User Experience for Multi-Device Ecosystems: Challenges and Opportunities

Ru Zhang
Consumer Business Group, Huawei
China
zhangru@huawei.com

Yuanchun Shi
Tsinghua University
China
shiyc@tsinghua.edu.cn

Björn Schuller
Imperial College London & University
of Augsburg
Germany
schuller@informatik.uni-
augsburg.de

Elisabeth André
University of Augsburg
Germany
andre@informatik.uni-augsburg.de

Sharon Oviatt
Monash University
Australia
sharon.oviatt@monash.edu]

Aaron Quigley
University of New South Wales
Australia
a.quigley@unsw.edu.au

Nicolai Marquardt
University College London
UK
nicolai.marquardt@acm.org

Ilhan Aslan
German Research Center, Huawei
Germany
ilhan.aslan@huawei.com

Ran Ju
Consumer Business Group, Huawei
China
juran@huawei.com

ABSTRACT

Smart devices have pervaded every aspect of humans' daily lives. Though single device UX products are relatively successful, the experience of cross-device interaction is still far from satisfactory and can be a source of frustration. Inconsistent UI styles, unclear coordination, varying fidelity, pairwise interactions, lack of understanding intent, limited data sharing and security, and other problems typically degrade the experience in a multi-device ecosystem. Redesigning the UX, tailored to multi-device ecosystems to enhance the user experience, turns out to be challenging but at the same time affording many new opportunities. This workshop brings together researchers, practitioners and developers with different backgrounds, including from fields such as computationally design, affective computing, and multimodal interaction to exchange views, share ideas, and explore future directions on UX for distributed scenarios, especially for those heterogeneous cross-device ecosystems. The topics cover but are not limited to distributed UX design, accessibility, cross-device HCI, human factors in distributed scenarios, user-centric interfaces, and multi-device ecosystems.

CCS CONCEPTS

• **Human-centered computing → Interaction design**; **Collaborative and social computing**; **Human computer interaction (HCI)**.

KEYWORDS

multi-device ecosystem, cross-device interaction, user experience

1 BACKGROUND

In recent years smart devices and ecosystem hardware have experienced not only an explosive growth but also an enormous diversification. All kinds of smart devices (e.g. watch, earphone, and smart speaker etc.) are productized for customized requirements and become increasingly popular in people's daily lives. For example, IDC reports that the worldwide wearables market will be nearly 500 million units by 2023 [4], and the smart home devices shipments will be more than 1.39 billion in 2023 [3]. With the popularity of diverse smart devices, it is natural for users to utilize proper devices for different tasks in a multi-device environment, i.e. to interact with a cross-device ecosystem. However, there are many difficulties and challenges in designing a multi-device UX including design (varying device characteristics, fidelity and foreground vs background interaction), technological (binding, heterogeneity, development support, sensing, security etc.), social (privacy, social acceptability, participation, exclusion, engagement), perceptual and physiological (human attention, overload, multi-device correspondence, coordination, switching) factors. From the perspective of end users, typical pain points in cross-device interaction are, for example, differences in operating systems and user interfaces, poor ability of data sharing, lack of understanding intent and so on.

Many previous efforts have been made to the topic of cross-device interaction. The major focus areas include multi-device collaboration [1, 15, 17, 24], distributed and adaptive interfaces [6, 20, 21, 26], middleware [13, 15, 27], and system ecologies [11, 18]. Several surveys [2, 9, 25] have made comprehensive and detailed review of the cross-device HCI topic, and a few recent workshops [5, 7, 10, 12, 16, 19, 22, 23] paid special interest to or related to the subject. Besides academic research, the topic has attracted many industrial interests and a few multi-device UX products [8, 14] have been released.

