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## HCI Research and Innovation in China: A 10-Year Perspective

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### ABSTRACT

In the past years, human computer interaction (HCI) research and innovation have developed substantially, leading to a number of fruitful research topics. In this paper, we surveyed the HCI research and innovation in China from a 10-year perspective. We analyzed the popular research methodology and topics among Chinese researchers, including human modeling, user interface techniques, context awareness, user acceptance and performance, user experience design, human-AI interaction, HCI applications and social influences. We also conducted a bibliography analysis on the published papers in top-tier conferences and journals, which revealed a significant rising trend, and a generally broad distribution of research types. Moreover, we described typical applications and the industry influence of the research outcomes. We concluded with implications and reflections for HCI researchers across the world and shared the future research trends envisioned by Chinese researchers.

### KEYWORDS

Human computer interaction; research and innovation; survey; China

## 1. Introduction

Human Computer Interaction (HCI) explores the information exchange between humans and computers, with the aim to understand people and design highly efficient and user-friendly techniques, which is a significant and attractive research field in computer science. Since the first ACM CHI (Conference on Human Factors in Computing Systems) conference sponsored by the ACM Special Interest Group on Computer-Human Interaction (SIGCHI) was held in the United States in 1982 ACM CHI history (2022), this conference has been held in several cities in the United States, Canada, the Netherlands and other countries, promoting researchers across the world to share their works and collaborate with each other. Nowadays, the research outcomes have been applied to numerous kinds of products (e.g., smartphones Harrison et al. (2011), tabletops MacKenzie and Buxton (1992), wearable devices X. Xu, Gong, et al. (2022)) and scenarios (e.g., smart home Qin et al. (2021), office Sinha et al. (2001), virtual/augmented reality Orts-Escolano et al. (2016)), significantly affecting both industrial development and the experience of daily living.

Due to the interdisciplinarity of the HCI research field, researchers with backgrounds in computer science, psychology, design, social science, physiology and more could all

make substantial contributions. Meanwhile, with the close connection between the research outcomes and real products, a number of end-user product companies across the world (e.g., Apple, Microsoft, Huawei) have invested a huge amount of effort in promoting research in related fields Wobbrock et al. (2009). Among all the countries, China has become one that should be especially paid attention to.

China is the country with the second largest population in the world, which brings one of the largest amount of users and potential researchers. There are also a number of world-affecting end-user companies in China (e.g., Huawei, Xiaomi, and OPPO). This broad foundation brings huge opportunities for HCI research and innovation in China. Also, due to the large variety of users and the world influence of Chinese companies, research outcomes in China are also important and valuable for researchers and practitioners in other countries.

Compared with the United States and Europe, the development of HCI research in China started later but exhibited a fast-rising trend. For example, the first ACM CHI publication from Chinese researchers was in the year of 2006 (CHI'06) H. Jiang et al. (2006). In comparison, Chinese researchers published 42 CHI papers in year 2022.<sup>1</sup> Furthermore, Chinese scholars have published a substantial number of HCI related articles in a diverse range of academic journals,

including psychology, ergonomics, transportation, management, etc. By analyzing the reasons behind the rapid development of the HCI research field in China, we expected to provide valuable implications and experience for researchers in a broader range.

In this paper, we surveyed the development of both Micro-HCI and Macro-HCI research and innovations in China in the past 10 years and analyzed the popular research methodology and topics by Chinese researchers. The past 10 year was the time that Chinese HCI researches rise at the fastest speed. Since the holding of the Ubicomp 2011 conference in Beijing, a large variety of research topics have grown in this time period. By analyzing this, we grouped the corresponding research into seven major categories: understanding and modeling humans, user interface techniques, context awareness, user acceptance and performance, user experience design, human-AI interaction, HCI applications and social influences. We also explained the detailed research topics within these categories and introduced representative research works.

We utilized a “hybrid” method to examine the representative HCI research authored by Chinese researchers. Specifically, we conducted a qualitative analysis to review representative research for aforementioned seven categories under Micro-HCI and Macro-HCI area. Additionally, we conducted a quantitative bibliography analysis on the publication statistics of China’s HCI research from 2013 to 2023 in top-tier venues which mostly focus on Micro-HCI research. Furthermore, we also reported the application of the research outcomes in the field of industry, in the form of both start-up companies and company-college collaborations.

Finally, based on the survey results, we drew conclusions on the reasoning behind the development of HCI research and innovation in China, which also shed light on the implications and reflections of HCI research in other countries. We also analyzed the opportunities in the future trend of Chinese HCI research, with the hope to promote a closer connection between researchers and practitioners in the corresponding field across the world.

## 2. Research topics

### 2.1. Overview

In the field of Human-Computer Interaction (HCI), research can be categorized into Micro-HCI and Macro-HCI, as

proposed by Shneiderman (T. Bi et al., 2019). Chinese researchers have made significant contributions to both Micro-HCI and Macro-HCI fields.

Both Micro-HCI and Macro-HCI entail the analysis of user behavior to enhance task and domain-specific satisfaction and efficiency. Micro-HCI focuses on the direct interaction between users and computers, emphasizing design of innovative interfaces, system implementation and validation of users guidelines for ubiquitous devices such as desktop, Web, mobile, and so on (Shneiderman, 2011). Macro-HCI, on the other hand, takes a broader perspective, exploring the impact of technology on human behavior, user experience, organizations, society and cultures.

In organizing our paper, we align with this dual categorization. The reason for this is twofold. Firstly, it allows for a comprehensive overview of HCI research, covering both the micro-level interactions and the macro-level societal implications. Secondly, it acknowledges the diverse contributions of Chinese scholars in both spheres. Our review aims to highlight these insights and underscore their importance in the overall landscape of HCI research. Additionally, the Macro-HCI field encompasses a diverse range of disciplines and research topics, exploring the interaction between technology and the human mind, behavior, social systems, and cultural contexts. Given its complex societal nature, the exploration of Macro-HCI predominantly relies on qualitative methods.

The mainstream of Chinese Micro-HCI research focused on investigating (1) the modeling of humans, (2) natural user interface, and (3) the awareness and usage of interaction context. The ultimate research goal of these three research dimensions is to optimize the interaction naturalness, which can be decomposed as the optimization of physical and mental models, interaction flow, gesture recognition, intention inference, etc. Figure 1 showed a unified computation model and representation of the three research dimensions, indicating their relations and contributions to the goal of interaction naturalness. Such a model and its decomposition are grounded on and complementary to the classical GOMS task model (Kieras, 1988) in HCI by extending its generalization capability in dealing with the emerging heterogeneous interaction scenarios (e.g., AIoT and VR/AR) and multi-modality interaction channels (e.g., gesture-based, voice-based, and tangible, as shown in Figure 2).

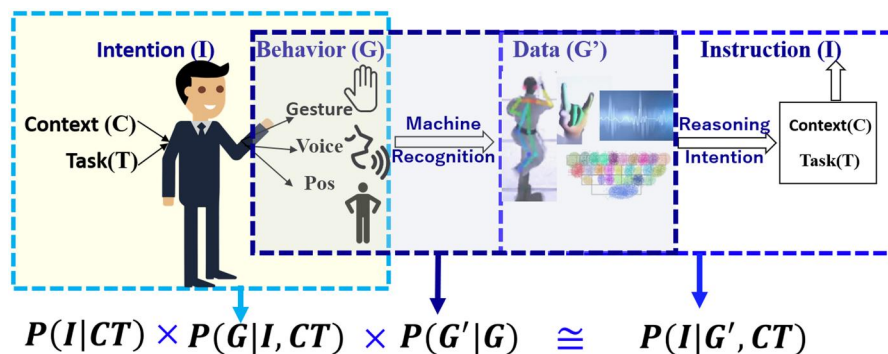
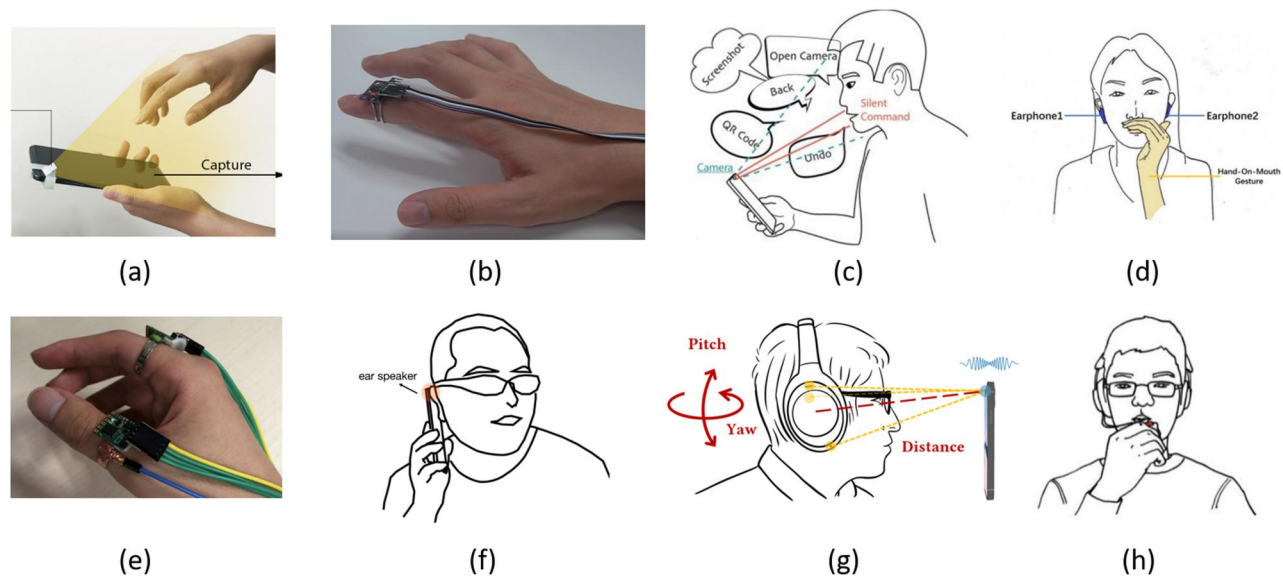


Figure 1. An overview of the Micro-HCI research framework in China.



**Figure 2.** Examples of user interface techniques presented by Chinese HCI researchers: (a) HandSee (C. Yu et al., 2019), (b) QwertyRing (Gu et al., 2020), (c) Lip-interact (K. Sun et al., 2018), (d) PrivateTalk (Y. Yan et al., 2019), (e) DualRing (C. Liang et al., 2021), (f) EarTouch (R. Wang, Yu, et al., 2019), (g) FaceOri (Y. Wang, Ding, et al. (2022)), (h) ProxiMic (Qin et al. (2021)).

From another perspective, the three research dimensions correspond to different stages where an interactive intention is expressed and processed. The relation between different stages can be modeled through probabilistic models such as Bayes theory (Oulasvirta, 2019). We identify three advantages of statistical-based (e.g., Bayesian reasoning) natural interactive intention understanding from an HCI-friendly point. First, the inference model is a “white box” with an interpretable structure so that the further study of its structure and sub-items is principled, which is helpful to produce scientific discovery and rule interpretation. Second, due to the “white box” attribute, combining prior knowledge with data is feasible and effective to build a satisfactory solution for heterogeneous computing tasks with limited data acquisition (e.g., for a prototype technique). Finally, the output of the research (e.g., behavior models, algorithms, etc.) can be generalized into knowledge that can be migrated to relevant HCI research.

The next four sections primarily focus on Macro-HCI research including (4) user acceptance and performance, (5) user experience design, (6) human-AI interaction and (7) HCI applications and social influences. Although some of the research is closely connected to the Micro-HCI techniques mentioned earlier, the subsequent research will present research topics from a more macroscopic perspective rather than the optimization of micro-level technology itself. Specifically, the research on user acceptance and performance with technology aims to understand how social and psychological factors influence users’ attitude and willingness to use new technology products. The social, management and environmental factors that influence decision-making and performance is also discussed. The user experience design is a user-centered approach for design, with a focus on understanding users experiences, behaviors, and attitudes towards products through user modeling and big data to improve product design. In addition, Chinese scholars proposed innovative theory on human-AI interaction, which clarifies

the fundamental principles governing the relationship between humans and intelligent agents (such as people-oriented, cooperation, responsibility, privacy, ethics, etc.). Lastly, we discussed the HCI applications in large industrial projects and its influences on people’s daily live. It is worth noting that Macro-HCI research are closely related with Micro-HCI techniques because social and psychological impacts of any techniques depend on the realization of techniques. In the following subsections, we illustrate the detailed research progress as well as the research trend of China’s HCI community on the above mentioned seven research dimensions.

## 2.2. Understanding and modeling human

Understanding and modeling how human processes interactive information is a very fundamental topic in HCI, which has been frequently researched by Chinese HCI researchers over the past years. An important theoretical basis for the topic is the Human Information Processing (HIP) model (Miller, 1988), which divided human information processing into three stages – perceptual processor, cognitive processor, and motor processor.

As an extension to this classical theory, Chinese researchers investigated the mechanism and the computational model of each component within the perception-cognition-motion loop for natural interaction. Specifically, the scattered research topics could be summarized into the following three aspects: (1) the understanding of perception and cognition, (2) the physiological mechanism for interaction, and (3) the modeling of natural human behavior. Below we survey the work for each aspect.

### 2.2.1. Understanding of human perception and cognition

The understanding of perception and cognition has been shed on different dimensions based on different interaction purposes. Two typical scenarios are task-oriented scenarios

and experience-oriented scenarios, which correspond to the performance and the satisfaction of interaction respectively. In task-oriented scenarios, users' mental (perception and cognitive) load, fatigue, the brain's processing time, and performance are more frequently considered and researchers have focused on modeling, measuring, and reducing the overall mental load, or the cost of perception and cognition, to facilitate natural interaction. In experience-oriented scenarios, researchers cast more attention on users' mental states, such as feelings and sentiments, aiming to find a better representation and computation model of them.

