

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

Research Report
2001

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1 Introduction

This report presents an overview of the research activity carried out at the Department of Computer and System Sciences “Antonio Ruberti” of the University of Rome “La Sapienza” during the year 2001.

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

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

The academic staff of the Department is composed by 24 professors, 19 associate professors, 15 researchers. They provide education at the undergraduate and graduate levels to several programs of the School of Engineering at “La Sapienza”, with main responsibility in the Engineering programs in Informatics, System and Control Science, and Management.

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

- Computer Science
- System Science
- Management Science

The Department offers four Ph.D. programs.

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 at three different sites:

DIS-Eudossiana

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

DIS-Buonarroti

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

DIS-Salaria

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

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

2.2 Facilities

Library The DIS library was established in 1970. Around 11,000 books and conference proceedings, plus 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/~bibdis>.

Research Laboratories

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

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

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

Associate Professors

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

Researchers

Anna BASSANINI	Luca BECCHETTI
Luca BENVENUTI	Claudia CALIFANO
Diego CALVANESE	Paolo DI GIAMBERARDINO
Paolo LIBERATORE	Carlo MANNINO
Laura PALAGI	Francesco QUAGLIA
Pierfrancesco REVERBERI	Massimo ROMA
Riccardo ROSATI	Marco TEMPERINI
Marilena VENDITTELLI	

Associate and Post Doctoral Researchers

Camil DEMETRESCU	Giovanni FASANO
Daniela IACOVIELLO (Post doc)	Luca IOCCHI (Post doc)
Giampaolo LIUZZI	Raffaella MATTONE
Andrea SANTORO	Roberta SESTINI

Staff members

Administrative

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

Technical

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

Auxiliary Services

Pia BONANNI Maria Carmina MASTROCOLA Antonio SIMEONI

Library

Angelina DE SALVO

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

2.4 Ph.D. Programs

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

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

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

Ph.D. students (working at DIS)

XVI course	XVII course
DI GIACOMO Paola	POLI Samantha

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

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

Ph.D. students

XIV course	XV course	XVI course	XVII course
BENEDETTI Marco	CALÌ Andrea	INZERILLI Tiziano	BAHADORI G. Shahram
CRESCENZI Walter	LAURA Luigi	KIMANI Stephen	BERARDI Daniela
FINZI Alberto	MARCHETTI Carlo	LEMBO Domenico	FARINELLI Alessandro
MECELLA Massimo	PIRRONE Marco	PIANURA Daniele	MANCINI Toni
VITALETTI Andrea	ROMANO Massimo	SCANNAPIECO Monica	OGLIETTI M. Alejandro
	SANTORO Andrea	VIRGILLITO Antonio	POLICELLA Nicola
		ZITO Fabio	SAVELLI Francesco

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

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

Ph.D. students (working at DIS)

XIV course	XVI course	XVII course
AVENALI Alessandro	MATTIA Sara	DEL SORBO Filomena
LAZZARI Cinzia	PICCIALLI Veronica	GARGIULO Alessandro
	TORELLI Renato	LOMBARDI Giuseppe

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, resource management for wireless systems.

Ph.D. students

XIV course	XV course	XVI course	XVII course
ADACHER Ludovica	CONFORTO Paolo	BRANDES Amit	LUCCHETTI Matteo
BETTINI Alessandro	TEMPERANZA Daniele	PASCUCCI Federica	POMPILI Dario
IANNITTI Stefano		PIETRABISSA Antonio	ZAVAGLI Massimo
		VERGARI Stefania	ZONFRILLI Fabio

Educational Laboratories

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

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

Person in charge: Daniele NARDI.

Location: Via Tiburtina 205, Roma.

PC and Workstations Lab “Paolo Ercoli” for advanced courses. About 75 PC and workstations for the teaching activities of third to fifth year of the laurea degree.

Person in charge: Roberto BALDONI.

Location: Via Eudossiana 18, Roma.

2.5 Contracts signed in year 2001

In the following, we list the research contracts signed in year 2001.

Contracts with the European Union

Contractor	Value (EURO)	Title	Project Leader
E.U.	28.440	Approximation and Online Algorithms for Optimization Problems (APPOL II)	Leonardi S.
E.U.	116.794	Intelligent Fault Tolerant Control in Integrated Systems (IFATIS)	Isidori A.
E.U.	6.800	Competence Development in international Oriented Companies (CIOCI) Project n. 18	Temperini M.

Contracts with Italian research Institutions

Contractor	Value (MLit.)	Title	Project Leader
A.S.I.	150	SACSO: Safety Critical Software for planning in space robotics	Carlucci L.
A.S.I.	140	MAARS: A Mobile Aero-Assisted Robotic System for Mars Exploration	Monaco S.
A.S.I.	50	PEGASO: Percept Golog for Autonomous agents in Space station Operations	Pirri M. F.
C.N.R.	55	Programma Multimediale Basi dati multimediali	Ausiello G.
C.N.R.	17	Algoritmi per l'ottimizzazione degli apparati di risonanza magnetica	Grippo L.
C.N.R.	30	Algoritmi di ottimizzazione globale per la progettazione di motori elettrici	Lucidi S.
C.N.R.	55	Pianificazione e monitoraggio in tempo reale dei soccorsi in gravi disastri	Nardi D.
C.N.R.	15	Metodi di ottimizzazione per l'adde- stramento di Support Vector Machines	Palagi L.
C.N.R.	15	Agente conversazionale e personificato	Schaerf M.

Contractor	Value (MLit)	Title	Project Leader
I.S.T.A.T.	120	Modelli e algoritmi per problemi di edit ed imputation	Sassano A.
M.U.R.S.T.	129	Metodologie ed infrastrutture cooperative per la qualità dei dati	Catarci T.
M.U.R.S.T.	45	Algoritmi efficienti per il sequenziamento delle richieste degli utenti e per l'allocazione di banda in reti senza fili	Marchetti Spaccamela A.
M.U.R.S.T.	148	Progettazione di reti wireless per la diffusione digitale e per l'UMTS: pianificazione ottima e comportamenti economici	Sassano A.
M.U.R.S.T.	77	Sistemi WEB affidabili	Ciciani B.

Contracts with others (companies, etc.)

