Surveying Personal Device Ecosystems with Cross-Device Applications in Mind

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ABSTRACT

To inform the design of cross-device applications, it is important to know what devices users typically have within reach in various settings in the home, in the workplace and on the move. We report on a survey carried out using an online questionnaire and discuss the most significant findings that should be taken into account in cross-device scenarios. The results are based on 293 participants covering a wide range of ages, nationalities, professions and living arrangements.

ACM Classification Keywords

H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

Author Keywords

personal devices, cross-device applications

INTRODUCTION

Cross-device applications allow one or more users to distribute the interface and functionality of an application across two or more devices. Such applications generally have one of three purposes: a) enabling a user to expand their screen real estate by exploiting additional co-located devices, b) distributing functionality so that one or more devices act as a controller for content on larger displays, and c) supporting synchronous collaboration by sharing information among different users' devices or moving information to a shared display.

Although there has been a lot of research interest in crossdevice scenarios, publicly deployed applications are limited and mainly of type b) where a smartphone or tablet is used as a remote control for another device. For example, YouTube TV¹ allows users to control videos shown on their TV from their smartphone, while LRPAD² enables an iPAD to be used as a controller for Adobe Photoshop Lightroom running on a

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laptop or desktop PC. Google's Chromecast³ provides a more general service for controlling different types of media on a TV from a smartphone or tablet, but requires a special device plugged into the TV.

While various applications of all three types have been developed within research projects, e.g. [23, 21, 18, 17, 10], studies have mainly been carried out in lab settings with a given set of devices. To inform the design of future cross-device applications, it is important to know more about personal device ecosystems and how these are evolving. Recent studies have tended to focus on how devices are currently used [12], often in specific settings such as the home [13] or the workplace [19]. Our goal was to complement the findings of these studies with information about the set of devices that users typically have access to in various settings, including travelling between work and home, or when out with friends.

We report here on a study carried out in November 2015 using an online questionnaire. The results presented are based on 293 complete submissions, where the participants covered a wide range of ages, countries of residence, professions and living arrangements. We first discuss related research, before presenting details of the questionnaire and methods used to recruit participants. This is followed by a summary of the results, where we focus on the more interesting findings, before discussing their relevance in the context of designing cross-device applications.

BACKGROUND

An early study looking at why and how people use multiple devices was carried out by Dearman et al. [4] in 2007. Their findings already revealed that many activities spanned multiple devices, with one of the major issues being the need to find easier ways of transferring and synchronising information across devices. The study consisted of interviews with 27 people of whom only 10 had smartphones. Clearly, the mobile device landscape has changed a lot in the last eight years with it now being common for people to have smartphones and tablets, with some also having smartwatches.

Recently, Kawsar et al. [13] used a combination of activity logs, a survey and interviews to study personal devices within family homes. They were particularly interested in analysing where and when certain devices tend to be used and for what.

¹http://www.youtube.com/tv

²http://www.lrpad.com

³http://www.google.com/chromecast/

They noted that tablets and smartphones had taken over from PCs as the main computing devices in many families.

A study of activities in distributed workspaces based on interviews [19], also found that smaller mobile devices such as tablets and smartphones had replaced PCs for many tasks. They identified parallel and serial usage patterns of multiple devices and concluded that better ways were required for coordinating activities across devices. A diary and interview study by Jokela et al. [12] also revealed both sequential and parallel patterns. Three parallel patterns were identified: a) resource lending, for example using a phone as a hotspot, b) unrelated parallel use with different devices used for different tasks, and c) related parallel use where multiple devices are used for a single task. Supporting related parallel use is commonly the goal of cross-device applications where the user interface of a single application is distributed across multiple devices.

Among the first cross-device scenarios to emerge were smart rooms [22, 11] which fall into the category c) as defined in the introduction and mainly were designed to support collaboration and creative tasks such as brainstorming. ePlan [2] is a more recent project in the same area that explicitly takes into account personal devices that users might have, such as tablets. Other collaborative scenarios include planning trips by using shared and personal devices [10, 15, 7].

