

Università di Roma “La Sapienza”
Dipartimento di Informatica e Sistemistica
“Antonio Ruberti”

Research Report
2004

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1 Introduction

This report presents an overview of the research activity carried out at the Department of Computer and System Sciences “Antonio Ruberti” of the University of Rome “La Sapienza” during the year 2004.

The Department of Computer and System Sciences (DIS) was established in 1983. Since 2001 it is dedicated to Antonio Ruberti, the eminent scholar who founded it.

The Department is devoted to the development of advanced research, innovative applications and professional skills in the area of information technology, system and control sciences, operations research and management.

The academic staff of the Department is composed of 24 full professors, 18 associate professors, 19 researchers. They provide education at the undergraduate and graduate levels to several programs of the School of Engineering at “La Sapienza”, with main responsibility in the Engineering programs in Informatics, System and Control Sciences, and Management. However, many other curricula include courses offered by DIS. The teaching activity is not described in this report but it can be found at <http://www.dis.uniroma1.it/students.html>

The academic staff work mainly on three primary research areas:

- Computer Science
- System Science
- Management Science

The research activity in each area is described in Section 3. In particular, in each area are individuated different streams of research carried out by different groups of people. In Section 3 it is reported, for each group, a detailed description of its research together with the people working in the group and a list of publications.

Furthermore the Department offers four Ph.D. programs in the three main areas of research, that are briefly described in Section 2 devoted to the general information.

2 General Information

2.1 Location

DIS is located at three different sites:

DIS-Eudossiana

Via Eudossiana 18, 00184 Roma
Phone +39 06 44585358, Fax +39 06 44585367
Administrative and Head offices
DIS Library
Robotics Laboratory, Systems and Control Laboratory
System Science research groups.

DIS-Buonarroti

Via Buonarroti 12, 00185 Roma
Phone +39 06 482991, Fax +39 06 47825618
Operations Research Laboratory
Combinatorial Optimization, Nonlinear Optimization, Industrial
Economics and Industrial Organization and Management
research groups.

DIS-Salaria

Via Salaria 113, 00198 Roma
Phone +39 06 49918487, Fax +39 06 85300849
Computer Science Laboratory
Computer Science research groups.

DIS is on the web at <http://www.dis.uniroma1.it>.

2.2 Facilities

Library

The DIS library was established in 1970. Approximately 11,000 books and conference proceedings, plus 392 journals subscriptions and 784 on-line journals are currently available. The purpose of the DIS Library is to provide the Department community with access to information in its many formats in order to support the teaching, learning, research and service functions of the Department. The Library facilities are also available to non-members of the Department, as resources allow.

The Library provide resources and services in an environment that fosters free and open enquiry, and serve as a catalyst for the interpretation, integration and application of knowledge in the fields of learning and research. As a public institution, it also develops initiatives that foster the cultural environment and the pursuit of learning in the Department and in the wider community.

During the year 2004 the DIS library has continued to organize the series of invited lectures, called "Incontri al Chiostro", which started in the year 2003. - These events were conducted under the supervision of Professor Lorenzo Farina. The lectures presented during the year 2004 were delivered by Ernesto Di Mauro, Marcello Cini, Maurizio Ferraris, Antonio Lepschy, Oliviero Stock, and Yuriy Castelfranchi.

Research Laboratories

DIS hosts several research laboratories, managed by different researching groups, and one extra laboratory located outside the Department. The following list reports name, purpose and the person in charge of managing each laboratory.

DAMSO The Laboratory of Data Analysis, Integrative Modelling, Simulation and Optimization is aimed at developing models and testing efficient algorithms for processing real world data coming from industrial and biosystems engineering.

Person in charge: Alberto DE SANTIS.

Location: DIS-Buonarroti

MIDLAB The primary goal of MIDLAB is to support leading-edge research and development on middleware bridging the gap between the latest research results and the current technologies.

Person in charge: Roberto BALDONI.

Location: DIS-Salaria

Network Control Laboratory The laboratory is devoted to the design, the simulation and the experimental validation of advanced resource management procedures for wireless networks.

Person in charge: Francesco DELLI PRISCOLI.

Location: DIS-Eudossiana.

Operations Research Laboratory The laboratory is devoted to the development of mathematical modeling and algorithms for the solution of mathematical programming problems.

Person in charge: Massimo ROMA.

Location: DIS-Buonarroti.

Robotics Laboratory The laboratory is devoted to the development and experimental validation of advanced planning and control techniques for industrial and service robots.

Person in charge: Alessandro DE LUCA.

Location: DIS-Eudossiana.

Service and Data Integration Laboratory The laboratory is devoted to support software development research prototypes for service-based and data-integration distributed systems.

Person in charge: Massimo MECELLA.

Location: DIS-Salaria

SIED Laboratory. SIED Laboratory (“Intelligent Systems for Emergencies and civil Defense”) is born from a collaboration between “Istituto Superiore Antincendi” and DIS with the goal to carry out activities to develop methodologies, techniques and tools to be used in rescue operations.

Person in charge: Daniele Nardi

Location: Via del Commercio, 13 (Istituto Superiore Antincendi), Roma

<http://www.dis.uniroma1.it/multirob/sied>

Systems and Control Laboratory The laboratory is devoted to the development and experimental verification of new control strategies.

Person in charge: Salvatore MONACO.

Location: DIS-Eudossiana.

Additional information on the activities carried out in the research laboratories can be found at <http://www.dis.uniroma1.it/reslabs.html>.

Educational Laboratories

DIS manages a system of two educational laboratories employed by teachers and by students in self-studying. The laboratories are dedicated to Paolo Ercoli, the founder of the Computer Science group of the Department. Laboratories are on the web at the address <http://www.dis.uniroma1.it/studlabs.html>

Computer Science Lab “Paolo Ercoli” for introductory courses. About 150 stations are available for undergraduate teaching activities.

Person in charge: Daniele NARDI.

Location: Via Tiburtina 205, Roma.

PC and Workstations Lab “Paolo Ercoli” for advanced courses. About 75 PC and workstations for graduate teaching activities.

Person in charge: Roberto BALDONI.

Location: Via Eudossiana 18, Roma.

2.3 People

GIANNI DI PILLO is the Director of the Department.

SANDRO MANCINI is the Administrative Secretary of the Department.

Faculty members

Professors

Giorgio AUSIELLO	Alberto ISIDORI
Carlo BRUNI	Maurizio LENZERINI
Luigia CARLUCCI AIELLO	Claudio LEPORELLI
Tiziana CATARCI	Stefano LUCIDI
Bruno CICIANI	Alberto MARCHETTI SPACCAMELA
Giacomo CIOFFI	Salvatore MONACO
Alessandro DE CARLI	Daniele NARDI
Alessandro DE LUCA	Alberto NASTASI
Gianni DI PILLO	Maria Luisa PETIT TARASCON
Francisco FACCHINEI	Francesca SANNA RANDACCIO
Claudio GORI GIORGI	Antonio SASSANO
Luigi GRIPPO	Marco SCHAERF

Associate Professors

Roberto BALDONI	Leonardo LANARI
Stefano BATTILOTTI	Stefano LEONARDI
Marco CADOLI	Umberto NANNI
Giuseppe ORIOLO	Fabrizio D'AMORE
Pier Luigi PICCARI	Giuseppe DE GIACOMO
Fiora PIRRI	Alberto DE SANTIS
Serenella SALINARI	Francesco DELLI PRISCOLI
Silvio SALZA	Lorenzo FARINA
Giuseppe SANTUCCI	Domenico LAISE

Researchers

Luca BECCHETTI	Carlo MANNINO
Luca BENVENUTI	Laura PALAGI
Roberto BERALDI	Francesco QUAGLIA
Claudia CALIFANO	Pierfrancesco REVERBERI
Camil DEMETRESCU	Massimo ROMA
Claudio DE PERSIS	Riccardo ROSATI
Paolo DI GIAMBERARDINO	Roberta SESTINI
Daniela IACOVIELLO	Marco TEMPERINI
Luca IOCCHI	Marilena VENDITTELLI
Paolo LIBERATORE	

Associate and Post Doctoral Researchers

Alessandro AVENALI	Giorgio MATTEUCCI
Lucas BORDEEAUX	Sara MATTIA
Renato BRUNI	Massimo MECELLA
Eloisa CAMPIONE	Veronica PICCIALLI
Andrea CARBONE	Luciana SALETE
Alberto FINZI	SCANNAPIECO
Luigi LAURA	Guido SCHAEFER
Domenico LEMBO	Antonino VIRGILLITO
Giampaolo LIUZZI	Andrea VITALETTI
Toni MANCINI	

Staff members

Administrative

Amelia ARRICALE	Maria Grazia GIACON
Antonietta CANGELLI	Sandro MANCINI
Beatrice DE CARLO	Tiziana VALENTINI
Paola FOLGORI	Maria Pia VANDILLI

Technical

Sergio BALDINI	Giuseppe FILACI
Giuseppe CAPOZI	Massimo PACINI
Mauro CICCI	Paola PACINI
Marco DI BONIFACIO	Antonio SAPORI
Anna Paola DI RISIO	Tiziana TONI

Auxiliary Services

Pia BONANNI Maria Carmina MASTROCOLA Antonio SIMEONI

Library

Angelina DE SALVO

Telephone numbers, E-mail addresses and home pages of people at DIS are available on the web at the address <http://www.dis.uniroma1.it/people.html>.

2.4 Ph.D. Programs

DIS directly hosts the Ph.D. programs in Computer Engineering and in System Engineering. Moreover, DIS cooperates in the Ph.D. programs in Bioengineering, hosted by the Department of Electronic, Computer and System Sciences of the University of Bologna and in Operations Research, hosted by the Department of Probability and Statistics of the University of Roma “La Sapienza”.

Bioengineering

The council of professors of the Ph.D. program in Bioengineering is coordinated by Guido Avanzolini (Dept. of Electronic, Computer and System Sciences of the University of Bologna).

The research topics are: modelling of biomedical systems, processing of biomedical data, signals and images, biomedical instrumentation, medical informatics, biomechanics, prostheses and bio materials.

Ph.D. students (working at DIS)

XVII course	XVIII course
POLI Samantha	ASTOLFI Paola

Computer Engineering

The council of professors of the Ph.D. program in Computer Engineering is coordinated by Giorgio Ausiello.

The research topics are: theory of algorithms, computer systems, databases, programming languages, theoretical computer science, image processing, artificial intelligence, VLSI, computational logics, performance evaluation.

Ph.D. students

XVII course	XVIII course	XIX course	XX course
BAHADORI G. Shahram	BERTINI Enrico	ALULLI Luca	CANDIDO Alessia
BERARDI Daniela	DONATO Debora	BONIFACI Vincenzo	CHIRICHELLO Antonella
FARINELLI Alessandro	FERRARA Andrea	MILANI Alessia	DI BELLO Lucia
MANCINI Toni	FRATINI Simone	MILANO Diego	FRATARCHANGELI Marco
OGLIETTI M. Alejandro	GRISETTI Giorgio	PECORA Federico	NOOR MIAN Adnan
POLICELLA Nicola	SARRACCO Fabiano	QUERZONI Leonardo	RIBICHINI Andrea
TUCCI PIERGIOVANNI Sara	ROMANO Paolo	SAVELLI Francesco	UGAZIO Giorgio
		RUZZI Marco	ZIPARO Vittorio Amos

Operations Research

The council of professors of the Ph.D. program in Operations Research is coordinated by Prof. Paolo Dell'Olmo (Dep. of Probability and Statistics, University of Rome "La Sapienza"). The research topics are: combinatorial optimization, nonlinear programming, network design, neural networks, logistics, management systems, industrial systems economy.

Ph.D. students (working at DIS)

XVIII course	XX course
CANALE Silvia	RISI Arnaldo
PARRELLO Emiliano	

System Engineering

The council of professors of the Ph.D. program in System Engineering is coordinated by Carlo Bruni.

The research topics are: systems theory, automatic control, nonlinear systems, intelligent control, robotics, flexible manufacturing systems, bio systems, modelling, identification, optimal control, resource management for wireless systems.

Ph.D. students

XVII course	XVIII course	XIX course	XX course
LUCCHETTI Matteo	CEFALO Massimo	CINAT David	BALDESI Gianluca
POMPILI Dario	FARINA Riccardo	FERRONE Claudia	CACALISCHIA Leonardo
ZAVAGLI Massimo	GRANATO Luigi	FREDA Luigi	CALATINO Michelangelo
ZONFRILLI Fabio	MOGNO Ilaria	GUAINELLA Emiliano	CHERUBINI Andrea
		MARCHETTI Ilaria	ROBUFFO GIORDANO Paolo
		SANTORO Gianfranco	SURACI Vincenzo
		USAI Andrea	

2.5 Contracts signed in year 2004

In the following, we list the research contracts signed in year 2004.

Contracts with the European Union

Contractor	Value (EURO)	Title	Project Leader
E.U.	540.000,00	Dynamically, Evolving, Large Scale information Systems "DELIS" CT n 001907	Leonardi

Contracts with Italian research Institutions

Contractor	Value (Euro)	Title	Project Leader
C.N.R.	29.438,04	Metodologie di integrazione di sorgenti semi-strutturate ed eterogenee	Lenzerini
C.N.R.	10.845,59	Progettazioni di reti con vincoli di capacità	Sassano
C.N.R.	13.994,34	Algoritmi per l'ottimizzazione della Qso in internet	Marchetti
C.N.R.	11.532,72	Individuazione delle più adeguate metodologie per l'analisi delle politiche pubbliche di rilievo strategico e di rilevanza innovativa	Catarci
MAE	84.700,00	Post Earthquake Emergency: methods, techniques and support instrumentation.	Nardi
MIPAF	590.714,16	Metodi di data mining per la gestione dei dati e rilevamento delle frodi in campo alimentare, ADM	Sassano
MIUR (COFIN)	33.000,00	Linguaggi formali per la definizione dei web services ed analisi del loro comportamento.	Schaerf
MIUR (COFIN)	29.000,00	Tecniche algoritmiche evolute e loro applicazioni ad internet ed al grafo web.	Ausiello
MIUR (COFIN)	33.000,00	Monitoraggio, rilevamento, riconfigurazione e controllo basato su un modello interno per sistemi distribuiti spazialmente	Isidori

Contracts with others (companies, foreign research institutions)

Contractor	Value (Euro)	Title	Project Leader
Alenia Spazio SpA	114.221,00	Telecomunicazioni satellitari	Delli Priscoli
Alenia Spazio SpA	104.170,00	Rete locale a banda larga ad accesso radio (WWLAN)	Marchetti
CM Sistemi SpA	27.468,00	Att. di ric.e sviluppo dei sistemi informativi avanzati - progetto IMI-MURST SIINDA-PARNASO	Catarci
CM Sistemi SpA	74.520,00	Progetto PICASSO	Lenzerini
Consiglio Superiore dei Lavori Pubblici	15.000,00	Progetto di informatizzazione del Consiglio Superiore	Leonardi
Fondazione Telethon	35.500,00	ASPICE: Assistive System for Patient's Increase of Communication, ambient control and mobility in absence of muscular Effort	Oriolo
ISIMM	25.000,00	Consulenza per supporto metodologico all'attivit di collaudo del Centro Servizi Multimediale	Sassano e Ciciani
Parades GEIE	15.000,00	Sintesi di modelli e controllori ibridi per applicazioni automobilistiche	Farina e Benvenuti
Space Engineering	22.860,00	Aspetti di ricerca nel settore satellitare	Delli Priscoli
System Service	16.000,00	Erogazione ore didattica per corso di aggiornamento Tecnico Valutazione Ambientale	Di Giamberardino
Telespazio SpA	14.022,07	Progetto preliminare di telecomunicazioni istituzionali per la sicurezza ed emergenze	Delli Priscoli

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3 Research Activity

3.1 Computer Science

3.1.1 Algorithm Engineering Group

The research activity of the group of Algorithm Engineering (AE) is concerned with the design, the engineering, the theoretical and experimental performance analysis of combinatorial algorithms for problems arising in modern Computer Systems and Networks, and in applications related to complex resource management problems. Our main research interests deal with the solution of optimization problems and the design of efficient data structures, with special emphasis on those applications involving large data sets. In particular we concentrate on:

1. algorithms that perform efficiently in a dynamically changing environment;
2. models and methodologies for the analysis and design of algorithms for information retrieval;
3. the efficient management of communication and information delivery and recovery in Wireless Networks and on the Internet;
4. the design and analysis of approximation algorithms for NP-hard optimization problems;
5. the design of on-line algorithms that work with incomplete information on the input instance;
6. the design and implementation of tools and platforms for the experimental analysis and visualization of the behavior of algorithms and data structures.

The achievements of the AE group are widely recognized. Giorgio Ausiello is Editor in Chief of Theoretical Computer Science, Series A, Algorithms and Complexity. He has also been awarded the title of 'Doctor Honoris Causa of Dauphine University'.

Members of the AE group are continuously involved in the Program and Steering Committees of prestigious International Conferences.

Giorgio Ausiello has been in the Selection Committee of the Goedel Prize during years 2003 - 2005. He is also involved in the Program Committee of the 32nd International Colloquium on Automata, Languages and Programming (ICALP'05).

Alberto Marchetti-Spaccamela has been member of the Steering Committee of the European Symposium on Algorithms and has been involved in the Program Committee of the 30th International Workshop on Graph-Theoretic Concepts in Computer Science (WG'04).