Contractor	Value (MLit.)	Title	Project Leader
Tecnospazio Spa	18	“MARVISS”: Mano Antropomorfa e Realtá Virtuale per sistemi Robotici della Stazione Spaziale	Pirri M. F.
12snap Italy srl	25	Sperimentazione di piattaforme basate su dispositivi cellulari/ hand held per la gestione di Mobile Commerce e Mobile Marketing	Catarci T. Santucci G.
INTECS SISTEMI Spa	10	Sistema per la diagnosi e predizione dei guasti per un sistema informatico integrato di manutenzione e gestione navale	Carlucci L.
Cassa italiana previdenza e assistenza dei geometri liberi professionisti	20	Monitoraggio dello stato di avanzamento dei lavori di sviluppo software eseguito dalla Ditta esterna. Validazione progressiva degli elementi software rilasciati nel tempo dalla ditta esterna. Collaudo finale del sistema informatico di supporto al sistema informativo della CASSA	Marchetti Spaccamela A.
T.R.S.	105	Tecnologie informatiche 'object oriented' nell'ambito del progetto MET IS 2000	Ausiello G.
C.M. SISTEMI Spa	79,200	Definizione di un sistema per l'integrazione dei dati	Lenzerini M.

Contractor	Value (MLit)	Title	Project Leader
T.V. FILES SPA	20	Aspetti di ricerca sullo sviluppo e commercializzazione di servizi e contenuti multimediali a banda larga su protocollo Internet trasmessi in modalità multicast via satellite	Delli Priscoli F.
SERCO LTD	9,680	PRUE Project Contratto Numero: IST-1999-20692	Catarci T.
I. & T. Spa	327,600	Formazione ricercatori per "e-Commerce"	Lenzerini M.
NETIKOS Spa	74	Contratto di Sponsorizzazione delle attività di ricerca volte alla realizzazione e partecipazione alle competizioni scientifiche RoboCup	Nardi D.
Project Automation Spa	30	Definizione di un progetto di ricerca per la investigazione di tecnologie software ed applicazioni innovative per la gestione della mobilità e dell'inquinamento atmosferico ed acustico nei grandi centri urbani	Nanni U.
Space Engineering Spa	55	Studio, sintesi e verifica presso un utente finale di un sistema di automazione industriale basato anche su tecniche di "soft computing"	De Carli A.

Contractor	Value (MLit)	Title	Project Leader
CRMPA - Centro di Ricerca in Matematica Pura ed Applicata	30	Studio e definizione di metodologie e linguaggi per la riorganizzazione e la valorizzazione del patrimonio culturale	Schaerf M.
Etnoteam Spa	20	Definizione dei requisiti di sistema e dell'architettura all'interno del EU-IST-AO326	Leonardi S.
Gruppo Editoriale L'ESPRESSO Spa	20	Studio e definizione di modelli per la previsione della vendita di prodotti editoriali	De Santis A. Farina L. Benvenuti L.
EOARD - European Office of Aerospace Research and Development	53.000 US\$	Monitoring and information fusion for search and rescue operations in large-scale disasters	Nardi D.

Framework Programmes

Contractor	Leader
ACCENTURE Spa	Di Pillo G.
CRMPA -Centro di Ricerca in Matematica Pura ed Applicata	Di Pillo 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 Committees of prestigious International Conferences. Alberto Marchetti-Spaccamela was co-chair in the Program Committee of the Workshop on Algorithm Engineering of year 2001. The AE group has recently organized several international scientific events and will organize in Rome ALGO 2002, where the European Symposium on Algorithms (ESA 2002), the Workshop on Approximation Algorithms for Combinatorial Optimization (APPROX 2002), and the Workshop on Algorithms in Bioinformatics (WABI 2002) 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 prestigious research institutions: Max Planck für Informatik (Saarbrücken, Germany), CTI-Patras (Greece), ETH

(Zurich, Switzerland), Université de Paris (Dauphine, France), Tel-Aviv University (Israel), AT&T - Research Labs (Florham Park, 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 “Resource Allocation in Computer Networks”; MURST National Project “Rete multimediale nell’evoluzione verso UTMS - Linea di ricerca Applicazione ai beni culturali”; EU-IST COSIN “Coevolution and self-organization in dynamical networks”.

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 and on directed hypergraphs. In particular, we have shown how to maintain all-pairs shortest paths in a graph with n vertices whose edges can assume at most S different real values in $O(Sn^{2.5} \log^3 n)$ amortized time per update. Queries about shortest paths are answered in optimal worst-case time. Although studied since the late 60’s, no previous fully dynamic algorithm was known for this problem. For the partially dynamic version of the problem, we have shown how to support increases in $O(Sn \log^3 n)$ amortized time per operation. In the special case of unit edge weights, both sequences of insertions and sequences of deletions can be supported in $O(n)$ amortized time per operation. Besides, new algorithms for maintaining shortest hyperpaths in a decremental setting have been devised. These results appeared in [9, 14, 12, 5].

Multilevel memories It is well known that current hw/sw platforms are based on hierarchical memory systems, aiming at the best exploitation of the capabilities of modern architectures. Since the traditional techniques for analysing/designing algorithms are closely related to a fixed memory model (RAM or external memory) they are unable to validate algorithms/programs to be run on real multilevel memory systems. On the other hand, algorithms showing good locality properties are expected to have satisfactory performance on such systems. In this framework, we are currently defining a model for analysing algorithms without making use of information about platforms which programs will run on. In such model, algorithm’s performance is measured in terms of locality (both spatial and temporal) and becomes independent on physical parameters. The detailed definition of the model is expected during 2002.

Distributed and network algorithms We have studied the problem of scheduling IP packets over a wireless link when multiple traffic classes are present. We have proposed efficient algorithms for this problem and have proved that they greatly increase performance, via extensive simulations. We have also studied standard mobile data technology, showing that Cellular Digital Packet Data (CDPD) can be used to localize mobile data users and to provide location based services. Results in this area appeared in [3, 13].

Approximate and on-line algorithms We have studied some aspects of weighted flow time on single and parallel machines, proving that the online algorithm Highest Density First is constant approximate and the Multi-level Feedback algorithm achieves the best possible performance when the arrival and the processing times of jobs are not known a priori. We have also considered the problem of on-line call admission and routing on trees and meshes, giving a new family of randomized algorithms with asymptotically optimal competitive ratios, and “good” probability to get a profit close to the expectation. In the case of optical networks, we have presented a general technique that allows us to reduce the problem of call admission and wavelength selection to the call admission problem, and giving randomized algorithms with logarithmic competitive ratios for specific topologies in switchless and reconfigurable optical networks. We have finally considered the on-line problem of serving a sequence of requests located at points of a metric space, presenting constant competitive algorithms for two version of this problem on general metric spaces and on specific topologies like line networks. This problem has a variety of relevant applications in logistics and robotics. Works in this area appeared in [1, 2, 10, 11, 6].

