

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

Research Report
2005

**Dipartimento di Informatica e Sistemistica (DIS)
“Antonio Ruberti”**

DIS-Eudossiana
Via Eudossiana 18, 00184 Roma, Italia
Phone +39 06 44585360
Fax +39 06 44585367

DIS-Buonarroti
Via Buonarroti 12, 00185 Roma, Italia
Phone +39 06 482991
Fax +39 06 47825618

DIS-Salaria
Via Salaria 113, 00198 Roma, Italia
Phone +39 06 49918487
Fax +39 06 85300849

Web site: www.dis.uniroma1.it

Contents

1	Introduction	1
2	General Information	3
2.1	Location	3
2.2	Facilities	3
2.3	People	5
2.4	Ph.D. Programs	8
2.5	Contracts signed in year 2005	10
2.6	Awards	11
3	Research Activity	12
3.1	Computer Science	12
3.1.1	Algorithm Engineering Group	12
3.1.2	Artificial Intelligence	24
3.1.3	Data and Knowledge Bases	37
3.1.4	Distributed Systems	43
3.1.5	Communication Networks	53
3.1.6	Distributed Software Architectures	55
3.1.7	Programming Languages and Methodologies	65
3.2	System Science	68
3.2.1	Biomedical Systems	68
3.2.2	Hybrid Systems	71
3.2.3	Identification and Optimal Control	74
3.2.4	Nonlinear Systems	77
3.2.5	Robotics	83
3.3	Management Science	92
3.3.1	Combinatorial Optimization	92
3.3.2	Nonlinear Optimization	96
3.3.3	Industrial Economics	99
3.3.4	Industrial Organization and Management	102
3.3.5	Integrative Modelling, Simulation and Data Analysis	105

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 2005.

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 31 full professors, 20 associate professors, 10 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 (94 of which active) 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 provides resources and services in an environment that fosters free and open enquiry, and serves 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.

Research Laboratories

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

ALCOR The Autonomous Agent Laboratory for Cognitive Robotics (ALCOR) is devoted to develop autonomous systems for operating in unstructured and rescue environments, as well as vision based security systems.

Person in charge: Fiora PIRRI.

Location: DIS-Salaria. <http://www.dis.uniroma1.it/alcor>

DAMS DAMS: The Laboratory of Data Analysis, Integrative Modelling and Simulation 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

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.

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

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.

SIED Laboratory The “Intelligent Systems for Emergencies and civil Defense” laboratory was 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>

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

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 the teaching activities of third to fifth year of the laurea degree.

Person in charge: Roberto BALDONI.

Location: Via Eudossiana 18, Roma.

2.3 People

Director of the Department

GIANNI DI PILLO

Administrative Secretary of the Department

SANDRO MANCINI (until 04/17)

MARIA PIA VANDILLI (starting from 10/01)

Faculty members*Professors*

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

Associate Professors

LucaBENVENUTI	Laura PALAGI
Fabrizio D'AMORE	Pier LuigiPICCARI
Giuseppe DE GIACOMO	Francesco QUAGLIA
Alberto DE SANTIS	Pierfrancesco REVERBERI
Lorenzo FARINA	Massimo ROMA
Domenico LAISE	Riccardo ROSATI
Leonardo LANARI	Serenella SALINARI
Paolo LEBERATORE	Silvio SALZA
Carlo MANNINO	Giuseppe SANTUCCI
Giuseppe ORIOLO	Marco TEMPERINI

Researchers

Luca BECCHETTI	Paolo DI GIANBERARDINO
Roberto BERALDI	Daneila IACOVIELLO
Claudia CALIFANO	Luca IOCCHI
Claudio DE PERSIS	RobertaSESTINI
Camil DEMETRESCU	Marilena VENDITTELLI

Associate and Post Doctoral Researchers

Alessandro AVENALI	Stephen KIMANI
Vincenzo BONIFACI	Giorgio KOCH
Daniele CALISI	Domenico LEMBO
Silvia CANALE	Giampaolo LIUZZI
Andrea CARBONE	Toni MANCINI
Alessandro CIMA	Carlo MARCHETTI
Fabio DE ROSA	Sara POGGI
Debora DONATO	Sara MATTIA
Andrea FERRARA	Raffaele NICOLUSSI
Alberto FINZI	Veronica PICCIALLI
Silvia GABRIELLI	Antonella POGGI
Giorgio GRISETTI	Sara TUCCI

Staff members

Administrative

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

Technical

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

Auxiliary Services

Pia BONANNI Maria Carmina MASTROCOLA Antonio SIMEONI

Library

Laura ARMIERI

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)

XVIII course

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

XVIII course	XIX course	XX course	XXI course
BERTINI Enrico	ALULLI Luca	CANDIDO Alessia	BELARDINELLI Anna
DONATO Debora	BONIFACI Vincenzo	CHIRICHELLO Antonella	DE LEONI Massimiliano
FERRARA Andrea	MILANI Alessia	DI BELLO Lucia	MARCHETTI Luca
FRATINI Simone	MILANO Diego	FRATARCHANGELI Marco	PASCUCCI Alessio
GRISSETTI Giorgio	PECORA Federico	NOOR MIAN Adnan	PATRIZI Fabio
SARRACCO Fabiano	QUERZONI Leonardo	RIBICHINI Andrea	SCIPIONI Sirio
TUCCI PIERGIOVANNI Sara	ROMANO Paolo	SAVELLI Francesco	SETTEMBRE Giuseppe Paolo
	RUZZI Marco	ZIPARO Vittorio Amos	TIPALDI Gian Diego

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 PARRELLO Emiliano	RISI Arnaldo

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

XVIII course	XIX course	XX course	XXI course
CEFALO Massimo	CINAT David	BALDESI Gianluca	FABBRI Filippo
FARINA Riccardo	FERRONE Claudia	CACALISCHIA Leonardo	GABRIELE Simone
GRANATO Luigi	FREDA Luigi	CALATINO Michelangelo	MAGNANTI Silvano
MOGNO Ilaria	GUAINELLA Emiliano	CHERUBINI Andrea	MERCURIO Andrea
	MARCHETTI Ilaria	ROBUFFO GIORDANO Paolo	
	SANTORO Gianfranco	SURACI Vincenzo	
	USAI Andrea		

2.5 Contracts signed in year 2005

In the following, we list the research contracts signed in year 2005.

Contracts with the European Union

Contractor	Value (euro)	Title	Project Leader
E.U.	205.500	TONES, Thinking Ontologies	G. De Giacomo
E.U.	236.500	SATSIX, Satellite-based communications system within IPv6 networks	F. Delli Priscoli
E.U.	193.520	AEOLUS, Algorithmic principles for building efficient overlay computers	A. Marchetti Spaccamela

Contracts with Italian research Institutions

Contractor	Value (Euro)	Title	Project Leader
MIUR	204.306	CELTIC - IMAGES Integrated multimedia architectures for next generation services	F. Delli Priscoli
MAE	92.200	Post Earthquake Emergency	D. Nardi
MIUR	8.000	Studio, progetto e realizzazione di algoritmi efficienti di classificazione mediante reti neurali artificiali di immagini di provini metallografici di ghisa sferoidale; modelli dinamici basati su reti neurali artificiali di fenomeni di frattura.	L. Farina

Contracts with others (companies, foreign research institutions)

Contractor	Value (Euro)	Title	Project Leader
Seicos Spa	45.00	Ricerca applicata e consulenza nell'area delle architetture interoperabili	R. Baldoni
Telecom Italia Spa	20.000	algoritmi e protocolli per un sistema di comunicazioni basato sul paradigma publish/subscribe	R. Baldoni
Sogei SpA	50.000	Supporto specialistico su qualità dei dati	T. Catarci
Alenia Spazio	83.300	Reti satellitari di tipo Critical Network Infrastructure	F. Delli Priscoli
CM Sistemi SpA	60.000	Metodi e linguaggi per la descrizione di servizi basata su ontologie	M. Lenzerini
IASI	6.250	Linguaggi per la rappresentazione dei mapping tra ontologie	M. Lenzerini
SM Sistemi SpA	20.000	Tecniche per la generazione di interfacce adattive	M. Lenzerini
Wind SpA	45.000	Analisi delle condizioni tecniche ed economiche per la formulazione di test di margin squeeze	P. Reverberi

2.6 Awards

Institution	Value (US)	Motivation	Holder
IBM	50.000	Research on "Peer to Peer Semantic Integration of Data Oriented Web Services"	M.Lenzerini

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 and Member of the Editorial Board of the International Journal of Foundations of Computer Science (IJFCS). 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 has also served on the Program Committees of the 32nd International Colloquium on Automata, Languages and Programming (ICALP'05), the 15th International Symposium on Fundamentals of Computation Theory (FCT'05), and the 16th Annual International Symposium on Algorithms and Computation (ISAAC'05).

Alberto Marchetti-Spaccamela is member of the Steering Committee of the European Symposium on Algorithms and has served on the 2005 Selection Committee for the National Olympiads in Informatics.

Stefano Leonardi has been Program Chair of the 13th Annual European Symposium on Algorithms (ESA'05) and has served on the Program Committee of the Workshop on Models and Algorithms for Planning and Scheduling Problems (MAPSP05). He is also guest editor of the Special issue for WAW'04 on the Journal of Internet Mathematics and member of the Editorial Board of the Journal of Interconnection Networks.

Camil Demetrescu has been Program Co-chair (with Roberto Tamassia) of the 7th

Workshop on Algorithm Engineering and Experiments (ALENEX'05) and has served on the Program Committee of the 31st International Workshop on Graph-Theoretic Concepts in Computer Science (WG'05). He is member of the Steering Committee of the ACM-SIAM Workshop on Algorithm Engineering and Experiments (ALENEX). He is also guest editor of the Proceedings of ALENEX/ANALCO'05.

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), Carnegie-Mellon University (Pittsburgh, PA, USA), Microsoft Research (Mountain View, CA, USA).

The AE group is presently involved in the following research projects: ALENIA Spazio "Wideband Wireless Local Area Network" (WWLAN); EU-IST "Coevolution and self-organization in dynamical networks (COSIN)"; EU Contract 001907 "Dynamically Evolving Large Scale Information Systems" (DELIS); MIUR National Project "Algorithms for the Next Generation Internet and Web: Methodologies, Design and Application" (ALGO-NEXT); FIRB National Projects - WEBMINDS and VICOM. A national committee of 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, Andrea Vitaletti, Luciana Saete Buriol, Guido Schäfer.

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

Group visitors Carlos Castillo, Bruno Escoffier, Gabriel Moruz.

Graphs and Networks. In the area of graph and network algorithms major emphasis has been devoted to the analysis and design of algorithms for dynamically evolving graphs and networks.

In [13], we present fully dynamic algorithms for maintaining 3- and 5-spanners of undirected graphs under a sequence of update operations. For unweighted graphs we maintain a 3- or 5-spanner under insertions and deletions of edges; each operation is

performed in $O(n)$ amortized time over a sequence of $\Omega(n)$ updates. The maintained 3-spanner (resp., 5-spanner) has $O(n^{3/2})$ edges (resp., $O(n^{4/3})$ edges), which is known to be optimal. On weighted graphs with d different edge cost values, we maintain a 3- or 5-spanner in $O(n)$ amortized time over a sequence of $\Omega(d \cdot n)$ updates. The maintained 3-spanner (resp., 5-spanner) has $O(d \cdot n^{3/2})$ edges (resp., $O(d \cdot n^{4/3})$ edges). The same approach can be extended to graphs with real-valued edge costs in the range $[1, C]$. All our algorithms are deterministic and are substantially faster than recomputing a spanner from scratch after each update.

In [3] we address the problem of dynamically maintaining minimum weight hyperpaths in a directed hypergraph in a decremental setting. For such a problem, we provide a new efficient algorithm that works for a wide class of hyperpath weight measures. This algorithm explicitly updates minimum weight hyperpaths in $O(L \cdot C + \max\{n, C\} \cdot \mathcal{H})$ worst case time under a sequence of L hyperarc weight increments and hyperarc deletions, where C is the maximum weight of minimum hyperpaths in \mathcal{H} and \mathcal{H} is the size of the representation of the hypergraph. Hyperpath weight measures are only required to belong to the class of *strict weakly superior functions*.

In [1], 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 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 $\tilde{O}(S \cdot k \cdot n^2)$ 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 [22, 23] we survey the main techniques developed in the literature for the maintenance of dynamic trees and dynamic graphs.

Algorithms for the Web. Recently major interest in algorithmics is being devoted to the study of algorithms for searching and retrieving information in the Web. What makes such an area challenging is the huge size of the Web graph and the enormous amount of documents stored in its nodes, two aspects that require the design of extremely efficient algorithms. In this domain we have addressed the following topics: information retrieval in the Web and the analysis of the structure of the Web and of its graph theoretic properties.

It is widely known that spectral techniques are very effective for document retrieval. Recently, a lot of effort has been spent by researchers to provide a formal mathematical explanation for this effectiveness. Latent Semantic Indexing, in particular, is a text retrieval algorithm based on the spectral analysis of the occurrences of terms in text documents. Despite of its value in improving the quality of a text search, LSI has the drawback of an elevate response time, which makes it unsuitable for on-line search in large collections of documents (e.g., web search engines). In [15] we present two approaches aimed to combine the effectiveness of latent semantic analysis with the efficiency of text matching retrieval, through the technique of query expansion. We show that both approaches have relatively small computational cost and we provide experimental evidence of their ability to improve document retrieval.

Recently, there has been a surge of research activity in the area of Link Analysis Ranking, where hyperlink structures are used to determine the relative authority of Web pages. One of the seminal works in this area is that of Kleinberg, who proposed the HITS algorithm. In [16], we undertake a theoretical analysis of the properties of the HITS algorithm on a broad class of random graphs. Working within the framework of Borodin et al., we prove that on this class (a) the HITS algorithm is stable with high probability, and (b) the HITS algorithm is similar to the INDEGREE heuristic that assigns to each node weight proportional to the number of incoming links. We demonstrate that our results go through for the case that the expected in-degrees of the graph follow a power-law distribution, a situation observed in the actual Web graph. We also study experimentally the similarity between HITS and INDEGREE, and we investigate the general conditions under which the two algorithms are similar.

Despite of being the sum of the decentralized and uncoordinated efforts by heterogeneous groups and individuals, the World Wide Web exhibits a well defined structure, characterized by several interesting properties. This structure was clearly revealed by Broder et al. who presented the evocative bow-tie structure of the Web, with a CORE comprised of a large strongly connected component, and four sets of vertices distinguishable from their relation with the CORE. The bow-tie structure is a relatively clear abstraction of the macroscopic picture of the Web, but it is very uninformative with respect to the finer details of the Web graph. In [17] we mine the inner structure of the Web graph. We present a series of measurements on the Web, which offer a better understanding of the individual components of the bow-tie. We also document the algorithmic techniques for performing these measurements. We discover that the scale-free properties permeate all the components of the bow-tie which exhibit the same macroscopic properties as the Web graph itself. However, close inspection reveals that their inner structure is quite distinct. We show that the Web graph does not exhibit self similarity within its components, and

we propose a possible alternative picture for the Web graph, as it emerges through our experiments. The focus of [18] is on the practical use of data stream algorithms for monitoring statistical and topological properties of large graphs such as the webgraph. By webgraph we mean the directed graph generated from the link structure of webpages: each webpage is a node and each hyperlink is an arc in this graph. We study experimentally the application of the algorithm of Datar and Muthukrishnan for maintaining the indegree rarity distribution and the density of low cardinality bipartite cliques in a graph read in a streamed fashion. The alpha-rarity of a stream is the ratio between the number of elements that appear exactly alpha times and the total number of different items in the stream. We present results and show that the approximated values are very close to the optima even when a low precision is requested. We are interested in computing properties of large graphs, as the webgraph, using data stream algorithms. In [19] we report results on computing the indegree rarity distribution of a graph obtained as a stream of edges. We implement a rarity algorithm proposed in the literature and show experimentally that the results approximate very well the optimal value with very limited use of memory and time. Moreover, considering some structure in the stream, we present results for the algorithm adapted for maintaining the rarity distribution of the number of cliques of size three.

Wikipedia is an online encyclopedia (www.wikipedia.org), available in more than 100 languages. If we consider each article as a node and each hyperlink between articles as a link, we have a wikigraph, the link structure of wikipedia. We can extract one wikigraph for each available language, with size ranging from less than 1000 nodes to more than 500 thousand nodes and more than 5 million links. Associated with each node there are timestamps, indicating the creation and update dates of each page, that allows to study how the graph properties evolve over time. In a first part of a study we presented in [31] we observe that wikigraphs maintain the main characteristics of webgraphs, for which temporal information is usually not available. We then study the temporal evolution of several topological properties of wikigraphs and relate this measures to the number of updates of the documents.

Algorithms for Optimization. In the area of NP-hard optimization problems we have concentrated mainly in two directions: the study of efficient algorithms for the on line version of classical optimization problems and the study of approximability properties and approximation algorithms for network design and network management problems. Besides we have addressed some foundational aspects concerning the completeness of optimization problems in approximation classes, under the differential approximation measure. In [8] we consider two on-line versions of the asymmetric traveling salesman problem with triangle inequality. For the homing version, in which the salesman is required to return in the city where it started from, we give a $(3+\sqrt{5})/2$ -competitive algorithm and prove that this is best possible. For the nomadic version, the on-line analogue of the shortest asymmetric hamiltonian path problem, we show that the competitive ratio of any on-line algorithm has to depend on the amount of asymmetry of the space in which the salesman moves. We also give bounds on the competitive ratio of on-line algorithms that are zealous, that is, in which the salesman cannot stay idle when some city can be served.

Vehicle Routing Problems are generalizations of the well known Traveling Salesman Problem. In [14] we focus on the on-line version of these problems, where requests are not known in advance and arrive over time. We introduce a model of lookahead for this class of problems, the time lookahead, which allows an on-line algorithm to foresee all the requests that will be released during next time units. We present lower and upper bounds on the competitive ratio of known and studied variants of the OLTSP; we compare these results with the ones from the literature. Our results show that the effectiveness of lookahead varies significantly as we consider different problems.

Next generation 3G/4G wireless data networks 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. This gives rise to a new class of parallel scheduling problems. In [2] 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 present provable results on the algorithmic complexity of these scheduling problems. In particular, we are able to provide very simple, online algorithms for approximating the optimal maximum response time. This relies on resource augmented competitive analysis. We also perform an experimental study with realistic data of channel conditions and user requests to show that our algorithms are more accurate than our worst case analysis shows, and that they provide fine-grained QoS to users effectively.

In [27] we introduce the notion of smoothed competitive analysis of online algorithms. Smoothed analysis has been proposed by Spielman and Teng [STOC 2001] 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 $[1, 2^K]$. We use a partial bit randomization model, where the initial processing times 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 of $O((2^k/\sigma)^3 + (2^k/\sigma)^2 2^{K-k})$, where σ denotes the standard deviation of the distribution. In particular, we obtain a competitive ratio of $O(2^{K-k})$ if $\sigma = \Theta(2^k)$. We also prove an $\Omega(2^{K-k})$ lower bound for any deterministic algorithm that is run on processing times smoothed according to the partial bit randomization model. For various other smoothing models, including the additive symmetric smoothing model used by Spielman and Teng, we give a higher lower bound of $\Omega(2^K)$. 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 the *multicommodity rent-or-buy* (MROB) network design problem we are given a network together with a set of k terminal pairs $(s_1, t_1), \dots, (s_k, t_k)$. The goal is to provision

the network so that a given amount of flow can be shipped between s_i and t_i for all $1 \leq i \leq k$ 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. Recently, Gupta et al. presented a 12-approximation for the MROB problem. Their algorithm chooses a subset of the terminal pairs in the graph at random and then buys the edges of an approximate Steiner forest for these pairs. This technique has previously been successfully used by the same authors for the single sink rent-or-buy network design problem. In [5] 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 [6] 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. Our algorithm is an original extension of known primal-dual methods for Steiner forests. An interesting byproduct of the work in this paper is that our Steiner forest algorithm is $(2 - 1/k)$ -approximate despite the fact that the forest computed by our method is usually costlier than those computed by known primal-dual algorithms. In fact the dual solution computed by our algorithm is infeasible but we can still prove that its total value is at most the cost of a minimum-cost Steiner forest for the given instance.

In [21] we consider a game-theoretical variant of the Steiner forest problem in which each player j , out of a set of k players, strives to connect his terminal pair (s_j, t_j) of vertices in an undirected, edge-weighted graph G . In this paper we design an approximately budget balanced and cross-monotonic cost sharing method for this game. we show that a natural adaptation of the primal-dual Steiner forest algorithm of Agrawal, Klein and Ravi [When trees collide: An approximation algorithm for the generalized Steiner problem in networks, *SIAM Journal on Computing*, 24(3):445–456, 1995] yields a 2-budget balanced and cross-monotonic cost sharing method for this game. We also present a negative result, arguing that no cross-monotonic cost sharing method can achieve a budget balance factor of less than 2 for the Steiner tree game. This shows that our result is tight. Our algorithm gives rise to a new linear programming relaxation for the Steiner forest problem which we coin the *lifted-cut relaxation*. We show that this new relaxation is strictly stronger than the standard undirected cut relaxation for the Steiner forest problem. An interesting

byproduct of this work is that our algorithm to compute a Steiner forest is $(2 - 1/k)$ -approximate despite the fact that the total dual produced by our algorithm is usually larger than those computed by known primal-dual algorithms. In fact the dual solution computed by our algorithm is infeasible for the undirected cut relaxation but we can still prove that its value is at most the cost of a minimum-cost Steiner forest for the given instance.

A Black Hole is a highly harmful stationary process residing in a node of a network and destroying all mobile agents visiting the node without leaving any trace. The Black Hole Search is the task of locating all black holes in a network, through the exploration of its nodes by a set of mobile agents. In [7] we consider the task of locating a black hole in a (partially) synchronous arbitrary network, assuming an upper bound on the time of any edge traversal by an agent. For a given graph and a given starting node we are interested in finding the fastest possible Black Hole Search by two agents (the minimum number of agents capable to identify a black hole). We prove that this problem is NP-hard in arbitrary graphs, thus solving an open problem stated in [Czyzowicz,Kowalski,Markou,Pelc-2004]. We also give a $7/2$ -approximation algorithm, thus improving on the 4-approximation scheme observed there. Our approach is to explore the given input graph via some spanning tree. Even if it represents a very natural technique, we prove that this approach cannot achieve an approximation ratio better than $3/2$.

In [20] we consider the problem of designing the fastest Black Hole Search, given the map of the network, the starting node and, possibly, a subset of nodes of the network initially known to be safe. We study the version of this problem that assumes that there is at most one black hole in the network and there are two agents, which move in synchronized steps. We prove that this problem is not polynomial-time approximable within $\frac{389}{388}$ (unless $P=NP$). We give a 6-approximation algorithm, thus improving on the 9.3-approximation algorithm from Czyzowicz et al. 2004. We also prove APX-hardness for a restricted version of the problem, in which only the starting node is initially known to be safe.

In computability and in complexity theory reductions are widely used for mapping sets into sets in order to prove undecidability or hardness results. In the study of the approximate solvability of hard discrete optimization problems, suitable kinds of reductions, called approximation preserving reductions, can also be used to transfer from one problem to another either positive results (solution techniques) or negative results (non approximability results). In [30] various kinds of approximation preserving reductions are surveyed and their properties discussed. The role of completeness under approximation preserving reductions is also analyzed and its relationship with hardness of approximability is explained.

In [4] we study completeness in differential approximability classes. In differential approximation, the quality of an approximation algorithm is the measure of both how far is the solution computed from a worst one and how close is it to an optimal one. The main classes considered are DAPX, the differential counterpart of APX, including the NP optimization problems approximable in polynomial time within constant differential approximation ratio and the DGLO, the differential counterpart of GLO, including problems for which their local optima guarantee constant differential approximation ratio. We de-

fine natural approximation preserving reductions and prove completeness results for the class of the NP optimization problems (class NPO), as well as for DAPX and for a natural subclass of DGLO. We also define class 0-APX of the NPO problems that are not differentially approximable within any ratio strictly greater than 0 unless $P = NP$. This class is very natural for differential approximation, although has no sense for the standard one. Finally, we prove the existence of hard problems for a subclass of DPTAS, the differential counterpart of PTAS, the class of NPO problems solvable by polynomial time differential approximation schemata.

