

Ubiquitous Intelligence in Agent Mining

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Abstract. Agent mining, namely the interaction and integration of multi-agent and data mining, has emerged as a very promising research area. While many mutual issues exist in both multi-agent and data mining areas, most of them can be described in terms of or related to ubiquitous intelligence. It is certainly very important to define, specify, represent, analyze and utilize ubiquitous intelligence in agents, data mining, and agent mining. This paper presents a novel but preliminary investigation of ubiquitous intelligence in these areas. We specify five types of ubiquitous intelligence: data intelligence, human intelligence, domain intelligence, network and web intelligence, organizational intelligence, and social intelligence. We define and illustrate them, and discuss techniques for involving them into agents, data mining, and agent mining for complex problem-solving. Further investigation on involving and synthesizing ubiquitous intelligence into agents, data mining, and agent mining will lead to a disciplinary upgrade from methodological, technical and practical perspectives.

1 Introduction

There is an increasingly evident need of integrating agents (namely multi-agent systems) and data mining (knowledge discovery from data) for complex problem-solving in both agents and data mining areas. Agent mining [1,2,3,6,11,16,15,19], namely agents and data mining interaction and integration¹, has emerged to be a new and promising discipline. Great efforts have been made on agent mining from aspects of theoretical foundation-building, technological fundamentals, and technical means and tools. More and more applications have been reported benefiting from the synergy of agents and data mining.

In agent mining, a critical issue is to deal with those issues commonly seen in both agents and data mining areas. Here are some examples. Both agents and data mining involve aspects such as domain knowledge, constraints, human roles and interaction, lifecycle and process management, organizational and social factors. Many agent and data mining systems are dynamic and need to cater for online, run-time and ad-hoc requests. With the involvement of social intelligence and complexities, both areas care about reliability, reputation, risk, privacy, security, trust, and outcome actionability. Research in one area can actually stimulate, complement and enhance that in the other.

¹ AMII-SIG: www.agentmining.org

A typical understanding of the above mutual issues existing in agents and data mining is from the angle of ubiquitous intelligence. Ubiquitous intelligence surrounds a real-world agent mining problem can be identified and categorized into the following types.

- Data intelligence,
- Human intelligence,
- Domain intelligence,
- Network intelligence,
- Organizational intelligence, and
- Social intelligence.

Furthermore, for agents, data mining and agent mining, it is necessary to not only involve an individual type of the above intelligence, but also consolidate the relevant ubiquitous intelligence into the modeling, evaluation, working process and systems. In this paper, we discuss the concepts and aims of involving each of the intelligence, and the corresponding techniques and case studies for involving them into agents, data mining, and agent mining.

The listed ubiquitous intelligence and the consolidation in a system open a new angle of observing key and mutual challenges in agents, data mining, and agent mining. Following this direction, we believe many issues in the above areas can be addressed or with solutions provided. As a result, many great opportunities will emerge with more advanced, effective and efficient methodologies, techniques, means and tools and applications in dealing with complex multi-agent, data mining and agent mining problems and systems.

2 Data Intelligence

2.1 What Is Data Intelligence

Definition 1. (*Data Intelligence*) tells interesting stories and/or indicators hidden in data about a business problem. The intelligence of data emerges in the form of interesting patterns and actionable knowledge.

There are two levels of data intelligence:

- *General level of data intelligence*: refers to the knowledge identified from explicit data, presenting general knowledge about a business problem, and
- *In-depth level of data intelligence*: refers to the knowledge identified in more complex data, using more advanced techniques, or disclosing much deeper information and knowledge about a problem.

Taking association rule mining as an example, a general level of data intelligence is frequent patterns identified in basket transactions, while *associative classifiers* reflect deeper level of data intelligence.

2.2 Aims of Involving Data Intelligence

We aim to disclose data intelligence from multiple perspectives. One of the angles to observe data intelligence is the data explicitness or implicitness.

- *Explicit data intelligence*, refers to the level of data intelligence disclosing explicit characteristics or exhibited explicitly. An example of explicit data intelligence is the trend of a stock market index or of a stock price dynamics.
- *Implicit data intelligence*, refers to the level of data intelligence disclosing implicit characteristics or exhibited implicitly. In stock markets, an example of implicit data intelligence is the trading behavior patterns of a hidden group in which investors are associated with each other.

Both explicit data intelligence and implicit data intelligence may present intelligence at either general or in-depth level.