Example scenarios for increasing screen real estate are quite common in the literature. They include map viewers [1, 21, 18, 9], data visualisation [1], and video players that distribute the video or additional content on annexed screens [23, 21, 15]. Scenarios of this type are often not clearly described as multi- or single-user. For example, the map viewers are able to distribute a map across multiple tablets, however, it is not specified how, or if at all, multiple users can interact with them. On the other hand, if the application primarily targets a single user, it is not clear how likely it is that they would actually have multiple tablets at hand.

In the controller category, video or music players [23, 21], photo viewers [5, 21], and slideshow presenters [17, 23] have all been used as demonstrator applications in research projects. These scenarios can fall into the single- or multi-user category, since it is often assumed that a single person uses a personal device as a controller and any number of users consume the content either on a large screen or on their personal devices.

A number of research projects investigated different styles of cross-device interaction [9, 16, 18, 20, 8], while another popular direction of research has been the design of web-based frameworks to support the development of cross-device applications [10, 23, 1, 21, 14, 7]. However, despite a large number of frameworks now being available, there are still few full-fledged cross-device applications. Most of the applications used as demonstrators are prototypes that fall into the categories of information sharing services, media services or map-based applications.

Further studies on personal device ecosystems could inspire and inform the design of new cross-device applications. In addition to knowing what activities users carry out on specific devices, it is important to know what set of devices users have access to at home, at work, travelling to and from work, socialising with friends and on holiday.

METHOD

Our primary goal was to find out what devices users typically have within reach in various settings, rather than focusing on how these devices are currently used. It was therefore more important to have a large number of participants with varied profiles than to carry out an in-depth analysis for a few individuals. For this reason, we opted for an online questionnaire and recruited participants through a variety of open channels such as social networking sites as well as direct contact with individuals known to us personally. This included emailing students in two of our courses inviting them to fill in the questionnaire and also asking them to try and recruit a family member or friend who was not an expert in IT. Participants were actively recruited during a three week period in November 2015.

The questionnaire consisted of 7 sections and a total of 38 questions. The topics of the sections were user profile, ownership of personal devices, at home, at work, on the move, multi-device applications currently used and possible cross-device scenarios. Most questions involved selections from a check list, but 5-level Likert items (strongly disagree to strongly agree) were used to indicate how interested a participant would be in five cross-device applications presented as scenarios. They could also propose their own scenarios in an open question.

RESULTS

The survey had 398 responses of which 293 (69% male, 31% female) were complete and included in the analysis. The ages ranged from under 20 to over 70 and we had residents of 26 different countries with the most coming from Switzerland (43%), Italy (18%), USA (14%), Germany (9%) and the UK (8%). 62% lived with family members, 18% with friends and 18% lived alone.

43% were full-time students and 63% were in part-time or full-time employment, with 33% of those in education or research and 27% working in the software/IT sector. Only those employees whose main place of work was not their home (86%), were required to complete the section about devices in the workplace.

Personal Devices

Fig. 1 gives an overview of participants' devices. While other studies have been interested in whether devices are shared among family members, e.g. [13], this was not relevant to our study as we simply wanted to know what devices were available. The figures therefore include shared devices as well as those where the participant was the sole user.

Since cross-device applications are designed to exploit the set of available devices, in some cases simply to increase screen real estate, we asked participants to include old devices that were no longer in regular use. As seen from the responses, it was quite common for people to have multiple devices of the same type (38% mobile phones, 9% tablets and 35% laptops). The reasons given for having multiple mobile phones are shown in Fig. 2. While reasons for having more than one

	none	one	two	three	more than three
mobile phone	0%	63%	23%	9%	9%
	0	183	68	25	17
tablet	38%	53%	8%	1%	0%
	112	154	22	4	1
laptop	4%	61%	26%	6%	3%
	13	178	76	16	10
e-reader	71%	29%	0.0%	0.0%	0%
	207	85	0	0	1
smart watch	88%	11%	1%	0%	0%
	258	33	2	0	0

