Mobile Taskflow in Context: A Screenshot Study of Smartphone Usage

Amy K. Karlson[1], Shamsi T. Iqbal[1], Brian Meyers[1], Gonzalo Ramos[2], Kathy Lee[3], John C. Tang[1,3]

[1]Microsoft Research
1 Microsoft Way, Redmond, WA

[2]Microsoft Corporation
11025 NE 8th, Bellevue, WA

[3]Microsoft Corporation
1310 Villa St, Mountain View, CA

{karlson, shamsi, brianme, gonzalo, kathlee, johntang}@microsoft.com

ABSTRACT
The impact of interruptions on workflow and productivity has been extensively studied in the PC domain, but while fragmented user attention is recognized as an inherent aspect of mobile phone usage, little formal evidence exists of its effect on *mobile* productivity. Using a survey and a screenshot-based diary study we investigated the types of barriers people face when performing tasks on their mobile phones, the ways they follow up with such suspended tasks, and how frustrating the experience of task disruption is for mobile users. From 386 situated samples provided by 12 iPhone and 12 Pocket PC users, we distill a classification of barriers to the completion of mobile tasks. Our data suggest that moving to a PC to complete a phone task is common, yet not inherently problematic, depending on the task. Finally, we relate our findings to prior design guidelines for desktop workflow, and discuss how the guidelines can be extended to mitigate disruptions to mobile taskflow.

Author Keywords
Mobile taskflow, cross-device tasks, diary study.

ACM Classification Keywords
H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

General Terms
Experimentation, Human Factors, Measurement.

INTRODUCTION
In recent years, mobile phones have become increasingly important in peoples' computing ecosystems, co-opting many of the tasks once performed solely at desktop or laptop PCs [9]. Traditionally PC-only applications, like email and web browsing, have branched out to phones, and have been largely successful at accommodating the *device* constraints, such as limited screen space and input capabilities. Yet these interface designs and interaction models have largely not accounted for the *situational* constraints that are common in mobile usage scenarios. For instance, mobile users' task-directed attention can become fragmented into spans lasting only a few seconds [15]. Yet accepting that there are additional constraints does not address the complete picture of smartphone *taskflow*. That is, do traditionally desktop tasks maintain the same component activities when they are carried out on the smartphone? Have the orders, rhythms, or methods of carrying out these activities been changed? And if so, are current systems adequately supporting these new models of taskflow brought about by such tasks "going mobile"?

Suspending ongoing taskflows due to external or internal interruptions has been studied in depth on the desktop PC [5]. Furthermore, characterizing the sources of disruption and users' management strategies have led to empirically-backed design guidelines for supporting taskflow and productivity at the desktop [7]. In this work we pursue complementary research of the effects on taskflow when similar tasks are carried out on a smartphone. The empirical work of Oulasvirta et al. [15] provided evidence that environmental distractions can dramatically affect low-level patterns of visual attention to a phone-based activity. We instead explore how mobility affects the completion of tasks on the whole, such as when phone tasks become suspended as a result of contextual or resource constraints.

While prior work has identified four phases involved in managing interruptions to workflow on the desktop—preparation, diversion, recovery and resumption [7]—it is uncertain whether this model applies for disruptions to smartphone tasks. For one, barriers to taskflow on a smartphone are not limited to interruptions, but also include practical limitations of the hardware and usage context. Another difference is that recovery (remembering to resume an interrupted activity) on the desktop is often aided by persistent visual cues, which are not commonly presented on smartphone displays. Finally, interruptions to mobile tasks that require completion on a PC impose crossover challenges to users in recalling and resuming those tasks.

We surmised that a variety of the challenges that thwart completing or resuming tasks on a smartphone are not encountered on the desktop. In order to uncover these novel challenges, we conducted two studies to gather empirical evidence of the types of barriers people face in accomplishing smartphone tasks, how users follow up from suspended mobile tasks, and how problematic these disruptions are to users. We first conducted a large-scale web survey designed to explore users' mobile task workflows, focusing on their use and management of

CHI 2010, April 10–15, 2010, Atlanta, Georgia, USA.

mobile email as an exemplar task that has crossed over from the desktop to the phone. Based on evidence that fragmenting email tasks across multiple devices can lead to pitfalls for users, we followed with a 2-week screenshot-based diary study to broadly catalog the more general types of taskflow disruptions that users face on their smartphones.

Taken together, our results allow us to offer three specific contributions. First, drawing from 386 *in situ* examples of barriers that originate in smartphone use, we present a generalized classification of impediments to smartphone taskflow. Second, we show that these barriers can lead to tasks becoming partitioned across devices. We identify the properties of such tasks and suggest why some cross-device taskflows work well and others do not. Finally, we relate our findings to prior design guidelines for desktop workflow, and discuss how the guidelines can be extended to mitigate disruptions to mobile taskflow.

RELATED WORK

Over the last decade, there has been growing interest in the impact of mobility on productivity. While early studies of mobile work typically focused outside the traditional workplace [10,16], many of the insights on the contextual constraints of mobile computing apply equally well to information workers, who, with the use of laptops and smartphones, have unprecedented flexibility in where and when to work. In 2001, Perry et al. [17] studied workers' data management activities around planned absences from desktop environments, and showed that phones (calls) were already proving valuable for coping with unanticipated data needs. Oulasvirta et al. [14] investigated how information workers who own multiple laptops and smartphones manage their devices, both physically (e.g., laptops as "trays") and with respect to the information users access through them. Through a broader sample of interviews, Dearman and Pierce [6] offered further insight into the difficulties encountered when accessing and managing data across a variety of devices. Our work extends this growing understanding of modern work practice by documenting taskflow specifically from the vantage of the mobile phone.

