An Overview of AI Research in Italy

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Abstract This chapter aims to provide an overview of the main Italian research areas and activities. We first analyze the collaboration structure of Italian research, which involves more than eight hundred scholars and researchers from both universities and industry. From a network perspective it appears to be scale-free. Next, we briefly illustrate the main subjects of investigation and applications. AI research in Italy goes back to the 1970s with an increase in the last twenty years and spans the main research AI areas, from automated reasoning and ontologies to machine learning, robotics and evolutionary computation.

1 Introduction

The 50th anniversary of the 1956 Dartmouth Conference was an occasion for AI research communities to look back on those fifty years of research, make a synthesis of the state of the art and consider future work. So it was in Italy, where the Italian Association for Artificial Intelligence (AI*IA) published a special issue on AI research state of the art, with particular emphasis on Italian research [123].

The special issue is the starting point of this chapter, aimed at providing an overview of the main Italian research areas and activities. AI research in Italy traces back to the 1970s with an increase in the last twenty years and spans the main research AI areas, from automated reasoning and ontologies to machine learning and robotics. In fact, the areas of interest are quite numerous and can be classified as follows:

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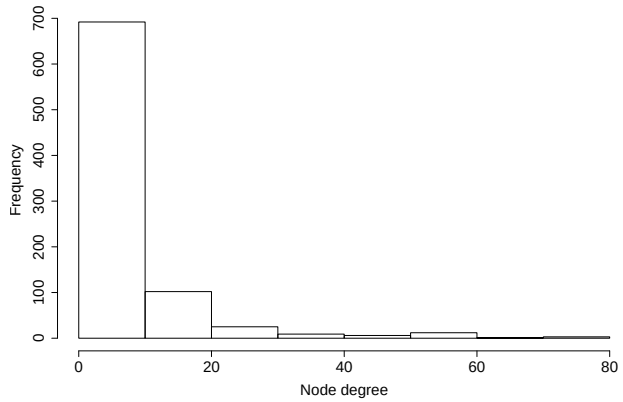

Fig. 1 Node degree frequency of Italian collaboration network in AI.

- Knowledge representation and reasoning
- Constraint Satisfaction and Optimization
- Planning and Scheduling
- Automated diagnosis
- AI and entertainment
- Machine learning and data mining
- Kernel machines, neural networks and graphical models
- Multiagent systems
- Robotics
- Genetic and evolutionary computation
- Complex systems

A rigid classification obviously introduces some inaccuracies and margins for arbitraries, especially because the borders between the areas are quite blurred. However, this list of AI research topics still is a representative description of AI domains of Italian research.

A general characteristic of Italian research (in AI) is that it is uniformly distributed throughout the country and the collaborations between universities and other institutions are quite tight. Moreover, the interaction with foreign research groups, both in Europe and outside it, is very lively. A selection of Italian research in AI is provided by the proceedings of the biannual conference organized by AI*IA, published by Springer in Lecture Notes in Artificial Intelligence series.

A picture of the publication and collaboration networks among AI Italian researchers and between Italian and foreign groups can be drawn by analyzing the properties of a representative sample of the collaboration graph built by analyzing

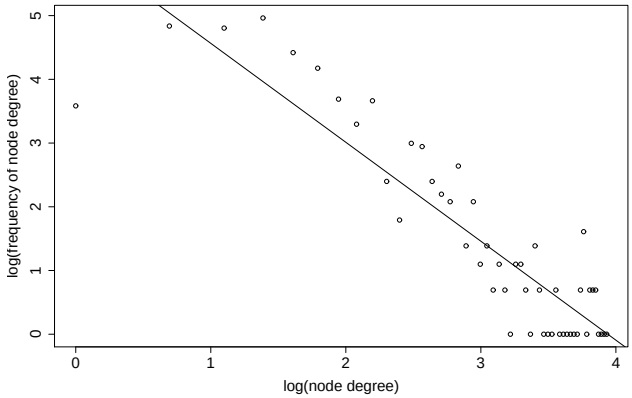

Fig. 2 Log transformation of node degree frequency of Italian collaboration network in AI, fitted with a line with slope equal to -1.553.

