Agent-Mining Interaction: An Emerging Area*

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Abstract. In the past twenty years, *agents* (we mean autonomous agent and multi-agent systems) and *data mining* (also knowledge discovery) have emerged separately as two of most prominent, dynamic and exciting research areas. In recent years, an increasingly remarkable trend in both areas is *the agent-mining interaction and integration*. This is driven by not only researcher's interests, but intrinsic challenges and requirements from both sides, as well as benefits and complementarity to both communities through agent-mining interaction. In this paper, we draw a high-level overview of the agent-mining interaction from the perspective of an emerging area in the scientific family. To promote it as a newly emergent scientific field, we summarize key driving forces, originality, major research directions and respective topics, and the progression of research groups, publications and activities of agent-mining interaction. Both theoretical and application-oriented aspects are addressed. The above investigation shows that the agent-mining interaction is attracting everincreasing attention from both agent and data mining communities. Some complicated challenges in either community may be effectively and efficiently tackled through agent-mining interaction. However, as a new open area, there are many issues waiting for research and development from theoretical, technological and practical perspectives.

1 Introduction

In the past twenty years, two of most prominent, dynamic and exciting research areas—autonomous agent and multi-agent systems (AAMAS) [32] and data mining (or knowledge discovery in databases (KDD))[17] have emerged and developed separately. These two independent research streams have been created and originally evolving with separate aims and objectives. They target individual methodologies and techniques coping with domain-specific problems and challenges in respective areas.

AAMAS (or for short agent) is a powerful technology for autonomous intelligent system analysis and design. It is also a thoughtful computing paradigm for dealing with system complexities in tackling open complex problems such as openness, distribution, human involvement, societal characteristics with a new

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perspective on computing and intelligence. Agent studies theoretical, methodological, experimental and practical issues in developing agent-based computing and agent-oriented intelligent systems. The major topics of interest consist of research on individual agents, multi-agent systems, methodology and techniques, tools and applications. The AAMAS technologies are currently contributing to many diverse domains such as software engineering, user interfaces, e-commerce, information retrieval, robotics, computer games, education and training, ubiquitous computing, and social simulation. The benefits from agent are comprehensive and diverse, from academic disciplines, to the sciences, the social sciences and the humanities.

On the other hand, data mining and KDD (for short mining) research the process of analyzing data to identify hidden but interesting patterns or relationships. KDD applies many existing computational techniques from statistics, information retrieval, machine learning, artificial intelligence, pattern recognition, and database technologies. KDD is increasingly widely deployed into varying applications and fields, for instance, web mining and services, text mining, telecommunications, retail, governmental service, fraud, security, business intelligence studies.

In recent years, an increasingly evident trend has emerged. The trend is the interaction and integration between agent and mining. Its development has reached to the level as a new and promising area, and towards a first-class citizen in the science and technology family[5,6,7,8,9].

As identified in a recent position meeting and related activities[5], there are many research topics and open issues from either part of agent and mining interaction. In particular, issues for agent-driven data mining, and issues for mining-driven agents are attracting research interest mainly. However, there are some mutually fundamental issues that are not paid attention in the emerging research. These issues are significant because of their fundamental and necessary roles in establishing a symbiotic relation between agent and mining.

In this paper, we present a systematic view of the evolution and development of agent-mining interaction and integration through a survey of related activities till today. Through a systematic investigation, we summarize key driving forces, originality, major research directions and respective topics, and the progression of research groups, publications and activities of agent-mining interaction. Both theoretical and application-oriented aspects are addressed.

Through reviewing the related work in the above areas, this survey evidences that

1. The agent-mining interaction is attracting ever-increasing attention from both agent and data mining communities,
2. The interaction and integration between agent and mining can greatly complement and strengthen each side of both communities. Some complicated challenges in either community may be effectively and efficiently tackled through agent-mining interaction,

3. Furthermore, as a newly emergent area, agent and mining interaction and integration has potential to create new interesting symbiosis opportunities in both academic and business worlds,
4. However, as a new open area, there are many issues waiting for research and development from theoretical, technological and practical perspectives.