Another angle of scrutinizing data intelligence is from either a syntactic or a semantic perspective.

- *Syntactic data intelligence*, refers to the kind of data intelligence disclosing syntactic characteristics. An example of syntactic data intelligence is itemset associations.
- *Semantic data intelligence*, refers to the kind of data intelligence disclosing semantic characteristics. An example of semantic data intelligence is temporal trading behavior embedding temporal logic relationship amongst trading behaviors.

Similarly, both syntactic data intelligence and semantic data intelligence may present intelligence at either general or in-depth level.

2.3 Aspects of Data Intelligence

Even though the mainstream agents and data mining focus on substantial investigation of varying data for hidden interesting patterns or knowledge, the real-world data and its surroundings are usually much more complicated. The following lists aspects that may be associated with data intelligence.

- Data type such as numeric, categorical, XML, multimedia and composite data
- Data timing such as temporal and sequential
- Data spacing such as spatial and temporal-spatial
- Data speed and mobility such as high frequency, high density, dynamic data and mobile data
- Data dimension such as multi-dimensional, high-dimensional data, and multiple sequences
- Data relation such as multi-relational, linkage record
- Data quality such as missing data, noise, uncertainty, and incompleteness
- Data sensitivity like mixing with sensitive information

Deeper and wider analysis is required to disclose in-depth data intelligence in complex data. Two kinds of efforts: data engineering and data mining, need to be further developed for processing and analyzing real-world data complexities such as multi-dimensional data, high-dimensional data, mixed data, distributed data, and processing and mining unbalanced, noisy, uncertain, incomplete, dynamic, and stream data.

3 Domain Intelligence

3.1 What Is Domain Intelligence

Definition 2. (*Domain Intelligence*) refers to the intelligence that emerges from the involvement of domain factors and resources into agents, data mining and agent mining, which wrap not only a problem but its target data and environment. The intelligence of domain is embodied through the involvement into modeling process, models and systems.

Domain intelligence involves qualitative and quantitative aspects. They are instantiated in terms of aspects such as domain knowledge, background information, prior knowledge, expert knowledge, constraints, organizational factors, business process, workflow, as well as environmental aspects, business expectation and interestingness.

3.2 Aims of Involving Domain Intelligence

Multiple types of domain intelligence may be engaged in agents, data mining and agent mining.

- *Qualitative domain intelligence*, refers to the type of domain intelligence that discloses qualitative characteristics or involves qualitative aspects. Taking stock data mining as an example, fund managers have qualitative domain intelligence such as “beating the market”, when they evaluate the value of a trading pattern.
- *Quantitative domain intelligence*, refers to the type of domain intelligence that discloses quantitative characteristics or involves quantitative aspects. An example of quantitative domain intelligence in stock data mining is whether a trading pattern can “beat VWAP²” or not.

The roles of involving domain intelligence in agents, data mining and agent mining are multi-form.

- Assisting in the modeling and evaluation of the problem. An example is “my trading pattern can beat the market index return” when domain intelligence of “beat market index return” is applied to evaluate a trading pattern.
- Making mining realistic and business-friendly. By considering domain knowledge, we are able to work on an actual business problem rather than an artificial one abstracted from an actual problem.

3.3 Aspects of Domain Intelligence

In the mainstream of agents and data mining, the consideration of domain intelligence is mainly embodied through involving domain knowledge, prior knowledge, or mining the process and/or workflow associated with a business problem.

In a specific domain problem, domain intelligence may be presented in multiple aspects, for instance, some of the following aspects:

² VWAP is a trading acronym for Volume-Weighted Average Price, the ratio of the value traded to total volume traded over a particular time horizon.

- Domain knowledge,
- Background and prior information,
- Meta-knowledge and meta-data
- Constraints,
- Business process,
- Workflow,
- Benchmarking and criteria definition, and
- Business expectation and interest.

4 Network Intelligence

4.1 What Is Network Intelligence

Definition 3. (*Network Intelligence*) refers to the intelligence that emerges from both web and broad-based network information, facilities, services and processing surrounding an agent, data mining or agent mining problem and system.

Network intelligence involves both *web intelligence* and *broad-based network intelligence* such as information and resources distribution, linkages amongst distributed objects, hidden communities and groups, web service techniques, messaging techniques, mobile and personal assistant agents for decision-support, information and resources from network, and in particular the web, information retrieval, searching and structuralization from distributed and textual data. The information and facilities from the networks surrounding the target business problem either consist of the problem constituents, or can contribute to useful information for actionable knowledge discovery and delivery in agents, data mining and agent mining.