We attempt to review the topic from a novel perspective of user experience for multi-device environment. On the one hand, today's popularity of smart devices have enabled multi-device UX services that were impractical before. On the other hand, cross-device UX still faces great challenges. Arguably, one can barely get pair-wise device interactions operating reliably outside the labs, and the notion of an ecosystem still seems far away. The interaction pathways and permutations explode rapidly as one's interaction begins to depend on one, two, or more devices. As a result, it's difficult for a UX designers to understand the expectations to craft good user experiences or effectively testing them. Sadly, most devices and systems are still seen as individual disconnected islands of interaction, thus users will struggle to even use their multiple devices in a sequential manner, such as (i) setting up a running route and music on a tablet at home, (ii) seamlessly using a smartwatch and earbuds during running, and (iii) doing modifications on a smartphone or the smartwatch mid-route.

Different from the prior research which mainly focused on cross-device interaction techniques, this workshop will concentrate on the *user experience* in a multi-device environment, aiming to attract researchers from multiple disciplines. We believe that a multi-device ecosystem is relevant for many domains and applications, including sports, games, dating, and smarthomes. For any domain and application the following directions will be given priority:

- Models, methodologies and tools for multi-device UX design
- Intent, emotion, and other social factors affecting UX in multi-device scenarios
- Feelings of control, autonomy, competence, connectedness, resonance etc. in multi-device ecosystem
- Future intelligent and multi-modal UIs in a multi-device scenario
- Evaluation methods and challenges for multi-device UX
- Interactive multimedia for cross-device environment
- UX adaptation and migration techniques
- Multiple users and users with different abilities in a multi-device ecosystem
- Contextual multi-device UX studies

2 ORGANIZERS

The organizing team is formed of experts with international, multi-disciplinary (e.g. distributed UX, affective computing, multimodal interaction, ubiquitous computing and so on), academic and industrial background, and experienced in workshop organizing. The brief introduction of the organizers are as follows.

Ru Zhang is a chief research scientist of the Software Technology Planning & Pre-Research department at Huawei Device, Co., Ltd.

She is leading the Distributed UX group working on cross-device interaction, human factors engineering and interactive multimedia. She has incubated many successful UX products such as Cast Engine and HiSuite for Huawei smartphone.

Yuanchun Shi is a Changjiang distinguished professor of the Department of Computer Science and the director of HCI & Media Integration Institute. She was the dean of Global Innovation eXchange (GIX) Institute of Tsinghua University. She had chaired several conferences like the ACM Ubicomp 2011. Her recent HCI contributions includes user behavior modelling, intelligent interaction techniques for mobile phones, large displays, and VR/AR headsets.

Björn Schuller is a full professor of artificial intelligence and the head of GLAM at Imperial College London/UK, full professor and chair of Embedded Intelligence for Health Care and Wellbeing at the University of Augsburg/Germany, co-founding CEO and current CSO of audEERING. He has served as General and Program Chair of several conferences including ACM ICMI and Interspeech. His research interests include machine learning, audiovisual signal processing, human-computer/robot-interaction, affective computing. His personal page is http://www.schuller.one/.

Elisabeth André is a full professor of Computer Science and founding Chair of Human-Centered Multimedia at the Faculty of Applied Informatics of Augsburg University. She is a member of the SIGCHI Academy and she has served as a General and Program Co-Chair of top-tier ACM SIGCHI conferences, such as ACM International Conference on Intelligent User Interfaces (IUI) in 2003 and 2011 and ACM International Conference on Multimodal Interfaces (ICMI) in 2016. Her research lies at the intersection between HCI and Affective Computing and aims to enhance the users' experience by incorporating affect as a key element into a user interface. She is the Editor-in-Chief of IEEE Trans. on Affective Computing. Her personal page is http://elisabethandre.de.

Sharon Oviatt is a professor of HCI and Creative Technologies at Monash University. She is the Director of Human-Computer Interaction and Human-Centred A.I group, and currently serves as the President and Chair of the Board of Directors of Incaa Designs, a non-profit with the aim of researching and designing new educational interfaces. Her main areas of research are human-centered, multimodal, mobile and educational interfaces.