**2.2.1.1. Mental load modeling and reduction in interaction tasks.** For the evaluation of mental load in interaction, researchers have formed four-factor indicators – response speed, psychological load, attention level, and alert state – from the analysis of human factors in typical interactive situations. Aiming at the goal of minimizing mental load, researchers investigated the effect of different components in the HIP model. For example, Rau and Zheng (2020) studied users' interaction characteristics under different cognitive loads and sentiment by leveraging an in-situ approach to simulate scenarios with different cognitive and sentiment levels with multi-channel input including video and audio in virtual reality. Rau and Zheng (2019) proposed a method to evaluate the direction of attention in perception, the refactoring of memory in cognition, and the learning process based on the combination of the EEG signal, the peripheral electrical signal, and the subjective index. Results demonstrated that the total volume of cognitive resources influenced the direction and the distribution of attention while the distribution of attention could coordinate cognitive assets such as working memory.

**2.2.1.2. Affective states, emotions and moods.** Regarding the evaluation of interaction satisfaction, based on the development of the frontier theory of emotional psychology, Jia et al. (2011) extended the classical valence-arousal model to the positive-negative arousal model, which better highlights the value and significance of positive emotions in natural interaction. Hu et al. (2017) has conducted an in-depth exploration of the characteristics of positive emotions, summarized and refined ten representative positive emotions (happiness, gratitude, tranquility, interest, hope, pride, entertainment, motivation, awe, and love). They also found that the above ten positive emotions can be merged into three clusters: (awe, gratitude, hope, motivation, and pride), with the characteristics of encouraging and invigorating; (entertainment, interest, and pleasure), characterized by lightness and pleasure; and (love, tranquility), with gentle and peaceful characteristics. The behavioral and neurophysiological data show that positive emotions and negative emotional experiences can coexist relatively independently at the same time. The state with high positive and negative emotional experiences corresponds to the activation of brain regions near the midline of the forehead, which may be related to self-awareness, conflict processing and other cognitive processes.

**2.2.1.3. Cognitive state for special population.** Moreover, researchers attempted to understand the cognitive state of the special population to meet their interaction needs and facilitate their interaction experience. For example, Q. Wu, Yu, et al. (2020) proposed an auxiliary wearable system for children with autism to transfer their common knowledge (e.g., of the traffic light) into the abstracted representation of social distance, helping them communicate better with others. X. Jiang et al. (2020) investigated patients with attention deficit hyperactivity disorder (ADHD) by designing a wearable system to generate visual, audio, and haptic-based interaction to evaluate their cognition capability indifferent dimensions quantitatively.

## 2.2.2. Physiological representation of the interaction naturalness

A user's perception and cognitive state can be reflected in specific physiological signals, such as EEG (Hu et al., 2019).

Based on the development of network neuroscience theories and methods emerging in recent years, Hu et al. (2017) designed and implemented an emotion recognition algorithm based on the "micro-state" feature of the EEG spectral energy space pattern. J. Chen et al. (2018) designed and implemented a new paradigm and system for character input in spatially encoded brain-computer interface with the potential of natural interaction, aiming at the modulation effect of visual evoked potentials of visuospatial attention. Based on the individual differences in emotional EEG responses. G. Zhao, Ge, et al. (2018) designed and implemented a psychological Big-Five personality evaluation method based on emotional EEG responses, and achieved good prediction performance on the results of the self-rated personality scale with a correlation coefficient of between 0.5–0.8.

As for the measurement and recognition of the cognitive state, the researcher investigated multi-modality sensing methods based on characteristics of different neural signals. Ding et al. (2021) developed a cognitive state recognition method based on frequency energy and extended differential entropy of neural signal, achieving an accuracy of over 70% for the recognition of arousal level, positive sentiment, negative sentiment, reaction time, cognitive load, attention level, and alert level with data segment less than 1 second, which is applicable for real interaction scenarios. Based on the response consistency of neural signal under the same interaction context, (J. Li et al., 2021) designed and implemented a real-time recognition algorithm to predict group sentiment, achieving a regression R-square of 0.61 and 0.70 for real-time arousal and potency score prediction with a 1-second time window on the movie viewing data set.

## 2.2.3. Input behavior modeling

Researchers have carried out research around the action modeling of natural input behavior in different channels, including hand gestural input (Gu et al., 2019; Z. Li et al., 2023; C. Liang, Yu, Qin, et al., 2021; T. Zhang, Yi, et al., 2020; T. Zhang, Yi, et al., 2018), voice input (Qin et al.,

2021; Y. Yan et al., 2019), head and gaze input (Y. Yan et al., 2020; C. Yu et al., 2017), etc. Research topics that China's HCI community has made progress in include input on constrained user interfaces, motion modeling without visual feedback, and natural input actions with semantics.

**2.2.3.1. Input on constrained user interfaces.** With the development of various input devices and corresponding user interfaces, the need for supporting user input on constrained user interfaces have become increasingly important. By modeling the spatial and temporal features of the user input behavior under the constrain of the user interfaces, researchers were able to develop intelligent algorithms and technologies to accurately decode the input from the deformed or limited input signal. For example, X. Yi et al. (2017) investigated the touching precision and behavior on an ultra-tiny touchscreen interface. Y. Yan et al. (2020) researched the behavioral features of head-based target selection in VR under different selection mechanisms. From the temporal perspective, a typical example is force control. Zhong et al. (2018) studied the modeling of continuous force control, building a Gaussian-based pressure control model on the accuracy and resolution to facilitate the continuous imprecise pressure input in the context of text entry. X. Xu, Yu, et al. (2019) investigated the resolution and capability of controlling the clenching force as a modality of discrete-level control. Y. Wang et al. (2021) studies the spatial and temporal features of the typing behaviors on touchscreen phones of users with Parkinson's disease.

**2.2.3.2. Eyes-free interaction.** Eyes-free interaction means interaction without the feedback or attention of visual information, which is an important method to reduce the mental load. Y. Yan, Yu, Ma, Huang, et al. (2018) studied the blind target acquisition ability in virtual reality, and carried out systematic research on the human proprioceptive ability. Y. Lu et al. (2017) explored users' behavior for one-handed eyes-free typing and validated the hypothesis that users can transfer their typing ability obtained from visible keyboards to eyes-free ones. Z. Xu, Wong, et al. (2019) investigated eyes-free tapping behavior and the spatial resolution on the micro fingertip surface.

**2.2.3.3. Gesture with semantics.** Gestures aligned with semantics can be beneficial for memorability and naturalness. Researchers have investigated the design and evaluation of natural body gestures with certain semantic implications. For example, Y. Lu et al. (2020) studied the design and interaction space of hand-to-hand gestures by representing them with gesture semantics such as touching positions and the touching type and evaluating them regarding their naturalness and disambiguity. Y. Yan, Yu, Ma, Yi, et al. (2018) studied semantic target selection gestures in virtual reality that mapped different gestures of holding different objects to distinguish different targets. Z. Li et al. (2023) explored voice-accompanying hand-to-face gestures to enhance natural voice interaction. This method conveys additional semantic information, crucial for indicating states

like wake-up readiness and input modality preferences. This approach aims to make voice interactions more intuitive and contextually rich.

**2.2.3.4. Interaction with moving targets.** Dynamic user interfaces have become more and more pervasive in our daily lives, including the change of UI layout and the moving of the targets (e.g., in virtual reality and on touchscreen devices). Different from interacting with static targets, this would bring difficulty for the users to accurately point at the targets, resulting in lower input speed and accuracy. To overcome these problems, J. Huang et al. (2018) first proposed the moving target selection framework based on Optimal Feedback Control theory in 2018, validating the efficacy of the framework in simulating the trajectory and variability of user movements. The proposed framework has since rapidly developed into a theoretical system covering high-dimensional spaces (J. Huang, Tian, et al., 2019; J. Huang et al., 2022) and time dimensions (J. Huang & Lee, 2019), considering the influence of speed, angle and size of targets (J. Huang, Tian, et al., 2020; H. Zhang, Huang, et al., 2023; Z. Zhang, Huang, et al., 2020), the effects of multi-modal stimulation (Y. Li et al., 2019), user movement ability and posture (Y. Zheng et al., 2021), and the emotional states of user (J. Huang, Peng, et al., 2020).

## 2.3. User interface techniques

The user interface is the media between human-machine information exchange. The very fundamental question of how to build efficient human-computer interfaces is promoted by the understanding of human motion control and information processing capability (e.g., the HIP model). The emerging ubiquitous computing techniques (such as wearable sensing, WIFI sensing, etc.) and scenarios (e.g., VR/AR, IoT) have brought new challenges and opportunities for new forms of human-computer interface. The next generation of user interfaces envisions the user's capability to interact with environmentally-distributed devices with unrestricted, unstructured, and natural behavior (e.g., voice and gestures). Such an interface paradigm emphasizes the naturalness and the always-availability from the human side, which is significantly different from the traditional graphic user interface. During the past years, Chinese HCI researchers have made contributions to the promotion of the next generation user interface techniques. Below we introduced the progress.

### 2.3.1. Natural input channels

The input channel of a user interface illustrates what input behavior the user is expected to perform and how the interface senses the user's behavior and parses it into the machine instructions. From the stand of natural human interface, the computer should process more complex and heterogeneous human behavior data to understand the user's input intention, which brings challenges to the balanced design of the input channel between the naturalness and the recognizability. We discussed two types of typical natural

input modalities as the input channel, as well as demonstrated some cases of leveraging multi-modality behavior for natural and efficient input.

**2.3.1.1. Gestural input.** Using different body parts, such as hands, fingers, arms, heads, and eyes, as input is a prevalent method for the natural user interface. Researchers always seek a design of the form factor that is less intrusive, more user-friendly, and allows the user to perform more complex or subtle gestures as input. Under such design goals, camera-based, wearable-sensor-based, and acoustic-based sensing methods are most widely adopted. For example, C. Yu et al. (2019) proposed HandSee, which fixed a prism above the front camera of a smartphone to construct a stereo vision system that extends the hand-to-phone interaction space beyond the screen. C. Liang, Yu, Qin, et al. (2021) proposed a full-time wearable system composed of merely two IMU rings (a quite compact hardware form) to sense various subtle and expressive hand gestures (e.g., micro-fingertip gestures and hand-to-surface gestures). Gu et al. (2019) proposed an AR+Ring system that supports touch interaction on any physical surface based on the IMU ring. Y. Wang, Ding, et al. (2022) presented FaceOri, an acoustic-based method to enable 6-DoF head tracking for head-gesture-based interaction. K. Sun et al. (2017) presented Float that enables one-handed target selection on smartwatches using IMUs and PPG sensors.

**2.3.1.2. Voice input.** Existing work of Chinese HCI researchers on voice input mainly focuses on 1) leveraging modern AI and NLP techniques to enhance the understanding capability and optimizing voice interaction flow based on human-centric design. For example, L. Pan et al. (2022) proposed a voice-based UI automation system that enables the user to teach the voice assistant with iterative dialogs. Fan et al. (2021) present a realtime voice-based editing system that enables the user to speak out the words to be modified without locating them with the assistance of the large pre-trained NLP model. K. Sun et al. (2018) investigated silent speech by analyzing the lip movements with computer vision, proposing a silent speech space of 44 commands.

**2.3.1.3. Touch input.** Touch interaction, which relies on users inputting commands through taps or swipes on a specific surface using their fingers or other body parts, offers a 'what-you-see-is-what-you-get' interaction experience. This has led to its wide application in various smart devices, such as smartphones, tablets, touchscreen terminals, wearable devices, etc. The intuitiveness and ease of use of touch interaction have made it one of the most popular methods in modern human-computer interaction. In the last decades, Chinese HCI researchers has contributed in various research topics on touch input, such as touch behavior modeling (X. Yi et al., 2017), novel touch sensing schemes Y. Wang et al. (2019), and touch interaction for special user groups (F. Tian, Fan, et al., 2019; Y. Wang et al., 2021).

Touch interaction is often troubled by the 'fat finger' problem, due to the limited size of the touch surface and the

richness of usage scenarios, making precise selection and operation a challenge. To address this issue, researchers have employed a series of innovative technologies aimed at enhancing the efficiency and accuracy of touch interactions. On one hand, the application of artificial intelligence algorithms has made significant advancements in touch interactions on constrained surfaces. For example, Yi et al.'s research delved into typing on miniature QWERTY keyboards using intelligent algorithms like Bayesian inference (X. Yi et al., 2017), proposing an efficient text input method based on Bayesian reasoning, which greatly increased input speed. Research by Yu et al. focused on the impact of feedback after finger pointing on touch efficacy, achieving a significant reduction in the rate of accidental touches (Yu et al., 2016). On the other hand, the development of smart sensing technologies has opened up new possibilities for expanding the touch input area. By extending the touchable area to body or object surfaces outside the device, such as the palm, arms, and face, a broader input bandwidth was achieved (Y. Wang et al., 2019). This method typically relies on multi-source sensors to capture the user's touch location on the body surface. Further, researchers also need to solve the unintentional touch issues on touchscreens (X. Xu et al., 2020). Additionally, the DRG-Keyboard, with dual IMU rings, realized a thumb-index finger sliding QWERTY mini keyboard, providing an efficient input method and good tactile feedback (C. Liang et al., 2022). Regarding touch interaction for special user groups, Tian et al. explore the detection of motor impairment in early Parkinson's disease through analyzing common touch gestural interactions on smartphones, achieving high accuracy in discriminating early PD subjects from healthy controls (F. Tian, Fan, et al., 2019). Wang et al. presented a novel touch-based typing algorithm for patients with Parkinson disease that remove their unintended touches to achieve fluent typing experience (Y. Wang et al., 2021).

