Università di Roma "La Sapienza"

Dipartimento di Informatica e Sistemistica
"Antonio Ruberti"

Research Report
2002

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Contents

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 2002.

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

The academic staff work mainly on three primary research areas:

- Computer Science
- System Science
- Management Science

The research activity in each area is described in Section 3. In particular, in each area are individuated different streams of research carried out by different groups of people. In Section 3 it is reported, for each group, a detailed description of its research together with the people working in the group and a 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. Around 11,000 books and conference proceedings, plus 392 journals subscriptions and 784 on-line journals are available. The library is located at DIS-Eudossiana; information about office hours and procedures can be found at `http://www.dis.uniroma1.it/bibdis`.

During the year 2002, a series of invited lectures entitled "Incontri al Chiostro" have been initiated. This event has been organized by the Library team with the scientific supervision of Professor Lorenzo Farina. The first lecture has been delivered by Professor Domenico Parisi on October 17, 2002 and was entitled "A new science: mental experiments in virtual laboratories". More information can be found at the website: `http://www.dis.uniroma1.it/bibdis/Chiostro.htm`

Research Laboratories

Computer Science Laboratory The laboratory is devoted to software development for various classes of systems and applications.
Person in charge: Massimo Mecella.
Location: DIS-Salaria

Network Control Laboratory The laboratory is devoted to the design, the simulation and the experimental validation of advanced resource management procedures for wireless networks.
Person in charge: Francesco Delli Priscoli.
Location: DIS-Eudossiana.

Operations Research Laboratory The laboratory is devoted to the development of mathematical modeling and algorithms for the solution of mathematical programming problems.
Person in charge: Massimo Roma.
Location: DIS-Buonarroti.

Robotics Laboratory The laboratory is devoted to the development and experimental validation of advanced planning and control techniques for industrial and service robots.
Person in charge: Alessandro De Luca.
Location: DIS-Eudossiana.

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

Gianni Di Pillo is the Director of the Department.
Sandro Mancini is the Administrative Secretary of the Department.

Faculty members

Professors

Giorgio Ausiello
Carlo Bruni
Luigia Carlucci Aiello
Tiziana Catarci
Bruno Ciciani
Giacomo Cioffi
Alessandro De Carli
Alessandro De Luca
Gianni Di Pillo
Francisco Facchinei
Claudio Gori Giorgi
Luigi Grippo
Alberto Isidori
Maurizio Lenzerini
Claudio Leporelli
Stefano Lucidi
Alberto Marchetti Spaccamela
Salvatore Monaco
Daniele Nardi
Alberto Nastasi
Maria Luisa Petit Tarascon
Francesca Sanna Randaccio
Antonio Sassano
Marco Schaerf

Associate Professors

Roberto Baldoni
Stefano Battilotti
Marco Cadoli
Mirella Casini Schaerf
Fabrizio d'Amore
Giuseppe De Giacomo
Alberto De Santis
Francesco Delli Priscoli
Lorenzo Farina
Domenico Laise
Leonardo Lanari
Stefano Leonardi
Umberto Nanni
Giuseppe Oriolo
Pier Luigi Piccari
Fiora Pirri
Serenella Salinari
Silvio Salza
Giuseppe Santucci

Researchers

Anna Bassanini
Luca Becchetti
Luca Benvenuti
Roberto Beraldi
Claudia Califano
Diego Calvanese
Claudio De Persis
Paolo Di Giamberardino
Daniela Iacoviello
Luca Iocchi
Paolo Liberatore
Carlo Mannino
Laura Palagi
Francesco Quaglia
Pierfrancesco Reverberi
Massimo Roma
Riccardo Rosati
Marco Temperini
Marilena Vendittelli

Associate and Post Doctoral Researchers

Alessandro Avenali
Alessandro Bettini
Renato bruni
Camil Demetrescu
Giovanni fasano
Stefano Iannitti
Giampaolo Liuzzi
Raffaella Mattone
Massimo Mecella
Catherine R. E. Pelachaud
Andrea Santoro
Roberta Sestini
Andrea Vitaletti

Staff members

Administrative

Amelia Arricale
Antonietta Cangelli
Beatrice De Carlo
Paola Folgori
Maria Grazia Giacon
Sandro Mancini
Tiziana Valentini
Maria Pia Vandilli

Technical

Sergio Baldini
Giuseppe Capozi
Mauro Cicci
Marco Di Bonifacio
Anna Paola Di Risio
Claudio Dollari
Giuseppe Filaci
Massimo Pacini
Paola Pacini
Antonio Sapori
Tiziana Toni

Auxiliary Services

Pia Bonanni Maria Carmina Mastrocola Antonio Simeoni

Library

Angelina De Salvo

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

2.4 Ph.D. Programs

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

Bioengineering

The council of professors of the Ph.D. program in Operations Research is coordinated by Guido Avanzolini (Dep. 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)

XVI course	XVII course
Di Giacomo Paola	Poli Samantha

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

XV course	XVI course	XVII course	XVIII course
Calì Andrea	Inzerilli Tiziano	Bahadori G. Shahram	Bertini Enrico
Laura Luigi	Kimani Stephen	Berardi Daniela	Donato Debora
Marchetti Carlo	Lembo Domenico	Farinelli Alessandro	Ferrara Andrea
Pirrone Marco	Pianura Daniele	Mancini Toni	Fratini Simone
Romano Massimo	Scannapieco Monica	Oglietti M. Alejandro	Grisetti Giorgio
Santoro Andrea	Virgillito Antonio	Policella Nicola	Sarracco Fabiano
	Zito Fabio	Savelli Francesco	Tucci Piergiovanni Sara

Operations Research

The council of professors of the Ph.D. program in Operations Research is coordinated by Gianni Di Pillo.

The research topics are: combinatorial optimization, nonlinear programming, network design, neural networks, logistics, management systems, industrial systems economy.

Ph.D. students (working at DIS)

XVI course	XVII course	XVIII course
Mattia Sara	Del Sorbo Filomena	Canale Silvia
Piccialli Veronica	Lombardi Giuseppe	Parrello Emiliano
Torelli Renato		

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

XV course	XVI course	XVII course	XVIII course
Conforto Paolo	Brandes Amit	Lucchetti Matteo	Cefalo Massimo
Temperanza Daniele	Pascucci Federica	Pompili Dario	Farina Riccardo
	Pietrabissa Antonio	Zavagli Massimo	Granato Luigi
	Vergari Stefania	Zonfrilli Fabio	Mogno Ilaria

2.5 Contracts signed in year 2002

In the following, we list the research contracts signed in year 2002.

Contracts with the European Union

Contractor	Value (EURO)	Title	Project Leader
E.U.	336.079	Facilitating Co-operation amongst European Public Administration employees through a Unitary European Network Architecture and the use of Interoperable Middleware Components. EU-PUBLICOM	R. Baldoni
E.U.	41.331	Middleware for Composable and Dynamically Adaptable Services MIDAS	R. Baldoni
E.U.	291.196	Satellite Broadband Multimedia System for IPv6 "SATIP6"	F. Delli Priscoli
E.U.	207.600	Satellite Integrated UMTS Emulator	F. Delli Priscoli
E.U.	206.000	SEWASIE - Semantic Webs and AgentS in Integrated Economies (IST-2001-34825)	M. Lenzerini
E.U.	179.000	INFOMIX - Computational Logic for Information Integration (IST-2001-33570)	M. Lenzerini
E.U.	220.020	Coevolution and Self-Organization in dynamical Networks. COSIN	S. Leonardi
E.U.	30.000	MENU, Model for a European Networked University for e-learning (e-learning Project n.2002–0510/001–001–EDU–ELEARN)	M. Temperini

Contracts with Italian research Institutions

Contractor	Value (Euro)	Title	Project Leader
A.S.I.	84.697	SACSO: Safety Critical Software for planning in space robotics CT IR/138/02	L. Carlucci
A.S.I.	34.714	Sottosistemi modulari intelligenti per l'automazone e la robotica spaziale (CT IR/139/02)	S. Monaco
A.S.I.	27.842	PEGASO: Percept Golog for Autonomous agents in Space station Operations CT IR/240/02	M. F. Pirri
ENEA Politecnico di Milano	52.527,44	Progetti Strategici MIUR Progetto VISPO Piattaforma Internet-based per l'Offerta di Servizi a Distretti Produttivi Virtuali	M. Lenzerini
C.N.R.	29.955	Progetto strategico MIUR - SP1 Metodologie di integrazione di sorgenti semistrutturate ed eterogenee (CTB 02.00459.ST97)	M. Lenzerini
C.N.R.	13.944	Progetto strategico MIUR - SP1 Algoritmi per l'ottimizzazione della QoS in internet. CTB 02.00461.ST97	A. Marchetti Spaccamela
C.N.R.	13.428	Progetto strategico MIUR - SP7 Progettazione di reti con vincoli di capacit. CTB 02.00501.ST97	A. Sassano

Contractor	Value (Euro)	Title	Project Leader
M.I.U.R. (COFIN)	32.000	Modelli e algoritmi dinamici per Internet e per il grafo del Web	G. Ausiello
M.I.U.R. (COFIN)	43.000	Rilevazione, localizzazione e compensazione di guasti in sistemi di controllo non lineari	A. Isidori
M.I.U.R. (COFIN)	38.000	Sviluppo ed analisi delle caratteristiche sperimentali e tecniche di linguaggi espressivi finalizzati alla specifica ed al model-checking di sistemi complessi	M. Schaerf
M.I.U.R. (FIRB)	1.259.788	MAIS, Multichannel Adaptive FIRB Information Systems	T. Catarci
M.I.U.R. (FIRB)	372.650	Ottimizzazione non lineare su larga scala	G. Di Pillo
M.I.U.R. (FIRB)	124.814	Telepresence Instant Groupware for higher Education in Robotics (TIGER)	G. Oriolo
M.I.U.R. (FIRB)	400.000	Automazione dell' Ingegneria del Software basata su Conoscenza (ASTRO)	M. Schaerf

Contracts with others (companies, foreign research institutions)

