# The Department of Computer Science University of Pisa

# Annual Research Report 2003

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## Abstract

This is the 2003 issue of the yearly report on research and teaching at the Department of Computer Science of University of Pisa. The main areas of current research are: Algorithms and Data Structures, Computer Architecture, Computer Networks, Arti cial Intelligence and Robotics, Databases and Information Retrieval, Computational Mathematics, Programming Languages, Software Methodology and Engineering. The Department o ers a program for undergraduate (Laurea and Laurea Specialistica) and postgraduate (Dottorato) studies. The Department also carries out research programs in cooperation with several computer companies on medium and long term research themes.



Edited by S. Pelagatti and A. Maggiolo Schettini.

# Contents

# 1 Introduction and Overview

## 1.1 Introduction

The University of Pisa was o cially founded on the 3rd of September 1343 with the *bulla \In Supremae Dignitatis"* by Pope Clemens VI, recognizing the longtime existence of a complex organization of studies at the university level and granting to Pisa the privileges of *studium generale*, namely that its diplomas should be valid in the whole Christian world. The rst faculties established were Theology, Law and Medicine. The University of Pisa alternated periods of good and bad fortune due to the sorts of the Republic of Pisa which lost its freedom in 1406 when it came under Florentine rule. In the 16th century the Botanical Garden (the oldest in the world together with the one of Padua) was founded, in the 18th century the chairs of Chemistry and Physics were created. There have been many famous scholars in the sciences including Galileo Galilei, Antonio Pacinotti, and, in the last century, Enrico Fermi, Enrico Bombieri and Carlo Rubbia. The University now has about 35,000 full-time enrolled students.

In 1955, the University of Pisa with the nancial support of the local public administrations of Pisa, Livorno and Lucca founded the \Centro Studi Calcolatrici Elettroniche" (Center for Studies on Electronic Computing Machines (CSCE)). The CSCE brought together a group of mathematicians, physicists and engineers with the aim of designing and constructing what would be the rst Italian scienti c computer. The project was successful, and the computer was actually constructed and employed in scienti c computations. The CSCE became a research institute of the National Research Council (CNR) with research groups in the major areas of Computer Science. In 1970 the CSCE was renamed \Istituto per l'Elaborazione dell'Informazione (IEI)".

In 1969, a number of researchers of CSCE joined the University of Pisa and the \Istituto di Scienze dell'Informazione" was established. With the new institute within the University, a four year undergraduate study program in Computer Science (\Laurea in Scienze dell'Informazione") was organized and put into action. In 1982, the institute was transformed into the actual Dipartimento di Informatica.

In 1986, an undergraduate school o ering a two year undergraduate study program in Computer Science (\Diploma della Scuola a Fini Speciali in In-

formatica") and a postgraduate school in Computer Science were launched.

In 1993, the undergraduate study program has been rearranged, with the introduction of two levels of undergraduate curricula: a three-years undergraduate study program (\Diploma Universitario in Informatica"), and a ve-years undergraduate study program (\Laurea in Informatica").

More recently, the undergraduate study program has been rearranged again, to meet the new requirements by Italian law. We currently have two three-years undergraduate study programs (\Laurea in Informatica", \Laurea in Informatica Applicata", based in La Spezia), and three ve-years undergraduate study programs (\Laurea Specialistica in Informatica", \Laurea Specialistica in Tecnologie Informatiche" and \Laurea Specialistica in Informatica per l'Economia e l'Azienda").

At present the department has 77 employees and 50 postgraduate students. There are 24 full professors, 21 associate professors, 4 assistant professors (assistenti), 18 assistant professors (ricercatori), 10 research fellowship holders (assegnisti) and 20 administrative and technical sta members (see Appendix A and Appendix E).

## 1.2 Current Research

Research in the Department falls into the following areas of ACM classi - cation: Algorithms and Data Structures, Computer Architecture, Computer Networks, Arti cial Intelligence and Robotics, Databases and Information Retrieval, Computational Mathematics, Programming Languages, Software Methodology and Engineering.

Fundings for researches come from the Ministry for Research and University (MIUR), from the CNR, from international projects (such as European Union projects) and from industrial projects. See Section 2 for a detailed description.

## 1.3 National Cooperation

The Department is involved in and/or leads several research projects funded by MIUR, CNR and other national research agencies (the name of the local responsible for each research subject is in parentheses):

1. \Tools based on Machine Learning methodologies for structural and functional genomics", (Starita) MIUR

2. \An intelligent informative system for studying Leukemia", (Starita), AIL (Italian Association on Leukemia)
3. \Integrated multidisciplinary design and realization of biologically active systems for biomedical applications", (Starita) MIUR
4. \Causal Models for Security", (Montanari) MIUR
5. \Computational Metamodels" (COMETA), (Montanari) MIUR
6. \Software Architectures with High Quality of Service for Global Computing on Cooperative Wide Area Networks" (Montanari) MURST 5%
7. \Enhanced Content Delivery", (Attardi) MIUR
8. \Problemi di usso per applicazioni nei trasporti", (Scutella) Programma di ricerca SP7 (SORSA) MIUR
9. \Software di simulazione e ottimizzazione su reti", Programma di ricerca SP7 (SORSA) (Scutella) MIUR
10. \De nizione e gestione delle speci che del Software di simulazione e ottimizzazione su reti", Programma di ricerca SP7 (SORSA) (Pallottino) MIUR
11. \Modelli ed algoritmi per problemi di vehicle and crew scheduling", (Gallo) MAIOR
12. \Algorithms and Software Tools for Fast Indexing and Searching Compressed Web Data" (Luccio) MIUR
13. "Software Architectures for Heterogeneous Access Applications: speci cation and re nement methods" (SAHARA), (Montangero) MIUR
14. \Metodi formali per la sicurezza" (MEFISTO), (Degano) MIUR
15. \Infrastructures for Mobile ad-hoc Networks" (IS-MANET), (Maestrini) MIUR

## 1.4 International Cooperation

The Department is involved in the following projects nanced by the European Community:

1. \AppSem II" (Applied Semantics II) Working Group in the 5th Framework Program of the EU (Ghelli)
2. \BIOPATTERN" (Starita) Network of Excellence, EU
3. \AGILE: Architectures for Mobility" (Corradini) EU
4. \Formal modeling and Veri cation for Mobile Distributed Systems " (PROFUNDIS), IST-FET European Project (Montanari), EU
5. \IQ-Mobile - Improving the Quality of Open Systems with Code", (Corradini) CNR/CNPq (Brasile)

6. \Syntactic and Semantic Integration of Visual Modeling Techniques" (SEGRAVIS), European RTN Network (Montanari)
7. \Network-aware programming and interoperability" (Montanari) Microsoft Research
8. \CodeBricks", (Cisternino) Microsoft Research
9. \Embodied Agents", (Cisternino) Microsoft Research
10. \Algorithms for Modelling and Inference Problems in Molecular Biology" (Grossi) Programme Bioinformatique inter EPST 2002-2004, French Ministry of Research
11. \Skeleton Based Programming and Scheduling for Grids" (Pelagatti) Vigoni Program, CRUI-DAAD Pisa-Muenster
12. "Design Environments for Global ApplicationS" (DEGAS), Degano, IST-FET-EU Project

An agreement of \scienti c cooperation" has been established with the Scuola Normale Superiore (Pisa) and the Ecole Normale Superieure (Paris). Within this framework common research activities as well as exchanges of researchers and students are being developed.

An agreement of cooperation is established between the University of Pisa and the Universidade de La Habana (resp. G. Levi).

The Department also collaborates with Scuola Superiore di studi e Perfezionamento S. Anna (Pisa) and University of Catania.

## 1.5 Research Evaluation

Recently Italian universities have been trying to establish e ective evaluation procedures for both teaching and research activities. Almost all of them (including the University of Pisa) have set up \evaluation teams" to coordinate such e orts. Within this framework, in 1999, the Dipartimento di Informatica created a committee to study research evaluation procedures tailored to the needs of the department. The committee included four members (V. Ambriola, G. Attardi, U. Montanari (Coord.), A. Starita). After some discussion, the committee suggested to perform an evaluation exercise focused on a two-day public workshop, which took place on July 8-9, 1999. The event consisted in presentations by various research groups of the department and discussions with a group of reviewers. Details on the event and the nal referee report can be accessed at **http://www.di.unipi.it/Evaluation/**.

## 1.6 Teaching

The Department o ers three levels of studies in Computer Science, i.e. two three-years undergraduate study programs (\Laurea in Informatica", \Laurea in Informatica Applicata"), three ve-years undergraduate studies (\Laurea Specialistica in Informatica", \Laurea Specialistica in Tecnologie Informatiche" and \Laurea Specialistica in Informatica per l'Economia e l'Azienda") and a PhD. program (\Dottorato in Informatica"). See Section 3 for a detailed description.

## 1.7 Computer Facilities

The department provides computing facilities for research, education and administrative purposes. All the facilities are connected to the Internet via the university service network, SeRRA and the Italian research network, GARR.

Computer services provided by the department guarantee basic authentication, email, WEB, backup and le sharing services. All these services are guaranteed for Linux, Windows and for MacOS X architectures.

Research computing facilities include a rough fteen Linux based servers, providing WEB services, Email, home backup and, of course, authentication. A Telesyn RAPIER 6M device provides level 2 and level 3 network connectivity with SeRRA, and, as a consequence, with the Internet. Within this year, a wireless network will be available covering all the Department rooms and guaranteeing access to full Department services to Department members as well as to WEB services only to Department visitors.

At the moment, all the machines providing resources and/or services to the department researchers use Intel or AMD processors. Internal connectivity is guaranteed by a single Fast Ethernet network (131.114.2.0/23), hosting the servers, researcher private machines, printers, etc. A completely separated, re-walled network hosts administrative o ce computers. The RAPIER device also behaves as a rewall with respect to the external world. Free access from inside the research network to the outside (Internet) world is guaranteed to researchers while accesses from outside are usually prohibited, but the standard ones (**`http`**, **`ssh`**, and the alike). A large number of personal machines (more than 200) are deployed in the di erent o ces and laboratories: currently, about are third of the machines run Linux (di erent

avors), are third run Windows (NT, 2000, 98, XP), and one third are either Macs or dual boot machines used both with Windows and with Linux. There are also a consistent number of portables that usually operate in dual boot mode and interconnect to internal LAN through department DHCP service. Seven network printers, accessible from all operating systems, provide high-quality laser printing facilities. A network scanner provides handy ways of delivering faxes as well as a fast way to acquire PDF versions of printed documents and to send them directly to the user mailbox. Other available equipment includes CD masterizers and digital cameras. The department's dial-up service is guaranteed using the SeRRA services that allow di erent accesses methods (e.g. ISDN or ADSL). Most of the research groups in the Department also operate their own servers, running di erent kind of services (high performance clusters, database machines, WEB servers of di erent a-vors, etc.). Last but not least, both data from administrative section and from teaching secretary are automatically made available at the department WEB site, supporting both research activity and teaching related activities.

The teaching related facilities include 20 servers both for general services, such as e-mail, and for speci c services required by speci c classes, such as three Oracle database servers required by the database class. These comput-ing facilities include two Linux boxes which we use as packet- ltering routers, and web and news caching proxies. Most of the servers are Intel-based ma-chines; 3 of them are running Windows 2000 for various Windows-based ser-vices, while 12 are running RedHat Linux. Notably, there is one Linux-based (equipped with a hardware MegaRAID array) and one Windows-based le server. Disk quotas allocated to individual students depend basically on the programs they follow and projects they are involved into; this ranges from a minimum of 5Mb to several hundred Mbs of space for individual home directory. Both Windows-based and Linux-based disk spaces are available to students on clients running either operating system. There is also a Dump Server with 480 GB of disk space (arranged in a software-based RAID5 array) which runs nightly disk-based dumps of all data. Furthermore, the depart-ment provides a dial-up service for students by means of a Cisco 2500 terminal server and 16 modems. Teaching computing facilities support two operating systems on client machines: Microsoft Windows XP and Linux (currently RedHat 8.0 with both GNOME and KDE environments, but we are migrat-ing to Debian during this year). All clients are Intel-based architectures: presently most of them are dual-boot machines of class PIII or PIV, while

of the older, PII-class machines two thirds boot only with Linux and the remaining only with Windows. These machines are currently being dismissed, however. Teaching computing facilities also provide CD mastering services for free software and teaching materials. These services are actually provided by a student group that had assigned some computing resources, to the purpose. Web services provided by both the research and the teaching computing facilities include: home pages for teachers and students, home pages of the di erent research/teaching projects hosted at the department, internal bulletin boards and laboratory monitoring services, web access to teacher's and researcher's email, technical report repository, etc. (for more details, see **http://www.di.unipi.it/** and **http://www.cli.di.unipi.it/**).

## 1.8 Library

The department o ers a Library as a service for the students of the undergraduate and postgraduate study programs, as well for professors and researchers of the whole University. The Library has been established in 1970, when the \Corso di Laurea in Scienze dell'Informazione" was started. Since the beginning of 1997, the Library has joined the libraries of the Departments of Mathematics and Physics in the \Biblioteca Interdipartimentale dei Dipartimenti di Matematica, Informatica e Fisica dell'Universita di Pisa" (MIF Library). At the end of 2001, slightly ahead to the rest of the department, the Library was physically merged to those of the Dipartimento di Matematica and the Dipartimento di Fisica in the new building at Polo Fibonacci. The MIF Library now contains over 32,000 books and more than 500 periodicals, with more than 350 active subscriptions, and is therefore an important knowledge source in the three cultural areas that it covers. The Library also o ers to its users access to a growing number of periodicals, journals and conference proceedings available in electronic format over the WWW, through its web site

**http://www.bibmif.unipi.it/**

A shift to online-only subscriptions is currently taking place, with several journals now being available only through web access.

The Library contents are indexed in the centralized index of all libraries of the Universita di Pisa, that can be consulted with any web browser at the address

**http://sba.adm.unipi.it:4505/ALEPH**

The system also handles the borrowing of books, providing availability information for each book and sporting bar-code readers for quick borrowing procedures.

The Library has 160 seated places for books and periodicals consultations *in loco*, with 11 computers for consulting the index and performing bibliographical searches; on average, about 70 books are borrowed every day, and it is estimated that more than 300 persons spend some time in the Library every day. 10 full-time employees of the Library take care of all the organizational aspects of the Library life, as well as assisting the users in their needs.

For 2004, the Dipartimento di Informatica has contributed to the budget of the Library, either directly or indirectly, with about 66,000 Euro, to be used entirely for new books acquisition and renewal of periodicals subscriptions.

# 2 Current Research

## 2.1 Project: Semi structured data management systems

Summary

The research goal is the design of a type system, a programming language, and a management system, to query and manipulate semistructured data, with the following requirements: (a) exibility of the type system, to make it possible to describe the common features of the elements of a semistructured collection; (b) expressive power of the query language, which must allow both data elements and their structure to be analyzed, and data with an irregular structure to be queried; (c) openness of the type system and the language, meaning that the collections to be queried may come from external sources, and in particular from the Web, and that the data produced by the language can be published on the Web, in particular in the XML format. The presence of a type system that allows some consistency checking is in contrast with the exibility needs of semistructured data. The conciliation of these two aspects represents one of the crucial aspects of the proposed research.

Keywords: Database programming languages, Type systems, Data models, Semistructured data, World Wide Web

### Background

The huge amount of data published via the World Wide Web has led to a number of research e orts on techniques to query and restructure semistructured data (SSD). These proposals have been recently extended to the issue of querying XML documents. The preferred approach to describe SSD is based on the use of a self-describing data, modeled as a labeled graph, without a prede ned schema, such as the Stanford's Object Exchange Model (OEM).

In OEM each object has an arbitrary number of attributes, with di erent or equal names, whose values are other objects or atomic data; a set $S$ with $n$ elements is represented as a record with n elds, all labeled $S$, each containing one element of the set. OEM is a \lightweight object model" in the sense that it supports a notion of \object identity" but it does not require the de nition of classes or types, arbitrary structures with arbitrary attribute names can be

modeled, and it does not support neither encapsulation nor object behavior. This approach has the advantage of exibility, but su ers some important drawbacks: (a) data is ine cient to store, since the schema is replicated with each data item; (b) queries are hard to evaluate e ciently; (c) queries are hard to formulate and cannot be typecheked. Indeed, a general problem with most SSD query language is the lack of any consistency control between data and query: when the query is written assuming a structure which does not correspond to the actual structure of data, no error is indicated, but an empty result is returned, even in the case of trivial errors such that the mistyping of a eld name. The use of type systems as a foundation for languages for SSD is a new research direction, aiming to overcome this limitation, which is being followed in particular by the database group at University of Pennsylvania and by the Hippo project in Glasgow.

Beside the data model de nition, the main issues which are currently investigated are the de nition of the corresponding query language and the query optimization techniques.

## Ongoing research

The database group has focused in the last few years on the following research issues:

Programming languages for object databases. The main contribution has been the design of the database programming language Fibonacci, a statically and strongly typed language, with a rich type system to model object databases in terms of objects with roles, classes and associations. It supports the typical functionalities of database languages (persistence, transactions, a query language, integrity constraints), and it provides a modularization mechanism, with modules as rst class values for the structuring of complex databases in interrelated units, and for the de nition of external schemas. The language has been implemented, and during this phase we studied the implementation of object with roles, the implementation of type-checking procedures, and the ef- cient use of persistent memory

Type theory for object programming languages. The activity of language design and implementation has been a persistent source of research problem which have been addressed at a more general type-

theoretic level; these type-theoretic studies, on the other side, have often been the basis of innovative design decisions in our database programming language research. This research may be categorized as: type-checking and strong typing problems, foundations for object-oriented database languages.

The current focus of the group is on the theme of semi structured data management system, as described in the rest of this section, and on the study of type systems which describe mobility or security properties of mobile code.

### Short term plans and expected results

The research goal is the design of a type system, a programming language, and a system, to query and manipulate SSD, with the following requirements: (a) exibility of the type system, so that the irregular structure of SSD can be described, (b) exibility of the query language, to allow data structure to be analyzed and the irregular structure of SSD to be tolerated, (c) openness of the type system and the language, meaning that the collections to be queried may come from external sources, and in particular from the Web, and that the data produced by the language can be published on the Web, in particular in XML format. The presence of a type system that allows some consistency checking is in contrast with the exibility needs of SSD. The conciliation of these two aspects is one of the crucial problems to be solved. The other basic issue is the realization of an e cienr system.

The research will be based on the theoretical framework of type theory. The past experience of the research group in database language design has shown that type theory has the necessary exibility to deal with both regular and irregular structures. In particular, it seems that a combination of a variation of record types with recursive types can be used to typecheck OEM-like data. A promising research direction is the study of type systems which include also collection and untagged union types to achieve exibility and expressivity. The relevance of the approach has been already recognized by other researchers (notably, R. Connor, P. Buneman, and B. Pierce), who have achieved interesting preliminary results. The query language will be OQL-like, extended with the operators provided by the proposed type constructors. Union types require a careful design of their operators to overcome the limitations of the "case" operator, provided by the traditional tagged unions, with operators based on pattern-matching on the expected value structure.

## Long term plans

In a longer term period, we expect to expand our research from the language design eld to the eld of query optimization. This is a eld which is rich of di cult problems, with important practical applications, even in simpler contexts.

Another interesting research direction which we may consider in a longer term scenario is the extension of the studied paradigm with code mobility. Code mobility is very convenient in the eld of query execution, since moving a query where data resides may be vastly faster than moving input data towards the query.

## Personnel and External Researchers

*Group leaders*: Antonio Albano (Professor), Giorgio Ghelli (Professor). Giovanni Conforti (PhD Student), Paolo Manghi (Post Doc), Carlo Sartiani (Post Doc).

*External researchers*: Renzo Orsini (Associate Professor) Univ. of Venice, Dario Colazzo (Post Doc) Univ. of Venice, Philippa Gardner (Lecturer) Imperial College, London.

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## 2.2 Project: Rigorous Methods for Requirements Capture and Software Architecture

### Summary

This project contributes to the current trends in software development methods by: a) relating requirements capture and architectural decomposition reliably, and b) transforming by controllable re nements the abstract architectural models down to a level where well-established design methods can be applied. The interest is in practical methods that can be used for rigorous high-level system development under industrial constraints. The focus is on three themes: a) capturing requirements and expressing them in abstract architectural models, b) nding paradigmatic architectural models to make explicit the di erent system views, and c) re ning the abstract architectural models into speci c architectures and code designs.

Keywords: Software Engineering, Requirements Capture, Software Architecture, Formal Methods, Abstract State Machines, Re nement.

### Background

Nowadays, the major problems of software engineering are encountered at the high levels of system development, both scienti cally and in the industrial practice. The modern software life-cycle models recognize that defects injected in the initial software development phases are the most expensive ones. Besides, there is a simultaneous need for heterogeneity, to capture the richness of di erent application domains, and for a uniform approach which unfolds the commonalities across domains and makes them available for analysis, validation, and veri cation. Current approaches to prevent errors early in the life-cycle include multiple high-level views of the system, to facilitate understanding by all stake-holders, domain speci c architectures, to factorize common facets of product lines, and executable architectures, to get early feedback on major design decisions. The early phases in software development are characterized by a) capturing the problem requirements reliably and in rigorous form, b) representing the basic architectural decisions taken to compose the system out of interacting components, and c) linking, in transparent and reliable ways, the abstract models to more detailed ones, paving the way to implementation. To foster error prevention in the up-stream modeling activities, current research looks for reliable techniques

to turn the informally presented requirements of the desired system into a functionally complete but abstract system description which a) can be read and understood by and justi ed to the customer as solving his problem, b) de nes every system feature as far as this is semantically relevant for the work the user expects the system to achieve, c) contains only what the logic of the problem requires for the system behavior, i.e. does not rely upon any further design decision belonging to the system implementation. Models with these characteristics have been called *ground models* by Borger. To contribute to the current trends in software development methods, we need to guarantee two capabilities: a) to relate requirements capture and architectural decomposition reliably, and b) to transform the abstract models by controllable re nements down to a level where an implementation can be built by well-established design methods. Finally, we are interested in practical methods that can be used for rigorous high-level system development also under industrial constraints.

## Ongoing research

Part of the current research has been motivated by former activity in software process technology, focused on two aspects: process modeling (in cooperation with European partners in the ESPRIT Working Group PROMOTER2) and environments for standards compliance, in cooperation with University College in London, inside RENOIR, an ESPRIT Network of Excellence.

The logic DSTL(x), now being studied for wider application to software design, was originally developed to master the complexity of software process models by a formal notion of re nement, in a framework enabling also the expression of architectural issues. Indeed, DSTL(x) has two modalities, one to deal with time and one to deal with distribution. The temporal part is an extension of Unity, to deal with events explicitly. Recent activity on the applicative side has been on the characterization of distributed architectures via the axiomatization of the underlying coordination patterns, and the development of a mobility model, Mob-adtl. These activities, once carried on in collaboration with European partners inside the ESPRIT Working Group COORDINA, have recently taken place in the context of the MIUR co-funded national projects SALADIN and SAHARA.

The activities take as a starting point a speci cation technique, which has already been used to verify functional properties at the architectural level.

More speci cally, DSTL(x) provides a) a logic, a re nement notion and the related proof system, which induce a methodology for the speci cation and composition of distributed systems; b) a prototype environment to support proofs, which is built on top of the Isabelle theorem prover; c) a model of subjective logic mobility, known as Mob-adtl, where locations are associated to authorities in charge of the communication and mobility policies of the mobile agents. The axiomatization of Mob-adtl xes only the general mobility framework, and leaves both the functionalities of the mobile agents, and the speci cs of the policies, open. Therefore, it facilitates the construction of systems in a compositional way, according to the proposed methodology. The approach has been validated with respect to security policies in potentially hostile environments, and with respect to the use of standard middleware, namely CORBA, as the target of the re nement of a speci cation.

The main activities on requirements engineering include de nition of methods and techniques for the extraction of semantic information from natural language requirements. A prototype environment has been realized and is on the course of being revised and completed with support for generation of initial ground models to be further transformed by the speci er. Other research is concerned with the structural analysis of requirements documents, the integration of industrial standard representation (like UML), and quantitative analysis of requirements processes supported by the environment. Part of these activities have been conducted in collaboration with European partners inside the ESPRIT Network of Excellence RENOIR and the MURST co-funded Project AI*IA, and thanks to an IBM Eclipse Innovation Award.

One thread of activity continues the research line of high-level modeling and analysis of systems (control software, instruction set architectures, programming languages implementations, and hardware design languages). Practical and concrete experience was gained during the last years in three main projects. The rst of them is the FALKO project on the high-level speci cation and implementation of a train simulation and planning system (Siemens Corporate Research, 1997{1999). The second one is the Java/JVM project (realized in cooperation with researchers at the University of Ulm, at ETH Zurich and at Siemens Corporate Research, 1998{2001) on a validated and veri ed speci cation and implementation of Java and the JVM architecture. The third is the ASM-UML project (in cooperation with University of Catania/I and University of Karlsruhe/D) to provide a rigorous and complete semantics to central UML concepts which allow one to link in a controllable

way UML and ASM design methods. On the basis of this experience the following three projects are being carried out: a) the ASM project where the focus is on the development of practically useful design and analysis methods and tools, in particular focused on re nement, b) the C#/CLR project (in cooperation with ETH Zurich) on ASM reuse for a validated and possibly veri ed speci cation of C# and of its underlying virtual machine CLR, c) the requirements engineering environment is being extended to generate high-level ASM models and initial UML models from the same requirements base, so that the two are linked by construction.

### Short term plans and expected results

We will focus on the conceptual and semantical facets of system (de-)composition, so that they can be mapped to widespread particular notations (like UML) and their tool support. Our research will address methods to develop, analyze and re ne high-level models of control intensive software systems, and will concentrate on three themes: a) capturing requirements and expressing them in ground models which are well suited for further system design, b) nding paradigmatic architectural models {ground model templates{ which allow one to make di erent system views explicit, and c) re ning the ground models and their architectural structure into speci c architectures and code design.

*Requirements Capture*. We will investigate the mechanical extraction of knowledge from requirements documents, as collections of unambiguous atomic statements. These \atoms", given a speci c modeling framework (e.g. FSMs, temporal logics, etc.), are interpreted to generate various system models. These interpretations will be done by domain-aware software agents (\modelers"), which produce models that can be visualized, and analyzed in terms of completeness, consistency and fundamental architectural constraints. The crucial concern is to come up with a trustworthy basis for the later detailed design, in a joint e ort by experts in the application domain and in system design. In the framework of Abstract State Machines (ASM) the models are expressed by rst-order statements and transition rules: we will investigate the usefulness of the machine character of ASMs for early validation and simulation of requirements, when given by use cases.

*Paradigmatic Architectural Models*. We intend to de ne a collection of ground model templates which capture paradigmatic architectural composi-

tion principles and make different system views explicit, in terms of static properties, user interfaces, communication mechanisms and notions of time.

We expect two concrete short-term results: the extension of the automatic support to Oikos-adtl in the specification of mobile systems and the definition of frequently used ASM composition principles (forms of submachine, conservative extension, lifting). The first goal will be reached by revising the specification logic, taking into account the requirements from the automation, and providing explicit support to the structuring of the specifications. As to the second goal, we will validate the ASM structuring principles through further experiments, e.g. by a complete but succinct high-level architectural definition of the virtual machine underlying C#.

*Refinement.* We will use refinement methods to link ground models and their architectural structure to a hierarchy of specific architectures and code designs, providing well documented and inspectable intermediate design steps. We will identify, as standard (formal) refinement steps, the mappings of the conceptual architecture to lower level architectures.

### Long term plans

We plan to link the proposed concepts to existing component based software development and analysis environments and their tool support. For requirements engineering the long term goal is an environment for writing and validating requirements, guided by an explicitly defined process, and for early prototyping through high-level simulation of ground models.

The long term goal with respect to DSTL(x) is to study its feasibility in the specification and design of global computing systems, to determine how far its structuring capabilities can be stretched in the specification and design of complex systems. This will involve the integration in the framework of new technical proposals, like web-services and bluetooth.

