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Designing and Evaluating Intelligent Agents' Interaction Mechanisms for Assisting Human in High-Level Thinking Tasks

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ABSTRACT

In the twenty-first century, people need to learn and apply high-level thinking skills, such as decision-making, problem-solving, and critical thinking, in their daily lives. Traditionally when in need, people can get help from human assistants to complete these thinking tasks, yet, such human experts are not always accessible. Intelligent agents, such as physical robots and virtual chatbots, are promising alternatives to the human assistants in these tasks. My doctoral research focuses on designing intelligent agents to assist human users and evaluating the impact of their interaction mechanisms (i.e., way of behaving) on user experience. Specifically, my works surround this theme by proposing: 1) an anticipation-autonomy framework that models the service robot's proactivity in decision-making support contexts (decision-making); 2) a bot assistant that helps users to solve the problem of writing poor-quality comments in online mental health communities either by assessing the writing performance or recommending writing examples (problem-solving); and 3) a chatbot in comparison to a non-conversational tool for facilitating people to read academic papers critically (critical thinking). My dissertation contributes to the design of intelligent agents for helping people in high-level thinking tasks and insights for developing appropriate interaction mechanisms for these agents in the future.

CCS CONCEPTS

• **Human-centered computing** → **Empirical studies in HCI**; **Empirical studies in interaction design**.

KEYWORDS

Intelligent agents; Robot; Bot; Decision-making; Problem-solving; Critical thinking

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1 INTRODUCTION

High-level thinking, such as decision-making, problem-solving, and critical thinking, are considered as essential skills that people need to learn in the twenty-first century [4]. Traditionally people can learn these skills or get help from human assistants to complete their high-level thinking tasks. For example, customers can receive information and recommendations from shop assistants to decide which product to buy, and students can learn to think critically about their reading materials with guidance and questions from their teachers. Yet, such human assistants are not always available to provide timely support to people in need. Intelligent agents, either in a physical (e.g., the humanoid robot Pepper) or a virtual (e.g., Internet bot, chatbot) form, are possible alternatives to help people in their high-level thinking tasks. For example, physical robots can serve as shop assistants [8] and receptionists [13] to provide information to users, and bots or chatbots can act as virtual teachers [20] and customer service agents [5] to help users solve problems.

While researchers are continuously empowering these agents with abilities (e.g., natural language processing, computer vision) to handle various user input, few works dig into the design of the agents' interaction mechanisms (i.e., way of behaving) for offering help in users' thinking process. This is an essential part for the success of agents' design as previous works (e.g., [1, 11, 14, 22, 23]) suggest that people are sensitive to intelligent agents' behaviors. For instance, people had better collaboration experiences with a physical robot NAO that handles their disengagement in a submissive manner than the one acting dominantly [23]. Agents that react inappropriately would impair user experience and consequently harm the benefits of both users and service providers behind the agents [9]. Yet, designing proper behaviors of intelligent agents is challenging in tasks of assisting users' high-level thinking, where they should not do all the jobs (e.g., make decisions) for humans but mainly help users form their own thinking. In other words, the agents' interaction design should specifically pay attention to the possible interference with humans' thinking process.

Thus far, my doctoral research has primarily focused on designing and evaluating intelligent agents and their interaction mechanisms for assisting human users in high-level thinking tasks. My general research goals are to design and build new agents that can assist people and identify the agents' proper ways of behaving in users' high-level thinking tasks. To achieve these goals, I propose a human-centered methodology on designing appropriate intelligent assistants. First, together with my co-authors, we identify scenarios where people usually need help from other humans in thinking tasks. Then, we proceed to the understanding of how human assistants provide support in these scenarios and summarize

their behavioral manners into some salient patterns. Next, we transfer these behavioral patterns to the design of agents' interaction mechanisms based on psychology literature and existing designs in relevant contexts. Finally, we evaluate how the intelligent agents and their different interaction designs affect human users' behaviors and perceptions in the thinking tasks. This methodology generally follows the human-centered design methods [6] by involving target users in the identification of problems, development of the solutions, and evaluation of the proposed systems. The form of intelligent agent in my research is not restricted to a specific type, e.g., robot, bot, and chatbot, and it depends on the users' needs in their tasks.