Aaron Quigley is a full professor of Human Computer Interaction and head of school in Computer Science and Engineering in the University of New South Wales in Sydney, Australia. His research interests include discreet computing, global HCI, pervasive and ubiquitous computing and information visualisation. He has previously organised workshops at CHI and AVI on multi-device interaction. His personal page is https://aaronquigley.org/.

Nicolai Marquardt is an associate professor in Physical Computing at the University College London. At the UCL Interaction Centre he works on projects in the research areas of ubiquitous computing, cross-device interaction, interactive surfaces, sensor-based systems, prototyping toolkits and physical user interfaces. He is co-author of the Sketching User Experiences Workbook (Morgan Kaufmann 2011) and Proxemic Interactions textbook (Morgan & Claypool 2015). His personal page is http://www.nicolaimarquardt.com/.

Ilhan Aslan is an HCI Expert at Huawei's German Research Center. He is leading a group in the Device Software Lab. He has a background in computer science and artificial intelligence and holds a PhD from the Center for HCI at Salzburg University. Ilhan has organized workshops at, for example mobile HCI and nordiCHI. His research focus is on limitations and future potentials of consumer devices. He utilizes embodied, multimodal, and intelligent interaction techniques to expand interaction spaces and create wellbeing sensitive UX.

Ran Ju is a research scientist of the Software Technology Planning & Pre-Research department at Huawei Device, Co., Ltd. He holds a PhD in computer science and his doctoral research is mainly on multimedia. Currently he is focusing on the research of interactive multimedia, e.g. AI based UX design and cross-device visual content (including GUI, image and video) adaptation.

3 WEBSITE

We have the website of this workshop at http://ux4mde.net. The web pages mainly contain the detailed introduction of this workshop and organizers, call for papers, submission guidelines, and papers upon acceptance. Important messages of key events will be posted on the main page in advance.

4 PRE-WORKSHOP PLANS

Before the workshop, we will first work on advertising the CFP to related researchers and soliciting high quality and original submissions. Since our topic is related to multiple directions, we will distribute the call for papers to multi-disciplinary email lists including HCI, ubiquitous computing, AI etc. Besides, we will post the workshop through social media, the organizers' personal circles, key research groups, and upcoming conferences.

After CFP and collection of submissions, we will invite related researchers to give high quality reviews. More than three reviewers will be assigned to each paper. The organizers will make a comprehensive consideration of all the reviews and select a final list to present at the workshop. After that, we will make a detailed program of the workshop. A flyer will be designed and distributed at the HCI venue.

5 WORKSHOP STRUCTURE

We plan to hold an online workshop of 4 hours flexibly on either May 8th or 9th. As the workshop will be entirely online, the date will be set considering all participants' time zones. The number of participants will be limited to 25. An exemplar schedule is shown in Table 1. Note the start time would be changed and finalized after paper acceptance. The detail of each stage is as follows.

Welcome and introduction to the workshop. The organizers will give a brief welcome and introduction of the workshop's agenda and goals.

Paper presentation. At this stage the authors will present their works in the form of oral presentation. Each presentation will be assigned with 5 minutes. The authors are encouraged to show videos or demos of their work. Each session will be chaired by a different organizer, and start with a brief introduction of the authors.

Schedule	Activity
14:00	Welcome and introduction to the workshop
14:10	Session 1: chaired by Organizer A (paper 1 - 4)
14:40	Questions and discussion about paper 1 - 4
14:50	Session 2: chaired by Organizer B (paper 5 - 8)
15:20	Questions and discussion about paper 5 - 8)
15:30	Break
15:40	Session 3: chaired by Organizer C (paper 9 - 12)
16:10	Questions and discussion about paper 9 - 12)
16:20	Group discussion and troubleshooting: chaired by Organizer D
17:00	Break
17:10	Case study and idea sharing: Chaired by Organizer E
17:50	Conclusion
18:00	Close

Table 1: Timeline of the workshop. The start time would be flexible during May 8-9.