Modern mobile devices such as smartphones have had an undeniable impact on users' concepts of work and working hours, as observed in the opportunistic use of phones to fill gaps of time [18] that invariably blur the lines between work and personal life [9]. Not surprisingly these habits impact how we coordinate and collaborate with other people [4,13]. But beyond Mazmanian's [12] study of how Blackberry adoption in corporations has changed users' relationships with email and the people with whom they connect, little attention has been given to how the mobile device impacts users' overall productivity. We posit that multi-device email practices may introduce new and disruptive discontinuities to taskflow. For example, manual workarounds, such as the anecdotal use of "mark as unread" on smartphones, suggest that the designs of today's systems and infrastructures may be exacerbating the already well-known problem of keeping important emails in view on the desktop [21]. To understand where users may be having difficulties with mobile email, as well as mobile tasks more generally, we asked our study participants to capture the contexts surrounding moments when they suspend tasks on the phone, including ones they planned to continue on a PC.

With a plethora of interruptions and increasing practices of multitasking, managing workflow on the desktop itself presents many challenges [5,8]. In a study of information workers using desktop computers, Mark et al. [11] found that work becomes fragmented due to interruptions and self-imposed time limits. In complementary work, Iqbal and Horvitz [7] characterized four phases associated with interruptions to workflow and corresponding recovery and resumption. They found that it could take up to 15 minutes for a user to resume an activity after being interrupted by an email or instant messaging notification on the PC. While notions of workflow with respect to task completion have generally not been applied to the mobile domain, Oulasvirta et al. [15] documented how mobile tasks contend for users' visual and cognitive resources, which may switch every few seconds between the device and the environment. Our work extends their examination of task fragmentation at the micro-level, to understand the causes of, and strategies for, managing suspensions of mobile activities at the task level.

Studying user needs in mobile computing scenarios presents a unique set of challenges. In contrast to a fixed, desktop computing environment, the user's freedom to change location and activity results in a broader range of applicable contexts [20]. Observation [6,14], *in situ* logging [9,15], interviews [6,14], diary studies [19] and experience sampling [3] (ESM) are typical methods adopted to address the dynamics of mobility. In this tradition, our work uses a diary approach in which users take screenshots of their phone *in situ*, but annotate them later from a PC. This design closely follows Carter's suggested diary study pipeline [2]: lightweight capture of memory-trigger media in-the-moment, followed by in-depth annotation and review from a PC along with in-person interviews.

The goal of our work is to develop a better understanding of smartphone taskflow in context by broadly sampling the moments during which flow, and possibly productivity, break down. We investigated: 1) barriers people face while engaging in tasks on their smartphones, 2) follow-up strategies users adopt in response, and 3) user frustrations corresponding to these moments. Our data bring new insight into the design requirements for systems supporting user activities, both on smartphones and in the context of tasks involving other devices such as laptops and PCs.

UNDERSTANDING TASKFLOW IN MOBILE DEVICES

As an initial step toward understanding how taskflow on a mobile device differs from that on the desktop, we administered an online survey, targeted to a randomly selected sample of smartphone owners across a large global software company. The survey focused primarily on mobile email management as a representative task commonly performed on both desktops and mobile phones. In particular, we queried respondents about: the frequency with which they performed typical email tasks (e.g., reading, replying, deleting, filing) on their phones, task completion strategies when an email task becomes partitioned across multiple devices, and pain points in current multi-device email management strategies. In addition to email-related activities, we also asked about other tasks they may have carried over from the desktop world—such as calendar, web, and document activities—to expose other activities where taskflows on the mobile device may depart from those established on the desktop.

Results

Of 240 respondents, 234 (male=175, female=56, unspecified=3) reported using smartphones: iPhones (24), Windows Mobile Smartphones (109), Windows Mobile Pockets PCs (91), Blackberries (3), Palms (3) and Other (4). More than half (128) of the respondents reported using mobile devices several times an hour, and the remaining reported using them several times a day.

As was expected for this population, mobile devices were overwhelmingly used for email activities. The most common activities were reading (91% at least several times a day) and deleting (63% at least several times a day) email. Reading (87%) and composing short emails (61%) on the device were considered *very important* to most of the respondents. Respondents did not, however, rely on their mobile device to compose long emails (61% were neutral or found it not important). Participants also reported relying heavily on their phones (at least several times a day) for reviewing calendar appointments (80%) and making phone calls (53%); a substantial number of users also used their phones at least several times a week for browsing the web (71%), text messaging (56%), and adding calendar appointments (52%).

Specific questions on the survey probed how users addressed difficulties in migrating email related tasks from their mobile devices to their PCs. 64% of the respondents reported that they typically relied on memory for follow-up of email read on their mobile device when they returned to their PC. 40% admitted that they sometimes forgot to follow up. 34% reported to often set the ‘unread’ flag on email as an additional memory aid. More than half of the respondents also responded to an open-ended question on their strategy for following up on email that was first read on the mobile phone. Leaving emails in the inbox as an indirect reminder to revisit them was listed by 22% of the respondents. Some users reported using flags (11%), although a few respondents remarked on the difficulty of setting a flag on a message. Less frequent strategies were the filing of emails into special folders (2%) and forwarding emails to self (1%).

Interestingly, having cited various workarounds to keep track of important emails, users generally felt their mobile email management strategies were effective at least *most* of the time (76%). Yet many of these respondents (47%) also reported breakdowns including forgetting to mark an email as unread, losing track of emails that need follow-up, and overlooking email that was subsumed by a larger volume of accumulated email.

Respondents also expressed a need for reminder tools to help resume activities that were suspended on the mobile device (median response: ‘somewhat important’), see Figure 1. For example, despite that current mobile email management strategies were mostly viewed to be effective by the respondents, they reported finding value in new tools that would help them follow up on emails that were first read on the mobile device (70% found this to be at least somewhat important), or resume email tasks that were interrupted due to environmental or resource limitations (62% found this to be at least somewhat important), suggesting that there is room for improvement in how email is presently managed on multiple devices. In fact, email management was not the only activity that users desired help on remembering and resuming—at least 60% of respondents felt that developing resumption aids on the phone for activities such as browsing, communications and note taking was important. Figure 1 illustrates the relative importance that respondents placed on such reminder tools, and importantly, draws attention to tasks beyond email where users are likely facing interruptions or barriers, and where assists for resuming tasks would also be welcomed.

