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Shenghua Liu

Interacting with Intelligent Agents

Key Issues in Agent-based Decision Support System Design

JYVÄSKYLÄN YLIOPISTO

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ABSTRACT

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The wide variety of uses of software agents in user-oriented systems have brought up a series of design considerations and present a radical reorientation in thinking about future human-computer interaction (HCI). The advent of agent technology broadens the way in interaction design and opens a vast realm in which agent designers have the opportunity to empower human beings. However, bad design and possible abuse of agents may cause untold frustrations, inconvenience and misery to users who interact with agents. In order to eliminate the negative effects of agent use, new design approaches need investigate how agent technology can be designed in the most humane way, at the same time aiming at improving the holistic integration between human mental processes and technological progress. This new interaction paradigm, evolved from traditional HCI, can be referred to as human-agent interaction (HAI). My research tries to ascertain the principles for designing, implementing and evaluating intelligent agents and such agent-based interactive computing systems for human use, based on current HCI research. This dissertation describes a framework to incorporate agent technology with conventional HCI design approaches. An empirical study on the agent-based decision-making is conducted within this framework. Critical design issues of the intelligent HAI are expatiated, with the focus on agents' impacts on the decision-making behavior of people. The goal is to provide a holistic view on future interaction design where the agent-based approaches are well organized to serve HCI research.

Keywords: software agents, human-agent interaction, intelligent interaction, user-centric design, multi-agent system, user-psychology

ACM Com Review Categories:

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H.5.2	User interfaces
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Article 2	Liu, S., Wahlstedt, A., & Honkaranta A. (2009). Agent-based Learning Management Systems: Upsides and Challenges for Supporting Users. In: A. P. dos Reis (Ed.), Proceedings of Intelligent Systems and Agents'09 (pp. 43-52). Lisbon, Portugal: IADIS Press.
Article 3	Liu, S., Helfenstein, S., & Saariluoma, P. (2008). Risks in Agent-supported Stock Market Trading Decision Making. In A. P. dos Reis (Ed.), *Proceedings of Intelligent Systems and Agents'08* (pp. 109-116). Lisbon: IADIS Press.
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Article 5	Liu, S., Helfenstein, S., & Wahlstedt, A. (2008). Social Psychology of Persuasion Applied to Human-Agent Interaction. *The Journal of Human Technology*, 4, 123-143.

LIST OF ACRONYMS

AAI	Agent-Agent Interaction
ABDS	Agent-Based Decision Support
BDI	Beliefs, Desires, and Intentions
CMA	Collaboration Management Agent
CSREA	Computer Science Research, Education and Applications
DSS	Decision Support Systems
ECA	Embodied Conversational Agent
EIASM	European Institute for Advanced Studies in Management
HAI	Human-Agent Interaction
HCI	Human-Computer Interaction
IADIS	International Association for Development of the Information Society
IBM	International Business Machines
IRMA	Intelligent Resource-Bounded Machine Architecture
JADE	Java Agent DEvelopment Framework
LMS	Learning Management System
MAS	Multi-Agent Systems
P2P	Peer-to-Peer
PRS	Procedural Reasoning System
RUR	Rossum's Universal Robots
RPD	Recognition Primed Decision
SOA	Service Oriented Architecture
UCD	User-Centric Design
VI	Virtual Instructor

1 INTRODUCTION

"It is with horror, frankly, that he rejects all responsibility for the idea that metal contraptions could ever replace human beings, and that by means of wires they could awaken something like life, love, or rebellion. He would deem this dark prospect to be either an overestimation of machines, or a grave offence against life."

The Author of Robots Defends Himself — Karel Capek, Lidove, June 9, 1935

Translation: Bean Comrad

Karl Capek's play, R.U.R. (Rossum's Universal Robots), popularized throughout Europe and America in the 1920's, once had an enormous success. In this early scientific play, the Czech playwright first brought the term 'robot' to our language. He always kept rejecting the idea that it is possible to create such humanized creatures, but this did not obstruct robots from becoming the protagonists of science fiction, plays and movies. Never tired, never mistaken, never afraid of extreme environments and never lazy, robots have exhibited their superior abilities in movies. Some of them even have the emotion and affection like human beings. All of these ideas reveal the expectations and complex feelings of humans towards robots, although most of them are the product of our fanciful imagination only. However, making a robot is not at all simple. The research and construction of robots involves integration of its mechanism, electronics, control, sensor, micro processing, artificial intelligence, etc. and is constrained by physical environment. Robots with certain functions, especially those with human characteristics, might be adaptable to complicated environments, but robots communicating with the user are still not ready for use. Nevertheless, the development of today's networks provides us with a valuable opportunity to make our real, dynamic and unpredictably complex information context accessible and not restricted by physical materials. This makes robot research step into a domain of pure software: autonomous, self-adaptive and cooperatively working software robot, the intelligent agent, (Wooldridge and Jennings, 1995), has the possibility to strut its stuff in the network-based world. Let's have a look at the following scenarios first:

Scenario 1: Your software assistant monitors stock quotas, performs market analysis reflecting your preferences, consults with other assistants and notifies you by sending emails or SMS messages to your mobile phone.

Scenario 2: Your software assistant searches for different Internet shops, gets recommendations from sellers, brokers, and other assistants. It may negotiate about price or form shopping coalitions with other agents in order to obtain discounts. The assistant brings you the best available offer for your approval.

Scenario 3: Teachers and students are represented by separate software assistants. When a student wants to have a meeting with the teacher, the student assistant issues a request for a possible free time slot to the teacher assistant, and the teacher assistant forwards the request to the teacher's calendar assistant to check whether the date is available. Then the teacher assistant and the student assistant will negotiate and decide about an acceptable meeting time, based on the information from their calendar assistants.

We may be familiar with these scenarios since they often appear in science videos and movies. The simple collection of scenarios used here aims to provide us with a vision of how agents work for us and presents a rough clue on the design considerations for agents in a broad sense. Currently the term "agent" has come to refer to the automation of some aspects of HCI, such as anticipating commands or autonomously performing actions. Their characteristics quite regularly include autonomy, adaptiveness, and pro-activeness. When equipped with professional knowledge, an agent assisting us can cover many aspects in our daily work, including information searching, advice, and information forecasting.

The employment of agents in HCI design has proven to be an effective way to construct robust yet flexible software architecture in which information communication between the user and the technical system is mediated by different kinds of agents. A powerful, flexible and robust software architecture based on a multi-agent framework can be constructed (Küngas and Matskin, 2005). The assistant agent could consult with other expert agents and provide the best suggestions on stock market trading (Kuo, Chen, and Hwang, 2001). One can make one's own decision, based on the personal agent's suggestion, or provide more information about preferences to that agent (Petrov and Stoyen, 2000; Stoyen, 2001). This new social collaborator, the software agent, has come out from the academic research area and entered our daily life.

The emergence of the software agent brings about a series of design considerations and presents a radical reorientation regarding how to think about supporting HCI. The new interaction paradigm, evolved from traditional HCI, is known as human-agent interaction (HAI). Since the dynamic HCI has enabled the theory of cognition to have a special role to play in understanding the interactions between people and ever-improving technologies (Schneider et al., 1984), the focuses of HAI are on how we design a user-adaptive agent and how we coordinate our activities, cognition in relation to the new tool of assistance for humans and the agents. The advent of agent technology opens a vast realm in which agent designers have the opportunity to empower human beings by employing agents in daily life and social interaction. However, bad design and possible abuse of agents may cause untold frustrations, inconvenience and misery to users. In order to eliminate the negative effects of agent usage, new design approaches need investigate how individual agents can be designed in the most humane way.

As agents can participate in daily activities, such as decision-making and persuasion, while interacting with people, more consequent evaluation and application of social psychological concepts could be used to guide the agents' behaviors during interaction. Certain parts of human cognition and communication skills could also be simulated by agents so that their behaviors would appear humane and life-like, people being more inclined to interact with objects which have the human's characteristics (Milewski and Lewis, 1997). Thus agents' subtle design would lean to the user-adaptive and user-centric design in order to align the agent's actions with the user's requirements and to make them more human-like. Since agents usually act in the role of assistants helping people to implement tasks, people's behaviors would inevitably be affected by the agents' suggestions, words or behaviors. Being aware of how agents could influence human cognition will contribute towards lessening the possible risks caused by those agents.

In addition, agent-based HCI systems should be designed to be ubiquitous for quickly and precisely addressing the issues concerning user requirements, values and cultural background (Zhu, Mutka, and Ni, 2006). Contextualized user modeling, including the user's profile, task specifications, and behavior models could help to adapt agents to the social environment by virtues of the knowledge of human cognition and technology. Therefore, the emphases in system design should be shifted from the technique oriented implementation, e.g. how to realize distributed communication, to the user adaptive interaction, e.g. how to improve human cognitive capacity by means of transcending human cognitive closures (Gorayska, March, and Mey, 1997). The design process means not only the merging of different technologies, but also, and more importantly, finding ways in which people adapt to the demands of new technology. What we really need to do is to study the holistic integration between human cognitive processes and technological progress.

1.1 Research motivation

One of the goals of HCI design is to provide users with an easy, enjoyable, and reliable way to operate a computer-based system (Gary and Judith, 2003; Norman, 1988; Shneiderman, 1998). Intelligent agent technology broadens the way in interaction design, freeing the whole process from desktop-centered thinking. It shows great potential in resolving complex communication, integration and analysis problems (Jennings and Wooldridge, 1998; Kushwaha et al., 2004). Nowadays more and more agent technology has been applied to HCI in order to leverage system modeling as well as to develop intelligent applications and smart technical infrastructure services. However, the emergence of new technology inevitably brings new questions, for example about how to wisely handle an innovation which is far from mature, both theoretically and practically speaking. If agents behave rigidly and in a machine-like manner, and their interaction is based on commands, it will impede their acceptance by the user. A poorly designed agents' interaction model which breaches the humans' etiquette may easily create aversions in people or arouse negative feelings towards the whole system. Even more, excessive suggestions and information from the agents will also increase people's cognitive load and may detract their minds, causing exhaustion during interaction, not to mention agent failures. Thus although the agent technology has offered new approaches to facilitate effective HCI, defective design of human aspects will encumber the usability of such agent-based interaction system and miss the goal of HCI.

In addition, so far most current agent research has been oriented towards the technical aspects of agent system, such as agent architecture, agent's communication language, ontology, algorithms, etc. There has not been too much study on the combination of agent design with the cognitive technology (Gorayska, March, and Mey, 1997) – this in spite of the research by the likes of Dautenhahn and Nehaniv (2000) and Sun (2006), who have probed into the human cognition with intelligent agents and multi-agent systems (MAS). We still lack knowledge about how to design intelligent agents for HCI, and a clear statement about how to organize HAI research as a science. On the other hand, the fruits from the research of Dautenhahn and Nehaniv (2000) and Sun (2006) and other related work have created concerns about the long-term cognitive and social effects of agent technology based on usability challenges: e.g., how will agent technology serve the interests of people, and how will it enhance human cognitive or social capabilities? These concerns not only refer to human-like intelligent agent design patterns but also to the culture-wide societal and psychological impacts of agent technology on human social behaviors, the influence being bidirectional. This view broadens the common notion of HCI, to encompass the interplay that occurs between humans and agents. Further investigation of the interplay of cognitive cues of humans and agents during interaction would have high significance in designing effective HAI, and the outcomes might facilitate the usability of intelligent agents. This engenders my basic motivation for HAI research with its challenges of how to use agents for promoting comfortable and effective interaction and how to organize different technologies for effective HAI.

1.2 Research goals

As HAI derives from traditional HCI, this research is inheritably a multidisciplinary study indebted to computer science, artificial intelligence, cognitive ergonomics, user psychology and so on. The research efforts are placed in the intersection of computer engineering and human cognitive study: interaction design for the cooperation between intelligent agents and human beings in the collaborated decision-making area.

On the most general level, work in HAI research aims to ascertain the principles for designing, evaluating, and implementing intelligent agents and such agent-based interactive systems for human use. The underlying purpose is to maintain the long-term trusting relationship between human and agents. Specifically, my research investigates how to structure the intelligent HAI by aligning the design of agent-based decision support (ABDS) with user-centric design (UCD). This requires not only that we design the interaction model and decision support system, but also that we investigate what it is that HAI implies: the functionality of an intelligent agent, its design challenges from a human perspective, the design rationales and how all these could be organized well together. Furthermore, after constructing the agent-based decision support system, the research strives to investigate the cognitive interplay between the agent and the human being from a behavioral perspective. Two sub-goals are derived in the process: 1) development of social competence for agents; 2) investigation and evaluation of agents' impact on humans' decision-making behaviors. On the one hand, since the agents' social behaviors are grounded on behaviors in the human society, the human communication skills naturally have much influence on the agents' behavior design. The study tries to incorporate psychological approaches into agent design to develop social competence for agents and to enhance the efficiency of collaborative work. On the other hand, in order to justify the design approach we also need to check what is the agents' impact on people's social behaviors, specifically in decision-making, and thus evaluate the use of agents in the implementation of collaborative tasks.

In practice, by virtue of incorporating human technology into the agent and agent-based system design, my research aims to design and implement an intelligent HAI, the agent-based decision support system in which the agent technology and human processes are integrated while respecting and preserving human wholeness. Thus the research goals can be summarized by the following aims:

- Structuring the interaction design for agent-based decision support.
- Investigating the cognitive interplay between the agent and the human being on the behavioral level during decision-making.
    - Development of social competence for agents.
    - Investigation and evaluation of agents' impact on humans' decision-making behaviors.

1.3 Research questions

As in other research on user-oriented computer systems, HAI places the emphasis on maintaining the relationships between human users and agents. In general, how to promote efficient interaction between human users and a computer system is a core question, which all HCI researchers have to confront with complete open minds (Bickmore and Cassell, 2001; Bickmore and Picard, 2005). After bringing the agent metaphor into HCI, this general question then leads to further investigation about adapting agents to the interaction purpose. Since my research tries to structure the design for intelligent HAI and apply to the agent-based decision support, the practical research questions are derived from the research goals.

The goal in orchestrating the interaction design firstly requires us to think about the basic requirements on the agent side to construct an effective HAI. That is the premise of the intelligent HAI research. Then the study needs to think about how to design the interaction model for agent-based decision support, the system architecture, and organize the human-agent and agent-agent communication. The second goal could be analyzed from two perspectives: from the human side we would like to know how human cognition issues, for example communication skills, could serve for agent design and furthermore, how to structure the agent-based system for the interaction purpose; from the agent side the question is how an agent can impact on people's task-implementation behaviors such as decision-making. Thus the research questions can be summarized as follows:

1.3.1 Q1: What are the prerequisites of feasible HAI?

This question can be reformulated to ask what the meaning of intelligent HAI is and would imply that one is assumed to be fully aware of both the pros and the cons of applying agent technology in HCI. Since HAI integrates the agents into the domain of interaction design, the requirement for the agents and the patterns of interacting with them are accordingly included with the question. From the agent design point of view, the benefits and risks of agent-based interaction need to be clarified; from the user's perspective, the prime question is what types of agents and which way(s) of interaction are regarded as intelligent. The awareness issues for appropriate requirements capture and design decisions, including human expectations and agent complexity; social affordance, and cognitive and interactive load should be concerned (Dautenhahn and Nehaniv, 2000). The expected outcome is that the prototype of interaction between human and agents is efficient in the service delivery so that the user's needs and requirements are met in time while the user is made feel comfortable. This helps to fulfill the first research goal.

1.3.2 Q2: How to organize interaction design for agent-based decision support?

The study on this question also contributes to the first goal of structuring the interaction design for intelligent HAI. HCI researchers advocate implicit HCI in which the input to the computer system is performed in the same way as humans do in their daily activities (Schmidt, 2000; Schmidt, Gellersen, and Merz, 2000). This would entail that agents captured users' needs and intentions in a way that would not trouble users at all in interaction. Not only should the human-agent communication be less constrained to the input from physical computer devices, but also the feedback from agents should be presented in an effective way. Human communication capabilities are asymmetric with those of the computer (Suchman, 1987), however. Humans can capture a computer's intent fairly quickly, while it is hard for a computer to understand human intention (Wang, 2007). Thus, how to build the channel between these two sides is quite important for structuring the agent-based decision support system. This also means that the relationship between the human and the agent should be clearly defined during the design phase and properly maintained during the interaction. Design technology and processes should be well organized so that the resulting interaction pattern would be both comfortable and efficient. In addition, since agent-based integration systems nowadays are normally MAS, the interaction in HAI also includes agent-to-agent communication. Fast information exchange among agents could facilitate service composition and thus construct a powerful service network where more services are made available for users. We need to concern ourselves about how to orchestrate the interaction not only between human and agents, but also between agents, to be able to properly implement an intelligent HAI.

1.3.3 Q3: How can an agent influence human's decision-making behavior?

The question implies two basic meanings. Firstly, the agent's response may have impacts on our perception of the world and our decisions as well. It is not difficult to understand that these impacts will directly influence the usability of the system no matter whether they are positive or negative. The analysis of these influences is of importance to the design of agent-based interactive systems: for example, how will we change to agent-supported decision-making in the specific interaction pattern between human and agents? It is helpful to know how humans' decision behaviors are influenced by agents. Secondly, it requires finding out what is the proper way for an agent to influence human's decision making. A key point then is: what can we learn from the social interaction research, in order to design the agent's interaction with users in a considerate and comfortable manner? Because interaction inevitably involves the consciousness of a human being, the investigation correspondingly needs to make use of social psychology and user psychology to capture the human users' intention. The issues also include how the agent performs in decision-making as well as how competent it is in making people trust it**.** It is thus important for the agent's effect on interaction how it expresses its ideas, thoughts, and suggestions to the users. The answer to this question has direct relevance to the second research goal. The solution to this problem would make people reassured in their work with agents and be conducive to maintain the long-term trusting interaction.

1.4 Research method and design technology

1.4.1 Experimental design method

As the main focus in this research is the relation between human beings and agents, the predictions and hypotheses made during the interaction design need to be justified and evaluated through experiments where both software agents and human beings are involved. Thus the experimental research methodology has been chosen as the main methodology for this HAI research.

As described in Donohue (1994), Pfleeger (1995), and Experiment Resources (2008), the first step in the experimental design is to define the research problem one is interested in. This helps to formulate the research hypothesis that can be tested. Two key terms we need to know in this step are *variable* and *hypothesis*: the former is a factor or element that can change in observable and measurable ways, the latter can be defined as an educated guess about the relationship between two or more variables (Shipley, 1980). After a hypothesis has been made, researchers can start designing the experiments to verify the hypothesis. Constructing an experiment includes sampling the groups, identifying and controlling the variables, constructing and validating the instruments to measure outcomes, designing of the experiment, and conducting a pilot study. The independent [1] and dependent [2] variables (Landman, 1988) are defined in this stage. The experiment is typically carried out by manipulating a variable affecting the experimental group or set. The effect that the researcher is interested in is then measured. There are lots of factors that need to be checked and followed, which makes the control one of the fundamental characteristics of the experiment. Once the experimental data has been collected, we could examine the information and draw conclusions about what has been found. Using statistics, researchers can summarize the data, analyze the results, and draw conclusions based on this evidence. The whole research follows all these steps and the details are explained in Chapter 3.