Contractor	Value (Euro)	Title	Project Leader
Alenia Marconi Systems s.p.a.	18.000	Uso di tecnologie object Oriented nei sistemi di controllo del traffico aereo	R. Baldoni
C.M. Sistemi s.p.a.	15.493	Sistemi di indagine e diagnosi assistita per la conservazione dei manufatti archeologici	T. Catarci
CRMPA	9.815	Definizione di un modello per la rappresentazione della conoscenza relativa al materiale didattico e progettazione di un tool per l'indicizzazione di tale materiale tramite metadata. Sub-contract prog. U.E. DIOGENE	M. Cadoli
Telespazio s.p.a.	10.329	Aspetti di ricerca finalizzata al settore satellitare	F. Delli Priscoli
Alenia Spazio s.p.a.	20.658	Aspetti di ricerca nello sviluppo di servizi e sistemi di telecomunicazione via satellite in ambito mobile	F. Delli Priscoli
Telespazio s.p.a.	12.500	Attività di supporto tecnico relativamente alle tematiche "Mobile Satellite" nell'ambito dei Progetti FUTURE E SAILOR	F. Delli Priscoli
Ente Tecnobiomedica s.p.a.	1.000	Modellistica del sistema di assistenza ventricolare mediante grafi di legame	L. Farina
Centro Tecnico Rete Unitaria P.A.	57.000	Accordo di collaborazione	C. Leporelli

Contractor	Value (Euro)	Title	Project Leader
WIND Telecomunicazioni s.p.a.	60.000	Analisi delle condizioni tecniche ed economiche di offerta dei servizi di u nbundling del local loop, ai fini della formulazione dei test di "margin squeeze"	C. Leporelli
Inspiring Software srl	26.658	Tecniche di visualizzazione avanzate per dati di fabbrica	G. Santucci
CRMPAC	11.879	Controllo di sistemi di workflow federati attraverso agenti software. Subcontract prog.U.E. GENESIS	G. Santucci
NFU Norwegian State Institution for Distance Education	6.000	CIOC, Competence Development in Internationally Oriented Companies (Project n.18)	M. Temperini

Framework Programmes

Contractor	Leader
ACCENTURE Spa	G. Di Pillo
CRMPA -Centro di Ricerca in Matematica Pura ed Applicata	G. Di Pillo

3 Research Activity

3.1 Computer Science

3.1.1 Algorithm Engineering

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 efficient solution of problems arising in geometric applications with emphasis on numeric robustness;
7. 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 Chairman of the Technical Committee on Foundations of Computer Science of the International Federation of Information Processing (IFIP – TC 1) since 1997 and Editor in Chief of Theoretical Computer Science, Series A, Algorithms and Complexity. Members of the AE group are continuously involved in the Program Committes of prestigeous International Conferences. Giorgio Ausiello was in the Program Committee of the 5th International Workshop on Approximation Algorithms for Combinatorial Optimization Problems (APPROX'02). Camil Demetrescu was in the Program Committee of the 10th European Symposium on Algorithms - Applied Track (ESA'02). Alberto Marchetti-Spaccamela was in the Program Committee of 10th European Symposium on Algorithms - Theory Track (ESA'02). Stefano Leonardi has been recently involved in several Program Committees, including the 15th ACM Symposium on Parallel Algorithms and Architectures (SPAA'03), the 6th International Workshop on Approximation Algorithms for Combinatorial Optimization Problems (APPROX'03), the 30th International Colloquium on Automata, Languages and Programming (ICALP'03), and the 14th ACM-SIAM Symposium on Discrete Algorithms (SODA'03).

The AE group has recently organized several international scientific events. In particular it has organized ALGO 2002, where the European Symposium on Algorithms (ESA 2002), the Workshop on Approximation Algorithms for Combinatorial Optimization (APPROX

2002), and the Workshop on Algorithms in Bioinformatics (WABI 2002) have been co-located, in Rome in September 2002. Besides it has organized the Workshop on Algorithms and Models for the Web in Udine (June 2002). A regular Seminar, the Interdepartmental Seminar on Algorithms (SIA), is also organized in cooperation with the Department of Computer Science of this University.

The AE group is currently cooperating with several prestigeous 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, USA), ICSI-Berkeley (USA), Brown University (Providence, USA).

The AE group is presently involved in the following research projects: EU-IST ALCOM-FT "Algorithms and Complexity in Future Technologies"; EU-IST APPOL "Approximation and On-line algorithms"; EU-RTN AMORE "Algorithmic Methods for Optimizing the Railways in Europe"; MURST "Resource Allocation in Computer Networks"; MURST National Project "Rete multimediale nell'evoluzione verso UTMS - Linea di ricerca Applicazione ai beni culturali"; EU-IST COSIN "Coevolution and self-organization in dynamical networks"; MURST National Project ALINWEB "Algorithmics for Internet and the Web".

Group members Giorgio Ausiello, Luca Becchetti, Fabrizio d'Amore, Camil Demetrescu, Paolo Giulio Franciosa, Luigi Laura, Stefano Leonardi, Alberto Marchetti-Spaccamela, Umberto Nanni, Andrea Vitaletti.

Graphs and Combinatorial Algorithms Part of our effort was devoted to studying dynamic path problems on directed graphs. In particular, we have considered the problem of maintaining all pairs shortest paths in a weighted directed graph. We have shown how to obtain effective query/update trade-offs for dynamic all pairs shortest paths, by introducing two new families of algorithms that improve the best known update bounds at the price of a non-constant query time. More recently, we have studied novel combinatorial properties of graphs and we have devised a completely new approach to the problem. Our approach yields a fully dynamic algorithm for general directed graphs with real edge weights that supports any sequence of operations in $O(n^2 \log^2 n)$ amortized time per update and unit worst-case time per distance query, where n is the number of vertices. This solves a long-standing open problem, improving substantially over previous results, and being the first algorithm that solves the dynamic all pairs shortest paths problem in its full generality. We have also studied the problem of constructing compact data structures for representing information about all pairs shortest paths in a weighted directed graph. In particular, for a directed graph G we have considered queries of the form: "What is the shortest path distance from vertex x to vertex y in G avoiding a failed link (u, v)?" We have shown that an oracle for such queries can be stored in $O(n^2 \log n)$ space with a constant query time. No non-trivial solution was known for this problem. These results appear in [13, 4, 5]. During 2002 an investigation on the fully dynamic maintenance of sparse spanners in a graph has also been started.

Information Retrieval Qiu and Frei showed that the use of a similarity thesaurus can be very effective if compared to other query expansion techniques. We have proposed a novel approch to calculate the similarity thesaurus, based on the Latent Semantic Indexing (LSI). We have also shown experimental evidence of the retrieval effectiveness of our approach. In a different work, we have considered the problem of collaborative filtering, introducing a random planted model of bi-categorical data. We have adapted the ideas of an algorithm due to Condon and Karp to develop a simple linear time algorithm to discover the underlying hidden structure of a graph generated according to the planted model with high probability. We have also given applications to the probabilistic analysis of the LSI in the probabilistic corpus models introduced by Papadimitriou et al. Our experimental analysis has shown that the algorithm might work quite well in practice. Results in this area appeared in [14, 15].

Distributed and network algorithms 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 for every user. This gives rise to a new class of parallel scheduling problems. We abstract general downlink scheduling problems suitable for proposed next generation wireless data systems, devise a communication-theoretic model for multirate wireless channels. Our focus is on optimizing the maximum response time of jobs, which is suitable measure for streams of user requests. We have presented provable results on the algorithmic complexity of these scheduling problems, devising very simple, online algorithms for approximating the optimal maximum response time.

In the Hose Model for Network Design problems we are not given a node-to-node traffic matrix, but just upper bounds on the total volume of traffic entering or leaving some set of terminals. The goal is to install capacity at a minimum cost as to support every traffic matrix satisfying the upper bound constraints. In this setting, we have considered problem of designing a minimum cost tree-network in the hose model. This problem is known to be NP-hard when we are given different upper bounds on the amount of traffic leaving or entering a terminal but polynomially solvable if the two bounds are equal for every specific vertex. We have shown that also the case where the total outgoing traffic is equal to the total incoming traffic is polynomially time solvable. Moreover, in this case, the cost of an optimal tree reservation is within a factor of three of the cost of an optimal reservation that is allowed to use arbitrary subgraphs.

In an another paper we have studied stochastic graph models of the WebGraph, presenting a new model that describes the WebGraph as an ensemble of different regions generated by independent stochastic processes. Models such as the Copying Model of Kumar et al. [FOCS 2001] and the Evolving Network Model by Barabasi are simulated and compared on several relevant measures such as degree and clique distribution.

Caching and prefetching have often been studied as separate tools for enhancing the access to the World Wide Web. In this setting, we have proposed integrated Caching and Prefetching Algorithms for improving the performances of web navigation, devising a new prefetching algorithm that uses a limited form of user cooperation to establish

which documents to prefetch in the local cache at the client side. We have shown that our prefetching technique is highly beneficial only if integrated with a suitable caching algorithm. Works in this area appeared in [2, 3, 6, 1].

Approximate and on-line algorithms We have studied the multicast routing and admission control problem on unit-capacity tree and mesh topologies in the throughput-model. The problem is a generalization of the edge-disjoint paths problem and is NP-hard both on trees and meshes. We have addressed both the offline and the online version of the problem: In the offline setting, we have given the first constant-factor approximation algorithm for trees, and an $O((\log \log n)^2)$-factor approximation algorithm for meshes. In the online setting, we have provided the first polylogarithmic competitive online algorithm for tree and mesh topologies. We have aldo studied the problem of scheduling parallel machines online, allowing preemptions while disallowing migration of jobs that have been scheduled on one machine to another. We have measured the quality of service provided by an algorithm by the average stretch, defined as the average ratio of the amount of time the job spends in the system (the response time) to its processing time. This problem is of relevance in many applications, e.g., wireless data servers and distributed server systems in wired networks. We have proved a first costant competitive ratio for this problem for the algorithm introduced in STOC99 by Awerbuch et al. for minimizing average flow time without migration. Finally, we have studied the on-line traveling salesman problem where the objective is to minimize the maximum flow time. This objective is particularly interesting for applications. However, it is possible to prove that there can be no competitive algorithm, neither deterministic nor randomized. We have introduced a natural restriction on the adversary for this problem on the real line. Our main result is an algorithm that achieves a costant competitive ratio against the non-abusive adversary. Results in this area appeared in [9, 12, 7]. In the framework of on-line algorithms, the study of the on line version of the so-called Quota Traveling Salesman Problem has also been started.

Experimentation and visualization We have surveyed different aspects in algorithm engineering as a field that provides methodologies and tools for developing and engineering efficient algorithmic codes. In this context, we have considered the role of algorithm engineering in integrating and reinforcing the traditional theoretical approaches for the design and analysis of algorithms, addressing issues related to design, analysis, implementation, tuning, debugging and experimental evaluation of computer programs for solving algorithmic problems. We have also applied different experimental methodologies to the analysis of agorithms for the two-layer crossings minimization problem, which arises in many applications such as diagram drawing and computer-aided circuit layout design. Based on those experiments, which yielded useful clues to the structure of the problem, we have proposed and analysed a new effective algorithm, based on solving feedback problems on directed graphs. Works in this area appeared in [10, 11, 8].

