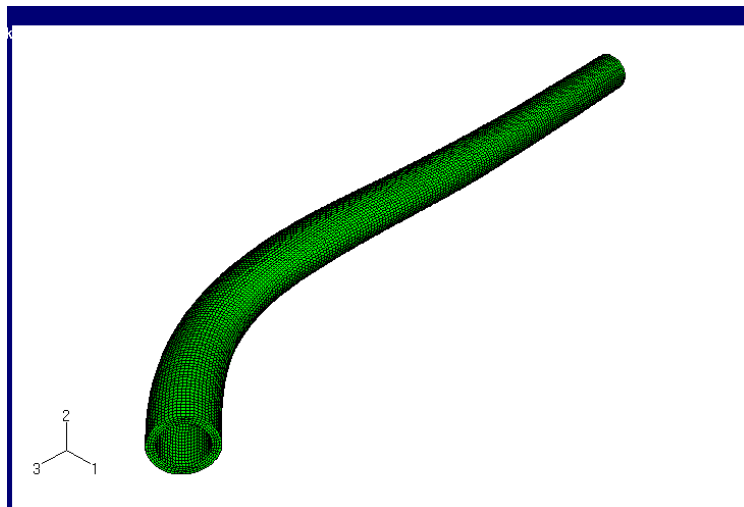
Figure 4. Mesh of the Coronary artery left anterior descending (LAD) healthy.
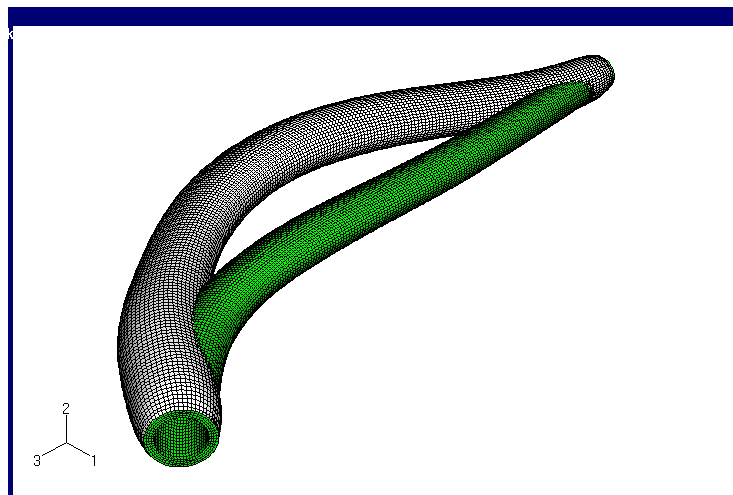
Figure 5. Mesh of the Coronary artery left anterior descending (LAD) healthy and mesh of its deformation.
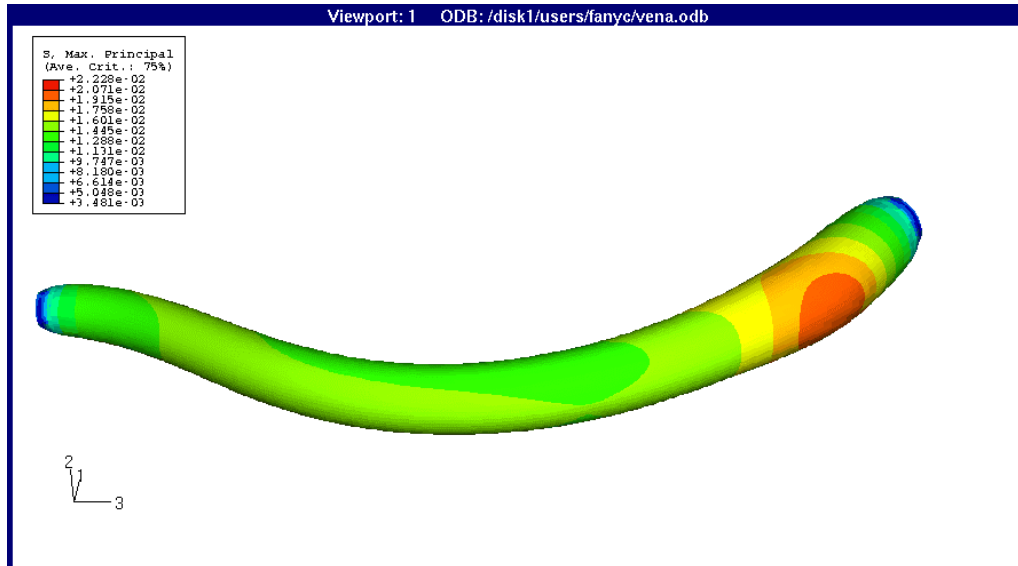
Figure 5. Stress maximum principal of the Coronary artery left anterior descending (LAD).

Problem 2: Description of blood material
To simulate the mechanical behaviour of the blood it is necessary to build a model of the constitutive behaviour.
Answer 2: In this part of the project, a Newtonian isotropic fluid has been selected as constitute equation. The associated problem of the incompressibility has been resolved using mixed finite element techniques. Different tests on synthetic problems show the advantages of the present approach.

Problem 3: Computational fluid dynamics
The finite element method is employed to create a finite dimensional approximation to the equation governing blood flow in arteries.
Answer 3: In this part of the project, the incompressible Navier Stokes equations for laminar flow has been selected to describe the motion of the blood flow.

Problem 4. Parallel computation issues.
Three-dimensional transient solutions of blood flow in arteries impose severe requirements on computer software and hardware architectures in memory storage and computational speed.
Answer 4:
-Hardware
Beowulf-class computers utilize cost-effective, mass-market, multi-hyphenated, commodity off-the-shelf technologies to deliver scientific and engineering computational cycles at the lowest possible price. These systems exploit a confluence of trends: commodity silicon technology, including microprocessor performance and memory density, which has improved tremendously in the past few years. Commodity networking, especially fast Ethernet at 1 gigabits/sec, has made it possible to design distributed-memory systems with tolerable bandwidths and latencies. Our system is formed by:

- Front-end: P4 Xeon dual, clock 1'7 GHz. 1GB central memory, RAMBUS 800Mhz
- Nodes: 5 x PIII dual, clock 1Ghz, 1GB central memory.
- Net: Switch Ethernet 1Gb/s and Switch Ethernet 100Mb/s.

-*Operating System*

Free operating systems, such as Linux, are available, reliable, well-supported, and are distributed with complete source code, encouraging the development of additional tools including low-level drivers, parallel file systems, and communication libraries. Industry standard parallel programming environments, MPI are commonplace across the spectrum of high-end supercomputers, and are also available for and well-suited to Beowulf-class systems.

- O. S.: Linux + PXE TCP/IP+BPROC
- Libraries: MPI

-*Software*

Modeling complex physical phenomena in three dimensions using partial differential equations(PDEs) often gives rise to systems of large sparse linear systems. Direct methods such as LU decomposition or Gaussian elimination techniques become very inefficient as problem size increases. They also require large storage space to perform the intermediate steps. Therefore robust and fast iterative methods such as the Krylov subspace methods become highly useful.

Iterative solvers require less memory and can yield to an approximate solution significantly faster than direct methods.

Aztec provides linear algebra tools for solving linear systems of sparse matrices on large scale MIMD systems. Aztec employs several Krylov subspace methods, conjugate-gradient methods, and includes preconditioners for improving convergence.

The user can choose between the following conjugate-gradient and preconditioners from Aztec when solving large sparse linear systems:

- Krylov subspace conjugate-gradient methods
- Conjugate gradient
- Conjugate gradient squared
- Transpose-free quasi-minimal residual
- Bi-conjugate gradient with stabilization
- Restarted generalized minimal residual

Preconditioners:

- K-step Jacobi-Neumann series polynomial
- Non-overlapping domain decomposition using a sparse direct solver
- Incomplete LU
- Block incomplete LU
- K-step, using symmetric Gauss-Seidel
- Aztec lets you choose between one of two standard methods for storing the sparse matrices:
  Modified sparse row (MSR)
  Variable block row (VBR)

The Finite Element Solver used are:

- FEAPFLOW
- MYDAS

2.4 Visualization and Information Extraction

The extraction of relevant physiologic information from the computational analyses poses significant challenges in scientific visualization.

Problem 1. Visualization techniques
A qualitative view of the flow field is obtained through contour and vector slices, streamlines, isosurfaces, and particle release methods.
Answer 1.Has been extracted from the VTK software library, different source code with different visualization techniques. VTK is an open-source, object-oriented software system for computer graphics, visualization, and image processing.

3 Success indicators

Estimating globally the activity inside our project, our opinion is that most research goals and consequences are being achieved. Different indicators are as follows:

At this moment, thanks to the project we have several PhD fellowships sponsored by different institutions.

We have published and submitted:
- reports of the research
- chapter (in press)
- papers to international journals
- presented papers in international and national conferences.

We are participating in an European Network proposal that gathers most of prestigious Medical Image analysis groups from all over the Europe (http://www.creatis.insa-lyon.fr/BHEN/).

We work in a close collaboration with the physician groups of the project,

We enjoy contacts with different international groups represented by famous Computer Vision and Medical Image Analysis researchers as: J. Suri, Philips, Cleveland, USA; N. Paragious, Siemens, Boston, USA; J. Reiber, Leiden, Leiden University Medical Center, The Netherlands; A. Amini from Washington University, St. Louis, USA. etc.

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Note: In this moment the project is at the beginning of the third year. The principal results on the whole, will be obtained in the next months.

PETRA: Oral Interfaces for Advanced Unified Messaging Applications. TIC2000-1735-C02

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Abstract

Nowadays, different messaging services are provided by different systems: voice messages, fax, e-mail,.. Therefore, users have to phone to hear their voice messages, to go to fax machines to read their faxes, to use PCs to update their e-mail account,... This circumstance, along with the present expansion of mobile telephony and Internet, leads to a new and powerful application of Computer Telephony Integration (CTI) technologies: the unified messaging. There are already some basic systems that permit the access to the e-mail by phone. However, an advanced unified messaging platform has to consider ergonomic and functional innovations that permit in a natural man-machine interaction environment an intelligent managing of any kind of information from everywhere and using the most suitable format for each circumstance. The project proposes the implementation of a new system that increments the levels of mobility, usability and confidentiality of existing systems by integrating telephony, fax and e-mail (including webmail-style HTML client acces) and by incorporating the new technologies of linguistic engineering, regarding to speech processing (oral interfaces for system control by automatic speech recognition and text-to-speech conversion, speaker authentication,...) and text processing (automatic classification and retrieval of documents, text summarization,...). The convergence of these technologies is a key factor for the development of a system with objectives so ambitious as those aimed in this project.

Keywords: Advanced unifyied Messaging, Speech Processing, Natural Language Processing, Hypermedia Systems, Knowledge Management.

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1 Project Goals

The global goal of the project is developing an advanced and flexible system for unified message management, which enhances the movility, usability and confidentiality levels of current systems, while keeping compatibility with main nowadays computer–phone integration platforms.

Movility and usability will be enhanced through intelligent information processing techniques and the use of varied source and destiny devices. This should increase Spanish companies competitivity and ease the usage of phone–based automated solutions to improve the efficiency of both public and private organizations.

The project includes three work lines:

1. Integration of phone, internet and fax services, including an e-mail access through HTML client (webmail), which will increase communication mobility and multimedia facilities. This line includes subgoals aiming to the development of a flexible modular architecture, which may present the same information in different forms through different devices (webmail, phone, fax) [Cid et al. 2002].

2. Development of advanced oral interfaces based on speech recognintion and understanding, speech synthesis, and speaker verification. The subgoals in this issue include the enhancement of robust voice signal processing, dialogue modelling based on keyword detection, proper noun recognition, improvement of speech synthesis techniques, speaker validation [Mariño & Nadeu 2002].