Game theory. Recently paradigms and mathematical concepts from game theory have been adopted in the analysis of resource management policies in large networks in order to maintain control over the degradation of network performances caused by the selfishness of users. In this area we have addressed the following problems. In [12] we consider the problem of Internet switching, where traffic is generated by selfish 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.

In [9] we are interested in the complexity of finding Nash equilibria with one uniformly mixed strategy (that is, equilibria in which at least one of the players plays a uniform probability distribution over some set of pure strategies). We show that, even in imitation bimatrix games, where one player has a positive payoff if he plays the same pure strategy as the opponent, deciding the existence of such an equilibrium is an NP-complete problem. We derive this result from the NP-completeness of graph-theoretical problems strictly related to this class of equilibria.

In [10] we investigate the complexity of finding uniformly mixed Nash equilibria (that is, equilibria in which all played strategies are played with the same probability). We show that, even in very simple win/lose bimatrix games, deciding the existence of uniformly mixed equilibria in which the support of one (or both) of the players is at most or at least a given size is an NP-complete problem. Motivated by these results, we also give NP-completeness results for problems related to finding a regular induced subgraph of a certain size or regularity in a given graph, which can be of independent interest.

Experimentation, visualization and applications. In algorithm engineering is particularly relevant to study and analyze the performance of algorithms not only from the theoretical point of view (through the classical worst case asymptotic analysis) but also by running experiments that allow to assess the practical behaviour of algorithms on real

life data. In this area we have continued our research program by addressing both the experimental study of specific graph algorithms and the design and development of an environment for algorithm visualization. In [28] 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 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 [11] we describe our own experience in preparing animated presentations of computer science concepts with Leonardo Web, a Java-based animation system that we have previously developed. Our discussion is aimed at highlighting how different visualization tools and techniques turned out to be useful in realizing effective Web-based teaching material. Our experience culminated in the preparation of an on-line repository of animated illustrations for a textbook on algorithms and data structures edited by McGraw-Hill in 2004.

Journals

- [1] Camil Demetrescu and Giuseppe F. Italiano. Trade-Offs for Fully Dynamic Reachability on DAGs: Breaking Through the $O(n^2)$ Barrier. *Journal of the Association for Computing Machinery (JACM)*, **52**(2), pp. 147–156, 2005.
- [2] Luca Becchetti, S. Diggavi, Stefano Leonardi, Alberto Marchetti-Spaccamela, S. Muthukrishnan, T. Nandagopal and Andrea Vitaletti. Parallel scheduling problems in next generation wireless networks. *Networks*, **45**(1), pp. 9–22, 2005.
- [3] Giorgio Ausiello, Paolo Giulio Franciosa and Daniele Frigioni. Partially Dynamic Maintenance of Minimum Weight Hyperpaths. *Journal of Discrete Algorithms*, **3**(1), pp. 27–46, 2005.
- [4] Giorgio Ausiello, Cristina Bazgan, Marc Demange and Vangelis Th. Paschos. Completeness in differential approximation classes. *International Journal of Foundations of Computer Science*, **16**(6), 2005.

Conference Proceedings

- [5] Luca Becchetti, Jochen Koenemann, Stefano Leonardi and M. Pal. Sharing the cost more efficiently: Improved approximation for multicommodity rent-or-buy. *Proceedings of the SIAM-ACM Symposium on Discrete Algorithms (SODA '05)*, pp. 375–384, 2005. Accepted for publication under minor revision in ACM Transaction on Algorithms.
- [6] Jochen Koenemann, Stefano Leonardi and Guido Schaefer. A group-strategyproof mechanism for Steiner forests. *Proceedings of the 16th Annual ACM-SIAM Symposium on Discrete Algorithms (SODA '05)*, 2005.

- [7] Ralf Klasing, Euripides Markou, Tomasz Radzik and Fabiano Sarracco. Hardness and approximation results for Black Hole Search in arbitrary graphs. *Proc. of 12th Colloquium on Structural Information and Communication Complexity (SIROCCO 2005) LNCS 3499*, pp. 200–215, 2005.
- [8] Giorgio Ausiello, Vincenzo Bonifaci and Luigi Laura. The On-line Asymmetric Traveling Salesman Problem. *Proceedings of the 9th Workshop on Algorithms and Data Structures 2005 (WADS 2005) - LNCS 3608 - Springer*, 2005.
- [9] Vincenzo Bonifaci, Ugo Di Iorio and Luigi Laura. New results on the complexity of uniformly mixed Nash equilibria. *Proceedings of the 1st Workshop on Internet and Network Economics (WINE)*, pp. 1023–1032, 2005.
- [10] Vincenzo Bonifaci, Ugo Di Iorio and Luigi Laura. On the complexity of uniformly mixed Nash equilibria and related regular subgraph problems. *Proceedings of the 15th International Symposium on Fundamentals of Computation Theory (FCT 2005)*, 2005.
- [11] Vincenzo Bonifaci, Camil Demetrescu, Irene Finocchi, Giuseppe F. Italiano and Luigi Laura. Portraying algorithms with Leonardo Web. *Proceedings of the WISE05 International Workshop on Web-based Learning, New York City, USA*, 2005.
- [12] Alex Kesselman, Stefano Leonardi and Vincenzo Bonifaci. Game-theoretic analysis of Internet switching with selfish users. *Proceedings of the 1st Workshop on Internet and Network Economics (WINE)*, pp. 236–245, 2005.
- [13] Giorgio Ausiello, Paolo Giulio Franciosa and Giuseppe Francesco Italiano. Small Stretch Spanners on Dynamic Graphs. *Proceedings of European Symposium on Algorithms (ESA 2005) - LNCS 3669 - Springer*, 2005.
- [14] Luca Allulli, Giorgio Ausiello and Luigi Laura. On the Power of Lookahead in On-line Vehicle Routing Problems. *COCOON 2005 - LNCS 3595 - Springer*, 2005.
- [15] Luigi Laura, Umberto Nanni and Fabiano Sarracco. Fast LSI-based Techniques for Query Expansion in Text Retrieval Systems.. *Proc. of 2nd Workshop on Text-based Information Retrieval (TIR-05)*, pp. 15–28, 2005.
- [16] Debora Donato, Stefano Leonardi and Panayiotis Tsaparas. Stability and Similarity of Link Analysis Ranking Algorithms. *Proc. of 32nd International Colloquium on Automata, Languages and Programming (ICALP 2005 - Track A)*. , 2005.
- [17] Debora Donato, Stefano Leonardi, Stefano Millozzi and Panayiotis Tsaparas. The inner structure of the Webgraph. *Proc. of 8th International Workshop on the Web and Databases (WebDB 2005)*, 2005. A short abstract appears in Proc. of the European Conference on Complex Systems (ECCS05).
- [18] Luciana Salete Buriol, Debora Donato, Stefano Leonardi and Tobias Matzner. Using Data Streams Algorithms for Computing Properties of Large Graphs. *Booklet of the Workshop on Massive Geometric Data Sets (Massive2005), Pisa*, pp. 9–14, 2005.

- [19] Luciana Salete Buriol, Debora Donato, Stefano Leonardi and Tobias Matzner. Data Stream Computation for Monitoring Statistics of Massive Webgraphs. *Proc. of Conference on Complex Systems (ECCS05)*, 2005.
- [20] Ralf Klasing, Euripides Markou, Tomasz Radzik and Fabiano Sarracco. Approximation bounds for Black Hole Search problems. *Proc. of 9th International Conference on Principles of Distributed Systems (OPODIS'2005)*, pp. 198–207, 2005.
- [21] Jochen Konemann, Stefano Leonardi, Guido Schaefer and Stefan van Zwam. From Primal-Dual to Cost Shares and Back: A Stronger LP Relaxation for the Steiner Forest Problem. *Automata, Languages and Programming, 32nd International Colloquium, ICALP 2005, Lecture Notes in Computer Science 3580 Springer*, pp. 930–942, 2005.

Articles in books

- [22] Camil Demetrescu, Irene Finocchi and Giuseppe F. Italiano. Handbook on Data Structures and Applications. Chapter 36: Dynamic Graphs, Dinesh Mehta and Sartaj Sahni (eds.), CRC Press Series, in Computer and Information Science, 2005.
- [23] Camil Demetrescu, Irene Finocchi and Giuseppe F. Italiano. Handbook on Data Structures and Applications. Chapter 35: Dynamic Trees, Dinesh Mehta and Sartaj Sahni (eds.), CRC Press Series, in Computer and Information Science, 2005.

Book

- [24] Camil Demetrescu, Roberto Tamassia and Robert Sedgewick. ALENEX/ANALCO 2005: 7th Workshop on Algorithm Engineering and Experiments and 2nd Workshop on Analytic Algorithmics and Combinatorics, Proceedings. SIAM, ISBN 0-89871-596-2, 2005.
- [25] Gerth Stolting Brodal and Stefano Leonardi. ESA 2005, 13th Annual European Symposium, Proceedings. Lecture Notes in Computer Science 3669. Springer, 2005.
- [26] Ozalp Babaoglu, Mark Jelasity, Alberto Montresor, Christof Fetzer, Aad P. A. van Moorse, Stefano Leonardi and Maarten van Steen. Self-star Properties in Complex Information Systems, Conceptual and Practical Foundations. Lecture Notes in Computer Science 3460, Springer, 2005.

Submitted papers, technical reports and others

- [27] Luca Becchetti, Stefano Leonardi, Alberto Marchetti-Spaccamela, Guido Schaefer and T. Vredeveld. Average case and smoothed competitive analysis of the multi-level feedback algorithm. *Accepted for publication in Mathematics of Operations Research*, 2005. A preliminary version appeared in proceedings of the IEEE Symposium on Foundations of Computer Science (FOCS), 2003.

- [28] Camil Demetrescu and Giuseppe F. Italiano. Experimental Analysis of Dynamic All Pairs Shortest Path Algorithms. *To appear in ACM Transactions on Algorithms*, 2005. Special issue devoted to the best papers selected from the 15th Annual ACM-SIAM Symposium on Discrete Algorithms (SODA'04).
- [29] Camil Demetrescu and Giuseppe F. Italiano. Fully Dynamic All Pairs Shortest Paths with Real Edge Weights. *To appear in Journal of Computer and System Sciences*, 2005. Special issue devoted to the best papers selected from the 42th Annual IEEE Symposium on Foundations of Computer Science (FOCS'01).
- [30] Giorgio Ausiello and Vangelis Th. Paschos. Reductions, completeness and the hardness of approximability. *To appear European Journal of Operations Research*, 2005.
- [31] Luciana Salete Buriol, Debora Donato, Stefano Leonardi and Stefano Millozzi. Link and Temporal Analysis of Wikigraphs. *Technical Report DELIS European Research Project*, 2005.

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”.

7. The study and development of new approaches to the generation, presentation and interaction with 2D and 3D graphical interfaces in a manner that is sensitive to technological, computational and cognitive constraints. These topics are described in the Section “Computer Graphics and Artificial Intelligence”.
8. The definition of methods and techniques for building computer vision systems that are able to detect and track multiple targets in real world environments. These topics are described in the Section “Computer Vision Systems”.

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, President of the IJCAI Award Committee, and President of FoLLI, the Association of Logic Language and Information; Luigia Carlucci Aiello and Marco Schaerf are in the Editorial Board of the Artificial Intelligence Journal; Fiora Pirri is permanent member of the Cognitive Robotics steering Committee; Daniele Nardi is member of the RoboCup Trustee Board; Marco Schaerf is President of the Italian AI Association (AI*IA).

The group at SIED Laboratory organized the Rescue Robotics Camp ¹, that took place from Oct., 29th to Nov., 2nd.

The project “Sistemi di Simulazione e Robotici per l’Intervento in Scenari d’Emergenza” (MURST) has been concluded. The project “Implementazione dell’architettura di supervisione del Robot Antartico di Superficie (RAS)” (ENEA) is on going. The project “ROBOTics for the CARE of elderly and disable people (ROBOCARE)” has been carried on. The project “Flir-OWS” (Galileo Avionica) has been started.

During 2005 the book [20] has been published. This monograph explain the basis of formal languages and logics.

Group members Luigia CARLUCCI AIELLO, Shahram BAHADORI, Anna BELARDINELLI, 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, Luca MARCHETTI, Daniele NARDI, Angelo ODDI [CNR], Marcelo OGLIETTI, Federico PECORA, Alessio PASCUCCHI, Fabio PATRIZI, Fiora PIRRI, Marco PIRRONE, Nicola POLICELLA, Massimo ROMANO, Riccardo ROSATI, Francesco SAVELLI, Francesco SCIALACQUA, Giuseppe Paolo SETTEMBRE, Marco SCHAERF, Gian Diego TIPALDI, Giorgio UGAZIO, Vittorio Amos ZIPARO

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.

Logical inference is an extraordinarily powerful computational device, and problems in logic are known among computer scientists for their high computational complexity. As

¹<http://sied.dis.uniroma1.it/camp>

an example, the prototypical recursively enumerable, non-recursive problem is to check whether a formula of first-order logic is valid. In other words a reasoner that represents its knowledge by means of a first-order formula and uses a sound and complete procedure for checking the validity of its knowledge has as much computational power as a Turing machine. The reasoner might give up full expressiveness and represent its knowledge in formulae of propositional logic, still using a sound and complete consistency checking procedure. In this case, it is important to recall that checking whether a formula of propositional logic is consistent is the paradigmatic NP-complete problem, which means that the reasoner faces a problem which probably requires exponential time.

In 2005, 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 [4] [1] [58] [57] [56] [7] [6] [5] [8] [3] [2] [23] [21] [22].

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 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 nonmonotonic reasoning and its connections to probabilistic reasoning. In particular, [28] provide for the first time a probabilistic semantics for a well-known nonmonotonic modal logic, establishing a new bridge between nonmonotonic and probabilistic reasoning, and gives a computational account of the asymptotic conditional validity problem in modal logic.

Reasoning under Uncertainty. The research on reasoning under uncertainty focuses especially on probabilistic reasoning about actions and on uncertainty reasoning for the Semantic Web. In particular, towards game-theoretic extensions of probabilistic reasoning about actions under partial observability, the works [26, 60, 62] and [27, 64] introduce a combination of partially observable stochastic games with agent programming in Golog and reasoning about actions in $\mathcal{C}+$, respectively. Towards sophisticated representation and reasoning techniques that allow for uncertainty reasoning in the Semantic Web, the works [24, 61] present a probabilistic generalization of description logic programs under the answer set and the well-founded semantics, while [65] explores the use of variable-strength conditional preferences for matchmaking and ranking objects in description logics.

Other works investigate the semantic and computational properties of different notions of probabilistic entailment as well as the computational properties of basic concepts in structural causal models. In detail, [10] presents an approach where probabilistic logic is combined with default reasoning from conditional knowledge bases, while [9, 25, 63] explore a variable-strength generalization thereof, and [11] investigates the computational properties of probabilistic entailment under coherence. Finally, [59] presents tractable cases for computational problems around Halpern and Pearl's notions of cause and explanation in structure-based causal models.

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.

During the year 2005, the Cognitive Robotics group continued its research activity on cognitive architectures for Rescue Robots. The DORO control architecture was extended with new modules and functionalities [29]. In particular, we introduced new algorithms for visual processing and victim finding, attentive exploration, and executive control. In this framework, a novel approach to human-robot interaction [31, 79] based on mixed-initiative reactive planning was designed and implemented. We tested the control system, considering its performances according to different working modalities [78].

A new outdoor mobile robot (SecuRO, based on the Shrimp platform from *Bluebotics*) was added to our Rescue Team (Alcor Team) [30] and a suitable control system has been developed.

We participated at RoboCup Real Rescue 2005 in Osaka, Japan, reaching the semi-finals. We depolyed both DORO and SecuRO for the competition. During the contests, DORO was able to autonomously detect victims deploying only image processing (DORO was the only system demonstrating this capability).

Beyond cognitive architectures, we investigated theoretical problems related to model-based control, reasoning, and perception.

In [32], we formally define a new hybrid framework combining temporal constraint reasoning and reasoning about actions. This framework is foundational for the DORO executive control system. Indeed, in [33] we specify both the model and the Golog interpreter used by our monitoring system for generating flexible plans on multiple timelines.

Concerning theoretical research on perception, [34] explores the integration of perceptual processing with reasoning. Dealing with “hypothesis formation”, this work proposes an algebra for composing the elementary figures and a probabilistic graphical model for reasoning about the composition.

In [54], we focus on topological map building in ambiguous spaces.

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 [19] we investigate the possibility of distributing the planning process among several agents via a distributed SAT procedure. In [38, 55] we address the problem of task assignment for a group of robots and present an asynchronous distributed algorithm for allocating tasks in a team of robots that ensures no conflicts on task allocation, with very low communication overhead. In [40] we propose a novel distributed task allocation algorithm for large-scale team of agents operating in dynamic environments (called LA-DCOP). We showed that LA-DCOP convincingly outperforms competing distributed task allocation algorithms while using orders of magnitude fewer messages. In [81] we propose a novel approach to cooperatively finding false sensor readings in domains such as

rescue response. Results in a simulation environment show that the approach is efficient, lightweight and reliable.

The soccer robot team SPQR-legged has participated in several events including the RoboCup 2005 competition obtaining good results ².

The design and realization of autonomous mobile robots engaged in a search and rescue mission has been a main research issue. In [15, 36] we provide an overview of the design choices and realization details of our autonomous rescue robot. In [80, 35] we present a navigation strategy based on a two level approach. Finally, we describe the exploration method, based on frontiers between free known space and unknown space. In [37], we present a novel approach to matching range measurements that works in the Hough domain. The approach does not rely on features extraction, but it matches dense data in a different convenient parameter space. In [39] we present an improved approach to learning grid maps with Rao-Blackwellized Particle Filters. We exploit the likelihood model of a scan-matching process to compute an accurate proposal distribution, thus resulting in a reduced number of samples needed. Moreover, we use a selective resampling strategy to reduce the number of resampling steps. In [42, 12] we present a novel approach to maintain particle diversity during actively closing loops. In [41] we present an integrated approach which simultaneously address mapping, localization, and exploration. We use a decision theoretic framework, considering different types of actions. By estimating the expected entropy of the particle filter we are able to determine the action which promises the highest expected uncertainty reduction.

Constraint based Architectures for Planning and Scheduling This line of research synthesizes methods for solving complex planning and scheduling problems. Additionally topics are addressed related to the exploitation of research outcomes in problem solving software architectures.

Research on scheduling have concerned the synthesis of algorithms for specific problems. In particular two innovative solutions have been obtained for scheduling spacecraft downlink commands [17, 73] and scheduling with quality functions [51]. Additionally the investigation on schedule execution and monitoring have continued producing consolidation of research on Partial Order Schedules [76, 50, 53] and a proposal for benchmark generation for project scheduling with temporal uncertainty [77, 14].

Concerning the architectures for scheduling the topic of interaction with real user has been addressed in two directions: producing user-oriented languages for knowledge engineering [48, 75] and evaluating users attitudes in mixed-initiative interaction [49, 70].

Research on planning has concerned several theoretical aspects and the more specific topic of integrating planning and scheduling features. On the theoretical side the problem of planning with incomplete information and sensing is studied in [13], while aspects related to concurrent and multi-agent planning are described in [52]. Different integration schema for planning and scheduling have been proposed. A component-based proposal based on a uniform constraint programming view is described in [16, 47, 72, 71]. An investigation that sees a planner and a scheduler as separate software modules is described in [74]. An

²<http://www.dis.uniroma1.it/~spqr/cms/>

integration schema intermediate between the previous two is used in [18].

Additionally, several of these techniques have been applied in two relevant projects: (a) ROBOCARE, in which software and robotic agents are integrated to obtain complex functionalities in a domestic environment [68, 67, 66, 69]; (b) MEXAR2, in which specific scheduling techniques have been used to solve a daily problem in the MARS EXPRESS mission of the European Space Agency [17, 73].

Computer Graphics and Artificial Intelligence The aims of the group is to develop intelligent interface aimed for Human-Computer Interaction. Talking virtual characters are graphical simulations of real or imaginary persons capable of human-like behavior, most importantly talking and gesturing. They may find applications in interactive virtual environments like dialog-based interfaces or computer games. Modeling and animating a complex structure like the human face is not a trivial task and several approaches have been already proposed in the scientific literature, each one solving the problem in the context of a particular application field (e.g. interactive, medical field and so on). We addressed the problem of automatic and rapid synthesis of facial motion as realistic as possible.

We proposed an anatomical physically-based method in [84]. The components of the anatomical model are a multi-layered soft tissue representing the facial skin, a muscle map and the underlying bony structure, including a movable jaw.

Moreover, we devised a Facial Motion Cloning (FMC) method in [45, 46] used to transfer the motion of a virtual face (namely, *the source*) to a mesh representing another face (*the target*), generally having a different geometry and topology.

Computer Vision Systems The problem of tracking people with computer vision based techniques is very important in many applications, ranging from security to elderly assistance. We have investigated the use of stereo vision for robust and efficient people tracking in two contexts: with cameras fixed in the environment, as well as with cameras mounted on a mobile platform (e.g., a mobile robot).

The works in [83, 43] describes a real-time people tracking system based on stereo vision that presents a novel approach to background modelling and subtraction that takes into account information about intensity, range, and edges. The use of stereo vision allows for an implementation robust to many conditions that occur in normal applications: illumination changes, shadows, reflections, etc. We also present a novel approach in tracking, in which information about location of people are integrated with appearance models of the people by using a Kalman Filter. The method is described in [44] and experimental results provided there show that the approach allows for reducing tracking errors that are generated when people come close and then separate each other, which is a major challenge for people tracking systems.

In [82] we describe a real-time people tracking system from a moving stereo camera. In this case background subtraction cannot be used and thus techniques of independent motion have been exploited, by adapting them to range information coming from the stereo camera. Experiments show the feasibility of the approach in tracking a moving person from a moving camera.

Journals

- [1] Marco Cadoli, Thomas Eiter, and Georg Gottlob. Complexity of nested circumscription and abnormality theories. *ACM Transactions on Computational Logic*, 6(2):232–272, 2005.
- [2] Marco Cadoli, Marco Gavanelli, and Toni Mancini. RCRA05: Giornata di lavoro su analisi sperimentale e benchmark di algoritmi per l'intelligenza artificiale. *Intelligenza Artificiale*, 2(3):12, Marzo 2005.
- [3] Marco Cadoli, Michela Milano, and Andrea Omicini. Agenti e vincoli: modelli, tecnologie e metodi per dominare la complessità. *Intelligenza Artificiale*, 2(1):14, Marzo 2005.
- [4] Marco Cadoli and Andrea Schaerf. Compiling problem specifications into SAT. *Artificial Intelligence*, 162:89–120, 2005.
- [5] Paolo Liberatore. Complexity and compilability of diagnosis and recovery of graph-based systems. *International Journal of Intelligent Systems*, 20:1053–1076, 2005.
- [6] Paolo Liberatore. On the complexity of case-based planning. *Journal of Experimental and Theoretical Computer Science*, 17(3):283–295, 2005.
- [7] Paolo Liberatore. Redundancy in logic I: CNF propositional formulae. *Artificial Intelligence*, 163(2):203–232, 2005.
- [8] Paolo Liberatore and Marco Schaerf. The complexity of model checking for propositional default logics. *Data and Knowledge Engineering*, 55:189–202, 2005.
- [9] Thomas Lukasiewicz. Nonmonotonic probabilistic reasoning under variable-strength inheritance with overriding. *Synthese*, 146(1-2):153–169, August 2005.
- [10] Thomas Lukasiewicz. Weak nonmonotonic probabilistic logics. *Artificial Intelligence*, 168(1-2):119–161, October 2005.
- [11] Veronica Biazzo, Angelo Gilio, Thomas Lukasiewicz, and Giuseppe Sanfilippo. Probabilistic logic under coherence: Complexity and algorithms. *Annals of Mathematics and Artificial Intelligence*, 45(1-2):35–81, October 2005.
- [12] C. Stachniss, D. Hähnel, W. Burgard, and G. Grisetti. On actively closing loops in grid-based fastslam. *Advanced Robotics - The Int. Journal of the Robotics Society of Japan (RSJ)*, 19(10):1059–1080, 2005.
- [13] Marcelo Oglietti. Understanding Planning with Incomplete Information and Sensing. *Artificial Intelligence*, 164(1-2):171–208, 2005.
- [14] Nicola Policella and Riccardo Rasconi. Designing a Testset Generator for Reactive Scheduling. *Intelligenza Artificiale*, 2(3):29–36, 2005.

