Università di Roma "La Sapienza"

Dipartimento di Informatica e Sistemistica "Antonio Ruberti"

Research Report
2000

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Contents

1 Introduction

This report presents an overview of the research activity carried out in the Department of Computer and System Sciences "Antonio Ruberti" of the University of Rome "La Sapienza" during the year 2000.

The Department of Computer and System Sciences 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 researches, innovative applications and professional skills in the areas of information technology, automation and automatic control, operations research and management.

The academic staff of the Department is composed of 23 professors, 19 associate professors, 15 researchers. They provide education at the undergraduate and graduate levels to several programs of the School of Engineering of "La Sapienza", with main responsibility in the Engineering programs in Informatics, Automation, and Management.

The academic staff is divided in three main research groups, corresponding to three main research areas, and named:

- Computer Science

- System Science

- Management Science

The Department offers three doctoral degree programs, one in each research area.

The research activity of each group, together with a list of publications, is described in detail in Section 3.

2 General Information

2.1 Location

DIS is located on 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 48299218
    Operations Research Laboratory, Operations Research, Management
    Science and Industrial Economics 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 110 journals subscriptions are available.
The library is located at DIS-Eudossiana; information about office hours
and procedures can be found at `http://www.dis.uniroma1.it/resources.html`.

Research Laboratories

Computer Science Laboratory   The laboratory, located at DIS-Salaria,
is devoted to software development for various classes of systems and applications.

Operations Research Laboratory   The laboratory, located at DIS-Buonarroti, is devoted to the development of mathematical modeling and algorithms for the solution of mathematical programming problems.

Robotics Laboratory   The laboratory, located at DIS-Eudossiana, is devoted to the development and experimental validation of advanced planning and control techniques for industrial and service robots.

Systems and Control Laboratory   The laboratory, located at DIS-Eudossiana, is devoted to the development and experimental verification of new control strategies.

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

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

Associate Professors

Roberto Baldoni	Stefano Battilotti
Marco Cadoli	Mirella Casini Schaerf
Fabrizio d'Amore	Alberto De Santis
Francisco Facchinei	Lorenzo Farina
Domenico Laise	Leonardo Lanari
Umberto Nanni	Alberto Nastasi
Giuseppe Oriolo	Pier Luigi Piccari
Fiora Pirri	Serenella Salinari
Silvio Salza	Francesca Sanna Randaccio
Giuseppe Santucci	

Researchers

Anna Bassanini	Luca Benvenuti
Claudia Califano	Diego Calvanese
Giuseppe De Giacomo	Francesco Delli Priscoli
Paolo Giulio Franciosa	Paolo Di Giamberardino
Stefano Leonardi	Carlo Mannino
Laura Palagi	Francesco Quaglia
Pierfrancesco Reverberi	Massimo Roma
Marco Temperini	

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	Marco Di Bonifacio
Anna Paola Di Risio	Claudio Dollari
Giuseppe Filaci	Rinaldo Lori
Massimo Pacini	Paola Pacini
Antonio Sapori	Tiziana Toni

Auxiliary Services

Maria Carmina Mastrocola   Pia Bonanni   Antonio Simeoni

Library   Angelina De Salvo

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

2.4   Teaching

Laurea degrees   The teaching activity of DIS is mainly carried out within the engineering curricula of the information science area, i.e., Computer Engineering, Electronic Engineering and Telecommunications Engineering. In addition, many other curricula include courses offered by DIS.

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

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.

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, biosystems, modeling, identification, optimal control.

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.

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.

Computer Science Lab "Paolo Ercoli" for introductory courses.
About 150 stations are available for undergraduate teaching activities.
Person in charge: D. 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.
Persons in charge: R. Baldoni.
Location: Via Eudossiana 18, Roma.

2.5   Grants

In the following, we list the research contracts started in year 2000.

Contracts with the European Union

Contractor	Value (ML £)	Title	Project Leader
E.U.	484	Futura tecnologia degli algoritmi	Ausiello G.
E.U.	398	Multicast over geostationary EHF satellites	Delli Priscoli F.
E.U.	82,3	Optimization for managers: a tutorial	Facchinei F.
E.U.	371,8	Algorithmic methods for optimizing the railways in Europe	Marchetti Spaccamela A.
E.U.	17,4	Approximation and on-line algorithms	Marchetti Spaccamela A.
E.U.	495,567	Embodied Believable Agents	Schaerf M.
E.U.	56,151	Intelligent agent in multimodal speech system	Schaerf M.
E.U.	78,700	Technological strategies of multinational companies and national systems of innovation.	Sanna Randaccio F.

Contracts with Italian research Institutions

Contractor	Value (ML £)	Title	Project Leader
A.S.I.	120	Toolkit creazione di pianificatori interattivi e sistemi modulari intelligenti per la robotica spaziale.	Carlucci L.
A.S.I.	115	Sottosistemi Modulari Intelligenti per l'Automazione e la Robotica Spaziale	Monaco S.
A.S.I.	80	MAARS-2005	Monaco S.
C.N.R.	40	La gestione delle emergenze nelle organizzazioni complesse. Valutazione di Investimenti irreversibili in condizioni di incertezza nei servizi in rete	Nastasi A.
E.N.E.A.	30	Definizione di procedure gestionali ottimizzate per sistemi di trasporto collettivo	Sassano A.
M.U.R.S.T.	125	Visite integrate di dati provenienti da sorgenti eterogenee: metodi e strumenti per la modellazione	Lenzerini M.
M.U.R.S.T.	30	Riconoscimento isolamento dei guasti nei sistemi non lineari	Isidori A.
M.U.R.S.T.	119	Pianificazioni di azioni e controllo sensoriale del moto di strutture robotiche articolate e di locomozione	De Luca A.
M.U.R.S.T.	66	Analisi visualizzazione di informazione e di interrogazione visuale in base di dati per il monitoraggio clinico	Santucci G.

Contracts with others (companies, etc.)

Contractor	Value (ML £)	Title	Project Leader
TECNOFARMACI	18	Corso di formazione prof.le	Cadoli M.
ANSALDO Ricerche	100	Sviluppo di sistemi di controllo di processo su sistemi in real-time e fault-tolerant	Carlucci L.
M.C.O. Italia	61,44	Analisi tecnico-operative inerenti applicazioni satellitari Orbcomm	Delli Priscoli F.
TELESPAZIO S.P.A.	32	Aspetti di ricerca relativi alle comunicazioni satellitari mediante il sistema Orbcomm	Delli Priscoli F.
I.B.M. ITALIA S.P.A.	172,8	Progetto SMO (System Management Ontology) e definizione di un approccio alla navigazione sul Common Information Model (CIM)	Lenzerini M.
A.M.A.	20	Realizzazione del sistema CRM per la Divisione Business Creation	Catarci T.
CREDIOP S.P.A.	160	Assistenza tecnica CREDIOP relativa all'espletamento delle procedure ai fini della gara per il rilascio di licenze individuali etc.	Leporelli C.

Contractor	Value (ML £)	Title	Project Leader
REGIONE LAZIO	144	Studio di fattibilità per la realizzazone del sistema informativo statistico della Regione Lazio	Marchetti Spaccamela A.
STEP S.P.A.	8	Corso di formazione prof.le	Ausiello G.
QUADRICS	50	Analisi e prototipizzazione di software per un PWS ("Parallel Web Server")	Ciciani B.
RAI WAY S.P.A.	110	Modelli e algoritmi di ottimizzazione per la pianificazione di reti di diffusione digitale	Mannino C.
CENTRO TECNICO PER LA RETE UNITARIA DELLA P.A.	120	Analisi e sviluppo delle metodologie della ricerca operativa per l'ottimizzazione della configurazione ed evoluzione delle reti informatiche	Leporelli C.
TELCORDIA TECHNOLOGIES Inc	19,62	Sviluppo della ricerca nell'ambito del middleware ad oggetti distribuiti	Ausiello G.

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 multilevel memories;
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.