In summary, the main goal of our survey was to document email strategies that people use when mobile, including mechanisms for following up on email when returning to a PC. While users reported that they found their mobile email management strategies to be successful most of the time, email is also a task that is relatively well synchronized between phones and PCs. Still, the types of manual, mental, and systematized strategies that respondents reported using to remember unfinished email tasks were not completely reliable, and users expressed interest in new tools to help them follow up on email. Furthermore, the survey identified other activities that users conducted on their mobile device that were subject to interruptions before completion. While the survey provided insight into how email is currently

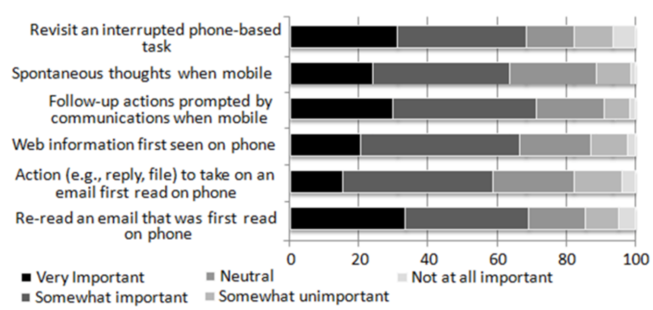

Figure 1. Distribution of responses (by percentage) indicating the importance of new tools to help users remember to resume tasks that become suspended on the mobile phone.

being managed across devices, it also made us curious about how these other tasks, which are generally less mature on the phone, are faring.

SCREENSHOT STUDY

We conducted a follow-up study to help capture and analyze user experiences across the range of tasks (beyond just email) being performed on smartphones. We sought to characterize the current smartphone taskflow, sources of obstacles to task completion, and the types of experiences that most frustrate today's users, to better understand the features needed to more effectively support recovery from task interruption. We set out to capture a large number of examples in which real users found themselves deferring the completion of a task while using a smartphone. By capturing details of the task being performed, usage context, user frustration, follow-up plans, and task urgency at the moment of deferral, we sought to distill design insights from what was and was not working well for users.

Participants

We recruited 12 iPhone and 12 Windows Mobile Pocket PC (PPC) phone users having a wide range of professional backgrounds from within our large software corporation. Each device group had 5 women and 7 men, with an overall median age of 35. We included the "consumer" oriented iPhone and the "business" oriented Windows Phone to cover the breadth of the smartphone category of devices.

Method

In order to collect information about specific moments of task interruption (which we will refer to as "barriers") we asked participants to capture screenshots of their mobile phone at the moment of disruption and then later annotate those screenshots using a web-based form. Participants were scheduled for two 1-hour in-office visits exactly two weeks apart. During the first visit, the study software was installed and users were trained in the study procedures. Training consisted of reading a handout describing the types of screenshots we wanted and the importance of timely uploads. After answering any questions users had about the procedure, which was overwhelmingly described as "pretty straightforward," the author led the participant through steps of capturing, uploading, and annotating an example screenshot. The second visit consisted of an hour-long semi-structured interview about the screenshots that had been captured and removing software from the phones.

The screenshot guidelines that we provided were intentionally general. Not only did we want to encourage as much participation as possible, but we were also searching for previously underreported phenomena, and so were cautious to avoid inadvertently limiting our potential findings. In addition to introducing the study in general, the document enumerated four broad categories of disruption we were interested in, and provided 3-5 concrete examples in each category. The instructions used the following hypothetical scenarios:

- You complete only *part of an activity* because the other part is tedious, time consuming or impossible (e.g., reading email but replying later);
- You *consciously wait* until returning to a desktop or laptop computer to perform a task (e.g., entering a calendar appointment, performing a web search);
- An activity you are doing is *interrupted* due to the environment (e.g., stop light changes, bus arrives);
- Any other activity you would want to *remember* to "get back to" or "address" or "complete" at a PC.

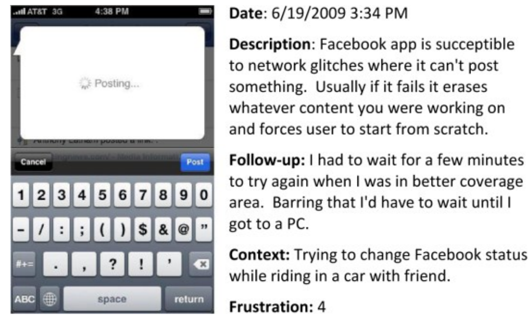

Figure 2. An example screenshot of a network problem.

We made every effort to keep the experience of participating in the study similar for iPhone and Pocket PC devices. All devices were configured such that a single button press or, on the iPhone, two simultaneous button presses would capture the screen. Once a day, at random times between 4-7pm, each participant received an email reminder to upload his or her new screenshots and annotate them from a browser. The study website presented each screenshot along with text fields that asked the participant for details about the type of barrier encountered, the context in which it occurred, and how the participant followed up (or intended to follow up). In addition, the form asked the participant's frustration level at the time of occurrence (1='Not at all frustrated', 5='Very frustrated'), the urgency of the task (1='No pressing time requirement', 5='As soon as possible'), and whether or not they had already completed the task at the time of annotation. The annotation page provided a 'Skip' button in the event that the participant accidentally uploaded a duplicate image.

Our decision to have users annotate their screenshots in batch once per day was intended to strike a balance between ease of use and quality of user feedback. We reasoned that the screenshots themselves would suffice as memory triggers when users recounted the details of the disruption later in the day. Because text input on mobile phones tends to be tedious, we deferred that task to the PC, keeping the effort on the phone as lightweight as possible. The web-based annotation interface was flexible enough to be used from any computer, thus encouraging study participation.

