INFORMATION SERVICES & USE
Volume 20, Number 4


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Agent research and development in Europe

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1. Introduction

While there is no commonly agreed upon definition, software agents can loosely be characterized as programs capable of carrying out tasks on behalf of their users with some degree of autonomy and "intelligence", while possibly moving from one platform to another across a network infrastructure. Over the past several years, interest in software agents has grown rapidly, leading to the research and development of a broad range of applications and functions, from news-filtering agents, shopping agents, supply chain scheduling agents, intelligent travel assistants, to learning assistants, and many others. Key factors behind the growing popularity of software agents have included the coming about of the Web and the associated emergence of electronic commerce, Personal Digital Assistants (PDAs) and a number of other developments. In an Information Society where the infrastructure hosts an ever growing range of resources and activities, software agents may eventually play a key role in helping people and organizations sort through and take full advantage of a vast and dynamic array of resources and services.

We divide agent-related R&D in Europe into five main activity areas. Two of these are "horizontal" activities, which are directed at the study and development of underlying technologies for agent systems. The remaining three activity areas are "vertical", and are directed at application areas for agent technology. Under horizontal activity areas, we include methodologies and software engineering for agent systems and agent-based social simulation. Under vertical activity areas, we include agent-mediated electronic commerce, intelligent information agents, and agents for telecommunications.

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1.1. Methodologies and software engineering for agent systems

It is crucial that the lessons of software and knowledge engineering are applied to the development and deployment of multi-agent systems. Most existing agent applications were developed in an ad hoc fashion, following little or no rigorous design methodology and with limited specification of the requirements or design of the agents or of the system as a whole. To develop methods with which both the requirements of such systems and the systems themselves can be modelled and specified at a conceptually acceptable level of detail, characteristics of real-world multi-agent applications need to be identified in relation to specific domains. Such specifications describe the semantics of systems without concern for implementation details, providing a basis for verification, validation and testing of the functionality of the systems in the light of the specified requirements. Specific topics addressed by European R&D groups include:

- requirements engineering for agent systems;
- techniques for specification of (conceptual) designs of agent systems;
- verification techniques for agent systems;
- specific ontologies for agent requirements and agent models;
- reuse of agent models and agent components; libraries of generic models of specific types of agents and agent components;
- validation and testing techniques; and
- tools to support the agent system development process.

The work on methodologies and software engineering for agent systems exploits synergy from the interaction with existing communities, (in particular the software and knowledge engineering communities), and has a strong emphasis on practical use in industry (for example, Daimler-Chrysler AG is developing agent-based methodologies for distributed manufacturing control).

Different groups within Europe have adopted a number of perspectives for engineering agent systems. The two most important of these are:

- A knowledge engineering perspective – drawing on the experiences of methodologies for knowledge-based systems. Europe has a long tradition in the development and exploitation of methodologies for agent systems, perhaps most obviously in the KADS work.
- A logic-based perspective – drawing on the wealth of experience with logic programming and logical semantics throughout Europe.

1.2. Agent-based social simulation

Computer simulation has proved useful for modelling phenomena of traditionally social scientific interest, such as cooperation, coordination, organisational behaviour, etc.

Multi-agent researchers soon came to realise how crucial these topics are within their field (see the last ICMA$S$ workshop on Multi-Agent Based Simulation, MABS98). In particular, the study of emergence of social phenomena such as organisational performance and optimisation, cultural norms, institutional forms has become a major direction of research in multi-agent systems. In turn, such social modelling brings into play a variety of normative concepts, such as conventions and obligations, and phenomena such as commitment and responsibility, and draws attention to how these phenomena evolve among computational agents in interaction.
These concerns have led social simulators to pay increasing attention to agent modelling. The many scientific events organized in the last years (SimSoc, ICCS&SS, etc.) show the rapid growing of the field. Dissatisfied with the model of the rational social action (see [35]), they have developed simulation models of social agents incorporating representations of cognition derived from other disciplines, such as cognitive science and social psychology. However, the issue of what level of complexity and which agent specifications are needed to meet which questions is a matter of debate and confrontation in the field.