3. Intelligent information management through the use of Natural Language Procesing (NLP) techniques for text classification and summarization, as well as for information retrieval. This taks includes the subgoals of advanced named entity recognition and correference resolution, document filtering, categorization and retrieval, and text summarization, being this last issue specially relevant for oral interfaces to electronic mail systems.

The confluence of speech processing and natural language processing technologies is a crucial factor in the development of such a system, which requires the concourse of a wide range of knowledge and experience in linguistic engineering.

2 Achieved level of success

2.1 Speech recognition and voice synthesis (Task 3)

When designing an interactive speech system, a good speech recognizer is the first step to achieve a quality and friendly system. Our speech recognition system is based on semicontinuous hidden Markov models. The sampled signal is processed to obtain three value vectors: the MFCC (Mel-Frequency Cepstral Coefficients) and their two first temporary derivatives. Each of these vectors is vector-quantified to the closest 6 (from a total of 512) codewords of the corresponding codebook. An utterance is recognized as a sequence of key-words or key-sentences and filling segments [Macho & Nadeu 2001a, Nadeu 2002].

The lexicon is acoustically modeled by using either whole words or demiphones, a context dependent sub-word unit that accounts for a half phoneme, either the left or right

part. Numbers and answers to critical request (yes or not) are provided with word models. Thereby the recognition rate increases and the control of the dialogue is improved. The rest of the lexicon is modeled by demiphones. A confidence recognition measure is computed using a free-grammar phoneme background model in order to validate the system outputs [Caballero et al. 2002, Nogueiras et al. 2002, Pradell 2002].

Regarding to speech synthesis, for applications focussed in a domain, one feasible option is to record a limited number of segments and concatenate them using templates. Due to the nature of the PETRA application, manipulation of e-mail messages, our text is not under control. In this case, it is necessary to use a text-to-speech (TTS) system, that is able to transform an arbitrary text into speech [Escudero et al. 2002, Pardàs et al. 2002, Pardàs & Bonafonte 2002].

A TTS system gives complete freedom but, regarding quality, it is not so natural. Most of the TTS systems generate the speech, first, concatenating elementary units (of the size of the phoneme) and, second, modifying the tone and duration of the unit to have the proper prosodic values. Both the concatenation of segments and the modification of the units degrade the quality of the speech. If the computational requirements are not critical (as in the case of voice servers), the best TTS systems use large speech databases containing several hours of speech. The databases contain many instances of each elementary unit. To produce a sentence, the system chooses the units of the database trying to reduce the number of concatenation points and to minimize the tone and duration modifications required to have the correct prosody. At present, these systems concatenate variable length segments as function words, common morphemes, triphones, diphones, etc.

Previously to concatenate the segments to produce the speech, a TTS system has to analyze the text and assign a prosodic description to the text. In PETRA, the TTS component receives its input from the text generator component that introduces prosodic tags to facilitate this task. The generated text includes the position and duration of pauses and some intonation and speed tags which has being introduced specifically for this project in the TTS component.

2.2   Oral Dialogue System (Task 4)

A dialogue system based on speech recognition has been designed with the aim to bring the user a friendlier access than the provided by a system working only with DTMF tones.

The dialogue is guided, namely the automatic system takes the initiative. However, the user is not obliged to follow rigid syntactic rules fixed by the system, and the lexicon is open enough to offer a friendly dialogue. To constraint the user answers, the system implicitly offers the vocabulary for the expected answer.

Using this strategy, we have implemented an effective and efficient real system. Dialogues based on mixed initiative or user's initiative are more natural. However, they are resource expensive due to that design is often application-dependent and to the bigger complexity of the error repair, and the anaphora and context resolution. Moreover, when dealing with this complexity, the system could become ineffective (the user gets non expected outputs from the system) [Pradell & Hernando 2002, Trias-Sanz & Mariño 02].

In the design of the strategy of a guided dialogue system, it is important to take care of the order and the subject of the question formulation. Regarding to the order, questions about information needed in different points of the dialogue are made first, for example, the place name question is mandatory for all the tasks that the system can develop, therefore it was asked first.

Interactive speech systems must deal with the speech recognition errors and misunderstandings. Thus, most of the effort in the strategy design has been focused on the detection and management of these problems. For this purpose, data confirmation and hand label prosody for language generation have been used.

All the recognized information is confirmed before it is used. Two types of confirmations are possible: explicit and implicit. In the explicit confirmation the user is directly asked about if a recognized value is correct. Explicit confirmations are used when much information is simultaneously confirmed or when the data to confirm is critical (the user telephone number). The implicit confirmations improve the dialogue fluency. They appear systematically in the beginning of the next question. In this case, when the user detects an error, he/she is able to repeat the data by using the keyword *correct*. At any moment, when the user says *no, error, correct,...*, the system understands that a dialogue error has occurred.

The user is able to interrupt the dialogue with the system at any time to correct it or to ask for a repetition/clarification. It is also possible to interrupt the system in order to answer a question before it is finished (e.g. an expert user that recognizes the question when the message begins). This possibility of barge-in contributes to a fluent dialogue, although it can imply problems in noise environments.

In order to obtain a friendly and successful dialogue, besides to pay attention to the question formulations and to make implicit confirmations, a complete aid system has been designed. There are two kinds of aids: automatic and requested by the user.

The system gives aid messages in the following cases:

- The system is not able to reliably recognize what the user says. In this case, three types of messages can occur while error persists: messages with examples of the type of answer that the system is waiting for, messages informing about key words of dialogue control, e.g. "repeat", and, finally, messages giving instructions to the user about the way he/she should pronounce,

- The user requests it directly. In this case, an explanation of the type of answer that is expected from the user is given. The present dialogue state can also be described.

- The user does not answer a question. The system may then suggest several possible answers.

The dialogue control module is based on a typical finite-state system. Each state is related with the acquisition of a particular user data, for example, the place he/she asks information for, the kind of information that he/she wants or the telephone number where he/she wishes to be warned. In all states, the system performs the same operations: the activation of the appropriate recognition grammar, the reproduction of the system voice message to ask for the user information and the recognition of the user utterance. The dialogue control module decides which is the following state depending on the recognition result and the dialogue history. The historical information is maintained by the dialogue control module by means of a data set that contains the present dialogue state, the previous one, the recognized data, and control variables.

The development of the dialogue system its being done in C++ and it's almost finished. There are implemented practically the totality of the phone access functionalities and the integration with the libraries for the mail server access developed for this project is completed.

The evaluation tests will show where the users presents more difficulties to understand with the system so we can improve the grammars and the help messages at that points.

Grammars are dynamically generated during the communication and are adapted to each user in function of the available folders in his mail accounts, his address book and the messages saved in his mailbox. With the keywords recognized and their confidence, the system decides if the user has answered a question or wants to start an action with the message he is listening (reply, forward, etc) and indicates to the response generator if it has to request a confirmation to the user a confirmation, give a message of help or start another function.

2.3 Speaker verification (Task 5)

A speaker recognition API has been implemented, that can guarantee a secure access through speaker verification to restricted areas (applications, physical access control...). If the security level is not too high, it is possible to forget about the tedious task of memorizing a password. The API needs enrolment: a voice pattern and a threshold for every speaker will be computed. When an unknown speaker requires authentication, incoming voice is compared with the pattern and a score is obtained. If this score is higher than the threshold, the match is accepted. It is a multiplatform interface easy to configure. It lets the user to select a great variety of options. It has also the possibility of adapting voice patterns to new incoming data, improving accuracy. Besides, it could be used in combination with speech recognition software and PKI systems. Its main features are: no need of password memorizing; optionally, a voice pattern could be improved with new data from the same speaker, improving accuracy; compatible with a speech recognition software; multiplatform (Win, Solaris,...), error rates around 1% for short sentences and 3% for connected digits with few training data; text dependent or text independent applications supported [Rodríguez et al. 2001a, Rodríguez et al. 2001b].

2.4 Advanced Text Processing Techniques (Task 6)

NLP applications such as the classification and summarization tasks in this project, it is necessary to rely on robust, wide-coverage language resources, which includes lexical databases, corpora, and linguistic processors.

Task 6 deals with the creation, updating and adaptation of new and existing resources for NLP processing. It involves two subtasks: the first refers to resource adaptation and extension, and the second to Information Retrieval resources.

With respect to the first, several lines are being followed:

- Linguistic Processors adaptation. This is mainly an engineering task, which aims to ease the integration of analyzers and resources, in this and in further projects. The proposed architecture is object oriented distributed, which makes each component independent of the others, and greatly eases its use from any application requiring NLP facilities. Additionally, objects which can be accessed via CORBA from any remote machine [Carreras & Padró 2002] enabling the construction of distributead applications.

  The management of the morphoogical database has been reimplemented to improve its portability, and thus the distribution of the linguistic work consisting in updating morphological rules and lexical entries.

Finally, a C++ recoding of the slower Perl modules is currently being undertaken in order to speed up the system, which is a critical issue, specially for on-line applications such as the current project.

- WordNet enrichment. On the one hand, the WN-Domain labels developed for Word-Net by the *Instituto de Ricerca Scientifica e Tecnologica* in Trento, have been ported to EuroWordNet, enabling its use in Spanish, Catalan and Basque. The use of WN Domains is a useful information source in tasks such as text categorization and word sense disambiguation.

  On the other hand, procedures for hierarchy mapping [Daudé et al. 2001] have been developed, and applied to different WN version, providing an accurate version independence to WN-based applications and resources. The mapping procedures have also been applied to multilingual hierachy mapping between Spanish dictionary-acquired taxonomies and WN. All these techniques should improve the quality and quantity of semantic knowledge stored in EuroWordNet.

- Corpus compilation (i). A corpus of e-mail messages has been compiled to be used as a workbench for classification and summarization tasks. The corpus consists of some 3,000 messages classified as spam (1,400) and non-spam (1,600), and is being used to train intelligent mail filters. Also, 200 messages from prototypical users (univesity professor/researcher) have been studied to stablish content, linguistic, functional, and structural features which may be of interest to adapt classification and summarization techniques to the particular case of e-mail message.

- Corpus compilation (ii). The building of a reference corpus for Spanish has been undertaken. The corpus aims to contain half a million word tokens morphosintactically annotated and syntactically parsed. Currently, 100,000 words have been hand annotated with morphosintactic information, and the corpus has been used to train and test a new version os the Spanish part-of-speech tagger, achieving a 97.2% precision. Current work is on the direction of enhancing the tagger precision through the use of hand written context rules.

Regarding the Information Retrieval resources subtask, work on multiword processing has been very productive. A prototype of a named entity recognition and classification system has been developed, based on machine learning techinques. The prototype [Carreras et al. 2002b] participated in the CoNLL'02 shared task[1], on named entity recognition. being classified in a clear first position among twelve participating systems from world top researchers in machine learning applied to NLP.

The training of such system required the compilation of a Spanish corpus of 800,000 words containing over 80,000 hand–annotated named entities, classified as PERSON, LOCATION, ORGANIZATION or OTHER [Arévalo et al. 2002b]. Part of this corpus constituted the training and test bench for the CoNLL'02 shared task.

Other work in the reseach on named entity recognition included the development and revision of large gazeteers, linguistic theoretical work on proper nouns and named entities, and the development of a grammar to detect complex named entites, which are usually compounds including simpler entities (e.g. *the president of the USA*).

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[1]http://cnts.uia.ac.be/conll2002/ner

2.5 Information Retrieval and Text Summarization (Task 7)

Regarding the document categorization task, several algorithms (Boosting, SVM's, ADT's, Winnow, NN's) have been implemented and thoroughly tested on categorization and filtering tasks. The algorithms have been tested on several standard domains for English, as well as on Spanish news corpora [Carreras & Màrquez 2001].

As particular results, an operative prototype for spam filtering is being used in beta test stage on the mailboxes of several group members. Also, a corporative message router which offers the customer a single interface, and redirects the message to the adequate department depending on its content is being developed, and will constitute a module in the final system.