The incentive structure for participants was as follows: all participants were given a base of $25 for participating in two 1-hour office visits. If participants provided at least 14 screenshots across 4 different days, they received an additional $25 and yet another $25 if they reached 24

Table 1. Follow-up category definitions with their associated screenshot count and mean user frustration levels (with SD).

Follow-up Category	Definition	Count N=358	Mean (SD)
Computer	*Moving to a computer to complete the task.*	225	2.7 (1.4)
Mobile	*Persisting with the mobile device to complete the task at a later time.*	105	3.7 (1.3)
Abandon	*Giving up on completing the task, usually because a time-sensitive task became irrelevant once a delay was encountered.*	19	3.4 (1.4)
External	*Using non-technical means for completing the task (e.g., asking someone).*	9	3.3 (1.2)

screenshots across at least 5 days. As an extra incentive, the top performer each week received a $25 bonus.

Analysis

A total of 467 annotated screenshots were submitted (223 iPhone, 244 PPC) across all 24 participants. Each participant submitted a median of 17.5 (μ=19.5) screenshots across a median of 4 (μ=4.25) different days. All authors engaged in an extensively iterative process to categorize the free-form text responses that participants submitted with their screenshots, yielding four stable classifications for barrier types, task types, follow-up types and contexts. The classification process resulted in the removal of 81 screenshots that did not depict obstacles to performing mobile tasks. Reasons for removal included screenshots depicting actions but not barriers, normal phone usage with no follow-up required (e.g., "checking status"), and duplicate uploads; 386 remained for further analysis.

CHARACTERIZING SOURCES OF FRUSTRATION

We first wanted to understand users' perception of frustration when encountering barriers to mobile tasks. We were interested in whether the manner in which tasks were followed up was any predictor of the level of frustration our participants felt in the moment of task interruption. We generally assumed that switching to another device to complete a task would be considered more frustrating than completing the task on the mobile device itself. To explore this hypothesis, we analyzed the frustration ratings that users provided according to where the task was (actually or intended to be) resumed.

The classification scheme that we developed to capture the general methods that participants used to complete suspended phone tasks yielded 358 screenshots which we coded into four follow-up categories. We excluded 28 of the 386 screenshots from this phase of analysis because we could not determine how the user planned to follow up with the task depicted in the screenshot. The follow-up categories, their definitions, counts and mean frustration levels (with standard deviations) are presented in Table 1.

We were surprised to discover that our data showed users were least frustrated when moving from a smartphone to a PC than any other means of follow-up. A Kruskal-Wallis test, corrected for tied ranks, found that the differences among rated frustration across the four follow-up categories were significant, $\chi^2(3, N=358)=33.47$, $p<0.0001$. Pairwise comparisons found that following up on the PC (Computer) was significantly less frustrating than following up on the smartphone (Mobile), $p<0.0001$.

While we expected that users would be frustrated when having to migrate to another device to complete their task, our data show that they were in fact more frustrated when having to follow up on the smartphone later. These data reflect that users are more concerned about completing the task, rather than on which device they complete it. Perhaps users' low expectations of what they can do on a smartphone blunt their frustration in having to move to a PC to complete the task, especially if a PC is nearby and they can work more efficiently on it. Furthermore, since users often work on their smartphones when they are "filling" time that would otherwise not be productive, they may not mind starting a task on a mobile device without completing it.

To explore users' frustration ratings with following up more closely, we analyzed the 358 screenshots according to what task participants were engaged in when they were interrupted. We wanted to understand if users' frustration ratings varied according to the task. We iteratively developed a coding scheme to characterize what task the user was involved in for each screenshot. Table 2 summarizes the task types for which we had at least 20 screenshots, together with how the user followed up and the average frustration rating (with standard deviations).

A Kruskal-Wallis test was performed on the 328 screenshots listed in Table 2 (i.e., for tasks with 20 or more screenshots). Results showed that the differences in frustration across these common task types was significant, $\chi^2(6, N=328)=28.16$, $p<0.0001$. Post-hoc tests showed that mean frustration for Email was significantly lower than for Social Networking, Media, and Maps/Transit. Frustration for Web tasks was significantly lower than for Media and Maps/Transit. Frustration for File Management tasks were significantly lower than for Maps/Transits tasks.

Looking more closely at users who followed up by migrating to a PC ('C') versus persisting on the smartphone ('M'), the lowest average frustration rating was recorded for migrating to complete Email tasks (2.4), while the highest was recorded for completing Social Networking tasks (4.2) on a smartphone. Users' frustration ratings were higher when following up on the smartphone compared to the PC for all tasks except the Web and Media.

Taken together, our data indicate differences in users' frustrations according to how well applications for different tasks are currently designed to manage migrating from smartphone to PC. One reason that migrating email tasks between devices evokes low frustration is that much of the application state in email tasks is maintained at the server level, and can be accessed from any device. Messages can

Table 2. List of task types and mean frustration grouped by follow-up: Computer (C), Mobile (M), and Total (T).

Task (Count)	Definition	Mean Frustration (SD)		
		C	M	Total
Email (172)	*Read, compose, or manage email in any native or web-based email app.*	2.4 (1.4)	3.9 (1.5)	2.7 (1.5)
Web (36)	*Use a web browser to seek information of any kind, apart from the more specific tasks listed below.*	3.2 (1.1)	2.3 (0.8)	3.1 (1.1)
Maps/Transit (26)	*Interact with any navigation information, e.g. maps, directions, traffic, public transit schedules.*	3.3 (2.1)	4.1 (1.1)	4.0 (1.1)
Scheduling (26)	*Interact with the one's personal schedule to add, browse, respond to, or forward appointments.*	3.4 (1.7)	3.4 (1.5)	3.4 (1.6)
Social Networking (24)	*Interact with any social networking applications, such as Facebook, MySpace, Twitter, LinkedIn, SMS.*	3.0 (1.4)	4.2 (1.3)	3.6 (1.4)
File Mgmt (24)	*Manage information, files, or apps.*	3.2 (1.8)	3.3 (1.0)	3.2 (1.2)
Media (20)	*Control, play, capture, or organize any non-text media (music, video, photos).*	4.0 (0.9)	3.7 (1.4)	3.7 (1.2)

be sent and received from any device, and in many cases, draft messages started on one device can be available from another device to complete the task. The current design of email applications offers good support for resuming those tasks across devices without losing user effort.