Articles in books

- [15] S. Bahadori, D. Calisi, A. Censi, A. Farinelli, G. Grisetti, L. Iocchi, and D. Nardi. Autonomous systems for search and rescue. In A Birk, S. Carpin, D. Nardi, Jacoff A., and S. Tadokoro, editors, *Rescue Robotics*. Springer-Verlag, 2005.
- [16] A. Cesta, S. Fratini, and A. Oddi. Planning with Concurrency, Time and Resources: A CSP-Based Approach. In I. Vlahavas and D. Vrakas, editors, *Intelligent Techniques for Planning*, chapter 8, pages 259–295. Idea Group Publishing, 2005.
- [17] A. Oddi, N. Policella, A. Cesta, and G. Cortellessa. Constraint-Based Random Search for Solving Spacecraft Downlink Scheduling Problems. In G. Kendall and A. Burke and S. Petrovic and M. Gendreau, editor, *Multidisciplinary Scheduling: Theory and Application*, pages 133–162. Springer, 2005.
- [18] M. D. R-Moreno, D. Borrajo, A. Oddi, A. Cesta, and D. Meziat. Planning and scheduling for workflow domains. In L. Castillo, D. Borrajo, M.A. Salido, and A. Oddi, editors, *Planning, Scheduling, and Constraint Satisfaction: From Theory to Practice*. IOS Press, 2005.
- [19] Marco Benedetti, Luigia Carlucci Aiello. SAT-Based Cooperative Planning: A Proposal. In *Mechanizing Mathematical Reasoning 2005*: 494-513.

Book

- [20] Luigia Carlucci Aiello and Fiora Pirri. *Strutture Logica Linguaggi*. Pearson Education, 2005.

Conference Proceedings

- [21] Lucas Bordeaux, Marco Cadoli, and Toni Mancini. CSP properties for quantified constraints: Definitions and complexity. In *Proceedings of the Twentyeth National Conference on Artificial Intelligence (AAAI 2005)*, pages 360–365, 2005.
- [22] Marco Cadoli and Toni Mancini. Using a theorem prover for reasoning on constraint problems. In S. Bandini and S. Manzoni, editors, *AI*IA 2005*, number 3673 in Lecture Notes in Artificial Intelligence, pages 38–49. Springer, 2005.
- [23] Toni Mancini and Marco Cadoli. Detecting and breaking symmetries by reasoning on problem specifications. In *SARA-05*, volume 3607 of *Lecture Notes in Artificial Intelligence*, pages 165–181. Springer, 2005.
- [24] Thomas Lukasiewicz. Probabilistic description logic programs. In *Proceedings of the 8th European Conference on Symbolic and Quantitative Approaches to Reasoning with Uncertainty (ECSQARU 2005)*, volume 3571 of *Lecture Notes in Artificial Intelligence*, pages 737–749, Barcelona, Spain, July 2005. Springer.

- [25] Thomas Lukasiewicz. Nonmonotonic probabilistic logics under variable-strength inheritance with overriding: Algorithms and implementation in NMPROBLOG. In *Proceedings of the 4th International Symposium on Imprecise Probabilities and their Applications (ISIPTA 2005)*, pages 230–239, CMU, Pittsburgh, PA, USA, July 2005.
- [26] Alberto Finzi and Thomas Lukasiewicz. Game-theoretic Golog under partial observability. In *Proceedings of the 4th International Joint Conference on Autonomous Agents and Multiagent Systems (AAMAS 2005)*, pages 1301–1302, Utrecht, The Netherlands, July 2005. ACM Press.
- [27] Alberto Finzi and Thomas Lukasiewicz. Game-theoretic reasoning about actions in nonmonotonic causal theories. In *Proceedings of the 8th International Conference on Logic Programming and Nonmonotonic Reasoning (LPNMR 2005)*, volume 3662 of *Lecture Notes in Artificial Intelligence*, pages 185–197, Diamante, Italy, September 2005. Springer.
- [28] Riccardo Rosati and Georg Gottlob. Asymptotic conditional probability in modal logic: A probabilistic reconstruction of nonmonotonic logic. In *Proceedings of the Nineteenth International Joint Conference on Artificial Intelligence (IJCAI 2005)*, pages 1378–1383, 2005.
- [29] Carbone, A., Finzi, A., Orlandini, A., Pirri, F., & Ugazio, G. 2005a. Augmenting Situation Awareness via Model-based Control in Rescue Robots. In *Proc. of the IEEE/RSJ Int. Conf. on Intelligent Robots and Systems (IROS)*, pages 1549–1555.
- [30] A. Carbone, G. Ugazio, A. Finzi, F. Pirri, A. Orlandini. RoboCup Rescue Robot League Team ALCOR. Team Description Paper. In *Electronic Proceedings of RoboCup 2005*.
- [31] Finzi, Alberto, & Orlandini, Andrea. 2005. Human-Robot Interaction Through Mixed-Initiative Planning for Rescue and Search Rovers. In S. Bandini and S. Manzoni, editors, *AI*IA 2005*, number 3673 in *Lecture Notes in Artificial Intelligence*, pages 483–494. Springer, 2005.
- [32] Finzi, Alberto, & Pirri, Fiora. 2005. Representing Flexible Temporal Behaviors in the Situation Calculus. In *Proceedings of the Nineteenth International Joint Conference on Artificial Intelligence (IJCAI 2005)*, pages 436–441, 2005.
- [33] Finzi, Alberto, & Pirri, Fiora. 2005. Representing Flexible Temporal Behaviors in the Situation Calculus. *Printed Notes of Commonsense 2005*.
- [34] Fiora Pirri. 2005 The usual objects: a first draft on decomposing and reassembling familiar objects images *Proceedings of XXVII Annual Conference of the Cognitive Science Society*, pages 1773–1778.
- [35] D. Calisi, A. Farinelli, L. Iocchi, and D. Nardi. Autonomous navigation and exploration in a rescue environment. In *Proc. of the 2nd European Conference on Mobile Robotics (ECMR)*, pages 110–115, 2005.

- [36] Bahadori, S. and Calisi, D. and Censi, A. and Farinelli, A. and Grisetti, G. and Iocchi, L. and Nardi, D. Autonomous Search and Rescue Robots In *Proc. of SAFE 2005*, 2005.
- [37] A. Censi, L. Iocchi, and G. Grisetti. Scan matching in the hough domain. In *Proc. of the IEEE Int. Conf. on Robotics & Automation (ICRA)*, pages 2739–2744, Barcelona, Spain, 2005.
- [38] A. Farinelli, L. Iocchi, D. Nardi, and V. A. Ziparo. Task assignment with dynamic perception and constrained tasks in a multi-robot system. In *Proc. of the IEEE Int. Conf. on Robotics and Automation (ICRA)*, pages 1535–1540, 2005.
- [39] G. Grisetti, C. Stachniss, and W. Burgard. Improving grid-based slam with rao-blackwellized particle filters by adaptive proposals and selective resampling. In *Proc. of the IEEE Int. Conf. on Robotics & Automation (ICRA)*, pages 2443–2448, Barcelona, Spain, 2005.
- [40] P. Scerri, A. Farinelli, S. Okamoto, and M. Tambe. Token approach for role allocation in extreme teams. In *Proc. of AAMAS 05*, pages 727–734, 2005.
- [41] C. Stachniss, G. Grisetti, and W. Burgard. Information gain-based exploration using rao-blackwellized particle filters. In *Proc. of Robotics: Science and Systems (RSS)*, pages 65–72, Cambridge, MA, USA, 2005.
- [42] C. Stachniss, G. Grisetti, and W. Burgard. Recovering particle diversity in a rao-blackwellized particle filter for slam after actively closing loops. In *Proc. of the IEEE Int. Conf. on Robotics & Automation (ICRA)*, pages 667–672, Barcelona, Spain, 2005.
- [43] S. Bahadori, L. Iocchi, G. R. Leone, D. Nardi, and L. Scozzafava. Real-time people localization and tracking through fixed stereo vision. In *Proc. of Industrial and Engineering Applications of Artificial Intelligence and Expert Systems (IEA/AIE)*, 2005.
- [44] L. Iocchi and R. C. Bolles. Integrating plan-view tracking and color-based person models for multiple people tracking. In *Proc. of IEEE International Conference on Image Processing (ICIP'05)*, 2005.
- [45] Marco Fratarcangeli and Marco Schaerf. "Facial Motion Cloning Using Global Shape Deformation". In *Eurographics Short Presentations*, pages 89–92, Dublin, Ireland, August 2005. MIRALAB, The Eurographics Association and The Image Synthesis Group.
- [46] Marco Fratarcangeli and Marco Schaerf. "Fast Facial Motion Cloning in MPEG-4". In *Proceedings of the 4th International Symposium on Image and Signal Processing and Analysis, 2005. (ISPA 2005)*, pages 310–315, 2005.
- [47] A. Cesta and F. Fratini. Controlling Complex Physical Systems Through Planning and Scheduling Integration. In M. Ali and F. Esposito, editors, *IEA/AIE 2005*, number 3533 in Lecture Notes in Artificial Intelligence, pages 197–207. Springer, 2005.

- [48] Amedeo Cesta, Gabriella Cortellessa, Federico Pecora, and Riccardo Rasconi. Mediating the Knowledge of End-Users and Technologists: A Problem in the Deployment of Scheduling Technology. In *Proceedings of the Int. Conf. on Artificial Intelligence and Applications*, pages 212–218, 2005.
- [49] G. Cortellessa, M.V. Giuliani, M. Scopelliti, and A. Cesta. Key Issues in Interactive Problem Solving: An Empirical Investigation on Users Attitude. In M.F. Costabile and F. Paternó, editors, *INTERACT 2005*, number 3585 in Lecture Notes in Computer Science, pages 657–670. Springer, 2005.
- [50] N. Policella, A. Cesta, A. Oddi, and S.F. Smith. Generating High Quality Schedules for a Spacecraft Memory Downlink Problem. In S. Bandini and S. Manzoni, editors, *AI*IA 2005*, number 3673 in Lecture Notes in Artificial Intelligence, pages 160–172. Springer, 2005.
- [51] N. Policella, X. Wang, S.F. Smith, and A. Oddi. Exploiting Temporal Flexibility to Obtain High Quality Schedules. In *Proceedings of the Twentieth National Conference on Artificial Intelligence, AAAI-05*, 2005.

Ph.D. Thesis

- [52] M. Oglietti. *The Planning Problem in AI: Structuring Domains and Evaluating Plans*. PhD thesis, Computer Science Engineering, University of Rome “La Sapienza”, March 2005.
- [53] Nicola Policella. *Scheduling with uncertainty: A proactive approach using Partial Order Schedules*. PhD thesis, Computer Science Engineering, University of Rome “La Sapienza”, March 2005.
- [54] Francesco Savelli. *Topological Mapping of Ambiguous Space: Combining Qualitative Biases and Metrical Information..* PhD thesis, Computer Science Engineering, University of Rome “La Sapienza”, March 2005.
- [55] Alessandro Farinelli. *Distributed Task Assignment for Real World Environments..* PhD thesis, Computer Science Engineering, University of Rome “La Sapienza”, March 2005.

Submitted papers, technical reports and others

- [56] Marco Cadoli, Francesco M. Donini, Paolo Liberatore, and Marco Schaerf. k-approximating circuits. *IEEE Transactions on Computers*. To appear.
- [57] Marco Cadoli and Toni Mancini. Automated reformulation of specifications by safe delay of constraints. *Artificial Intelligence*. To appear.
- [58] Marco Cadoli and Toni Mancini. Combining Relational Algebra, SQL, Constraint Modelling, and Local Search. *Theory and Practice of Logic Programming*. To appear.

- [59] Thomas Eiter and Thomas Lukasiewicz. Causes and explanations in the structural-model approach: Tractable cases. *Artificial Intelligence*. To appear.
- [60] Alberto Finzi and Thomas Lukasiewicz. Game-theoretic agent programming in Golog under partial observability. In *Proceedings of the IJCAI-2005 Workshop on Game-Theoretic and Decision-Theoretic Agents (GTDT 2005)*, Edinburgh, Scotland, UK, July 2005.
- [61] Thomas Lukasiewicz. Stratified probabilistic description logic programs. In *Proceedings of the ISWC-2005 Workshop on Uncertainty Reasoning for the Semantic Web (URSW 2005)*, pages 87–97, Galway, Ireland, November 2005.
- [62] Alberto Finzi and Thomas Lukasiewicz. Game-theoretic Golog under partial observability. Technical Report INFSYS RR-1843-05-02, Institut für Informationssysteme, Technische Universität Wien, April 2005.
- [63] Thomas Lukasiewicz. Nonmonotonic probabilistic logics under variable-strength inheritance with overriding: Algorithms and implementation in NMPROBLOG. Technical Report INFSYS RR-1843-05-03, Institut für Informationssysteme, Technische Universität Wien, May 2005.
- [64] Alberto Finzi and Thomas Lukasiewicz. Game-theoretic reasoning about actions in nonmonotonic causal theories. Technical Report INFSYS RR-1843-05-04, Institut für Informationssysteme, Technische Universität Wien, June 2005.
- [65] Thomas Lukasiewicz and Jörg Schellhase. Variable-strength conditional preferences for matchmaking in description logics. Technical Report INFSYS RR-1843-05-11, Institut für Informationssysteme, Technische Universität Wien, December 2005.
- [66] A. Cesta, G. Cortellessa, F. Pecora, and R. Rasconi. Exploiting Scheduling Techniques to Monitor the Execution of Domestic Activities. *Intelligenza Artificiale (Italian Journal of Artificial Intelligence)*, 2005. to appear.
- [67] A. Cesta, G. Cortellessa, F. Pecora, and R. Rasconi. Intelligent Supervision for Ambient Intelligence: Customizing Scheduling Technology. In *Proceedings of the IEE Workshop on Intelligent Environments, University of Essex, Colchester, UK*, 2005.
- [68] A. Cesta, A. Farinelli, L. Iocchi, R. Leone, D. Nardi, F. Pecora, and R. Rasconi. “Robotically Rich” Environments for Supporting Elderly People at Home: the RoboCare Experience. In *Proceedings of the Symposium on “Robot Companions: Hard Problems and Open Challenges in Robot-Human Interaction”, AISB 2005 Convention, Hatfield, UK*, 2005.
- [69] A. Cesta and F. Pecora. The RoboCare Project: Intelligent Systems for Elder Care. In *Proceedings of the AAAI Fall Symposium on Caring Machines: AI in Elder Care, Washington, DC, USA*, 2005.

- [70] G. Cortellessa and A. Cesta. Towards a reliable evaluation of mixed-initiative systems. In *Proceedings of AAAI Fall Symposium on Mixed-Initiative Problem-Solving Assistants, Arlington, VA, USA, 2005*.
- [71] S. Fratini and A. Cesta. The Integration of Planning into Scheduling with OMP. In *Proceedings of the 2nd Workshop on Integrating Planning into Scheduling (WIPIS) at AAAI-05, Pittsburgh, USA, 2005*.
- [72] S. Fratini, A. Cesta, and A. Oddi. Extending a Scheduler with Causal Reasoning: a CSP Approach. In *Proceedings of Workshop on Constraint Programming for Planning and Scheduling at ICAPS, Monterey, CA, USA, 2005*.
- [73] A. Oddi and N. Policella. Improving Robustness of Spacecraft Downlink Schedules. *IEEE Transactions on Systems, Man, and Cybernetics – Part C*. to appear.
- [74] F. Pecora and A. Cesta. Evaluating Plans through Restrictiveness and Resource Strength. In *Proceedings of the 2nd Workshop on Integrating Planning into Scheduling (WIPIS) at AAAI-05, Pittsburgh, USA, 2005*.
- [75] F. Pecora, R. Rasconi, G. Cortellessa, and A. Cesta. User-Oriented Problem Abstractions in Scheduling, Customization and Reuse in Scheduling Software Architectures. *Innovations in Systems and Software Engineering*. to appear.
- [76] N. Policella, A. Cesta, A. Oddi, and S.F. Smith. Schedule robustness through Solve-and-Robustify: generating flexible schedules from different fixed-time solutions. In *Proceedings of Workshop on Constraint Programming for Planning and Scheduling at ICAPS, Monterey, CA, USA, 2005*.
- [77] Nicola Policella and Riccardo Rasconi. Looking for a Common Scheduling Perturbations Benchmark. In *Proceedings of the International Workshop on Constraint Solving under Change and Uncertainty at CP-05, Sitges, Spain, 2005*.
- [78] Carbone, A., Finzi, A., Orlandini, A., Pirri, F., & Ugazio, G. 2005b. Situation Aware Rescue Robots. In *Proc. of IEEE International Workshop on Safety, Security and Rescue Robotics (SSRR)*, pages 182–188, Kobe, Japan, June 2005.
- [79] Finzi, Alberto, & Orlandini, Andrea. 2005. A Mixed-Initiative Approach to Human-Robot Interaction in Rescue Scenarios. In *Printed Notes of Workshop on Mixed-Initiative Planning And Scheduling at ICAPS*, pages 36–43, Monterey, CA, USA, 2005.
- [80] D. Calisi, A. Farinelli, L. Iocchi, and D. Nardi. Autonomous navigation and exploration in a rescue environment. In *Proc. of IEEE International Workshop on Safety, Security and Rescue Robotics (SSRR)*, Kobe, Japan, June 2005.
- [81] A. Farinelli and P. Scerri. Low-overhead cooperative detection of false sensor readings. In *Proc. of AAMAS workshop: Challenges in the Coordination of Large Scale Multi-Agent Systems (LSMAS)*, pages 11–16, Utrecht, July 2005.

- [82] M. Agrawal, K. Konolige, and L. Iocchi. Real-time detection of independent motion using stereo. In *Proc. of IEEE Workshop on Motion*, 2005.
- [83] S. Bahadori, G. Grisetti, L. Iocchi, G. R. Leone, and D. Nardi. Real-time tracking of multiple people through stereo vision. In *Proc. of IEE International Workshop on Intelligent Environments*, 2005.
- [84] Marco Fratarcangeli. "Physically Based Synthesis of Animatable Face Models". In *Proceedings of the 2nd International Workshop on Virtual Reality and Physical Simulation (VRIPHYS05)*, pages 32–39, Pisa, Italy, 2005.

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.
- Information Access, with particular interest on designing applications for multiple user interfaces, and studying the impact of technologies, especially mobile, on digital libraries.
- E-learning, and in particular the study of how to make accessible information contents.

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 innovazione tecnologica nella formazione e attuazione delle politiche pubbliche"; IST Project INFOMIX (IST-2001-33570); IST Project SEWASIE (IST-2001-34825); IST NoE DELOS (G038-507618).

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

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. The work reported in [11] investigates DLs 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. The work in [2] resulted in the implementation of a description logic reasoning system, called QuOnto [10], which is able to deal with very large amount of extensional knowledge by exploiting the current relational technologies for storing and querying data. In [3], starting from some of the results in [11] data complexity bounds are given for query answering in several DLs drawing precise boundaries between LOGSPACE, NLOGSPACE-hardness, PTIME-hardness, and NP-hardness DLs. In [2], 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. Description Logics (DLs) are playing a central role in ontologies and in the Semantic Web, since they are currently the most used formalisms for building ontologies. Both semantic and computational issues arise when extending DLs with rule-based components. In [3, 13] a general framework for integrating ontologies and rules is defined, which provides for a clear treatment of the above semantic issues. Moreover, general decidability and complexity results for reasoning in such systems combining ontologies and rules are defined. Finally we mention that the group is participating to the EU project TONES on reasoning tasks for DL-based ontologies that has started on September 2005 and will end in August 2008. The coordinator of the unit in Rome is Giuseppe De Giacomo.

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, in [4] data integration has been discussed by a logic perspective, taking the abstract viewpoint that the global schema is an ontology expressed in a class-based formalism. The expressive Description Logic ALCQI has been considered, that fully captures class-based representation formalisms, and it has been shown that query answering in data integration, as well as all other relevant reasoning tasks, under such a logic is decidable. The problem of designing a data warehouse system, i.e., a data integration system in which integrated data are materialized in the global schema, and

its application within the Telecom Italia information system has been faced in [5], where a methodology based on a conceptual representation of the Enterprise model has been developed. The problem of modeling (virtual) data integration systems from a more general perspective has been studied in [6], where a comprehensive logical framework has been provided (also for dealing with integrity constraints on the global schema and data at the sources inconsistent with respect to such constraints). Data inconsistency in the presence of global integrity constraints has been the subject of several papers produced by the group members also within international scientific collaborations, and both from a theoretical and practical view point. In [14] and in [15] the problem has been addressed in the simplified setting of a single relational database schema, in the presence of classical key dependencies and exclusion dependencies. In [16, 17, 18] the important results achieved in the EU project IST-2001-33570 INFOMIX (in which the group has been actively involved in the last years) and the prototype resulting from implementation activities carried out in the project have been described.

Members of the group participated in international activities about data integration and database theory by editing a special issue of the Journal of Applied Logic [7], a special issue of the Theoretical Computer Science journal [8], and presenting the following invited talks:

- “Logical foundations for data integration”, invited talk by Maurizio Lenzerini at the 31st Annual Conference on Current Trends in Theory and Practice of Informatics, SOFSEM 2005, Slovak Republic, January 22-28, 2005;
- “Logiche Descrittive per l’Integrazione di dati e servizi”, invited talk by Maurizio Lenzerini at the Covegno FORUM-PA on “I sistemi informativi basati sulle logiche descrittive: Stato dell’arte e prospettive”, Roma, November 2005.

Furthermore, Riccardo Rosati and Giuseppe De Giacomo have been lecturers at the European Summer School in Logic, Language and Information (ESSLLI 2005), at the Heriot-Watt University of Edinburgh, Scotland 8-19 August, 2005, with a course on “Logic-based information integration”.

We finally point out that the topic of data integration is addressed in the context of the activity of the DASI lab (<http://www.dis.uniroma1.it/dasilab/>).

View-based Query Processing. 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. In [9] several of such notions are compared and relationships between them are analyzed. Also, an in-depth study of the decidability of view-based query containment of recursive queries [1].

Information Visualization. Information Visualization is the discipline that studies how to produce computer-based, visual, interactive representations of abstract phenomena in order to enable their exploration and analysis. Its main purpose is to leverage the extraordinary perceptual and cognitive capabilities of humans to literally "have a view" on large and complex information and permit to produce, assess and communicate interesting hypothesis and facts on a specific analytical problem. 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 clutter reduction for information visualization. Visualizations often suffer of distortion effects caused by the large volume of data and/or complex configurations of items on the screen. The aim of clutter reduction is to reduce noise on the screen and produce veridical information. Our group has analyzed the problem in depth and provided several recovery techniques. We produced various sampling-based methods and explored alternative solutions [21] [20] [22] [26].

Information Access. Mobile computing is one of the major innovations of recent years. The wide spread of mobile devices, applications and connected services permits today to access information anytime anywhere and to bring along personal information while staying mobile. This enormous innovation has stimulated research in computer science towards several directions. Our group is mainly focused in the aspects related to interaction with mobile applications and their user interface. The research challenge has to do with 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 and that users can access shared content with a wide heterogeneity of devices. 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 [25]. Additionally, we provided a user-based adaptive technique to produce mobile user interfaces tailored on the specific user. The application continuously monitors the interaction with the system and guesses optimal arrangements of information on the screen. The technique permits to reduce screen space consumption and user interaction [19]. It is worth noting that we organized a workshop on mobile devices "PSMD: International Workshop on Plastic Services for Mobile Devices" during INTERACT 2005.

As far as user interfaces to digital libraries, we have been involved in user interface design and information visualization in digital libraries (DLs). In the process, we have been exploring the requirements for DL user interface design. An interesting development of the work on user requirements in DLs has been an investigation on how ubiquitous computing can be exploited to support digital library tasks and how ubiquitous computing can facilitate seamless and effective interaction with digital and physical artifacts [30] [19]. We have also analyzed how information visualization can be useful in DLs by establishing an association/link between the requirements for DLs with relevant information visualization techniques [23] [24].