1.4.2 Design technology

HAI design is multidisciplinary work which requires cooperation of different technologies. But that doesn't mean that we just roughly mix different technologies together. The research has chosen UCD as the design rationale, based on which several psychological approaches are adopted in the emotional design for agents and user modeling is incorporated into the system design.

As stated in Carroll (1992, 1997), in the history of HCI, approaches have been created for the design science of HCI as an analytic model, as iterative

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1 The independent variable is the circumstances or characteristics which the researcher can manipulate in his effort to determine what their connection with the observed phenomenon is.

2 The dependent variable is the circumstances or characteristics that change, disappear or appear when the researcher implements the independent variable.

incremental development and as design rational. Among them, the most important one is the design rationale, which explicitly lists the design criteria and explains why these criteria have been made. Derived from HCI, the whole design process of HAI must be in accordance with the UCD design criteria (Abras, Maloney-Krichmar, and Preece, 2004; Johnson, Johnson, and Zhang, 2005; Mao et al., 2005; Norman and Draper, 1986), which have significant influence on all HCI systems. The idea is that design specifications should be initiated from a human perspective and the ultimate outcome must satisfy human common sense. The research further applies emotional design in structuring the agent behavior model via psychological approaches.

Much more effort has been put in the integration of psychological approaches into the agent's emotional design. Based on my research about the relationships between humans and agents in decision-making, reifying psychology in HAI design helps to synthesize the guidelines to develop intelligent user-adaptive agents and agent-based decision support systems for them. For instance, agent structure and interface design could recur to social psychology in order to improve the usability by incorporating those well studied communication skills in human society, e.g. the theories of heuristic model of persuasion (Chaiken, 1980). The employment of the psychological approach in design assists the investigation on the mutual influence between human and agent, which is conducive to solving the third research question.

Moreover, the user's needs and requirements should be quickly and precisely captured in time so as to make the whole system more user-adaptive. An effective way is to abstract the user’s preference and routine behaviors into a computational user model that can be understood by the system. User modeling is important to many systems that attempt to adapt their behaviors to various classes of users in order to interact more intelligently (Kass and Finn, 1988). User modeling skills (Benedek et al., 2004; Kass and Finn, 1988; McCalla et al., 2000) are thus needed for the whole system to trace user requirements, which is compatible with the UCD design. Specifically, user modeling in a MAS-based HAI would be broader than in a single HCI system (McCalla et al., 2000). Traditional modeling principles should be extended to fit the distributed multi-agent environment.

1.5 Research articles

The outcome of the research was reported and documented in published articles. If we number the articles included in this dissertation from A1 to A5 and the research questions in Section 1.3 from Q1 to Q3, the focus, target context, and the contribution of each article can be presented as in Table 1. The details of each article and their contributions are introduced in Chapter 4.

Article 1 was finished in the early stage of the research. It aims to investigate a way to construct a powerful service network via agents which could be considered as one of the premises of HAI (Q1). Again the architecture of the service network composes one part of the HAI organization (Q2). Article 2 presents an agent approach to orchestrate a learning management system (LMS) via probing into the advantage and challenge of using agents. This is the background study for further investigation into HAI system, which contributes to Q1 and Q2. Article 3 and 4 start to investigate the use of agents in agent supported decision-making. The research results were expatiated via a stock market and a product development management scenario. They served for the agents' influence on people's behaviors (Q1 and Q3). In Article 5, social psychology is applied to agent persuasion. The socio-design for agents and communication skills are discussed. Since Article 5 talks not only about the interaction design but also about the individual agent development and the agent's impact on people's decision-making, it is clearly in relation to Q2 and Q3. The whole research was initiated by a literature review on agent development, agent-based interaction, user modeling skills, methodology in HCI and the definitions of cognitive science and user psychology. This was the theory preparation for my research in which I learned the current status of research on agent technology and HCI and how they merge together. Although the literature review is not listed as the publication most of its contents have been merged into the introduction of intelligent HAI.

TABLE 1 Overview of research articles

Article	Domain	Focus	Context	Research contribution
A1	Agent-based service composition	Agent communication and service composition	P2P multi-agent system	Q1, Q2
A2	HAI system design	Pros and cons of agent-based interaction	Learning resource management	Q1, Q2
A3, A4	Interaction design	Agent-supported decision-making	Product management, stock market	Q1, Q3
A5	Interaction design	Agent persuasion and trust in interaction	Learning resource management	Q2, Q3

1.6 Basic concepts

Agent. From the three scenarios described in the first chapter, it is easy to figure out the common properties of software agents: they can implement tasks autonomously; they can perceive their situation and generate proper responses according to the change of the conditions; and they have their roles in helping people doing various tasks. Although the definitions of the agent have been provided by different researchers and organizations, which have differences in their definitions, they all describe the properties a software agent should have.

Normally a software agent has the following properties (Wooldridge and Jennings, 1995):

Autonomy: agents operate without the direct intervention of humans or others, and have some kinds of control over their actions and internal state.

Reactivity: agents perceive their environment and respond in a timely fashion to changes that occur in it.

Pro-activeness: agents do not simply act in response to their environment; they are able to exhibit goal-directed behavior by taking the initiative.

Social ability: agents interact with other agents (and possibly humans) via some kind of agent communication language.

These common properties actually compose to the definition of agents. An agent is a social or communicative object to other objects with the characteristics of autonomy, reactivity, pro-activity, and social ability. The property of autonomy focuses on the agent's ability in controlling its internal state. When a new task is delegated, an agent has to autonomously determine precisely what the objective is and evaluate how this objective can be reached in an effective manner. Reactivity and pro-activeness means an agent should be able to affect the environment. When an agent performs the necessary action to achieve objectives, its behavior usually appears as goal-directed. In addition, software agents often need to interact with other entities (either humans or software agents) in order to accomplish their objectives. Such interchanges may range from simple requests to complex negotiations.

Decision-making. Decision-making is a cognitive process leading to the selection of a course of action among alternatives, which can be rational or irrational. Rational process, such as structured rational decision-making, is an important part of all science-based professions, where specialists apply their knowledge in a given area to make informed decisions between alternatives based on estimates of the values of those alternatives (Kepner and Tregoe, 1965). A structured decision-making process normally includes task analysis, weighting of all options and evaluation. The quality of the decision thus may be influenced by the complexity of the issue that needs to be handled and also by the decision-maker's personal knowledge level, mental condition and recognition capability. With user tasks and technology becoming increasingly more sophisticated, machines, computers and software programs also progressively come into the domain of decision-making. Decision support systems (DSS) therefore have been introduced to help people in their decision-making (Alter, 1980; Druzdzel and Flynn, 1999; Power, 2002).

Trust. The definition of trust adopted in this thesis is the term which reflects the expectation one actor has about another's future behavior to perform given activities dependably, securely, and reliably based on experiences collected from previous interactions (Grandison and Sloman, 2000; Mui, Mohtashemi, and Halberstadt, 2002; Skopik, Schall, and Dustdar, 2009).

Persuasion. Efforts to change attitudes are attempts at persuasion. Central routes to persuasion require more time, energy, or expertise than peripheral routes. (Kosslyn and Rosenberg, 2005) Persuasion attempts can be thwarted by strong attitudes, opposition, forewarning, and selective avoidance. In his publication, Cialdini (Cialdini, 2001) defined six types of influence: reciprocity, commitment and consistency, social proof, authority, liking and scarcity. These methods reflect the process of guiding people and oneself toward the adoption of an idea, attitude, or action by rational and symbolic means. There are also theories about the use of "heuristic model of persuasion" (Chaiken, 1980) and Petty and Cacioppo's (1981) "central versus peripheral framework". In those theories people's compliance with appeals often follow simple decision-making rules that are based on little evaluated (contextual) persuasive cues, such as likability of the message source, the connotations of expertise, and social (e.g., majority) reference.

User-centric design. Most current design approaches in HCI are referred to as UCD, the user-centric design (Carroll, 1997; Norman, 1986; Rosson and Carroll, 2002). The basic idea of this design philosophy is that all design should begin with the needs and desires of users. A good design pattern should adequately consider the human factor during interaction, make users more comfortable, and involve the user in significant amounts of learning time or in significant learning efforts (Chapanis, 1991a, 1991b). This means that design should stem from the user's perspective with the intention of achieving better usability and tangibility. Users must take the center-stage in the design of any computer system. Users' needs should be caught in time and met to the best of the system's ability.

Implicit interaction. According to the definition of Schmidt (2000), implicit interaction is an action performed by the user, which is not primarily aimed at interaction with a computerized system but which understands action as an input to that system. This kind of implicit interaction is based on the idea of using human activity in the real world as input to computers, which makes humans interact with agents in a natural fashion, the same way as they perform their everyday life activities in a human society (Abowd and Mynatt, 2000; Abowd, Mynatt, and Rodden, 2002; Schmidt, 2000). Ideally, users could operate the interface with complete disregard for the agent, and the agent could also actively display suggestions in the interface based on inputs implicitly collected from users (Adler et al., 2001; Isbister et al., 2000). This implicit HAI design implies the building of user models and initialization of user profiles.

User modeling. A general user model normally contains any type of information about the user that might be useful to an application. The basic content of a user model is the user's profile which contains the user's basic background information, like interests, preferences, as well as the user's goals, plans, attitudes and the beliefs about the world and systems (Kass and Stadnyk, 1992). A user model is built based on the profile so that an agent's action will better accord with the user's preferences. Typically, the user models have either been acquired implicitly or explicitly changed on the basis of observation of the user's actions. The user model could also be a record of the user's past actions, together with a critical rule base which captures the general rules the agent has developed to characterize the user's preferences (Fleming and Cohen, 1999). This means that the user model is actually the user's behavior model which is abstracted from the user's routine actions. This behavior model could be merged with the action rules generated from the system's plan library as the responses to users. The user model also includes the user's task specification. User's tasks are concerned with shared understanding, explanations, justifications, argumentation about actions and built as one part of the user's model (Fischer, 2001).

User psychology. User psychology (Moran, 1981; Oulasvirta and Saariluoma, 2004, 2006) as a specific use of applied psychology has been incorporated into agent design as a useful approach to human mentality in agent-based interaction contexts. User psychology describes and analyzes human behaviors with psychological concepts and bases interaction and service design on this knowledge. User psychological design is not necessarily technology-driven; it may investigate forms of human activities rather than solve usability-like immediate interaction problems (Rosson and Carroll, 2002).

Emotional design. Emotions have a crucial role in the human ability to understand the world and in how they learn new things (Norman, 2003). Investigating emotions and using emotional explanations in interaction design makes sense when we evaluate the importance of objects, issues, people or events (Saariluoma, 2004). A typical example of applying psychology of emotions to interaction design is to analyze the acceptability of interface and usability design (Jacoby et al., 1998).

1.7 The structure of the thesis

The structure of this dissertation is organized in five chapters. In Chapter 1, introduction of the research is presented. Chapter 2 gives an overview on the agent-based interactive system, including research literature related to the HAI design, HAI architecture, implication of intelligent HAI, design challenges, and the human aspects in HAI design. Chapter 3 describes a practical HAI implementation and narrows down the topic to the design of agent-based decision support system. Critical design issues such as system modeling, interaction design, and agent design via a psychological approach are discussed. Chapter 4 is the summary of published articles. The discussion and conclusion are presented in the last Chapter 5.

2 INTELLIGENT HUMAN AGENT INTERACTION

Today, agent technology is widely applied to the industrial engineering sector to enhance the efficiency of information processing, to solve nagging productivity problems and to simplify the complex interactivity in workflows. This is evidenced by the existence of various agent-based applications in different areas, e.g. financial domain (Tesfatsion, 2002; Zhang et al., 2004), medical applications (Dautenhahn and Werry, 2000), educational usage (Doswell, 2004; Marcus and Gould, 2000), etc. Context-aware agents are able to adapt to their surroundings, learn, and solve special tasks with specialized expert knowledge (Adler et al., 2001). Users can delegate work to an agent, normally serving as a personal servant, which is obedient to orders and committed to the user's goals. Agents can represent us and perform our work under extreme conditions, especially if modeled in some details to reflect our personal qualities and preferences (Usmani and Kirk, 2008). The flexibility of agents opens up numerous possible uses for them. Powerful, flexible and robust software architecture can be constructed based on a multi-agent framework in which communication between humans and computers is delegated to many kinds of agents. However, using agent-based approaches to design an intelligent interface for user-oriented systems faces many challenges. It is not a trivial problem how HAI should be organized. In this chapter, I will describe work related to HAI as well as the basic architecture of an agent-based interactive system, the components associated with it, and the interactions that take place in each layer. Specific design issues such as the implications arising from HAI, design challenges, and the necessity of taking into account human aspects in agent design are briefly discussed. The purpose is to give an overview of the design issues involved with the HAI system. That will then, in the next chapter, pave road for further design issues related to the agent-based decision support system.

2.1 Related work

HCI stands in the intersection of psychology, social sciences, computer science and technology (Carroll, 1997). Born out of the traditional HCI, intelligent HAI design, from the interaction point of view, would have similar design rationales, challenges, and dependencies on several research areas in the HCI domain. In addition, agent architecture and its usage in interactions have been well studied during last decades. That previous research will help us in finding out how to improve and contribute to the intelligent HAI. By presenting the related work here I hope to be able to indicate the novel points of this research, i.e., how it complements the work done in relation to the current usage of agents in HCI.

2.1.1 Agent architecture

Naturally an essential element in HAI is the software agent. As mentioned in Section 1.6, software agents are autonomous, reactive, proactive, and also have social ability. Agent's concepts and its associations have connections both to computing and to human cognition. But the agent's ability is not limited to a simple response to some stimulus. It may have a model of behavior and intentions that can be satisfied by implementing corresponding goals. Researchers have distinguished three kinds of agent architectures: deliberative architecture, reactive architecture and hybrid architecture (See Appendix 1).

In the deliberative agent architecture (Huhns and Singh, 1998; Rao and Georgeff, 1995), agents have an internal data structure, which is typically used to record information about the state and history of the environment. The best known deliberative agent architecture is the BDI (Beliefs, Desires, and Intentions) system. IRMA (Bratman, Israel, and Pollack, 1988) and PRS (Ingrand, Georgeff, and Rao, 1992) are typical embodied BDI structures. These agents represent their beliefs, intentions, and desires in modular data structures and perform explicit manipulations on these structures to carry out means-ends reasoning or to plan recognition. Figure 1 shows a BDI agent adapted from Ingrand, Georgeff, and Rao (1992). Resembling the way that humans behave, an agent can perceive the environment (input), and affect it (output). Beliefs are the agent's representation of the environment. Agents represent the status of the environment with symbols, will receive the stimulus and will be chained to new beliefs. Desires are the motivational state of the agent: they represent objectives or situations that the agent would like to accomplish or bring about. Intentions are the deliberative state of the agent: they represent what the agent has chosen to do and what the agent expects the environment to be. Each agent is equipped with a plan library, representing the agent's procedural knowledge. The plan library contains mechanisms that can be used by the agent in order to realize its intentions. The data flow is managed by the interpreter which will update the beliefs based on the acquired information retrieved from the environment.

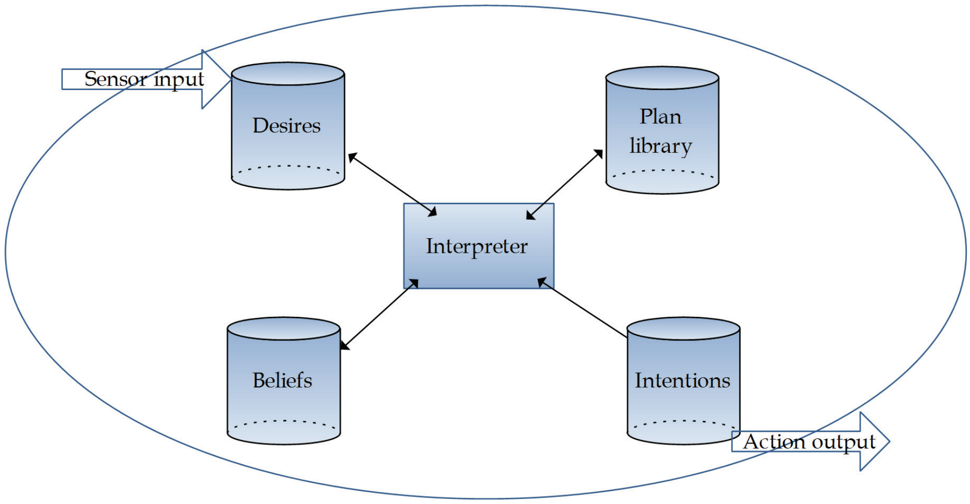

FIGURE 1 BDI structure agent (adapted from Ingrand, Georgeff, and Rao, 1992)

In contrast, in reactive architectures agents have no states. The behaviors of purely reactive agents can be simply represented as a function and based entirely on the present. A reactive architecture can be viewed as a stimulus-response model in which reactive agents do not take past events into account and cannot foresee the future (Wooldridge, 2000). It is a behavior-based model of activity as opposed to the symbol manipulation model used in planning. In reactive architecture, there is no need to revise the world model when perturbations change the world in unexpected ways. This kind of architecture is considered very flexible and adaptive because the agent can manage its resource capabilities in unpredictable worlds. From the practical perspective, a simple reactive agent is easy to implement, but has less functionalities than deliberative agents. The third option, hybrid architectures, attempts to combine the best of the reasoning and reactive architectures. Basically hybrid architecture could be implemented through two layers, a reactive layer and a reasoning layer. Due to this two-layer construction, the hybrid structure is claimed to lack a control framework to embed the agent's subsystems to manage the interactions between the layers.

In my research on agent-based decision support, agents are designed as the BDI agents, which have the deliberative architecture. They are able to interpret the decision request into their internal data structure and track the state. User's needs and actions are also supposed to be recorded by the support agents.

2.1.2 Science design in HCI

HCI research endeavors to provide an understanding of both human users and the computer system in an effort to make interactions easier and more satisfying. This means that we have to have a deep understanding of both users and relevant technologies as well as of how these are intertwined. This goal is especially important when we work with an emerging technology such as agents. The guidelines for designing effective HCI are thus important also in designing intelligent HAI for agent-based systems.

As stated in Carroll (1992), in the history of HCI there have been attempts and approaches to create a design science for HCI. At its core, software psychology is seen to constitute the historical foundation for the current HCI. The origins of HCI in software psychology posed two problems that became the touchstones for the field during the 1980s. One of these was the problem of determining what design and development work is really like and understanding how it might be supported. The other problem was that of determining what content the field of psychology, and perhaps social science more broadly, might have to offer to HCI and how that content could best be cultivated and applied in the development context. To overcome this problem, Carroll (1992, 1997) proposed an analytic model, iterative incremental development, and design rational as the approaches to consider.

