Understanding Usability Challenges in Shifting between Multiple Devices during a Task

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***Abstract*—The use of multiple interactive devices in conducting one task is becoming more and more commonplace today. However, as the user interfaces (UIs) and interaction strategies have mostly been designed for individual devices or for a small number of paired devices, spontaneously combining different devices may result in usability issues that are worse than it was before the change takes place. In this paper, we present and demonstrate the concept of *device composite* – a combination of devices together with a set of suitable user interfaces and interaction strategies which will be activated when these devices are used together. Focusing on the usability side of the multi-device usage scenarios, we categorize the device composites into six basic interaction settings or configurations, and discuss corresponding usability issues associated with them. Two of the composite situations were developed into a fully-working prototype device ecosystem, and a user study was conducted with 18 participants. Findings and insights are reported suggesting further design directions for multi-device usability.**

Keywords—device composite, device combination, context-aware shift, multi-device interaction, multi-device usability

I. Introduction

The increased availability of computing devices, the variety of cloud storage services and the supportive ad-hoc wireless networks have enabled how people interact with digital information to suit their needs. End-users can start a task on one device and complete it on another, for example, starting reading an e-book on a tablet at home and finishing it on a phone in a bus. They can also plan how to coordinate their devices for an intended usage, for example, using a Bluetooth keyboard or a phone as a complementary input device to a smart TV, turning a tablet into a home media hub with its visual content shown on a smart TV screen and audio content pushed to stereo speakers. In addition, co-located devices have also been leveraged for reducing efforts for resource intensive task [1, 2] (e.g. sensing, task offloading).

The challenges presented by the dynamic changes in device use combination and/or in device role within an ecosystem of devices include the spontaneous nearby device discovery and communication [3, 4], the continuity in content and task [5, 6] and the inter-usability between devices [6]. Imagine that after arriving an unfamiliar city, you are trying to locate the shuttle bus location on a map displayed on your phone screen. Zooming in, panning the map on the small screen of your phone eventually mount up your distress. Had you known the existence of a public interactive display around the corner – coincidently out of your view, you could have output the current view of the map to the large display to help you locate the station of the shuttle bus more easily. When and how should this knowledge of helpful nearby devices be made known to you in particular and to other users in general? How would your phone initiate the negotiation with the unknown display to "move" the current view of map on your phone to the screen space of the display? What would be the best interaction strategy when these two devices are used together to complete a task? Would it be possible to predict that this spontaneous combination use of a phone and a large display would help the user to accomplish the task better? These are some of the questions that are becoming more relevant today when our experiences of interacting with computers are more and more characterized by using multiple interactive devices to accomplish a task.

In this paper, we investigate the usability issues arising from using multiple interactive devices to perform a task by (1) enumerating and characterizing different types of multi-device usage settings, followed by specifying the usability challenges in supporting the optimal interaction strategies for each, (2) identifying the usability issues and challenges in shifting from one setting to another from the end-user's point of view, and (3) developing a prototype multi-device ecosystem that represents an expected multi-device shifting situation to conduct user study and gain insights.

II. Related Work

A. Spontaneous Coordination of Devices for a Task

The prevalence of interactive devices in our everyday life has empowered us to use multiple devices for our daily tasks. Common reasons for coordinating multiple devices include information sharing and functional compatibility [7]. In summarizing how device(s) can be spontaneously used to support the goal of user(s), we borrow the classification of multi-device use by Denis and Karsenty [6] as a way to review multi-device usages.

Redundant device use. All devices support the same features for a user's task, thus the user can choose to use any of the devices for the task based on the user context, the availability of devices and the characteristics of the task. For example, a user checks emails on a phone but replies them using a laptop.

Exclusive device use. Each device provides different features for a user's task. This setting seems to be the most uncommon in the context of multi-device uses. For example, a

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phone can be used as an optical mouse (input device) to control how the information should be rendered on a large display (output device) [8].

Complementary device use. One or more devices (secondary devices) are used to improve or augment the operation of the other device (primary device) to optimally carry out a task. This has been the most common setting of multi-device uses, for example, adding a Bluetooth speaker to a laptop to watch YouTube, placing two or more co-located mobile devices next to one another to display a photo across the combined screen [9-11].