4.2 Aims of Involving Network Intelligence

The aims of involving network intelligence into agents, data mining and agent mining include multiple aspects, for example, to

- Involve data and information from a community or team
- Involve and mine web data,
- Involve and mine network data,
- Support pattern mining and decision-making,
- Support decision-making on top of mined patterns and knowledge, and
- Support social agent and data mining systems by providing facilities for social interaction in a team.

In particular, we care about

- Discovering the business intelligence in networked data related to a business problem, for instance, discovering market manipulation patterns in cross-markets.
- Discovering networks and communities existing in a business problem and its data, for instance, discovering hidden communities in a market investor population.
- Involving networked constituent information in pattern mining on target data, for example, mining blog opinion for verifying market abnormal trading.
- Utilizing networking facilities to pursue information and tools for actionable knowledge discovery, for example, involving mobile agents to support distributed and peer-to-peer mining.

4.3 Aspects of Network Intelligence

In saying network intelligence, on one hand, we expect to fulfill the power of web and network information and facilities for agents, data mining and agent mining in terms of many aspects, for instance,

- Information and resource distribution
- Linkages amongst distributed objects
- Hidden communities and groups
- Information and resource from network and in particular the web
- Information retrieval
- Structuralization and abstraction from distributed textual (blog) data
- Distributed computing
- Web network communication techniques
- Web-based decision-support techniques
- Dynamics of networks and the web
- Multiagent-based messaging and mining

On the other hand, we focus on disclosing web and network intelligence. In this regard, there are many emergent topics to be studied. We list a few here.

- Social network mining
- Hidden group and community mining
- Context-based web mining
- Opinion formation and evolution dynamics
- Distributed and multiple source mining
- Mining changes and dynamics of network
- Multiagent-based distribute data mining

5 Human Intelligence

5.1 What Is Human Intelligence

Definition 4. (*Human Intelligence*) refers to (1) explicit or direct involvement of human knowledge or human as a problem-solving constituent, etc., and (2) implicit or indirect involvement of human knowledge or human as a system component.

Explicit or direct involvement of human intelligence may consist of human empirical knowledge, belief, intention, expectation, run-time supervision, evaluation, and an individual end user or expert groups. An example of explicit human intelligence is for a domain expert to tune parameters via user interfaces. On the other hand, implicit or indirect involvement of human intelligence may present as imaginary thinking, emotional intelligence, inspiration, brainstorm, reasoning inputs, and embodied cognition like convergent thinking through interaction with other members in assessing identified patterns. Examples of involving implicit human intelligence are user modeling for game behavior design, collecting opinion from an expert group for guiding model optimization, and utilizing embodied cognition for adaptive model adjustment.

5.2 Aims of Involving Human Intelligence

The importance of involving human into data mining has been widely recognized. With the systematic specification of human intelligence, we are able to convert agent mining toward more human-centered, interactive, dynamic and user-friendly, enhancing the capability of dealing with complex agent mining issues, forming closed-loop agent mining systems, and strengthening the usability of agent mining.

- Human-centered capability: The involvement of human, including individual and group knowledge, experience, preferences, cognition, thinking, reasoning etc. and more broad aspects linking to social and cultural factors (we will further expand this in social intelligence), makes it possible for utilizing human intelligence into enhancing agent mining capability. Based on the depth and breadth of human involvement, the cooperation of human with agent mining can be human-centered or human-assisted;
- Interactive capability: The involvement of human is through interactive interfaces. This forms interactive agent mining capability and systems, to effectively and sufficiently cater for human intelligence into agent mining;
- Improving adaptive capability: Real-life agent mining applications are often dynamic. Agent mining models are often pre-defined and cannot adapt to the dynamics. The involvement of human intelligence can assist with the understanding and capture of such dynamics and change, and guide the corresponding adjustment and retraining of models;
- User-friendliness: The catering of user preferences, characteristics, and requests in agent mining will certainly make it more user-friendly;
- Dealing with complex agent mining issues: Many complex issues cannot be handled very well without the involvement domain experts. Complex knowledge discovery from complex data can benefit from inheriting and learning expert knowledge, enhancing the understanding of domain, organizational and social factors through expert guidelines, embedding domain experts into agent mining systems, etc.
- Closed-loop agent mining: In general, agent mining systems are open. As we learn from disciplines such as cybernetics, problem-solving systems are likely to be closed-loop in order to deal with environmental complexities and to achieve robust and dependable performance. This is the same for actionable knowledge discovery and delivery systems. The involvement of human can essentially contribute to closed-loop agent mining.
- Enhancing usability of agent mining: Driven by the involvement of human intelligence and the corresponding development and support, the usability of agent mining systems can be greatly enhanced. Usability measures the quality of a user's experience when interacting with an agent mining system.