The design process in HCI usually resorts to iterative incremental development which is a cyclic software development process that allows developers to take advantage of what has been learnt during earlier development stages (Larman and Basili, 2003). Analytic models, such as the user model, provide a framework for analyzing systematically the goals, methods and actions that comprise routine human computer interactions (Fischer, 2001; Santos et al., 2003). Work on analytic models has provided a rich and diverse conceptual foundation for HCI. Iterative development and analytic model converge at a design rationale which is based on the explicit listing of decisions made during a design process and the reasons why these decisions were made (Jarczyk, Löffler, and Shipman, 1992). This design rationale has been applied in the HCI design to integrate advances in iterative development and analytic models. Explicit discussion and debate are supported to clarify what was intended, considered, planned, decided and accomplished in the design process. By these means, the design analysis of implicit goals and the underlying tradeoffs among goals can be explicitly used to guide the design evaluation of user performance and experience. This broad reification of the design process allows iterative development to be more systematic and more manageable (Carroll, 1997).

The approaches in the HCI design mentioned above could be elaborated upon and adapted to an agent environment if supplemented with consideration of agent-specific features. Inheriting from the progress in building a science of HCI, a design framework for HAI could be constructed by applying the HCI design approaches into an agent-based context.

2.1.3 UCD for HAI

Providing users with a well-designed user interface for better interaction with computer systems has been the essential goal in interaction design for agent-based interactive systems. When designing a cognitive MAS, which is sensitive to the user's needs, designers should consider not only the traditional issues of robustness, efficiency and scalability but also the analysis of the relationship between human and agents: for instance, how humans perceive and respond to agents and how an agent, within the constraints of its particular purpose for which it was designed, could meet the cognitive and social needs of human beings. This is necessary in order to make the agent-based systems more usable, useful, and learnable. Murray, Schell, and Willis (1997) described the UCD methodology for developing software products and how the methodology was used by IBM to design solutions that meet customer needs. In other research, some taxonomies were proposed as bases for human modeling of agents, to make those agents predictable. The solutions in these taxonomies include, for instance, consistently pairing simple observable actions with inputs, or making the causes and rules governing an agent's behavior transparent, or making the purpose, capability, and reliability of the agent available to the user (Lewis, 1998). These taxonomies introduced the methodology of user-centered design for agents. Human issues are considered as basic elements during the design phase.

By employing the UCD for agents in the design, an emblematic agent-based interface can be made to appear as life-like characters or as other objects with which people are better accustomed to interact (Kopp et al., 2005). The agent may be displayed as a text, a human-looking character, a cartoon character, and so on. Because social evaluation and attribution of friendliness highly depends on appearance (Dehn and Mulken, 2000; Koda and Maes, 1996; Sproull et al., 1996), avatar agents with an animated appearance are preferred in user interfaces to expedite interaction. Although Parke (1991) recommended avoiding an overly realistic appearance since this may result in unreasonable expectations, agents that resemble the user in appearance, gender, ethnicity, etc. are still rated higher and seem to be widely accepted. Users are more inclined to delegate tasks to a system represented by a human-like face (Milewski and Lewis, 1997).

2.1.4 User modeling in agent system

User modeling is necessary in the UCD design to satisfy the heterogeneous needs of its users. The utilization of user modeling to make the design user adaptive is straightforward for an agent-based system. The current state-of-art user modeling is not necessarily built on general models of user behaviors. In domain specific modeling, one could start with limited scenarios and model as many features of users as necessary for each scenario. These partial models could then be improved or extended via experimental simulation (Zimmerman, 2007). A well-structured homogeneous MAS is an ideal modeling environment and suitable for this purpose. Various scenarios that involve human activities could be simulated within it. The agents' autonomy and learning ability would allow them to represent user populations and contribute towards adaptability. Thus user modeling and system adaptability can be approached through the agent paradigm (Chepegin et al., 2003; Fleming and Cohen, 1999; Moukas and

Maes, 1996). Researchers recently have shown great interests in the integration of user modeling and agent technology. Girardi, Marinho, and Oliveira (2005) present a system of agent-based architectural and detailed design patterns for user modeling based on usage mining in MAS context. Lee, Sung, and Cho (2001) describe a conversational agent that utilizes a user model constructed on Bayesian network for its responses, which are consistent with the user's goals. That user model could help in responding to user queries appropriately while being consistent with user goals. User modeling in a MAS-based HAI would be more comprehensive than in the traditional HCI system. When designing a HAI system that is sensitive to the user's needs, the designers should consider the possibilities of user modeling made available by distributed MAS. For instance, it has been argued in Vassileva, McCalla, and Greer (2003) that processes such as user information retrieval, aggregation, and interpretation of user modeling information created by different agents will become the main focus of user modeling research.

2.1.5 Emotional interaction design for agents

Emotions have a decisive role in the human mind from the individual's point of view when we evaluate the importance of objects, issues, people or events (Power and Dalgleish, 1997). Personal values are highly emotionally charged. People are aware of how things are, but they need emotions to define what things mean to them. Many services have emotional dimensions. Many dating or art services are tightly interrelated with human emotions. This close connection of emotions to motives and the effect of emotions in determining the importance of issues manifest that investigating emotions and using emotional explanation is essential to interaction and agent design. At the moment, we know very little about these emotion issues for HAI design, but it is self-evident, from a psychological point of view, that emotion challenges must be met (Olson and Olson, 2000).

Several psychological approaches have been employed to bridge human mentality in agent-based interaction design. One of them is user psychology (Moran, 1981; Oulasvirta and Saariluoma, 2004, 2006) – the specific use of applied psychology. It describes and analyzes human behavior with psychological concepts and bases interaction and service design on this knowledge. The user psychological design is not necessarily technology-driven: it may deal with forms of human activities rather than solve usability issues such as immediate interaction problems (Rosson and Carroll, 2002). Nevertheless, in user psychological thinking it is also important to deal with some ideas about new technologies and the demands they set for human users. This helps us in anticipating the kinds of psychological theories and the forms in which they may become in focus in the coming years. Less well known psychology areas such as psychology of subselves (Gretchen, 1992) and narrative psychology (Jerome, 1986) have been considered both for the agent and HAI design. All these fundamentals provide the theoretical base for applying psychology to the agent's emotional design. For example, research in agent design indicates that integral agent architecture is based on the sophisticated models of the user drawn from psychology (Norman, 1988; Goschnick and Sterling, 2002). When a sub-agent has been found lacking in capability to achieve a specific intention, an external agent can be called upon as if it were an internal sub-agent (Goschnick and Sterling, 2002). In addition, inspired by the narrative psychology, artificial agents can be designed to produce narratively comprehensible behavior by structuring their visible activity in ways that make it easy for humans to create narrative explanations of them (Sengers, 1997).

2.1.6 Agent-based decision-making, planning, and persuasion

Human-agent collaborative problem solving is another new area that attracts many researchers. The motivation is based on the desire to release people from the burden of repetitive and redundant work, simplify the complex interactivity in workflows, and enhance the efficiency and accuracy of information processing. Several software computing technologies have been adopted to facilitate human-agent collaboration in decision-making, planning, persuasion, etc. For instance, using agents in decision-making and persuasion has been tested and measured by several researchers. Researchers have investigated the potential of recommendation agents for electronic shopping and their influence on human decision-making by shaping user preferences (Häubl and Murray, 2001). The decision support agents can execute selective cognitive decision-making functions together with or instead of the user (Subramanian et al., 2006; Yifan, 2003) The RPD-enabled (Recognition-Primed Decision) agent (Fan et al., 2005) was designed to support decision-making teams by anticipating information relevant to their decisions based on a shared mental model. The results of the related research indicated that human teams when supported by agents can perform better in time pressure situations. Harvey, Decker, and Carberry (2005) implemented a multi-agent system for decision support through negotiation and presentation assembly processes. They also demonstrated the positive influence of the user model on content selection and presentation, thus improving system output. Other research issues include collaborative control (Fong, Thorpe, and Baur, 2003), motion planning for safety (Alami et al., 2005; Kulić and Croft, 2005), team centric autonomy (Bradshaw et al., 2004), and social order (Feltovich et al., 2004), etc. Allen and Ferguson (2002) developed the architecture of human-agent collaborative scheduling and planning, in which a collaboration management agent (CMA) is used to maintain the status of the overall plan and to manage re-planning for exception cases. Most of the research referred to sheds light on the positive sides of agents in collaboration work, but there is a lack of study on agents' impacts on human’s decision-making behavior, especially on the possible risks involved.

Some research like that of Pasquier et al. (2006) aimed to develop an argumentation framework for an agent, to construct an argument that was best suited to persuade other agents in a particular situation with a given standpoint. Social psychological insight (Rahwan, 2005) was applied to help in the exploration of belief/decision formation within a single agent and social interaction among many agents. But this research mainly concentrated on the agent-agent interaction. Some other research concerned agent communication skills and the influence of such in the buildup and sustainment of a trusting collaborative relationship between the user and the agent. The core interest was the agent's ability to effectively persuade users during decision-making tasks in system interaction (e.g., Fogg, 2002; Katagiri, Takahashi, and Takeuchi, 2001; Parise et al., 1999; Stiff and Mongeau, 2002; Stock, Guerini, and Zancanaro, 2006). Social factors, such as affiliation, authority and conformity, have been taken into account in interface agent design, but more factors need to be studied yet for effective and persuasive HAI, e.g. the strategies for persuading people.

2.2 General architecture of agent-based interaction system

Because agents and humans are the basic elements in an agent-based interactive system, the interactions normally take place within two layers: the interaction between human and agent(s) (HAI layer) and the interaction among agents (AAI layer), as shown in Figure 2. This two-layer interaction arrangement is a typical implementation of the service oriented architecture (SOA) together with the HCI design. The merit of this architecture is that each service interface which abstracts away its underlying complexity is reified in a single agent. Users can access independent services without knowledge of the service's platform implementation. In order to design such HAI system, we need to employ different design approaches according to different design considerations in each layer.

Interactions that occur in the HAI layer treat the agent-based interface as an intermediary which bridges the users to the system domain and diversified services. The advantages of this kind of agent-based interaction are evident. Task complexity could be decreased by bringing expertise to the user in the form of expert critiquing, task completion or co-ordination. Normally, there is an avatar agent which takes care of the interactive jobs between users and the system, including all user related communication processes such as information collection from users, responses to user requests and service presentation. When the user interacts with the interface agent, she/he actually interacts with the services that the system provides behind the interface. The functional complexity of the system is well hidden by the interface agent, so that users only need to put their tasks to the software assistant. Such interface agents communicate with the user in order to better ascertain the user's requirements, demands and ideas, and provide feedback to the user. A more natural interaction environment (e.g. anthropomorphic), to which people are more accustomed, can also be provided (Kopp et al., 2005). The interface agent usually has a human appearance in such environments. When people need help during interaction, they can easily find "somebody" to ask for.

The saying "springing up like mushrooms" doesn’t exaggerate the number of ways that agent-based interaction applications in this layer have increased: information searching (Wu, Ngu, and Pradhan, 2006), software assistants (Fischer et al., 1996), collaborative filters (Good et al., 1999), shopping references (Häubl and Murray, 2001) and auction androids (Chavez and Maes, 1996), just to mention a few. The embodied conversational agent (ECA) even shares some human properties in face-to-face communication. It can recognize and respond to verbal and nonverbal input, generate verbal and nonverbal input, deal with conversational functions of behavior and also participate actively in discourse (Cassell et al., 2000; Johnson, Rickel, and Lester, 2000; Raidt et al., 2005). These applications may even seem to employ certain expertise to support users in solving particular problems.

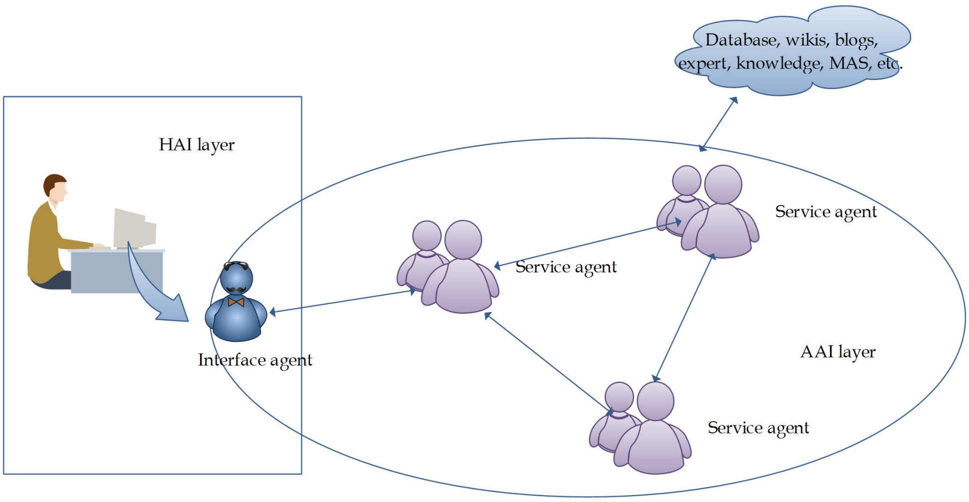

FIGURE 2 General architecture of the HAI system

In the AAI layer, a single service provided by each agent presents a simple interface for obtaining that service. Autonomous agents in the system communicate and cooperate with each other to handle the user’s requests. A goal-directed task such as decision-making can be performed by agent collaboration without human intervention. If the user requirements are beyond the ability of the local system’s service, a cross-system interaction implemented by the agents will empower the system services and make the system more robust. The AAI layer has to do with the implementation of techniques and service composition, in accord with the elementary meaning of the interaction, these functionalities actually forming the main part of the system's physical implementation. Thereby, although my research mostly concerns human-agent interaction, investigating service composition and how agents could better coordinate themselves will help in providing the agent-agent interaction with more humane features.

2.3 Implications of intelligent interaction

2.3.1 Intelligent interaction

No matter what layer the agents work in, the quality of the interaction is usually determined by how 'intelligent' the system is. Agents' adaptiveness and reactivity allow them to perceive the context and adapt to their surroundings quickly. But when the terminal interaction object becomes the human being, being no longer the software entity, such 'intelligence' needs a closer look. Intelligent interaction is not simply constrained to problem-solving abilities; more must be done to satisfy human users. HCI researchers have predicted that the next-generation computing in HCI will develop anticipatory user interfaces that are human-centered, built for humans and based on naturally occurring multimodal human communication (Pantic et al., 2008; Wang et al., 2005). In this vision of the future, computer-based devices will have the ability to anticipate humans' needs and thus give rise to a set of greatly challenging issues concerning interaction between the technology and humans. Keeping this in mind, HAI, the novel HCI introducing agent technology, needs to incorporate the research in human aspects, so that the outcomes from the interaction will satisfy both sides, but first and foremost, be pleasing to the human users. Users' requirements should be captured and understood by agents in a highly efficient way, and the feedback to users should be presented in a skillful manner through every stage of interaction. The interaction pattern should consider both sides to ensure efficiency as well as usability.

One popular view is that implicit interaction is appropriate for designing user-adaptive interfaces using agent technology. Users' requirements are better captured by monitoring their behaviors without paying too much attention to their consciousness (Abowd and Mynatt, 2000; Abowd, Mynatt, and Rodden, 2002; Schmidt, 2000). The resulting communicative organization should be in accord with the human etiquette and social expectations. The agent interface requires an even deeper understanding of users than the design of the system's functionalities since the interface must match the skills, expectations and needs of the intended users. In addition, although people are aware of how things are, they need emotions to define what things mean to them (Power and Dalgleish, 1997). This means that personal values are highly emotional, and we must find effective ways of personalizing the emotional dimensions of agent environments so as to make the agent's behavior understandable. Assistance from agents should not be too salient to create side effects by increasing the cognitive load of users. Again, the trust relationship between human and agents is a fundamental constituent of intelligent HAI. People's trust on the agents or system they interact with in one sense determines the usability of the HAI system. Some research claims that the perceived intelligence of and trust on a system, as well as its credibility, is increased when an anthropomorphic interface is used (Bengtsson et al., 1999; Burgoona et al., 2000). Oliviera and Sarmento (2003) even ran experiments to test if their emotional models were realistic enough to make a human participant believe that they were interacting with another human being.

Furthermore, the realization of intelligent interaction heavily relies on the 'intelligence' of the agent. From the classical AI's point of view (Daniel, 1993; Russell and Norvig, 2003), the special properties of these software robots endow them with capabilities for flexible, interactive and intelligent interaction. Their autonomy and proactiveness free people from many nagging and repetitive tasks, contributing to efficiency. Goal-directed task selection, involving decision-making, can be performed by those agents without human intervention. Their adaptiveness and reactivity allow them to adapt to their surroundings quickly, perceive the context in which they operate and react appropriately. Nevertheless, Sengers (1997) pointed out that no matter how smart artificial creatures become, AI will not have completely fulfilled the dreams we have had for it until agents are not just smart but also intentional, like living creatures with their own desires, feelings, and perspectives on the world. Thus some researchers are mostly concerned about the extent to which the agents should mimic human appearance and social behavior and thus hide their "artificial" appearance and behavior (Dautenhahn, 1998; Druin and Hendler, 2000).

The social competence of agent seems to be essential to intelligent interaction. Research on social intelligent agents indicates a new potential social role that the agents are likely to adopt in the society (Dautenhahn, 1998, 1999; Dautenhahn and Nehaniv, 2000). They are perceived as powerful research tools for establishing a science of the social mind, which is an approach towards understanding social intelligence in humans. Agents can allow us to extend and multiply our single physical presence into many virtual entities. Agents would appear as life-like characters through which different roles and personalities could be experienced in virtual, consequence-free environments. A virtual face may attract user attention, and the more human-like it is the more entertaining the user interface will be found. Interaction with such social agents, if complemented with sufficient experience with social interactions in real life, can raise our awareness about the importance of personal social interactions and the appropriateness of different modes of communication and interaction (Dautenhahn and Nehaniv, 2000).

2.3.2 Challenges in agent design

There is a particular corollary of a general principle in HCI design: a designer should preserve, as far as possible, the structure and semiotics of the source domain in the structure itself and semiotics of the user's target domain where interaction is situated (Goguen, 1999). In relation to this principle, when designing such an HAI system, a system designer who works on a dynamic agent-based environment looking for a way to apply an agent approach in problem-solving usually needs to solve two major challenges in agent design.

