Systems Thinking in Human-Computer Interaction

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Abstract

This position paper outlines the extent that systems thinking is present in Human-Computer Interaction (HCI) research and practice through different forms of feedback loops in it, and how systems thinking could be used in HCI more explicitly in the future research and practice to address the complexities of the design and use of modern interactive computing systems in the socio-technical landscape. While the HCI as a field is inherently multidisciplinary, the traditional HCI approaches and paradigms often focus on optimizing specific aspects of human-computer interaction, overlooking the interdependencies and systemic feedback loops that arise from these individual interactions and from the HCI field as a whole. Systems thinking, with its holistic and multidisciplinary perspective, could help to better understand and design human-technology interactions now and in the future. Systems thinking has potential to improve HCI research and practice, providing a more comprehensive and effective approach for designing interactive systems that meet the constantly evolving technologies, needs of users and the new socio-technical challenges.

Keywords

Socio-Technical Systems, Human-Computer Interaction, Systems Thinking, Feedback loops

1. Introduction

This position paper explores systems thinking in Human-Computer Interaction (HCI). HCI is a scientific and practical discipline that designs, studies, encapsulates and theorizes the rich interactions between users, information technology systems, and contexts of use in personal and organizational levels. The development of these interactions and the related research and practice has implications on the socio-technical level and can shape society at large. HCI has different levels of analysis in human-technology interaction, it utilizes different theoretical frameworks, theories, practices, and paradigms from other disciplines, it cooperates with other academic disciplines to study human-technology interaction, and crosses the disciplinary boundaries and contributes to other disciplines. HCI is the most human-oriented discipline within the Information and Communication Technology (ICT) field [36].

HCI studies and conceptualizes the relationships and interconnections between individuals, practices, organizations and different contexts in which they use ICT technologies to augment their capabilities as part of their everyday work and life to achieve their goals and intentions. Because HCI is a relatively young discipline, it has benefited from developing, expanding and evolving together with technological advances and other disciplines in the ICT field. HCI is by nature very flexible, and it has been drawing concepts, theoretical lenses and paradigms very conveniently from other disciplines, such as social sciences, philosophy, computer science, cultural anthropology, and engineering, among many others.

The socio-technical systems approach focuses on reaching a common goal between the social systems and the technical systems that are interacting with each other [4]. These common goals cannot be reached if the interactions between individual users and the technologies that they are using are not designed well [26]. The socio-technical HCI focuses on balanced and innovative relations and interactions between users, tasks, technology, and organization [7]. Some studies

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have argued that the very concept of usability in HCI could be a useful lens through which interactions at all levels of socio-technical systems could be observed in a more holistic way [34]. Usability is one of the central concepts in HCI [34]. Usability can be seen as a way to simplify the complexity of systems, and to save different resources of different stakeholders (e.g. energy, user time, development time, cognitive resources, user actions, etc.).

HCI is a complex and multifaceted field, and while the interaction between users and technology may seem easy, in reality there are many different aspects that make designing and studying this human-technology interaction very difficult. Humans use their senses to get information from the system and use their body to create inputs in order to make the system react in a way that will help humans to achieve something. Humans can interact with many different kinds of technologies, ranging from traditional computers to mobile devices, wearables, gaming devices, physical devices, and many others. Furthermore, humans can interact with technology through many different input/output modalities, such as through traditional display and computer peripherals, touchscreen, voice, natural language, eye tracking, etc. Also, humans can interact with technology for many different purposes, such as to process information, to solve problems, for fun, etc. Furthermore, there complexity of the ICT systems can vary from the simplest mobile application to complex computer games and information systems.

Therefore, HCI is a complex problem by nature. Studying and understanding humans is difficult, and the focus on HCI research and practice is often on the technologies that these humans will be using. However, the users don't know about the technologies behind the user interface, and they don't really care about the technological side of the systems that they are using. For users, the user interface that they are interacting with is the representation of the system, no matter what technologies are used behind the scenes. It can also be argued that without the user the technology would be meaningless, so HCI research and practice should focus on humans, technology, and their interactions. However, humans are complex and unpredictable, having different requirements, backgrounds, mental models and might not always act in rational or optimal ways. Because the design and use of systems are separate, the designers do not know the users inherently. Therefore, more often than not, the HCI problems are found only when the design is used by real users for real purposes in real contexts of use, when it is too late to do any meaningful redesign.

