TEAMING UP WITH INTELLIGENT AGENTS – A WORK SYSTEM PERSPECTIVE ON THE COLLABORATION WITH INTELLIGENT AGENTS

Completed Research Paper

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Abstract

Intelligent agents may become our co-workers. As intelligent agents powered by agentic information systems are acquiring more capabilities, humans consider teaming up with them in ever more circumstances. However, research and practice still face major uncertainties and difficulties when implementing intelligent agents into work systems together with humans. We address the lack of guidance on how to design work systems in which human and intelligent agents can collaborate, by investigating the central aspects that describe the collaboration of human and intelligent agents in work systems. We do so by building on a literature review on human-robot interaction and taking the work system perspective. This results in two contributions. First, we identify 16 important design dimensions of collaboration between human and intelligent agents. Second, we assemble these dimensions into a task-related framework that highlights specific design parameters and important considerations when designing work systems where human and intelligent agents collaborate.

Keywords: Human-AI Collaboration, Intelligent Agents, Artificial Intelligence, Work System.

1 Introduction

The collaboration of humans with intelligent agents that are powered by artificial intelligence (AI) promises substantial productivity improvements in work systems. Besides intelligent agents' automation potential, research has shown that through collaboration humans and intelligent agents can actively leverage their complementary strengths (Dellermann et al., 2019). It has become apparent, not least with the recent breakthrough in large language models, that intelligent agents will be relevant to almost every business function. With the expected proliferation of AI applications and agentic information systems (IS), human and intelligent agents' work will increase to intersect across employees, teams, departments, and even companies. However, beyond considering individual human-computer interactions, there is little to no guidance on how to holistically design the collaboration of human and intelligent agents in work systems to leverage the collaborators' complementary strengths. In work systems, humans and machines do not only interact but "[…] perform work […] to produce specific products/services for specific internal and/or external customers" (Alter, 2013, p. 82). When concentrating on individual human-computer interactions, the system perspective is disregarded, albeit such a perspective is relevant for designing work systems that effectively leverage the potential of collaboration between human and intelligent agents beyond simple bilateral settings. In the exemplary case of software engineers teaming up with so-called copilots (e.g., GitHub Copilot), collaboration settings are multilateral requiring to integrate several human and intelligent agents' work into larger software projects. The deficiency of a system perspective is problematic for two reasons. First, the agency of current and future intelligent agents contrasts traditional machines and IT systems (Berente et al., 2021). While most of today's uses of intelligent agents represent settings of delegation from human to intelligent agent akin to work system theory's conceptualization of technology (Alter, 2023), future intelligent agents will blur the boundaries between participants and technology components of a work system by reversing the direction of work delegation or removing humans from work systems altogether (Baird and Maruping, 2021). Second, researchers' and practitioners' ability to identify and understand problems or issues of collaboration between human and intelligent agents in work systems is hampered by the lack of knowledge about how to describe such settings, their design choices, and dependencies. This can result in unexploited opportunities (e.g., inefficient workflows) or severe constraints (e.g., harm employees' mental health) in newly designed collaborative work systems.

A variety of related research fields already exist that potentially provide valuable insights and possible starting points to address this deficiency of knowledge. Crucial aspects of human interaction with technology are a topic in the human-computer interaction (HCI) field, which deals with the creation and implementation of interactive computing systems for human use and the relationship between them (Issa and Isaias, 2015). However, the HCI field takes a human-centric perspective on the relationship between humans and computing systems and, thus, often lacks a bilateral, task-centric perspective on collaboration, which is key to analyzing work systems (Alter, 2013). Recent large language models emphasize the need for a task perspective as users can now not only use prompts to request pre-trained capabilities but adjust a model's task spectrum by describing the desired task (i.e., in-context learning). Another well-explored discipline is human-robot interaction (HRI), which deals with the communication between robotic systems and humans (Goodrich and Schultz, 2007). Although the HRI field takes an agentic and task-centric perspective, existing studies only focus on one or selected aspects of the collaboration setting. In the IS domain, based on these streams of literature, the recently emerged discourse on human-AI collaboration seeks to integrate their findings (Braun et al., 2023). While initial research in this discourse already yielded insightful frameworks regarding specific aspects of human-AI collaboration (e.g., team-performance (Zercher et al., 2023)), an approach to comprehensively describe and analyze collaboration of human and intelligent agents in work systems is still missing. Such a framework would help to identify and visualize design choices when using intelligent agents (Alter, 2023) and would inform the purposeful design of their collaboration in work systems to make the best possible use of the collaborators' complementary strengths. Hence, we ask:

How can we conceptualize the collaboration between humans and intelligent agents in work systems?

To approach this research question, we conducted a systematic literature review (vom Brocke et al., 2009; vom Brocke et al., 2015; Webster and Watson, 2002). We contribute to the discourses on the collaboration of human and intelligent agents as well as on work system design in two ways. First, we describe 16 dimensions that represent important aspects of bi- and multilateral collaboration of human and intelligent agents. Second, using work system theory, we assemble these dimensions into a conceptual framework that allows to describe and research the collaboration of human and intelligent agents in a work system from a task perspective. The framework represents an effort to theorize on the relationships between the identified dimensions and addresses uncertainties and difficulties when implementing intelligent agents into human-driven work systems. We break with the isolated view of human-computer interactions and introduce a conceptual framework to take a work system perspective.