Firstly, the independent software entity, i.e. the intelligent agent, is still far away from realization. The agent is different from the common computer software as regards the autonomy that makes the agent's behavior unpredictable in certain circumstances. Improving the functionality of the intelligent agent is the premise for an effective HAI. For instance, in the AAI layer, interaction such as information exchanging, message delivering, service publishing and discovery, and resource sharing is purposely carried out by agents. Since the agents have their goals and beliefs, they need to negotiate with each other when conflicts occur. The outcome behaviors of the system are often compromises between different agents under the control mechanism of their own. Although this agent-agent interaction does not affect human users directly, it determines the quality of the services the system can provide; therefore the HAI system designer should not ignore it. The design focus should be on applying sociability in the agent design so that agents would be able to cooperate with other software components through certain communication and coordination protocols. Hierarchical relationships of separate agents in different components should be explicitly identified. In this sense, the communication strategies in human societies might prove beneficial to the agent's cooperation arrangements in MAS (Rahwan, 2005).

Apart from the cooperation mechanism, another deficiency in agent design is the lack of knowledge concerning human beings. Although the notions about agent have occupied a major role in defining research in social and behavioral science, current design approaches to MAS generally focus on the technical aspects of agent design. Most research seeks to solve technical problems when designing agent architecture, communication language, ontology, and interaction algorithms. Even in agent model design, although the infrastructure has its origins in the cognitive framework of the human being, the designer's attention is usually directed at the architecture level. Efforts to design an agent from a human perspective are far behind those made from the technology perspective. Because the agent's ability goes beyond interaction with software entities only, once agents try to communicate with audiences such as human users, their behavior will inevitably be required to appear humane in its characteristics, to some extent at least, and the interaction design may become more complicated. This implies that agents should not only have the capability to perceive what people are saying, doing and thinking, but also be comprehended and accepted by their human users. The lack of awareness on human issues in the agent model and functionality design may hinder the effectiveness of their interaction with a human user.

In addition, the general lack of knowledge about human intentions and other characteristics referred to earlier would be augmented by the lack of knowledge of human behaviors. The user needs should be exactly and timely reflected in the system for user adaptive purposes. The uncertainty about people's behavior increases the complexity of the interaction. For example, without a careful analysis of the discourse context of a gesture in natural pointing behavior there would be a high risk of reference failure (Wahlster, 1998). Designing a HAI system, hereby, requires the ability to predict behaviors of both agents and human under ever-changing circumstances. Understanding only the unilateral behavior model in HAI is not enough for design. Thus, HAI research is multidisciplinary work that requires more concentration on the human aspects in agent and interaction design.

2.4 Human aspects in HAI design

As a sub-area of HCI, HAI addresses the combination aspects of human cognition and social agent technology integrated by using human behavior models in agent design (Dautenhahn, 1997, 1998, 1999). The agent-based interaction approach has advantages over human-based approach when dealing with user requests and service delivery. But this efficiency in information processing does not mean high usability in interaction. It is more important to think how to work with a human user. Human aspects are essential to the completeness and robustness of the agent and interaction design in both general and individual levels.

Generally speaking, a conversation between the user and agents is more complex than that based on the conventional stimulus and response model as the reactive agent architecture uses. The interaction could take place in a 3D environment where human-agent interaction is supported by a multi-modal interface via video, audio and haptic hardware. The dynamic and multi-model interaction environment sets high requirements for agents, for example, in respect to user models, including facial expression/gesture recognition, user action observation, the user's need anticipation, service presentation and so on. Cultural background and etiquette also need to be taken into account if the expected users come from different areas (Bickmore, 2002). Specifically, if we are to build agents that truly appear intelligent enough to handle conversation with human users we need to include the necessary human properties in our design of agents. There is some evidence that people are willing to ascribe human-like characteristics, such as emotion and intelligence, to artificial entities (e.g., Bourke and Duffy, 2003). Thus, humanizing would make interfaces easier and more comfortable to use (e.g., Norman and Draper, 1986; Shneiderman, 1998; Walker, Sproull, and Subramani, 1994). Therefore, in the HAI layer, we shall focus on the interaction models and associated design approaches concerning the user's requirements, needs and intentions. The main point is to humanize the interaction without compromising efficiency.

At the individual level, functionality components within an agent are usually put intentionally in a black-boxing domain layer that consists of independent functionalities such as sensor input and action output, which I introduce in Section 2.1.1. One usual way to design the behavior of autonomous agents is by the use of the rule-based action-selection algorithm where an agent's action is triggered by certain conditions and the best action is dynamically selected based on the predefined rules and actual circumstances (Maes, 1989). This design approach is superior in simplifying the service presentation without augmenting the user's cognitive load. Such layer in the domain hides the great complexity of the business logic; people do not need to care about what happens inside the box and where the services come from. However, since the agent's behaviors depend on the predefined rules and dynamic conditions, the drawback of the algorithm is our incapability in explicitly describing the logic of one single behavior and the connections among behavior sequences. Users may be interested to know why the agent performs such and such action but the changes in the agent's behaviors usually fall short of explanation. Having to ignore the diachronic structure of behavior is against the idea from narrative psychology that people create meaning by structuring the relations of behaviors over time (Jerome, 1986). The difference between the atomistic standpoint of the agent designer and the narrative viewpoint of the eventual agent audience can undermine the designer's ability to construct intentionally understandable agents (Sengers, 1997). A good example is given in Sengers (1997), clearly stating the necessity of a user perspective in agent design. Building an autonomous agent by simply copying the atomic attributes from a living creature does not meet the user's expectation of the agent. Making the agent human-like depends more on the quality of observable behavior that forms the basis by which audiences try to understand the agent than on any single emulated attribute the agent owns.

Consequently, research on achieving the potential of agents during the interaction and on the design of particular agents should be complemented by the study of human cognitive issues such as emotional design, user psychology, user modeling, and so on. To create a really intelligent agent and interaction model probably forces us to tap into user psychology, socio-technology, and model design, which HCI researchers have shown more interests in. Many theoretical issues related to socio-cultural processes have already been touched upon in the current research on MAS. As said in Sun (2006), if we ever try to understand cognition in the broad context of socio-cultural environments in which cognitive agents exist, these issues will be found intellectually profound and will have a significant impact on cognitive science.

3 AGENT-BASED DECISION SUPPORT

HAI design is multidisciplinary work and may include a multiple design rationale, technology, and involve various types of applications. Looking into each of these areas requires tremendous efforts and is out of the scope of this thesis. As HAI is too broad an area to be a subject for an empirical study, the research probes into a more typical problem solving area, the agent-based decision-making support. Normally, agent-based decision support requires agents to have at least two kinds of abilities: the ability to make decisions according to users' requirements and among several alternatives within a certain context, and the ability to skillfully and in an acceptable way present its suggestions to human users without causing them annoyance. My research deals with both of these two topics, investigating how to design such agent-based DSS and the agent's impact on people's decision-making. In my approach, an agent-based decision support framework is constructed and interaction is then organized, through psychological approaches, under that framework. Several experiments are accordingly designed and conducted to verify the mutual influence between humans and agents: the impact of people's cognitive skills on agents' behaviors and agents' impact on people's decision-making behaviors. The goal is to seek answers to three research questions concerning what the prerequisites of an intelligent HAI are, how to organize it, and how agents influence people in decision-making.

3.1 Experimental design method

The overall research complies with the experimental design procedure as briefly introduced in Section 1.4.1: identifying the problems, formulating hypotheses and deducing its consequences, constructing the experiment, conducting the experiment, analysis, and conclusions. Concretely, the research was directed to investigate agents' support in decision-making for different aspects in different application branches such as finance, production management, and resource management. In each case the research proceeded following the experimental design steps with some more details added:

- Problem identification: The research questions in Section 1.3 are root problems the study pursues to solve them. In each of the application branches, the research problems turned into more specific areas to find out, for instance, what the advantages and risks in agent-based decision-making are, and how we should design an agent for decision-making support.
- Hypothesis: In a way similar to the problem identification, the hypotheses were detailed, taking into account some specifics of each of the application area. For example, a normal agent presents the risk of time-primed decision-making, task performance could be enhanced by suggestions from an agent skilled in communication, and so on. Independent and dependent variables were clearly defined in this phase, and then semantic hypotheses were translated into relations between various dependent variables.
- Theoretical diagnosis: Relevant theories of UCD, emotional design, psychology, user modeling, decision-making, and persuasion were studied and then subjected to a careful selection process to construct the agent-based decision support.
- Experiment design: Context-based experiments and surveys were designed for evaluation. In practice, this phase included building proper scenarios to test the hypothesis, having an agent architecture design which would empower the agent to have decision-making abilities and skills to satisfy the requirements, sampling groups to study, etc.
- Conduct of the experiment: Independent variables were manipulated in this phase to affect the experimental groups. Most of the volunteer participants in the participant group were university students or researchers who were native Finnish speakers with qualified English reading and speaking skills. All the experiments were carried out in English as was the communication with the participants.
- Results analysis: The results analysis and measurements were performed using statistical methods to find out the relations between variables.
- Conclusion: Conclusions were drawn after the analysis. This included a summary of the benefits and risks in using agents and of their impacts on the social behavior of people, as well as solution proposals for constructing agent-based interactions.

In practice, the agent-based decision support model and system architecture were first constructed as a framework, under which the research was conducted following the experimental method steps above.

3.2 Agent-based decision support model

The agents' high ability for fast information sharing and processing may be of considerable benefit to people, considering the ever-increasing amount of information, on the one hand, and people's limited mental capacity to deal with it, on the other. Due to the limited information processing capacity of the human working memory, users may feel strongly tempted to rely on the agent's recommendations in order to reduce their decision-making effort (Häubl and Murray, 2001). This beneficial property has been embodied in agents to assist people in making decisions on different authority levels - an agent can assist people in making decisions by merely offering useful information and serving in advisory functions or even by making decisions on the user's behalf. In this respect, intelligent agents could replace people in some simple and repetitive tasks, such as spam filtering in an email system, arranging meeting schedules, and in busting malicious viruses. This type of assistance would free people from burdensome work, and it would still be possible to intervene the whole course by, for example, creating an exception capture mechanism or by dealing with certain conditions in order to prevent possible perilous situations. Thereby, as a compromise, agents could provide problem solving solutions for people, allowing them to decide whether to adopt the solution or not. The aim of confining the agent to an advisory role is to ensure the user's comfort by involving the user. This kind of agent usage has been applied to most recommended systems for decision-making support (Petrov and Stoyen, 2000; Stoyen, 2001; Sueyoshi and Tadiparthi, 2008). Research results have further indicated that human teams, when supported by agents, could perform better in intense time pressure situations (Fan and Yen, 2004).

My research inherits the idea that the role of agent in the decision-making process should be confined that of an advisor. The definition of agent-based decision-making can be thought of as being based on a process where an agent makes the decision only as a suggestion which the human user still can override. The agents could suggest a decision and try to sell it then to the users by the help of their different communication skills. The outcome of an agent-supported DSS is indeed the result of synthesis of human and agent decisions from a holistic point of view. An interaction model should reflect this distinguishing feature that guides the interaction course in decision-making support. From this point of view, the social welfare function proposed by Harsanyi (1977), which deals with choices by a group of individuals in a society, seems appropriate for modeling the decision-making process in agent-based DSS. This model has been used in MAS (Jennings and Campos, 1997) and could still be implanted to a HAI system.

In the human society, the decision-maker can either be a group making a joint decision or an individual making a choice that may have global consequences. Similarly in a multi-agent based system, one agent's decision might have impact or be impacted by the decisions of other agents. An individual agent needs to consider the influence of other agent's ideas and, moreover, its decision should be overridable by human users due to the asymmetric characteristics of the HAI system. Therefore, the agent-supported decision-making progress could be translated into a computational model by extending the idea of social welfare function - the sum of all decision-makers' payoffs or utilities in a given solution. The model that follows is extended and modified from Hogg and Jennings (1999) and Jennings and Campos (1997).

First, the general theory of social welfare is formalized as:

$$W = \sum Yi \quad i \in (1, n) \qquad (1)$$

where *W* is social welfare and Y_i is the preference of an individual *i* among *n* individuals in the society. The goal of the decision-making process is the maximum value of social welfare function. Hogg and Jennings (1999) adopted this social welfare function in order to ascertain the social impact of an action within a society of agents. According to Harsanyi's formulation of social choice, each individual agent's preferences are represented by the von Neumann-Morgenstern cardinal utility function. Hence, social welfare function (1) becomes the aggregation of an individual agent's utility function.

$$W = \sum \lambda_i \mu_i \quad i \in (1, n) \qquad (2)$$

where λ_i represents the weight given to agent i's utility function μ_i in the overall equation. W is defined as the weighted summation of the individual utilities. This utility function could be applied to our agent-supported system where the final outcome of the system is the composition of the decision actions made by all the participants (both the human user and the agents) involved in the system. The decision-makers in the system produce collective decision actions A = {a1, a2, a3, …am} over given situations. Thus equation (2) could be rewritten as

$$W(A) = \lambda_h \mu_h (a_h) + \sum \lambda_j \mu_j (a_j) \quad j \in \{A\text{-}h\} \qquad (3)$$

where a_h denotes the human user's decision action and a_j is an agent's action. This formula has a significantly different meaning to that presented in Hogg and Jennings (1999), though it looks similar. In the formula of Hogg and Jennings (1999), an agent's decision on a certain social situation could be expressed in terms of its preferred action and according to what the effect the action has on other agents. The meaning of formula (3) is that the social effect of a decision is the sum of human preferences together with the suggestion of assistant agents in all situations. Since the human user always takes up the center stage in the procedure, the weight of the human user's decision action is larger than those of the agents, and it is possible to set the weighting of a specific agent's utility function to zero (even for all agents). That means the human user can eliminate the influence of agents on his/her decision-making. For example, setting all agents' weighting λ_j to zero removes any utility benefit consideration from the human user's decisions. In this way, the human can regulate the control over the system by adjusting the weight to individual or group agents. This model reflects the essence of the agent-supported DSS where the agent works as the advisor and the human being will make the final decision.

3.3 Agent-based decision support system

3.3.1 Decision-making process within a single agent

Each agent in a MAS works as an autonomous component in the system and has the ability to make decisions based on a request, which constitutes the system design on a base level. The decision-making process within an intelligent agent is designed to simulate the course of human decision-making. Figure 3 illustrates how the decision is made within a single agent. Once the task inputs from the environment (the user or other agents) have been received, e.g. a decision needs to be made, agents would start the process of problem analysis. Within this procedure, some predefined checking will apply to the input in order to validate and filter the incoming information. Redundant or malicious input will be filtered and only the useful parts will remain. The corresponding beliefs, goals, or strategy plans will then be generated with the support of the knowledge repository in order to prepare the decision options.

In order to solve the problems in a specific area, the agent usually equips itself with certain knowledge for decision support like other knowledge-based systems (Efraim, 1993). The knowledge base in the knowledge repository is used for this purpose. That is normally the database which contains a collection of data about experiences related to solutions. If the decision support system is designed as a rule base, a plan library which has certain rules for certain conditions is needed. Even the user model could be embedded into the knowledge repository to provide more human information. After the problem analysis, those decision options will be sent to the alternative evaluation component, and then the agent starts to explore multiple alternatives. The outcome data will be compared and purposely selected to make a decision based on available cues and rules. In any given situation, no matter whether the request is from a human user or other agents, the agent has to present its decision or information to the requester in a proper manner. Specifically, if the agent interacts with a human being, the decision-making process, including problem analysis, decision generation, evaluation, and modification, is performed according to the user's feedbacks, attitude towards, and satisfaction about the decision. As a response to the users' action, the agent's decision is translated into communicative, goal-directed agent behaviors, providing the user with suggestions, advices, and proposals concerning task decisions.

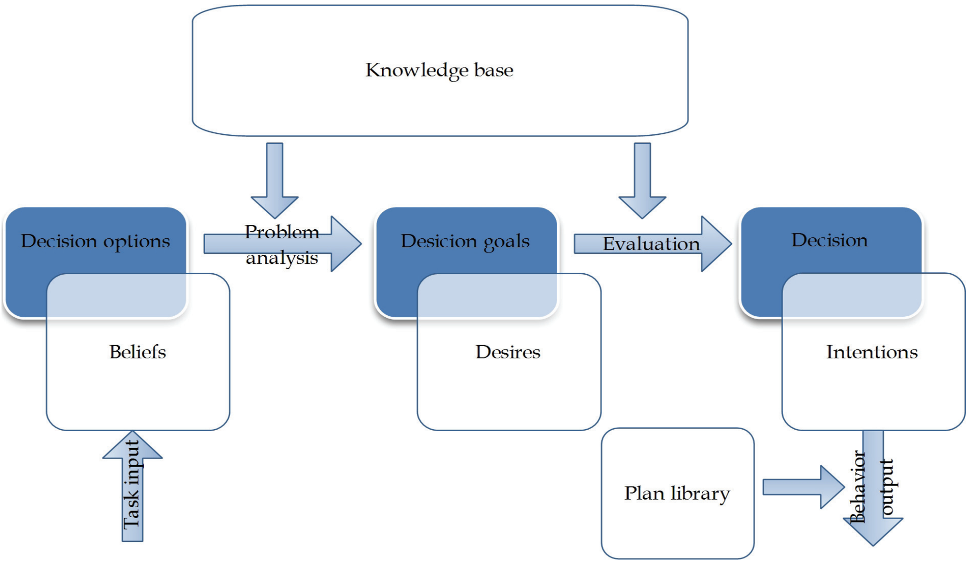

FIGURE 3 Decision-making process within an agent

3.3.2 Multi-agent support in decision-making

A prominent advantage of MAS is that its agents can cooperate together to achieve a common goal, which might not be possible to implement by a single atomic agent. In today's applications, MAS is usually combined with a P2P network (Gorodetsky et al., 2007; Küngas and Matskin, 2005). The agents can communicate with P2P network for resource allocation and sharing. This combination facilitates resource sharing and management in MAS, enabling fast and efficient communication in the P2P network. Thus a common DSS could be deployed in a multi-agent platform in an attempt to improve the efficiency of the system. If an individual agent couldn’t provide the service required, it would forward the request to other agents, which might have the ability to meet the requirements. Even with multi-agent support there might arise a case where none of the agents can implement the task but through agent cooperation. In such cases, problems could be decomposed into several sub-problems and assigned to different agents, by which action the complexity of the issues could be decreased (Wooldridge and Jennings, 1995). Thus the common goals could still be achieved by the collaboration of individual agents. This means that specific agents in the agent-based decision-making support system could be designed to perform sub-tasks decomposed from a decision request, depending on the requirements of each task. For example, the steps in the decision-making process described in Figure 3, like problem analysis and evaluation, could be viewed as tasks assigned to certain agents cooperating in decision-making. Those agents would have different task-specific roles, including that of an interface agent, a database agent, and user agent, to perform in the system. In an agent-based decision-making support system, we mainly classify the agents' roles into three kinds on a system level (See Figure 4).

- Interface agents: Agents that directly interact with human users.
- Decision-making agents: Agents that analyze problems, evaluate the decision options, and make proposals to people.
- Resource agents: Agents that interact with other network resources for information discovery.