Stefano Leonardi has been involved in the Program Committees of the Workshop on Models and Algorithms for Planning and Scheduling Problems (MAPSP05), the 1st International Workshop on Algorithmic Aspects of Wireless Sensor Networks 2004, the 3rd International Conference on Fun with Algorithms (FUN04), the 21th International Symposium on Theoretical Aspects of Computer Science (STACS04), and the International Workshop on Self-* Properties in Complex Information Systems 2004. He is also Program Chair of the 13th Annual European Symposium on Algorithms (ESA'05) and has been Program Chair of the 3rd Workshop on Algorithms and Models for the Web-Graph (WAW 2004).

Camil Demetrescu has been involved in the Program Committees of the 12th European Symposium on Algorithms 2004 (ESA'04) - Design and Analysis Track, the 9th Scandinavian Workshop on Algorithm Theory 2004 (SWAT'04), the 4th Workshop on Algorithmic Methods and Models for Optimization of Railways 2004 (ATMOS'04), and the 31st International Workshop on Graph-Theoretic Concepts in Computer Science (WG'05). He has also been invited to join the Steering Committee of the ACM-SIAM Workshop on Algorithm Engineering and Experiments (ALENEX) from 2005 to 2008 and has been Program Co-chair (with Roberto Tamassia) of the 7th Workshop on Algorithm Engineering and Experiments (ALENEX'05).

The AE group has recently organized several international scientific events. In particular, the group has organized the "45th Annual IEEE Symposium on Foundations of Computer Science" (FOCS'04) in Rome in October 2004. This is the first time in 44 years this prestigious symposium is held outside North America. In conjunction with FOCS, the group has also organized the "Workshop on Algorithms and Models for the Web" (WAW'04). *Algorithmica* devoted a special issue to papers presented during the ALGO 2002 event, held in Rome in September 2002, and organized by the Algorithmic group. This collection of papers on Approximation and On-line algorithms has been edited by Stefano Leonardi and appears in *Algorithmica*, volume 40, chapter "Approximation and On-line Algorithms".

A regular Seminar Program, the Interdepartmental Seminar on Algorithms (SIA), is also organized in cooperation with the Department of Computer Science of this University (see <http://www.dis.uniroma1.it/sia/>).

The AE group is currently cooperating with several prestigious research institutions: Max Planck für Informatik (Saarbrücken, Germany), CTI-Patras (Greece), ETH (Zurich, Switzerland), Université de Paris (Dauphine, France), Tel-Aviv University (Israel), AT&T - Research Labs (Florham Park, NJ, USA), ICSI-Berkeley (USA), Brown University (Providence, RI, USA), Microsoft Research (Mountain View, CA, USA).

The AE group is presently involved in the following research projects: EU IST "Approximation and On-line Algorithms (APPOL2)"; EU-RTN AMORE "Algorithmic Methods for Optimizing the Railways in Europe"; MIUR "Resource Allocation in Computer Networks"; MIUR National Project "Rete multimediale nell'evoluzione verso UTMS - Linea di ricerca Applicazione ai beni culturali"; EU-IST "Coevolution and self-organization in dynamical networks (COSIN)"; EU Contract 001907 "Dynamically Evolving Large Scale Information Systems" (DELIS); MIUR National Project ALGO-NEXT "Algorithmics for Internet and the Web"; FIRB National Projects - WEBMINDS and VICOM. A national committee of the MIUR has also approved a financial support of 1M-Euro in three years for the institution at the University of Rome "La Sapienza" of an *Excellence Centre* that aims at creating new scientific and technical synergies in the area of transportation and logistics. A major role in this project is played by the Algorithm Engineering group at DIS.

Faculty members. Giorgio Ausiello, Luca Becchetti, Fabrizio d'Amore, Camil Demetrescu, Stefano Leonardi, Alberto Marchetti-Spaccamela, Umberto Nanni.

Post-docs. Luigi Laura, Luciana Salete Buriol, Guido Schäfer, Andrea Vitaletti.

PhD students. Luca Allulli, Vincenzo Bonifaci, Debora Donato, Fabiano Sarracco, Andrea Ribichini.

Graphs and Combinatorial Algorithms. In [28] we present the first fully dynamic algorithm for maintaining all pairs shortest paths in directed graphs with real-valued edge weights. Given a dynamic directed graph G such that each edge can assume at most S different real values, we show how to support updates in $O(n^{2.5}\sqrt{S\log^3 n})$ amortized time and queries in optimal worst-case time. This algorithm is deterministic: no previous fully dynamic algorithm was known before for this problem. In the special case where edge weights can only be increased, we give a randomized algorithm with one-sided error that supports updates faster in $O(S \cdot n \log^3 n)$ amortized time.

We also show how to obtain query/update trade-offs for this problem, by introducing two new families of randomized algorithms. Algorithms in the first family achieve an update bound of $\tilde{O}(S \cdot k \cdot n^2)$ ¹ and a query bound of $\tilde{O}(n/k)$, and improve over the previous best known update bounds for k in the range $(n/S)^{1/3} \leq k < (n/S)^{1/2}$. Algorithms in the second family achieve an update bound of $\tilde{O}(S \cdot k \cdot n^2)$ and a query bound of $\tilde{O}(n^2/k^2)$, and are competitive with the previous best known update bounds (first family included) for k in the range $(n/S)^{1/6} \leq k < (n/S)^{1/3}$.

In [8] we study novel combinatorial properties of graphs that allow us to devise a completely new approach to dynamic all pairs shortest paths problems. Our approach yields a fully dynamic algorithm for general directed graphs with non-negative real-valued edge weights that supports any sequence of operations in $O(n^2 \log^3 n)$ amortized time per update and unit worst-case time per distance query, where n is the number of vertices. We can also report shortest paths in optimal worst-case time. These bounds improve substantially over previous results and solve a problem that has been open for over thirty years. Our algorithm is deterministic, uses simple data structures, and appears to be very fast in practice [15].

In [27] we present an algorithm for directed acyclic graphs that breaks through the $O(n^2)$ barrier on the single-operation complexity of fully dynamic transitive closure, where n is the number of edges in the graph. We can answer queries in $O(n^\epsilon)$ worst-case time and perform updates in $O(n^{\omega(1,\epsilon,1)-\epsilon} + n^{1+\epsilon})$ worst-case time, for any $\epsilon \in [0, 1]$, where $\omega(1, \epsilon, 1)$ is the exponent of the multiplication of an $n \times n^\epsilon$ matrix by an $n^\epsilon \times n$ matrix. The current best bounds on $\omega(1, \epsilon, 1)$ imply an $O(n^{0.575})$ query time and an $O(n^{1.575})$ update time in the worst case. Our subquadratic algorithm is randomized, and has one-sided error. As an application of this result, we show how to solve single-source reachability in $O(n^{1.575})$ time per update and constant time per query.

In [29] we devise algorithms for maintaining dynamically graph spanners, i.e., sparse subgraphs that preserve the distances in the original graph within an approximation ratio. In

¹Throughout the paper, we use $\tilde{O}(f(n))$ to denote $O(f(n)\text{polylog}(n))$.

particular, we show how to maintain a spanner with $O(n^{3/2})$ edges in an unweighted undirected graph with n vertices in $O(n)$ time per edge insertion or edge deletion, amortized over a sequence of $\Omega(n)$ operations. Distances are maintained within a factor of 3 of the distances in the original graph (3-spanner). Recently [36], the work has been extended to maintain a 5-spanner with $O(n^{4/3})$ edges.

In [34] we propose a dynamic shortest path algorithm for an application on computing statistical properties of networks subject to path distance minimization. The graph under assumption is undirected, unweighted and has a dynamic topology, e.g., at any time arcs can be inserted to or removed from the current topology.

In [35] we address the issue of assigning OSPF weights and multiplicities to each arc, aiming to design efficient OSPF networks with minimum total cost needed to route the required demand and handle any single arc or router failure. We propose an evolutionary algorithm for this problem, and present results applying it to several real-world problem instances.

In [24, 25] we survey the main techniques developed in the literature for the maintenance of dynamic trees and dynamic graphs.

Algorithms for the Web. The main goal of this research line is to analyze the structure and to measure the properties of the directed graph induced by the Web hyperlinked structure comprised by the html pages and the links among them. Because of the rapid pace at which the real Webgraph is growing over the time, it is necessary to develop and use collection of routines that are able to deal with massive graphs stored in files in secondary memory. Our main contribution, in the first part of the last year, was the implementation of such a library of routines [31]. Our routines are able to generate graphs according to many of the random models presented in literature in order to reproduce properties of the real Webgraph. In order to measure such properties, we also provide programs that can measure these graphs (the ones generated according to known models) as well as real samples of the Webgraph. We present a "multifile" format to represent graphs in secondary memory; we include routines that convert some graph-file formats from/to our .ips multifile format. Binaries and source code of all the program of this library are freely downloaded from the European Research Project Cosin website; to compile them the gcc compiler version ≥ 2.9 and linux operating system are needed. The library has been tested with graphs up to 2 billion edges.

This library allows us to conduct an experimental study of the large scale properties of web graphs on a large crawl from 2001 of 200M pages and about 1.4 billion edges made available by the WebBase project at Stanford. We report our experimental findings on the topological properties of such a graph, such as the number of bipartite cores and the distribution of degrees, PageRank values, and strongly connected components in [9]. Moreover we were able to compare the features of many of the models that have been proposed so far in the literature and analyze the differences with the real WebBase sample [10]. Most of the results of our measurements, with a panoramic view of the stochastic graph models and the algorithmic challenges that such a huge structure poses, are summarized in [18].

We also observed that the *bow-tie* structure of the Web revealed by Broder et al. is

a relatively clear abstraction of the macroscopic picture of the Web graph, but it is very uninformative with respect to the finer details of the Web graph. In order to mine the inner structure of the bow-tie, we introduce some other statics. These new measurements allowed us to understand better the structure of the single components of the *bow-tie*. The *daisy* picture for the Webgraph that emerges from this experimental study is presented in [30].

The last part of our work consists of a theoretical analysis of the Link Analysis Ranking Algorithm with emphasis on the properties of stability and similarity of well-designed ranking algorithm. These properties were first introduced and studied by Borodin et al. In [33], we prove that on a broad class of random graphs (a) the HITS algorithm is stable with high probability, and (b) the HITS algorithm is similar to the InDegree algorithm, the simple heuristic that assigns to each node weight proportional to the number of incoming links.

Our experimental studies confirm the presence of power laws with coefficients 2.1 in most of the properties we analyzed. The main problem we have to face is the lack of fresh samples of the Webgraph. For instance, we observed a different percentage composition of the WebBase bow-tie component if compared with previous measurements of Broder. However, due to the lack of newer crawls, we are not able to conjecture if the same measures won't be repeated on more recent and bigger samples.

Algorithms for Optimization and Games. In [5] we have introduced the notion of smoothed competitive analysis of online algorithms. Smoothed analysis has been proposed by Spielman and Teng to explain the behaviour of algorithms that work well in practice while performing very poorly from a worst case analysis point of view. We apply this notion to analyze the Multi-Level Feedback (MLF) algorithm to minimize the total flow time on a sequence of jobs released over time when the processing time of a job is only known at time of completion. The initial processing times are integers in the range $[1..2^K]$ and they are smoothed by changing the k least significant bits under a quite general class of probability distributions. We show that MLF admits a smoothed competitive ratio that exponentially decreases as the variance of the distribution increases. A direct consequence of our result is also the first average case analysis of MLF. We show a constant expected ratio of the total flow time of MLF to the optimum under several distributions including the uniform distribution.

In [3] we study a randomized version RMLF of the MLF algorithm described above. We prove that this randomized version of the Multi-level Feedback algorithm is competitive for single and parallel machine systems, in our opinion providing another theoretical validation of the goodness of an idea that has proven effective in practice along the last two decades.

In [6] we study the problem of scheduling parallel machines online, allowing preemptions while disallowing migration of jobs that have been scheduled on one machine to another. For a given job, we measure the quality of service provided by an algorithm by the *stretch* of the job, defined as the ratio between the amount of time spent by the job in the system (the *response time*) and its processing time. The scheduling goal is to minimize the average stretch.

We prove an $O(1)$ competitive ratio for this problem. Our result shows that migration is not necessary to be competitive for minimizing average stretch; in contrast, we prove that preemption is essential, even if randomization is allowed.

In [4] we explore the quality of service (QoS) that is achievable by *semi-clairvoyant* on-line scheduling algorithms, which are algorithms that only require approximate knowledge of the initial processing time of each job, on a single machine. We give a semi-clairvoyant algorithm that is $O(1)$ -competitive with respect to average flow time on one single machine. We also show a semi-clairvoyant algorithm on parallel machines that achieves up to constant factors the best known competitive ratio.

It is known that the clairvoyant algorithm SRPT is optimal with respect to average flow time and is 2-competitive with respect to average stretch. Thus it is possible for a clairvoyant algorithm to be simultaneously competitive in both average flow time and average stretch. In contrast we show that no semi-clairvoyant algorithm can be simultaneously $O(1)$ -competitive with respect to average stretch and $O(1)$ -competitive with respect to average flow time. Thus in this sense one might conclude that the QoS achievable by semi-clairvoyant algorithms is not competitive with clairvoyant algorithms.

In [2] we consider downlink scheduling in next generation 3G/4G wireless data networks. These allow multiple codes (or channels) to be allocated to a single user, where each code can support multiple data rates. Providing fine-grained QoS to users in such networks poses the two dimensional challenge of assigning *both* power (rate) and codes to every user. We abstract general downlink scheduling problems suitable for proposed next generation wireless data systems. Our contribution includes a communication-theoretic model for multirate wireless channels. In addition, while conventional focus has been on throughput maximization, we attempt to optimize the maximum response time of jobs, which is more suitable for streams of user requests. We are able to provide very simple, online algorithms for approximating the optimal maximum response time. We also perform an experimental study with realistic data of channel conditions and user requests that strengthens our theoretical results.

In [13] we explore the effects of locality on the performance of paging algorithms. Traditional competitive analysis fails to explain important properties of paging assessed by practical experience. In particular, the competitive ratios of paging algorithms that are known to be efficient in practice (e.g. LRU) are as poor as those of naive heuristics (e.g. FWF). It has been recognized that the main reason for these discrepancies lies in an unsatisfactory modelling of locality of reference exhibited by real request sequences. We propose an adversarial model in which the probability of requesting a page is also a function of the page's age. In this way, our approach allows to capture the effect of locality of reference. We consider several families of distributions and we prove that the competitive ratio of LRU becomes constant as locality increases, as expected. We also prove that the performance of FWF rapidly degrades as locality increases, while the converse happens for LRU.

In [14] we consider the *multicommodity rent-or-buy* (MROB), in which we are given a network together with a set of k terminal pairs. The goal is to provision the network so that a given amount of flow can be shipped between all terminal pairs simultaneously.

In order to provision the network one can either *rent* capacity on edges at some cost per unit of flow, or *buy* them at some larger fixed cost. Bought edges have no incremental, flow-dependent cost. The overall objective is to minimize the total provisioning cost. In this paper we give a 5.5-approximation for the MROB problem by refining the algorithm of Gupta et al. and greatly simplifying their analysis. The improvement in our paper is based on a more careful adaptation and simplified analysis of the primal-dual algorithm for the Steiner forest problem due to Agrawal, Klein and Ravi. Our result significantly reduces the gap between the single-sink and multi-sink cases.

In [1] we consider the Quota Traveling Salesman Problem. This is a generalization of the well known Traveling Salesman Problem. The goal of the traveling salesman is, in this case, to reach a given *quota* of sales, minimizing the amount of time. In this paper we address the on-line version of the problem, where requests are given over time. We present algorithms for various metric spaces, and analyze their performance in the usual framework of competitive analysis. In particular we present a 2-competitive algorithm that matches the lower bound for general metric spaces. In the case of the halfline metric space, we show that it is helpful not to move at full speed, and this approach is also used to derive the best on-line polynomial time algorithm known so far for the On-Line TSP (in the homing version).

In [12] we present an overview of several on-line optimization problems which involve exploration or chasing, in the framework of metrical service systems.

Two chapters of the handbook “Optimization Combinatoire” have also been prepared, one concerning approximation preserving reductions [23] and one on on-line algorithms [22].

In [19] we design an approximately budget-balanced and group-strategyproof cost-sharing mechanism for the Steiner forest game. An instance of this game consists of an undirected graph $G = (V, E)$, non-negative costs c_e for all edges $e \in E$, and a set $R \subseteq V \times V$ of k terminal pairs. Each terminal pair $(s, t) \in R$ is associated with an agent that wishes to establish a connection between nodes s and t in the underlying network. A feasible solution is a forest F that contains an s, t -path for each connection request $(s, t) \in R$. Previously, Jain and Vazirani gave a 2-approximate budget-balanced and group-strategyproof cost-sharing mechanism for the Steiner tree game — a special case of the game considered here. Such a result for Steiner forest games has proved to be elusive so far, in stark contrast to the well known primal-dual $(2 - 1/k)$ -approximate algorithms for the problem. The cost-sharing method presented in this paper is 2-approximate budget-balanced and this is tight with respect to the budget-balance factor.

In [11] we present cost sharing methods for connected facility location games that are cross-monotonic and competitive and that recover a constant fraction of the cost of the constructed solution. The novelty of this paper is that we use randomized algorithms and that we share the expected cost among the participating users. As a consequence, our cost sharing methods are simple and achieve attractive approximation ratios. We also provide a primal-dual cost sharing method for the connected facility location game with opening costs.