2 Foundations

2.1 An intelligent agent perspective on artificial intelligence

According to Nilsson (2010, p. 13), AI "[…] is that activity devoted to making machines intelligent, and intelligence is that quality that enables an entity to function appropriately and with foresight in its environment". To approach the AI concept, Russell and Norvig (2010) consider agents, which perceive their environment through sensors and perform actions based on these perceptions. To integrate the concepts of AI and software-based agents, we adopt the well-established definition of Jennings and

Wooldridge (1998) and define intelligent agents as "[…] a computer system that is capable of flexible autonomous action in order to meet its design objectives" (Jennings and Wooldridge, 1998, p. 4). We build on this definition of intelligent agents, because, on the one hand, it emphasizes the AI application's ability to make flexible decisions that are intelligent in the sense that they contribute to the application's objectives, and, on the other hand, it emphasizes the AI application's ability to act autonomously and collaborate with other agents. This definition is consistent with the conceptualizations of AI by Berente et al. (2021) and of agentic information systems by Baird and Maruping (2021). Importantly, it not only focuses on the capabilities of today's AI systems but will also cover future information systems of increasing autonomy and agency. Based on Jennings and Wooldridge (1998) we consider an intelligent agent to be *responsive* (i.e., perceptive and reactive to its environment), *proactive* (i.e., proactively acting towards its objective), and *sociable* (i.e., interactive with other human or intelligent agents).

2.2 Collaboration in work systems

We understand collaboration as the "[…] process in which two or more agents work together to achieve shared goals" (Terveen, 1995, p. 67). As a process, collaboration takes place and evolves over a certain period and happens within its environment. Collaboration requires four fundamental activities. Collaboration requires agents to *communicate* to define goals, negotiate over how to proceed, and evaluate the progress and results (Mattessich and Monsey, 1992; Terveen, 1995). Collaboration requires agents to process tasks, i.e., to take actions and co-manage their tasks to achieve their shared goals (Wang et al., 2020). Collaboration requires agents to determine which actions will be done by which agent and who will be *responsible* for which actions (Terveen, 1995). Collaboration requires agents to negotiate and decide on their level of control (i.e., *authority*) regarding their actions toward the tasks to coordinate their operations (Terveen, 1995).

We consider the collaboration of agents to be placed in an organizational context. To that end, we are building on the work systems literature. Bostrom and Heinen (1977) use the term *work system* in their work on socio-technical theory. They describe that "[…] a work system is made up of two jointly independent, but correlative interacting systems – the social and the technical" (Bostrom and Heinen, 1977, p. 17). Notably, Bostrom and Heinen (1977) emphasize the integration of these two systems to be crucial for any design or redesign of a work system. This is important for our research, as the collaboration of human and intelligent agents precisely focuses on such integration from a perspective that is neither human- nor technology-biased. Building on the term work system as used by Bostrom and Heinen (1977), Alter (2013) provides a comprehensive overview of work system theory. Following Alter (2013), we understand a work system as "[…] a system, in which human participants and/or machines perform work (processes and activities) using information, technology, and other resources to produce products/services for internal and/or external customers" (Alter, 2013, p. 75). Processes and activities serve as the component in a work system that participants, technologies, and information have to be aligned to (Laumer et al., 2016). This is in line with our task-centric perspective on the collaboration of human and intelligent agents. Further, work systems are typically part of a larger organizational context, which defines the environment and strategies that the particular work system is operating in, as well as the infrastructure (e.g., technical resources used by the work system but managed outside of it) that the work system is using (Alter, 2013).

2.3 Related work

Humans interacting and collaborating with technological artifacts is not a new topic. Licklider (1960) coined the concept of a complementary relationship between humans and computers, where humans set the goals and perform the evaluations, while the computing machines take over a supporting role performing routine work. According to Carroll (2002, p. xxvii), HCI "[…] is the study and the practice of usability. It is about understanding and creating software and other technology that people will want to use, will be able to use, and will find effective when used". However, while the HCI field holds important knowledge regarding communication aspects of the interaction between humans and intelligent agents, it leaves out a two- or even multi-sided perspective on collaboratively solving tasks in a work system.

Another related research stream is HRI, which is closely related to the field of HCI as robots can be considered as computing systems (Yanco and Drury, 2002). This field of study takes a more agentic perspective considering the interaction between humans and robotic systems (Young et al., 2011). This notion is significant to our research, as it allows a two- or even multi-sided perspective on collaboratively solving tasks in a work system. Moreover, this agentic view allows for incorporating task aspects as humans are typically interacting with robots to complete tasks. Therefore, the research field of HRI offers a multitude of links to our research regarding the collaboration of human and intelligent agents. We will elaborate on the specific knowledge of the HRI field relevant to our study when we present the results of our literature review in the results section.

However, research still lacks a comprehensive and tangible model describing the collaboration of human and intelligent agents in work systems to accomplish tasks. Prior work has only focused on isolated aspects (e.g., human- or technology-centered) and perspectives (e.g., communication between humans and technological artifacts) of the collaboration process between humans and intelligent agents. Hinsen et al. (2022) presented a framework to describe interactions between human and intelligent agents, comprising of nine interaction dimensions. The framework is designed using insights gathered from interviews with experts and focuses on individual interactions. Zercher et al. (2023) investigate the effects of team-AI collaboration on team performance and find, among others, that processes such as intragroup communication and coordination become less effective. Braun et al. (2023) review literature on human-AI collaboration from a teamwork perspective and find, that with increasing organizational complexity human-AI teamwork needs to be designed with a focus on communicational requirements of humans. They build a framework of temporal collaboration phases, but they do not focus on organizational design dimensions of work systems that leverage collaboration between humans and intelligent agents. Yet, current research falls short to cover the collaboration in all its complexity to make it explicable in work systems. Furthermore, previous research has not considered a joint task perspective between humans and intelligent agents, which is central to the collaboration process. Thus, our paper seeks to disentangle, integrate, and ultimately augment the existing findings to create a comprehensive framework revisiting the collaboration of human and intelligent agents in work systems from a joint task perspective. We do so, by building on the work by Hinsen et al. (2022) because their framework seeks to identify general dimensions of interactions between human and intelligent agents rather than focusing on specific aspects (such as, e.g., team performance by Zercher et al. (2023) or communication by Braun et al. (2023)).

