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Continuity in Multi-Device Interaction: An Online Study

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ABSTRACT
Techniques for multi-device interactions are finding their way into commercial products. This means that people are now exposed to possibilities of interacting with and across their devices, and this presents a valuable opportunity for studying their uptake and use in real life. In this paper we investigate and discuss the emerging multi-device interaction concept of "continuity", which allow an activity to begin on one device and continue on another. We present a study of the challenges people have experienced in the use of a specific new product offering such functionality, namely Apple's Continuity. The study was done through surveying 3361 posts from technology web sites, discussion forums, and blogs, with a qualitative analysis of 1603 posts. Our findings present challenges in six themes of *privacy, appropriation, customization, awareness, exclusion,* and *troubleshooting* in relation to continuous interaction across devices. We further discuss the high-level implications of our findings through four design considerations for continuity in multi-device interaction.

Author Keywords
Continuity; multi-device interaction; digital ecosystems.

ACM Classification Keywords
H.5.2. Information interfaces and presentation (e.g., HCI): User Interfaces.

INTRODUCTION

There has been an increasing interest in multi-device interactions and distributed user interfaces in HCI in recent years. Several papers have presented research into new possible ways of interacting with and across multiple devices, demonstrating new input technologies [4, 14, 21], interaction techniques [8, 13, 20, 22], prototyping toolkits [5, 8, 9], and applications that take advantage of these new interaction capabilities [7, 11, 12, 17]. As examples, Chen et al. [4] present a way of supporting multi-device gestures, Hamilton and Wigdor [8] propose a set of interaction techniques for chaining functionality and managing cross-device relationships, and Kreitmayer et al. [12] explore how interaction across shared tablets and a wall display can be used to improve peer discussion in a classroom setting.

In parallel with this research, techniques for multi-device interactions are also finding their way into commercial products. This means that people outside the realms of research are being exposed to these new possible ways of interacting with and across their devices; smartphones, tablets, laptops, TVs, wearables, etc., in concert rather than individually, gradually transforming their collection of devices into larger ensembles. The propagation of multi-device interaction beyond research laboratories presents a valuable opportunity for studying the uptake and user experience of these new ways of binding together and interacting with "systems of systems" in real-life contexts.

Multi-device interaction is done in many different ways, depending on, for example, whether devices are used simultaneously or sequential, how many people are involved in the interaction, and what specific interaction techniques are deployed. Capturing these differences on a conceptual level, Sørensen et al. [24] divide multi-device interaction into four groups of communality, collaboration, complementarity, and continuity. Of particular interest, the group of "continuity" covers the emerging use of multiple devices in sequence where an activity or interaction begins on one device and continues on another. As detailed in [24] the concept of continuity is found in an increasing number of commercial products functioning across devices. For example, cloud services like DropBox support continuity through synchronization of files, and streaming services like Netflix support it by allowing the viewer to migrate between players and pick up where they left.

This development calls for studies of continuity in multi-device interaction. How do people perceive and experience this way of interacting with their devices? How and when do they use it? Where does it work, and where does it fall short? What are the enablers, challenges and limitations?

Here we present a study of the challenges people have experienced in the use of continuity for multi-device interaction in the real world. The study looks at one specific product with such functionality, namely Apple's Continuity. We present challenges within six themes relating to interactions that span across devices. We then further discuss some of the higher-level implications, through six design considerations for continuity features in multi-device interaction.

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RELATED WORK

In an analysis of different types of interaction principles for digital ecosystems, Sørensen et al. [24] surveyed a selection of systems and services facilitating multi-device interaction in various forms. From this they derived a conceptual framework dividing multi-device interaction into four groups of communality, collaboration, complementarity, and continuity. As also described by Levin [13], the latter two, in particular, capture the difference between simultaneous and sequential use of multiple devices. Complementarity describes simultaneous multi-device use where one device "complements" another. Examples of this include Nielsen et al. [17] who show how multiple tablets and smartphones can be "stitched" together to form a larger interactive display surface, and Grubert et al. [7] who show how interface widgets can be distributed across multiple devices by extending the display boundaries of a smart watch using a head-mounted display. Continuity, on the other hand, describes sequential multi-device use where interactions move, or transition, from one device to another.