Regarding automatic summarization, two main lines have been followed. On the one hand, a linguistic–based approach which aims to exploit discourse structure to perform automatic summarization. On the other hand, a statistical–oriented approach is also being explored.

PhD students are working in both lines. In the first, the discourse structure is captured through the detection of discourse markers. A thorough theoretical study of discourse markers has been performed [Alonso et al. 2002b, Alonso et al. 2002c], an automatic tool for statistical detection of markers in unsupervised text has been developed [Alonso et al. 2002d], and both have been used to create and enhance a discourse marker lexicon [Alonso et al. 2002a] which is used in the summarization system [Alonso 2001a, Alonso 2001b]. In the second, lexical chains are used as relevance indicators to select text sentences or paragraphs that will constitute the abstract [Fuentes & Rodríguez 2002] .

Additionally, both systems have been put to collaborate in a hybrid system which offers promising results [Alonso & Fuentes 2002].

As necessary resources for this research, a small reference corpus for Spanish summarization has been developed, hand tagging the relevant sentences in a corpus of news items. The corpus was used to test both the summarizer prototype based on lexical chains and the linguistic system. The performance on a domain such as e-mail messages will be probably lower than on news agency texts, so, it is possible that in a future, either a sumamrization-oriented corpus of e-mail messages is build, or the usage of the summarizer in the system is restricted to long, well-written messages and attached documents.

2.6 Integration (Task 9)

Modules and prototypes developed in taks 3 to 7 are progressively being integrated in the final system. Nevertheless, the more intense work in this task will start on the last three months of 2002, and last all over 2003.

3 Result indicators

Results of the project include the formation of the following personnel:

- Alberto Abad. Telecommunications Engineer. PhD Student. He works on spoken dialogue implementation under the supervision of Javier Hernando.
- Laura Alonso. Linguist. PhD student, Universitat de Barcelona. She works on knowledge based automatic summarization, based on discourse structure. Under the supervision of Lluís Padró (UPC) and Irene Castellón (UB).

- Jordi Atserias. Software Engineer. UPC Project researcher. He works on semantic parsing, and in constraint-based language understanding, aiming to develop integrated methods to solve several Language processing tasks, ranging from speech recognition to semantic parsing. Under the supervision of Lluís Padró (UPC) and Germán Rigau (EHU).

- Isaac Chao. Undergraduate student. He is working on project modules and integration, which will be his degree project.

- David Hernando. Undergraduate student. He is working on project modules and integration, which will be his degree project.

- Pere Pujol. Telecommunications Engineer. Project researcher. He works on robust speech recognition in adverse conditions under the supervision of Climent Nadeu.

- Javier Rodríguez. Telecommunications Engineer. PhD Student. He works on speaker verification under the supervision of Javier Hernando.

- Luis Villarejo. Software Engineer. PhD Student. He works on database managing and standard voice xml languages under the supervision of Nuria Castell.

Publications on the research developed inside the project are listed in the bibliography at the end of this paper. Nevertheless, it is remarkable the publication id the PhD thesis of J.Pradell [Pradell 2002] under the supervision of Dr. Nadeu, which has been partially funded by this project.

Also, the project is related to the following European projects

- Majordome - Unified Messaging System (E!-2340). Its aim is to introduce the unified messaging system that let users access E-mail, voice mail, and faxes from a common 'in-box', and, in turn, make all types of messages accessible directly and/or remotely via Internet or mobile. Participants: Electricité de France, Escuela de Telecomunicaciones de París, Holistique (Francia), Real Instituto de Tecnología (Suecia), Euroseek (Suecia), Software602 (Chequia), Vodafone, Vecsys (Fracia), Universidad de Patras, Multitel (Bélgica), Babel Technologies (Bélgica) and Mensatec.

- NAMIC, News Agencies Multilingual Information Categorisation (IST-1999-12392). News document classification techniques developed in this project were adapted to e-mail routing and filtering. Participants: University of Rome (Tor Vergata), University of Sheffield, Free University of Brussels, Knowledge Stones inc. (Roma), International Press Telecommunications Council, Agenzia ANSA, Agencia EFE and Financial Times

Regarding technology transfer, the companies which expressed interest in participating in the project (Airtel -now Vodafone-) and Retevisión Móvil accomplished the proposed goals, contributing in the specification task, and in promoting/distributing the developed systems. In addition, Vodafone collaborates in the project designing and performing field tests.

Also, under request of the Secretary of Telecommunications and Information Society and the Meteorology Service of the Catalan government, the we have recently developed an innovative meteorological voice portal that is available to the Catalan public. The aTTemps system (accés Telefònic al Temps, phone access to weather) is a voice-operated portal that gives easy access for real-time automatically gathered meteorological information and weather forecasts.

It is a new and real service in Catalonia available to users for tourism and leisure purposes, and professionals with a need for immediate, and accurate meteorological data, such as civil defense members. The user requests data of any municipality or spot, i.e. tourist resorts, by establishing a friendly oral dialogue by means of a phone call. Furthermore, the system also provides a warning and alarm service: the user is informed through a phone call or a text message to his/her mobile phone whenever certain meteorological conditions occur in a place of interest. The oral dialogue system has been evaluated with the PARADISE framework.

Finally, the City councils of Barcelona and Vilanova i la Geltrú have expressed their interest in the e-mail routing modules included in the project, which could help to provide a single interface between citizens and administration. Up to now, collaboration has been limited to the provision of an e-mail message training corpus sent to Barcelona city web page, but a prototype running in Barcelona web server is expected to be ready by the end of the project.

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SISHITRA: Text-to-text and speech-to-speech Catalan-Spanish hybrid translation systems TIC2000-1599-C02

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Abstract

In the European multilingual society, *machine translation* can play an important role helping communication between its citizens. The goal of the SISHITRA project is to develop machine translation systems from Valencian (Catalan) to Castilian (Spanish) and from Castilian to Valencian that work both with text and with speech.

To achieve this goal, deductive (linguistic) and inductive (example-based) methodologies are combined. Both types of knowledge are represented as finite-state transducers. Several prototypes (general text-input and specific-task speech-input translation systems) have being produced and they are now being evaluated.

Keywords: Morphological Analysis, Finite-State Transducers, Word Graphs, Statistical Machine Translation, Search Algorithms, Pruning Techniques, Syntactic Analysis, Lexical Disambiguation, Semantic Disambiguation, Corpus Acquisition, Categorized Language.

1 Introduction

Rule-based techniques are the usual approach for building general machine translation systems. However, example-based approaches have raised an increasing interest in machine translation during the last decade. Indeed, example-based approaches have shown competitive performance in dealing with translation tasks in restricted domains and have also been useful to deal with some subproblems that arise in rulebased translation, such as POS tagging [1, 7] or finding non-strictly linguistic relations among words or phrases in specific tasks [3, 4, 2]. On the other hand, finitestate machines have been successfully used to implement both rule-based

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and example-based machine translation systems and also to develop useful tools for natural language processing [11, 10, 8, 9]. Finite-state techniques are appreciated for their simplicity and high time performance.

The increasing demand of tools that allow a better information exchange between people who belong to different linguistic communities had led the involved research groups to address two different and previous projects with similar goals and techniques (finite-state transducers): *InterNostrum* [5] and *TAVAL* [12]. Based on the experience acquired in those projects, they decided to propose a joint project: *SISHITRA*. This new project takes advantage of the high degree of sequentiality existing between Spanish and Catalan, that makes possible to avoid the analysis of complex word alignments and big changes in syntactic structures.

2   The SISHITRA project

2.1   Goals of the SISHITRA project

The primary goal of the SISHITRA project was:

> *The construction of Valencian (Catalan) to Castilian (Spanish) and Castilian to Valencian translation systems.*

The translation between two languages can be performed from text or speech to produce text or speech in the target language. The lack of translation systems from Valencian speech and the reduced number of suitable systems applied to Valencian, as a dialectal variety of Catalan, has led the applicant groups to propose the following, concrete objectives:

1. The construction of text-input translation systems for several Castilian to Valencian and Valencian to Castilian tasks.

2. The construction of a speech-input Valencian to Castilian translation system oriented to specific tasks.

The experience of the applicant groups in different translation methodologies (statistical, based on finite-state transducers, linguistic) makes it possible to bring up hybrid approaches that will allow to carry out the previous objectives if the following scientific objectives are reached:

1. The development of methodologies for learning finite-state transducers.

2. The development of statistical methodologies for translation.

3. The development of techniques for the automatic extraction of a bilingual lexicon.

Together with the following technological objectives:

1. The development of tools based on automata and finite-state translators for handling the linguistic knowledge.

2. The development of tools for the automatic construction of a bilingual lexicon from parallel corpus.

3. The development of tools for the construction of a Castilian-Valencian bilingual corpus, morphologically and syntactically aligned and labeled.

4. The development of a statistical disambiguation system for Valencian and Castilian.

5. The construction of a morphologically labeled and syntactically analyzed parallel corpus.

6. The generation of Valencian acoustic models.

7. The implementation of finite-state transducers from Valencian to Castilian and Castilian to Valencian.

2.2 Organization of the SISHITRA project

2.2.1 Tasks of the project

The project is independently organized into five modules and two subprojects. Each module is split into a variable number of tasks and every task is assigned to one of the two subprojects. Every subproject consists of those tasks that are under the responsibility and organization of one of the two participating groups even if researchers from both groups will participate during its development.

MODULE 0. Project coordination and tasks definition.

  TASK 1. Project coordination. ITI[1].

  TASK 2. Definition of tasks to address. UA[2].

MODULE 1. Data acquisition.

  TASK 1. Design and acquisition of a collection parallel texts. UA.

  TASK 2. Tagging and filtering of text data. UA.

  TASK 3. Design and acquisition of oral data collection. ITI.

  TASK 4. Tagging and filtering of oral data. ITI.

MODULE 2. Construction of acoustic, lexical and language models for Valencian and Castilian.

  TASK 1. Construction and evaluation of acoustic and lexical models. ITI.

  TASK 2. Language model construction and evaluation. ITI.

MODULE 3. Construction of finite-state translators for Valencian ⇔ Castilian translation.

  TASK 1. Construction of finite-state translators for Valencian ⇔ Casitilian translation. ITI.

  TASK 2. Incorporation of statistical techniques in the construction of finite state transducers. ITI.

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MODULE 4. Incorporation of linguistic knowledge in the construction of finite state transducers.

    TASK 1. Automatic construction of bilingual dictionaries. UA.

    TASK 2. Development of tools for morphologic and syntactic labeling of bilingual parallel corpus. UA.

    TASK 3. Construction of lexical disambiguation systems. UA.

MODULE 5. Prototyping.

    TASK 1. Basic prototype construction and evaluation. ITI.

    TASK 2. Robust prototype construction. ITI.