**2.3.1.4. Head and eye gaze input.** Head and eye gaze input primarily focuses on utilizing computer vision and eye-tracking technology as a method of user input, involving the latest generation of head and eye tracking technology and the understanding of gaze movement behavior. Chinese HCI researchers focused on two main research directions: (1) Developing intelligent, portable, non-invasive, and high-precision gaze tracking input devices, and building supportive software and hardware systems for gaze input (Cheung & Peng, 2015; J. Liu et al., 2022); (2) Studying intelligent methods to understand eye movements, states, and intentions, and accurately perceive them. The research involves gaze-based natural interaction technology that merges multiple channels to enhance the precision of gaze input (Lyu et al., 2023; Y. Yan et al., 2018; C. Yu et al., 2017). For example, Cheung et al. presented an eye gaze tracking system with a web camera in a desktop environment, making gaze-based interaction accessible in ordinary desktop settings (Cheung & Peng, 2015). Based on high-fidelity commercial head and eye tracking system, Yan et al. investigated efficient gazed-based target selection mechanism (Y. Yan et al., 2018) while Yu et al. investigated eye movement behavior and developed

efficient stroke-based decoding algorithms in a gaze-based typing task (C. Yu et al., 2017). Using new technologies to study intelligent methods for representing and accurately perceiving eye movements, behaviors, states, and intentions, such as solving the common Midas Touch problem in eye movement input, i.e., the discrepancy between input intent and error, is essential. Research on natural interaction technology based on eye-tracking and multimodal fusion is also crucial.

#### **2.3.1.5. Multi-modality human behavior as input interface.**

For the convenience of conveying the intention, users sometimes tended to perform the input behavior with two or more modalities that are organically combined (e.g., voice + hand gestures). For example, PrivateTalk (Y. Yan et al., 2019) combined natural voice commands with a cover-mouth gesture to indicate the trigger of the voice assistant. Similarly, Qin et al. (2021) and Z. Yang et al. (2019) implement the voice wakeup techniques by bringing the phone close to the mouth.

#### **2.3.2. Multi-modality information output**

Multi-modal information output can effectively improve production efficiency based on multi-resource theory because it can transmit information to users through multiple perceptual channels at the same time. J. Zheng et al. (2020) reviewed channel bandwidth quantification methods for multimodality in natural interaction. Rau and Zheng (2019) studied the redundancy effects of visual, auditory, and tactile information, single-modal and multi-modal channel capacity, modal information encoding characteristics, and the performance of each modality in a dual-task scenario. Rau et al. (2020) studied the impact of visual, auditory, and tactile continuous and discontinuous irrelevant information on the performance of the main reading task, and compared the interference effects of unimodal and multimodal irrelevant information. D. Liu and Rau (2020) proposed to use the spatial inconsistency of audio-visual information to improve people's underestimation of depth distance in VR.

#### **2.3.3. Fusion of input and output interface**

The research on the fusion method of input and output interfaces mainly includes tactile stimulation and perception. D. Wang, Wang, Zhang, et al. (2019) reviewed current research on force feedback glove devices. Y. Zheng et al. (2018) proposed a design method for a lightweight, large workspace force feedback glove. Han et al. (2017) proposed a passive kinesthetic force feedback method for rotational input on smart rings. H.-R. Tsai et al. (2021) propose a wearable device to provide 3D force guidance upon the forearm in VR. Teng et al. (2019) proposed a haptic input-output method for interacting with chairs.

### **2.4. Context-awareness**

Using the context-aware channel fusion method to design an effective natural interaction interface is an important content to realize multi-user multi-interface natural interaction.

In summary of the above topics, domestic research mainly focuses on three aspects: non-intrusive perception of real-time context of user state and behavior, context-sensitive mental model, and cloud-fusion-based multimodal interaction.

#### **2.4.1. Non-intrusive sensing techniques**

From the perspective of humans and the environment, many studies focus on radio frequency signal sensing techniques. Sensing techniques based on wireless radio frequency signals such as WiFi that are ubiquitous in the environment to sense changes in the environment, and can penetrate walls, occluders, and other indoor obstacles. D. Zhang, Wang, et al. (2017); F. Zhang, Zhang, et al. (2018) studied wireless situational awareness and recognition based on radio frequency signals. Based on the wireless perception theory based on the Fresnel zone reflection model and the diffraction model, the researchers studied the specific scenarios of several situational perceptions: breath detection (D. Wu et al., 2017; Zeng et al., 2018; Zeng et al., 2020, 2019), area perception (S. Li, Liu, et al., 2020; X. Li et al., 2018) and gesture recognition (W. Chen et al., 2020; D. Wu, Gao, et al., 2020). S. Li et al., 2017; X. Li et al., 2017) using the widely existing wall in the daily environment as the perceptual boundary of the area division, extracting the boundary perception feature reflecting the dynamic reflection signal energy caused by people in the WiFi signal, and realizing the accurate identification of the human activity area.

Using non-intrusive identification of user physiological characteristics and scenarios, it can provide an evaluation method for the naturalness of interaction and user experience, and design an interaction mode that best matches the user's state.

#### **2.4.2. Context-aware mental model**

When faced with special situations and user states, users' abilities are constrained by their own conditions, scenarios, and tasks. In order to design natural interactive interfaces for barrier-free and special states where audio-visual and touch modalities are occupied, it is necessary to study the modeling of context-sensitive user psychology to match appropriate interaction technologies.

Y. Li et al. (2018); Qiao et al. (2018); Qiao et al. (2020); J. Zhang, E, et al. (2021) studied the mental model of human-computer interaction for monitoring and command tasks. The theory of network correlation complexity is proposed for air traffic control tasks. Y. Sun, Zhang, et al. (2019) studied the mental model of a pilot's landing scenario S. Ma et al. (2019, 2020); S. Ma et al. (2017) studied the effect of diabetes and hypoglycemia on driving mental models. G. Liu et al. (2019) studied the interaction design of online shopping situations for blind people.

#### **2.4.3. Interaction performance optimization**

In the face of diverse and variable multi-modal interaction interfaces, jointly optimizing the interaction path from the aspects of human ability and computing resources is an

important method to realize natural human-computer interaction. The current mainstream interaction method is based on a single interaction channel, and the interaction effect is relatively limited in complex scenarios. Researchers are committed to building a multi-channel human-computer interaction experiment platform and a service robot aggregation experiment platform.

S. Li, Shi, et al. (2020) proposed a perceptually enhanced task learning and planning model, which is oriented towards a perceptually enhanced robotic limb. By learning to build its own behavior library locally, it can generalize the objects and actions in the behavior library according to the knowledge graph, and then expand the behavior library. C. Liang, Yu, Wei, et al. (2021) proposes Auth + Track, an authentication model that continues tracking after one authentication, which is used for continuous authentication of smartphones. Qin et al. (2021) proposes a close-to-mic speech detection method based on a single microphone, which can be used to activate the voice input of handheld and wearable devices without wake-up words. Z. Yang et al. (2019) proposes a method of bringing the mobile phone close to the mouth to wake up voice input, while using multi-modal signals such as a microphone, IMU, camera, and proximity sensor. Y. Yan et al. (2019) proposes to automatically wake up the voice input in the headset by using the mouth-covering gesture, which makes the voice input more private and convenient. L. Pan et al. (2022) proposes a method to map voice interaction to GUI operation sequence, and proposes to continuously improve the system with interactive question answering.

## **2.5. User acceptance and performance with technology**

The study of user acceptance and intention to use products is a crucial aspect of Macro-HCI research, as it helps identify factors that influence user attitudes toward new technologies and their behaviors. Additionally, research on human performance in computing environments primarily utilizes psychological and ergonomic methods to evaluate human-computer interaction efficiency.

### **2.5.1. User acceptance of new technology**

Acceptance refers to users' positive attitudes toward new information technologies and willingness to use or buy related products W. S. Lin, 2012; Lowry et al., 2014; T. Wang et al., 2015, such as autonomous vehicles (H. Liu, Yang, et al., 2019), online meeting platforms (R. Wu & Yu, 2022), and virtual reality technology (J. V. Chen, Ha, et al., 2022), and Internet social media (H. C. Lin & Ho, 2018; B. Xu et al., 2012).

In the early stage of the past decade, researchers focused on users' attitudes toward e-commerce and social networking sites. Firstly, several studies analyzed customers' usage and purchasing behaviors on e-commerce websites based on cognitive and affective perspectives. For example, Lowry et al. (2014) found that consumers tended to show greater trust and more willingness to make transactions on a

credible e-commerce website, whose logo had traits of expertise and trustworthiness. T. Wang et al. (2015), from an affective perspective, found that consumers' intention to purchase significantly increased as their identification with social networking sites (SNS) increased. Other early studies focused on how people's personality, perceived enjoyment, and perceived usefulness of instant messaging systems affect their willingness to use instant messaging systems (W. Wang, Hsieh, et al., 2012; W. Wang, Ngai, et al., 2012). In addition, users' self-exposure and knowledge-sharing intentions in online communities are also affected by personality, privacy concerns, attachment motivation, social support orientation, and disposition to trust (J. V. Chen, Widjaja, et al., 2015; Shih et al., 2012; B. Xu et al., 2012).

After 2016, researchers paid more attention to the public's acceptance of mobile devices, smart TVs, live streaming commerce, autonomous vehicles, VR/AR, and other emerging smart products (virtual assistants, smart speakers, chat/service robots, smart watches, etc.). For instance, H. Liu et al. (2019) proposed three indices for acceptance of autonomous vehicles (AVs) and found that Chinese citizens' trust in AVs can either directly contribute to their acceptance of AVs or indirectly influence acceptance through their perceived benefits of AVs. Another study examined the effectiveness of virtual shopping stores and confirmed that the interactiveness and vividness of VR shopping platforms promoted users' sense of telepresence and playfulness, thus raising their urge to purchase (J. V. Chen, Quang-An, et al., 2022). For a better human-AI collaboration, J. Jiang et al. (2022) investigated how three different types of post-hoc explanations influence users' acceptance of advice from AI and reported that AI explainability (XAI) may not always be desirable. As users' epistemic uncertainty increases, only providing the rationale of prediction can promote users' acceptance of AI's advice, whereas either showing the confidence scores for advice or offering alternative advice had aversive effects.

Under the COVID-19 pandemic since 2020, researchers have been highly interested in studying users' acceptance of new online products, such as online learning, telecommuting, telecare, online meeting platforms, and VR tours (Chai et al., 2022; Le et al., 2024; Lee et al., 2022; L. Peng et al., 2022; C.-Y. Su & Chiu, 2021; R. Wu & Yu, 2022). X. Wang, Liu, et al. (2022) showed that students' active engagement in online learning promoted their perceived usefulness and perceived ease of use. Similarly, a study by Chai et al. (2022) found that perceived usefulness and perceived ease of use had a positive impact on users' adoption of telecommuting as well as their favorable attitude towards telecommuting. These findings identified the key factors that explain users' attitudes and behaviors, and might promote users' acceptance of new technologies.

### **2.5.2. Human performance in computing environment**

Researchers studied individuals' physiological and psychological responses during human-computer interaction, such as muscular activity (Hsiao & Cho, 2012; Ko et al., 2016; M. I. B. Lin et al., 2020), attentional fluctuation (M. He et al.,

2022; W. Liu et al., 2021), fatigue and working performance (J. G. Chen et al., 2016; Z. Chen et al., 2014). For example, a frequently cited investigation showed that individuals with chronic neck and shoulder pain had increased muscular activity than those without chronic pain when texting on smartphones (Xie et al., 2016). In addition, Chan Alan Hoi Shou and colleagues at the City University of Hong Kong published a series of papers on how monitor-related factors affect human performance. Specifically, they studied the impact of monitor position and placement angle on working performance (Chan & Hoffmann, 2015; Hoffmann & Chan, 2017; Hoffmann et al., 2019), the spatial compatibility of display-control configurations' effect on multitasking performance (S. N. Tsang & Chan, 2015, 2018; S. N. H. Tsang et al., 2021). These findings provide valuable guidance for improving human performance during human-computer interaction.

Another part of these articles explored factors that influence employees' (e.g., police officers, nuclear power plant staff, drivers, firemint, pilots) performance in computing-related working environments (Y. C. Liu & Jhuang, 2012; Lyu et al., 2022; Niu et al., 2018; Qiao et al., 2022; Shupsky et al., 2021; Trapsilawati et al., 2015). These studies mainly focus on decision-making performance (e.g., accuracy, reaction speed) (Y. C. Liu & Jhuang, 2012; Lyu et al., 2022; Shupsky et al., 2021; Trapsilawati et al., 2015), human-computer trust (Niu et al., 2018), mental workload (Qiao et al., 2022), and computer's security (Shupsky et al., 2021). For instance, compared to the manual condition, conflict resolution aid (CRA) is able to promote air traffic controllers' performance and reduce workload under different time pressure conditions or traffic density conditions (Trapsilawati et al., 2015; Trapsilawati et al., 2016). Even in the unreliable blocks, trust in the CRA aid was degraded, yet the performance was not adversely affected. It provides empirical evidence on using computer technology to improve work performance in the intelligent age. In addition, there are also studies focusing on improving individual comfort through environmental settings in this environment (M. I. B. Lin et al., 2022; Tao et al., 2022). For instance, one highly cited study suggests that using a soft mat can easily alleviate workers' discomfort when their work requires long periods of standing in front of the computer (M. I. B. Lin et al., 2022).

The extensive usage of digital main control rooms (MCRs) in Chinese Nuclear Power Plants made it necessary for Chinese researchers to update their knowledge about operators' performance in conventional MCRs. Studies on human performance under simulated accidents or emergency situations of the digital system have achieved a series of results. An increased amount of accessible information led the participants to seek more and think shallower, and thus decreased diagnostic accuracies (Lyu et al., 2022), which was replicated by another study using event-related potential (ERP) technique (Tang et al., 2022). In addition, information congruence (K. Chen & Li, 2015), information seeking and information integration (Lyu & Li, 2019, 2020),

human cognitive style and acquisition methods are associated with diagnostic accuracy (D. Pan et al., 2020).