While the cited work here and the categories are meaningful in ways to support further studies of multi-device usage in general, the usability issues inherent in such usages could be more effectively investigated in the dynamic context of user-initiated device combinations: how optimal, known UIs and interaction strategies – designed for single devices or pairwise device combinations – can be leveraged to accommodate changes in the way multiple devices are used together.

B. *Spontaneous Interaction with Nearby Devices*

Spontaneous coordination of multiple devices requires discovering the presence of nearby devices to begin with. Several techniques for establishing dynamic device association have been proposed in the literature and commercial community include the use of synchronous gestures (e.g. bumping two devices together [12], holding two devices together and shaking them [13], pressing and releasing the buttons on both devices at the same time [14]), spatial sensing mechanisms (e.g. combination of nearfield channel and standard wireless channel to determine the location of devices surrounding a user [4]), or beacons and tags [15]. Connections between devices can be further augmented with social relationships between the users, such that each device is identified by its social profile [16, 17]. While these studies are all important steps to understand the context-aware multi-device environment, one issue that warrant more in-depth exploration and understanding is the usability dimension within this connected combination of devices, and at the time of shifting the user interaction from one combination of devices to another during a task.

III. Device Composites

Moving from one device combination to another requires an additional specification to accommodate the changes in user interfaces (UIs) and interactions. For example, moving from a single-user single-device interface to a multi-user single-device one requires the specification of how the device is shared and which user can control the interaction [18]. Likewise, further issues need to be addressed when multiple users change from sequential to simultaneous access of information on a device. The main question is how usability issues would or should be handled to accommodate the changes in device use in different contexts.

What if each combination of devices, together with a set of UIs and interactions suitable for that combination, is treated as a *composite* such that one of this recommended set of UI-interaction is activated when these devices are used together? This conceptual approach is similar to the concept of the *encapsulation* – a fundamental concept that refers to the bundling the data and the methods operating on that data in object oriented programming (OOP) approach – and *reuse* [19]. Designing basic individual components to be used as part of an elastic, dynamic computing environments in a bottom-up fashion is seen in the philosophy of recombinant computing [3]. We set to identify the basic device composites that can build up to describe any complex multi-device usage situations in a way that better helps describe and consider the end-user interactivity side of the picture.

A. *Device Composites*

We define *Device Composite* as the combination of devices together with a set of UIs and interaction strategies suitable for that combination. Focusing on device-to-device relationship when devices are used independently or in conjunction with one another to support a user's task, six basic device combinations (*Device Solitude, Exclusive Input-Output, Shared Input, Shared Output, Shared Input-Output and Device Companion*) and two sub device settings (*Equivalent and Parent-Child*) emerge (Fig. 1). A device is represented by a circle. I and O denote an input and output device respectively. The line connecting 2 circles indicates the devices are used in combination. The arrow denotes the information flow from an input device to an output device. The three dots appearing after a circle denote the fact that more devices can be connected in the same way.

1) *Device Solitude*

This most basic device composite refers to the use of a single device for a task. UI and interaction strategy for single-device use has been well studied by the design community. There is a wealth of design knowledge in the form of design principles, guidelines and heuristics, and device-/brand-specific standards that embody decades of studies and commercial successes/failures. Because this body of knowledge has mostly assumed a single-device interactivity (be it desktop computer, laptop, mobile, etc.) in a specific, constrained context of use, one of the issues raised when seeing this category of device composite is whether such principles and knowhow still hold true when extended to different device composites.