Broadly speaking, the field has two objectives:

- Theory-testing and -building. Agent-based social simulation is used to implement and explore artificial societies of agents (cf. [7,13,21]). In particular the following issues are being addressed: (a) Social dynamics: special attention is paid to the formation and spread of opinion groups (for a survey, see [24]) and coalitions. (b) Social dilemmas: Cellular Automata have been applied to the study of the evolution of cooperation [4] and to the solution of inter-agent and inter-group interferences (cf. [32,51]). (c) Social organisations and institutions is a topic of growing interest in both the computer science and the social science communities. This includes several sub-fields, e.g., organizations (see the “swarm” approach), organizational performance and optimization (see the SOAR approach), the emergence of institutions, etc. (d) Social hierarchy, i.e., affiliation (cf. the MICROBES project developed by Drogoul and his colleagues of the Laforia group at Paris VI, France) and differentiation (cf. the EOS and the DE-CENT projects developed by Jim Doran and associates at the University of Essex, UK). Examples of agent-based simulation studies addressing one or other of these issues may be found in the Journal of Artificial Societies and Social Simulation (JASSS, http://www.soc.surrey.ac.uk/JASSS/JASSS.html).

- Application. Simulation models are traditionally aimed to predict and possibly optimize intervention on natural/artificial social phenomena. More specifically, the necessity of agent-based simulation models is increasingly felt [7,47]) when, (a) external factors (e.g., physical events) must be integrated with social and economic ones (Integrated Assessment Modelling, sustainable socio-economic development), (b) properties at the agent level must be considered in the development and verification of policies (participatory policy-making), (c) optimization of artificial phenomena, such as Computer Supported Cooperative Work, virtual and horizontal organizations.

So far, social simulators have largely shared a “weak” model of the agent, be it essentially static (as in Cellular Automata modelling), or dynamic (as in evolutionary game-theory, adaptive agents and neural nets). However, the necessity for a “stronger” view and model of the agent is now growingly acknowledged in the field (cf. BDI-like agents implemented on the DESIRE platform, and the SOAR-like agents implemented in a declarative language called SDML; for a comprehensive account of the toolkits developed in the field, see [20]).

1.3. Agent-mediated electronic commerce

The Internet continues to spawn new markets, and electronic commerce is changing many market conventions. Old commercial practices are being adapted to the new conditions of immediacy brought forth by the global networks, and new products, services, as well as new practices, are beginning to appear. Agent-based technologies could play a critical role in this regard with the potential of eventually delivering unprecedented levels of autonomy, customization and general sophistication in the way electronic
commerce is conducted. At the same time, a number of theoretical, technological, economic, sociological and legal issues will need to be addressed before such opportunities become reality. The main themes explored by researchers in agent-mediated electronic commerce in Europe are:

1.3.1. Electronic institutions

The design of electronic auctions is receiving attention from several groups. Focus is both on platforms (e.g., IIIA in Barcelona) and on formal modelling (e.g., University of Bath). As the notion of trust plays a central role in trade, methods for enforcing the actions taken by agents are necessary. The design of the electronic equivalent to traditional institutions seems to be a reasonable research direction [36]. It is thus not strange that time-honoured institutions as Auction Houses have become one of the first electronic market places mediated by agents (FM). Different groups are looking for the development of electronic market places in Europe (IIIA, BT Labs, SICS). The European Union has funded several projects with this objective in mind: MEMO, ACTIVE, AIMEDIA, and GAVEL.

1.3.2. Negotiation strategies for agents

Perhaps the most fundamental and powerful mechanism for managing inter-agent dependencies at runtime is negotiation. Different groups are looking at this mechanism from different perspectives: models for negotiation [49], argumentation [39] or simulation [25].