In this paper we focus on continuity and one of the major bodies of work on this area has focused on creating new interaction techniques for it. Marquardt et al. [14] developed four interaction techniques for information sharing between mobile devices used by people standing in an F-formation, informed by observed behaviors of micro-mobility. Out of these, two techniques facilitate continuity from one device to another, namely *tilting* devices towards each other to preview and copy information, and using *portals* to drag information between *federated devices*. These were both tested with a basic information sharing and viewing task. Quite differently, Schmidt et al. [22] propose an interaction style that uses a mobile phone for tangible input on a touch surface in a way similar to a stylus. Combining this with the use of the interaction capabilities of the phone itself, they propose 12 specific interaction techniques, out of which four facilitate continuity-type interaction for data transfer, feedback, personalization and authentication. The use of these is illustrated with different application ideas, e.g. a calendar and browsing through a music store. Hamilton and Widgor [8] contributed with the Conductor framework that includes a set of continuity techniques for bonding devices into "duets", and passing information through "cues". Also experimenting with continuity between devices, Rädle et al. [22] compared interaction techniques based on spatial awareness between devices, like in [14], with techniques working independent of this, like in [8]. Findings from this study indicated a preference towards the former, but also showed that such interaction techniques must be designed with care, and are difficult to get right. Finally, within the notion of continuity Karlson et al. [11] introduced "versionet", a copy-aware software prototype that allowed its users to better manage files that were scattered among a variety of devices.

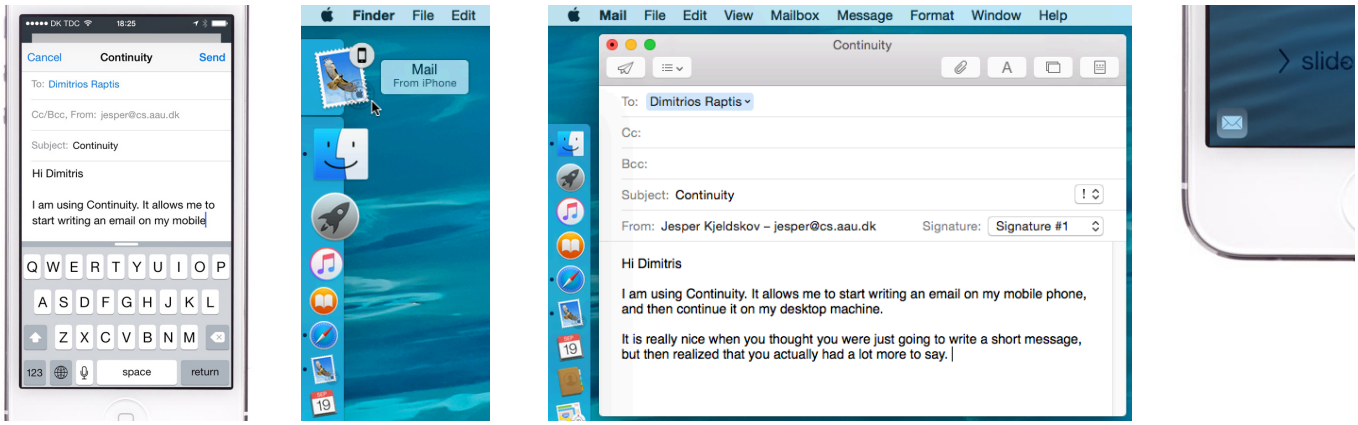
Complementing this technical and application-oriented work, a smaller number of studies have investigated multi-device interaction as it is experienced, used and facilitated in real world settings. Wäljas et al. [27] conducted a 4-week field study of three cross-device web services focusing on transitions between desktop UIs and mobile devices, and how tasks are picked up after these transitions. This study showed that users easily understand when a web-service is distributed across devices, and are very happy with the ability to shift easily from one to another that this enables. At the same time, however, users reportedly also quickly build up expectations for consistency, and that all devices be kept up-to-date in real time. Based on this it is highlighted that synchronization and task migration support are crucial for achieving continuity across devices, and that continuity-enabling features need to work "out of the box". Bales et al. [2] also conducted a field study of cross-device web service use, looking particularly at re-accessing content between computers and smart phones. From this study it was found that continuing a web activity on a different device is not very well supported, but people can be very creative at making their devices interact for this purpose, although this is usually quite cumbersome. In a diary study combined with interviews, Jokela et al. [10] investigated how people combine multiple information devices commonly used in the home, such as smartphones, computers, tablets and media centers, in their everyday life for tasks as well as leisure. This identified four main usage patterns, of resource lending, related and unrelated parallel use of devices, and sequential use. Sequential use accounted for 37% of the multi-device use cases reported and was triggered by either changes to the character of the task or activity, the physical environment or social context, or due to technical limitations of the first device used. The study also identified a number of practical challenges of using several devices together, sequentially or in parallel, such as incompatibilities between different digital ecosystems. As also observed in [2], this often required people to find creative workarounds, for example by resorting to core functions such as e-mail.

STUDY

Complementing previous research studies on techniques for multi-device interaction and continuity, we have conducted a study on real-life experiences and challenges in the large scale. In order to achieve this, we decided to study an off-the-shelf, real world system and secondly to embrace an innovative way for collecting data. Similar approaches have been also successfully used in other studies within HCI [e.g. 18] and are often coined as *digital ethnography* [19].