The remaining of this paper is organized as follows. Section 2 discusses challenges in agent and mining communities. In section 3, we present an evolutionary map of agent-mining interaction. Research directions and topics are summarized in Section 4. Section 5 lists some of useful research resources for the agent-mining interaction. A case study is briefed in Section 6. Conclusions are drawn in Section 7.

2 Challenges in Agent and Mining Communities

As addressed in[5,6,7], agent can enhance data mining through involving agent intelligence into data mining systems, while an agent system can benefit from data mining via extending agent knowledge discovery capability. Nevertheless, the agent-mining interaction symbiosis cannot be established if mutual issues are not solved. These mutual issues involve fundamental challenges hidden in both sides and particularly the interaction and integration. Figure 1 presents a view of issues in agent-mining interaction. It highlights the part of mutual issues.

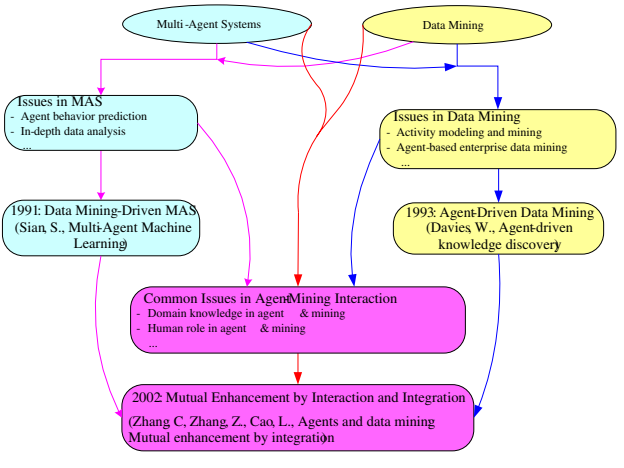

Fig. 1. Issues in agent-mining interaction

Mutual issues constraining agent-mining interaction and integration consist of the following categories.

- Human issues, namely the roles and human intelligence that may be better played or involved by humans to support agent-mining interaction.

- Domain issues, namely the roles and domain intelligence that may be essential in agent-mining interaction.
- Data and knowledge issues, namely the roles and data/knowledge intelligence in building agent-mining symbionts.
- Nonfunctional issues, namely the roles of nonfunctional aspects in building agent-mining symbionts.

Why do these issues matter both sides of agent and mining, and the interaction and integration between agent and mining? There are both explicit reasons and implicit ones. Explicit reasons may include the following system complexities.

– Explicit limitations and challenges in pure agent systems, as addressed in [5,6,7], that can be complemented by data mining, for instance, data mining driving agent learning, user modeling and information analysis.
– Explicit limitations and challenges in pure data mining systems, as discussed in [5,6,7], that can be better serviced by agent technology, for instance, agent-based data mining infrastructure, agents for data management and preparation, agent-based service providing.

Implicit driving forces for including the above mutual issues are equally significant.

– Agent-mining symbionts are substantially essential for dealing with complex intelligence phenomenon and system complexities in complex intelligent systems. Simple intelligent systems and other issues that can be tackled using one side of technologies, for instance, an agent-based data integration system, may not necessarily involve both sides.
– Intelligence emergence in agent-mining interaction may massively strengthen problem-solving capability of an intelligent system, which cannot be played by either part.
– Implicit roles need to be discovered through interdisciplinary studies, which may extremely promote either one side or the whole of an agent-mining integrative system, once the roles are disclosed and properly developed.

3 Evolution of Agent-Mining Interaction

3.1 Fast Progression

We draw a conclusion that agent-mining interaction and integration is emerging as a new member of scientific family due to the following survey findings.