1.3.3. Agent-mediated retailing

An important aspect of retailing is to optimise targeted advertising. Companies are interested in producing the most appropriate advertising to increase the efficiency of commerce. Techniques like data mining (to cluster shoppers) or profiling (to permit personalised communication) belong to the technological repertoire that the European projects MIMIC and AIMEDIA are using. Case-based reasoning is being used on project WEBSELL to design shopping assistants. Project NECTAR also uses agent technology to design virtual shops.

1.3.4. Agent standards

There is a commonly shared belief within Europe on the importance of producing standards and specification environments as outcomes of current research. To this end, FIPA (the foundation for Intelligent Physical Agents – see http://www.fipa.org/) with its agenda for developing open interoperability standards for agents, is currently the focus of considerable attention.

1.3.5. Agent-mediated interaction with public administrations

The European Union has a long tradition on helping citizens on the interaction with Public Administrations. For instance, the IDA (Interchange of Data between Administrations) programme aiming at enabling EU agencies to interchange administrative documentation, or SIMAP, an electronic procurement programme. Projects like SUPPLYPOINT propose building virtual supply chains to help SMEs to participate in public procurement. Intermediation by means of autonomous agents is one of the elements to be supported within the fifth Framework Programme.

1.3.6. Legal aspects

There are several European Directives that regulate the protection of individuals with regard to the processing of personal data, on the free movement of data and on misleading advertising. These different Directives together with the different national laws give shape to the legal framework where agent-mediated electronic commerce must be placed. Current research projects take into account this framework in the specification of the management of data by agents. A project giving legal assistance to agent development projects is ECLIP (Electronic Commerce Legal Issue Platform) which studies the legal implications, and limitations, of personalised communication over Internet.
1.3.7. Profile matching

The modelling of user preferences is essential if an agent is to be instructed to perform an automated mediation task. The agent will be faced with different choices and it must be able to establish preferences among them. Different techniques to model profiles, like for instance rough sets (VUA), are being used. Data mining is another candidate for profile generation being explored in projects MIMIC and AIME-DIA. A slightly different approach is being taken within the project TREVI to determine the relevance of information.

1.3.8. Mobile agents

The need for mobile agents is acknowledged by many groups. Many researchers and developers see agents as programs roaming a network to collect business-related data in order to help users to buy goods. The research efforts concentrate on how to guarantee termination, security or exactly-once protocols. To protect agents against malicious hosts agents should contain time-limit validity, and electronic money with expiration date, apart from the need for third parties to provide security to transactions. Proposals have been made to provide anonymity in transactions and on-line trusted third parties for secure contract signing [8]. Projects like MULTIPLECX look for secure transactions that can be scalable over Internet. Among the results obtained so far we could mention the Mole software developed at the University of Stuttgart.

1.3.9. Agents architectures for electronic commerce

Different groups are following a deliberative approach to agent design, like modelling using BDI, goals, plans, persuasion. Different approaches to agent architectures are used, for instance, using case-based reasoning or fuzzy rules [34]. It is commonly believed that economic models will be useful for agents in e-commerce scenarios. However, most theoretical models from economics are not valid for multiple encounters, which is a more than probable scenario for agent-mediated electronic commerce than one-to-one scenarios. There is a view that useful techniques will also come from other fields, such as the social sciences. Also, a clearer connection between logic and game theory, and models for electronic commerce are missing. For instance, there is an obvious connection between the logical modelling of obligations and electronic commerce, where obligations are of vital importance (e.g., for modelling contracts).

From the practical point of view, there is common agreement in that agents will necessarily have to be adaptive. Mobility will be, also, in the long term, an essential issue. The modelling of trust, the creation of virtual enterprises and the enormous variety of legal issues that the community has to face will become crucial in the next years.

There is a rich variety of interests in what concerns application domains. Marketplaces, electricity management (Enersave AB) and retailing are the most common. Other applications are on business (ADEPT project), banking, telecommunications, finance, marketing, insurance (DIALS project), and shopping assistants.