The studied system

As a first step in the process of selecting an appropriate system for studying continuity of interaction, we reviewed candidate off-the-shelf systems. Since we wanted to increase the breadth of our study we focused on systems that facilitated continuity for a variety of activities. For this reason, we quickly excluded existing systems implementing continuity for a single activity, such as DropBox for file synchronization. Through this process we ended up with 3



(a) (b) (c) (d)

Figure 1. In the Handoff example above, the user starts writing an email on his mobile phone (a). On his desktop computer a Mail Handoff icon appears in the Dock (b). Clicking on this migrates the email from the phone to the desktop computer where the user can then continue writing (c). Conversely, when writing an email on a desktop computer, this can be migrated to a mobile device through the Mail Handoff icon that appears on the lock screen (d).

candidate systems, Apple's Continuity, Samsung's Flow and Microsoft's Continuum and all included a variety of activities as well as a variety of devices. From these three candidate systems we opted for Apple's Continuity for the single reason that it was the first released and thus there were a lot of available data for studying it in detail.

In short, Apple's Continuity functionalities particularly increase integration between devices and services within the Apple ecosystem, and let people use nearby iPhones, iPads and Macs together or move seamlessly between them, by means of synchronization and migration [24]. It consists of three specific features: *Phone, SMS* and *Handoff*. With *Phone* users can place and answer phone calls on all of their devices using their iPhone as a conduit, and with *SMS* all messages (SMS, MMS, and iMessages) sent and received from their iPhone are synchronized to all other devices. Finally, and most notably, with *Handoff* the user can start using an application on one device and then migrate to another one nearby. This works for a range of Apple apps: Mail, Safari, Maps, Messages, Reminders, Calendar, Contacts, Pages, Numbers, and Keynote, and is also available for third-party apps. An example of the Handoff feature is illustrated in Figure 1.

Process

In order to identify continuity challenges within multi-device interaction in real world settings, we opted for data from digital sources where people were likely to express problems and questions that they had encountered in their everyday use of the studied system. Since the Internet is widely used by people to voice their opinions on technology and/or ask for help, we decided that an online study of web posts, discussion forum posts, and blog posts would be a suitable methodological approach for our research.

For the first two weeks of May 2015 we conducted a thorough online search using various search strings, such as "Apple Continuity", "Handoff" and "Phone and SMS", while using both Google and Bing as search engines. From this process 124 relevant webpages were identified. Most of them contained an article that discussed, reviewed, or provided advice for Apple's Continuity. In this category belonged technical websites (e.g. CNet, Macworld, iMore and Verge) and blogs (e.g. iGeeksBlog and GSM Arena). Furthermore, a smaller number of relevant webpages came from focused discussion forums (e.g. MacRumors, AppleInsider and Apple Discussions) and general discussion forums (e.g. Reddit and Gizmodo), where users' discussions were initiated by a user's question or statement in relation to Apple's Continuity. From these 124 unique webpages we collected 3361 comments. All data, including comments, meta-data and discussion thread-structure, were downloaded for offline filtering and analysis.

As our second step, we filtered the 3361 collected comments in a repetitive process, aiming to produce a dataset free of noise from non-relevant information. The majority of removed comments were brand-oriented, where people deviated from discussing the studied system and got engaged on what company is best at making continuity features, who developed them first, what mobile phone or operating system is best, etc. Comments that simply explained the studied system, such as *"continuity connects your Apple devices"*, or just praised other posts, such as *"good write-up"*, were also removed. The same was the case with technical questions, such as *"will my mid-2011 Air work?"* or *"should I jailbreak?"*, along with their responses, as well as, all "yes/no" answers. Advertisements and ironic comments that were out of context, like *"it will be great to transfer my work from the laptop to my dishwasher"* were also removed. Finally, we also removed comments where users were meta-commenting or teasing each other, such as *"I apologize for my lack of punctuation"*, or *"dear Apple fanboy, I surrender"*.

This process left us with 1603 unique comments. In terms of reported contexts of use, these were quite varied and covered both work and domestic settings, including offices, homes, cars, public transport, cafes, restaurants, etc. In terms of hardware, the dataset included posts related to iPhones, iPads, iPods, as well as desktop and laptop Macs. Finally, in terms of activities, all activities that were continuity-enabled by Apple were present in the dataset.

The 1603 comments were then analyzed through a combination of open coding adapted from grounded theory [23] and iterative affinity diagramming [3]. First, one of the authors produced an affinity diagram by printing all comments and by pinning them on a carton board. Our initial affinity diagram included 16 individual categories and sub-categories and it was collaboratively discussed and revised four times. In the end and because comments were often positioned in multiple themes, the starting 1603 comments were positioned into 6 themes of challenges (1662 comments), and one theme of expressions of excitement about continuity (128 comments).