2) *Exclusive Input-Output*

In the Exclusive Input-Output composite, each device takes a role either as input or output device (denoted as I or O in Fig. 1) in a connected ecosystem of devices. Many multi-device practices as of today fall into this category (e.g. keyboard connected to a desktop PC, Bluetooth button as an input device

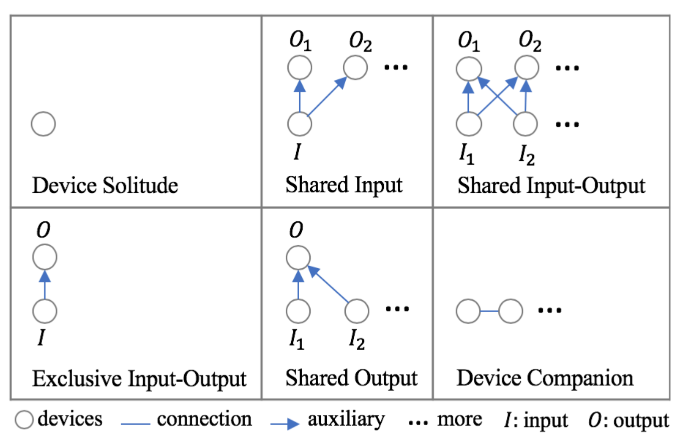

Fig. 1. Basic device composites

to a Virtual Reality (VR) headset [20], smartwatch as a remote control to a large display [21]), where a secondary or supporting I/O device might have been purposefully developed for that specific role. Due to this, most of design knowledge available today that had assumed Device Solitude composite may still apply here, although this requires more studies in itself. Another major usability issue is the lack of sustainability: if one of the devices becomes unavailable, it might not be possible to continue the task (e.g. the large display does not come with touch screen, making the connected mobile devices the only way to input).

3) Shared Input

In the Shared Input composite, content is output to two or more output devices (denoted as O_1 and O_2 in Fig. 1). For example, a pen stroke across two tablets was used for cross-device file transfer or for moving a graphic object across the other screen [22]. While this can be seen as an extension of the Exclusive Input-Output composite, there are quite different usability implications between the two. Adding an additional output device would require reconsidering the UI and interactivity between the newly added output device with current ones and with the shared input device, in the way that does not compete for user attention. For example, in Panelrama [23], when an input command was issued by one of the devices in a setup of 5 tablets (4 tablets were placed next to one another to display 4 pages of a research paper, and the 5th tablet which was not belong to the joining devices showed a reference list), which device screen should the user divert attention to?

4) Shared Output

In the Shared Output composite, the user provides input commands to the system using more than one local input modality or external input devices (denoted as I_1 and I_2 in Fig. 1). For example, restaurant guests used their phones to vote for video tracks to be played on a remote display [24], individuals transferred content from personal devices to a table top [25]. Use of multiple input devices most likely implies the user will need to tend to the different input devices within a session, thus an interaction mechanism needs to be considered to ensure the user attention is at the right input devices (as well as at the central output device for feedback). In addition, it is essential to manage parallel input and clearly give feedback each input on the shared output device.

5) Shared Input-Output

In the Shared Input-Output composite, multiple users leverage local/external input devices (denoted as I_1 and I_2 in Fig. 1) to interact with local/external output devices (denoted as O_1 and O_2 in Fig. 1). Its simplest form is the merging of the Shared Input and Shared Output composites. The main usability implication for this device composite is the system feedback on individuals' input on an output device, and input by one user across multiple output devices. A potential example scenario for the Shared Input-Output composite is a situation when multiple users use personal devices to access information on distributed public situated displays. While not very commonly practiced today, such situations may become more widespread around the communal urban spaces in the coming years.

6) Device Companion

The Device Companion composite refers to situations in which one or more devices are used to support the operation of another device. Each device functions independently in terms of input and output modalities. This composite is similar to the complementary device use (section II.A.3) but further categorized into 2 sub settings:

- *Equivalent device setting:* utilizing the same capabilities and/or functionalities of multiple devices helps boosting the task efficiency, for example, broadcasting a song to multiple speakers, or displaying the same visual information on several devices [9]. Removing a device in this combination only effects the quality of task output (e.g. task completion time, sound quality) but does not cease the task.