– Ever increasing and a decent number of publications: an initial literature review has disclosed that there are around 150 conference and journal papers, 7 books and proceedings, and some technical reports published by 2006 on

topics associated with agent and mining interaction and integration[1] This uptrend is getting increasingly clearer than before in recent three years. Figure 2 illustrates an incremental change of the number of papers published from 1997 to 2005 by major presses including Springer, IEEE and ISI press. It shows a major number rise from 2003. In 2005, the number of publications almost triples that of 2003.

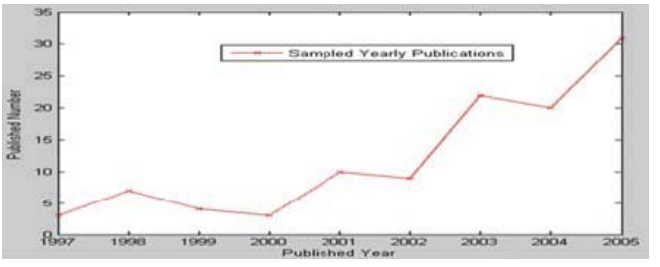

Fig. 2. Incremental change of publication numbers

Table 1 further summarizes the quantity distribution of publications in terms of major search engines. The hit numbers are more or less associated with corresponding publishers that published the papers.

Table 1. Paper publisher distribution

	ACM Portal	IEEExplore	SpringerLink
Hit Number	8	59	48

– Ever increasing level and quality of papers: With the increase of publication numbers, publication quality is also extremely improved. A typical trend is that more and more journal papers and books/proceedings published after 2003. For instance, two specific books have been published [29,31]. In addition, every year can see some papers accepted by top-ranking conferences and journals such as AAMAS [22], PAKDD [26], and IEEE journals [18,19,24,28] in both communities. Table 2 also presents a comparative statistics of two workshops: the standalone AIS-ADM2005 and the IADM2006 colocated with IEEE/ACM/WIC WI-IAT2006. The above indicators reflect the quality progression of publications.

[1] In this paper, the literature survey is undertaken through information retrieval by the following search engines: Google, IEEEXplore, SpringerLink, ACM Portal, Science@Direct, infosci, amazon, ISI, etc. Further action has been on investigating individual research groups and researcher's websites. The survey results are available from the Agent & Mining Interaction and Integration website (www-staff.it.uts.edu.au/˜lbcao/amii/amii.htm).

Table 2. Paper publisher distribution

	Submission number	Accepted papers	Attendees
AISAMD2005	29	17 (58.6%)	30
ADMI2006	45	15 (30%)	40

- Ever increasing number of professional activities: Another typical indicator of whether a research topic is evolving into a new separate area is the number and quality of professional activities, and the involvement of key research groups and researchers from both communities in these activities. Table 3[2] summarizes the numbers of professional activities in this area till 2006, which include workshops, special issues, tutorials, and books. Another landmark is the Open Position Meeting joint with IADM2006. This event presented 7 position talks by active research groups from Australia, Canada, China, Greece, Poland and Russia. The meeting also pointed out the significance of setting up an international steering committee to guide the development of agent-mining interaction.
- Increasing transparent academic voice pursuing a separate area and a first-class citizen in the scientific family: this is evidenced by panel discussions in AIS-ADM2005[3] and an open position meeting joint with IADM2006[4].

Table 3. Decent numbers of professional activities

	Workshops	Special issues	Tutorials	Panel discussions
Number	5	1	7	2

3.2 Evolutionary Characteristics

Further, we investigate some of evolutionary characteristics of this area. In particular, there are following key driving forces.

- From one-way to two-way interaction: The area was originally initiated by involving data mining into agent to enhance agent learning [10,30]. Recently, issues in two-way interaction and integration are broadly studies in different groups.
- Mutual needs: As discussed in [9], people have found many issues in each of the related communities. These issues cannot be tackled by simply developing internal techniques. Rather, techniques from the other discipline can greatly complement the problem-solving when they are combined with the existing techniques and approaches.

[2] Searched in December 2006 by using keywords.
[3] Int. workshop on Autonomous Intelligent Systems: Agent and Data Mining 2005.
[4] Int. Workshop on Agent and Data Mining Interaction, 2006.