E-Learning. In the field of e-learning, our main focus has been accessibility. One of the main developments has been the realization of a methodology for creating/authoring accessible e-learning content and resources [28]. The methodology is based on simplicity, doing away with what is not necessary in order to give room to/include what is necessary. On the same note, we have proposed accessibility guidelines that are intended to be referred to/used during the process of creating accessible e-learning content. The guidelines that we have proposed are based on an association between disabilities and critical content types. We are also in the process of developing an environment for supporting didactical and pedagogical experts in developing accessible e-learning artifacts through the proposed methodology [27]. We are also engaged in research efforts pertaining to usability and accessibility evaluation in e-learning [29]. It is worth noting that we were involved in organizing a workshop on “eLearning and Human-Computer Interaction” in collaboration with the University of Bari during INTERACT 2005.

Journals

- [1] D. Calvanese, G. De Giacomo, M.Y. Vardi: Decidable containment of recursive queries. *Theor. Comput. Sci.* 336(1): 33-56 (2005).
- [2] D. Berardi, D. Calvanese, G. De Giacomo: Reasoning on UML class diagrams. *Artif. Intell.* 168(1-2): 70-118 (2005).
- [3] R. Rosati. On the decidability and complexity of integrating ontologies and rules. *Web Semantics*, vol. 3, num. 1, pages 41-60, 2005.
- [4] D. Calvanese and G. De Giacomo. Data integration: A logic-based perspective. *AI Magazine*, 26(1):59-70, 2005.
- [5] D. Calvanese, L. Dragone, D. Nardi, R. Rosati, and S. M. Trisolini. Enterprise modeling and data warehousing in telecom italia. *Information Systems*, 31(1):1-32, 2006.
- [6] A. Calì, D. Lembo, and R. Rosati. A comprehensive semantic framework for data integration systems. *Journal of Applied Logic – Special Issue on Logic-based Methods for Information Integration*, 2(3):308-328, 2005.
- [7] T. Eiter and D. Lembo. Introduction to the Special Issue on Logic-based Methods for Information Integration. *Journal of Applied Logic*, 10(3):251-252, 2005.
- [8] M. Lenzerini. Introduction to the Special Issue on Database Theory (select papers from ICDT 2003). *Theoretical Computer Science*, 336(1):1-2, 2005.

Conference Proceedings

- [9] D. Calvanese, G. De Giacomo, M. Lenzerini, M.Y. Vardi: View-Based Query Processing: On the Relationship Between Rewriting, Answering and Losslessness. *ICDT 2005*: 321-336.

- [10] A. Acciarri, D. Calvanese, G. De Giacomo, D. Lembo, M. Lenzerini, M. Palmieri, R. Rosati: QuOnto: Querying Ontologies. AAAI 2005.
- [11] D. Calvanese, G. De Giacomo, D. Lembo, M. Lenzerini, R. Rosati: DL-Lite: Tractable Description Logics for Ontologies. AAAI 2005.
- [12] D. Calvanese, G. De Giacomo, D. Lembo, M. Lenzerini, R. Rosati: Data Complexity of Query Answering in Description Logics. Description Logics 2005.
- [13] Riccardo Rosati. Semantic and Computational Advantages of the Safe Integration of Ontologies and Rules. In Proceedings of PPSWR 2005, pages 50-64, 2005.
- [14] L. Grieco, D. Lembo, M. Ruzzi, and R. Rosati. Consistent query answering under key and exclusion dependencies: Algorithms and experiments. In *Proc. of the ACM 14th Conf. on Information and Knowledge Management (CIKM 2005)*, pages 792–799, 2005.
- [15] L. Grieco, D. Lembo, M. Ruzzi, and R. Rosati. Experimenting efficient query answering over inconsistent databases. In *Proc. of the 13th Italian Conf. on Database Systems (SEBD 2005)*, pages 300–307, 2005.
- [16] N. Leone, T. Eiter, W. Faber, M. Fink, G. Gottlob, L. Granata, G. Greco, E. Kalka, G. Ianni, D. Lembo, M. Lenzerini, V. Lio, B. Nowicki, R. Rosati, M. Ruzzi, W. Staniszki, and G. Terracina. Data integration: a challenging asp application. In *Proc. of the 8th Int. Conf. on Logic Programming and Non Monotonic Reasoning (LPNMR 2005)*, pages 379–383, 2005.
- [17] N. Leone, T. Eiter, W. Faber, M. Fink, G. Gottlob, G. Greco, E. Kalka, G. Ianni, D. Lembo, M. Lenzerini, V. Lio, B. Nowicki, R. Rosati, M. Ruzzi, W. Staniszki, and G. Terracina. The infomix system for advanced integration of incomplete and inconsistent data. In *Proc. of the ACM SIGMOD International Conference on Management of Data (SIGMOD 2005)*, pages 915–917, 2005.
- [18] N. Leone, T. Eiter, W. Faber, M. Fink, G. Gottlob, G. Greco, E. Kalka, G. Ianni, D. Lembo, V. Lio, B. Nowicki, R. Rosati, M. Ruzzi, W. Staniszki, and G. Terracina. Boosting information integration: The infomix system. In *Proc. of the 13th Italian Conf. on Database Systems (SEBD 2005)*, pages 55–66, 2005.
- [19] E. Bertini and A. Cali and T. Cartaci and S. Gabrielli and S. Kimani. Interaction-based Adaptation for Small Screen Devices. In *Proceedings of the User Modeling International Conference (UM)*, 2005.
- [20] E. Bertini and G. Santucci. Improving 2D scatterplots effectiveness through sampling, displacement, and user Perception. In *Information Visualization 05 - 9th IEEE International Conference on Information Visualization, 2005*, 2005.
- [21] E. Bertini and L. Dell’Aquila and G. Santucci. Reducing Infovis cluttering through sampling, displacement, and user perception. In *IEEE Symposium on Information Visualization, 2005 Interactive Poster*, 2005.

- [22] E. Bertini and L. Dell'Áquila and G. Santucci. SpringView: Cooperation of Radviz and Parallel Coordinates for View Optimization and Clutter Reduction. In *CMV'05 - 3rd International Conference on Coordinated & Multiple Views in Exploratory Visualization*, 2005.
- [23] E. Bertini and L. Di Bello and S. Kimani. The Pivotal Role of Visualization in Digital Libraries. In *International Workshop of the EU Network of Excellence DELOS on Audio-Visual Content and Information Visualization in Digital Libraries (AVIVDiLib)*, 2005.
- [24] E. Bertini and T. Catarci and L. Di Bello and S. Kimani. *Visualization in Digital Libraries*. 2005.
- [25] E. Bertini, G. Santucci. Modeling user-system data exchange to design adaptive interfaces. In *PSMD: International Workshop on Plastic Services for Mobile Devices*, 2005.
- [26] G. Ellis and E. Bertini and A. Dix. The Sampling Lens: Making Sense of Saturated Visualisations. In *CHI Extended Abstracts*, 2005.
- [27] S. Gabrielli and V. Mirabella and M. Teso and T. Catarci. The Design of an Authoring Interface to Make eLearning Content Accessible. In *Proceedings of Human-Computer Interaction-INTERACT 2005*, 2005.
- [28] S. Gabrielli and V. Mirabella and S. Kimani and T. Catarci. Learning Accessibility: A Comprehensive Approach to Content Development. In *Proceedings of the Workshop e-Learning and Human-Computer Interaction at INTERACT 2005*, 2005.
- [29] S. Gabrielli and V. Mirabella and S. Kimani and T. Catarci. Supporting Cognitive Walkthrough with Video Data: A Mobile Learning Evaluation Study. In *Proceedings of the International Conference on Human-Computer Interaction with Mobile Devices and Services (Mobile HCI)*, 2005.
- [30] S. Kimani and E. Bertini. Exploiting Ubiquitous Computing to Support Digital Library Tasks. In *Proceedings of HCI International 2005*, 2005.

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 2005 members of the group were involved in several Program Committees of prestigious International Conferences (e.g., ICDCS, DSN, WORDS, NCA, ANSS, 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, Francesco QUAGLIA, Leonardo QUERZONI, Paolo ROMANO, Andrea SANTORO, 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 modelled 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.

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 before 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 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.

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 (Web-based) 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 (autonomous) 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 distributed 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. The latter aspect makes our solutions particularly attractive for the case of very high degree of replication of the application access point, with distribution of the replicas within infrastructures geographically spread on public networks over the Internet (e.g. Application Delivery Networks), namely a configuration that also provides 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, in general settings, 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 presented innovative, application level protocols tailored for Web transactional applications (e.g. e-Commerce applications), which attempt to reduce the impact of network congestion on the latency experienced by the end users. The intuition underlying our proposals 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 back-end database systems. We complete our proposals with efficient mechanisms that prevents multiple, undesired updates on the back-end databases and, at the same time, strongly limit the additional load on the ASP infrastructure due to the increased amount of requests from the privileged users.

The issue of QoS has been addressed also for the case of classical content delivery applications, for which it is becoming increasingly clear that different Web Sites may request different QoS levels to the same Content Delivery Networks (CDN), due to both

their business targets and their financial availability. In this context, we have identified some resource management issues, and the related parameters, which affect the behavior of a CDN supporting different QoS levels for each of its Web sites, and have presented an analytical model for the evaluation of the provided QoS levels on the basis of both the specific assignment for the previous parameters and the available resources within the CDN. The model has also been employed to analyze the behavior of two different CDN configurations: (i) Exclusive Cache Node Assignment, where the cache nodes within the CDN are assigned to serve only requests for Web Sites that subscribe to a given QoS class; (ii) Shared Cache Node Assignment, where each cache node can serve requests for multiple QoS classes. We have used real world data as input parameters of the model to test the behavior of the two different configurations and the tradeoffs of a configuration over the other.

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 implemented a Time Management Converter (TiMaC) for HLA based simulation systems. TiMaC is a layer interposed in between the federate and the underlying RTI in order to map the conservative Time-Management interface onto the optimistic one. In this way, TiMaC transparently supports optimistic execution for federates originally designed for the conservative approach, which is achieved without the need for developing any ad-hoc RTI system. TiMaC relies on a software architecture for transparent treatment of checkpointing/recovery of the federate state, namely Magic State Manager (MASM), we have also designed and developed, and implements a set of additional facilities required to support the whole tasks associated with the mapping of conservative onto optimistic Time-Management interfaces.

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.

Orthogonally to the synchronization problem among federates, we have also explored software diversity and active replication of application level simulation components, so to allow the whole HLA simulation system to take performance advantages from the “best instant responsiveness” among all the involved replicas. Within this scenario, our view of software diversity-based active replication entails the adoption of different third party libraries supporting typical simulation related tasks (for instance different libraries supporting calendar queues for the maintenance of the pending event set at the application level) or even the same library, but with different choices for the parameters determining its run time behavior, and then exploiting the timing of actions provided by the replica exhibiting the best run-time behavior for the specific synchronization conditions within the run, or even within specific phases of the run itself. This points out an important aspect related to our proposal. In particular, software diversity as intended in our approach, does not necessarily mean having different implementations of a same simulation entity based on, e.g., different types of data structures and algorithms. It might simply mean employing different (or differently parameterized) third party libraries in support of simulation related, general purpose, application level tasks in order to originate diversity-based replicas. Hence our replication approach can provide real run-time advantages with no (or minimal) effort from teams of application programmers, who are not necessarily required to provide diversity-based implementations of a same application level simulation component. This means in practice following a kind of “Opportunistic N-Version Programming” such as the one followed in the context of replication in support of fault tolerance.

Beyond providing the framework for software diversity-based replication, we propose the design and implementation of an Active Replication Management Layer (ARML), which transparently supports software diversity-based replicas of a same HLA federate simulator, by showing them as a single logical entity. The implementation of ARML has been based on C technology and standard POSIX APIs. Hence it results portable across any kind of POSIX compliant operating system (e.g. UNIX systems). Also, such an implementation has been tailored for SMP and cluster based systems and, for being integrated with the well known Georgia Tech B-RTI package, even though the design principles underlying the implementation remain valid independently of the specific RTI to which replication handling facilities should be added.

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 labeled 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.

Journals

- [1] F. Quaglia and A. Santoro, Modeling and Optimization of Nonblocking Checkpointing for Optimistic Simulation on Myrinet Clusters, *Journal of Parallel and Distributed Computing*, vol.65, no.6, pp.667-677, 2005.
- [2] P. Romano, F. Quaglia and B. Ciciani, A Lightweight and Scalable e-Transaction Protocol for Three-Tier Systems with Centralized Back-End Database, *IEEE Transactions on Knowledge and Data Engineering*, vol.17, no.11, pp.1578-1583, 2005.
- [3] A. Santoro and F. Quaglia, Software Supports for Event Preemptive Rollback in Optimistic Parallel Simulation on Myrinet Clusters, *Journal of Interconnection Networks*, vol.6, no.4, pp.435-458, 2005.
- [4] A. Santoro and F. Quaglia, Transparent State Management for Optimistic Synchronization in the High Level Architecture, *SIMULATION: Transactions of The Society for Modeling and Simulation International (Special Issue on Selected Papers from PADS 2005)*.

Conference Proceedings

- [5] F. Quaglia and P. Romano, Reliability in Three-Tier Systems without Application Server Coordination and Persistent Message Queues, *Proc. 20th Annual ACM-SIGAPP Symposium on Applied Computing (SAC)*, Santa Fe, New Mexico, USA, ACM Press, March 2005.
- [6] P. Romano, F. Quaglia and B. Ciciani, Design and Analysis of an e-Transaction Protocol Tailored for OCC, *Proc. 5th IEEE Symposium on Applications and the Internet (SAINT)*, Trento, Italy, IEEE Computer Society Press, January/February 2005.
- [7] A. Santoro and F. Quaglia, Transparent State Management for Optimistic Synchronization in the High Level Architecture, *Proc. 19th ACM/IEEE/SCS Workshop on Principles of Advanced and Distributed Simulation (PADS)*, Monterey, CA, USA, IEEE Computer Society Press, June 2005.
- [8] P. Romano and F. Quaglia, A Path-Diversity Protocol for the Invocation of Distributed Transactions over the Web, *Proc. IEEE International Conference on Networking and Services (ICNS)*, Papeete, Tahiti, French Polynesia, IEEE Computer Society Press, October 2005.

- [9] A. Cosentino, M. Pedicini and F. Quaglia, Supporting Function Calls within PELCR, *Proc. International Workshop on Developments in Computational Models (DCM)*, Lisbon, Portugal, ENTCS, July 2005.
- [10] B. Ciciani, F. Calderoni, A. Santoro and F. Quaglia, Modeling of QoS-oriented Content Delivery Networks, *Proc. 13th IEEE International Symposium on Modeling, Analysis and Simulation of Computer and Telecommunication Systems (MASCOTS)*, Atlanta (Georgia, USA), IEEE Computer Society Press, September 2005.
- [11] A. Santoro and F. Quaglia, A Version of MASM Portable Across Different UNIX Systems and Different Hardware Architectures, *Proc. 9th IEEE International Symposium on Distributed Simulation and Real Time Applications (DS-RT)*, Montreal, Qc. Canada, IEEE Computer Society Press, October 2005.
- [12] F. Quaglia, A. Santoro and B. Ciciani Towards Transparent Optimistic Synchronization in HLA, *Proc. FIRB-Perf Workshop on Techniques, Methodologies and Tools for Performance Evaluation of Complex Systems (FIRB-Perf 2005)*, Torino, Italy, IEEE Computer Society Press, September 2005.
- [13] R. Baldoni, J.M. Helary, S. Tucci-Piergiovanni, Group Reliable Communication in Ad-Hoc Mobile Networks: a few results and a case of study. *International Conference on Pervasive Services*. Santorini-Greece, July 2005
- [14] J. Hlary, A. Milani Efficient Partial Replication to Improve Locality in Large-Scale Systems, International workshop on Locality Preserving Distributed Computing Methods, DISC 2005 Co-located Workshop, 2005
- [15] R. Baldoni, S. Cimmino, C. Marchetti, Total Order Communications: a Practical Analysis, 5th European Dependable Computing Conference, Budapest, Hungary, 2005

Submitted papers, technical reports and others

- [16] F. Quaglia and P. Romano. Ensuring e-Transaction with Asynchronous and Uncoordinated Application Server Replicas. Pending revision on *IEEE Transactions on Parallel and Distributed Systems*.
- [17] P. Romano, F. Quaglia and B. Ciciani A Simulation Study of the Effects of Multipath Approaches in e-Commerce Applications, *Proc. 20th IEEE International Parallel and Distributed Processing Symposium - DPDNS Workshop (IPDPS)*, Rhodes Island, Greece, IEEE Computer Society Press, April 2006, to appear.
- [18] F. Quaglia, Enhancing the Performance of HLA-Based Simulation Systems via Software Diversity and Active Replication, *Proc. 20th IEEE International Parallel and Distributed Processing Symposium - APDCM Workshop (IPDPS)*, Rhodes Island, Greece, IEEE Computer Society Press, April 2006, to appear.

- [19] A. Santoro and F. Quaglia, Transparent Optimistic Synchronization in HLA via a Time-Management Converter, *Proc. 20th ACM/IEEE/SCS Workshop on Principles of Advanced and Distributed Simulation (PADS)*, Singapore, IEEE Computer Society Press, May 2006.
- [20] P. Romano, F. Quaglia and B. Ciciani, Design and Evaluation of a Parallel Edge Server Invocation Protocol for Transactional Applications over the Web , *Proc. 6th IEEE Symposium on Applications and the Internet (SAINT)*, Phoenix, Arizona, USA, IEEE Computer Society Press, January 2006, to appear.
- [21] M. Pedicini and F. Quaglia, PELCR: Parallel Environment for Optimal Lambda-Calculus Reduction, *ACM Transactions on Computational Logic*, to appear.
- [22] A. Santoro and F. Quaglia. Multiprogrammed Non-Blocking Checkpoints in Support of Optimistic Simulation on Myrinet Clusters. Submitted to *Journal of Systems Architecture*.
- [23] F. Quaglia. Spatial Uncertainty in Parallel Discrete Event Simulation: a Framework and an Application to Optimistic Synchronization. Submitted to *Journal of Parallel and Distributed Computing*.
- [24] P. Romano and F. Quaglia. Supporting Real-Time Web Transactions via Path Diversity and Multi-Version Precommit. In preparation for submission to an international conference.
- [25] P. Romano and F. Quaglia. Providing e-Transaction Guarantees by Relying on Timeouts as Failure Detectors. In preparation for submission to an international conference.
- [26] J. Hlary, A. Milani, About the efficiency of partial replication to implement Distributed Shared Memory, Technical report - IRISA, Campus de Beaulieu - 2005
- [27] R. Baldoni, C. Marchetti, S. Tucci Piergiovanni, A. Virgillito Fully Distributed Three-Tier Active Software Replication to appear in *IEEE Transactions on Parallel and Distributed Systems*, 2006
- [28] R. Baldoni, S. Scipioni, S. Tucci Piergiovanni, Communication Channel Management for Maintenance of strong overlay connectivity To appear on *11th IEEE Symposium on Computers and Communications*, 2006
- [29] R. Baldoni, S. Cimmino, C. Marchetti/ A Classification of Total Order Specifications and its Application to Fixed Sequencer-based Implementations *Journal of Parallel and Distributed Computing*, volume 66, num. 1, pages 108-127, 2006
- [30] R. Baldoni, S. Bonomi, L. Querzoni, A. Rippa, S. Tucci Piergiovanni, A. Virgillito/ Evaluation of Unstructured Overlay Maintenance Protocols under Churn (to appear) *International Workshop on Dynamic Distributed Systems (IWDDS)*, 2006

3.1.5 Communication Networks

The research group in Communication Networks has been recently organized by grouping together several research activities which were previously carried out in other two research areas (namely, algorithm engineering and distributed systems).

Group members Roberto Baldoni, Roberto Beraldi, Alberto Marchetti Spaccamela, Andrea Vitaletti.

Roberto Beraldi has been among the organizers and he is the co-chair of the first Workshop of Dynamic Distributed Systems, to be held in conjunction with ICDCS conference 2006.

In particular the group is interested in the following topics:

- Mobile Ad Hoc Networks
- Wireless sensor networks

Mobile Ad Hoc Networks We are investigating several aspects related to Mobile Ad Hoc Networks (MANET). Under the theoretical point of view, some results concerning group communication are studied in [4].

In [3] we have proposed a probabilistic protocol for unicast routing in MANET, which has been extended in [8]. The central idea is to exploit estimations of the proximity of the target node, which are casted as hints. This provides a high resilience to topological changes as well as local self-healing capabilities.

The results in [2] report a novel protocol for content-based publish-subscribe in a MANET. The distinguish feature of the protocol is that in order to diffuse an event in the network no logical overlay infrastructures are required. The paper has been selected among the best ones for being published in a special issue on mobile systems [1].

The work described in [9] presents a gossip protocol for path discovery in MANETs. The main idea is to polarize the spreading of the searching message only towards the location of the target node. This is quite different from traditional gossip protocols where the whole network is covered. And indeed much more convenient.

Wireless and sensor networks In [6] we propose 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 floodings. Ns2- based simulation results show that Directed Diffusion Light is able to almost double the network lifetime, to halve the average energy consumption, and to reduce the control overhead to one third the one of DD.

The problem of matching user profiles arises in several applications where demand and supply profiles need to be matched, e.g., in information systems for recruitment, real estate, or dating agencies. In [7] we present SmartDate, a system that matches profiles

of users that need to be matched for dating. The system runs on mobile devices and operates in multichannel mode; the matches take into account the location of the user at the time he/she issues a query. The matchmaking technique implemented in our system uses rigorous logic formalisms and is based on formal reasoning tasks. Since the best results are presented to the user at each query issued to the system, the technique allows for a user-based adaptation of the interface offered by the system, thus making possible an optimization of the small screen space available in mobile devices

Journals

- [1] R. Baldoni, R. Beraldi, G. Cugola, M. Migliavacca, L. Querzoni, Proximity-Based Content-Based Routing in Mobile Ad Hoc Networks, *International Journal of Pervasive Computing and Communications*, volume 1, num. 4, 2005

Conference Proceedings

- [2] R. Baldoni, R. Beraldi, G. Cugola, M. Migliavacca, L. Querzoni, Structure-less Content-Based Routing in Mobile Ad Hoc Networks, in proceedings of the *International Conference on Pervasive Services.*, Santorini, Greece, 2005
- [3] Baldoni, R. Beraldi, L. Querzoni, A Hint-Based Probabilistic Protocol for Unicast Communications in MANETs in *Proceedings of the International Conference on Parallel and Distributed Systems (ICPADS '05)*, Fukuoka, Japan, July 2005, 2005
- [4] R. Baldoni, J.M. Helary, S. Tucci-Piergiovanni, Group Reliable Communication in Ad-Hoc Mobile Networks: a few results and a case of study. *International Conference on Pervasive Services.* Santorini-Greece, July 2005
- [5] R. Baldoni, R. Beraldi, G. Cugola, M. Migliavacca, L. Querzoni, Structure-less Content-Based routing in Mobile Ad Hoc Networks, *International Conference on Pervasive Services.* Santorini-Greece, July 2005.
- [6] A. Marcucci, M. Nati, C. Petrioli and A. Vitaletti. Directed Diffusion Light: Low Overhead Data Dissemination in Wireless Sensor Networks. *VTC '05-Spring: Proceedings of the IEEE 61st Semiannual Vehicular Technology Conference*, 2005.
- [7] M. Berghella, A. Cali, A. Capata, T. Catarci, P. Cerrocchi, P. Masi, M. Oppedisano, E. Trevisani and A. Vitaletti. SmartDate: User Adaptation in Location-Based Mobile Matchmaking. *PSMD '05: Proceedings of the 2005 International Workshop on Pervasive Services for Mobile Devices*, 2005.

Submitted papers, technical reports and others

- [8] R. Baldoni, R. Beraldi, L. Querzoni A hint-based probabilistic protocol for unicast communications in MANETs (extended version) (to appear) *Ad Hoc Networks*, 2006.
- [9] R. Beraldi, A directional gossip protocol for path discovery in MANETs *IEEE Workshop on Wireless Ad hoc and Sensor Networks- WWASN 2006* (to appear), 2006

3.1.6 Distributed Software Architectures

The Distributed Software Architectures is an 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 Systems and Unstructured Peer-to-Peer.
- 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 (FIRB 2003) eG4M - eGovernment for Mediterranean Countries; Progetto MIUR (PRIN 2005) ESTEEM; Progetto IST “EU-PUBLI.com”; IST FP6 Network of Excellence “INTEROP”; IST FP6 Network of Excellence “DELOS”; Progetto IBM SUR GRANT “Hyper”.