3 Research Method

We conducted a systematic literature review based on widely-accepted recommendations (vom Brocke et al., 2009; vom Brocke et al., 2015; Webster and Watson, 2002) that synthesizes the existing knowledge in the HRI field to inform our framework design and to identify perspectives of the collaboration of human and intelligent agents that are relevant for future research (vom Brocke et al., 2015). As suggested by Webster and Watson (2002), the systematic literature review comprises three phases: (1) literature search, (2) literature selection, and (3) literature analysis.

Due to the interdisciplinarity of our research field, we considered three leading scientific databases relevant to our research goal: the Association for Information Systems eLibrary (AISeL), as it is the well-established database for IS literature, as well as Web of Science (WoS) and EBSCOhost, as they both index a broad range of literature ranging from more technical, computer-science literature to more business-oriented and management literature. Together, these three databases ensure broad coverage of the topic. In the literature search phase, we (1) conducted a preliminary search, (2) iteratively developed and tested the search string, and (3) used the final search string in the title, abstract, and keywords search. To define our research scope, we first conducted a preliminary literature search. To that end, we used the keywords "human computer interaction", "human machine interaction" and "human robot interaction" as extensively researched fields in combination with "artificial intelligence" in the initial title, abstract, and keywords search. These preliminary searches yielded large initial results, which made it necessary to narrow down the search (e.g., "Human Computer Interaction" yielded 17,322 results on WoS and 4,165 on AISeL, "Human Robot Interaction" yielded 9,883 results on WoS and 156 on AISeL). We discovered that the fields of HCI and human-machine interaction do not specifically focus on a task perspective, and the preliminary search yielded mostly results concerned with design of software user interfaces and user experience. The HRI field, on the other hand, proved to yield great potential to be examined from a task-centered perspective and therefore ensures the relevance of our findings. While modern robotic agents are not what we would consider a proper intelligent agent as per our definition, they represent some of the most advanced agents based on AI technologies. We thus are confident that the HRI literature is the best foundation for our work. Further, later on in the process the framework by Hinsen et al. (2022), which in turn is rooted in the HCI literature, will be used in the coding of the literature, ensuring that relevant insights from HCI literature are incorporated into our framework. In the second step, based on this initial understanding and the first literature sample, we developed search strings with relevant keywords centered around the terms "human robot interaction" and "artificial intelligence". We then iteratively adjusted the constructed search strings by testing the search results' relevance and feasibility. Therefore, we conducted searches in titles, abstracts, and keywords. This way, we could identify highly relevant keywords regarding collaboration processes to then build the following comprehensive search string consisting of three parts:

("human robot interaction" OR "human robot cooperation" OR "human robot collaboration" OR "human robot teamwork" OR "human robot team" OR "human robot system*" OR "human robot relationship" OR "human robot interactivity")* ***AND*** *("framework" OR "taxonomy" OR "model" OR "classification" OR "categorization")* ***AND*** *("artificial intelligence" OR "machine learning")*

As our research goal is to conceptualize the collaborative task fulfillment between humans and intelligent agents, we included different terms indicating some collaborative efforts in the first part of the search string. The second part of the search string limits the search results to papers that include some sort of structured categorization since we aim to synthesize existing frameworks and models and augment them with a task-centered dimension. By adding "artificial intelligence" and "machine learning" in the third part, we ensure to only include papers dealing with agents based on AI technologies, to increase the relevance of our research outcome. A final search in titles, abstracts, and keywords resulted in a sample comprising a total of 952 papers (Web of Science: 712, AISeL: 143, EBSCOhost: 97). Removing duplicates led to 919 publications which we then screened for inclusion.

In the literature selection phase, we first conducted a title and abstract screening, followed by a full-text screening. In the first step, we screened the titles and abstracts considering three ex-ante-defined exclusion criteria: (1) the paper focuses on interaction without any collaborative efforts or a joint task perspective involved, (2) the paper discusses no AI-enabled robots or agents, and (3) the study takes a one-sided approach in the sense of focusing on only one actor while neglecting the respective counterpart. This first exclusion iteration resulted in 161 eligible papers. In the second step, we conducted a full-text screening of all 161 papers leading to the exclusion of additional 123 studies, which resulted in a total of 38 relevant publications. Moreover, we used forward and backward searches to augment the number of sources with papers that are significantly influential due to their high citation count and their relevance regarding our research scope (Okoli and Schabram, 2010; Webster and Watson, 2002). This way, we could include 7 additional papers, leading to a final set of 45 publications eligible for review, comprising of both conceptual and empirical papers.