Conference Proceedings

[1] L. Laura, S. Leonardi, G. Caldarelli and P. De Los Rios. A Multi-Layer Model of the WebGraph. In *2nd International Workshop on Web Dynamics*, Honolulu, Hawaii, May 2002.

[2] L. Becchetti, S. Diggavi, S. Leonardi, A. Marchetti-Spaccamela, S. Muthukrishnan, T. Nandagopal and A. Vitaletti. Parallel Scheduling Problems. In *Next Generation Wireless Networks Proceedings Fourteenth Annual ACM Symposium on Parallel Algorithms and Architectures (SPAA 02)*, pp. 238-247, 2002.

[3] M. Curcio, S. Leonardi and A. Vitaletti. An Experimental Study of Prefetching and Caching Algorithms for the World Wide Web. In *Proceedings of the 4th Workshop on Algorithm Engineering and Experiments (ALENEX'02)*, San Francisco (CA), January 2002.

[4] C. Demetrescu and G.F. Italiano. Improved Bounds and New Trade-Offs for Dynamic All Pairs Shortest Paths. In *Proceedings of the 29-th International Colloquium on Automata, Languages, and Programming (ICALP'02), Málaga, Spain*, July 2002.

[5] C. Demetrescu and M. Thorup. Oracles for Distances Avoiding a Link-failure. In *Proceedings of the 13th Annual ACM-SIAM Symposium on Discrete Algorithms (SODA'02), San Francisco, CA*, January 2002.

[6] G.F. Italiano, S. Leonardi, G. Oriolo. Design of Networks in the Hose Model. In *Proc. of the 2nd International Workshop on Approximation and Randomization Algorithms in Communication Networks*, pp. 65-76, Carleton Scientific Press, 2002.

[7] M. Lipmann, S.O. Krumke, L. Laura, A. Marchetti-Spaccamela, W.E. de Paepe, D. Poensgen, L. Stougie. Non-abusiveness helps: An O(1)-competitive algorithm for minimizing the maximum flow time in the online traveling salesman problem. In *Proceedings of the 5th International Workshop on Approximation Algorithms for Combinatorial Optimization*, Lecture Notes in Computer Science, Springer, 2002.

Submitted papers, technical reports and others

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3.1.2 Artificial Intelligence

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

In particular, we are concerned with the following topics:

1. The development of suitable formalisms to support various aspects of reasoning, and to combine different logics, which in the following pages are collected under the title "Commonsense Reasoning".

2. The specification of formal languages for representing structured knowledge in different contexts, and for reasoning over such knowledge with suitable computational properties. These topics are illustrated in the Section "Description Logics".

3. The study of computational properties of formalisms, languages, and reasoning tools. These topics are illustrated in the Section "Complexity of Reasoning".

4. The definition of methods and techniques for reasoning about actions, and for the design and the realization of embodied agents (in particular mobile robots) that are able to accomplish complex tasks in real environments. These topics are described in the Section "Cognitive Robotics and Reasoning about Actions".

5. The techniques for the design and implementation of Cognitive Agents that cooperate in the achievement of a common goal, in multi-robot and multi-agent systems. These topics are described in the Section "Multi-robot and multi-agent systems".

6. The development of heuristics and suitable formalisms to realize flexible architectures for planning and scheduling. This work is described in the Section on "Constraint-based Architectures for Planning and Scheduling".

The international recognition of the achievements in the field of Artificial Intelligence and Knowledge Representation are highlighted by the Presidency of the Board of Trustees of IJCAI - International Joint Conference on Artificial Intelligence, the main worldwide conference on AI, held by Luigia Carlucci Aiello. Fiora Pirri is permanent member of

the Cognitive Robotics steering committee. Daniele Nardi is member of the RoboCup Executive Committee. Paolo Liberatore was co-chair of STAIRS-2002.

Marco Cadoli was invited speaker at the 2nd International Workshop on Complexity in Automated Deduction.

The members of the group have partecipated at the Program Committes of several International Conferences, among which: IEEE Symposium on Logic in Computer Science (LICS 2002), 2nd Int. Symposium on Foundations of Information and Knowledge Systems (FoIKS 2002), 8th International Conference on Principles of Knowledge Representation and Reasoning, RoboCup Symposium 2002, German Conf. on Artificial Intelligence 2002.

The robot Armand0 AAAI 2002 (Edmonton) the Robot Exhibition & Competition for exploring a maze.

The research activities have been supported by various institutions and in the framework of different programs, whose financial support is gratefully acknowledged, namely ASI, CINI, CNR, CEE-Magixter, ENEA, AFOSR, CEE-Galileo, MIUR.

Group members Luigia Carlucci Aiello, Shahram Bahadori, Daniela Berardi, Marco Cadoli, Andrea Calí, Diego Calvanese, Amedeo Cesta [CNR], Giuseppe De Giacomo, Francesco M. Donini [Univ. della Tuscia], Alessandro Farinelli, Andrea Ferrara, Alberto Finzi, Giorgio Grisetti, Luca Iocchi, Domenico Lembo, Maurizio Lenzerini, Paolo Liberatore, Thomas Lukasiewicz, Toni Mancini, Daniele Nardi, Angelo Oddi [CNR], Fiora Pirri, Marco Pirrone, Nicola Policella, Massimo Romano, Riccardo Rosati, Francesco Savelli, Marco Schaerf.

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, abduction, contextual reasoning, etc. Many formalisms, which also require to combine several logics, have been devised in the knowledge representation research community to challenge the limitations of classical formalisms. Our research group worked in default logic [32, 10], probabilistic default reasoning [9, 1, 33], and nonmonotonic modal logics [5].

Description Logics The goal of the research in Description Logics (DL) is to study the foundations of a logical approach to structured knowledge representation languages, with regards to both the expressive power and the computational properties of the associated reasoning techniques [20]. Automata-based techniques to reason on expressive variants of DLs are presented in [19]. The use of DLs to formalize UML class diagrams and to reason on them is shown in [17, 13]. DLs have also been successfully applied to information integration [11], and to the development of ontologies [18]. These represent notable examples of the use of knowledge representation techniques to the area of databases and data management in general [12]. DLs have been applied to Peer-to-Peer Electronic Commerce formalizing the matching of supply and demand through suitable extensions of the

definitions of subsumption and satisfiability [36, 35]. Finally, a nonmonotonic extension of DLs is presented in [5].

Complexity of Reasoning Efficiency of AI systems is important for their success, as it is important in all engineering projects. If we are to use logic as the major tool for Knowledge Representation and Reasoning we have to deal with computational aspects. During the year 2002, the AI group has continued the investigation on fundamental properties of complexity of reasoning, with the overall goal of designing computationally efficient and adequately expressive systems for Knowledge Representation and Reasoning. In particular, research has focused on general complexity results, computational complexity of specific logical formalisms, algorithms for specific forms of reasoning, logical compilation of knowledge, experimental analysis of computationally hard problems, approximation of logical inference to gain efficiency, languages for the specification of hard problems. The main publications in this topic have been: [2, 45, 3, 8, 15, 16, 14, 23, 31, 30, 48, 50, 49, 47].

Cognitive Robotics and Reasoning about Actions The research at DIS on Cognitive Robotics and Reasoning about Actions focus on several theoretical, applicative and experimental aspects. From the experimental point of view the group working on Cognitive Robotics has built in 2002 a mobile manipulator ArmHand1 (successor of ArmHand0) endowed with a rich sensory system, formed by sonars, encoders, and two ccd color cameras mounted on a pan-tilt head, and a cognitive architecture allowing it to navigate in an unkown environment (like a maze), picking up blocks and gaining the exit. ArmHandOne has been exibithed at the AAAI-2002 Exibition and Competition in Edmonton, at the National conference on Intelligent Systems and Advanced Robotics in Frascati.

Research interests include: cognitive architectures[42] defining the formal structure of reasoning, acting and perceiving. As a crucial component of the cognitive architecture, perception and recognition [43] is faced with a recognition by components approach based on *SymGeons recognition*. In the past years we have been formilizing a theory for managing uncertainty both in the initial knowledge base and as an effect of non deterministic actions, then in [44] we deal with diagnosis and failure management; deliberation and execution of complex actions [40]; planning under incomplete information [41].

Multi-robot and Multi-agent Systems The research within this field has been carried out by considering both physical agents (i.e. mobile robots) and software agents. In the realm of mobile robotics, we have developed a multi-robot system composed by 4 Sony AIBO legged robots, that has participated to the RoboCup 2002 competition in Japan [34]. During this year our research has addressed two different aspects of the localization problem, that are: position tracking and global localization. The main results on this concern the position tracking problem [7], and the global localization problem [29]. Moreover, we have studied techniques for multi-robot coordination in a dynamic environment with constraints on the resources [26], as well as a planning algorithm for generating plans with cyclic structures, that are used for action synchronization between two robots [27]. As for multi-agent systems, we have studied the problem of designing, implementing and evalu-

ating such systems in a scenario caused by a large-scale disaster (such as an earthquake) in which the task is to perform victim search and rescue operations. In this context, we have addressed the problem of defining a simulated disaster scenario [58, **?**] and to develop a Cognitive Agent Development Kit, for realizing multi-agent systems acting in this environment [52]. Finally, we have studied techniques for integrating the information on the environment coming from different sources [22].

Constraint-Based Architectures for Planning and Scheduling This line of research is aimed at developing constraint-based methods for automated planning and scheduling.

Different specific aspects has been addressed during this year like (a) new solution techniques for complex project scheduling problems with cumulative resources [4], (b) different integration schemata for planning and scheduling techniques [39], and (c) an analysis of the use of planning and scheduling components to coordinate multi-agent systems [38].

A different research activity aims at integrating the basic research on constraint satisfaction problems (CSP) in software architectures for scheduling problems. A specific activity that has required a huge effort during this year has been connected to a study for ESA-ESOC. A complete system called MEXAR has been developed and delivered in July 2002. MEXAR solves a specific data downlink problem on MARS-EXPRESS an ESA program that will be lauched in 2003. A complete description of this work is given in [51], specific aspects are described in [21, 37].

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3.1.3 Data and Knowledge Bases

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

- Theoretical and application-oriented aspects of visual formalisms for databases and database design, with special focus on Visual Query Languages and Interfaces, Visual Data Mining, Databases and the Web, 2D and 3D Data Visualization, Adaptive Interfaces, Visual Metaphors, Controlled Studies and Usability Testing.
- Database Modeling, Data Integration, Data Mining and Data Warehousing.
- Cooperative Information Systems, with special focus on Service Oriented Computing, Data Quality in Cooperative Systems, Applications of Cooperative Technologies and Architectures to real scenarios.