2.2.2 Chronogram

Tasks	Leader	First year	Second year	Third year
Module 0 Task 1 Project coordination	ITI	■■■■■■■■■■	■■■■■■■■■■	■■■■■■■■■■
Module 0 Task 2 Task definition	UA	■■■■□□□□□□□	□□□□□□□□□□□	□□□□□□□□□□□
Module 1 Task 1 Design & acquisition text data	ITI	■■■■□□□□□□□	□□□□□□□□□□□	□□□□□□□□□□□
Module 1 Task 2 Filtered & labeled textual data	UA	□□■■■■■■□□□	□□□□□□□□□□□	□□□□□□□□□□□
Module 1 Task 3 Oral data acquisition & design	ITI	□■■■■■■■□□□	□□□□□□□□□□□	□□□□□□□□□□□
Module 1 Task 4 Filtered & labeled oral data	ITI	□□□□□■■■■■■	■■■□□□□□□□□	□□□□□□□□□□□
Tasks	Leader	First year	Second year	Third year
Module 2 Task 1 Acoustic model construction	ITI	□□□□□□□□■■■	■■■■□□□□□□□	□□□□□□□□□□□
Module 2 Task 2 Language model construction	ITI	□□□□□□■■■■■	□□□□□□□□□□□	□□□□□□□□□□□
Module 3 Task 1 Finite translator construction	ITI	□□□□□□□□■■■	■■■■□□□□□□□	□□□□□□□□□□□
Module 3 Task 2 Statistical methods	ITI	□□□□□□□□□□■	■■■■■□□□□□□	□□□□□□□□□□□

Module 4 Task 1 Bilingual dictionary construction	UA	□□□□□□■■■■■	■■■■■□□□□□	□□□□□□□□□□
Module 4 Task 2 Morphologic labeling tool	UA	□□□□□□□□□□	□□□■■■■■■■	■■■□□□□□□□
Module 4 Task 3 Lexic disambiguation	UA	□□□□□□□□□□	□□□□□□□□■■■	■■■■■□□□□□
Module 5 Task 1 Base prototype construction	ITI	□□□□□■■■■■■	■■■■■■□□□□	□□□□□□□□□□
Module 5 Task 2 Robust prototype construction	ITI	□□□□□□□□□□	□□□□□□■■■■■	■■■■■■■■■■

3 Degree of performance

3.1 Achievements

3.1.1 General settings

1. The coordination of the subprojects has been carried out by means of 3 joint general meetings.

2. A web server (`http://www.internostrum.com/sishitra`) has been developed to keep track of the advances and to share efficiently the information.

3.1.2 Data acquisition

Different bilingual corpora have been acquired in the project. Specific tools have been implemented to collect data from the web.

1. *Diari Oficial de la Generalitat Valenciana*(DOGV): A sentence-aligned bilingual corpus has been built based on the DOGV. The corpus contains all issues between October, 1999 and May, 2001. This corpus is composed by 15,000,000 Castilian running words and 15,350,000 Valencian running words. The vocabularies were composed by 52,000 Castilian words and 52,000 Valencian words.

2. *El Periódico de Cataluña*: This is a newspaper that produces electronic news in Catalan and Castilian. The corpus contains all issues between October,1999 and May, 2001. This corpus is composed by 18,200,000 Castilian running words and 19,000,000 Valencian running words. The vocabularies were composed by 131,700 Castilian words and 131,500 Valencian words.

3. *European Union jurisprudence*: In Danish, German, English, Spanish, Finnish, French, Italian, Dutch, Portuguese, Swedish and Greek. 13,000,000 running words for Spanish and 11,000,000 running words for English. The Spanish vocabulary was composed by 67,000 words and the English vocabulary by 41,000 words.

4. *European Union legislation*: Similar to the previous one with 16,000,000 running words for each language.

The corpora for the lexical and semantic disambiguation:

1. *Lexical disambiguation*: corpus LexEsp with labels defined in the previous project TAVAL (70 labels). The corpus was composed by 90,000 Castilian running words.

2. *Semantic disambiguation*: The corpus contained 5,100,000 Castilian running words and 5,350,000 Valencian running words. The vocabularies contained 124,000 Valencian words and 120,000 Castilian words. The number of ambiguous Castilian words was 6,370.

The corpora for the transducers that are devoted to speech input were:

1. *Valencian-Castilian tourist task*. The corpus was an adaptation of a previous Spanish-English corpus [13]. The domain of the corpus was typical human-to-human communication situations at a reception desk of a hotel. The corpus was composed by 200,000 pairs. (1,900,000/1,930,000 Valencian/Castilian running words). The vocabularies were composed by 775/689 Valencian/Castilian words.

2. *Valencian-English tourist task*. This corpus is similar to the previous one but the target language was English.

3. *Weather forecast*. From different TV news, 3 hours of speech were collected about weather forecast, some of them in Castilian and some in Valencian. The text transcriptions were translated using the InterNOSTRUM system and, later, revised. The total number of pair sentences was 1333 (35,000/36,000 Valencian/Castilian running words). The vocabularies were composed by 2,700/2,500 Valencian/Castilian words.

3.1.3 Acoustic models

A Valencian speech corpora is now available to train acoustic models:

- 2,400 sentences from 40 speakers.

- 25 Valencian context-independent phones (hidden Markov models) are being trained.

Castilian context-independent phones are available from previous projects.

3.1.4 Finite-state transducers

The finite-state transducers were built for the tourist and weather forecast tasks using the corresponding corpora described above. The MGTI technique was used to infer the finite-state transducers [6]. The performances of the transducers for text-input translation were:

1. Tourist task for Valencian to Castilian: 0.1% of translation word error rate (Controlled, large corpus of two similar languages)

2. Tourist task for Valencian to English: 3.8% of translation word error rate (Controlled, large corpus of two quite different languages)

3. Weather forecast task for Valencian to Castilian (spontaneous transcriptions and very small corpus of similar languages): 8% of translation word error rate.

3.1.5 Text-input hybrid transducer

The text-input hybrid transducer is an improved version of the TAVAL translation system:

1. The bilingual dictionary has been corrected and enlarged.

2. The statistical lexical disambiguation system has been improved using a revised corpus.

3. A statistical semantic disambiguation system has been introduced in order to deal with some difficult Castilian words.

4. A tool for the assessment of the translation produced by a transducer has been developed. This assessment is based on the comparison with (multiple) references and on the number of edition operations required to correct it.

3.1.6 Incorporation of linguistic knowledge

1. An algorithm for maintaining dictionaries incrementally has been implemented and published as a regular paper in *Computational Linguistics* 28(2):207–216, 2002.

2. Two morphologic dictionaries (Valencian and Spanish) have been built, as well as a translation dictionary including the correspondences between lexical forms of both languages. All together, the dictionaries allow for the translation of over 100000 surface forms.

3. A set of tools for aiding the annotation of corpora has been developed. First, a software was built that helps linguists (by means of a graphical interface and an incremental architecture) to choose among several candidate morphological labels. Second, a software for generating, manipulating and storing (in XML format) syntactic parses. Third, a simple procedure to align bilingual texts that works incrementally and with small corpora helps to build bilingual dictionaries.

3.1.7 Prototypes

The prototypes developed in the project are:

- A general text-input translation system for Castilian to Valencian (an improved version of the previous available TAVAL system).

- A tourist speech-input translation system for Valencian to Castilian.

- A tourist speech-input translation system for Valencian to English.

- Weather forecast speech-input translation system for Valencian to Castilian.

3.2 Difficulties

The refinement of the dictionaries is being a time consuming task. The general text-input translation system for Valencian to Castilian has been postponed to the last period.

4 Result indicators

4.1 Trainees

Some researchers have worked in this project as a part of their Ph.D.:

- Laia Meritxell Arenas Beneyto (ITI)
- Alicia Garrido Alenda (UA)
- José Ramón Navarro Cerdán (ITI)
- Sergio Ortiz Rojas (UA)
- Juan Antonio Pérez Ortiz (UA)

4.2 Technology transfer

- UA:

  The "Caja de Ahorros del Mediterráneo", a major savings bank in Spain, and the Universitat d'Alacant are using some of the translation tools designed in the project as part of their automatic translation system interNOSTRUM (online at `http://www.internostrum.com`).

  Some preliminary contact has been established with OVSI ("Oficina Valenciana para la Sociedad de la Información") and "Grupo Enciclopedia Catalana", who are interested in using the outputs of the project.

  The technology developed in this project will also be used to build a Spanish-Portuguese machine translation system commissioned by "Universia", a university consortium funded by "Banco Santander", one of the main banking institutions in Spain.

- ITI:

  A new European project (TT2) has recently started with the aim of developing a Computer-Assisted Translation system that will help to solve a very pressing social problem: how to meet the growing demand for high-quality translation.

  The technology developed in this project will also be used to build a Spanish-Basque machine translation system by a consortium of Basque companies and commissioned by a Basque research program

4.3 Publications

4.3.1 Journals

1. Rafael C. Carrasco and Mikel L. Forcada: "Incremental Construction and Maintenance of Minimal Finite-State Automata", *Computational Linguistics* 28(2):207–216, 2002.

2. Antonio Molina and Ferran Pla, "Shallow Parsing using Specialized HMMs", Journal of Machine Learning Research, Vol. 2, pp. 595–613, MIT-Press, 2002.

3. Antonio Molina and Ferran Pla and Encarna Segarra "Una formulación unificada para resolver distinto problemas de ambigüedad en PLN", Revista para el Procesamiento del Lenguaje Natural, Vol. 29, 2002.

4.3.2 Proceedings

1. R. Canals-Marote and A. Esteve-Guillén and A. Garrido-Alenda and M.I. Guardiola-Savall and A. Iturraspe-Bellver and S. Montserrat-Buendia and S. Ortiz-Rojas and H. Pastor-Pina and P.M. Pérez-Antón and M.L. Forcada: "The Spanish-Catalan machine translation system interNOSTRUM", in B. Maegaard ed., Proceedings of the Machine Translation Summit VIII, Machine Translation in the Information Age, pages 73–79, 2001.

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4. I. García, F. Casacuberta "Search Algorithms for Satistical Machine Translation based on Dynamic Programing and Pruning Techniques ", Proceedings of the Machine Translation Summit MT SUMMIT VIII, pag: 115-120, (Santiago de Compostela, Spain) September 2001

5. Ferran Pla and Antonio Molina, "Part-of-Speech Tagging with Lexicalized HMM", Proceedings of International Conference on Recent Advances in Natural Language Processing (RANLP2001), Tzigov Chark, Bulgaria, 2001.

6. J. Tomás, F. Casacuberta "Monotone Statistical Translation using Word Groups" Proceedings of the Machine Translation Summit VIII. (Santiago de Compostela, Spain) 2001

7. J. Tomás and J. M. de Val and F. Fabregat and F. Casacuberta and D. Picó and A. Sanchis and E. Vidal, "Automatic Development of Spanish-Catalan Corpora for Machine Translation, Proceedings of the Second International Workshop on Spanish Language Processing and Language Technologies, pp. 175–179, (Jaén, Spain), 2001.

8. F. Casacuberta, E. Vidal, J.M. Vilar. Architectures for speech-to-speech translation using finite-state models. In Proceedings of ACL02 Workshop on Speech-to-Speech Translation, Philadelphia, USA, July 2.002.

9. Mikel L. Forcada: "Using multilingual content on the web to build fast finite-state direct translation system", in Proceedings of the 2nd ELSNET MT Roadmap Workshop at TMI 2002 (Keihanna/Kyoto, Japan, March 16 2002), 2002.

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4.3.3 Invited conferences

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2. F. Casacuberta, "Finite-state transducers for speech-input translation", Proceedings of the Workshop on Automatic Speech Recognition and Understanding, december 2001, Maddona di Campliglio, Italy. IEEE Press.

3. Ferran Pla, "The Superficial Syntactic Analysis or the simplification of a complex task." ("El Análisis Sintáctico Superficial o la simplificación de una tarea compleja.") September 2002, Valladolid, Spain. SEPLN-2002

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Parallel Computing on Low-cost Platforms/ New Methodologies for High-level Design and Verification TIC1999-0474

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Abstract

This project coordinates two research areas that share common resources.

The subproject "Parallel Computing on Low-cost Platforms" is aimed to developing efficient and robust numerical methods designed to be run on multicomputer platforms based on low cost commercial systems interconnected through high-speed networks. Portability, easy-design and development of the parallel code will be promoted by using standard language extensions (e.g. openMP) integrated on a problem-solving environment. Selected numerical simulation applications will be parallelized on fields such as Weather Forecasting and Air-quality prediction, Fluid Dynamics and Non-linear Optic.