In the **coding step**, we then iteratively created a concept matrix and conducted coding, harmonized the concepts, and synthesized our findings. We used the model introduced by Hinsen et al. (2022) comprising nine human-AI interaction dimensions as the initial concepts for our coding scheme: *interaction transparency*, *interaction impulse*, *interaction result*, *action direction*, *action channel*, *action frequency*, *interaction frequency*, *interaction dependency*, and *interaction environment*. We chose this approach for two reasons: First, we avoid overlooking important dimensions and, thus, ensure the comprehensiveness of our results. Second, although Hinsen et al. (2022) does not cover a task perspective, their interaction modeling approach rooted in the HCI literature still represents a relevant knowledge base for our research purpose. During the coding, we analyzed the full text of all 45 papers and examined which collaboration dimensions the papers discuss or which perspectives the papers took on the collaboration of human and intelligent agents. We then marked the corresponding passages, coded them accordingly, and subsumed our findings in the concept matrix. This way, we clustered the codes into different categories according to the dimensions they explore. Simultaneously, we explored and documented emerging dimensions not covered by the initial coding scheme. Throughout the coding process seven additional dimensions emerged that were not covered by the initial set of dimensions by Hinsen et al. (2022). These dimensions are *action space, number of interactors, collaboration control, collaboration strategy, delegation, turn taking,* and *team roles*. We subsequently embedded these dimensions into our concept matrix, resulting in a total set of 16 dimensions. An excerpt from the concept matrix is depicted in Table 1. The final set of 16 dimensions is presented in Section 4.

Articles	**Concepts** (dimensions of collaboration between agents)			
	Collaboration control	Delegation	Collaboration strategy	…
Baird and Maruping (2021)		x		
Kuang et al. (2018)	x	x		
Yang et al. (2022)	x		x	
…				

Table 1. Excerpt from the concept matrix that we used to analyze the literature.

We then used the elements of work systems theory as described by Alter (2013) to guide the **framework development step** based on the identified 16 dimensions. We seek to develop a framework as an initial effort to make sense of the identified dimensions from the literature and to set them into relation to each other. As Webster and Watson (2002) highlight, developing a conceptual model and propositions is key to a good literature review. When discussing the knowledge systematized in the concept matrix, we realized that a theoretical perspective could significantly strengthen the explanatory power of our insights by allowing us to relate the identified constructs to each other and develop a conceptual framework. As work systems theory emphasizes the integration of the social and technical systems in a work system (Bostrom and Heinen, 1977) and considers the tasks and processes as the central component of alignment in a work system (Alter, 2013), we used this theory to guide the development of a framework based on our identified dimensions. We iteratively developed the framework by integrating the identified dimensions. We did not finish until we derived a framework that integrates every dimension found in the literature and qualifies as internally consistent. We also solicited feedback at an international research symposium on “augmented intelligence at work”, where we presented the framework. The researchers’ feedback let us adjust the subtleties of the model and inspired our thoughts on future research. The results of our framework development step are presented in Section 5.

4 Results

In the following, we introduce the 16 dimensions of the collaboration of human and intelligent agents we identified from the literature review. The dimensions are depicted in Table 2. We grouped the dimensions into four aspects related to agents and team, communication, environment, and task processing.

General aspect	Dimensions	References
Agents and team	Number of interactors	(Debowski et al., 2021; Debowski et al., 2022; Kuang et al., 2018; Özgelen and Sklar, 2015; Vallès-Peris and Domènech, 2021; Yang et al., 2022; Yazdani et al., 2018)
	Interaction transparency *	(Chen et al., 2017; Endsley, 1995; Lakhmani et al., 2016; Lyons, 2013; Matarese et al., 2021; Tse and Campbell, 2018; Zhou and Tian, 2020)
	Interaction dependency *	(Dehkordi et al., 2021; Kuang et al., 2018; Nichols et al., 2021; Özgelen and Sklar, 2015; Zhao et al., 2020)
	Team roles	(Bao et al., 2021; Chacón et al., 2021; Debowski et al., 2021; Debowski et al., 2022; Di Zhang et al., 2022; Kuang et al., 2018; Molina et al., 2018; Özgelen and Sklar, 2015; Seeber et al., 2019; Sycara and Sukthankar, 2006; Yazdani et al., 2018)
Communication	Action channel *	(Holzapfel, 2008; Jung et al., 2004; Lakhmani et al., 2016; Mukherjee et al., 2022; Yang et al., 2022)
	Action direction *	(Molina et al., 2018; Rogozińska-Pawełczyk, 2020; Thomaz and Chao, 2011; Tse and Campbell, 2018; Yang et al., 2022)
	Interaction frequency *	(Agostini et al., 2017; Epstein, 2015; Hoffman, 2019; Horiguchi et al., 2000; Mukherjee et al., 2022; Murphy, 2004; Siemon and Wank, 2021)
	Action frequency *	(Letheren et al., 2021)
	Interaction impulse *	(Hakli, 2017; Kuang et al., 2018; Molina et al., 2018; Nichols et al., 2021; Yazdani et al., 2018)
Environment	Action space	(Debowski et al., 2021; Debowski et al., 2022; Letheren et al., 2021; Molina et al., 2018; Zhang and Wang, 2020)
	Interaction environment *	(Buerkle et al., 2021; Correa et al., 2010; Murphy, 2004; Vallès-Peris and Domènech, 2021; Wang et al., 2018; Yazdani et al., 2018)
	Interaction result *	(Chen et al., 2021; Kuang et al., 2018; Nichols et al., 2021; Tse and Campbell, 2018; Uluer et al., 2021; Wiethof and Bittner, 2021; Zhang and Wang, 2020)
Task processing	Collaboration control	(Kuang et al., 2018; Molina et al., 2018; Nichols and Okamura, 2016; Yang et al., 2022; Yazdani et al., 2018)
	Delegation	(Baird and Maruping, 2021; Kuang et al., 2018)
	Collaboration strategy	(Yang et al., 2022)
	Turn taking	(Hoffman, 2019; Nichols et al., 2021; Thomaz and Chao, 2011)

Table 2. Identified dimensions from the literature, grouped into four higher-level aspects of collaboration. Dimensions based on Hinsen et al. (2022) are marked with an asterisk.