The AE group has recently organized several international scientific events and will organize in Rome CONF 2002, where the European Sym-

posium on Algorithms and the Workshop on Approximation Algorithms will be co-located. 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 on Future Technologies"; EU-IST "Approximation and On-line algorithms"; EU-RTN AMORE "Algorithmic Methods for Optimizing the Railways in Europe"; MURST "Algorithms for Very Large Data Sets"; MURST "Resource Allocation in Computer Networks"; MURST National Project "Rete multimediale nell'evoluzione verso UTMS - Linea di ricerca Applicazione ai beni culturali".

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. We have introduced a general framework for casting fully dynamic transitive closure into the problem of reevaluating polynomials over matrices. Using this technique, we have devised a new deterministic algorithm that improves the best known bounds for both fully-dynamic and deletion-only transitive closure on general directed graphs. Our algorithm maintains explicitly the transitive closure as a Boolean matrix, supporting updates in $O(n^2)$ amortized time and queries in unit worst-case time. We have also proved that it is actually possible to break through the $O(n^2)$ barrier on the single-operation complexity of fully dynamic transitive closure, solving a problem that has been open for many years. These results appeared in [10].

Geometric Computing   Geometric computing aims at making available practical primitives to applications of computational geometry, satisfying requirements of efficiency and numerical robustness. The task of fulfilling such requirements has made unpractical many approaches to widely studied problems, such as the computation of a Euclidean spanning tree on a set of points, or testing whether a set of hyperrectangles with many dimensions are mutually disjoint or not, geometric problems arising in the computational biology and in data mining. Researches are ongoing in such area, focussed on the numerical robustness of basic geometric algorithms and on the practical tuning of algortithms on hyperrectangles. Published results are expected during the 2001.

Distributed and network algorithms   The potentialities of integrating caching and prefetching of Web pages in reducing end user latency are investigated. A prefetching algorithm, based on a minimal interaction with the user, is proposed. It is also proved through real traces based simulations that, if integrated with an appropriate caching strategy, the algorithm proposed outperforms several, well known web caching heuristics. We also devised a fully dynamic and distributed algorithm for all pairs shortest path. The algorithm works for networks with real, positive weights on the arcs. The algorithms allows for updates with the minimal possible number of exchanged messages with respect to insert, delete, weight increase and decrease operations. The results appeared in [5, 14].

Approximate and on-line algorithms   We have studied the problem of assigning fractions of a shared satellite link's capacity to a set of requests, subject to feasibility constraints and so as to maximize the number of admitted requets. We propose constant approximation algorithms, based on a linear programming formulation of the problem and on a sophisticated rounding procedure. We have also considered the problem of on line scheduling a series of requests on a set of identical machines. This is a classical problem in the theory of algorithms. The goal is minimizing end user's perceived latency. Competitive algorithms are proposed, both when a user request is completely revealed to the algorithm at release time and when the processing time of a request is only known at completion time. The proposed algorithms asymptotically achieve the best possible competitive ratios. Finally, we have addressed the problem of

efficiently routing agents over the Internet by exploiting approximation algorithms for the TSP and the minimum latency problem. Works in this area appeared in [1, 3, 13, 4, 12].

Experimentation and visualization   We have performed several experimental studies to investigate the practical performances of algorithms. In particular, we have considered the fully dynamic single-source shortest paths problem in digraphs with arbitrary arc weights, showing that dynamic algorithms can be faster by several orders of magnitude than recomputing from scratch with the best static algorithms. We have also addressed the one-sided crossing minimization problem, studying its strong relationship with the problem of computing minimum feedback arc sets in directed graphs and devising a new algorithm with very good practical performances. Other work has been done in designing and implementing the software tool for algorithm visualization Leonardo, now widely distributed with thousands of users worldwide. Works in this area appeared in [2, 6, 7, 8, 9, 11].

Journals

[1] S. Albers, N. Garg, and S. Leonardi. Minimizing stall time in single and parallel disk systems. *Journal of the ACM*, 47:6, 2000.

Conference Proceedings

[2] P. Crescenzi, C. Demetrescu, I. Finocchi, and R. Petreschi. Reversible Execution and Visualization of Programs with LEONARDO. *Journal of Visual Languages and Computing*, 11(2), 2000. An exteded abstract appears in *Proceedings of the 1-st Workshop on Algorithm Engineering* (WAE'97), Venice, Italy, September 1997, 146-155. Leonardo is available at the URL: `http://www.dis.uniroma1.it/~demetres/Leonardo/`.

[3] G. Ausiello, S. Leonardi, and A. Marchetti-Spaccamela. On salesmen, repairmen, spiders and other traveling agents. In *In Proceedings Italian Conference on Algorithms and Complexity, CIAC 2000, Lecture Notes in Computer Science 1767, 1-16*, 2000.

[4] L. Becchetti, S. Leonardi, and S. Muthukrishnan. Scheduling to minimize average stretch without migration. In *Proceedings of the 11th ACM-SIAM Annual Symposium on Discrete Algorithms (SODA '00)*, 2000.

[5] S. Cicerone, G. Di Stefano, D. Frigioni, and U. Nanni. A fully dynamic algorithm for distributed shortest paths. In *Proceedings of the Latin American Theoretical Informatics (LATIN 2000). Lecture Notes in Computer Science, vol. 1776, pp. 247-256*, 2000.

[6] C. Demetrescu, E. Di Giacomo, I. Finocchi, and G. Liotta. Visualizing geometric algorithms with wave: System demonstration. In *Proc. of the 10th Annual Fall Workshop on Computational Geometry (CG'00), University at Stony Brook*, 2000.

[7] C. Demetrescu and I. Finocchi. Break the "right" cycles and get the "best" drawing. In B.E. Moret and A.V. Goldberg, editors, *Proc. of the 2nd International Workshop on Algorithm Engineering and Experiments (ALENEX'00)*, pages 171–182, 2000.

[8] C. Demetrescu, I. Finocchi, and G. Liotta. Visualizing algorithms over the web with the publication-driven approach. In *Proc. of the 4-th Workshop on Algorithm Engineering (WAE'00), Saarbrücken, Germany. September 5-8*, 2000.

[9] C. Demetrescu, D. Frigioni, A. Marchetti-Spaccamela, and U. Nanni. Maintaining shortest paths in digraphs with arbitrary arc weights: An experimental study. In *Proc. of the 4-th Workshop on Algorithm Engineering (WAE'00), Saarbrücken, Germany. September 5-8*, 2000.

[10] C. Demetrescu and G.F. Italiano. Fully dynamic transitive closure: Breaking through the $O(n^2)$ barrier. In *Proc. of the 41st IEEE Annual Symposium on Foundations of Computer Science (FOCS'00)*, pages 381–389, 2000. Full paper available at the URL: `http://arXiv.org/abs/cs.DS/0104001`.

[11] C. Demetrescu and G.F. Italiano. What do we learn from experimental algorithmics? In *Proceedings of the 25th Interna-*

tional Symposium on Mathematical Foundations of Computer Science (MFCS'00), Bratislava, Slovak Republic, August 28 - September 1, 2000.

[12] S. Leonardi, A. Marchetti-Spaccamela, and A. Vitaletti. Approximation algorithms for bandwidth and storage allocation under real time constraints. In *Proceedings of the* 20th Conference on Foundations of Software Technology and Theoretical computer Science (FST TCS 2000)*, pp. 409-420, LNCS 1974, Springer-Verlag*, 2000.

Technical report and others

[13] L. Becchetti and S. Leonardi. Non-clairvoyant scheduling to minimize the average flow time on single and parallel machines. Rapporto del Dipartimento di Informatica e Sistemistica N. 16-00, 2000. To appear in *Proceedings of the 33rd ACM Symposium on the Theory of Computing*.

[14] M. Curcio, S. Leonardi, and A. Vitaletti. Integrated prefetching and caching for the world wide web via user cooperation. Manuscript, 2000.

3.1.2 Artificial Intelligence

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

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 development of methodologies and techniques for access control and computer security based on formal logics. This aspect is

addressed in the Section "Application of AI Techniques to Computer Security".