In [32] we consider the problem of Internet switching, where traffic is generated by self-

ish users. We study a packetized (TCP-like) traffic model, which is more realistic than the widely used fluid model. We assume that routers have First-In-First-Out (FIFO) buffers of bounded capacity managed by the drop-tail policy. The utility of each user depends on its transmission rate and the congestion level. Since selfish users try to maximize their own utility disregarding the system objectives, we study Nash equilibria that correspond to a steady state of the system. We quantify the degradation in the network performance called the price of anarchy resulting from such selfish behavior.

We show that for a single bottleneck buffer, the price of anarchy is proportional to the number of users. Then we propose a simple modification of the Random Early Detection (RED) drop policy, which reduces the price of anarchy to a constant. We demonstrate that a Nash equilibrium can be reached if all users deploy TCP Vegas as their transport protocol. We also consider some natural extensions of our model including the case of multiple Quality of Service (QoS) requirements, routing on parallel links and general networks with multiple bottlenecks.

Using idle times of the processors is a well-known approach to run coarse grained parallel algorithms for extremely complex problems. In [20] we present on-line algorithms for scheduling the processes of a parallel application that is known off-line on a dynamic network in which the idle times of the processors are dictated by an adversary. We also take communication and synchronization costs into account.

Our first contribution consists of a formal model to restrict the adversary in a reasonable way. We then show a constant factor approximation for the off-line scheduling problem. As this problem has to take communication cost into account, it can be seen as a generalization of many NP-hard parallel machine scheduling problems. Finally, we present on-line algorithms for different models with constant or with “nearly constant” competitive ratio.

Experimentation, visualization and applications. Directors are reactive systems that monitor the run-time environment and react to the emitted events. Typical examples of directors are debuggers and tools for program analysis and software visualization. In [16] we describe a cross-platform virtual machine that provides advanced facilities for implementing directors with low effort.

In [7], we describe Leonardo Web, a collection of tools for building animated presentations that can be useful for teaching, disseminating, and e-learning. Presentations can be created via the combined use of a visual editor and a Java library. The library allows it to generate animations in a batch fashion directly from Java code according to an imperative specification style. Batch-generated animations can then be refined and customized using the editor. Presentations can be finally viewed with a simple Java player, which ships both as a stand-alone application for off-line deployment and as a Java applet embedded in a Web page. The player supports step-by-step and continuous execution, reversibility, speed selection, and smooth animation.

In [15], we present the results of an extensive computational study on dynamic algorithms for all pairs shortest path problems. We describe our implementations of the recent dynamic algorithms of King and of Demetrescu and Italiano, and compare them to the dy-

dynamic algorithm of Ramalingam and Reps and to static algorithms on random, real-world and hard instances. Our experimental data suggest that some of the dynamic algorithms and their algorithmic techniques can be really of practical value in many situations.

In [17], we report on our own experience in studying a fundamental problem on graphs: all pairs shortest paths. In particular, we discuss the interplay between theory and practice in engineering a simple variant of Dijkstra's shortest path algorithm. In this context, we show that studying heuristics that are efficient in practice can yield interesting clues to the combinatorial properties of the problem, and eventually lead to new theoretically efficient algorithms.

In [21] we describe the status of an on-going research on Architectural and Building Collaborative Design - a joint effort of experts of various disciplines. The resulting framework concerns mainly the architectural and building design, but the main ideas apply also to other contexts where heterogeneous project teams are involved in a cooperative design effort. Among the main issues, a special attention devoted to: (i) an integrated model of the structure of the networked architectural design process (operators, activities, phases and resources), (ii) the required knowledge and constraints (distributed and functional to the operators and the process phases), and (iii) the algorithms for the maintenance of the consistency of the project which is going to be built within the provided constraints.

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3.1.2 Artificial Intelligence

The Artificial Intelligence research group is mainly working in Knowledge Representation and Reasoning, Planning, and Cognitive Robotics.

In particular, we are concerned with the following topics:

1. The study of computational properties of formalisms, languages, and reasoning tools. These topics are illustrated in the Section “Complexity of Reasoning”.
2. The study of the reasoning mechanism of intelligent agents in realistic domains. These topics are described in the Section “Commonsense Reasoning”.
3. The techniques for reasoning under uncertainty, which are based on a probabilistic representation, and used, in particular, to select the best action to execute in a dynamic environment. This is addressed in the Section “Reasoning under Uncertainty”.
4. The definition of methods and techniques for reasoning about actions, and for the design and the realization of embodied agents (in particular mobile robots) that are able to accomplish complex tasks in real environments. These topics are described in the Section “Cognitive Robotics and Reasoning about Actions”.
5. The techniques for the design and implementation of Cognitive Agents that cooperate in the achievement of a common goal, in multi-robot and multi-agent systems. These topics are described in the Section “Multi-robot and multi-agent systems”.
6. The development of heuristics and suitable formalisms to realize flexible architectures for planning and scheduling. This work is described in the Section on “Constraint-based Architectures for Planning and Scheduling”.

The international recognition of the achievements in the field of Artificial Intelligence and Knowledge Representation are highlighted by the following achievements.

Luigia Carlucci Aiello is a member of the Board of Trustees of IJCAI - International Joint Conference on Artificial Intelligence and President of FoLLI, the Association of Logic Language and Information and invited speaker at Robocup Symposium (Lisbon, July 2004); Fiora Pirri is permanent member of the Cognitive Robotics steering Committee; Daniele Nardi is member of the RoboCup Executive Committee and co-chaired the 2004 RoboCup Symposium (Lisbon, July 2004).

The activity of the SIED Laboratory² (“Sistemi Intelligenti per le Emergenze e la Difesa civile”, located in “Istituto Superiore Antincendi”, in Rome) started in May, 2004. The group at SIED Laboratory organized the Rescue Robotics Camp³, that took place from Oct., 29th to Nov., 2nd.

The project “Implementazione dell’architettura di supervisione del Robot Antartico di Superficie (RAS)” (supported by ENEA) has been carried on, with some experimentations in the area of Tonale. The project “Sistemi di Simulazione e Robotici per l’Intervento in Scenari d’Emergenza” (partially supported by MIUR) has been carried on. The participation to the network of excellence EC-Vision has supported partially the activity with the Robocup rescue.

The Alcor and SPQR teams were the third and fourth award winners at the Robocup Rescue competition in Lisbon 2004.

Group members Luigia CARLUCCI AIELLO, Shahram BAHADORI, Marco CADOLI, Daniele CALISI, Andrea CARBONE, Amedeo CESTA [CNR], Giuseppe DE GIACOMO, Alessandro FARINELLI, Alberto FINZI, Simone FRATINI, Giorgio GRISSETTI, Luca IOCCHI, Riccardo LEONE, Paolo LIBERATORE, Thomas LUKASIEWICZ, Toni MANCINI, Daniele NARDI, Angelo ODDI [CNR], Marcelo OGLIETTI, Federico PECORA, Fabio PATRIZI, Fiora PIRRI, Marco PIRRONE, Nicola POLICELLA, Massimo ROMANO, Riccardo ROSATI, Giuseppe SARDINA, Francesco SAVELLI, Marco SCHAEF, Luigi SCOZZAFAVA, Giorgio UGAZIO,

Complexity of Reasoning Efficiency of AI systems is important for their success, as it is important in all engineering projects. If we are to use logic as the major tool for Knowledge Representation and Reasoning we have to deal with computational aspects. During the year 2004, the AI group has continued the investigation on fundamental properties of complexity of reasoning, with the overall goal of designing computationally efficient and adequately expressive systems for Knowledge Representation and Reasoning. In particular, research has focused on constraint problem solving [42, 31, 20, 33] and in reasoning about actions [26].

Commonsense Reasoning Research in commonsense reasoning studies the reasoning mechanisms of an intelligent agent operating in realistic domains, and develops suitable formalisms to support various aspects of reasoning, such as nonmonotonic reasoning, belief

²www.dis.uniroma1.it/~multirob/sied

³www.dis.uniroma1.it/~multirob/camp04

revision, preference representation, etc. Many formalisms, which also require to combine several logics, have been devised in the knowledge representation research community to challenge the limitations of classical formalisms. Our research group worked in default logic [3], belief revision [4], and preference representation [21].

Reasoning under Uncertainty The research on reasoning under uncertainty focuses especially on reasoning about actions under probabilistic uncertainty. In particular, [27, 28] present a novel formalism for reasoning about actions with sensing, which allows to deal with probabilistic as well as nondeterministic effects of actions. Towards game-theoretic extensions of probabilistic reasoning about actions, [30, 29, 34] introduce a first-order extension of Markov games and a combination of Markov games with agent programming in Golog.

Other works explore novel notions of probabilistic entailment as well as explanations in the structural-model approach to causality. More precisely, [32, 35] present an approach where probabilistic logic is combined with default reasoning from conditional knowledge bases, while [7] explores a combination of probabilistic logic programming with the information-theoretical principle of maximum entropy. Finally, the work [6] investigates computational issues related to Halpern and Pearl's explanations and partial explanations in structural causal models under probabilistic uncertainty.

Cognitive Robotics and Reasoning about Actions Cognitive Robotics and Reasoning about Actions, at DIS, focuses on multidisciplinary research concerning different high and low level robotics behaviours and their interactions with the real world environment.

The works in [45] and in [44] describe a formalism and a planning algorithm for strong cyclic planning with incomplete knowledge and sensing action. In [43] an approach to flexible planning and scheduling based on a suitable mapping of the Constraint Based Interval Planning paradigm into the Situation Calculus is presented. Policies of Markov Decision Processes (MDPs) determine the next action to execute from the current state and, possibly, the history (the past states). In [1], some problems related to the size of succinctly represented policies are analyzed. The paper [12] addresses the problem of integrating small-scale and large-scale spatial ontologies for robotic mapping purposes. While paper [14] demonstrates the great impact of the planarity constraint on the reduction of topological ambiguity in robot map-building. Exploiting such a constraint, common in many real world applications, proves effective and inexpensive. In [13] a preselective perception process is presented, that builds an observation state including also a saliency map of the features of the image. In [49] indoor environment recognition is coupled with people detection exploiting the hierarchical structure of human body to obtain a very efficient classifier. In [9, 18, 36] the problem of integrating deliberation with program execution is studied from a general semantical point of view, under the framework of the Situation Calculus. Specific properties of programs that can be considered as good deliberated plans are studied, and sound implementation of the deliberation process under quite general circumstances is presented. In [26], an automated reasoner for reasoning about actions in

Reiter's Situation Calculus Basic Action Theories is proposed. The fundamental characteristic of such a proposal is that it relies on standard relational database technology, and hence it promises to be scalable to very large data-centric domains.

Multi-robot and Multi-agent Systems Multi-Robot Systems (MRS) and Multi-Agent Systems (MAS) are often used for implement complex systems acting in complex environments. The effectiveness of such systems is mainly related to the ability of the agents to coordinate each other in an effective way. In this context we have made an exhaustive analysis of the MRS [2] providing a new taxonomy for classifying recent works in the field. Moreover, we have developed a new technique for dynamic task assignment that is based on a token passing approach by using a limited network bandwidth [15]. While in [16] constraints in the execution of the robots activities have been considered. Information Fusion techniques applied to MAS have been investigated in [47]. Moreover, the ability of creating a map of an unknown environment has been specifically studied in [48], by proposing an an improved Rao Blackwellized particle filter with two new features: the computation of an highly informative proposal distribution and a particle replication schema which exploits the loop closure knowledge.

In the context of MAS, we addressed the problem of task assignment for large scale MAS in [19, 17], the proposed approach is able to allocate tasks in highly dynamic environments in a totally distributed fashion, minimizing the communication overhead.

Finally, MAS and MRS technology have been used in two different contexts: to coordinate a team of agents involved in a rescue process [19], to coordinate robots and intelligent sensors in a domestic environment for elderly assistance [5, 10]. A software architecture to support the development of MAS and MRS applications has been described in [46].

Constraint based Architectures for planning and Scheduling This line of research is aimed at developing constraint-based methods for solving planning and scheduling problems automatically.

Research on scheduling has investigated different approaches to schedule execution and monitoring. In particular, several proactive approaches to synthesize plans retaining temporal flexibility have been described in [24, 23].

A different research activity has been related to a study previously carried out for the European Space Agency (ESA-ESOC) in the framework of the Mars Express mission. Specific research results are described in [40, 41].

In a different project, called RoboCare, a scheduling system has been integrated with a sensor network to produce an Intelligent Sensorized Environment to monitor elderly people at home [5, 10]. Modeling work needed to taylor the scheduling system is described in [38].

Other activities have been dedicated to the study of architectures for integrating planning and scheduling features. An approach fully based on a constraint-based formalization is presented in [11]. A hybrid integration schema is described in [25, 37], while a component based approach is experimented in [22].

A new line of research has started to formally investigate different aspects of planning

systems: planning with incomplete information and sensing is studied in [50], while aspects related to concurrent and multi-agent planning are described in [39].

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3.1.3 Data and Knowledge Bases

The research activities of the group working on Data and Knowledge Bases are mainly oriented towards the following topics:

- Description Logics, i.e., the specification of formal languages for representing structured knowledge in different contexts, and for reasoning over such knowledge with suitable computational properties;

- Data Integration, with special focus on data integration under integrity constraints, data inconsistency, and preference-driven data integration;
- View-based Query Processing, and in particular view-based query answering, rewriting and containment;
- Information Visualization, with special focus on theoretical and application-oriented aspects of visual formalisms for data-bases and database design, on Visual Query Languages and Interfaces, Visual Data Mining, and clutter reduction;
- Mobile Information Access, with particular interest on designing applications for multiple user interfaces, and studying the impact of mobile technologies on digital libraries;
- E-learning, and in particular the study of how to make accessible information contents;
- XML Data Modeling and Data Quality Models, facing fundamental aspects of XML data modeling and modeling data with the associated quality.

The group is presently involved in several research projects, including the following: Progetto MIUR (FIRB) MAIS - Multichannel Adaptive Information Systems; Progetto CNR "VICE"; Progetto CNR-FISR "Le nuove tecniche di governo e l'innovazione tecnologica nella formazione e attuazione delle politiche pubbliche"; IST project INFOMIX (IST-2001-33570); IST project SEWASIE project (IST-2001-34825).

Group members: Enrico BERTINI, Tiziana CATARCI, Giuseppe DE GIACOMO, Silvia GABRIELLI, Stephen KIMANI, Domenico LEMBO, Maurizio LENZERINI, Valeria MIRABELLA, Antonella POGGI, Riccardo ROSATI, Marco RUZZI, Silvio SALZA, Giuseppe SANTUCCI, Monica SCANNAPIECO.

Past Group members: Andrea CALÌ, Diego CALVANESE, Luca DE SANTIS.

Members of the Data & Knowledge Bases group have been involved in the Program Committees of prestigious International Conferences and Workshops, including VLDB 2004, ICEIS 2004, DIWeb 2004, SEBD 2004, DL 2004, ACM GIS 2004.

Research activity is described in the following, by grouping works and contributions of the group for each of the above mentioned topics.

Description Logics. The goal of the research in Description Logics (DL) is to study the foundations of class-based knowledge representation formalisms, with regards to both the expressive power and the computational properties of the associated reasoning techniques. [18] starts an investigation with the goal of devising a DL that, on the one hand, is rich enough to express the fundamental constructs of class-based formalisms (ISA between

classes, typing of associations, etc.), and on the other hand, admits reasoning tasks that are polynomial in the size of the data. Among the most significant tasks investigated, and for which data complexity remains polynomial, we mention query answering of conjunctive queries over a knowledge base, which is an advanced form of query answering under constraints over databases with incomplete information. In [34], the relationship between DLs and UML class diagrams is studied, and the computational complexity of reasoning in UML class diagrams is characterized giving lower bounds and matching upper bounds. In [20, 21] finite model reasoning in UML class diagrams (i.e., the problem of checking whether a class is forced to have either zero or infinitely many objects) is studied and a reduction to finite model reasoning in DLs is devised. Also, these papers show how to use off-the-shelf tools for constraint modeling and programming to develop a finite model reasoner for UML class diagrams. The main insight in doing so is to tackle the class combination explosion by resorting to the solution of an auxiliary CSP problem. Finally, towards sophisticated representation and reasoning techniques for the Semantic Web, [23, 24] present an integration of description logics and logic programs under the answer set and the well-founded semantics.

Data Integration. Data integration is the problem of combining the data residing at different heterogeneous sources, and providing the user with a unified view of these data, called *global schema*. The interest in this kind of systems has been continuously growing in the last years, both in academy and industry. The Data and Knowledge research group has addressed several among the most important problems that arise in data integration, both from a theoretical and a practical point of view. More specifically, the problem of integrating data in the presence of integrity constraints specified on the global schema has been studied in [1] and in [36], where an in-depth investigation of query answering in the presence of data that may result incomplete and/or inconsistent with respect to the integrity constraints has been carried out. Dealing with inconsistency in data integration by taking into account preference assertions specified on the sources to be integrated is the subject of [22] and [26]. Then, a prototype system implementing most of the techniques presented in the above works and some convincing experiments have been described in [17], whereas a comparison between data integration and data federation has been the subject of [32]. The problem of modeling data integration systems has been faced in [3], and in [2], where a comprehensive framework for data integration has been presented. Furthermore, integration of information sources that may have local ontologies to be accessed through a global ontology has been considered.