The group is presently involved in several research projects, including the following: LAURIN (Telematics Program, Libraries Project LB-5629/A); Progetto MIUR: Programma Multimediale nell'evoluzione verso UMTS, linea di Ricerca "Applicazione ai Beni Culturali"; Progetto MIUR (COFIN): "Analysis, information visualization, and visual querying in databases for clinical monitoring"; Progetto MIUR (COFIN): "From data to information: integration, warehousing and mining of heterogeneus sources"; Progetto MIUR (COFIN): "Methodologies and tools for data quality inside cooperative information systems"; Progetto MIUR (FONDO STRATEGICO 2000): "VISPO - Piattaforma a Servizi per Distretti Virtuali". Progetto MIUR (FIRB): MAIS - Multichannel Adaptive Information Systems; Progetto IST "Sewasie"; Progetto IST "Infomix"; Progetto IST "EUPUBLI.com". Research projects with: AMA S.p.A., 12Snap S.p.A., IBM Tivoli, Gruppo CM.

Group members Andrea Calì, Diego Calvanese, Tiziana Catarci, Giuseppe De Giacomo, Stephen Kimani, Domenico Lembo, Maurizio Lenzerini, Massimo Mecella, Giuseppe Santucci, Silvio Salza, Monica Scannapieco.

Data Integration. Data integration is the problem of combining the data residing at different heterogeneous sources. In data integration the user has to be provided with a unified view of the data at the sources, called *global schema*. The interest in data integration systems has been continuously growing in the last years, both in academy and industry. The group has addressed several among the most important problems in the design of a data integration system, and in particular: comparing the expressiveness of formalisms for data integration systems, modeling the relationship between the sources and the global schema, processing queries expressed on the global schema, dealing with integrity constraints on the global schema, query answering in the presence of access limitations on the sources. The results of the research on these topics are reported in [23, 11, 6, 12, 13, 18, 14, 19, 17, 21, 22, 7].

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. There are two approaches to view-based query processing, called query rewriting and query answering, respectively. Both approaches are investigated in [1, 15, 16].

Visual Formalisms for Representing and Accessing the Information. It comes as no surprise that in this day and age, data still present formidable challenges to effective and efficient data exploration and discovery of knowledge. Hardware, databases and network technologies have witnessed tremendous breakthroughs. Consequently, many individuals and organizations have been able and are still able to acquire, store, share and disseminate vast amounts of data. Notwithstanding the foregoing, there often exist non-trivial relationships among data items in the enormous set of data. Be that as it may, the technological breakthroughs have also rendered it possible to accommodate more complex data types such as multimedia data types. Consequently, the ever-increasing data are characterized by enormity and complexity. The inherent power of the human-vision channel enables both recognition and understanding of overwhelming data at an instant. Visual exploration and visual discovery systems can tap into the foregoing outstanding resource primarily by employing relevant and effective visual strategies within the visual interface. The group has a long tradition in exploiting such strategies through visual query and visualization systems [2, 3, 8, 20, 32].

Last year we concentrated specifically on exploitation of visual strategies in supporting the user throughout the entire process of exploring and discovery knowledge. The research work ranged from visual information access on the Web [9], through representing and visually querying temporal data [4], to visual data mining [38, 10, 24, 25, 26, 39].

Digital Libraries. Among the wide range of digital libraries, an interesting subclass is constituted by those exclusively dealing with newspapers' clippings. LAURIN is an EU-

funded Project involving seventeen participants from several countries, including a large group of libraries that want to make easily available and give wide visibility to the large cultural heritage they collect and catalog daily. The LAURIN system is organized around a *central node*, which is connected via the Internet to a set of *local nodes*, one for each participating library. The central node contains indexing data about all clippings stored in the local nodes, and a centralized copy of a multilingual Thesaurus with globally validated entries. The digitalized clippings and their full-text are stored in the local nodes, together with a local, possibly personalized, copy of the Thesaurus. A constant flow of information from the local nodes to the central node ensures that the latter is up to date. A suite of friendly interfaces are available to accomodate the needs of various user classes. [20].

Data Quality in Cooperative Information Systems. Data quality is a challenging issue addressed in different research areas, especially within traditional IS's. When the target context of data quality becomes open IS's, new opportunities as well as new problems arise. Open IS's can live in loosely coupled contexts, like the Web, or tightly coupled ones, like Cooperative Information Systems (CIS's). Our research is especially focused on data quality in CIS's. One of the ambitious goals of CIS's is to enable the automation of large-scale business processes that cross system and organizational boundaries. It has been widely recognized that the success of such inter-organizational processes depends upon the ability of autonomous systems to share and to understand each other's data. But the ability of those systems to manage the *quality* of the data they share and exchange is equally, critically important. In "real world" scenarios, an organization $\mathcal{A}$ may not request data from an organization $\mathcal{B}$ if it does not "trust" $\mathcal{B}$'s data, i.e., if $\mathcal{A}$ does not know that the quality of the data that $\mathcal{B}$ can provide is high. Therefore, lack of cooperation may occur due to lack of quality certification.

Uncertified quality can also cause a deterioration of the data quality inside single organizations. If organizations exchange data without knowing their actual quality, it may happen that data of low quality spread all over the CIS. On the other hand, CIS's are characterized by high data replication, i.e., different copies of the same data are stored by different organizations. From a data quality perspective, this is a great opportunity: improvement actions can be carried out on the basis of comparisons among different copies, in order either to select the most appropriate one or to reconcile available copies.

The achieved results have mainly regarded: *(i)* data quality conceptual modeling [31, 30, 27, 28], *(ii)* methods for modeling processes in order to detect quality critical paths [35], *(iii)* techniques to improve data quality [42, 41, 34, 33].

Cooperative Architectures and Service Oriented Computing. *e*-Services are autonomous platform-independent computational elements that can be described, published, discovered, orchestrated and programmed for the purpose of developing distributed interoperable applications.

e-Services possess the ability to engage other services in a computation in order to: *(i)* conduct a complex business transaction; *(ii)* complete a task; or *(iii)* solve a problem and expose their features programmatically over the Internet (or intra-net) using standard

Internet protocols like XML and HTTP; and *(iv)* can be implemented via a self-describing interface based on open Internet standards.

The research in this area regards some main facets: *(i)* formalization and modelling of *e*-Services, in order to provide a richer semantics enabling client applications to compose and orchestrate different *e*-Services [36, 40]; *(ii)* composition and orchestration of *e*-Services [36, 29]; *(iii)* application of service oriented computing to real cooperative scenarios, e.g., *e*-Government [5] and cooperative software development tools [37].

Journals

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3.1.4 Distributed Systems

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

- Theory of distributed and mobile computing.
- Highly performing, available Web systems.
- Parallel/distributed simulation.
- Dependable middleware.
- Dynamic Networking.
- Interconnection networks.
- Parallel Computing.

In 2002 members of the group were involved in the following Program Committees of prestigious International Conferences: ICDCS, PADS, DOA, WORDS, DISC. In 2002, Roberto Baldoni was Program Chair of the ACM POMC (Principles of Mobile Computing) that was held in Toulouse (France) and General Chair of the International Workshop on Fundamentals of Middleware Technology (Irvine, USA).
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).
The DS group is presently involved in the following research projects: EU-IST EU-PUBLI.COM; EU-IST MIDAS, MURST FIRB "Multichannel Information Systems"; MURST COFIN "Metodologies and tools for Data Quality inside cooperative information systems"; AleniaMarconiSystems "Component-based architectures for Air Traffic Control Systems"; MIUR "Fondo Speciale" "Software Infrastructure for Mobile ad-hoc networks". The distributed systems group is member of "CABERNET" Network of Excellence in Distributed Systems Architectures chaired by Brian Randell. Finally in 2002 the DS created two specific IT labs: MIDLAB (http://www.dis.uniroma1.it/~midlab) and the cluster computing lab.

Group members Roberto Baldoni, Roberto Beraldi, Bruno Ciciani, Stefano Cimmino, Giacomo Cioffi, Mariangela Contenti, Carlo Marchetti, Daniele Pianura, Marco Emilio Poleggi, Francesco Quaglia, Paolo Romano, Andrea Santoro, Alessandro Termini, Antonino Virgillito, Fabio Zito.

Theory of Distributed Computing

Causality. A fundamental problem in distributed computing consists in tracking causal dependencies between a subset of events occurring during a distributed computation, called relevant events and denoted as R. This is usually tackled by timestamping events in R in such a way that the causal dependency or concurrency between two events can be detected just analyzing their timestamps. If this analysis is a simple comparison between timestamps, we say that causality can be tracked "on-the-fly". *Vector clocks* are the appropriate mechanism to track causality on-the-fly, yet 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. Several known methods have to face the problem of the size of piggybacked information that is prohibitive.

It has been proved the impossibility to find a method different from vector clocks that both tracks causality on-the-fly and piggybacks on messages an amount of information less than one vector clock, implies that as we reduce the number of entries piggybacked on messages to a given $k < n$, causality cannot be tracked on-the-fly. In particular, we pointed out a tradeoff between the size k and the number of pairs of causal dependencies on-the-fly detectable. We presented a general scheme for tracking causality, called k-dependency vectors, which exploits that tradeoff.

Checkpointing. A local checkpoint of a process in a distributed computation is a local state dumped onto stable storage. Messages of the distributed computation define dependencies between local checkpoints. Achieving consistency of global checkpoints (with one local checkpoint for each process) is an important problem for many distributed applications (e.g. fault-tolerant applications, distributed debuggers, applications that rely on global properties detection, etc.). In this context we have determined a characterization for two well know properties for checkpoint and communication patterns: No-Z-Cycle and Rollback-Dependency Trackability. Other studies concern (i) the consistency problem for global checkpoint consistency in transaction systems and (ii) some impossibility results for RDT implementation.

Distributed Shared Memory. Distributed shared memory (DSM) is a powerful abstraction for interprocess communication in loosely-coupled distributed system. In these systems each process runs on a separate host and no physical shared memory is available. Neverthless, the DSM abstraction provides a shared address space which applications can access through Read and Write operations. This abstraction is implemented by a specific software layer built between the application and the underlying message-passing system. Substantially, this software layer is responsible for maintaining the shared memory consistency. Different consistency models can be supported, e.g. sequential, atomic, causal, FIFO (or PRAM), in order to provide the most appropriate set of abstractions to the application. 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 respect to the level of semantics coherence, performances and scalability. We have especially been focusing on improving existing protocols for ensuring causal consistency providing (1) more efficient protocols that exploit writing semantics, and (2) protocols that allow higher concurrency by relaxing ordering constrains without loosing the causal consistency.