Experimentation and visualization We have addressed the role of visualization in algorithm engineering, studying the main approaches and existing tools and identifying difficulties and relevant examples where visualization systems have helped developers gain insight about algorithms, test implementation weaknesses, and tune suitable heuristics for improving the practical performances of algorithmic codes. We have also performed an extensive comparative study of the main approaches used in algorithm visualization and we have devised a novel technique for supporting smooth animation of algorithms. Works in this area appeared in [4, 7, 8].

Journals

- [1] G. Ausiello, E. Feuerstein, S. Leonardi, L. Stougie and M. Talamo. Algorithms for the on-line traveling-salesman. *Algorithmica*, Vol 9, n. 4, pp. 560-581, 2001.
- [2] B. Awerbuch, Y. Azar, A. Fiat, S. Leonardi and A. Rosèn. On-line competitive algorithms for call control in optical networks. *Algorithmica* 31(1), pp. 29-43, 2001.

- [3] L. Becchetti, F. Delli Priscoli, T. Inzerilli, P. Mahonen, and L. Munoz. Enhancing IP service provision over heterogeneous wireless networks: a path toward 4G. *IEEE Communications Magazine*, Vol.: 39, Issue: 8, pp. 74–81, Aug. 2001
- [4] C. Demetrescu and I. Finocchi. Smooth Animation of Algorithms in a Declarative Framework. *Journal of Visual Languages and Computing (JVLC)*, 12(3), Special Issue devoted to selected papers from the 15th IEEE Symposium on Visual Languages, Academic Press, 2001.
- [5] P.G. Franciosa, D. Frigioni and R. Giaccio. Semi-dynamic breadth-first search in digraphs. *Theoretical Computer Science*, 250(1–2), pp. 201–217, 2001.
- [6] S. Leonardi, A. Marchetti-Spaccamela, A. Presciutti and A. Rosén. On-line Randomized Call-Control Revisited. *SIAM Journal on Computing* 31(1), pp. 86-112, 2001.

Book

- [7] C. Demetrescu, I. Finocchi, G.F. Italiano, and S. Naeher. Visualization in algorithm engineering: Tools and techniques. In *Experimental Algorithmics State-of-the-Art Survey*. R. Fleischer (ed.), LNCS, Springer Verlag, 2001.
- [8] C. Demetrescu, I. Finocchi, and J.T. Stasko. Specifying algorithm visualizations: Interesting events or state mapping? In *Software Visualization State-of-the-Art Survey*. S. Diehl (ed.), LNCS 2269, Springer Verlag, 2001.

Conference Proceedings

- [9] G. Ausiello, P.G. Franciosa, and D. Frigioni. Directed hypergraphs: Problems, algorithmic results, and a novel decremental algorithm. *ICTCS 2001*, Lecture Notes in Computer Science 2202, 312-327, Springer 2001
- [10] L. Becchetti and S. Leonardi. Non-Clairvoyant Scheduling to Minimize the Average Flow Time on Single and Parallel Machines. In *Proc. 33-rd ACM Symposium on the Theory of Computing*, pp. 94-103, 2001.
- [11] L. Becchetti, S. Leonardi, A. Marchetti-Spaccamela and K. Pruhs. Online Weighted Flow Time and Deadline Scheduling. In *Proc. APPROX 01, LNCS 2129*, Springer eds., pp. 36-47, 2001.
- [12] C. Demetrescu and G.F. Italiano. Fully dynamic all pairs shortest paths with real edge weights. In *Proc. of the 42nd IEEE Annual Symposium on Foundations of Computer Science (FOCS'01), Las Vegas, NE, October 14-17, 2001*.

- [13] R. Jana, T. Johnson, S. Muthukrishnan and A. Vitaletti. Location based services in a wireless WAN using cellular digital packet data (CDPD). *MobiDE 2001*: 74-80

Ph.D. Thesis

- [14] C. Demetrescu. *Fully Dynamic Algorithms for Path Problems on Directed Graphs*. Ph.D. thesis, Department of Computer and System Sciences, University of Rome “La Sapienza”, February 2001.

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

7. The study of computational properties of formalisms, languages, and reasoning tools. These topics are illustrated in the Section “Complexity of Reasoning”.
8. 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 Sixth International Conference on Logic Programming and Nonmonotonic Reasoning, LPNMR 2001. Daniele Nardi was invited speaker at the Workshop on RoboCup, at the RoboCup German Open 2001. The members of the group have participated at the Program Committees of several International Conferences, among which IJCAI-01, Agents-01, ATAL-2001, KI-2001, KRDB-01, RoboCup2001, ECP01, FMII-01, LPAR-01; Maurizio Lenzerini was organizer of Knowledge Representation meets Databases (KRDB-01), held in Roma, September 2001. Amedeo Cesta has been Program Chair of the European Conference on Planning (ECP-01) held in Toledo (Spain) September 2001. Nicola Policella was winner of the 2001 AI*IA Prize for Best Master Thesis.

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

Group members Luigia CARLUCCI AIELLO , Marco BENEDETTI, Daniela BERRARDI, Marco CADOLI, Andrea CALÍ, Diego CALVANESE, Amedeo CESTA [CNR], Giuseppe DE GIACOMO, Francesco M. DONINI [Politecnico di Bari], Alessandro FARINELLI, Alberto FINZI, Luca IOCCHI, Domenico LEMBO, Maurizio Lenzerini, Paolo Liberatore, Toni MANCINI, Fabio MASSACCI [Univ. di Siena], Daniele NARDI, Angelo ODDI [CNR], Fiora PIRRI, Marco PIRRONE, Nicola POLICELLA, Massimo ROMANO, Riccardo ROSATI, Francesco SAVELLI, Marco SCHAERF.

Common Sense Reasoning Commonsense reasoning is the study of 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 epistemic logic [8] and belief revision [6].

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. A survey of reasoning techniques for expressive variants of DLs is given in [10]. The extension of such DLs with identification constraints and functional dependencies is studied in [20]. A formalization of UML class diagrams in terms of DLs has been given in [18]. Exploiting such a formalization, a comparison of state of the art DLs reasoning systems, based on their ability to reason on UML class diagrams of increasing complexity, is reported in [14]. DLs have also been successfully applied to information integration, and to the integration of ontologies [19, 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. 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 [3].

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. 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 results of this research are published in [42, 12, 13].

Cognitive Robotics and Reasoning about Actions Cognitive Robotics and Reasoning about Actions are areas concerned with the theory and the implementation of robots that reason, act and perceive in changing, incompletely known, unpredictable environments. Such robots must have higher level cognitive functions that involve reasoning, for example, about goals, actions, when to perceive and what to look for, the cognitive states of other agents, time, collaborative task execution, etc.