By contrast, the two tasks which show higher frustration rates when migrating to a computer, Web and Media, reflect designs that do not support seamless transitions across devices. The application state for browsing and navigating web sites (e.g., web history, bookmarks), is typically kept locally on the device and not shared. Thus, resuming a web task on another device often requires repeating the effort required to browse and navigate to that site. Similarly, starting to view a video or streaming media on a mobile device would require a fair amount of re-work to find the media and the specific point in time to resume viewing it on another device. Our frustration data identifies important design considerations in how applications can support migrating tasks across different devices.

CHARACTERIZING MOBILE TASK BARRIERS

Our analysis of users' frustration ratings indicated differences in how well applications for different tasks are currently designed to manage migrating from mobile to computer devices. To translate these observations into concrete design guidelines for future systems, we focused on the specific usage barriers that caused frustration.

Table 3 describes the coding scheme for barriers captured in the screenshots along with the count of screenshots and unique participants, mean and median frustration ratings, percentage of tasks followed-up on the phone and PC and the percentage of tasks that were completed by the time users annotated the screenshots. For the follow-up column, colored bars in each row add up to 100%; black is Mobile %, grey is Computer %, and white is any other type of follow-up, such as described in Table 1; labels are provided only for phone and follow-up). In analyzing the screenshots, it became clear that many participants interpreted our capture guidelines to include general user experience annoyances or user interface inefficiencies with their devices (Usability Problems and Inefficient UI respectively). In addition 5% of the screenshots represented Software Failures (i.e., "bugs"). While we include these for completeness at the bottom of Table 3, we don't discuss them in any further detail because we deemed them to be too closely tied to a specific application instantiation to provide general insight into mobile workflow challenges.

Email Related Deferral

We classified 127 (33% of all screenshots) as relating to email tasks that were deferred until some point after the time the screenshot was taken. While there were a variety of reasons for which an email was not fully handled, we segmented the scenarios into three distinct groups: emails with outstanding action items, emails that remained unread, and emails whose next step was only a written reply.

Email: Unfinished Action Items

The largest number of email related screenshots (17% of all screenshots) required resources unavailable on the phone (e.g., files, time, people, data). Just under half (46%) of those were characterized by larger multi-step tasks (cross-categorized under "Complex Tasks"). At other times (44%) the participant needed access to a corporate file share, a corporate software tool or a PC file to complete the task. Five of the screenshots in this category required advanced email features that were not implemented on the phone, such as forwarding an invitation on behalf of someone else.

Impact: Emails that generated or represented incomplete tasks were clearly quite common, but as a group, seemed to be associated with low median frustration (1) overall. The fact that this group had among the greatest percentage of outstanding tasks (40%) at the time of annotation supports our interpretation that many of the screenshots seemed to represent larger tasks that might have been deferred even if the emails had been read on a PC. Low user frustration ratings may indicate that the item's presence in the inbox is sufficient to remind users of these unfinished tasks.

Email: Unfinished Read

The second-most common reason that participants took screenshots of their email was because they could not completely "consume" or read an email (12% overall). As with the previous category, a considerable number (15) of these emails referenced data that the user was unable to access from the smartphone, either because the phone did not have the capability to render/play an attachment or required additional permissions (corporate file shares) to locate the file. For other emails, the output limitations of the phone played a role in users finding the task too arduous to pursue, such as the email required an extra step to download the full message, the message referenced a website the user anticipated would render poorly, or the message was too long to bother reading on a small screen.

Impact: Although participants had completed reading a greater percentage of the emails reported in this category than they had completed in the previous category (73% vs. 60%), participants seemed to be somewhat more frustrated by not completing these tasks *in situ* (median of 2 vs. 1). The screenshots with higher frustration captured times when participants seemed interested in viewing the email at that moment, but could not. Given that phones are generally better suited to reading and reviewing email rather than replying, it is understandable that users would be annoyed from time to time when they have no way to access the content of an email they otherwise have the time to read. Indeed, 55% (5/9) of the above-average frustration scores (4 or 5) were during bus rides, versus only 5% of the remaining examples. Despite the current limitations users face today, these problems may subside as devices become more capable of rendering a wider variety of content.

Email: Unfinished Reply

The least common type of email deferral that we encountered in the screenshots was for emails where users needed only to type a reply but chose not to (17, or 4% of all screenshots). Participants overwhelmingly stated that the reply required "too much work" or would take "too long". An interesting minority of screenshots were those that required rich formatting, special characters, and spell check.

Impact: Unfinished email replies were generally seen as more frustrating (median 3) to participants than the other types of email barriers, which is surprising given that practically speaking, deferral was a calculated choice, not a strict barrier. The fact that fewer of these tasks were completed on average at the time users annotated their screenshots than Unfinished Read tasks might indicate that the natural moment of wrapping up the task had been missed, causing more frustration and loose ends than desired. Potential assists to users could come in the form of reminders for dangling emails that the owner typically replies to (according to any number of metrics), and continuing to research ways to reduce the limits on speed and expressivity of mobile input.

Missing Functionality

Ninety (23%) of the participants' screenshots indicated that their phone lacked some specific functionality required to complete their task. Beyond the email-related shortcomings mentioned above, the episodes reported typically resulted from the phone supporting a more limited "mobile version" of an application.