- *Parent-Child device setting:* content is displayed fully on a device (parent) while partial content is shown on the other device(s) (child). This complementary pattern is seen often in situations when a larger screen device acts as a main display and a smaller screen device takes part as a sub display [26]. In the task offloading situations, the parent device decides which job components to be offloaded to its child devices (e.g. offloading heavy processing tasks to improve responsiveness and battery efficiency [2, 27]). Such a setting typically means that the user is already aware of the connection, thus would divert the attention to a particular device in this setting. The system feedback in responding to a user's input should be promptly to avoid confusing the user. This composite may require the user's expertise level on each device and the services it offers [6] to effectively coordinate devices.

In summary, when there are multiple devices taking on the similar role for a task (e.g. output devices in the Shared Input, or Equivalent device setting which is under the Device Companion composite) if the secondary device suddenly gets disconnected for some reasons (e.g. battery is low, device is out of order, etc.), the task can still be carried out without the added features. However, if the added features are what the user relies on, the disconnection/unavailability of added devices may cause the stop of the task until the affected device becomes available or being replaced.

B. Shifting between Device Composites

We define *Device Composite Shift* as the change of the interaction setting from one device composite to another. It involves the substitution, adding or removing one or more devices, thus may alter the way the user engages with devices. Depending on the user context (e.g. user's goal/task) or environment context (e.g. available devices, the number of users involving in the interaction), the user interaction may change from sequential to simultaneous multi-device use, or vice versa.

A sequential multi-device interaction describes a situation in which a task is started on one device and resumed on another [5]. For example, using a smartwatch/phone as an input device for interaction with a large display is the Exclusive Input-Output composite (Fig. 2a). When the user alternately uses the phone and the smartwatch to control the display, it is the shift from Exclusive Input-Output to sequential Shared Output (Fig. 2b). Technically this shift will require the synchronization and migration of data/state between the smartwatch and the phone to ensure the task continuity [5], but in terms of end-user usability, the potential interruption of the task, sudden changes in the interaction style/UI, as well as issues of user attention scattered on 3 different devices are some of the issues to address.

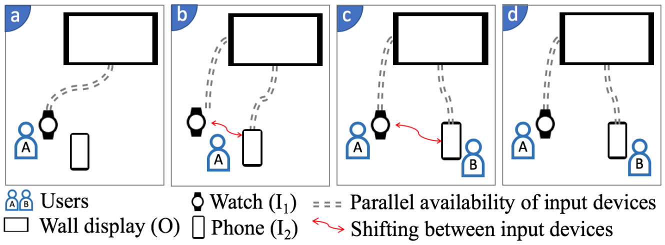

Fig. 2. An example of device composite shift from Exclusive Input-Output to Shared Output

A parallel multi-device interaction involves the use of more than one device at the same time for the tasks [5]. When more people join in the interaction with the display using their personal devices, the shift from Exclusive Input-Output to the Shared Output results in the push of the suitable UI to handle interactions from different users (e.g. using color scheme as visual indicator for objects selected by different users). This multi-user sequential form of Shared Output (Fig. 2c) is different from the single-user sequential Shared Output discussed above in that it may not be possible to migrate the data/state across input devices. The shift to the Shared Output can take the parallel form (Fig. 2d) when each user is designated for a distinct interaction zone on the large display. The Shared Output device composite would push the spatial partition of graphical UI (e.g. splitting screen views, creating separate workspaces) to accommodate. In this situation, the device composite may also be seen as multiple instances of the Exclusive Input-Output.

IV. System Prototype: Design and Implementation

We implemented a prototype using the above example to guide the study of usability issues in device composite shifts.

Design. We prototyped a video searching and browsing application called Media Browsing. The application runs on a large display which accepts users' input commands from external input devices such as smartwatches and smartphones. Combining the use of devices with extreme gap in screen size (watch/phone + large display) inevitably requires suitable UI and interaction scheme optimal for inputting and outputting of content on the selected devices. Aiming to facilitate a user's visual focus on browsing video content on the distant display, we use the hop-to-select traverse strategy proposed in [21]. With this strategy, the user can maintain a constant eye-contact to the distant display even for an elaborate information navigation, as the input devices use only a combinations of relative touch gestures (e.g. swipe-left/right, double-tap anywhere, etc.) that do not require the user to look down at the devices at all.