FINDINGS

Our data analysis identified six themes of challenges that characterize people's experiences with continuity in multi-device interaction (Table 1). The majority of comments were related to troubleshooting of technical problems for making continuity work (39,1%), and issues of exclusion from being able to use the continuity functions (23,3%). These two themes accounted for 651 and 388 comments respectively. Other notable challenges were concerned with issues of appropriating continuity functions into existing work and home practices (14,3%), and limited awareness and understanding of these new multi-device functions (9,4%), accounting for 237 and 156 comments. Finally, there were notable challenges in relation to concerns about people's privacy (7,6%), and issues of apparent limited support for customization of continuity functions across people's devices (6,3%), accounting for 126 and 104 comments respectively.

Challenges	Number of comments	
Privacy	126	7,6%
Appropriation	237	14,3%
Customization	104	6,3%
Awareness	156	9,4%
Exclusion	388	23,3%
Troubleshooting	651	39,1%
Sum	1662	100%

Table 1. Identified challenges and number of comments.

We consider these six themes the main contribution of our research, as they provide relevant insight for researchers and practitioners working on designing, developing and proliferating continuity features for multi-device interaction. In the following we present the themes in detail.

Privacy

Privacy came out as one of the more important challenges of continuity both in terms of user attitude, but also in terms of use experiences. We identified aspects of privacy in 126 comments that primarily concerned the fact that in Apple's Continuity, devices have the status of being private and personal while in reality they are actually often shared in social contexts (like in families). But privacy also related to the fact that different personal devices are occasionally used in public situations.

To elaborate, in Apple's Continuity, the basic assumption is that devices that belong to a single digital ecosystem are solely personal. But this is not always the case. Often devices are used in families between household members. Several comments articulated profound concerns on how personal data could be affected or even exposed or shared with other people - in particular with family members. Thus, users indicated strong concerns about adopting continuity, as they were unsure of privacy consequences as illustrated by the following comments:

> *"How will this work with families that share accounts? My wife and I have iPhones and iPads. Will I be able to tell the devices to group calls and apps to my devices and hers to hers?"*

> *"It can get painful when you get an SMS, and your wife/child gets it because (s)he has your tablet in the hands [...] The next step is getting a hot photo texted by your girlfriend on your TV while your parents are there for a visit."*

Others expressed not only concerns, but actually reported on cases where privacy had been broken, as one user said, *"This is awesome. Your wife is using your iPad and your ex-girlfriend calls your phone … love it"*. Similar experiences were raised by teenagers in families who were anxious about protecting their privacy from their parents, *"…need to change my iCloud account, otherwise my dad will see all my SMSs…"* or feared that their private and personal lives would be affected *"Creepy O-O my p*rn universe is f*cked"*. In summary, several comments related to privacy of multi-device interaction in families, as the devices could be shared among several family members.

Our data further showed that even if devices were in fact personal, they would sometimes be used in situations where privacy was still problematic, as devices were used for different purposes, for example, both work and pleasure, or devices were used in public situations. Several comments reported on work contexts where users expressed concerns on how to distinguish between work and personal data. Some reported that they did not want personal and work data to be synchronized across their devices, *"I have turned Continuity off. I'd like to selectively use it at work, but I don't want things like my iMessages showing up on company devices"*. Separating between work and personal data was important for many users, and sometimes personal

devices would be used in public situations where others could witness, for example, phone calls or text messages, as reported by one academic lecturer:

> *"I'm an academic supervisor and share data and fundamentals on my computer screen with my students regularly. It's annoying and unprofessional to have my phone calls popping up on my screen."*

While most comments about privacy raised concerns, a few users were much less concerned about privacy and enjoyed the opportunities of continuity, *"I have two iPhones, one personal and one work, and it's rather nice to have every call and text from both show up on my Mac and iPad"*.

Finally, from the 126 comments on privacy, 44 comments expressed privacy concerns on ownership of personal data and security of personal data. Firstly, many expressed their distrust in corporations (e.g. Apple), *"The concept is great, but operationally having to give Apple my data and information is invasive and troubling! And unnecessary!"* Secondly, many users were concerned with security and if groups or individuals could hack into these new features, *"Watch for that hotspot feature to get exploited somehow in the next year or two. If the Mac is somehow able to set the SSID on the hotspot remotely, that's kind of scary"*. Others were inspired by movies to highlight the same issue and pinpoint the damage specific individuals could do, *"Sounds like Tyler Durden* [Fight Club] *has a new medium"*. Thirdly, we found comments where users raised questions on how government agencies could take advantage of data in multi-device interaction and thereby increase the degree of surveillance. The clearest depiction of this issue was derived from a user who said *"SMS relay to the NSA"*.

Appropriation

Appropriation was a second key challenge identified in our data and was found in 237 comments. Appropriation issues cover how successfully people could incorporate continuation of activities into their everyday interactions. We discovered appropriation challenges primarily relating to issues of disruption and experiences of minor difficulties. But we actually also found several positive experiences or attitudes related to appropriation in continuity. We have included appropriation as a challenge for continuity as it revealed a number of interesting concerns, but we illustrate both negative and positive comments about appropriation.