The subproject "New Methodologies for High-level Design and Verification" is conceived as a research action aimed at creating an integrated environment where high-level synthesis decisions and their verification can be treated within a common framework, having a rigorous mathematical basis where design correctness can be checked. A tool for fully automated verification of the behavioural design cycle will be developed. On the other hand, the possibility of efficiently mapping design solutions on reconfigurable hardware devices is another goal of this research. Special attention is devoted to the recent proposals for coarse-grain dynamically reconfigurable devices.

Keywords: Supercomputation, Parallel Computing, Parallel Programming Tools, Parallel Numerical Algorithms, Problem-solving environments, Advanced Architectures for Processors, Formal Verification, Behavioural Synthesis, High-level Verification, Dynamically Reconfigurable Devices, FPGAs, Temporal Partitioning.

Introduction

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The two basic working lines of our research group have been included in this project. The aggregation of these two lines into only one project, instead of two independent ones, has been fruit of a decision based on several different economical as well as scientific and technical reasons.

Because of the framework of this project the exposition of results will be presented separately for each of its two main co-modules.

Parallel Computing in Low-Cost Computing Platforms (Modules 0101, 0102, 0103)

Objectives

The goals at the proposal time of module 0101 (Design of efficient and robust multigrid algorithms) were structured in two main topics:

1. Design of parallel robust multigrid methods with optimal numerical properties for all kinds of anisotropies.
2. Optimization of memory hierarchy in present computers.

These topics are strongly related with the goals of Modules 0102 (Evaluation of low-cost architectures) and 0103 (Developments of challenge applications) and consequently, we have jointly considered these three topics in this final report.

Multilevel techniques are generally accepted as fast and efficient methods for solving a wide range of partial differential equations, especially elliptic operators. For this kind of problems, standard multigrid algorithms based on classical iterative methods, such as Gauss-Seidel or damped Jacobi, exhibit an optimal complexity (the computational work is linearly proportional to the number of unknowns), optimal memory requirements and good parallel efficiencies. However, the efficiency of the standard multigrid methods degenerates dramatically in the presence of anisotropies. For example, they occur naturally in the field of Computational Fluid Dynamics (CFD) where grid nodes are usually concentrated in certain regions of the computational domain for accuracy reasons or to capture small scale physical phenomena. These anisotropic situations lead to a worsening of the efficiency of standard multigrid methods and make robust algorithms mandatory.

Furthermore, the algorithms should exhibit a high degree of parallelism and efficiently exploit memory hierarchy in order to take advantage of present parallel computers. In particular, different alternatives for the parallel implementation of the target methods have been tested considering mainly low-cost platforms.

Level of Success

In order to evaluate different robust strategies we have first developed a parallel multigrid library based on MPI that implements all the possible combinations of smoothers (points, lines and planes) and management of grids. This library has been used to study different numerical test: from simple simulations based on the diffusion or the convection-diffusion equations to more complex applications such as a flat-plate boundary layer. These numerical kernels characterize the main features of some challenge applications in meteorological simulations, computational fluid

dynamics and non-linear optics. In addition, we have also applied this kind of techniques on cloth simulation.

In most situations a multigrid solver based on semicoarsening and a four-color plane-implicit smoother manages to reduce the residual norm by nearly five orders of magnitude in the first five cycles on the finest grid. The asymptotic convergence rate is equal to 0.19, which is close to that obtained for the Poisson equation with a semi-coarsened smoother. In addition, the solver is fully robust: the convergence rate is independent of grid sizes and grid stretching factors.

From an architectural point of view, multigrid methods often reach a disappointingly small percentage of their theoretically available CPU performance. This pathology is mainly caused by the employment of point-wise smoothers, which have to perform global sweeps through data sets that are too large to fit in the cache. Some authors have successfully improved cache reuse (locality) using well-known data access and data layout transformations. However, the improvements that can be achieved using these techniques in our target solvers are not relevant since fortunately plane smoothers exploit blocking in an implicit way. That is, the algorithms considered in this research are cache-conscious by construction. To parallelize the solvers we have opted to employ a 2-D grid partitioning in the semicoarsened direction. Unlike 3-D decompositions, this strategy avoids the need for a parallel block tridiagonal solver that has been demonstrated to have a low efficiency for small problems. A 1-D grid decomposition was also found to be non-scalable due to the multigrid critical level problem.

In complex simulations such as a highly stretched flat-plate boundary layer, satisfactory efficiencies (higher than 0.8) have been obtained on different parallel computing platforms for up to 32 processors simulations. If both the number of processors and the size of the problem are increased, the efficiency becomes worse, although only decreasing logarithmically.

Finally, we should remark that the experience acquired by the group on these kind algorithms has allowed us to optimize other applications with similar structure (from an algorithm point of view) and to apply multilevel optimizations in other contexts such as cloth simulation or interaction visualization of digital elevation models. In particular, we have achieved significant improvements on the implementation of the discrete wavelet transform, which is a valuable tool for a wide variety of applications, especially in image and video coding. In fact, state-of-the-art standards such as MPEG-4 or JPEG-2000 are based on this technology.

Module 0104: Processor Architecture

Objectives

The objectives of this module at the proposal time were structured in three basic researching lines:

1. Evaluation and design of data prediction techniques in microprocessors.
2. Integration of the data predictor with the architecture of the processor and evaluation of its potential to improve performance and to reduce complexity.
3. Analysis of the interaction among data prediction and other architectural techniques that improve ILP (instruction level parallelism), and its application to advanced processors.

<u>Level of Success</u>

With regard to objective 1, we have evaluated several data prediction techniques, such as last value predictors, stride predictors, context predictors and hybrid predictors and a new model has been proposed for low cost hybrid predictors. As opposite to the traditional hybrid predictors that use various distinct predictors and a selection mechanism, the predictor that has been proposed is based on various plans of overlapped prediction and a finite state machine that decides when it is necessary to use each part of the predictor. From the results obtained can be deduced that this predictor obtains similar results of predictability than context predictors, but for a quite smaller hardware price, so the cost-quality factor is far better than that of other predictors.

Upon culmination of objective 2, all the predictors analyzed have been integrated in the architecture of a superscalar processor. To do that we have employed the out-of-order architecture simulator Simplescalar v3, extensively accepted and used by the scientific community. It permits adjusting the majority of parameters of the processor and thus to test a great distinct number of configurations. Likewise distinct mechanisms of confidence have been practiced to determine of the quality of the predictions generated by the predictor, such as saturated, reset counters and counters based on history. The results obtained show that value prediction is certainly a technique that can exploit efficiently the ILP of superscalar processors, since the improvements in the performance of the processor are significant and a great deal more promising for future generations of processors, when complexity increase (processor wide and instruction window). From the results obtained we have been able to deduce that the hybrid predictor proposed is the one that better results obtain for a moderate hardware price. Likewise, of the distinct mechanisms of confidence analyzed, we have arrived at the conclusion that the most conservative mechanisms (reset counters) are the ones that obtain more satisfactory results, since they reduce notably the failures of prediction and therefore the times of penalty by failure.

Finally, in relation to objective 3, the techniques of prediction have been implemented in embedded and low-consumption architectures; we have also developed a power consumption analysis model that permits to carry out an adjustment of the parameters of the prediction mechanisms to improve the performance of advanced processors without increasing significantly the power consumed.

Module M0201: Applicability of Formal Methods to Architectural Synthesis.

<u>Objectives</u>

The objectives at the proposal time of this module were structured in three basic researching lines:

1. The formal verification of high-level synthesis processes.
2. The formal automatic circuit design.
3. The systematization of advanced design methodologies as formal derivation processes.

Regarding the first objective, the formal verification of high-level synthesis processes, we tried to develop a fully-functional environment for the automatic verification of this kind of processes. Hence, the aforementioned environment had to formally emulate the design process carried out by external algorithms in order to verify their correctness. As a consequence, we would achieve two important improvements. Firstly, lessen the test complexity – from exponential to polynomial –

and secondly, reach a high degree of resoluteness in the detection of erroneous design decisions. Therefore, we defined the capabilities for this environment, which are the following:

> The simulation of different behaviours
> Correct transformation of behaviours.
> The interaction with a wide range of theorem proves in order to increase its knowledge database.
> Interaction with an external synthesis tool, to verify its design decisions.
> Interaction with very well-known commercial-design environments.

Considering the second objective, the formal automatic circuit design, we settled as our main goal to deep into the study of new optimisation algorithms able to explore new kind of solutions that emerge in the fields of semantic synthesis. Furthermore, it is mandatory to take into account that those semantic fields adopt a common representation – either equations or terms – not only for the mathematical formalization of behaviours, but also for the formalization of the features involved in the whole design process, for instance, data-types, library of components, numeric representations, etc.

Finally, the overall goal of the third objective, the systematization of advanced design methodologies as formal derivation processes, was the definition of a starting point for a new period of basic researching. It deals with the systematization and applicability of advanced design techniques, which could be included in both the formal verification and the formal design environments. Among the aforementioned techniques, the following ones are included:

> The analysis of mutual exclusiveness, trying to attain a better exploitation of the hardware. It tackles the creation of a unified model that overcomes the erroneous detections and the undetectable exclusions that turn up in previous approaches.
> The addition of the re-timing concept to the high-level design flow as another way to modify the trade-off cost/performance in a native specification.
> The reverse engineering of RT designs considered as another genuine choice for the verification of a design.
> The behavioural segmentation – functional, structural or control-flow – in order to achieve a higher time performance for a specific circuit
> The manipulation of recursive and iterative behaviours to simplify the expressions of the complex ones.

<u>Level of Success</u>

The first researching objective of this module, the formal verification of high-level synthesis methodologies, has been successfully completed after the development of the whole set of tools (5), reference manuals (5) and tutorials (2) for the aforementioned chasing purpose. Moreover, we have checked its practical viability with the aid of specific plug-ins to link them with very well-known commercial-design environments. The tools that constitute the environment are the following:

- eqcomsh: compiler of the formal-specification behavioural language
- eqsynsh: formal behavioural handler with automatic derivation
- eqsimsh: behavioural simulator

- eqbsynsh: formal verifier of high-level design processes
- eqbsyn: graphical interface for the environment

Nowadays, all of them are available for several platforms, namely, PC under MS-DOS, PC under Windows and Sun Workstation under Solaris. Moreover, both user and reference manuals have been deployed for every single tool to provide full support. In the future, it is planned to make the environment entirely accessible via WWW for the researching community. As a result of this approach, four papers have been published.

The second and third objectives, the formal automatic circuit design and the systematization of advance design methodologies as formal derivation processes, have been two productive ones not only in the number of publications. In fact, they have envisaged an additional researching field that will be extended on the upcoming years. A thorough analysis on the issue of mutual exclusiveness execution has been done, as well as on manipulation of heterogeneous behaviours, reverse engineering at the register-transfer level and re-timing of algorithmic specifications. In addition, with the help of the first two analyses, a theoretical structure has been defined and it has allowed the proposal of a number of new algorithms for automatic synthesis in currently uncovered applicability fields in the literature. Thus, fifteen papers have been published concerning this approach and it is expected that next year, 2003, two Ph.D. theses will be defended.

M0202 Partitioning, placement and routing in Multi FPGA systems.

Objectives

A key step in Multi-FPGA system design is the study of spatial partitioning. Here the main problems are the reduced number of I/O pins that limits the percentage of logical occupation, and the slowness of the tools of placement needed to make the estimation of consumed pins in the partitioning phase. In addition, most of the proposed systems does not consider the topology of the board, therefore they do not compute the consumption of input/output resources that takes place when it is necessary to use some FPGAs of the system to route signals, nor the possible extra delays that can appear in the critical paths.

The objective of our work was to make a partition considering the topology of the card. It was possible to evaluate directly (without estimators) the real consumption of resources of input-output and the real occupation of the FPGAs. With such information the final mission was to try to maximize the use of the available logical blocks while respecting the time restrictions. The attainment of this objective would allow implementing more complex applications on a given Multi-FPGA board.