4.1 Dimensions related to agents and team

Four of the identified dimensions are related to the agents and the team of agents that are participating in the human-AI collaboration. These dimensions are *number of interactors, interaction transparency, interaction dependency,* and *team roles.* The dimensions *interaction transparency* and *interaction dependency* are based off Hinsen et al. (2022), while *number of interactors* and *team roles* are new dimensions that emerged from our literature analysis. The *number of interactors* refers to the total number of collaborating human and intelligent agents, ranging from simple one-to-one collaboration settings of one human and one intelligent agent to complex networks of multiple human and intelligent agents (Vallès-Peris and Domènech, 2021; Yang et al., 2022). Examples described in the literature include settings where one human supervises multiple intelligent agents by assigning tasks (Özgelen and Sklar, 2015; Yazdani et al., 2018) or a virtual teammate that acts as a facilitator in a creativity workshop (Debowski et al., 2021; Debowski et al., 2022). The *interaction transparency* describes the degree of shared intent and awareness of the human and the intelligent agent, allowing agents to understand and anticipate each other's behavior (Lakhmani et al., 2016; Matarese et al., 2021). Due to the autonomous nature of intelligent agents, they have the ability to act independently which in turn requires coordination and cooperation (Lakhmani et al., 2016). As human and intelligent agents act in a tandem to on shared tasks and make joint decisions along the way, they need "a common understanding of the situation, the task, the team members and their respective duties" (Lakhmani et al., 2016, p. 297) to give clarifying feedback and collaborate effectively (Tse and Campbell, 2018; Zhou and Tian, 2020). *Interaction dependency* describes the level of dependency between different tasks and actions (Dehkordi et al., 2021). It describes to which extent one agent's actions affect the performance of other collaborating agents in the team (Zhao et al., 2020). The literature describes settings of pooled interdependence (hardly interdependent), sequential interdependence (moderately interdependent), and reciprocal interdependence (highly interdependent) (Zhao et al., 2020). The amount of coordination needed among the collaborating agents tends to increase with the degree of interaction dependency (Dehkordi et al., 2021). Finally, *team roles* describe the different functions the human or the intelligent agent can fulfill during collaboration. In the literature, the roles assistant, supervisor, and companion are described (Bao et al., 2021; Chacón et al., 2021). The roles of the agents largely determine the team members' perception of one another and the distribution of responsibility in relation to their joint task (Bao et al., 2021).

4.2 Dimensions related to communication

Five out of the 16 identified dimensions are related to the exchanging of information between collaborating agents in any form and direction. These dimensions are *action channel, action direction, interaction frequency, action frequency,* and *interaction impulse.* All of these dimensions are based off the set of dimensions described by Hinsen et al. (2022). The *action channel* describes the different forms of expression and perception through which an agent can express, for instance, its intentions or commands and perceive external stimuli respectively (Hinsen et al., 2022; Jung et al., 2004). Literature emphasizes that it is important that human agents can interact with intelligent agents in a style that seems natural to them (Holzapfel, 2008), in particular acoustically, optically, and haptically (Yang et al., 2022). The *action direction* indicates the direction of each individual action in a collaboration process, either uni- or bidirectional (Hinsen et al., 2022; Jung et al., 2004). In contrast to this definition, our findings from the reviewed literature indicate that in task-centered collaboration of agents the direction has to be bidirectional, as collaboration and communication requires reciprocal interaction of the participating agents (Molina et al., 2018; Rogozińska-Pawełczyk, 2020; Thomaz and Chao, 2011; Tse and Campbell, 2018; Yang et al., 2022). The *action frequency* refers to the number of individual actions during one interaction (Hinsen et al., 2022), while *interaction frequency* refers to the number of interactions in a certain period of time (Hinsen et al., 2022). Regarding the collaboration of human and intelligent agents, we find that the literature distinguishes low (e.g., intelligent agent performs his actions while the human agent is away), medium (e.g., interaction of intelligent and human agents during an assembly task), and high action frequency (e.g., constant turn-taking during creative story drafting) (Letheren et al., 2021). Therefore, action frequency in collaboration is determined by the field of application and the task that is to be achieved by the collaborating agents. In contrast, interaction frequency of collaboration is determined by the level of autonomy of the intelligent agent (Mukherjee et al., 2022), as highly autonomous intelligent agents might operate completely without any human interaction due to their independent control and autonomous decision-making ability (Siemon and Wank, 2021). Finally, the *interaction impulse* describes the starting point of a collaboration as well as the reason for it and can either be initiated by the human or the intelligent agent (Hinsen et al., 2022). With current intelligent agents based on weak AI systems, generally interaction impulses are given by human agents by sending action directives to intelligent agents (Molina et al., 2018), e.g., in settings such as surgery (Kuang et al., 2018) and search and rescue operations (Yazdani et al., 2018). However, one might insinuate that with increasing autonomy of intelligent agents in the future, intelligent agents might take initiative and give interaction impulses for collaboration.