We plan to use the ASM approach to study the role different computation models have for software architectures (sequential versus distributed computation, forms of interaction, in particular different communication models). We also want to understand better the trade-off between the uniformity and thus generality of the resulting approach on the one side, and on the other side the advantages gained by tailoring the development technique to specific domains, capturing the peculiarities of the different applications domains.

## Personnel and External Researchers

*Project leaders* Vincenzo Ambriola, Egon Borger, and Carlo Montangero. Giorgio Fruja (ETH Zurich), Vincenzo Gervasi (U. of Pisa), Amjad Hudaib (U. of Pisa), Paola Inverardi (U. of L'Aquila), Alina Kmiecik (U. of Lodz, Poland), Elvinia Riccobene (U. of Catania), Laura Semini (U. of Pisa), Simone Semprini (U. of Pisa), Robert Staerk (ETH Zurich), Didar Zowghi (UTS Sydney).

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## 2.3 Project: Adaptive and Web Computing

### Summary

In this project we explore or develop models, software technology, libraries, knowledge bases, linguistic corpora and tools, presentation metaphors, learning algorithms to produce adaptive agents capable of interacting with people at a level as close as possible to the human level.

Keywords: Web computing, adaptive agents, information extraction, text categorization, knowledge management, language analysis, generative programming, multistage programming.

### Background

A pervasive computing environment consists of elements of varying number (nodes, clients, servers) and of varying type (devices) and handles data items of varying types.

Developing such environment requires suitable infrastructures (Web Computing) and technologies (Adaptive Agents, Generative Programming).

#### *Web Computing*

Transforming the Web from primarily a document transfer system to a platform for Web applications, involves developing an architecture that supports Web objects interacting with each other.

Web computing involves hence a suitable Web object model, encompassing both document publishing and distributed object communication.

Web Services have emerged recently as a standard platform for Web Computing. We have been pioneering its usage in developing speci c Web Services for instance for providing a Search Engine service.

Nevertheless Web services only provide one-way request/reply communication from client to server.

Developing fully interactive applications is di cult with current Web technology. Users can only get updates by hitting some button or clicking a link on their browsers and re-generating an entire new page.

Two-way Web requires the ability for the application to incrementally modify the page contents, without incurring a round-trip with the server.

We are developing a solution to this problem based on sophisticated use of facilities provided by Dynamic HTML, combined with scripting conventions.

Web applications are a typical example of staged computations, where a server side program produces code to be run at the client side. The server side program itself is generated by other tools like CMS.

Currently such stages are expressed in di erent programming lanugages (either traditional or scripting languages), various types of preprocessors (ASP, JSP, etc), markup languages (HTML, XML) and must be deployed manually by storing the various pieces in appropriate locations. Both developing and debugging such applications is quite complex, since each element must be handled separately.

We plan to develop a uniform computational model for multistage computations, that allows expressing all the various stages, within a single framework. A complex multistage application can be programmed in a single source le, containing all the information required to separate the various stages and trigger their execution at the right time. Information about each stage is carried as metadata associated to the portable executable.

*Generative Programming*

Generative programming concentrates on solving software engineering problems in families, by automatically generating the code for each instance of a problem. Generative programming builds implementations from code patterns and lower-level components, according to directives expressed through metadata.

Techniques of generative programming will be employed for supporting Web applications and in particular staged computations.

### *Adaptive Agents*

Agent systems are a metaphor for cooperative tools that help performing specific tasks on behalf of a user (collecting and filtering information, monitoring and alerting, etc.) exploiting their built-in abilities.

An adaptive agent instead improves its behavior by extracting knowledge thorough interactions with the environment. Adaptive agents play a role in achieving the vision of the computer of the future as an intelligent assistant. This vision goes beyond the current desktop metaphor of interacting with a computer. This metaphor has proved to be intuitive and effective but it intrinsically limits user actions to precise and simple clerical tasks.

## Ongoing research

### *Generative Programming*

Generic Programming is a form of Generative Programming, where specific instances of programs are generated from specializing templates or type parameters.

Support for generic programming is being included in extensions to programming langugages like Java and C#.

We have cooperated with Microsoft Research in the development of C# Generics.

### *Template Metaprogramming*

Within a traditional programming language like C++, one can exploit the mechanisms of C++ templates for achieving generative programming.

Through template metaprogramming one can force the compiler to perform computations on types at compile time. The mechanism is quite cumbersome although so powerful as Turing complete.

Exploiting this mechanism, we have been able to provide support for reflection in C++. The compiler is instructed to produce metaclass objects that describe classes. Such class objects can be exploited at run time to perform various tasks, for instance object serialization.

The technique has been the basis for the development of IXE, a high performance class library for indexing and search, used in building several search engines.

*Code Generators and Staging*

Our goal is to match the expressive power of template metaprogramming, working however at the normal language (rather than meta-language) level and providing a facility that is programming language independent.

The solution consists in a library, called CodeBricks, that allows manipulating abstractions of code fragments, which contain Intermediate Language (IL) code, but retain enough information about high-level types to be able to perform type checking and veri cation.

CodeBricks allows performing transformations on the code abstractions at the IL while retaining the illusion of manipulating source programs. When using a common intermediate language like ECMA CIL, as in our implementation of the library, code fragments produced by di erent languages can be used together.

CodeBricks provides a mean for a programmer to generate low level code, by letting the compiler to take care of the nitty-gritty details, and assembling fragments of code that resemble building blocks providing suitable primitives.

The approach gives the programmer detailed control on the process of code generation, while being able to perform specializations and optimizations in the code produced. For instance a *Domain Speci c Language* can embedded within a general purpose language, by having speci c code to be produced for the Domain Speci c parts of the language.

A special case of generative programming is *multistage programming*. Manipulating code objects is a mean to produce the various versions of the program that will run at di erent stages.

Performing such transformations at the IL level, allows stages to be run on di erent language processors, rather than within a single processor as in traditional source-level approaches (e.g. MetaML).

This activity is supported by a grant from Microsoft Research.

*Web Programming*

More and more often Web applications are built as staged computations, where the server-side program dynamically generates code to be run on the client side. The serveer-side program itself is generated from other tools like a Content Management System.

Currently the various stages are expressed in di erent programming lan-

guages (both traditional and scripting languages), using several types of preprocessors (ASP, JSP, etc.), markup lnaguages (HTML, XML), and they must be made available by trasferring each component in suitable locations (often on separate machines).

Developing and debugging this kind of applications is quite hard, since each component of the applciation must be handled separately, with separate tools.

To address this problem, we are developing a general model of staged computations, that allows expressing within a single framework computations at the various stages.

A multistage computation could be expressed within a single program le, annotated with suitable hints to generate the code for each stage and to activate their execution at the proper time. The required information for each stage is carried as metadata within the generated executable code.

*Indexing and Search*

IXE is a C++ class library for indexing and searching large collections of documents. The library has been designed for e ciency and scalability, handling multiple collections of documents with overall size of several Terabytes. Several applications have been built using the library, ranging from Web Search Engines, local disk indexing and retrieval, document management systems, specialized indexing and search of multimedia collection.

IXE provides the facilities of typical search engines, including boolean combinations, phrase searches, proximity search.

IXE exploits carefully designed data structures and algorithms, optimized for the speci c tasks: for instance multiple keyword queries are dealt through the Small Adaptive Set Intersection algorithm, which has been shown to be optimal among the known algorithms.

Query processing in IXE is provided through a generalized cursor interface, so that all kind of queries (boolean, proximity, multiple collection, etc.) can be dealt through a single cursor operator.

IXE achieves a performance that is 10-20 faster than similar commercial products, in particular it can index 2GB/hour and it handles 20 queries per second on a 2 million document collection on a single Pentium III Linux PC.

IXE provides the information retrieval facilities required in more complex applications. Programming the library, for instance we developed a special-

ized paragraph search tools, which returns relevant paragraphs instead of documents, as needed in Question Answering applications.

IXE was developed through a grant from Ideare SpA.

*Question Answering*

While traditional Information Retrieval systems return a list of documents ranked in order of relevance to a query expressed in terms of keywords, a Question Answering system consists in nding a precise answer (no more than a paragraph) to a query expressed in natural language.

Question Answering combines techniques of information retrieval, natural language processing, information extraction, in order to provide with reasonable precision answers to short factual queries.

PiQASso is a complete question answering system, that competed in the QA tracks at the TREC 10 (2001) conference, ranking among the best ten systems.

PiQASso parses the query, identi es the answer type and performs a paragrpah search, extracting relevant paragraphs from the document collection using IR techniques; a series of lters are then applied to each candidate answer, ruling out those that do not appear to contain a proper answer.

These lters analyze:

- the expected answer type, based on a classi cation of question types (location, person, organization, measure, date ...);
- the structure of the sentence, trying to nd semantic relation matches between candidate answer and question.

Both during indexing and analysis of candidate answer paragraphs, several lexical and linguistic corpora are exploited, in particular

- gazeteers, containing person names, geographic locations, etc.
- WordNet, a thesaurus of the English language which provides synonyms, hypernyms and hyponyms and resolving lexical ambiguities;
- collection of idiomatic phrases.

*Automated Categorization*

Techniques for automated categorization of Web documents help building catalogues and facilitate retrieval of material on the Web. Classi cation is traditionally performed by extracting information for indexing a document from the document itself. Categorization by context is a novel technique for automatic categorization based on the following hypotheses:

1. a Web page which refers to a document must contain enough hints about its content to induce someone to read it
2. such hints are su cient to classify the document.

The approach exploits techniques of linguistic analysis. We developed an improved version of TreeTagger, a statistical part of speech (POS) tagger, revising its memory management and adding an Italian lexicon.

Techniques for concept learning are useful for building the category pro- les required to perform document classi cation. We are exploring the idea that language and concepts can be learned just from interaction with other agents. Starting from a set of classi ed documents we build conceptual representations for categories. The concept associated to a category is derived according to a principle of economy, alternating generalization and specialization steps.

*Best Bets*

ClickWorld is an industrial research project, in cooperation with KSolutions SpA, that aims at developing tools and techniques for proactive personalization in support to the construction of complex Web sites.

As part of the project we developed techniques for producing \Best Bets", i.e. selecting and presenting to the visitor of a Web site a set of items related to the interests that the visitor has expressed, either explicitly, through a query, or implicitly, based on his pro le and navigation history.

The technology enhances traditional search techniques, by creating specialized collections of documents based on criteria determined by the site maintainer (for instance, time freshness, regional relevance, advertisement targets). Such collections are automatically maintained and queried in parallel with general collections, after expanding the query with suitable keywords in order to widen the search.

A peculiar feature of the BestBets technique is that it inverts the direction of search: while normally a single query is matched with a large number of documents in a collection, in a BestBets search a number of queries is to be matched with a single item, which describes a particular user, for instance a user pro le or the set of terms supplied in a user query.

For this reason, BestBets cannot use the standard indexing and search technique and we devloped speci c algorithms and data strcutuers for thir implementation.

### Short term plans and expected results

Filing and retrieving documents is a task where a higher level of interaction through adaptive agents can be exploited. Web search engines have shown that people nd convenient to delegate the knowledge on where documents are stored and to interact with the engine through simple natural language queries. Nevertheless it is still the user responsibility to determine which documents contain the exact information he needs and to extract it for completing his task.

We wish to go beyond the ability to retrieve relevant documents and support directly the user task. For instance, we may want to provide answers to user questions. However we would like to work at the conceptual level, rather than the syntactic level. Identifying concepts and relations among them in the documents will enable such kind of processing and answering questions.

Among the aspects to be studied are:

Categorization techniques. Supporting automated categorization by tools for generating category pro les and concept matching.

Concept learning. Extracting relevant concepts from training collections, exploiting thesauri and ontologies.

Identi cation of relations among concepts, creating or extending thesauri and ontologies.

Link analysis to determine relevance and authoritativeness of sources

Question answering.

In particular we plan to continue earlier work on search and categorization of documents, refining the techniques with the addition of semantic linguistic analysis.

*Graphics and Interaction*

Within a cooperation with ST Microelectronics and CNR-ISTI, we are developing a 3D graphics library for use on hand-held devices. The library conforms to a subset of OpenGL, and hardware support will be designed to support the library to be embedded in future generation processors.

We have developed a multimodal presentation system for dynamic object scenarios based on 3D interactive animations, coordinated with adaptive spoken comments. User profiling and comments production are performed through the interaction with a human-like agent. The presentation system works in conjunction with an expert authoring system for sail racing scenarios. The software architecture is modular and flexible, explicitly targeted to the Web environment. Moreover it is general enough to be easily reused in other domains and applications involving dynamic object scenarios.

*Embodied Agents*

The control component of a robot can be modeled as an adaptive agent.

A robot with abilities of moving, speaking and seeing, may interact with humans in the physical environment and behave as an embodied interface agent capable of performing or helping perform simple tasks.

This research aims at developing a platform for building autonomous interface agents embodied in robots. The robot provides a physical body and a set of core facilities needed to communicate and to interact in the physical world.

This research is supported with a grant from Microsoft Research.

## Software Artifacts and Open Source

The group delivers many of its results as software artifacts, usually available on the net or in Open Source collections.

ECL ECL is an implementation of the Common Lisp language, embeddable in C applications. It is available on SourceForge at the page:

http://ecls.sourceforge.net.

CMM CMM is a customisable memomry manager for C++, that has been used in particular by Sun Microsystem in the implemetation of Java. The code is available at: http://www.di.unipi.it/ attardi/cmm.html.

IXE IXE is a high performance library for indexing and search based on C++ template metaprogramming.

IXE Crawler is a Web crawler that uses techniques of asychronous IO to achieve high performance without overloading the OS with large number of threads.

NE tagger is a named entity tagger based on the technique of Maximum Entropy.

The group contributes also to projects in the OpenSource community, for instance:

TreeTagger a Part-of-Speech tagger based on statistical techniques combining HMM and decision trees. Available at: http://www.ims.uni-stuttgart.de/projekte/corplex/TreeTagger/DecisionTreeTagger.html.

cURL libcURL is a multiprotocol file transfer library. Several changes and bug fixes have been supplied for its use in the IXE crawler. Available at: http://curl.haxxe.se.

rddtool a tool for memorizing and visualizing a series of temporal values. Available at: http://people.ee.ethz.ch/ oetiker/webtools/rrdtool/.

### Long term plans

In many situations the patterns of information that are to be dealt by computers are so complex that a traditional logic-based approach is no longer appropriate. Providing computer agents with intelligent abilities requires building programs or knowledge bases so complex that are impossible to handcraft. On the other hand large collections of training data have become available as well as the computing power to process them. A challenge for research lies in building intelligent systems by combining knowledge acquired by training with prior knowledge from established bodies.

This approach can provide agents with the ability to deal with unstructured data or free text, which still represent the vast majority of information sources.

Agents must be capable of acquiring the vocabulary, the ontologies and the mode of expressions of their users. This will form the basis for understanding the user needs and providing assistance in performing his tasks.

### Personnel and External Researchers

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## Funded Projects

Enhanced Content Delivery, Fondo Progetti Speciali MURST, 1999.

Piattaforme Abilitanti per Griglie Computazionali ad Alte Prestazioni, Fondo per gli Investimenti della Ricerca di Base, 2002.

Applied Semantics II, EU 5th Framework Program Thematic Network.

ClickWorld, KSolutions SpA, Progetto di Ricerca Industriale, Legge 488/92.

Multistage Programming, Rotor Grant, Microsoft Research.

Gra ca 3D per applicazioni a basso consumo di potenza, ST Microelectronics.

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## 2.4 Project: Specification and Verification of Distributed Systems

### Summary

Purpose of the project is to tackle the problem of designing distributed systems, also mobile and real-time. The research will concentrate on the study of formalisms with adequate semantics to support specification, implementation and verification of the wanted properties (in particular safety and security), and on the development of software tools to help in this purpose.

Keywords: distributed systems, mobility, real-time, specification, verification, implementation, tools

### Background

Our society is becoming more and more dependent on computer networks. Unsafe behaviors must be avoided, and data which are elaborated, transmitted or stored need some form of protection. Cryptographic algorithms have been proposed to protect information which is transmitted on communication networks. However, cryptography is mainly used as a building block of many

complex applications where the correctness of the cryptographic algorithm is not a guarantee per se of the correctness of the applications.

Only the development and use of formal tools may allow analysts and designers to describe faithfully, to analyze in detail and to prove the correctness of systems. Formal specifications and application of verification techniques may significantly reduce the risk of errors in the development of systems, compared with traditional informal specification and testing.

The application of formal methods to the development of validated systems mainly concentrates on specification languages, with semantics adequate to support implementation and verification, and methods and tools for verifying specifications with respect to properties expressed in suitable formalisms.

*Specification formalisms*

In recent years a number of automata have been proposed for modeling real-time systems. The behavior of such systems is described in terms of acceptance or non-acceptance of timed sequences. Automata such as the ones mentioned, are finite automata equipped with a set of variables; with the states an evolution law is associated which gives the values of variables with time passing and transitions are labeled with guarded sets of assignments to variables. The most general case is that of Hybrid Systems, which allow describing systems consisting of discrete and continuous components interacting among themselves and with a physical environment.

Parallel composition and hierarchical structuring of states appear to be key constructs of a formalism for complex specifications.

With mobile devices and the possibility of moving code between devices on the World-Wide Web, concepts of mobility have been proposed, and formalisms to express mobility have been defined.

The pi-calculus has been introduced to describe concurrent systems whose topology may change as the effect of the communication of channel names. A recent proposal, Ambient Calculus, is based on the new concept of ambient mobility. The Ambient Calculus has been proposed both as a core programming language for the World-Wide Web and as a model for reasoning about properties of mobile processes, including security.

*Veri cation of properties*

The correctness of a system with respect to a desired behavior is veri ed by checking whether a structure that models the system satis es a formula describing that behavior.

The fact that the system cannot reach unwanted states (*safety*) and that there is no possibility of leakage of information (*security* and *privacy*) are among the most interesting properties.

Continuous variables give rise to in nite models, hence the need of dealing with nite approximations which ensure holding of the considered property in the original model. But also with nite models the computational e ort (*state explosion*) may be an obstruction to veri cation.

## Ongoing research

*Speci cation formalisms*

We have de ned a model, Timed Automata with Non-instantaneous Actions, which allows representing real-time systems in a suitable way. Timed Automata with Non-instantaneous Actions extend the timed automata model by dropping the assumption that actions are instantaneous. We have investigated the expressiveness of the new model, comparing it with classical Timed Automata [Barbuti, De Francesco, Tesei 2001].

We have studied subclasses of Communicating Automata obtained by admitting, or not, diagonal clock constraints and constant updates, and by letting, or not, sequential automata to update the same clocks. Such subclasses recognize the same languages, but di er from the point of view of succinctness. Moreover some subclasses are polynomially closed with respect to union and intersection, while others do not enjoy such properties [Lanotte, Maggiolo, Tini 2003].

We have de ned an extension of Communicating Hierarchical Automata which allows dynamic activation of components (DHMs). We have given an SOS semantics for DHMs, we have investigated interesting subclasses, and shown how to use the formalism for describing problems of security [Lanotte, Maggiolo, Peron, Tini 2003].

We have introduced Monotonic Hybrid Systems, a subclass of Hybrid Systems with variables changing monotonically with time. The subclass includes known subclasses of Hybrid Systems, such as Integrator Systems and

Timed Automata. In the discrete time case and under some restrictions, its expressiveness is the same as that of Timed Automata, but descriptions are more succinct [Lanotte, Maggiolo 2002].

We have considered Hybrid Systems with real and integer variables, parameters and arrays [Lanotte 2003 a]. The model has been successfully employed to describe time-dependent processes and embedded systems. We have considered also cases with conditions on variables expressed by both linear and polynomial formulas and we have given some expressiveness results.

*Logics and veri cation. Applications to safety and security*

As regards Monotonic Hybrid Systems we have studied conditions under which properties veri ed assuming discrete time hold true also with dense time, and we have given an algorithm for veri cation [Lanotte, Maggiolo 2002].

We have de ned a logic to express properties of information ow. This logic allows expressing attacks and properties guaranteeing security in systems both with time and without. We have described problems of web security and algorithms for encrypting and decrypting keys. We have given al algorithm for verifying a property expressed in the logic and proved that the algorithm always terminates for Timed Automata [Lanotte, Maggiolo, Tini 2003].

We have studied the non-interference property in real-time systems. We have tackled a problem of timing attack on web privacy, by means of three di erent approaches. We have done a comparative analysis on results [Gorrieri, Lanotte, Maggiolo, Martinelli, Tini, Tronci 2003].

We have proved decidability of weak probabilistic bisimulation for a class of Timed probabilistic Automata, We have used the result for verifying security of a timed probabilistic protocol which guarantees the non-repudiation property [Lanotte, Maggiolo, Troina 2003].

In [Troina, Aldini, Gorrieri 2003] we have abandoned the assumption of perfect cryptography and proposed a new equivalence for expressions.

We have studied a notion of non-interference for real-time system represented by Timed Automata. The non-interference notion we have de ned (timed non-interference) depends on a number $n$ representing a minimum delay between actions such that the system meets the desired behavior [Bar-

buti, De Francesco, Santone, Tesei 2002]. We have characterized a decidable notion of timed non-interference [Barbuti, Tesei 2002].

We have also started a study aiming at a classi cation of timing attacks on privacy [Gruska, Lanotte, Maggiolo 2002].

*Abstract interpretation*

Nowadays, the enormous growth of the Internet, and, consequently, of mobile code makes the problem of secure information ow of great importance. We have shown how abstract interpretation can be applied to the analysis of secure information ow to easily derive sound semantic rules for static program certi cation[Barbuti, Bernardeschi, De Francesco 2002a][Barbuti, Bernardeschi, De Francesco 2002b]. Often, the mobile code is written in Java. The Java Virtual Machine embodies a veri er which performs a data- ow analysis applied to a type-level abstract interpretation of the code. The current implementations of the bytecode veri er present a signi cant problem: there are legal Java programs which are correctly compiled into a bytecode that is rejected by the veri er. We have proposed to enhance the bytecode veri er to accept such programsby de ning an abstract domain which is more expressive than the one used in standard veri cation [Barbuti, Bernardeschi, De Francesco, Tesei 2002].

We have introduced an abstract interpretation framework for the Ambient Calculus [Levi, Ma eis 2001,2004]. The framework is based on a new semantics called *normal semantics* which is designed precisely to support the development of analyses. Then, we have derived within this setting two analyses computing a safe approximation of the run-time topological structure of processes. Such a static information can be successfully used to establish interesting security properties. We illustrate this point by applying the analyses to several critical examples taken from the literature.

*Static Techniques for Mobile Systems*

We have proposed a variant of the Ambient Calculus, called Safe Ambients Calculus (SA) [Levi, Sangiorgi 2003]. The modi cation has several advantages: in SA it is easier to control the interferences, especially the so called grave interferences, which are critical and may be regarded as programming errors; a type system can be de ned that remove all grave interferences; SA

has also a useful algebraic theory, which simpli es the task of proving the correctness of programs, and simpler programs which require less conditions for correctness. Furthermore, the static techniques, based on Type Systems or Control-Flow Analyses, are more precise in SA than in standard Mobile Ambients. This because, due to the presence of coactions, in SA it is easier to argue on the temporal ordering of execution of the basic interactions, such as the movements, the opening and communication.

In [Degano, Levi, Bodei 2000] we have de ned a Control Flow Analysis for SA, which re nes the Control Flow Analysis of Nielson et al. with contextual information. The analysis computes a safe approximation of the run-time topology of processes. This information permits to reason about the movements and the opening of ambients and to prove several security properties. We have studied in particular the applicability of the analysis to establish a secrecy property.

Moreover, we have studied the so called evolving types of SA, where the type of the process running inside an ambient may vary as the computation proceeds. In [Levi 2003] we have extended the types of [Levi, Sangiorgi 2003] by focussing on evolving communication. The more exible types permit to de ne ambients, where the type of the data exchanged may vary as the internal computation proceeds or after opening.

Moreover, we have studied the relations between the SA model and other modi cations of MA, in particular Boxed Ambients (BA). In BA, di erently from MA/SA, there is no ambient dissolution and new primitives are introduced for exchanging values across ambient boundaries. In[Levi, Bodei 2004] we have presented the following contributions: (i) an encoding of BAinto SA; (ii) a new Control Flow Analysis for SA, which is an adaptation of the Control Flow Analysis of Nielson et al., obtained by pro tably exploiting the presence of coactions. The analysis computes a sound approximation of the run-time behaviour of processes, by giving information about the evolution of the ambients hierarchy, and about which capabilities may be exercised and which messages may be exchanged inside any ambient. Finally, we have shown that the analysis, when applied to the encoded processes, permits to accurately verify Mandatory Access Control policies of the source processes. Speci cally, it permits to obtain better results than the type systems designed for BA.

Projects in which the participants are involved:

- MURST Project MEFISTO (Metodi formali per la sicurezza e il tempo).

## Short term plans and expected results

We shall continue studies on Concurrent Timed Automata and on Monotonic Hybrid Systems.

We shall also continue studies on Dynamic Hierarchical Machines (DHMs). We want to introduce a concept of location to limit both communication among DHMs and creation of DHMs by means of constraints taking into account location boundaries.

We shall continue the study on timing attacks on privacy.

We plan to study new type systems for establishing security properties in the Mobile Ambient Calculi. In particular we are interested in studying the problems of access control to resources which is rather complex in this setting.

We plan to continue to use abstract interpretation techniques for checking security properties.

## Long term plans

The advantage of using formal speci cation, validation and code generation in a coherent and integrated fashion are generally recognized. Many tools have been developed both in academic and industrial research settings. Some of these tools are powerful enough to be considered for serious industrial application.

Our long term aim is to contribute to a design methodology based on formal methods which can be accepted in a wider range of industrial projects.

Crucial points in the de nition of such a methodology are:

- the formal de nition of adequate formalisms able to express synchronous, asynchronous, distributed, real-time and mobile aspects of systems,
- the de nition of concepts of safety, security and privacy, and the de - nition of logics to express them,
- the de nition of abstract interpretations for checking security properties,

- the development of formal veri cation techniques which can handle the complexity of typical design,

- the interaction with existing tools and design processes.

## Personnel and external researchers

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## 2.5 Project: Reduction Machines for Combinatory Languages

### Summary

The nal goal of the project is the de nition of an extended combinatory calculus for declarative languages of the last generation, including mechanisms for handling events and communications as well as mechanisms for inferential programming. The new calculus is studied on the base of a main characteristic: the de nition of a reduction machine for it, suitable for mobile computing. The fall of the cost of hardware equipments together with a tremendous increasing of processor speed, makes mobile computing even more relevant in applications of information technology. By guaranteeing security and portability of code, at various levels, we deem that a combinatory code can be a good base for mobile computing.

After the work on the combinatory approach of the past years, we are actually focusing on the aspect of parallel computing which could be fruitfully used. In particular we are actually studying the problems related to the parallel computation of uni cation.

Keywords: Combinators, reduction machines, events, declarative programming, mobile computing, security, portability, uni cation.

### Background

Declarative languages are widely considered as the theoretical and methodological basis for the de nition of programming languages, suited to all the

various applications of computing. Recently, the need for secure programming on the one hand and programming for supercomputing on the other hand, brought people to consider such languages as the only ones which can support good certi ed code and more, code that can be checked to t into the various contexts in which mobile computing can be involved. Eventually declarative code is easily structured in closed parts (expressions) which can be computed separately on independent machines.

Interesting subjects to develop are:

Since [Tarski-Givant 1987] introduced a calculus for complete rst order logic without variables, till nowadays, much progress has been made and interesting results are obtained as far as combinatory calculus for logical and relational programming is concerned. We also, [Bellia and Occhiuto 1999], have de ned one combinator for uni cation. It allows to deal with uni cation by means of abstracts of terms of rst order formulas. It furnishes a linear reduction system for uni cation. Nevertheless logic programming (or, better logic languages) requires many more ad hoc mechanisms than those provided by rst order logic: constraints, negation and also control mechanisms which are not logic. Hence the question arises on how to extend these combinatory theories to deal with such mechanisms [Broome and Lipton 1994].