Currently, there are several platform developments in Europe. We already mentioned different European projects like AIMEDIA whose objective is to end up with a product to be commercialized in the short term. In their case a kind of electronic “one-stop shop” that will provide users with profile managers, shopping agents and shopping assistants. The ZEUS agent toolkit, developed at BT Labs, permits programmers to develop agents to participate in market places [6]. At the Swedish Institute of Computer Science an agent-based market infrastructure has been developed that includes facilities for signing contracts, advertising, searching, brokering, matchmaking and negotiation [14]. At the Artificial Intelligence Research Institute (IIIA) of the Spanish Scientific Research Council a platform to design
electronic auction houses has been developed. It permits the use of different auction strategies and provides programmers with templates to define agents [45].

1.4. Intelligent information agents

The research and application area of intelligent information agents is of rapidly increasing importance. In fact, it can be seen as one of the key technologies for the Internet and the world-wide Web. But what are information agents, what impact will they have on computing early in the next century, and what are the perspectives of European R&D in information agent technology?

Roughly speaking, information agents are computational software systems that have access to multiple, heterogeneous, geographically distributed information sources, as in the Internet, or corporate intranets. The main task of information agents is to perform active searches for relevant information in non-local domains on behalf of their users or other agents. This includes retrieving, analysing, manipulating, and integrating information available from multiple autonomous information sources. Intelligent information agents have to face up to the increasing complexity of modern information environments, ranging from relatively simple in-house information systems, through large-scale multi-database systems, to the visionary ‘info-sphere’ of the Internet. According to [30] intelligent information agents may have different characteristics dependent on the concrete application domain; they may be adaptive, self-interested rational, co-operative, or are even mobile. Thus, research on, and development of, fielded systems of information agents in the Internet is a challenging task, and is crucial for the development of next generation open information environments.

In part, there are many approaches and implemented solutions available from advanced databases, knowledge bases and distributed information systems technology to meet some of these demands. In addition, the effective and efficient access to information on the Web has become a critical research area recently. Access to heterogeneous, distributed information sources may be achieved by utilizing so-called middleware platforms, like OMG CORBA, DCOM, or Java RMI; besides, standard APIs for retrieving data from several relational databases are available, like JDBC/SQILJ and ODBC. But the development of smart information agents in the open, dynamically changing Cyberspace is a tougher challenge. It requires a strong expertise from several related research areas, such as Artificial Intelligence (AI), Distributed AI, Information Retrieval, Cognitive Sciences, Computer Supported Collaborative Work (CSCW), and Human–Computer Interaction. Some main issues will be discussed in the following.

1.4.1. Adaptive agents in changing network and information environments

Modern information environments are mainly open and might change rapidly over time. Thus, the agents have to deal with uncertain, incomplete and vague information in an efficient, reliable way such that they are able to make intelligent decisions on the fly. One approach to achieve more flexible behavior of single or teams of collaborating information agents in an open environment is to enable them for gradual adaptation. That means, that an adaptive information agent may cope with any kind of dynamic change such as change in usable bandwidth, location and content of information sources in the Internet (e.g., in SMASH project in medical domain). However, only few implemented systems of collaborating information agents currently show adaptive behavior. Strictly speaking, not much is known about the relation between single and multi-agent adaptation, and vice versa.

1.4.2. Personal assistants, and human–agent interaction

In addition, adaptive personal assistants have to anticipate the user’s needs and preferences as fast and conveniently as possible. In order to accomplish this goal, different techniques for user profiling,
reputation and recommendation are used. Research and development of learning personal assistants or intelligent interface agents on the Web became most popular, and this will probably continue for the next years.

Advanced forms of user guidance and interaction through potentially shared virtual information spaces might be realized by, e.g., techniques from virtual reality, synthetic characters, like animated creatures or believable avatars. Main efforts in this direction has been carried out by projects in the European R&D initiative I3Net started in 1997 [26], like AIA, Puppet, and Campiello project.