My works to date have investigated the proposed methodology for intelligent agents' interaction design in assisting high-level thinking via three projects: **1) Decision-Making Task – Service Robot's Proactivity.** When people need support for decision-making such as which product to buy at the stores, they may expect the help to come proactively (e.g., without their explicit requests) or reactively. This pattern of offering help is framed as productivity for human assistants and are shown to affect user perception and behaviors in decision-making [3, 16], yet little is known about the design and effects of robot's proactivity. My first project proposes an anticipation-autonomy framework for robot's proactivity and evaluates user perceptions and behaviors under different proactivity conditions. **2) Problem-Solving Task – Writing Assistant's Assessment and Recommendation Methods.** When the sensitive persons, e.g., those with mental health issues, need help from an agent to solve the problems at hand, they may easily get hurt if the agent uses the wrong assisting methods, e.g., criticizing their performances. In my second project, we develop a writing bot assistant for peers to draft supportive comments for others in online mental health communities, and we compare the effects of its assessment (e.g., score writing performance) and recommendation (e.g., suggest similar writings) modes on user satisfaction and behaviors. **3) Critical Thinking Task – Reading Assistant's Conversational Style.** In critical thinking tasks such as reading academic papers critically, people may not be used to have an agent that actively offers help in the process. While conversational agents are generally engaging in many other tasks, they may intervene in users' thinking processes and be not as useful as the non-conversational tools in critical thinking tasks. My ongoing project designs a chatbot facilitator that asks users critical thinking questions when they are reading each section of academic papers, and we compare the usefulness and user experience of it against a static list of the same questions. In the next section, I will present these three projects in more detail and discuss their insights for intelligent agents' interaction design in corresponding thinking tasks.

Background: I am a fourth-year Ph.D. student supervised by Professor Xiaojuan Ma¹ in the Department of Computer Science and Engineering at the Hong Kong University of Science and Technology (HKUST). I am currently preparing for my thesis proposal about the design and evaluation of human-agent collaboration. My expected completion date for the Ph.D. program is in July 2021.

¹<https://www.cse.ust.hk/mxj/>

Figure 1: Low, medium and high proactivity of robots based on an anticipation-autonomy policy framework [18].

2 WORK TO DATE

2.1 Service Robot's Proactivity in Supporting Human Decision-Making

My first project targets the scenarios where people need support for decision-making and investigates the design of agents' behavioral policy in offering help. It is motivated by the organizational literature of human assistant's proactivity [3, 16] and that people are sensitive to robot's behaviors [19]. For example, robot shop assistants that proactively or reactively give product recommendations may impact customers' shopping experience. Based on the definition of human's proactivity [3, 16], we define robots' proactivity as the anticipatory action that robots initiate to impact themselves and/or others. We further formulate three levels of robot proactivity (*low*, *medium*, *high*) in two dimensions – anticipation and autonomy (Fig. 1):

- *Low-proactivity*: the robot makes no assumption and needs the users to explicitly tell what they want; the robot only responds upon request and needs a large amount of user input (autonomy 1-2), e.g., providing a complete set of choices.
- *Medium-proactivity*: the robot makes some assumptions and lets the user verify them; the robot needs some amount of user input to take automatic actions (autonomy 3-5), e.g., providing limited choices like "A or B".
- *High-proactivity*: the robot makes strong assumptions (e.g., users need help, like popular items, etc.) and actively offers it; the robot automatically takes action with very small amount of user input (autonomy 6-8).