Finally, we point out that members of the group participated to international activities about data integration by editing a special issue of an international journal [8], and presenting the following invited talks:

- “Quality-aware data integration in peer-to-peer system” at the International Workshop on Information Quality in Information Systems 2004, IQIS 2004, Paris, France, June 18, 2004;
- “Ontologies for interoperability”, invited tutorial by Maurizio Lenzerini at the In-

terop workshop on Enterprise Modelling and Ontologies for Interoperability, EMOI 2004, Riga, Latvia, June 7-8;

- “Data integration: past, present, and future”, invited talk by Maurizio Lenzerini at the Workshop su Metodi statistici per l’integrazione di dati da più fonti, Roma, Italy, December 9-10, 2004;
- “Information Integration under Integrity Constraints”, invited talk by Riccardo Rosati at the Dagstuhl Seminar on Logic-Based Information Agents, Dagstuhl, Germany, April 2004.

View-based Query Answering View-based query processing is the problem of processing a query posed to a database only on the basis of the information on a set of views, which are again queries over the same database. Several recent papers in the literature show that the problem is relevant in many aspects of database management, including query optimization, data warehousing, data integration, and query answering with incomplete information. In the last year, our research has been mainly focused on the study of the fundamental notions in view-based query processing of rewriting, answering and losslessness, and of the relationship between them [19]. Also, an in-depth study of the decidability of view-based query containment of recursive queries [4].

Information Visualization. Information Visualization is a young and rapidly expanding research field that incorporates knowledge from: human-computer interaction, computer graphics, data analysis, to allow users to efficiently and effectively explore abstract information visually. The basic idea is that of creating interactive visual representation of data so that the human visual capabilities can be exploited to detect interesting trends and patterns, explore overviews of large data repositories and rapidly ask for detailed information on specific objects. Our activity last year has focused on visual data mining and clutter reduction for information visualization.

Visual data mining fuses techniques coming from data mining, that are typically algorithmic and run complex data analysis in a batch fashion, with visualization that is typically interactive and allows the user to analyze data interactively. In the last year a Ph.D. thesis on the topic was produced [35] and some papers about a visual data mining environment (VidaMine) that incorporates various visual and algorithmic techniques in one integrated environment were published [28, 5, 13].

Clutter reduction deals with the problem of reducing clutter in data visualization. Clutter often arises in visualizations when trying to represent large or particularly complex datasets. Our group has investigated the problem and provided some recovery techniques. In particular, we proposed a model for defining clutter in a formal way and provided techniques to deal with it through sampling techniques [14, 15].

Mobile Information Access. The rapid growing of mobile technologies during last years brings interesting new challenges in the world of information access. The possibility to interact with mobile computing appliances anywhere and anytime opens the way to a

large range of new interesting applications. The fact that users access information while being mobile, that their context can be continuously changing, that their devices are inherently limited because of limited computational power, screen space, and interaction, that users can access shared content with a wide heterogeneity of devices, pose new interesting issues that must be address if we want to provide successful applications.

In this context we explored the problem of designing applications for multiple user interfaces, that is, applications that are designed once and can be deployed to a wide range of devices with little effort [16]. In addition, we explored the idea of using mobile technologies in the context of digital libraries and proposed new potentially interesting applications [12].

E-learning. A line of research has also investigated the issue of making accessible information contents in the area of eLearning. Main outcomes have been the development of a methodological approach and a set of guidelines [30, 31] to steer the creation of accessible eLearning courses, by identifying critical contents (in particular, for visually impaired learners) and translating-substituting them with didactically accessible alternative representations. Initial studies have also been conducted to validate the approach proposed and to inform the design of an authoring interface supporting accessibility for eLearning [6, 25].

XML Data Modeling and Data Quality Models. XML has a tree-structured data model, used to uniformly represent structured as well as semi-structured data. There is a fundamental tension in XML data modeling: (i) data represented as deep trees are often un-normalized, leading to update anomalies, while (ii) normalized data tends to be shallow, resulting in heavy use of expensive value-based joins in queries. We have proposed a solution to this modeling problem consisting of a novel multicolored trees (MCT) logical data model, which is an evolutionary extension of the XML data model, and permits trees with multicolored nodes to signify their participation in multiple hierarchies [27].

The issue of modeling data with the associated quality has been investigated. Quality of data is expressed in terms of accuracy, completeness, consistency and currency of data. An XML-based data model for representing and easily querying quality data is presented in [29]. The preliminary steps towards an algebra for evaluating the completeness dimension in the relational model are presented in [33]. The members of the group have participated to international activities concerning data quality research issues by authoring a tutorial presented at an International conference [11], editing a special issue of an international journal [7], and editing the proceedings of an International workshop [10]. Also, Tiziana Catarci has been program co-chair of the 3rd International Conference on Ontologies, Databases and Applications of SEmantics (ODBASE) 2004, and edited the proceedings of the conference [9]. Many results achieved in the field of Data Quality Models are presented in [37].

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3.1.4 Distributed Systems

The research activity of the Distributed Systems group focuses on theoretical aspects of distributed computing, design and performance analysis of parallel/distributed computing systems and middleware technology. In particular, the group is interested in the following topics:

- Theory of mobile and distributed computing.
- Dynamic distributed systems.
- Highly performing and dependable Web systems.
- Parallel/distributed simulations.
- Federated simulation systems.
- Parallel computing.

In 2004 members of the group were involved in several Program Committees of prestigious International Conferences (e.g., ICDCS, DSN, WORDS, DISC, PADS, DS-RT)

The Distributed Systems group is currently cooperating with several prestigious research institutions: INRIA and LAAS (France), Hebrew University of Jerusalem (Israel), Technion (Haifa, Israel), EPFL (Lousanne, Switzerland), University of Texas at Dallas (USA), AT&T - Research Labs (Florham Park, USA), CMU (USA), IBM Research Center T.J. Watson (USA), Georgia Institute of Technology.

The DS group is presently involved in the following research projects: EU-IST EU-PUBLI.COM; MAIS; IS-MANET; MURST FIRB “Wide-scalE, Broadband, MiddleWare for Network Distributed Services (WEBMINDS)” ; MURST FIRB “Performance Evaluation of Complex Systems” .

Group members Roberto BALDONI, Roberto BERALDI, Bruno CICIANI, Stefano CIMMINO, Giacomo CIOFFI, Carlo MARCHETTI, Alessia MILANI, Adnan NOOR MIAN, Daniele PIANURA, Marco Emilio POLEGGI, Francesco QUAGLIA, Leonardo QUERZONI, Paolo ROMANO, Andrea SANTORO, Alessandro TERMINI, Sara TUCCI PIERGIOVANNI, Antonino VIRGILLITO.

Theory of Distributed Computing

Causality. A fundamental issue of distributed computing is cooperation among processes. Cooperation includes both communication and synchronization, and is achieved by exchanging messages. An important problem in analyzing distributed computations is the amount of information. Event abstraction can be used to reduce the apparent complexity of a distributed computation. An event represents some activity performed by some process and is considered to take place at an instant in time. Typically, the lowest-level observable events, or primitive events, are computations local to processes and interprocess-communication. Thus a distributed computation is modeled as a set of events. Since among these events there could be cause-effect relations, there is also the problem of tracking these causal dependencies. This is usually tackled by timestamping events in such a way that the causal dependency or concurrency between two events can be detected just analyzing their timestamps. *Vector clocks* are the traditional mechanism to track causality on-the-fly. Their major drawback lies in the fact that each message has to carry an array of n integers, where n is the number of processes.

Moreover, since the real cause-effect relation between events depends on the application semantics, the traditional system of vector clocks does not effectively capture the cause-effect relations. In this sense, we propose a new system of vector clocks to track causality order relation in the context of distributed shared memories [10].

Distributed Shared Memory. Distributed shared memory (DSM) is a powerful abstraction for interprocess communication in loosely-coupled distributed systems. In these systems each process runs on a separate host and no physical shared memory is available. Thus, DSM provides the illusion of a physically shared memory on top of a message passing system. From an implementation point of view, this abstraction is provided by a specific software layer, memory consistency system, built between the application and the underlying message-passing system. Substantially, on each node there are an application process that invokes read and write operations on the shared memory and a memory consistency process which is in charge of the real execution of those operations. In other words, that software layer is responsible for guarantee that operations made by the application processes return consistent values. What consistent values mean depends on the consistency model we choose, that is the semantics to access the shared memory. Different consistency models can be supported, e.g. sequential, atomic, causal, FIFO (or PRAM). Each consistency model provides different features in terms of scalability, concurrency, coherence semantics. Our research has been focusing on causal consistency since it provides a good trade off between semantics coherence and performances. In particular, this consistency criterion allow wait-free read and write operations, that is each memory consistency process can locally compute the result for the operation invoked by the corresponding application process. This lead to more concurrency than that allowed by stricter consistency criteria (atomic, sequential).

Over asynchronous distributed system, causal memory abstraction has been traditionally realized through complete replication and broadcasting write operations updates to other processes. Thus, to ensure causal consistency a vector clock system has traditionally been used to track the causality order relations between operations at the distributed computation level. Since the traditional vector clocks system relies on the happened be-

fore relation introduced by Lamport and due to its well-known inability to effectively track causality, existing protocols introduce unnecessary constraints to provide causal memories. These protocols reduces the concurrency allowed by the causality order relation. For this reason, improving existing protocols has been our focus of attention. We have introduced an optimality criterion and we have implemented an optimal protocol. From an operational point of view, an optimal protocol strongly reduces its message buffer overhead. Simulation study shows that the optimal protocol roughly buffers a number of messages of one order of magnitude lower than non optimal ones based on the same communication primitive.

Theory of Distributed Computing

In the context of asynchronous distributed systems with infinitely many processes, we study the problem of maintaining connectivity among a set of processes forming a group in a dynamic context where processes can arrive to and depart from the group and processes have a partial knowledge of other processes belonging to the group.

In this setting we provided in [10] a few impossibility results and a deterministic protocol solving the connectivity problem. Moreover, in such a dynamic context, we gave (i) the specification of a service of reliable broadcast showing that it is equivalent to our connectivity problem and (ii) a specification of a service of atomic broadcast inside the group and a solution based on the protocol presented to solve the connectivity problem.

This problem has also instantiated in the context of mobile ad-hoc networks [?].

Highly performing, available Web Systems

Fault Tolerance. A recently proposed abstraction, called e-Transaction (*exactly-once Transaction*), specifies a set of properties capturing end-to-end reliability aspects in three-tier transactional systems. Roughly speaking, a system complying with the e-Transaction abstraction, ensures that a client request gives rise to a transaction that is committed exactly once, despite failures (e.g. crash of the contacted application server during the processing of the request). In this context we have presented protocols providing e-Transaction guarantees for single database and multiple databases in the back-end tier. In both cases, the key idea consists in distributing, across the back-end tier database(s), some recovery information reflecting the transaction processing state. This information is manipulated within innovative protocols that provide non-blocking guarantees even in the case of multiple databases in the back-end. These protocols also exhibit the advantages of (i) keeping the application servers within the middle-tier stateless, and (ii) avoiding any coordination among them. Our solutions are therefore suited for the case of application servers distributed both on a local area network and, more important, on a geographical scale, namely a configuration that can even provide the additional advantages of reduced user perceived latency and increased system availability.

Quality-of-Service. Quality-of-Service (QoS) provisioning in the Internet has been a topic of active research in the last few years. However, due to both financial and technical reasons, the proposed solutions are not commonly employed in practice. As a consequence, the Internet architecture is still mainly oriented to a best effort delivery model, which does

not provide any guarantee neither on the message delivery latency, nor on the probability that a service residing at some host becomes temporarily unreachable due to network congestion. In this context, we have addressed such an issue by presenting an innovative, application level protocol tailored for Web transactional applications, which attempts to reduce the impact of network congestion on the latency experienced by the end users. The intuition underlying our proposal is to exploit the intrinsic potential of parallelism commonly exhibited by Application Service Providers (ASPs) infrastructures, where the application access point is replicated over a large number of geographically distributed edge servers. At this purpose we allow privileged classes of users to concurrently contact multiple, replicated access points so to increase the probability to timely reach at least one of them and promptly activate the application business logic for the interaction with a back-end database system. We complete our proposal with an efficient mechanism that prevents multiple, undesired updates on the back-end database and, at the same time, strongly limits the additional load on the ASP infrastructure due to the increased amount of requests from the privileged users.

Actually, we are currently investigating on the possibility to exploit the parallelism proper of large ASP infrastructures in order to improve the user perceived QoS through multi-path redundancy also for the case of Web applications relying on data layers consisting of multiple back-end databases. To this end, we propose an innovative transaction management scheme, called Multi-Version Precommit (MVP), to be performed at the level of each single transactional service, which can be used as the building block to achieve non-blocking processing of multiple instances of a same transaction while still allowing safety, and thus ensuring that only one transaction instance gets committed. In essence, the MVP scheme we propose is aimed at achieving a higher level of concurrency among transactions acting on the same data, so that data blocked by a precommitted transaction are sometimes allowed to be accessed by other transactions. This is done in order to increase the flexibility in data access so to provide a mean for efficiently overcoming run-time anomalies that can have an impact on the user perceived system responsiveness.

Parallel/distributed simulation

Optimistic methods for parallel/distributed simulation let concurrent processes execute simulation events whenever they are available, optimistically assuming that the execution does not violate causality. Checkpoint-based rollback is used to recover from out of order computations.

In this context, a first objective was the definition of checkpointing mechanisms to reduce the overall checkpointing-recovery overhead. To this purpose, we have designed, implemented and tested a Checkpointing and Communication Library (CCL) for clusters based on Myrinet switches, which supports both fast message delivery and also CPU offloaded, i.e. DMA based, checkpointing functionalities. An analytical model for non-blocking checkpointing has been also developed to determine a cost effective re-synchronization semantic between CPU and DMA activities.

For the same type of cluster architecture, we have also studied how to implement efficiently event preemptive rollback operations, having the ability to interrupt the current event execution in order to timely activate rollback operations. This approach has the

ability to reduce dissemination of causally inconsistent results to peer simulation processes.

Finally, we have explored how uncertainty on the occurrence of the events within the simulated system space can be explored for increasing the flexibility in the synchronization scheme among simulation objects within the simulation system. We have exploited the uncertainty concept for both reducing the rollback overhead, in case of optimistic simulation, and more in general for reducing the forward computation cost for both parallel and serial simulation systems. Finally, we have also studied the impact of uncertainty on the response rate in case of interactive distributed simulation, and more in general in case of simulation as a tool for decision makers in time constrained environments.

Federated simulation systems

The High Level Architecture (HLA) is a standard for the integration and the interoperability of autonomous simulators. Its target is the building of complex simulation systems (federations in the HLA terminology) through the use of a Run-Time Infrastructure (RTI) acting as a middleware component, which offers a general set of services to each involved simulator (i.e. to each federate). A major problem to address in HLA federations is how to ensure correct order (i.e. timestamp ordering) for the execution of simulation events at each involved federate. This is also referred to as the synchronization problem. To cope with this problem, the HLA specification defines a suite of services, called Time-Management, to be offered by the RTI in support of synchronized execution among federates. However, this suite does not cover all the possible tasks associated with synchronization requirements. As a consequence, the application programmer is itself charged with the responsibility to circumvent such a lack and implement within the federate code modules to support those tasks. More in depth, according to the HLA specification, the RTI interface does not offer to the federate any access to services to checkpoint and/or recover its state. Hence, optimistic (i.e. rollback-based) synchronization, namely the most parallelism effective synchronization scheme also having the advantage of exhibiting performance relatively independent of the lookahead of the simulators within the federation, requires checkpointing and state recovery mechanisms to be built in the federate code. Unfortunately, the effort to implement these mechanisms inside the federate code discourages the adoption of this synchronization approach, at the cost of reduced performance.

To provide a way to address such an issue, we have designed and developed a software architecture, called MAgic State Manager (MASM), allowing completely transparent checkpointing/recovery of the federate state. Once integrated within the RTI, MASM allows optimistic synchronization to be carried out without the need for having modules for state management within the federate software, hence strongly simplifying the application programmer job. This is done by also maintaining the RTI interface compliant to the HLA standard.

The original implementation of MASM has been based on the use of both user level modules and kernel patches specifically designed to perform an ad-hoc memory management supporting checkpointing/recovery within the LINUX kernel, with parts of the software even being machine dependent (in that case the target hardware architecture was IA-32). The advantage from this approach is in the performance effectiveness achievable by performing low level operations related to the ad-hoc memory management directly within

the kernel and also in a manner optimized for the specific underlying hardware. However, that implementation results hardly portable, if not portable at all, across different types of UNIX systems or different types of hardware architectures, especially when considering non-open source operating systems and operating systems not allowing dynamic insertion of modules to augment the kernel functionalities.

To tackle such a problem, we have also developed a version of MASM completely based on user level, machine independent modules, which have been designed and developed by only relying on top of conventional UNIX system calls conforming to recent POSIX standards. Additionally, the re-engineering performed in this version allows avoiding the need for static linking of specific application libraries, which was instead required in the original MASM design. This enables straightforward portability of MASM on those UNIX systems for which the common approach to perform dynamic linking of application libraries is adopted.

Parallel Computing

Recent results in the field of functional programming have shown how the reduction of λ -terms can be mapped onto a particular graph rewriting technique known as Directed Virtual Reduction (DVR). In this technique each computational step corresponds to a transition from a graph G to a graph G' obtained through the *composition* of two labelled edges insisting on the same node. Typically such a composition originates additional nodes and edges within the graph.

By exploiting DVR we have developed PELCR, namely a Parallel Environment for Lambda-Calculus Reduction, which allows edge compositions to be performed concurrently by supporting the graph distribution among multiple machines. This environment relies on a strategy for DVR, namely *half combustion*, which we have introduced to achieve a higher level of intrinsic parallelism in the edge composition. While developing PELCR we have adopted both a message aggregation technique, allowing a reduction of the communication overhead, and a fair policy for distributing dynamically originated load among processors. Additionally, we have used a set of other optimizations, e.g. allowing the maintenance of relatively low size for the manipulated data structures so not to incur problems related to their management at the application level or due to the management of large process memory images at the operating system level. As a last note, the software modules composing PELCR have been developed with the C language and using a standard interface for message passing, i.e. MPI, thus making PELCR itself a highly portable software package.