4.3 Dimensions related to the environment

Three out of the 16 identified dimensions are related to the environment in which the collaboration of human and intelligent agents is taking place: *action space*, *interaction environment*, and *interaction result*. While the dimensions *interaction environment* and *interaction result* are based on Hinsen et al. (2022), further insights regarding the action space emerged in our literature review. The *interaction environment* describes the collaboration's context and the condition of the external surroundings (Hinsen et al., 2022). Intelligent agents are required to identify the context of collaboration to ensure safety and productivity (Wang et al., 2018), and the environment determines the context of use by which an intelligent agent can be classified (Vallès-Peris and Domènech, 2021). An intelligent agent that assists humans in lifting objects may be considered a care robot when lifting patients in a medical environment, or as an industrial robot in a production environment (Vallès-Peris and Domènech, 2021). Literature distinguishes structured (e.g., personal assistance or entertainment) and unstructured environments (e.g., manufacturing or space exploration) (Buerkle et al., 2021; Correa et al., 2010; Murphy, 2004; Yazdani et al., 2018). Further, the *action space* describes the spatial setting in which the human and the intelligent agent collaborate with one another. It can either be characterized as virtual (Debowski et al., 2021; Zhang and Wang, 2020) or physical (Letheren et al., 2021; Molina et al., 2018). Finally, the dimension *interaction result* indicates how the outcome of the collaboration affects the environment (Hinsen et al., 2022).

4.4 Dimensions related to task processing

Four out of the 16 identified dimensions are related to collaborative task processing of human and intelligent agents: *collaboration control*, *delegation*, *collaboration strategy*, and *turn taking*. All of these dimensions newly emerged in our literature review. The *collaboration control* indicates the level of autonomy each agent has regarding its actions and its freedom towards task execution (Yang et al., 2022). Literature emphasizes that a spectrum of collaboration control levels is necessary, with the appropriate combination of human and intelligent agents' collaboration control is determined by their joint task (Nichols and Okamura, 2016; Yang et al., 2022). *Delegation* describes the "transferring of rights and responsibilities for task execution and outcomes" (Baird and Maruping, 2021, p. 317) among the collaborating human and intelligent agents. This is closely related to the dimension *team roles*, as the role of an agent is contingent on the responsibilities and rights possessed or transferred (Baird and Maruping, 2021). As intelligent agents are becoming increasingly autonomous, human agents can transfer more complex rights, responsibilities, and tasks to them, or intelligent agents can even delegate to human agents (Baird and Maruping, 2021). The dimension *collaboration strategy* describes the joint plan of action and task fulfilment of the collaborating agents. Depending on team roles and the configuration of collaboration control, the collaboration strategy can be classified as human-dominant, intelligent-agent dominant, or consensus (Yang et al., 2022). Finally, the *turn taking* dimension describes the reciprocal interactions of the collaborating agents towards the joint task (i.e., the command and response patterns in task execution) (Hoffman, 2019; Thomaz and Chao, 2011).

5 Towards a Conceptual Framework

In this section, we describe our conceptual framework that takes a dynamic perspective on the collaboration of human and intelligent agents in work systems. The framework's components and their relations are depicted in Figure 1 using an entity relationship model. The framework is based on the 16 dimensions of collaboration of human and intelligent agents identified from the literature. It comprises structural components that are present in such setting, as well as dynamic components that describe the behavior of the structural components. We propose this framework as an initial step of theorizing and setting the identified dimensions into relation to each other. In doing so, we aim to facilitate describing and analyzing work systems of human and intelligent agents' collaboration.

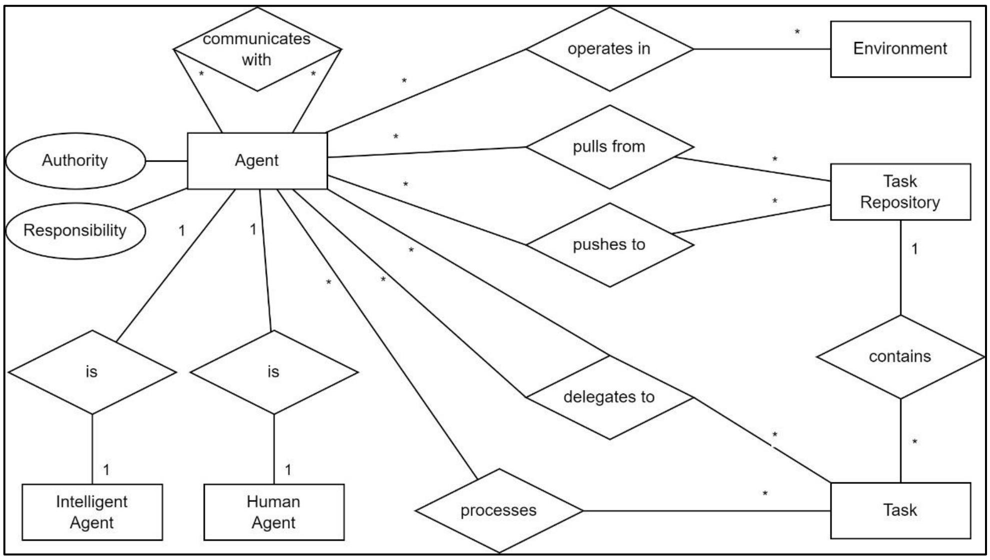

Figure 1. Entity-relationship model of the framework's components.