Another aspect of the de nition of a combinatory calculus for declarative programming, is the de nition of a calculus with (based on) supercombinators [Hughes 1982] which is able to reduce the huge [Broda and Damos 1997] dimension of the code (expressions) obtained using a xed number of combinators. This is a fundamental problem if we want to:

- use a combinatory code in mobile computing,
- reduce the code fragmentation of independent parts in supercomputing.

To study solutions, we started with studying techniques of parallel reduction for the mechanisms which are the kernel of declarative languages, such as uni cation or the substitution rule.

Studying the theories, like monads, to understand if and to what extent they can furnish a suitable support to the integration of the logical and

the functional features and as such provide mechanisms to deal with logical variables and higher order. Monad has been successfully developed to interface the functional paradigm with various frameworks: state, I/O, streams [Scholz 1999].

## Ongoing research

In this period the group has investigated the problem of parallel uni cation and of the design of parallel uni cation algorithms. In [Dwork at al 1984] uni cation was proved to be *LogSpace* complete for *P*, which essentialy means that parallel uni cation algorithms cannot signi cantly speed up the computation, compared to the sequential ones. As a consequence the interest raised on studying the structure of the classes of (the inputs of) the *MGU* problem [Kanellakis and Ravesz 1989, Bellia and Occhiuto 1999b]. In fact, whatever is the application involving uni cation there are in nitely many inputs for which the computation will never be required. For these reasons, it is interesting to investigate on the properties of the classes which can be fruitfully dealt with using parallel computation and on the design of parallel algorithms which behaves well for such classes. In this respect, the structure of the classes of *MGU* problem appears much richer and intricate than that of *MCV*. In fact, the complexity bound of the *MCV* problem essentially depends on the depth of the input while this is not true for the *MGU* problem: We prove in [Bellia and Occhiuto 1999a, 2002] that *MGU* limited to inputs of depth bound by a constant is not simpler than the general *MGU* problem. Moreover, we discusses two measures, *depth* and *width*, which are complementary in giving the input size and result into two subclasses of *MGU*, *MGU(k-depth)* and *MGU(k-width)*, which are proved equivalent in between.

Furthermore in [Bellia and Occhiuto 2003], based on the notion of interleaving variable and of n-axioms uni cation, the new uni cation class $AMGU^{k}_{p=h}$ has been de ned. The class is solved in polylog PRAM-time and is an upper bound for the uni cation classes known to fall in the complexity class *NC*. Inputs of $AMGU^{k}_{p=h}$ admit an unrestricted number of repeated variables and an unrestricted arity on term constructors, even if they have a bound on the interleaving variables.

## Short term plans and expected results

The group is planning to terminate the studies on parallel un cation by de n-ing an inferential parallel uni cation algorithm. The idea is to use inference rules to reduce the structure of the terms to be uni ed. The correct solution is obtained through a sequence of transformations more and more fast to compute with. Of course the reduction is not always possible but the result-ing process should be more e cient for almost all classes of the uni cation problem. Inferential algorithms for operators are interesting to investigate in the perspective of an integration of such operators into a combinatory calculus. In fact inference can be (easily) translated into the reduction rules needed to de ne the machine support of the calculus. This would be the next step which conclude the investigation on parallel uni cation.

## Long term plans

The nal goal of the project is the de nition of a combinatory calculus and its reduction machine for declarative languages. A program in a combinatory language has the following properties:

extentionality is widely exploited. Refer to Backus's Lecture at the ACM Award in 1977.

it needs no environments and no closures to compute,

partial computations are naturally provided by reducta,

it has no store locations, hence it is easier to control accesses out of the allocated memory space.

We deem that such properties make combinatory languages very inter-esting to investigate as the basis for mobile computing, which requires safe and certi ed code.

## Personnel and External Researchers

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## 2.6 Project: Design and Management of Parallel, Distributed and Mobile Systems

### Summary


In this project, several problems related to the design and management of computing systems in which a multitude of entities interact or compete for

accessing a common set of resources, are addressed. The assumed systems can have a common reference point (namely, a shared memory), or not, and the involved active entities can communicate via fixed or dynamic patterns (this last feature representing mobile systems).

In spite of this generality, it is possible to produce abstract models capturing the essential features shared by such systems, ignoring the unimportant physical details. In this project we address several specific problems, namely routing and cooperation enforcement in mobile ad-hoc networks,fault and intrusion tolerance and recovery, packet scheduling, video transcoding for mobile terminals, network performance in grid systems, clock synchronization, formulated on general models of parallel and distributed systems. This allows to apply the obtained results in a wide variety of situations. Moreover, we address the problem of extracting common patterns of algorithms in parallel and distributed systems (algorithmic skeletons) and provide them as building blocks for applications to be run (and moved) between parallel, distributed and mobile targets.

Keywords: parallel and distributed systems, message and process scheduling,routing, network performance, network monitoring, mobile ad-hoc networks, LEO/MEO satellite constellations, algorithms and complexity, game theory, algorithmic skeletons, intrusion tolerance

## Background

Computing systems composed of several interconnected processing entities, either cooperating toward a common goal, or concurrently contending for a common set of resources, are the most common systems presently in use. Such systems range from parallel processing ones, in which the processing entities are tightly coupled, and have free access to common resources, like memory and a global clock, to distributed processing, with no common memory and no common timing. Examples of these systems are massively parallel processing systems, and computer networks, like LAN's and Internet. Recently, a new kind of distributed systems, in which the processing entities can freely move, and continue to operate while moving (the mobile systems) emerged as a viable alternative in many application areas.

All these systems share common features, as well as striking differences, and rely on algorithmic methods for optimal design and convenient management of their operations. In this research project, relevant problems related

to the design and management of parallel, distributed and mobile systems, are considered.

Technology alone is not a panacea: when proper actions are not pursued, the system can interrupt its service because of not reported faults. This can be the cause of serious problems for both the system and the users depending on it. Another problem not solved by technology alone is the users' uncontrolled access to the common medium, which may result in a poor utilization of the common resource, causing a degradation of the overall system performance, thus eliminating the bene ts of the costly new adopted solutions.

We believe that the realization of high-speed, high performance, cost-e ective, reliable and transparent distributed and parallel computing systems requires new approaches, based on sophisticated algorithmic solutions and mathematical tools, like game theory. When such solutions turn out to be impractical, the obtained results can be used as fundamental limits to more practical approaches, and thus contribute to form a foundation of parallel and distributed computing. The research community working in this eld has recently indicated the above approach as a very promising one, and the related activity has already produced papers published in the most respected scienti c journals, and has witnessed a owering of new workshops and conferences dedicated to the algorithmic aspects of design and management of parallel and distributed systems. Furthermore, the number of research projects on these subjects that are funded by diverse authorities is growing at a very fast pace. It is the purpose of this proposal to investigate and experimentally evaluate such approaches, thus following the above research line.

On the applications side, advances in technology are usually exploited at the expense of a long software development process tied to a particular target machine. The research community has recognized the lack of a reliable unifying computational model as a central problem in machine independent parallel and distributed software development. We believe that such model needs to make easy the expression of common algorithmic patterns on different targets and provide the user with reliable complexity costs. In the past ve years, models based on algorithmic skeletons have had encouraging results for parallel applications with statically predictable structure. We intend to investigate whether the bene ts of algorithmic skeletons can help in the de nition of an unifying model for parallel, distributed and mobile

settings.

## Ongoing research

The research actually pursued in this project can be sketched as follows:

*Packet scheduling in distributed systems*

On-line and o -line packet scheduling in single-hop multichannel communication systems (like High Speed Switches, Optical networks, wireless LAN's, etc.), and in connected single-hop multichannel communication systems, both for real-time and not real-time tra c.

Scheduling of BSP- and LogP-like computations for distributed computing systems

*Network monitoring for network aware applications*

Network aware (distributed) applications are able to optimize their operation using results produced by network monitoring tools: we focus on monitoring tools and on architectures that make available their results, paying special interest to Grid environments.

*Algorithmic Skeletons*

Integration of task parallel and data parallel activities on network of workstations. Design of transformational systems for the systematic derivation of skeletal programs from speci cations. Case studies using real applications.

*Web Caching*

Optimization of web caching systems. Memory saving and routing in web caches clusters, with and without fault tolerance.

*Integrating LEO Satellite Constellations into Internet Backbone*

Investigating the use of LEO satellite constellations for solving the new challanges posed on Internet: guaranteed services and ubiquitous access.

*Trading E ciency and Intrusion Tolerance*

Byzantine failures, and their approximate solution: relationship between approximation and time complexity.

*Wireless Networks*

routing algorithms, dependable data storage and retrieval, failure recovery, cooperation enforcement, video transcoding.

The members of this group are involved in the following national and international projects:

- National Project IS-MANET on "Infrastructures for Mobile ad-hoc Networks"
- National Project VICOM on "Virtual Immersive Communication"
- National Project on "Resource Allocation in Wireless Networks"
- EEC Project "ALCOM"
- EEC Network of Excellence "ARACNE"
- CNR curiosity-driven project MaD-WiSe on Management of Data in Sensor Networks
- International Project DataTAG
- INFN Project INFN-GRID
- INFN Project IPM (Internetwork Performance Measurement)

## Short term plans and expected results

We shall study message and packet scheduling, as well as network monitoring results production. These two problems are very relevant for achieving high performances and easy of programming in distributed systems.

In particular, we shall propose new models for representing and studying these problems, investigate their computational complexity, propose optimal algorithms and fast sub-optimal heuristics, study the properties of such algorithms and heuristics, and implement them. Speci cally:

> about *scheduling problems*, we shall investigate optimal message scheduling in single-hop, multichannel communication systems. In particular, we shall investigate message and packet scheduling problems with the

objective of minimizing the makespan, or schedule length. Several different tra c and system features will be considered. First, *on-demand* scheduling will be studied. This problem require that the messages presented to the system by the users are scheduled immediately, without waiting for a large number of requests to come, before computing the schedule for all of them at once. This problem is gaining increasing importance, and can also be applied to mobile communication in "ad hoc" single hop systems. Another feature that will be considered is *real time* constraint. Real time scheduling arises in all time sensitive applications, like multimedia, process control, and new applications like monitoring in health care, and stock exchange informations. Both periodic and sporadic tra c will be considered. Besides, a di erent cost function, namely jitter, will be investigated. Jitter is specially relevant when dealing with multimedia (voice and video) tra c, since delay uctuations cannot be tolerated by such applications, while the loss of some packet is not prejudicial to system correct working. Special emphasis will be given to experimental evaluation of the proposed algorithms. Finally, we shall study scheduling of *interconnected single-hop systems*. In this case, scheduling and routing must be solved at once, since they in uence each other: an optimal routing can overload intermediate systems, thus leading to very long schedules. On the other hand, an optimal schedule needs a load balancing, which could be achieved at the expenses of unacceptably long paths. LEO's satellite constellations, like the IRIDIUM system, fall into this category of distributed systems.

concerning *network monitoring for grid aware applications*, we are mainly concerned with Grid environments, and we are going to implement a real scale prototype. For those network characteristics that require clock synchronization, we are going to use the know-how and tools matured during past years activity. In order to improve the scalability of the network monitoring infrastructure, we introduce Grid partitioning, and map grid services to such partitions: systematic monitoring will be limited to routes connecting partitions. In the spirit of the DATATag project (which pursues Grid integration) the prototype is interfaced with two popular Grid Information Services: R-GMA, designed and implemented in the frame of the European DATAGRID project, and

MDS, part of the Globus Toolkit. We expect to integrate our prototype in the MDS based INFN-GridICE monitoring tool.

The tools implemented during the past activity will be used to run real scale experiments.

*Trading E ciency and Intrusion Tolerance*

Our everyday life depends on the correct working of critical distributed systemslike air tra c control, power plant control, but also stock market, government services, just to cite few. At the same time, attacks to such systems are becoming more and more frequent. The problem has been investigated since many years, and has been modelled as Byzantine failures. Many techniques have been proposed for solving such problems. However, such techniques do not take into account the computational e ort they require, thus making them unattractive for practical use. In this research, we shall look for new techniques that solve the problem with a certain degree of approximation, but require little computational e ort, so to be attractive also for applications require low power consuption, like mobile ad-hoc networks.

On the algorithmic skeleton side, we will analyze common structures of parallel an distributed applications and de ne a skeleton model starting from these structures. The investigation will move from the analysis of key applications and validate the expressivity of the model against standard benchmark suites. A key point to be addressed will be the de nition of skeletons for irregular and dynamic applications, which are crucial distributed and mobile setting. This will involve the de nition of suitable execution models for nesting dynamic skeletons and the derivation of reliable approximation of skeleton execution costs. Our investigation will include the derivation of optimized implementation templates for the skeleton proposed and tests on real machines.

About web caching, we shall investigate the impact of novel routing and storing schemes on the overall performance of web caching clusters. In particular, we shall study compact routing and storing of documents in web caches so to save time and memory when the system is operational. A comparison with known proposals, like Oceanstore, will be performed.

The integration of LEO satellite constellations and Internet is a novel and very promising research area. The purpose of using LEO satellites for

internet tra c is manyfold: reduce the congestion, improve the quality of service, allow a better connection of mobile users by providing a global planet coverage. Besides, this should be the testbed for interplanetary internet, namely the computer network that in the future will connect all the processing equipment that humans send on planets other than the earth (mars, for instance). This is a novel research area and many problems must be investigated. To cite few, medium access control proper routing and load balancing, congestion control. We shall focus on these problems giving solutions that take into account the special features of LEO satellites: high latency, low communication quality, low on board memory and processing power.

Major issues in mobile, ad hoc networks are how to implement routing in such a dynamic context and how to guarantee consistency, integrity and con- dentiality of the global information. Existing solutions for wired networks or personal communication networks can hardly be adapted to these networks due to di erent constraints/requirements in terms of energy, mobility, memory and processing capacity. Furthermore, a typical problem of ad-hoc networks is the cooperation enforcement in networks of heterogeneous users. One of the most important problems when dealing with mobile terminals is power awareness. Energy conserving habits can suggest to users of multi-hop networks to refrain from forwarding messages toward the nal destination. If such a behaviour spreads in the network, no message will be forwarded, and so no communication will take place. The nal and fatal consequence of this is network disruption.

The activity in the short term for mobile ad hoc networks can be detailed as follows:

- develop a new routing algorithm for ad hoc networks which exploits a virtual, topology-independent structure of the network to reduce the costs of path setup in the routing algorithm. This algorithm will be compared with the state of the art routing algorithms by means of simulation under di erent conditions of network load, mobility and density of mobile nodes.

- de ne models of data distribution in order to provide data availability and con dentiality and recovery algorithms. These models and algorithms should be designed taking into considerations the di erent characteristics of sensor and mobile networks.

- de ne models of users behaviour in multihop ad hoc networks with the aim of studying the basic limits of classes of policies implemented with the purpose of forcing users to cooperate in forwarding messages. These

models and results can be used to propose and study the performances of new policies, properly designed following the guidelines obtained as above.

Finally, video transcoding for mobile terminals in cellular networks will be investigated. In particular, we shall concentrate on the problem of avoiding still frames in moving pictures when the communication channel has a dynamic bandwidth. This problem shall arise in next generation cellular systems, like UMTS, which adopts a CDMA channel access protocol, with variable channel bandwidth. Fast processing of frames are in order for avoiding still pictures and guaranteeing acceptable video quality at the same time.

### Long term plans

On a longer horizon we shall investigate the scheduling problem known as *call control*. This is a special kind of on demand scheduling, in which some requests can be refused. Such a refusal can be necessary in order to maintain a good quality of service for other ongoing communications, and is specially important in mobile ad-hoc systems. Besides, multicasting will be considered also.

As for network monitoring, an emerging problem is the design and the production of the layout, which consists of the grid partitioning description and of the monitoring plan. Such step is presently awkward, and exposed to human mistakes. If the GlueDomains were successful, an appropriate step for its further deployment might be the design of an appropriate support for the Grid monitoring layout.

Long term issues in mobile networks include the following points:

- design and implementation of an a mobile ad hoc networks based on commercial laptops/palms equipped with wireless interfaces 802.11/bluetooth;
- interconnection of ad hoc networks with existing satellite and/or wired networks;
- design and implementation of protocols to support data storage and retrieval, enforce cooperation and ensure information con dentiality and dependability.

On the long term, we hope to be able to assess the potential of skeletal models as uni ed models for parallel and distributed systems. To do this we will need to use skeletons to derive real applications across distributed, parallel and mobile settings. This might involve the development of small prototypes which assist the application development and help the program-

mer in choosing the best skeletal structure for a given program. Another important step will be the formalization of the the expressiveness of skeletal models and the characterization of the class of applications which can bene t form their use.

Finally, we plan to investigate video transcoding techniques based on frame skipping where the decision taken on what frame to skip is derived by probabilistic arguments instead of deterministic ones. Besides, bu er occupancy results (on the average) will be sought.

## Personnel and External Researchers

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## 2.7 Project: Software adaptation

### Summary

The objective of the project is to contribute addressing the issues raised by the ever-increasing need of integrating heterogeneous software components to form distributed applications. The project focuses on the development of formal methodologies and tools for the adaptation and coordination of software elements that present mismatching interaction behaviour. The work embraces both theoretical aspects (formal methods, languages, semantics) and experimental issues (prototype implementation and assessment).

Keywords: adaptation, components, coordination, distributed systems, formal methods.

### Background

Software adaptation is widely recognised to be one of the crucial issues in Component-Based Software Engineering. The possibility for application builders to easily adapt o -the-shelf software components to work properly within their application is a must for the creation of a true component marketplace, and for component deployment in general. Available component-oriented platforms address software interoperability at the signature level,

typically by means of Interface Description Languages (IDLs). IDLs are a sort of *lingua franca* for specifying the functionalities o ered by heterogeneous components that were developed in di erent languages. IDL interfaces de ning the signature of the methods o ered by a component are an important step towards software integration, since they solve signature mismatches between components in the perspective of adapting or wrapping them to overcome such di erences. However, even if all signature problems may be overcome, there is no guarantee that the components will suitably interoperate as mismatches may also occur at the protocol level, because of the di erences in the protocols de ning the behaviour of the components involved. While case-based testing can be performed to check the compatibility of software components, more rigorous techniques are needed to lift component integration from hand-crafting to an engineering activity.

The ever-increasing growth of computer networking broadens the need of software adaptation for distributed applications emerging from the interaction of large numbers of heterogeneous components. Well-de ned methodologies and tools are needed to facilitate the dynamic integration and coordination of active components running on stationary servers as well as on mobile devices. In this perspective, increasing attention is being paid to approaches based on a *separation of concerns*, which advocate a neat separation of interaction and computation aspects. Such a separation leads to de ning exible models for coordinating and orchestrating the interaction of di erent components, and it has proven to help mastering the complexity of large applications while fostering software re-usability.

## Ongoing research

One of the objectives of the project is to contribute to the de nition of models and languages for specifying the interaction of heterogeneous concurrent software systems. In this perspective, we have been analysing di erent competing models for expressing inter-process communication and synchronization. In particular we have been focusing on comparing the expressive power of coordination models that rely on shared dataspaces, inspired by and extending the generative communication model of Linda. A hierarchy of data-driven coordination models has been established in terms of the notion of language embedding.

A second stream of activities has been devoted to developing models and

techniques for specifying and analysing the interaction behaviour of systems consisting of large numbers of heterogeneous components. The idea here is to extend traditional component interfaces with a description of the interaction protocol followed by a component, and to exploit that to dynamically and e ciently verify properties such as compatibility and deadlock freedom, as well as security properties. The use of di erent languages (Linda and subsets of the -calculus) to describe behavioural patterns is being experimented.

The most recent activities have been devoted to developing the foundations of a formal methodology for the adaptation of components presenting behavioural mismatches. The main ingredients of the methodology are the inclusion of behaviour speci cations in component interfaces, and a simple, high-level notation for expressing adaptor speci cations. Given an abstract speci cation, a fully automated procedure derives a suitable *component-in-the-middle* (adaptor) capable of letting two mismatching components successfully interoperate.

The above described activities have been partly supported by the participation in national research projects (M.I.U.R. TOSCA and NAPOLI) and by bi-lateral cooperation projects with Belgium and Spain.

## Short term plans and expected results

Our plan is to develop a full- edged methodology supporting the *soft* adaptation of heterogeneous software components that present di erent types of behavioural mismatches. Indeed, when two mismatching protocols cannot be fully adapted one another, a partial adaptor may be nevertheless generated in many cases. Such a form of soft adaptation will exploit the notions of sub-servicing and access rights, which are of primary importance for commercial applications. To illustrate the idea, consider a mobile client wishing to use some services o ered (subject to certain access rights, and according to some interaction protocol) by a stationary service in its proximity. While a full adaptation of the two protocols may not be feasible, a (dynamically generated) soft adaptor may let the two components successfully interoperate by possibly sub-servicing the client while respecting the access policies of the server. Other aspects we intend to investigate include the application of the methodology to the adaptation of Web services, and the capability of re-using existing (previously generated) adaptor components.

On the experimental side, we intend to develop environment prototypes

supporting all the phases of the proposed methodology (interface de nition, adaptation speci cation, and adaptor deployment). Such implementations will allow experimenting and assessing the adaptation methodology on a large number of available protocols.

### Long term plans

Our long term plans include the integration of the proposed methodology with available CBSE environments. The availability of engineered implementations of the methodology (to be developed in cooperation with other parties, under adequate funding premises) will condition the potential impact of the results on state-of-art technology.

We also plan to investigate the application of automated reasoning techniques to automate the whole process of adaptation trading, in particular the generation and the assessment of adaptation proposals. Indeed, the availability of such capabilities will pave the way for the exploitation of software adaptation techniques in pervasive computing scenaria.

### Personnel and External Researchers

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## 2.8 Project: Analysis and Synthesis of Numerical Algorithms

### Summary

The common feature of the research in this eld is the development of mathematical tools for the design and analysis of algorithms for the e cient solution of computational problems. Particular interest is devoted to the analysis of structures, to their exploitation and to the complexity analysis of problems in both sequential and parallel model of computation. Especial attention is addressed to numerical issues of problems arising from applications.

Keywords: numerical analysis, linear problems, matrices

### Background

The introduction of computers entailed developing the analysis and synthesis of computational methods for studying and solving mathematical problems, the core of the Computational Mathematics. The great speed of existing computers made it possible to solve problems of increasing complexity. This opened up interesting new research elds, such as the determination of the intrinsic complexity of a problem or the analysis of numerical stability of a computational method or the analysis of the conditioning of a problem.

Without thorough knowledge of the mathematical methods, computer use for solving technical and scienti c problems can be highly onerous. Uncertainties and errors are always present because they are introduced at various levels: in planning the mathematical model describing the phenomenon, in the associate numerical model, in the methods for solving the numerical model, in implementing the algorithms and nally in the development of the corresponding software.

The techniques used for solving numerical problems are an irreplaceable source of algorithms, with distinctive concreteness, understandability and implementability features. By studying numerical algorithms it is possible to detect problems and methods present in various elds of mathematics and computer science. An analysis of numerical algorithms gives important suggestions for better implementing machine arithmetics; algorithms analysis is itself a source for suggesting various possible rede nitions of computer structure.

## Ongoing research

The project deals mainly with issues like reliability, e ciency, complexity of algorithms and their applications in the following elds.

a) Solution of large dimensional linear systems. Most of the problems presently studied arise in partial derivatives di erential equations, in queueing theory, in computer algebra and in image processing. For structured problems, algorithms based on the analysis of structures and on the Toeplitz matrix technology have been devised, which show to be much faster than the currently available ones. For unstructured problems, automatic adaptive algorithms have been studied with the aim of obtaining the best trade-o between accuracy and computational cost. Sparsity properties of block Hessenberg matrices arising in a common multi-queueing problem have been evaluated and a stable recursive divide-and-conquer method, with low memory requirements have been devised.

b) Computational properties of matrix algebras: the relation between matrix algebras and displacement formulas for structured matrices are a major example of a wider applicability of classes of matrices commutative and closed (with respect to product) in matrix computation.

c) Problems from image processing and image restoration have been investigated, with the aim of developping advanced mathematical methodologies.

d) Mixed algebraic-numerical approaches for solving linear algebra problems involving structured matrices with coe cients over a ring have been considered.

e) The use of programming language JAVA to investigate algorithms for problems with structured matrices has been studied.

### Short term plans and expected results

1. New instances of matrix algebras will be investigated in order to detect their possible relevance to displacement decompositions and the improvement of numerical methods for solving Toeplitz systems.

2. The e ectiveness of preconditioned conjugate gradient for the the solution of large ill-conditioned linear systems arising in queueing problems is under investigation.

3. The problem of image restoration involves the solution of linear systems with block Toeplitz with Toeplitz block matrices. We aim to devise fast and stable direct methods for the solution of this problem.

4. A large JAVA Library for studying matrices computation is under development.

### Long term plans

The study of structure properties and informative content of matrices and the research of e cient algorithms for operating on both structured and unstructured matrices in distributed calculus models and/or parallel ones will be continued.

### Personnel and External Researchers

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## 2.9 Project: Analysis of Security and Performance for Concurrent and Mobile Processes

### Summary

We propose to study security properties of distributed, concurrent and mobile systems, speci ed in suitable process algebras. We will use proof techniques mainly based on Flow Logic, and we will exploit Enhanced Operational Semantics to describe system behaviour. We expect to obtain methods and tools that help in the production of secure systems and in the design of secure programming languages for global applications. In the same framework, we plan to develop techniques and tools for the analysis of the performance of mobile systems. Also, we will investigate the close relationships between

biological and mobile processes aiming at a cross-fertilization between the two elds.

Keywords: Security, Concurrency, Mobility, Operational Semantics, Static Analysis, Systems Biology

## Background

Security of computer systems is an essential requirement for all applications, due to the widespread di usion of distributed systems and networks. Being concerned with the dynamic behaviour of systems, the security problem is in general undecidable, and several techniques have been devised to study and establish properties su cient to guarantee that a system is secure.

A great deal of research is done nowadays on the use of formal methods for the analysis of cryptographic protocols and applications, for the study of secure mobile code and access to distributed resources, as well as for information ow security. Among the various formal approaches followed, we cite the following: Process Algebras, Abstract Interpretation, Static Analysis and Type Theory, Modal Logics, First Order Logic with Induction, Model Checking and Theorem Proving.

In this project, we mainly concentrate on Process Algebras and Static Analysis. Process algebras are executable speci cation languages for the description of concurrent systems. Their behaviour is represented by the actions they perform, structured as transition systems. A speci cation composes these actions via a few basic operators, like the sequential and parallel composition, nondeterministic choice and scope restriction. Static analysis provides a repertoire of automatic and decidable methods and tools for analysing properties of systems. Among these, we are mainly interested in Flow Logic, in particular in Control Flow Analysis.

Flow Logic is oriented towards the construction of tools that automatically support code analysis and optimization, and it is therefore complementary to other approaches more prescriptive in style, e.g. Type Systems. Essentially, Flow Logics predict at compile-time safe and computable approximations to the set of values that the objects of a program may assume during its execution.

Mobility poses new challenges to the performance evaluation of systems. Syntax-driven operational semantics has been enhanced in several ways in order to better support these kinds of quantitative analysis. The main di-

rections consist of enriching the labels of transitions with stochastic or probabilistic information, as well as with aspects related to the implementation, such as distributed environments, architectural constraints and so on. Statistical methods are then used to obtain performance measures.

Systems Biology is a eld that studies the system-level structure and behaviour of complex systems made up of molecular components. The components interact each other, in ways known from molecular biology. As a matter of fact, biological systems can be modelled as computing agents in a process calculus, by interpreting biological interactions as communication between mobile processes. The overall goal is to explicitly describe the evolution of biological systems by showing the relations between their components and the interactions in which they are involved, to help the selection of which experiments are to be actually performed.