5.3 Aspects of Human Intelligence

The aspects of human intelligence in agents, data mining and agent mining are embodied through many ways.

- Human empirical knowledge,
- Belief, intention, expectation,
- Sentiment, opinion
- Run-time supervision, evaluation,
- Expert groups
- Imaginary thinking,
- Emotional intelligence,
- Inspiration,
- Brainstorm,
- Retrospection,
- Reasoning inputs, and
- Embodied cognition like convergent thinking through interaction with other members in assessing identified patterns

6 Organizational Intelligence

6.1 What Is Organizational Intelligence

Definition 5. (*Organizational Intelligence*) refers to the intelligence that emerges from involving organization-oriented factors and resources into agents, data mining and agent mining. The organizational intelligence is embodied through its involvement into the system process, modeling and systems.

6.2 Aims of Involving Organizational Intelligence

In a complex organization, the involvement of organizational intelligence is essential in many aspects, for instance,

- Reflecting the organization reality, needs and constraints in business modeling and finding delivery
- Satisfying organizational goals and norms, policies etc. regulation and convention,
- Considering the impact of organizational interaction and dynamics in the modeling and deliverable design,
- Catering for organizational structure and its evolution in data extraction, preparation, modeling, and delivery.

6.3 Aspects of Organizational Intelligence

Organizational intelligence consist of many aspects, for example

- Organizational structures related to key issues such as where data comes from and who in which branch needs the findings
- Organizational behavior related to key issues such as the business and data understanding and finding delivery of how individuals and groups act in an organization
- Organizational evolution and dynamics related to key issues such as data and information change, affecting model/pattern/knowledge evolution and adaptability

- Organizational/business regulation and convention related to key issues such as business understanding and finding delivery, including rules, policies, protocols, norms, law etc.
- Business process and workflow related to key issues such as data (reflecting process and workflow) and business understanding, goal and task definition, and finding delivery etc.
- Organizational goals related to key issues such as problem definition, goal and task definition, performance evaluation, etc.
- Organizational actors and roles related to key issues such as system actor definition, user preferences, knowledge involvement, interaction, interface and service design, delivery etc.
- Organizational interaction related to key issues such as data and information interaction amongst sub-systems and components, data sensitivity and privacy, and interaction rules applied on organizational interaction that may affect data extraction, integration and processing, and pattern delivery and so on.

7 Social Intelligence

7.1 What Is Social Intelligence

Definition 6. (*Social Intelligence*) refers to the intelligence that emerges from the group interactions, behaviors and corresponding regulation surrounding an agent mining problem.

Social intelligence covers both *human social intelligence* and *animat/agent-based social intelligence*. *Human social intelligence* is related to aspects such as social cognition, emotional intelligence, consensus construction, and group decision. *Animat/agent-based social intelligence* involves swarm intelligence, action selection and the foraging procedure. Both sides also engage social network intelligence, collective interaction, as well as social regulation rules, law, trust and reputation for governing the emergence and use of social intelligence.

7.2 Aims of Involving Social Intelligence

In designing complex problem-solving systems in social environment, both human social intelligence and agent-based social intelligence may play an important role, for instance,

- Enhancing social computing capability of agent mining methods and systems,
- Implementing agent mining and evaluation in a social and group-based manner, under supervised or semi-supervised condition,
- Utilizing social group thinking and intelligence emergence into complex agent mining problem-solving,
- Building social agent mining software on the basis of software agents, to facilitate human-mining interaction, group decision-making, self-organization and autonomous action selection by data mining agents. This may benefit from multi-agent data mining and warehousing,

- Defining and evaluating social performance including trust and reputation in developing quality social agent mining software, and
- Enhancing agent mining project management and decision-support capabilities of the identified findings in a social environment.