4. The developments of new algorithms for SAT, i.e. for checking propositional Satisfiability. This research is reported in the Section "Propositional Satisfiability".

5. 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".

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

7. 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.

Maurizio Lenzerini was invited speaker at the "Knowledge Representation Meets Data Bases International Workshop", Berlin, August 2000. Daniele Nardi was invited speaker at the "European Conference on Artificial Intelligence", Berlin, August 2000. He also led the SPQR Team of our Department to the fourth position at the World Championship of Soccer for Sony legged robots (RoboCup 2000), Melbourne, August 2000. Giuseppe De Giacomo was invited speaker at "Advances in Modal Logic – International Conference on Temporal Logic (AiML-ICTL'00)", Leipzig, Germany, october 2000. Domenico Mastrantuono won the AI*IA thesis award.

The research activities have been supported by various institutions and in the framework of different programs, whose financial support

Group members   Luigia Carlucci Aiello, Marco Benedetti, Marco Cadoli, Andrea Calí, Diego Calvanese, Amedeo Cesta [CNR], Giuseppe De Giacomo, Francesco M. Donini [Politecnico di Bari], Alberto Finzi, Luca Iocchi, Domenico Lembo, Maurizio Lenzerini, Paolo Liberatore, Fabio Massacci [Univ. di Siena], Daniele Nardi, Angelo Oddi [CNR], Fiora Pirri, Marco Pirrone, Massimo Romano, Riccardo Rosati, Enver Sangineto, Andrea Schaerf [Univ. di Udine], Marco Schaerf.

Common Sense Reasoning   As a general issue, commonsense reasoning investigates the reasoning mechanisms of an intelligent agent operating in realistic domains. Research in commonsense reasoning 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 the following areas: belief revision [8, 9, 32, 33], nonmonotonic reasoning [39], modal logic [13, 40], and abduction [29, 34].

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 regard to both the expressive power and the computational properties of the associated reasoning techniques. Expressive variants of Description Logics are studied, and extended with identification constraints and functional dependencies. In [6] the analysis of the description logic $\mathcal{ALC}$ has brought to a novel tableaux method which solves the validity problem with global axioms (resp. non-empty TBoxes) in provably exponential time.

   We also studied the relationship between DLs and other formalisms used in knowledge representation and in Databases, and the possibility to profitably exploit expressive DLs to reason on UML class diagrams. A comparison of state of the art DLs reasoning systems is performed, based on their ability to reason on UML class diagrams of increasing complexity.

DLs have been successfully applied to information integration, and to the integration of ontologies. Finally, the problem of answering queries using views in the context of knowledge bases expressed in DLs is addressed [20, 21].

Application of AI Techniques to Computer Security Advanced techniques of automated reasoning, planning as satisfiability and theorem proving have been applied to the *specification and verification of security protocols*, and in particular to industrial strength protocols such as the SET protocol by VISA and Mastercard. The results of this research are reported in [16, 22, 42].

A new technique, called *logical cryptanalysis*, has been proposed for the encoding of hard cryptographic problems (such as RSA factoring or known plaintext attacks to DES) into satisfiability problems. According to this transformation a cryptographic attack is mapped into a model generation problem of logical theories for which efficient algorithms are known. Results of this research have been published in [11, 35] .

Propositional Satisfiability Algorithms for the propositional satisfiability problem (SAT) are usually partitioned between direct model search methods and refutation based approaches. Both classes have their strength, but no one is clearly superior to the other in all cases. Hybrid approaches could be proposed, bridging the gap between so different philosophies. After some preliminary investigations, we found the main pier of such a bridge in the use of autarkies and some theoretical extensions thereof. The resulting approach is described in [17, 41]. A novel algorithm is proposed, related data structures are studied and an experimental comparison is also made. Quite promising results are obtained both in term of efficiency and in term of effectiveness with respect to some application domain. The long term goal of our research is the construction of a distribute planner based upon a distributed SAT solver, according to the ideas developed in the "planning as satisfiability" community.

Cognitive Robotics and Reasoning about Actions. Cognitive robotics is a recent research field that aims at designing and realizing embodied agents (such as mobile robots) that are able to accomplish

complex tasks in real environments and that, to this purpose, can be controlled at a high level by providing them with a description of the world and of the tasks to be performed. The cognitive capabilities of the robot are provided by the deductive properties of a logic-based formalism for reasoning about actions. The research at DIS has been concerned with all aspects of Cognitive Robotics, going from the actual realization of working robots (in relation with the RoboCup) to investigations on formalisms for reasoning about actions.

The RoboCup competition [37] is an event conceived for comparing robotic technologies in a common setting given by a soccer match between robotic teams. We take advantage of this competition for setting up a team of robot soccer players and for experimenting several techniques for mobile robots control and navigation, image processing and vision, and for team coordination. [15, 23, 24, 25, 30, 36].

Because of the complexity of the RoboCup environment and the tasks to be accomplished, integration of reasoning capabilities for the development of *cognitive robotic soccer players* led to very expressive action theories [26, 31].

The Situation Calculus is the most used formalism for reasoning about actions in Artificial Intelligence. Its expressive richness allows the integration of various aspects of dynamic systems in a unique formalism. In cooperation with people of Cognitive Robotics Group at the University of Toronto, several issues related to the Situation Calculus have being investigated at DIS. In particular: axiomatic foundations of the Situation Calculus with probability.

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 2000, the AI group 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: [1, 2, 3, 4, 5, 10, 14, 18, 19].

Constraint-Based Architectures for Planning and Scheduling
This activity concerns different research aimed at realizing flexible architectures for solving planning and scheduling problems. The formal reference framework is the constraint-satisfaction problem solving (CSP). Attention is paid at involving the human user in the solution process, with a so-called *mixed-initiative interaction.*

A constraint-based architecture is centered on a constraint data-base that represents the basic solution as a set of constraints among set of variables. Specialized algorithms manipulate constraints for checking their consistency and pruning inconsistent states. On this specialized representation, search decisions are performed by algorithms specialized for solving classes of problems. The same representation is functional for allowing the interaction of a user with the solution space.

We studied algorithms and heuristics for different scheduling problems, the management of temporal constraint networks, and we developed complete software architectures for classes of problems [12, 27, 28, 38].

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3.1.3 Data and Knowledge Bases

The research activities of the group working on Data Knolwedge Bases are oriented mainly towards three topics:

- Theoretical and application-oriented aspects of visual formalisms for databases and database design, with special focus on Visual Query Languages and Interfaces, Databases and the Web, 2D and 3D Data Visualization, Adaptive Interfaces, Visual Metaphors, Controlled Studies and Usability Testing.

- Design and performance modelling of parallel and distributed database systems, with particular focus on Data Warehousing, Parallel Database Systems, Query Optimization, and Workflow Management Systems.

- Database modeling, cooperative information systems, data integration, data warehouses and data mining, semi-structured data modeling.

- Cooperative Technologies and Architectures, including E-services and E-goverment.

The group is presently involved in several research projects, including the following: LAURIN (Telematics Program, Libraries Project LB-5629/A). Progetto MURST: Programma Multimediale nell'evoluzione

verso UMTS, linea di Ricerca "Applicazione ai Beni Culturali". Progetto MURST (COFIN): "Analysis, information visualization, and visual querying in databases for clinical monitoring". Progetto MURST (COFIN): "From data to information: integration, warehousing and mining of heterogeneus sources". Research project with: AMA S.p.A., 12Snap S.p.A., IBM Tivoli, Gruppo CM.

Group members Carlo Batini, Andrea Calì, Diego Calvanese, Tiziana Catarci, Giuseppe De Giacomo, Maurizio Lenzerini, Massimo Mecella, Giuseppe Santucci, Silvio Salza, Monica Scannapieco.

Data integration Data integration is the problem of combining the data residing at different sources, and providing the user with a unified view of these data, called global schema. The interest in this kind of systems has been continuously growing in the last years. The group has addressed several of the most important problems in the design of a data integration system, including dealing with heterogeneity of the sources, specifying the mapping between the global schema and the sources, processing queries expressed on the global schema. The results of the investigation on these subjects are reported in [26, 27, 18]

View-based query answering View-based query answering is the problem of answering 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 [10, 7, 14, 11, 12, 13, 4].