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3.1.5 Communication Networks

The research group in Communication Networks has been recently organized by grouping research activity previously done in other research areas (algorithm engineering and distributed systems). Department members partially involved are R.Baldoni, R.Beraldi,

A.Marchetti Spaccamela; all these people still contribute to the previous mentioned research areas. In particular the group is interested in the following topics:

- Dynamic Networks
- Wireless and sensor networks

Dynamic Networks This research topic focuses on network of computers with systematic topological change. The topology change can either be triggered by a physical movement in the network or by a middleware layer that runs on top of an existing fixed network and reorganizes the topology for the purpose of improving the efficiency of communications. We are investigating several aspects of the first kind of dynamic networks in the case when the devices forming the network is composed of a collection wireless mobile devices that need to communicate and move at the same time without a fixed infrastructure, called MANET (Mobile Ad Hoc Network).

We have considered theoretical aspects in group communication in MANET [12]. In [1] we have proposed a probabilistic protocol for unicast routing in MANET, which has been generalized in [8]. Finally, results in [9] reports a novel protocol for content-based publish-subscribe. Dynamic networks arising from logical reconfiguration have been studied in [2, 3, 4]

Wireless and sensor networks

In [10] We present three localized techniques for broadcasting in large scale ad hoc networks, i.e., for the problem of disseminating a message from a source node to all the nodes in the network. Aim of the proposed techniques is to define broadcasting mechanisms that are simple, thus generating low overhead, energy efficient, for deployment in resource-constrained networks, and reliable, in that all the nodes receive the intended message with very high probability. The three schemes follow two different approaches for data dissemination. A comparative performance evaluation has been performed via simulations among the three proposed techniques and a previous solution for ad hoc broadcast. We have evaluated various metrics of interests versus different nodes distributions, which include the uniform and a more realistic Hill distribution that takes into consideration certain characteristics of sensor nodes deployment in uneven areas. Our results show that the on-line approach and one of the proposed virtual topology-based solutions offer the desirable compromise between energy saving, network load and reliability.

The mobile phone market lacks a satisfactory location technique that is accurate, but also economical and easy to deploy. Current technology provides high accuracy, but requires substantial technological and financial investment. In [5] we present the results of experiments intended to asses the accuracy of inexpensive Cell-ID location technique and its suitability for the provisioning of location based services. We first evaluate the accuracy of Cell-ID in urban, suburban and highway scenarios (both in U.S. and Italy), we then introduce the concepts of discovery-accuracy and discovery-noise to estimate the impact of positioning accuracy on the quality of resource discovery services. Experiments show that the accuracy of Cell-ID is not satisfactory as a general solution.

In contrast we show how Cell-ID can be effectively exploited to implement more effective and efficient voice location-based services.

Despite this unsatisfactory situation in [5, 6] we introduce the idea of combining Cell-ID location and voice services to improve the quality of positioning accuracy. We show how the simple and economic Cell-ID location technique can be effectively exploited to implement more effective and efficient voice location services.

In [11] we introduce Directed Diffusion Light, a variant of the well-known protocol Directed Diffusion (DD), which results in significant savings in terms of exchanged control messages and energy consumption, and improvements in network lifetime. Directed Diffusion Light defines local rules to generate a sparse virtual topology over which DD can be run. This decreases the costs associated to the required DD periodic flooding. Ns-2 based simulation results show that, when 300 sensor nodes are deployed over a squared area of side 200m Directed Diffusion Light is able to increase the network lifetime almost five times, to halve the average energy consumption, and to reduce the control overhead to one third the one of DD.

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3.1.6 Distributed Software Architectures

The Distributed Software Architectures is a new interdisciplinary area merging the competencies of some members of the Data and Knowledge Bases group and of the Distributed Systems group, with the aim of providing leading-edge research both at the infrastructure and application layer.

The topics addressed are both theoretical and application-oriented, in the fields of:

- Service Oriented Computing, with specific focus on Data Quality Support, Service Composition, Adaptive Computing and Cooperative Applications in e-Government and Other Specific Scenarios.
- Peer-to-Peer Computing, with specific focus on Peer-to-Peer Data Integration and Interoperability, DHT-based Peer-to-Peer and Autonomic Computing.
- Middleware Platform, with specific focus on Dependable Middleware, Group Toolkits and Communication Middleware.

The area comprises several projects, including the following: Progetto MIUR (FIRB 2001) MAIS - Multichannel Adaptive Information Systems; Progetto MIUR (FONDO STRATEGICO 2000) "VISPO - Piattaforma a Servizi per Distretti Virtuali"; Progetto MIUR (FONDO STRATEGICO 2000) "Società dell'Informazione - sottoprogetto SP1 - Reti Internet: Efficienza, Integrazione e Sicurezza"; Progetto IST "EU-PUBLI.com"; IST FP6 Network of Excellence "INTEROP"; IST FP6 Network of Excellence "DELOS"; Progetto IBM SUR GRANT "Hyper".

Group Members Roberto BALDONI, Roberto BERALDI, Daniela BERARDI, Tiziana CATARCI, Giuseppe DE GIACOMO, Fabio DE ROSA, Domenico LEMBO, Maurizio LENZERINI, Carlo MARCHETTI, Massimo MECELLA, Diego MILANO, Leonardo QUERZONI, Riccardo ROSATI, Monica SCANNAPIECO, Sara TUCCI PIERGIOVANNI, Antonino VIRGILLITO. Members of the group have been involved in the Program Committees of prestigious International Conferences, including ICDCS 2004, EDCC 2004, DSN 2004, DOA 2004, CoopIS 2004, WISE 2004, ICSOC 2004, BPM 2004, ODBASE 2004, ICSNW 2004, SCC 2004, SAINT 2004.

Data Quality Support Quality of data, consisting of data accuracy, consistency, completeness and currency, has always been poor, but when data were confined to single isolated contexts, it was possible to easily treat data quality problems, or even, in some cases, ignore them. Instead, modern information systems are often the result of multiple systems interacting with each other. The research is focused on data quality in Cooperative Information Systems (CISs), i.e., distributed and heterogeneous information systems that cooperate requesting and sharing information, constraints, and goals. We have proposed an overall architecture for exchanging and improving data quality in CISs [1]. The core service of the architecture is a novel example of quality-driven data integration system deployed in a P2P fashion [4, 5].

Enhancements of the results, to be applied to the general issue of quality of service, has been considered in [11].

Service Composition Services (also called *e*-Services or Web Services) are autonomous platform-independent computational elements that can be described, published, discovered, orchestrated and programmed for the purpose of developing distributed interoperable applications.

Our research has been particularly focused on automatic service composition. Service composition addresses the situation when a client request cannot be satisfied by any available service, but a composite service, obtained by combining “parts of” available component services, might be used. Our approach to automatic service composition tackles simultaneously the following issues [27]: *(i)* presenting a formal framework where services are clearly defined and the problem of automatic service composition is precisely characterized [2, 28]; *(ii)* providing sound, complete and terminating techniques for computing service composition in quite significant cases (both composite and component services modeled as finite state machines), and providing a computational complexity characterization of the algorithms for automatic composition [28, 6, 7, 29, 8]; and *(iii)* implementing our service composition techniques in an open source prototype tool [9, 28].

Our techniques are recognized at international level among the first ones which have been proved to be correct wrt the semantics. In particular members of the group gave invited tutorial on automatic service composition at the 2nd International Conference on Service Oriented Computing (ICSOC 2004), and become active members of SWSL (Semantic Web Services Language) <http://www.daml.org/services/sws1>, which is a working group of the Semantic Web Service Initiative [3].

Automatic service composition is also related to the issue of compatibility/substitutability of services. It addresses the situation in which a component service, already part of a composition becomes suddenly unavailable and another service must be found that can has “at least” the same behavior of the obsolete one. This issue has been addressed in [10].

Adaptive Computing The adaptive computing research activity is devoted to study and analyze adaptive aspects of cooperative information systems in highly mobile contexts, such as ones of Mobile Ad hoc NETWORKS (MANETs), i.e., networks of mobile devices (PDAs, smartphones, laptops) which communicate each other across wireless channels (802.11x, Bluetooth), without a wired backbone infrastructure, and in a peer-to-peer fashion. The most important peculiarities of these systems are the strict collaboration among mobile devices constituting the network. The peculiarities of software development on such specific computing platforms has been considered in [12].

The main goal is designing and developing a platform able to provide a communication software level and to support the development of distributed applications for MANET contexts, specifically, applications able to support cooperative work in MANET contexts. But such a software coordinator typically requires continuous connections (e.g., for data/information sharing, activity scheduling and coordination, etc.) among devices, and in general continuous connections are not guaranteed in MANET. So far the basic problem has been how to resolve possible disconnections of devices, to let software coordinator appropriately address connection anomalies and maintain the network connected. In [30] it has been presented a Markov-based model validated through experimental results, and has been outlined a pervasive architecture that can be built on top of such a predictive software.

In [31] the group also proposed an algebraic approach for modelling workflow progress as well as its modifications as required by MANET topology transformations. The approach is based on Algebraic Higher-Order Nets and sees both workflows and topologies as tokens in the network, allowing their concurrent modification.

Cooperative Applications in e-Government and Other Specific Scenarios The paradigm of the Service Oriented Computing (SOC) can be effectively applied in designing and deploying Cooperative Information Systems, i.e., systems in which multiple organizations integrate data and applications services across heterogeneous networks in order to achieve common goals and processes.

Specifically, in [13] a peer-to-peer service-based architecture is proposed, focusing on addressing e-Government applications and cooperative workflows spanning multiple European administrations. Conversely in [32] the applicability of the approach based on cooperative workflows and services to virtual districts is studied. Finally, in [14] the applicability of the service paradigm to digital libraries is investigated.

Peer-to-Peer Data Integration and Interoperability Currently computers are changing from isolated systems to entry points to information exchange networks. This change

of perspective makes particularly interesting to study how autonomously developed software applications can actually interoperate. Besides technological problems, which are currently being tackled with success from both industrial and scientific research, one of the most interesting and difficult issue is how to make autonomus application interoperate at the semantical level. That is, how to make possible to share a significant fragment of the data and process semantics across different software systems. In (data intensive) peer-to-peer systems, each peer exports data in terms of its own data schema. Interoperation is obtained by defining suitable mappings among the data exported by the various peers. Peers are autonomous, and such mappings are created and deleted dynamically. The fundamental problem in this setting is how to perform query answering on a peer, fully exploiting the data at the various peers which are available to it through the mappings. Semantical interoperation in (data intensive) peer-to-peer systems has been studied in [15, 16, 17, 18], and have been presented in some invited talks at DIWeb 2004 and at the ARISE Workshop on Exchange and Integration of Data.

Members of the group are involved in the research activities of the IFIP 2.6 group on data semantics. They contributed to a study concerning “emergent semantics systems”, i.e. P2P-based systems in which the semantic interoperability problem is addressed in a bottom-up fashion starting from interactions among participating peers [19, 20].

The research of the group on data interoperability is also placed within European research efforts that deal with interoperability among systems and interoperability among enterprises [21].

DHT-based Peer-to-Peer Peer-to-peer decentralized systems (P2P) have become extremely popular in the latest years. However, most P2P systems still consist in simple applications such as file sharing or chat systems. The main reason for this is that complex applications often require powerful communication primitives that nowadays are not offered by P2P systems. Our research work in this field faced this issue addressing the realization of two complex primitives, i.e. content-based publish/subscribe (pub/sub) communication and mutual exclusion, on top of existing P2P structured overlay infrastructures (Distributed Hash Tables - DHTs).

We introduced a novel architecture for implementing content-based pub/sub communications on top of DHTs. This architecture overcomes some well-known limitations of existing pub/sub infrastructures, i.e. lack of self-configuration and of adaptiveness to dynamic changes. This is achieved by devising a mediator stratum between the rich subscription semantics of content-based pub/sub systems and the simple logical addressing scheme of overlays. We identified the lack of native support for one-to-many communication by DHTs as the main impediment for efficient system operation; for this reason we also introduced a novel primitive for one-to-many message delivery, and showed, through simulation study, how this can improve performance of the architecture [33].

We also explored how to provide consistency based on distributed mutual exclusion via quorum systems. We conducted a simulation study that showed how quorum systems directly applied to P2P networks are not scalable due to the high load imposed onto the underlying network. Basing our work on these results we introduced some design principles for both grid-based and hierarchical quorum systems that help to boost their performance.

These design principles consist in dynamic and decentralized selection of quorums and in the exposition and exploitation of internals of the DHT such as the finger table. Our study showed that, combining both design principles, it is possible to minimize the number of visited sites and the latency needed to obtain a quorum [34].

Autonomic Computing Autonomic computing is an emerging approach to complex computing systems where self-managing components interact and control the whole system with a minimum human interference. The term derives from the body's autonomic nervous system, which controls key functions without conscious awareness or involvement. Autonomic techniques are especially effective in those systems where a coordinated human intervention is impossible, like in large-scale decentralized peer-to-peer applications.

In our research work we investigate how autonomic techniques can be applied to a distributed event-based communication middleware in order to provide self-management and self-adaptation for performance enhancement in large-scale scenarios. Our work focuses on two main problems of current distributed event-based middleware: the difficulty of achieving a Internet-size scalability and the low robustness due to the highly dynamic behavior of participants. We introduced distributed self-organization capabilities in the system that enable it to:

- modify at runtime the application-level network in order to improve performance. This is done through an algorithm which, working only on a local basis, creates clusters of nodes that manage subscribers with similar interest [26, 22, 35];
- rearrange nodes in the network when single nodes fail; to reach this goal we introduced a simple algorithm which is able to automatically keep the whole network always connected by just exploiting local information at nodes [23].

We developed a prototype of the system and conducted an extensive simulation study. This study show how autonomous behavior effectively allows to reduce the number of messages generated by the system thus increasing the performance and scalability of the whole system.

Dependable Middleware The effective integration of systems and software components that favors and preserves efficiency and dependability gathers growing interest from the research community. In this area, our contributions focus on the design of middleware services enabling the implementation of non-functional requirements such as high availability and fault tolerance. In particular, we investigated three-tier architectures for software replication, which turn out to be a viable mean to achieve fault tolerance of a service whose replicas are deployed on a wide area network [37]. We showed how to design middleware services that exploit a three-tier architecture to implement replication protocols that enforce a strong consistency criterion. Strong consistency provides clients with the illusion of interacting with non-replicated objects, i.e. to implement *transparent* replication. This requires all replicas to receive all the request from clients in the same order.

A three-tier architecture separates the operation of ordering of the requests coming from clients, executed by the middle-tier, from their actual execution done by the replicas (i.e., the end-tier). In this way placement of replicas is left to the service provider while the placement of middle-tier replicas is in charge to the protocol designer. The latter can then deploy them on a stable part of the distributed system to ensure a fast termination of the agreement algorithm avoiding undesirable service unavailability periods. The three-tier protocol is fault-tolerant and ensures termination (a client will eventually receive a reply) even when only one end-tier replica is correct (i.e., non-crashed).

A proof of concept of our protocols has been developed in the context of the Interoperable Replication Logic (IRL) system (<http://www.dis.uniroma1.it/~irl>), which exploits a three-tier architecture and specialized protocols to implement transparent replication of distributed objects compliant with the Common Object Request Broker (CORBA) standard.

Group Toolkits Total Order (TO) is a widely investigated communication abstraction implemented in several distributed systems. Intuitively, a TO primitive ensures that processes of a message-passing distributed system deliver the same sequence of messages. This property is extremely useful for implementing several applications. Implementations of the total order, namely group communication toolkits are nowadays widely recognized as good candidates for implementing systems with stringent nonfunctional requirements, e.g. fault-tolerance, timeliness, throughput, scalability. In this context, group communication systems have several success stories showing efficiency and effectiveness of some well-known features easing the achievement of fault tolerance and high availability. However, there are several subtleties that still deserve clarification, especially among practitioners that can get confused by the relevant amount of theoretical work done in this area.

Our research on this topic follows two directions [36]. We first present existing TO specifications organized into a hierarchy, and then we identify how specifications differ in terms of the possible behavior of faulty processes. A further issue we deem relevant for practitioners is performance. In order to assist practitioners in finding the TO implementation that best matches both applications correctness and performance requirements, we present a simple yet meaningful performance analysis of the implementations in real systems of the discussed TO primitives. The results show that the performance of a TO primitive depends on the combination of three factors, (i) the enforced TO specification, (ii) the TO protocol used to implement that specification, and (iii) the way the protocol is implemented. Further work [24] has been devoted to the comparison between a TO implementation and a message-passing asynchronous middleware platform. In particular, we compare their functionalities and their performances in order to point out the different characteristics of the two systems and identify the scenarios they are more suited to.

Communication Middleware A communication middleware is a software tool aimed at the diffusion of information over a large-scale distributed system spanning an Internet-size network. Communication middleware infrastructures following the publish/subscribe paradigm are effective scalable communication systems that allow a large-scale many-to-many interaction involving a huge number of users. Participants to a publish/subscribe

system does not interact directly but they are decoupled by a distributed event service that implements routing of notifications from producers to consumers. Producers of information (publishers) issue notifications to the event service. These are delivered by the event service to all subscribers that declared interest in it.