Questions and discussion about papers. Participants give questions and discuss about the papers presented at the session. This stage will be limited to 10 minutes.

Group discussion and troubleshooting. At this stage, we will have a group discussion involving all participants. The organizer will give 3 to 5 topics for discussion. Participants will freely exchange views about the topics and discuss about the challenging problems with the others.

Case study and idea sharing. The organizers will introduce a few use cases from both academia and industrial society. Each case includes a description of the domain and the challenge to take up. Participants will work together to refine the cases, give suggestions on the challenges, and further explore new ideas towards premium multi-device UX.

Conclusion. The organizers will make a summary of the workshop. Participants will remark a few directions for future study. Minutes will be posted on the website after the workshop.

6 DISTANCE ENGAGEMENT

We will provide a videoconferencing link (e.g. Zoom, WebEx etc.) for the workshop. We will schedule proper time to tackle the time differences of different participants. The details of the schedule and remote access guidance will be posted on the workshop website after paper acceptance.

7 POST-WORKSHOP PLANS

Summaries and photos of the workshop will be posted on the workshop website. The results of the workshop will be communicated to the larger HCI community by submitting a summary to a magazine (e.g., ACM Interactions). We also consider to prepare a special issue in a selected journal (e.g., TOCHI) following the conference. All the workshop participants will be invited to submit an extended article of their submission to the special issue.

8 CALL FOR PARTICIPATION

Smart devices have pervaded every aspect of humans' daily lives, with an increasing number of personal devices – such as smartphone, tablets, watches, smart speakers, and laptops. With this emerging diverse multi-device ecology of smart devices, it remains challenging for users to best utilize devices for different tasks, partially due to inconsistent UI styles, unclear coordination, varying fidelity, lack of understanding intent, or limited data sharing and security. Therefore, in this workshop we want to address challenges for redesigning the UX tailored to multi-device ecosystems, to enhance the user experience and leverage new opportunities for cross-device UX design.

Themes and Goals

This workshop aims to serve as a meeting point for worldwide researchers of multiple fields including HCI, ubiquitous computing, AI, physiology etc. to share new ideas and experiences, discuss about the challenges and explore future directions related to distributed UX. We invite submissions on a wide range of multi-device UX research topics, including, but not limited to:

- Models, methodologies and tools for multi-device UX design
- Intent, emotion and other social factors affecting UX in multi-device scenarios
- Feelings of control, autonomy, competence, connectedness, and resonance in multi-device ecosystem
- Future intelligent and multi-modal UIs in a multi-device scenario
- Evaluation methods and challenges for multi-device UX
- Interactive multimedia for cross-device environment
- UX adaptation and migration techniques
- Multiple users and users with different abilities in a multi-device ecosystem
- Contextual multi-device UX studies

Submissions

We solicit stimulating, original, previously unpublished ideas on completed work, position papers, and/or work-in-progress papers. Potential participants are asked to submit 4-6 page position papers in the form of ACM Extended Abstracts. Please submit your paper via the online Precision Conference Solutions. Submissions will be accepted based on the originality and relevance of their chosen topic, as well as the potential contribution to the workshop. Papers will be peer reviewed by the workshop's Program Committee.

On the Day

The number of participants is restricted to 25. At least one author of each accepted paper must register for the workshop and for one day of the conference itself. Participants will be invited to present a position statement at the workshop. We further encourage papers that propose new research directions or could generate lively debate at the workshop.

Important Dates

- Release call for workshop position papers: 15 December, 2020
- Submission deadline: 21 February, 2021
- Acceptance notification: 11 March, 2021
- Camera-ready deadline: 16 March, 2021
- Workshop day: Saturday 8 May or Sunday 9 May, 2021

REFERENCES

[1] Frederik Brudy, Joshua Kevin Budiman, Steven Houben, and Nicolai Marquardt. 2018. Investigating the role of an overview device in multi-device collaboration. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. Association for Computing Machinery, New York, NY, USA, 1–13.