the publications collected in the DBLP database [86].[1] We studied the graph resulting from a representative sample of papers published by Italian research groups in AI and observed that the different Italian authors are more than eight hundred in number and the foreign authors involved as co-authors are about four hundred. We also analyzed the collaboration network, restricted to Italian authors only, defined as the undirected graph in which nodes correspond to authors and two nodes are connected if the two corresponding authors had at least one joint publication. The frequency of node degree is plotted in Figure 1. Very interestingly, but not surprisingly, the collaboration network seems to be scale-free, that is, the node degree is described by a power-law distribution: roughly, few authors have a huge number of links, while many have just a few [22]. Indeed, in Figure 1 we can observe that the points, plotted in log-log scale, can be fitted by a line with slope equal to -1.553. Hence, the frequency of node degree k is ruled by the following law: $\text{freq}(k) \sim k^{-1.553}$. This result is in accordance with previous results [23] and suggests that scientific collaboration in Italy is governed by the same dynamics as international collaboration networks.

In the remainder of this chapter we briefly describe the main contributions of Italian research groups to each of the AI areas listed above. For each domain a representative selection of works is mentioned; however, the aim of this overview is not to provide a complete list of topics and publications, but rather to draw a high level picture of Italian AI research. Moreover, since we are obviously not immune from human frailities, notwithstanding our efforts in trying to cite all the main Italian

[1] We parsed and processed the XML file containing the publications collected in DBLP at the time of writing (October, 2007).

scholars and researchers, some might still be missing and we apologize to them and to our readers in case of such an accident.

2 Knowledge representation and reasoning

A large fraction of Italian research in AI is devoted to logic-based knowledge representation and automated reasoning. Since the 1980s, there is a strong interest in logics for AI, especially on logic formalisms [141], modal logics [117], metareasoning [81, 57], and spatial logic [3]. The use of logics has several advantages: it is declarative and high level, it has a formal semantics, has an embedded reasoning apparatus and it is intuitive.

The interest in the *satisfiability problem* (SAT) and its extensions, such as *Quantified boolean formulas* (QBF), is quite strong, as proved by the active research in SAT and QBF solvers [116, 11, 27].

Italian researchers also strongly contributed in the development of research into ontologies, since the late 1980s. The contributions are in two directions: one with focus on knowledge representation languages with predictable computational behaviour and sound and complete inference algorithms [113, 53]; the second aiming at addressing ontology in a systematic and principled way [173, 121]. The studies on ontologies have been largely applied to the semantic web [175, 101]. The activeness of research in the field is also witnessed by the role played by the Italian community in the *Applied Ontology* journal [8], published by IOS Press, that includes Italian researchers on the editorial board, as well as in co-editing.

An important contribution of ontologies to the strictly related field of natural language processing (NLP) can be found in [106], in which an upper level ontology named DOLCE (Descriptive Ontology for Linguistic and Cognitive Engineering) is proposed. Contributions in NLP from Italian researchers can also be found in [9, 4, 24, 25]. For a detailed survey of Italian contributions to research in ontologies, we forward the interested reader to [54].

As far as automated reasoning is concerned, the Italian community has contributed to theoretical and practical achievements. In [110] the definition of a generic theorem prover is presented. The study of formalisms for automated reasoning as a search problem is proposed in [41] while search strategies for SAT solvers are outlined in [40]. Tractable reasoning problem classes are surveyed in [48] along with methods for automated model building. Tableau methods for non-monotonic reasoning have been investigated and surveyed in [150].

The current scenario shows very active research in extensions of logic programming, such as answer set programming [131, 89, 82, 51] abductive logic programming [126], disjunctive logic programming[52], many-valued logic [7], temporal action logic [115]and model checking [29, 97].

Automated reasoning finds widespread application in the field of multiagent systems programming and verification [6, 16, 164, 15, 83], bioinformatics [152], secu-

rity protocols [58], web systems and applications [31, 5]. In particular, web services and their composition is a very active area of application [138, 122].