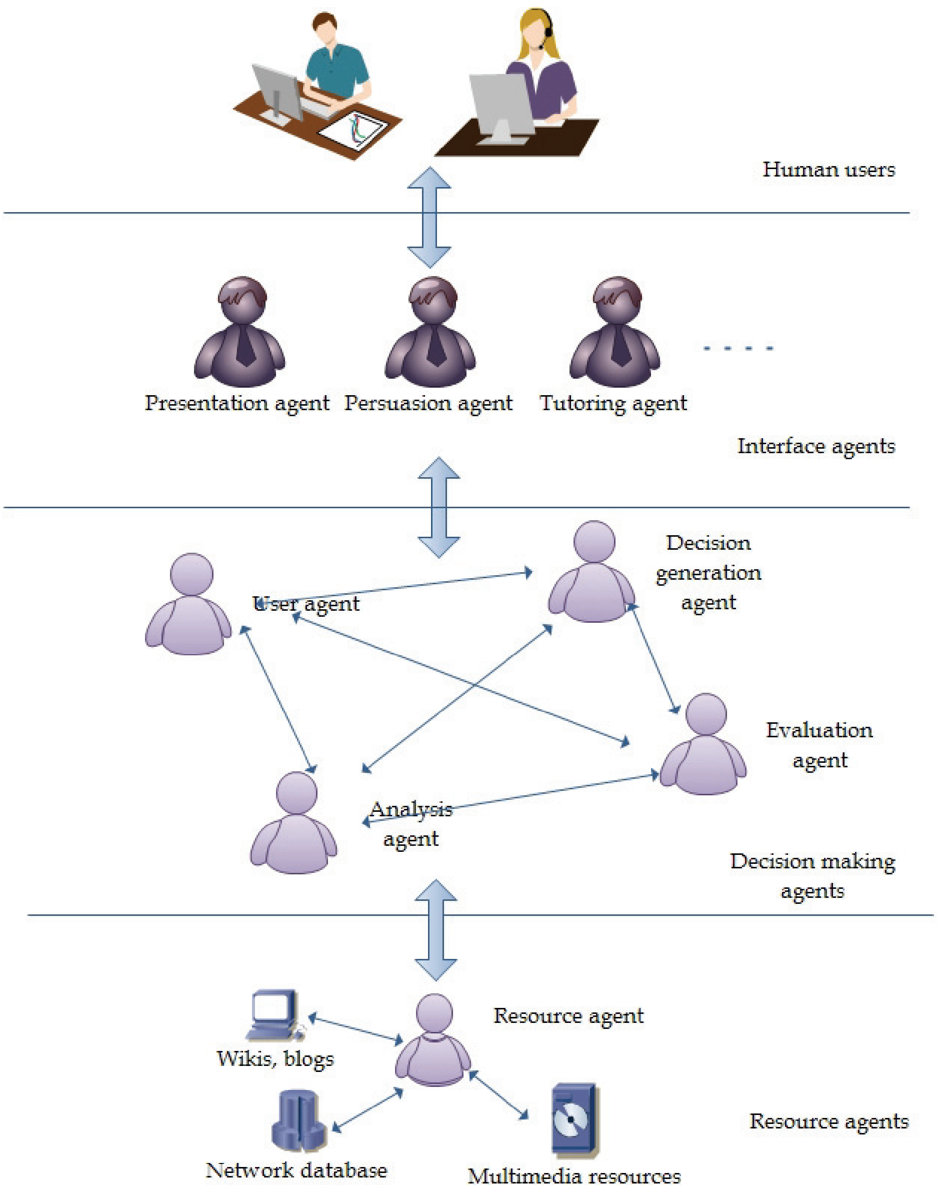

FIGURE 4 Architecture of the agent-based decision support system

Interaction occuring in this system is the two layers of interaction: HAI and AAI gearing at the interface agents (See Figure 5). Interface agents lie between the human users and decision-making agents and deal with input and output issues. These agents detect people's behaviors via multi-perception technology and present suggestions from the system to its users. The idea is that interface agents would determine the user profiles to personalize the performance of an agent or to improve the assistance provided by the agent. The requirements for decision-making captured by the interface agents are delivered to decision-making agents. These agents, in turn, will cooperate with each other in order to prepare the decision support system. Since the local service may not always be able to satisfy the ever-increasing user demands, the resource agents search the information from other systems, platforms and any multi-media network services via Internet. Thus the decision is not made by one specific agent but by the collaboration of a community of agents.

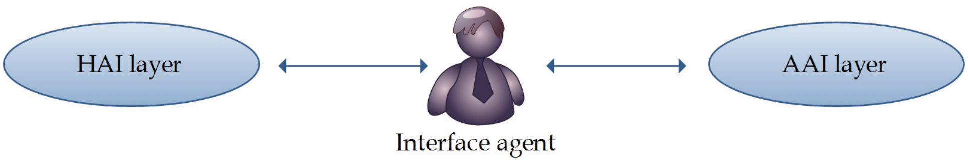

FIGURE 5 The two layers of interaction

An important feature in this multi-agent support decision-making is the agent's collaboration. The decision-making agents and resource agents have to interact with one another in order to achieve an agreement or share information. Cooperation and collaboration between the agents are necessary for the whole network to stabilize it from the technical point of view. Although this agent-agent interaction does not affect human users directly, it determines the quality of services the system can provide. Because BDI agents may have different kinds of goals, which may overlap, relate or conflict with each other, the final behaviors are usually results of compromises between different agents under the control mechanism of their own. Coordination strategies for agents are required in order to better adjust their behaviors and harmonize them. A coordination strategy can be seen as a pattern of decision-making and communication among a set of agents performing activities to coordinate task execution. The way various agents cooperate in a MAS can either be determined by a) external processes: e.g. the norms and social laws (Shoham and Tennenholtz, 1992); or b) internal processes: by the agents themselves. The coordinating process in b) resembles partial global planning (Durfee and Lesser, 1991), where, after the decomposing process, agents are needed to generate short-term goals to implement the tasks. Generally, the planning procedure in b) involves three iterated stages: (1) each agent decides what its own goals are and generates short-term plans (2) the agents exchange information to determine where plans and goals interact (3) the agents alter plans so as to better coordinate their own activities. This general procedure simulates collaboration in a human society. This also illustrates how human behavior can have a deep influence on the agent's design. Human-centric soft paradigms are considered valuable to enable effective collaboration and to reduce the chances of conflict during information searching processes.

3.4 User modeling

One basic requirement of UCD is that the functionality of the whole system should fit the ultimate users' needs (Norman and Draper, 1986). From a viewpoint of the system design, all the justified user requirements should be mapped into the engineering concepts, including the functional components and data structures, in a way that the computer-based system could easily understand, process, and store them. Thus the analytic user model is required for this purpose and should be built and merged into the system design.

In the MAS context, traditional user modeling has evolved to distributed user modeling. User modeling in a MAS-based HAI would be broader than in a single HCI system. Hence, in designing a cognitive HAI that is sensitive to the user's needs, the designers should consider not only the traditional issues of robustness, efficiency, and scalability but also the new issues about user modeling in distributed MAS. More complex issues need to be considered when building distributed user models for MAS.

First of all, in MAS distributed user modeling approaches, monolithic user modeling is replaced by distributed user model fragments. As a consequence, processes such as user information retrieval, aggregation, and interpretation of user modeling information created by multiple agents will become the main topics in user modeling research (Vassileva, McCalla, and Greer, 2003). The key to making sense of the distributed user models is the ability to interpret multi-model information from multiple relevant heterogeneous sources and to integrate this information as needed into a user model. Thus, the main question boils down to how to integrate all this information in a distributed context. The system should provide an effective way for the users to locate the agent which has a model of relevant user characteristics in its possession and to validate possible inconsistent user information.

In the agent-based DSS, this point has been solved by user agents, and the modeling process could be referred to the internal coordinating process in MAS as mentioned in Section 3.3. The user modeling is reified as the user agent which offers user's information for the humanzing communication. For instance, the decision support system within the distributed LMS can help the tutor in decision-making for the management of learning resources. Teachers could be represented by a teacher agent and students by student agents, these agents containing the basic information of the users. In addition, each user agent would only hold those user model fragments which would correspond to the partial plans created by each agent. A single agent cannot have a view of the whole system, so it does not generate a user model for the entire problem. Instead, by fusing local data and information, these user model fragments are integrated into a partial global user model. Here it must be kept in mind that user model fragments are usually suspect, containing invalid and outdated data. Human invention is needed for the integration of the global model and for information correction.

Secondly, user modeling normally requires the use of knowledge representation models for the information needs of people to improve organizational communication and organizational learning (Kass and Stadnyk, 1992). One explicit way to do that is by improving the mechanism of information input. Human beings use various senses to gather information from the outside world, and, similarly, the computer-based system can perceive the external environment through a multi-perception technology. The main goal of using multi-perception is to find out about the user's intention by using integration techniques for the various kinds of inputs (Maybury, 1995). This point is also solved by the collaboration work between interface agents and user agents. Interface agents forming part of a multi-perception model have achieved successful results in integrating symbolized information, for example, in resolving references in natural language sentences (Cohen et al., 1997). They are able to capture the user's movements, such as gaze and gestures with the help of a digital camera, collect sounds through microphones, and also generate vocal commands or feedback through speakers. The information thus gathered will be transferred to the user agents as the action records of the user, and the user agents will then conduct an intention analysis based on this raw data. Applications of multi-perception technology have promoted the robustness and flexibility of the computer system and enabled the system to receive more useful information from the outside world and thus, by reducing uncertainty, make more precise decisions.

3.5 Emotional design for HAI

In the architecture presented in Figure 5, it is shown that the two levels of interaction, HAI and AAI, are only bridged by interface agents, which are in an important position for the information exchange between human users and the agent-based decision-making support system. By modeling and simulation of the collaborative process, we could treat interface agents as human beings and work together with them. However, these agents are not real human beings nor could we regard them as common software programs; the collaboration working models have been made different from the traditional software by the introduction of agents' impact and human cognition issues. Certain design considerations regarding the interface agents are essential for the system to maintain a trusting relationship with human users.

3.5.1 Building a trusting relationship with human being

The main advantages of using agents are that, with their help, people can delegate workload and enhance interaction outcomes. However, when we use agents as assistants in our decision-making process, there are some questions to be expected from the critics: how can we ensure that the user feels safe if delegating tasks to autonomous agents? would it be catastrophic if agents fail or provide misleading information? – and - what would the risks be? Those worries bring the discussion about trust to our agent-based interaction design.

Trust is actually an anthropomorphic term capturing many issue complexes involving mutual human-machine modeling, awareness, and coordination (Lewis, 1998). People's trust and will to collaborate with agents demands their own type of interaction resources. People might doubt or feel reluctant to accept an agent's decision or the information provided by an agent, especially if they are not convinced about or cannot validate the trustworthiness of the agent. For this reason, system designers should focus more on building a trustful connection between users and the agent-based decision-making system.

Regarding to my research I adopt the definition of trust where trust reflects the expectation one actor has about another's future behavior to perform given activities dependably, securely, and reliably based on experiences collected from previous interactions (Grandison and Sloman, 2000; Mui, Mohtashemi, and Halberstadt, 2002; Skopik, Schall, and Dustdar, 2009). This definition connotes two meanings: it deals with one's expectation for a reliable performance and it is based on one's previous experience. This actually sets two challenges for the agent design in decision-making support. Obviously, the agent's competence is essential for the trust people will put to the agent. Specifically, the intelligence here means the agent's ability to acquire the knowledge it needs to decide when to help the user, what to help the user with, and how to help the user. It also has to do with the accuracy with which the prediction agents can provide this information for people. Constantly improving the agent's competence would help to establish a confident relationship between the human being and the agents. This trusting relationship can make people reassured when working with agents and conducive to the smooth and effective progression of that work. However, the agent's super abilities in information search, its validation skills and efficiency are not the only requirements in gaining the trust of the human operator. It should also be a good mediator between the knowledge and the user to avoid any trouble in communication (Fogg, 2002). A well-designed approach should carefully deal with the competence criterion and consider lots of details in interaction, such as the knowledge presentation for users, a simplified and neat interface for adaptive interaction, well-structured argumentation skills and so on. The idea of confining the agent's role to that of a serving advisor is helpful for gaining the trust since it is then the human user who will control the ultimate decisions. Moreover, the trust is based on someone's previous experience (Grandison and Sloman, 2000; Mui, Mohtashemi, and Halberstadt, 2002). When the user is familiar with the system, a trust-based relationship is easily set up if the agent seems competent. But how could we gain people's trust right at the start? In my research I aim using emotional design for the agents to gain users' trust. My design also considers the tricky situation where trust is affected by a failure of advisory agents in some issues. The experimental results in Article 5 show that lost trust can be recovered if the malfunctioning agent manages to revert back to its normal status.

3.5.2 Emotion based design for agents

The agent-based interaction approach has the advantage of dealing with the user requests and service delivery. But this efficiency in the information processing does not mean high usability in interaction. The formula presented in Section 3.2 describes the model for the agent-based decision-making support and reflects the asymmetric roles of agents and human users in the interaction. But the formula doesn't speak about the rules guiding the agent behavior. Having this model is not the goal of the research, neither it is enough for informing us about agent-based decision support. We need to find a way to examine how and to what extent agents can influence people's decision-making.

According to my research, the way to influence people proceeds via two steps: first, by attracting people with an opinion and, then, by convincing people about the idea. What is it then that makes the agent and its suggestion look attractive? One interesting clue from the psychology, in this context, is given in the answer to the question: why are we attracted to some people' opinions and not to the opinions of others. The reasons for this could include repeated contact and similarity (Kosslyn and Rosenberg, 2005). In our intimate relationships, we are more likely to be attracted to people with whom we have repeated contact or we regard as similar to ourselves. E.g. when people live in a close proximity, they can't help but get attracted to each other due to repeated contact (Delany et al., 1993). Similarity is the second factor in the development of liking: the more similar a stranger's attitudes are to our own, the more likely is the attraction between us (Montoya and Horton, 2004; Tesser, 1993). Even similar ways of communicating can lead to increased attraction and liking. In general, the greater the similarity, the more probable it is that our liking for another person will endure (Byrne, 1971). A similar way of thinking may easily lead to common topics during a conversation between two persons. The same culture, the same language, the same appearance or even the fact that both are coming from the same place could be the reasons making people know each other quickly.

Knowing the reason for attraction is important for HAI. Repeated contact between users associated with a certain kind of interaction model will make people more used to that particular interaction model and consequently make them rely more on that kind of interaction. It is thus essential to make the interface agents more similar to human beings. There is evidence that people are willing to ascribe human-like characteristics, such as emotion and intelligence, to artificial entities (e.g., Bourke and Duffy, 2003). Moreover, humanizing would make interfaces easier and more comfortable to use (e.g., Shneiderman, 1998; Walker, Sproull, and Subramani, 1994). To influence people in the hoped-for manner, a lot of work is required in designing emotional agents endued with human features in some levels.

Having a human likeness has two main consequences for the agents and the human operator. First, because social evaluation and attribution of friendliness highly depend on appearance (Dehn and Mulken, 2000; Koda and Maes, 1996; Sproull et al., 1996), avatar agents with an animated appearance are preferred in user interfaces and expedite interaction. A life-like agent which resembles the user in appearance, gender, or ethnicity has been shown to be more acceptable by people (Dautenhahn and Nehaniv, 2000). Second, to make the agents' behaviors appear even more humane and life-like, human cognition, communication skills, and the way of thinking could also be simulated. So the goal would now be to make the agents behave more like a real human being in accordance with their more human appearance.

Furthermore, apart from the similarity in the appearance and single behaviors, we should also think about the relation between behaviors. In an interaction involving agent-based decision support, the agent needs to provide suggestions to the human user under certain circumstances and in line with the user's requirements. This interaction taking place as an ongoing conversation between the system and the user is rather more complex than the conventional stimulus and response model. Human likeness of the agent depends more on the quality of the agent's overall observable behavior, which forms the basis by which audiences try to understand the agent (Sengers, 1997). The user may be interested in why the agent is performing a certain action, or having a certain opinion, but the agent's behaviors are usually hard to explain. The logical relations of consecutive behaviors become essential for the completeness and robustness of the agent and interaction design. The lack of diachronic structure in the agent's behavior will not satisfy the user's expectations of the agent. Thus, when the agent makes a statement, we would like to have that agent be endued with an ability to explain why such suggestion is generated, and more importantly, the explanation routine needs to fit our human customs.

3.5.3 Agents in persuasion

The essential step in influencing people is to 'sell' the ideas and suggestions to the human user, i.e., to persuade people by communication. Due to the user's and the agent's asymmetric roles in the interaction the agents need to persuade the user and not the other way round. As users are always in the dominating part of agent-supported decision-making, it is usually not easy for an agent to change the user's mind once a decision has been made. People may not follow the agent's suggestions or guidelines, even though the suggestions might be useful to them. Thus, the agent's effect on interaction is determined not only by the apparent usefulness of its suggestions but also by the way that its ideas, thoughts and suggestions to the user are expressed. Thus, agents need persuasive skills to sell their thoughts to their audience. This evidently goal-directed persuasive behavior requires more support in the form of social communication skills that exist in human society.

My research efforts in agent-based decision support mainly focus on how to make agents influence people with more skillful persuasion. Particularly, HAI is not restricted only on providing information, or working as a web crawler. An agent's ability in HAI has evolved from a simplified response to the input, as when passively adapting to a user's action, to positively affecting the user's intention. The BDI structure offers a good platform for an intelligent agent to influence the user's thoughts, attitude, and decisions. By exerting its communication skills with human beings, an agent may acquire the capability to persuade people to accept its ideas. The agent's behavior in the course of persuasion is completely goal-driven and a manifests its competence to perform an interactive act. The promotion of an agent's role in the interaction is tied with the enhancement of that agent's intelligence.

In order to influence people, help them in decision-making and change their attitudes, communication skills are essential to an interface agent. The ways agents influence people's mind are similar to skills that are valued in human-human interaction when exchanging ideas, acquiring information, and making bargains, etc. Human response towards agents suggests that people might regard HAI as having the same social dynamics as human-human interaction (Katagiri, Takahashi, and Takeuchi, 2001). Our own attitudes and behavior are invariably influenced by the attitudes and behavior of other people as well as by our social roles/relationships towards them. Consequently, the design of interface agents needs to consider the social aspects of HAI in an attempt to not only facilitate our work but also to lead us towards making accurate inferences about how an agent is likely to think, decide, and act on the basis of its external traits such as its appearance, voice, and communication style. The outcomes from social psychology research have provided a mature way and criterion for developing agent behaviors which mimic human skills.