Level of success

To solve the problem we have developed two tools of partition and placement for Multi-FPGA boards.

The first one is a partitioning and simultaneous placement tool that uses evolutionary computation for the resolution of NP-complete problems, and that uses graphs to represent the solutions. In

this tool, we have implemented an evolutionary algorithm that allows us to make the partitioning using a simple encoding. In order to guide the algorithm, we have studied and developed a multi objective cost function that deals with the main ties of the problem: the shortage of input/output pins and the balance of CLB between all the FPGAS of the system. With this algorithm a problem of preservation of the structure of the graph appeared to us. To solve it, a technique of partitioning based on the expansion spanning tree of the graph was developed, which does not destroy the initial structure and that is based on the edges and not on the nodes, as it was usual in previous genetic tools used for the resolution of the problem. In addition, the problem of the premature convergence, that appears because codification uses a reduced number of genes, has been solved by means of a regeneration operator. This operator activates itself automatically when it detects that the best individual repeats itself a number certain of times. These techniques have been incorporated to a simple genetic algorithm, a compact genetic algorithm and a compact genetic algorithm with local search. The simple genetic algorithm had the problem of an excessive consumption of memory; this problem was solved with the implementation of a compact genetic algorithm (cGA). cGA has also the problem of giving slightly inferior solutions to those of the simple genetic algorithm, problem that was solved including local search in the compact genetic algorithm. Finally, since the greater computational cost occurred in the calculation of the cost function, we decided to parallelize the algorithm. We have made three parallel implementations of coarse grain and three topologies of communication: ring topology, mater-slave topology, and topology all-to-all, reaching the conclusion that the topologies master-slave and the all-to-all topology undergo a problem of premature convergence that does not undergo with a ring topology. By means of the use of a singular matrix of inexact relation, we consider not only the connections between FPGAS directly connected but also the connections between nonadjacent FPGAS.

In the second tool we have modelled a mesh multi-FPGA system like an only one FPGA of great size, representing the borders between FPGAS of the board as a superposed group. From this scheme the simultaneous partition and placement is made by means of an optimization algorithm that we called combinatorial thermodynamic optimization that is an adaptation of the simulated annealing algorithm and that avoids the adjustment of the parameters of the algorithm. This algorithm looks for the minimum number of cuts through the superposed groups. The placement updates each iteration to consider the consumption of input/output pins and the balance of CLBs between the FPGAS. For the resolution of the problem of the routing evaluation in the placement phase we have developed the RSR algorithm. This method is based on the temporary use of undetermined rectilinear regions. Its main advantage is the good results obtained in small calculation times. The speed of this algorithm can be taken advantage of in a double sense. On the one hand, it is fast enough to be used for measurement during the optimisation of the placement, instead of using the congestion that is the usual technique. With this new direction, the placement is optimised for a specific routing tool. On the other hand, it is possible to be used directly like a routing tool, therefore the uncertainty is eliminated on the routing in the placement stage and this allows a greater focalisation of the optimisation process towards the objective of reducing the congestion. The use of this algorithm in the phase of placement on FPGAs has allowed us to widely reduce the local congestion and therefore the necessary channel.

Module 0203: Embedded Systems Synthesis using dynamically reconfigurable HW

<u>Objectives</u>

The proposed tasks according to the goals of the module were the following:

1. Study of the basic block that must be a coarse grain FPGA that would assume the role of the configurable logic blocks in the fine grained FPGAs. The size of the basic block must be big enough in order that the interconnection area is not the predominant part in the device.
2. Study of a typical complex application (high performance DSP and multimedia applications)
3. Study of the different temporal partition options of the tasks that make up the application
4. Algorithm to attain the following goals: Minimizing context loading, maximizing data reuse, and maximizing overlapping of computation and data transfers

<u>Level of success</u>

Regarding the first task we have concluded that among the different alternatives the architecture of a basic block must be similar to the data-path of a processor. This basic block could be considered as a reconfigurable cell with an ALU to implement the usual basic functions. Apart from that it contains multiplexers to choose the ALU's inputs, a register to store the result's sign and a registers bank to use the former generated results. Inside each cell there is a configuration register (context) that stores the bits with all the information needed to specify completely the cell configuration. As there is not any control unit, the control information is included in the context. The context is the binary code that specifies the functionality implemented by the reconfigurable cells and the active interconnections among cells. The context defines the ALU´s function, the control bits to the inner multiplexers, the used registers, etc..

In DSP and multimedia applications there are a set of complex tasks (kernels) that are frequently used. If we are able to describe an application in terms of kernels we can say that these kernels are the computation grains. Thus, the design process of the applications is done at a high level, simplifying and speeding the code writing.

During this project several DSP and multimedia applications has been characterized. Moreover, synthetic applications have been developed to probe some other goals that have been also targets in our work.
Applications that have been studied are: MPEG (Motion Picture Export Group) standard of video compression, ATR (Automatic Target Recognition); Ray Tracing algorithm to get synthetic images with photographical quality.

We have included in the compilation environment a kernel library where is stored all the information related to the implementation of each kernel such as; computation time, input data size, output data size, context size, computation granularity, computation time that can be overlapped with context loading

We have developed three schedulers to check different options and the advantages that each one can present. The kernel scheduler states when the macro-tasks (kernels) must be executed. The

data scheduler establishes when the data have to be transferred. The context scheduler plans when the contexts must be transferred.

The applications could be represented by a set of kernels with dependencies among them that could be visualized in a dataflow graph. In order to have the best performance we have pursued the following goals; minimize context loading, maximize data reuse, maximize overlapping of computation and data transfers.

Our kernel scheduler has considered the three factors that have an impact in the execution time (data transfers, context loading and execution time of the kernels). The data scheduler has been designed taking into account that data transfers have to be minimized. As a consequence the execution time and power consumption have been reduced. The algorithm is implicit in the above subsections. In order to learn details of the algorithms you have to examine the publications that we include in this final report. See those related with Kernel Scheduler and Context and Data Schedulers.

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Technology transference

Technology transfer has been attained by the use of our results in MORPHOTEC, spin-off company of the University of California at Irvine, U.S.A. Dr. Maestre, one of the components of our group and author of several papers supported by the project, is now staff member of that company.

Four development contracts with CASA (EADS) Space Division for the optimization of coding for analysis of structures.

One contract with INFOS Ingenieria for the development of a 1 to N Biometric system.

Development of High-Performance Software in Heat and Mass Transfer to Optimize the Design of Thermal Systems and Equipment TIC1999-0770

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Abstract

This project focuses on the continuation of the work that the Group is being carried out in the framework of its main research line: *"Numerical Simulation and Experimental Validation of Heat and Mass Transfer Phenomena; Application to the Design of Thermal Systems and Equipment"*. Starting from the know-how and numerical and experimental facilities developed by the Group, the goal of the project is the continuous improvement of numerical simulation methodologies in order to contribute to the development of algorithms for the calculation and design of thermal systems and equipment of industrial interest. Thus, and with a long term planning, the work was divided in four different but interrelated levels: **i)** mathematical formulation of heat transfer and fluid dynamics phenomena with the aim of developing general and accurate models suitable for the design of thermal systems and equipment; **ii)** development and implementation of numerical techniques with the aim to elaborate robust and efficient models (wide range of convergence and both moderate memory and convergence time) and using verification techniques (code verification and verification of the numerical solutions); **iii)** software development and parallelization of the Navier-Stokes equations, design of parallel algorithms and parallelization of software; **iv)** experimental studies for validation purposes (modeling errors). The possible applications of the project are aimed to the simulation of thermal systems and equipment in which the achievements obtained in this project were applicable. In this way the acquired know-how has been almost immediately applied to the companies with which the Group collaborates, and also to propose new collaborations with other industrial sectors.

Keywords: Heat and Mass Transfer, Fluid Dynamics, Turbulence, RANS, DNS, Phase Change, Multiphase Flows, Combustion, Radiation, Numerical Methods, CFD, HPCN.

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1 Objectives of the Project

The basic objective of the project has been the continuous improvement of mathematical models and numerical simulation methodologies to the development of algorithms for the calculation and design of thermal systems and equipment of industrial interest. The work was divided in four different but interrelated levels: **i)** mathematical formulation of heat transfer and fluid dynamics phenomena with the aim of developing general and accurate models suitable for the design of thermal systems and equipment; **ii)** development and implementation of numerical techniques to create robust and efficient models (wide range of convergence and both moderate memory and convergence time) and using verification techniques (code verification and verification of the numerical solutions); **iii)** software development and parallelization of the Navier-Stokes equations, design of parallel algorithms and parallelization of software; **iv)** experimental studies for validation purposes (modeling errors).

The advance in the first level, *formulation of the phenomena*, is aimed to the consolidation and the in-depth analysis of basic topics in heat and mass transfer in order to elaborate physical-mathematical models. These topics are: turbulence models using RANS (Reynolds-Average Navier-Stokes) methodologies, turbulence models using LES (Large Eddy simulation) and DNS (Direct Numerical Simulation), solid-liquid phase change models in multicomponent fluids; multidimensional models of multiphase flows using the VOF (Volume of Fluid) technique, study of the radiation in participant media using DOM (Discrete Ordinates Method) and Monte Carlo techniques, multidimensional combustion taken into account complex chemical kinetics and reduced mechanisms; etc. The second level above mentioned, *numerical techniques*, is aimed to, starting from finite volume discretization techniques, the development of more accurate and stable discretization schemes, the implementation of new techniques of coupling of the conservation equations, the development of more efficient solvers, generalization to non-structured grids, developing of filters to detect software mistakes (code verification) and also a direct control of the truncation errors of the numerical solutions (verification process). The third level, *software development and parallelization of the Navier-Stokes equations*, has the objective of designing new algorithms with the intention of being parallelized and also the parallelization of already available software conceived for sequential computers, and the building of more modular structures which make it easier the abstraction of the kind of data and platform (parallel or sequential). Finally, the fourth level, *experimental validation*, allows determining the range of application of the assumptions made in the mathematical models developed (validation process).

These objectives are being reaching with a research team composed by four professors and associate professors, two contract researchers and thirteen doctorate students (six of them have already finished their doctoral thesis and other three will finished their thesis within the next year, see subsection 3.1). In the last year, five more doctorate students have been incorporated in tasks directly related with the main objectives of this project. To perform the work a Beowulf parallel computer has been assembled at CTTC to obtain high performance computing facilities at relatively low cost. Currently the cluster is composed by 70 AMD K7 processors at 900 MHz running Linux and with a fast ethernet network (100 Mbits/s). Different experimental facilities have been constructed with the objective of validating the advanced numerical models developed. It is interesting to point out the efforts spent in the evaluation of velocity fields by means of PIV (Particle Image Velocimetry) techniques.

2   Level of Success Obtained in the Project

The project started at the end of 1999 and it will finished at the end of this year. Most of the work has been accomplished following the steps indicated in the project proposal. A brief summary of the most important achievements of the project is here presented.

Turbulence has been analyzed using RANS and DNS techniques. More effort than the initially foreseen has been dedicated to DNS (the highest level of simulation) in detriment of LES models. Both LES and DNS need large computational resources and (from a point of view of high-performance computing) have the same problem: the need to solve efficiently large Poisson equations using parallel computers. A Direct Schur decomposition [17][23][28] and a Direct Shur-Fourier Decomposition algorithms [submitted to NHTB] have been designed and implemented with this purpose. Both allow to solve accurately two-dimensional and three-dimensional Poisson equations with just one message, providing speed-ups of at least 24 in a low cost PC cluster with a conventional 100 Mbits/s network and 36 processors.

Different RANS models (linear and non-linear two-equation models and algebraic Reynolds stress models) have been analyzed and implemented in different applications [10][31]. Special emphasis has been given to the generalization of the models to three-dimensional simulations.