The study of users is central to HCI. Technology itself is not as important as how users use technology and how they perceive, process, and respond to information presented by technology. Humans and computers/technology are systems that exchange information, using time and energy to achieve something, which usually involves creating new information. The HCI also examines cognitive workload, decision-making, and the adaptation of interfaces to support user needs and contexts [13, 19, 21].

Therefore, in theory HCI helps humans to augment their capabilities through technology, but in practice designing the technology so that it will help the users rather than hinder them has always been a challenge since the dawn of the computing age. Humans still waste time and energy trying to achieve something using technological means but too often they encounter badly designed systems that are not suitable for their needs [37].

Human-Computer Interaction (HCI) has evolved over time into a multi- and even transdisciplinary discipline that examines the dynamics between users and technological systems [36]. This fast-paced evolution has been driven by the need to enhance usability and accessibility, ensuring that technology serves human capabilities and needs rather than being a barrier. HCI is flexible, iterative and exploratory, freely influenced by and borrowing from other disciplines, such as psychology, engineering, ergonomics, ethnography, and many others. Concepts, frameworks, theoretical lenses, processes and other concepts are borrowed from other disciplines and adapted to the requirements of HCI to fit best into reality. This multidisciplinary, open, flexible and exploratory attitude, rather than focusing on the technology, has made it possible for HCI researchers and practitioners to create more intuitive and effective user interfaces that can cater to diverse user needs, no matter the technological advances and other complexities. As technology and computing has become more integrated into daily lives, HCI research addresses not only the

technical aspects of interface design but also the cognitive, emotional, and social dimensions of user experience [1, 29, 32].

To address these complexities, HCI researchers have developed countless frameworks, models and theoretical lenses, but often these focus on individual contexts or problems, rather than having a holistic approach. The engineering approach for these kind of problems would be to try to split them into smaller, more manageable blocks. However, in HCI such smaller blocks or more siloed perspectives, such as individual tasks, goals or user interface elements, do not make any sense alone from the perspectives of users or designers. Beyond these individual elements, there are the mental models, expectations, tasks and goals of the users. Furthermore, there are technological, organizational, social, and physical contexts of use.

The act of design is defined as choosing from possible future ways of how a user will interact with the system. This act of choosing between possible alternatives puts the responsibility of the result of this design act and its outcome firmly on the designer [5]. Therefore, designing human-technology interactions of socio-technical systems also involves ethical aspects [37]. The risks of design activity and the ethical implications of research and the ethical and moral responsibility of the designers and researchers have been highlighted in the literature (see, e.g. [31, 37]). The literature also discusses the complexities of design and how the implications of new technologies and designs should be discussed before their deployment, rather than after their deployment [42].

The designers of human-technology interactions in socio-technical context are professionally and ethically responsible towards the users and other stakeholders, companies and other organizations, society in general, and environment and sustainability. Such a complex and holistic responsibility is very difficult to address from the disciplinary-oriented and problem-oriented viewpoints of HCI practitioners and researchers.

Further complicating the ethical dimension in HCI is the rapid emergence of dark designs in our everyday life. These developments show that HCI cannot focus only on optimization of individual aspects of human-technology interaction, but must also address ethics of design, designer responsibility and dark design [37]. In order to address these complex issues that require breaking the boundaries of disciplines, HCI must adopt approaches, theories, concepts and methods from other disciplines, such as from ethics and philosophy [37].

Therefore, the HCI as a whole is a collection of many parts and aspects that are interconnected to each other in a complex way where the whole is greater than the sum of its parts. As ICT systems themselves have become more complex and interconnected, utilizing new input/output modalities, and new technologies (e.g. AI) and design issues (e.g. ethics of design, raise of dark design) have emerged, there is a need to adopt a more holistic and systemic approach for understanding and designing human-technology interactions. One such more holistic and systemic approach could be systems thinking. Therefore, we next outline the concept of system and systems thinking.

2. Systems thinking

A system is a set of interacting units with relationships among them [24, 27]. The boundary of the system separates the system inside the boundary from everything that is outside this boundary and this system [27]. Interdisciplinary systems thinking sees the environment as a composite of interrelated systems [27]. The borders of different disciplines are crossed to make more creative and effective research work, while still valuing the conventional disciplinary research work [27].