In our research we surveyed state-of-the-art solutions and provided a formal characterization of pub/sub interaction [25, 38, 26]. In particular we showed how decoupling introduces delays between i) the production of a notification and its delivery to subscribers (diffusion delay) and ii) the declaration of interest by a subscriber and its registration in the event service (subscription/unsubscription delay). Such delays could lead to notification loss scenarios where an event is not delivered to an intended subscriber even though it was issued when the subscription was active. We developed a model of pub/sub interaction based on a formal framework of a distributed computation. The framework abstracts the event service through the two delays, defining safety and liveness properties that precisely characterize the semantics of the event service. We studied the notification loss phenomenon by presenting a simulation study and an analytical model. The latter measures the percentage of notifications guaranteed by an event service implementation to a subscriber.

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3.1.7 Programming Languages and Methodologies

Our group hosts the reasearch activities of a number of scientists, coming from university, Research and industrial bodies.

Group members Gianna Cioni (IASI-CNR), Attilio Colagrossi (Presidenza del Consiglio dei Ministri), Carla Limongelli (DIA-Università di Roma Tre), Massimiliano Parlione (IBM), Andrea Sterbini (DSI-Università “La Sapienza”), Marco Temperini.

We work on

1. development of methodological and applicative respects of the *Open and Distance Learning* model.
2. the principles of object-oriented programming languages and their applications in distributed (object-oriented) programming;
3. modeling an inferential engine based on an axiomatization of the map algebra;

Open and Distance Learning We work on the configuration of courses, tailored on the didactic needs of the single learner.

Besides a basic mathematical logic and automated reasoning approach ([1, 2, 3]), we pursue that topic also by the adaptation and application of planning methodology ([7, 8]) and with the use of learning objectives ([9]).

Working in the ODL area, we participate and have participated into interesting EU and multinational research initiatives:

- Socrates Project no 56544-CP-1-98-1-NO-ODL-ODL *EuroCompetence*,
- *Competence Development in Internationally Oriented Companies (CIOC)*, funded by the NFU (Norwegian State Institution for Distance Education, project n. 18, 2000-2002), with participants from TEI Thessaloniki from Greece, DIS - La Sapienza from Italy, NITOL, TISIP Trondheim and Siemens Metering from Norway, Siemens from Switzerland, University of Greenwich from United Kingdom;
- *mENU* (model for a European Networked University for e-learning, elearning project n.2002-0510/001-001-EDU-ELEARN, <http://www.hsh.no/menu/>, [4, 5, 6]).
- recently the proposal of project *QUIS* (QUality, Interoperability and Standards in e-learning), has been accepted for funding, under grant n. 2004 - 3538 /001 - 001 ELE-ELEB14QUIS <http://www.tisip.no/quis/>.

Distributed object-oriented programming Being interested in inheritance in object-oriented programming, we have started an activity on the application of inheritance into distributed object-oriented programming environments. This activity has led to the definition of a scheme for supporting *distributed inheritance* in object-oriented programming. Our concern is the application of object-oriented principles in distributed computing. In

particular we focus on the use of the inheritance mechanism for the definition of class hierarchies distributed through a set of computing sites (communicating via internet or an intranet) The activity on this subject has been conducted so far through development of *Laurea* thesis, not reported here.

Map calculus We have continued our activity in modeling an inferential engine based on an axiomatization of the map algebra. This inferential engine is modeled using the predicate logic formalism supported by an existent theorem prover (Otter). Moreover we are investigating on the realization of our approach by means of several other theorem prover that are directly defined for use in algebraic logic (such as *Libra*, or *RALF*).

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- [9] G. Fernandez, A. Sterbini, M. Temperini. Component-based automated e-learning ACCEPTED FOR PRESENTATION AT WBE05

3.2 System Science

3.2.1 Biomedical Systems

The research activity in this scientific area lies, at present, in two main projects: analysis and modelling of metabolic systems and analysis of brain potentials related to motor control.

The group is made up of people from different institutions. In particular from IASI-CNR, Roma; Istituto di Clinica Medica-Policlinico A.Gemelli, Università Cattolica del Sacro Cuore, Roma; Obesity Research Center, St. Luke Hospital, Columbia University, New York; Istituto di Fisiologia Umana, Università di Roma "La Sapienza", Roma.

Group members Alessandro BERTUZZI (IASI-CNR), Alberto GANDOLFI (IASI-CNR), Geltrude MINGRONE*, Aldo Virgilio GRECO* (*Istituto di Clinica Medica-Policlinico A. Gemelli Università Cattolica del Sacro Cuore-Roma) Fabio BABILONI⁺, Claudio BABILONI⁺, Febo CINCOTTI⁺, Filippo CARDUCCI⁺ (⁺Istituto di Fisiologia Umana, Università di Roma "La Sapienza"), Serenella SALINARI.

Analysis and Modelling of Metabolic Systems In the context of this project, in the last year, the interest was mainly focused on the analysis of i) lipid metabolism, ii) new substrates for nutrition and iii) body composition using non-invasive techniques as bioimpedance analysis (BIA). i) Since a lipid rich diet seems to be involved in the pathogenesis of insulin resistance, the aim of the study was to assess the effect of an oral meal composed by saturated fatty acids on the Insulin Secretion Rate. To this purpose we are using deconvolution methods and ad hoc developed experiments and mathematical models. ii) We test the possibility of using dodecanedioic acid as an energy source during exercise. To this purpose we investigated the effect of an oral load of C12 compared to an oral glucose load during prolonged physical exercise of moderate intensity in healthy volunteers and in type 2 diabetic subjects. A compartment model of C12 metabolism was also developed. The analysis by the model and by the indirect calorimetry methods shows that a relevant amount of C12 was taken by the tissues and oxidized in association with a reduction of glucose oxidation. In addition, since C12 ingestion does not affect insulin secretion, a simultaneous lipid mobilization is promoted, translating, mainly in diabetic subjects in a larger lipid oxidation. In conclusion, C12 seems to be a suitable energy substrate during exercise. iii) We are testing the possibility of using an Electric Impedance Tomography (EIT) system to assess the composition of sections of interest in human body. Since the reconstruction of the internal tissue distribution on the basis of bioimpedance measurements is an ill-conditioned problem, the tissue composition will be computed starting from a "standard representation" of the section to be analyzed. This "standard section" should be suitably deformed to be adapted to the measured data of bioimpedance, under the constraints of the anthropometric measurements.

Analysis of Brain Potential related to Motor Control In the last year, the research activity involved problems connected with i) the study and the implementation of

EEG-based Brain Computer Interfaces; ii) The estimation of the effective and functional human cortical connectivity; iii) the analysis of the brain potential modifications in patients affected by the Alzheimer disease (AD). i) In this context, since a practical desire is to use as few scalp electrodes as possible, methods for the pre-processing, processing and classification of EEG changes in power spectra, were explored from the point of view of their application in a clinical context. In particular, a quasi-realistic head model and a standard system, as electrode montage, were used. ii) Advanced methods for the modelling of human cortical activity from combined high-resolution electroencephalography (EEG), magnetoencephalography (MEG) and functional magnetic resonance imaging (fMRI) data were tested. These methods include a subject's multicompartiment head model constructed from magnetic resonance images, multidipole source model and regularized linear inverse source estimates of cortical current density. Determination of the priors in the resolution of the linear inverse problem was performed with the use of information from the hemodynamic responses of the cortical areas as revealed by fMRI. iii) In this year the study was aimed at mapping the distributed electroencephalographic sources specific for mild Alzheimer's disease (AD) compared to vascular dementia (VaD) or normal elderly people (Nold) and the distributed EEG sources sensitive to the mild AD at different stages of severity. The impact of the cholinergic system and the cortico-cortical connections (known to be impaired in the Alzheimer disease) on the relationship between individual EEG frequencies and their relative power bands were also investigated.

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3.2.2 Hybrid Systems

The research activities of the group cover different topics ranging from the integration of hard computing and soft computing techniques, nonlinear digital and switching systems, positive systems to non conventional approaches to modelling, analysis, identification and control of dynamical systems from different areas.

Indeed the title itself of this research group summarizes the variety of methodologies and application fields. The common frame stands in overcoming and broadening the conventional approach in the analysis and design of complex dynamical systems.

National and international research projects include: MARS (Mobile Autonomous Robotic System for Mars Exploration), orthesis automation and various projects sponsored by the Italian Space Agency (ASI).

International collaborations include: the Laboratoire des Signaux et Systèmes, CNRS, Ecole Supérieure d’Electricité, Gif-sur-Yvette, Department of Electrical Engineering, University of L’Aquila.

Group members Alessandro DE CARLI, Claudio GORI GIORGI, Salvatore MONACO, Claudia CALIFANO, Paolo DI GIAMBERARDINO, Francesco LAGALA (Lecturer), Roberto RONCHINI (Lecturer), Amit BRANDES.

Emergent and innovative control strategies The research activity involved problems connected to the design of intelligent controller at higher level in the organization of Industrial automation.

Most relevant publication in this area are: [2, 3, 4, 8, 9].

Discrete-time systems As well known, the discrete dynamics is usually represented by a difference equation in the state and control variables. A new representation, based on an exponential description of the dynamics, was proposed by the participants to this research group. In this framework the discrete dynamics is described by the combined action of two terms: a difference equation representing the drift which acts as a ”jump”, and a differential equation, related to the variation of the dynamics with respect to the

control. Such a mathematical description provides a unified framework for describing systems composed by discrete and continuous components. Such an approach is applied to give series expansions of the solution to nonlinear multi-time scale differential equations in [10] while in [11] the problem of computing the normal forms at the first order of approximation is investigated and a first solution is proposed. The representation of multi input dynamics in this context is introduced and its properties are discussed in [12]. The problem of noninteracting control with stability via dynamic feedback has also been studied and solved in [13]. A first solution to the design of observers for multi output system is proposed in [7].

Digital and switching control A digital controller can be set following different approaches: by implementing a *digital equivalent* of a continuous controller, by designing a discrete controller based on a discrete-time model of the plant, taking eventually into account the coexistence of continuous and sampled signals. This last approach allows to satisfy more interesting control requirements such as dead beat or minimum time control. On the other hand, its main limits stand in the difficulty of computing sampled models and the lack of easy design methods. A new design procedure has thus been recently proposed, based on the idea of modifying the given plant by a preliminary continuous feedback for achieving a dynamics which can be easily controlled in discrete time. This hybrid control scheme enables naturally to tackle the coexistence of discrete and continuous signals. Work on this topic concerns the control of mobile robotic systems, underactuated mechanical structures, induction motors, space crafts [1].

In [5] the performance of a supervisory control scheme for largely uncertain nonlinear systems using the newly introduced state-dependent dwell-time switching logic has been studied. The proposed supervisory control architecture is shown to regulate to zero the state of the system without requiring the switching to stop in finite time. A significant class of systems to which the control architecture can be applied is the class of linear systems subject to input saturation. The case of discrete-time nonlinear systems has been studied in [6].

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3.2.3 Identification and Optimal Control

The scientific interest of the group lies in two main areas: modeling, identification and filtering for discontinuous 2D signals and dynamical systems; deterministic and stochastic optimal control.

In the first area the problems of edges detection and motion estimation from sequence of blurred and noisy images have been considered;also the problem of state estimation in respiratory gas exchange models has been studied.

In the second area the application of filtering and optimization techniques to traffic control in a wireless communication network was considered (part of this latter research was developed in the framework of the SATIP6 and SAILOR projects belonging to the Information Society and Technology programme, sponsored by the 5th Framework EU programme); moreover a global population-based optimization procedure was investigated.

Group members Carlo BRUNI, Francesco DELLI PRISCOLI, Claudia FERRONE, Luigi GRANATO, Daniela IACOVIELLO, Giorgio KOCH, Matteo LUCCHETTI, Ilaria MARCHETTI, Caterina SCOGLIO.

Edge detection and motion estimation from images time sequences These problems have received a great deal of attention due to their importance in many scientific fields (biomedicine, geophysics, communications, robotics, etc), and are by no mean trivial, since measured images are usually degraded by blurring effect and additive noise.

The problem of analyzing degraded images time sequences has been considered, assuming that the represented objects can non rigidly move and in particular that motion and deformation law is described by an affine time dependent transformation on \mathbf{R}^2 . At a first time the possibility of recovering the image content has been studied, assuming full information about the motion law. In this case the estimation problem is linear with respect to the edge sizes and the high dimensionality drawback has been solved by a suitable preprocessing procedure. As a second issue the problem of motion estimation has been considered: this is a nonlinear problem and therefore suitable approximate filtering techniques are requested. Possible linearization procedures and/or gaussian approximations have been considered.

In this framework, the applicative biomedical problem has been studied of reconstructing the pupil edge by processing the degraded data obtained by a sequence of images obtained by a suitable device (pupillometer). This problem is of remarkable importance in order to acquire non invasive diagnostic information in several pathological contexts.

Modeling and Filtering of Biomedical Systems The gas exchange mechanism in the respiratory system has been described by a simple linear dynamical model and by a more complex non linear model. The problem of estimating the state variables, of medical interest, has been solved either by the classical Kalman filtering method or by approximate (extended Kalman) filters. Analysis of the obtained approximations has been performed, with application to simulated and real data; also comparisons with the results given by classical biomedical approaches to the above problem have been performed.

Modeling, filtering and optimal control of communication networks The problem of congestion and admission control from a base station in a wireless communication network has been considered. As a first step the problem of modeling the network as a stochastic dynamical system has been tackled, with the aim of formulating an optimal control problem, transforming the quality of service requirements into suitable analytic constraints. A simplified formulation of the problem has been considered, characterized by the decomposition of the time control interval into a sequence of subintervals, thus dealing with a sequence of easy optimization problems. An on line suboptimal solution for the initial problem can be given following this approach.

Also the problem of optimal filtering in traffic estimation for bandwidth brokers has been studied. An online estimation procedure for the traffic on a communication link has been proposed, based on a dynamical stochastic model constituted by a birth and death process, on the processing of the current noisy measurements from the link and on the minimization of the estimate error variance. The estimation problem is intrinsically non gaussian but a finite dimensional solution has been given. Attention has also been devoted to the possibility of deriving approximate, computationally more convenient, filtering procedures and to the validation of these latter with respect to the optimal one.

The possibility of exploiting the above filtering and forecasting procedures has also been considered in order to formulate and solve an optimal dynamical band allocation problem, with the specific aim of minimizing the number of bandwidth renegotiations.

Population-Based Global Optimization Methods Attention has been dedicated to a population-based global optimization method which is characterized by a suitable bearths control strategy, aimed to intensify the search in the most promising subregions of the admissible set. This approach can be of interest in optimal control problem of complex dynamical systems, possibly in the presence of time changes (continuous optimization) or of unpredictable and unmodeled disturbances (stochastic optimization).

Also the potentialities of artificial life global optimization algorithms have been evaluated when dealing with the control problem of a local energetic network with a cost function which includes the amount of energy production and the associated loss.

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3.2.4 Nonlinear Systems

The research group in Nonlinear Systems is involved in the development of the following topics: analysis and control of switched nonlinear systems, control under communication constraints, dynamic feedback linearization, fault detection for nonlinear systems, nonlinear regulation, resource management in wireless systems, stabilization of nonlinear systems, stochastic stabilization of nonlinear systems.

Group members Stefano BATTILOTTI, Paolo CONFORTO, Francesco DELLI PRISCOLI, Claudio DE PERSIS, Emiliano GUAINELLA, Tiziano INZERILLI, Alberto ISIDORI, Ilaria MARCHETTI, Antonio PIETRABISSA, Dario POMPILI, Gianfranco SANTORO.

Analysis and control of switched nonlinear systems We studied in [10] the performance of a supervisory control scheme for largely uncertain nonlinear systems using the newly introduced state-dependent dwell-time switching logic. The proposed supervisory control architecture is shown to regulate to zero the state of the system without requiring the switching to stop in finite time. A significant class of systems to which the control architecture can be applied is the class of linear systems subject to input saturation. The case of discrete-time nonlinear systems has been studied in [12].

Control under communication constraints We studied how to code information generated by dynamical systems to control nonlinear systems via finite bandwidth communication channels. In [11], we showed how the class of dynamic encoders introduced by Tatikonda and Liberzon allows to achieve global stabilization results for *any* non-linear systems which is stabilizable via standard (i.e. with no encoding) feedback, no matter when the transmission of the feedback information is allowed. This result can be extended to the case when only partial state information is available for feedback. For the class of uniformly observable nonlinear systems, the result was proven in [20] by embedding a suitable observer in the encoder. In both cases of full- or partial-state measurements, an upper bound on the data rate needed to achieve the stabilizability result is exhibited. In general, this data rate will not be minimal. However, in [21], [43] we were able to design a new class of encoders by which we achieve global or semi-global stabilization results using an average data rate which can be made arbitrarily close to the minimal one. The result is obtained by recursively designing the encoder and the controller.

Dynamic feedback linearization A constructive procedure for linearizing a nonlinear system by dynamic state feedback has been given in [1] based on prolongations. The algorithm proposed computes a set of prolongation indices using a set of necessary geometric conditions.

Fault detection for nonlinear systems In the paper [3] we propose an innovative way of dealing with the design of fault tolerant control systems. We show how the nonlinear output regulation theory can be successfully adopted in order to design a regulator able to offset the effect of all possible faults which can occur and, in doing so, also to detect and isolate the occurred fault. The regulator is designed by embedding the (possible nonlinear) *internal model of the fault*. This idea is then applied to the design of a fault tolerant controller for induction motors in presence of both rotor and stator mechanical faults.