5.1 The framework's structural components

Agents. The framework's conceptualization of agents is based on the dimensions *number of interactors, interaction transparency, interaction dependency* and *team roles*. Agents are characterized along the following three features. First, considering the scope of action, an agent can either proactively take action, process a task, or communicate with other agents (e.g., to get information for task fulfillment or to negotiate responsibilities or authorities) (Jennings and Wooldridge, 1998; Mattessich and Monsey, 1992; Terveen, 1995; Wang et al., 2020). Second, an agent has responsibilities and authorities (Terveen 1995). And third, an agent perceives its environment and is aware of other agents, their intentions, and their characteristics to a certain degree (Debowski et al., 2021; Jennings and Wooldridge, 1998). Relating to work systems in general, our definition of agents encompasses both participants (i.e., human agents) as well as technologies in the form of intelligent agents. While we still consider them to be aligned via the task that they collaborate on in the work system (Alter, 2013), we emphasize their similarity in characteristics by subsuming these components under the term *agent* in the specialized case of a work system that encompasses the collaboration of human and intelligent agents. This diverges from the differentiation between humans and technology as defined in work systems theory (Alter, 2013), yet the agentic nature of intelligent agents moves them closer to human agents in behavior while the technology-focused aspects recede to the background.

Tasks and task repositories. The framework's conceptualization of tasks and task repositories is based on the dimensions *collaboration control* and *delegation*. A task comprises of logically connected activities required to transform some input (e.g., information) into the desired output. Based on work systems theory, the tasks represent a central component of alignment for the agents in the work system (Alter, 2013; Laumer et al., 2016). We use task repositories as an auxiliary concept to explain a task's whereabouts when it is not being processed by an agent. A task repository's manifestations can range from an agent's mental model of task responsibilities and authorities (e.g., the human agent implicitly derives a task for themselves from a conversation) to a shared database (e.g., scrum backlog of a team). Accordingly, several collaborating agents (e.g., a department) might agree on a shared task repository (e.g., ticket tool of an IT service department) that can serve as a means for shared task management and progress tracking (Wang et al., 2020). Introducing the task-centered perspective and the concept of task repositories is a key difference to the dimensions as described by Hinsen et al. (2022). It allows to track tasks across agents as well as within and across different work systems. Additionally, this understanding also allows us to model disconnected task repositories and, thus, explain how tasks might get stuck when no agents see their responsibility to take over the task. Further, responsibilities and authorities are attributed to tasks (Baird and Maruping, 2021; Bao et al., 2021) that reflect inherent organizational hierarchies and authority structures in work systems (Bostrom and Heinen, 1977).

Collaboration environment. The framework's conceptualization of the environment is based on the dimensions *number of interactors*, *interaction transparency*, *interaction environment*, *interaction result,* and *action space*. The collaboration process of the work system's agents takes place in an environment (i.e., the surroundings and setting of the collaboration as well as the external factors which influence the human's and the intelligent agent's task fulfillment) (Alter, 2013). To that end, work systems of human and intelligent agents' may be subject to specific social or cultural influences from the environment, e.g., as humans may even fear AI-powered intelligent agents (Jöhnk et al., 2021).

5.2 The framework's dynamic components

Within a work system, there can be multiple moving tasks, and tasks might even accumulate or be forgotten. Next to the structural components, the framework also comprises four dynamic components to capture the moving of tasks: task processing, delegation, communication, and collaboration strategy.

Task processing requires an agent to perform activities. The task processing dynamic of the framework is based on the dimensions *interaction impulse*, *interaction result*, *collaboration strategy*, and *turn taking* of the literature review. With agents performing activities, the task's state will proceed. The task processing dynamic of our framework is based on our task-centered approach and is not covered in existing frameworks such as Hinsen et al. (2022). Further, the collaboration strategy defines the collaboration mode of the work system's collaborating agents (Yang et al., 2022). Either a human or an intelligent agent can initiate a task (Hinsen et al., 2022). This also implies that the agent creating a task must not necessarily process the task. The agent might split or merge tasks and, therefore, logically disconnect or connect activities. Due to intelligent agents' independent control and autonomous decision-making ability, they can process tasks without human intervention (Siemon and Wank, 2021).

Besides task processing, we also consider **delegation** as a key dynamic component of our framework, based on the insights from the dimensions *delegation* and *collaboration control* of the literature review**.** Our framework allows both the human and intelligent agent to initiate a collaboration and, thus, also delegate tasks. As defined in the section above, delegation happens via task repositories. Our framework explicitly not only considers delegation from human to intelligent agents, but also from intelligent to human agents. Thereby we incorporate recent discussions on delegation reversal (Baird and Maruping, 2021; Demetis and Lee, 2018). Baird and Maruping (2021) proposed three mechanisms that explain the delegation process: appraisal (agent's assessment of another agent's capabilities, complementarities, and compatibility), distribution (transferring rights and responsibilities, negotiation, and regulation), and coordination (managing the delegation relationship and actions to achieve the objectives).

Communication allows for exchanging information between agents in any form and direction. This concept is based on the dimensions *action channel*, *action direction, interaction frequency*, *action frequency*, and *interaction impulse*. Information is a central component of work systems and plays a key role in task processing (Alter, 2013), making communication of information central to agents' collaboration. In contrast to individual interactions between human and intelligent agents as described by Hinsen et al. (2022), in task-oriented collaboration the communication can span across multiple interactions of agents. This allows information exchange between agents beyond single interactions and therefore enables collaboration (Mukherjee et al., 2022). Recent developments of LLMs being able to keep track of context across interactions represent a good example.