Impact: Of the remaining 39 non-email screenshots in this category, none were considered by the authors to be Complex tasks (below), and so might have reasonably been completed on the phone had the functions been provided. Relatively low overall frustration (median 2) indicates that people generally accept these limitations, but it is also

Table 3. Mobile task completion barriers, in decreasing order of representation in participant (Ppt) screenshots (SS). Follow-up is broken down by mobile (M) and computer (C).

N=386	#SS's/#Ppts		Frustration mean (med)	Follow-up		% Complete
				M	C	
Email	iPhone	PPC				
Unfinished Action Item	34/4	31/7	1.8 (1)		89%	60%
Unfinished Read	12/6	33/8	2.2 (2)		93%	73%
Unfinished Reply	14/6	3/3	2.6 (3)		100%	65%
Missing Functionality	57/12	33/9	2.6 (2)		91%	65%
Output Problems	17/8	35/11	3.1 (3)		87%	62%
Network Problems	23/7	21/8	4.1 (4)	45%	32%	84%
Complex Tasks	22/6	21/7	2.3 (3)		91%	60%
Cost/Benefit Choices	17/9	14/8	2.5 (3)		94%	77%
Environmental Factors	1/1	28/4	2.2(1)	55%	28%	75%
Input Challenges	17/7	5/5	2.5 (2)		95%	68%
Reminders	2/1	3/3	1.7 (1.5)		83%	33%
Usability Problems	46/9	34/9	3.7 (4)	58%	15%	65%
Inefficient UI	17/8	20/9	3.5 (4)	41%	49%	86%
Software Failures	7/6	12/7	3.8 (4)	37%	47%	63%

important to note that people are clearly using their phones as ancillary PCs and will increasingly hit walls imposed by scaled down versions of PC applications. More investigation is necessary to understand which features are most valuable to pursue. Otherwise, systems can help users by saving and transferring state across devices to facilitate task resumption in a more appropriate context for the user.

Output Problems

Despite advances in screen resolution and rendering capabilities, small screens still pose considerable challenges to information presentation on phones, as seen in 52 (13%) of our participants' screenshots. Almost half (40%) of these screenshots presented or referenced web pages that did not display or function properly on the phone.

Impact: Overall, output challenges cause moderate frustration (median 3) and incompletion rates (38%). High frustration ratings generally indicated instances when users tried and failed to access information to perform a task, as opposed to anticipating the problem and choosing to wait. While expected advances in mobile web browsers will go a long way toward solving many of these problems, others that involved reading, digesting, or getting an overview of information seem to indicate a need for generalized alternate, flexible and simultaneous views of information. While nearly all phones impose a single-app/window view model, our data suggest that this design can be too limiting for some tasks, which would benefit from the ability to display multiple apps or windows at variable resolution.

Network Problems

We identified 44 (11%) screenshots that represented network failures or latency long enough to cause the user to abandon their task. These failures affected task completion both for accessing information (email, calendar, web sites) as well as publishing information (like status notifications). Most of the time users captured these problems with screenshots of network failure dialogues (Figure 2), but at other times, the participants incidentally noticed that their data had not synchronized properly, such as missing a calendar appointment.

Impact: Network problems inspired the highest reported median frustration level (4) of any barrier. This relatively high level of frustration is understandable given the extensive effort that users expended in trying to overcome the barrier: rebooting, restarting apps, switching networks, and numerous re-attempts. User comments also captured sentiments about the unpredictability and mystery of outages: "*…I don't know why…for some reason could not connect…I am uncertain whether this error occurred due to an issue with the Gmail service or the device.*" Failures resulting in lost work, such as un-posted comments, were consistently rated with frustration of 4 or 5. Interestingly, network failures had the highest completion rate (86%) suggesting that despite the high frustration it engenders, it does not especially impact task completion (e.g., people do not forget to check email or post a status message), as many were even completed on the phone itself, versus waiting or migrating to a PC. Rather network failures expose missed opportunities, wasted effort, and delayed gratification.

Unfortunately, network inconsistency is likely to be a way of life for mobile users, so systems will need to be designed to minimize the negative impact on users, such as by preemptive information caching, notifying users of returns to connectivity, and minimizing rework by caching sufficient details of the task to enable retry on behalf of the user (e.g., by saving a local copy of a status post).

Complex Tasks

We classified 43 (11%) of the screenshots as complex tasks: those which required multiple steps (e.g., filling out a web form or survey), access to other resources (e.g., people, data), data collection and analysis (*"I need to do some research before responding to the mail"*), and which we estimated would take more than 2 minutes [1] to complete.

Impact. Overall frustration with unfinished complex tasks was low (median 2) reflecting the fact that users had little expectation of performing the task on the phone in the first place. Even so, it would be interesting to consider systems that allow users to manage these larger tasks as collections of subtasks, some of which are farmed out to the phone and checked off, so to speak, during "dead time" [18].

Cost/Benefit Choices

We characterized 31 (8%) of the screenshots as relating to choices the user made in weighing the relative cost to benefit of attempting to accomplish the task on the phone. In all cases the screenshot represented tasks that seemed possible to do on the phone but that users considered to be "too slow" to enter or download, "too much work" in terms of total steps, or needing better I/O throughput.

Impact: Given that participants' annotations indicated that they were making an intentional decision to defer their task, we were surprised that they also reported moderately high frustration (median 3). However, the fact that most (77%) of these screenshots were already completed on a PC at the time they were annotated suggests users may have sensed a missed opportunity in not finishing the task on their phone.

Environmental Factors

Environmental factors affecting the completion of mobile tasks included external interruptions (people, traffic lights, phone calls, arriving at bus stop) as well as context of use (e.g., not enough time) that caused a task that otherwise could be accomplished on the phone, to be delayed. We characterized 29 (8%) of the screenshots as being prompted by environmental factors.