Any progress towards a flexible, more convenient human–agent interaction (HAI) could help to increase the human user's acceptance of information agents for doing his everyday's business on the Web. Such an interaction includes, e.g., an effective multimedia representation of available information as well as individually sensitive, multi-dimensional navigation within the Cyberspace. This relies in particular upon precise information about possibly different user communities, domains of discourse, tasks and context. However, HAI and its application to information agents still is quite an uncharted territory.

1.4.3. Mobile information agents and security

A potential feature of information agents which recently started to attract large interest is mobility. A mobile information agent is programmed to be able to travel autonomously over the Internet from one site to another for the execution of his tasks or queries on different servers. Such agents may enable, e.g., dynamic load balancing in large-scale networks, reduction of data transfer among information servers and applications, migration of small business logic within medium-range corporate intranets on demand, and may perform a more flexible and efficient information discovery among certain circumstances. There is an ongoing discussion about the payoff from applying mobile agent technology in different application domains. Ongoing efforts to come up with a standard for mobile agent system platforms show first results, like OMG MAP [33], and FIPA. In Europe several projects on mobile agents and computing have been set up, like ACTS MIAMI, and AMASE project. Also, a few mobile (information) agent systems and platforms have been developed, like ARA [40], or MIAOW [19], besides non-European efforts, like IBM Aglets, Mitsubishi Concordia, and ObjectSpace Voyager.

Some main related issues concern the assignment of server resources to visiting agents, code persistence, recovery from failures, and a platform-independent development of mobile agents [42]. Moreover, in open networks, the security problems and costs of potential solutions might outweigh the benefits of mobility. The question of security goes in both directions: How can database servers be protected from malicious actions of mobile agents, and, how can an information agent, packed with private data and information, be protected from malevolent servers and other agents while traveling through the Cyberspace [52]?

The main application area of mobile agent technology is currently the area of telecommunications [44] where it is being used as a part of a decentralized service architecture of next-generation networks such as TINA [31]. In only a few years some systems of mobile information agents might be able to operate on heterogeneous and wireless connected hand-held devices and wearable intelligent computers as well [41].

1.4.4. Utilitarian negotiation and trading by rational information agents

Sophisticated agent-based trading remains to be a key challenge for economists, computer scientists and business managers as well. It might reshape the way we think about economic systems and business processes in an increasingly networked world. In the open Cyberspace, information agents are paid and have to pay for any services they provide to their customers. Even network bandwidth recently has started to become a traded commodity on-line.
Methods for flexible multilateral contracting among agents, decentralized utility-based negotiation and dynamic supply chain management are main components in the design of rational information agents. In Europe some advanced research efforts have been done in that direction such as the development of methods for utilitarian coalition formation among information agents [30] (CASHMERE project), agent-mediated auctions [37] (FishMarket project), and agent-based marketplaces (see also Section 1.3). At marketplaces and auctions in the Internet multiple rational information agents from different providers may meet each other to exchange relevant data for their customers, and to negotiate individual amounts of charges for service provision.

Effective trust and security mechanisms to facilitate e-commerce transactions in a digital economy is important; in particular, trust shall be built up gradually, involving only manageable risks for customers and vendors when utilizing rationally collaborating information agents. The situation becomes even more complex since customers, vendors and their products, services and quality may change rapidly over time. There is still no satisfactory method known to react on such changes in an appropriate way.

1.4.5. Agents for telecommunications and telematics

Probably the most active application area for agent technology in Europe is currently telecommunications. With the continuing convergence of software and communication technologies, agents are seen as a natural technology with which to provide many of the applications services required to gain competitive advantage in the increasingly competitive environment of the telecommunications sector. Issues of significant interest to the European telecoms community include:

- identification and analysis of telecommunications applications and telematics services where agent technology can add substantial value as opposed to other, more conventional technologies. These applications and services include service and network management; mobility supporting services; electronic commerce;
- identification and analysis of requirements for an infrastructure for agent-based applications and services;
- analysis of a methodology for agent-oriented software development for telecommunications applications and telematics services.