Figure 1. Type and number of personal devices used by participants

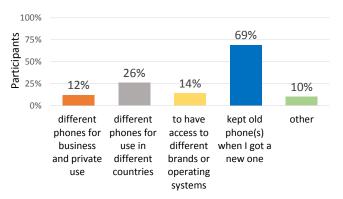


Figure 2. Reason given for having multiple mobile phones

phone included having separate private and business phones, 69% answered that it was due to keeping the old phone when updating to a new model. Similar figures for old devices were found in the reasons for having multiple devices in the case of tablets (56%) and laptops (61%).

At Home

Participants were asked to specify what they considered to be their main computing device at home and the results are shown in Fig. 3. The most popular answer was a laptop (58%), and the second most popular a PC (38%). These percentages are relatively high compared to other studies, which may be due to the fact that a large proportion of our participants were studying computer science (37%) or IT professionals (17%).

A significant percentage of those who had a PC or laptop as their main device, had an additional second screen (44% for PC users, 42% for laptop users). Fig. 4 shows the additional devices that participants usually have within reach when using their main computing device. As might be expected, a large percentage (91%) have their phones nearby, but significant numbers also have a tablet (28%) or laptop (20%).

Since cross-device applications are often designed to take advantage of large screens, we asked participants how many televisions (TVs) they had in their home and where they were

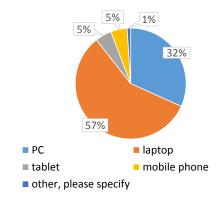


Figure 3. Type of main computing device at home

located. Here there were interesting cultural differences as shown in Fig.6. Our results indicate that it is more common to have a TV in the kitchen and bedrooms in Italy than in Switzerland, Germany or the USA.

23% of participants had no TV. When asked what device they would use to view a film on their own, 51% answered TV and 44% a laptop, PC monitor or tablet. Note that we did not explicitly ask about smart TVs as we felt that the term might confuse some participants and, since people are tending to replace old TVs with smart TVs, the distinction is not highly relevant when considering potential future applications.

Fig. 5 provides an overview of the types of device that people usually have access to in various places within their home. While our responses showed a tendency for younger people to have more devices with them than older people in general, it was interesting to note that the difference is not as great as some might expect. For example, in the over 40s, 49% had access to a single device in bed and 21% had access to two devices, while the corresponding figures for those below the age of 30 were 51% and 32%. The main difference between the age groups was seen in the figures for devices in the toilet where 63% of under 30s typically have one device with them and 13% two devices, while 32% of over 40s had one device and none had more than one device.

	mobile phone	tablet	laptop	e-reader	smart watch	none of the above
in bed	76%	25%	17%	13%	2%	14%
	222	74	51	39	7	40
cooking in the kitchen	69%	18%	8%	1%	4%	23%
	203	52	24	2	12	68
eating dinner	62%	9%	12%	0%	4%	34%
	182	25	36	0	12	99
having a bath	20%	4%	1%	1%	1%	75%
	58	12	4	3	3	221
using the toilet	65%	8%	1%	2%	4%	32%
	190	24	3	6	12	93

Figure 5. Type of devices that participants usually have within reach in different areas of their home

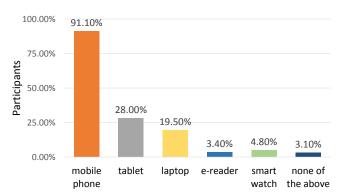


Figure 4. Type of additional devices that participants have within reach when using their main computing device at home

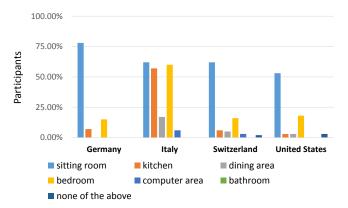


Figure 6. Rooms at home used by participant where there is a television

At work

We asked participants if they had a dedicated desk at work. 77% had a desk and 76% of those had a PC at their desk. 54% had a single monitor on their desk, while 41% had two and 2% had three.