Impact: Very low median frustration (1) and relatively high completion rates (75%), the majority of which were finished on the phone (55%), indicate that environmental factors do not pose a large threat to productivity. Presumably many environmental interruptions are momentary, allowing users to return to the task quickly, without losing phone state between attempts.

Input Challenges

The 22 (7%) input challenges represented in our data set captured problems specifically inherent to the low speed of text entry and absence of formatting capabilities on the phone. The low overall frustration rating (median 2) and moderate short-term completion rate (68%) indicates that people generally accepted this limitation and have strategies for completing such tasks on a PC (95%).

Reminders

A small but interesting subset of screenshots (6 total) represented occasions during which the participant captured a photo as a memory aid for completing the task at a future point when near a PC. Participant frustration was low (median 1) likely due to the fact that the users were not hitting a barrier with the phone, but rather using it to provide a bridge from an external setting to a desktop.

Differences by Device Type

We specifically included both iPhone and Pocket PC (PPC) users in our study because we wanted to capture breadth in the range of challenges that people faced in maintaining mobile taskflow. In this spirit, we made no distinction between the user groups in our classification exercises or statistical analyses. Yet, through our familiarity with the data, we did observe some trends in the relative strengths of the platforms, such as the PPC having better support for Microsoft Exchange services and iPhone having a more compelling web experience. Despite these task-specific differences, however, the first two columns of Table 3 show that our participant groups had surprisingly similar experiences with respect to the frequency and types of taskflow disruptions they encountered, which suggest that our classification scheme for mobile barriers captures characteristics that are inherent to mobile computing in general, rather than to a specific device model. In keeping with this broader scope, the following sections discuss and draw design inspiration from the elements that are invariant across platforms, as those are the ones that embody issues inherent to mobility.

Reflections on Barrier Findings

From our large sample of *in situ* examples of breaks in mobile taskflow, we derived nine generalized sources of mobile task interruption. Reflecting upon the barrier categories of Table 3 and what they mean in terms of how systems can help users manage mobile interruptions more effectively, we noticed three even more general groupings.

First, some of the barriers we captured may simply be the temporary growing pains of a field that is rapidly changing. For example, disruptions caused by Missing Functionality, Network Problems, and of course the user interface shortcomings depicted in the last three rows of Table 3, will all tend to decrease in frequency and severity with advances in technology and interface refinements. Furthermore, the fact that many of these barriers were rated to be highly frustrating means that they may have already caught the attention of industry players, who will respond accordingly.

The second grouping we notice is one made up of barriers that result from inherent aspects of mobility, and as such, are those that are likely to persist for the foreseeable future. Environmental Factors embody the unpredictable nature of mobile contexts, which are generally prone to external interruption, while task suspensions due to Cost/Benefit Choices and Complex Tasks are hallmarks of the contextual variability of users' cognitive, physical, and/or temporal resources while mobile. It is primarily for this class of challenges to mobile taskflow that we seek guidelines for reducing the manual and mental burdens users currently assume with today's infrastructures.

The final grouping we identified includes all email-related barriers, which we observed users to be managing relatively well today. The vast majority of email screenshots depicted intentional task deferrals to a PC environment, and users' modest to low frustration levels suggest that users are comfortable with and confident in current structures to support this partitioning. We believe constructive lessons can be drawn from examining email closely, and emulating its successful constructs when extending other, less mature tasks to the mobile phone.

DISCUSSION

The fundamental motivation behind our investigation was to understand how barriers to taskflow manifest on a mobile device and to form insights into how such disruptions to taskflow could best be addressed. Motivated by survey responses suggesting that our participants would welcome assistance in managing tasks that become suspended on their mobile phones, we asked users to record moments when they deferred a task and their reasons and frustrations when doing so. The large number of *in situ* experiences that we collected during our study offers evidence of the regularity with which our study population experienced breaks in taskflow on the phone. Importantly, the classification we derived from these samples demonstrates that many of the barriers people face are inherent to, and will persist with, mobile computing. But perhaps the most striking observation was the frequency with which mobile disruptions caused a task to become partitioned across more than one device—over 70% of our 386 screenshots captured task suspensions that users expected to complete on a PC, many of which were strategic decisions by the user. While our own prior work established that users perform similar *types* of tasks on phones and PCs [9], we had lacked evidence that users partition stages of the *same* task across phones and PCs. And that many of these switches are strategic suggest they should be supported, not eliminated.

Thus, one perspective that our data offers is in how mobile user experiences are situated within a larger context of tasks that are completed on a PC. This inspires us to focus on design implications not only for the mobile device in isolation, but also for tasks that extend beyond the mobile device to users' computing ecosystems. In establishing the relevance of taskflow to mobile phones, we find that the considerable research on interruption management at the desktop extends naturally to the mobile phone, but suggest that systems also must support inevitable task transitions across devices.

Iqbal and Horvitz [7] offer two directions for recovering from interruptions on the desktop: *reminding* users of unfinished tasks and assisting users in *efficiently rehydrating* task context. In desktop environments, open application windows serve both to retain state and indirectly remind users of suspended tasks. It is interesting to consider how the absence of these cues may be hampering mobile users, and motivates thought on how similar models might be realized in the mobile context to remind and assist users in resuming suspended activities. Yet we have also shown that task rehydration is relevant beyond the phone, calling for task state to be synchronized across phones and PCs. In fact, our data support this approach: users' consistent, device-independent view of the email inbox is likely the reason that participants reported relatively low frustration when they deferred handling an email until reaching a PC. In contrast, the lack of shared web browser state between PCs and phones may explain why involuntary suspension of web tasks caused users significantly higher subjective frustration than for email tasks.