## 2.6. User experience design

Accurate and reliable user modeling, as well as natural and efficient product design, are effective ways to enhance user experience. Both academia and industry are using new paradigms and technologies to guide user research.

### 2.6.1. Cognitive and behavioral modeling

As an auxiliary means of evaluation and prediction, user modeling can guide the generation of new designs and functions to improve the human-computer relationship. The Chinese researchers focus on modeling to recognize human states, intentions, interaction behavior, and user experience.

It is important for an automatic system to monitor operators' real-time workload and mental state. Researchers were interested in evaluating the personnel's workload and mental state by monitoring their psycho-physiological status. For example, one of the highly cited studies used six physiological indicators (pupil size, blink rate, blink duration, parasympathetic/sympathetic ratio, total power, and heart rate variability) to accurately predict the personnel's mental workload when they perform emergency operating procedures (EOP) in nuclear power plants (Q. Gao et al., 2013). Ding et al. (2020) collected users' multimodal physiological signals (heart rate, heart rate variability, electromyography, electrodermal activity, and respiration) to monitor their mental workload during mental arithmetic tasks. The results showed that the machine learning classification model combining physiological signals and task performance can achieve accuracy at 96.4%. Similarly, individual profiles, facial expressions, and physiological signals were modeled to detect drivers' stress (X. Zhou, Ma, et al., 2022).

To facilitate human-AI cooperation, AI needs to accurately and effectively identify human intentions. T. Liu et al. (2015) developed a hidden Markov model (EHMM) approach to make inference of human intention. D. Wei et al. (2022) used a joint model of LSTM and MLP to recognize human-robot interaction intentions based on human skeletons and environmental features. Moreover, to help humanoid robots predict the user's intentions, Y. Zhao and Zeng (2022) proposed a brain-inspired intention model using reinforcement learning which required fewer training than the Q-learning method. In addition, researchers have also been interested in models for the machine's intention. For example, X. Wang et al. (2021) used an air target's parameters such as azimuth, distance, horizontal speed, heading angle, altitude, etc., to model its intention (attack, cover, reconnaissance, surveillance, and others) by using the deep neural network learning model.

Fitts' law provides an important theoretical basis for predicting reaction time for human-computer interaction. H. Song (2012) proposed new modified Fitts' laws to predict reaction time for restricted display fields (smartphones, portable PCs, and head-mounted displays) and small

components on these graphical user interfaces (H. Song et al., 2012). Hoffmann et al. (2013) modified Fitts' law to capture shrinking targets in applications such as shooting games. In addition, a modified Fitts' law was established for measuring head rotation (as an input mode) movement time in a data-inputting task, which will help design the best arrangement of display (Hoffmann et al., 2017). Deng et al. (2019) also proposed a three-phase model (acceleration, deceleration, and correction) based on the logarithmic function to successfully predict the movement time of positioning tasks in a 3D virtual environment. W.-J. Hou, and Chen (2021) further showed that Fitts' law can be applied to predict eye-based selection time in virtual reality. Such user models can provide a reference for the design of user interfaces and interactive input modes.

Researchers worked hard to model user experience to improve the design of various products. For example, M. T. Tsai et al. (2014) used bounding box based background white-space fraction ( $W_{B_b}$ ) to establish a perceptual aesthetics model for human-computer interface text-overlaid images, and the optimal  $W_{B_b}$  value is about 0.8 calculated by subjective score. Dou et al. (2019) proposed a deep learning model with knowledge transfer training to automatically compute and quantify webpage aesthetics, and the model predicted results were highly related to user aesthetics rating. C. Yang et al. (2023) first carried out interface color imagery matching cognition experiments and found that the amplitude of waves N400 and P300 are key components reflecting the matching/non-matching conditions between mobile interface color and the imagery word. Then, they used the average amplitude data of N400 or P300 as the classification basis to establish the color imagery inference model by Extreme Learning Machine (ELM) to predict users' perception in different color designs.

### 2.6.2. Design and improvement

Due to the emergence of new interaction scenarios and technologies, the traditional WIMP (windows, icon, menu, pointer) paradigm based on desktop metaphor can no longer meet users' needs (Fan et al., 2018). New paradigms and metaphors have to adapt to a huge variety of tasks (e.g. games, companionship, etc.) and natural interaction methods (e.g. language, gesture, etc.). In recent years, Chinese researchers have proposed some new paradigms based on the avatar metaphor, which regards the computer as a certain social representation (e.g. assistants, friends, nursing workers, etc.) and is more suitable for natural human-computer interaction. X. L. Zhang et al. (2018) proposed RMCP (role, modal, commands, presentation style) paradigm for front-end intelligent systems. For example, a home intelligent nursing robot (intelligent system) is a caregiver (role) who can interact with the human in the voice and visual modality (modal), recognize user's postures and instruction (commands), and also use voice or body movements to present information to the user (presentation style). Similarly, H. Wang et al. (2018) proposed the ASLI (avatar, scenario, language, instrument) paradigm for the Bots-based human-computer interaction system. For instance, the intelligent

assistant (avatar) in a smart watch can recognize users' voice and position through the microphone and GPS (instrument), and send the speed reminder to the user through voice (language) while running outdoors (scenario). These new paradigms provide a new framework for natural human-computer interaction in the intelligent era.

Big data played a critical role in portraying users' profiles which can efficiently guide the improvement of user experience. Users' Big data have been widely used in recommendation systems, intelligent decision-making, user portrait, requirement analysis, and availability analysis H. Tan, You, et al. (2020). For example, the personalized recommendation system contributes to 10% of orders at JD.com and Taobao's recommendation system covers nearly 100 business scenarios. Toutiao also uses the personalized news recommendation engine to increase the view number. In terms of intelligent decision-making, Alibaba has trained an automated poster design system called "Luban" by using massive data of human-designed posts, which can generate 8000 product banners in one second. Moreover, researchers also developed a method to make the user portrait by combining quantitative and qualitative analysis (H. Tan et al., 2022). For instance, they generated typical user portraits for mobile photo application users (H. Tan & Guo, 2019) and tablet computer users (H. Tan et al., 2022) to understand user needs and preferences, thus supporting the optimization of product design.

In the past decade, researchers were also interested in developing new learning and education systems with emerging computing technologies. For example, virtual reality was used to help students adapt to new culture (L. Gao et al., 2021). A tablet-based pedagogical system was designed to improve communication skills of autism children (Chien et al., 2015). It is worth noting that the gamified design of education system has gained more and more attention. Researchers developed not only a multi-dimensional evaluation framework for gamified learning experience (Law & Sun, 2012), but also many learning games for different practical purposes. For instance, a game for Cantonese opera well supported learning opera movements (Pang et al., 2022), and a story-based creativity game also improved children's creativity effectively (Yeh et al., 2023).

Researchers also designed new products to improve human performance under various situations. For instance, a study on the design of takeover warning showed that the two-stage warning system was promising in improving safety (S. Ma et al., 2021). They have also proposed a vibration cue system to reduce motion sickness for passengers under automatic driving (D. Li & Chen, 2022). In addition, a haptic device supported remote intimate interaction by collecting and transmitting kiss messages (Saadatian et al., 2014), the web-based collaborative reading annotation system improved readers' digital reading performance (Jan et al., 2016).

Many Chinese companies, especially large IT companies, took user experience seriously and set up their user experience (UX) department. Alibaba, the leading e-commerce company, for example, established its 1688UED as early as 1999. Other IT companies such as Huawei, Tencent,

Netease, and Baidu also founded their UX department to improve the usability of their service and products between 2005 and 2010. In addition to the UX department in the IT industry, user experience organizations in China such as the UXACN, UXPA, and UX alliance for domestic appliances have also developed rapidly and attracted attention from both industry and academia.

### 2.6.3. UX paradigm framework and the corresponding method

There is a rising demand for new UX paradigms that can accommodate diverse user needs and intelligent HCI features. Chinese scholars have new developments in UX methodology and paradigm. For example, W. Xu (2023) proposed the "User experience 3.0" paradigm framework (illustrated in Figure 3) from a perspective of intelligent ecosystem and social technology system, which covers five categories of UX methodologies: ecological experience, innovation-enabled experience, AI-enabled experience, human-AI interaction-based experience, and human-AI collaboration-based experience. The continuous development of UX paradigm will support the research and application of UX in intelligent systems.

### 2.6.4. Emotional experience design

Emotion also plays a very important role in human-computer interaction. Through the expression of emotion, people can communicate and understand each other more conveniently. J. Zhao, Chen, et al. (2018); J. Zhao, Chen, et al. (2019) studied methods for continuous emotion recognition using dynamic speech interaction and dynamic interaction with attention mechanism for emotion recognition.

J. Liang et al. (2019) combined multimodal emotion recognition in a cross-cultural context to mitigate the impact of culture on multimodal emotion recognition. J. Zhao, Li, et al. (2019) proposed a multimodal interaction strategy based on multimodal information to facilitate multimodal emotion recognition across different cultures. G. Zhao, Ge, et al. (2018) analyzed the changes in the EEG signal during the user's viewing of emotional material to predict the user's five personalities.

In the past decade, Chinese researchers have conducted specialized evaluations of Emotional Experience for different interaction systems or technologies. X. Peng et al. (2018) conducted an assessment of user acceptance, user comparative impressions, and pronunciation performance by presenting three distinct modes of a three-dimensional virtual talking head: audio only, human face video, and audio-visual animation of a three-dimensional talking head. The research findings suggest that users exhibit higher acceptance and preference for the 3D virtual talking head, with a relatively better performance in pronunciation learning. Building upon this research, X. Peng, Chen, et al. (2020) delved deeper into understanding the impact of different talking heads on learners' achievement emotions, cognitive load, and pronunciation learning performance.

Additionally, X. Peng, Huang, et al. (2020) extended the investigation by comparing the influence of emotional challenges on player experiences between virtual reality (VR) and personal computer (PC) conditions. The results indicated a significant enhancement in participants' emotional responses, appreciation, immersion, and presence when exposed to VR. Researchers collected players' perceived challenge ratings and extracted physiological features (ECG, EDA, EMG, skin temperature, and respiratory activity) during gameplay. Employing various machine learning methods,

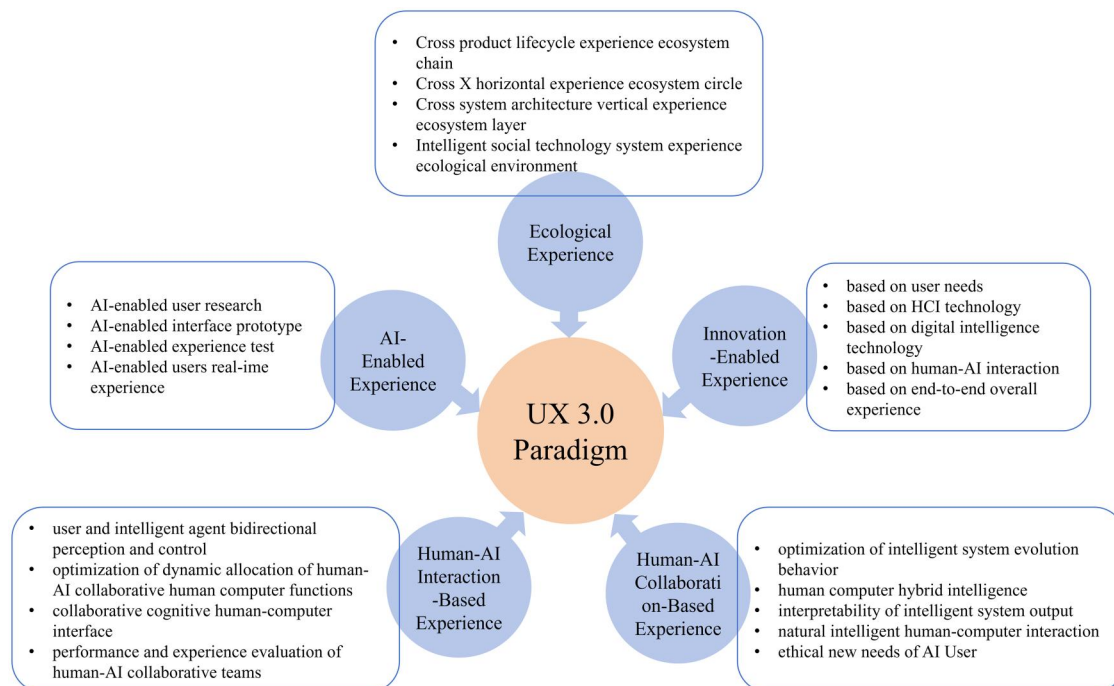


Figure 3. The conceptual framework of the "UX 3.0" paradigm in the era of artificial intelligence. This figure was adapted from W. Xu (2023).

they achieved an impressive approximate 80% detection accuracy for challenge experiences (X. Peng et al., 2023).

These studies are intricately designed to evaluate users' specific emotional experiences in human-computer interaction, providing a valuable reference for the exploration of achievement emotions within HCI systems.

## 2.7. Human-AI interaction

Human-AI interaction is a crucial area of research in the era of artificial intelligence. To explore this field, we first introduce the innovative theory that provides a fundamental framework for human-AI interaction research. Then, the empirical research like emotion recognition, human-virtual and mixed environments interaction, and driver-autonomous vehicle interaction will be discussed.