As in human societies, the communication skills that the agents are endowed with include the ability to interact with people in a given social context in specific ways that are socially acceptable or valued and at the same time personally beneficial, mutually beneficial, or beneficial primarily to others. This involves verbal and non-verbal behavior, which constitute the basic elements of social skills (Hargie, 1997). To perform skillfully, an individual in a human society must be able to identify the intent implicitly expressed by other people and make sophisticated judgments about the form and timing of an appropriate response. Thus, also a skilled individual agent needs to take cognizance of the others involved in the encounter. The extensive research conducted on communication skills can guide the agent design which endows agents with the capacity to influence people's behavior. According to the theories of the heuristic model of persuasion (Chaiken, 1980), people's compliance with appeals often follows simple decision-making rules that are based on little-evaluated (contextual) persuasive cues, such as the likeability of the message source, the connotations of expertise, or social (e.g., majority) pressures. Another design-relevant finding related to social collaboration is the positive correlation between people's willingness to cooperate and the frequency and richness of communication (e.g., Deutsch, 1958; Wichman, 1972). In addition, friendliness, social liking, and request justification, among many others, have clearly been shown to positively affect cooperation motives (e.g., Cialdini, 1984; Langer, 1978; Swingle and Gillis, 1968). During the research, my colleagues and I have proposed five communication-skill relevant dimensions for our exploration of agent persuasion (See Table 2).

TABLE 2 Dimensions of agent persuasion

Dimensions	Meaning
Friendliness	The agent should be friendly, which is in line with most of the criteria in interface design.
Anthropomorphism	Agents with human-like attributes may attract people more than agents with machine-like attributes.
Informativity	Explosive information could make people impatient. The agent's advice or decisions should be useful to the user.
Persuasiveness	Agents' words should include persuasive cues to affect users' minds.
Adaptivity	Collaborative style and skill are usually not pre-definable in absolute terms but must evolve and adapt to the HAI settings, especially the style and preferences of the user.

Friendliness is usually accompanied by a friendly appearance and an eloquent communication style. The combined effect of these as agent attributes should make users feel comfortable and willing to interact with the interface agent. The anthropomorphic representation allows the introduction of a rich set of easily identifiable behavioral cues for social interaction (Hargie, 1997; King and Ohya, 1996; Takama, Dohi, and Ishizuka, 1998). Especially at initial exposure to the agent, this kind of representation may make the agent seem more intelligent, capable of a higher level of agency, and more trustworthy as well. Informativity means that, when there is a need for more information, the agent should provide more assistance. However, very exhaustive information should be avoided since it can make people impatient or they may experience an information overload. The dimension of persuasiveness is concerned with more specific elements generating social influence. These elements include persuasive cues pertaining to influence schemes of request justification, reciprocation, commitment and consistency, social proof, liking, authority, and scarcity (Cialdini, 1984). All of the above-mentioned dimensions outlining the communication skills of the agent must be modifiable to take into account user goals and actions; in other words, they must be adaptive.

With these five particular dimensions of communication skills, a life-like agent is supposed to have the potential ability to change users' attitudes. However, one of my interesting research experiments has revealed that reactance to the agent's messages of the persuasive kind would most probably emerge; if the participants were forced to heed the agent's words their task performance might deteriorate. Reactance in psychology refers to the natural human reluctance to accept external authority and the need to retain a sufficient level of autonomy during decision-making (cf. Brehm's theory of psychological reactance, 1966). It therefore brings an important HAI-design criterion to agent persuasion: that is, the nature of collaboration with agents should be subtle rather than explicit or overly salient. Their persuasion behavior should be subtle enough so that people would not feel that the agents are lecturing them but, at the same time, sufficiently clear so that people could understand their message. Information should not be given too much at a time either, as it takes energy and time for people to think about it. Persuasive cues that are too complicated may generate psychological reactance in users, which will compromise the agent′ assistance in collaborative work. We should strive to retain a human-centric feel to the interaction by avoiding situations in which the users experience the agent as a central actor.

3.6 Agent’s impacts on decision-making behavior

One of the goals of the research is to investigate the cognitive interplay between human and agent on the behavioral level. In the previous section, I have shown how people’s communication skills can be applied in emotional design for intelligent agents in persuasion. It is actually hypothesized, on the basis of theoretical design considerations, that an emotional agent will surpass an unskillful agent in its attempts to establish collaboration. Hence it is well worth to check the agent’s impacts on people’s decision-making behavior regarding performance enhancement and risk prevention. A series of experiments were conducted and a posttest questionnaire was designed to verify the effect of agents to people’s decision-making behaviors (See Table 3). The overall effects were analyzed on several aspects, including assistance to decision-making, confidence level of the participants and their task performance. The results of the experiments indicate that agents' informative messages have significant impacts on people’s decision-making behaviors.

TABLE 3 Experiments of agent-based decision-making support

Experiment scenario	**Agent’s assistance**	**Agent’s type**	**Quality of agent’s information**	**Number of participants**
Stock market	Price and trend prediction	Unskillful, no appearance	Not always correct. Price prediction is better than trend	64
Product development	Sales data and trend prediction	Unskillful, no appearance	Sales data prediction is nearly the same as the actual data, which is better than trend prediction	16
Learning content management	Making a decision suggestion	Unskillful/ skillful, no appearance/ human appearance	Exp 1: agent randomly issuing false information during phase 2 but correct information in phases 1 and 3 Exp 2: agent always correct	54

Assistance to decision-making. A clear majority of the agent-supported participants assessed the agent as helpful, influential on their decision-making, and appropriate in the interaction design. According to all the questionnaire responses after the experiments, the agent's usefulness was considered as good. Most of the participants admitted the agent's assistance in their decision-making, even though only simulated agents, which hardly had any communication skills, were used in the stock market and product development experiments. Participants without agents' support in the product development experiment had more difficulty in reaching their yearly decision in time. They usually left the launch of the product development more frequently to the final months of the year. Compared to the human group and the less skillful agent group, participants working with more skillfully communicating agents found it easier to make decisions while, nevertheless, being less hurried in making them, and regarded agent support as appropriate. Moreover, their answers indicated that the human-like appearance of agent felt comfortable and did not affect their decisions.

Confidence. People's trust on the agent could be reflected by their confidence on the decision they made while supported by the agent. From the analysis of the stock market experimental results, people seem readily adapt their decision-making to the agent's information when facing time pressures. In contrast to the spontaneous decision-making behavior of the non-agent groups, agent-supported participants' activity appeared more assured and homogeneous. This may be due to a more salient and common decision-making base available to the agent-supported subjects who participated in trading, as well as their increased trading confidence. This agent-support effect on confidence is also verified by the product development experiments, in which the agent group's task performance confidence grew to a clearly superior level compared to the demeanor of the participants in the non-agent group. In the learning management experiment, the collaborative relationship between the user and the agent in the persuasive agent group seemed deeper and evident. The participants were more likely to agree with the agent's words even when the agent provided a misleading suggestion, and thus seemed to exhibit more blind trust. But in their answers to the questionnaire, a clear majority did not believe that the agent persuaded them to make wrong decisions. The research explained this in terms of cognitive downside in heuristic processing: error vulnerability and negligence (see, e.g., Shiffrin and Schneider, 1977), as well as cognitive dissonance (Festinger, 1957) induced by a persuasive agent making misleading suggestions. Also, by analyzing the experiment result we found that, with a persuasive agent, the collaborative HAI was built up gradually, and not halted even by an occasional unreliability in agent suggestions. This was reflected in the participant's task performance.

Task performance. The experiment results in the stock market and production development area show that agent assistance is risky because it has potential to create negative effects on performance outcomes while boosting users' task confidence. In the stock market experiment, the participants in the agent group seemed to be influenced by the more problematic tendency predictions and lost opportunities to cash in on the real price development. In the product development experiment, even though the agent's prediction was better than before, the actual task performance in the agent group was inferior. The reason for this might be partly due to distrust towards the agent's predictions. On the other hand, users might overvalue certain agent information and thus undervalue or even ignore other relevant information sources (e.g. information in graphical plots). In either of these cases, the compromised performance tells about the necessity of caution when judging the agent's value in fast decision-making. We need to be cautious in creating agents that efficiently and effectively can convince users without compromising their other interaction tasks.

The results of the learning management experiment substantiated the claim that people's performance, when supported by an agent, could be improved, and, importantly, an agent with persuasive communication skills could be superior to a communicatively less skillful agent. An interesting finding is that the agent-supported task performance did not decline below the level of the group without agent support during the phase in which the agent randomly provided misleading suggestions at certain times. It became obvious that the participants' task learning curve generally benefited from agent support. The participants developed a greater decision-making proficiency during the initial phase of the experiment, which made them partly immune to the disruptions in agent support. Even more impressively, a positive collaboration can be restored by a persuasive agent. Although dissonance may be greatest for participants in the persuasive group in the context of the agent making flawed suggestions, trust and effective HAI can also be quickly restored. The difference in the subsequent trust restoration was most substantial between participants who had a persuasive agent and those who did not. In this experiment, task performance was also checked against decision-making speed: the agent-supported group necessitated slightly longer interaction times than the human group, but there was no significant difference between the persuasive agent and the unskillful agent. Thus the superior performance of the persuasive-agent-supported group did not necessary come at the cost of a longer interaction time when compared to the unskillful-agent-supported group. Actually, according to the questionnaire results, although participants working with the persuasive agent received the largest amount of information, in principle requiring more interaction time, they experienced least task time pressure and found the information given by the agent as the most appropriate.

3.7 Discussion

My research in agent-based decision-making and persuasion focuses on how human beings are influenced by an agent's suggestion in various decision-making scenarios. The agent-support decision-making model is translated into a social welfare function. The intrinsic meaning of this software based agent-support decision-making model reflects the dominant role of human in HAI. Based on this model, an agent-based decision-making system, in which agents work collaboratively and in harmony with human actions, is constructed. Human knowledge, social factors, communication skills and user psychological factors permeate entire managerial decision processes in different parts of the system. One of the goals in designing persuasive agent is to gain the user's trust when providing agent support for the user in decision-making. Maintaining that trust based relationship with human users is one of the goals of intelligent HAI, and with certain communication skills, agents do have the potential to change the user's attitude. However, trusting agents create a potential risk for the system. The system designers must ensure that the failure of an agent will not be catastrophic. This is necessary in order to build a robust system that copes well with unpredictable variations in a dynamic environment with minimal damage, alteration or loss of functionality.

3.7.1 The risk of trust

Although there is considerable evidence of the advantages of using agents in various applications, this does not ensure that the role of agents in the whole system will always be appropriately considered. Being aware of the risks of agents is necessary when evaluating this promising software technology. This is essential not only for the current usage of agents but also for the future HAI design.

Trust and experience are the most important issues to consider when designing a HAI system (Grandison and Sloman, 2000; Mui, Mohtashemi, and Halberstadt, 2002). The usability of a particular AI system stems from people's trust in that system, while empirically the trust towards a system comes from people's experience of that system. People naturally find it unpleasant if they are forced to work with a system which they do not trust and are not willing to use. In this sense, lack of trust in the system may be predictive of the risks of using that system, which stresses the necessity of UCD to HAI. If a lack of knowledge of the unfolding narrative, etiquette or custom is combined with the ability to interact with a complex context in a relatively uncontrolled manner, the potential risks may arise for the user to perform actions that are not only contrary to the plan shared by other agents but even harmful to the coherence of the narrative (Riedl, Saretto, and Young, 2003).

To make human users trust the system, enhancing the competence of the system as well as adopting human characteristics and human-like behavior in the system design, are the effective ways for this purpose. But gaining trust is not the only factor that improves the usability of agents and the efficiency of the HAI system. From another perspective, becoming more trusted by human users would also increase the risk of suffering more losses. The failure of agents in their tasks could cause a tragedy if people gave agents too many privileges. The dilemma here is caused by the necessity to gain the trust of the human user while preventing the negative consequences that could arise from blind trust.

This means that even though the agents are autonomous, their behaviors still need to be constrained to a scope programmed or controlled in advance by human beings. The system should have a mechanism that ensures that even if agents' suggestions are complete nonsense, the consequences do not need to be catastrophic.

3.7.2 Confidence and performance

The cognitive impacts of agents in agent-based decision support have been analyzed here by investigating their influence on people' confidence and actual performance. The research indicates that overconfidence and risk-proneness are natural effects in areas where the use of agents in assessing, forecasting, and scheduling is increasing rapidly in importance and is essential for dealing with growing data complexities and competitive pressures. Whilst agents' assistance can reduce user task complexity and provide valuable information for decision support, users may apply their boosted confidence in a manner that is not the best possible for their own interests, and their performance could then be said to have been deteriorated by agents' assistance.

The finding actually tells something about people's attitude towards support from an expert when they need help. The expert's words would strengthen the people's confidence in their action at that moment but might also bring some risks associated with blind trust. The results from the experimental simulations of agent-based decision support in the stock market and product development management area underscore the influence of overconfidence on the payoff from agents. The strengthening of a user's confidence may not always translate readily into augmented task performance and may, in fact, lower the performance. This means that when using agents for decision support in progressively more technology-dependent managerial decision-making environments, one should be aware of the adverse effects while continuing to improve the agent's efficiency in decision-making.

More interestingly, the result also indicates that an inappropriate suggestion by the agent will not cause too much loss of confidence to that agent if a trusting relationship had been established earlier**.** Even when the subjects noticed that the agent's advice was not always correct in the experiment, most of them still thought the agent was being helpful to their decision-making and chose to trust in the agent. The phenomenon is in a certain kind of agreement with and could be explained by the prospect theory (Kahneman and Tversky, 1979; Tversky and Kahneman, 1992). In that theory, people's attitudes toward risks concerning gains may be quite different from their attitudes toward risks concerning losses**.** When offered a choice formulated in gains people's behavior might display risk-aversion but when offered essentially the same choice formulated in losses their behavior might display risk-seeking. In the agent-based decision-making support, trusting in the agent's suggestion carries the risk of loss if the agent's suggestion fails. But this could be compensated by the people's risk-seeking attitude according to the prospect theory, and thus trust relation could still be maintained.

4 OVERVIEW OF THE ARTICLES AND THE CONTRIBUTION

So far I have presented the whole process for the ABDS design and expatiated in each of the steps how the framework is constructed, how the interaction is organized, and how the agent can influence the human's decision-making actions from the psychological point of view. In this chapter, I would like to provide a summary of the different agent-based application areas in which the research was conducted. Here we take a closer look into the areas of decision-making, persuasion, production management, learning management, and agent collaboration through service composition as well. The articles presented here are the research results arrived at by theoretical argumentation from the research questions. The publication details of the papers and authors are listed for each paper.

4.1 Article 1: Agent-based Web Service Composition in JADE via JXTA

Liu, S., Küngas, P., & Mastkin, M. (2006). Agent-based Web Service composition with JADE and JXTA. In H. R. Arabnia (Ed.), *Proceedings of the International Conference on Semantic Web and Web Services*, SWWS'06 (pp. 110-116). Las Vegas, Nevada, USA: CSREA Press.

This paper was published in the early stage of the research and, more than other articles published later, puts the emphasis on how to organize agent communication for the purpose of service completeness in MAS. Although the paper focuses on the technical layer of MAS and doesn't touch the cognitive level of HAI, the physical implementation of the agent services described constitutes the foundation of the intelligent HAI.

One of the goals of HAI is to provide people with ubiquitous services, which meet its users' requirements as far as possible. The services that a HAI system can provide determine the capability of the system and have a direct impact on usability. A single agent might not always satisfy constantly changing system requirements in a dynamic context, and making a fast linkage between different but related services in MAS is a meaningful precondition for constructing an effective HAI. Moreover, the combination of MAS with the Semantic Web presented in the approach keeps with the state of art in distributed system evaluation.

The paper describes an efficient automated Web service composition algorithm which was designed for a P2P-based multi-agent environment. The MAS testing environment was built on the JADE platform, which is currently one of the best-known agent development frameworks and complies with the FIPA specification (Aart et al., 2002). Since Web services middleware has been integrated to the JADE agent system, all of its agents can implement and access Web services as computational resources. The experimental system presented is an inter-platform message exchange mechanism for JADE using JXTA protocols. In the service composition algorithm, several related services are connected to a service network, and a user's requirement can be met by transferring the request through the service network. Moreover, the service composition algorithm has been optimized so that the users' requests can be delivered in the shortest possible way. The experiment verified that this automated service composition algorithm is feasible to provide a basic, extensible prototype for Web service composition in agent-based systems – a prototype, which can be extended to resolve more abstract and complicated service composition tasks. However, this paper only considers services with a single input and a single output, which is the simplest case for automated service composition. This should be extended to suit for more complicated services with multiple inputs and outputs.

4.2 Article 2: Agent-based Learning Management Systems: Upsides and Challenges for Supporting Users

Liu, S., Wahlstedt, A., & Honkaranta, A. (2009). Agent-based Learning Management Systems: Upsides and Challenges for Supporting Users. In: A. P. dos Reis (Ed.), *Proceedings of Intelligent Systems and Agents'09* (pp. 43-52). Lisbon, Portugal: IADIS Press.

This paper addresses the advantages and challenges of using virtual instructors (VIs) for e-Learning. A VI may act as a virtual teacher within a LMS. There may also be a group of collaborative agents forming a MAS for orchestrating more complex activities than what the VI can provide. The agent-based multi-agent approach has its advantages: teachers can save time, manage learning resources and increase the interactions in teaching and supervising courses. VIs can also help students as LMS users when they encounter problems; they may, for example, recommend actions or distribute student questions to available teachers. There are also many challenges in developing VIs for LMS, including the external appearance of the VI, embedding VIs into LMSs, and the competence and deep knowledge about the learning domain to be taught that is required. The paper claims that animated pedagogical agents can offer promise as a means of making computer-aided learning more engaging and effective. An agent must be able to interact with the learner in a manner that appears believable. Further studies for clarifying the teachers' and students' needs for VIs are proposed. Moreover, the paper also supports that cooperating VI with Web services can provide some possibilities for solving the problem of compatibility between LMSs.

4.3 Article 3: Risks in Agent-supported Stock Market Trading Decision Making

Liu, S., Helfenstein, S., & Saariluoma, P. (2008). Risks in Agent-supported Stock Market Trading Decision Making. In A. P. dos Reis (Ed.), *Proceedings of Intelligent Systems and Agents'08* (pp. 109-116). Lisbon, Portugal: IADIS Press.

This paper deals with agent-support decision-making in the financial area, describing two experiments carried out in a virtual stock market setting. It has been argued that a supportive agent in price prediction has a potentially negative impact on people's recognition primed decision (RPD) making behavior. The technical capacity and reliability of the agent itself (e.g., agent failures) has been questioned and the user's sense-making and appreciation of the agent influence (e.g., trust in agent-based interaction design) has been questioned as well.