Feedback control is one of the key concepts of systems [27]. A simple example of feedback control system is a thermostat that controls the temperature of a heater [28]. A more complex example of a feedback loop in a system is driving a car [11]. The drivers observe the environment outside the car and the dials inside the car with their senses and control the car with their hands and feet using different controls in the car [27]. Learning to drive a car takes some time and effort, because of all these complexities. Over time, the driver gains experience and learns to react to

different kinds of feedback even without thinking, having developed a semi-automatic feedback loop for driving.

Systems thinking is a form of philosophical thinking that is a product of the last century [18, 27, 38]. It emerged as a result of the identified fragmentation of the science as a natural result for the need to have a narrow focus on the research due to ever increasing amount of scientific literature that was needed to be learned to be able to conduct research on a specific field [27]. Systems thinking focuses on solving complex problems that are beyond the scope of traditional scientific disciplines that are often siloed. Systems thinking has been applied to different disciplines and fields. For example, there have been studies that have advocated systems thinking as means for a more holistic approach in the context of different disciplines, such as in science education [30].

Systems thinking produces system archetypes and one of the most important archetypes is feedback through positive and negative feedback loops, as well as control loops [27]. They govern how systems behave, adapt, and self-regulate, and they enable systems to respond to changes inside and outside of their systems and to maintain stability, depending on the type of feedback [25, 43]. Positive feedback loops amplify changes within a system, leading to exponential growth or decline [25]. Negative feedback loops counteract changes and promote stability and equilibrium [25]. Systems and their behavior can be designed, observed, and theorized through these feedback loops. Next, we outline the different forms of feedback loops that are inherent in HCI. By examining these feedback loops, we can assess the extent to which this particular system archetype exists in HCI at different levels.

3. Human-in-the-loop: Systems thinking in HCI

There have been some recent research using a form of systems-theoretical perspective in HCI to highlight the importance of feedback and to foster designs that accommodate both humans and technological agents [3]. This research identifies the systems-theoretical perspective as useful for applications in autonomous robotics, human-in-the-loop decision making, and hybrid intelligence systems. Human autonomy and integration of humans and technological agents is crucial for effective collaboration and emergent behavior [3].

Other papers that have addressed the feedback loops in HCI in some way have identified the feedback loop between user and technology as the basis of computer-human interaction, identifying this interaction as a self-correcting feedback loop and a cybernetic system [12, 35] or applied the optimal feedback control theory in the HCI context, modeling human and computer as a single dynamical system with feedback-driven adaptation [15]. Conceptualizing usability through cybernetics perspective and as a feedback loop on the conceptual level has been identified as a potential answer to the calls for new, contemporary and open perspectives [35].

However, while HCI research has identified some potential feedback loops in HCI at different levels, as well as possible benefits of exploring them further and using them in HCI research and practice, these feedback loops in HCI have not been outlined or systematically studied so far from the systems thinking perspective.

The largest feedback loop in HCI consists of the whole HCI as a discipline., which has been continually evolving to address new challenges, including technological advances, ethical considerations, accessibility, and the impact of computing on society, aiming to create interactive systems that are effective, inclusive, and responsive to the complexities of human life [10, 29, 41]. This constant evolution of HCI as a discipline through changes in technology, use of technology, society, scientific paradigms and needs of the ICT industry, where the research and practice are in constant interaction to produce and test new paradigms, concepts and methods, has been identified as a cybernetic feedback loop [35]. This is the largest feedback loop in HCI, encompassing the whole discipline and its evolutionary development.

There is also a dedicated feedback loop identified between HCI research and practice [10]. In this feedback loop, the ideas and theories emerging in the research are in constant interaction with results from practice where these ideas and theories have been tried in practice [10]. In HCI, these

feedback loops encompassing the HCI as a field and the HCI research and practice leads to the survival of the most fit design solutions, theories, concepts, methods, etc. For example, HCI methods that have been found useful, such as usability testing, have become widespread in both research in practice, while less useful methods and concepts have disappeared into obscurity.

Mental models of the users is one form of feedback loop that exists in HCI on individual level. Humans develop and use mental models as internal representations of the external world, in order to save cognitive resources. These mental models are a cognitive structure that forms the basis of reasoning, decision making, and behavior, and provide a mechanism through which we filter and store new information. Mental models are constructed by individuals based on their personal experiences, perceptions, and understanding of the world around them. The concept of schema by Piaget is similar to mental models and often considered to be the precursor to them. Piaget defines schema as a unit of understanding in the context of learning, where organized patterns of behavior, planned action or thought are formed based on previous experiences. Schemas adopt new ideas or concepts through assimilation. Mental models are often difficult to change, so sudden changes in user interfaces and input/output modalities can result difficulties for users, when they try to update their mental models.