Group Members: Carola AIELLO, Roberto BALDONI, Roberto BERARDI, Daniela BERARDI, Tiziana CATARCI, Giuseppe DE GIACOMO, Massimiliano DE LEONI, Fabio DE ROSA, Davide LA MANNA, Domenico LEMBO, Maurizio LENZERINI, Carlo MARCHETTI, Massimo MECELLA, Diego MILANO, Leonardo QUERZONI, Riccardo ROSATI, Ruggero RUSSO, Monica SCANNAPIECO, Sara TUCCI PIERGIOVANNI, Sirio SCIPIONI, Antonino VIRGILLITO.

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. Our 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 that has been extensively validated on real data [4]. The detailed design and implementation of a quality-driven data integration service is described in [10]. An experience of data quality assessment and improvement in an *e*-Government project is described in [6].

In [5], a solution to the problem of addressing data quality improvement under a process perspective is described. Specifically, IP-UML is proposed as a methodology for data quality improvement design. IP-UML includes the definition of a UML profile for data quality; such a profile is based on the IP-MAP framework and has the advantage

of giving a more formal definition to the main concepts related to quality improvement, as well as of organizing such concepts into a set of models useful to implement software systems.

Data cleaning methodologies for XML data are increasingly important, due to the diffusion of this type of data. We have proposed a methodology for XML data cleaning based on a uniform representation of domain knowledge through an ontology [11].

Finally, an analysis and systematization of the state of the art on the data quality dimensions and metrics is presented in [7].

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 [1, 13, 15, 33, 12] tackles simultaneously the following issues: *(i)* presenting a formal framework where services are clearly defined and the problem of automatic service composition is precisely characterized; *(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; and *(iii)* implementing our service composition techniques in an open source prototype tool.

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 WWW 2005 Conference, and become active members of SWSL (Semantic Web Services Language) <http://www.daml.org/services/swsl>, which is a working group of the Semantic Web Service Initiative.

Other work has been conducted on the issue of orchestration of services, by focusing on substitutability issues [3] and on how to have distributed orchestration enactment [16].

We finally point out that the topic of data integration is addressed in the context of the activity of the DASI lab (<http://www.dis.uniroma1.it/dasilab/>).

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 [14].

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 [2] 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.

We finally point out that the topic of data integration is addressed in the context of the activity of the DASI lab (<http://www.dis.uniroma1.it/dasilab/>).

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 [16] a peer-to-peer service-based architecture is proposed, focusing on addressing e-Government applications and cooperative workflows spanning multiple European administrations.

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 it 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 issues is how to make autonomous applications interoperate at the semantical level. That is, how to make it 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 peers' schemas. Peers are autonomous, and such mappings are created and deleted dynamically. One of the fundamental problems 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. The group of distributed software architecture has addressed the problem of semantic peer-to-peer data integration both from the theoretical and practical view-point. In particular, the problem of modelling peer-to-peer data integration systems has been addressed in [17], where a multi-modal epistemic formalization has been proposed, based on the idea that each peer is conceived as a rational agent that exchanges knowledge with other peers. In the same paper, the issue of possible inconsistencies arising from the interaction between peers is considered, and a nonmonotonic extension of the logic is proposed that is able to repair mutual inconsistent information flowing from different peers.

The topic of peer-to-peer data integration and interoperability is addressed in the context of the activity of the DASI lab (<http://www.dis.uniroma1.it/dasilab/>).

DHT-based Systems 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 [23]. 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 [21]. Another decentralized solutions for DHT-based quorums has been presented in [18]. Differently from previous work, here a bi-dimensional DHT is based and quorums are used for building a distributed memory with atomic semantics. We proposed an architecture which maintains the atomic semantics despite the fact nodes continuously join and leave the system and abruptly crash. The architecture is self-organizing and self-healing in the sense that it is able to respond to variations in both the system composition and the load variations, adapting the composition of the quorum to the actual distribution of requests over nodes.

Unstructured Peer-to-Peer P2P systems are at present a widespread technology as well as a hot research topic. A P2P system is a highly dynamic distributed system in which nodes perpetually join and leave. For these characteristics, a P2P system can reach a potentially infinitely wide scale with a transient population of nodes.

Overlay networks have emerged as viable solutions to support a P2P application in an efficient and scalable manner maintaining a satisfactory level of reliability. An overlay is a logical network built on top of – and generally independently from – the underlying physical computer network, by the peers (nodes) of the P2P system. Any overlay

should exhibit a proper topology to support specific classes of P2P applications, *unstructured* overlay networks have emerged to effectively support large scale dissemination and flooding-based content searching. An unstructured overlay shows good global properties like connectivity (for reliability), and low-diameter and constant-degree (for scalability) without relying on a deterministic topology. *Overlay maintenance* is the fundamental problem consisting in preserving the topological properties of an overlay despite continual arrivals and departure of nodes. Current approaches to overlay maintenance address different variants of the problem under different kinds of assumptions, for the problem and its underlying computational model have never been precisely defined.

In this respect our research has focused on two aspects: the first one consisted in the experimental evaluation of current overlay maintenance protocols in a common framework in order to understand their limits and to make a comparison of different solutions. To this end, in [25] we compare two overlay maintenance protocols well suited to unstructured P2P systems, namely SCAMP and Cyclon, in an event-based simulation setting including concurrent and interleaved join and leave operations as well as variable message transfer delay. This simulation setting allows to point out surprising results for both protocols. In particular, under a continuous and concurrent replacement of nodes, permanent partitioning of the overlay arises after a very small number of join/leave operations.

The second aspect regards the formal specification of the overlay maintenance problem and its underlying computational model. The problem has been firstly formally defined in [24, 27]. [28] defines a specification of the problem, namely Eventual Strong Connectivity, stating that the overlay is connected from an arbitrary point of time onwards. Specifically, a safety property is presented which encapsulates overlay *connectivity* (the core property of any overlay allowing any two nodes to communicate) along with a liveness property enforcing the ability of new nodes to participate in the overlay. The precise definition of the problem allows to point-out limitations of the use of redundant topologies to ensure connectivity. Moreover, a protocol which maintains overlay connectivity most of the time and able to dynamically repair the overlay when failures occur is introduced. The protocol is equipped with a dynamic reconfiguration mechanism that rearranges the topology in order to achieve good scalability properties in periods when the overlay population changes very slowly. A simulation study conveys the very fact that the presented protocol is practically reasonable in this respect.

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, load balancing and fault tolerance.

We showed in [31] how to design middleware services that exploit a three-tier architecture to implement replication protocols that enforce a strong consistency criterion, i.e. to implement transparent replication for fault tolerance of a service whose replicas are deployed on a wide area network. 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.

Service replication can be also exploited for achieving higher scalability through load distribution among replicas. In [8] we investigate a basic Least-Loaded-First (LLF) load sharing approach and found that the high task size variation that exists in heavy-tailed workloads often causes smaller tasks to be severely delayed by large tasks. Then we proposed a size-based approach, called the least flow-time first (LFF-SIZE), which reduces the delay caused by size variation while maintaining a balanced load in the system. LFF-SIZE takes the relative processing time of a task into account and dynamically assigns a task to the fittest server with a lighter load and higher processing capacity. LFF-SIZE also uses a multi-section queue to separate larger tasks from smaller ones. This arrangement effectively reduces the delay of smaller tasks by larger ones as small tasks are given a higher priority to be processed. The performance results performed on the LFF-SIZE implementation shows a substantial improvement over existing load sharing and static size-based approaches under realistic heavy-tailed workloads.

Finally, in [22] we study clustering architectures for enabling the reuse of obsolete hardware that would be otherwise discarded. Two clustering systems were tested: OpenMosix and LTSP, which differ for their architecture (centralized vs. decentralized) as well as for the purpose of their design (HPC vs. low-cost cooperating terminals). Our experiments show that the performance of a clustered architecture entirely composed of obsolete hardware is comparable to that of a modern single-process architecture. This solution, apart for possibly bringing obvious economical and environmental benefits on the long-term, can find an immediate application in contexts with economical constraints for example in development and cooperation projects for third-world countries.

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 [20, 30]. 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.

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. We realized a comprehensive survey of the state-of-the-art in the publish/subscribe area [29]. In particular, we developed a generic layered architecture of a pub/sub system, by identifying and classifying the common elements of any system. For each layer, we surveyed the various algorithms that have been proposed, focusing on the assumption they rely on and the constraints they impose on other layers. Any existing pub/sub solutions can be obtained by plugging a specific algorithm at each layer, including those tailored for very specific environments such as Mobile Ad-Hoc Networks or Sensor Networks. We have selected two basic algorithms for event diffusion and studied their behavior [26] in the context of peer-to-peer networks characterized by a high frequency of nodes arrivals and departures. Our study shows that routing information becomes rapidly obsolete when nodes in the system frequently changes, then the presence of an expiration mechanism can greatly aid reducing the waste of memory and maintain routing information accurate.

The decoupling and asynchrony properties of the publish-subscribe paradigm makes it very appealing for dynamic wireless networks like MANETs. As we point out in [29], the implementation of an efficient dispatching service for a MANET is a challenging problem. Common solutions for fixed networks (like those based on centralized servers or static brokers' networks) are clearly not suited for settings that exhibit even a discrete degree of mobility. In [19, 9] we proposed a novel algorithm for content-based data distribution in MANETs, based on a completely different approach. The idea at the basis of our approach was to exploit mobility of nodes together with the broadcast-based communication model proper of wireless links to maintain approximate information on subscription locations. Events are distributed in the network leveraging this information: each node autonomously decides if and when to forward an event, basing its decision on the information previously collected on the location of subscriptions matched by that event.

Another novel pub/sub system has also been proposed [32], namely DPS. DPS is a

self-organizing and self-healing pub/sub system where nodes participating to the system completely self-organize among themselves, and exchange information with no logically centralized infrastructure. DPS nodes form tree structures that favor efficient and scalable event distribution, allowing to exclude from the diffusion all the nodes that are not interested in the event. DPS is self-healing in the sense that the tree structure is repaired by nodes themselves in case of nodes leaving or failing, without any external intervention and only relying on local information.

Journals

- [1] D. Berardi, D. Calvanese, G. De Giacomo, M. Lenzerini, M. Mecella, *Automatic Service Composition Based on Behavioral Description*, International Journal of Cooperative Information Systems, 14(4),2005.
- [2] F. De Rosa, A. Malizia, M. Mecella, *Disconnection Prediction in Mobile Ad hoc Networks for Supporting Cooperative Work*, IEEE Pervasive Computing, 4(3), 2005.
- [3] V. De Antonellis, M. Melchiori, L. De Santis, M. Mecella, E. Mussi, B. Pernici, P. Plebani, *A Layered Architecture for Flexible Web Service Invocation*, Software Practice & Experience, 36(2), 2005
- [4] D. Milano, M. Scannapieco, T. Catarci, *P2P Data Quality Improvement in the DaQuinCIS System*, Journal of Digital Information Management (ISSN 0972-7272) **3** (2005), no. 3.
- [5] M. Scannapieco, B. Pernici, E. Pierce, *IP-UML: A Methodology for Quality Improvement based on IP-MAP and UML.*, Advances in Management Information Systems - Information Quality Monograph (AMIS-IQ Monograph) Sharpe, M.E., April 2005.
- [6] M. Bertoletti, P. Missier, M. Scannapieco, P. Aimetti, C. Batini, *Improving Government-to-Business Relationships through Data Reconciliation and Process Re-engineering.*, Advances in Management Information Systems - Information Quality Monograph (AMIS-IQ Monograph) Sharpe, M.E., April 2005.
- [7] M. Scannapieco, P. Missier, C. Batini, *Data Quality at a Glance*, Datenbank-Spektrum **14** (2005).
- [8] R. Baldoni, J. Broberg, Z. Tari, and A. Y. Zomaya. A least flow-time first load sharing approach for distributed server farm. *Journal of Parallel and Distributed Computing. Volume 65 , Issue 7 (July 2005) Pages: 832 - 842*, 7 2005.
- [9] R. Baldoni, R. Beraldi, G. Cugola, M. Migliavacca and L. Querzoni. Proximity-Based Content-Based Routing in Mobile Ad Hoc Networks. *International Journal of Pervasive Computing and Communications, Vol.1, Num.4, 2006, Troubador Publishing LTD.*

Conference Proceedings

- [10] D. Milano, M. Scannapieco, and T. Catarci, *Design and Implementation of a P2P Data Quality Broker*, Proceedings of the International Conference on Interoperability of Enterprise Software and Applications (INTEROP 2005), Geneva, Switzerland, 2005.
- [11] D. Milano, M. Scannapieco, and T. Catarci, *Using Ontologies for XML Data Cleaning*, Proceedings of the OTM Workshop on Inter-organizational Systems and Interoperability of Enterprise Software and Applications (MIOS+INTEROP), Larnaca, Cyprus, 2005.
- [12] D. Berardi, D. Calvanese, G. De Giacomo, M. Mecella, *Composition of Services with Nondeterministic Observable Behavior*, Proceedings ICSOC 2005.
- [13] D. Berardi, D. Calvanese, G. De Giacomo, R. Hull, M. Lenzerini, M. Mecella, *Modeling Data and Processes for Service Specifications in COLOMBO*, Proceedings CAiSE 2005 INTEROP Workshop on Enterprise Modeling and Ontologies for Interoperability (EMOI-INTEROP 2005) (Porto, Portugal, 2005), ISBN 972-752-077-4.
- [14] F. De Rosa, M. Mecella, *Designing and Implementing a MANET Network Service Interface with Compact .NET on Pocket PC*, Proceedings of the 3rd International Conference on .NET Technologies (.NET 2005) (Plzen, Czech Republic, 2005), published as a special issue of the Journal of .NET Technologies, **3** (2005), no. 1 – 3, 77 – 86, ISSN 1801-2108.
- [15] D. Berardi, D. Calvanese, G. De Giacomo, R. Hull, M. Mecella, *Automatic Composition of Transition-based Semantic Web Services with Messaging*, accettato per la pubblicazione in Proceedings of the 31st International Conference on Very Large Data Bases (VLDB 2005) (Trondheim, Norway, 2005).
- [16] M. Contenti, M. Mecella, A. Termini, R. Baldoni, *A Distributed Architecture for Supporting eGovernment Cooperative Processes*, Proceedings of the TED Conference on eGovernment (TCGOV 2005) (Bozen-Bolzano, Italy, 2005), Springer-Verlag, LNAI 3416, pp. 181-192.
- [17] D. Calvanese, G. De Giacomo, D. Lembo, M. Lenzerini, and R. Rosati. Inconsistency tolerance in p2p data integration: an epistemic logic approach. In *Proc. of the 10th Int. Workshop on Database Programming Languages (DBPL 2005)*, 2005.
- [18] E. Anceaume, M. Gradinariu, V. Gramoli, and A. Virgillito. P2P Architecture for Self-* Atomic Memory. In *Proceedings of the 8th International Symposium on Parallel Architectures, Algorithms and Networks (I-SPAN 2005)*, Las Vegas, Nevada, December 2005, 12 2005.
- [19] R. Baldoni, R. Beraldi, G. Cugola, M. Migliavacca and L. Querzoni. Structure-less Content-Based Routing in Mobile Ad Hoc Networks. In *proceedings of the International Conference on Pervasive Services (ICPS '05)*, Santorini, Greece, July 2005.

- [20] R. Baldoni, S. Cimmino, and C. Marchetti. Total Order Communications: a Practical Analysis. *5th European Dependable Computing Conference, Budapest, Hungary, April 20-22, 2005*, 4 2005.
- [21] R. Baldoni, R. Jiménez-Peris, M. Patiño Martínez, L. Querzoni, and A. Virgillito. Dynamic Quorums for DHT-based P2P Networks. In *in Proceedings of the 4th IEEE International Symposium on Network Computing and Applications (IEEE NCA05), Cambridge, MA, USA, July 2005*, 7 2005.
- [22] R. Baldoni, D. Lamanna, and R. Russo. Distributed software platforms for rehabilitating obsolete hardware. In *First international conference on Open Source Systems (OSS2005), Genova, Italy, 2005*, 2005.
- [23] R. Baldoni, C. Marchetti, A. Virgillito, and R. Vitenberg. Content-Based Publish-Subscribe over Structured Overlay Networks. In *25th IEEE International Conference on Distributed Computing Systems ICDCS 2005*, 6 2005.
- [24] R. Baldoni and S. T. Piergiovanni. A Peer-to-Peer Membership Notification Service. In *in Proceedings of the Third International Workshop on Databases, Information Systems and Peer-to-Peer Computing (DBISP2P05), Trondheim, Norway, August 2005.*, 8 2005.

Submitted papers, technical reports and others

- [25] R. Baldoni, S. Bonomi, L. Querzoni, A. Rippa, S. T. Piergiovanni, and A. Virgillito. Evaluation of Unstructured Overlay Maintenance Protocols under Churn. Technical report, Dipartimento di Informatica e Sistemistica, 2005.
- [26] R. Baldoni, G. Cortese, F. Morabito, L. Querzoni, S. T. Piergiovanni, and A. Virgillito. On The Accuracy of Event Distribution Lists for Publish/Subscribe. Technical report, Dipartimento di Informatica e Sistemistica, 2005.
- [27] R. Baldoni and S. T. Piergiovanni. Group Membership for Peer-to-Peer Communication. Technical report, Dipartimento di Informatica e Sistemistica, Universit di Roma, 2005.
- [28] R. Baldoni and S. T. Piergiovanni. Self-Maintenance of Overlay Connectivity. Technical report, 2005.
- [29] R. Baldoni and A. Virgillito. Distributed Event Routing in Publish/Subscribe Communication Systems: a Survey. Technical report, Dipartimento di Informatica e Sistemistica, 2005.
- [30] R. Baldoni, S. Cimmino, and C. Marchetti. A Classification of Total Order Specifications and its Application to Fixed Sequencer-based Implementations. *To appear in Journal of Parallel and Distributed Computing*, 2006.

- [31] R. Baldoni, C. Marchetti, S. T. Piergiovanni, and A. Virgillito. Fully Distributed Three-Tier Active Software Replication. *To appear in IEEE Transactions on Parallel and Distributed Systems 2006*, 2006.
- [32] E. Anceaume, M. Gradinariu, A. K. Datta, G. Simon, and A. Virgillito. A Semantic Overlay for Self-* Peer-to-Peer Publish/Subscribe. To appear in *26th IEEE International Conference on Distributed Computing Systems ICDCS 2006*.

Ph.D. Thesis

- [33] D. Berardi Automatic Service Composition. Models, Techniques and Tools. PhD Thesis, Dipartimento di Informatica e Sistemistica, Università di Roma “La Sapienza”, Roma, 2005.

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 (DI - Università “La Sapienza”), Alberto Budoni (DAU - Università “La Sapienza”), L. De Bonis (Dip. SAVA, Università del Molise), Marco Temperini (DIS - Università “La Sapienza”).

We work on

1. development of methodological and applicative aspects of the *Open and Distance Learning* model.
2. the principles of object-oriented programming languages and their applications in distributed (object-oriented) programming;
3. application of ICT to collaborative working and participation planning;

Open and Distance Learning We work on the configuration of courses, tailored on the learning needs of the individual learner: A basic mathematical logic and automated reasoning approach has been extended with the adaptation and application of planning methodology ([2]) and with the definition and use of *learning objective templates* ([1]).

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

- *EuroCompetence* (A university - workplace model for developing knowledge for European Collaboration), Socrates Project Number : 56544-CP-1-98-1-NO-ODL-ODL.

- *CIOC* (Competence Development in Internationally Oriented Companies), 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), elearning project n.2002-0510/001-001-EDU-ELEARN, <http://www.hsh.no/menu/>.
- *QUIS* (Quality, Interoperability and Standards in e-learning), Agreement n. 2004 - 3538 /001 - 001 ELE-ELEB14 <http://www.tisip.no/quis/>, [3, 4]).

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 is conducted so far through development of *Laurea* thesis.

Support to collaborative working and participation planning We have started this year an interdisciplinary activity, in collaboration with colleagues from the area of Environment Engineering ([5]). The activity has been focussed on the design and development of a prototypal web application supporting the discussion about plans (*projects*). The web-site provides basically the users with means to express and collect opinions; one further aim is to allow for content analysis to both support decision making and represent the so-called *image* that the community shares about its urban/territorial environment.

Conference Proceedings

- [1] G. Fernandez, A. Sterbini, M. Temperini. Component-based automated e-learning. 4th Int. Conference on Web-Based Education (WBE 2005), Feb 21-23, 2005, Grindelwald, Switzerland. (2005)
- [2] C. Limongelli, A. Sterbini, M. Temperini. Automated course configuration based on automated planning: framework and first experiments First International Conference on Methods and Technologies for Learning (ICMTL 2005), Mar 9-11, 2005, Palermo, Italy (2005)

Submitted papers, technical reports and others

- [3] F. Di Domenico, A. Sterbini, M. Temperini. QUIS analysis of commercial and experimental e-learning systems. *Project QUIS: Quality, Interoperability and Standards in*

e-learning, Agreement n. 2004 – 3538 /001 – 001 ELE–ELEB14. Deliverable, Work Package 4, Dec. 2005

- [4] A.M. Bianco, M. De Marsico, M. Temperini. Standards for e-learning. *Project QUIS: QQuality, Interoperability and Standards in e-learning*, Agreement n. 2004 – 3538 /001 – 001 ELE–ELEB14. Deliverable, Work Package 5, Dec. 2005
- [5] A. Budoni, L. De Bonis, M. Temperini. Rethinking PPGIS in the perspective of free and open content systems. Accepted for presentation at 25TH Urban Data Management symposium (UDMS 2006), May 15-17, 2006, Iborg, Denmark (2006)

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; Istituto di Fisiologia Umana, Università di Roma "La Sapienza", Roma; IRCCS S.Lucia, Roma.

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

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) and body composition using non-invasive techniques as bioimpedance analysis (BIA). i) Mathematical models were recently proposed in literature to estimate the time-course of Insulin Secretion (ISR) by the pancreatic β -cells during different experimental sessions. The first approach, regarding the glucose-stimulated insulin secretion in 24 h multiple-meal tests, represents the ISR by a three component model: 1) a static component, that relates insulin secretion rate (ISR) to plasma glucose concentration; 2) a potentiation factor, that modulates the static component in time by taking into account the influence of a variety of hormonal stimuli on the β -cell; 3) a dynamic component, that takes into account the rapid pancreatic response to glucose rise. The time-course of the potentiation factor, together with the parameters of the static response and the amplitude of the dynamic component, were estimated by the deconvolution technique from the C-peptide and glucose concentration data. Another recent approach, relative to ad hoc designed experiments allows calculation of insulin secretion rate using a dynamic model where ISR depends on changes in plasma glucose concentration other than on the time derivative of circulating glucose. However, the above mentioned models do not take into account the emerging evidence that cytosolic long chain acyl-CoAs (LC-CoAs) cover a key role as coupling factor for insulin secretion and that both glucose and free fatty acids (FFAs) are signaling through LC-CoA. It has been hypothesized that nutrients stimulate insulin secretion through the simultaneous activation of two pathways. One involves accelerated ATP production and increase in intracellular Ca^{2+} . The other is dependent on the generation and accumulation of excess citrate in the cytosol, and increase in cytosolic malonyl-CoA, which in turn blocks LC-CoA transport into mitochondria. Glucose-stimulated insulin secretion is in fact associated with decreased NEFA oxidation. In this last year we elaborated a new mathematical model that describes the dual control of insulin release by glucose and FFA.

Based on this model, data of multiple-meal experiments were analysed. Parameters of b-cell function were estimated in control subjects as compared to obese patients before and after diet. ii) During the 2005 a first method to test the possibility of using an Electric Impedance Tomography (EIT) system to assess the composition of sections of interest in human body, was developed. This method utilizes an extended Kalman filter to solve the inverse problem of estimating the conductivity/resistivity distribution in electrical impedance tomography images. This approach has been tested using, as a first step, simulated images with a simple geometry, and, successively, validated by bioimpedance data recorded at different heights, by a ring of electrodes, disposed on the leg of some subjects. The subjects completed also an MRI scan of the leg to acquire MRI images of the same sections, reconstructed from the bioimpedance data, to be used as references. Next steps will regard to test the possibility of using the a priori information on the section tissue composition to improve the image reconstruction and to extend the method to other body districts of interest.