### 2.7.1. Theoretical exploration

Concerns surrounding the development of artificial intelligence have led to the proposal of the Human-Centered AI (HCAI) framework, which advocates designing AI to facilitate humans rather than replace them (W. Xu, 2019). Chinese scholars have actively participated in the theoretical development of Human-AI Interaction. W. Xu (2019) highlighted two major challenges faced by HCAI: the explainable and comprehensible problem and the useful and usable problem, both of which emphasize the need for effective Human-AI interaction. In a recent study, Ozmen Garibay et al. (2023) identified six grand challenges in building HCAI systems and technologies, which include developing AI that prioritizes human well-being, is responsible, respects privacy, incorporates human-centered design and evaluation frameworks, is governance and oversight enabled, and respects human cognitive processes at the human-AI interaction frontier. Therefore, human-computer interaction (HCI) professionals are well-positioned to take a leading role in designing not only explainable and comprehensible AI but also useful and usable AI. In line with this, W. Xu (2022) further elaborated on the theoretical framework of HCAI, emphasizing the technical, human, and ethical aspects of AI, and committing to developing sustainable, powerful, and human-controlled AI, useful, usable, and human-driven decision-making AI, and ethical and responsible AI.

With the proliferation of AI technology, AI products are increasingly prevalent in both industry and daily life. However, the interaction between humans and AI differs from traditional Human-Machine or Human-Computer interaction. In interactions with non-intelligent systems, machines are often viewed as auxiliary tools that support human operations. In contrast, the autonomous nature of AI systems allows for a two-way "cooperative interaction" between the AI agent and human, which is similar to a human-human team (Johnson & Vera, 2019). As a result, a new kind of human-machine relationship has emerged, where autonomous agents may evolve from supporting

human operations to working as teammates alongside human operators (Kaber, 2018).

### 2.7.2. Empirical research

Emotion recognition is a crucial research field on human-computer interaction. Researchers showed that Micro-expressions can reveal genuine emotions (Chen et al., 2015). Micro-expressions are brief involuntary facial expressions that take less than 260 ms to onset or last less than 500 ms (W.-J. Yan, Wu, Liang, et al., 2013). Fu Xiaolan and colleagues at the Institute of Psychology Chinese Academy of Sciences have previously released four micro-expression databases: CASME, CASME II, CAS(ME)2, and CAS(ME)3 (J. Li et al., 2022; Qu et al., 2018; W.-J. Yan, Wu, Liu, et al., 2013; W.-J. Yan et al., 2014). Because this series of micro-expression databases are naturally expressed or spontaneous facial expressions rather than posed expressions, they have achieved higher ecological validity and have been widely used around the world. Based on these databases, S. J. Wang et al. (2015) propose a novel tensor independent color space (TICS) model to recognize micro-expressions, which had better performance in recognizing facial color than RGB color space. Y.-J. Liu et al. (2015) used a SVM classifier with the Main Directional Mean Optical-flow (MDMO) feature to recognize micro-expression. These kinds of micro-expression recognition systems would have broad applications in national safety, police interrogation, and clinical diagnosis (W.-J. Yan et al., 2014). Other Chinese researchers also developed conversational emotion recognition models based on auditory features. For example, Tao and colleagues from the Institute of Automation Chinese Academy of Sciences used a multimodal learning framework called conversational transformer network (CTNet), and personality-enhanced iterative refinement network (PIRNet) to make conversational emotion recognition model (Lian et al., 2021, 2024).

Chinese researchers are also interested in the machine behavior of intelligent systems. First, they studied safety-oriented machine behavior from the perspective of human perception, interaction process and alarm design. For example, they found that the perceived safety of autonomous vehicles was influenced by their worry more than dread (H. Tan, You, et al., 2020). During the process of automatic vehicle takeover and handover, interaction initiative and situation urgency are two key issues in the design of interactive process between human and intelligent vehicles (H. Tan & Zhang, 2022). In terms of alarm design, they showed that the multimodal warning is better than unimodal warning for driving performance and user experience though multimodal warning may increase the driver's pressure and cognitive load (Y. Zhang & Tan, 2021). Secondly, researchers also found that human-like machine behavior can improve user experience. For instance, they found that the proactive behavior of social robots can facilitate users' perception of the robot's warm anthropomorphic attribute (H. Tan, Zhao, et al., 2020). In addition, intelligent speakers with proactive behavior that request consent before execution have good satisfaction in both high and low emergency tasks (Y. Zhao et al., 2021). Besides, static machine behavior such as

human-like appearance also affects users' expectations of smart systems. For example, "arms" are supposed to be included in anthropomorphic design of whole body, but whether to add "mouth" should be considered carefully because it makes users' affection into two opposing ends.

VR and Metaverse are closely connected, as they both aim to provide an immersive experience for users. Metaverse provides a platform for users to carry out various activities such as socializing and entertainment, while VR is a technology that allows users to interact with the virtual world and other inhabitants in a more immersive way. Tong and colleagues have used VR technology to provide users with a sense of being in the natural environment and embodied interaction. They effectively reduced the phantom limb pain of patients through repetitive exposure to VR intervention, which provides the patients with the illusion that their amputated limbs are moving by mirroring the movements of their intact limbs in virtual body (Tong, Wang, et al., 2020). Compared with traditional mirror therapy, VR-based intervention has stronger analgesic effects by giving patients a better sense of embodiment of their phantom limb. On the other side, they developed a VR game, which lets nonpatients "inhabit" a virtual body of a patient, to increase their empathy and reduce prejudice toward people who live with chronic pain (Tong, 2021; Tong, Gromala, et al., 2020; Tong et al., 2017).

As a large online computing platform composed of large-scale individual users and devices, the success of Metaverse relies heavily on the natural and user-friendly human-computer interaction in a virtual or mixed environment (Z. Tan et al., 2022). Chinese researchers use it to support learning, working and daily live scenarios (S.-M. Wang, Yaqin, et al., 2022; X. Xu, Zou, et al., 2022). For example, Y. Wang, Lee, et al. (2022) put forward a virtual-physical blended classroom that contains two physical classrooms from two universities and one digital classroom hosted in the edge-cloud synchronized computing devices. This Metaverse classroom enables users (i.e., learners and educators) to be physically present at different campus while their digital bodies can interact with other campuses' users in visual classroom. Metaverse augments consumers' interactive experience in the immersive virtual space. Y.-C. Huang and Liu (2020) created a new vision of online shopping platform by using VR technology, which included five different spaces represented as the shopping categories, such as Amazon and Uniqlo. Users are able to touch the virtual goods and ask for help in virtual environment. In addition to online shopping, other industries such as exhibition and tourism can also benefit from metaverse (Y. Wang, Siau, et al., 2022).

### 2.7.3. Driver-autonomous vehicle interaction

Inspired by the rapid development of artificial intelligence, the demand for highly automated vehicles (HAVs) is an ever-growing trend. Frequent interaction with intelligent cockpits during driving has become a common distraction that can reduce drivers' vigilance and cause driving risks (Cunningham & Regan, 2018). J. Chen, Wang, et al. (2022) study showed that a fuzzy synthetic evaluation model (FSE)

can holistically assess the safety of the human-computer interaction design of in-vehicle information (IVI). To maintain drivers' vigilance, many innovative methods were proposed for detecting drivers' status. For instance, researchers developed a drowsiness detection system by incorporating Google Glass (J. He et al., 2017), Meng et al. (2016) proposed the design of a fatigue warning system in order to reduce professional drivers' fatigue driving. Moreover, researchers explored the potential of new imaging techniques such as near-infrared spectroscopy in detecting driver mental workload (L.-P. Li, Liu, et al., 2019; T. Liu et al., 2016).

In addition, models have been established to recognize driving behavior for ensuring driver safety. These models used drivers' activities (e.g., head movement, eye movement, etc.), and vehicle motion states (e.g., vehicle trajectory, distance, speed, etc.) to predict driving behavior. A frequently cited paper on driving behavior modeling developed a back-propagation neural network model using the eye and head movements, and vehicle motion states in natural road driving to predict driver's lane-changing behavior (J. Peng et al., 2015). L. Bi et al. (2014) established a dual-task model for driving behavior under the influence of visual distraction. A queuing network model was developed to detect drivers' lane-changing intentions (L. Bi et al., 2015). G. Lu et al. (2015) built a crossing behavior model for straight-moving drivers under crossing conditions and identified the relative speed of two straight-moving drivers as a key factor influencing drivers' decisions. These models might help smart vehicles to predict drivers' potentially dangerous driving behavior and prevent traffic conflicts.

As automated vehicle become popular, researchers were also interested in developing better control algorithms to improve traffic safety. The advanced driver assistance systems (ADAS) are promising for improving traffic safety in a mixed driving environment where automated vehicles (AVs) and conventional human-driven vehicles coexist. Based on the Shanghai Naturalistic Driving Study (SH-NDS) data, researchers calibrated the Responsibility-Sensitive Safety model (RSS) introduced by Shalev-Shwartz et al. (2017) for car-following and lane-changing safety-critical events (SCEs) with elitist non-dominated sorting genetic algorithms (NSGA-II) (S. Liu, Wang, et al., 2021; X. Xu, Wang, et al., 2021). Studies on NDS data also showed that automatic preventive braking (APB) is able to improve driving safety without reducing traffic efficiency and driving comfort in the car-following SCEs and prevent conflicts between motorized and non-motorized vehicles (NMVs) (W. Zhou & Wang, 2022; W. Zhou, Wang, et al., 2022).

Another significant challenge in building autonomous driving algorithms is to make the AV able to emulate human drivers' intelligence and driving styles, i.e., human-like driving, while staying within safety bounds. Zhu et al. (2018) proposed a new framework for human-like autonomous car-following planning by using a deep deterministic policy gradient (DDPG) algorithm. The car-following model was trained on 2,000 car-following periods extracted from the SH-NDS. Moreover, a forward collision warning (FCW)

systems compatible with drivers' risk perceptions and behavioral responses have been developed to reduce rear-end crashes. X. Wang et al. (2016) collected braking behaviors under different rear-end scenario risk levels to model drivers' expected response deceleration (ERD) and improve the existing FCW timing algorithm by adopting a piecewise function. The results demonstrated that this proposed piecewise function was well compatible with drivers' expectations and make the algorithm more robust.

## 2.8. HCI applications and social influences

The technological innovation and application of human-computer interaction contribute not only to national key programs, but also extend to the industry and daily life (intelligent navigation devices, assistive applications, and medical training systems). The following subsections will explain the impact of HCI applications from multilevel perspectives.

### 2.8.1. Contributing to national key programs

The human factors engineering team from Astronaut Center of China systematically studied astronauts-computer interaction in a variety of space missions. Their findings have been applied in many Chinese space missions and have contributed to the success of extravehicular operations. For example, they carried out a serial of studies on human-computer interface, characteristics of operation tasks, capabilities and limitations of astronauts in order to ensure the safety and effectiveness of the manipulator on the China Space Station (Chen et al., 2015; Tang et al., 2017; Xue et al., 2014). First, they identified key cognitive factors related to space manipulator teleoperation and designed the information display interface, control interface, and control mode for manipulator based on human cognitive processing (Tang et al., 2016; Tang et al., 2017). Secondly, they investigated the impact of camera type on robotic teleoperation tasks and choose a camera configuration scheme to ensure operational safety and reduce the operator's cognitive load. Additionally, a hand controller polarity scheme was also customized to the operating habits and mental models of the astronaut for more accurate and stable manipulation operation. They also identified the critical factors that influence astronauts' performance of the manually controlled rendezvous and docking (manual RVD) task (W. Liu et al., 2016; Y. Tian et al., 2012; Y. Tian, Chen, et al., 2019; C. Wang et al., 2014). For instance, they found that highlight the numerical data of the pitch deviation ( $\theta$ ) and the yaw deviation ( $\phi$ ) on the interface is useful for improving operator's performance (W. Liu et al., 2016).

Innovative research on human-computer interaction in the intelligent pilot system also contributed greatly to the development of intelligent cockpit at the Commercial Aircraft Corporation of China (COMAC). Their research team focused on intelligent decision-making, touch, and voice control technologies for human-robot co-driving in the next-generation intelligent cockpit of commercial

aircrafts (W. Xu, 2022). For example, by using Fully Convolutional Networks, the pilot's position can be precisely recognized so that the auto-pilot system can change control strategy according to the pilot's position (H. Yi, 2021). T. Zhang, Shi, et al. (2021) develop an adaptive human-machine interaction framework by using both pilot's physiological indicators and the aircraft's operational status to evaluate the pilot's cognitive status so that the single pilot operation (SPO) can be adjusted to an appropriate automation level. Their simulation also showed that the system can stabilize the pilot's cognitive load at an optimal level when the automation level in the single pilot operation (SPO) was adjusted accordingly. In addition, COMAC has attained several proprietary technologies in the field of airborne intelligent systems, such as portable operation aids for aircraft control and flight crew fatigue warning methods.

### 2.8.2. Improving safety in nuclear power plant

In recent years, China has had the most nuclear reactors under construction. Meanwhile, the Fukushima nuclear accident in March 2011 reminds us of how crucial safety is to the sustainability of the nuclear industry. New human-system interfaces (HSIs) designs, especially team-oriented designs were hot topics of nuclear safety research. Y. Chen et al. (2017) proposed an operation-unit-based integrated design and an action-based integrated design, and compared these two with the existing separated-displays design under simulated situations. The results indicated that the operation-unit-based integrated design yields the best performance. Q. Gao et al. (2015) proposed team-level integrated Computer-based procedures (CBPs), and examined their effects on team processes using simulated emergency operating procedures. The results revealed that compared with the traditional procedure design, the integrated CBP reduced the effort of team communication and improved team transparency. For similar purpose, the team mutual awareness toolkit for digital interfaces was designed to improve the operators' mutual awareness while not imposing extra mental workloads (She & Li, 2017). She et al. (2019) showed that user-defined shared displays (users can define what information to share with their teammates) exhibited shorter individual diagnosis time, and shared information quality was positively correlated with team mutual awareness.

The alarm system is another important design consideration in MCRs (X. Wu & Li, 2018). Seo et al. (2019) proposed an adaptive alarm interface for digital control panels, which is incorporating the good features of both alarm-tile interfaces and alarm-bar interfaces. The results revealed that this integrated design is superior to the latter two interfaces in terms of understanding parameter trending and alarm detection. X. Wu et al. (2017) explored the effects of integrated designs of alarm and process information on diagnosis performance. As far as the diagnosis performance is concerned, the alarm displays integrated with process information are consistently better than the process displays integrated with alarm information. All the forementioned findings can guide the improvement of the team-oriented HSIs with an integrated alarm system.