Usability testing is another form of feedback loop that exists in HCI on a practical level. It refers to the process of intentionally observing potential users as they interact with a systems prototype before it is fully developed and launched [10]. These observations feed into design, and the resulting redesign is then further tested with potential users. Ideally, this iterative and incremental loop will continue until the design of the system meets the requirements of the users, and the users can use this system with effectiveness, efficiency, and satisfaction. Usability testing emerged and gained popularity when the theoretical models of user-computer interaction failed to provide practical design guidelines for HCI practitioners.

Another practical level feedback loop in HCI is found in the different levels of user-technology interaction [37]. In this feedback loop, user interface design, usability design, user experience design and service design form a hierarchical, incremental and iterative framework, where the design decisions made in one level introduce changes to the design in other levels [37]. Often the HCI researchers and practitioners focus on just one level of user-technology interaction.

Organization-Information System feedback loop is an organizational level feedback loop in HCI. In this feedback loop, an organizational information system is in constant input/output loop with organization and its needs, as well as with the competitive, economical and legislative environment of the organization, as well as with different stakeholders [20]. Information systems (IS) design, Scandinavian information systems tradition and participatory design have had a great impact on HCI. Scandinavian IS tradition emphasizes progressive IS evolution, user participation, anti positivism, action-oriented research approaches and innovative theoretical foundations for IS [17]. Participatory design highlights the importance of addressing the social and technological needs of the users when creating IS and speaks for user participation and agency during IS design and development [26]. While personal and entertainment computing have become dominant in the ICT sector, IS design is still the backbone of organizations on local, national and global levels.

Next, we outline how taking into account the systems thinking in general and these feedback loops in particular could help to the HCI researchers and practitioners to better theorize, design and observe the human-technology interactions.

4. Potential benefits of Systems Thinking in HCI

As outlined above, HCI has inherent feedback loops on many levels: in HCI as a discipline, in HCI research and practice, in organizational level, between different user-technology interaction levels, in user-technology interaction, in mental models. Therefore, HCI as a discipline has already manifestations of one of the archetypes from systems thinking and it can be argued that more explicit focus on systems thinking could help HCI research and practice in many ways. Further

theoretical and empirical research is of course needed, but there are some potential benefits that systems thinking could bring to HCI.

Systems thinking, with its emphasis on interconnections, interdependencies, and feedback loops, could offer a more holistic framework for addressing the challenges and opportunities in the HCI in the evolving socio-technical landscape of the future. By applying systems thinking more explicitly, researchers and designers of human-technology systems could be able more easily move beyond the optimization of individual human-computer interaction components to consider the broader context and dynamic behaviors of interactive systems in the wider socio-technical landscape.

Furthermore, systems thinking could be useful for helping to design new technologies with interaction opportunities that are usable, resilient, adaptive, and aligned with human values, ethics, and goals. Building upon this systems thinking approach, HCI researchers could better explore the different HCI concepts and their interconnections, such as for example user cognition, interface aesthetics, and technological capabilities. By mapping these relationships through systems thinking, researchers could better understand the bigger picture of HCI as a field and create better theories, framework and methods to support the HCI practitioners. This holistic perspective could also allow the consideration of contextual factors, such as cultural influences, ethical and environmental issues, which may have large effects on how users interact with technology, how designers design these technologies and how the HCI research study the design and use of these technologies.

The application of systems thinking in HCI could facilitate the development of more resilient and adaptive interfaces. By understanding the system as a whole, designers could anticipate potential issues and create interfaces that are able to handle unexpected user inputs, changing user requirements or emerging societal needs. This holistic approach could also eventually evolve into the integration of further feedback mechanisms in ICT systems that would allow the system to learn and evolve based on user interactions, therefore leading to systems and interfaces that would become increasingly intuitive and personalized over time. There have been calls for adaptive user interfaces and personalized systems to better support individual users (see, e.g. [6, 33]).

Systems thinking could offer a holistic lens for understanding, researching, designing and evaluating Human-Computer Interaction (HCI) by viewing interactions as part of complex, dynamic systems rather than isolated user-interface events. As technology evolves, HCI must keep pace with technological evolution. For example, adopting a systems-theoretical perspective could better support the integration of autonomous and collaborative systems into everyday life, supporting both structured cooperation and emergent behaviors in interactive environments [3]. This could help HCI research to better address the future challenges presented by the growing complexity and adaptability of modern interactive technologies [3, 40].