Analysis of Brain Potential related to Motor Control In the last year, the research activity involved problems connected with i)The estimation of the effective and functional human cortical connectivity; ii)the analysis of the brain potential modifications in patients affected by the Alzheimer disease (AD).

i) The concept of brain connectivity plays today a central role in the neuroscience. While functional connectivity is defined as the temporal coherence between the activities of different brain areas, the effective connectivity is defined as the simplest brain circuit that would produce the same temporal relationship as observed experimentally between cortical sites. The most used method to estimate effective connectivity in neuroscience is the structural equation modeling (SEM), typically used on data related to the brain hemodynamic behavior. However, the use of hemodynamic measures limits the temporal resolution on which the brain process can be followed. In this year the use of the SEM approach on the cortical waveforms estimated from the high-resolution EEG data, which exhibits a good spatial resolution and a higher temporal resolution, was proposed. We performed a simulation study, in which different main factors were systematically manipulated in the generation of test signals, and the errors in the estimated connectivity were evaluated by the analysis of variance (ANOVA). Such factors were the signal-to-noise ratio and the duration of the simulated cortical activity. Since SEM technique is based on the use of a model formulated on the basis of anatomical and physiological constraints, different experimental conditions were analyzed, in order to evaluate the effect of errors made in the a priori model formulation on its performances. The feasibility of the proposed approach has been shown in a human study using high-resolution EEG recordings related to finger tapping movements. ii)In the last year the study was aimed to test the hypothesis that cortical electroencephalographic (EEG) rhythms change across normal elderly (Nold), mild cognitive impairment (MCI), and Alzheimer's disease (AD) subjects as a function of the global cognitive level. Resting eyes-closed EEG data were recorded for subjects belonging to these classes and processed by a software to localize the cortical sources of the EEG components. The EEG sources presented both linear and nonlinear (linear, exponential, logarithmic, and power) correlations with the global cognitive level

(as revealed by mini mental state examination score) across all subjects showing that analysis of the data from a large populations supports the 'transitional hypothesis' of a shadow zone across normality, pre-clinical stage of dementia (MCI), and AD.

Journals

- [1] F.Cincotti, D.Mattia, A.Timperi, M.Mattiocco, L.Bianchi, S.Salinari, M.G.Marciani, and F.Babiloni. The use of high resolution EEG and the estimation of cortical activity for brain computer interface applications. *In AKAY M. AND HE B.: Neural Engineering. NEW YORK: Jhon Wiley and Sons*, 2005.
- [2] F.Babiloni, C.Babiloni, F.Carducci, G.L.Romani, P.M.Rossini, A.Basilisco, L.Astolfi and S.Salinari. Solving The Neuroimaging Puzzle: The Multimodal Integration Of Neuroelectromagnetic And Functional Magnetic Resonance Recordings. *In: M. HALLETT, L.H. PHILLIPS, II, D.L. SCHOMER, J.M. MASSEY. Advances in Clinical Neurophysiology, (Supplements to Clinical Neurophysiology, Vol. 57). : Elsevier B.V.*, 2005.
- [3] L. Astolfi, F. Cincotti, D.Mattia, S.Salinari Estimation of human cortical connectivity with the multimodal integration of fMRI and high resolution EEG. *In L.COSTANDOU: Medical Image Analysis Methods. BOCA RATON (FL): CRC Press (UNITED STATES).*, 2005.

Conference Proceedings

- [4] L.Astolfi, C.Babiloni, F.Carducci, F.Cincotti, A.Basilisco, P.M.Rossini, S.Salinari, S.Cerutti, D.Ben Dayan, L.Ding, Y.Ni, B.He and F.Babiloni. Estimation of the cortical connectivity by high resolution EEG and structural equation modeling: simulation and application to finger tapping data. *IEEE TRANSACTIONS ON BIOMEDICAL ENGINEERING.* vol.52, pp. 757-768, 2005.
- [5] L.Astolfi, F.Cincotti, D.Mattia, C.Babiloni, F.Carducci, A.Basilisco, P.M. Rossini, S.Salinari, L.Ding, Y.Ni, B.He and F.Babiloni. Assessing cortical functional connectivity by linear inverse estimation and directed transfer function: simulations and application to real data. *CLINICAL NEUROPHYSIOLOGY.* vol. 116, pp. 320-332, 2005.
- [6] L. Astolfi, F. Cincotti, D.Mattia, M.Lai, F.De Vico Fallani, S.Salinari, L.A.Baccala', M.Ursino, M. Zavaglia and F.Babiloni. Causality estimates among brain cortical areas by Partial Directed Coherence: simulations and application to real data. *INTERNATIONAL JOURNAL OF BIOELECTROMAGNETISM.* vol. 7, 2005.
- [7] L. Astolfi, F. Cincotti, D.Mattia, M.Lai, F.De Vico Fallani, S.Salinari, L.A.Baccala', M.Ursino, F.Nocchi, M. Zavaglia and F.Babiloni. Using multivariate estimates to assess directed causality between cortical areas of the brain. Simulations and application during the imagination of a limb movement in Spinal Cord Injured patients.

The 16th Meeting of the International Society for Brain Electromagnetic Topography. October 5 -8. Bern, Switzerland. 2005

- [8] L. Astolfi, F. Cincotti, D.Mattia, M.Lai, F.De Vico Fallani, S.Salinari, L.A.Baccala', M.Ursino, M. Zavaglia and F.Babiloni. Comparison of different multivariate methods for the estimation of cortical connectivity: simulations and applications to EEG data. *27th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBS)*. 1-4 September. Shangai, China. 2005
- [9] L. Astolfi, F. Cincotti, D.Mattia, M.Lai, F.De Vico Fallani, S.Salinari, L.A.Baccala', M.Ursino, M. Zavaglia and F.Babiloni. Causality estimates among brain cortical areas by Partial Directed Coherence: simulations and application to real data. *BEM and NFSI 2005*. 12-15 May. Minneapolis, USA. 2005

Submitted papers, technical reports and others

- [10] C.Babiloni, E.Cassetta, G.Dal Forno, C.Del Percio, F.Ferreri, R.Ferri, B.Lanuzza, C.Miniussi, D.V.Moretti, F.Nobili, R.D.Pascual-Marqui, G.Rodriguez, G.L.Romani, S.Salinari, O.Zanetti, and P.M.Rossini Donepezil effects on sources of cortical rhythms in mild Alzheimers disease: responders vs. non responders *NEUROIMAGE* , To appear.
- [11] L. Astolfi, F. Cincotti, D. Mattia, M.G.Marciani, F.De Vico Fallani, S.Salinari, L.A.Baccala', M.Ursino, M. Zavaglia, L. Ding, J.C. Edgar, G.A.Miller, B.He and F. Babiloni. A Comparison of different cortical connectivity estimators for high resolution EEG recordings. *HUMAN BRAIN MAPPING*. , To appear.
- [12] Salinari S, Bertuzzi A., Gandolfi A., Greco A.V., Scarfone A., Manco M., Mingrone G. Dodecanedioic acid overcomes metabolic inflexibility in type 2 diabetic subjects. Submitted.
- [13] L. Astolfi, F. Cincotti, D. Mattia, M.G.Marciani, F.De Vico Fallani, S.Salinari, L.A.Baccala', M.Ursino, M. Zavaglia and F. Babiloni. Cortical connectivity patterns during the intention of limb movements in normals and in a spinal cord injured patient estimated with the Directed Transfer Function. *IEEE ENGINEERING IN MEDICINE AND BIOLOGY MAGAZINE*.,To appear.
- [14] L. Astolfi, F. Cincotti, D. Mattia, M.G.Marciani, F.De Vico Fallani, S.Salinari and F. Babiloni. Stima della connettivita cerebrale mediante EEG ad alta risoluzione spaziale. *AUTOMAZIONE E STRUMENTAZIONE*. ,To appear.

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 as well as non conventional approaches to modeling, 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, (Lecturer), Roberto RONCHINI (Lecturer), Amit BRANDES.

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

More in detail in the area of Industrial Automation, the main interest was to test the validity of the conventional identification tools to a real set of data measured in a multi-input multi output continuous plant and to suggest suitable improvements: in particular in the area of manufactory plants, a new approach to the motion control design of a multi axes motion has been proposed and applied.

In [5] it has been shown that approaches to the parameter identification have given unsatisfactory results due the peculiarities of the measured data. A new way to solve the parameter identification problem has been therefore proposed and applied. The obtained results was very satisfactory. In [6], the approach based on the virtual reality simulation of a manufactory plant has been applied to optimize the functionality of the plant and to select the most appropriate drive. The improvement obtained was considered very useful from the plant integrator.

Finally some aspects on autonomous robot navigation in unknown environments using image analysis for map construction and motion planning have been investigated in [[7], [11], [15]].

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 solutions to approximate feedback linearization and nonlinear normal forms, dynamic decoupling, nonlinear sampling, observer theory and the problem

of computing the solution of multi-time scale differential equations [3], [8], [2], [10], [4] and [9]

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], [14].

Journals

- [1] A. Brandes and S. Monaco. Fusion of delayed measurements as a last-squares optimization problem, *Med. J. of Meas. And Cont.* , 1, pp.152-164, 2005.
- [2] C. Califano, S. Monaco and D. Normand-Cyrot. Non-linear non-interacting control with stability in discrete time: a dynamic solution, *International Journal of Control* 78 (6), pp. 443-459, 2005.
- [3] S. Monaco and D. Normand-Cyrot. Normal forms and approximated feedback linearization in discrete time, *Systems and Control Letters* , 2005.

Conference Proceedings

- [4] C. Califano, S. Monaco and D. Normand-Cyrot. On the Observer Design of multi output systems in Discrete-Time. In *Proceedings of the Control and Decision Conference*, Siviglia, Spain, December 2005.
- [5] A. De Carli, G.L. Giorni. Evaluation of the Interaction Degree in a Multi-input Multi-output Plant. A Case of Study, In *Proceedings of the Seventh Italian Conference on Chemical and Process Engineering*, Taormina, Italy, May 2005
- [6] A. De Carli, O. Marinelli Un nuovo modo di progettare la Movimentazione Controllata. In *Atti del 49 Convegno Annuale ANIPLA Automazione e ottimizzazione di processo per una gestione efficiente dei cicli produttivi*, Napoli, November 2005
- [7] P. Di Giamberardino and A. Usai. Dynamical Reconstruction of a 3D Elevation Map Using Stereovision from a Mobile Robot. In *Proceedings 24 IASTED Int. Conf. on Modelling, Identification and Control*, Innsbruck, Austria, February 2005.

- [8] S. Monaco and D. Normand-Cyrot. On Extended controller forms of nonlinear discrete-time systems: the single-input case. In *Proc 16th IFAC World Congress*, Prague, Czech Republic, July 2005.
- [9] S. Monaco and D. Normand-Cyrot. Quadratic feedback linearization and normal forms for two-input discrete-time systems. In *Proc 16th IFAC World Congress*, Prague, Czech Republic, July 2005.
- [10] S. Monaco and D. Normand-Cyrot, C. Califano. On the differential/difference representation of sampled dynamics. In *Proceedings of the Control and Decision Conference*, Siviglia, 2005.
- [11] A. Usai and P. Di Giamberardino. Local Path Planning in Unknown Environment by Local 3D Elevation Map Construction. In *Proceedings 2nd International Conference on Informatics in Control, Automation and Robotics*, Barcelona, Spain, September 2005.

Submitted papers, technical reports and others

- [12] S. Monaco, D. Normand-Cyrot and C. Califano. Volterra series representation and chronological series, Submitted to *IEEE TAC*, 2004.
- [13] S. Monaco and D. Normand-Cyrot. Some comments about normal forms under sampling, Submitted to *submitted ACC 06*, 2005.
- [14] A. Usai and P. Di Giamberardino. Nonholonomic mobile robot visual servoing: a multirate digital approach. Accepted for publication in *8th WSEAS International Conference on Automatic Control, Modelling & Simulation*, Prague, Czech Republic, 2006, AND to the WSEAS Journal.
- [15] A. Usai and P. Di Giamberardino. Autonomous Robot Motion in Unknown Environment by Local 3D Elevation Map Construction. Accepted for publication in *Integrated Computer-Aided Engineering*.

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 IMAGES and EuQoS projects belonging to the Information Society and Technology programme, sponsored by the 6th 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 SCOGGIO.

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. In particular gaussian approximations and Montecarlo methods have been considered. Particular attention has been dedicated to the selection of the processed pixels, according to their informative content.

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 same problem have been performed. Useful conclusions have been provided about the choice of the model and the related filtering procedure with reference to the respiratory system volume and the measurement instrumentation precision.

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 and forecasting in traffic estimation for bandwidth brokers has been studied. The possibility of exploiting these estimation procedures has 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 A population-based global optimization method has been proposed which is characterized by a suitable births 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).

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.

Journals

- [1] Bruni C., Delli Priscoli F., Koch G., Vergari S., Traffic Management in a Band Limited Communication Network: an Optimal Control Approach, *Int. Journal of Control*, **vol. 78**, n.16, nov. 2005.
- [2] Iacoviello D., Lucchetti M., Parametric Characterization of the form of the Human Pupil from Blurred Noisy Images, *Computer Methods and Programs in Biomedicine*, **vol. 77**, 2005.

Book

- [3] Bruni C., Iacoviello D., Metodi Variazionali per il Controllo Ottimo. Complementi ed Esercizi. *Euroma*, Sept 2005.

Conference Proceedings

- [4] Bruni C., Ferrone C., Lucchetti M., A population-Based Global Optimization Procedure Characterized by a Births Control Strategy, *IASTED Conference on Computational Intelligence*, Calgary, Canada, July 2005.
- [5] Annunziato M., Bertini I., Lucchetti M., Orsini G., Pannicelli A., Pizzuti S., Ottimizzazione in linea di una rete energetica con una metodologia basata su un ambiente di vita artificiale. *International Workshop on Natural and Artificial Immune Systems (NAIS 2005)*, Vietri sul mare, Salerno, Italy, June 9-10, 2005.
- [6] Annunziato M., Lucchetti M., Orsini G., Pizzuti S., Artificial life and Online Flows Optimization in Energy Networks, *2005 IEEE Swarm Intelligence Symposium*, Westin Pasadena, California, June 8-10 2005.

- [7] Ferrone C., An Artificial Life Global Optimization Procedure for Possibly Time Varying Cost Functions, *Riunione Annuale CIRA*, Tropea, Sept 2005.
- [8] Marchetti I., Controllo Ottimo Tempo-Discreto per l'Ammissione delle Chiamate in Reti di Telecomunicazioni, *Riunione Annuale CIRA*, Tropea, Sept 2005.

Submitted papers, technical reports and others

- [9] Brandes A., Bruni C., Granato L., Estimation of Respiratory Gas Exchange: a Comparative Study of Linear and Nonlinear Model-based Estimation Techniques, *IEEE Transactions on Biomedical Engineering*, to appear.
- [10] Bruni C., Iacoviello D., Koch G., Lucchetti M., Filtering Images Sequences from a Moving Object and the Edge Detection Problem, *Computers and Mathematics with Applications*, to appear.
- [11] Bruni C., Ferrone C., Lucchetti M., Global Optimization for Possibly Time Dependent Cost Functions by a Population Set Based Algorithm with Births Control, *Computers and Mathematics with Applications*, to appear.
- [12] Anjali T., Bruni C., Iacoviello D., Scoglio C., Optimal Bandwidth Allocation for Label Switched Paths: an On-Line Predictive Approach, *Computer Networks*, Submitted.
- [13] Bruni C., Delli Priscoli F., Koch G. Marchetti I., An Optimal Approach to the Connection Admission Control Problem, *International Journal of Control*, submitted.
- [14] Bruni C., Delli Priscoli F., Koch G. Marchetti I., Discrete Time Optimal Solution for the Connection Admission Control Problem, *IEEE J. on Selected Areas in Communications*, submitted.
- [15] Bruni C., Delli Priscoli F., Koch G. Marchetti I., Connection Admission Control in Cellular Networks: a Discrete Time Optimal Solution, *IEEE INFOCOM 2006*, Barcelona, April, 23-29, submitted.

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, Fabio CELANI, Paolo CONFORTO, Francesco DELLI PRISCOLI, Claudio DE PERSIS, Emiliano GUAINELLA, Tiziano INZERILLI, Alberto ISIDORI, Ilaria MARCHETTI, Andrea MERCURIO, Silvano MIGNANTI, Antonio PIETRABISSA, Dario POMPILI, Gianfranco SANTORO.

Control under communication constraints In [8] a methodology is presented which allows to design encoder, decoder and controller for stabilizing a nonlinear system in feedforward form using saturated encoded state feedback under standard assumption, namely local Lipschitz property of the vector field defining the system. n (respectively, $n+1$) bits are used to encode the state information needed to the purpose of semi-globally (globally) stabilizing an n -dimensional system. It is additionally proven that the data rate employed is the minimal possible to achieve the control objective.

The problem of semi-global asymptotic stabilization of nonlinear continuous-time systems under data rate constraints when only output measurements are available is studied in [27]. We consider systems which are uniformly observable and we design an “embedded-observer” decoder and a controller which semi-globally stabilize this class of systems, provided that an appropriate observer gain is chosen.

A new class of dynamic encoders for continuous-time nonlinear control systems which update their parameters only at discrete times is considered in [14]. We prove that the information reconstructed from the encoded feedback can be used to deliver a piece-wise constant control law which yields semi-global practical stability. The result is achieved by assuming a property weaker than asymptotic stabilizability.

The paper [13] shows how previously published results on hybrid feedback stabilization of systems with quantized signals hold under weaker assumptions. Consequently, we are able to examine as special interesting cases nonlinear systems which are globally asymptotically and locally exponentially stabilizable and stabilizable by dynamic *observer*-based feedback.

Nonlinear regulation The works [23, 24] show how the theory of nonlinear adaptive observers can be effectively used in the design of internal models for nonlinear output regulation. The theory substantially enhances the existing results in the context of adaptive output regulation, by allowing for not necessarily stable zero dynamics of the controlled plant and by weakening the standard assumption of having the steady state control input generated by a linear system.

The work [9] considers a servomechanism problem in which the command and control functions are distributed in space, and hence the system consists of different components linked by a communication channel of finite capacity. The desired control goal is achieved by designing appropriate encoders, decoders and internal models of the exogenous signals. As an application, it is described how the output of a system can be forced to track a reference signal generated by a remotely located nonlinear oscillator.

The work [10] addresses the design of internal model-based regulators for nonlinear systems by error feedback in the general “non-equilibrium” framework recently proposed by Byrnes and Isidori and complements the earlier results by showing how, in the case of a system having higher relative degree, output regulation can be achieved by means of a (dynamic) pure error feedback.

The main goal of the work [11] is to show that the so-called “immersion assumption” is not in principle needed in solving a problem of nonlinear output regulation by output feedback. Under the only assumption that the zero dynamics of the controlled system have bounded trajectories, it is shown that there exists a controller solving the problem.

The design procedure illustrated in the paper is based on some recent results, developed by Andrieu and Praly, on the theory of nonlinear state observers originally proposed by Kazantiz and Kravaris. The internal model obtained in this way is a linear Hurwitz system with nonlinear output map.

Resource Management in wireless systems This research has mainly been performed in the framework of six European Union (fifth and sixth framework programme) research projects (named DAIDALOS, EuQoS, IMAGES) entailing a net financing for the year 2005 of about 350.000 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 2005, 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 2005 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 2005, about 25 work contracts have been granted on these activities to young engineers and about 45 theses have been discussed on these issues. In 2005 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, Mignanti), 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 stochastic systems The paper [1] studies 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 sigma-algebras and measurements affected by a sample continuous and strongly Markov stochastic process adapted to the same filtration of sigma-algebras. We propose a step-by step design, based on splitting the system S into one-dimensional interconnected systems $S(j)$, $j = 1, \dots, n$; after finding for

each disconnected system $S(j)$ a measurement feedback controller $C(j)$, we put together all these controllers into one candidate controller for the overall system $S(j)$ 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 introduce 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. In [2], we study the problem of feedback stabilization of a family of nonlinear stochastic systems with switching mechanism modeled by a Markov chain. We introduce a novel notion of stability under switching, which guarantees a given probability that the trajectories of the system hit 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 illustrate this methodology by constructing measurement feedback controllers for a wide class of stochastic nonlinear systems.

Stabilization of nonlinear systems A nonlinear system is semiglobally practically stabilizable if, given two spheres centered at the equilibrium, one of arbitrarily large radius and one of arbitrarily small radius, it is possible to design a feedback so that all the trajectories originating in the large sphere in finite time enter and remain in the small sphere. Within the small sphere, trajectories may converge to equilibria or to nontrivial limit sets. The work [5] characterizes and classifies, for a special class of nonlinear systems, the structure of these omega-limit sets.

Stabilization of nonlinear systems via partial measurement feedback In [3] we give a general result on the control of linear systems with measurement nonlinearities and multiple inputs and multiple outputs. We prove that if the measurement nonlinearities satisfy a sector condition and the system has vector relative degree and its invariant zeroes have nonpositive real part then there exists a linear measurement feedback controller which semiglobally stabilizes the system. In [16] we propose a certainty equivalence principle for the stabilization of nonlinear systems via measurement feedback, which clarifies the connection between the solution of a couple of Hamilton Jacobi inequalities (HJI) and the design constraints imposed on the control and the estimation error fed back in the control loop by the observer itself. Once a solution of these HJI's has been found a measurement feedback controller can be directly implemented. This controller has different features with respect to classical controllers: in classical control schemes an observer consists of a “copy” of the system plus a term proportional to the error between the actual measurement and the “estimated” measurement. Here, we allow a term which is nonlinear function of this error. This result is particularly powerful in conjunction with step-by-step strategies as illustrated by an application to feedforward systems.

Journals

- [1] S. Battilotti. Stochastic stabilization of nonlinear systems in feedforward form with noisy outputs. *IEEE Transactions on Automatic Control*, **50**, 100-105, 2005.

- [2] S. Battilotti and A. De Santis. Dwell time controllers for stochastic systems with switching Markov chain. *Automatica*, **41**, 923-934, 2005.
- [3] S. Battilotti. Control of linear systems with measurement nonlinearities. *IEEE Transactions on Automatic Control*, **50**, 1872-1877, 2005.
- [4] C. Bruni, F. Delli Priscoli, G. Koch, S. Vergari. Traffic management in a band limited communication network: An optimal control approach. *International Journal of Control*, **78**, 16, 1249-1264, 2005.
- [5] C.I. Byrnes, F. Celani, A. Isidori. Omega limit sets of systems that are semiglobally practically stabilized. *Int. J. of Robust and Nonlinear Control*, **15**, 315-333, 2005.
- [6] F. Delli Priscoli, A. Isidori, Control engineering approach to congestion control and scheduling in wireless local area network. *Contr. Engng. Practice*, **13**, 541-558, 2005.
- [7] F. Delli Priscoli, A. Pietrabissa. Hop-by-hop congestion control for ad hoc wireless-LAN: A model-based control approach. *International Journal of Control*, **78**, 12, 887-905, 2005.
- [8] C. De Persis. n -bit stabilization of n -dimensional nonlinear systems in feedforward form. *IEEE Transactions on Automatic Control*, **50**, 3, 299-311, 2005.

Articles in books

- [9] A. Isidori, L. Marconi, C. De Persis. Observers as internal models for remote tracking via encoded information. In *Control and Observers Design for Nonlinear Finite and Infinite Dimensional Systems*, T. Meurer, K. Graichen, E.D. Gilles eds., Springer Verlag, LNCIS 322, 3-18.