### 2.8.3. Healthcare

Chinese researchers used AI technology to provide social support to online healthcare communities. Z. Peng et al. (2020) put forward a prototype MepsBot to provide assistance in writing assessment or recommendation for online community. L. Wang, Wang, Tian, et al. (2021), developed a generalizable chatbot architecture (CASS) based on advanced neural network algorithms to provide users emotional support on an online health community. Chinese researchers also developed some auxiliary diagnosis systems. For example, Cai et al. (2019) developed a system to assess autism spectrum disorders (ASDs) by extracting body movement, facial expressions, and gaze features. F. Tian, Fan, et al. (2019) explored the method to detect motor impairment in early Parkinson's disease (PD) patients by analyzing users' touch gesture on smartphones.

However, there were obstacles faced by computer-based healthcare services. For instance, clinical decision support system (so called "Brilliant Doctor") had difficulties being applied in rural area, because of incompatibility with local environments, technical limitations and usability barriers D. Wang et al. (2021). To promote online clinical platform, X. Ma et al. (2018) analyzed how patients and caregivers interact with healthcare professionals on an online "Ask the doctor" (AtD) platform, proposing implications for designing better online AtD services.

### 2.8.4. Rehabilitation and assistance for diverse needs groups

Innovative approaches in HCI technologies have led to promising solutions for improving the daily lives of the Disabled. For people with visual disabilities, Lan et al. (2015) developed smart glasses that recognize the environment and provide voice prompts to assist the blind in navigating complex environments, while Bai et al. (2017) created intelligent navigation devices for visually impaired people to move in complex indoor environments. In addition, Qiu et al. (2020) designed social glasses, allowing the blind to react to social staring behavior and improve communication. For better communication between disabled persons using hand gestures and people without specific training, T. Song et al. (2021) proposed a new quality-aware HCI framework to understand complex human gestures. And for people with physical disabilities or limb movement disorders, B. Zhang, Yin, et al. (2017) proposed a synchronous robot-control system by recognizing surface electromyography (sEMG) of human upper limb movement, which is an ideal model for wearable exoskeleton systems that can help disabled people who cannot contract muscles on their own.

These solutions have also been applied to assist aged adults. Kang et al. (2022) designing a social interaction system for senior residents in nursing homes. An et al. (2023) proposed the ABTE-NET to organize older adults' life stories so that caregivers can better understand the lives of older adults. Choi et al. (2017) reviewed the effect of exergame interventions on fall prevention for the elderly.

In addition, many HCI technologies have also been used in the treatment and rehabilitation of diseases. For instance,

Scholars have designed robot-enhanced therapy for children with ASDs to improve their social skills (Billing et al., 2020; Cao et al., 2019). A tablet-based pedagogical system (i.e., iCAN) was designed to improve the communication skills of autism children (Chien et al., 2015); X. Liu et al. (2015) also constructed a platform based on NAO humanoid robot for training movement imitation ability, which could develop social skills of children with ASD. T. Su et al. (2023) created a Leap Motion-based building-block training system which generate highly realistic virtual scene to help patients with mild Alzheimer's disease.

### 2.8.5. Senior-adaptable

As the aged population in China increase, the General Office of the State Council of China issued an initiative called The Implementation Plan for effectively Solving the difficulties of the elderly in using smart Technologies on November 15, 2020. The Ministry of Industry and Information Technology immediately issued the Special Action Plan for Aging and Barrier-Free Transformation of Internet Applications, which emphasized the websites and mobile applications (Apps). The Telecom Terminal Industry Association and China Electronic Video Industry Association soon jointly issued three group standards covering the senior-adaptable design and test for Mobile Terminals and Smart TVs. Chinese researchers have also become increasingly interested in studying how seniors adapt to life and social changes caused by emerging computer technologies, especially AI-based intelligent systems, to maintain or improve senior citizens' functioning and independence.

One major aspect of senior-adaptable studies is to investigate senior citizens' attitudes toward online social services (e.g. telecare, remote rehabilitation, social media, virtual shopping) and acceptance of new information technology products, especially those equipped with AI technologies. Chen, K. and his colleagues, a productive research team on this topic, studied senior users' acceptance of smartphones (Q. Ma et al., 2016), computer-based assistive technology (K. Chen, 2020), tablet-based cognitive training program (K. Chen et al., 2021), as well as their antecedent factors. A highly cited article on senior users' acceptance used a structural equation model to show six key antecedent factors for the Chinese elderly to accept smartphones: younger age, higher education level, being non-widowed, better economic conditions, and relatively lower cost (Q. Ma et al., 2016).

Studies in the early stage of the last decade focused on senior users' attitudes toward mobile instant messengers (Chou & Liu, 2016), smartphones (Q. Ma et al., 2016), and communication applications (J. Zhou et al., 2017), etc. In recent years, however, researchers paid more attention to senior users' acceptance of new technologies such as smart wearable systems (J. Li, Ma, et al., 2019; Z. Ma et al., 2023) and virtual reality (W. Xu, Liang, et al., 2023). For instance, senior citizens' willingness to use smart wearable systems was shown to be positively associated with their perceived usefulness, compatibility of products, facilitating conditions, and their self-reported health status (J. Li et al., 2019). In

addition, W. Xu, Liang, et al. (2023) explored the key factors that influence Chinese older adults' acceptance of virtual exergames. They showed that the characteristics of senior citizens (younger age, being retired, a higher education, better financial means, and a good health condition) and the features of exergames (perceived usefulness, ease of use, and enjoyment) could affect their intention to get involved in VR exergames.

In terms of elderly-oriented product design, researches have also gradually shifted from classic commodities to information technology products. Unlike researches in the early half of the last decade which mainly focused on commodities, most of the recent studies proposed elderly-oriented designs to help senior users adapt to emerging information technology, such as smart TV (Ouyang & Zhou, 2019), ATM (H. Huang, Yang, et al., 2019), and video game (R. W. L. Yu & Chan, 2021). For example, Zhou, J. and colleagues, a group of researchers from Chongqing University, have been working on senior-friendly designs for many electronic products, such as handheld computers (J. Zhou et al., 2012), communication applications (J. Zhou et al., 2017), smart TV (Ouyang & Zhou, 2019), screen mirroring (Ouyang et al., 2021), smartphone apps (Z. Zhou, Zhou, et al., 2022) and so on.

#### 2.8.6. e-Commerce

Electronic commerce is a business strategy that relies on smart devices to conduct online shopping, greatly altering the way consumers, businesses, and product services interact in China. Agricultural e-commerce is a powerful force in helping to alleviate poverty in rural areas of China. Several studies have analyzed the factors influencing the development of agricultural e-commerce in China. H. Li, Liow, et al. (2022) utilized the Technology-Organization-Environment (TOE) framework and identified the entrepreneurial orientation (EO) as a moderator influencing the adoption of e-commerce strategies. M. Liu, Min, et al. (2021) collected data from 480 apple farmers and discovered that education level, smartphone usage, off-farm employment, and social capital significantly influence farmers' decisions to adopt e-commerce.

In addition, Live Streaming Commerce (LSC) as an emerging e-commerce model is flourishing in China and garnering global attention. Streamers, acting as intermediaries between merchants and consumers, maintain an independent identity from the merchants. They actively engage with potential customers through live streaming platforms to enhance their willingness to place orders (Y. Wang, Lu, et al., 2022). Y. Sun, Shao, et al. (2019) pointed out that LSC is a new social media form. X. Zhang, Cheng, et al. (2023) discovered that impulsive buying behaviors in LSC are primarily motivated by affective intensity associated with social presence.

#### 2.8.7. e-Government

Electronic government (e-government) is the strategic use of information and communication technologies to provide governments an efficient digital way to interact with citizens

(Mensah, 2019; Y. Yang, 2017). Over the past decade, China has witnessed remarkable progress in various aspects of e-government research and application.

The integration of cutting-edge technologies such as cloud computing, Artificial Intelligence (AI) and blockchain into e-government systems has significantly enhanced the convenience and transparency of Chinese government services. The infusion of AI into e-government services results in the widespread adoption of chatbots and virtual assistants, ensuring swift and effective responses to user queries. For example, China innovatively expands e-government services through social networking service applications (Y. Yang, 2017). A district in Guangdong Province applied blockchain to e-government in China, aiming to solve problems of identity, credit, and information disclosure by building a secure and reliable digital identity system (H. Hou, 2017). Until now, prominent commercial platforms such as Weibo, WeChat, and Alipay have incorporated government services, enabling citizens to make utility payments, electronic funds transfers, and licenses renewal conveniently. According to Alipay's 15th anniversary report on people's livelihood services released this year, more than half of Chinese families have access to e-government services through mobile phones. In general, the advancements in e-government have proven to be mutually beneficial for both Chinese citizens and the government (S. Li et al., 2021).

#### 2.8.8. Education

In the past decade, researchers were also interested in developing novel learning and educational systems with emerging computing technologies. For example, the online course commenting tool (DanMooc) supported students' interaction in MOOCs by allowing viewers to share comments at the top of the video screen. This encouraged learners to engage in discussions (Y. Chen et al., 2019). L. Gao et al. (2021) designed a Virtual Reality application enabled learners to experience typical western festivals to better adapt to the new culture. Besides, it is worth noting that the gamified design of the educational system has gained more and more attention. Researchers not only developed a multi-dimensional evaluation framework for gamified learning experiences (Law & Sun, 2012), but also created many learning games for various practical purposes. For instance, a game designed for Cantonese opera effectively supported the learning of opera movements (Pang et al., 2022), while a story-based creativity game demonstrated significant improvements in children's creativity (Yeh et al., 2023).

### 3. Bibliography analysis

To understand the bibliography and growth of China's HCI research from a temporal perspective, we conducted a quantitative analysis on the publication statistics of China's HCI research from 2013 to 2023, which was in line with previous analysis methods (Daneels et al., 2021; Salminen et al., 2021; Tyack & Mekler, 2020). Publications included for analysis were drawn from three representative venues – CHI, UIST,

Ubicomp (including Pervasive, IMWUT, and ISWC),<sup>2</sup> as they are most prestige HCI conferences and journals that includes state-of-the-art HCI research topics and updates. The selection of these venues is the same as CS Ranking, an authoritative ranking website in computer science. Noticeably, in the “CCF Recommended List of International Conferences and Periodicals,”<sup>3</sup> these three venues are also ranked A in the field of HCI. Therefore, although our quantitative analysis criteria preclude works that have been published in other relevant venues (e.g., International Journal of Human Computer Studies, ACM CSCW, IEEE VR), we believe that the results of our analysis are still valuable for both Chinese and international HCI researchers.

Macro-HCI involves broader research topics compared to Micro-HCI, such as motivation, social collaboration, trust and well-being, engagement, as well as the emotional experience (T. Bi et al., 2019 b). It encompasses studies from a wide range of disciplines, including psychology, ergonomics, sociology, and management science, and others. It is very difficult to find all Macro-HCI studies spread among the aforementioned disciplines for a quantitative analysis. Therefore, we carried out a qualitative review on Macro-HCI research mentioned earlier in the Sections 2.5–2.8.

Our data analysis method consists two stages – literature search and statistical analysis. For the literature search procedure, we first applied a time filter of 2013–2023 and a region filter of mainland China, HongKong, Macaw, and Taiwan on the CSRanking website<sup>4</sup> to filtered our all the active Chinese HCI scholars who have published at least two papers on the target venues from 2013 to 2023. Then we retrieved all the publications on CHI, UIST, and Ubicomp authored by above-mentioned scholars from the DBLP database.<sup>5</sup>

We focused on the three top-tier HCI venues on the CSRanking website,<sup>6</sup> and analyzed the papers with at least one active Chinese author (defined as faculties from mainland China, HongKong, Macaw, and Taiwan who have published at least two papers on these venues from 2013 to 2023).

Our analyzed dimensions include *research type*, *research method*, *research domain*, and *research metrics*. These dimensions are derived from philological concepts and existing HCI surveys T. Bi et al. (2019); Carlsson (2004); Lazar et al. (2017); Salminen et al. (2021). For each dimension, we recruited experienced HCI researchers to manually labeled each publication with one or more descriptive tags for classification. Below we presented a detailed statistical analysis of these bibliography data.

### 3.1. Number of papers, citations, and awards

As described above, our survey involved a total of 82 faculties and 597 publications. Figure 4 showed the number of published papers each year. It is evident that the number of publications showed an overall upward trend from 2013 to 2023. And a significant increase was observed in years 2016, 2018, and 2021. In 2013, there were only 11 papers published across the venues. However, in 2021, this number has dramatically increased to 98, which was 8.9 times that in

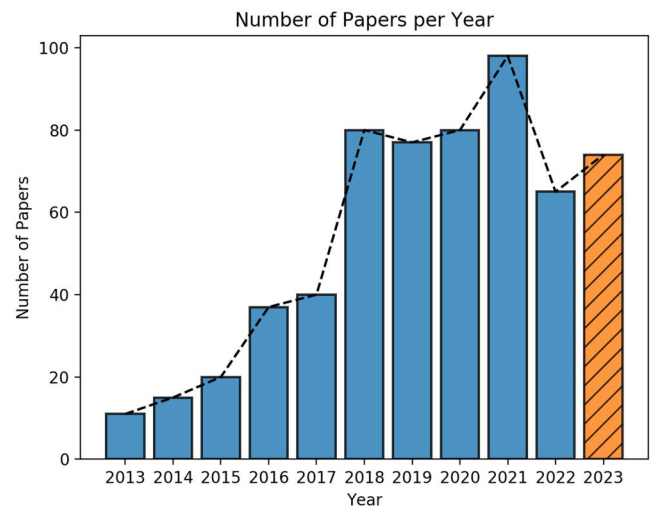


Figure 4. Number of published papers in each year.