Semi-structured data modeling Semistructured data are data that are self-describing, irregular, and with a structure that is partially known, or subject to frequent changes. They are usually formalized in terms of labeled graphs, and capture data as found in many application areas, such as web information systems, digital libraries, and data integration.

Database researchers are studying several aspects of semistructured data, including how to model such data, how to query and restructure them, and how to store and manage them. On the other hand, there are many kinds of reasoning that can be carried out on semistructured data in order to support the above tasks. The goal of the research carried out by the group in this subject is to study methods and techniques for performing such kind of reasoning [7, 30].

Visual Formalisms for Representing and Accessing the Information   Access to information scattered all over the world is becoming increasingly common. Users of these facilities tend to be people with little or no background in computer science. Consequently, data retrieval techniques have to move away from textual languages and invent and apply visual interaction techniques that bring query formulation closer to the world the user is familiar with. Visual query systems and information visualization are the two facets of modern approaches to human-computer interaction. The group has a long tradition of working in this area [3, 23]. During the last year we concentrated specifically on representing and visually querying temporal data, in particular by formalizing ad-hoc visual temporal query primitives and designing the TVQE system [25, 21].

Digital Libraries   Among the wide range of digital libraries, an interesting subclass is constituted by those exclusively dealing with newspapers' clippings. The many heterogeneous subjects treated in newspapers and the great number of different newspapers made it necessary for clipping archives to focus on particular topics. 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. 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 [8, 9, 15, 22].

Information System Usability   It is by now generally accepted that the factors that mainly influence the success of computerization projects

are human and organizational factors rather than technological. The objective of a computerized project is not to provide a multiple functional or technologically innovative product without defects. Instead, it is the productive interaction between a software system and the user who utilizes it. In literature the achievement of this goal is often associated to the qualitative software characteristic called *usability*. The activity of part of the group has been always directed towards joining usability and database research [1]. Recently, it concentrated in particular on the Public Administration application field [16].

Multimedia Tools for Cultural Heritage Exploitation   One of the advantages of recent multimedia technology is the availability of tools that allow one to easily and often remotely access the huge artistic-cultural heritage of the world. Plinius is a government funded project aiming at building a suite of software tools for a better exploitation of the cultural resources of Pompei archaeological area. The main objectives of the Plinius Project are: offering ad-hoc services of search and navigation to researchers and scientists accessing in particular Pompei data, but also any other database containing cultural heritage related information; adopting advanced hypertextual, multimedia and virtual reality based techniques to set-up guided tours and interactive kiosks attracting the visitors; designing a cultural heritage oriented authoring system to help the author to create both virtual and real exhibitions [5].

Web Information Access   The management and retrieval of Web data has recently received significant attention. Among the various approaches, systems have been proposed whose main goal is to provide a framework to integrate different and heterogeneous information sources into a common domain model. The Web-At-A-Glance (WAG) system falls in this category, its key characteristic being that instead of requiring an explicit description of the sources, it attempts to semi-automatically classify the information gathered from various sites based on the conceptual model of the domain of interest. The initial WAG prototype dealt exclusively with "standard" Web pages. During this year, we extended the WAG system to deal with form pages. In particular, the system first semi-automatically extracts a conceptual schema for the form page, and then fills and submits the form in consequence of a user query expressed

on the domain conceptual schema [17].

Cooperative Technologies and Architectures A Cooperative Information System (CIS) is defined as a large number of cooperating component systems, distributed over large, complex computer and communication network, and working together cooperatively, requesting and sharing information, constraints, and goals. Building such new systems poses some major challenges, that include to develop tools and products that can bring together incompatible information sources and software, and to develop technologies that permit continuous enhancement and evolution of current massive investments in information sources and systems. In [20][24][2] such issues are addressed, specifically the development of integration components which are wrappers of legacy information systems and the design of a complex architecture for their integration.

E-Government E-Commerce and E-Business are classical contexts in which to apply the CIS paradigm; a new and innovative context in which to consider the development of CIS is the E-Government one, and specifically the Italian E-Government initiative. It aims at the definition, design and deployment of a Nationwide Public Administration Network able to connect public administrations among them, and at designing a Nationwide Cooperative Information System of Italian PA atop the network [29][28]. The research [19][6] is focusing on a critical analysis of such initiative, in order (i) to derive methodological suggestions for a development process specifically tailored for CISs, and (ii) to test innovative solutions according to a `codesign` approach.

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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 computing.

- Highly performing, available Web systems.

- Parallel/distributed simulation.

- Dependable middleware.

- 3-tier architectures.

- Mobile systems.

- Communication protocols.

- Interconnection networks.

Members of the group are continuously involved in the Program Committes of prestigeous International Conferences such as ICDCS, PADS, SRDS, DOA, WORDS, COOPIS, ISORC. Members have also recently chaired the Program Committee of WORDS'01 [17] and the "Tutorial and Short Paper" Program Committee of DOA'01 [15].

The distributed systems group is member of "CABERNET" Network of Excellence in Distributed Systems Architectures chaired by Brian Randell.

Group members   Roberto Baldoni, Roberto Beraldi, Bruno Ciciani, Giacomo Cioffi, Carlo Marchetti, Daniele Pianura, Marco Emilio Poleggi, Francesco Quaglia, Andrea Santoro, 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 [24], 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.

In [8] it is 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 [18], 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 [1, 16] and Rollback-Dependency Trackability [19]. Other studies concern (i) the consistency problem for global checkpoint consistency [33] in transcation systems and (ii) some impossibility results for RDT implementation [21].

Highly performing, available Web systems   In systems with multiple cooperative Web proxies, some proxy can serve cache misses of other proxies. Any form of cooperation requires some exchange of information among proxies to be settled. To achieve this, there are two classical, opposite solutions: the Query Protocol (QP) and the Informed Protocol (INF). In QP, upon a local cache miss, a proxy broadcasts a query message to locate the document within the global cache. In INF, each proxy frequently informs the others about changes in its set of cached documents. In this way, documents can be located within the global cache without the need for query mechanisms.

Parallel simulation   Optimistic methods for parallel/distrubuted 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, an analytical model for the determination of "optimal" checkpoint positions has been presented in [32], also, a model for the case of hybrid recovery (forward/backward) has been developed in [26] . In addition, we have developped and tested a Checkpointing and Communication Libray (CCL) for clusters based on Myrinet switches, which supports both fast message delivery and also CPU offloaded checkpointing functionalities [31]. We have also addressed the scheduling problem of multiple simulation processes hosted by the same machine, which has strong impact on the amount of causality violations, and we have presented several solutions. The first one [13] is based on global state information collected through a light feedback system (previous solution use only information local to the machine). Other solutions [14, 11] are tailored for applications with high variance of either the event granularity or the tasks (namley events) spreading factor.

3-tier Architectures In the last twenty years "Commercial Off-The-Shelf" (COTS) systems have also given a shot to the passage from two-tiers architecture to three-tiers distributed systems architecture. Three-tier architectures are becoming widespread in current distributed applications. The middle tier actually separates clients from backend servers implementing many of the application logic.

We study the problem of adding Quality-of-Service to a raw client server interaction by interposing a midtier with specific QoS enhancement.

The most visible result of this wide study is the development of the Interoperable Replication Logic (see next paragraph) and several studies on implementation of portable interceptors.

IRL (Interoperable Replication Logic) IRL is a research project carried out at Dipartimento di Informatica e Sistemistica of the University of Rome "La Sapienza", `http://www.dis.uniroma1.it/∼ irl`.

IRL final goal is to implement the Fault Tolerant CORBA specification, a standard for the development and the deployment of distributed, fault tolerant, CORBA application. IRL has been designed as a set of CORBA compliant objects handling object replication.