Nonlinear regulation In [4] we show how nonlinear internal models can be effectively used in the design of output regulators for nonlinear systems. This result provides a significant enhancement of the non-equilibrium theory for output regulation, which we have presented in the recent paper “Limit Sets, Zero Dynamics, and Internal Models in the Problem of Nonlinear Output Regulation”. Paper [13] deals with the design of an internal model-based semiglobal output feedback regulator for nonminimum phase nonlinear systems. By taking advantage of the design tool proposed in a recent paper by A. Isidori, we show how the problem of output regulation can be reformulated into an output feedback stabilization problem of a suitably-defined extended auxiliary system. The output feedback stabilization of the extended auxiliary system is addressed in the second part of the paper where an observer-based stabilizer is proposed. The existence of the latter is characterized in terms of necessary and sufficient conditions which can be interpreted as nonlinear non-resonance conditions between the modes of the exosystem and the zero dynamics of the controlled plant.

Resource Management in wireless systems This research has mainly been performed in the framework of three European Union (fifth and sixth framework programme) research projects (named DAIDALOS, EuQoS, and SAILOR) entailing a net financing for the year 2004 of about 300.000 Euro. These projects, performed within consortia involving major European universities/research centers, manufactures and operators, aim at the research, the design, the development and the standardisation of advanced wireless networks. The scientific responsible for all the above-mentioned projects is Prof. Francesco Delli Priscoli.

In 2004, the DIS role in the framework of these projects mainly concerned the research, the design, the simulation (by using either the NS-2, OPNET, or C++) and the implementation (Linux real-time) of:

- Connection Admission Control (CAC) procedures;
- Dynamic Capacity Assignment (DCA) procedures;

- Congestion control and scheduling procedures;
- Routing procedures;
- Broadcast and multicast procedures;
- Service delivery and service discovery.

During 2004 the research on the above-mentioned issues have been performed, in a synergistic way, by many DIS Professors, Researchers and PhD Students, also availing of the cooperation of INFOCOM Department. In 2004, about 20 work contracts have been granted on these activities to young engineers and about 40 theses have been discussed on these issues.

In 2004 several innovative contributions have been produced by properly combining competences and methodologies relevant to the following areas (among brackets the people actively involved are reported): control (Bruni, Delli Priscoli, Guainella, Isidori, Koch, Pietrabissa, Santoro), information (Inzerilli, Suraci), operation research (Mannino, Sassano, Parrello) and telecommunication (Cusani, Dini, Razzano). These contributions are reported in several papers submitted to major international conferences and reviews, several deliverables relevant to the above-mentioned projects and master theses.

Stabilization of nonlinear systems In nonlinear control theory, the equilibrium of a system is semiglobally practically stabilizable if, given two balls centered at the equilibrium, one of arbitrarily large radius and one of arbitrarily small radius, it is possible to design a feedback so that the resulting closed-loop system has the following property: all the trajectories originating in the large ball enter into the small ball and stay inside thereafter. In [33], given certain classes of nonlinear systems that are semiglobally practically stabilized, we focus on the problem of characterizing the structure of the omega-limit set that attracts the trajectories that start inside the large ball.

Stochastic stabilization of nonlinear systems We have studied in [29] the problem of globally stabilizing through measurement feedback a class of uncertain stochastic nonlinear systems in feedforward (or upper triangular) form, with state equations affected by a Wiener process adapted to a given filtration of σ -algebras and measurements affected by a sample continuous and strongly Markov stochastic process adapted to the same filtration of σ -algebras. We have proposed a step-by-step design, based on splitting the system Σ into one-dimensional interconnected systems Σ_j , $j = 1, \dots, n$; after finding for each disconnected system Σ_j a measurement feedback controller \mathcal{C}_j , put together all these controllers into one candidate controller for the overall system Σ and prove that it is possible to tune the controller parameters in such a way that the closed-loop system is stable in some probabilistic sense. To this aim, we have introduced a concept of practical stability in probability, which corresponds to having a large probability of being the state small in norm whenever the noise affecting the measurements has a “small” second order moment. We have also studied the problem of feedback stabilization of a family of nonlinear stochastic systems with switching mechanism modeled by a Markov chain

([30]). We introduce a novel notion of stability under switching, which guarantees a given probability of the system trajectories hitting some target set in finite time and remaining thereafter. Our main contribution is to prove that if the expectation of the time between two consecutive switching (dwell time) is “sufficiently large” then the system is stable under switching with guaranteed probability. We have illustrated this methodology by constructing measurement feedback controllers for a wide class of stochastic nonlinear systems.

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3.2.5 Robotics

Robotics research at DIS is committed to the development and experimental validation of planning and control techniques for manipulators and mobile robots.

The DIS Robotics Laboratory was established in 1987. The following robotic equipment is available: the 8R-dof redundant manipulator *DEXTER* (by Scienza Macchinale); the two-link underactuated arm *Pendubot* (by Quanser), equipped with a vision system; the *Butterfly*, a simple mechanism for nonprehensile manipulation; two mobile robots with two-wheel differentially-driven kinematics: *MagellanPro* (by IRobot), with an ultrasonic-infrared sensor suite and an on-board pan-tilt camera, and *Khepera* (by K-Team), a mini

mobile robot with infrared sensors; two four-legged robot dogs *AIBO* (by Sony). The Laboratory is on the web at <http://www.dis.uniroma1.it/labrob>.

Active grants include the MIUR FIRB *TIGER*, the Telethon *ASPICE*, and the MIUR *MATRICES* national projects, as well as the participation to the IST *IFATIS* european project. The national scientific contributions of the MIUR project *MISTRAL* have been summarized in the edited book [7]. In 2004, we have cooperated with the following foreign institutions: the *LAAS-CNRS* in Toulouse, the *ENSTA* in Paris, the *IRCyN* in Nantes, the *IITB-Fraunhofer* in Karlsruhe, the *University of Tokyo*, the *Johns Hopkins University*, Baltimore, MD, and the *Northwestern University*, Evanston, IL. At the national level, we have collaborations with *Scuola Superiore S. Anna* in Pisa, *DII-Università di Siena*, *DIS-Università di Napoli Federico II*, *Università Cattolica* in Roma, and *DIA-Università di Roma Tre*.

Group members Alessandro BETTINI, Massimo CEFALO, Andrea CHERUBINI, Alessandro DE LUCA, Riccardo FARINA, Luigi FREDI, Stefano IANNITTI, Raffaella MATTONE, Giuseppe ORIOLO, Paolo ROBUFFO GIORDANO, Marilena VENDITTELLI, Fabio ZONFRILLI.

Modeling and Control of Flexible Robots Joint elasticity is the main source of vibration in industrial robots, when harmonic drives, belts, or long shafts are used as transmission elements, and is expressly introduced in compliant manipulators for a safer human-robot physical interaction. For robots with elastic joints, we have shown that a dynamic state feedback controller allows to obtain exact linearization and input-output decoupling, a result useful for trajectory tracking tasks. The dynamic feedback linearization algorithm has been extended also to the mixed case of robots having only some joints elastic, while the remaining ones are assumed to be rigid [8]. Interestingly, dynamic feedback can be used also for regularizing the control effort of ill-conditioned static state feedback laws based on system inversion. For example, this happens in robots with visco-elastic joints, when damping of the springs at the joints is present but small [15]. For regulation problems, a PD control law with on-line gravity compensation has been proposed, which asymptotically stabilizes any desired fixed configuration using only motor measurements [9]. This controller has been experimentally evaluated on the *DEXTER* arm [16]. The same approach has been extended to regulation tasks in the cartesian space, realizing a compliance control scheme. A gravity-biased motor position variable is used for gravity compensation, as well as in the direct and differential kinematics terms of the controller [17].

Lightweight manipulators with very slender mechanical design usually implies the presence of link flexibility, with associated control difficulties (e.g., non-minimum phase of the end-effector position output). We have provided a solution to the problem of planning and controlling rest-to-rest motions in given time for a single flexible link, with or without modal damping. The approach has been extended in different ways also to the nonlinear case, in particular for the two-link *FLEXARM* available at *DIA* and for general planar multi-link flexible arms, with experiments performed at *IRCyN* [1].

Underactuated Robots Underactuated mechanical systems have less command inputs than generalized coordinates, raising very challenging planning and control issues. The problem of planning point-to-point motions for general robotic systems subject to non-integrable differential constraints (of first order, i.e., on velocities, or of second order, i.e., on accelerations) has been studied in [6]. Four case studies have been considered: the plate-ball manipulation system, the general two-trailer mobile robot, a two-link robot with flexible forearm, and a planar robot with two passive joints in the absence of gravity. The first two case studies are non-flat nonholonomic kinematic systems, while the last two are flat underactuated dynamic systems. The planning methods are based on the dynamic feedback linearization and iterative steering techniques. As a result of a cooperation with the *Northwestern University*, a motion planning algorithm has been proposed in [2], achieving a minimum number of control switchings in a rest-to-rest motion for the *Snakeboard* platform. The approach exploits the kinematic controllability property of underactuated dynamic systems. Other work is under way on the *Pendubot* and the *Butterfly* systems available in the Lab.

Planning and Control for Nonholonomic Systems Wheeled vehicles in rolling contact with the ground or dextrous manipulation devices are robotic systems subject to nonholonomic (i.e., non-integrable) first-order differential constraints. A general framework for the stabilization of general nonholonomic systems, i.e., systems that do not possess special properties such as exact nilpotentizability or flatness, is presented in [18]. Stabilization to a desired configuration with an exponential rate of convergence is obtained combining two tools: an iterative control scheme and a nilpotent approximation of the system. Convergence, stability, and robustness of the proposed scheme are proved and illustrated by an application to the plate-ball manipulation system. Inspired by another nonholonomic system of this kind, the general 2-trailer mobile robot, a more theoretical study was performed in cooperation with *ENSTA* and *LAAS-CNRS* concerning the use of nilpotent approximations for systems with singularities [3]. It is shown how to build a nonhomogeneous nilpotent approximation whose vector fields vary continuously around singular points, proving also that the associated privileged coordinates provide a uniform estimate of the control distance.

Visual Servoing For wheeled nonholonomic mobile robots equipped with an on-board camera, we have developed in cooperation with *DII-Università di Siena* a visual servoing algorithm based on epipolar geometry that allows to steer the robot toward a desired target object using only image-based feedback information and no a priori knowledge of the 3D structure of the object [10]. In particular, the epipoles are first extracted by suitably processing the current and the desired image, and then driven to the desired location by a control law based on input-output exact linearization. In [19], we have presented a two-level visual scheme for driving a nonholonomic mobile robot to intercept a moving target. On the lower level, the pan-tilt platform which carries the on-board camera is controlled so as to keep the target at the center of the image plane. On the higher level, the relative position of the ball is retrieved from the pan/tilt angles through simple geometry, and used to compute a control law driving the robot to the target. The proposed visual

interception method is validated through simulations as well as experiments on the mobile robot *MagellanPro*.

Exploration using Probabilistic Techniques The use of probabilistic techniques for motion planning among obstacles has received increasing attention, especially for high-dimensional problems in complex environments. In this area, we have proposed a method for sensor-based exploration of unknown environments by a mobile robot [11]. The method is based on the randomized incremental generation of a data structure called Sensor-based Random Tree (SRT), which represents a roadmap of the explored area with an associated safe region. Two exploration strategies have been designed, based on different perception assumptions: one is conservative and particularly suited to noisy sensors (SRT-Ball), while the other is confident and performs better in cluttered environments (SRT-Star). The two strategies have been critically compared by simulations as well as experiments on the *MagellanPro* robot. A frontier-based modification of the basic SRT method has also been devised in order to improve its efficiency by biasing the randomized generation of configurations towards unexplored areas. In [12, 20], effective implementations of this strategy are proposed for SRT-Ball and SRT-Star, with comparative simulations showing the benefits of the modified techniques. Another application of probabilistic methods is proposed in [21], where we consider the problem of planning collision-free motions for a mobile manipulator whose end-effector must travel along a given path. Algorithmic solutions are devised exploiting the natural partition of generalized coordinates between the manipulator and the mobile base, whose nonholonomy is accounted for at the planning stage. The approach is based on the randomized generation of configurations that are compatible with the end-effector path constraint. The performance of the proposed algorithms is illustrated by several planning experiments.

Legged Locomotion Various aspects of biped locomotion are analyzed in [14]. A walking generator/controller for a planar 5-dof biped robot with passive feet is first developed following an input-output feedback linearization approach and suitably exploiting the resulting zero dynamics. The obtained method is fully parametric, so that walking can be achieved in principle with different step lengths and locomotion speeds. Some of the ideas used in the planar case are then extended and used to devise a three-dimensional walking generator/controller based on the inverted pendulum approximation. The resulting scheme was implemented and successfully tested on the humanoid robot *UT-Theta*, developed at the Department of Mechano-Informatics of the *University of Tokyo* [22]. This prototype is equipped with an innovative knee joint which can switch between active and passive operation, requiring the design of a specific hybrid controller [23].

Fault Detection and Isolation in Robots and Nonlinear Systems In the fault detection and isolation (FDI) problem for controlled plants, detection consists in generating on-line diagnostic signals in correspondence to potential faults that may affect system components; fault isolation occurs when each specific fault can be discriminated from all other faults or disturbances. Based on the use of generalized momenta, we have developed

an FDI scheme for any type of actuator fault in robot manipulators, providing also an adaptive version to cope with uncertainties in robot dynamics [13]. The further issue of fault identification (i.e., estimating the time evolution of the fault input) has been addressed in [24], using an \mathcal{H}_∞ -based observer design. All these schemes have been tested experimentally on the *Pendubot*. For Euler-Lagrange mechanical systems affected by possibly concurrent faults acting at the acceleration level, necessary and sufficient conditions for FDI and a complete design of the residual generators have been given, addressing also the issue of kinematic singularities [25]. As an application, the detection and isolation of faults of a force/torque sensor located at the robot end-effector has been considered [26]. The same FDI concept can be used also to detect collisions of a robot arm at any point along the structure and in the absence of extra (force or contact) sensors [27]. In addition, a suitable handling of the residual signals allows to perform a hybrid force/motion task while in contact with a compliant environment of unknown geometry.

For general nonlinear systems, the differential-geometric approach to FDI has been extended in [28] to two relaxed problems: detection and isolation of faults belonging to a given set, and construction of a minimal set of faults that can be detected and isolated and that contains an assigned set of faults (possibly, a singleton). Using these results, one can also determine weaker necessary (and sufficient) conditions that allow isolation of single faults under the assumption of their non-concurrency. In this framework, a suitable procedure has been also proposed for modeling state sensors failures so as to yield a faulted model which is affine in the inputs. The resulting fault inputs are always concurrent in blocks and an hybrid-type FDI scheme can be defined, based on continuous-time residual generators and on the combinatorial processing of their outputs. Considering multiple non-concurrent faults of sensors and actuators, the complete procedure has been presented for two case studies: a three-tank fluid heating system [29] and the *IFATIS* pilot plant [30].

Medical Robotics An example of the potentialities of robotics methodologies applied to Medicine is given by the *Steady-Hand* system developed at the *Johns Hopkins University* for assistance in surgical operations. Vision and force sensing are integrated with virtual fixtures in order to help the surgeon in driving a hand-held tool during fine motion. As a result of a cooperation with one of our Ph.D. students, virtual fixtures have been defined and tested experimentally for different motion tasks (positioning —both at micro and macro scales, tracking, avoidance of obstacles), in association with a human-robot cooperative control scheme [4]. Moreover, using our past experience on fuzzy-based processing of sensor data in mobile robots, fuzzy rules have been applied to genotypic data from HIV patients for classifying performance and thus selecting alternative drug therapies [5].

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3.3 Management Science

3.3.1 Combinatorial Optimization

The research activity of the Combinatorial Optimization Group is mostly devoted to theoretical and computational aspects related to i) design of telecommunication networks and ii) automated data correcting.

The group is currently cooperating with Maastrich University, Konrad Zuse Zentrum fr Informationstechnik Berlin, Universit di Roma Tor Vergata, Universit dell'Aquila, Universit di Lecce and Politecnico di Milano. Also, it is cooperating with the Italian Public Authority for Telecommunication and with ISTAT. It is currently involved in several national and international research project, including the MURST project "Optimization Models and Algorithms for Design and Management of Telecommunication Networks", the MIPAF project ADM (Agricultural Data Mining) and the European IST Project SAILOR (devoted to third generation networks).

Group members Renato BRUNI, Silvia CANALE, Carlo MANNINO, Sara MATTIA, Emiliano PARRELLO, Antonio SASSANO.

Antenna positioning and frequency assignment in wireless networks Radio and television broadcasting, cellular mobile telecommunication systems, satellite-based cellular networks and many other important civil and military applications require a huge number of antennas to be located on the territory so as to maximize the coverage or some kind of measure of the service. All wireless applications make use of the radio spectrum to establish communications between a transmitter and a receiver. Since the radio spectrum is a limited resource, an important phase in wireless network design is to efficiently solve the Frequency Assignment Problem (FAP), that is the problem of assigning available radio frequencies to the base stations of a radio network in such a way that interference requirements are satisfied and suitable objective functions are optimized. Also, several radio-electrical parameters (such as emission power and antenna tilt) can be established in order to increase the quality of the received signals. A comprehensive model along with a multi-phase solution algorithm is proposed in [12] to tackle the problem of designing digital and analog broadcasting networks operating in a same geographical area. A relevant parameter for digital broadcasting network is the transmission delay (or *time offset*). An algorithm for the time offset optimization problem is studied in [2].