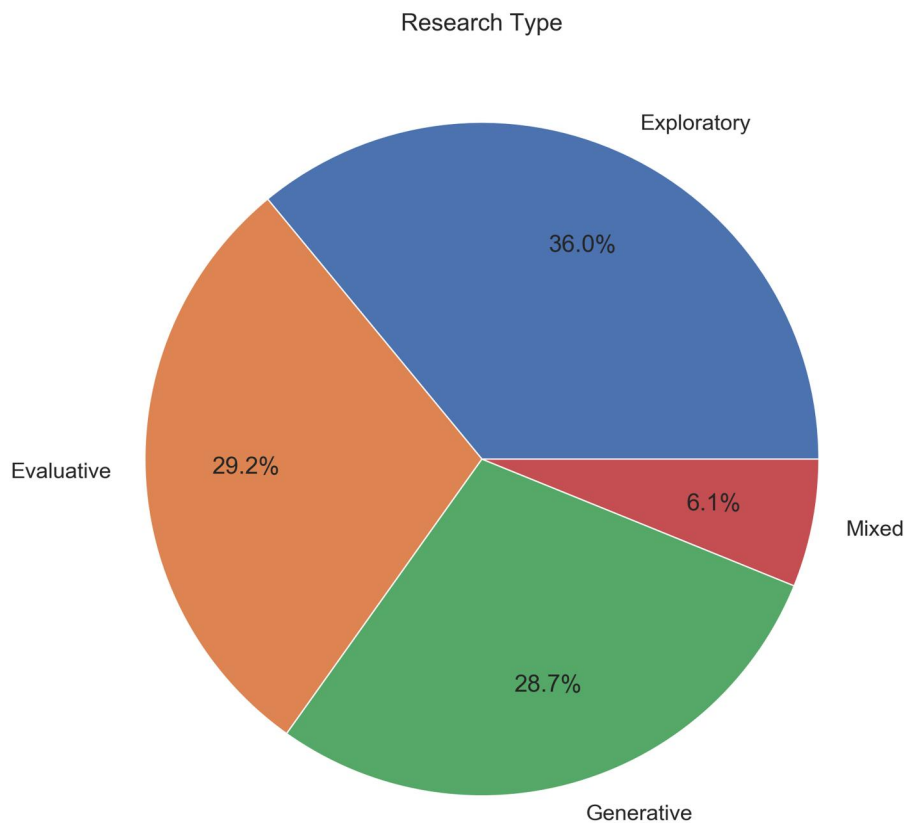
2013. These suggested that Chinese researchers could publish much more high-quality works than ever. Considering the institutions of the authors, we retained the aforementioned 82 faculty members as representatives of the main institutions involved in the completion of the work, and removed the other authors from the list of paper authors. Each paper will be evenly distributed among the faculty members involved in the paper. According to this statistical method, Mainland contributed the majority of the publications (376.5), followed by Hong Kong (126.5) and Taiwan (94.0). The top 5 institutes with the most publications were Tsinghua University (117.6), The Hong Kong University of Science and Technology (84.3), National Taiwan University (53.2), Peking University (44.2), and Chinese Academy of Sciences (41.3).

In addition to the number of publications, we noticed that these papers have gained a total of 11,299 citations, resulting in an average of 19 citations per paper. More importantly, among all the publications, 14 papers have won the honorable mention award, and 4 works have won the best paper award H. Li et al. (2016); Z. Lu et al. (2019); Z. Xu, Wong, et al. (2019); S. Zhao et al. (2016). These all suggested the high quality of these works.

### 3.2. Research types

Inspired by a common classification of HCI research type,<sup>7</sup> we chose the following four tags to describe our data: exploratory, evaluative, generative, and mixed. Note that it was possible that one publication corresponded to more than one tag. After manually labeling, we found that 431/597 papers corresponded to only one tag, while 131 and 35 papers corresponded to 2 and 3 tags, respectively. By inspecting the co-occurrence between different tags, we found that “exploratory” and “evaluative” have the most frequent co-presence (74 times).

Figure 5 showed the distribution of publications with different research types (for papers with multiple tags, we only took the top-1 tag for classification). “evaluative” and “exploratory” were the most frequent research types, which



**Figure 5.** Distribution of the publications with different research types.

covered about 65.2% of all papers in total. “Generative” papers constituted 28.7%, which was slightly fewer. There were only 6.1% papers that were “mixed”.

### 3.3. Research methods

As shown in Figure 6, the top 5 research methods in these papers were system implementation (43.8%), design (29.0%), comparison study (11.7%), interview (8.8%), and concept generation (4.7%). Noticeably, “system implementation” and “design” added up to 62.8% of all the publications, indicating that the HCI research trend in China (T. Bi et al., 2019) values practical instruments on individuals, emphasizing proposing, implementing, and evaluating specific interactive techniques in different scenarios and tasks (e.g., text entry (C. Yu et al., 2017), wearable interaction (C. Liang et al., 2022), VR/AR techniques (Y. Yan et al., 2018) and WIFI sensing (F. Zhang, Zhang, et al., 2018).

Among all the publications, 274, 268, and 55 publications corresponded to one, two, and more than two research methods respectively. “System implementation” and “Design” were most frequently co-occurred (139 times) from the statistics. We also found that “design” (29.0%) and “comparison” (11.7%) co-occurred with other research methods most of the time rather than appearing alone.

### 3.4. Research domain

HCI researches cover a large variety of research domains. To elicit the representative domains for our analysis, we

referred to the ACM SIGCHI’s categories of first-level sub-committees and generated 12 research domains: interactive techniques, VR/AR, sensing, fabrication, understanding people, user experience, accessibility, health, games and play, learning/education/families, privacy and security, and others.

Figure 7 showed the distribution of publications with different research domains. We found the proportion of different domains was generally well-distributed, indicating the versatile research interest of China’s HCI community. The top 5 most frequently researched topics are sensing (22.7%), interactive techniques (15.6%), user experience (14.9%), understanding people (10.1%), and VR/AR (7.2%), adding up to 70.5%.

### 3.5. Research metric

Regarding the research metric, most of the publications focused on understanding, discussing, or improving the interaction performance (45.5%), usability (24.7%), user experience (24.6%), and privacy (3.7%) of certain HCI tasks or application scenarios (see Figure 8). Recalling the research topics in the previous section, these numbers shed light on the research value of China’s HCI community: (1) interaction performance (associated with computational interaction tasks) and human factors (affecting the usability and the experience) are most valued; (2) researchers generally paid less attention to privacy and other metrics in evaluation, which may be specific to the custom. However, there were still some works that explored privacy issues (e.g., Gorm and Shklovski 2016). And with the introduction of

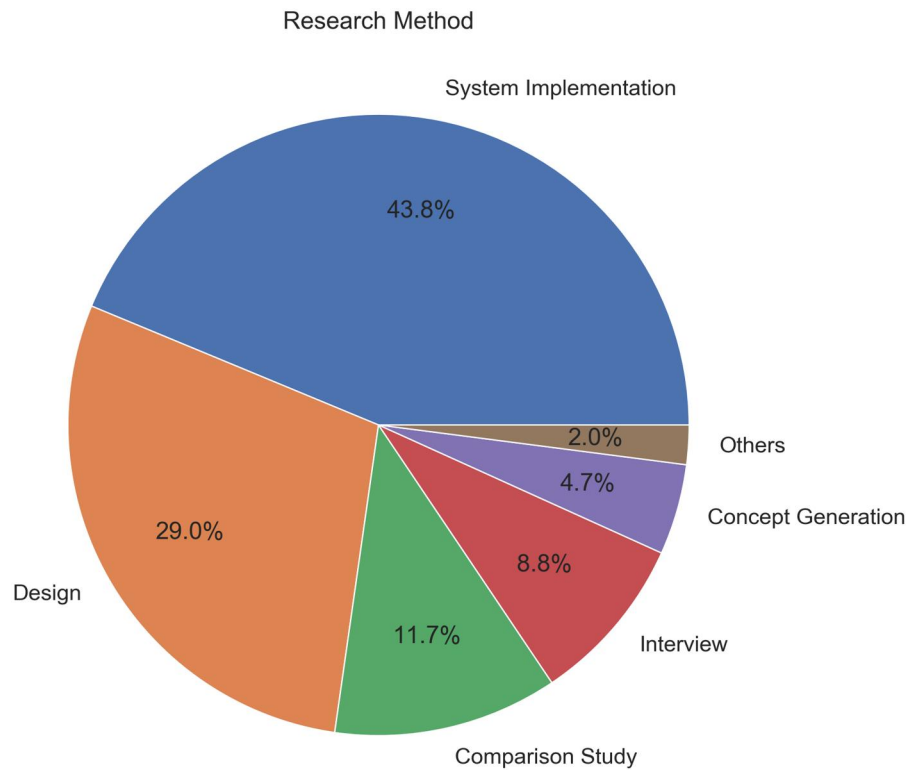


Figure 6. Distribution of the publications with different research methods.

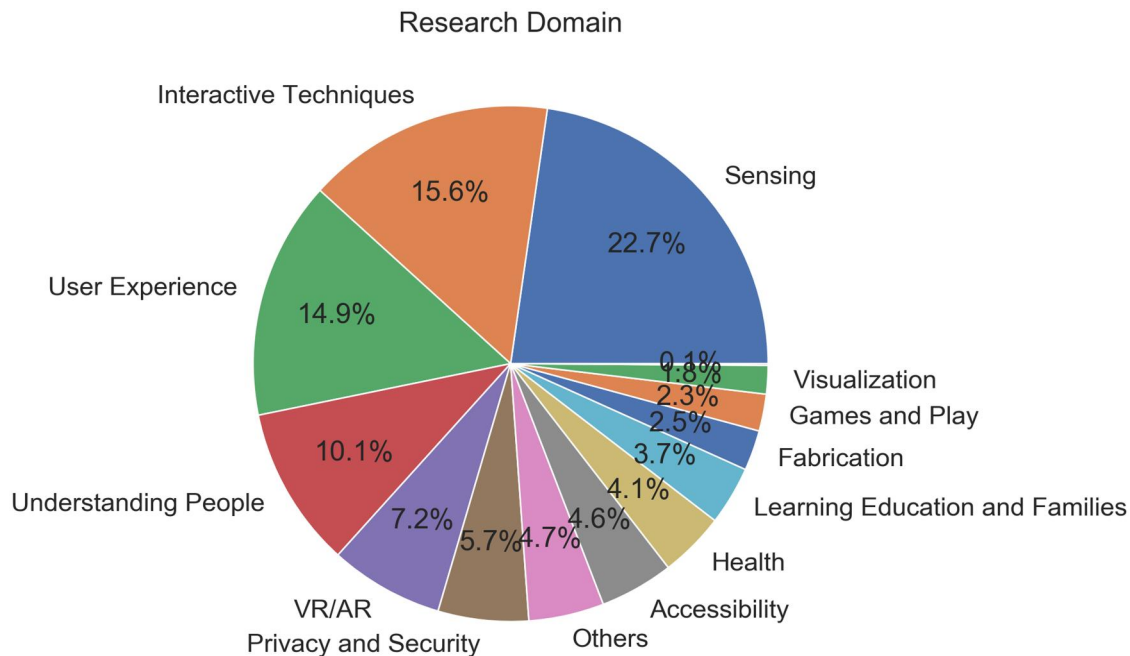


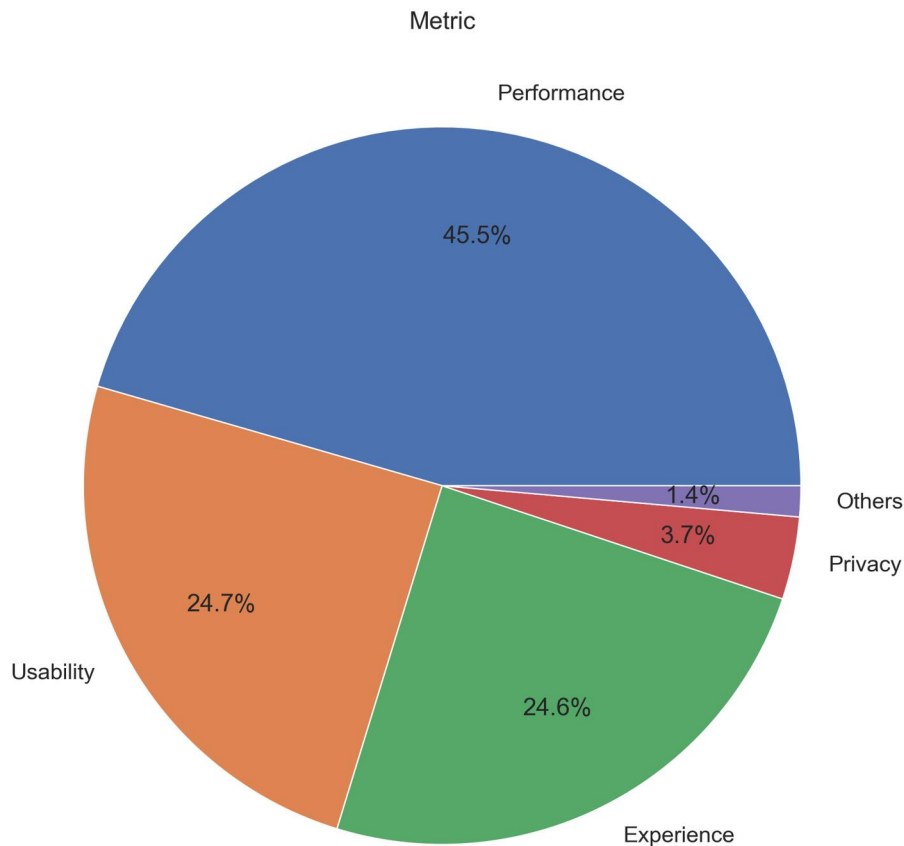
Figure 7. Distribution of the publications with different research domains.

privacy-preserving laws in recent years, this may become a fast-growing research field in China.