- Intrinsic associations and utilities: The interaction and integration between agent and mining is also driven and connected by intrinsic associations and utilities, as discussed in [7,8,9], in both communities.
- Application drives: Application request is one of the key driving forces of this new trend. In Section 4.3, we present some of major application domains and problems that may be better handled by both agent and mining techniques.
- Major research groups and researchers [6] in respective communities tend to undertake both sides of research. Some of them are trying to link them together to solve problems that cannot be tackled by one of them only, for instance, agent-based distributed learning [20,21,22,15,16], agent-based data mining infrastructure [4,5,16], data mining driven agent intelligence enhancement [4,25].
- Broad research from theoretical, technological and practical perspectives: publications and projects have involved not only technological issues, but also theoretical and practical problems. A cross-disciplinary and multi-dimensional study roadmap is becoming clearer.

On the other hand, we also draw an evolutionary tree of this area by combining the emergence of significant landmarks and events in the life of agent-mining interaction (see Figure 3). The survey clearly indicates us that agent-mining interaction and integration has emerged as a prominent, challenging, dynamic and exciting area.

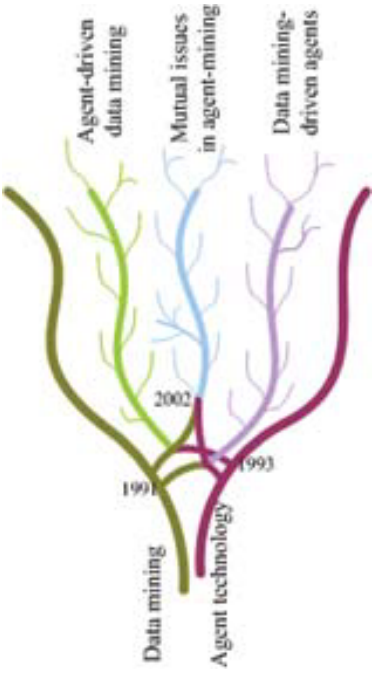

Fig. 3. Evolution of agent-mining interaction as a scientific area

4 Research Directions in Agent-Mining Interaction

In investigating research directions and topics in agent-mining interaction area, we summarize an overview as shown in Figure 3.

4.1 Data Mining Driven Agents

The agent-mining interaction was originally initiated by data mining driven agent learning in 1991 [10,30]. Data mining has potential to enhance agent technology through introducing and improving learning and reasoning capability of agents. For instance, the following illustrates some of popular research topics.

- Collaborative learning in multiagents
- Data mining-driven agent learning, reasoning, adaptation and evolution
- Data mining-driven multiagent communication, planning and dispatching
- Data mining-driven user modeling
- Data mining-driven user servicing
- Data mining-driven network servicing
- Data mining-driven agent recommender
- Data mining-driven trading agents
- Data mining agent assistant
- Data mining enhancing agent intelligence enhancement
- Decentralized clustering in large multi-agent systems
- Distributed learning in agent coordination
- Distributed learning in multi-agent systems
- Emergent agent organization and behavior
- Information gathering agents
- Learning agents
- Web mining agents
- Self-learning agents, etc.

4.2 Agent Driven Data Mining

In sometime around 1993, another effort was started on agent-based data mining [11,12,13]. It is to utilize agent technology to enhance data mining. The enhancement may be embodied in terms of varying aspects, for instance, infrastructure, distributed processing, human involvement. The following lists some of research topics.