The research at DIS on Cognitive Robotics and Reasoning about Actions focus on several aspects, including: cognitive architectures [31]; diagnosis and failure management [29, 28, 30]; foundations of theory of actions [4]; planning under incomplete information [34].

Multi-robot and Multi-agent Systems One of the main features of an intelligent agent is the ability to cooperate with other agents in order to achieve a common goal. The RoboCup competition has been organized with the aim of providing Artificial Intelligence and Autonomous Robotics research with a common experimental setting given by a soccer match between robotic or virtual agents teams. We have participated to RoboCup 2001 (Seattle, August 2001) with a team of legged robots [35] and a team of self-designed wheeled robots [33]. In the RoboCup setting we have exploited several research issues concerning multi-robot systems [11]. In particular, we have developed techniques for localization [32] mobile robots control and navigation, image processing and vision, and for team coordination [2]. 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* [24, 9].

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 2001, the AI group has continued the investigation on fundamental properties of complexity of reasoning, with the overall goal of designing computationally efficient and adequately expressive systems for Knowledge Representation and Reasoning. In particular, research has focused on general complexity results, computational complexity of specific logical formalisms, algorithms for specific forms of reasoning, logical compilation of knowledge, experimental analysis of computationally hard problems, approximation of logical inference to gain efficiency, languages for the specification of hard problems. The main results on the topic have been published in [1, 5, 17, 16, 15, 37, 40, 38, 39].

Constraint-Based Architectures for Planning and Scheduling This line of research is aimed at developing constraint-based methods for automated planning and scheduling. Different specific aspects has been addressed during this year like (a) new solution techniques for complex project scheduling problems with cumulative resources [41], (b) specific constraint propagation techniques for resource constraints [7], and (c) complete algorithms for more complex temporal representation called the Disjunctive Temporal Problem [36]. A different research activity aims at integrating the basic research on constraint satisfaction problems (CSP) in a software

architecture for scheduling problems named O-OSCAR. New activities have developed a module for user-solver interaction [25], a basic execution controller for the scheduler [27], and an application for a specific data downlink problem on MARS-EXPRESS an ESA program under development [26]. A new line of research has been activated on the integration of different planning and verification techniques for complex space problems. Initial results are described in [23, 22].

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3.1.3 Data and Knowledge Bases

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

- Theoretical and application-oriented aspects of visual formalisms for databases and database design, with special focus on Visual Query Languages and Interfaces, 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-Government.

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 heterogeneous sources”. Progetto MURST (COFIN): “Methodologies and tools for data quality inside cooperative information systems”. Progetto MURST (FONDO STRATEGICO 2000): “VISPO - Piattaforma a Servizi per Distretti Virtuali”. Progetto CEE “Sewasie”, Progetto CEE “Infomix”. 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, Stephen KIMANI, Domenico LEMBO, Maurizio LENZERINI, Massimo MECELLA, Giuseppe SANTUCCI, Silvio SALZA, Monica SCANNAPIECO.

Data integration Data integration is the problem of combining the data residing at different 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 [1, 2, 12, 21, 13, 14, 23, 21, 27, 10, 11].

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 [22, 24, 15].

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 [20, 3, 9].

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 [8, 25, 26, 16]. 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 [28, 29].

Digital Libraries Among the wide range of digital libraries, an interesting subclass is constituted by those exclusively dealing with newspapers' clippings. LAURIN is an EU-funded Project involving seventeen participants from several countries, including a large group of libraries that want to make easily available and give wide visibility to the large cultural heritage they collect and catalog daily. The LAURIN system is organized around a *central node*, which is connected via the Internet to a set of *local nodes*, one for each participating library. The central node contains indexing data about all clippings stored in the local nodes, and a centralized copy of a multilingual Thesaurus with globally validated entries. The digitalized clippings and their full-text are stored in the local nodes, together with a local, possibly personalized, copy of the Thesaurus. A constant flow of information from the local nodes to the central node ensures that the latter is up to date. A suite of friendly interfaces are available to accommodate the needs of various user classes. [5].

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. Among the main objectives of Plinius is designing a cultural heritage oriented authoring system to help the author to create both virtual and real exhibitions [4].

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 [18][7][17] such issues are addressed, specifically the development of CIS's based on the coordination of different services (referred to as E-Services) offered by different organizations.

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 based on an E-Service approach is the E-Government one, and specifically the Italian E-Government initiative. The research [6][19] is focusing on a critical analysis of such initiative, in order (i) verify the appropriateness of the E-Service-based approach to such a context, (ii) to derive methodological suggestions for a development process specifically tailored for Government CIS's, and (iii) 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 Committees of prestigious International Conferences such as ICDCS, PADS, SRDS, DOA, WORDS, COOPIS, ISORC. Members have also recently chaired the Program Committee of WORDS'01, the "Tutorial and Short Paper" Program Committee of DOA'01 and the Program Committee of PADS'02.

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

The DS group is presently involved in the following research projects: EU-IST EU-PUBLI.COM; MURST "Resource Allocation in Computer Networks"; MURST "Methodologies and tools for Data Quality inside cooperative information systems". The distributed systems group is member of "CABERNET" Network of Excellence in Distributed Systems Architectures chaired by Brian Randell.

Group members Roberto BALDONI, Roberto BERARDI, 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, yet their major drawback lies in the fact that each message has to carry an array of n integers, where n is the number of processes. Several known methods have to face the problem of the size of piggybacked information that is prohibitive.

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

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

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

1. Scalable protocols for cooperative web proxy cache sharing.
2. Global caching algorithms in web clusters.

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

As respect with the second issue, we have analyzed how to improve Web cluster performance through global caching. We have considered different cache cooperation approaches for replica discovery, such as on-demand and periodic information exchange, and various mechanisms for retrieving requested documents from a remote node, such as hand-off, migration and replication-based. All the schemes have

been evaluated through a detailed workload and simulation model. The results have shown that a cluster with cooperative caches can perform even twofold better than a traditional Web cluster with no server cooperation.

Parallel simulation Optimistic methods for parallel/distributed simulation let concurrent processes execute simulation events whenever they are available, optimistically assuming that the execution does not violate causality. Checkpoint-based rollback is used to recover from out of order computations. In this context, a first objective was the definition of checkpointing mechanisms to reduce the overall checkpointing-recovery overhead. To this purpose, an analytical model for the determination of “optimal” checkpoint positions has been presented, also, a model for the case of hybrid recovery (forward/backward) has been developed. In addition, we have designed, implemented and tested a Checkpointing and Communication Library (CCL) for clusters based on Myrinet switches, which supports both fast message delivery and also CPU offloaded checkpointing functionalities.