The main IRL project features are: (1) Interoperability: allowing transparent interactions among replicated IRL objects and application objects deployed on ORBs from different vendors. (ii) Pluggability: IRL can

be deployed on many CORBA 2.4 compliant ORBs, without requiring modifications to the local ORB and to the native OS. Previous features allow to design applications composed by replicated and highly available CORBA objects and to simplify IRL application deployment and management. Papers addressing different aspects of IRL can be found in [4, 5, 6, 22, 23, 28].

Portable Interceptors   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. Until now CORBA paid little attention on providing tools for building reliable distributed applications which could take an effective advantage from the distributed nature of the platform. OMG has introduced also the notion of CORBA portable interceptors. The aim of CORBA interceptors is to add services to a CORBA object in a transparent, flexible and portable way. The interception layer is logically interposed between a client and a server object. Operationally, the client and the server have their own customizable interceptors that cooperate to offer ad-hoc functionalities. This frees CORBA applications to handle such functionalities. In [27] some practical lessons learned by programming CORBA interceptors and extensive performances study are presented, in order to understand which tasks can be executed by interceptors for enhancing reliability in CORBA applications.

Mobile Systems   In the context of mobile computing, we focus on the following aspects:

Time and location-dependent algorithms In several scenarios, a mobile computing system can be considered to be a distributed computing system with the additional notion of node mobility. In several mobile computing applications, the actions taken by a node will be influenced not only by the *happened before* relationships in the system, but also by the location of the nodes [25].

Routing Routing is one of the main challenge in a mobile network where there is no wired infrastructure ("ad-hoc" mobile network). In such a setting, each node acts as a router and thus a network topology change occurs whenever a new link between two nodes is established or an existing one fails.

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 [9].

Communication Protocols   Asynchrony of communication channels is one of the major causes of nondeterminism in distributed systems. To cope with such an asynchrony basic communication modes have been defined: rendez-vous (sometimes called synchronous), logically instantaneous, First-in-First-out (FIFO) and causally ordered are the most known and used. We worked on several aspects of such communication modes: definition of new communication modes, designing of communication protocols and architectures for communication protocols. In particular we focused on Δ-causal ordering abstraction. Such an abstraction extends the basic notion of causal ordering to cope with unreliable communication networks with real-time delivery constraints. We suppose messages can be lost and have a limited time validity, Δ, after which their data can no longer be used by the application. Δ-causal ordering requires to deliver as much messages as possible within their validity time in such a way that these deliveries respect causal ordering [7].

Failure Detection   The study on failure detection follows two distinct directions. The first designs and implements a failure detection service to detect crash failures. The second handles failures more subtle than crashes such as arbitrary failures, mute failures, omission failures.

Handling Crash Failures In this work we present the designing of a Failure Detection Service (FDS) based on the notion of unreliable failure detectors introduced by Chandra and Toueg. FDS is able to detect crashed objects and entities that permanently omit to send messages without imposing changes to the source code of the underlying protocols that use this service [10, 29]. This paper can be also seen as a first step towards a distributed implementation of a *heartbeat-based* failure management system as defined in Fault-Tolerant CORBA specification [30].

Handling weaker failure semantics In this work we try to understand how to build reliable systems in an environment where arbitrary failures can occurs [2, 3, 20]. In particular we show which are the main services needed to solve the consensus problem in asynchronous system.

We also identify several classes of failure detectors which depends on the particular distributed algorithm to be executed.

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 [33]. While developing the model, particular attention was posed on binary toroidal topologies, which have been proven to be useful for general purpose processing.

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3.1.5   Programming Languages and Methodologies

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

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

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

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

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

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 [2]. 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). We have presented the theory with some application in [1].

Open and Distance Learning After thye experience with the Socrates Project no 56544-CP-1-98-1-NO-ODL-ODL *EuroCompetence* [3] we have started a new collaboration with our european partners in a project on *Competence Development in International Oriented Companies* (CIOC, partcipants from TISIP Trondheim, Siemens Metering, University of Greenwich, NITOL and TEI Thessaloniki).

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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.

Cooperations   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   A. Bertuzzi, A. Gandolfi (IASI-CNR), G. Mingrone, A. V. Greco (Istituto di Clinica Medica-Policlinico A. Gemelli Università Cattolica del Sacro Cuore-Roma) F. Babiloni, C. Babiloni, F. Cincotti, F. Carducci (Istituto di Fisiologia Umana, Università di Roma "La Sapienza"), S. Salinari.

Analysis and Modeling of Metabolic Systems   In the context of this project, models of kinetics and metabolisn of dicarboxylic acids have been developed to investigate the possibility of using these substances as an alternative energy substrate. In particular, in the last year, the metabolism of dodecanedioic acid (C12) has been investigated by "in vivo" experiments and mathematical compartmental models. The estimates of model parameters, against the experimental data, predicted an average and a maximal calorie delivery suitable for C12 utilization for nutritional purposes. More recently the interest was extended to the analysis of body composition with a particular regard to the estimation of muscle mass. In this frame the structure of skeletal muscle, at cellular level, has been described by a compartmental model. This model allowed to estimate the hydration of muscle both in normal and obese subjects, evidencing that, in obeses, the ratio between the intracellular muscular water and muscular tissue can't be assumed to be constant as in normals. The possibility of using non-invasive and non-expensive techniques, such as Bioimpedance Analysis, to assess muscular mass is also under investigation.

Analysis of Brain Potential related to Motor Control   In the last year, the interest was mainly focused to a new research theme regarding the study and the implementations of EEG-based Brain Computer Interfaces. These devices require on-line detection and classification of mental states from spontaneous or suitably transformed EEG signals, recorded by a limited number of electrodes. In particular Surface Laplacian (SL) was proved to be a more suitable technique for the detection of EEG

patterns with respect to the use of unprocessed raw potentials. From these considerations, the performance of global computational methods for the estimation of SL from a limited number of electrodes, has been investigated. At the same time, different types of classifiers have been implemented in order to compare their performance in the recognition of mental patterns.

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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 summarises 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: MAARS (Mobile Aero-Assisted Robotic System for Mars Exploration), orthesis automation and various projects sponsored by the Italian Space Agency (ASI). International collaborations include: the Australian National University, Research School of Information Sciences and Engineering, Laboratoire des Signaux et Systèmes, CNRS, Ecole Superieure d'Electricité, Gif-sur-Yvette, Department of Electrical Engineering, University of L'Aquila.

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

Emergent and innovative control strategies   In a complex system control, emergent and innovative control strategies allows to improve its flexibility and performance without introducing significant modifications in existing control structure and instrumentation. Intelligent control, applied to the supervisory level, has these peculiarities and can be considered as the natural evolution of expert systems. Hard-ware and soft-ware methodologies offer the suitable tools for its design and implementation. A design procedure based, on a feasible controlled system simulation, has been worked out to improve the flexibility of a controlled plant and to foreseen latent and incipient faults. It has been applied to a working machine and in a packaging machine and very satisfactory results has been attained.
Most relevant publication in this area are [13] and [14].

Discrete-time systems   As well known, the discrete dynamics is usually represented by a difference equation in the state and control variables. In the nonlinear context, a new representation, based on a exponential description of the dynamics and derived through the formal expansion in Volterra's series, has been introduced. In this framework the discrete dynamics is described by the combined action of two terms: a difference equation describing the drift jump, and a differential equation, related to the variation of the dynamics with respect to the control. The characterization of the structural properties of the dynamics as well

as the solution of several control problems, find their natural setting in this framework, see for example [4].

Digital control A digital controller can be set following different approaches: by implementing a *digital equivalent* of a continuos controller, by designing a discrete controller based on a discrete-time model of the plant, taking eventually into account the coesistence of continuous and sampled signals. This last approach allows to satisfy more interesting control requirements such as dead beat control or minimum time ones. 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 coesistence of discrete and continuous signals. The work on this topic concerned the control of mobile robotic systems, underactuated mechanical structures, induction motors, space crafts and automotive systems.
Most relevant publications in the area of discrete-time systems and digital control are: [3], [8], [10] and [2],[6],[7],[11], [12],[15].