Graph Theory. Interval graphs and their extensions (such as graphs with fixed boxicity) play a crucial role in graph theory and network optimization. A generalization of interval graphs, the so called *k-thin* graphs are introduced and their properties are investigated in [3], [15].

Network Design The problem of designing good quality and low cost networks arises in several real-life applications like transportation and telecommunication ones. One of the most important problems of this kind is the Network Loading Problem (NLP). The problem is the following: given a set of traffic demands to be routed between the nodes of the network, the goal is to choose capacities for the edges of the graph such that all the demands can be shipped simultaneously, minimizing at the same time the capacity installation cost. The aim of the work is the study of the properties of the Network Loading polyhedron, in order to characterize all valid inequalities, give condition for these inequalities to be facet-defining, develop separation techniques to be used within Branch&Cut framework to solve the problem, test the algorithm using real-life unsolved instances. The results are reported in [4].

Satisfiability and Minimally Unsatisfiable Subformula Selection Propositional satisfiability (SAT) is a central problem in many different fields, e.g. Artificial Intelligence, Cryptography, Database Systems, logic circuit design and testing. Moreover, SAT carries considerable theoretical interest as the original NP-complete problem. Therefore, the study of practically efficient algorithm for solving such problem is very important. A computational evaluation and comparison of a new family of conflict-based branching heuristics for evolved DPLL SAT solvers is reported in [5, 13]. Such family of heuristics is based on the use of new scores updating criteria developed in order to overcome some of the typical unpleasant behaviors of DPLL search techniques. The obtained solver is

described in [6].

Another connected problem, in the case of unsatisfiable formulae, is the selection of a minimally unsatisfiable subformula within a formula. Such problem is approached by using a modification of Farkas' lemma in [8].

Data Mining, Classification and Error Correction Data Mining is in general the process of extracting useful information from large amount of data. In particular, two relevant data mining tasks are Classification and Error Correction.

Given a set of data which are already grouped into classes, the Classification problem consists in predicting whose class each new data belongs to. Among the various approaches to the problem, the methodology of the logical analysis of data is considered. With respect to the standard procedure, enhancements based on probability considerations are presented: the quality of each cut-point is evaluated [7], so that a weighted set covering problem for the selection of the optimal support set is solved in [11].

When dealing with large datasets, a common problem is the localization of errors and the reconstruction of corrupted information, called Error Correction. Such problems are generally tackled by using a set of rules. By using a linear inequality encoding for such rules, integer linear programming models of the above problems are developed and solved in [1, 9]. The proposed approaches have strong computational advantages on other existing approaches, and it have been used in the correction of the Italian Census of Population 2001.

Computational Molecular Biology, Peptide Sequencing Several computationally demanding problems arise from biological and medical research. In particular, Sequencing problems are among of the most important and frequent. Data obtained from the mass spectrometry analysis of a generic compound, constituted, according to specific chemical rules, by an unknown sequence of components, should be processed in order to determine such sequence. By formulating a mathematical model for such combinatorial problem, structural limitations of known methods are overcome, and efficient solution algorithms based on branching are presented in [10]. Moreover, spectrometry data can be used to build a propositional logic formula, whose models represent coherent interpretations of the set of data and can be used to generate all possible correct results of the analysis itself [14].

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3.3.2 Nonlinear Optimization

The research activity of the Nonlinear Optimization group is devoted to the theoretical analysis, the development and the computational experimentation of methods for solving Nonlinear Optimization problems. The solution of problems arising from real world application is also of interest.

The Nonlinear Optimization group is currently cooperating with: Istituto di Analisi dei Sistemi ed Informatica IASI-CNR; Dipartimento di Ingegneria Elettrica, Università di L'Aquila; Istituto Nazionale per Studi ed Esperienze di Architettura Navale INSEAN.

During 2004, the Nonlinear Optimization group has been mainly involved in the MIUR-FIRB National Research Program "Large Scale Nonlinear Optimization".

Group members Gianni DI PILLO, Francisco FACCHINEI, Giovanni FASANO, Luigi GRIPPO, Giampaolo LIUZZI, Stefano LUCIDI, Laura PALAGI, Veronica PICCIALI, Massimo ROMA, Marco SCIANDRONE [IASI-CNR].

Unconstrained Optimization The research activity in unconstrained optimization has been mainly devoted to the definition of new methods for solving large scale problems. In this context, Conjugate Gradient-type algorithms have been studied from both theoretical and computational point of view. Their use within unconstrained optimization framework led to the definition of global convergent algorithms which cope with indefinite Hessian matrices. To handle this latter case, a complete relationship between the Lanczos and the planar Conjugate Gradient algorithms has been carried out, too. Moreover, the problem of iteratively computing negative curvature directions without any matrix storage and its use within truncated Newton methods has been considered [1, 5, 7]. Finally, a truncated Gauss-Newton method for large-scale nonlinear least-square problems has been proposed and numerically tested [6].

Constrained Optimization Problems with both general constraints and constraints with a particular structure have been addressed. In particular, a new derivative-free algorithm globally converging towards stationary points for the finite minimax problem has been defined by converting the original problem into a smooth one by using a smoothing technique [9]. Moreover, a particular class of nonlinear mixed variable optimization problems has been considered and two globally convergent minimization algorithms have been defined. The peculiarity of these problems is that the structure and the number of variables depend on the values of some discrete variables and for fixed values of the integer variables, the corresponding continuous optimization problem contains no constraints and a large number of variables [3].

Nonlinear optimization algorithms for training neural networks have been considered, too. In particular, an algorithm for training Support Vector Machines (SVM) based on decomposition methods has been proposed [10].

Finally, a primal-dual algorithm superlinearly convergent to second order stationary points of nonlinear programming problems has been improved with the aim of tackling large dimensional sparse cases [4].

Applications in Industrial Engineering An important aspect of the research was the definition of optimization algorithms for solving problems arising from real world applications. In particular, two important applications have been considered: the design of small low-cost, low-field multipolar magnet for Magnetic Resonance Imaging with a high field uniformity and the optimal design of induction electric motors. As regards the first application, the considered design problem has been converted into a global optimization one and this latter problem has been solved by means of a new derivative-free global optimization method which is a distributed multi-start type algorithm controlled by means of a simulated annealing criterion [2]. As regards the second application, the optimal design problem has been formulated as a mixed variable programming problem and solved by means of two different solution strategies [8].

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- [5] G. Fasano. Lanczos-Conjugate Gradient method and pseudoinverse computation, in unconstrained optimization. Submitted to *Journal on Optimization Theory and Applications*, 2004.
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3.3.3 Industrial Economics

This group mainly investigates the theoretical explanations and empirical implications of three interrelated phenomena: (i) technological innovation, (ii) strategic behavior of Multinational Enterprises (MNE) in R&D intensive industries, (iii) national and multi-lateral policies on foreign direct investment (FDI) and globalization. The main research topics are connected with the analysis of FDI and R&D in oligopolistic industries. Also aspects of regulation and competition policy are dealt with. We have participated to a project on “Multinationals and Innovative Strategies by Firms: Implications for Italian Competitiveness” financed by the Italian Ministry for University and Education (MIUR). We have been collaborating with several European Universities, such as Leuven Katholieke Universiteit, Belgium; University of Reading, UK; Universidad Complutense de Madrid, Spain.

Group members Eloisa CAMPIONI, Maria Luisa PETIT, Francesca SANNA-RANDACCIO, Roberta SESTINI.

Production and R&D Internationalization Several projects were carried out in this area. A first strand of research examines the trade-offs faced by a multinational company when choosing whether to assign a foreign subsidiary an active role in innovation, deciding thus if its R&D should be centralized or, at least partly, decentralized. The model focuses on how the interplay of internal and external knowledge flows interacts with the nature of host market competition to influence the choice of the multinational to effectively disperse internationally its R&D. Our analysis addresses both the case of R&D undertaken abroad in association to production and that of pure research labs abroad [4]. The drivers of R&D decentralisation are also analysed [2]. A second strand of research has examined a different feature of R&D internationalization. In particular we have analyzed whether the possibility to absorb technological knowledge operating in another country can be an incentive for a firm to invest abroad (“technological sourcing through FDI”). Obviously, also local firms take advantage of the closer location of the multinational firm, absorbing more quickly the technological knowledge produced by the latter. Introducing this “location” element into the analysis, we studied how these differences in the transmission of knowledge may affect the firms’ incentive to innovate and their behavior in an international market [3]. Finally we analysed the issue of multilateral FDI policies. The failed attempt to launch a multilateral negotiation on FDI rules within the Doha Round is discussed [1]. It is argued

that dropping FDI from the Doha agenda is not a success for developing countries and represents a missed opportunity also for developed countries.

Regulation and Competition Policy This line of research investigates alternative regulatory policies that affect the viability of pricing discriminatory behavior by a regulated incumbent firm. We built up a stylized model of an industry with product differentiation where there are (potentially) two firms, an incumbent and an entrant (or a competitive fringe). We studied how two different regulatory schemes - Relative and Absolute - might influence pricing decisions by the incumbent firm, the development and the extent of competition, and social welfare. We found that the Relative regime is not particularly effective in protecting captive customers. However, due to the fact that it makes more costly for the incumbent regulated firm to reduce its competitive price, this is generally higher than under the Absolute regime. Hence, the Relative regime is more able to foster competition, as it may induce entry by some firms that would not be active under the Absolute regime or a greater supply being the number of firms invariant. The effects on aggregate welfare are not clear-cut [5].

Underprovision of Quality and Regulation Another line of research has studied the functioning of a market for an experience good. Given that informational problems bring about inefficiencies, possible policies able to improve upon second-best equilibria are compared, with a special focus on the role of self-regulatory organisations. In particular we introduced a Self-Regulating Organisation (SRO) that sets a common minimum quality standard. The SRO represents a self-enforcing credible mechanism if there is an incentive for each member to punish eventual deviant members. It is found that a SRO is always enforceable for low-type firms, provided there is some consumers' mobility, while it is such for high-type firms if the population of sellers is not too heterogeneous in terms of skill levels [6].

Optimal design of contractual interactions and the macroeconomy This line of research deals with the interactions between several heterogeneous agents in economic situations affected by incomplete information problems. We focus on the optimal design of contracts when one party can simultaneously sign many agreements. We contribute to the theoretical discussion on the optimal mechanism design in a context of multi-principal multi-agent games with the aim to clarify some counter-intuitive results [8]. In a parallel research line, we are interested in the relationship between firms' access to credit markets and business cycles. We set-up a sequential economy, where the business fluctuations reflect fundamental distortions in the intertemporal structure of production. Credit markets help sustaining the viability of the economy along an out-of-equilibrium transition [7].

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3.3.4 Industrial Organization and Management

Our research field comprises general issues in industrial economics and organization, as well as specific sectors, such as network industries. In particular, we deal with the following topics:

- regulation and competition in the pharmaceutical industry;
- transport networks' management;
- signalling models in oligopolistic competition;
- information and communication industries;
- auction-based market mechanisms;
- multicriteria decision making and corporate strategy;
- accounting and finance.

We have worked on a number of applied research projects funded by public institutions and firms. In particular we have analysed for Wind Telecomunicazioni S.p.A. the implementation problems of the new regulatory framework for electronic communications markets within the European Union; in this context we have carried out an in depth analysis of the market for local loop unbundling from a regulatory and antitrust point of view. We

are among the proponents of the Centre for Transportation and Logistics Research that has been founded at the University of Rome "La Sapienza" in 2003 and has been financed by the Ministry of University and Research as a centre of excellence.

Group members Alessandro AVENALI, Anna BASSANINI, Domenico LAISE, Claudio LEPORELLI, Giorgio MATTEUCCI, Alberto NASTASI, Pier Luigi PICCARI, Pierfrancesco REVERBERI.

Regulation and competition in the pharmaceutical industry National regulation generates price differentials between countries stimulating arbitrage by international distributors. Harmed manufacturers counteract using vertical price-squeeze or non-price discrimination. We show that: i) either under regulatory commitment or discretion, there are non-linear relationships between technology/market conditions and the first-movers pricing strategy; ii) public service obligations on distributors allow regulators to manipulate parallel exports so as to improve national welfare; iii) to prevent sabotage, regulation should provide manufacturers with adequate countervailing incentives; iv) coordinating national agencies alleviates negative regulatory and market externalities. Therefore, static and dynamic efficiency concerns may arise within a regional exhaustion regime of intellectual property rights. [11].

Transportation networks' management The growing importance of inter-network exchanges in infrastructure-based utilities influences regulatory choices and access pricing for downstream services using the networks. We analyze this problem in a setting where the infrastructure managers of two bordering countries are in charge of pricing the access to their networks for downstream transport firms that provide international services. Network costs can be financed through public funds and user charges. In this context, access prices are affected by the incomplete internalization of consumers' surplus and infrastructure costs; we analyze how this distortion at the access pricing level generates a distortion in the levels of public funds dedicated to infrastructure financing.[7]

Signalling models in oligopolistic competition We carry out an analysis of the entry strategies in oligopolistic industries in the presence of asymmetric information. In particular we consider a context where a home firm signals her private cost information by expanding in a foreign firms country. Credible signalling to deter counter-entry may occur through a direct investment (but not through exports), and may even entail entering an unprofitable market. While this produces social benefits, uninformative signalling may be welfare-reducing. Hence, we argue that moderate to high location costs may be socially desirable. We also show that there are not simple monotonic relationships between technology/demand conditions and firms entry modes. Thus, the signalling interpretation of international expansion makes it possible to explain some controversial empirical findings on a theoretical round. [12].

Information and communication industries We analyse operational implications of local loop unbundling to set up appropriate price squeeze tests to prevent market foreclosure. We apply these tests to the 2002 Reference Offer proposal for residential fixed access in Italy, and find that competition might be frustrated. Consistent with the European New Regulatory Framework, we propose remedies that pursue dynamic efficiency, providing incumbents with adequate incentives to share with entrants both the benefits from scale economies and the costs of competition. We also recommend assessing the welfare effects of a geographic de-averaging of the unbundling wholesale price. [4, 5, 9].

Auction-based market mechanisms We study how scarce resources can be traded via auction mechanisms. In particular, we focus on combinatorial auctions, which enhance the efficiency of market exchanges in environments characterized by complementarity or substitutability relations between the goods at sale [8]. However, this type of auction requires dealing with hard optimization problems, that require specific solution techniques [6, 8, 10].

Multicriteria decision making and corporate strategy Our research illustrates the advantages connected to applying the multicriteria methodology founded on the notion of outranking to the benchmarking analysis of organizational learning capability. In fact, such a methodology solves the multicriteria benchmarking problem without incurring in the theoretical and empirical disadvantages of the traditional approaches [1, 2, 3].

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3.3.5 Integrative Modelling, Simulation and Data Analysis

The *Integrative Modelling, Simulation and Data Analysis* group was established at DIS in 2004. The research takes advantage of methodologies coming from diverse disciplines such as large scale dynamical modelling, simulation and optimization. Reference applications are in the broad field of complex system management science with the aim of developing models and testing efficient algorithms for processing large amount of real world data coming from industrial and biosystems engineering by means of an integrative approach.

Current main research areas are: Embedded and Reactive Real-Time Systems in Automotive Management, Computational Optimization in System Biology, Image Processing and Computer Vision, Complex Algorithms and Data Mining.

Ongoing projects:

- Advanced Research on Architectures and Design of Electronic Systems
- Experimental analysis, modelling and simulation of the DNA damage response in *E. coli*
- Dynamic clustering methods for genome wide expression data using mRNA decay data
- Long term effects of perturbations in metabolic networks
- Analysis and characterization of the microstructure of materials from SEM images

International and national collaborations:

Istituto di Biologia e Patologia Molecolari (CNR), Istituto Nazionale di Ricerca per gli Alimenti e la Nutrizione, Istituto Superiore di Sanit , Department of Biomedical Engineering (Boston University), German Research Center for Biotechnology, IASI (CNR), PARADES, Di.M.S.A.T. (Universit  di Cassino), Fonderghisa S.p.A.

The members of the group are: Luca BENVENUTI, Alberto DE SANTIS, Lorenzo FARINA and Ilaria MOGNO (PhD student)

Embedded and Reactive Real-Time Systems in Management Embedded systems are electronic components integrated onto a physical plant. The most challenging embedded systems, called reactive real-time systems, control the behaviour of the plant so that models and control techniques as well as simulation tools are needed when the algorithms are implemented on a given HW-SW architecture.

Most relevant publication in this area are: [5], [6].

Computational Optimization in Systems Biology Computational optimization in systems biology is a research program that links biologists and engineers in a multidisciplinary approach to the systematic analysis of large scale and complex dynamical biological phenomena. The main interest is on modelling (positive systems) and on the analysis of the dynamic properties of interacting genes, metabolites and proteins in the cell.

Most relevant publications in this area are: [1], [2], [3], [8], [9], [10], [11].

Signal Processing and Computer Vision Digital signal processing is concerned with the theoretical and practical aspects of representing and extracting information from real data; it has a significant impact in most of the scientific and technical areas of management sciences. Current applications of interest in the research group are within the areas of industrial engineering, man-machine interaction, medical technology, science of materials and mechanical structures fault diagnosis.

Most relevant publication in this area is: [4], [7], [12].

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- [15] A. De Santis, D. Iacoviello, Optimal Piecewise - Constant Segmentation of Images by Neural Networks, *submitted*
- [16] L. Benvenuti and L. Farina, Nonnegative matrices in digital signal processing *submitted*
- [17] L. Benvenuti and L. Farina, The Geometry of the Reachability Set for Linear Discrete-time Systems with Positive Controls *submitted*