[2] Frederik Brudy, Christian Holz, Roman Rädle, Chi-Jui Wu, Steven Houben, Clemens Nylandsted Klokmose, and Nicolai Marquardt. 2019. Cross-device taxonomy: survey, opportunities and challenges of interactions spanning across multiple devices. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*. Association for Computing Machinery, New York, NY, USA, 1–28.

[3] International Data Corporation. 2019. Worldwide Smart Home Devices Forecast to Maintain Steady Growth Through 2023, Says IDC. https://www.idc.com/getdoc.jsp?containerId=prUS45540319 Accessed Sep 23, 2019.

[4] International Data Corporation. 2019. Worldwide Wearables Market to Top 300 Million Units in 2019 and Nearly 500 Million Units in 2023, Says IDC. https://www.idc.com/getdoc.jsp?containerId=prUS45737919 Accessed Dec 16, 2019.

[5] Alan Dix, Aaron Quigley, Sriram Subramanian, and Lucia Terrenghi. 2010. Workshop on coupled display visual interfaces. In *Proceedings of the International Conference on Advanced Visual Interfaces*. Association for Computing Machinery, New York, NY, USA, 408–410.

[6] Niklas Elmqvist. 2011. Distributed user interfaces: State of the art. In *Distributed User Interfaces*. Springer-Verlag London, London, UK, 1–12.

[7] Joel Fischer, Martin Porcheron, Andrés Lucero, Aaron Quigley, Stacey Scott, Luigina Ciolfi, John Rooksby, and Nemanja Memarovic. 2016. Collocated interaction: new challenges in 'same time, same place' research. In *Proceedings of the 19th ACM Conference on Computer Supported Cooperative Work and Social Computing Companion*. Association for Computing Machinery, New York, NY, USA, 465–472.

[8] Google. 2018. https://flutter.dev/.

[9] Steven Houben, Nicolai Marquardt, Jo Vermeulen, Clemens Klokmose, Johannes Schöning, Harald Reiterer, and Christian Holz. 2017. Opportunities and challenges for cross-device interactions in the wild. *Interactions* 24, 5 (2017), 58–63.

[10] Steven Houben, Nicolai Marquardt, Jo Vermeulen, Johannes Schöning, Clemens Klokmose, Harald Reiterer, Henrik Korsgaard, and Mario Schreiner. 2016. Cross-Surface: Challenges and Opportunities for 'bring your own device' in the wild. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems*. Association for Computing Machinery, New York, NY, USA, 3366–3372.

[11] Steven Houben, Paolo Tell, and Jakob E Bardram. 2014. Activityspace: Managing device ecologies in an activity-centric configuration space. In *Proceedings of the Ninth ACM International Conference on Interactive Tabletops and Surfaces*. Association for Computing Machinery, New York, NY, USA, 119–128.

[12] Steven Houben, Jo Vermeulen, Clemens Klokmose, Nicolai Marquardt, Johannes Schöning, and Harald Reiterer. 2015. Cross-surface: Workshop on interacting with multi-device ecologies in the wild. In *Proceedings of the 2015 International Conference on Interactive Tabletops & Surfaces*. Association for Computing Machinery, New York, NY, USA, 485–489.

[13] Maria Husmann, Michael Spiegel, Alfonso Murolo, and Moira C Norrie. 2016. UI testing cross-device applications. In *Proceedings of the 2016 ACM International Conference on Interactive Surfaces and Spaces*. Association for Computing Machinery, New York, NY, USA, 179–188.

[14] Apple Inc. 2019. SwiftUI. https://developer.apple.com/xcode/swiftui/.

[15] Clemens N Klokmose, James R Eagan, Siemen Baader, Wendy Mackay, and Michel Beaudouin-Lafon. 2015. Webstrates: shareable dynamic media. In *Proceedings of the 28th Annual ACM Symposium on User Interface Software & Technology*. Association for Computing Machinery, New York, NY, USA, 280–290.