In order to verify the implicit hypothesis here, two experiments were carried in a virtual agent-supported stock market environment. The actions of a human group and human-agent groups were analyzed to find the agents' impacts on people's stock market trading actions. From the analysis of our experimental results, we concluded in the paper that people readily adapt their decision-making to the agent's information when facing time pressures. The investigations underscored the fact that the participants' trading behavior was drastically influenced by instances of change in agents' trend predictions. This supports the finding that the agents' prediction would boost people's confidence and steadiness in their stock market trading behavior, with potentially negative effects on performance, however. The paper proposes that an enhancement to the agents' competence - an improvement to the prediction algorithm, for example – with the help of other robust neural networks, might be one possible way to deal with the deficiencies encountered. On the other hand, the designer needs to consider also how to efficiently and effectively convince users without compromising their other interaction tasks. Future work described in this article includes analysis of different user attributes, such as expertise, gender, and cultural background, which should be considered, both with regards to the task at hand as well as with regard to interaction and decision-making styles in general.

4.4 Article 4: Decision Making with Intelligent Agents: A Practical Aspect of Future Product Development Management

Liu, S., Helfenstein, S., & Saariluoma, P. (2008). Decision Making with Intelligent Agents: A Practical Aspect of Future Product Development Management. In *Proceedings of the 15th International Conference on Product Development Management* (pp. 116). Brussels, Belgium: EIASM.

The focus of this paper is on the effect of agent-support applied to the domain of business forecasting and corporate product development management. The concrete task investigated is timely launching of a new product, dependent on sales volume data. The findings of this investigation are in line with those of prior research using agents in stock market prediction, i.e., that the influence of agents is not necessarily as straightforward or beneficial as would be desirable. The experiment results of this research reveal that agents could reduce user task complexity and provide valuable information and decision-making support, thus improving users' efficiency and increasing their confidence. However, this enhancement does not always readily translate into augmented task performance. Users may also ill-apply their confidence boosted by the agent assistance. Therefore, this paper advocates that optimization of the agents' forecasting algorithm and complex MAS be regarded as secondary in value to the concern of building a trustworthy and reliable relationship between the human user and agent.

4.5 Article 5: Social Psychology of Persuasion Applied to Human-Agent Interaction

Liu, S., Helfenstein, S., & Wahlstedt, A. (2008). Social Psychology of Persuasion Applied to Human-Agent Interaction. *The Journal of Human Technology*, 4, 123-143.

The authors in this paper discuss and evaluate an approach to apply a social, psychologically enriched, and user-centered approach to agent architecture design. The major aim is facilitation of HAI, by making agents not only algorithmically more intelligent but also socially more skillful in communicating with the user. A decision-making model and communicative argumentation strategies have been incorporated into the agent architecture. In the experiments conducted in the context of resource management task environment, enhancement of human task performance is demonstrated for users supported by a persuasive agent. This superior performance seems to be rooted in a more trusting collaborative relationship between the user and the agent, rather than in the appropriateness of the agent's decision-making suggestions alone. Especially the second experiment demonstrates that interface interaction design should follow the principles of task-orientation and implicitness. Making the influence of the agent too salient can trigger counter-intentional effects such as user reluctance, resistance, and discomfort.

The paper concludes that the research on agent design should focus not only on the agent's algorithmic sophistication in solving a problem but also on its ability to communicate in an apt manner with human users, the reason being that the effectiveness of HAI is often questioned regarding the trust that people would grant to agents. The work presented in this article explicates an improvement to the conventional BDI agent structure by incorporating two important models into the intention component: decision-making and argumentation. The decision-making model helps the agent to formulate its intention according to the input from the environment and the reasoner's actions. The argumentation model handles the presentation of the intention to the user, applying social psychologically based communication skills in order to make the agent's arguments more persuasive. This kind of persuasive agent design, if applied with consideration, is user task effective and best suited for building up of trusted, long-term HAI relationships.

4.6 The contribution of the research

The work extends HCI research to an interaction area between technology and systems engineering, concentrating on the development of the agent and the agent-based interactive system from the cognitive level, using psychological approaches. The whole research is carried out within an agent-based decision support framework, and attempts are made to find out the cognitive influences between human and agent. This HAI research, getting inspiration from human communication, extends previous research on HCI and on the use of autonomous agent technologies. Some aspects of system design will lead to the development of technologies compatible with human preferences. Basically the contribution of the research consists of the following points:

- Firstly, it facilitates the agent research with the help of techniques from the psychology domain. Its goal is cooperated human-agent interaction. The psychological research as a contributor to the interface agent design has been emphasized throughout the interactive system design. It maintains that the effectiveness of agent support is at its strongest when the agent can communicate its suggestions in a skillful and persuasive manner. This is justified by the findings from applying psychological approaches to the emotional design of interface agents and by investigation on the relation between the user’s confidence and the user's actual performance in decision-making. The argumentation about the psychology design must proceed alongside the technology design for the decision support agents in order to consolidate the usage of user psychology and broaden the research in the intelligent agent design.

- The research evaluates and verifies the use of agents in several interaction applications, such as the learning management system, and the decision support in the financial and production management areas. Not only the advantages but more constructively, the risks of using agents in the collaborative problem solving have been considered. Agents' impacts on tuning people’s decision-making behaviors have generally been found to be positive, although possibly causing undesirable result in the performance. This could lead to further research regarding agents' influence on human’s social behavior.
- In addition, the design process in the agent-based decision support system has been summarized and practically carried out through a series of experiments, which could conduce to the combination of the MAS and DSS.
- Last, the service composition algorithm proposed in the research could also promote the completeness of the MAS and the development of the individual agent by combining the agent technology with the Semantic Web. This will give inspiration to further research on the agent system and architecture design.

5 CONCLUSION

Agent technology has developed fast during recent decades, and agents now have more advanced physical and 'mental' capabilities, such as large capacity memory, advanced logic reasoning ability, and high functionality effectors. This development inevitably has the propensity to provide technical advances for application purposes of certain kinds only, for example, for agent architecture, agent language, and ontology design. However, in the interaction area research, there seems to be an urgent need to shift the study emphasis from technology to the human user's view (Carroll, 1997; Rosson and Carroll, 2002). The agent interface design need to be enhanced to adopt more anthropomorphical cues in order to make the agent more suitable for interaction. Improvements should thus be made to increase the agents' cognitive abilities. In my research I advocate that HAI design should focus more on social interaction and cognition issues. Agents are required not only to implement the tasks delegated to them by human users but also satisfy users on a cognitive level. Thus the study traverses the problem solving area in typical human-agent collaboration. This is the area where there is a strong need for agent-based decision-making, especially in the support for economic issues, in product management, and in the learning management system. Use of agents to help humans in decision-making was demonstrated in this dissertation using a multi-agent approach which combined user modeling, emotional design and agent collaboration. The purpose here was to investigate how the agent can influence people's decision-making behaviors and what the advantages and risks of applying agents for the decision-making support system are. The critical design issues for the agent-based decision support system have been explained in detail, and the design process is summarized to describe how the different disciplines are adopted and serve for certain steps in the whole course.

Figure 6 illustrates the design process for the agent-based decision support and indicates how the different design technology aspects, such as user modeling and emotional design, are organized. Shown in Figure 6, the process starts with the agent-based decision support model which defines the overall control of the holistic decision-making process. As described in Section 3.2, the model clearly shows the agent's role in the human-agent collaborative decision-making and that the social effect of a decision is the sum of human's preferences together with the suggestion of assistant agents in all situations. Based on this model, an agent-based decision-making support system could be designed on a high level, classifying the architecture into two layers of interaction: HAI and AAI. The service offered by agents could be optimized via AAI and made available to human users via HAI. In addition, the system structure could be simplified as two layers of interaction geared at interface agents (see Figure 4), and the design focus thus placed on the interaction design for interface agents. The design flow becomes divided into two branches: user modeling and interaction modeling.

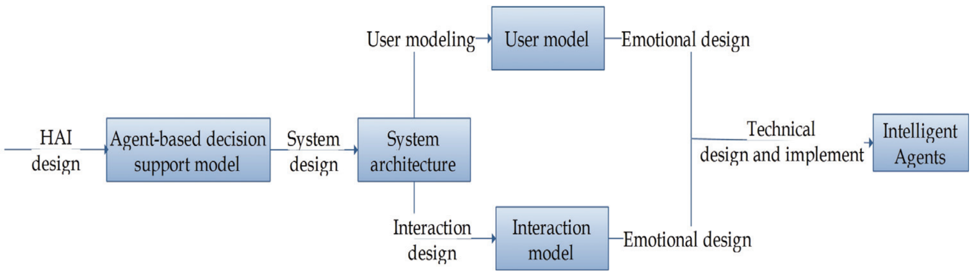

FIGURE 6 Design process for agent-based decision support

The user's needs are required to interpret to computational user models through the user modeling technology. The modeling process is actually performed among several agents by fusing user model fragments into a partial global user model. Then those resulting user models are embedded into the system and can be refied as user agents capable of dynamically offering the user's information for humanized communication.

Interaction modeling, forming the main part of the research, aims to design an interaction pattern, which 1) guides interface agents to properly provide decision support for users during interactions, and 2) guides the agents to cooperate with each other in order to achieve the best possible service. The formula in Section 3.2 is only a mathematic model related to the process; it is not related to the interaction and thus it is not meant be used for guiding the agents' interaction behaviors. Thus we need emotional design for the interaction in order to define the interaction specification for interface agents. The goal is to make that interaction humane, comfortable, and effective. Psychological knowledge, e.g. about user psychology and social psychology, is needed for the analysis of the user's intentions, for social communication skill simulation, and so on. The outcomes from this interaction modeling are those rules/specifications which can be used to guide the agents' behaviors when making suggestions to human users and when interacting with other agents (e.g. Table 2). The psychological approaches are adopted to make the agent's behaviors more understandable and effective.

The combined results from the user modeling and interaction model via emotional design provides the intelligent agents with an ability to make decisions in accordance with a specific situation, social skills to communicate with human users, and persuasive skills to present suggestions. During an interaction, the interface agent works as an adviser to human users, providing suggestions accompanied by various emotional cues. The features the agent possesses are what have been defined in the interaction model. In the implementation phase all these feature need to be embodied in an actual interface agent. Practical issues have to be concerned about how to create an intelligent agent(s) and associated technical implementation such as service composition, distributed collaboration, information exchange, peer to peer communication, etc. Although technical design is not the main topic of this dissertation, it is the basic premise of the intelligent HAI since it deals with all the physical implementation of the services.

The whole design process complies with Carroll's idea of software psychology (Carroll, 1992, 1997), with the approaches to creating a design science of HCI, and with the UCD criterion. By following certain steps, it is possible to establish an approach to integrate intelligent agents into an interactive system and organize different technologies to implement an intelligent HAI. UCD and emotional design are chosen here as the design rational and implemented through psychological approaches. User modeling is embedded into the system design to adaptively reflect user requirements. The whole design process is conducted as an iterative development.

A series of experiments simulating the different scenarios of agent usages were carried out. The results of these experiments reveal how the agent's suggestions can impact the human's decision-making behaviors in time-primed conditions. The agent's suggestion is meant to provide a quick solution under complex conditions, and might boost people's confidence in their decisions. The experimental results show that agent-based decision support increase the user's confidence and make the decision behaviors more stable. This kind of decision support increases the user's task performance confidence to a very high level, which was verified by both the stock market simulation and production development management experiments. Agent-supported participants' activity appeared more assured and homogeneous compared to the spontaneous decision-making behavior in the non-agent groups. Hence the agent's decision-making support could be used as a way to tune the user's decision-making behavior in order to stabilize it.

However, as discussed previously, the use of an agent in decision support doesn't make the decision that of a high quality in an absolute sense. A quick and succinct suggestion may put the users into a bewildering situation, which makes their decision-making even more difficult. To increase the payoff we should either improve the agent's ability or decrease the effort associated with using an agent. For example, to raise the quality of the agent's suggestions, real efforts should be made to improve the agent's inner decision-making algorithm. But the quality of the decision is still difficult to measure in the design phase, and it is hard to ensure that the suggestions from agents are always the best due to the complexities in the practical situation. Even agents' functional completeness can have the potential risk of decreasing the user's performance, e.g. by excessively boosting the user's confidence or by making the user to overlook other related factors. The deficiencies caused by neglecting the user's psychological dimensions may decrease the utility of agents.

Therefore my research findings give support to the claim that the agent's algorithmic sophistication, in terms of nominal utility, must be clearly distinguished from actual human-agent interaction outcomes, in terms of factual utility. We should keep in mind that if too many insights and mental efforts are required from the end-user, it may involve too much work, making the user exhausted and uncomfortable. The agent's assistance in decision-making should be subtle enough so that it would not create psychological reactance, but should also be sufficient for people to understand it. Thus emotional design is considered as essential for both the interaction and agent design to create the capability of maintaining a trusting relationship. Agents' similarity in their external appearance to humans, their human-like demeanor, and narrative relationship between behaviors convince people persuasively while reducing the side effects of the agents' influence. These attributes have been justified by using the agent in decision-making via five dimensional communication skills of persuasion. The most inspiring phenomenon found during the experiments was that people's decision-making skills were improved during collaboration with persuasive agents and are restored to their earlier higher level once the agent has recovered from a failure. That means a failure by the agent would not be catastrophic if the agent could restore its performance in the tasks that follow. This has the effect of encouraging agent usage in DSS and suggests that there are benefits from a more emotional design of interface agents. We may conclude that the effectiveness of agent support could be at its best when the agent can communicate its suggestions in a skillful and persuasive manner. Emotional design through various psychological approaches, e.g. social psychology, will make the human-agent collaboration closer and more cooperative, which agrees with the principle of trusting interaction. Thus, basic user psychological research must be carried out in tandem with technical development programs in order to produce desirable outcomes.

5.1 Answers to the research questions

At the beginning stage of the research, the research questions were posed as the problems and challenges that my study needed to deal with. They quite realistically describe the design requirements for implementing the intelligent HAI. As shown in Figure 7, the corresponding answers would summarize the results of my research, and provide a holistic view on both the challenges and solutions in the HAI research. Further, they can be used to guide interaction and agent design from a scientific specification to the engineering realization.

What are the prerequisites of feasible HAI?

The HAI research in this thesis uses the word *intelligent*, which explicitly describes the type of interaction between human and agent pursued here. The first research question tries to find clarity to what the so-called intelligent HAI really means and what is required as a prior condition for the research. The premise of my study consists of being aware of the implications of intelligent HAI and envisaging both the pros and cons of using agents in human-agent interaction. Thus, they are the prerequisites of feasible HAI.

The implications of intelligent HAI actually propose the design requirements. As analysis in Chapter 2 points out, the connotation of 'intelligent' refers to the agent's abilities in HCI. The user's requirements should be captured and understood by the agents, and the feedback to users should be presented skillfully through every stage of the interaction. This implicit interaction helps to preserve a natural interaction manner while capturing the user needs. More importantly, in the explicit interaction the assistance from agents should not be too salient to increase the cognitive load of users too much. The 'intelligent' attribute in the agents' behavior implies that intentional cues could be used to hide their artificial appearance. Their behaviors should be narratively structured so as to make them more understandable by human users. Human values are thereby required to be respected when designing agents. Their communicative organization should be in accord with the human etiquette and social expectations so that the utility of the interaction pattern would be ensured without compromises in efficiency. Agents with adequate knowledge about the users, e.g. about their cultural backgrounds, would facilitate communication and help to eliminate misapprehensions.

On the other hand, the meaning of intelligent HAI has to do with a feasible interaction course. The interaction should be carefully organized in order to satisfy both sides, and especially it should please the human users. As the interaction is bidirectional, there are implications both for the human as well as for agent components. First, the agent's cognitive ability can be analyzed from the human's perspective and improved with the help of user psychology and communication models. What we have applied in the analysis of human operations can also be utilized in analyzing an agent's behavior. Also human's cognition during the collaborative HAI can be influenced by the agent's social ability regarding to the decision-making behavior and actual task performance. Since the human cognition takes a critical part in this bidirectional setup, my research concludes that when designing a cognitive HAI which is sensitive to the user's needs, the designers should consider not only the traditional issues of robustness, efficiency and scalability but also the impact of human information.

My research also reveals the advantages and risks of using agents in the interaction for decision-making support. The experimental work strengthens the argument for using agents in human-agent collaboration tasks. Their adaptiveness and reactivity allow them to adapt to their surroundings quickly, to perceive the contexts in which they operate and to react appropriately. Their social ability engages other components, through various communication and coordination protocols, to collaborate in implementing common tasks. The theoretical side of agent employment is discussed and presented in practical industrial and pedagogical environments. Agents' suggestions and advice could strengthen the users' confidence in their judgment, especially when under time pressures. This is confirmed by the decision-making experiments in the areas of stock market and product development management.

Meanwhile, my work is not restricted to finding the advantages that agents bring but has a wider interest in the potential risks, dilemmas or restrictions of agent support in HAI tasks. Although a lot of evidence has brought support for agent usage in collaborative decision-making – which can provide, for the human participant, a psychological effect reminiscent of expert involvement –, correctness of the decision may not follow, and the performance of the people may not correspond to their boosted confidence. This may be caused by two main reasons. The first is that the agent's suggestion and predictions might not be good enough due to the limitations of the algorithm in the agent model. Inaccuracies due to the agent and system failures or disruptions are always a real threat in HCI settings. The second reason is due to people's conceptions about the agent. Even if the agent's suggestions could be verified as correct, the user would not always be satisfied with that support. Too salient, redundant and dogmatic suggestions would increase users' mental load, increasing their reluctance towards following the advice by the agent. For this reason, acquiring people's trust becomes a very crucial aim in designing agents. Thus, appropriate interaction models are needed to facilitate the establishment of trusting relationships.