Quite a few users reported problems on appropriating the technology because they were trying to figure out how to take full advantage of it:

> *"I think it's a feature I still need to fully integrate into my workflow for it to become natural, and it's not widely enough available yet to be instantly comfortable for me."*

This user acknowledges the value of continuing activities, but highlights that more time is needed in order to fully appropriate the new features. A few other users reported that they were trying to solve minor conflicts between Apple's Continuity and their existing usage patterns. For example, one user stated that there was a conflict between the way migration was achieved and the cover of his iPad:

> *"I need to work out how to fit this into my iPad usage model. My iPad is in a smart case, and so the screen is either covered, or auto unlocked when I uncover it. Therefore, I don't get the chance to swipe on the handoff symbol on the bottom left of the screen."*

This illustrates how existing usage patterns can be forced to change with the introduction of new technological features in a digital ecosystem. Change can have a positive effect as we have presented above, but often a negative one too. The negative side was documented in 76 comments where users reported how continuity features disrupted them. The majority of these comments were either related to audio issues, *"sometimes you don't want to hear three devices ringing at the same time"*, or were from users who worried about the effect of continuity on device battery life, *"I say goodbye to battery life"*.

In 64 comments belonging to the appropriation theme, users discussed, imagined, and even demanded the continuity features to be extended into more of their everyday activities. Spotify, iTunes, and Evernote were some of the applications mentioned, *"Handoff to iTunes could be a game changer. The concept of well integrated seamless audio experience from home -> car -> headphones -> office would be amazing"*. Here the user not only overcame problems of appropriating continuity, but also envisioned how this could be applied to more activities, like a listening-to-music morning routine.

As mentioned in the beginning of this section, we found quite a large number of comments that were positive and/or constructive on appropriation. In 97 comments, users expressed how the continuation of activities immediately seemed meaningful and relevant, and one person even characterized it as a *"logical, evolutional next step"* for his digital ecosystem, while another as a *"natural thing to do"* and *"a sign of good design"*. Within these 97 comments many elaborated on how well continuation of activities served them in a private context. Some also presented cases where they managed to solve existing problems through Apple's Continuity:

> *"I love the Handoff. I get spotty reception at home so I can place my phone in a good area and get SMS messages.*

Appropriation also occurred in several other contexts of use beyond the home, such as work, or on public transport. For example, a person expressed how synchronization improved workflow because he did not have to switch between two devices in order to call landlines and mobile phones, but could accomplish these tasks using only his computer:

"I spend most of the day on the phone for work. Using Continuity for cell phone calls is a thing of beauty. I never have to take my headphones off."

The same was also the case for a commuter that did not have to reach for her phone to answer a call, but could use her laptop instead, *"I can now leave my phone in my backpack and work on my laptop and answer/make phone calls with my laptop."*

Customization

Several users reported challenges related to customization. We found 104 comments on customization that generally caused frustration among users. The first challenge of customization deals with setting up and actively selecting which devices to include. Some users articulated that too little guidance was provided on how to set up Continuity, and felt they were required to be familiar with too many technical details:

"You call this progress? This is complexity upon complexity - which is fine when you hide it. But no, you need to know the network, the protocols ... who cares?"

Such content was quite common among the 104 comments and often involved detailed discussions between users where they criticized existing functionality and suggested alternatives, like this comment *"... this entire process is absurdly complicated. A user should be able to instruct Siri to set this up, then confirm the changes with Touch ID ..."*.

By default, Apple's Continuity is enabled for all applications that are part of the framework and exclusion is not possible, as expressed by the following person, *"As far as I can tell, there is no way to turn off Handoff for specific applications or email accounts. It's either all on or all off"*. Therefore, users cannot exclude, for example, mails from being continued to other devices, as they are facing an all-or-nothing approach. They must synchronize and migrate all activities across all devices, or none.

Additional control was requested at the level of specific applications, where opportunities for customization were also limited as illustrated here: *"If you opt for taking incoming calls on your computer (you can turn the feature off altogether), you cannot currently mute the ringer"*. Alternatively, users found it difficult to locate functionality for customization, *"Maybe I am just getting old, but I never would've looked in face time to turn off a cell phone call"*.

Therefore, the lack of possibilities in customization made some users engage in discussions on possible solutions on how to regain control. As an example, one user suggested the development of a manager that would allow him to properly control Continuity, as he argued:

"An essential component that Apple HAS to ship with OSX 10.11 is some sort of 'Personal Cluster Manager' which shows the state of ALL your various devices, how they are connected, what services flow between them…".

But as stressed in a few comments, novice users might experience problems in understanding and interacting with such mechanisms, and those users might not have the necessary know-how or skills to manage complex settings and setups.