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

Finally, we have addressed the problem of tailoring optimism to proper simulation model execution dynamics, to reduce the likelihood of causality violations for the specific execution.

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 back-end 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 mid-tier with specific QoS enhancement.

In this context we have introduced a novel software replication technique, namely *asynchronous active replication*, interposing a mid-tier between clients and server replicas in order to maintain strong replica consistency despite of client, server and mid-tier failures. This technique allows (i) to deploy server replicas within an *asynchronous* distributed system and (ii) to implement very thin clients (unaware of replication).

The most visible practical result of this wide study is the development of the Interoperable Replication Logic (see next paragraph) and several studies on implementations 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 is a software infrastructure for software replication that comply to 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. (2) 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. To achieve previous features, IRL adopts an “above the ORB” design implementing *asynchronous active replication*. As a consequence IRL inherits the advantages of such replications techniques.

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. We have presented some practical lessons learned by programming CORBA interceptors and an extensive performances study, in order to understand which tasks can be actually demanded to interceptors for enhancing 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.

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.

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. 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.

Handling weaker failure semantics. In this work we try to understand how to build reliable systems in an environment where arbitrary failures can occurs. 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. 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 research activities of a number of scientists, coming from university, Research and industrial bodies.

We work 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. 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 most recent developments of the theory, with some applications, in [2, 1].

Open and Distance Learning After the experience with the Socrates Project no 56544-CP-1-98-1-NO-ODL-ODL *EuroCompetence*, we have started a new collaboration with our european partners in a project on *Competence Development in Internationally Oriented Companies* (CIOOC, funded by the NFU (Norwegian State Institution for Distance Education, project n. 18, 2000-2002, participants from TISIP Trondheim, Siemens Metering, University of Greenwich, NITOL and TEI Thessaloniki) [3].

Recently, a new initiative has been approved for funding by the European Community: MENU (Model for a European Networked University for e-learning, Directorate general for education and culture, project number NO001ELEARN011, <http://www.hsh.no/menu/>).

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3.2 System Science

3.2.1 Biomedical Systems

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

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

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

Analysis and Modeling of Metabolic Systems In the context of this project, models of kinetics and metabolism of dicarboxylic acids have been developed to investigate the possibility of using these substances as an alternative energy substrate. In the last year 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 a more accurate estimate of the muscle hydration both in normal and obese subjects. The interest was also focused on non-invasive, non expensive techniques for the "in vivo" body composition estimation. In particular the Bioimpedance technique seems to be useful for estimating the muscular volume distribution along the lower limb in normal and obese subjects.

Analysis of Brain Potential related to Motor Control In the last year, the interest was mainly focused to 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. At the same time, different types of classifiers have been implemented in order to compare their performance in the recognition of mental patterns. In this context an object oriented model for cognitive bio-feedback systems has been developed.

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3.2.2 Hybrid Systems

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

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

National and international research projects include: MAARS (Mobile Aero-Assisted Robotic System for Mars Exploration), orthosis 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 Supérieure d'Electricité, Gif-sur-Yvette, Department of Electrical Engineering, University of L'Aquila, PARADES Research Lab.

During 2001, a patent has been obtained by S. Monaco, A. Pignatelli and G. Filaci: SACS - Spacecraft Attitude Control Simulator - a platform for attitude control experiments, Patent n. 01302943 by ASI (Italian Space Agency).

Group members Alessandro DE CARLI, Claudio GORI GIORGI, Salvatore MONACO, Lorenzo FARINA, Luca BENVENUTI, Claudia CALIFANO, Paolo DI GIAMBERARDINO, Raffaella MATTONE (Lecturer - Part Time), Leonardo DAGA (Lecturer), Francesco LAGALA (Lecturer), Roberto RONCHINI (Lecturer), Amit BRANDES.

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

Most relevant publications in this area are [17], [18] and [2].

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 an 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.

Most relevant publications in the area of discrete-time systems are: [1], [12] and [6].

Digital control A digital controller can be set following different approaches: by implementing a *digital equivalent* of a continuous controller, by designing a discrete controller based on a discrete-time model of the plant, taking eventually into account the coexistence of continuous and sampled signals. This last approach allows to satisfy more interesting control requirements such as dead beat or minimum time control. On the other hand, its main limits stand in the difficulty of computing sampled models and the lack of easy design methods. A new design procedure has thus been recently proposed, based on the idea of modifying the given plant by a preliminary continuous feedback for achieving a dynamics which can be easily controlled in discrete time. This hybrid control scheme enables naturally to tackle the coexistence of discrete and continuous signals. Work on this topic concerns the control of mobile robotic systems, underactuated mechanical structures, induction motors, space crafts. Moreover, the design of hybrid controllers and the verification of several closed-loop performances has been studied for a detailed, cycle-accurate hybrid model of an automotive engine. The hybrid control approach used is based on a two-step process. In the first step, a continuous approximation of the hybrid problem is solved exactly and then, the control law so obtained is adjusted to satisfy the constraints imposed by the hybrid model.

Most relevant publications in the area of digital control are: [5], [4], [20] and [19]. Most relevant publications in the area of automotive systems control are [7], [13] and [14].

Positive systems Positive systems are characterized by the specific property that the state and output variables remain nonnegative whatever the positive input sequence might be. These systems are quite common in applications where input, output and state variables represent positive quantities such as populations, consumption of goods, densities of chemical species and so on. During the year 2001, the work on this topic has focused on applications of the theoretical results developed by this group on the positive realization problem. It has been presented a procedure for designing fiber optic filters directly in the optical domain avoiding costly electro-optic and optoelectronic conversions. Another application regards the identification problem for positive systems, in fact, the information on positivity of input/state/output variables stem directly from the intrinsic nature of the problem, so that it is a-priori available. It has been presented a methodology for constraining within positive systems, the model to be identified.

Most relevant publications in this area are: [8], [3], [10], [21], [11] 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; moreover identification of compartmental models is investigated in pharmacokinetics problems and various metabolics processes.

In the second area the application of the optimization techniques to traffic control in a wireless network is mainly considered (part of this latter research was developed 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, Matteo LUCCHETTI, Caterina SCOGGIO, 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 degraded by blurring effect and additive noise. We formulate these problems as global constrained optimization problems over suitable functional spaces, properly 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 have been proposed, 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.

In the same context the problem of on line identification of discontinuities in 1D signals has also been considered with possible applications to fault detection and Kalman filter compensation.