- Activity modeling and mining
- Agent-based enterprise data mining
- Agent-based data mining infrastructure
- Agent-based data warehouse
- Agent-based mining process and project management
- Agent-based distributed data mining
- Agent-based distributed learning

- Agent-based grid computing
- Agent-based human mining cooperation
- Agent-based link mining
- Agent-based multi-data source mining
- Agent-based interactive data mining
- Agent-enriched ontology mining
- Agent-based parallel data mining
- Agent-based web mining
- Agent-based text mining
- Agent-based ubiquitous data mining
- Agent knowledge management in distributed data mining
- Agent for data mining data preparation
- Agent-human-cooperated data mining
- Agent networks in distributed knowledge discovery and servicing
- Agent service-based KDD infrastructure
- Agent-supported domain knowledge involvement in KDD
- Agent system providing data mining services
- Automated data mining learning
- Autonomous learning
- Distributed agent-based data preprocessing
- Distributed learning
- Domain intelligence in agent-based data mining
- Mobile agent-based knowledge discovery
- Multi-agent reinforcement learning
- Multi-agent knowledge discovery
- Protocols for agent-based data mining
- Self-organizing data mining learning, etc.

4.3 Mutual Enhancement Issues in Agent-Mining Interaction

After years of unorganized development of the above discussed one-way effect, people further recognize fundamental mutual issues in agent-mining interaction [4,9,33,2], which involve common issues of both parties. The studies on these mutual issues can not only tackle problems towards one-way enhancement as discussed in Sections 4.1 and 4.2, but also two-way strengthening in building a super-intelligent agent-mining symbiont. However, these issues have not attracted sufficient attention in the community.

- Architecture and infrastructure problems
- Actionable capability of agent-mining symbionts
- Constraints in agent and mining
- Data intelligence in agent and mining
- Domain knowledge in agent and mining
- Domain intelligence in agent and mining
- Evaluation issues such as technical significance and business expectation
- Gap filling between technical and business expectations

- Human intelligence and role in agent and mining
- Human-system interaction
- Intelligence metasynthesis in agent and mining
- Knowledge management in agent and mining
- Metadata and meta-knowledge in agent and mining
- Nonfunctional issues such as usability, expendability, openness
- Ontology issues in agent and mining
- Organizational issues such as business factors, process
- Performance issues such as effectiveness, efficiency, scalability
- Social issues such as security, privacy, trust
- Services request and response, service-oriented management
- System management, etc.

4.4 Application Studies

Besides the above technical development, agent-mining interaction is actually driven by broad and increasing applications [7]. At the same time, many researchers focus on the development of agent-mining systems for dealing with specific business problems. In this way, business problems can be better handled compared with using unilateral technology. For instance, we summarize the following application domains.

- Artificial immune systems
- Artificial and electronic markets
- Auction
- Business intelligence
- Customer relationship management
- Distributed data extraction and preparation
- E-commerce
- Finance data mining
- Grid computing
- Healthcare
- Internet and network services, eg., recommendation, personal assistant, searching, retrieval, extraction services
- Knowledge management
- Marketing
- Network intrusion detection
- Parallel computing, eg., parallel GA
- Peer-to-peer
- Semantic web
- Social intelligence & social network analysis
- Supply chain management
- Trading agents
- Text mining
- Web mining, etc.

5 Research Resources on Agent-Mining Interaction

At this point, more and more research resources are coming up on agent-mining interaction. This is evidenced by not only papers but research books. For a systematic and comprehensive understanding of the area of agent-mining interaction, the website AMII[5] collects both original and state-of-the-art information in terms of research topics, groups, projects, activities and open issues. This website presents a systematic one-stop portal of the area. Furthermore, references [5,6,7,8,9,16,22] summarize challenges and prospects of agent-mining interaction and integration from both theoretical and practical perspectives.

On the other hand, there are some resources highlighting one side of the problem. For instance, the book [25] discusses agent intelligence through data mining, while [27] highlights intelligent agents for data mining and information retrieval. The report [9,6] mainly highlights mutual issues in agent-mining interaction. Proceedings [2,14,23] collect papers from the workshops AIS-ADM2005 and IADM2006.

6 F-Trade: An Agent-Mining Symbiont

In this section, we briefly introduce an agent-mining symbionet – F-Trade[6] to illustrate the development and use of agent-mining interaction technology in tackling both research and business issues. Figure 4 shows some screenshots of the F-Trade.