Understanding and optimizing the complex relationships between humans, computers, and their environments is a challenge in HCI research and practice, where systems thinking could help future HCI research and practice. By considering entire systems and feedback loops within systems and between systems, rather than focusing on isolated components in interaction, HCI researchers could help HCI practitioners to create more adaptive, effective, and user-centered interactive systems.

Systems thinking could help HCI practitioners to identify easier the optimal level of automation and human involvement [22, 23]. Ideally, humans and computers should act as collaborating partners, rather than being locked in rigid roles and fighting for agency. Furthermore, applying systems thinking might support the design of human-in-the-loop interactions, especially in complex or unstructured environments, such as humans interacting with AI. Systems thinking might also help to ensure that technology leverages human strengths while providing appropriate support through the strengths of technology [16]. This might result in more natural, error-free, understandable, efficient and effective collaborations between humans and cutting-edge technologies.

While it is relatively easy to address individual goals when designing humen-technology interactions, these individual goals might be contradictory or conflicting. Systems thinking could encourage the HCI researchers and practitioners to identify and directly address potentially conflicting goals, such as maximizing the usability while minimizing the security concerns by conceptualizing and reflecting on the broader impacts of design choices. This could lead to more usable, satisfying, and adaptable interactive systems [16, 23].

Systems thinking could help the HCI researchers and practitioners to study, theorize, design and evaluate next-generation technologies, for example Human-AI interaction and sustainable, ethical sociotechnical systems (see, e.g. [3]). It could help with the integration of user-centered, participatory, and ethical design practices and ensure that interactive systems are adaptable, transparent, and aligned with human values, universal ethics and organizational goals (see, e.g. [8, 39, 41]).

By adopting systems thinking, HCI research and design could better address the increasing complexities of modern information systems, such as those found in decision support, command and control, and other kinds of intelligent systems [13, 21, 44]. Systems thinking might also help to integrate different emergent cognitive, organizational, and technological factors that have been complex and challenging for HCI research and practice (see, e.g. [13, 21, 40]).

By recognizing interdependencies within and between different systems in HCI, systems thinking could allow user centered design to better address how changes in one part of the system (e.g., on user interface, usability, user experience or service design level) can have an effect on other interactions levels and other aspects of the human-technology interaction (e.g., learnability, user motivation, organizational workflow). This approach might help the HCI researchers and practitioners to overcome common boundaries and obstacles in the complexity of HCI that can limit the effectiveness of traditional user-centered models and methods [14, 45].

Furthermore, systems thinking could help the HCI practitioners to identify the key points in design, namely the areas in the human-technology interface where design changes can have the greatest positive impact on usability and user experience [2, 14]. It could also help the designers to better balance user needs with broader goals of the ICT system and organization using it, such as efficiency, scalability, and security.

5. Conclusions

This position paper has explored the systemic challenges in HCI research and practice, the extent that HCI as a discipline has already one form of archetype from systems thinking, namely feedback loops at different levels, and the possible benefits of further integrating systems thinking in HCI. This position paper argues that by embracing a systems perspective, HCI researchers and practitioners could better address the complexities of modern technology use, from individual user experiences to societal impacts, ethics and prevention of dark designs.

However, this position paper is just one small step, and further theoretical and empirical research is definitely needed. For example, there are also other archetypes in systems thinking and also these should be explored, adapted and used in HCI context, if possible. Other archetypes in systems thinking include hierarchy and modularity, optimization and decision-making, and degree of centralization [27]. System theories and archetypes are the grammar of system thinkers [27]. Therefore, by exploring the existing system theories and archetypes in HCI, adapting them to HCI context and building on them, HCI researchers and practitioners could create a more holistic understanding of HCI as a discipline. Furthermore, HCI researchers could create better theories, frameworks, concepts and methods based on this holistic understanding. Therefore, it can be argued that HCI could benefit from exploring, adapting and using the grammar of system thinkers.

One of the limitations of this position paper is that there might be additional feedback loops in HCI that have not yet been identified. However, the numerous inherent feedback loops that have been identified in HCI so far should make applying systems thinking in HCI research and practice easier than in other, more siloed and rigid scientific disciplines.

Hopefully this position paper will further invigorate the discussion and research of the role and possibilities of systems thinking in HCI and in the design of socio-technical systems.

Declaration on Generative AI

The author(s) have not employed any Generative AI tools.

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