The number of additional monitors that could viewed from their normal work position is given in Fig. 7. It is not clear whether these were some form of public or semi-public displays, or screens of colleagues, but it does show that, in many work environments, there are additional displays within view that could potentially be cyber-foraged [3].

Fig. 8 shows the additional devices that participants typically had within reach at their desk.

Since several projects have proposed the use of phones in the workplace to detect user presence, infer user activities or interact with displays, we asked participants if they typically have their phone on them in their local work area. A significant proportion (34%) do not carry their phones on them, with the figure close to 50% for females. This shows that it is problematic for researchers to assume that people always have their phones with them in working environments.

On the move

Fig. 9 provides an overview of the devices that participants carried to and from work. Nearly everyone carries a phone, with 10% carrying two phones. Nearly half (47%) carry a laptop, while 17% carry a tablet and 9% an e-reader. This shows that there could be a lot of potential for cross-device working for those who travel to work on public transport.

The number of devices that participants take with them when meeting friends for drinks or dinner drops as might be expected, but most still carry a phone, 3% a tablet, 2% an e-reader and 3% a laptop. This suggests that cross-device applications for such scenarios should focus more on sharing of information between phones.

In contrast, most participants took several devices with them on holiday. Almost all participants take a phone with them (89% one, 10% two), 47% take a laptop, 40% a tablet, 23% an e-reader and 7% a smartwatch. When combined with devices of family and friends, and possibly devices in hotel rooms such as a smart TV, this suggests that there could be a lot of potential for cross-device applications in holiday settings.

	none	one	two	more than two
mobile phone	1%	89%	10%	0%
	1	141	16	0
tablet	83%	17%	0%	1%
	131	26	0	1
laptop	53%	47%	0%	0%
	84	74	0	0
e-reader	91%	9%	0.0%	1%
	207	14	0	3
smart watch	87%	11%	0%	1%
	138	18	0	2

Figure 9. Type and number of devices that participants carry when travelling to and from work

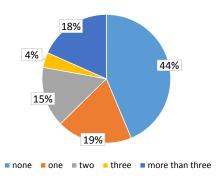


Figure 7. Number of additional displays in view from their desk for participants with a dedicated desk and PC at work

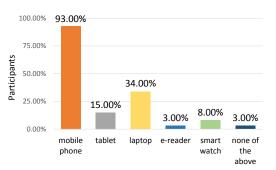


Figure 8. Additional type of devices within reach while working at their desk for those participants with a dedicated desk and PC at work

Scenarios

In the final section of the questionnaire, we presented five scenarios and asked participants to indicate whether or not they would like to be able to use different devices in the way described.

The scenarios were influenced by prototypes developed within various cross-device research projects and are:

- **A. YouTube** You decide to relax by watching some YouTube videos in your sitting room. You would like to be able to watch them on your television using the display on your mobile phone to search for videos and control the sound, fast forward, replay etc.
- **B. Image Processing** You are selecting and processing images from your holiday on your main computer. You would like to be able to view the images on the main display of your computer while using a tablet to scroll through the collection of images, add ratings and select ones for deletion.
- **C. Online Course** You are accessing an online language course on your PC and have to answer some questions to check whether you understood one of the lessons. If you

have problems, you would like to be able to review the lesson on your tablet and also do some dictionary checks on your phone.