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. It's worth noting that some classes of systems extensively studied by a large number of researchers are, in every respect, positive systems. The work on this topic has focused on the minimality problem for positive realizations and it has been presented a result for characterizing minimal positive realization in the case of third order transfer functions with positive real poles for the discrete–time case. More details can be found at the web site: `http://sistemi.ing.uniroma1.it/People/farina/Praga2001Minima lity_file/frame.htm`.
Most relevant publications in this area are: [1], [5] and [9].

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3.2.3 Identification and Optimal Control

The scientific interest of the group lies in two main areas: modeling and identification of discontinuous signals and of dynamical systems, deterministic and stochastic optimal control. In the first area 1D and 2D signals are dealt with, focusing on the problem of image reconstruction and discontinuities detection from blurred and noisy data; identification of compartmental models is investigated in pharmacokinetics problems and various metabolics processes. In the second area optimal tracking problems for linear stochastic systems and robust stabilization of stochastic nonlinear systems are investigated; also the problem of fault detection by multiscale analysis is investigated, in order to properly compensate a Kalman filter. Finally the application of the optimization tecniques to traffic control into a wireless network is considered (this latter research takes place in the framework of the WINE project belonging to the Information Society and Technology programme, sponsored by the 5th Framework EU programme).

Group members Carlo Bruni, Alberto De Santis, Francesco Delli Priscoli, Daniela Iacoviello, Giorgio Koch (Collaboratore esterno), Stefania Vergari.

Images reconstruction and segmentation 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 degradated by blurring effect and additive noise. We formulate these problems as global constrained optimization problems over suitable functional spaces, suitably modeling the admissible images set. Minimum distance functionals are considered as performance criteria. Compactness and convexity properties of admissible sets of 2D discontinuous functions have been investigated thus establishing results about the existence and uniqueness of a robust optimal solution. Efficient numerical procedures are on study aimed to allow: i) the image reconstruction, as solution of a global optimization problem; ii) the image segmentation, as a result of the application of local statistical hypothesis tests.

Identification of linear compartmental models Compartmental models describe systems whose dynamics represents balances and fluxes of positive quantities (matter, energy, resources, etc.). Compartmentality constraints ensure that the system impulse response is positive. Sufficient conditions are known ensuring the existence of positive state-space realizations of increasing order for a given positive impulse response. These conditions are exploited in the identification of compartmental systems from real data with applications to pharmacokinetics and metabolic processes.

Optimal control and robust stabilization of stochastic systems The problem of modeling the traffic behaviour on a wireless internet network has been considered and the related control problem was formulated as an optimization problem, transforming the quality of services requirements (jitter requirement, maximum delay requirement, minimum admitted rate requirement) into suitable analytical constraints. Numerical procedures are on study for solving the optimization problem. The optimal linear-quadratic-gaussian tracking problem was studied, under the assumption that the reference signal is a random process, with a known, non zero mean value. The solution does exist, unique, and its closed form is given. Also the problem of detecting faults in the output measurement device for linear systems has been studied, assuming that these faults can be modeled by unknown jumps in the bias of the output noise. The on line identification of such discontinuities essential in order to suitably compensate a Kalman filter working on the system output data. Finally a robust stabilization problem has been studied for stochastic nonlinear systems with a given target set. An output feedback controller is designed, which ensures that the trajectories in the state space remain inside a suitable neighborhood of the region of attraction and that, in a finite time, definitely enter the target set. Both these two events can be assigned a probability as close as possible to one. This new notion of semiglobal stabilization in probability with a target set was introduced and the output controller was investigated by Lyapunov arguments.

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3.2.4   Nonlinear Systems

The research group of Nonlinear Systems is involved in the development of the following topics: intelligent guidance, fault detection, robust stabilization and tracking of nonlinear systems, connection admission control and congestion control.

Group members   Stefano Battilotti, Francesco Delli Priscoli, Alberto Isidori, Leonardo Lanari.

Intelligent guidance   One of the main objectives of this research is to develop a control structure, using only sensed information about the error between actual and prescribed path, in which the guidance of a vehicle is achieved by means of an error-feedback control which incorporates an "internal model" of the "external" operational conditions (such as any trajectory requirement, or any dominant disturbance) and the internal model is constantly adapted as the vehicle experiences different external disturbances and/or path prescriptions. As an example, we have applied this design philosophy to the problem of autonomous landing of an air vehicle on a ship in high seas. We have considered the maneuver of a VTOL aircraft in a lateral/vertical plane and assumed that the ship on which the aircraft is landing oscillates vertically, due to rough sea state. On this example, we have demonstrated the effectiveness of the internal-model-based design in off-setting large model uncertainties and tracking an oscillating target. In our simulations, the landing platform

was assumed to oscillate vertically, with a motion consisting of a super-position of a finite number sinusoidal functions of unknown frequencies, amplitudes and phases.

Fault detection The problem of fault detection and isolation in dynamical systems is the problem of generating diagnostic signals sensitive to the occurrence of faults. Regarding a fault as an input acting on the system, a diagnostic signal must be able to "detect" its occurrence, as well as to "isolate" this particular input from all other inputs (disturbances, controls, other faults) affecting the system behavior. One specific diagnostic signal (also called residual) must be generated per each fault to be detected, each diagnostic signal being sensitive only to one particular fault. Set in these terms, the problem of fault detection and isolation has very much the connotation of a problem of designing a system which, processing all available information about the plant, yields a "non-interactive" map between faults (viewed as inputs) and residuals (viewed as outputs). A complete solution to this problem for linear systems (which includes existence conditions as well as methods for the construction of a detection filter) was obtained about a decade ago. This solution approach is based on the classical tools of geometric analysis for non-interacting control pioneered about two decades earlier by M. Wonham. However, attempts to extend this solution to nonlinear systems had failed, because of an obstruction in extending one of the said tools (the so-called "output injection") to the case of nonlinear systems. In our research, using suitable differential-geometric methods, we have been able to somehow circumvent this obstruction and we have been able to arrive at a characterization of conditions for the existence of a detecting filter, as well to an appealing construction algorithm, that generalize in a quite satisfactory manner the results that hold for linear systems.

Robust stabilization and tracking of nonlinear systems We studied the problem of semiglobally stabilizing a nonlinear systems with outputs affected by uncertainties and deterministic noise. It is assumed that a dynamic model of the noise is not available. The problem can be split up into a state feedback stabilization problem and a filtering problem. The applicability of the results is illustrated on the class of nonlinear uncertain systems with a upper triangular structure (feedforward systems)

and lower triangular structure (feedback systems).

We also studied the problem of globally stabilizing a nonlinear systems with outputs affected by uncertainties and deterministic noise. It is assumed that a dynamic model of the noise is not available. A Lyapunov based constructive setup for solving the problem is proved by extensively using three basic ingredients: limited output injection, filtered Lyapunov functions and dissipation inequalities. The problem can be split up into a state feedback stabilization problem and a filtering problem. The applicability of the results is illustrated on the class of nonlinear uncertain feedforward and feedback systems. Moreover, several nonlinear input/output constraints are taken into account, such as input saturations and output limitation.

The problem of global tracking of a class of nonlinear systems (which includes robotic manipulators) via partial state measurement. The assumption of linearity with respect to the state variables not available for feedback is removed and quadratic nonlinearities are allowed. It is proved that if tracking via state feedback can be achieved and the unboundedness observability property (UO) holds, then tracking can be also achieved via output feedback. The UO property essentially requires that the state cannot have finite escape time if the output is bounded.

Connection admission control and congestion control   This research is performed in the framework of six European Union (fifth framework programme) and one European Space Agency (ESA) research projects (named WINE, WIND-FLEX, GEOCAST, BRAHMS, VIRTUOUS, SUITED and DOMINO 2) entailing a net financing for DIS of about 1.500.000 Euro for research activities covering the period 2000-2002. 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 role in the framework of these projects mainly concerns the research, the design and the simulation (by using the OPNET tool) of the following resource management procedures: (i) Connection Admission Control (CAC) procedures which control the admittance of new connections in the wireless network. In case a new con-

nection is admitted a Quality of Service (QoS) contract (specifying the connection target performance in terms of minimum bit rate, maximum packet transfer delay, maximum packet delay jitter and maximum packet loss) is established; (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 aim of respecting the QoS contracts and of maximizing the throughput; (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. These activities involve control, information, optimization, operation research, telecommunication competences and methodologies; in particular, during 2000, this research has involved many DIS Professors, Researchers and PhD Students belonging to control, information and operation research areas.