Several efforts have been done in improving the stability of the resolution of multiphase flows with large difference between physical properties, specially in density and viscosity, using VOF (Volume of Fluid) techniques for computing the evolution of the free surface. These techniques have been applied to the simulation of absorption of water vapour in falling liquid films [13].

Research on combustion phenomena has been focused to the multidimensional numerical simulation and phenomenological analysis of methane/air laminar flames [1][2][22]. Detailed transport and chemical models have been employed (for instance, for the highest level of modeling considered, the last release of the full GRI-Mech mechanism with 325 reactions and 53 chemical species has been taken into account). Currently, special attention is given to the modeling of turbulent flames. RANS techniques for compressible flows (Favre-averaging) and Eddy break-up models for the reaction rates, have been employed for the preliminary results obtained.

The Radiative Transfer Equation (RTE) has been solved in both two and three dimensions for different geometries. The Discrete Ordinate Method (DOM) has been employed to compute the energy flux of radiation. The convection-radiation coupling between RTE and the Navier Stokes equation has been broadly study in the benchmark case of a heated cavity [15]. Radiant heat transfer in flames has been study assuming optically thin radiation between the hot combustion gases and the cold surrounding making use of the Planck mean absorption coefficient [30].

All improvements achieved in the numerical simulation of the mentioned above heat and mass transfer phenomena have had their direct implementation to the general purpose CFD code (called DPC) designed by the Group [16]. DPC is conceived as the Group's CFD tool to be employed in applied subjects [3][7][12]. A post-processing verification tool has been developed to asses the quality of the numerical solutions [14][29][31]. Specifically, one of the most relevant improvements reached during the project is the generalization of the code to deal with structured-nonstructured grids. Another aspect to point out is related to the parallelization of the code. Thus, two lines have been explored:

i) use the domain decomposition method to optimize the discretization and to parallelize the

code [13][30]. The discretized governing equations are solved in each subdomain (block) with the appropriate boundary conditions (inner iteration). Once all blocks have been calculated, information of the interpolation boundaries is transferred among the different blocks (outer iteration). Blocks are simultaneously solved by different CPUs. The processors communicate only once per outer iteration.

ii) use a single domain and parallel Krylov subspace algorithms (CG, BiCGSTAB, GMRES) to solve the scalar fields [24]. Parallel techniques such as the Direct Schur methods indicated above are not appropriate because they are based on a decomposition of constant discretization coefficient matrices [17].

A DNS code for Beowulf clusters has been developed using the aforementioned DS and DSFD algorithms and Symmetry-Preserving discretization schemes. The code has been developed in C language using an object-oriented design. Using 36 processors, the code allows simulations with 3×10^6 nodes in less than 8 seconds, including the time needed for statistical analysis of the results. It is currently under verification [17][28].

Different experimental set-ups have been constructed to validate the mathematical models developed [18][25][34][32][6][21][19][20]. A promising experimental techniques has been used to measure instantaneous velocity fields in gases. The fluid is seeded by small particles (typically 1-5 micrometers) and a light-sheet generated by an expanded beam of a dual Nd-Yag laser illuminates the particles into the flow [31].

Most of the basic work performed under this project (computational and experimental) has been used in applied subjects involving the optimization of thermal systems and equipment [4][5][6][7][8][9][12][13][19][20][21][25][26][27][33][34].

3 Indicators of Results

3.1 Doctorate Thesis

Six doctorate thesis have been performed within the framework of this project: [17], [18], [24], [30], [31], [32]. All these thesis have obtained the maximum qualification (Sobresaliente Cum Laude por unanimidad). Within the next year the following thesis, which are being performing within this project, will be finished: Carles Oliet, Numerical simulation and experimental validation of the thermal and fluid dynamic behaviour of compact heat exchangers; Kilian Claramunt, Development of advanced computational methodologies for the characterization of combustion processes; Jesus Castro, Simulation of heat and mass transfer phenomena in the critical elements of absorption cooling machines of LiBr-H2O. Experimental validation and application to design.

3.2 Publications

Up to now more than 45 publications have been performed within this project. Six have been published in well known journals within this area (Int. J. of Heat and Mass Transfer, Int. J. of Fluids Engineering, Numerical Heat Transfer, Applied Thermal Engineering, Int. J. of Heating, Ventilating, Air-Conditioning and Refrigerating Research). Nowadays, there are four papers submitted in international journals and five more will be sent before the end of this project. Other publications have been presented in different international congresses, such

as the 8th Int. Conf. on Numerical Combustion (Florida), EuroSun200 (Copenhagen), Int. Compressor Engineering Conference (Indiana), 5th ECCOMAS Computational Fluid Dynamics Conference (Barcelona), ISES Forum 2000 (Mexico), Int. Parallel CFD 2001 Conference (The Netherlands), Int. Conf. on Compressors and Their Systems (London), etc. A list of the most relevant publications has been enclosed in the forth section (References) of this technical summary.

3.3 Transfer of Technology

Even though this project mainly involved a fundamental research line, most of the work performed has a clear impact on the applied research line of the Group. In fact, the incidence on this applied line is almost immediate for the different companies with which the Group collaborates in the framework of contracts and national and international research projects (see next subsection). Furthermore, the project will allow to continue this line and open future collaborations. A list of some of the contract with companies performed during the project is given below:

- Title: Development of a numerical and experimental infrastructure for the design and optimization of flat plate collectors (ref. C3520). Company: MADE Energías Renovables, S.A. Period: 1999-2001. Funds: 12.700.000 pts.
- Title: Development of a numerical simulation code for the thermal and fluid dynamic behaviour of thermal energy storage tanks. Experimental validation. Application to equipments design and their behavior predictions in working real conditions (ref. C3521). Company: MADE Energías Renovables, S.A. Period: 1999-2001. Funds: 11.200.000 pts.
- Title: Evaluation of the thermal and fluid-dynamic behavior of compact heat exchangers manufactured by RADIADORES CEREZO company. Numerical simulation and experimental validation (ref. C3797). Company: RADIADORES CEREZO S.A. Period: 1.12.1999 - 1.12.2001. Funds: 7.500.000 pts.
- Title: Simulación numérica de instalaciones de energía solar térmica con colectores planos con superficie transparente aislante y con superficie selectiva de alta eficiencia (ref C3770). Company: MADE Energías Renovables, S.A. Period: 1999-2000. Funds: 5.500.000 pts.
- Title: Adecuación del código AGLA de simulación de fachadas multifuncionales ventiladas para la simulación y diseño de colectores solares planos de aire integrada en las fachadas y/o techos de los edificios (ref C3771). Company: MADE Energías Renovables, S.A. Period: 1999-2000. Funds: 5.500.000 pts.
- Title: Desarrollo y validación experimental de códigos de alto nivel para el diseño de compresores herméticos (ref C3907). Company: ELECTROLUX ESPAÑOLA, S.A. (Unidad Hermética). Period: 2000 -2002. Funds: 20.000.000 pts.
- Title: Evaluation of the thermal and fluid-dynamic behaviour of compact heat exchangers manufactured by RADIADORES CEREZO company. Numerical simulation and experimental validation (ref. C3797). Company: RADIADORES CEREZO S.A. Period: 1.09.2000 - 31.02.2002. Funds: 6.500.000 pts

3.4 Participation on International Research Projects and Transfer of Technology

In all the European projects listed below the Group (CTTC-UPC) acts as general co-ordinator or co-ordinator of the RTD performers. The work is oriented to the thermal and fluid dynamic

optimization of thermal systems and equipment of interest to the companies involved in the project. This optimization is performed by means of both advanced numerical and experimental tools developed by the RTD performers. The present TIC project has been essential in the development of these basic-fundamental tools.

- EC Project: CRAFT-JOULE Programme (ref. 50-52-3509) (ref. CTT n^o E0472). Title: Stagnation Proof, Transparently Insulated Flat Plate Collectors (STATIC). Institution: European Commission, Directorate-General XII. RTD performers: UPC (Co-ordinator), FHG. SME proposers: SUNWIND, AESOL , ITELSA, MATEC, MADE. Period: 1998-2001. Project budget: 651.600 Euro. Funds to UPC: 201.449 Euro.
- EC Project: CRAFT-JOULE Programme (ref. 50-52-3510) (ref. CTT n^o E0469) Title: Air-cooled Water-LiBr Absorption Cooling Machine of Low Capacity for Air-Conditioning (ACABMA). Institution: European Commission, Directorate-General XII. RTD performers: UPC (Co-ordinator), INTA. SME proposers: DISOL, SUNWIND, AESOL , MADE. Period: 1998-2001. Project budget: 721.000 Euro. Funds to UPC: 243.300 Euro.
- EC Project: CRAFT-JOULE Programme (ref. JOE3-CT98-7012) (ref. CTT n^o E0490). Title: Thermal and fluid-dynamic optimization of fin-and-tube heat exchangers with the purpose of obtaining significant reduction of both volume and weight (FATHERP). Institution: European Commission, Directorate-General XII. RTD performers: UPC (Co-ordinator), TUD. SME proposers: TEFRINCA, TALLERES ORDOÑEZ, CENTAURO, CASTANHEIRA HENRIQUES, CASTILLO BLANCO, RADIADORES ORDOÑEZ. Period: 1999-2001. Project budget: 589.200 Euro. Funds to UPC: 215.800 Euro.
- EC Project: CRAFT-JOULE Programme (ref. JOE3-CT98-7014)(ref. CTT n^o E0495). Title: Supervision System for Solar Processes-S3. Institution: European Commission, Directorate-General XII. RTD performers: UPC, DIGI, ITYER. SME proposers: TECSOL, ENERSOFT, JGIN, SYSTRON, EESE. Period: 1999-2001. Project budget: 301.000 Euro. Funds to UPC: 45.570 Euro.
- EC Project: CRAFT Programme (ref. CRAFT − 1999 − 70436 − "ARTISC") (ref. CTT n^o E00692). Title: Refrigeration, heating and air-conditioning using an absorption refrigeration system heated by transparent insulated solar collectors (ARTISC). Institution: European Commission, Directorate-General XII. RTD performers: UPC, CRIC. SME proposers: ITELSA, ENERMATOS, TRAVER, SOLARIN, SUNSTRIP. Period: 2001-2003. Project budget: 871.474 Euro. Funds to UPC: 321.600 Euro.
- EC Project: CRAFT Programme (ref. CRAFT − 1999 − 70967 − "ASFIC") (ref. CTT n^o E00695). Title: Advanced Solar Facades with Integrated Collectors-accumulators for domestic hot water and space heating applications (ASFIC). Institution: European Commission, Directorate-General XII. RTD performers: UPC. SME proposers: BR, ALPAL, PERCURSO, BCN REGIONAL. Period: 2001-2003. Project budget: 871.474 Euro. Funds to UPC: 396.592 Euro.
- EC Project: CRAFT Programme (ref. CRAFT − 1999 − 70878 − "STATIC-2") (ref. CTT n^o E00694). Title: Stagnation proof transparently insulated flat plate solar collector − 2 (STATIC2). Institution: European Commission, Directorate-General XII. RTD performers: UPC, FHG. SME proposers: ITELSA, ELCA, MATEC, SUNWIND. Period: 2002-2004. Project budget: 990.736 Euro. Funds to UPC: 372.562 Euro.
- EC Project: CRAFT Programme (ref. CRAFT − 1999 − 71024 − "COMHEX"). Title: Optimisation of Gas-Liquid Compact Heat Exchangers Considering Their Interaction with the Rest of the System (COMHEX). Institution: European Commission, Directorate-General XII. RTD performers: UPC. SME proposers: RADIADORES CEREZO, TALLERES ORDOÑEZ, PMG LUFTECHNIK, JOSEF FRIEDL. Period: 2002-2004. Project budget: 776.650 Euro. Funds to UPC: 351.060 Euro.