Conference Proceedings

- [10] C.I. Byrnes, A. Isidori and L. Marconi. Further results on output regulation by pure error feedback. In *16th IFAC World Congress*, Prague, 2005.
- [11] C.I. Byrnes, A. Isidori, L. Marconi and L. Praly. Nonlinear output regulation without immersion. In *Proc. 44th IEEE Conference on Decision and Control, and the European Control Conference 2005*, Seville, Spain, 3315-3320, 2005.
- [12] F. Delli Priscoli and A. Pietrabissa. Robust adaptive congestion control for next generation networks. In *Proc. of the IFAC World Congress*, Prague, June 2005.
- [13] C. De Persis. On feedback stabilization of nonlinear systems under quantization. In *Proc. 44th IEEE Conference on Decision and Control, and the European Control Conference 2005*, Seville, Spain, 7698-7703, 2005.
- [14] C. De Persis and D. Nešić. Practical encoders for controlling nonlinear systems under communication constraints. In *Proc. 44th IEEE Conference on Decision and Control, and the European Control Conference 2005*, Seville, Spain, 434-439, 2005.

- [15] A. Pietrabissa, F. Delli Priscoli, A. Fiaschetti and F. Di Paolo. Controllo di congestione adattativo e robusto rispetto a ritardi variabili. 49° Convegno Anipla, Napoli, M18-1, 2005.

Submitted papers, technical reports and others

- [16] S. Battilotti. A separation result for systems with feedback constraints. To appear on *Systems and Control Letters*.
- [17] C. Bruni, F. Delli Priscoli, G. Koch and I. Marchetti. An optimal approach to the connection admission control problem. Submitted to *IEEE Journal on Selected Areas on Telecommunications*, Special Issue on “Nonlinear Optimization on Communication Systems”.
- [18] C. Bruni, F. Delli Priscoli, G. Koch and I. Marchetti. Discrete time optimal solution for the connection admission control problem. Submitted to the *International Journal of Control*.
- [19] P. Conforto and F. Delli Priscoli. Game theoretic model and distributed admission control for an innovative distributed qos routing. Submitted to the *International Journal of Control*.
- [20] F. Delli Priscoli and P. Dini. A quality of service support module (qasm) for a wireless multi-segment integrated 3g network. Submitted to the Special Issue on “The Synergy of Space and Terrestrial Communications in Next-generation Hybrid Wireless Systems” of *IEEE Wireless Communications*.
- [21] F. Delli Priscoli, T. Inzerilli and R. Mort. Challenges for a fully IP-based satellite system. To appear on *Space Communications*.
- [22] F. Delli Priscoli, C. Mannino and M. Muratore. Joint mac scheduling and transport format choice for UMTS uplink transmission. Submitted to *Wireless Personal Communications*.
- [23] F. Delli Priscoli, L. Marconi, A. Isidori. A New Approach to Adaptive Nonlinear Regulation. To appear on *SIAM J. Contr. and Optimiz.*.
- [24] F. Delli Priscoli, L. Marconi, A. Isidori, Adaptive Observers as Nonlinear Internal Models. To appear on *Systems and Control Letters*.
- [25] F. Delli Priscoli, L. Marconi and A. Isidori. A new approach to adaptive nonlinear regulation. Submitted to the Mathematical Theory of Networks and Systems (MTNS) Conference.
- [26] F. Delli Priscoli and A. Pietrabissa. Robust model-based control of communication networks. Submitted to *International Journal of Control*.
- [27] C. De Persis. On stabilization of nonlinear systems under data rate constraints using output measurements. *Int. J. Robust and Nonlinear Control* (in press).

- [28] J.-S. Kim, T.-W. Joon, A. Jadbabaie and C. De Persis. Input-to-state stable finite horizon MPC for neutrally stable linear discrete-time systems with input constraints. *Systems & Control Letters*, **55**, 293-303, 2006.
- [29] A. Pietrabissa, F. Delli Priscoli, A. Fiaschetti, F. Di Paolo. A robust adaptive congestion control for communication networks with time-varying delays. Submitted to the 2006 CCA/CACSD/ISIC.

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 currently available: the 8R-dof redundant manipulator *DEXTER* (by Scienza Machinale); the two-link underactuated arm *Pendubot* (by Quanser), equipped with a vision system; the *Butterfly*, a simple mechanism for nonprehensile manipulation equipped with a vision system; two mobile robots with two-wheel differentially-driven kinematics: *MagellanPro* (by IRobot), with a SICK laser range finder, an ultrasonic-infrared sensor suite and 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* and the Telethon *ASPICE* national projects, as well as the STREP *CyberWalk* and the PR *PHRIDOM* EU projects. In 2005, we have cooperated with the following foreign institutions: the *LAAS-CNRS* in Toulouse, the *ENSTA* in Paris, the *DLR* in Wessling (Germany), and the *University of Tokyo*. At the national level, we have collaborations with *Scuola Superiore S. Anna* in Pisa, *Fondazione Santa Lucia* in Roma, *DII-Università di Siena*, *DIS-Università di Napoli Federico II*, and *DIA-Università di Roma Tre*.

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

Modeling and Control of Elastic Joint Robots Joint elasticity is the main source of vibration in industrial robots, when harmonic drives, belts, or long shafts are used as transmission elements. For a simplified class of robots with elastic joints, we have shown in the past that dynamic feedback linearization can be successfully applied for trajectory tracking tasks. This solution has been generalized in [16] to the case of configuration-dependent inertial couplings between motors and links, and to the mixed case of robots having some joints rigid and other elastic. 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 the usually small damping of the springs at the joints cannot be neglected [4].

For regulation problems, a PD control law with on-line gravity compensation has been proposed [1], which globally asymptotically stabilizes any desired configuration using only motor measurements. The control transients are considerably improved. 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 [2]. These controllers have been experimentally evaluated on the *DEXTER* arm, in cooperation with the *Scuola Superiore S. Anna*.

Underactuated Robots Underactuated mechanical systems (i.e., with less command inputs than generalized coordinates) raise very challenging planning and control issues. In [17] and [19], the control problem is addressed for the *Butterfly*, an interesting example of 2-dof underactuated system. This robot consists of a butterfly-shaped rotational link on whose rim a ball rolls freely. The control objective is to stabilize the robot at a given unstable equilibrium. To this end, a technique is developed based on the existence of homoclinic trajectories.

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 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 [3]. 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. The above work requires an a priori estimate of some ‘critical distance’ inside which the convergence of the local steering method (designed on the nilpotent approximation of the system) is guaranteed. A globally convergent steering algorithm for general nonholonomic systems which does not require the estimation of this critical distance is developed in [5].

An interesting case arises when a manipulator arm is mounted on a nonholonomic mobile platform. Typically, these systems are kinematically redundant for the Cartesian tasks to be performed with the robot end-effector. A simple, compact kinematic model for such nonholonomic mobile manipulators can be derived by combining the manipulator differential kinematics with the admissible differential motion of the platform. Based on this model, redundancy resolution schemes originally developed for standard manipulators can be directly extended, in particular the Projected Gradient and the Reduced Gradient optimization-based methods [20].

A basic problem arising in planning the motion of nonholonomic systems among obstacles is the computation of the distance between the robot and the obstacles which takes into account the nonholonomic constraints (sub-Riemannian distance). This problem has been solved in [21] for the Reeds and Shepp car (one of the most used kinematic model for a car-like robot). In particular, by modeling both the robot and the obstacles as rigid objects of

polygonal shape, the distance has been defined as the length of the shortest feasible (i.e., taking kinematic constraints into account) path between the robot's polygon perimeter to the boundary of the polygons representing the obstacles in the environment. The solution is based on Pontryagin's Maximum Principle, together with the transversality conditions accounting for the fact that the final robot orientation is free (the robot can crash into obstacles with any orientation). The solution has been generalized to the Dubins' car (a car that can move only forward) in [22].

Exploration of virtual worlds with unconstrained locomotion possibilities for the user is the main objective of the European research project *CyberWalk*. This will be achieved through the use of an actuated platform (the *CyberCarpet*) that compensates for the walker's locomotion in such a way to keep her/him close to the platform center. Since the platform has only two actuating devices (linear and angular), the corresponding control problem is similar to that of nonholonomic wheeled mobile robots. Based on a kinematic model of the system, a velocity control design achieving input-output decoupling and linearization has been proposed in [23]. The presence of control singularities in this scheme has been handled in [24]. Furthermore, the feedback stabilizing part of the control law, which is based only on the user's pose information, has been complemented by a feedforward term derived from an observer of the a walker's intentional velocity.

Visual Servoing For wheeled nonholonomic mobile robots equipped with an on-board pinhole camera, we have developed, in cooperation with *DII-Università di Siena*, an image-based visual servoing algorithm based on epipolar geometry. The robot is steered toward a desired target object with no a priori knowledge of the 3D structure of the object [25]. 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. The above approach has been extended to the case of on-board catadioptric (wide-angle) camera in [26], in order to eliminate the problem of keeping the image features in the field of view during motion.

In [6] and [27], we have presented a two-level visual scheme for intercepting a moving target with a nonholonomic mobile robot. On the lower level, the pan-tilt platform carrying 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 and experiments on the mobile robot *MagellanPro*.

Motion Planning The use of probabilistic techniques for motion planning among obstacles has received increasing attention, especially for high-dimensional problems in complex environments. In [7], 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 compati-

ble with the end-effector path constraint. The performance of the proposed algorithms is illustrated on several complex planning test cases.

Another contribution to the area of motion planning is given in [28], where a simple strategy is presented for improving the connectivity of probabilistic roadmaps by genetic post-processing. In particular, the objective is to increase the roadmap density in narrow passages, where many of the existing probabilistic planners perform poorly. To this end, we associate to each individual (i.e., to each robot configuration) an easily computable fitness function based on the distance between disjoint components of the roadmaps. Straightforward selection, crossover and (possibly) mutation operators are then applied to improve the quality of the population. Numerical results in different workspaces, including a well-known benchmark, have shown the effectiveness of the proposed strategy.

Sensor-based Exploration The probabilistic approach is being used also for reactive motion planning and exploration. In this area, we have proposed a frontier-based technique for sensor-based exploration of unknown environments by a mobile robot [8]. 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. The random mechanism for generating new configurations is biased towards unexplored areas. Experimental results are presented for the *MagellanPro* robot using ultrasonic sensing. The proposed method has been extended in [18] to the case in which a robotic manipulator explores an unknown workspace carrying a camera on its end-effector (eye-in-hand).

In [29], the SRT method has also been modified so as to obtain an integrated exploration strategy, i.e., an algorithm which takes into account localization as well as map building when planning the next action. In particular, a continuous localization procedure based on natural features of the safe region is integrated in the scheme. Both the information gain and the localization potential are taken into account when evaluating the next candidate configurations to be explored. Extensive simulation, as well as experiments on the *MagellanPro* robot, show the performance of the proposed technique.

Another outgrowth of the basic SRT method is the multi-robot exploration strategy presented in [30]. In this case, a collection of SRTs is built, with each SRT representing a roadmap of the area explored by one of the robot in the team with an associated collision-free region. To improve the exploration efficiency and to avoid conflicts, decentralized cooperation and coordination mechanisms are introduced, which can be implemented also in the case of a limited communication field.

Legged Locomotion Biped locomotion is a topic of particular interest in advanced robotics. A walking generator/controller for a planar 5-dof biped robot with passive feet has been developed in [9], 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*. This prototype is equipped with an innovative knee joint which can switch between active and passive operation, requiring however the design of a specific hybrid controller [10].

Fault Detection and Isolation 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; 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 in the past an FDI scheme for any type of actuator fault in robot manipulators. The further issue of fault identification (i.e., estimating the time evolution of the faulted torque input) has been addressed in [11], using an \mathcal{H}_∞ -based observer design. The FDI schemes have been implemented on the *Pendubot* arm.

More in general, for dynamic nonlinear systems affine in the inputs, the differential-geometric approach to FDI has been extended in [12] 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. These results have been experimentally validated on a robotic case study [31]. In this framework, a suitable procedure has been proposed for modeling state sensors failures so as to yield a faulted model which is still affine in the (fault) 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: the *IFATIS* pilot plant [13] and a three-tank fluid heating system [32].

Physical Human-Robot Interaction For robots in anthropic domains, safety and dependability issues in the robot mechanical design, control design, and software supervision have to be revisited. Focusing on physical side of the problem (tasks with contact or strict cooperation between humans and robots, handling of unexpected collisions), a safer human-robot interaction requires a lightweight arm design and the introduction on purpose of compliant elements (soft covering, compliant transmissions/actuators) [14]. Quick collision detection and post-impact reaction strategies are fundamental capabilities for a robot manipulator that shares its workspace with humans, with the goal of preventing severe injuries due to accidental contacts.

Robot generalized momenta can be used for detecting collisions (seen as system faults) of a robot arm with its environment (including humans). A collision may occur at any point along the structure and can be detected even in the absence of extra (force/torque or contact) sensors [15]. A suitable handling of the ‘residual’ signals allows then to perform, e.g., a hybrid force/motion task while in contact with a compliant environment of unknown

geometry. Elaborating on mechanical energy and generalized momentum, an efficient collision detection method has been presented in [33]. As soon as collision is detected, the controller reduces the apparent arm inertia and the robot is safely and smoothly driven away from the collision area, using directional information gathered from the residual signals at the collision time. The approach, first formally developed for rigid robot arms and then extended to the case of robots with elastic joints, has been experimented successfully on several human-robot collisions using the *DLR-III* lightweight manipulator.

Service Robotics Assistive technology is an emerging area where robotic devices can be used to strengthen the limited abilities of individuals with motor impairment or to help them achieve independence in the activities of daily living. In [34], we present a project (funded by the Italian Telethon Foundation and in collaboration with *Fondazione Santa Lucia*) aimed at developing a system that provides remote control of home-installed appliances, including robotic devices such as the Sony *AIBO*. In particular, the design of the robot navigation system is described in [35]. Single step, semi-autonomous, and autonomous operating modes have been realized to provide different levels of interaction with the *AIBO*. Automatic collision avoidance is integrated in all cases. The performance of the navigation system is shown by simulations as well as experiments. At this time, the system is under clinical validation, in order to obtain a definitive assessment through patient feedback. ;/div;

Journals

- [1] A. De Luca, B. Siciliano, and L. Zollo. PD control with on-line gravity compensation for robots with elastic joints: Theory and experiments. *Automatica*, 41(10):1809–1819, 2005
- [2] L. Zollo, B. Siciliano, A. De Luca, E. Guglielmelli, and P. Dario. Compliance control for an anthropomorphic robot with elastic joints: Theory and experiments. *ASME J. of Dynamic Systems, Measurements, and Control*, 127(3):321–328, 2005.
- [3] G. Oriolo and M. Vendittelli. A framework for the stabilization of general nonholonomic systems with an application to the plate-ball mechanism. *IEEE Trans. on Robotics*, 21(2):162–175, 2005.

Conference Proceedings

- [4] A. De Luca, R. Farina, and P. Lucibello. On the control of robots with visco-elastic joints. *2005 IEEE Int. Conf. on Robotics and Automation*, pp. 4297–4302, Barcelona, E, 2005.
- [5] F. Jean, G. Oriolo, and M. Vendittelli. A globally convergent steering algorithm for regular nonholonomic systems. *Joint 44th IEEE Conf. on Decision and Control/European Control Conf. 2005*, pp. 7514–7519, Seville, E, 2005.

- [6] F. Capparella, L. Freda, M. Malagnino, and G. Oriolo. Visual servoing of a wheeled mobile robot for intercepting a moving object. *2005 IEEE/RSJ Int. Conf. on Intelligent Robots and Systems*, pp. 2021–2027, Edmonton, CAN, 2005.
- [7] G. Oriolo and C. Mongillo. Motion planning for mobile manipulators along given end-effector paths. *2005 IEEE Int. Conf. on Robotics and Automation*, pp. 2154–2160, Barcelona, E, 2005.
- [8] L. Freda and G. Oriolo. Frontier-based probabilistic strategies for sensor-based exploration. *2005 IEEE Int. Conf. on Robotics and Automation*, pp. 3881–3887, Barcelona, E, 2005.
- [9] F. Zonfrilli, D. Wollherr, and Y. Nakamura. Walking control of the humanoid *UT-Theta*. *12th Int. Conf. on Advanced Robotics*, pp. 698–704, Seattle, WA, 2005.
- [10] D. Wollherr, F. Zonfrilli, and Y. Nakamura. Active-passive knee control for the humanoid *UT-Theta*. *12th Int. Conf. on Advanced Robotics*, pp. 692–697, Seattle, WA, 2005.
- [11] A. De Luca and R. Mattone. An identification scheme for robot actuator faults. *2005 IEEE Int. Conf. on Intelligent Robots and Systems*, pp. 1127–1131, Edmonton, CAN, 2005.
- [12] R. Mattone and A. De Luca. Conditions for detecting and isolating sets of faults in nonlinear systems. *Joint 44th IEEE Conf. on Decision and Control/European Control Conf. 2005*, pp. 1005–1010, Seville, E, 2005.
- [13] R. Mattone and A. De Luca. Geometric and hierarchical FDI for the IFATIS two-tank pilot plant. *16th IFAC World Congr.*, Praha, CZ, 2005.
- [14] A. Albu-Schäffer, A. Bicchi, R. Chatila, A. De Luca, A. De Santis, G. Giralt, G. Hirzinger, V. Lippiello, R. Mattone, R. Schiavi, B. Siciliano, G. Tonietti, and L. Villani. Physical human-robot interaction in anthropic domains: Safety and dependability. *4th IARP/IEEE/EURON Works. on Technical Challenges for Dependable Robots in Human Environments*, Nagoya, J, 2005.
- [15] A. De Luca and R. Mattone. Sensorless robot collision detection and hybrid force/motion control. *2005 IEEE Int. Conf. on Robotics and Automation*, pp. 999–1004, Barcelona, E, 2005.

Ph.D. Thesis

- [16] R. Farina. *Trade-off between Precision and Operative Safety in Robots with Intrinsic Compliance*. Ph.D. Thesis, Università di Roma “La Sapienza”, 2005.
- [17] M. Cefalo. *Energy-based Control of Underactuated Mechanical Systems with an Application to the Butterfly Robot*. Ph.D. Thesis, Università di Roma “La Sapienza”, 2005.

- [18] L. Granato. *Sensor-based Exploration of Unknown Environments with Robotic Manipulators*. Ph.D. Thesis, Università di Roma “La Sapienza”, 2005.

Submitted papers, technical reports and others

- [19] M. Cefalo, L. Lanari, and G. Oriolo. Energy-based control of the Butterfly robot. Submitted to *8th IFAC Symp. on Robot Control*, Bologna, I, 2006.
- [20] A. De Luca, G. Oriolo, and P. Robuffo Giordano. Kinematic modeling and redundancy resolution for nonholonomic mobile manipulators. Accepted for presentation at *2006 IEEE Int. Conf. on Robotics and Automation*, Orlando, FL, 2006.
- [21] P. Robuffo Giordano, M. Vendittelli, J.-P. Laumond, and P. Souères. Nonholonomic distance to polygonal obstacles for a car-like robot of polygonal shape. Submitted to *IEEE Trans. on Robotics*, July 2005.
- [22] P. Robuffo Giordano and M. Vendittelli. The minimum-time crashing problem for the Dubins’ car. Submitted to *8th Int. IFAC Symp. on Robot Control*, Bologna, I, 2006.
- [23] A. De Luca, R. Mattone, and P. Robuffo Giordano. The motion control problem for the CyberCarpet. Accepted for presentation at *2006 IEEE Int. Conf. on Robotics and Automation*, Orlando, FL, 2006.
- [24] A. De Luca, R. Mattone, and P. Robuffo Giordano. Feedback/feeforward schemes for motion control of the CyberCarpet. Submitted to *8th IFAC Symp. on Robot Control*, Bologna, I, 2006.
- [25] G. L. Mariottini, G. Oriolo, and D. Prattichizzo. Image-based visual servoing for nonholonomic mobile robots using epipolar geometry. Submitted to *IEEE Trans. on Robotics*, December 2005.
- [26] G. L. Mariottini, G. Oriolo, and D. Prattichizzo. Image-based visual servoing for non-holonomic mobile robots with central catadioptric camera. Accepted for presentation at *2006 IEEE Int. Conf. on Robotics and Automation*, Orlando, FL, 2006.
- [27] L. Freda and G. Oriolo. Vision-based interception of a moving target with a non-holonomic mobile robot. Submitted to *Robotics and Autonomous Systems*, December 2005.
- [28] G. Oriolo, S. Panzieri, and A. Turli. Increasing the connectivity of probabilistic roadmaps via genetic post-processing. Submitted to *8th IFAC Symp. on Robot Control*, Bologna, I, 2006.
- [29] L. Freda, F. Loiudice, and G. Oriolo. A randomized method for integrated exploration. Submitted to *2006 IEEE/RSJ Int. Conf. on Intelligent Robots and Systems*, Beijing, PRC, 2006.

- [30] A. Franchi, L. Freda, G. Oriolo, and M. Vendittelli. A randomized strategy for cooperative robot exploration. Submitted to *7th Int. Works. on the Algorithmic Foundation of Robotics*, New York, NY, 2006.
- [31] R. Mattone and A. De Luca. Relaxed fault detection and isolation: An application to a nonlinear case study. Accepted for publication in *Automatica*, August 2005.
- [32] R. Mattone and A. De Luca. Nonlinear fault detection and isolation in a three-tank heating system. Submitted to *IEEE Trans. on Control Systems Technology*, October 2005.
- [33] A. De Luca, A. Albu-Schäffer, S. Haddadin, and G. Hirzinger. Collision detection and safe reaction with the DLR-III lightweight manipulator arm. Submitted to *2006 IEEE/RSJ Int. Conf. on Intelligent Robots and Systems*, Beijing, PRC, 2006.
- [34] A. Cherubini, S. Brusino, G. Oriolo, F. Aloise, F. Cincotti, and D. Mattia. Development of a multimode navigation system for an assistive robotics project. Submitted to *2006 IEEE/RSJ Int. Conf. on Intelligent Robots and Systems*, Beijing, PRC, 2006.
- [35] F. Cincotti, F. Aloise, F. Babiloni, M. G. Marciani, D. Morelli, S. Paolucci, G. Oriolo, A. Cherubini, S. Brusino, F. Sciarra, F. Mangiola, A. Melpignano, F. Davide, and D. Mattia. Brain-operated assistive devices: The ASPICE project. Accepted for presentation at *1st IEEE/RAS-EMBS Int. Conf. on Biomedical Robotics and Biomechatronics*, Pisa, I, 2006.

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 für Informationstechnik Berlin, Università di Roma Tor Vergata, Università dell'Aquila, Università 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 MIPAF project ADM (Agricultural Data Mining) and the European IST Project SAILOR (devoted to third generation mobile wireless networks) and IMAGES (devoted to QoS in next generation IP networks).

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

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. A short history of this problem along with standard models and algorithms is reviewed in [5]. A new solution approach is then presented in [5]: such an approach outperformed other known approach on the famous FAP-web testbed (ZIB-Berlin).

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 [1], [8].

Using Mixed Integer Programming to Solve Power Grids Blackout Problems

During the last decade, several large-scale failures of national power transmission networks took place. The most recent were the blackouts of the U.S. Northeast and Eastern Canada of August 2003, and the September 2003 blackout that affected Italy. In addition, Brazil experienced large blackouts in 1999. These blackouts affected large numbers of people over wide geographical areas, with substantial economic impact. Had the event lasted more than a few days, the human cost would have been quite large. The issue of how

to prevent – or at least make less likely – catastrophic blackouts in a large network is complex, involving engineering, economic and even political issues. In [10] we consider two optimization models to address the following generic question: given a network, how do we protect it at minimum cost so as to make it (more likely to) survive a potential cascade?

paragraphSatisfiability 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 [12]. 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.

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 modified version of Farkas' lemma in [3].

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

Given a set of data which are already grouped into classes, the Classification problem consists in predicting whose class each new data belongs to. With respect to standard logic based classification procedures, enhancements based on probability considerations are presented: the quality of each cut-point is evaluated, so that a weighted set covering problem for the selection of the optimal support set is solved in [9].

When dealing with large datasets, a common problem is the individuation of errors and the reconstruction of the corrupted information. This is called Error Correction, or, better, Information Reconstruction. By using a linear inequality encoding for of the whole problem, integer linear programming models are developed and solved in [4]. 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.

Moreover, in order to shorten computational times, a preventive subdivision of the datasets can be carried out by means of a specialized Clustering procedure. Such procedure, called algorithm of the spherical neighbourhoods [6], has been developed for hierarchical demographic data and shows for them better performances than other known Clustering algorithms.