3 Constraint Satisfaction and Optimization

Constraint satisfaction and optimization was born as a rib of the AI area of knowledge representation and reasoning but it has been influenced by other areas such as programming languages, operations research, graph theory and software engineering. Nowadays all the concepts studied in this field are integrated into Constraint Programming (CP) languages. CP is now an established powerful paradigm for solving hard combinatorial search/optimization problems [139]. Italian research on constraint satisfaction dates back to the early seventies with the studies by Ugo Montanari on picture processing [145]. Nowadays, Italian research is mostly divided into a stream oriented towards theoretical aspects and solvers and a stream aimed at using constraint based techniques for solving real life applications.

As far as theoretical aspects are concerned, properties of Constraint Logic Programming languages are studied using partial evaluation [99] and abstract interpretation [13]. Concurrent constraint programs have been investigated in Italy, by defining extensions of the standard programming paradigm where notions of time can be modelled [39].

With regard to solvers, Italian research has been devoted to studying constraint solvers on sets/multi-sets [90], *soft constraint* solvers [36, 35] including several constraint classes, such as fuzzy, possibilistic, probabilistic and weighted, solvers integrating operations research techniques in CP [144], and solvers integrating metaheuristics and stochastic local search in a constraint based framework [38, 108, 107].

On the application side, many fields have been investigated by Italian researchers: planning and scheduling (see Section 4), temporal reasoning [158, 163], security and quality of service [37], bioinformatics [153], embedded systems-on-chip design [30], timetabling [142], system verification [87].

4 Planning and Scheduling

The design of systems able to make plans autonomously to accomplish a target task and to allocate actions and resources efficiently while satisfying given constraints is one of the most notable goals of AI. Research in planning and scheduling is quite vigorous since the 1970s and the main Italian contribution to the field can be found in works addressing the issue of designing efficient planning and scheduling techniques. This goal is achieved especially by exploiting alternative formulations, such as model checking and SAT, in the case of planning; whereas, in the case of scheduling advanced metaheuristic techniques are used. Representative examples of these researches can be found in [14, 62, 74, 28] in which planning problems

are mainly tackled by reformulations. CP and metaheuristics can also be used effectively to solve both planning and scheduling problems, as discussed respectively in [66] and [109].

5 Automated diagnosis

The main contribution of Italian research in automated diagnosis can be found in advances in model-based diagnosis, that face the problem of providing fault diagnosis by using one or more models of the system to be analyzed. Among the main contributions brought from Italian research we mention works on different kinds of modeling, such as causal models [75] and process algebras [77]. In general, the problem is computationally hard and in recent years a number of approaches have been investigated for making the diagnosis process more efficient. Among these approaches, the one that makes use of multiple models has been deeply studied by Italian researchers [72, 178, 160, 42]. A significant contribution is the one in [71], in which a simpler version of the diagnosis problem is automatically derived by exploiting the amount of current observations on the problem.

Off-line vs. on-line diagnosis has been deeply studied, in a collaboration between the University of Torino and *Centro Ricerche Fiat* (Fiat Research Center); in particular, the problems arising in embedding diagnostic software in vehicles equipped with on-board electronic control units have been tackled in [60, 76].

A detailed overview of Italian research in the field, along with a rich bibliography, can be found in [78].

6 AI and entertainment

One of the most active research areas in AI is the one comprising game playing, intelligent and affective user interfaces, collaborative and virtual environments. Italian contributions to this field are in games, entertaining communication and educational entertainment.

A representative work in game playing is *WebCrow* [91], a crossword puzzle solver that is composed of a web-query and information processing module for retrieving candidate answers to crossword clues, and a probabilistic-CSP module that tries to fill the crossword grid in the best way. One of the strengths of *WebCrow* is that it is designed to be independent of the language used for the puzzles.

Entertaining communication characterizes intelligent multimedia interfaces and tries to reproduce the peculiarities of human communication, such as humour and storytelling. Italian research contributed to this topic with the HAHAcronym project [171], whose goal is to develop a system able to produce humorous versions of existing acronyms or, dually, to create amusing acronyms from a given vocabulary. which formalize the origins of humor as unexpected meanings or behaviors.