2. Three exemplar projects

In this section, we give an overview of three projects currently underway that are funded by the European Commission. The idea is not to give a technical introduction to the projects, but to give a feel for the breadth of agent-related issues being investigated under the banner of European funding. The projects range from teaching agents in classrooms, through agents for negotiation in e-commerce scenarios, through to agents for manufacturing control.

2.1. Intelligent agents in NIMIS

One of the main goals of the NIMIS project is to provide young pupils an enhanced classroom interaction through using networked computers and highly interactive and collaborative learning environments, combined with a large interactive display (electronic board), in a framework called the Computer integrated Classroom (CiC). NIMIS aims to provide effective support for children developing:

- reading skills through a range of activities,
- notions of narrativity through a range of activities,
- their ability to take a 2nd person or 3rd person perspective across a range of situations.

To achieve these goals, NIMIS is developing a range of suitable applications and material for young learners (e.g., support for school-beginners learning to read and write through writing, revising and publishing the pupils' own stories with integrated multimedia features). This development takes advantage of today's technology in the growing area of intelligent agents, using it in three different ways: agents as software components; agents as synthetic personae to help, mediate, advise and motivate children and agents as synthetic characters in a story creation environment.

The main reason for the use of agents as components is the reusability and possibility of sharing knowledge between agents. The use of agents is thus a development booster in the sense that it will help the application designers and programmers to reuse the components developed by others. The idea is that each application (ex. story creation application, reading through writing, story writing, puzzles, etc.) would be seen as a social agent that communicates with other agents (applications) using the software environment provided within NIMIS. Such communication will rely on a base framework that allows the interaction between agents through the exchange of KQML performatives.

In this use of intelligent agents in NIMIS we will explore animated or personalised agents appear in the form of artificial creatures that possibly talk to the users by speech synthesis or canned phrases. These agents will be attached to the developed applications (e.g., a reading through writing application, a puzzle application, etc.) and will provide contextual feedback according to the specificity of the application. The behaviour of the agents will be achieved through an architecture that embeds the representation of the agents' emotional state, aiming for a high degree of believability. Using believability in synthetic agents, we expect to raise the level of interaction between children and the applications.

The work on agents in the NIMIS has just started and obviously there are many technical problems that need to be investigated. For example, how to combine the control by the children and by the agent on the agent's behaviour. What is the role of the director of the story? How can the freedom given to the children in performing the actions of their characters be reconciled with the need to obtain a well structured story in the end? Agent technology is crucial for answering these concerns.

2.2. Competitive agents in CASBA

The CASBA project is intended to improve existing electronic commerce services and develop new services in order to create a flexible electronic marketplace. The basic idea is to use electronic auctions combined with automated negotiation techniques in the provision of a framework for future e-commerce scenarios. CASBA is developing two main products:

- The CASBAmarket – a tool for setting up and administering electronic markets.
- This tool is intended to be used by Internet service providers.
- The CASBAagent – a tool for the creation of specialised agents, which will access these markets and trade in them.

Agents in CASBA are not endowed with the authority to actually transact on a user's behalf. Rather, CASBA agents will negotiate and agree deals in principle, but then return to their owner for the authority to complete the deal.

CASBA is developing and making use of the following technologies:

- electronic payment tools and procedures;
- web and email servers with secure protocols;
- intelligent agent support environments;
- database support;
- administration tools including control, directories, and access statistics.

2.3. Multi-agent manufacturing control in HMS

The Holonic Manufacturing System (HMS) consortium is making use of the holon concept in the development of a technology for manufacturing industries. The goal is to attain in manufacturing stability in the face of disturbances, adaptability and flexibility in the face of change, and efficient use of available resources. A holon is an autonomous, co-operative building block of a manufacturing system for transforming, transporting, storing and/or validating information and physical objects.