Highly performing, available Web systems In the this area we focused our research activities on the following issues:

1. Scalable protocols for cooperative web proxy cache sharing.

2. Global caching algorithms in web clusters.

As respect to the first issue, we have proposed a cooperative protocol specifically designed for systems of dozen or hundreds of web proxy cache servers with no centralized control. By means of real traces, we have also compared a prototype implementation of the new protocol with classical protocols. The results point out a strong reduction of the amount of transferred information to manage cooperation. Such an overhead reduction is achieved without performance degradation in terms of latency and cache hit rate. Given these results, we have also presented a real implementation of the protocol achieved by modifying the Squid Software.

As respect with the second issue, we have analyzed how to improve Web cluster performance through global caching. We have considered different cache cooperation approaches for replica discovery, such as on-demand and periodic information exchange, and various mechanisms for retrieving requested documents from a remote node, such as hand-off, migration and replication-based. All the schemes have been evaluated through a detailed workload and simulation model. The results have shown that a cluster with cooperative caches can perform even twofold better than a traditional Web cluster with no server cooperation.

Parallel 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 checkpointing functionalities. Specifically, in CCL memory-to-memory data copies associated with checkpoint operations proper of optimistic simulation systems are chaged to programmable DMA engines on board Myrinet network cards. This allowing data copy to be performed in a non-blocking mode, i.e. CPU activities are not suspended while checkpointing is in progress. An analytical model for non-blocking checkpointing has been also developed to determine a cost effective re-synchronization semantic between CPU and DMA activities. Actually, re-synchronization is needed to maintain data consistency when DMA is accessing the same memory area to be update by the CPU while processing simulation events.

Another problem we have addressed is the scheduling of multiple simulation processes hosted by the same machine, which has strong impact on the amount of causality violations. In this context, we have presented a general framework for the scheduling problem,

which constituted the basis for the development of performance effective scheduling algorithms. One of such algorithms, tailored for applications with high variance of the event granularity has been also presented.

We have also addressed the issue of tailoring optimism to proper simulation model execution dynamics, to reduce the likelihood of causality violations for the specific parallel execution. In this context we have presented an algorithm that controls the level of optimism depending on output data from a reduction system that provides each simulation process with a "near perfect" snapshot of relevant synchronization information related to neighbour processes in the communication graph of the application.

Finally, have 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.

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. Efficiency in the parallel execution is achieved thorugh an application level message aggregation technique, overlying the MPI layer, that collects application messages destined to the same machine, and delivers them using a single MPI message. This is mandatory since graph rewriting derived from the application of DVR is a fine grain task. A scheduling algorithm to determine a well siuted sequence of edge compositions in order to increase the effectiveness of aggregation has been also embedded within PELCR.

Interconnection networks An interconnection network can be the performance bottleneck of massively parallel systems, i.e. without adequate communication bandwidth, machines might be forced to wait for message arrivals, and system performance degradation will occur. This problem can be overcome by improving the network performance through appropriate message routing techniques. In this context we have presented an analytical model for the message delivery delay of a recent switching technique, namely wormhole, combined with the PAR (Planar Adaptive Routing) strategy. While developing the model, particular attention was posed on binary toroidal topologies, which have been proven to be useful for general purpose processing.

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 focuses on the design of middle-

ware services enabling the implementation of non-functional requirements such as high availability and fault tolerance.

IRL. In particular, we investigated three-tier architectures for software replication, which turn out to be a viable mean to achieve fault tolerance of a service whose replicas are deployed on a wide area network. We showed how to design middleware services that exploit a three-tier architecture to implement replication protocols that enforce a strong consistency criterion. Enforcing strong consistency is particularly effective to provide clients with the illusion of interacting with non-replicated objects, i.e. to implement *transparent* replication. 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.

The Common Object Request Broker Architecture (CORBA) is an established standard for object-oriented distributed applications used in many contexts where heterogeneous technologies have to coexist and interoperate through a computer network. Until now CORBA paid little attention on providing tools for building reliable distributed applications which could take advantage from the distributed nature of the platform. As a consequence, IRL is one of the few platforms that implements the recent Fault-tolerant CORBA standard.

Portable Interceptors. Object Management Group (OMG, the organization that supervises the CORBA standard) has recently introduced also the notion of CORBA portable interceptors. The aim of CORBA interceptors is to enable developers to extend the quite static semantic of a CORBA remote object invocation in a transparent, flexible and portable way. This is achieved through the specification of an interception layer logically interposed between a client and a server object. Operationally, the client and the server have hooks to customizable interceptors that can cooperate to offer ad-hoc functionalities. This separation of concerns favors reuse and frees CORBA applications from handling such functionalities explicitly. In this context, we presented some practical lessons learned from programming CORBA interceptors and an extensive performances study, showing which tasks can be actually demanded to interceptors for enhancing CORBA applications and the cost of adopting interceptors to implement such tasks.

Middleware for Egovernment. The spreading of network technologies and the emergence of Internet allows the development of new interaction business paradigms, commonly referred to as e-Business or e-Commerce. Although this new business paradigm has initially emerged in the commerce context, indeed there are other contexts: specifically, some important initiatives for the definition of what is referred to as e-Government are undertaken in many countries. A possible solution to reach the aim of e-Government consists at defining and designing a common framework based on component-based middleware technologies.

Dynamic Networks This research topic focuses on network of computers with systematic topological change. The topology can either be triggered by a physical change in the network or by a middleware layer that runs on top of an existing fixed network.

Mobile Ad Hoc Networks Mobile Ad Hoc Networks (MANETs) are self-organizing networks composed by many wireless portable computers with a short transmission range. Nodes of a MANET do move while communicating, giving rise to a time varying network topology. Routing is one of the main challenge in a mobile network, since each node acts as a router. Our aim is to study routing protocols for mobile networks that are able to efficiently track topology changes and thus are able to deliver all messages sent through the network. We also consider the problem of designing basic services (as distributed mutual exclusion) suitable to cope directly with such topological changes.

Overlay Networks Overlay networks are built on top of an existing networking infrastructure such as the Internet, using only a subset of the available network links and nodes. An overlay network link may consist of many actual links in the underlying network. We consider overlay networks with time varying links whose creation and deletion expresses a self-reconfiguration capability of adapting both to network conditions and to application requirements. The first direction in this study is exploiting dynamic networks in content-based publish/subscribe communication paradigm to achieve efficient distribution topology.

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3.1.5 Programming Languages and Methodologies

We work on

1. development of methodological and applicative respects of the *Open and Distance Learning* model.

2. the principles of object-oriented programming languages and their applications in distributed (object-oriented) programming;

3. modeling an inferential engine based on an axiomatization of the map algebra;

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

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

Open and Distance Learning We work on the configuration of courses, tailored on the didactic needs of the single learner [2, 1].

We participate and have participated in interesting EU and multinational projects: after the experience with the Socrates Project no 56544-CP-1-98-1-NO-ODL-ODL *Euro-Competence*, we have started a new collaboration with our european partners in a project on *Competence Development in Internationally Oriented Companies* (*CIOC*, funded by the NFU (Norwegian State Institution for Distance Education, project n. 18, 2000-2002), with participants from TEI Thessaloniki from Greece, DIS - La Sapienza from Italy, NITOL, TISIP Trondheim and Siemens Metering from Norway, Siemens from Switzerland, University of Greenwich from United Kingdom [4]. Then, recently, a new EU project is being carried on: *mENU* (model for a European Networked University for e-learning, elearning project n.2002–0510/001–001–EDU–ELEARN, `http://www.hsh.no/menu/`, [3]).

Distributed object-oriented programming Being interested in inheritance in object-oriented programming, we have started an activity on the application of inheritance into distributed object-oriented programming environments. This activity has led to the definition of a scheme for supporting *distributed inheritance* in object-oriented programming. Our concern is the application of object-oriented principles in distributed computing. In particular we focus on the use of the inheritance mechanism for the definition of class hierarchies distributed through a set of computing sites (communicating via internet or an intranet) The activity on this subject has been conducted so far through development of *Laurea* thesis, not reported here.

Map calculus We have continued our activity in modeling an inferential engine based on an axiomatization of the map algebra. This inferential engine is modeled using the predicate logic formalism supported by an existent theorem prover (Otter). Moreover we

are investigating on the realization of our approach by means of several other theorem prover that are directly defined for use in algebraic logic (such as Libra, or RALF).

Submitted papers, technical reports and others

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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 modeling of metabolic systems and analysis of brain potentials related to motor control.

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

Group members Alessandro Bertuzzi (IASI-CNR), Alberto Gandolfi (IASI-CNR), Geltrude Mingrone*, Aldo Virgilio Greco* (*Istituto di Clinica Medica-Policlinico A. Gemelli Università Cattolica del Sacro Cuore-Roma) Fabio Babiloni$^+$, Claudio Babiloni$^+$, Febo Cincotti$^+$, Filippo Carducci$^+$ ($^+$Istituto di Fisiologia Umana, Università di Roma "La Sapienza"), Serenella Salinari.

Analysis and Modeling of Metabolic Systems In the context of this project, in the last year, the interest was focused on the analysis of body composition using non-invasive non-expensive techniques as bioimpedance analysis (BIA). As a first step, the lower limb was selected as the study site for its simple geometry and tissue composition. Moreover the muscle mass of limbs accounts for an estimated 75 %-80% of total body muscle mass. The profile of the muscle cross-sectional areas along the limb was evaluated from multiple BIA measurements by the utilization of a simple mathematical model. The values of the estimated muscle areas resulted in good agreement with those computed from MRI images. Next, the study was extended to the evaluation of the lower limb muscular mass of lean and obese subjects using a reduced number of measurement points. In this case the evaluations of the muscular mass was compared with the values obtained by the DEXA

technique. The results confirmed the possibility of using bioimpedance analysis for the estimation of thelimb muscular content and profile.

Analysis of Brain Potential related to Motor Control In the last year, the research activity involved problems connected with the study and the implementation of EEG-based Brain Computer Interfaces. In this context, methods for the pre-processing, processing and classification of EEG changes in power spectra, during a task concerning the imagination of a repetitive movement of a finger were developed. An experimental device for cognitive bio-feedback was also developed. More recently, methods based on a modelling approach were tested, in order to investigate on the functional connectivity of the cortical sources. This approach seems to be useful in evidencing abnormalities in cortical sensorimotor processing of patients affected by mild to moderate Alzheimer disease.