7.3 Aspects of Social Intelligence

Aspects of social intelligence are in multiple forms. We illustrate them from human social intelligence and animat/agent-based social intelligence respectively.

Human social intelligence aspects consist of aspects such as *social cognition*, *emotional intelligence*, *consensus construction*, and *group decision*.

- *Social cognition*, aspects related to how a group of people process and use social information, which can inform how to involve what information into agent mining,
- *Emotional intelligence*, aspects related to a group of people's emotions and feelings, which can inform interface and interaction design, performance evaluation and finding delivery for agent mining.
- *Consensus construction*, aspects related to how a group of people think and how thinking evolves in a group toward a convergence, in particular, under a divergent thinking situation, which can inform the conflict resolution if people with different background value different aspects in pattern selection or if there is a conflict between technical and business interest,
- *Group decision*, aspects related to strategies and methods used by a group of people in making a decision, which can inform the discussion between business modelers and end users.

Animat/agent-based social intelligence aspects consist of

- Swarm/collective intelligence, aspects related to collaboration and competition of a group of agents in handling a social data mining problem, which can assist in complex data mining through multi-agent interaction, collaboration, coordination, negotiation and competition, and
- Behavior/group dynamics, aspects related to group formation, change and evolution, and group behavior dynamics, which can assist in simulating and understanding structure, behavior and impact of mining a group/community.

In addition, both human/agent social intelligence also involves many common aspects, such as

- Social network intelligence,
- Collective interaction,
- Social behavior network,
- Social interaction rules, protocols, norms etc.,
- Trust and reputation etc. and
- Privacy, risk, security etc. in social context.

8 Discussions

The involvement of ubiquitous intelligence is very important for handling open complex problems, such as open complex intelligent systems [8] and open complex agent systems [9]. Besides the individual engagement of each type of intelligence, more critical problem is to synthesize them into a problem-solving system. This comes to an interesting but difficult problem, namely how they can be integrated. Methodologies and approaches for doing so are not currently mature, just as the studies on the five proposed types of intelligence.

We have had a few trials in this regard, which are essentially helpful for detailing ubiquitous intelligence in constructing open complex agent systems, data mining systems, and agent mining systems.

- Intelligence meta-synthesis [17,18,14]: This is a methodology proposed to deal with open complex giant systems [17,18]. It proposes a general framework of integrating human intelligence, computer intelligence into problem-solving systems, in particular, by establishing a hall for workshop of meta-synthesis from qualitative to quantitative. Agent-based prototypes have been built for applying metasynthesis in handling macro-economic decision-making [13].
- Metasynthetic computing [9]: This is a computing technique proposed to construct systems, mainly open complex intelligent systems, by utilizing the methodology of intelligence meta-synthesis. A typical solution is to integrate agents, services, organizational and social computing for handling open complex systems [10], by establishing an *m-space* powered by *m-computing* and *m-interaction* [5].

A typical example of involving ubiquitous intelligence into data mining is *domain driven data mining* [4] for actionable knowledge discovery and delivery [12].

There are many open issues in involving and integrating ubiquitous intelligence into agents, data mining, and agent mining. We believe that the studies on this will lead to great opportunities for innovative methodologies, techniques, means and tools, as well as applications in the relevant areas including agents, data mining, and agent mining. This will consequently and definitely promote the transfer of the relevant disciplines toward more advanced, effective and efficient stage from methodological, technical and practical aspects.

9 Conclusion

Agents, data mining and agent mining face many critical mutual issues. In this paper, we propose the concept of ubiquitous intelligence to describe and address these issues. They are

- Data intelligence, refers to both general level and in-depth level of data intelligence from both syntactic and semantic perspectives;
- Human intelligence, refers to both explicit or direct and implicit or indirect involvement of human intelligence;
- Domain intelligence, refers to both qualitative and quantitative domain intelligence;

- Network intelligence, refers to both web intelligence and broad-based network intelligence,
- Organizational intelligence, refers to organizational goals, structures, rules, and dynamics, and
- Social intelligence, refers to both human social intelligence and agent/animat-based social intelligence.

We have discussed their definition, aims, aspects and techniques for involving them into agents, data mining, and agent mining.

In our other works, preliminary examples and case studies have been presented to illustrate these concepts. In particular, we have proposed a methodology, namely *intelligence meta-synthesis* and *metasynthetic computing* for synthesizing ubiquitous intelligence into domain-driven actionable knowledge delivery.

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