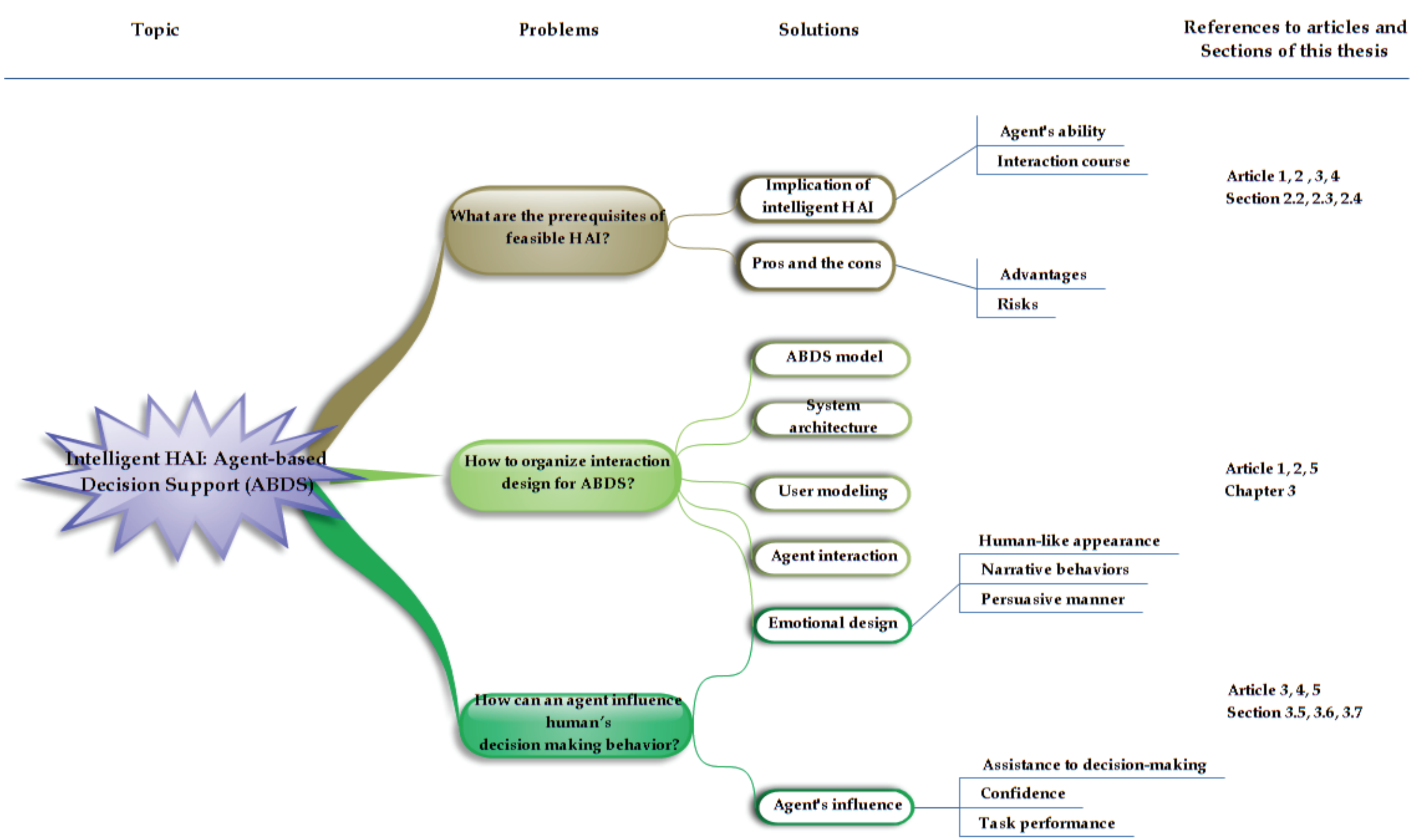

FIGURE 7 Problems and solutions of the research

How to organize interaction design for agent-based decision support?

The answer to this question can be understood as the way we implement the intelligent HAI, and it is basically answered by Figure 4 and 6. As described at the beginning of this chapter, we firstly need an interaction model which describes the interaction within the system in a clear manner. In a HAI system, people typically interact with agents to obtain help, and agents communicate with each other in search of services. Thus, in the agent-based decision-making model, collaborating agents suggest decisions, which can be overridden by human users. The design of agent communication skills used for interacting with human users can be distinguished from the skills needed for interacting with other agents. These two types of interaction are bridged by the interface agents, which perform the perception and motion jobs for the system and hide the most complex data processing from the user. For the interaction in HAI, since the other counterpart in that interaction and also the creator of the agents is a human being, the communication skills naturally stem from the communication skills in human society. This is why the human aspects often influence the intelligent agent and HAI pattern design. My research shows that, by employing a cognitive approach, psychological facts as well as conceptual methods and theories can be used and reified, in the agent design. The integration of the knowledge from human technology research makes the intelligent HAI realizable, the agent-based decision-making support being a good example.

When designing a HAI system, UCD and the emotional design approach determine the user's roles in the design and make the interaction more user-oriented by taking personal values into account. User modeling ensures the user's needs can be captured by the system in an effective and feasible way. The user modeling techniques can improve the HAI system by making it mimic the user's routine behaviors on some level so that the user's preferences could be better understood by the system. Traditional design principles should be extended to fit the distributed multi-agent environment. This could be achieved by distributed modeling. An implicit interaction pattern should be based on captured needs of the user behaving naturally in the system.

In addition, the organization of communication is required to be accordant with the user's customs and etiquette. Poor design which breaches the human etiquette may arouse peoples' aversion towards the system or create a feeling contrary to the intended. A robot-like agent which only provides plain suggestions is inefficient in decision support that requires emotional design respecting the user's personal traits and embedding the corresponding elements to the design during the course of the design. Social, emotional and detailed knowledge must be incorporated into agents in order to maintain the relationship in the most natural manner. In this research, psychological approaches are considered as the effective way to implement the emotional design and make the agent more human like. For example, social and narrative psychology is helpful in designing persuasive agents and has been proved to have a positive effect to people's decision-making performance.

Agent-based integration systems nowadays are normally MASs, and the type and quality of service these systems can provide is the premise of intelligent interaction. Any interaction between the agents is also required to be well organized. The research has proposed a possible way for the agents' collaboration through service composition. Fast information exchange among various agents could facilitate the service composition; thus, a powerful service network where more services would be available for users should be constructed.

How can an agent influence human's decision-making behavior?

The effectiveness of HAI is often questioned about the degree of trust that people would grant to agents. In addition, the challenges of a trustable HAI include the question of trust on agents and the potential risks of agents' autonomy, which could have negative implications on performance. My research sets out to find how agents can influence people in a more convincing manner and what the actual impacts on human users are during the decision-making. The essence here is to clarify the design considerations for designing an interface agent for decision support.

It has been pointed out that the emotion based design of interface agents is essential to establish a trusting relationship between the human being and agents. Rigid and repeatedly presented suggestions by the agent may just annoy people in an interaction. If the agent's suggestions tax people's thinking excessively, those suggestions may disturb them. This agrees with the theory of Dugan (2003). Agents should first be recognized as "good" assistants to human users, not just as dummy computer tools. One possible way to assist people in decision-making proceeds via two steps: first by attracting them with an opinion and then by convincing them about the idea. Repeated contact, having similarity in the external appearance, human-like demeanor, and narrative behavior are supposed to make people more used to a particular interaction model. Designing through a psychological approach will empower the agents with more skills to influence peoples' minds. Cognitively structured persuasive agents have been designed to incorporate communication skills based on the theories of social psychology, and they have been deployed in decision-making scenarios. Experimental results in persuasion methods have confirmed the assertion that agents with social communication skills have more influence on peoples' decision-making. Moreover, that influence should be gained by persuasion that is both tender and implied. Considerate behavior may add trust to the interaction.

Peoples' decision-making behaviors were analyzed to find out how they became persuaded and how their decisions were influenced by the agents' suggestions. The analysis considered three aspects: assistance to decision-making, confidence, and task performance. It was found that people's decision-making confidence can be boosted by the agent's suggestions, but that this boost in confidence doesn't directly translate into a task performance. Human users always want to retain a healthy degree of autonomy; influence exertion by the agent can easily go overboard and trigger user discomfort and reactance. Thus the interaction design should refrain from making the persuasive nature of design and collaborative demands all too salient or agent-centered. This actually reinforces the essentiality of UCD in the HAI design.

Importantly, the experimental results reveal that an agent with persuasive communication skills could be superior to an agent with less persuasive communication skills in supporting people's decision-making. Using consistent, socially and psychologically sophisticated communicative cues is better than persuasive messages per se for agents to achieve the best effect. With the persuasive agent, a collaborative HAI, which won't be halted even by occasional unreliability in the agent's suggestions, can be built up gradually. Based on these findings, my study recommends that the future research of agent design should not only focus on the agent's algorithmic sophistication in problem-solving but also on its ability to communicate in a manner suitable with human users. An effective HAI can be maintained by suitable communication skills. The trust recovery mechanism is especially important in rebuilding the trust when the relationship is broken. With a good trust restoring mechanism, the persuasive agent-supported decision-making model can be used to construct positive collaboration, and even if the agent's suggestions are sometimes misleading or false, such disruptions do not need to be catastrophic.

5.2 Issues for future research

Interaction problems in agent technological environments are complex, because the technology has so many new capabilities. This is why we think that it is necessary to fully employ human knowledge for HAI design. This demands patience, since the study of human technology must also be constantly evaluated. The psychological approach used in the research was mainly demonstrated in the case of a single individual agent. This could lead to a more interesting investigation on the social influences between a human being and a couple of communicative, skillful agents. The work anticipated could be based on the implementation of several interface agents as illustrated in Figure 4. The complexity would necessarily be augmented during the course of evolution from a single agent to a multi-agent based interface. This multi-agent based interface would constitute an environment in which the 3D interaction can occur (Bowman et al., 2004). The research into the 3D HAI design will draw on new findings, investigating more the relation between cognitive factors. Secondly, the research would orchestrate the HAI design by getting deeper into the agent's impacts on decision support. This further work could land on a more extensive human-agent collaborative problem-solving area and investigate there the use of the agent in other critical conditions, for example, in car driving, or event handling in emergencies. The requirements from critical real-time situations will pose more challenges for agent design. Also, with the maturing of the mobile technology, mobile devices are becoming a necessity in our daily lives. It would be fruitful to combine the agent and mobile technology for our mobile devices. Then the findings from the current HAI design could contribute and evolve with the future smart mobile device design for humans. Last, although mainly the agent research is the receiving side of inspiration – from the human cognition in our case – also we could learn from the upsides of agents. As the research trajectory is multi-disciplinary, it could be inspired by the agent's distinguishing properties, i.e., proactiveness, adaptivity, and associativity. We could actively detect problems in agent-human relations, be adaptive to the requirements coming on the fly, socialize to find solutions using different technologies, get help from other domains, and so on. The entire research could properly line up with agent-oriented software engineering not only in content, but also on a cognitive level.

YHTEENVETO (FINNISH SUMMARY)

Agenttiteknologia ei ole enää uusi konsepti tietojenkäsittelyn tutkijoille ja ohjelmistojen suunnittelijoille. Agentit ovat muuttumassa autonomisiksi, mukautuviksi ja ennakoiviksi, ja soveltuvat näiden sosiaalisten piirteiden ansiosta käyttäjään sopeutuvaan vuorovaikutukseen; niiden työn muuttuessa yksinkertaisemmaksi ja kehittämisen helpommaksi ne ovat pian hyvin sopusoinnussa jokapaikan vuorovaikutuksen (ubiquitous interaction, Schmid et al., 2002) vaatimusten kanssa HCI (Human-Computer Interaction, ihmisen ja tietokoneen välinen vuorovaikutus):ssä. Silti agenttiteknologian käyttö vuorovaikutussuunnittelussa on monimutkainen kysymys. Suunnittelussa painotetaan yhä enemmän älykästä vuorovaikutusta. Tämä tarkoittaa sitä, että suunnittelijoiden täytyy tehdä enemmän kuin vain jatkaa HCI:n laajentamista. Lisäksi dynaaminen HCI on antanut kognition teorialle erityisen roolin ihmisen ja jatkuvasti kehittyvien teknologioiden vuorovaikutuksen ymmärtämisessä (Milewski and Lewis, 1997). Se on aina keskittynyt siihen, miten me todellisuudessa toimimme ympäristössä ja kuinka koordinoimme tekemisiämme siellä; kognitio ja sen relevantit menetelmät avaavat aivan uuden näkökulman HCI:n suunnitteluun ja tukemiseen ja antavat meille uusia mahdollisuuksia digitaalisten laitteiden ja ohjelmistojen suunnitteluun. Agenttien käyttäytymisessä agenttiteknologian yhdistäminen sosiaaliseen kognitioon on lupaava lähestymistapa. Ihmisten kanssa vuorovaikutuksessa olevat agentit esittäisivät tietyllä tasolla inhimillisiä sosiaalisia piirteitä. Tieto sosiaalisesta kognitiosta ja psykologiasta helpottaisi älykkäitä agentteja "ajattelemaan" ihmisiä, vaikuttamaan ihmisiin ja suostuttelemaan heitä. Niinpä tutkimukseni ottaa selvää siitä, kuinka agentteihin perustuva vuorovaikutusjärjestemä pitäisi organisoida pyrittäessä parantamaan holistista integraatiota ihmisen henkisten prosessien ja agenttiteknologian kehittymisen välillä kognitiivisten lähestymistapojen, kuten sosiaalisen kognition, psykologian ja ihmiskeskeisen teknologian avulla.

Väitöskirja selittää ensin agentteihin perustuvan vuorovaikutusjärjestelmän perusrakenteen ja miksi inhimillisiä aspekteja tarvitaan agenttisuunnittelussa, antaen myös yleiskatsauksen HAI-tutkimuksesta. Sen jälkeen keskitytään yksityiskohtaisemmin siihen, kuinka organisoida niin kutsuttu älykäs HAI (Human-Agent Interaction, ihmisen ja agentin välinen vuorovaikutus) ja rajataan käsittely agenttiperustaisen päätöksenteon tukijärjestelmän suunniteluun. Koko tutkimus on keskittynyt kolmeen kysymykseen, jotka antavat tutkimukselle suunnan. Ensimmäinen kysymys, "mikä on älykkään HAI:n edellytys?" koettaa löytää vastauksia siihen, mitä ovat älykkään vuorovaikutuksen merkitys ja seuraamukset. On ehdotettu, että älykäs HAI tarkoittaa, että älykkyys pitäisi toteuttaa sekä vuorovaikutuksen että yksittäisen agentin tasolla, niin että vuorovaikutus voisi sopeutua käyttäjän tarpeisiin ja että kontekstitietoiset agentit voisivat kunnolla ennakoida käyttäjän toiminnan. Muita lähemmän tarkastelun arvoisia kysymyksiä ovat esimerkiksi millaisia palveluita pitäisi tarjota ja kuinka tarjota lisää palveluita (agentin näkökulma), ja kannattaako ottaa riski ja käyttää agenttiteknologiaa (ihmisen näkökulma). Nämä ovat HAI:n haasteita, jotka kannattaisi pitää mielessä ja ratkaista tutkimuksen avulla.

Toinen tutkimuskysymys on miten organisoida älykäs HAI, mikä näyttäisi olevan tämän väitöskirjan ydin. Koska suunnittelun mittasuhteet kokonaisuudessaan ovat liian laajat empiiriseen tutkimukseen, työssä on rajoituttu käsittelemään agenttiperustaista päätöksenteon tukijärjestelmää, joka on tyypillinen ihmisen ja agentin yhteistoiminnallisen ongelmanratkaisun sovellusalue. Työ vuorovaikutuksen muotojen suunnittelussa, järjestelmäarkkitehtuurisuunnittelussa ja yksittäisten agenttien suunnittelussa on lyhyesti tiivistetty agenttiperustaisen päätöksenteon tuen yhteydessä. Ensin on esitetty järjestelmämalli, jossa kokonaisrakenne on jaettu kahteen kerrokseen: HAI-kerrokseen ja AAI-kerrokseen. Suunnitteluun liittyviä kysymyksiä on pohdittu molemmilla tasoilla. HAI-kerroksessa tärkein seikka suunnittelussa on vuorovaikutuksen inhimillistäminen tinkimättä tehokkuudesta. Käyttäjämallintamisen taidot on sisällytetty järjestelmäsuunnitteluun, jotta ne mukautuisivat dynaamisesti käyttäjävaatimuksiin. AAI-kerroksessa agentit aktivoidaan tekemään palveluiden suunnittelua jonkinlaisten kommunikaatio- ja koordinointiprotokollien avulla. Erityisesti väitöskirja visioi käyttöliittymäagenttien ottamista tärkeään asemaan järjestelmässä näitä kerroksia yhdistettäessä. Niitä on valmisteltu tähän tunnesuunnitteluvaiheessa psykologisten lähestymistapojen kautta.

Kolmas kysymys on löytää kognitiivinen ihmisen ja agentin välinen vuorovaikutus päätöksentekoprosessissa. Toisaalta ihmisen kognitio on hyvänä mallina agentin suostutteleville piirteille. Sosiaalipsykologian ja agenttiteknologian yhdistelmää on konkretisoitu sovellettaessa kommunikointitaitoja suostuttelevalle agentille. Tutkimukseen liittyvä koe osoitti, että agenttituki olisi vaikuttavimmillaan jos agentti kommunikoisi sen ehdotukset taitavalla ja suostuttelevalla tavalla. Toisaalta on tutkittu kysymyksiä agentin vaikutuksista ihmisiin. Tällaisia ovat esimerkiksi riskit, joita otetaan luotettaessa agentteihin ja käyttäjän itsetunnon kohoaminen liittyen itse suoritukseen. Tähän perustuen tämä tutkimus tukee sitä, että käyttäjäpsykologista perustutkimusta pitää jatkaa ja pitää ensisijaisena tai ainakin yhtä tärkeänä teknisesti ja liiketaloudellisesti orientoituneisiin ohjelmiin verrattuna.

Tiivistettynä, kun oleellinen askel teknologiavetoisessa HCI-suunnittelussa on löytää käyttöä olemassa oleville ja nouseville teknologioille (Rosson ja Carroll, 2002), niin uusi vuorovaikutuselementti agenttina HAI:ssa vaatii enemmän johdonmukaista arviointia ja psykologisten käsitteiden soveltamista agentin käyttäytymisen ohjaamiseksi vuorovaikutuksessa. Siinä missä agenttien kehittäminen on perinteisesti keskittynyt teknisiin elementteihin, hieman vähemmän on yritetty ymmärtää, miten käyttäjät vakuutetaan hyödyntämään agentin ehdotuksia ja tukemaan sen tarjouksia. Näin ollen tämä väitöskirja tukee sitä, että agenttisuunnittelussa pitäisi ottaa huomioon paitsi miten tehdä agenteista algoritmisesti, myös sosio-ekonomisesti älykkäitä. Tutkimukseni perimmäinen tarkoitus ja väitöskirjani ydin on toteuttaa älykästä ihmisen ja agentin välistä vuorovaikutusta ja innostaa tulevaisuuden vuorovaikutussuunnittelua auttamaan ihmisiä käyttämään ja kokemaan tehokkaasti siihen liittyviä palveluita ja laitteita.

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APPENDIX 1 AGENT ARCHITECTURE

Architecture	Characteristics	Example
Deliberative Architectures	Contains an explicitly represented, symbolic model of the world. Makes decisions (e.g. about what actions to perform) via symbolic reasoning	IRMA, PRS
Reactive Architectures	Describe very simple behavior, but hardly applicable for more complex actions. • Cannot plan ahead. • Actions come only from perceptions. • Assumes mutually exclusive rules and no rule conflicts. • Reactive agents are difficult to predict and has a simple representation.	Concurrent reactive agents (Costa and Feijó, 1996); JackMOO (Shi et al., 1999)
Hybrid Architectures	Build an agent out of 2 subsystems: 1. A deliberative one: containing a symbolic world model which develops plans and makes decisions in the way proposed by symbolic AI. 2. A reactive one which is capable of reacting to events without complex reasoning.	Touring machine (Ferguson, 1992); InteRRaP (Muller, 1997)

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