## Ongoing research

Together with the DIKU group leaded by Hanne Riis Nielson and Flemming Nielson, we started using Control Flow Analysis to check security properties of the -calculus. One important point is that our technique has a cubic time implementation. In particular, we have been able to deal with extetensions to the -calculus that admit messages to be structured terms. Among these there is the spi-calculus, that o ers terms for encryption and constructs for decrypting them, so making it easier to specify cryptographic protocols. We also developed LySA, a dialect of the spi-calculus with encryption/decryption primitives and suitable annotations for expressing easily some security properties, among which amthentication. By using Flow Logic we checked so far some con dentiality and authentication properties of protocols. Among them, we mention:

- *secrecy*: classi ed information is never disclosed to an unauthorized external user, even in presence of an active attacker that can intercept, send and forge fraud messages. In other words, a con ned principal only communicates public information to the external environment, and con nes its secrets within itself, no matter of its running environment;

- *no read-up/no write-down*: considers principals with levels of security, and checks that those at high level never send information to those

at low level. This property is part of the so-called Mandatory Access Control policy;

- *non-interference*: at run-time a secure principal is neither a ected by communications with a potential attacker, nor the attacker can deduce any information about the principal by looking at its computations;

- *authentication*: a con dential message is delivered to the intended receiver, only. Several well-known authentication properties have been speci ed in LySA and shown to guarantee authentication (or not to), in full agreement with the literature.

We also compared from a dynamic point of view the standard Dolev-Yao attacker with an attacker that may decrypt a message even without knowing the key, with a given probability. A rst result shows that the two notions asymptotically coincide, so linking sonehow the so-called computational approach to security with the formal one.
We studied the problem of controlling the accesses to distributed resources in the Bytecode from a static point of view. Our data ow analysis approximates the sets of permissions that are enjoyed at certain program points, so improving the e ciency of stack inspection. Also, other program optimizations are possible, that do not compromise secure access to resources. These include elimination of redundant checks or a di erent placing of them, dead code elimination, as well as more problematic optimizations like tail call elimination and method inlining.

Together with Riccardo Focardi and Corrado Priami, we also studied *message authentication* from a dynamic point of view. This property demands that the receiver of a message should be able to ascertain its origin. We used an enhanced semantics of the -calculus, that o ers a kind of \authentication primitive". Indeed, the new semantics provides each sequential process of a whole system with its own local space of names. Availability of localized names, which cannot be forged by users, guarantees by construction that a message has been generated by a given entity. Message authentication is therefore immediate. This approach is then applied also to *entity authentication*, i.e. principals should be aware of the identity of partners they are communicating with. Variants of the above properties have been established also for the spi-calculus.

Corrado Priami and Pierpaolo Degano started using their EOS (enhanced structural operational semantics) for mobile computations for evaluating system performance. The transitions of the system are assigned costs by looking at their enhanced labels, only. These costs re ect the possibly distributed architecture on which applications run. One then obtains Markov chains, and performance evaluation is carried out using standard tools. In this way early quantitative evaluation is possible, on the very speci cations, at the same time when qualitative analysis is made and on exactly the same semantic model. We applied this technique to LySA, so permitting the designer of a protocol to study how performance a ects security.

Work on modelling biological systems as global applications is ongoing in cooperation with Corrado Priami and Cosima Baldari. We endowed the -calculus with a new \causal" reduction semantics; we then modelled a couple of well characterized bio-chemical processes as -processes, the causal behaviour of which faithfully respect experiments *in vitro*. Also, the results of our rst experiments are more accurate than those obtained by similar approaches, both because they describe the whole evolution of processes (reactants and reactions) and because they re ect the causal relations between reactions.

## Short term plans and expected results

Our research will still address security problems both from a static and from a dynamic point of view, the operational approach to semantics using as common framework.

We plan to extend the properties mentioned above and to statically study other properties, analysed in the literature mainly using dynamic techniques. Examples include a full treatment of Mandatory and Discretionary Access Control, Authentication and also Integrity properties.

We shall continue the work on security properties from a dynamic point of view using the EOS approach. In particular we would like to study more in detail the interplay between performance and security issues. In the same line, we plan to investigate how time and interaction rates may be described within our EOS approach, so to combine causal and stochastic aspects in a single model.

In this way we can describe more accurately the evolution of both protocols and of biological systems, thaht are our main case studies.

Also, we shall improve the available prototypal tools based on the operational semantics of systems. One needed extension to our interpreters is providing the user with graphical tools to display the evolutions of processes.

The above will be mainly carried on in the DEGAS project, funded by the EU as a FET project. DEGAS aims to build a two level programming environment for global applications. At one level a system is speci ed using UML, at the other it is formally analysed using the static and dynamic techniques brie y outlined above; mapping should be provided from the UML representation of the application to the one based on process algebra, and viceversa. The work on UML is actually carried on in tight cooperation with the group leaded by Carlo Montangero. The overall goal is to o er a prototypical proof of concept environment that hides to the user as much as possible of the formal treatment. We will also tune our development with case-studies on wireless telecommunication applications.

### Long term plans

The techniques for analysing processes mentioned above can be made more accurate. There are several lines to pursue. One is increasing the descriptive power of the analysers, which often contrasts with their e ciency. Another is studying the impact of security on the speci cation languages used, e.g. on UML or on LySA and considering which extensions or which annotations are needed. Particularly relevant are here extensions that explicitly consider time, probabilities and other quantitative measures. Indeed, there is a wide class of security attacks that exploit time; also, di erent kinds of cryptographic keys o er di erent degrees of security, often expressed in probabilistic terms; and a user can be interested in a system to be secure with a certain probability | the lower the probability, the cheaper the system.

Needless to say, e cient tools are mandatory, for experimenting in real cases, e.g. those proposed in DEGAS, the actual applicability of the techniques we propose.

The overall goal of applying the technology developed for Global Computing to System Biology is to explicitly and accurately describe the evolution of complex biological systems in computational terms. This will enable biologists to anlayse the behaviour of biological entities more accurately and to design modi cations to them, guaranteeing that some speci c properties are satis ed. So, the cost of carrying on actual experiments *in vitro* can be

reduced by simulating them *in silicio*. On the other side, the various interaction patterns of biological systems and the di erent ways of evolution they follow may suggest new primitives in the area of concurrent and mobile processes.

Results from our studies might in uence the design of programming languages that o er secure, e cient and exible ways of exchanging and processing information, thus enhancing the design and implementation of global applications. This is our ultimate, very long term goal.

## Personnel and External Researchers

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## 2.10 Project: Models and algorithms for transportation problems and logistics

### Summary

The activity of the Operations Resarch group is focused on two di erent but interacting subjects:

the development of mathematical models of real-world decision problems;

the study of the properties of these mathematical models and their use for the development of corresponding algorithmic solution methods.

The main sources of the real-world problems, the group is involved in, belong to two di erent application areas: transportation and logistics/management. Optimization models (both single- and multi-objective), equilibrium models and simulation models are developed in these contexts, according to the speci c application. The group has developed expertise in algorithms for network optimization problems, both polynomial and $NP$-hard, heuristic and exact methods for combinatorial optimization problems and algorithms for large-scale convex optimization. Several of these algorithms have been implemented in e cient and well-engineered codes that have been made available to the scienti c community.

The following description of the research activity of the group is divided into three main sections. The rst two sections describe the research on models and algorithms for real-world problems arising in transportation and logistics/management, respectively. The third section describes the activities related to the development of general-purposes optimization algorithms and software, whose results are used within { and often motivated by { the real-world applications.

Finally, in a fourth section, some other individual research activities, which at present do not t into the main resarch lines of the group, are brie y described.

## Transportation

Applications in this area are traditional for the group. In the last years we focused mainly on three topics: airline crew rostering, transportation planning models and dynamic transportation models.

### *Airline crew rostering*

The airline crew rostering problem has been formulated as a 0-1 Multicommodity Flow problem with additional constraints. Some aspects of its polyhedral structure have been investigated, leading to the de nition of a family

of valid inequalities which are shown to be quite e ective from a computational point of view [18]. A heuristic approach has been proposed which attempts at exploiting some of the peculiarities of the model proposed: an initial feasible solution, obtained by solving a constrained shortest path problem for each crew member, is iteratively improved by exchanging (sequences of) activities among the employees.

*Transportation planning models*

In transit assignment problems in which passengers perceive the service in terms of frequency, it is crucial to correctly describe the passengers behavior when waiting at the stops. In [35] we propose a general mathematical description of the waiting process under more general assumption than those in current models; in particular, the availability at the stop of reliable on-line information of the remaining waiting time for each line has been included in the model. Our aim is to extend the analysis of the waiting at the stops along the line described in [12]. Moreover, we plan to generalize the existing equilibrium transit models to di erent types and levels of service and to develop robust algorithms to be included in commercial packages.

Furthermore, in [36] we proposed an interurban collective transportation model in which the travel times are explicitly taken into account and we provide a relaxed version in which it is possible to nd the equilibrium passenger assignment solution.

*Dynamic transportation models*

Many transportation problems require a formulation in which the travel time has to be explicitly taken into account so that a trip is described as a movement both in space and time. Formulations of this type are obtained by making use of properly de ned time-space graphs. The problem of nding minimum time paths in a space-time network within a reoptimization framework is analyzed [22]. Several path problems in space-time graphs, in which tra c lights are present, have been studied and solved [2, 3].

## Logistic and Management problems

Such a wide eld includes many theoretical problems and interesting applications. Our research in this eld has been focused essentially on location

and distribution aspects and on management problems arising within public utilities.

*Location and distribution problems*

Location (and distribution) theory and applications have been studied [43], and several heuristic algorithms, based on the local search \multi-exchange" paradigm, have been proposed for their solution. Interesting results have been obtained for the single-source capacitated facility location problem [1], and for the ***p***-vertex capacitated facility location problem [42]. Heuristics of this type have allowed to improve the performances of the current logistic network of an Italian rm [4], yielding valuable global savings. At present, we are studying some regional location and distribution problems, where vehicles have to be assigned to regional depots in order to deliver goods to the clients. Furthermore, we plan to study resource scheduling problems arising in the workload management of ATM devices.

Some obnoxious facility location problems have been studied. For them new mathematical models and e cient algorithmic approaches have been proposed. Speci cally, exploiting the available expertise on Bundle methods for NonDi erentiable Optimization [25], the obnoxious facility location problems have been solved by a Lagrangean decomposition approach [19]. One of the subproblems resulting from the Lagrangean decomposition is an extension of the 0-1 multidimensional knapsack problem; this problem has numerous other practical applications. A heuristic approach, based on a nested tabu search algorithm in which neighborhoods of di erent structure are exploited, has been proposed [20]. Furthermore, instances generated during the experimental investigation, related to the Multi-demand Multidimensional knapsack problem, have been inserted as benchmark instances into the OR-Library maintained at the Imperial College, at the address **`http://mscmga.ms.ic.ac.uk/info.html`**.

*Management problems in utilities*

We have studied a set of di cult optimization problems arising in the production of electrical energy. A part of the study has focused on the short-term management of electrical energy production, on a daily or weekly basis, by a group of heterogeneous units, both of thermal type and hydroelectric ones.

E cient heuristics based on Lagrangean techniques have been developed for this problem [15] and compared with di erent approaches [14]. These approaches have then been extended to handle the free market case [16]. Also, certain facet-de ning inequalities for these problems have shown a potential for improving the performances of enumerative approaches [27]. In a di erent but related context, an optimization problem faced by a public utility generating both heat and electricity with renewable sources (geothermal and waste, respectively) has been modeled and solved [5].

The research is continuing, in collaboration with other research groups, to devise more e cient approaches, both heuristic and exact, for these and other variants of the problems.

### Optimization Software standardization and development

As most of nowadays optimization approaches require complex solution techniques where several optimization algorithms interact, the need of reliable and e cient codes implementing the \basic blocks" of these sophisticated approaches is growing. We have worked to develop standard interfaces and optimization software implementing them, both adapting existing codes and developing new algorithmic approaches.

Network structured problems often appear as subproblems of more complex and demanding applications [15, 17, 23], especially when Lagrangean techniques are used. We developed an abstract interface for solvers of single-commodity Min Cost Flow (MCF) problems, and ported a number of available e cient MCF solvers under that interface. The resulting codes, freely available at **`http://www.di.unipi.it/optimize/Software/MCF.html`**, have already been used by many researchers worldwide for their research activities. We have studied the performances of these codes under cost reoptimization [29], showing that the relative performances of the codes for \one shot" optimization do not always correctly predict which code is most e cient under di erent usage, and therefore the importance of being able to use di erent solvers for di erent application with a low e ort.

Other classes of network problems are being studied; in particular, some recent algorithmic development for Shortest Path Tree (SPT) reoptimization [37, 38] have motivated the proposal of an abstract interface for SPT solvers and an e ort to collect and develop e cient SPT codes, in collaboration with a team of Napoli and Salerno Universities. Also, *longest path problems* have

been addressed and a heuristic algorithm with a performance guarantee has been proposed for their solution [44]. Furthermore, reoptimization issues in the context of maximum ow computations have been investigated [45, 46, 47].

The standardization process is continuing with other classes of optimization software, such as general-purpose nondi erentiable optimization solvers, \generalized" Bundle methods [25] and solvers for linear and nonlinear structured optimization problems based on Interior Point techniques.

## Other research activities

### *Multicriteria optimization*

The studies in this area are quite new for our group and have been the topic of a recent Ph.D. dissertation.

We developed a deep analysis of Lagrangean regularity, proposing a classi cation of multiobjective problems based on Lagrangean regularity; we obtained not only very weak regularity conditions but also those ones that guarantee boundednees and uniqueness of the multipliers [10]. Applications to both scalar and vector saddlepoints of Lagrangean related to multiobjective problem have been developed, leading to new and stronger optimality criteria [7]. Moreover, second order optimality conditions have studied for smooth vector optimization problems [8]. Two other rather innovative topics have been investigated: the rst deals with general di erentiability concepts for set{valued maps and the corresponding optimality criteria [9], which can be applied within a duality framework, while the second proposes a new way to analyze [11] for a pair of dual multiobjective problems.

The current research is mainly devoted to multicriteria problems involving nonsmooth functions. We plan also to analyze e cient solutions methods, not based on scalarization techniques, in order to identify optimal solutions with particular properties such as being the best approximation of the ideal point.

### *Simulation techniques*

The interest for simulation has been growing in the last years. In [13] a multiagent simulation model for the analysis of the di usion of B2B e-commerce technologies has been proposed and its results have been analyzed. The use

of System Dynamics techniques to help decision makers in the process of allocating resources to the di erent activities in the Public Education area in a medium size Municipality has been analyzed. We have designed and built a model which includes a population submodel, which allows us to take into account the dynamics of the aging and immigration of the population [6]. This line of research is being pursued in collaboration with the University of Palermo.

The use of System Dynamics to analyze con icts in conjunction with the ABC paradigm proposed by J. Galtung is being investigated.

*Interior point methods*

A theoretical study of the spectral properties of the matrices forming the \core" system of the IP method when applied to MCF problems has been pursued [31]. The results motivated the study of a new family of preconditioners for the solutions of these systems by the Preconditioned Conjugate Gradient method [28]. The research will continue, extending the results to nonlinear ow problems and large-scale problems with predominant network structure like Multicommodity Flow [21] and Network Design [23] problems.

*Ethics and Operations Research*

The relevance of ethics in Operations Research has been investigated. In particular two ethical principles, which can help O.R. researchers and practitioners in their activity have been presented and discussed in [32].

## Personnel and External Researchers

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Giancarlo Bigi (Assistant Professor), Carolina Billi (Ph.D. student), Paola Cappanera (Postdoc fellow), Antonio Frangioni (Assistant Professor), Stefano Pallottino (Professor), Zhang Qinghua (Ph.D. student), Maria Grazia Scutella (Associate Professor), Claudia Sodini (Ph.D. student).

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## 2.11 Project: Systematic development of semantics, static analysis and veri cation techniques by abstract interpretation

### Summary

We describe our current and future research activities in the area of applications of abstract interpretation theory to semantics, analysis and veri cation. Most of the current activity is related to logic programming and recently to functional programming.

Keywords: Abstract interpretation, semantics, static analysis, veri cation, logic programming, functional programming.

### Background

*Abstract interpretation* is a general theory for approximating the semantics of discrete dynamic systems, originally developed by Patrick and Radhia Cousot in the late 70's as a unifying framework for specifying and validating static program analyses. The *abstract semantics* is an approximation of the concrete one, where exact (concrete) properties are replaced by approximated properties, modeled by an abstract domain.

The framework of abstract interpretation is general enough to be applicable to any semantics. It can be useful to study hierarchies of semantics and to reconstruct data- ow analysis methods and type systems. It can be used to prove the safety of an analysis algorithm. However, it can also be used to systematically derive \optimal" abstract semantics from the abstract domain.

The *systematic design* aspect can be pushed forward, by using suitable abstract domain design methodologies (e.g. domain re nements), which allow us to systematically improve the precision of the domain. A number of operators have been designed to systematically improve precision, reduce complexity, and modularize analyses by re ning, simplifying and decomposing domains.

Abstract interpretation was originally intended as a method for automatically generate program invariants and can be very useful in *program veri cation*. For example, a su cient condition for the partial correctness of a program w.r.t. an intended abstraction of the semantics $\boldsymbol{S}$ (abstract speci- cation) can be obtained by proving that $\boldsymbol{S}$ is a pre- xpoint of the (abstract) semantic evaluation function.

Abstract interpretation is language-independent. It was particularly successful (as other semantics-based techniques) in the framework of declarative (e.g. functional, logic, constraint) languages, because of their direct mathematical semantics. Results achieved for declarative languages can be meaningful also for other more practical languages.

## Ongoing research

The most important results related to our activity are

the de nition of a framework for the systematic generation of semantics (including nitely computable ones), together with a classi cation of abstractions.

the extension of the framework to Prolog (leftmost selection rule, backtracking, tree pruning operators) and to normal logic programs.

the extension to observable properties, somewhat related to in nite derivations. The results are an and-compositional xpoint semantics modeling nite failures, an e ective inductive veri cation technique for nite failure, based on further abstractions of the xpoint semantics, and various computable approximations of properties related to termination.

the extension to concurrent constraint languages and to Hereditary Harrop Formulas (the pure version of -Prolog).

the extension of declarative debugging to abstract diagnosis, where one can cope with di erent abstractions (both in the speci cation and in the semantics).

the de nition of a veri cation framework, where one can reason about partial correctness, using the pre- xpoint su cient condition. The framework allows us to reconstruct all the existing veri cation techniques, simply by choosing di erent abstractions of a concrete traces xpoint semantics.

the development of some new domain re nement operators and their application to the design of optimal domains for groundness and type analysis.

It is worth noting that a compositional xpoint semantics is always needed in the su cient condition for partial correctness. For all the above extensions ( nite failure, concurrency, implications in intuitionistic logic), there did not exist a compositional xpoint semantics modeling interesting observables. Abstract interpretation allowed us to systematically derive such a semantics from a concrete traces semantics.

The current activity is related to some extensions of the semantic, analysis and veri cation frameworks.

we study the problem of completeness for abstract domains. We provide a constructive method to derive complete abstract domains and propose a framework based on propositional linear logic to de ne and represent abstract objects as formulas in suitable fragments of propositional linear logic. within this framework, we are able to characterize the property of condensing and provide a methods to re ne abstract domains to be condensing. We propose a re ning for abstract domains by means of optimal semantics and derive a new domain for sharing analysis of logic programs.

We give a logical interpretation of several domains for groundness analysis of logic programs which allows us to compare the relative precision of the di erent domains.

We propose a goal-dependent framework for analysis of logic programs obtained by using both uni cation and matching operators and provide optimal operators for a domain of sharing properties.

we investigate probabilistic extensions of programming paradigms, and we study their semantics to the purpose of de ning semantics-based methods for the analysis of program's properties. Starting from a semantical model based on operator algebras, we have developed a method for approximating the semantics of probabilistic program and obtaining a quantitative estimate of the precision lost. We have used this method to develop semantics-based analyses of security properties (con nement) and their approximate versions ( -con nement). We have also used the linear semantics to quantitatively compare the expressiveness of a class of languages. Finally, we have extended CHR so as to be able to specify and implement randomized constraint solvers and programs.

we apply the abstract interpretation approach to functional languages. The idea is to de ne tools for type inference and type veri cation of ML-like functional languages, using abstract interpretation techniques. By extending the Damas-Milner type inference algorithm, with a (bounded) xpoint computation we succeed in getting a better precision and solving some problems of the ML type inference algorithm without resorting to more complex type systems (e.g. polymorphic recursion). Reconstructing the Damas-Milner type inference algorithm as an abstract interpreter on a suitable type domain allows us to deeply investigate the property of the inference system: our type interpreter turns out to correspond to a type system, which lies between monomorphism and polymorphic recursion. We show how to transform the analyzer into a tool for type veri cation, using an existing veri cation method based on abstract interpretation. The resulting type veri cation method can be exploited to improve the ML type inference algorithm, when the intended type of functions is speci ed by the programmer.

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National Project \Automatic program certi cation by abstract interpretation" (2000-2001), funded by MURST (University and Research Ministry), national coordinator: Roberto Giacobazzi (University of Verona).

National Project \Abstract interpretation, type analysis and control- ow analysis" (2001-2002), funded by MURST (University and Research Ministry), national coordinator: Giorgio Levi.

## Short term plans and expected results

Abstract domains.

The research goal is the design of a tool to manipulate domains in the framework of abstract interpretation. The aim is to design, starting from an initial domain, a re ned abstract domain which satis es some given requirements, providing both the domain objects and the domain operations in a fully automatic way. We expect to expand our research to the development of a language for expressing the observable properties and a formalism to express the requirements of the nal re ned domain. We also plan to study suitable representations of abstract domain objects in order to e ciently implement the abstract operators. In particular, we want to explore the possibility to implement abstract domain operations by means of proof systems. This idea follows a current trend in abstract interpretation of logic languages which are often abstracted in domains of logical formulas in propositional (classic, intuitionistic and linear) logic. As a very long term research, we plan to exploit the large amount of results concerning static analysis of logic programs and also the above techniques regarding the implementation of domains of formulas to develop a parallelizing compiler for logic programs. We also plan to apply our results to the development of domains for studying program equivalences and relations, such as bisimilarity. We plan to use program equivalences to verify properties of security protocols.

Assertions and speci cation languages.

In program veri cation, a speci cation is usually given by means of assertions (i.e. formulas in a suitable formal speci cation language), while in our case a speci cation is (extensionally de ned as) the intended abstract semantics. On the other hand, assertions clearly de ne an abstract domain (as shown by the Cousot's even in the early papers on abstract interpretation). The problem to be solved is how to systematically derive the abstract semantic evaluation function corresponding to a suitable language of assertions. We will consider this problem both for logic languages and for simple higher-order functional languages.

Probabilistic extensions.

We plan to study various process equivalence relations, which are known in the theory of concurrency, from a probabilistic abstract interpretation point of view. As a result of this study we expect to be able to analyze reactive concurrent systems in order to obtain a quantitative estimate of their actual con nement. We will apply the probabilistic abstract interpretation framework also for the approximate analysis of programs properties other than con nement, such as for example groundness in the eld of logic programming.

We also plan to continue the investigation on quantum programming languages, with the aim of de ning a formal (both operational and denotational) semantics for a quantum version of the concurrent constraint programming paradigm. This would help the formalization in a high-level language of the various quantum algorithms which have been de ned up to now and which are usually expressed in terms of hardware circuits or Turing machines.

Type inference and type systems.

Type are currently used in order to verify properties of languages. Type can address many di erent properties such as security properties. We plan to apply our abstract interpretation approach to type system able to address security property. This allows us to systematically derive type inference algorithms and to investigate the properties of di erent type systems de ned \ad hoc".

### Long term plans

One promising solution to the problem of veri cation of code coming from untrusted sources is the approach known as *Proof Carrying Code (PCC)*. According to the PCC approach, mobile code is supplied with a formal proof that it satis es a speci cation de ned by the host system, which will then simply check the proof, to ensure that the code complies with its policy. One step forward is the idea of extending compilers with proof-generation capabilities (*certifying compiler*). In most current (experimental) implementations of the PCC idea, properties expressed in speci cations are essentially type properties and certi cation boils down to type inference and veri cation.

Several techniques are available to improve the speci cation and certi cation capabilities of a PCC system. These include proof systems, model checking and data ow analysis. We believe that abstract interpretation is now scienti cally mature, although not yet fully explored in the context of automatic program certi cation. Abstract interpretation provides both a general enough setting where di erent type systems, proof methods, and data ow analysis techniques can be reconstructed and combined, and a strong enough theory to assist in the correct speci cation and implementation of program certi cation systems. On one side, abstract interpretation can be viewed as a common interface for validating code by standard program analysis, proof methods, and type-based validation methods. On the other side, it is particularly adequate to cope with highly dynamic systems. Properties which need to be proved are in fact subject to change, because of the evolution of the environment. Several systematic design techniques are available (systematic design of the abstract semantics, systematic design of domains from the property of interest) to make it easier the adaptation to new requirements. Moreover, a program certi er which is systematically derived from the concrete language semantics is more reliable and exible. Finally, abstract interpretation based certi cation methods are intrinsically modular (if the collecting semantics is compositional). This is of course relevant to the issue of scalability of the techniques.

Some of our current activities are relevant to the applicability of abstract interpretation techniques to certi cation in a PCC approach. In particular:

> Our attempt to better understand and to make some experiments with assertions as abstract domains, speci cation languages and veri cation based on the corresponding abstract semantics, if successful, will make

it possible to reconstruct assertion based veri cation methods as instances of a more general method. In particular we will be able to understand the limits of the approach, typically in terms of constraints on the speci cation language.

The combination of partial evaluation and analysis, which is essentially partial evaluation of an interpreter obtained by combining (by a sort of reduced product operation) the standard interpreter and an abstract interpreter, can be viewed as a method to generate at the same time the compiled code and the abstract property. One can build on this idea to de ne a certifying compiler, which generates a proof that the inferred property satis es the speci cation.

## Personnel and External Researchers

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## 2.12 Project: Algorithms and Data Structures for Massive Data Sets

### Summary

This group has been active in the development of computational models describing the functioning of real systems, and in the design and analysis of algorithms and data structures. Here, we focus on the design and analysis of algorithms and data structures for searching and updating large data sets, such as HTML and XML repositories, that are possibly stored in secondary storage devices. Compression, and any related space-saving technique, will play a crucial role in our techniques for combining space and access-time reduction. In addition to carrying on an analysis and validation of the proposed techniques, we perform experiments to test their performance in the practical setting. Also, we set up publicly available software libraries for data indexing, compressing and mining in order to *bridge the gap* between theory and practice (e.g., see the homepage of the team members).

Keywords: Compression, data structures, massive data sets, pattern matching, searching and sorting, secondary storage, string algorithms, text indexing, Web IR.

### Background

Computers contain a hierarchy of memory levels, each one having its own capacity and performance. Operating systems take advantage of these issues through caching and prefetching heuristics. Many applications, however, require processing and management of very large data sets that are spread over the whole memory hierarchy. Here the ow of data among the memory levels becomes the major computational bottleneck because the *locality* in the pattern of memory references is usually not guaranteed, so that caching and prefetching methods do not produce an appreciable speed-up. Substantial gain in performance can only be attained by directly exploiting the memory

hierarchy in the design of algorithms and data structures, via proper design methods which should be di erent from those deployed thus far.

In order to design and carefully analyze the scalability and query performance of a data structure, we need computational models that abstract in a reasonable way the *I/O-subsystem*. Accurate disk models are complex, and it is virtually impossible to exploit all the ne points of disk characteristics systematically, either in practice or for algorithmic design. To capture in an easy, yet signi cant, way the di erences between the internal (electronic) memory and the external (mechanical) disk, the scienti c community has adopted the *external memory model*, proposed by J.S. Vitter and E. Shriver (1994). Here a computer is abstracted to consist of a two-level memory: a fast and small internal memory, and a slow but arbitrarily large external memory formed by a pool of *disk*s. Data between the internal memory and the disks are transferred in blocks (called *disk blocks*). Since disk accesses are the dominating factor in the running time of many algorithms, the asymptotic performance of the algorithms is evaluated by counting the total number of disk accesses performed during the computation. This is a workable approximation for algorithm design.