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 one, transforming the quality of services requirements (jitter, maximum delay, minimum admitted rate requirements) into suitable analytical constraints. The existence and uniqueness of optimal solution have been proved and numerical procedures have been studied for its computation.

Also the problem of optimal capacity allocation for a Label Switched Path in a MPLS Network have been dealt with as a quadratic programming problem; the attention was focused on possibility of yielding quasi-on line suboptimal solutions. The optimal linear-quadratic-gaussian tracking problem was studied, under the assumption that the reference signal is a random process, with a known, time variable, non zero mean value. The solution does exist, unique, and its closed form is given. 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. Extension of such a methodology to nonlinear systems based on neural networks was also considered. Furthermore robust stabilization for a class of nonlinear distributed parameter systems was studied for large space structures in large attitude maneuvers.

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3.2.4 Nonlinear Systems

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

Group members Stefano BATTILOTTI, Francesco DELLI PRISCOLI, Alberto ISIDORI, Antonio PIETRABISSA.

Resource Management in wireless systems This research is mainly performed in the framework of eight European Union (fifth framework programme) and one European Space Agency (ESA) research projects (named WINE, WIND-FLEX, GEOCAST, BRAHMS, VIRTUOUS, SUITED, NATASHA, SATIP6 and DOMINO 2) entailing a net financing for DIS of about 1.800.000 Euro for research activities covering the period 2000-2003. These projects, performed within consortia involving major european universities/research centers, manufactures and operators (about 10 companies per project), aim at the research, the design, the development and the standardisation of third generation (UMTS at 2 Mbps) and fourth generation (wireless broadband system at 100 Mbps) wireless terrestrial and satellite systems. The DIS scientific responsible for all the above-mentioned projects is Francesco Delli Priscoli.

In 2001, the DIS role in the framework of these projects mainly concerns the research, the design and the simulation (by using the OPNET tool) and the implementation (Linux real-time) of the following Resource Management procedures:

(i) Connection Admission Control (CAC) procedures which control the admittance of new connections in the wireless network with the aim of avoiding network overloading. In case a new connection is admitted, the CAC procedures negotiate a Quality of Service (QoS) contract specifying the QoS guarantees (in terms of minimum bit rate, maximum packet transfer delay, maximum packet delay jitter and maximum packet loss); (ii) Congestion control procedures which dynamically control the admittance in the wireless network of the traffic emitted by the sources relevant to the connections in progress (i.e. the ones admitted by the CAC procedures) with the contrasting aims of maximizing the admitted traffic and of respecting the QoS guarantees for such traffic; (iii) Scheduling procedures which dynamically assign the air interface capacity resources (e.g. time slots) to the packets admitted (by the congestion control procedures) into the wireless network with the aim of maximizing the exploitation of the air interface capacity, while avoiding too long queuing delays.

During 2001 the research on the above-mentioned issues have been performed, in a synergistic way, by many DIS Professors, Researchers and PhD Students, also availing of the cooperation of INFOCOM Department. In 2001, about 25 work contracts have been granted on these activities to young engineers and about 30 theses have been discussed on these issues. In 2001 plenty of innovative contributions have been produced by using control (Bruni, Isidori, Delli Priscoli, Koch, Pietrabissa, Vergari, Pompili), information (Marchetti, Becchetti, Inzerilli), operation research (Sassano, Mannino, Lombardi, Del Sorbo) and telecommunication (Cusani, Dini, Razzano) competences. These contributions are reported in about 20 papers submitted to major international conferences and reviews, a plenty of Deliverables relevant to the above-mentioned projects (technical reports, software OPNET models and hardware realisations), 3 patents and the above-mentioned theses.

Nonlinear regulation with adaptive internal model [1, 2, 9, 10] The objective of this research is to develop a control structure which, using only sensed information about the error between actual and prescribed path, asymptotic tracking of uncertain trajectories 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. We have proposed an adaptation mechanism for a large class of (minimum-phase) nonlinear systems and analyzed its convergence for arbitrary compact sets of initial conditions.

Fault detection for nonlinear systems [2, 13, 14] 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). In our research, using suitable differential-geometric methods, 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. Moreover, the theory has been also extended to deal with the presence of measurement noise.

Robust stability and regulation of nonlinear systems [7, 8, 11, 12] In this research, we have addressed the problem of globally asymptotically stabilizing a general class of nonlinear feedforward systems in presence of uncertain parameters affecting the model of the system and un-modeled actuator dynamics. This work can be seen as a nontrivial extension of a previously developed results on the stabilization of feedforward with time-varying and uncertain feedforward gains. To solve the problem we assume a controllability condition on the linear approximation of the plant and input-to-state stability for the un-modeled actuator dynamics.

We also 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 an upper triangular structure (feedforward systems) and lower triangular structure (feedback systems).

Moreover, we 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.

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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 Scienza Macchinale) 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 the MURST *MISTRAL* national project, 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 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. An algorithm for uniform scaling of trajectories under torque constraints is presented in [13], generalizing the results of the rigid case. The adoption of lightweight manipulators to replace slow and massive robots may prove very useful for large structures. Lightness or very slender mechanical design usually implies the presence of link flexibility, with associated control difficulties (e.g., non-minimum phase of the end-effector position output). We have solved the rest-to-rest motion problem in given time for a general single flexible link [5] and for the two-link planar robot with flexible forearm (the *FLEXARM* available at Università di Roma Tre), including one flexible mode [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 [7], while the fallacy of some stabilization techniques is pointed out in [1]. A general controllability analysis (in particular, a test for STLTC) has been developed for planar robots with one passive joint [14]. For robots with the first two actuated joints (of any type) and a rotational

passive third joint, we have proposed a method for motion planning between two states and an associated trajectory tracking controller, based on dynamic feedback linearization. This approach works with or without gravity, and can be extended to nR planar robots with the last joint passive [15] or even with the last $n - 2$ joints passive, under a mechanical condition on the centers of percussion [8, 21]. More difficult is the case of 2-dof robots in the absence of gravity, with only the first (rotational or prismatic) joint actuated. A stabilization strategy for a PR robot has been proposed in [9], 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 an iterative steering technique for achieving stabilization to a desired configuration in a robust way (i.e., rejecting small non-persistent perturbations) [2]. The plate-ball system (moving a rolling sphere on a plane using only the two $x - y$ commands of a top plate) is an example of nonholonomic system that does not admit a chained-form representation. For such system, we have computed open-loop motion commands, based on a nilpotent approximation of the kinematic equations. When applied iteratively, this steering law yields stabilization with exponential convergence [10]. On the experimental side, we have validated several nonlinear feedback controllers on the *SuperMARIO* mobile robot [3] using encoder measurements. For this unicycle-like robot, dynamic feedback linearization is a viable option for trajectory tracking and parking tasks [16]. We have also used visual feedback (obtained from a camera fixed in the environment) and compared the control performance with and without this exteroceptive sensing [17].