F-Trade [4] is initialism of Financial Trading Rules Automated Development and Evaluation, a web-based automated enterprise infrastructure for trading strategies and data mining on stock/capital markets. The system offers data connection, management and processing services. F-Trade supports online automated plug and play of, and automatic input/output interface construction for trading signals/rules and data mining algorithms, data sources, and system components. It provides powerful and flexible supports for online backtesting, training/test, optimization and evaluation of trading strategies and data mining algorithms. Users can plugin, subscribe, supervise and optimize trading strategies and data mining algorithms in a human-machine cooperated manner.

F-Trade is built in Java agent services on top of Windows/Linux/Unix. XML is used for system configuration and metadata management. A super-server serves for the application server, another one acts as data warehouse. It is constructed with online connectivity to distributed data sources including huge stock data in AC3[7] as well as user-specific data sources.

Major roles played by agent in the F-Trade consist of agent service-based architecture, agent-driven human interaction, agent for data source management, data collection and dispatch agents roaming to remote data sources, agentized trading strategies and data mining algorithms, agent and service recommenders

[5] http://www-staff.it.uts.edu.au/~lbcao/amii/amii.htm.
[6] www.f-trade.info, www.ftrade.info
[7] www.ac3.org.au.

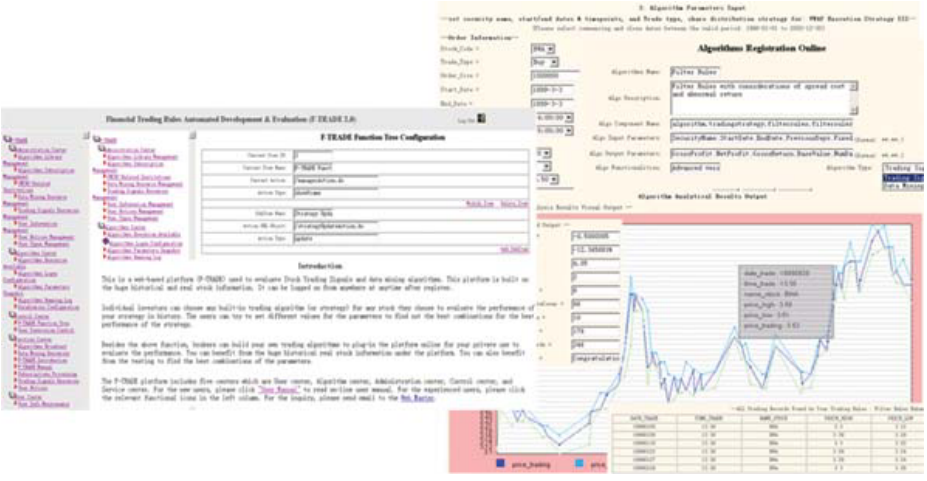

Fig. 4. F-Trade: an agent-mining symbiont

providing optimum algorithms and rules to users, and so on. On the other hand, data mining assists the system in aspects such as data mining-driven trading rule/algorithm recommender agents, data mining-driven user services, data mining-driven trading agent optimizers, mining actionable trading rules in generic trading pattern set, parameter tuning of algorithm agents through data mining, etc. Mutual issues involve ontology-based domain knowledge representation and transformation to problem-solving terminology, human involvement and agent-based human interaction with algorithms and the system for algorithm supervision, optimization and evaluation, etc.

7 Conclusions

Agent and data mining interaction and integration has emerged as a prominent and promising area in recent years. The dialogue between agent technology and data mining can not only handle issues that are hardly coped with in each of the interacted parties, but also create innovative and super-intelligent techniques and symbionts. In this way, both communities and its interactive emergence can be massively enhanced.

In this paper, we present a high-level overview of the area development and major directions. The investigation highlights the following findings: (1) agent-mining interaction is emerging as a new area in the scientific family, (2) the interaction is extremely promoting the progress of agent and mining communities, (3) it is creating ever-increasing development of innovative and significant techniques and systems towards super-intelligent symbionts, however, (4) as a new area, it just starts and has many open issues waiting for a decent involvement of research resources in particular practical and research projects from both communities.

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