5.3 Outlook on task-centered collaboration of human and intelligent agents

We sought to build a theoretical framework to set the identified dimensions into relation with each other. Therefore, the framework represents an initial effort of theorizing on the collaboration of human and intelligent agents. It helps us understand the peculiarities and design choices of task-centered collaboration of human and intelligent agents in work systems. To that end, one could use our framework's components to model and describe one's specific work system constellation. We deem it promising to model and study the collaboration of human and intelligent agents in work systems of varying contexts, ranging from one-to-one collaboration to complex networks comprising multiple different agents and multilateral collaboration. We hypothesize that issues and design requirements for collaboration of human and intelligent agents in work systems depend on the context's specific constellations and, thus, require a precise understanding of the considered instantiation collaboration. The components of our framework can provide such a precise understanding. In future research, we intend to build on these theoretical insights to develop a practical modelling tool. Exemplary topics, where such a modeling tool might be useful, provide the motivation for further research:

- Research may investigate how false information cascades along processes and across department boundaries in an organization. E.g., ChatGPT may be used to generate a text which is subsequently passed to another department that is unaware of the text's origin and potential faultiness.
- Task dependencies may have a largely different impact on huge work systems, compared to settings where only two agents collaborate. Research may investigate how such dependencies are impacting the collaboration of human and intelligent agents, and how they differ across work system setups.
- Scholars might study which team roles are relevant for the collaboration of human and intelligent agents in different work systems, and whether or how the roles are changing depending on aspects such as the scale or the environment of the work system.
- Researchers may explore how to purposefully decide where in a team's processes different agents are collaborating, such that their strengths complement each other, and technostress is minimized.

The literature on work systems also outlines potential for further research. Besides the central components of collaboration that we included in the framework so far (agents, tasks, task repositories, and environment), work systems theory comprises further components. These include, for example, customers, infrastructure, and strategies (Alter, 2013). While we have not considered these components thus far, in the pursuit of extending our framework, we seek to also study and contextualize these components. Besides that, the feedback from presenting our framework at a symposium made us curious to extend our framework regarding the following aspects: How to model individual and organizational learning from intelligent agents? How to model that employees do not only communicate with intelligent agents but develop and train them? How to model collaboration of human and intelligent agents beyond the work system or corporate boundaries? What happens if a totally autonomous work system tries to collaborate with other (not automated) work systems? We see it as a strength that our framework and the research perspective do not lead to a dead end but offer a solid foundation to be extended.

6 Conclusion

We aimed to increase the understanding of the collaboration of human and intelligent agents in work systems. We did so using a systematic literature review resulting in 16 dimensions that are relevant to describe and design collaboration between human and intelligent agents. Further, we propose a framework that sets these dimensions into relation to each other in the context of work system theory.

Our contribution is twofold. First, the 16 identified dimensions represent a contribution to the knowledge base on the collaboration of human and intelligent agents. We extend the dimensions of interaction by Hinsen et al. (2022) with task-centered insights on collaboration. We build on existing knowledge on human-AI interaction and contribute task-centered dimensions of collaboration. Second, using these dimensions, we propose a framework that provides a structured conceptualization of the collaboration of human and intelligent agents by building on the concept of work systems as the setting in which the collaboration is placed. The framework sets the dimensions into relation to each other, and represents an initial effort of theorizing on the collaboration of human and intelligent agents. The framework in its current form represents a mainly theoretical contribution by structuring the relevant dimensions of the collaboration of human and intelligent agents in work systems. It reveals parameters and dependencies to consider when analyzing or designing work systems that leverage collaboration of human and intelligent agents. It may provide a basis for developing a practice-oriented modelling tool in the future that facilitates communicating the structure of work systems leveraging collaboration with intelligent agents and identify as well as explain emerging issues. In its current form, e.g., enterprise architects or

AI strategy consultants could use our framework's components to describe and communicate specific work system constellations that they are designing. Such descriptions are always a composition of our framework's components: agents, tasks, task repositories, and the environment encompassing the work system. A future modelling tool could facilitate this by adding visual representations of the components.

However, our paper comes with some limitations. First, we limited our literature search to three relevant databases. In the future, we seek to extend our literature review by insights from further databases (e.g., Scopus, JSTOR). However, we followed widely accepted recommendations (vom Brocke et al., 2009; vom Brocke et al., 2015; Webster and Watson, 2002) to rigorously conduct the literature review. Thus, we are confident to have covered all relevant aspects of the literature. Second, while we built on a framework rooted in the HCI literature, our literature search did not explicitly include HCI search terms. Therefore, in a further development of our framework, we seek to expand our search term. Third, the identification of collaboration aspects solely relied on academic literature. We assume that empirical data (e.g., qualitative interventions in the industry or interviews with experts and practitioners) will allow us to add additional aspects to consider. We see the aspects identified from HRI literature as a good starting point for discussing the current version of the framework. Fourth, our understanding of intelligent agents is somewhat ahead of the current technological state of the art. Today's IS and AI applications in productive work systems are still limited in their abilities below what we would consider a full-fledged intelligent agent. Nevertheless, we are convinced that following the theoretical discourse on intelligent agents is the right decision to contribute a framework that adds to a cumulative research tradition.

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