- D. Meeting Friends You are meeting three friends for coffee and they ask you about your recent holiday. You want to show them some images that you have on your mobile phone and tell them about the places and people in the images. Since it is difficult for all three friends to view the images on your phone at the same time, you would like to be able to select images on your phone to be displayed on their phones. When you point to a person or place in the image on your phone screen, a marker would appear on the images displayed on your friends' phones to indicate where you are touching the image.
- E. Planning Trip You are on holiday with a friend and planning a walk in the mountains for tomorrow. You are both in your hotel room. You would like to be able to search for information on routes and images using the tablet you brought with you, while your friend searches for information about trains and buses on their mobile phone. Each of you could select information on your personal device to be displayed on the television in your room, including the possibility to display different information side-by-side.

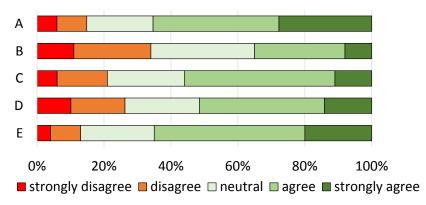


Figure 10. Participant's feedback on whether they would like to be able to use multiple devices as described in five cross-device scenarios (A-E)

Participants had to indicate their agreement or disagreement using a five point Likert scale and the results are shown in Fig. 10.

The feedback was generally positive with a significant proportion of participants agreeing that they would be interested in using the applications, with scenarios A (YouTube) and E (Planning Trip) being the most positively received with 65% answering either strongly agree or agree in both cases. A majority of participants responded with strongly agree or agree for C (56%) and D (52%) as well. Scenario B was of less interest with only 35% answering strongly agree or agree, but this could be due to it being a more specialised application scenario suited to keen photographers.

DISCUSSION

The results from our study indicate that there is a lot of potential for cross-device applications given how common it is for users to have multiple devices on their person or within reach in everyday settings. It is not simply a matter of having multiple devices at home, but the fact that many users have access to multiple devices in different areas of the home such as the kitchen and bedroom as well as the living area. While some devices such as TVs are in fixed locations, others such as phones, tablets and e-readers are moved around the home as users move from one area to another. This could open up new application domains beyond using mobile devices as remote controls for media players.

The fact that commuters often carry multiple devices while travelling to and from work suggests that the ability to work across these devices could be highly beneficial to increase screen real estate while working on trains, planes etc. Further, new forms of cross-device interaction could be supported to transfer data between devices or coordinate actions. For example, [6] describes a framework for developing cross-device applications where a combination of tilt and tap gestures on a mobile phone could be used to interact with other devices such as a second phone and tablet.

Our study showed that a significant number of PC workplaces are equipped with multiple monitors, yet so far there are few cross-device applications that exploit this. At the same time, it is common for a range of other devices including phones, tablets and laptops to be within range while users are working at their desks. Therefore investigating cross-device scenarios for individual users at their desk could be a fruitful direction of research and development in addition to the collaborative scenarios that have been a focus of previous research in workplace settings. However, it is important to note that a significant percentage of users in our study (34%) do not carry their phones with them as they move around locally within their workplace. In the case of females, the percentage was even larger (50%). Since users should not be expected to change their behaviour, this should be taken into account when designing cross-device applications for the workplace that extend beyond the locality of a user's desk.

Other interesting settings involve users on their travels since it is now common for users to take multiple devices with them, and applications could exploit smart TVs in hotel rooms as well as combinations of devices of travel companions. Our scenario of planning a trip in a hotel room received a particularly positive response from participants.

While most participants had access to multiple devices in each of these settings, the variation among settings in terms of the number and type of devices available, highlights the importance of developing applications that adapt to the particular set of devices accessible at any point in time.

Another finding of our study was that users often keep old devices when they upgrade to a newer model. Jokela et al.[12] suggested that old devices could be used in more specialised roles, for example an old tablet permanently mounted in the kitchen. We think this should be considered in cross-device scenarios and have recently started to investigate this.

CONCLUSION

We reported on a study that, taken together with previous studies on the current usage of devices in specific settings, could inspire and inform the design of new types of cross-media applications. We believe it is important that the research community continues to carry out a range of studies on personal device ecosystems given how quickly the landscape of devices is evolving and the growth in ownership.

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