Recently a surge of interest was devoted also to the notion of *cache-oblivious algorithm* proposed by Frigo *et al.* (1999). An algorithm is cache-oblivious if it has no memory-hierarchy-speci c parametrization (like the RAM algorithms), so it does know the existence of the memory hierarchy but it does not know the memory hierarchy parameters (block size and memory-level size). A single cache-oblivious algorithm has optimal performance for *all possible values* of the memory parameters, and thus it is e cient on *all* memory hierarchies simultaneously. While these results seem impossible, a recent body of research has developed algorithms and data structures that perform as well, or nearly as well, as standard external-memory solutions which know all about the memory hierarchy.

In this context data compression is an attractive choice, if not mandatory, not only for storage saving but also for its favorable impact on algorithmic performance. Indeed "*space optimization is closely related to time optimization in a disk memory*" [Knuth, 1998] because it allows a better use of the fast and small memory levels close to the CPU (i.e. L1 or L2 caches), reduces the cost of disk accesses, virtually increases the disk and memory bandwidth, and comes at a negligible cost because of the signi cant speed of current CPU. For instance, IBM has recently installed on the eServers x330 a novel mem-

ory chip (based on the Memory eXpansion Technology) that stores data in a compressed form thus ensuring a performance similar to the one achieved by a server with double real memory but, of course, at a much lower cost. All of these considerations have driven developers to state that it is *more economical to store data in compressed form than uncompressed*, so that a renewed interest in compression techniques raised within the algorithmic community.

It is not surprising, therefore, that we are witnessing in the algorithmic eld a renewal of interest in the design of either *cache-oblivious* algorithms, or external-memory algorithms, or *compressed* data structures that try to reduce as much as possible not only the I/O complexity but also the auxiliary information kept for indexing purposes. Such a research trend has lead recently this group to some surprising results on the design of *compressed* and/or *cache-oblivious* indexes whose impact goes far beyond the indexing problem. These results lie at the crossing of three distinct research elds | compression, algorithmics, databases | and orchestrate together their latest achievements, thus showing once more that the design of a data structure is nowadays an interdisciplinary task.

## Ongoing research

Our background on the design of algorithms and data structures is currently applied to areas involving computationally demanding environments and massive data applications largely spread over the Internet. Our current research is devoted to fast indexing and searching on compressed data focussing on some tightly connected topics.

Compressed indexes. The main goal is to provide data structures that take advantage of the compressibility of the input data by decreasing the space occupancy at no signi cant slowdown in the query performance. The overall space occupancy should be a small function of the entropy of the underlying data set, thus achieving space optimality in a strong information-content sense. In this context we achieved much interesting results, published in top international conferences | like ACM STOC, IEEE FOCS and ACM-SIAM SODA | and we provided some publicly available software libraries implementing the proposed solutions. Currently we are engineering the proposed data structures with the aim of more e ectively combine I/O-performance and compression.

Biased queries. The distribution of the queries in search engines is generally biased, that is, some words are more commonly queried than others (e.g., \MP3"). Self-adjusting data structures exploit biased distributions to provide faster access to items more frequently accessed. We have devised a self-adjusting version of the String B-tree data structure [Ferragina-Grossi, JACM 99] for information retrieval and searching. We are currently implementing and testing this new approach.

Implicit data structures. We have extended the notion of implicit data structures, i.e. one that uses space strictly close to the input, to handle large data sets in machines with hierarchical memory. We have investigated how to design an implicit B-tree to save space, accounting for the number of I/Os as the relevant cost of the performance. We are obtaining a collection of e cient I/O algorithms for searching, inserting and deleting data while saving space. While we do not claim the methods, as stated, are easily implementable, preliminary experimental results show that the implicit B-tree could be useful in practice. Standard implementations occupy six times more space than that of implicit B-trees, and this can give a payo in performance in several cases (e.g., in using the memory-bound and fast primitive **mmap** to access les). An interesting byproduct of these techniques are new methods for main memory data structures and for novel in-place sorting algorithms.

Cache-oblivious data structures. Farach *et al.* (2003) have solved optimally in the cache-oblivious model the problem of searching a xed-topology tree, with a known probability distribution onto its leaves. Cache-oblivious tree mapping strategies for static and dynamic trees storing atomic keys are also known. String data structures, like suf- x trees and String B-trees, although tree-based cannot be e ciently mapped to disk because they have their edges labeled with arbitrarily long substrings. This prevents all known cache-oblivious techniques to be applied to this case. There is therefore the need to investigate carefully this problem with the goal of devising new, more powerful, techniques for cache-oblivious string indexing and mining. We also are studying how to obtain space-saving data structures with e cient cache-oblivious access to data.

Compression techniques. We have provided a general boosting technique

for Textual Data Compression. Qualitatively, it takes a good compression algorithm and turns it into an algorithm with a better compression performance guarantee. More precisely, it can turn, in optimal linear time, *any memoryless* compressor into a compressor that uses the \best possible" contexts. Technically, our boosting technique builds upon three main ingredients: the Burrows-Wheeler Transform (BWT), the Su x Tree data structure, and a greedy algorithm to process them. Such a technique is inherently combinatorial because it does not need to assume any prior probabilistic model about the source emitting the input text, and it does not deploy any training, parameter estimation and learning. Two instantiations of our boosting technique have yield better compression algorithms than some of the best known ones, i.e., **LZ77**, **LZ78**, **PPMC** and the ones derived from the BWT. New techniques for implementing the so-called second step of the BWT are also being investigated.

New Web IR-tools. Recently, we extended our interest to design of IR-tools for helping Web users in nding their data over the net. There is a surge of commercial interest on these IR-tools (e.g. Vivisimo, Copernic, Groxis), but the scienti c literature lacks of knowledge about their design which thus remains mainly a *black art*. Given our expertise on indexing and compression, we are starting an investigation of this challenging topic.

This group participates into the following major research projects:

Algorithms and Data Structures for Internet and the Web (ALINWEB). \Project of Major National Interest" co- nanced by MIUR of Italy. National coordinator G. Di Battista (Univ. Rome 3).

Technologies and Services for Enhanced Content Delivery (ECD). \Fondo Speciale Innovazione 2000", MIUR of Italy. National coordinator G. Attardi (Univ. Pisa).

High-performance Distributed Platform. \Fondo Speciale 2000", MIUR of Italy. National coordinator M. Vanneschi (Univ. Pisa).

Grid Computing. MIUR PNR 2001-2003 (FIRB). National coordinator M. Vanneschi (Univ. Pisa).

The French program bioinformatique EPST 2002 \Algorithms for Modelling and Inference Problems in Molecular Biology". Project leader: Marie-France Sagot (INRIA-Alpes, France).

The network of excellence NEMIS that brings together researchers, academics and practitioners of the Text Mining domain.

### Short term plans and expected results

We wish to concentrate our attention on the following short terms goals:

Experiments on the data structures related to compressed dictionaries and to IP lookup problems, engineering a method previously presented in the literature.

New techniques for managing arbitrarily long strings in the cache-oblivious model. These investigations will be accompanied by experimental tests on real text collections.

New algorithmic tools to compress and index data. In particular we aim at deploying our deep knowledge in the eld of indexing compressed data to the case of XML les. Here compression and indexing may play a crucial role being XML les much large, redundant and structured. Actually we aim at extending the functionalities and properties of the FM-index (Ferragina-Manzini, IEEE FOCS 2000) to this kind of data.

Further theoretical studies and experiments on the boosting technique are required to establish whether it is appealing also in the real setting.

Develop novel IR-tools for the e cient and e ective mining of Web data. Actually we are investigating the so called *Web-snippet clustering* problem introduced by *NorthernLight* and then improved in its e cacy by many others commercial softwares. We aim at studying this challenging problem from a scienti c point of view (just four papers are available in the literature!), by deploying our knowledge on indexing data structures and algorithms for information retrieval. We also aim at designing an open-source software which implements this IR-tool, based upon commodity components, in order to allow the community to start a productive investigation of such a promising research eld.

## Personnel

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V. Ciriani (Postdoc), G. Franceschini (Ph.D. Student), A. Gull (Ph.D. Student).

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## 2.13 Project: Models of Distributed Computing

### Summary

This group has been active for over a decade in the development of computational models describing the functioning of real systems. Here we focus on various aspects of distributed computing, including routing and fault tolerance in distributed system, and the analysis of robot movements.

Keywords: Distributed computing, Mobile Robots, Routing, Fault tolerance, Black Hole.

### Background

Our approach to the study of computational models has been aimed at a description of the functioning of real systems. This has been a general trend in recent years, when the massive applications of parallel and distributed machines have raised a substantial interest in the related algorithmic paradigms. We approached the study of distributed systems from di erent perspectives, aiming at analyzing and better understanding the problematic involved in such systems in di erent areas of applications.

One of our interest has been to address security problems in networked environments that make use of mobile agents (e.g., World-Wide-Web, Data Grid). In particular, we are interested in nding e ective strategies that let a set of autonomous mobile agents to locate a highly harmful item in the network, a stationary process destroying visiting agents upon their arrival. Quite di erent problematic come from the engineering and arti cial intelligence areas. In fact, another signi cant part of our work is that of analyzing a rather particular distributed system, populated by a set of "simple" autonomous robots that can freely move on a two dimensional plane (i.e., the robots are equipped with motorial and sensorial capabilities). We aim at reaching a better understanding of what these robots might do and under

which conditions: that is, we tackle the problem from a computational and algorithmic perspective.

Aside from its intrinsic theoretical value, our interest in this eld is strongly connected to the development of algorithms and applications for very large data sets, that constitute the bulk of present and planned future research of this group (see the project: \Algorithms and Very Large Data Structures"). As another e ect, the study of the limits of parallel computation has lead to some unexpected results in logical design, thereby opening a new research line that is now independently followed in the project: \Multi-level Synthesis of Boolean Functions".

## Ongoing research

This group has been active for many years in the development of di erent computational models and paradigms. Distributed systems have been extensively investigated, studying redundancy for fault tolerant functioning, the power of routing strategies, and computational model to describe the behavior of groups of mobile robots. All these studies are still under way.

## Short term plans and expected results

In the eld of distributed algorithms, studies on patterns of faulty processors that prevent a whole system to work will be continued. Furthermore, we are interested in modifying the computational models designed for mobile robots studies, in order to better capture the subtleties and the problematic involved in the design of real robots.

## Long term plans

It is not particularly signi cant to analyze this point in depth, but some lines of tendency can be clearly drawn. The studies on computational models will remain of great importance in the future, until some basic results will be obtained. Among them, a universally acceptable model of grid computation capable of capturing the main features of data processing on real life distributed machines.

## Personnel and External Researchers

A. Bernasconi (Research Associate), P. Ferragina (Associate Professor), R. Grossi (Associate Professor), F. Luccio (Professor), L. Pagli (Professor). V. Ciriani (Postdoc), N. Pisanti (Postdoc), G. Prencipe (Postdoc), G. Franceschini (Ph.D. Student).

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## 2.14 Project: Computational Biology

### Summary

This group has developed a computational model named PaTre that aims to reconstruct genes duplication history. Secondly, we have designed algorithms

and data structures for several molecular biology motivated problems such as computation of suitably de ned genomic distances, and the inference of repeated motifs in biological sequences. This project is based on such a background that is tightly linked and partially overlapping with the two other projects of the group on "Computational models" and "Algorithms and Data Structures for Massive Data Sets". Here we focus on the interaction between computational models and biological processes; we describe our tool for the inference of gene duplications inside families of paralog genes, and our studies concerning the de nition and the e cient copmputation of a notion of basis for the the repeated patterns with don't cares in biological sequences.

Keywords: gene duplication, basis of repeated motifs.

## Background

Our studies focus in algorithms for genome analysis. Laboratories produce a huge and rapidly increasing amount of biological data worldwide: in particular it is estimated that available biosequence data sets double their size every year. The need of storing and updating these data with great e ciency has motivated the rapid growth of computational biology. A major class of problems in computational biology is related to genome comparison and to the inference of genome rearrangements. The aim of the latter is to infer information about the way genomes evolved and to perform comparative studies on such hypotheses. These studies must be conducted in cooperation with molecular biologists and require a strong algorithmic expertise due to the size of input data and to the combinatorial di culties that arise. Biologists aiming at understanding some properties of biological sequences may also look for repetitions with some degree of approximation; in fact, such repetitions are likely to represent biological signals where repetitions correspond to functionally meaningful features. As an example, promoter sequences that are common to several di erent sequences are strong candidates to indicate co-regulated genes. Indeed, nding repetitions became an important task in genome annotation, and current methodologies do not result in satisfying tools.

## Ongoing research

**Genome Analysis** In the field of genome analysis, and in particular in that of gene duplication analysis, we have developed a technique for the inference of gene duplications inside a single genome, based on the "tranformation distance". Our main result is to obtain a tree structure from pairwise distances. From this structure we infer a hierarchy among genes of the same family that might correspond to the evolution of the family itself. Biologists who are collaborating with us validated our results and steered our choices.

**Genomic Distances** We have also addressed the problem of computing the syntenic distance between two multi-chromosomal genomes, which is computationally difficult. In this field we have proved some propertied concerning the diameter of such distance and designed an algorithm for computing it in some special cases.

**Motifs Extraction** Our most recent efforts are in the area of repeated motifs extraction. Within this area, our efforts go in two directions:

Starting from the unanimous observation that finding all repeated patterns with don't cares (or any other form to allow a limited degree of approximation as it is required in biological applications) is inherently difficult due to the possible exponential size of the output, we have conceived a new way to address the problem that attempts to overcome this drawback. The idea is to generate only a small (of linear size) subset of the repeated patterns - a *basis* - that can be computed in polynomial time and that can generate all the other repeated motifs. In this direction, we have defined such a basis and conceived an efficient algorithm to compute it. Moreover, we have performed comparative studies with respect to other possible notion of basis, with particular attention to their evolution for growing values of the minimum amount of occurrences required.

We have focused our attention on the inference of structured motifs which are particularly suitable for the detection of promoter sequences and thus to individuate co-regulated genes. For this task, we are working on possible algorithmical improvements of

an exhisting tool (named SMILE) that look promising. These improvements consist in a dynamic management of the su x tree data structure.

This group participates into the following major research project:

Algorithms for Modelling and Inference Problems in Molecular Biology. French Program Bioinformatique EPST 2002.

Vinci french-italian project 2002.

## Short term plans and expected results

Concerning the tool for genes duplications history reconstruction, we are performing several biological applications in order to drive the next steps of our research. These will most likely lead us to design methods that compare gene families using suitably conceived tree comparison tecniques applied to the trees output by our tool that represents the genes family duplications history.

Our next goal in repeated motifs extraction is to design biologically driven analysis and use of the basis of repeated motifs. Also, we are investigating the possibility to extend this method to the inference of common motifs to a set of two or more input sequences. This extension could lead to design new notions of resemblance and similarity among biological sequences. Finally, we are investigating a possible new data structure which is actually su x tree that dynamically changes according to the structure required for the motif.

## Personnel and External Researchers

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## 2.15 Project: Multi-level Synthesis of Boolean Functions

### Summary


We address some problems arising in logical synthesis. In particular we study e cient minimization of EXOR-AND-OR networks exploiting function regularities, and analyze the testability of networks containing EXOR gates.

Keywords: Boolean function, Pseudoproduct, SPP form, Autosymmetry, Regularity, Logical synthesis, Testability.

## Background

The standard synthesis of Boolean functions is performed with Sum of Products (SP) minimization procedures, leading to two level circuits. Multi-level minimization is much harder, but the size of the circuits can signi cantly decrease. In all cases the algorithms for exact minimization have exponential complexity, hence the time to attain minimal forms becomes huge for increasing size of the input. Several techniques for three level minimization have been proposed for di erent algebraic expressions. Among them EX-SOP forms, where two SP forms are connected in EXOR; and Sum of Pseudoproducts (SPP) forms, consisting of an OR of pseudoproducts, where a pseudoproduct is the AND of EXOR factors. Experimental results show that the average size of SPP forms is approximately half the size of the corresponding SP, and SPP forms are also smaller than EX-SOP. Therefore, nding e cient SPP minimization algorithms is an important goal. Another relevant issue in this eld is testability of the proposed forms, as three-level networks, as well as networks containing EXOR gates, are generally hardly testable. Our research is aimed at solving these problems.

## Ongoing research

Recently introduced, three-level logic SPP forms allowed the representation of Boolean functions with much shorter expressions than standard two-level Sum of Products (SP) expressions, or other three-level logic forms. On the other hand SPP networks have a cumbersome theory, their minimization time is high, and the unbounded fan-in EXOR gates in SPP expressions are not easily implementable in the current technology. Consequently our current main aims are: 1) rephrasing SPP theory in a well-known algebraic context to obtain an easier description of the networks; 2) introducing much faster algorithms for SPP synthesis; 3) de ning new models of SPP networks with bounded fan-in EXOR gates, or bounded number of EXOR gates, whose minimization time is strongly reduced and whose minimal forms are still very compact; 4) exploiting regularities of the input function in order to decrease the minimization complexity.

To pursue these goals we have given a new algebraic description of SPP forms using a ne spaces, that leads to a canonical representation of the functions on which we are basing new e cient minimization algorithms. In this framework we are also studying SPP forms with bounded fan-in gates which imply simpler hardware realizations, and for which the minimization time is drastically reduced.

Second we study the regularity of a Boolean functions through the new concept of \autosymmetry", in order to decrease their minimization time. A function $f$ of $n$ variables is expressed by its autosymmetry degree $k$, $0 \quad k \quad n$. For $k > 0$ a new function $f_k$ is identi ed in polynomial time, such that $f_k$ is \equivalent" to, but smaller than $f$, and depends on $n \quad k$ variables only. The important fact is that, given a minimal SPP form for $f_k$, a minimal SPP form for $f$ is built in linear time. Experimental results show that a large percentage of classical benchmark functions are autosymmetric, and the SPP minimization time is critically reduced for them. We are also studying a new promising EXOR-AND-OR (ORAX) form for autosymmetric functions, as a trade-o between SPP and SP forms.

Beside the synthesis problem, testability is a major aspect of the design process. Up to 40% of the overall design costs are due to testing. For this, aspects of testability should be considered from the very beginning. For several two-level forms detailed studies on testability have been performed. But, to the best of our knowledge, for three-level networks testability has not been considered so far.

The testability of SPP forms is studied from a theoretical and practical point of view. We are studying testability of SPP forms under two static fault models, i.e. the Stuck-At Fault Model (SAFM) and the Cellular Fault Model (CFM).

The classical stuck-at fault model (SAFM) is well-known and used throughout the industry. In SAFM it is assumed, that a defect causes a basic cell input or output to be xed to either 0 or 1. Thus, all failures with this e ect will be detected by tests for stuck-at faults. The strongest cell-based fault model to control the correct static behavior of a combinational circuit is the CFM which tries to completely verify the function of each basic cell in the circuit. Under the stuck-at fault model we have proved that general SPP networks, minimized with respect to the number of literals, are free of redundancies by construction. Whereas it can be shown by counter-examples that SPPs, minimized with respect to the number of products, are not fully

testable. Now we are studying the circuits with respect to the more general cellular fault model.

### Short term plans and expected results

In the minimization process of SPP forms, no EXOR sharing has been considered. The possibility to share EXOR gates could be exploited during the set covering step, and an \ad hoc" set covering procedure could be de ned.

New method have been recently proposed for performing multi-output minimization of SP adding $\log m$ output variables instead of $m$ (where $m$ is the number of outputs in the function). It is shown how to choose a good encoding of the outputs in order to achieve a nearly optimal SP form. A challenging problem would be nding a good encoding also for SPP forms.

The number of prime pseudoproducts is in general much greater than the number of prime implicants and we are still not able to deal, in reasonable time, with hard functions (e.g., the hardest functions in the Espresso benchmarks). Therefore, an interesting future direction is the investigation on implicit SPP minimization algorithms whose complexity no longer depends on the number of pseudoproducts to manipulate.

More work is needed in the treatment of don't care conditions. Our present de nition of autosymmetry for an incompletely speci ed function $f$ is rather restrictive, as it takes all the don't cares of $f$ as points of the function $g$ to be actually synthesized. Another approach would be selecting *only a subset* of don't cares of $f$ as points of the function $g$, in order to maximize the autosymmetry degree and reduce the size of the nal circuit. Thus far we have been unable to propose a polynomial time algorithm for such a selection.

An interesting property of EXOR gates is their excellent testability. Indeed we have already verify the good testability properties of SPP forms under the SAF model. It is focus of current work to study more complex fault models, that allow to model dynamic behavior, like e.g. path-delay faults.

Finally, we have just started studying heuristics for the SPP synthesis problem in order to design more e cient minimization algorithm.

## Long term plans

It is di cult to analyze this point in depth, but a line of tendency can be clearly drawn. The study and exploiting of regularities of Boolean functions will remain of great importance in the next several years. Thus it might be relevant to de ne and study other \regularities" of Boolean functions, in order to derive networks similar to those used in function decomposition, but with di erent gates in the additional level of logic.

## Personnel

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## 2.16 Project: Light perception in microorganisms and UV-stress in ecosystems

### Summary

This research line is conducted in cooperation with the Biophysics Institute of the National Research Council of Italy, which make available its experimental laboratories. This research is focused on the interactions between light and biosphere, in particular on light perception in microorganisms and on UV-stress.

Keywords: phototaxis, photophobic responses, ciliates, agellates, Fabrea salina, Dunaliella salina, Ophryoglena ava, Euplotes focardii, proteomics, electrophoresis, theoretical models.

### Background

Light and biosphere are intimately connected: the solar radiation, in fact, is of a fundamental importance for life on the Earth. Light can a ect living organisms in several di erent ways: it acts as energy source in photocoupling processes (e.g.: photosynthesis), as signal in photoperception processes (e.g.: phototmovements, vision), as activation agent for metabolic pathways (e.g.: blue-light activated repair complexes), a.s.o. The two main research lines in this eld are: the photoperception in ciliates and the e ects of UV-B irradiation on marine microorganisms.

### Ongoing research

Photosensory perception in microorganisms The capability to use light as signal to process in order to obtain information about the surrounding environment is started early in the biological evolution: very old

organisms, like bacteria and archeobacteria, possess di erent photoreceptor molecules, which allow them at least to distinguish between light presence/absence, but in many cases they are also able to distinguish light direction and many other features of the light stimulus. We have investigated, by means of behavioral, biochemical, immunocytochemical, electron microscopy, microspectro uorimetric and electophoretic techniques, the photoperception in the ciliates: Fabrea salina, Ophryoglena ava, and we are currently investigating the Antarctic ciliate Euplotes focardii.

UV-e ects on ecosystems UV radiation, and in particular UV-B (280-315 nm), are usually stopped by the stratospheric ozone layer. The progressive depletion of the ozone, mainly due to anthropic activities, is causing an increase of the UV-B doses reaching the biosphere. We are studying the consequence of medium- and high-doses UV-B exposure on some marine microorganisms: the ciliate Fabrea salina, the green alga Dunaliella salina and the Antarctic ciliate Euplotes focardii.

## Personnel and External Researchers

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## 2.17 Project: Models & Languages for Open Distributed Systems

### Summary

Our plan is twofold. We want to carry on fundamental studies in the main stream of computer science, and we want also to contribute to the solution of practical problems employing innovative techniques. The work is theoretical, but also experimental in part. The scenario is wide area programming with its problems about scalability, connectivity, heterogeneity and autonomy. We work on coordination, web service orchestration, software architectures (in particular concerning security, quality of service (QoS) and dynamic recon g-uration), mobile and higher order concurrency, mobile committed languages, tile logic, nite state veri cation, graph rewriting systems, coalgebras and constraint solving and programming.
Keywords: coalgebras, concurrency, coordination, graph rewriting, constraints

### Background

Highly distributed networks have now become a common platform for large scale distributed programming. While a number of useful Internet applications can be developed using the standard client-server paradigm, Internet applications distinguish themselves from traditional applications on *scalability* (huge number of users and nodes), *connectivity* (both availability and bandwidth), *heterogeneity* (operating systems and application software) and *autonomy* (of network nodes and administration domains having strong control of their resources). Hence, other programming paradigms (thin client and application servers, collaborative \peer-to-peer", code-on-demand, mobile agents) seem more appropriate for applications over Internet. These emerging programming paradigms require on the one hand mechanisms to support mobility of code and computations, and e ective infrastructures to support coordination and control of dynamically loaded software modules. On the other hand, an abstract semantic framework to formalize the *model of computation* of Internet applications is clearly needed, and missing in part. Such semantic framework may provide the formal basis to discuss and motivate controversial design/implementation issues and to state and certify properties in a rigorous way.

The scenario we outlined above is very appealing from the scienti c point of view, since lots of the concepts to be made precise and most of the open problems involve fundamental issues of computer science research. More speci cally, models, languages and logics are needed which are i) distributed, interactive & concurrent; ii) open & recon gurable; iii) higher order & typed; iv) equipped with abstract compositional semantics; v) e ciently veri able. While research has been quite successful on several of these issues separately, their combination is not well understood, and it is the object of our study.

The aspects of the above research scenario which we consider most relevant for our research are: (i) the *coordination approach*, employed in particular to design *security architectures*, *web service orchestration* and *programmable QoS*; (ii) *mobile and higher order concurrency*, in particular for *distributed* and *committed* process description languages supported by *nite state veri cation*; (iii) *graph rewriting systems*, as a proper generalization of Petri nets, for the speci cation of concurrent and distributed systems; (iv) *coalgebras* for the speci cation of interactive systems with a hidden state space; (v) *constraint solving and programming*, in particular its *non-crisp* version, for expressing and solving synchronization conditions and distributed constraints.

## Ongoing research

Inspired by the -calculus and by the coordination language Linda, the study of programming languages for mobility and coordination has been undertaken with the de nition and implementation of the language KLAIM (in collaboration with the university of Florence). Special attention is given to types for security and access control. Models of computation for web service orchestration and important classes of applications (telecommunications, groupware, ad hoc networks) are also studied in two MIUR-CNR projects. In particular, QoS requirements expressed as distributed/concurrent constraints are considered, which can be solved with e cient algorithms. The constraints are based on certain mathematical structures (c-semirings), where both classical and soft constraints can be expressed, thus representing features like costs, probabilities, preferences, and similar. Also, the problem of negotiating and committing among multiple partners in a completely dynamic and open setting is studied. Based on zero-safe nets, a previously developed extension of Petri nets where a natural notion of transaction can be expressed, on

LINDA and on the JOIN calculus (a kind of higher-order, mobile version of nets) new e cient commit algorithms are developed, and language extensions (e.g. TRALINDA) accommodating transactional concepts are designed.

A general model of computation, called *tile logic* was introduced several years ago. Tiles (formally double cells of a double category) are rules de ning the behavior of open con gurations, i.e. system components, which may interact through their interfaces. Research on tile logic includes work on algebraic and logical properties of monoidal and cartesian double categories and on the de nition of rst order and higher order versions of them. Moreover, tiles were studied as a foundation for open, distributed and interactive systems. In particular expressive tile models were found for non-interleaving process algebras (causal tree semantics) and logic programming. Also a core ection has been observed between the categories of tiles and of rewriting systems. This universal construction allows us to see the same computation as a transaction (lower level) or as a transition (abstract level). Tile logic is executed by translating it into rewriting logic, which has quite e cient implementations.

We explore how coalgebraic techniques can be used for representing compositional, interactive systems. Ongoing studies show that coalgebras de ned on a category of algebras are adequate for certain classes of speci cations (which include and non-trivially generalize most formats used in process algebras by allowing structural axioms). This setting guarantees that bisimulation is a congruence with respect to the algebraic operators. In particular, su cient conditions of wide applicability have been found which allow to lift a coalgebra from the category Set to the category of relevant algebras: essentially they require that structural axioms bisimulate. When name permutations are included in the algebraic operators, name handling (creation, passing, alpha conversion) becomes easier to represent. In particular bisimilarity for -calculus and similar languages becomes expressible in purely coalgebraic ways, without crippling side conditions in its de nition.