Computational Molecular Biology, Peptide Sequencing Several computationally demanding problems arise from biological and medical research. In particular, Sequencing problems are of great relevance in several applicative fields. 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 [2, 13]. 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 [7].

Machine Learning and Boosting Boosting techniques have emerged in machine learning as one of the most promising and powerful methods for supervised learning and nowadays are commonly used to solve data classification and regression problems. A boosting algorithm usually combines individual hypotheses, called *weak learners*, to produce more accurate classification rules. Given a *dictionary* \mathcal{D} of hypotheses, the *classifier* is defined as a conic combination of base hypotheses. As the family \mathcal{D} is usually very huge, many heuristics have been proposed to identify the optimal combination (e.g. AdaBoost).

The present research focuses on the formulation of the boosting problem for data classification problem as a Linear Programming Problem. The following issues are addressed:

- Definition of a *proper dictionary* consisting in the family of linear classifiers. In the past these learning machines have been often used for data classification (e.g. Perceptron algorithm, Support Vector Machine in both soft and hard formulation, Decision Tree, Set Covering Machine with data dependent hyperplanes). Here we consider the subset H of vectors that are *separable* by hyperplanes ([11, Chapter 2]).
- *Boosting formulation* as Linear Programming problem. The aim is that of identifying a conic combination of a subset of hypotheses in \mathcal{D} , i.e. a linear combination with non negative coefficients, such that the generalization capability of the classifier is as large as possible while the misclassification error over the training set is minimized. The problem of selecting the hypotheses to combine is formulated as a Linear Programming problem where continuous non negative variables represent the weights to be assigned to selected hypotheses in \mathcal{D} ([11, Chapter 3]).
- Because of the huge amount of separable subsets, solving the boosting problem with respect to the entire dictionary \mathcal{D} may turn out to be practically impossible. We propose a *column generation algorithm* that implements an implicit exploration of dictionary \mathcal{D} in order to efficiently solve the LP problem and introduce a *pricing problem* that, starting from a current solution of the master problem, selects a separable subset H with the best compromise in terms of *regularization* and *loss function* ([11, Chapter 4]).

Our main contribution is represented by the implicit description of weak learners in dictionary \mathcal{D} and the efficient optimization approach to problem of *simultaneously* generating and combining the hypotheses to define a strong learner. It turns out to be the first

attempt to formulate both tasks in a single optimization algorithm. Moreover the work presents a general framework to combine the better aspects of Boosting algorithms and Support Vector Machines.

Journals

- [1] S. Chandran, C. Mannino, G. Oriolo. On the cubicity of certain graphs. *Information Processing Letters* 94 (3), 113-118, 2005.
- [2] R. Bruni, G. Gianfranceschi, G. Koch, On Peptide De Novo Sequencing: a New Approach, *Journal of Peptide Science* Vol. 11, 225-234, 2005.
- [3] R. Bruni, On Exact Selection of Minimally Unsatisfiable Subformulae, *Annals of Mathematics and Artificial Intelligence* Vol. 43(1-4), 35-50, 2005.
- [4] R. Bruni, Error Correction for Massive Data Sets, *Optimization Methods and Software*, Vol. 20(2-3), 295-314, 2005.

Articles in books

- [5] E. Amaldi, A. Capone, F. Malucelli, C. Mannino, Optimization problems and models for planning cellular networks, di prossima pubblicazione su *Handbook of Optimization in Telecommunication*, Eds. M. Resende and P. Pardalos, Springer Science.

Conference Proceedings

- [6] G. Bianchi, R. Bruni, R. Nucara, A. Reale, Data Clustering for Improving the Selection of Donors for Data Imputation, *Proceedings of CLADAG2005*, Parma, Italy, 2005
- [7] R. Bruni, Solving De Novo Peptide Sequencing via Propositional Logic (Extended abstract), *Proceedings of the annual conference AIRO*, 2005

Submitted papers, technical reports and others

- [8] C. Mannino, G. Oriolo, F. Ricci, S. Chandran. The stable set problem and the thinness of a graph. To appear in *Operations Research Letters*.
- [9] R. Bruni, Reformulation of the Support Set Selection Problem in the Logical Analysis of Data, to appear on *Annals of Operations Research*.
- [10] D. Bienstock and S. Mattia, Using Mixed Integer Programming to Solve Power Grids Blackout Problems, *CORC technical report TR-2005-07* (2005).
- [11] S. Canale, Boosting in large dictionaries with a column generation approach, PhD thesis, University of Rome *La Sapienza* (2005).
- [12] R. Bruni and A. Santori, A Computational Study of New Updating Criteria for Conflict-Based Branching Heuristics in DPLL Algorithms for Satisfiability, submitted to *Discrete Optimization*.

- [13] R. Bruni, A Combinatorial Approach for finding the Composition or the Sequence of a Polymer, submitted to Journal of Mathematical Biology.

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. Problems arising from real world applications are also an important part of the research activity.

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; Institut für Statistik ISDS, Universität Wien; Department of Computer Science and Information Engineering, National Taiwan University.

During 2005, 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 [INSEAN], Luigi GRIPPO, Giampaolo LIUZZI, Stefano LUCIDI, Laura PALAGI, Veronica PICCIALLI, Arnaldo RISI [IASI-CNR], 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 framework, the use of planar Conjugate Gradient (CG) algorithms within truncated Newton methods has been proposed, enabling to efficiently handling also the indefinite case. Such planar CG algorithms have been also shown to be an effective tool in the iterative computation of negative curvature directions without any matrix storage. Preconditioning strategies for truncated Newton methods have been also defined, aiming at improving the overall behaviour of the method in tackling large scale problems [2, 3, 15, 9]. Moreover, globally convergence versions of the Polak-Ribière method have been proposed for solving large scale unconstrained problems [4].

Finally, new nonmonotone stabilization strategies for the solution of large systems of nonlinear equations has been proposed [16, 17].

Constrained Optimization Problems with both general constraints and constraints with a particular structure have been addressed. In particular, primal-dual algorithms for inequality constrained problems have been defined [1, 12]. The distinguishing feature of the first one consists in generating a sequence converging to points which satisfy the second order necessary conditions for optimality. The second one relies on exploiting as much as possible the local nonconvexity of the problem.

As regards problems with particular structure, the research has been devoted to Standard Quadratic Programming Problems (StQP) where the objective function is quadratic and the constraints are linear. The first StQP problem considered consists in finding the smallest value of a indefinite quadratic form over the standard simplex. This problem

has been solved by first reformulating as a special homogeneous program over the unit sphere and successively by using an exact penalty function approach for this problem. Another application arises in the field of Support Vector Machines (SVM) for (statistical) classifying massive data. The SVM training problem is a convex StQP usually so large in the dimension that standard methods cannot be used for its solution. Hence a particular decomposition method has been proposed and the asymptotic convergence has been established [7, 8].

Nonlinear mixed variable optimization problems have been also considered, namely problems involving both continuous and discrete variables. A general globally convergent algorithm model for a class of such problems has been defined and proved to be effective in solving a real optimal design problem [6].

Variational Inequalities Another topic of interest concerned the *Generalized Nash Equilibrium problems* (GNEP). It has been shown that for a large class of problems, a generalized Nash equilibrium can be calculated by solving a variational inequality. Moreover, Newton methods for GNEP have been analyzed in detail [13, 14].

Global Optimization A theoretical analysis of the algorithm *Particle Swarm Optimization* for the solution of global optimization problems has been developed in [10]. In particular, it has been shown how an iterate of the algorithm can be reformulated by means of a dynamic linear system.

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 induction electric motors and the ship design. As regards the first application, the considered design problem has been solved by means of a formulation of the problem as a mixed variable programming problems. As regards the second application, some new enhanced versions of well known global optimization methods have introduced in order to solve a realistic ship design problem [5, 11].

Journals

- [1] G. Di Pillo, S. Lucidi, and L. Palagi. Convergence to 2^{nd} order stationary points of a primal-dual algorithm model for nonlinear programming. *Mathematics of Operations Research*, 30:897–915, 2005.
- [2] G. Fasano. Planar-Conjugate Gradient algorithm for large-scale unconstrained optimization Part 1: Theory. *Journal of Optimization Theory and Applications*, 125:523–541, 2005.
- [3] G. Fasano. Planar-Conjugate Gradient algorithm for large-scale unconstrained optimization Part 2: Application. *Journal of Optimization Theory and Applications*, 125:543–558, 2005.

- [4] L. Grippo and S. Lucidi. Convergence conditions, line search algorithms and trust region implementations for the Polak-Ribière conjugate gradient method. *Optimization Methods and Software*, 20:71–98, 2005.
- [5] G. Liuzzi, S. Lucidi, V. Piccialli, and M. Villani. Design of induction motors using a mixed-variable approach. *Computational Management Science*, 2:213–228, 2005.
- [6] S. Lucidi, V. Piccialli, and M. Sciandrone. An algorithm model for mixed variable programming. *SIAM Journal on Optimization*, 215:1057–1084, 2005.
- [7] L. Palagi and I. Bomze. Quartic formulation of standard quadratic optimization. *Journal of Global Optimization*, 32:181–205, 2005.
- [8] L. Palagi and M. Sciandrone. On the convergence of a modified version of SVM^{light} algorithm. *Optimization methods and Software*, 20:311–328, 2005.
- [9] M. Roma. A dynamic scaling based preconditioning for truncated Newton method in large scale unconstrained optimization. *Optimization Methods and Software*, 20:693–713, 2005.

Submitted papers, technical reports and others

- [10] E.F. Campana, G. Fasano, and A. Pinto. Particle swarm optimization: dynamic system analysis for parameter selection in global optimization frameworks. Technical Report 2005–023, INSEAN, Roma, 2005.
- [11] E.F. Campana, G. Liuzzi, S. Lucidi, D. Peri, V. Piccialli, and A. Pinto. New global optimization methods for ship design problems. Technical Report 2005–1, INSEAN, Roma, 2005.
- [12] G. Di Pillo, G. Liuzzi, and S. Lucidi. A primal–dual algorithm for nonlinear programming exploiting negative curvature. Technical Report 16–2005, Dipartimento di Informatica e Sistemistica “A. Ruberti”, Università di Roma “La Sapienza”, 2005.
- [13] F. Facchinei, A. Fisher, and V. Piccialli. Generalized Nash equilibrium problems and Newton methods. Submitted to *Mathematical Programming*.
- [14] F. Facchinei, A. Fisher, and V. Piccialli. On generalized Nash games and variational inequalities. Submitted to *Operations Research Letters*.
- [15] G. Fasano and M. Roma. Iterative computation of negative curvature directions in large scale optimization: Theory and preliminary numerical results. Technical Report 12–2005, Dipartimento di Informatica e Sistemistica “A. Ruberti”, Università di Roma “La Sapienza”, 2005. To appear on *Computational Optimization and Applications*.
- [16] L. Grippo and M. Sciandrone. Nonmonotone derivative-free methods for nonlinear equations. Technical Report 01–2005, Dipartimento di Informatica e Sistemistica “A. Ruberti”, Università di Roma “La Sapienza”, 2005.

- [17] L. Grippo and M. Sciandrone. Nonmonotone globalization of inexact difference/Newton-iterative methods for nonlinear equations. Technical Report 18–2005, Dipartimento di Informatica e Sistemistica “A. Ruberti”, Università di Roma “La Sapienza”, 2005.

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; University of Leicester, UK; Universidad Complutense de Madrid, Spain.

Group members 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 [2]. A second strand of research has taken into account 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 [6], [7].

Cross-border Mergers and Acquisitions and Technology Transfer This line of research has been devoted to identify the optimal FDI mode (greenfield investment or acquisition) in a two country, two firm Cournot model with differing technological levels and country sizes, allowing for asymmetric equilibria. A firm entering the foreign market through greenfield investment has to pay a set up cost, while entry through acquisition involves a bargaining process which determines who will buy whom and at what price.

The model explicitly allows for M&A implementation costs. International transfer of technology is also costly, but an acquisition allows the firm to choose the best technological practice in each country. It is found that lower greenfield set up costs (multilateral investment liberalisation) may actually increase the incentives for acquisition. Furthermore, it is shown that a technological leader from a small country needs not only a strong technological lead in order to be the acquirer, but also an efficient know-how management system [1].

Obstacles to Innovation and Multinational Firms in the Italian Regions This research project has analysed how the probability of perceiving as important the obstacles to innovation is affected by different firm-, sector- and region-specific features. Among the firm's characteristics taken into account there are: size; type of ownership, i.e. whether the firm belongs to a foreign-owned group, a nationally-owned group, or is a single domestic firm; firms' innovativeness. The estimated model considers sectoral specificities and includes the macro-area in which the firm is located (North-west; North-east; Centre; South). The empirical analysis is carried out on Italian firm-level data provided by the third Community Innovation Survey (CIS3), with reference to the period 1998-2000. The major finding of this study is that important differences on how obstacles to innovation are perceived by firms occur both across regions and across types of firms. Overall, as compared to the reference category, which is a non-innovative single domestic firm, located in the South of Italy and operating in the real estate sector, firms located in the North and in the Centre of the country and belonging to either foreign- or Italian-owned groups tend significantly less frequently to perceive obstacles to innovation as relevant [3].

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. It is well-known that price capped firms enjoy a large degree of pricing discretion, which may harm both consumers and the development of competition. Hence we studied two different regulatory schemes - Relative and Absolute - meant to limit such a discretion. The first one places a fixed upper limit to the prices charged in captive markets; the other constrains the captive prices relatively to the prices set in the more competitive markets. 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. While the effects on aggregate welfare are ambiguous, there is some evidence that the Relative regime is more likely to increase consumers' surplus and social welfare the more efficient are the competitors [4], [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, some regulatory 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 only if the population of sellers is not too heterogeneous in terms of skill levels [8].

Conference Proceedings

- [1] L. Grunfeld and F. Sanna-Randaccio. Who buys whom in international oligopolies with FDI and technology transfer? In *Proceedings of the EIBA 31th Annual Conference, Norwegian School of Management, Oslo (cd-rom)*.

Submitted papers, technical reports and others

- [2] F. Sanna-Randaccio and R. Veugelers. Multinational knowledge spillovers with centralized versus decentralized R&D: a game theoretic approach. To appear in *Journal of International Business Studies*.
- [3] S. Iammarino, F. Sanna-Randaccio and M. Savona. Obstacles to innovation and multinationals firms in the Italian regions. Firm-level evidence from the Third Community Innovation Survey. In A. Tavares and A. Teixeira, editors, *Multinationals, Clusters and Innovation: Does Public Policy Matters?*, Palgrave, MacMillan, New York. To appear.
- [4] A. Iozzi, R. Sestini, and E. Valentini. Pricing Discretion and Price Regulation in Competitive Industries. CEIS Tor Vergata – Research Paper Series. vol. 23, no. 69. January 2005.
- [5] A. Iozzi, R. Sestini, and E. Valentini. Pricing Discretion and Price Regulation in Competitive Industries. To appear in *Journal of Regulatory Economics*.
- [6] M.L. Petit, F. Sanna-Randaccio, and R. Sestini. Localized Spillovers and Foreign Direct Investment: a Dynamic Analysis. Technical Report 07–05, Dipartimento di Informatica e Sistemistica “A. Ruberti”, Università di Roma “La Sapienza”, May 2005.
- [7] M.L. Petit, F. Sanna-Randaccio, and R. Sestini. Localized Knowledge Flows and Foreign Direct Investment with Endogenous R&D: a Dynamic Analysis. Submitted
- [8] R. Sestini. Are You a Doctor or a Quack? Provision of Quality and Self-regulation in a Market for Professional Services. Submitted.

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, 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 (Parallel Trade - PT). 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 [3]. Concerning the incentives to invest in product quality in the presence of international arbitrage, we show that: i) PT may increase investments if the re-imported product is of lower quality than the domestic product, but reduces investments with perfect substitutes; ii) price regulation (with PT) raises investments when the investment cost is not too convex; iii) the regulated price determines whether quality is exported, but does not affect marginal investment incentives. These findings dilute theoretical and policy concerns about the effects of PT on welfare (including investments) [6, 12].

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 firm's 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 [13].

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 [11]. Furthermore, we analyse the incentives that a facility-based firm has to invest in network quality while selling local access to both a downstream subsidiary and an independent firm. We show that access price regulation is welfare-enhancing, since it fosters competition while preserving investment incentives. This result is robust to four model specifications: i) the regulator credibly commits before the investment stage; ii) there exist consumer switching costs; iii) the rival firm considers (partial) backward integration; iv) the access owner is vertically separated. Thus, we reverse some negative literature findings and dilute policy concerns about the effects of behavioural and structural regulation on welfare (including investments) [7]. As regard the mobile termination issue, an analysis is carried out where we evaluate the opportunities of introducing forms of regulation (symmetric or asymmetric) in the mobile termination market [4].

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 [8, 9]. In [10] we explore interesting potentialities of the Vickrey-Clarke-Groves (VCG) mechanism in the auctions context under the assumption of players with independent and private valuations and with no budget constraints. First we apply the VCG rule to a coalition of bidders in order to measure the minimum effort, in terms of submitted bids, that the coalition has to support to win, given the valuations systems of the opponents (i.e. the second price of the coalition). Then we introduce and formulate the problem of determining that partition of players into coalitions which maximize the auctioneers

revenue in the case whereby such coalitions take part to a VCG auction each one as a single agent; in particular, we provide an NP-hard integer linear formulation of this problem. We also generalize this issue by allowing players to simultaneously belong to distinct coalitions in the case that players valuations systems are separable. Finally, we propose some applications of these theoretical results. For instance, we exploit them to define a class of new payment rules which are placed, in a sense, between the VCG rule and first-price one, and to determine the highest losing bids in combinatorial auctions.

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, 5].

Journals

- [1] L. Biggiero, G. Iazzolino and D. Laise. Financial Performance Measurement: a Multicriteria Methodology, *The Journal of Financial Decision Making*, Vol. 1, issue 2, 2005.
- [2] D. Laise, P. Migliarese and S. Verteramo. Knowledge Organization Design: a diagnostic tool, *Human System Management*, 24, pp.121-131, 2005.
- [3] G. Matteucci and P. Reverberi. Price regulation and public service obligations under international arbitrage, *Journal of Regulatory Economics*, 28, pp. 91-113, 2005.

Articles in books

- [4] C. Leporelli. Terminazione mobile: prime riflessioni sul rapporto tra i suggerimenti della teoria e le decisioni regolamentari. In Frova S. editor, *La regolamentazione delle remunerazioni della terminazione fra operatori mobili*, Carocci, 2005.

Conference Proceedings

- [5] L. Biggiero, G. Iazzolino and D. Laise. On Multicriteria Business Performance Measurement. *Proceedings of 2nd International Conference on Enterprise Systems and Accounting*, Thessaloniki, Greece, July 2005, pp.3-19.
- [6] G. Matteucci and P. Reverberi. Regolamentazione dei prezzi ed investimenti in qualit in presenza di arbitraggio internazionale, *Atti della XVI Riunione Scientifica Annuale dell'Associazione Italiana di Ingegneria Gestionale (AiIG)*, Catania, Ottobre 2005.
- [7] M. Restaino and P. Reverberi. One-way access pricing, imperfect competition and network investments, *XVI International Telecommunications Society European Regional Conference ITS 2005*, Porto, Portugal, September 2005.

Submitted papers, technical reports and others

- [8] A. Avenali and A. Bassanini. Simulating combinatorial auctions through automated rational agents. Submitted.
- [9] A. Avenali. Resolution Branch and Bound and an Application: the Maximum Weighted Stable Set Problem. Submitted.
- [10] A. Avenali. Exploring the VCG Mechanism in Combinatorial Auctions: the Threshold Revenue and the Threshold-Price Rule. *Technical Report n. 11-05, Dipartimento di Informatica e Sistemistica, Università degli Studi di Roma "La Sapienza"*, 2005.
- [11] C. Leporelli and P. Reverberi. "Pro-competitive regulation of local loop unbundling". Submitted.
- [12] G. Matteucci and P. Reverberi. Parallel trade, quality investments and regulation, *Technical Report n. 05-05, Dipartimento di Informatica e Sistemistica, Università degli Studi di Roma "La Sapienza"*, 2005. Submitted.
- [13] A. Nastasi and P. Reverberi. "Foreign market entry strategies under asymmetric information". Submitted.

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 Systems 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*
- Computational methods for the analysis of genome wide expression data
- Topological features and criticalities 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 (INRAN), Istituto Superiore di Sanità, Department of Biomedical Engineering (Boston University), IASI (CNR), PARADES, Di.M.S.A.T. (Università 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: [2], [6]³, [7], [13].

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], [3], [4], [5], [10], [12].

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 are: [8], [11], [14], [15], [16], [17].

Journals

Journals

- [1] M.C. Palumbo, A. Colosimo, A. Giuliani and L. Farina, Functional essentiality from topology features in metabolic networks: a case study in yeast, *Federation of European Biochemical Societies (FEBS) Letters*, 579, (2005) 4642-4646

³This paper has received the 2005 IFAC Congress Application Paper Prize

- [2] A. Balluchi, L. Benvenuti, S. Engell, T. Geyer, K. H. Johansson, F. Lamnabhi-Lagarrigue, J. Lygeros, M. Morari, G. Papafotiou, A. L. Sangiovanni-Vincentelli, F. Santucci and O. Stursberg, Hybrid control of networked embedded systems, *European Journal of Control*, 11, (2005) 478-508

Conference Proceedings

- [3] A. De Santis, Mathematics is the next biology's microscope, *International Workshop on Systems Biology: the state of art*, Roma, 2005
- [4] L. Farina, Gene regulation: a dynamic perspective, *International Workshop on Systems Biology: the state of art*, Roma, 2005
- [5] M.C. Palumbo, A. Colosimo, A. Giuliani and L. Farina, Spotting topological and functional criticalities in metabolic networks, *International Workshop on Systems Biology*, Milano, 2005
- [6] A. Balluchi, L. Benvenuti, C. Lemma, A. Sangiovanni-Vincentelli and G. Serra, Actual engaged gear identification: a hybrid observer approach, *16th IFAC World Congress*, Prague, Czech Republic, 2005
- [7] A. Balluchi, L. Benvenuti and A. Sangiovanni-Vincentelli, Hybrid systems in automotive electronics design, *4th Conference on Decision and Control and 8th European Control Conference*, Seville, Spain, 2005
- [8] G. Avanzini, A. De Santis, The legacy of C. Possio to flight dynamics and hydrodynamics, *Conference on System Modeling and Optimization*, Turin, 2005

Submitted papers, technical reports and others

- [9] L. Farina, Announcing the "Antonio Ruberti Young Researcher Prize", *IEEE Control System Magazine*, 6, (2005) 124-125
- [10] M.C. Palumbo, L. Farina, A. Colosimo, K. Tun, P.K. Dhar and A. Giuliani, Networks everywhere? Some general implications of an emergent metaphor, *Current Bioinformatics*, to appear
- [11] L. Benvenuti and L. Farina, Nonnegative matrices in digital signal processing, *Signal Processing*, to appear
- [12] L. Benvenuti and L. Farina, The geometry of the reachability set for linear discrete-time systems with positive controls, *SIAM J. Matrix Analysis*, to appear
- [13] A. Balluchi, L. Benvenuti, A. Ferrari and A. Sangiovanni-Vincentelli, Hybrid systems in automotive electronics design, *International Journal of Control*, to appear
- [14] A. De Santis, D. Iacoviello, Discrete level set approach to image segmentation, *DIS Technical Report n.13*, submitted to *International Journal of Computer Vision*, 2005

- [15] A. De Santis, O. Di Bartolomeo, D.Iacoviello, F.Iacoviello, Optimal Binarization of Images by Neural Networks, *submitted to Pattern Analysis and Applications*
- [16] A. De Santis, O. Di Bartolomeo, D.Iacoviello, F.Iacoviello, Quantitative shape evaluation of graphite elements in ductile iron, *submitted to Material Characterisation*
- [17] A. De Santis, D.Iacoviello, Optimal Piecewise-Constant segmentation of Images by Neural Networks, *submitted to JOTA*
- [18] A.De Santis, O. Di Bartolomeo, D.Iacoviello, F.Iacoviello, Procedure alternative per l'analisi quantitativa di immagini applicate alle ghise sferoidali, *submitted to La Metallurgia Italiana*