In the field of educational entertainment, Italy made an important contribution with AI systems for museum guides with the PEACH system [172] that comprises seamlessly integrated mobile and stationary components and in which the user has a personalized profile and the guide dynamically adapts to the user preferences.

7 Machine learning and data mining

Italian research in Machine learning (ML), in its traditional meaning, was initially pioneered by researchers from the Universities of Torino and Bari, joined also by personnel from the *Ugo Bordoni* Foundation, IBM Italia and the Telecom research lab (TiLab). This core group then grew and many other Italian universities contributed to research in ML. Italian research in ML now forms a dense collaboration network, with many links to foreign countries and it is present in the most important *fora* of the subject. A description of this historical aspect, along with a detailed bibliography, can be found in [92].

The main contributions can be found in concept learning for classification tasks, both with supervised approaches [94, 136, 32, 169, 140] and unsupervised approaches (namely, clustering), such as [59] and multiple classifier systems [103]. Important contributions can also be found in computational learning theory [65], complexity of learning [44, 114], changes of representation and incremental methods [165, 95] and probabilistic knowledge and logic programming [161].

Applications of ML have also received the attention of the Italian ML community. ML has been applied to the semantic web [133], for the classification of web documents [64], for intelligent processing of printed documents [93] and for intelligent searching in digital libraries [132].

On the data mining side, we mention works on the extraction of association rules from databases [134], on handling geographical information [135], automatically building models of sequences [43, 104] and data visualization [127].

8 Kernel machines, neural networks and graphical models

Italian research in statistical and probabilistic learning is distributed in many theoretical and applicative fields, from the issue of bridging statistical learning and symbolic approaches, to bioinformatics and image recognition. An important contribution to statistical and probabilistic learning applied in structured domains can be found in [102] in which a framework for unifying artificial neural networks and belief nets in the context of structured domains is proposed. Research is also quite active in the combination of statistical and symbolic learning, such as kernel methods with Inductive Logic Programming [128] or with Prolog trees [154].

Important contributions come also from studies in recursive neural networks. For example, in [34] the authors define a methodology that makes it possible to feed

recursive networks with cyclic graphs, thus extending their applicability and establishing their computational power and in [119] sufficient conditions for guaranteeing the absence of local minima of the error function in the case of acyclic graphs are presented. The studies reported in [170, 143] address the issue of applying recursive networks on structured data.

As for applications of kernel methods and artificial neural networks, we mention works in bioinformatics such as the ones in [184, 183, 33, 159] in which neural networks and kernel methods are successfully applied in several biological and chemical contexts, and contributions in document analysis such as [118] and references therein. Finally, we mention a work describing a neuro-symbolic language for monotonic and non-monotonic parallel logical inference by means of artificial neural networks [45].

9 Multiagent systems

Research in multiagent systems (MAS) spans many different AI areas, from Distributed AI to robotics and programming languages and also important related disciplines such as sociology, ethology, biology and economics. In the last ten years, Italian (and European) researchers strongly contributed to research in MAS by producing important advances on many fronts. Notably, the AI*IA working group on MAS is very active and counts hundreds of participants from Italian and European universities and industries [80].

The initial steps of research in MAS were aimed at designing intelligent agent architectures and defining, first, proper communication languages, then infrastructures and development tools. A remarkable contribution from Italy is JADE [26], nowadays the most used agent-oriented platform. Coordination plays a crucial role in MAS and Italian researchers made a contribution to this subject [46, 73] and produced coordination technologies, from field-based [137] to tuple-based [147, 151] control and coordination infrastructures [84]. Moreover, Italian scholars contribute to MAS research from the perspective of cognitive science, e.g., [157, 96] and artificial institutions, see, for instance, [100].

Applications of MAS are widely spread among many real-life sectors and Italian research groups produced relevant or prominent contributions to a large number of applications. For instance, in information management [47, 105], health care [10], decision support systems [155] and bioinformatics [12].