Certain classes of automata, called *History Dependent* Automata (HD-automata) have been introduced in the past, which are able to allocate and garbage collect names. Process algebras with causality and locality information, Petri nets equipped with history preserving bisimulation, and synchronous and asynchronous -calculus can be veri ed via HD-automata. Behavioral properties related to dynamic network connectivity, locality of resources and processes, and causality among events can be formally veri ed

on nite HD-automata. In this line, we are part of the IST-FET European project PROFUNDIS within the Global Computing (GC) initiative, where generalizations of HD-automata including fusions and spatial operators are studied. Tools for HD-automata (HAL) have been implemented in the past in collaboration with IEI-CNR (now ISTI-CNR). Within PROFUNDIS, additional tools for automata minimization are being developed. Their design takes advantage of the research about coalgebras we previously mentioned. Also a general veri cation architecture is under development, where the various tools are seen as web services available on the net and developed by geographically distributed sites. Veri cation applications are programmable via the coordination/orchestration languages previously mentioned, while distributed veri cation is clearly an interesting case study for coordination research. On the more foundational side, the relationships among several metamodels for calculi with name-passing have been investigated, including permutation algebras, named sets and sheaf categories, with the aim of establishing a bridge between such di erent approaches to the abstract speci cation of nominal calculi.

In the area of Petri nets, several variants of the basic models have been considered, including *contextual* nets (which can read tokens without consuming them), *inhibitor* nets (where the presence of a token on a place can inhibit the ring of a transition), and *pre-nets*, i.e., nets where a linear order is imposed on pre- and post-conditions of transitions. Several categorical constructions of ordinary nets have been generalized, to a certain extent, to such models, including adjunctions for the operational semantics and for the unfoldings in terms of event structures.

In the area of graph rewriting, the topics which are addressed range from the semantical foundations to their use for specifying and verifying concurrent and distributed systems. Concerning foundations, the emphasis is on generalizing analogous results for Petri nets. A concurrent semantics based on event structures, processes, and unfolding constructions has been developed. In particular, it has been shown that the construction of the associated event structure is a core ection in the case of the single pushout approach, and only functorial in the double pushout approach. Concerning abstract semantics, history preserving bisimilarity, previously de ned for contextual Petri nets, has been extended to graph transformations in the double pushout style. The construction often derives a nite HD-automaton, which can be minimized and model checked. A variant of the single pushout approach has

been de ned, called linear grammars for ordered graphs, which allows for a resource-conscious rewriting. For these grammars a tile-based semantics has been introduced, which allows for a universally de ned operational semantics which guarantees compositionality via colimits. Besides the single and double pushout approaches, also the Synchronized Hyperedge Replacement approach is studied, and found particularly expressive for modeling software architectures and distributed, open and mobile systems. In particular it has been shown how it is strictly related to a particular interpretation of logic programming, which also allows for an e cient implementation. Synchronized hyperedge replacement has been used to provide an operational semantics to CommUnity, a simple architecural design language.

Several analysis and veri cation techniques have been studied. For the veri cation of properties of distributed, mobile systems modeled with graph transformation, a methodology has been developed. Properties are expressed in a temporal logic which is a propositional -calculus where the state predicates are formulae of a monadic second order logic, interpreted over graphs. The veri cation technique, applicable to a fragment of such logic, makes use of nite approximations of the unfolding of the graph transformation system. Also, a symbolic technique has been developed for the analysis of security protocols, that avoids the explict construction of the whole, possibly in nite state-space of protocols. Based on this technique, a tool called STA (Symbolic Trace Analyzer) has been implemented and successfully experimented on well-known protocols. Finally, a static analysis technique has been developed, which allows to handle in a formal way optimization techniques for mobile code in presence of security policies based on stack inspection, allowing for just-in-time optimization also in presence of dynamic linking of software libraries.

A simple version of higher-order (term) graphs has been de ned employing the closed version (Lambda-GS) of certain monoidal (GS-monoidal) categories previously introduced. Multi-algebras are also studied, where operations return a set of results rather than a single result, which are useful for de ning nondeterminism algebraically. For multi-algebras, Lawvere construction has been extended, by interpreting them as functors from certain categories weaker than cartesian. A simple inequational deduction system has also been derived for computing inclusions between relations computed by a multi-algebra, and it has been proved that term graphs provide a consistent and complete axiomatization. A symbolic operational semantics equipped

with bisimilarity has been developed for a process calculus where transitions are labelled with temporal and spatial logic formulas. In some cases the symbolic semantics can be e ciently computed using uni cation.

We participate to the IST-FET-GC European project AGILE with research on graph rewriting, tiles, and their applications to software architectures of mobile and open systems based on wide area networks. In the area of graph rewriting and visual systems we are also partners of the European RTN network *SEGRAVIS*. We contributed with a total of three chapters to the *Handbooks* on graph rewriting, edited by Grzegorz Rozenberg and others.

### Future work

We propose to employ the notion of coordination as a fundamental structuring concept for interactive, open and secure architectures. The mathematical foundations of coordination are partially missing and we plan to study them relying on the formal notions we developed, like graph rewriting, tile logic and HD-automata. The long term (and ambitious) goal is to provide a semantic-based environment to specify, validate, implement and test Internet applications.

A strong interaction is expected between the work on graph transformations and tiles and the more applied development on coordination languages and software architectures. Moreover, research is under way to develop a representation of the KLAIM language in the process calculus and graph transformation styles in order to de ne notions of observations and of behavioral equivalences as a basis for veri cation. We also intend to check the theoretical developments by designing and implementing suggestive case studies, taking advantage of the KLAIM prototype.

About veri cation, we plan to extend the HD-automata techniques to the analysis of security protocols. We intend to address the problem of developing a speci cation logic for open and untrusted dynamic networks and its model checking techniques. Also we plan to enrich HD automata with data in the form of term substitutions, obtaining a model of computation close to logic programming. Symbolic execution on this model could provide an e ective veri cation technique for important classes of security properties.

Finally, we intend to develop a methodological framework based on graph rewriting and tile logic for accommodating the semantic integration of *aspect-speci c visual languages*.

## Personnel and External Researchers

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## 2.18 Project: Computer, Communication and Education

### Summary

The rapid and widespread di usion of computer and information technologies and their products raises the problem of in what areas and how computer and information sciences can contribute to the eld of education. This problem is speci cally connected with Areas of Arti cial Intelligence and Man-Machine Interaction but also involves many other areas of Computer Science (Hypermedia, Data Bases, Networks and Telematics) as well as other branches of knowledge, principally Education and Cognitive Sciences.

Keywords: Communication, Education, Cognitive, Interaction, Cooperation

### Background

Computer-aided education is characterized by an increasingly wider variety of technological tools to help teaching/learning, distance learning and the spread of culture (museums, itineraries, institutions etc). The aim is to raise the awareness and curiosity of users by stimulating them with images and lively and attractive images and involving them in choosing to carry out actions either completely independently or by interacting with others at di erent times and in di erent locations. In these conditions interactive operations become paramount that are based on the exchange of information and on the processing of common results to be developed by a variety of people (students, teachers, guides, instructors, moderators) who work within

the same organisation or in organisations that may be very distant from each other. On the other hand, it is also increasingly important to give stability, accumulation and continuity to the materials used in the various applications, despite the huge variety and rapid changes in the requirements and needs of the user, and in the possibilities o ered by the technology (equipment, its features, and types and forms of the information itself). Consequently, to develop these tools hypermedia technologies are more and more frequently used, along with databases and communication networks, which are integrated with each other and associated with concepts and techniques derived from arti cial intelligence and the cognitive sciences.

## Ongoing research

Our aim is to integrate the speci c functionality of: Hypermedia, Data Bases, Telematics, i.e. remote network communication, in order to: 1) give stability and continuity to the applications; 2) allow for the accumulation and adaptability of the data; 3) enhance and make more involving the communicative and didactive potential of the materials via interactive access; 4) widen the possibility of adapting the materials to various uses by di erent typologies; i) users (students, teachers, guides, museum workers, visitors, specialists etc); ii) application environments (schools, training, distance education, di usion of culture etc); means of exploitation (local, remote, deferred) etc; 5) facilitate the re-use of the same information in di erent environments, in order to reduce production and maintenance costs, in particular in relation to expensive data eg 3D interactive modelling. To this end we have designed, developed and tested development environments, de ned as a combination of: i) a methodology centred around certain reference people (data administrator, thematic-disciplinary expert, data producer) which has been made practical via: ii) a set of functions and tools for its application. This approach was initially applied to 'traditional' data (texts, images, lms and already existing animations) and was then extended to interactive 3D graphics and tested on widely di erent applications (historic buildings and architecture on the one hand, and natural fauna and paleontological examples on the other). This approach is based on: i) the dynamic composition of presentation pages on the basis of data extracted from a multimedia database; ii) the possibility to create an overall schema that describes the data, the speci cations, speci c sub-schemas for particular applications, user typologies and related

means of presentation. We have thus decided to adopt the capabilities o ered by a speci cally articulated multimedia data model which describes multimedia objects in terms of their physical characteristics, their structure, and their contents. It consists of three parts: a Multimedia Description Model (MDM), which provides a structural view of raw multimedia data; a Multimedia Presentation Model (MPM), which describes the temporal and spatial relationships among di erent structured multimedia data and the Multimedia Interpretation Model (MIM) which allows semantic interpretations to be associated with structured multimedia data.

## Short term plans and expected results

The approach adopted can be extended in the following directions: 1) organize and heighten the ways of reusing information, and in correlation; 2) abstraction of connection and presentation schemas of the various materials; 3) integrating arti cial intelligence techniques in order to maximise the interaction and exploitation by the user. In relation to 1) we can observe that: a) The possibility of reuse is strongly dependent on the availability of a well-organized environment, like the digital archive developed for previous projects. This acts as a multimedia repository of the collected material, supporting hypermedia developers to search and to retrieve, in a very e ective way, what needs to be reused for application development. The digital archive also acts as an editorial environment, which makes the process of storing new contents and maintaining the overall body of knowledge sources easy, e cient, and well organized. b) A multimedia repository where data are stored in di erent formats, guarantees that the digitized material can be accessed in the long term. This makes reuse "over time" possible. The problem of format obsolescence is extremely important and critical, especially in the case of archives containing historical data. c) In many cases, it is useful to enable the reuse of parts of applications, besides the multimedia contents. Research work is needed to understand how application components (modules) can be reused, how subparts of an application can be extracted. d) Related to the previous aspect an archive of reusable application components needs to be created. This also entails de ning appropriate mechanisms for the selection of the relevant application modules (query mechanisms) together with a suitable query formulation interface.

## Long term plans

Provide a strong integration of the application with the multimedia repository so that the application can acquire data stored only when needed, by using query by content mechanisms instead of directly accessing the objects.

## Personnel and External Researchers

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## 2.19 Project: Advanced methodologies in Machine Learning and Computational Intelligence


### Summary

The proposers have experience in Arti cial Intelligence methodologies, ranging from Computational Intelligence to Machine Learning approaches such as Neural Networks, Evolutionary Computation, Fuzzy Systems, Adaptive Processing of Structured Information, Pattern Recognition. This knowledge led to the development of new methodologies which have been exploited for the design of successful systems in di erent application domains.

In consideration both of the fast growth of information sources due to the explosion in use of Internet, and of the need to nd signi cant data sets in very large data base or for Applied Science elds, and to give new human-like capabilities to advanced robotics devices, the proposers, on the basis of their experience, recognize the need to deepen the open problems in the existing approaches pertaining to their eld of interest. To this aim, they propose the extension to the processing of structured data (e.g. sequences, trees, graphs) of standard machine learning methods, actually restricted only to treat domains of attribute-value data. Besides, the propose to pursue improvements of current technologies for integration of the symbolic and subsymbolic paradigms. During the short term period the proposers will investigate on the possibility of extending the computational capabilities of neural networks for the treatment of structured domains as well as issues concerning more general Machine Learning methodologies in Pattern Recognition and in the emerging Evolutionary Computation paradigm. The long term aim is to de ne computational frameworks, for the development of intelligent systems in di erent application elds, able to describe and to exploit all the signi cant obtained results of Computational Intelligence and Machine Learning, together with their integration with symbolic methodologies.



Keywords: Computational Intelligence, Machine Learning, Neural Computation, Evolutionary Computation, Pattern Recognition, Robotics.


### Background

In recent years, the eld of Computational Intelligence together with AI showed a renewed, growing interest for the symbolic and sub-symbolic representation of knowledge, mainly due to the development of agents and multi-

agent systems theory that has revitalized the eld and has given new challenges for developing formalisms, methodologies and languages suitable for these systems. At the same time, the di usion of telematic networking has allowed an extraordinary growth of information sources so that the combination of distributed and heterogeneous information has become a critical problem. A promising solution to the management, search and integration of these information sources seems to be the design and development of systems based on intelligent hybrid agents, able to extract knowledge from data of di erent nature and to reason about the acquired knowledge. In these systems each agent is specialized to interact with a speci c source of information, but it is also able to cooperate with other components of the system, to nd a solution to the users' requirements, retrieving information even if the actors are di erent and located in di erent places. The technologies available to build such systems span from conceptual models to multi-agent systems, to the languages and architectures necessary to implement them, to machine learning, soft computing, data mining and knowledge extraction methodologies. Most of these methodologies are based on statistical methods and biologically based computational paradigms such as neural networks, genetic algorithms and evolutionary programming. The nal goal would be to develop autonomous intelligent agents, and/or able to solve all the classes of problems where the information is complex, not clearly stated and the management of uncertainty is important. Moreover, in the case of robotics, the goal would be to develop modules really provided with nearly human capabilities. In order to reach this goal, methodologies incorporating both conceptual and sub-conceptual processes, naturally leading to the integration of symbolic, connectionist and/or other paradigms that are developing in the eld of machine learning, are needed.

## Ongoing research

The proposers have developed several systems that integrate multi-paradigm techniques. In particular, in V European Framework, we designed and developed a complex, web- based, multilingual system for acquisition and exchange of information among medical people and patients. This system has manyfold advanced aspects being capable to manage di erent classes of information and answer to questions posed both by medical people or by patients. Still in the same eld of application, we are developing a distributed system,

for the Department of Oncological Medicine and Transplants, which will allow not only the treatment of patients, but also investigations about the possible relationships among pathologies, symptoms and genetic information by means of unsupervised data mining techniques, based on neural networks. At same time, together with the Division of Diagnostic and Interventional Radiology of the University of Pisa, we are developing a system for processing NMR Mammographic Images by classical Pattern Recognition methods. After that, in dependence of the possible enhanced lesions, the images are automatically classi ed by means of an adaptive classi er based on arti cial neural networks.

Moreover, in collaboration with the Harward Medical School, we plan to analyze the images of their database so to compare their and our classi cation methods.

In collaboration with the Department of Neurosciences of Pisa University, a research has been developed aiming at the development of automatic methods in Clinical Neurology. Three kinds of signals have been studied: a) Spontaneous Electroencephalogram recorded during sleep. A method for the quantitative description of the sleep macrostructure (stage transitions) and the sleep microstructure (transient events that do not imply any stage transition)has been implemented and proven; b) Ultrasound Doppler images obtained from the transcranial artery. For this problem an automatic system has been developed in order to distinguish the \High Intensity Transient Signals" corresponding to solid emboli from those corresponding to gaseous emboli; c) Verbal data elicited after forced awakening from the various sleep stages. A method for the automatic detection and classi cation of possible cognitive links between the di erent dream sources has been introduced and evaluated.

Concerning neural networks for structures, the proposers have investigated both theoretical issues and real-world applications. They have proposed a rst approach to deal with contextual information in structured domains by Recursive Neural Networks (RNN). The proposed model, i.e. Contextual Recursive Cascade Correlation (CRCC), a generalization of the Recursive Cascade Correlation (RCC) model, is able to partially remove the causality assumption by exploiting contextual information. They formally characterize the properties of CRCC showing that it is able to compute contextual transductions and also some causal supersource transductions that RCC cannot compute. They de ne also a general recursive framework for

unsupervised processing of structured data. This general framework o ers a uniform notation for training mechanisms of di erent models and insights into theoretical issues from the SOM literature to the structure processing case.

The application eld of the processing of structures has been the study of Quantitative Structure-Property Relationship (QSPR) and Quantitative Structure-Activity Relationship (QSAR) of various classes of chemical compounds. To this purpose they developed an uni ed framework, based on functional transduction, to present the traditional approach and to introduce the new one based on neural network for structures. By this formalism it is possible to prove that RNNs can be a suitable tool for the automatization of two fundamental parts of the QSPR/QSAR analysis, i.e. the encoding and mapping phases. In particular, the generality and exibility of the structured representation allows to deal with various tasks and classes of compounds, characterized by a quite high morphological complexity. These applications have been funded and developed within MIUR Projects COFIN in 1999, 2000, 2001, 2002, 2003.

The research within Evolutionary Computation has shifted towards Genetic programming. In fact, recently the problem of Automatic Subroutine Discovery has been analyzed and how the modality of use of genetic operators in the tournament selection to prevent Code Bloat in Genetic Programming.

In the eld of Advanced Robotics, the collaboration with the ARTS Lab. of Scuola Superiore di Studi S. Anna is continuing searching to give human capabilities to robotics devices by arti cial neural networks. A Neurocontroller for di erent Robotic Manipulators which is based on Neural Models, biologically-inspired, of the visual-motor coordination has been designed and implemented.

We are involved into the following projects:

\Development of a telematic, multimedial tool for the rehabilitation of people with language disturbances", funded by Italian CNR 2001/2003. This project is developed in collaboration with the University of Siena, and the Software House Synapsis S.r.l.,Livorno.

\A Web-Based System for physiatrists of the Locomotor Apparatus", funded by Italian CNR 2001/2003. This project is developed in collaboration with the University of Roma, and with the \Centro geriatrico 'I Fraticini"' of Firenze.

\WOMAN II", European Project IST-2001-32672 for 2001/2003, in Health

Telematics, in collaboration with the Gynecological Clinics from Fifteen European Countries.

\Design of biologically active molecules by neural network techniques applied to QSAR studies and by investigation of ligand-macromolecule interactions", (Co n 1999/2000, jointly funded by Pisa University and MIUR. In collaboration with the \Dipartimento di Chimica e Chimica Industriale" and \Dipartimento di Scienze Farmaceutiche" of Pisa University)

\Neural Networks for Learning in Structured Domains: Methods and Applications". (Co n 2000/2001, jointly funded by the University of Pisa and MIUR. In collaboration with \Dipartimento di Ingegneria Informatica" of the University of Siena and the \Dipartimento di Scienze Farmaceutiche" of the University of Pisa)

\Interdisciplinary integrated design of active biological systems for biomedical and pharmacological applications". (Co n 2001/2002, jointly funded by the University of Pisa and MIUR. In collaboration with \Dipartimento di Ingegneria Informatica"of the University of Firenze and with the \Dipartimento di Chimica e Chimica Industriale" of the University of Pisa and Napoli.

\Tools based on Machine Learning methodologies for structural and functional genomics" (Co n 2002/2003, jointly funded by the University of Padova and MIUR. In collaboration with \Dip. di Matematica Pura e Applicata", Univ. di Padova, \Dipartimento di Ingegneria Informatica" of the University of Firenze and Dipartimento di Ingegneria Informatica" of the University of Siena).

\An intelligent informative system for studying Leukemia", Funded by AIL( Italian Association on Leukemia).

\Integrated multidisciplinary design and realization of biologically active systems for biomedical applications" (Co n 2003/2005. In collaboration with Dip. di Chimica e Chimica Industriale - Univ. di Pisa, Dip. di Scienze e Tecnologie chimiche e dei Biosistemi- Univ. di Siena, Dip. di Chimica - Univ. di Bologna, Dip. di Chimica - Univ. di Napoli).

\BIOPATTERN: Network of Excellence (NoE)" funded by the European Community, whose actors are 37 Academic and Industrial Partners, from 8 European Countries. The aim fo the NoE is the analysis and evaluation of the existent methodologies for treatment of biological data and the proposal of new ones. (2004-2006).

## Short term plans and expected results

In the short term period we would like to extend and improve the performance of the described systems by including evolving Pattern Recognition and Machine Learning techniques, such as Support Vector Machines and Boosting algorithms aiming to apply the results to the construction of Intelligent Systems for Medicine, Robotics and, in general for the Applied Sciences.

Concerning the adaptive processing of structured domains, we will proceed to develop the following issues: theoretical properties of current models, unsupervised learning algorithms, new supervised learning algorithms, non-stationary and contextual models, analysis of the internal representations, SVM and Kernel-based methods for structured data, QSAR and QSPR applications.

In the eld of Evolutionary Computation we want to face the problem of studying the possibility to integrate methods developed independently in the frame of Genetic Based Machine Learning, and in the connectionist paradigm and to transfer the results into applications of interest, such as data mining in very large medical databases.

## Long term plans

In the eld of neural networks we plan to develop hybrid models for processing structured data using di erent approaches coming from statistical learning theory and/or Relational Data Mining. This study will be based on the experience acquired in the current researches. The scope of applications can be further expanded and exploit for various problems in the area of Cheminformatics and Bioinformatics.

The experience acquired in developing web-based intelligent systems for Medicine toghether with the developed methods of Machine Learning will be used for developing a system for a focused search on web, based on GRID technology,in the framework of a FIRB Project. The application eld may be medical imaging and/or general multivariate medical information.

Concerning the modeling of perceptual information, we aim at developing hybrid systems (evolutionary + neural + fuzzy) to process the sensory information and to solve low-level and high-level decision tasks on a arti cial\head", capable of binocular vision (now available at the Advanced Robotic Lab, of Scuola Superiore di Studi S. Anna of Pisa), to exploit models

of Computer Vision.

## Personnel and External Researchers

*Project leader*: Antonina Starita (Full Professor),
*Internal Personnel*: Umberto Barcaro (Associate Professor), Franco Masulli (Associate Professor), Alessio Micheli (Postdoc Research Fellow), Fabio Aiolli (PhD Student), Franco Alberto Cardillo (PhD Student), Flavio Baronti (PhD Student).
*Collaborators (by contracts on research funds/fellowship)*: Elena Palanca, Katuscia Cerbioni, Pablo Rossi.
*External Collaborators*: Prof. Alessandro Sperduti (Dip. di Matematica Pura e Applicata, Univ. di Padova), Prof. Paolo Dario (SSSUP), Prof. Eugenio Guglielmelli (SSSUP), Dr.ssa Cecilia Laschi (SSSUP), Prof. Marco Gori (Dip. di Ing. Inf., Univ. di Siena), Prof. Paolo Frasconi (Dip. di Ing. Informatica, Univ. di Firenze), Prof. Roberto Solaro (Dip. di Chimica e Chimica Industriale, Univ. di Pisa), Prof. M.R. Tine (Dip. di Chimica e Chimica Industriale, Univ. di Pisa), Dr.ssa A.M. Bianucci (Dip. di Sci. Farma., Univ. di Pisa), Prof. M. Petrini (Div. di Ematologia Oncologica del Dip.di Oncologia, dei trapianti e delle nuove tecnologie in medicina), Prof. R. Barale (Dip. di Genetica, Universita‘ di Pisa), Prof. D. Caramella (Divisione di Radiologia Diagnostica and Interventistica, Univ.di Pisa), Dr. R. Cioni (Clinica Neurol., Univ. di Siena), Dr. F. Giannini (Clinica Neurol., Univ. di Siena), Dr.ssa D. Majidi (Synapsis srl, Livorno), Dr. Peter Tino (School of Computer Science, The University of Birmingham, UK) Prof. Barbara Hammer (Department of Mathematics/Computer Science, University of Osnabruck, De), Dr. Diego Sona (ITC-IRST, Trento).
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**http://dendrite.di.unipi.it**

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## 2.20 Project: Tools and Methodologies for Data and Knowledge Engineering

Summary

This project is carried on by KDD Lab { the Knowledge Discovery and Delivery Laboratory, a joint research group of the Computer Science Department and ISTI (Institute of Italian National Research Council). The objective of the research group is the development of theory, techniques, architectures and systems for extracting, delivering and managing knowledge.

The mission of the research group is to pursue fundamental research, strategic applications and higher education in the areas of:

Knowledge discovery and web mining

Complex reasoning and discovery in Geographic Information Systems

Natural Language processing and text mining

Architectures for cooperative computing

Fundamental research of the Lab is aimed at producing advances in the principles of Knowledge Discovery, Delivery and Management and their enabling technologies.

Strategic applications are challenging ones, where new principles and technologies are put at work; such applications play two roles: as demonstrators to assess the research achievements, and as stimulus to identify new unsolved problems that foster new research.

The research group operates in a multidisciplinary fashion, integrating expertise in databases, computational logic, geographic information systems, and natural language processing.

The research group is in charge of the scienti c organization of ECML/PKDD 2004, the co-located European Conf. on Machine Learning and the Conf. on Principles and Pratice of Knowledge Discovery in Databases, which will take place in Pisa in September 2004.

Keywords: computational logic, logic-based database and knowledge representation languages, knowledge discovery, data mining, web mining, spatio-temporal reasoning.

## Research Topics

The central goal of the project is to develop new computational methods for the analysis of large and complicated data sets, i.e., to develop methods that help to extract knowledge from data, to manage knowledge in a cooperative way, and to deliver it to the end users.

The methods for handling knowledge are based on algorithmic and statistical approaches, logic based techniques, database techniques and machine learning methods.

The research of the group can be viewed as an intertwined combination of six research areas.

### Knowledge Discovery Support Environment - Data Mining Query Languages

Most knowledge-intensive data analysis applications require the combination of two kinds of activities: knowledge acquisition, and reasoning on the acquired knowledge according to the domain rules. Data mining techniques are an answer to the rst issue, in that they extract from raw dataimplicit knowledge at a higher abstraction level. There is the need of knowledge discovery support environments and data mining query languages, capable of integrating knowledge extraction and knowledge manipulation to the purpose of developing vertical data analysis applications which incorporate data mining technology. In this context, the research group is exploring several directions:

*LDL-Mine*: is a logic database language (rule-based, SQL-compatible) that facilitates the integration of mining and querying by allowing a uniform treatment of extracted knowledge with domain-speci c knowledge. LDL-mine deals e ectively and uniformly with data preparation, model extraction, model evaluation and analysis, thus providing a powerful formalism where methodologies for classes of challenging applications can be conveniently designed. Currently, the language is able to express Frequent Patterns, Bayesian Classi er, Discretizer, Decision Trees, Clustering.

*Frequent Pattern Discovery in Databases*: A special research line is oriented to frequent pattern discovery. The aim is twofold. On one side we investigate how to design a highly expressive primitive for frequent

pattern discovery in databases, which could be added to a relational query language. On the other side we investigate the optimization techniques that make such primitive e cent enough to be embedded into a database management system. A speci c data reduction technique has been developed, which exploits certain kinds of user-speci ed constraints to the purpose of dramatically optimizing the discovery of frequent patterns.

*KDDML-MQL:* MQL is an SQL-like algebraic language for the speci - cation of knowledge extraction problems, which supports combination of various forms of knowledge by means of nested operators, as well as composition of steps of the knowledge discovery process. MQL is based on the lower-level environment KDDML (KDD Markup Language), which exploits XML for the representation of the extraction process and extracted patterns.

Web mining and Content Delivery

Web mining is the discovery and analysis of useful information from the World Wide Web. It comes in three avors:

*web content mining*, which aims at constructing higher-level models of semi-structured data contained in web sites;

*web usage mining*, which aims at discovering usage patterns from web logs of browsers, web servers and proxy servers;

*web structure mining*, which aims at constructing models of web site structure in terms of page interconnections.

In order to construct a vertical data/web mining application, a whole knowledge discovery process has to be set up, where actual data mining is preceded by data consolidation, selection and preprocessing, and followed by knowledge evaluation and validation; in this perspective, we adhere to the vision of data mining as a database- and datawarehouse-centered activity.

In this context, the research group is exploring several directions:

*Warehousing of Web Usage Data*: Web access data are hidden within log les in a raw format. There is the need to prepare raw log data

for web mining, by cleaning and reconciling them, by organizing them in appropriate storage structures which provide access methods, by re-constructing higher level notions of user sessions and clickstreams. The Web Warehouse provides a solid basis for multidimensional analysis and mining, which can be progressively extended to deal with web content.