Awareness

Apple's Continuity offers new ways of interacting or using digital devices and we discovered that many users were not aware of the new features provided by continuity. We have combined these experiences in the challenge of awareness, based on 156 comments.

Users were often unaware of the possibilities offered by Continuity for their devices and reported surprise regarding new device behavior. For example, some expressed their surprise because devices were suddenly ringing, *"Why are all my iPhones and my iPad receiving my calls?"*. Some tried to gather information by posing questions or initiating discussions and several indicated that they would disable the functionality, *"Thank god, the first time my iPad rang it freaked me out!! Gonna disable it"*. The main reason for doing so was the fact they felt that Continuity was disturbing their everyday routines without asking for permission:

"I'm absolutely furious that Mac would assume that people want this 'feature' and has the nerve to turn it on by default. I don't want my phone to have any connection to my computer whatsoever".

One of the expressed problems was that Apple's Continuity is enabled by default through a software update, and several users were not even aware of this new feature. Lack of awareness was also observed in comments where users expressed their difficulties in finding online documentation and support, or where they had misconceptions on what continuity was. As an example, a user connected a mobile phone and a laptop with a cable and expected activities to be continued, *"This Handoff technology should work when the iOS device is plugged in the Mac via USB cable. Why doesn't it?"*

Another important area where confusion happened due to lack of knowledge was in relation to the proxemic requirements of Continuity. In order to use Continuity, people must have their devices physically close as they have to establish a Bluetooth connection. The lack of awareness of its proxemic requirements, especially as there were no affordances that could guide the users, led to frustration and confusion, as many could not understand why it did not work, *"They said it would work everywhere in your house. Nope!"* These misconceptions were further enhanced by the fact that people applied their prior experiences with technology and expected similar behavior from Continuity, *"Why does it need Bluetooth? Why doesn't it work like Dropbox over any network?"*

Exclusion

Exclusion characterizes conditions that preclude use of Apple's Continuity and was identified in 216 comments. Exclusion was mainly expressed as a result of using older Apple hardware or software versions, using non-Apple hardware devices, or due to legal restrictions in certain countries. Interestingly, users were quite active with comments on how to overcome exclusion and provided several ideas for hacking.

Exclusion was experienced by several people using older Apple devices not able to run Continuity. This was found in 161 comments. Several users expressed their frustration about being excluded from using Continuity due to older hardware *"Yes? Kind of ironic that it's called Continuity, when it breaks with all Macs older than two years"*. In many of these comments, economic issues were highlighted as the main challenge, *"I'd like Handoff and the features of it, but there's a Standoff between Apple and my wallet."*

Another exclusion case was identified in 52 comments and was related to people who owned devices developed by another company, *"But it still only works with Apple stuff. Not so great for the rest of us"*. In the majority of comments, users expressed that they would love to be able to continue activities across their devices too, and a few of them went a step further and directly asked for such obstacles to be removed:

> *"Not so useful, because the world doesn't end with Samsung, in the same way it does not end with Apple. But if we can sync all Android devices (or even ANY devices) through a default protocol ... now we talking"*.

Finally, we identified political barriers in three comments. For example, a user expressed his concerns on whether he could continue his activities since FaceTime, a core component of Apple's Continuity, was banned in his country:

> *"We don't have FaceTime in United Arab Emirates as it's a banned service. Does that mean that I can never use Continuity for calls in UAE?"*

Quite interestingly, we discovered many suggestions on overcoming challenges of exclusion. In fact, this was seen in 172 comments, and involved some sort software or hardware hacking. Hacking occurred at two levels, mostly for enabling Continuity, but in a few cases for customizing it. In software hacking, patches for enabling continuity were quickly released from the hacking communities and were discussed among users. In relation to hardware, many suggested replacing existing components with Continuity compatible ones, *"It is possible to replace the default card inside a MacBook with one that Continuity supports."*

Troubleshooting

Perhaps not surprisingly, we identified a very high number of problems related to troubleshooting, and 651 comments specifically addressed this. Troubleshooting deals with failures and problems, which users experienced when trying to use Continuity. But it also involves many discussions on how to solve and overcome these problems.

The large number of comments in relation to this challenge makes sense due to the complexity of the technology and the underlying infrastructure, and the fact that it applies to a variety of devices with different hardware and software versions. But also that people continue their activities in different contexts. One of the expressed fundamental issues facilitating these failures was poor reliability:

> "*Some days my office sounds like a Vegas casino when the phone rings, with four or five devices each playing a different ringtone. But sometimes only the iPhone rings."*

As illustrated by this quote, users were often unaware of why devices would behave in different ways. Although such failures generally frustrated users, we also found cases where the failures were so fundamental that users were unable to use Continuity. One user described such a situation for sound quality:

> *"When I place calls all I get on my end is a Mickey Mouse sounding voice that you can barely understand and the caller can't hear me at all."*

Besides simply mentioning these failures, the majority of comments provided instructions for fixing problems with Continuity as illustrated by the following comment:

> *"Make sure Bluetooth is on on all your devices and that they are connected to the same network Handoff must be enabled to all devices. Sign out from iCloud and then log back in. Restart all the devices. The magic is gone*".