MAS is also strictly related, and often interwoven, with other research areas, such as simulation of social and biological systems. Along these research lines, representative Italian contributions can be found in [17] –in which crowd behavior is modeled by means of cellular automata– and, in [56], that presents a MAS framework for systems biology. Relevant contributions in the simulation and analysis of social systems can be found in [61] and works by the same author.

10 Robotics

In this section we outline the major contribution of Italian researchers in the field of AI robotics. First of all, Italian research groups have regularly taken part in international robotics competitions since the 1990s. Good results have been achieved in the RoboCup competitions: in the Middle-size league with ART (Azzurra Robot Team) [146], developed by teams from several universities and the Consorzio Padova Ricerche, and in the Humanoid Robot league with the humanoid robot Isaac [125] designed by Politecnico of Torino. As is often the case, the quest for smart robots able to carry out complex tasks also brings important advances in theory and methodology. Indeed, the development of ART led to the definition of effective communication and coordination protocols [124].

Another Italian project to be mentioned is RoboCare [162], that is currently running and is aimed at designing intelligent robots for human assistance.

One of the problems related to robotics is artificial vision. In Italy, there are several groups studying this subject, see for example [156, 67, 69, 85]. Artificial vision has been successfully applied to autonomous vehicles [179] and exploited in the TerraMax competition.

Relevant results in the field of AI robotics and swarm intelligence have been achieved by the group of Stefano Nolfi at CNR (Italian Research Center), especially in the context of European projects such as Swarm-bots [174]. Among the main contributions, we mention the work on evolutionary robotics and collective behaviour [148, 180].

Finally, more in the line of foundational research, there are some notable works in action theories, such as the ones on situation calculus formalism [98], dynamic logics [112] and fluent and event calculi [70]. It is important also to mention works in which a way to bridge the gap between action theory and applications on real robots is proposed [63, 68].

11 Genetic and evolutionary computation

Evolutionary computation (EC) is inspired by Darwin's theory of natural selection and evolution and it is one of the most prominent and successful examples of AI techniques inspired by biological phenomena and metaphors. Its biological roots connects it tightly to other fields such as Ant algorithms, Particle swarm and Artificial immune systems. Moreover, EC provides a set of methods and tools that can be applied effectively in many fields of AI, such as robotics, fuzzy logics and neural networks. Italian research in EC is distributed among all the facets of the field and involves universities and institutions all over the country. Several of the best-known researchers in EC and related fields are Italian. For instance, Riccardo Poli is a world leader in genetic programming [130], Marco Dorigo is the inventor of *ant colony optimization* [88] and Marco Tomassini is a very well known researcher in EC and complex systems [176].

A selection of Italian contributions to EC can be classified in the following areas: classification [49], image processing [50, 149], cellular evolutionary algorithms and cellular automata [111, 182], test pattern generation [79], genetic programming [177] and hybrid architectures [176].

12 Complex systems

Complex systems sciences (CSS) include disciplines like physics, dynamical systems, computer science, biology and sociology and it overlaps with many areas of AI [168]. Besides core principles such as information processing, computation and learning, common themes between CSS and AI are neural networks, evolutionary computation, multiagent systems and robotics. Italian research in CSS is spread among these domains and involves both academia and industry. The most active topics are artificial life, systemic, simulation of multiagent systems, cognitive processes, evolutionary computation and neural networks. There are also important international events promoted by Italian researchers, such as the Agent Based Modeling and Simulation symposium (ABModSim) [1] and the International Conference on Cellular Automata and Industries (ACRI) [2]. A carefully compiled list of websites devoted to CSS research in Italy, along with further bibliographic references, can be found in [21].

One of the main contributions of Italian research in CSS & AI is surely to be found in simulation of multiagent, social and biological systems. In particular, topics related to cellular automata [20] have characterized Italian research since the 1970s and have been applied in many contexts, ranging from ecology [120], to rubber compounds [18], cellular biology [166], traffic [55] and crowd behaviour [19]. Moreover, we find important contributions also in genetic networks [167] and social-economic systems [129].

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