*Adaptive Web Mining architecture*: We have developed an intelligent web caching architecture, capable of adapting its behavior on the basis of the access patterns of the clients/users. Such usage patterns, or models, are extracted from the historical access data recorded in log files. The LRU (least recently used) cache replacement policy adopted by web and proxy servers has been extended by making it sensible to web access models, extracted from web log data. This activity leads to the design of a general adaptive web mining architecture characterized by: 1) an off-line analysis module which constructs and maintains a model extracted by mining historical access data, and 2) an on-line module which uses the model to offer specific enhanced services. Web caching is one example of such services: others are personalization and recommendation services, as well as enhanced services for content access.

*Enhanced delivery of web search results*: web mining methods may be deployed to improve either quality or efficiency of web search. Particularly promising is the use of specialized clustering techniques for automatic categorization of web search results, in order to provide a semantically richer presentation of search results in response to user's queries. On the efficiency side, interesting performance improvements are achieved employing an adaptive web mining architecture to the purpose of caching web search queries.

*Web Mining support Environments*: The development of web mining applications, such as a recommendation system, requires tailoring the KDD process around specific data types, specific data access structures, specific preprocessing and mining primitives. We are designing and implementing an environment which supports a semantic view of web objects equipped with language constructs to manipulate and analyze such objects. Such formalism is an instance of the general DMQL that the Lab is consolidating.

*Transactional Clustering*: web usage sessions can be viewed as transaction, namely tuples of variable size of categorical data: standard clustering techniques are not directly applicable to them. We adapted the notion of distance used in the K- Means algorithm to represent transactions dissimilarity, and rede ned the notion of cluster centroid. The cluster centroid is used as the representative of the common properties of cluster elements: a task which is essential to e ectively explain the clustering results. A further advantage of the approach is that the extreme e ciency of K-Means clustering makes it usable on-line.

Geographic Knowledge Discovery and Reasoning Digital geographic datasets are growing at an increasingly rapid pace, aided by mobile telecommunication technology and location-aware devices. This creates tremendous opportunities for data mining techniques to discover knowledge about behavioural patterns from collections of evolving and moving objects, which change their position in time, and possibly also their shape or other signi - cant features. There are still many open issues in this eld. Many technologies need to be advanced and integrated, for instance: spatio/temporal data mining; spatio/temporal reasoning; uncertainty management; incorporation of computational intelligence into spatial data analysis; geo-referenced visualization. In this context, one exciting challenge is to devise privacy-preserving methods for data mining from sources that typically contain personal sensitive data, in order to extract useful knowledge without infringing personal privacy rights.

*Complex Reasoning on Geographical data*: The manipulation of such complex data of very large size, and often of very di erent nature, has become one of the challenges of todays research. There are many aspects that still present open problems, such as the handling of uncertainty and imprecision, the lack of a temporal component associated with geographic data and the discovery of interesting patterns in geographic data. It is worth noticing that all these features require reasoning and adequate knowledge representation formalisms. It is evident that the more computers support humans, the more they have to be capable of providing high-level mechanisms to reason on data.

*Spatio Temporal Reasoning*: In the last four years, within the project DeduGIS, the Lab has been involved in envisaging a new generation of

Geographical Information Systems, characterized by enhanced capabilities to support spatio-temporal reasoning and semantic integration of diverse data models. One interesting products of this project is the language MuTACLP. MuTACLP is a knowledge representation language based on constraint programming that provides facilities for modeling and handling spatio-temporal information, together with some basic operators for combining di erent spatio-temporal knowledge bases. A protype which integrates MuTACLP with a commercial GIS has been delivered within the project DeduGIS.

*Uncertainty and Qualitative Reasoning*: To explicitly represent and reason with spatial uncertainty is under investigation within the project Dedugis. In particular, we are studying the semantics of various qualitative constructs of nearness and how such construct might be used within a knowledge representation formalism such as MuTACLP.

*Applications*: A real application has been developed in collaboration with biologists from the University of Siena. The study regards the biology and behavioral ecology of the crested porcupine. Many questions concerning the mating system and the social structure of this animal are still open. Such questions often involve both temporal and spatial aspects, which are usually strictly correlated. Another interesting application of spatio temporal reasoning which is currently under speci cation, is about archeological sites.

*Spatio Temporal Clustering*: this research line addresses the speci c problem of clustering objects that are both spatially and temporally referenced. There two major issues that are worth to be studied: (1) how to de ne suitable distance functions for spatio-temporal objects, and (2) how to deal with the computational cost raised from the adoption of such distance functions within various clustering techniques. The main contributions of our work are a general schema for distance functions, which is provided to tackle the rst point, and a repertoire of optimization techniques, based on properties of the general schema, which are developed and experimentally evaluated.

### Natural Language Processing and Text Mining

The aim of this line is to study the impact of advanced methodologies in knowledge management and knowledge discovery in the literary analysis in humanistic elds. The research is aimed at designing systems where the information retrieval process is based on a "search by an idea" versus a "search by key-words or string of characters". The search in this context is strongly related to the ontological reoresentatin of the domain. In particular, the Labs goal is to create tools which allow to retrieve the content of a text, either as a linguistic, stylistic and rethoric speci cally organized material, or in his historic, social and cultural context. In particular, the chosen application domain is the people of the Dante's "aldil". The expressiveness we are looking for should be able for example to look for those context of the text where a speci c allegorical form is used, or which allegorical forms are more frequently used? Such a system requires a conceptual organization of the text which will be based on conceptual map and subsumption logic.

### Logic based cooperative computing

The objectives of this research is the investigation of computational and logical models for describing, analyzing, and verifying individuals and aggregates of computational entities with heterogeneous knowledge, objectives roles and patterns of behaviour and interaction. The societies of computational entities are expected to be capable of interacting in a global, open, and dynamically changing environment.

### Active Projects

*Technologies and Services for Enhanced Contents Delivery (2002-2004)*. Funded by Italian Ministry of Research (MIUR). The project focus on developing tools and technologies for delivering enhanced contents to nal users. This entails identifying relevant material from various sources, transforming it, adding to it metadata and other useful distinguishing information, organizing it and delivering the most relevant material to interested users in a timely fashion. The research group is responsable for the action on Web Mining.

*ISTI Curiosity Driven Project: Privacy Preserving Pattern Discovery (P3D)*: The goal is to develop an environment for frequent pattern

discovery o ering a collection of e cient algorithms that can capture and adapt themselves to several characteristics of the data sets ranging from data density, domain constraints, and privacy requirements.

*WebDigger*: an environment for intelligent analysis of Web data (2002-2003). Funded by the Fondazione Cassa di Risparmio di Pisa. The project aims to develop an innovative Web Mining environment that help users in prototyping Web Mining applications. The research is conducted jointly by our research group and the HPC-lab of ISTI.

*KDNET*: Knowledge Discovery Network of Excellence. The KDNet is an open Network of participants from science, industry and public sector. The major purpose of this European initiative is to integrate real-life business problems into research discussions and to collaborate in shaping the future of Knowledge Discovery and Data Mining. Our Joint Lab is member.

*Dedugis*: (2000-2004) Esprit4-LTR project 27781, funded by EC. The main project objectives are : 1) to explicitly represent and reason with spatial uncertainty in systems, and 2) to integrate qualitative techniques, for dynamic spatial uncertainty handling and representation into state-of-the-art systems. The role of the reserach group is to evaluate which contributions for representing and reasoning on spatial uncertainty may come from Datalog based formalisms.

*Piattaforma abilitante complessa ad oggetti e ad alte prestazioni (2002-2004)*. Funded by Italian Ministry of Research (MIUR) The goal of the project is to integrate within an innovative High Performance platform web mining and web search functionalities.

*Progetto FIRB: Piattaforme abilitanti per griglie computazionali a elevate prestazioni orientate a organizzazioni virtuali scalabili (2003-2005)*. Funded by Italian Ministry of Research (MIUR). This basic research project regards enabling technologies for distributed high-performance Computational Grids, oriented to the development of complex multi-disciplinary applications and scalable Virtual Organizations in highly dynamic and heterogeneous contexts. The role of the Lab, is to adapt the KDDML-MQL environment into the services of the GRID infrastructure.

*SOCS*: (2002-2004) IST-2001-32530, funded by EC. The objectives are the investigation of computational and logical models for describing, analysing and verifying societies of logic based computational entities. The role of the research group is in the speci cation of interaction patterns and in the design of the reasoning capabilities and knowledge management. The scienti c coordinator of SOCS, Francesca Toni, is currently with our department, on leave from the Department of Computing of the Imperial COllege, London.

## Personnel and External Researchers

*Group leaders*: Franco Turini (Professor, Dip. di Informatica), Dino Pedreschi (Professor, Dip. di Informatica).

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## 2.21 Project: Architectures and Programming Tools for High Performance Computing

### Summary

The research group is involved in a set of research activities that all contribute to the \Architecture and programming tools for high performance computing" research track:

design and development of high performance, parallel programming environments supporting di erent structured parallel programming models (skeletons, coordination languages, components, shared memory, \mixed" models)

parallel run time/library/middleware design and implementation

methodologies and tools to achieve e cient parallelization of irregular problems

optimization techniques either exploiting statically available information or run time based

high performance cluster and network parallel and distributed computing, GRID computing

high performance data mining algorithms

Several researchers are involved in the activities concerning this project, the core group being constituted by M. Vanneschi, F. Baiardi, M. Danelutto, L. Ricci, M. Aldinucci, S. Campa, M. Coppola, P. Mori, C. Zoccolo.

## Background

Recent advances in parallel and distributed computing architectures made evident that there is a huge gap between the rough computing power available and the programming models and tools available to develop high performance applications on these architectures.

In the eld of programming models, advanced models (algorithmic skeletons, design patterns, components) are becoming more and more interesting and look like to be able to overcome traditional models (plain message passing or shared memory models as well as data parallel ones, such as HPF) in a short time. In the eld of compiling techniques, new techniques are being designed that take advantage of the knowledge relative to the underlying target architecture as well as of the knowledge derived from (structured) source code to produce highly optimized object code. Concerning run time supports, layered implementation techniques, frameworks and JIT techniques all provide e ective mechanisms and ways of implementing very e cient, portable and extensible run time supports for high performance programming environments. Last but not least, computing GRIDs introduced new problems, such as those related to heterogeneity and dynamicity that must be faced and solved in order to be able to take complete control (and advantage) of these new distributed architectures.

On the application side, irregular problems (Barnes Hut, Fast Multipole Method, Adaptive Multigrid Methods for the solution of partial di erential equations) pose several problems with respect to both memory constraint and completion time when uniprocessor architectures are considered. As a matter of fact, only parallel machines provide the computational power and

the main memory capacity required to solve such large scale problems. Due to the features of irregular problems, the parallel solutions based on the most common current high level parallel programming tools (like HPF or Open MP) achieve low e ciency, and low level tools, like MPI or a shared memory, are required, at the moment, to achieve reasonable performance. Therefore a standard parallelization methodology and or higher level programming tools are needed to cope with such irregular problems.

The research group is closely following the research activity in these elds and actually, most of the members are involved in research activity concerning some of these topics. Group members have been and currently are responsible of di erent activities in several national research projects, either as national coordinators or as responsible of project work-packages involving di erent university, national research council and industrial partners. In particular, M. Vanneschi is the coordinator of a big national FIRB project (GRID.it) that involves many national research institutions and has European visibility.

## Ongoing research

The group has recently been involved in the national research project ASI-PQE2000 *Earth observation application development with High Performance Computing Tools* (a project co-funded by Italian National Space Agency and Italian National Research Council) that led to the development of ASSIST (*A Software development System based on Integrated Skeleton Technology*). ASSIST is a research framework aiming at providing the user with a high performance, structured parallel programming environment based on the skeleton-coordination concepts. In the meanwhile, ASSIST is intended to be an experimental testbed for di erent techniques and concepts related to structured parallel programming environments design and implementation. The rst version of the environment includes a skeleton based coordination language (ASSIST-cl), a compiler producing code for CLAM (the Coordination Language Abstract Machine) and a version of CLAM running on top of plain TCP/IP cluster/network of workstations. This ASSIST release has been conceived, designed and implemented exploiting object oriented and design pattern techniques in such a way that most of the features sported by the environment can easily be reimplemented in di erent, possibly more e cient, ways, without a ecting the overall ASSIST design, if such new techniques

will become available. Furthermore, a layered implementation of ASSIST run time support allows new features to be introduced, again without a ecting the overall ASSIST design.

At the moment, the group is involved in several national projects that build on the ASSIST experience to achieve new goals:

within the Italian National Research Council *1999 Strategic project* \E-science enabling technologies and applications" and, in particular, within the subtopic \Structured programming environment for GRID computing" the feasibility a GRID port of ASSIST is being investigated. The high structuring of source code achieved by using ASSIST-cl in conjunction with the design of the ASSIST run time support have already been demonstrated to the suitable for targeting GLOBUS-like GRID environments

within the National Research Council project *2000 Strategic project* \Enabling platforms based on distributed objects for ICT" and, in particular, within the subtask *Portable programming environment based on parallel components* the aspects related to interoperability and components are investigated

within the Italian National Research Council *FIRB* project GRID.it *Enabling platforms for high-performance computational grids oriented to scalable virtual organizations*, the concepts of ASSIST will be used to design a prototype parallel programming environment that suitable to develop testbed multidisciplinary high performance applications on a range of parallel architectures including workstation networks and clusters and Grid.

within the *SAIB* project, funded by the industrial partner S.E.M.A., the ASSIST technology will be used to develop an high performance programming environment suitable to develop industrial quality high performance data mining applications prototypes as well as a prototype of a User Modeler Server based on parallel data mining technology.

Besides this main research line, group members are involved in di erent other activities, that all contribute to the project mentioned. In particular:

parallelization methodology to be applied to irregular problems are studied. In particular, our approach, is based on the hierarchical representation of the domain and de nes three main strategy: a strategy to map the elements of the domain onto the processing nodes of the parallel architecture, a strategy to update the mapping during the computation to equally distribute the computational load among the processing nodes, and a strategy to collect elements that have been mapped onto remote nodes In this context, members of the group are developing a software tool that implements the strategies de ned by the methodology. The sequential irregular application represents the elements distribution in the domain through a tree, and the computation is based on operations on this tree. Our software support distributes the tree among the local memories of the processing nodes, and implements the operations on the tree, hiding to the user all the details of the tree mapping and of the communications among the processing nodes.

distributed shared memory supports have been developed on top of the plain TCP/IP protocol stack, aimed at providing facilities to either further layers of basic/middle-ware software or to structured parallel programming languages compiler back-ends. Some of the tools developed (or under development in the group) allow seamless access to distributed shared data structures from plain C in the context of POSIX workstation clusters

di erent parallel implementations of di erent data mining algorithms and techniques have been designed, implemented and tested on architectures ranging from clusters to MPP

di erent libraries have been designed providing skeleton support within traditional sequential programming environments (Java, C, C+MPI)

proper tools have been designed and developed to help programmers in the development of e cient parallel applications with structured parallel programming languages such as those derived from skeletons

### Short term plans and expected results

The group is currently involved in di erent projects, as mentioned above and in preparing trials concerning programming environments for GRID for di erent European research projects. The expected results of these projects (most spanning over one to three years) include:

assessment of the techniques used in the design of the ASSIST run time support targeting workstation networks and clusters, and development of new, more e cient implementation techniques concerning some particular aspects of the ASSIST environment that are not completely satisfactory in the current status

implementation and deployment of a prototype structured parallel programming environment targeting the GRID architectures, exploiting all the power typical of these environments while accurately dealing with all the heterogeneity and dynamicity aspects of GRIDs

development of a component based parallel programming framework suitable to support multidisciplinary, high performance applications, while guaranteeing wide software reuse and interoperability capabilities

### Long term plans

The group long term plans include a set of activities aimed at investigating how new methodologies and techniques, often coming from di erent, separate research areas, can be exploited to support parallel programming environments more and more user friendly as well as more and more performant. Such methodologies and techniques include hardware stu (PIM (processors in memory), networking technologies, memory hierarchy/NUMA models) as well as software stu (parallel design patterns, components, frameworks, PSE, Web Services, GRID middle-ware, Peer-to-peer technology).

Still the group goal in the long term can be summarized as \development of methodologies and tools supporting user friendly high performance application development".

## Group members

Marco Vanneschi (full professor, group leader), F. Baiardi, M. Danelutto (associate professors), L. Ricci (research assistant), S. Campa, C. Zoccolo, P. Mori (PhD Students), M. Aldinucci, M. Coppola (research associates), P. Ciullo, S. Magini, A. Paternesi, P. Pesciullesi, A. Petroccelli, E. Pistoletti, L. Potiti, R. Ravazzolo, M. Torquati, P. Vitale (research fellows).

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# 3 Programs of Study

Since 1969 the University of Pisa has been in a strong position for teaching Computer Science. Pisa o ers three levels of studies in Computer Science; two three-years undergraduate program of studies (\Laurea in in Informatica" and \Laurea in in Informatica Applicata"), three ve-years undergraduate program (\Laurea Specialistica in Informatica" \Laurea Specialistica in Tecnologie Informatiche" \Laurea Specialistica in Informatica per l'Economia e per l'Azienda") and a graduate program (\Dottorato in Informatica").

## 3.1 Undergraduate Curricula (Laurea and Laurea specialistica)

### 3.1.1 Introduction

In 1969 the University of Pisa started a four-years program leading to the \Laurea in Scienze dell'Informazione" (Laurea Degree in Information Science). It was the rst program of its kind in Italy and, afterwards, it was replicated in several other universities.

The course was aimed at providing students with a strong scienti c background in computer science and with extensive technical skills for designing computer based systems. So far, thousands of students graduated in this curriculum, who have found employment in research, computer manufacturing companies, software houses, and public and private administrations. In the last few years the number of new enrollments in the programme ranged from around three to four hundred per year.

In 1986, an undergraduate school o ering a two year undergraduate of studies program in Computer Science (\Diploma della Scuola a Fini Speciali in Informatica") was launched. The program was intended as a terminal professional degree to emphasize practical system building experience.

Starting from the academic year 1993/94, the program of studies has been completely restructured, with the introduction of two levels of undergraduate curricula, aimed to two di erent degrees, called \Diploma Universitario in Informatica" and \Laurea in Informatica", roughly equivalent to B.S. and M.S in Computer Science, according to international standards.

In the academic year 2001/02, the programs of studies were completely re-

designed, according to the italian law. A three-years undergraduate program (\Laurea") started, together with and a ve-years undergraduate program (\Laurea specialistica"). The Laurea Specialistica degree can be obtained, after the Laurea degree, by two more years of studies.

The curriculum for the Laurea is organized in a rst period of two years, devoted to basic studies in Computer Science, Mathematics and Computer Laboratories; and a third year focused on high-level professional training, in which theoretical knowledge complements the know-how necessary for professional activity.

Teaching is given in two semesters. The rst from October to mid December, the second from mid February to mid of May. There are three examinations periods: one at the end of the rst semester, the second at the end of the second semester, and the third in September. Courses can give di erent credits (in ECTS standard).

### 3.1.2 The Laurea degree

#### Laurea in Informatica

*First year*
Mathematical Analysis, 8 credits
Language and Methods of Mathematics, 6 credits
Programming Foundations, 9 credits
Algebra, 6 credits
Physics, 6 credits
Programming Methodologies, 6 credits
Laboratory of Introduction to Programming, 4 credits
Laboratory of Programming of Data Structures, 4 credits
English Language, 3 credits
Elective courses on professional issues, 6 credits

*Second year*
Computer Architecture, 10 credits
Operating Systems, 6 credits
Algorithms, 6 credits
Numerical Calculus, 6 credits
Probability and Statistics, 6 credits

Operation Research, 6 credits
Laboratory of Concurrent Programming, 4 credits
Laboratory of System Programming, 6 credits
Elective courses, 9 credits

*Third year*
Computer Networks, 6 credits
Databases, 6 credits
Software Engineering, 6 credits
Laboratory of Network Programming, 6 credits
Elective courses in Computer Science, 18 credits
To ful ll the requirements for the Laurea, a student must present a project developed under practical training in a company or other institution, under the supervision of an internal supervisor and an external tutor.

#### Laurea in Informatica Applicata

The Laurea is oriented to Computer Science and Logistics. It di ers from the Laurea in Informatica essentially because the elective courses are substituted by courses related to simulation, logistics and economics, such as:
Simulation and Logistics, 9 credits
Economics of marine transportations, 6 credits
Integrated logistics, 9 credits

### 3.1.3 Lauree specialistiche

The Laurea specialistica degree requires two more years of studies after the Laurea.

#### Laurea specialistica in Informatica

The curriculum of the Laurea specialistica in Informatica is quite general. It is organized in basic courses and elective courses.
*Basic courses*:
User Interface Constructions, 9 credits
Intelligent Systems, 6 credits

Speci cation and proof techniques, 6 credits
Computability and Complexity, 9 credits
Compilers, 6 credits
Programming Languages, 6 credits
*Two courses among the following ones*:
Combinatorial Optimization, 6 credits
Computational Mathematics, 6 credits
Physics Models, 6 credits
*Elective courses*: 42 credits

To ful ll the requirements for the Laurea specialistica in Informatica, a student must present an original thesis developed under a supervisor.

### Laurea specialistica in Tecnologie Informatiche

The curriculum of the Laurea specialistica in Tecnologie Informatiche is oriented to technology. It is organized around several di erent areas. A group of basic courses is common to all the areas; other courses are speci c for each area; others are elective.
*Basic courses*:
User Interface Constructions, 9 credits
Intelligent Systems, 6 credits
Advanced Programming, 12 credits
Parallel and Distributed Architectures, 9 credits
Programming Languages and Computability, 6 credits
*Two courses among the following ones*:
Combinatorial Optimization, 6 credits
Computational Mathematics, 6 credits
Physics Models, 6 credits
Telecommunications, 6 credits

The proposed areas are presently the following:

High Performance Computing Platforms
Databases and Information Systems
Interaction and Communication
Programming Technologies and Languages

Intelligent Systems

To ful ll the requirements for the Laurea specialistica in Tecnologie Informatiche, a student must present an original thesis developed under a supervisor.

### Laurea specialistica in Informatica per l'Economia e per l'Azienda

The curriculum of the Laurea specialistica in Informatica per l'Economia e per l'Azienda concentrates on information sciences and the integration of this discipline with various applications within economics. This integration is crucial for several activities. Consider, for example, distributed systems for stock management, for recording and settlement of ( nancial and other) transactions, e-marketing, work- ow management, information provision, planning and logistics, decision-support activities, etc.
*Basic courses*:
Political Economics, 10 credits
Company Economics, 10 credits
Statistics, 5 credits
*Courses in the following areas*, 35 credits:
Company economics
Economics
Jurisprudence
Computer Science
*Elective courses in Computer Science*, 15 credits

To ful ll the requirements for the Laurea specialistica in Informatica per l'Economia e per l'Azienda, a student must present an original thesis developed under a supervisor.

## 3.1.4 Sta

Roberto Barbuti is the Coordinator of the Laurea programs. Presently Roberto Barbuti is also coordinator of the Laurea specialistica in Informatica and Laurea specialistica in Tecnologie Informatiche. Antonio Albano is the Coordinator of the Laurea specialistica in Informatica per l'Economia e per l'Azienda. Ms Rosaria Mongini and Mr Enrico Carpentras are the secretaries

of the curricula in CS. Dr Maria Elisa Carboni is the teaching manager of the curricula.

The Board of Study includes the following members. *Full Professors*: Albano, Ambriola, Attardi, Barbuti, Boerger, Bonuccelli, Capovani, Degano, Gallo, Germano, Ghelli, Levi, Luccio, Maestrini, Maggiolo{Schettini, Montanari, Montangero, Pagli, Pallottino, Pedreschi, Romani, Starita, Turini, Vanneschi. *Associate Professors*: Baiardi, Barcaro, Bellia, Bevilacqua, Brogi, Corradini, Cazzaniga, Danelutto, Ferragina, Ferrari, Grossi, Guerrini, Leoni, Mancarella, Masulli, Menchi, Morreale, Pelagatti, Scutella, Simi. *Assistant Professors*: Bernasconi, Bigi, Bodei, Bozzo, Bruni, Chessa, Ciu oletti, Del Corso, Di Pierro, Frangioni, Gadducci, Gervasi, Gori, Lagana, Marangoni, Mole, Piram, Ricci, Ruggieri, Scozzari, Semini, Spadafora.

### 3.1.5 Laurea in Informatica Umanistica

The Department is also actively involved in the\Laurea in Informatica Umanistic", active since the academic year 2002/03 under the Faculty of Letters and Philosophy.

The curriculum aims at providing a solid culture in the literary, linguistic, storic, geographic and artistic elds, together with a good level of competence in computer science. Graduates should be able to autonomously apply computer science methods and tools to the processing of languages, texts, images and cultural contents in general and to keep up with technological innovations.

Students are required to become uent in one of the languages of the European Union, besides Italian, and to acquire speci c skills in professional writing and communication.

The balance between the di erent disciplines is as follows: 25 credits in Italian literature and linguistics; 45 credits in Latin, philology, glottology, foreign literature, history; 20 credits in history of arts, geography; 50 credits in computer science.

A nal project consists in producing humanities content in the most appropriate electronic form.

### 3.1.6 Laurea in Scienze per la Pace

The Department is also involved in the\Laurea in Scienze per la Pace", an interfaculty programme active since the academic year 2001/02.

The curriculum aims at providing the graduates with the basic methodological tools and the cultural background needed to operate in sectors such as Mediation and Conciliation, International Cooperation, Non-pro t Organizations and Con ict Transformation. The need to operate in situations characterized by con icts and high levels of complexity requires a interdisciplinary approach, and, in fact, the teaching covers areas as di erent as Law, Science, Humanities and Economy.

The balance between the di erent disciplines is roughly as follows: 30 credits in law studies; 52 credits in antropology, psycology, sociology, history and geography; 20 credits in economy; 34 credits in sciences, mathematics, statistics and computer science.

Students are required to become uent in one of the languages of the European Union, besides Italian.

An internship in an organization operating in one the sectors of interest for the programme is required. The internship, which in some cases may include a period of work abroad, is performed under the supervision of an internal supervisor and an external tutor.

## 3.2 Graduate Program

### 3.2.1 Introduction

The Department has a three-year Ph.D. program in Computer Science. Ten to fteen students are admitted each year. The competition is open both to Italian and to foreign citizens. Usually the University of Pisa o ers ve studentships which also cover the annual fee of about 1000 dollars. Additional studentships are o ered by the School for Graduate Studies \Galileo Galilei"(see below). Research founding for students is provided by the research groups and projects they choose to participate in. The Ph.D. program participates in the Italian Partnership (IP) of Ph.D. programs in Computer Science, a liated to the European Educational Forum (EEF) supported by the EC to organize advanced schools. With the sponsorship of the EEF, IP organizes the International Spring School for Graduate Studies in Computer Science, which is held every year in March at Bertinoro. Information on EEF is at the site http://www.win.tue.nl/EEF/ and on IP at the site http://www.di.unito.it/ lambda/ip.html.

### 3.2.2 The Study Program

Students must have an Italian laurea or the university degree equivalent of an M.Sc. degree, in order to apply. Foreign applicants must provide full documentation of their university studies, including course pro les. The deadline for application is about October 15th. Rules for application and forms may be found on the web site: http://www.unipi.it/dottorati. The admission examination takes place around November and requires a general knowledge of computer science theory and applications, together with a deeper knowledge of some advanced research topics in computer science. English may be chosen as the language for the examination.

The admission examination consists in a written and an ora1 part. The aim of the written part is the evaluation of the capabilities of the candidate as regards analysis and synthesis, problem formalization, knowledge of the basics of computer science. This should be achieved by requiring the solution of at least three of a number of exercises which are proposed and which cover the spectrum of disciplines of interest for the school, plus a short dissertation on a research subject in computer science chosen by the candidate. The aim of the oral part of the examination is the evaluation of the attitude of the

candidate to do research.

Foreign students who are not resident in Italy and possess a university degree equivalent to an M.Sc. degree granted by a foreign university, may be admitted on the basis of the documentation presented. Students admitted and who do not have any nacial support (e.g. from their own countries or from the Italian Ministry for Foreign A airs) are eligible for special studentships made available by the School \Galileo Galilei". The deadline for applications is about July 15th. Rules for application and forms are at the site: http://www.unipi.it/dottorati/bandostranieri.htm.