The HMS consortium has adopted a reference architecture which is built around three types of basic holons: order holons, product holons, and resource holons. Each of them is responsible for one aspect of manufacturing control, be it logistical aspects, technological planning, or resource capabilities, respectively. These basic holons are structured using object-oriented concepts like aggregation and specialization. Staff holons can be added to assist the basic holons with expert knowledge. These allow for the use of centralized algorithms and for the incorporation of legacy systems. Figure 1 illustrates the relationships of these holons.

Interaction between a large number of low level holons results in a complex system behavior, which is difficult to understand, to control and to predict. Structuring (through aggregation of) the holons in a hierarchy is the appropriate solution to tackle this complexity.

Such holonic systems seem to be a natural application for agent technology. Moreover, a major benefit from agent technology is that software-engineering principles from object-oriented software development can be applied in a more complete manner. Indeed, the main advantages from OO development come from the use of essential models, which reflect the world of interest. Agents, being active objects, are better suited for the construction of such essential models in manufacturing than passive objects. In addition, they provide essential models that know about their history, about their future (forecast, what-if), and about their own most relevant properties. All this is relevant in the manufacturing control context.

Developments in multi-agent technology that build on logic programming, universal languages for agent communication, and general-purpose constraint satisfaction probably are less likely to make substantial contributions to the type of multi-agent systems on which this paper reports. The subject matter in the domain typically is either to specialized and performance-critical or too simple and commonplace to offer an application area for this type of research. Insights from this type of research are likely to have

![Figure 1. Basic building blocks of a HMS and their relation.](image-url)
value, but practical implementations and tools are unlikely to survive the demands of on-line manufacturing control tasks.

3. Conclusions

Agent technologies might one day assist people in their daily lives reminding them of important tasks or commitments, helping them sort through their mail, selecting interesting pieces of news, helping them make travel arrangements, shopping for various items, and more generally anticipating their needs and assisting them in planning for a broad range of activities. They might support people at work in providing them with powerful workflow management functionality or help organizations identify new business opportunities and new business partners. They might facilitate the creation of new partnerships and generally help provide for a much more versatile and responsive digital economy. Over the past several years, a number of initial applications has been fielded and many more are being explored. Clearly, a number of hurdles must be overcome if this technology is ever to deliver on its many promises. These challenges include attempting to endow agents with higher levels of “intelligence” (and a deeper understanding of our needs and objectives) and enabling them to carry out more complex tasks on our behalf without making us feel too nervous about the outcome. Issues of interoperability and openness will need to be addressed if agents are ever to be able to interact with one another (e.g., ask for help, advertise services, negotiate, self-organize, etc.). Tremendous scalability challenges will also need to be overcome. In the process, economic models may also have to be revised/reinvented and issues relating to trust, privacy and liability will need to be addressed. From the beginning, Europe has been an active player in this area, providing support for projects for the past fifteen years, initially on a relatively small scale and more recently, as the technology matures, through broader collaborative initiatives. These efforts are starting to pay off and have enabled the “old continent” to position itself as a prominent player in this leading edge area. A distinguishing factor of European programs in this area is the emphasis they place on coordination and the support of value-adding activities that go beyond the scope of specific projects. Examples include networking activities that tie into international standardization and inter-operability efforts, educational activities and policy issues. Another distinguishing factor lies in a holistic approach, in which technology is not developed in a vacuum but where research is generally anchored in practical application contexts.