- EC Project: CRAFT Programme (ref. CRAFT − 1999 − 70604 − "OPICS"). Title: OPtimised Integrated Collector Storage: low-cost solar thermal systems for houses and offices (OPICS). Institution: European Commission, Directorate-General XII. RTD performers: UPC. SME proposers: DISOL, CIVILMAC, FOELCA, ENERMATOS. Period: 2002-2004. Project budget: 767.930 Euro.

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Distributed and/or Heterogeneous Parallel Computation: Image Processing and Global Optimization
TIC99-0361

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Abstract

The goal of this project is studying efficient methods for computationally expensive problems using massively parallel computers. This project will deal with a set of real world applications for which our research group has wide experience. Some applications coming from the field of image processing, such as 3D image reconstruction from projections, segmentation, visualization, etc, can only be solved by multi-computers. Moreover, we try to prove the usefulness of massively parallel computation for solving global optimization problems, where new hybrid methods for parallelizing these irregular problems are studied: managing irregular data structures, mixing SIMD and MIMD parallel models. Our goal consists of solving these kind of problems on heterogeneous parallel systems and also for shared and distributed memory multiprocessors. Finally, we would like to highlight the interest of this project from both theoretical and practical point of view because massively parallel computation is the only known solution to treat most of real world problems in the fields of image processing and global optimization.

Keywords: Parallel computing, Global Optimization, Image Processing.

1 Project Goals

Globally, the goal of our project consists of searching for efficient and feasible solutions to computationally expensive problems by creating parallel algorithms and experimenting with their implementation on parallel and distributed computers. This project deals with real life applications coming from several fields. All these applications represent a special class of problems characterized by managing *irregular and dynamic* data structures. Efficient parallelizations of these algorithms involve the use of (i) parallel computing on supercomputers or networks of workstations, (ii) sophisticated code optimization techniques, (iii) intelligent use of hierarchical memory systems in the computers and (iv) awareness of communication latencies. From the experience of the design and parallelization of several algorithms, theoretical models for a wide set of irregular problems can be designed. This global and general goal can be described by the following specific objectives:

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1.1 Algorithms for 3D Image Reconstruction from Projections

This work concerns the analysis of several aspects of 3D Reconstruction from Projections problem: (i) We are interested in investigating new iterative algorithms based on the concept of *Blobs* which from a theoretical point of view should produce more accurate results than the traditional *voxel* based methods, and therefore provide visually better reconstructed volumes; (ii) designing a new methodology for testing iterative reconstruction methods by the use of multidimensional global optimization methods for a better estimation of the free parameters of the reconstruction process; (iii) developing parallel implementations of these algorithms for 3D image reconstruction from projections which will allow to determine the 3D structure of large volumes in reasonable computation time from the execution on parallel computer architectures. We are interested in finding general parallel strategies which efficiently run on different parallel systems such as a distributed-shared memory multiprocessor or a Network of Workstations or PCs.

1.2 Middle Level Image Processing

In the context of parallel image processing, there exists a set of algorithms characterized by the use of irregular and dynamic data structures. Examples of this kind of algorithms are thinning or skeletonization and segmentation. Both are complementary algorithms to the problem of image reconstruction from projections. In this work, strategies for 2D and 3D are analyzed and parallel version developed and evaluated.

1.3 Lossless Image Compression

Our group is interested in developing module based compression software. This software must be able to work as a Lossy and a Lossless compression method, depending on the requirements of the system where it is used. Techniques such as arithmetic coding, neural network predictors or vector quantization are taken into account to develop this software for lossless image compression. We are mainly interested in using our techniques in fields such as telemedicine, teleastronomy or telemicroscopy.

1.4 Global Optimization Algorithms

This part of our project concerns the development of both stochastic and deterministic global optimization algorithms. We study these algorithms from several perspectives: (i) Theoretical, where new techniques are mathematically analyzed; (ii) technical by implementing and evaluating the new algorithms, both sequential and parallel alternatives and (iii) applied by using our methods for solving real life problems.

1.5 Matrix Computation Parallel Algorithms

This topic concerns with the study of algorithms which typically work with sparse matrices, so that irregular computations due to the irregularity of the sparse matrices appear. We specifically deal with the eigenvalue-eigenvector problem for huge and sparse matrices from a parallel computing point of view, so proposing new models and strategies for data distribution, studying the workload balance and memory management problems.

2 Degree of project success

This section is organized in five items following the same structure than Section 1.

2.1 Algorithms for 3D Image Reconstruction from Projections

We have analyzed the application of blob-based series expansion methods in electron tomography of complex biological specimens, with a special emphasis on the computational perspective. First, we have made use of efficient iterative methods to tackle the problem of image reconstruction. Additionally, high performance computing (HPC) techniques have been applied to face the high computational demands and take advantage of parallel systems. The new iterative reconstruction methods we have implemented are very efficient, providing least squares solutions in a small number of iterations. This parallel strategy allows iterative methods to take between 5 and 8 computation minutes per iteration in the reconstruction of a $512 \times 512 \times 512$ volume. In this way, High Performance Computing is making it possible to deal with *grand challenge* applications (e.g., reconstructions of $2048 \times 2048 \times 2048$) currently unapproachable by uni-processor systems due to the computational resource requirements [13, 14, 15].

We also investigated some improvements to the current methodology for testing iterative reconstruction algorithms. The main improvement consists of the inclusion of a multidimensional global optimization algorithm (Parallel Controlled Random Search algorithm) to obtain the optimal estimate of the free parameters of the process. The obtained results allow us to claim that global optimization methods, and in particular the PCRS algorithm, seem to be a very powerful and helpful tool to compare the performance of several reconstruction algorithms. This is mainly due to all the algorithms are evaluated under the best conditions of equality and optimality. [9, 10, 11, 12]

2.2 Middle Level Image Processing

In this context, practical implementations of two parallel thinning algorithms on a multicomputer system were carried out and analyzed. Implementations were conceived for a multiprocessor using the SPMD (Single Program Multiple Data) programming model. Our main goal was to investigate data partition/distribution among processors for parallel thinning algorithms as a representative type of algorithms where communications take place between neighbor processors and the work load for each processor depends on the input data. It was shown how the efficiency of the parallel implementation can be improved through the application of a preprocess based on the analysis of the work load balance. 3D Thinning algorithms were also studied, parallelized and evaluated. Parallel implementations of a region growing segmentation algorithm based on the *Split-and-Merge* approach have also been carried out. The region growing problem is representative of a class of irregular problems with strong data dependencies and unpredictable load fluctuations. This kind of problems requires the use of specific load balancing schemes to achieve efficient parallel implementations. In our parallel approaches we propose and analyze several strategies for the selection of region identifiers and their influence on execution time and load distribution. The optimal implementation includes a dynamic load balancing scheme. [28, 29, 30, 31, 32].

2.3 Lossless Image Compression

In this topic of our project, we have introduced a lossless progressive image transmission system (LPIC) based on a specific wavelet transform and the efficient encoding method known as SPIHT for the potential application in telemicroscopy, teleastronomy and telemedicine environments. This system has been compared to the standard Progressive-JPEG (P-JPEG) by means of a task-oriented methodology that guarantees an objective comparison for the task at hand. The results that have been obtained allow us to claim that LPIC clearly outperforms P-JPEG during the whole transmission process. Furthermore, the fact that our LPIC is a lossless image compressor method ensures that the image that finally is received at the end of the transmission is an exact replica of the original one. Techniques for speeding up the SPIHT progressive image compressor and its use for astronomical images were also tested. [26, 27, 35, 36, 37, 38, 39].

2.4 Global Optimization Algorithms

Our research deals with two different methods: Deterministic and stochastic global optimization. Our group has been working on both alternatives from four different points of view: (i) mathematical by designing new reliable methods; (ii) technical by implementing and evaluating algorithms; (iii) applied by testing algorithms for real problems and (iv) high performance computing by implementing parallel solutions on multiprocessors. The deterministic global optimization algorithms are based on *Branch and Bound* and *Interval Arithmetic*. Some of our contributions consisted on devising new support functions and selection, subdivision and rejection criteria. The first zero crossing point for a real function and finding the minimal root in a set of multi-extremal one-dimensional functions were also studied. Based on our new algorithms, solutions for practical problems such as packing circles in a square, facility location or ray tracing have been analyzed. [1, 2, 3, 4, 5, 6, 7, 8, 40].

The stochastic global optimization algorithms we have developed are of a population type. More specifically we have studied and developed new parallel global optimization algorithms: *PCRS (Parallel Controlled Random Search)* and *UEGO, an evolutionary algorithm for solving global optimization problems*. PCRS has also been used for solving problems from the field of image processing. [20, 21, 22, 23, 24, 25, 33, 34].

2.5 Matrix Computation Parallel Algorithms

We have developed efficient parallel implementations of the eigenproblem of large, symmetric and sparse matrices based on the Lanczos methods for tridiagonalizing matrices. Two different approaches to the eigenproblem have been parallelized: One based on the *Bisection* and the *Inverse Iteration* methods and the other based on the *Divide-and-Conquer* method. Our interest has also been focused on designing data partitions which obtain load balance of both sparse and dense structures, simultaneously. This data distribution problem has been formulated as a Set Partitioning Problem subject to the *uniformity* constraint. Two heuristic strategies for data distribution based on permutations have been proposed: ABO (*Average Based Ordering*) and GPB (*Generalized Pivoting Block*). Both methods include a pre-process stage of low computational cost. [16, 17, 18, 19].

3   Indicators of results

During the development of this project M.G. Montoya, V.G. Ruiz and E.M. Garzón (members of the research group) finished their PhD degree [29, 36, 17]. The advisor of these PhD dissertations was Dr. Inmaculada García Fernández and the subjects investigated were directly related to the topics described in items 1.2, 1.3 and 1.5. Currently, J.A. Martínez García, J.F. Sanjuan Estrada, J.A. Alvarez Bermejo and S. Tabik are working on their PhD.

Most of the results obtained from our research in this project have been published as papers in relevant scientific journals (18 papers), as chapters of books (4 contributions) and as papers in proceedings of international conferences (15 articles).

Some of our results have been transferred to the industry by a contract for a research project with the firm TEDIAL (Tecnologias Digitales Audiovisuales, S.L.). The objective of this project is to create tools for progressive and lossless image transmission and decoding DICOM files. Additionally, we have developed software for teleastronomy which is currently tested at the Astronomy Center at Calar Alto (CAHA).

In the field of parallelization of 3D image reconstruction from projections we have been working in an international project: *Parallel Computing of 3D Biological Structures and New Methods for Querying Databases* (Convenio de Cooperacion Cientifica y Tecnologica entre España y los Estados Unidos. Ministerio de Asuntos Exteriores). In this project, besides our research group, the CNB (Centro Nacional de Biotecnologia) and the National Center for Microscopy and Imaging Research (university of California) took part. Project No. 99109.

Our group has also been funded by the Ministerio de Asuntos Exteriores for the Hungarian and Spanish cooperation program. The project *Reliable Methods for Global Optimization and its Parallel Implementation* was carried out by our group and the group coordinated by Dr. T. Csendes of the University of Szeged (Hungary).

A summary of our cooperation at the international and national level is: **Centro Nacional de Biotecnologia** and **the National Center for Microscopy and Imaging Research (University of California)** for *parallel computing 3D image reconstruction from projections for biological structures* (see references [13, 14, 15]. **Department of Informatics, University of Szeged (Hungary)** [2, 3, 5, 8, 25, 33, 34, 40], **Universita della Calabria (Italy)** [1, 6, 7] and **University of Wageningen (The Netherlands)** [22, 23, 24] for *Stochastic and deterministic methods for global optimization and its parallel implementation*. **Astronomy Center at Calar Alto** [27] for *progressive image transmission for teleastronomy*. **Universidad de Malaga** [20, 21] in *application of global optimization to image processing problems*.

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