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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 both advanced and industrial manipulators and mobile robots.
The DIS Robotics Laboratory was established in 1987. The following robotic equipment is currently available: a 6-dof robot (*Zebra-ZERO* by IMI) with a 6D-force/torque sensor, an 8R-dof redundant manipulator (*DEXTER* by Scienzia Machinale) with an additional 2-dof dextrous gripper, a two-wheel differentially-driven mobile robot (*SuperMARIO*, developed in our Laboratory) with an external color CCD camera and a Matrox frame grabber, and a two-link underactuated arm (*Pendubot* by

Quanser). The Laboratory is on the web at
`http://labrob.ing.uniroma1.it`.
Active grants include MURST *RAMSETE* and *MISTRAL* national projects, as well as other projects funded by ASI and CNR. In the last years, we have cooperated with three foreign institutions, the *LAAS-CNRS* in Toulouse, the *IPA-Fraunhofer* in Stuttgart, and the Department of Computer Science at the *Johns Hopkins University* in Baltimore. There is also a continuing collaboration with members of DIA, at the *Università di Roma Tre*.

Group members   Fabio Maria Antoniali, 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, with cross-inertial components of the actuating motors, and shown that a dynamic state feedback controller allows to obtain exact linearization and input-output decoupling. A review of existing control methods and the simplifications of a combined feedforward/feedback approach are presented in [7]. 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 solved the rest-to-rest motion problem in given time for a general single flexible link [21] and for the two-link planar robot with flexible forearm (the *FLEXARM* available at Università di Roma Tre), including one flexible mode [22].

Planning and Control for Robots with Redundancy   Kinematic redundancy is purposely introduced in robot manipulators to achieve more dexterity in the primary task execution. The redundant degrees of freedom (dof) can be used to generate an internal joint motion that reconfigures the structure according to additional task specifications or perfor-

mance criteria. We have conducted a comparative study on the performance of two on-line numerical techniques that locally exploit the redundancy, namely the classical projected gradient method and our previously proposed reduced gradient method. Both velocity- and acceleration-level schemes have been designed and implemented on the 8R-dof *DEXTER* manipulator [6].

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 review of the solved cases and of the status of the art can be found in [23], while the fallacy of a proposed stabilization technique is pointed out in [14]. For planar robots with the first two actuated joints (of any type) and a rotational passive third joint, we have developed a method for motion planning between two general states and an associated trajectory tracking controller, based on dynamic feedback linearization. The approach works with or without gravity [8, 9]. More difficult is the case of a 2R or PR robot in the absence of gravity, with only the first (rotational or prismatic) joint actuated. A stabilization strategy has been proposed in [1, 20], based on three phases: *i)* alignment of active joint to its desired value, *ii)* transition to suitable state regions, *iii)* repeated application of an error contracting open-loop command (iterative steering).

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 nonholonomic systems that can be transformed via feedback into the so-called chained form, we have developed two techniques for achieving stabilization to a desired configuration in a robust way (i.e., rejecting small non-persistent perturbations): the iterative steering technique, which is described in general in [17], and the learning technique [4]. A car pulling two off-hooked trailers (the *general* two-trailer system) and the plate-ball system (moving a rolling sphere on a plane

using only the two $x - y$ commands of a top plate) are two examples of nonholonomic systems that do not admit a chained-form representation. For these systems, we have computed open-loop motion commands, based on a nilpotent approximation of the kinematic equations. When applied iteratively, these steering laws yield stabilization with exponential convergence [12, 24]. On the experimental side, we are continuing the activity aimed at validating several nonlinear feedback controllers on the *SuperMARIO* mobile robot [15]. For this unicycle-like robot, dynamic feedback linearization is a viable option for trajectory tracking and parking tasks [10].

Perception and Navigation with Mobile Robots   In the recent past, we have investigated map building of unknown environments using ultrasonic data and the associated robot navigation task. More accurate maps can be obtained by fusion of laser and ultrasonic data, based on fuzzy techniques [16]. Currently, we are improving techniques for the localization problem, i.e., estimating the location (position and orientation) of a mobile robot from sensory data and a priori knowledge of the environment. In [11], ultrasonic sensor measures are combined with inertial (gyro) and odometric data to keep a correct estimate of the robot location. Two algorithms with the classical predictor-corrector structure of the Extended Kalman Filter (EKF) have been developed and tested on a robotic wheelchair, equipped with five wide-beam sonars and undergoing severe wheel slippage. We have also proposed an innovative solution to the localization problem, based on a multi-modal nonlinear filter in the bayesian framework. The new filter can outperform EKF, since it correctly deals with the nonsmooth observations arising in indoor environments with piecewise linear boundaries [5, 13, 18].

Automation and Service Robotics   Automation of different off-factory activities goes under the broad name of service robotics. One interesting example of such robotic applications is the automatic sorting of garbage items from a moving conveyor belt for recycling purposes. In [2], experimental results on the sorting of recyclable packaging in a robotic prototype cell at IPA-Fraunhofer are reported. The robot controller uses the height profile of the randomly distributed objects on the conveyor, sampled with a laser beam and a CCD camera, in conjunction with fuzzy

techniques, in order to get a 3D model and localize the best gripping point for any item. A neural classifier is used then to identify the objects to be sorted out. Performance evaluation and optimization of gripping rate or system throughput has been also considered [3]. Another instance of service robotics is the robotic assistance in a surgical operation. In the Steady-Hand Robot, in development at the Johns Hopkins University, vision is integrated with virtual fixtures for driving the surgeon's hand-held tool during fine motion [19].

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3.3 Management Science

3.3.1 Combinatorial Optimization

The research activity of the Combinatorial Optimization Group is mostly devoted to theoretical and computational aspects related to i) design of telecommunication networks and ii) automated data correcting. The group is currently cooperating with Maastrich University, Konrad Zuse Zentrum fr Informationstechnik Berlin, Oslo University and Universit 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, WINDFLEX and COST279.

Group members Alessandro Avenali, Renato Bruni, Carlo Mannino, Sara Mattia, Antonio Sassano.

Frequency Assignment in Wireless Networks. Radio and television broadcasting, terrestrial mobile telecommunication systems, satellite-based cellular networks and many other important civil and military 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 radio 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. Several 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); and an exact dynamic programming procedure to optimize over cluster of cells in GSM networks. Publications in this field are [1, 4, 5]

Data Correction and Satisfiability When dealing with large amounts of collected information, the relevant problem of data correcting arises.

Error correction problems turn out to be very computationally demanding. They are modelled as Propositional Satisfiability and Set Covering problems. The proposed models have strong computational advantages on other existing approaches, and the statistic quality of corrected data is very satisfactory. The proposed procedure is tested on a real-world case of Census.

As for the second point, the problem of improving an enumerative (DPLL-style) approach to Propositional Satisfiability, and the problem of selecting a small unsatisfiable subset of clauses inside an unsatisfiable CNF formula, are considered. Within a complete solution framework, we propose procedures which improve the performance of an enumerative approach, and are able to rapidly select an unsatisfiable subformula. Publications in this field are [2, 3, 6]

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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.

The Nonlinear Optimization group is currently 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).

Group members Gianni Di Pillo, Francisco Facchinei, Giovanni Fasano, Luigi Grippo, Cinzia Lazzari, Giampaolo Liuzzi, Stefano Lucidi, Laura Palagi, Veronica Piccialli, Massimo Roma, Marco Sciandrone [IASI-CNR].

Unconstrained Optimization The research activity in unconstrained optimization has been mainly devoted to the definition of new methods for solving large scale problems. In this setting, the class of truncated Newton methods has been considered and new algorithms belonging to this class have been proposed with the aim to efficiently solve also "difficult" problems, such as highly nonlinear and ill–conditioned problems. In particular, new linesearch algorithms which use negative curvature directions have been defined and numerically tested, showing that the proposed approach is very effective in the solution of large scale nonconvex problems [6] [8] [11].