Journals

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3.2.2 Hybrid Systems

The research activities of the group cover different topics ranging from the integration of hard computing and soft computing techniques, nonlinear digital and switching systems,

positive systems to non conventional approaches to modelling, analysis, identification and control of dynamical systems from different areas.

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

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

International collaborations include: the Laboratoire des Signaux et Systèmes, CNRS, Ecole Superieure d'Electricité, Gif-sur-Yvette, Department of Electrical Engineering, University of L'Aquila, PARADES Research Lab.

Group members Alessandro De Carli, Claudio Gori Giorgi, Salvatore Monaco, Lorenzo Farina, Luca Benvenuti, Claudia Califano, Paolo Di Giamberardino, Raffaella Mattone (Lecturer - Part Time), Leonardo Daga (Lecturer), Francesco Lagala (Lecturer), Roberto Ronchini (Lecturer), Amit Brandes.

Emergent and innovative control strategies The research activity involved problems connected to the design of intelligent controller at higher level in the organization of Industrial automation. Incipient fault detection and intelligent supervisory has been applied to a mechanical system in order to improve its productivity and efficiency. In order to attract users to apply intelligent control, a set a tutorial paper has been prepared and diffused in large diffusion technical journals.

The intelligent control of complex plants requires the application and adaptation of different innovative methodologies typical of the soft computing. Another example of application has been developed dedicated to the intelligent management of the fuel gas network in refinery. A quite similar approach has been followed to the design of the control strategy for a complex packaging machine. The aim of the research is to indicate the innovative procedures for the design of advanced controller.

Most relevant publication in this area are: [14, 13, 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. The problems of noninteractive control with stability and feedback stabilization of nonlinear dynamics which exhibit chaotic behavior have been studied and solved in this context.

Most relevant publications in the area of discrete-time systems are: [4, 21, 7, 12].

Digital 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. Moreover, the design of hybrid controllers and the verification of several closed–loop performances has been studied for a detailed, cycle-accurate hybrid model of an automotive engine. The hybrid control approach used is based on a two-step process. In the first step, a continuous approximation of the hybrid problem is solved exactly and then, the control law so obtained is adjusted to satisfy the constraints imposed by the hybrid model.

Most relevant publication in the area of digital control is: [18].

Most relevant publications in the area of automotive control are: [20, 19, 8, 9].

Positive systems Positive systems are characterized by the specific property that the state and output variables remain nonnegative whatever the positive input sequence might be. These systems are quite common in applications where input, output and state variables represent positive quantities such as populations, consumption of goods, densities of chemical species and so on. During the year 2002, the work on this topic has focused on the regulation problem for state constrained systems, on exploring the relationships between positive and compartmental systems, and on the identification problem for positive systems, in fact, the information on positivity of input/state/output variables stem directly from the intrinsic nature of the problem, so that it is a-priori available. It has been presented new methodologies and applications for constraining within positive systems, the model to be identified.

Most relevant publications in this area are: : [1, 2, 3, 6, 16, 17, 10, 11].

Journals

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Articles in books

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3.2.3 Identification and Optimal Control

The scientific interest of the group lies in two main areas: modeling, identification and filtering of discontinuous signals and dynamical systems, deterministic and stochastic optimal control.
In the first area 2D signals are dealt with, focusing on the problem of image reconstruction and discontinuities detection from blurred and noisy data.
In the second area the application of filtering and optimization tecniques to traffic control in a wireless communication network is considered (part of this latter research was developed in the framework of the SATIP6 and SAILOR projects belonging to the Information Society and Technology programme, sponsored by the 5th Framework EU programme).

Group members Carlo Bruni, Francesco Delli Priscoli, Daniela Iacoviello, Giorgio Koch (Research Contractor), Matteo Lucchetti, Caterina Scoglio (Georgia Institute of Technology), Stefania Vergari.

Images reconstruction and filtering These problems have received a great deal of attention due to their importance in many scientific fields (biomedicine, geophysics, communications, etc), and are by no mean trivial, since real data are usually degraded by

blurring effect and additive noise. The images reconstruction has been formulated as an optimal estimation problem, taking into account the degradation effects (blurring and additive noise) that usually characterize the experimental data. Particular attention has been devoted to the problem of edge detection, which, from a mathematical point of view, corresponds to the identification of discontinuities in 2D degraded signals. Theoretical results have been given about existence, uniqueness and robustnessof the optimal solution and efficient numerical procedures have been proposed.

More recently the problem of analyzing images time sequences has been considered, assuming that the represented objects can rigidly move. The possibility of recovering the image content as well as the motion parameters has been studied, by exploiting suitable non linear filtering methodologies.

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

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.

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

Finally, attention has been dedicated to an artificial life algorithm as a tool for continuous optimisation. This procedure can be of interest in optimal control problem of complex dynamical systems in the presence of unpredictable and unmodeled disturbances. Some first interesting results have been achieved by applying the above algorithm to the control of simulated complex systems.

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3.2.4 Nonlinear Systems

The research group of Nonlinear Systems is involved in the development of the following topics: resource management in wireless systems, nonlinear regulation with adaptive internal model, stabilization of nonlinear systems, fault detection for nonlinear systems, analysis and control of switched nonlinear systems, stochastic stabilization of nonlinear systems.

Group members Stefano Battilotti, Paolo Conforto, Francesco Delli Priscoli, Claudio De Persis, Alberto Isidori, Antonio Pietrabissa, Dario Pompili.

Resource Management in wireless systems This research is mainly performed in the framework of seven European Union (fifth framework programme) research projects (named WIND-FLEX, GEOCAST, VIRTUOUS, SUITED, NATASHA, SATIP6 and SAILOR) entailing a net financing for DIS for the year 2002 of about 500.000 Euro. These projects, performed within consortia involving major european universities/research centers, manufactures and operators (about 10 companies per project), aim at the research, the design, the development and the standardisation of third generation (UMTS at 2 Mbps) and fourth generation (wireless broadband system at 100 Mbps) wireless terrestrial and satellite systems. The DIS scientific responsible for all the above-mentioned projects is Francesco Delli Priscoli. In 2002, the DIS role in the framework of these projects mainly concerns the research, the design and the simulation (by using either the OPNET tool, or C++) and the implementation (Linux real-time) of the following Resource Management procedures: (i) Connection Admission Control (CAC) procedures which control the admittance of new connections in the wireless network with the aim of avoiding network over-loading. In case a new connection is admitted, the CAC procedures negotiate a Quality of Service (QoS) contract specifying the QoS guarantees (in terms of minimum bit rate, maximum packet transfer delay, maximum packet delay jitter and maximum packet loss); (ii) Congestion control procedures which dynamically control the admittance in the wireless network of the traffic emitted by the sources relevant to the connections in progress (i.e. the ones admitted by the CAC procedures) with the contrasting aims of maximizing the admitted traffic and of respecting the QoS guarantees for such traffic; (iii) Scheduling

procedures which dynamically assign the air interface capacity resources (e.g. time slots) to the packets admitted (by the congestion control procedures) into the wireless network with the aim of maximizing the exploitation of the air interface capacity, while avoiding too long queuing delays, (iv) procedures for the optimal determination of the UMTS cellular layout in such a way as to minimize the number of Base Station with the constraint of serving a given offered traffic distributed over a given geographical area. During 2002 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 2002, about 30 work contracts have been granted on these activities to young engineers and about 50 theses have been discussed on these issues. In 2002 plenty of innovative contributions have been produced by properly combining competences and methodologies relevant to the following areas (among brackets the DIS people actively involved are reported): control (Bruni, Isidori, Delli Priscoli, Koch, Pietrabissa, Vergari, Pompili, Conforto), information (Marchetti, Becchetti, Inzerilli), operations research (Sassano, Mannino, Lombardi, Del Sorbo, Parrello) and telecommunication (Cusani, Dini, Razzano). These contributions are reported in about 25 papers submitted in 2002 to major international conferences and reviews, a plenty of Deliverables relevant to the above-mentioned projects (technical reports, C++ programs, software OPNET models and hardware realisations) and the above-mentioned theses.

Nonlinear regulation with adaptive internal model In paper [3] we address the design of an autopilot for the autonomous landing of a VTOL vehicle on a ship whose deck oscillates in the vertical direction due to high sea states. The deck motion is modeled as the superposition of a fixed number of sinusoidal functions of time, of unknown frequency, amplitude and phase. We design an internal-model based error-feedback dynamic regulator that is robust with respect to uncertainties on the mechanical parameters that characterize the model and secures global convergence. The stabilization method is based, in part, of the results of [4].

Stabilization of nonlinear systems Papers [5] and [6] deal with open issues on stabilization of nonlinear systems. It is well-known that, in a globally minimum phase nonlinear system, high-gain output feedback can be used to steer trajectories from any arbitrarily large compact set to any arbitrary small neighborhood of the origin. The question, however, of describing the asymptotic behavior of the closed loop system so obtained inside this small neighborhood has remained open. In paper [5] we address this question. In particular, we describe explicitly, in terms of properties of the open-loop system, the structure of certain compact attractors that might exists and determine their stability in the sense of Lyapunov. In paper [6], an adaptive dynamical output feedback law is introduced for a class of nonlinear non-minimum phase systems to achieve practical stabilisation, that means the output will asymptotically tend to a pre-specified neighbourhood of the origin. In case of linear systems, adaptive stabilisation is proven.

Fault detection for nonlinear systems The research summarized in the paper [7] has focused on the problem of detecting faults in the presence of measurement noise. Building up on the geometric approach developed in previous works, it is shown how to design a detection filter such that the effect of the measurement noise on the diagnostic signal is attenuated while the influence of the fault on the diagnostic signal is preserved. The result is achieved by formulating the fault detection problem in a game-theoretic setting in which noise and fault are viewed as antagonistic players.

Analysis and control of switched nonlinear systems Paper [21] deals with the supervisory control of very poorly modeled linear systems in the presence of input constraints. It is shown how to design a supervisory control architecture which is capable of regulating to zero the state of the uncertain system. This can be done by adopting the so-called hysteresis switching logic, whose functioning guarantees the switching to stop in finite time, a situation which is unlikely to occur in more demanding applications, such as those for which uncertainties are time-varying. In order to deal with these critical scenarios, a new switching logic has been introduced, namely the state-dependent dwell-time switching logic. The properties of switched systems with such a switching logic have been analyzed in [22, 47]. The application to the supervisory control of nonlinear highly uncertain systems possibly in the presence of input constraints has been considered in [48, 23]. Paper [24] shows the possibility to extend the proposed scheme to the supervision of model predictive controllers. The work has been carried out in collaboration with A.S. Morse (Yale University, New Haven, CT), R. De Santis (Rome, Italy), A. Jadbabaie (University of Pennsylvania, Philadelphia, PA), T.-W. Yoon (Korea University, Seoul, Korea).