To evaluate the impact of robot proactivity on decision-makers perceptions and behaviors, we conduct a within-subject (*low* vs. *medium* vs. *high* proactivity), Wizard-of-Oz experiment with 36 participants in a simulated shopping scenario. In the mixed-method analyses, we run ANOVA to compare user perception towards robots with different levels of proactivity, and we conduct a thematic analysis to qualitatively understand their behaviors in each condition. Participants reflect that the high-proactivity robot is the least appropriate though it can provide rich information, while the medium-proactivity robot is more helpful as it helps to narrow down choices. The thematic analysis further reveals that the participants could adjust their turn-taking behaviors to the robots' manner, and they have more control over the conversation with the low-proactivity robot by actively making requests. However, they

Figure 2: Design of MepsBot [17]. (a) Assessment mode: (i) report IS and ES scores and (ii) give feedback for improvement. (b) Recommendation mode: (iii)&(iv) suggest example comments that could be semantically similar to user's writing, with highlighted feature words.

engage better with the medium-proactivity robot, with sufficient opportunities to express their thoughts and feelings.

From our experimental findings, we derive several design considerations for the service robot's manner. For example, robot agents should infer decision-makers' information needs based on some reasonable assumptions. However, instead of directly offering information based on the anticipated needs, in most cases it is deemed more considerate for the robot to verify its mental model prior to taking any action. Also, agents' behavioral policy should be adaptive to users' emotional reactions. For example, when a service robot approaches a user and proposes to help, if the user says "no" or expresses impatience or avoidance, it may be better for the robot to reduce its level of proactivity. This work contributes to an anticipation-autonomy framework for designing intelligent agents' behavioral policy and adds to the understanding of how people perceive and interact with service robots.

2.2 A Bot Assistant for Writing Supportive Comments in Online Mental Health Communities

While the first project studies robot's behavioral policies for supporting human users in decision-making, my second work looks to a problem-solving task and investigates how an agent should help peers draft supportive comments (note: unsupportive comments can cause problems for both commenters and posters) in online mental health communities (OMHCs). Textual comments

from peers with informational support (IS; e.g., advice) and emotional support (ES; e.g., encouragement) are beneficial to members of OMHCs [7, 21]. However, many comments are not of high quality in reality [12, 15]. Inspired by the human teachers' and moderators' ways of offering writing feedback and the design of existing writing support technologies, we summarize two types of assisting methods that an intelligent agent can use to help peers improve the comments' quality. One method is to assess (AS) the text [24], and the other is to recommend (RE) writing examples [2, 10] on the fly. However, the AS-mode or RE-mode assistants could raise concerns about frustration [24] or sincerity [10], which may become sensitive issues in the context of OMHCs. In this project, we design a MepsBot to explore user perception and behaviors given two types of in-situ writing assistance. We first build up machine-learning models to estimate the levels (i.e., *low*, *medium*, and *high*) of informational and emotional support in user's drafted comment. We then implement MepsBot with two assisting methods (Fig. 2):

- *AS-mode* MepsBot detects and displays the levels of IS and ES of an input draft, and it suggests ways to improve.
- *RE-mode* MepsBot suggests high-quality example comments that are semantically similar to the user's current draft from a recommendation pool.

To evaluate how they perceive and work with different types of MepsBot's assisting mechanisms, we conduct a mixed-design

Figure 3: Screenshots of the simulated community: (a) original full page; (b) full page with the RE-mode MepsBot; (c) the target support-seeking post; (d) the text box for writing a comment; (e) buttons of the comment flow, e1 ↔ e2 if users click (i) “Preview” or (ii) “Back to edit”; (f) recent posts and their comments; (g) MepsBot shows up with the first click on “Preview” and keeps visible until the click on “Continue to submit” [17]

study with 30 participants in a simulated online depression community (Fig. 3). Specifically, we run mixed ANOVAs and independent-samples t-tests to quantitatively compare user perceptions of interacting with MepsBots in different mode, and conduct a thematic analysis to dig into how they re-edit the comments during the process. The results show that both types of MepsBot improve participants’ confidence in and satisfaction with the IS and ES manifested in their comments. The AS-mode MepsBot motivates participants to refine their expressions and is perceived as easier to use, while the RE-mode MepsBot stimulates users to re-edit the support-related content in their comments.