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 [4]. 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. We have proposed an innovative localization solution, based on a multi-modal nonlinear filter in the bayesian framework. The new filter can outperform the classical Extended Kalman Filter, since it correctly deals with the nonsmooth observations arising in indoor environments with piecewise linear boundaries. The

results have been confirmed experimentally on a ATRV-Jr mobile robot [11].

Legged Robots A new research activity deals with planning and controlling the motion of legged robots. A low-energy biped locomotion strategy has been proposed for the Sony ERS-210, the ‘Aibo’ dog designed only for quadruped gaits, fully exploiting the dynamics in the double support phase [18].

Automation and Service Robotics Automation of different off-factory activities goes under the broad name of service robotics. In the past, we have dealt successfully with the robotized sorting of garbage items from a moving conveyor belt for recycling purposes. 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 and force sensing is integrated with virtual fixtures in order to help the surgeon in driving a hand-held tool during fine motion [12]. The definition of virtual fixtures for different motion tasks (positioning, tracking, avoidance of obstacles) and the associated human-robot cooperative control schemes are presented in [22]. Experiments with different operators have been conducted at both micro and macro scales [19]. For process automation in unstructured environments, efficient clustering methods are often required when a continuous and large flow of data must be classified, e.g., in motion-based scene segmentation for video surveillance. A novel on-line competitive clustering algorithm has been developed in [20].

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3.3 Management Science

3.3.1 Combinatorial Optimization

The research activity of the Combinatorial Optimization Group is mostly devoted to theoretical and computational aspects related to i) design of telecommunication networks and ii) automated data correcting. The group is currently cooperating with Maastrich University, Konrad Zuse Zentrum für Informationstechnik Berlin, Oslo University and Università dell’Aquila. Also, it is cooperating with the Italian Public Authority for Telecommunication and with ISTAT. It is currently involved in several research project, including MURST “Optimization Models and Algorithms for Design and Management of Telecommunication Networks”, and the European Projects VIRTUOUS, FUTURE, 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. 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). [8, 2]

Satisfiability and Consistency Restoring The Satisfiability of a CNF propositional formula is a central problem for a number of areas of information processing and computation. A new DPLL-style approach to Propositional Satisfiability is proposed. Comparison on existing methods are very encouraging.

Moreover, in the case when a CNF formula is unsatisfiable, a relevant problem is the selection of a small unsatisfiable subset of clauses inside such CNF formula. This problem typically arises when unsatisfiability denotes an inconsistency, and consistency should be restored. Within a complete solution framework, we propose a procedure able to rapidly select an unsatisfiable subformula. [6, 1, 3]

Data Correction Data correctness is a crucial aspect of data quality, and, in practical cases, it has always been a computationally demanding problem. Such problems are generally tackled by using a set of rules. When such rules are only of a logical kind, the problems are modelled as Propositional Satisfiability and Set Covering problems. The proposed models have strong computational advantages on other existing approaches. When the rules are both of a logical and of a mathematical kind, an integer linear programming model of the problem is developed. The above computational advantages still hold. The proposed procedure is tested on a real-world case of Census, and the statistic quality of corrected data is very satisfactory. [4, 5, 7]

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3.3.2 Nonlinear Optimization

The research activity of the Nonlinear Optimization group is devoted to the theoretical analysis, the development and the computational experimentation of methods

for solving Nonlinear Optimization problems. The solution of problems arising from real world application is also of interest.

The Nonlinear Optimization group is currently cooperating with: Istituto di Analisi dei Sistemi ed Informatica IASI-CNR; Dipartimento di Ingegneria Elettrica, Università di L'Aquila; Dipartimento di Tecnologie Biomediche, Università di L'Aquila. During 2001, the Nonlinear Optimization group has been involved in several research projects including the following: ENEA/MURST (Sistemi di supporto alla progettazione con reti neurali di sistemi di combustione), CNR/MURST (Ottimizzazione di apparati “dedicati” di risonanza magnetica per uso clinico), CNR/MURST (Applicazione di metodi di ottimizzazione per la progettazione di motori elettrici industriali), CNR-Agenzia2000 (Metodi di ottimizzazione per l'addestramento di Support Vector Machines), COFIN/MURST (Algorithms for Complex System Optimization).

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

Unconstrained Optimization The research activity in unconstrained optimization has been mainly devoted to the definition of new methods for solving large scale problems. In this setting, the class of truncated Newton methods has been considered with the aim to efficiently solve also “difficult” problems, such as highly nonlinear and ill-conditioned problems. In particular, the preconditioning of truncated Newton methods has been studied, aiming at defining and handling a new preconditioner suited for large scale unconstrained problems. Moreover, a new Conjugate Gradient-type method for solving indefinite linear systems arising in large scale optimization has been proposed [13] [16]. A new efficient nonmonotone implementation of the Barzilai-Borwein gradient method for large-scale unconstrained minimization has been defined in [14].

A survey on large scale unconstrained optimization is reported in [8].

Constrained Optimization Problems with both general constraints and constraints with a particular structure have been addressed. In particular, a truncated Newton-type method for solving smooth nonlinear large scale optimization problems with inequality constraints has been considered; the method proposed possesses some very favourable features, like the global convergence under mild assumptions and the superlinear convergence of primal variables without strict complementarity. Moreover, primal-dual algorithms models have been defined with convergence towards 2^{nd} order stationary points [11] [12].

As concerns augmented Lagrangian functions for nonlinear programming problems, a new exact augmented Lagrangian function with improved exactness proper-

ties for the solution of general nonlinear programming problems has been proposed. In the case of two-sided constraints problems, an exact augmented Lagrangian function has been defined with the distinguishing feature to be defined by employing only one multiplier for each two-sided constraint [4] [10].

The constrained minimization of SC^1 functions subject to inequality constraints has been also of interest, and in this framework a new local and global feasible QP-free algorithm has been proposed. [17].

A survey on large scale trust region problems is reported in [7].

Nonlinear Complementarity The research activity in the field of nonlinear complementarity has been mainly devoted to the development of algorithms with improved reliability and scalability. Building upon a strong theoretical background, the semismooth algorithm has been proposed with the potential to meet both these requirements. The results on a large set of test problems showed that the proposed algorithm is reliable, efficient and suited for very large scale problems [5].