The last part of this comment exemplifies that users not only provided instructions on how to address problems, but often they also expressed their disappointment for Apple in general, Finally, some user comments on troubleshooting dealt with official software updates that solved known problems.

DISCUSSION

We have conducted an online study of continuity in multi-device interaction based on user experiences and comments on their use of Apple's Continuity. Based on 1603 comments, which we analyzed, coded, and affinity diagrammed we identified six challenges that characterize people's experiences with continuity. The six challenges are: privacy, appropriation, customization, awareness, exclusion, and troubleshooting.

While the insights from these six challenges constitute a contribution to the knowledge on continuity in multi-device interaction, we further contribute with four design considerations for improving the use and user experience of continuity features and functionality in the future.

Personal Activities with Shared Devices

The studied system is characterized by the assumption that all the devices within a digital ecosystem are solely personal and used only by one individual. Similar assumptions also exist in other continuity-enabled systems, such as Samsung's Flow. However, as our findings clearly illustrated, this is often not the case. For example, several comments showed that very often family members will be using the same device, at different times and for different purposes. This resulted in situations where personal activities were continued into devices that were, in fact, not part of a particular user's digital ecosystem at the time. Similar results were also identified in previous studies for various products, which they might be personal in the beginning, but often become social [e.g. 6].

What we observed is that the way continuity of activities was achieved in the studied system, contradicted the situated social interactions [15]. In other words, personal activities were continued to individuals that were not part of the activity in the first place. Surprisingly, our study illustrated that only a few users seemed to actually understand and realize this complication and the unintended consequences of informally sharing devices. For those few users this problem caused frustration, embarrassment, and tensions, and some of them even stressed that this was in itself a showstopper for them using the studied system.

As a recommendation to future designers on ways to tackle the identified issue, we refer them back to the theoretical framework that informed our study. Sørensen et al. [24] explain continuity in terms of migration and synchronization, where many devices (or artifacts as they call them) are used sequentially and involve *one* user engaged in an activity. At the same time, they also propose *communality* [24] to define sequential multi-device interaction involving *many* users. Consequently, we propose to future designers of continuity features for personal activities to implement mechanisms that would allow users to switch their devices to "communal mode" whenever they believe its necessary. According to Sørensen et al. [24] there are two ways of achieving that: *personalization* and *generalization*. Personalization can be achieved by using multiple user accounts (a feature that is slowly introduced to mobile operating systems), and generalization by detaching a device from any user that interacts with it. For example, when children are playing a game on a mobile device it may be unnecessary to log in with a user account, but instead they can play in a device mode that is generic and independent from any user.

Shared Activities with Personal Devices

A similar but slightly different aspect of continuity is about shared *activities*. Quite interestingly, in our study we discovered comments related to shared activities where people would use personal devices in a shared, public situation. Continuity was problematic for these cases as personal interaction could be continued on a shared display, e.g. a lecturer presenting on a projector.

While our study showed that people generally perceive devices as either personal or shared, for the above mentioned cases perhaps makes more sense to talk about whether the activity they are used for is personal or shared. In the study by Marquardt et al. [14], for example, the activity involving multi-device interaction may involve several shared and personal devices, but has a collaborative nature where more users interact with them sequentially and simultaneously. Again, the framework presented by Sørensen et al. [24] can be used to unpack this situation, and provide pointers for multi-device interaction design. According to [24] this can be supported through either *division* or *merging* of the interfaces of many personal devices into a shared activity. Our studied system offered no such abilities, but we opt future designers to consider whether the activities they are designing for are shared or not and implement supporting mechanisms accordingly. For example, the previously mentioned lecturer who was engaged in a shared activity could be provided with the possibilities to pause the continuation of his personal activities, to select in which screen continuation should take place (laptop or projector), to define which activities are meaningful to be continued in such setting, or to merge his interface with his students and enter a different mode of interaction.

Control and Flexibility

In the studied system continuity was embedded to all activities (applications) and for all devices that belonged to the same ecosystem without any control mechanisms. This approach proved to be problematic as many users wanted to be able to bring the system closer to their needs and wants by customizing it. The fact that lack of control can lead to breakdowns is a known finding within HCI research. For example, Barkhuus and Dey [1] identified that users *are willing to accept a large degree of autonomy from applications as long as the application's usefulness is greater that the cost of limited control*.