We derive several design considerations for technological writing assistants in online mental health communities. For instance, MepsBot could intervene more proactively rather than wait for the user’s trigger in cases where people are stuck for a long time, but it should first verify with users if they need help [18], like asking “would you like to have a tip”. Also, MepsBot could inquiry about user preference at the beginning and adapt its assisting methods based on the comment’s quality. For example, MepsBot can act in AS mode if the comment is of high quality. When the comment is of low IS/ES or is too short, the MepsBot can activate its RE mechanism to offer some good examples for reference. Nevertheless, intelligent agents should make their assisting methods transparent.

This project contributes to a bot system for helping peers to draft supportive comments in OMHCs, and it adds to the understanding of user perceptions and behaviors under the two assisting methods (i.e., assessment and recommendation) in the problem-solving tasks.

2.3 A Chatbot Facilitator for Reading Academic Papers Critically

My ongoing project (under review) explores the possibility of chatbot facilitators in a critical thinking task – reading papers critically. Critical reading is an important skill for researchers to learn from and make use of the existing papers. To learn and exercise this skill, they can get guidance socially from human teachers and peers or more accessibly, from online guidelines compiled by experts. Conversational agents or chatbots can take advantage of both the imitated social interaction and the accessible online guidelines to facilitate readers in critical reading. However, they may bring interference to users’ reading and thinking processes and be not as useful as the non-conversational guidelines. In this project, we design a chatbot that asks section-level critical thinking questions on the fly to facilitate users in paper reading. It is located in the sidebar of a web reading interface and will prompt a question that matches with a section that is in the current page or is of users’ interest during the reading process. We compare its usefulness and

user experience against the conventional checklist of instructions and critical questions (denoted as “Guideline”) via a within-subjects lab study with 24 participants. The results show that the chatbot significantly improves users’ perceived engagement in the critical reading process and perceived performance in paper reinterpretation compared to the Guideline. Users also favor the chatbot’s contextualized questions and interaction flexibility. Design insights from our findings include dynamic integration of the bot into the paper’s content to further mitigate the interference and personalized assisting style (e.g., conversational or non-conversational) to the user’s research experience. This work contributes a chatbot facilitator for critical paper reading and demonstrates its usefulness in critical thinking tasks.

3 DISSERTATION STATUS AND CONTRIBUTIONS

I have completed three projects surrounding the research theme of intelligent agents’ interaction mechanisms for assisting humans in high-level thinking tasks, that is, decision-making, problem-solving and critical thinking. In general, my proposed agents and their interaction design based on the identification of user needs, summaries of human assistants’ behavioral patterns, and inspirations from the existing design of similar technologies (the proposed methodology), are useful and widely accepted by the participants in our experiments. The next steps to enrich my dissertation include: 1) conducting field studies to evaluate our designed agents (e.g., Meps-Bot) and their interaction mechanisms (e.g., proactivity) in users’ tasks of decision-making, problem-solving, and critical thinking. 2) applying the proposed methodology to other high-level thinking tasks like creativity and innovation [4]; and 3) compiling a set of design guidelines for intelligent agents’ behaviors in assisting humans in these thinking tasks.

To summarize, my doctoral research contributes a proactivity framework for designing agents’ behavioral policy and two agents (i.e., MepsBot for writing and a chatbot for reading) that offer on-the-fly assistance to users. I conduct experiments to evaluate the user experience of our agents with different interaction designs. These experiments can deepen our understandings of users’ perceptions and behaviors when intelligent agents are helping them in different manners. In a broader scope, the insights from our studies are also likely to benefit researchers and designers who need to develop agents with appropriate behaviors.

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