Appendix A. European-funded R&D in agent technology

Since the mid eighties, the European Community has funded research and development in information and communication technologies through a succession of research programs. Best known among these are ACTS/RACE, TELEMATICS, and ESPRIT as well as their common successor, the "Information Society Technologies" (IST) program which was launched in late 1998 with a total budget of 3.6B Euros (approx. US$ 4B) over a period of four years. These pre-competitive programs have combined a mix of long-term research activities with more applied efforts, bringing together industry and academia across Europe in consortia that typically have to include partners from at least two participating countries. These countries include the 15 Member States of the European Union (i.e., Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Portugal, Spain, Sweden, The Netherlands, and The United Kingdom) as well as a growing number of associate countries (see Webpages below for details). One of the first European agent R&D project was ARCHON (Architecture for Cooperating Heterogeneous Online Systems), which was launched in 1989 to research and develop
multi-agent control applications. ARCHON was deployed in Iberdrola, Northern Spain, where it is responsible for managing power distribution in part of Spain’s electricity distribution network. The past few years have seen a surge of activity in software agents leading to a total of about 50 projects. Application areas include electronic commerce (e.g., CASBA and AIMEDIA projects), mobile agents (e.g., CLIMATE cluster of twelve projects), learning assistant agents (e.g., NIMIS), wearable assistant agents (e.g., COMRIS), Geographical Information Systems (e.g., AGENT), manufacturing management (e.g., MASCADA, TERPSICHERE, etc.) to name just a few. This portfolio of activities is a combination of standalone projects and more coordinated initiatives (e.g., CLIMATE cluster in mobile agents or the recently launched “Universal Information Ecosystems” initiative, an interdisciplinary research program aimed at exploring new technologies and solutions to take full advantage of an infrastructure with a trillion or more “infohabitants”). These projects are further coordinated through initiatives such as the AGENTLINK network of excellence (see following sidebar), which allows researchers from industry and academia to self-organize along themes and activities of common interest. This is further complemented by activities that look at policy or legal issues. An example is the E-CLIP project which explores legal issues in electronic commerce and provides a bridge between R&D and policy issues.

For additional information, the reader is invited to consult the following Webpages:

- Information Society Technologies (IST) program: http://www.cordis.lu/ist/
- ACTS program: http://www.uk.infowin.org/ACTS/
- ESPRIT program: http://www.cordis.lu/esprit/home.html
- TELMATICs program: http://www2.echo.lu/telematics/
- Universal Information Ecosystems initiative: http://www.cordis.lu/ist/fetuie.htm

Appendix B. AgentLink: Co-ordinating European agent R&D

As part of its programme of R&D activities in information technology, the European Commission funds a number of “Networks of Excellence”. The goal of a Network of Excellence is broadly to provide a communication and cooperation infrastructure for a specific, strategically important area. Networks contain a number of members, or “nodes”, which are typically either university departments active in research in the area, or companies active in research and development in the area. Funding is supplied by the commission primarily to enable communication between these nodes and support activities of common interest. The objective is to create synergy among researchers and projects and promote value-adding activities that go beyond the scope of specific projects. Examples of such activities include the organization of seminars, workshops, and conferences but also participation in international standardization efforts, educational activities (e.g., summer schools), development of new curriculum guidelines, competitions, publication of newsletters, etc. It is hoped (and indeed expected) that networks will act as facilitators for new collaborations. Such collaborations may be informal (in the sense of two nodes who start working on a joint research project) or formal (in the sense of project proposals, industrial collaborations or new emerging from the network).

In May 1998, the European Commission began funding “AgentLink” – the Network of Excellence for agent-based computing. AgentLink divided its activities into four main areas:

- Gain competitive advantage for European industry by raising awareness of agent technology, promoting technology transfer from research to industry, focusing research activities on industrially-relevant issues, and bringing together and focusing European industrial consortia on promising new areas of development.
- Promote excellence in European agent systems research, by bringing together researchers in areas of common interest, promoting cross-fertilisation of research skills, promoting research collaboration on promising areas of European strength, and raising awareness of European agent research activities.
- Promote the excellence and relevance of teaching and training in agent-based systems across Europe by organising summer schools to present courses on a range of agent-related issues, and disseminating curricula, courses, and teaching materials; and finally
- Provide a pan-European infrastructure for communicating the results of the network and debating relevant issues.

Although full AgentLink membership is only open to nodes that satisfy the rules for participation in European projects (see Appendix A on "European-funded R&D in agent technology"), AgentLink associate member status is available (free) to international centres carrying out significant agent R&D work. See the AgentLink WWW site (http://www.AgentLink.org/).

References