Course requirement is of six credits, where a credit corresponds to a twenty hours course. Credits are acquired attending postgraduate courses offered either at the Department or in other departments and advanced schools, in Italy or abroad. Studentships of the University are increased to support study periods abroad.

A thesis proposal, supported by an academic advisor, is presented after one year. The nal thesis is due at the end of the three year period. An extension of one year is possible. The thesis, written in English, is reviewed by two international referees and published in a special report series of the Department.

### 3.2.3 Sta

Andrea Maggiolo Schettini, Professor of Computer Science, is the Coordinator of the Program.

The Board of Study includes the following members: A. Albano, G. Attardi, R. Barbuti, M. Bonuccelli, E. Boerger, A. Brogi, M. Capovani, P. Degano, P. Ferragina, G. Ferrari, G. Gallo, G. Ghelli, R. Grossi, G. Levi, F. Luccio, P. Maestrini, A. Maggiolo Schettini, U. Montanari, C. Montangero, L. Pagli, D. Pedreschi, A. Starita, F. Turini, and M. Vanneschi.

### 3.2.4 The School for Graduate Studies \Galileo Galilei"

The School for Graduate Studies \Galileo Galilei" is an advanced educational centre open to Italian and foreign students. Its main objective is to train highly quali ed Ph.D. students in Chemical Sciences, Computer Science, Physics, Applied Physics, and Mathematics. The School aims at promoting the exchange of experience on scienti c, cultural, and social grounds between

the individual Ph. D. programs, so as to strengthen their educational impact. The tradition of the ve graduate programs already in existence was to welcome the best students from all over Italy and from abroad. In order to attract graduates from other Italian and foreign universities even more e ectively, the School o ers special studentships for them. More information on the School can be found at the site http://www.di.unipi.it/galilei/.

# A Administrative Organization

The Department of Computer Science was established in 1982 by transforming the \Istituto di Scienze dell'informazione" established in Pisa in 1969. The Department pursues research in computer science, and has responsibility for all undergraduate and postgraduate courses in computer science given in the Science Faculty.

The chairman of the department is responsible to the Chancellor, who is also the Chairman of the Administrative Council, for the administration of the department. The chairman is, as well, responsible for preparing the department budget. He is a professor elected by the members of the department and his appointment as chairman is for a period of three years, which can be renewed at most once. The present chairman, Ugo Montanari, was appointed in October 2002.

In addition to the responsibility for the administration of the department, the chairman is expected to act as spokesman for the department, and, in collaboration with the Department Board, to provide initiative for the evolution of the department, to encourage research and teaching activities, and so on.

The Department Board, headed by the chairman, is elected every 4 years and consists of 2 professors, 2 associate professors, 2 assistant professors, the Associate Chairman, 1 representative of the technical-administrative sta and the administrative secretary. The main purpose of the Department Board is to assist and advise the chairman in the management of the department. The current members of the Department Board are: U. Montanari, C, Montangero, R. Barbuti, F. Turini, M. Simi, M. Danelutto, A. Frangioni, E. Bozzo, L. Petrellese and the administrative secretary, P. Fabiani.

The Department Council, headed by the chairman, consists of all the members of the department. The main purpose of the Department Council is to determine department policy. The Department Council takes decisions about the annual budget, discusses and takes appropriate action on research and equipment strategy both for didactic and for research purposes. The undergraduate and postgraduate programs in computer science have their own councils which decide on programs and activities but rely on the department for founding.

A synthesis of the department nal balance sheet for the scal year 2002 is shown in table 1. In table 2 the primary revenues of 2002 are compared to

| *Revenues* | | *Expenses* | |
|---|---|---|---|
| Initial cash fund | 680 749,00 | General expenses | 226 433,00 |
| Incomes | 3 479 901,00 | Didactic exp. | 210 571,00 |
| | | Research exp. | 2 310 553,00 |
| | | Other exp. | 105 010,00 |
| | | Final cash found | 1 308 083,00 |
| | 4 160 650,00 | | 4 160 650,00 |

Table 1: A synthesis of the department nal balance sheet for the scal year 2002. Entries are Euro.

| | *2003* | *2002* |
|---|---|---|
| University funding for: | | |
| laboratory | 88 392,00 | 69 675,00 |
| administration (funzionamento) | 130 725,00 | 167 466,00 |
| graduate education | 24 832,00 | 31 594,00 |
| teaching | 56 872,00 | 264 538,00 |
| International relations | 30 372,00 | 29 325,00 |
| MIUR | 174 600,00 | 405 140,00 |
| Private companies (c/terzi) | 1 286 401,00 | 945 662,00 |
| EU | 204 951,00 | 525 123,00 |
| CNR | 259 262,00 | 137 299,00 |
| Donations | 59 007,00 | 12 912,00 |

Table 2: Main sources of founding.

those of 2001.

The University provides resources for undergraduate education (laboratory and library) and resources for postgraduate education.

The research activities are heavily dependent on external sources, where private companies and Commission of the European Union, CEU, are the main contributors. Additional funds are provided by the Italian Government, MIUR, and the National Research Council, CNR.

*Department Leadership*

Ugo Montanari, Chairman
Carlo Montangero, Associate Chairman
Andrea Maggiolo, Chairman of PhD Courses Board
Roberto Barbuti, Chairman of Undergraduate Courses Board
Marco Danelutto, Director of Computing Services

*Administrative-Technical o ces*

Paola Fabiani, Administrative Manager
Isa Carpita, Administrative Assistant
Letizia Petrellese, Secretary of Director
Rita Cantini, Administrative O cer
Claudia Giorgetti, Administrative O cer
Marilisa Carboni, Undergraduate Program Manager
Rosaria Mongini, Undergraduate Program Coordinator
Enrico Carpentras, Undergraduate O cer

Paolo Rosellini, Telephone Operator
Sandra Berti, Telephone Operator
Luigi Salzano, Telephone Operator

Edi Barea, Computer Systems, Operator
Anna Bertanza, Computer Systems, Technical Sta
Ruggero Giordano, Computer Systems, Technical Sta
Rebecca Micheletti, Computer Systems, Technical Sta
Roberto Puccetti, Computer Systems, Technical Sta
Laura Redini, Computer Systems, Technical Sta
Antonio Fernando Zoglio, Web Services, Technical Sta
Luca Francesconi, Computer Systems, System Administrator
Dario Besseghini, Computer Systems, System Administrator

# B Publications

## External publications since 2001
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05/99 Marco Pistore, History Dependent Automata.

06/99 Salvatore Ruggieri, Veri cation and Validation of Logic Programs.

01/00 Paolo Baldan, Modeling concurrent computations: from Contextual Petri Nets to Graph Grammars.

02/00 Chiara Bodei, Security Issues in Process Calculi.

03/00 Vincenzo Gervasi, Environment Support for Requirements Writing and Analysis.

04/00 Rene Moreno, A Semantic Framework for Analysis and Veri cation of Concurrent Constraint Programs.

05/00 Alessandra Ra aeta, Spatio-temporal Knowledge Bases in a Constraint Logic Programming Framework with Multiple Theories.

06/00 Paolo Santi, Evaluation of a Fault Diagnosis Algorithm for Regular Structures.

07/00 Nicola Fausto Spoto, Analysis of Logic Programs through Linear Re nement.

08/00 Simone Tini, Structural Operational Semantics for Synchronous Languages.

09/00 Andrea Zavanella, Skeletons and BSP: Performance Portability for Parallel Programming.

01/01 Gianluca Amato, Sequent Calculi and Indexed Categories as a Foundation for Logic Programming.

02/01 Stefano Bistarelli, Soft Constraint Solving and Programming: A General Framework.

03/01 Giuseppe Manco, Foundations of a Logic-Based Framework for Intelligent Data Analysis.

04/01 Paolo Manghi, Extracting Typed Values from Semistructured Databases.

01/02 Sergio Di Bona, Analysis and Understanding of Deformable 3D Images.

02/02 Davide Marchignoli, Natural Deduction Systems for Temporal Logics.

03/02 Nadia Pisanti, Segment-based Distances and Similarities in Genomic Sequences.

04/02 Giuseppe Prencipe, Distributed Coordination of a Set of Autonomous Mobile Robots.

05/02 Massimo Coppola, Structured Parallel Programming Support to Data Mining Problems.

06/02 Ernesto Lastres, A Semantic framework for Hereditary Harrop Formulas based on Abstract Interpretation.

07/02 Mirco Nanni, Clustering Methods for Spatio-temporal Data.

08/02 Diego Sona, A Proposal for a Neural Abstract Machine.

01/03 Valentina Ciriani, Three{Level Logic Synthesis: Algebraic Approach and Minimization Algorithms.

02/03 Ruggero lanotte, An Automaton-theoretic Approach to Safety and Security in Real-time Systems.

03/03 Andrea Bracciali, Behavioral Patterns and Software Composition.

04/03 Antonio Caruso, Diagnosability of Regular Structures.

05/03 Antonio Cisternino, Multi{stage and Meta{programming Support in Strongly Typed Execution Systems.

06/03 Amjad Hudaib, Formal Description of Software Architecture patterns: The Asynchronous Case.

07/03 Marco Tarini, Advanced Techniques of Rendering-oriented 3D Acquisition.

08/03 Emilio Tuosto, Non{functional Aspects of Wide Area Network Programming.

09/03 Marco Aldinucci, Dynamic Shared Data in Structured Parallel Programming Frameworks.

10/03 Francesco Bonchi, Frequent Patterns Query: Language and Optimizations.

11/03 Leporini Barbara, Usability Evaluation of Accessible Web Sites.

12/03 Marchetti Eda, Software Testing in the XXI century: Methods, Tools and New Approaches to Manage, Control and Evaluate This Critical Phase.

13/03 Micheli Alessio, Recursive Processing of Structured Domains in Machine Learning.

14/03 Mori Paolo, Solving Irregular Problems on Parallel Architectures: A Methodology and a Supporting Library.

15/03 Sartiani Carlo, E cient Management of Semistructured XML Data.

Abstracts and postscript versions of the theses can be found on the website

**http://www.di.unipi.it/phd/**.

Paper copies of Doctorate Theses can be requested free of charge to

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Tel. +39 050 2213302
Fax. +39 050 2213256
E-mail: ammannati@dm.unipi.it

# D Department Technical Reports 2003

1. TR-03-01 Luzi, A.; Cieliebak, M.; Prencipe G. \The Weber Point can be Found in Linear Time for Points in Biangular Con guration" January 12, 2003

2. TR-03-02 Pisanti, N.; Crochemore, M.; Grossi, R.; Sagot, M.-. \Bases of Motifs for Generating Repeated Patterns with Don't Cares" January 24, 2003

3. TR-03-03 Franceschini, G.; Grossi, R. \Optimal Space-Time Dictionaries over an Unbounded Universe with Flat Implicit Trees" January 30, 2003

4. TR-03-04 Hammer, B.; Micheli, A.; Sperduti, A. \A General Framework for Self-Organizing Structure Processing Neural Networks" February 14, 2003

5. TR-03-05 Ambriola, V.; Gervasi, V. \The Circe approach to the systematic analysis of NL requirements" March 14, 2003

6. TR-03-06 Franceschini, G. \An in-place sorting algorithm performing $\boldsymbol{O}(\boldsymbol{n}\log\boldsymbol{n})$ comparisons and $\boldsymbol{O}(\boldsymbol{n})$ data moves" March 17, 2003

7. TR-03-07 Frangioni, A.; Manca, A. \A Computational Study of Cost Reoptimization for Min Cost Flow Problems" March 18, 2003

8. TR-03-08 Ferrari G.; Montangero C.; Semini L.; Semprini S. \The Mob-adtl Model and Method to Design Network Aware Applications" June 13, 2003

9. TR-03-09 Romani, F. \MAJA: Matrix Computation in Java" June 18, 2003

10. TR-03-10 Ferragina, P.; Manzini, G. \Optimal compression boosting in optimal linear time using the Burrows-Wheeler Trasform", July 03, 2003

11. TR-03-11 Ghelli, G.; Conforti, G. \Decidability of Freshness, Undecidability of Revelation" July 24, 2003

12. TR-03-12 Bevilacqua, R.; Del Corso, G.M. \Existence, Uniqueness and Algorithms for Matrix Unitary Reduction to Semiseparable Form" July 23, 2003

13. TR-03-13 Dell'Olmo, P.; Hansen, P., Pallottino, S., Storchi, G. \On uniform $\boldsymbol{k}$-partition problems" August 26, 2003

14. TR-03-14 Gentile, G.; Nguyen, S.; Pallottino, S. \Route choice on transit networks with on-line information at stops" November 03, 2003

15. TR-03-15 Pallottino, S.; Sechi, G. M.; Zuddas, P. \A DSS for Water Resources Management Under Uncertainty by Scenario Analysis" December 23, 2003

16. TR-03-16 Baldan, P.; Bracciali, A.; Bruni, R. \Symbolic Equivalences for Open Systems" December 31, 2003

17. TR-03-17 Billi, C.; Gentile, G.; Nguyen, S.; Pallottino, S. \Ripensando all'attesa alle fermate" December 23, 2003

Technical Reports published after 1995 can be consulted on WWW at

**http://www.di.unipi.it/ricerca/TR/tr.html**

Paper copies of Doctorate Theses and Technical Reports can be requested to

Biblioteca di Matematica Informatica Fisica
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56127 Pisa, Italy
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Fax. +39 050 2213256

# E Faculty { Research Areas

## Professors

| | |
|---|---|
| Antonio Albano | Databases and Information Retrieval |
| Vincenzo Ambriola | Software Methodology and Engineering |
| Giuseppe Attardi | Arti cial Intelligence and Robotics |
| Roberto Barbuti (Laurea and Laurea Specialistica Co-ordinator) | Programming Languages |
| Maurizio Bonuccelli | Computer Networks |
| Egon Borger | Software Methodology and Engineering |
| Milvio Capovani | Computational Mathematics |
| Pierpaolo Degano | Programming Languages |
| Giorgio Gallo | Operations Research |
| Giorgio Germano | Algorithms and Data Structures |
| Giorgio Ghelli | Databases and Information Retrieval |
| Giorgio Levi | Programming Languages |
| Fabrizio Luccio | Algorithms and Data Structures |
| Piero Maestrini | Computer Networks |
| Andrea Maggiolo-Schettini (Dottorato Co-ordinator) | Programming Languages |
| Ugo Montanari (Chairman) | Programming Languages |
| Carlo Montangero (Associate Chairman) | Software Methodology and Engineering |
| Linda Pagli | Algorithms and Data Structures |
| Stefano Pallottino | Operations Research |
| Dino Pedreschi | Programming Languages |
| Francesco Romani | Computational Mathematics |
| Antonina Starita | Arti cial Intelligence and Robotics |
| Franco Turini | Programming Languages |
| Marco Vanneschi | Computer Architecture |

## Associate Professors

| | |
|---|---|
| Fabrizio Baiardi | Computer Architecture |
| Umberto Barcaro | Arti cial Intelligence and Robotics |

| | |
|---|---|
| Marco Bellia | Programming Languages |
| Roberto Bevilacqua | Computational Mathematics |
| Antonio Brogi | Programming Languages |
| Andrea Corradini | Programming Languages |
| Marco Danelutto (Director Computing Services) | Computer Architecture |
| Paolo Ferragina | Algorithms and Data Structures |
| Gianluigi Ferrari | Programming Languages |
| Roberto Grossi | Algorithms and Data Structures |
| Giovanna Guerrini | Databases and Information Retrieval |
| Gualtiero Leoni | Databases and Information Retrieval |
| Paolo Mancarella | Programming Languages |
| Francesco Masulli | Arti cial Intelligence and Robotics |
| Ornella Menchi | Computational Mathematics |
| Eugenio Morreale | Arti cial Intelligence and Robotics |
| Susanna Pelagatti | Computer Networks |
| Maria Grazia Scutella | Operations Research |
| Maria Simi | Arti cial Intelligence and Robotics |
| Konstantinos Stathis | Programming Languages |
| Francesca Toni | Programming Languages |

Assistant Professors (Assistenti)

| | |
|---|---|
| Maria Rita Lagana | Learning and teaching through the new technologies |
| Francesco Mole | |
| Pietro Piram | |
| Ippolito Spadafora | |

Assistant Professors (Ricercatori)

| | |
|---|---|
| Anna Bernasconi | Algorithms and Data Structures |
| Giancarlo Bigi | Operations Research |
| Chiara Bodei | Programming Languages |
| Enrico Bozzo | Computational Mathematics |

| | |
|---|---|
| Roberto Bruni | Programming Languages |
| Amedeo Cappelli | Computational Linguistics |
| Stefano Chessa | Computer Networks |
| Augusto Ciu oletti | Computer Architecture |
| Gianna Del Corso | Computational Mathematics |
| Alessandra Di Pierro | Programming Languages |
| Antonio Frangioni | Operations Research |
| Fabio Gadducci | Programming Languages |
| Roberta Gori | Programming Languages |
| Roberto Marangoni | Computational biology |
| Laura Ricci | Computer Architecture |
| Salvatore Ruggieri | Programming Languages |
| Francesca Scozzari | Programming Languages |
| Laura Semini | Programming Languages |

*Assegnisti (Research fellowship holders)*

Paola Cappanera
Valentina Ciriani
Antonio Cisternino
Andrea Esuli
Vincenzo Gervasi
Ruggero Lanotte
Alessio Micheli
Paolo Manghi
Nadia Pisanti
Giuseppe Prencipe

## Graduate Students

| Student/Supervisor | Project/Research area |
|---|---|
| Dario Colazzo | Databases |
| *G. Ghelli* | |
| Fabio Aiolli | Arti cial Intelligence and Robotics |
| *A. Starita* | |
| Alessio Bacciardi | Computational Mathematics |

| | |
|---|---|
| *D. Bini* | |
| Alessandro Tommasi | Arti cial Intelligence and Robotics |
| *G. Attardi* | |
| Arwa Zabian | Computer Networks |
| *M. Bonuccelli* | |
| Luiz Albini | Computer Networks |
| *P. Maestrini* | |
| Rita Borgo | Computer Graphics |
| *C. Montani* | |
| Simone Semprini | Software Methodology and Engineering |
| *C. Montangero* | |
| Luca Tesei | Programming Languages |
| *R. Barbuti* | |
| Alessandro Urpi | Computer Architecture and Networking |
| *M. Bonuccelli* | |
| Giorgio Vecchiocattivi | Computational Mathematics |
| *M. Pellegrini* | |
| Miriam Baglioni | Databases |
| *F. Turini* | |
| Massimo Bartoletti | Programming Languages |
| *P. Degano* | |
| Sonia Campa | Computer Architecture and Networking |
| *M. Danelutto* | |
| Franco Cardillo | Arti cial Intelligence and Robotics |
| *A. Starita* | |
| Giovanni Conforti | Databases |
| *G. Ghelli* | |
| Michele Curti | Programming Languages |
| *P. Degano* | |
| Gianni Franceschini | Algorithms and Data Structures |
| *R. Grossi* | |
| Gaetano Impoco | Computer Graphics |
| *C. Montani* | |
| Francesca Martelli | Computer Networks |
| *M. Bonuccelli* | |
| Gaia Maselli | Computer Networks |

| | |
|---|---|
| *M. Bonuccelli* | |
| Hernan Melgratti | Programming Languages |
| *U. Montanari* | |
| Salvatore Rinzivillo | Databases |
| *F. Turini* | |
| Corrado Zoccolo | Computer Architecture and Networking |
| *M. Vanneschi* | |
| Maurizio Atzori | Databases |
| *P. Mancarella* | |
| Flavio Baronti | Arti cial Intelligence and Robotics |
| *A. Starita* | |
| Marco Callieri | Computer Graphics |
| *C. Montani* | |
| Stefano Cataudella | Programming Languages |
| *R. Barbuti* | |
| Antonio Gulli' | Algorithms |
| *P. Ferragina* | |
| Viorel Lucian Hancu | Arti cial Intelligence and Robotics |
| *G. Attardi* | |
| Yan He | Computer Networks |
| *S. Pelagatti* | |
| Ivan Lanese | Programming Languages |
| *U. Montanari* | |
| Claudia Sodini | Operations Research |
| *G. Gallo* | |
| Angelo Troina | Programming Languages |
| *A. Maggiolo Schettini* | |
| Daniela Tulone | Computer Networks |
| *M. Bonuccelli* | |
| Roberto Zunino | Programming Languages |
| *P. Degano* | |
| | |
| Byalynicka-Birula Iwona | Algorithms |
| *R. Grossi* | |
| Coletta Alessio | Programming Languages |

| | |
|---|---|
| *G. Levi* | |
| De Col Daniela | Databases |
| *F. Turini* | |
| Lonetti Francesca | Computer Networks |
| *M. Bonuccelli* | |
| Milazzo Paolo | Programming Languages |
| *A. Maggiolo Schettini* | |
| Passaro Alessandro | Arti cial Intelligence |
| *A. Starita* | |
| Popescu Razvan-Andrei | Programming Languages |
| *A. Brogi* | |
| Puppin Diego | Computer Architectures |
| *M. Vanneschi* | |
| Scordino Claudio | |
| Terreni Giacomo | Programming Languages |
| *P. Mancarella* | |

# F Seminars 2003

Andrea Bracciali (Dipartimento di Informatica). *Bisimulation by Unification*. Feb. 2003.

Vladimiro Sassone (COGS, University of Sussex, Brighton UK). *Deriving bisimulation congruences: A 2 categorical approach*. Feb. 2003.

Roberto Di Cosmo (PPS Paris VII and INRIA Roquencourt) *Free Software: the reasons of a success*. Feb. 2003.

Alessio Guglielmi (Technische Universitaet Dresden). *Deep Inference*. March 2003.

Maxime Crochemore (Marne-la-Vallee) and Marie-France Sagot (INRIA). *Algorithms for Pattern Discovery and Searching in Sequences*. March 2003.

Erik Meijer (Microsoft Research). *X# Overview: Unifying the Object-Oriented, Relational and Hierarchical Data Models*. April 2003.

Erik Meijer (Microsoft Research). *What's in CLR 2? (Generics and other)*. April 2003.

Simone Montangero (Scuola Normale Superiore, Pisa). *Experimental quantum computer implementations: successes and open problems*. April 2003.

Alina Kmiecik (Department of Computer Science, Technical University of Lodz (Poland)). *Architectural transformations*. May 2003.

Giuseppe Longo (Ecole Normale Suprieure, Parigi) *L'intelligibilit dello spazio, il continuo e le teorie della conoscenza*. May 2003. Presso Aula Magna del Dipartimento di Matematica \L. Tonelli".

Domenico Laforenza (ISTI-CNR, Pisa) *Introduzione al GRID. Il Globus Toolkit, i processi di standardizzazione nel mondo ed in Europa*. May 2003.

Catherine Canevet (Laboratory for Foundations of Computer Science, University of Edinburgh) *Performance Modelling with the UML*. May 2003.

Marco Danelutto (Dipartimento di Informatica) *Pathology of the GRID: ovvero Modelli di programmazione per griglie*. May 2003.

Richard Banach (University of Manchester) *Retrenchment: Motivations and Prospects*. May 2003.

Jan Jurjens (Department of Informatics, TU Munich) *Secure Systems Analysis with UML*. May 2003.

Domenico Talia (Univ. della Calabria). *Distributed Knowledge Discovery on Grids: An Architecture and Tools*. June 2003.

Divesh Srivastava (AT&T Labs-Research) *Phrase Matching in XML*. June 2003.

Andrew V. Goldberg (Microsoft Research) *A Practical Shortest Path Algorithm with Linear Expected Time*. June 2003.

Hatem Ben Amor (GERAD and Ecole Polytechnique Montreal) *Stabilized Column Generation and Applications*. July 2003.

Salvatore Orlando (Universita' di Venezia e ISTI-CNR). *Gestione delle risorse e scheduling in ambiente Grid*. July 2003.

Enrico Franconi (University of Manchester) *(Description) Logics for Information Modelling and Access { How to use an ontology*. July 2003

Enrico Nardelli (Universit dell'Aquila) *Sicurezza e certi cazione dei servizi su rete realizzati su griglie di calcolo*. July 2003

Antonio Brogi (Dipartimento di Informatica) *Software adaptation*. July 2003.

Nelson Maculan (Universidade Federal do Rio de Janeiro, COPPE - Programa de Engenharia de Sistemas e Computaccao, Politecnico di

Milano, Dipartimento di Elettronica e Informazione) *Integer programming formulations with polynomial number of constraints and variables for combinatorial optimization problem in graphs* . July 2003.

Ernesto Pimentel (Universita di Malaga, Spagna) *Formal mehods and software engineering.* July 2003.

Carlos Canal (Universita di Malaga, Spagna) *Software architectures, patterns and frameworks.* July 2003.

Johan Natt och Dag (Software Engineering Research Group, Department of Communication Systems, Lund Institute of Technology) *Continuously Managing Large Amounts of Requirements: Finding Support through Linguistic Analysis.* July 2003.

Dino Mandrioli (Dipartimento di Elettronica e Informazione del Politecnico di Milano) *Il tempo nei modelli informatici: considerazioni, analisi, proposte* Nov. 2003.

Angelo Gargantini (Dipartimento di Matematica ed Informatica, Universita di Catania). *Metamodelling ASM in practice: an ASM test generator*. Nov. 2003.

Elvinia Riccobene (Dipartimento di Matematica ed Informatica, Universita di Catania). *Towards an Interchange Language for ASM* Nov. 2003.

Mikael Buchholtz (Technical University of Denmark). *Control Flow Analysis for Security Protocols*. Dec. 2003.

Martin Davis (Prof. Emeritus at University of California at Berkeley). *The Myth of Hypercomputation*. Dec. 2003.

Bolzoni, Borger, Romani (Scuola Normale Superiore, Dipartimento di Informatica). *Informatica e civilta: logica, tecnologia e sapienza*. Dec. 2003.

# G Visiting academics and students 2003

The following academics have visited the department during 2003 : Publio Suarez Sotomonte, Maurice Ter Beek, Jim Lipton, Alessio Guglielmi, Paola Quaglia, Markus Hagenbuchner, Rene Moreno, Nguyen Sang, Adrian Nicolae Carcu, Maria Teresa Gomes Chao, Maxime Crochemore, Marie-France Sagot, Philippa Gardner, Luciano Garcia, Flavio Morais Assis Silva, Kai Brunnler, Roberto Di Cosmo, Ernesto Pimentel, Catherine Canevet, Magnus Johansson, Jan Jurjens, Mikael Buchholtz, Joshua Guttman, Carlos Canal, Barbara Hammer, Roberto Iannett, Thom Fruehwirth, Leila Ribeiro, Fernando Luis Dotti, Michael Baldamus.

We also hosted Vivek Sinha (from India) as a stage student.

# H Events 2003

In 2003, the Department hosted the following events:

*Linux Day 2003: Open Source Workshop 0.1* Il GULP e il Master in Management dell'Open Source organizzano, nell'ambito della giornata Linux Day 2003, il primo di sei Open Source Workshop. Pisa, 29 novembre 2003, presso Dipartimento di Informatica, Sala Gerace, Via Buonarroti 2, ore 10:00-13:00 e presso Polo Fibonacci, Aula A, Via Buonarroti 4, 15:30-18:30 e ore 21:00.

*Net&System Security: Le nuove frontiere dell'IT-Security* Convegno sulla sicurezza informatica organizzato dall'associazione @System, in collaborazione con Assosecurity e con il patrocinio del Dipartimento di Informatica di Pisa. del IIT-CNR, Provincia e Comune di Pisa. Pisa, 21 ottobre, presso Auditorium CNR, ore 9:00.

*AI*IA 2003* Ottavo Congresso Nazionale dell'Associazione Italiana per l'Intelligenza Arti ciale, Polo Fibonacci, Pisa 23-26 settembre 2003.

# I Mailing Addresses, Phone, and Electronic Mail

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WWW: **http://www.di.unipi.it**

An alphabetically ordered list of the Department members (with phone numbers, web and mail addresses) can be found at

**http://compass.di.unipi.it/amministrazione/persone/persone.asp**

[1]it will become \Largo B. Pontecorvo, 1c". From late Spring 2004, please check our website to know what is the current valid address)