[16] Bart Knijnenburg, Paritosh Bahirat, Yangyang He, Martijn Willemsen, Qizhang Sun, and Alfred Kobsa. 2019. IUIoT: intelligent user interfaces for IoT. In *Proceedings of the 24th International Conference on Intelligent User Interfaces: Companion*. Association for Computing Machinery, New York, NY, USA, 139–140.

[17] Ekaterina Kurdyukova, Matthias Redlin, and Elisabeth André. 2012. Studying user-defined iPad gestures for interaction in multi-display environment. In *Proceedings of the 2012 ACM international conference on Intelligent User Interfaces*. Association for Computing Machinery, New York, NY, USA, 93–96.

[18] Michal Levin. 2014. *Designing multi-device experiences: An ecosystem approach to user experiences across devices*. " O'Reilly Media, Inc.", Sebastopol, CA, USA.

[19] Andrés Lucero, Aaron Quigley, Jun Rekimoto, Anne Roudaut, Martin Porcheron, and Marcos Serrano. 2016. Interaction techniques for mobile collocation. In *Proceedings of the 18th International Conference on Human-Computer Interaction with Mobile Devices and Services Adjunct*. Association for Computing Machinery, New York, NY, USA, 1117–1120.

[20] Sangeun Oh, Ahyeon Kim, Sunjae Lee, Kilho Lee, Dae R Jeong, Steven Y Ko, and Insik Shin. 2019. FLUID: Flexible User Interface Distribution for Ubiquitous Multi-device Interaction. In *MobiCom'2019*. ACM, Association for Computing Machinery, New York, NY, USA, 42.

[21] Seonwook Park, Christoph Gebhardt, Roman Rädle, Anna Maria Feit, Hana Vrzakova, Niraj Ramesh Dayama, Hui-Shyong Yeo, Clemens N Klokmose, Aaron Quigley, Antti Oulasvirta, et al. 2018. Adam: Adapting multi-user interfaces for collaborative environments in real-time. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. Association for Computing Machinery, New York, NY, USA, 1–14.

[22] Martin Porcheron, Andrés Lucero, Aaron Quigley, Nicolai Marquardt, James Clawson, and Kenton O'hara. 2016. Proxemic Mobile Collocated Interactions. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems*. Association for Computing Machinery, New York, NY, USA, 3309–3316.

[23] Aaron Quigley, Alan Dix, Miguel Nacenta, and Tom Rodden. 2012. Workshop on Infrastructure and Design Challenges of Coupled Display Visual Interfaces: in conjunction with Advanced Visual Interfaces 2012 (AVI'12). In *Proceedings of the International Working Conference on Advanced Visual Interfaces*. Association for Computing Machinery, New York, NY, USA, 815–817.

[24] Norbert A Streitz, Jörg Geißler, Torsten Holmer, Shin'ichi Konomi, Christian Müller-Tomfelde, Wolfgang Reischl, Petra Rexroth, Peter Seitz, and Ralf Steinmetz. 1999. i-LAND: an interactive landscape for creativity and innovation. In *Proceedings of the SIGCHI conference on Human Factors in Computing Systems*. Association for Computing Machinery, New York, NY, USA, 120–127.

[25] Lucia Terrenghi, Aaron Quigley, and Alan Dix. 2009. A taxonomy for and analysis of multi-person-display ecosystems. *Personal and Ubiquitous Computing* 13, 8 (2009), 583.

[26] Alexander Van't Hof, Hani Jamjoom, Jason Nieh, and Dan Williams. 2015. Flux: Multi-surface computing in Android. In *Proceedings of the Tenth European Conference on Computer Systems*. Association for Computing Machinery, New York, NY, USA, 1–17.

[27] Jishuo Yang and Daniel Wigdor. 2014. Panelrama: enabling easy specification of cross-device web applications. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. Association for Computing Machinery, New York, NY, USA, 2783–2792.