Global Optimization Global optimization represented an important topic of research. In particular, the approach based on the “filled functions” has been considered and, in this context, new classes of functions for global optimization has been proposed [15].

Neural Networks The problem of the supervised neural network training has been considered and new convergent algorithms for learning in neural network has been proposed. In particular, convergent decomposition techniques for training “radial basis” neural networks have been proposed [1]

A survey on unconstrained optimization in neural network is reported in [6].

Applications in Industrial Engineering An important aspect of the research was the definition of optimization algorithms for solving problems arising from real world applications. In particular, the following applications have been considered: the design of electrical synchronous industrial motors and the design and optimization of dedicated magnets for magnetic resonance imaging. The use of global optimization techniques allowed to obtain new designs of electrical motors with significantly improved efficiency and new multipolar magnets with a high uniformity level of the magnetic field in magnetic resonance imaging [2] [3] [9].

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3.3.3 Industrial Economics

This group mainly investigates the theoretical explanations and empirical implications of three interrelated phenomena: (i) technological innovation, (ii) strategic behavior of Multinational Enterprises (MNE) in R&D intensive industries, (iii) national policies and 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 participated to the EU network on “The Relationships between Technological Strategies of Multinational Companies and the National Systems of Innovation” (5th Framework Programme) and to the project on “R&D investment in an international context” financed by the National Research Council. We have been collaborating with several European Universities, such as Leuven Katholieke Universiteit, Belgium; University of Reading, UK; Universidad Complutense de Madrid, Spain; University of Technology, Sidney, Australia.

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

R&D Competition and Foreign Direct Investment Research in this area has aimed to analyze the effects of geographically localized spillovers on the internationalization decisions of firms. By using dynamic game methods, we have analyzed how differences in the transmission of knowledge due to geographical vicinity may affect the levels of effective R&D and innovation for each firm and each country. Within the same framework, we have also investigated whether the possibility to absorb higher knowledge can be an incentive for firms to invest abroad [2], [3].

National and Multilateral Rules on FDI and Globalization This line of research has aimed, on one hand, 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 [1], [4]. It has also highlighted why new multilateral rules on foreign direct investment are necessary, and why such rules should be the result of a Multilateral Agreement on Investment (MAI) within the ongoing WTO Round (the so-called Development Round) [10].

R&D Internationalization This strand of research examines the trade-offs faced by a multinational company when choosing whether to assign a foreign subsidiary an active role in innovation, thus when deciding if its R&D should be centralized or, at least partly, decentralized. The model focuses on how the interplay of internal and external knowledge flows interacts with the nature of host market competition to influence the choice of the multinational to effectively disperse internationally its R&D [6].

Regulation and Competition Policy This line of research investigates alternative regulatory policies that affect the viability of pricing discriminatory behavior by a price capped firm. We investigated how two alternative regulatory schemes - Relative and Absolute - might influence pricing decisions, the entry decision by potential competitors and social welfare. Two different models were developed: in the first one the new entrant's supply function per unit of capital is inelastic, while in the second one it is unit-elastic. Under both hypotheses 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 is more likely to foster competition. Via the effect induced by competition upon prices, welfare is higher under the Relative scheme [7],[8],[9].

Unbalanced growth models and sectoral employment performance The research activity in this area has investigated the reasons behind the US superior

performance in job creation in the service sector with respect to EU countries. We employed as theoretical framework the Baumol model of “unbalanced growth”. Stemming from the observation that empirical evidence does not confirm its predictions on asymptotic stagnation, we proceeded to relax its four main assumptions. 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. Empirical analysis on the correlation between wage dispersion and unemployment rate in EU countries, US and Japan validates the theoretical predictions of the analysis [5], [11].

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3.3.4 Industrial Organization and Management

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

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

We have participated to the strategic project "Optimization and Simulation for Telecommunications Networks" financed by the Italian University and Research Ministry. We have also begun collaborating with CREDIOP in the working group supporting the Ministry of Communications for the assignment of Wireless Local Loop licenses in Italy.

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

Regulation of vertical structures In this research area, our main focus is on the telecommunications and pharmaceutical industries. As regards telecommunications, we study in particular the evolution of the mobile sector from regulation to facility-based competition. Since the latter is unable to eliminate asymmetries and incentives to collusion, we argue that regulation holds a significant residual role [1]. In fact, the persistence of technological bottlenecks and the need for bilateral agreements concerning access networks must be accounted for when reducing or altogether eliminating regulation [5, 6].

In the pharmaceutical sector, we discuss whether and how the scope for parallel trade in a market characterized by incomplete information is extended as compared with the complete information case [10, 17, 20].

Firms' entry strategies in oligopolistic markets We analyze the entry strategies of firms operating in oligopolistic markets characterized by incomplete information. In the environment we consider, private information about cost is signalled by a home firm by expanding in the country of a foreign firm which, in turn, has the possibility of counter-entry. We study how technology and demand conditions influence the firms' international expansion modes, and study the main features of different equilibria in terms of consumer surplus [11, 21]. In the second place, we propose an efficient heuristic for solving the problem of a potential entrant who has to evaluate the profitability of a given market, depending on an established firm's unknown and unobservable multidimensional type [18].

Transportation networks' management We study both general issues and specific industries, such as the railroad one. We first deal with the general problem of inferring traffic flows on a given network by placing the optimum number of counting points [2, 9]. Then, we concentrate on the on-going deregulation process in the railroad sector [22]. We propose a market-based model for allocating rail network capacity and we present numeric results for the main Italian line [4, 12]. In the second place, we examine how the growing importance of international exchanges influences regulatory choices and access pricing for downstream services using the infrastructures [7, 8, 13, 14]. Finally, we study the extent of the economies of scale and density for downstream transport operators by estimating their costs through a translog function [19].

R&D competition Research in this field is aimed to the analysis of firms' innovation activities in oligopolistic market structures. In particular, we deal with an environment where firms are engaged in cost-reducing R&D activities to maximize their market shares. We discuss the effects of spillovers variations, absorptive capacity and public R&D investment on firms' private investment, as well as the scope for substituting extramural knowledge with in-house R&D [3].

Multicriteria decision making and corporate strategy We first analyze how multicriteria benchmarking analysis can be conducted by making use of an out-ranking procedure. The application of an ELECTRE-type methodology enables to implement benchmarking even when firms are not directly comparable [16]. Then, we argue that the evaluation of technology policy is intrinsically multicriteria in nature and exemplify the use of conflicting criteria in making the related choices [15].

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