Constrained Optimization Both problems with general constraints and constraints with a particular structure have been treated. In particular, Newton -type algorithms for solving smooth nonlinear optimization problems with general constraints and bound constraints on the variables have been considered. A distinguishing feature of the proposed approach is to exploit the particular structure of the constraints so as to limit the computational burden as much as possible. Moreover the use of exact merit functions for the solution of large scale constrained optimization problems has been considered [2] [7] [9] [11].

The constrained minimization of SC^1 functions has been also of interest and in this framework, a new feasible locally convergent algorithm has been defined [13]. Moreover new convergence results for the nonlinear Gauss–Seidel method have been obtained and globally convergent "proximal–point" algorithms have been defined [5].

Variational Inequalities and Nonlinear Complementarity The research activity in the field of variational inequalities has been mainly devoted to the study of structural and stability properties. Moreover, a general linesearch scheme which enables to define and analyze known and new semismooth algorithms for the solution of nonlinear complementarity problems has been defined. The particular problem of identifying those variables that are zero at a solution of a complementarity problem has been also studied and the theoretical properties of the identification technique have been analyzed and numerically tested. This technique is particularly suited to interior–point methods but can be applied to a wider class of methods [1] [3] [12].

Neural Networks The problem of the supervised neural network training has been considered and new convergent online algorithms for learning in neural network has been proposed [4].

Applications in Industrial Engineering An important aspect of the research has been 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 synchronus industrial motors and the design and optimization of dedicated magnets for magnetic resonance imaging [10].

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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 behaviour of Multinational Enterprises (MNE) in R&D intensive industries, (iii) national policies and globalisation. 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 partecipated 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   Research in this area concerns the process of technological innovation in an international setting. By way of static and dynamic games, we have analysed how the firms' mode of foreign expansion influences the incentive to innovate as well as the effects of R&D activities and technological spillovers on the firms' choice of whether to export or produce abroad. In particular, in the current year we have considered the case in which firms invest abroad in order to absorb the knowledge locally avaliable, that is the case usually called "technology sourcing through FDI" [1], [2], [6], [8].

National Policies and Globalisation   This line of research has aimed to clarify 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. The model helps defining which are the best policies for attracting investments from abroad and for enhancing the beneficial effects of these investments. The importance of coordinating FDI policies with policies directed to foster the national Science and Techology system is stressed [9], [11].

The WTO and the Governance of the Global Economy   This strand of research examines whether new multilateral rules on foreign direct investment are necessary, and whether such rules should be the result of a Multilateral Agreement on Investment (MAI) within the next WTO Round. It is shown why international co-operation leading to multilateral rules may lead to a rise in world welfare. Four potential scenarios on how international FDI rules might evolve and the position of different countries are discussed. It is argued that a multilateral negotiation on FDI should take into account development needs and should be part of the next WTO Round []industrialecon-5, [4], [10], industrialecon-6.

Regulation and Competition Policy This line of research has investigated how regulation of pricing discriminatory behaviour by a price capped firm can affect its pricing decision, the entry decision by potential competitors and social welfare. We compared two alternative regulatory schemes - Relative and Absolute - in terms of fostering competition and maximising social welfare. The main findings are that the Relative regime generally grants higher likelihood of entry at a given scale. Moreover, when the scale of entry is no longer a binary choice variable the Relative regulatory regime proved to be able to encourage competition. Via the effect induced by competition upon prices, welfare is higher under the Relative scheme [5].

Unbalanced growth models and sectoral employment performance The research activity in this area has been devoted to explain the superior US performance in job creation in the service sector if compared with EU countries. We employed as theoretical framework the Baumol model of "unbalanced growth". Since the empirical evidence does not confirm its predictions on asymptotic stagnation, we proceeded to relax the four main assumptions of the model. We found 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 [7], [12], [13].

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3.3.4   Industrial Organization and Management

Our research activity is oriented toward general issues in industrial economics and organization, as well as specific industries, with particular reference to network utilities. We mainly deal with the following topics:

- regulation of vertical structures;
- firms' entry strategies;
- innovation and regulation of information technology markets;
- transport networks' management;
- R&D competition;
- multicriteria decision making and corporate strategy.

We have participated to the strategic project "Risk Management in Complex Organizations" financed by the Italian National Research Council. We have also collaborated with CREDIOP in the working group supporting the Ministers' Committee for the assignment of UMTS licenses in Italy.

Group members   Anna Bassanini, Domenico Laise, Claudio Leporelli, Giorgio Matteucci, Alberto Nastasi, Pierfrancesco Reverberi.

Regulation of vertical structures   Research in this area is aimed at analyzing the scope for the regulation of vertical relationships between firms, in particular with respect to telecommunications and the pharmaceutical industry. In the telecommunications sector, the research has

focussed on the new vertical market structures that emerge in the mobile sector, where policy is aimed at reducing the role of regulation in favor of facility-based competition. However, the latter does not eliminate asymmetries deriving from consumers' switching costs and scarcity of sites. Moreover, in the absence of regulation, the possibility of reaching temporary agreements about access to existing networks is reduced as the operational flexibility of the entrants increases [15]. Finally, the existence of unavoidable technological bottlenecks requires a slower pace in reducing regulation [16].

In the pharmaceutical sector, we have analyzed parallel trade as an opportunistic behaviour by an international wholesaler having private information about local demands in two distinct markets where a multinational firm operates [7], [18].

Firms' entry strategies in oligopolistic markets   Research in this field is aimed at studying the role of information in defining firms' entry strategies in oligopolistic markets characterized by incomplete information. We consider an environment where a home firm signals her private cost information by expanding (either through a direct investment or through export) in the country of a foreign firm, which has the possibility of counter-entry. The relationships between technology and demand conditions on the one side and firms' international expansion modes on the other are analyzed, together with the welfare effects of different types of equilibria as compared to those obtained under complete information [8], [19].

Innovation and regulation in information technology markets
Research in this field is directed toward the analysis of the main trends in the development of information technology markets. In particular, we have first analyzed the relationship between innovation and the level of competition in the market [6]. We have then discussed the pricing strategies of different operators. These pricing decisions show varying features according to underlying technologies, market structures and the role and scope of regulation [2]. These characteristics influence operators' choices both in intermediate [3] and final markets [1].

Transportation networks' management   Research in this field has first been devoted to the management of transport networks, developing techniques aimed at inferring traffic flows [12]. Then, the analysis has concentrated on the on-going deregulation process in the railroad sector. A game-theoretic model for the decentralized allocation of network capacity is proposed [10], together with simulations results on the main Italian rail line [9], [4]. In the second place, the effects of the strategic interaction between infrastructure managers of different countries on international services are discussed by modeling the problem in a game-theoretic framework [5], [11]. Finally, the costs of railroad operators are estimated by making use of a translog function, in order to ascertain the existence of economies of scale and density [17].

R&D competition   Research in this field has been stimulated by the changes in production technologies of various industries, which require the analysis of firms' innovation activities in oligopolistic market structures. In particular, we have discussed the different scenarios that can emerge due to (cooperative or non cooperative) firms' behavior with respect to R&D activities, as well as public intervention to favor innovation. The analysis of the equilibria yielded by each scenario has allowed us to compare the level of social welfare attained under different policy choices [14].

Multicriteria decision making and corporate strategy   The research activity has been mainly devoted to discussing the links between multicriteria decision making and corporate strategy [13]. Financial decisions are analyzed in a multicriteria environment, where problems cannot be expressed by a utility function, and neoclassical economic theory cannot be used. However, outranking methods provide strictly formal rational solutions, which are consistent with behavioral economic theory. Our research highlights that real strategic choices are consistent with the behavioral theory of the firm and thus neoclassical economic theory is no longer the only theoretical and empirical frame of reference. Multicriteria analysis, conducted on the basis of outranking methods, can provide strictly rational solutions to strategy choice problems.

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