Stochastic stabilization of nonlinear systems In [8] we have considered nonlinear dynamical systems, consisting of a linear nominal part perturbed by model uncertainties, nonlinearities and both additive and multiplicative random noise, modeled as a Wiener process. In particular, we have studied the problem of finding suitable measurement feedback control laws such that the resulting closed-loop system is stable in some probabilistic sense. To this aim, we have introduced a new notion of stabilization in probability, which is the natural counterpart of the classical concept of regional stabilization for deterministic nonlinear dynamical systems and stands as an intermediate notion between local and global stabilization in probability. This notion requires that, given a target set, a trajectory, starting from some compact region of the state space containing the target, remains forever inside some larger compact set eventually enters any given neighbourhood of the target in finite time and remains thereinafter, all these events being guaranteed with some probability. We also found Lyapunov-based sufficient condition for achieving stability in probability and a separation result which splits the control design into a state feedback problem and a filtering problem. Finally, in [8] we pointed out constructive procedures for solving the state feedback and filtering problem with arbitrarily large region of attraction and arbitrarily small target for a wide class of nonlinear systems, which at least include feedback linearizable systems. The generality of the result is promising for applications to other classes of stochastic nonlinear systems. In the deterministic case, our results

recover classical output feedback stabilization results. In [49] and following [8] we approximated the linear nominal part of a nonlinear stochastic dynamical system through neural networks and implemented on-line adaptation of the parameters characterizing these networks.

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3.2.5 Robotics

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

The DIS Robotics Laboratory was established in 1987. The following robotic equipment is available: the 6R-dof robot *Zebra-ZERO* (by IMI), with a 6D-force/torque sensor; the 8R-dof redundant manipulator *DEXTER* (by Scienzia Machinale), with an additional 2-dof dextrous gripper; the two-link underactuated arm *Pendubot* (by Quanser), equipped with a webcam for telelaboratory; two mobile robots with two-wheel differentially-driven kinematics: *SuperMARIO* (developed in our Laboratory), with an external color CCD camera and a Matrox frame grabber, and *Magellan Pro* (by IRobot), with an ultrasonic-infrared sensor suite and an on-board pan-tilt camera. The Laboratory is on the web at `http://labrob.ing.uniroma1.it`.

Active grants include the MURST 2000 *MISTRAL* and the FIRB 2002 *TIGER* national projects, as well as the participation to the MIUR 2002 *MATRICS* national project and to the IST-2001 *IFATIS* European project. During the last years we have cooperated with several foreign institutions, in particular: the *LAAS-CNRS* in Toulouse, the *IPA-Fraunhofer* in Stuttgart, and the Department of Computer Science at the *Johns Hopkins University* in Baltimore, the *ENSTA* in Paris. There are also local collaborations with DIA at the *Università di Roma Tre* and with DMA in our same School of Engineering.

Group members Alessandro Bettini, Alessandro De Luca, Stefano Iannitti, Raffaella Mattone, Giuseppe Oriolo, Marilena Vendittelli.

Modeling and Control of Flexible Robots Joint elasticity is the main vibrational disturbance in (otherwise rigid) industrial robots whenever harmonic drives, belts, or long shafts are used as transmission elements. For robots with elastic joints, we have derived complete dynamic models and shown that a dynamic state feedback controller allows to obtain exact linearization and input-output decoupling. An algorithm for uniform scaling of trajectories under torque constraints is presented in [6], generalizing the results of the rigid case. The adoption of lightweight manipulators to replace slow and massive robots may prove very useful for large structures. Lightness or very slender mechanical design usually implies the presence of link flexibility, with associated control difficulties (e.g., non-minimum phase of the end-effector position output). We have provided a solution to the rest-to-rest motion problem in given time for a general single flexible link and verified the method experimentally on the flexible arm of DMA [5]. The approach is being extended also to the nonlinear case, in particular to the two-link FLEXARM available at DIA.

Underactuated Robots Mechanisms that can perform complex tasks with a small number of actuators/sensors are desirable in view of their reduced cost and weight. Underactuated mechanical systems, i.e., with less command inputs than generalized coordinates, pose very hard control problems. A survey of control properties and of planning and feedback control techniques is provided in [15]. A general controllability analysis (in particular, a test for STLC) has been developed for planar robots with one passive joint [7]. For robots with the first two actuated joints (of any type) and a rotational passive third joint, we proposed a method for trajectory planning between two equilibrium states and an associated trajectory tracking controller, based on dynamic feedback linearization. This approach works with or without gravity and can be extended to nR planar robots having the last joint passive [1] or even to the case when the last $n-2$ joints are passive, under a special mechanical condition on the location of the centers of percussion of the links [8, 17].

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. Even if instantaneous velocities are constrained, the configuration space may be fully accessible by suitable maneuvers. For the plate-ball manipulation system (moving a rolling sphere on a plane using only the two $x-y$ commands of a top plate), an example of nonholonomic system that does not admit a chained-form representation, we have proposed an iterative steering technique, based on the use of a nilpotent approximation of the kinematic equations, that achieves stabilization to a desired configuration in a robust way (i.e., rejecting small non-persistent disturbances) and with an exponential rate of convergence [19]. Inspired by another nonholonomic system that does not admit a chained-form representation (namely, the general 2-trailer mobile robot), we have also performed a more theoretical study concerning the use of nilpotent approximations for systems with singularities [20]. At these

points, where the growth vector changes, homogeneous nilpotent approximations are not continuous with respect to the approximation point. The geometric counterpart of this is the non-uniformity of the sub-Riemannian distance estimate based on the classical Ball-Box Theorem. With reference to a class of driftless systems, which includes the general 2-trailer system, we show how to build a nonhomogeneous nilpotent approximation whose vector fields vary continuously around singular points, proving also that the associated privileged coordinates provide a uniform estimate of the distance. On the experimental side, we have compared several nonlinear feedback controllers on the *SuperMARIO* mobile robot using encoder measurements; in particular, dynamic feedback linearization is a viable option for trajectory tracking and parking tasks [2]. We have also used visual feedback (obtained from a camera fixed in the environment) and compared the control performance with and without this eteroceptive sensing [9]. The presence of obstacles has been considered in [10], where a collision-free path is planned using the A* algorithm with different nonholonomic-based heuristics. In addition, the vision system is used both for environment acquisition and for motion feedback control.

Motion Planning using Probabilistic Techniques A new direction of research for our group is the use of probabilistic techniques for motion planning among obstacles. In [13] we present a resolution-adaptive strategy aimed at increasing the efficiency of such techniques. The method represents a modification of the RRT-Connect planner, with the objective of reducing the computational load by performing less collision checks in problems involving many dof's and complex environments. The problem of planning collision-free motions for a redundant robot whose end-effector must travel along a given path is addressed in [12]. Complete solution algorithms are presented based on a simple mechanism for generating random samples of the configuration space that are compatible with the end-effector path constraint.

Legged Robots This research activity deals with planning and controlling the motion of legged robots. In particular, a low-energy biped locomotion strategy has been proposed for the Sony ERS-210, the 'Aibo' dog designed only for quadruped gaits, fully exploiting the dynamics in the double support phase [14].

Fault Detection and Isolation in Robots Robots may experience different types of sensor/actuator failures during operation, causing a degradation of performance or a complete loss of control [18]. In the problem of fault detection and isolation (FDI), detection consists in generating on-line diagnostic signals (residuals) in correspondence to potential faults that may affect the system; fault identification occurs when a residual allows discriminating a specific fault from other faults or disturbances. We have developed a new method, based on the use of generalized momenta, for detecting and isolating a general class of actuator faults in robot manipulators [16]. The method does not need acceleration estimates nor simulation of the nominal robot dynamics.

Automation and Service Robotics Automation of different off-factory activities goes under the broad name of service robotics. A perspective on future application trends in service robotics is provided in [3]. An example is given by the Steady-Hand Robot system developed at the Johns Hopkins University for assistance in surgical operations. Vision and force sensing are integrated with virtual fixtures in order to help the surgeon in driving a hand-held tool during fine motion. Virtual fixtures have been defined and tested experimentally for different motion tasks (positioning —both at micro and macro scales, tracking, avoidance of obstacles), in association with a human-robot cooperative control scheme [4]. For process automation in unstructured environments, efficient clustering methods are often required when a continuous and large flow of data must be classified, e.g., in motion-based scene segmentation for video surveillance. A novel on-line competitive clustering algorithm has been developed in [11].

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3.3 Management Science

3.3.1 Combinatorial Optimization

The research activity of the Combinatorial Optimization Group is mostly devoted to theoretical and computational aspects related to i) design of telecommunication networks and ii) automated data correcting. The group is currently cooperating with Maastrich University, Konrad Zuse Zentrum für Informationstechnik Berlin, Universit di Roma Tor Vergata and Università dell'Aquila. Also, it is cooperating with the Italian Public Authority for Telecommunication and with ISTAT. It is currently involved in several research project, including MURST "Optimization Models and Algorithms for Design and Management of Telecommunication Networks", and the European Projects VIRTUOUS, FUTURE, SAILOR, WINDFLEX and COST279.

Group members Renato Bruni, Silvia Canale, Carlo Mannino, Sara Mattia, Emiliano Parrello, Antonio Sassano.

Antenna positioning and frequency assignment in wireless networks Radio and television broadcasting, cellular mobile telecommunication systems, satellite-based cellular networks and many other important civil and military applications require a huge number of antennas to be located on the territory so as to maximize the coverage or some kind of measure of the service. This problem was addressed in [7], where a two-phase heuristic procedure is discussed for digital and analog broadcasting.

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. New models are investigated and new solution techniques are proposed. Specifically, a branch-and-cut algorithm for the minimum span problem based on an exact formulation which extends the well known hamiltonian path relaxation for (FAP) is presented in [2] Finally, in [6] it is proposed a dynamic programming procedure to solve FAP in GSM networks.

Network Design The problem of designing good quality and low cost networks arises in several real-life applications like transportation and telecommunication ones. One of the most important problems of this kind is the Network Loading Problem (NLP). The problem is the following: given a set of traffic demands to be routed between nodes of the network, the goal is to choose capacities for the edges of the graph such that all demands can be shipped simultaneously, minimizing the capacity installation cost. More than one mathematical formulation is known for the NLP. The so called capacity formulation is studied, and a banch-and-cut approach, based on the separation of metric inequalities, is proposed to solve the problem.