In relation to devices, our findings, particular in the awareness theme, illustrate two focal points. Firstly, the users find it difficult, or even impossible to figure out which devices are currently part of their digital ecosystems. From an HCI perspective, we would argue that many users did not have a clear mental model (if any) of the Continuity setup. The importance of mental models when interacting with technology is well known in HCI, and in order to achieve seamless continuous interaction we need to make sure that users have an understanding of the functionality of an ecosystem. Part of the problem seems to reside in the fact that people have rather complex, dynamic, and constantly changing digital ecosystems. They include newer and older devices, different manufacturers, multiple user accounts, are connected to different Wi-Fi's, etc. Thus, determining whether all, or only a subset of your devices

are part of continuity is by no means trivial. The second focal point is the need to be flexible and move beyond manufacturer's restrictions and many users discussed in detail the flexibility to be able to continue activities to any device, independently from the manufacturer. The same observation also emerged in a previous study by Jokela et al. [10] where they found that in multi-device interaction incompatibility issues between different digital ecosystems constitute a substantial problem. Our data showed that many resulted to hacking in order to bypass this problem. This also resonates with previous research, where users had to be creative in order to be able to continue their activities on other devices [2] or needed to come up with workarounds to be able to achieve the potentials of continuity [4, 8].

In relation to activities, our data showed that users discussed the possibility to control which activities are to be continued and when. This is quite interesting as the users saw the potential of continuity features beyond Apple's implementation. As an example, one could imagine that phone calls from certain people would be part of continuity, but only for specified devices and in certain situations. In terms of continuity being "*an activity or interaction that begins on one device and continues on another*" [24], this would - through managing it - specify boundary conditions for the migration of activities or interactions to happen. Furthermore, users liked the fact that in the current setup an activity was not limited to a specific device, but could be performed in a variety of them. For example, many liked that they were allowed to answer phone calls from any device and not just through their phone. We believe this provided flexibility should be extended to more activities and devices as it allows users to appropriate a new technology in contexts that no developer and/or designer can predict.

By investing more into control and flexibility, we may develop digital ecosystems that *"feel as one"*, as stated by one of our participants. In order to do that we need to rethink the activities people perform in various contexts of use under the prism of multi-device interactions, design appropriate control mechanisms (which by all means is no trivial task), and provide the necessary *infrastructure*; the core functionality that would allow any device to become part of any ecosystem, independently from its manufacturer.

Transparency and Trust

A major theme that emerged from our analysis was users' concerns for privacy and security. A significant proportion of the collected comments depicted mistrust, particularly towards big IT manufacturers and various government agencies. Our results indicate that many people are worried about their data and request more information on what is stored, where it is stored and for how long. This observation is hardly new as it is known in literature that privacy concerns may have a significant negative effect on trust [25] and that people feel vulnerable when they have no control over their personal data [26].

The difference now is that we have moved from the level of individual devices to digital ecosystems. Our data showed that this expansion increased users' concerns, because through the continuation of activities, more data in relation to their personal life exist and therefore more data are susceptible to risks. We propose that future designers should tackle this challenge by investing in transparency and trust. Users should be clearly informed on how their data are treated and what kind of information is stored. Additionally, alternatives should be provided to the users. For example, instead of storing multi-device interaction data centrally, users can be provided with the possibility to use their personal machines to store and manage their data.

CONCLUSIONS

We presented an online study of the challenges people have experienced in the use of Apple's Continuity as an example of the emerging types of multi-device interactions that allow an activity to begin on one device and continue on another. Through an analysis of 1603 comments on technology web sites, discussion forums, and blogs, we identified six themes of challenges for this type of multi-device interaction namely *privacy*, *appropriation*, *customization*, *awareness*, *exclusion*, and *troubleshooting*. Based on these six challenges, we also discussed four design considerations for improving the real world use of continuity in multi-device interaction or multi-device interactions in general, for *personal activities with shared devices*, *shared activities with personal devices*, *control and flexibility*, and *transparency and trust*.

A number of limitations characterize our study. Firstly, the focus on online forum user comments to a large extent illuminated negative and problematic issues of adapting and using Apple Continuity– as in contrast to previous studies where positive issues and opportunities of continuity in more general have been shown. But despite this focus, our analysis also found positive user experiences primarily within appropriation of Apple Continuity with comments like "*magical"*, "*killer feature", and "cool"*. But we acknowledge that a different research method could show additional dimensions of continuity. Secondly, the focus on one system namely Apple Continuity is a limitation in the sense that other systems or technologies might display other advantages or disadvantages. For our study, it was essential to learn something about real-world use and based on a substantial user population. But hopefully future studies can complement our findings on studies of other technologies.

We believe that both the six challenges as well as the four design considerations that emerged from an in-depth study of a real world system will be useful to future designers of continuity features and multi-device interactions in general. Firstly, by allowing them to quickly focus on key areas that need their attention, and secondly by reflecting on them and thus improving the quality of their designs.

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