In addition to improving the synchronization of relevant task state across devices [6], our data indicate that it is also important to convey on which device that state originated. For example, the practice of marking an email as unread from the mobile device is a sign that a binary read/unread status is too coarse to reflect the distinct stages of "read" and "handled" which are more routinely separated in time (and even place) on a mobile device than on a desktop. This example shows how performing tasks on the mobile device may require some reflection to the user when they return to a PC. Thus synchronization infrastructures may need to track which user interactions were accomplished on which devices to give the user a more meaningful sense of the progress of the task (e.g., show email items read from the phone in a distinctive way from those read on a PC).

Decomposing tasks into meaningful subtasks is one strategy that could allow users to more effectively maintain task progress when tasks span devices. We posit that the lower frustration ratings for mobile email than for web activities may be attributable to how email management tasks divide into distinct sub-tasks that users can perform independent of one another (e.g., read, compose, reply, file, delete). Other mobile tasks may benefit from this solution, but more investigation is necessary to understand how the principles apply in task-specific ways. For example, beyond sharing visited web links between PCs and phones, web clients know many more details about the progress of a browsing task that could be valuable to users when resuming a suspended phone-based session on another device, including the original search terms used, links followed, and interaction histories. Tracking activities at a finer level of detail, sharing these data with all of a user's devices, and surfacing them visually in a device-sensitive manner may help smooth the continuation of activities that are suspended on one device and resumed on another.

CONCLUSION

The goal of our investigation was to develop a deeper understanding of the nuances of managing taskflow on mobile devices. Our survey documented strategies being used for mobile email management and also led us to consider other tasks (e.g., web browsing, communications, scheduling) that are extending into the mobile arena. Our screenshot study helped us understand how the barriers that users encounter with mobile tasks often lead them to move to another device to complete the task. Thus, our findings open a window to a richer landscape of how multiple tasks (beyond just email) flow across multiple devices (not just phones). While more investigation is needed to understand the how our proposed design directions should be adapted to specific tasks, we see great opportunity for applying these insights to improve the design of systems that support seamless mobile and cross-device taskflows.

REFERENCES

1. Allen, D. Getting Things Done. Penguin Group (2001).
2. Carter, S. and Mankoff, J. When participants do the capturing: the role of media in diary studies. In *Proc. CHI 2005*, ACM Press (2005), 899-908.
3. Consolvo, S., Walker, M. Using the Experience Sampling Method to Evaluate Ubicomp Applications. *Pervasive Computing 2*, 2 (2003), 24-31.
4. Churchill, E. F. and Wakeford, N. Framing mobile collaborations and mobile technologies. In *Wireless World: Social and interactional Aspects of the Mobile Age*, B. Brown and N. Green, Eds. Springer (2002), 154-179.
5. Czerwinski, M., Horvitz, E., and Wilhite, S. A diary study of task switching and interruptions. In *Proc. CHI 2004*, ACM Press (2004), 175-182.
6. Dearman, D. and Pierce, J. S. It's on my other computer!: computing with multiple devices. In *Proc. CHI 2008*, ACM Press (2008), 767-776.
7. Iqbal, S. T. and Horvitz, E. 2007. Disruption and recovery of computing tasks: field study, analysis, and directions. In *Proc. CHI 2007*, ACM Press (2007), 677-686.
8. Jin, J. and Dabbish, L. A. Self-interruption on the computer: a typology of discretionary task interleaving. In Proc *CHI 2009,* ACM Press (2009), 1799-1808.
9. Karlson, A. K., Meyers, B. R., Jacobs, A., Johns, P., and Kane, S. K. Working Overtime: Patterns of Smartphone and PC Usage in the Day of an Information Worker. *In Proc. Pervasive 2009*, Springer (2009), 398-405.
10. Kristoffersen, S. and Ljungberg, F. "Making place" to make IT work: empirical explorations of HCI for mobile CSCW. In *GROUP 1999*, ACM Press (1999), 276-285.
11. Mark, G., Gonzalez, V. M., and Harris, J. 2005. No task left behind?: examining the nature of fragmented work. In *Proc. CHI 2005*, ACM Press (2005), 321-330.
12. Mazmanian, M., Orlikowski W.J., Yates, J. CrackBerrys: Exploring the social implications of ubiquitous wireless email devices. In *Designing Ubiq. Envir*, (2005), 337-343.
13. Nilsson, M. and Hertzum, M. Negotiated rhythms of mobile work: time, place, and work schedules. In *Proc. GROUP 2005*, ACM Press (2005) 148-157.
14. Oulasvirta, A. and Sumari, L. Mobile kits and laptop trays: managing multiple devices in mobile information work. In *Proc. CHI 2007*, ACM Press (2007), 1127-1136.
15. Oulasvirta, A., Tamminen, S., Roto, V., and Kuorelahti, J. Interaction in 4-second bursts: the fragmented nature of attentional resources in mobile HCI. In *Proc. CHI 2005*, ACM Press (2005), 919-928.
16. Pascoe, J., Ryan, N., and Mores, D. Using while moving: HCI issues in fieldwork environments. ACM Trans. Comput.-Hum. Interact. 7,3 (2000), 417-437.
17. Perry, M., O'Hara, K., Sellen, A., Brown, B., and Harper, R.: understanding access anytime, anywhere. *ACM Trans. Comput.-Hum. Interact. 8*, 4 (2001), 323-347.
18. Rattenbury, T., Nafus, D., and Anderson, K. 2008. Plastic: a metaphor for integrated technologies. In *Proc. UbiComp 2008*, ACM Press (2008), 232-241.
19. Sohn, T., Li, K. A., Griswold, W. G., and Hollan, J. D. A diary study of mobile information needs. In *Proc. CHI 2008*, ACM Press (2008), 433-442.
20. Tamminen, S., Oulasvirta, A., Toiskallio, K., and Kankainen, A. Understanding mobile contexts. *Personal Ubiquitous Comput. 8*, 2 (2004), 135-143.
21. Whittaker, S. and Sidner, C. Email overload: exploring personal information management of email. In *Proc. CHI 1996*, ACM Press (1996), 276-283.