Satisfiability, Data Mining, Image Reconstruction The Satisfiability of a CNF propositional formula is a central problem for a number of areas in information processing and computation. In the case of unsatisfiable CNF formulae, the selection of a minimal unsatisfiable subformula (MUS) within a given CNF is a very relevant problem. Such problem is approached by using a procedure based on Farkas' lemma, thus solving a linear programming problem. A study of the cases when this can guarantee an exact solution for the MUS selection problem is presented in [3].

Data correctness is a crucial aspect of data quality, and, in practical cases, it results a computationally demanding problem. Such problems are generally tackled by using a set of rules. By using a binary encoding for both rules and data, and by adding additional integer variables, ILP models of the above problems are proposed and solved in [4, 5]. The proposed models have strong computational advantages on other existing approaches, and results on real-world applications are very satisfactory.

In many real-world applications, image reconstruction from blurred noisy data is required. By estimating the jumps between adjacent pixels during a preprocessing phase, a Bayesian approach converting the reconstruction problem into an optimization problem is proposed in [1].

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3.3.2 Nonlinear Optimization

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

The Nonlinear Optimization group is currently cooperating with: Istituto di Analisi dei Sistemi ed Informatica IASI-CNR; Dipartimento di Ingegneria Elettrica, Università di L'Aquila; Dipartimento di Tecnologie Biomediche, Università di L'Aquila.

During 2002, the Nonlinear Optimization group has been involved in several research projects including the following: ENEA/MURST (Sistemi di supporto alla progettazione con reti neurali di sistemi di combustione), CNR/MURST (Ottimizzazione di apparati "dedicati" di risonanza magnetica per uso clinico), CNR/MURST (Applicazione di metodi di ottimizzazione per la progettazione di motori elettrici industriali), COFIN/MURST (Algorithms for Complex System Optimization).

Group members Gianni Di Pillo, Francisco Facchinei, Giovanni Fasano, Luigi Grippo, Giampaolo Liuzzi, Stefano Lucidi, Laura Palagi, Veronica Piccialli, Massimo Roma, Cinzia Lazzari [IASI-CNR], 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, new globalization strategies for the Barzilai and Borwein method have been proposed based on suitable relaxation of the monotonicity requirements; in particular, a class of algorithms that combine nonmonotone watchdog techniques with nonmonotone linesearch rules has been defined and the global convergence of the scheme has been proved. The extensive computational study performed on many large dimensional unconstrained optimization problems showed the effectiveness of this approach; in fact the resulting algorithm appears comparable with more sophisticated quasi-Newton methods, outperforming the monotone methods in tackling difficult and ill–conditioned problems [2].

Moreover, planar conjugate gradient algorithms have been studied and their use for solving large scale unconstrained problems has been investigated. Both the theoretical aspects and the computational ones have been of interest. In particular, some new classes of planar conjugate gradient algorithms have been defined and embedded within truncated Newton method frameworks. Furthermore, an extensive numerical investigation has been performed showing the efficiency of the proposed planar conjugate gradient schemes in solving nonconvex large scale problems [6, 7, 8].

Furthermore, the formulation of an effective preconditioning strategy which enables to improve the behaviour of truncated Newton methods in tackling large scale problems has been considered. In particular, a diagonal preconditioner which carries out a dynamic scaling strategy has been defined and numerically tested [13].

Constrained Optimization Problems with both general constraints and constraints with a particular structure have been addressed. In particular, the attention has been focused on truncated Newton-type scheme for solving large scale problems. As regards general constraints, the use of truncated Newton direction has been investigated in the framework of exact augmented Lagrangian functions for nonlinear programming. In fact, a primal-dual algorithm for the solution of general nonlinear programming problems has been proposed where the core of the method is an efficient local algorithm relying on a truncated scheme for the computation of the search direction and thus well–suited for large scale problems. As concerns the solution of minimization problems with simple bounds a truncated Newton–type method has been considered, too. The algorithm proposed is based on a simple, smooth unconstrained reformulation of the bound constrained problem. The global convergence of a general scheme requiring the approximate solution of a single linear system at each iteration has been proved and the superlinear convergence rate has been established without requiring the strict complementarity assumption. The numerical experiments performed showed that the algorithm is efficient and competitive with other existing codes [5, 1].

Methods for large and dense problems with a special structure of the constraints, namely bounds on the variables and one linear constraint have been considered. Problems of this type arise in training Support Vector Machines (SVM). SVM problem has the additional property of having a convex quadratic objective function. Due to the dimensionality, traditional methods cannot be applied, so that decomposition algorithms have been proposed with different selection rules for the construction of the subproblems. The use of a proximal point term modification of the objective function, enables to prove new convergence results of existing schemes and also to define new methods [10, 12].

Finally, it has been considered a particular class of nonlinear mixed variable optimization problems where the structure and the number of variables of the problem depend on the values of some discrete variables and where no convexity assumption is satisfied. A general algorithm model for the solution of this class of problems has been defined and minimal requirements for ensuring the global converge have been identified. A particular derivative free algorithm for solving the particular case where the continuous variables are linearly constrained and the derivative information is not available has been proposed [11].

A survey on nonlinear programming method [3] has been published in the Handbook of Applied Optimization (HAO was runner up (honorable mention) for the Associate of American Publishers' (AAP) Outstanding Professional and Scholarly Titles of 2002 in the computer science category).

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, the following applications have been considered: the design of electrical industrial motors and the design and optimization of dedicated magnets for magnetic resonance imaging. As regards industrial motors design, in order to tackle all the conflicting goals that define the problem, the use of global multi-objective optimization techniques has been investigated showing that the approach is viable. As concerns the magnetic resonance device, the design of small low–cost, low–field multipolar magnets

for magnetic resonance imaging with a high field uniformity has been considered. The realization of such magnetic resonance apparatuses would greatly benefit the diagnosis, prognosis and the therapy of many pathologies. By introducing appropriate variables, the considered design problem is converted into a global optimization one and this latter problem is solved by means of an improved version of a controlled random search algorithm [4, 9].

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3.3.3 Industrial Economics

This group mainly investigates the theoretical explanations and empirical implications of three interrelated phenomena: (i) technological innovation, (ii) strategic behavior of Multinational Enterprises (MNE) in R&D intensive industries, (iii) national policies and globalization. The main research topics are connected with the analysis of foreign direct investment (FDI) and R&D in oligopolistic industries. Also aspects of regulation and competition policy are dealt with. We have participated to the EU network on "The Relationships between Technological Strategies of Multinational Companies and the National Systems of Innovation" (5th Framework Programme) and to the project on "R&D investment in an international context" financed by the National Research Council. We have been collaborating with several European Universities, such as Leuven Katholieke Universiteit, Belgium; University of Reading, UK; Universitad Complutense de Madrid, Spain.

Group members Maria Luisa Petit, Francesca Sanna–Randaccio, Roberta Sestini.

R&D Competition and Foreign Direct Investment This line of research has analyzed the effects of geographically localized spillovers on the internationalization decisions by firms. By using dynamic game methods, we have investigated how differences in the transmission of knowledge due to geographical vicinity may affect the levels of effective R&D and innovation for each firm and each country. In particular we assumed that multinationals and exporters operate with different degrees of technological spillovers [3].

National and Multilateral Rules on FDI and Globalization Research in this area has aimed at clarifying in which setting foreign direct investment from abroad has a positive impact on the receiving country, leading to an increase in the productivity of the recipient sector and thus having a positive effect on growth [1]. Moreover, it has been

highlighted why new multilateral rules on foreign direct investment are necessary, and why such rules should be the result of a Multilateral Agreement on Investment (MAI) within the ongoing WTO Round (the so-called Development Round) [9].

R&D Internationalization This 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 [6]. The impact of R&D internationalization on host countries is also analyzed [10].

Regulation and Competition Policy This line of research investigates, on one hand, alternative regulatory policies that affect the viability of pricing discriminatory behavior by a regulated incumbent firm. We studied how two different regulatory schemes - Relative and Absolute - might influence pricing decisions, the entry decision by potential competitors and social welfare. While the effect on entry is clear-cut, the welfare ranking between the two rules is ambiguous [2],[7]. Another line of research has studied the functioning of a market for an experience good. Given that informational problems bring about inefficiencies, possible policies able to improve upon second-best equilibria are compared, with a special focus on the role of self-regulatory organizations [8],[5].

Unbalanced growth models and sectoral employment performance Research activity in this area has investigated the reasons behind the US superior performance in job creation in the service sector with respect to EU countries. We concluded, carrying out both theoretical and empirical analysis, that employment growth in the services is not in itself an appropriate policy objective, due to a long-term tradeoff between productivity and employment growth, and that wage differentiation may just delay asymptotic stagnation [4].

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3.3.4 Industrial Organization and Management

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

- regulation of vertical structures;
- transport networks' management;
- information and communication industries;
- auction-based market mechanisms;
- multicriteria decision making and corporate strategy.

We have collaborated with CREDIOP in the working group supporting the Ministry of Communications for the assignment of Wireless Local Loop licenses in Italy.

Group members Alessandro Avenali, Anna Bassanini, Domenico Laise, Claudio Leporelli, Giorgio Matteucci, Alberto Nastasi, Pier Luigi Piccari, Pierfrancesco Reverberi.

Regulation of vertical structures In this research area, our main focus is on the pharmaceutical industry. In particular, we investigate a rationale for parallel trade as an opportunistic behavior by an international wholesaler having private information about demands in two markets where a multinational operates. We formulate a screening game where the wholesaler signals on market sizes through selecting a contract from the menu proposed by the multinational. In this context, we study the influence of asymmetric information on profits and welfare [13]. Moreover, we analyze the scope for segmented regulation and its consequences on market efficiency [5].

Transportation networks' management We concentrate on the on-going deregulation process in the railroad sector. First, a market-based model for the decentralized allocation of network capacity is proposed ([1]). Then, the effects of the strategic interaction between infrastructure managers of different countries on international services are discussed by modelling the problem in a game-theoretic framework [8, 9]. Finally, we study the extent of the economies of scale and density for downstream transport operators by estimating their costs through a translog function [12].

Information and communication industries We analyze the role of information and communications technologies on the financial bubble blown up in the year 2000, highlighting the causal relationships and feedbacks between the evolution of the regulatory framework and industry structures on the one side, and the turbulence of financial markets, on the other. We argue that one of the most important real effects of the financial crisis concerns the slowing evolution toward market competition [4, 11]. Then, we study the residual role of regulation in the transition of the mobile sector to facility-based competition [3].

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 [2]. However, this type of auction requires dealing with hard optimization problems, that require specific solution techniques [6, 7].

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 [10].

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