#### 4. Research application

Human-computer interaction is the decisive technology for user terminal performance, and natural interaction is the development trend. Due to the user's state being relaxed and the intention expression is not strict in natural interaction,

the serious problems of high data noise and low input precision are caused, and the interaction efficiency needs to be improved urgently. Many relevant scholars continued to carry out in-depth research on principles and technologies in a targeted manner, breaking through the key problems of "inaccurate" finger input, "unclear" action intentions, and "insufficient understanding" of words in natural interaction and realized a variety of user terminals and systems. Breakthroughs have been made in natural interaction



**Figure 8.** Distribution of the publications with different research metrics.

technologies, such as intelligent text and voice input methods, full-screen mobile phone mistaken touch recognition, smart glasses gesture interaction, etc.

Typical technological innovations and applications include:

1. X. Yi et al. proposed an intelligent text input method based on the Bayesian model of finger motion control ability, and the influence of input interface size, input speed, visual attention, and other factors on the user's input motion control ability on the touch screen is quantified, and the language model is used to infer the user's input intention effectively solves the problem of inaccurate finger input caused by "fat" fingers and visual distraction. Furthermore, the method is integrated into the input methods of various terminals such as mobile phones and tablets, which significantly improves the error correction ability of text input. The input accuracy of the soft keyboard of mobile phones is more than 10% higher than that of Google, and the speed of intelligent text input without visual aiming is higher than that of tablet computers. Up to 2.6 times that of Apple's iPad, and 2.4 times that of Microsoft Hololens on large screens and head-mounted displays.
2. Y.C. Shi et al. proposed an accurate action intention recognition method based on the motion parameter time series model, and the correlation between the pre-, synchronous, and post-action and the intentional input action in time and space is established, which supports

the acquisition of small-scale training data sets. The algorithm model accurately distinguishes the user's intentional or unintentional input solving the problem of judging the interaction intention on the continuous perception interface. The virtual object grasping technology in VR that does not require visual attention based on this method can reduce the target acquisition time by 20%; compared with the anti-mistouch ability of the full-screen mobile phone touch intention discrimination algorithm integrated into the Huawei mobile phone operating system more than 12 times lower than the then-latest models of Samsung (Galaxy S10) and Apple phones (iPhone X).

3. J. Jia et al. proposed an optimization method for speech intent understanding based on weakly supervised recognition of paralinguistic information, and the world's largest non-performative emotional stress public corpus is constructed. In the "voice wake up" scenario, the accuracy of user intent understanding has increased by 7%, and the technology has been integrated into Sogou's voice input series products. Sogou's voice input has been invoked nearly 800 million times a day on average, accounting for 70% of the domestic voice input service market, ranking first in the country.

In recent years, the field of human-computer interaction technology has been developing vigorously in China. The application has been deployed on the interactive interface of smartphones, AR glasses, tablet computers, text and voice

input methods, voice search, interactive large screens, intelligent classrooms, intelligent command rooms, etc. The technical performance is significantly better than that of Google, Apple, Samsung, and Microsoft, helping the independent innovative products gradually occupy the market advantage at home and abroad.

## 5. Conclusions

In this paper, we surveyed the research and innovation in the field of HCI in China in the past 10 years, with the aim to explore the emerging trends and implications for the whole community. We sought to answer the following questions: (1) How has the research and innovation in the field of HCI in China evolved in the past 10 years? (2) What are the reasons behind the development of HCI research in China? (3) What are the main research topics and methods for Chinese researchers? (4) What implications can be drawn from the development of HCI in China? In this section, we summarize the answers to these questions, provide implications, and discuss future trends for the research community.

### 5.1. Evolution of HCI in China

Today's HCI landscape in China has transformed significantly compared to a decade ago. The significant increase in top-tier HCI venues reflects this change. The research topics have expanded from limited areas such as *user interface techniques* to a larger scope including *understanding and modeling human, user interface techniques, context awareness, user acceptance and performance with technology, user experience design, human-AI interaction, and domain applications including healthcare, e-commerce, education, etc.* We believe that China's HCI development has mirrored its rapid technological advancement and economic growth. As China's technology sector burgeoned, so did its HCI landscape, shifting from a computer system that can communicate with humans ("usable") towards more user-centered design principles and practices ("user friendly"). This transition marked a significant evolution in the approach to HCI in China, moving beyond basic functionality to create systems that are not only easy to use but also deeply resonate with users' needs and preferences. Furthermore, China's significant investment in artificial intelligence and mobile technology has propelled novel HCI research and applications. This trajectory not only reflects China's broader technological aspirations but also underscores the country's commitment to shaping a user-centric digital future. As China continues to advance in this field, its contributions are likely to have substantial implications for the global understanding and development of HCI.

### 5.2. Implications and reflections

This paper highlights key implications for HCI researchers, emphasizing the importance of collaboration in research and innovation. Collaboration manifests in two forms:

industry-academia partnerships and interdisciplinary teamwork. Industry links are vital as companies, in direct contact with end-users, offer invaluable insights into research problems and practical applications of research outcomes. This collaboration narrows the gap between research prototypes and market-ready products. Thus, joint research projects or shared laboratories are highly recommended for HCI researchers and practitioners.

Moreover, HCI's interdisciplinary nature necessitates a diverse research team, including expertise from computer science, psychology, social sciences, and more. Such a mix is critical for HCI's sustained growth, fostering a collaborative environment where varied perspectives merge.

Additionally, effective higher-level management, encompassing institutional policies and research community organization, is crucial for fostering research and innovation. Our analysis shows that researcher-company collaboration benefits significantly from institutional support. Equally important is the research community's structure, including conferences and academic events, which are instrumental in connecting researchers across various fields, particularly benefiting junior researchers. Therefore, creating and strengthening a collaborative network that integrates industry, academia, and research, grounded in interdisciplinary cooperation among government, research institutions, universities, enterprises, and research associations, is an essential prerequisite for advancing and developing the field of human-computer interaction.

Furthermore, it is also important for educational system to facilitates the growth of integrated disciplines of human-computer interaction, encompassing computer science, psychology, biomedical engineering, and industrial design. Such an effort is necessary for the development of these disciplines, and cultivation of a high-caliber talent pool. In the realm of talent development, there should be a push for interdisciplinary graduate studies, dismantling barriers between disciplines, and a focus on nurturing students' capacities in interdisciplinary, systematic thinking, innovation, application, and collaboration (X. Wei & Liezhong, 2018, 2020).

Finally, it is urgent to develop standards and principles for human-computer interaction design meeting the need of intelligent systems which also align with the emotional and cultural context of the Chinese population. Especially in key application areas, we endeavor to develop pertinent specifications and standards for interaction design, seamlessly integrating them into various stages of product design, assessment, and supervision (X. Wei & Liezhong, 2018, 2020).

### 5.3. Opportunities for diverse contributions

While HCI research in China has seen rapid growth, particularly in computational aspects, there's vast potential for Chinese researchers to diversify. This potential is not only a testament to the country's technological advancements but also a reflection of its diverse cultural and social fabric. The rapid growth of the HCI field in China opens doors for a

multitude of contributions from various sectors and disciplines. One significant opportunity lies in the intersection of HCI and traditional Chinese cultural elements. By integrating cultural aesthetics and philosophies into HCI design, there's a chance to create unique and culturally enriched user experiences. This fusion not only caters to the domestic market but also offers global audiences a glimpse into Chinese culture through technology. Another area of opportunity is in the realm of education and research. With China's increasing emphasis on technology and innovation, there is a growing need for educational programs and research initiatives focused on HCI. This will not only nurture local talent but also attract international scholars and practitioners, fostering a global exchange of ideas and innovations. Moreover, China's vast and diverse population presents a unique opportunity to explore HCI in the context of accessibility and inclusivity. Developing technologies that cater to different age groups, abilities, and social backgrounds can lead to more inclusive digital solutions. This approach aligns with the global movement towards creating technology that is accessible to all, further positioning China as a leader in responsible and inclusive tech development. In addition, the burgeoning start-up culture in China provides a fertile ground for innovative HCI applications. Entrepreneurs and tech companies can leverage the latest advancements in AI, machine learning, and mobile technologies to create novel user experiences and interfaces.

#### **5.4. Industry-academia synergy**

The relationship between industry and academia in China's HCI development has been mutually beneficial and increasingly interdependent. On one hand, academic research in HCI provides theoretical foundations and innovative methodologies that fuel industrial applications. Universities and research institutes in China are at the forefront of exploring new paradigms in HCI, delving into areas like user experience design, user interface techniques, and human-AI interaction, etc. These academic pursuits not only contribute to the body of knowledge but also offer fresh insights and technologies that can be adopted by the industry. On the other hand, the industry provides real-world applications and practical challenges that guide academic research. The rapid growth of China's tech industry, with giants like Huawei, Alibaba, and Tencent, offers a rich landscape for HCI application. These companies not only implement cutting-edge HCI technologies but also provide valuable feedback and data that inform academic research. Their involvement in HCI extends to funding research projects and collaborating on joint ventures with academic institutions. This close interaction ensures that academic research remains aligned with market needs and technological advancements. Furthermore, this synergy is nurtured through various initiatives such as industry-sponsored labs, collaborative research projects, and joint conferences. These initiatives create platforms for knowledge exchange, professional networking, and the co-creation of innovative solutions. The "Industry-Academia Synergy" in China's HCI sector is a driving force

behind the country's technological innovation. By combining the exploratory and theoretical strength of academia with the practical and application-oriented approach of the industry, China is positioning itself as a leader in the global HCI community. This collaboration not only accelerates the development of new technologies but also ensures that these innovations are grounded in real-world usability and effectiveness.

#### **5.5. Future trends**

Human-Computer Interaction (HCI) technology is at the forefront of computer science, continually breaking new ground in user-computer interaction and dramatically expanding the user centered scenarios. Currently, computing has evolved from desktop to mobile and is now entering a new phase characterized by the integration of humans, cyberspace, and physical space, driven by the Internet of Things (IoT). In this "ternary space," efficient and natural information exchange between humans, cyberspace, and physical space is key. This technology is vital for making diverse applications in ternary space accessible.

However, challenges persist in supporting user interaction in unstructured environments. Overcoming these requires the development of natural and seamless human-computer interactions, involving aspects like modeling interaction capabilities, deducing interaction intentions, optimizing interaction pathways, and building integrated development environments (IDEs) for mutual scenes. Further, as cyberspace becomes more sophisticated, we can expect to see more advanced and seamless digital interactions. This could include more immersive virtual environments and improved interfaces that allow for more natural and intuitive user interactions.

HCI is shifting towards making machines more adaptable to human nature and capabilities in manipulation, perception, and cognition. The emerging focus is on Human-Machine Hybrid Intelligence, where cognitive mechanisms and machine intelligence systems are tightly coupled. This integration enables mutual adaptation and collaboration, fostering a two-way exchange of information and knowledge, and ultimately enhancing intelligent decision-making capabilities.

Furthermore, the HCI in intelligent era should also take human factors as a key variable in human-computer interaction. Especially in complex human-machine systems for aviation, aerospace, nuclear plants, and transportation, operators' cognitive processes and psychological status are still essential components to be understood by the designer of intelligent system.

Another important trend is to enhance human-computer cooperation from social, cognitive, and emotional perspectives of user-centered framework. Especially over the past decade, the transformation from traditional Human-Computer interaction to a more collaborative "human-machine teaming" cooperation requires further development of Human-Centered AI (HCAI) framework and research model of Human-AI interaction (W. Xu, 2019; W. Xu, Ge,

et al., 2021). The popularity of mobile computing and the emergence of new technologies such as VR have brought new interaction environments, and put forward new requirements for the design of HCI interfaces (H. Wang et al., 2018). Therefore, it is necessary to carry out research on new interaction paradigms and metaphors to guide the design and application of micro HCI. In the wave of intelligent manufacturing, HCI professionals should use various new technologies to promote user experience and satisfaction in many emerging areas such as airborne intelligent systems, autonomous vehicles, and humanoid robots.

Another significant trend is the customization of HCI design to reflect China's rich cultural context. This involves designing interfaces and interactions that not only cater to the functional needs of users but also resonate with their cultural preferences and values. Such culturally-aware HCI designs can enhance user engagement and satisfaction, particularly in a diverse country like China.

As China's HCI research and development continue to grow, there is an opportunity for increased international collaboration and contribution to the global HCI discourse. This could lead to a more diverse and inclusive international HCI community, with China playing a key role in shaping global standards and practices. Further, with increasing global awareness about sustainability and ethics in technology, future HCI development in China is likely to incorporate sustainable design practices and ethical considerations. This could involve creating energy-efficient interfaces, ensuring user privacy and data security, and addressing the ethical implications of AI and automation in HCI.

In summary, HCI in China is expected to be characterized by a blend of technological innovation, cultural customization, user-centric design, sustainability, and global collaboration. These trends not only align with China's broader technological ambitions but also reflect its commitment to creating a more user-friendly, inclusive, and responsible digital future.

## Disclosure statement

No potential conflict of interest was reported by the author(s).

## Notes

1. <https://www.whatthehci.com/chi22/countries>
2. International Conference on Pervasive Computing (Pervasive) is the older conference on pervasive computing before 2012. International Symposium on Wearable Computers (ISWC) is the short paper track of Ubicomp. Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies (IMWUT) is the journal series since 2017 archiving long papers from the Ubicomp conference.
3. [https://www.ccf.org.cn/Academic\\_Evaluation/By\\_category/](https://www.ccf.org.cn/Academic_Evaluation/By_category/)
4. <https://csrankings.org/>
5. <https://dblp.org/>
6. <https://csrankings.org/#/fromyear/2013/toyear/2023/index?chi&asia>
7. <http://ueberproduct.de/en/4-types-of-research/>

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