To raise user awareness of the shift possibilities, we use shifting cues in both explicit (a context-aware message dialog) and implicit (a floating UI button) forms. A change of state from disconnected to connected and vice versa is alerted to the user by a sensory output modality available on devices. Audio feedback is used on the phone and haptic feedback is used on the watch (the watch used does not come with speakers).

Implementation. The application was developed in Java. Google MessageApi [28] and Nearby Messages API [29] were used to facilitate the communication among devices. The application runs on Motorola smartphone (Android 7.1), Lenovo Phab 2 Plus (Android 6.0) and Motorola 360 smartwatch (AndroidWear 2.11). To simulate a wall display, a Mod projector cradle on which the Motorola phone mounted was used to project information to the wall.

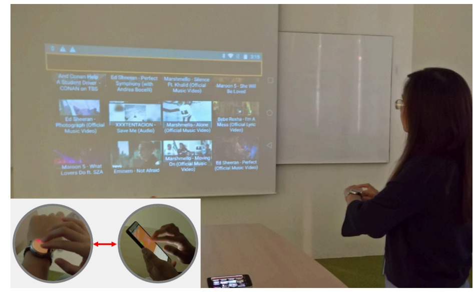

Fig. 3. Interacting with large display using personal devices

V. User Study

Participants. 18 students and researchers, age range from 21 to 55, from a local university participated in our user study. Each participant owns 3.1 interactive IT devices on average, majority are phone, laptop and tablet/desktop PC. All of them use at least 2 devices (phone and tablet/PC) on a daily basis.

Procedure. The user study was conducted in a lab setting (Fig. 3), each session lasted about 30 minutes. Participants were assigned 3 tasks. Each task involved the searching for videos by entering a pre-defined search term and the navigation within the search results. The search terms given were different in length – 6 characters (task 1), 17 characters (task 2) and 33 characters (task 3). At any time, participants were able to shift the input between the smartwatch and the smartphone (sequential Shared Output) or coordinate their input commands (parallel Shared Output). We encouraged participants to think aloud during tasks. All sessions were video-recorded for analysis.

After completing all tasks, participants were asked to fill out a questionnaire which consisted of a set of open-ended questions about the experiences they had during the session. For example, any difficulties encountered when coordinating multiple devices for the task, whether of not the context-aware shifting cues influenced their choices of devices, their perception in device shift. Participants were also asked to rate on five-point Likert scales how easy/difficult they considered it was, in terms of mental and physical effort, to initiate the shift from the watch to the phone and subsequent shifts between them. Participants' verbal comments (transcribed from video recording), answers (from questionnaires), choices of devices were analysed to detect emergent categories.

VI. Findings and Insights

A. User Perception on Device Composite Shift

Majority of participants appreciated the flexibility in shifting their interaction between the smartwatch and the phone at any time. "*Different devices have their merits for certain actions of the tasks, so shifting allows the best from both (devices)…*" (P7). A common, quick assessment shared by most of participants was based on the usability of an interface modality for a given action, and the complexity of the task, influencing the device selection decision. 4 out of 18 participants shifted the interaction from the watch to the phone during their task sessions. Reasons for shifting to the second device after short interaction with the first device included the expectation of faster and easier task completion (after shifting), and the consideration on the worthiness in device shifting (P2, P9 and P16). Participants (e.g. P2, P5) preferred to maintain the continuity in device usage, thus endured the usability issues, while performing this task.

B. User Perception on using Other People's Devices

Three groups that exhibited different attitudes and behaviours towards the use of devices belonging to others were observed from our study (Table I). The "Unlikely" response from group 1 reflected their doubt if they ever want to use other people's devices. The popular "Possibly" response was received from those more concerned on the urgency of the unplanned tasks or the unforeseen situations they would be in. The "Probably" response came with certain conditions to be satisfied: the close relationship (e.g. family, close friend) with the device's owner, trusted public devices, and the measures of personal data protection and security being taken.

C. Design Considerations for Device Composite Shift

Determining an Ideal UI-Interaction Strategy. The needs for determining ideal UI and interaction strategy for combination of devices with diversity of screen sizes call for attention from the systems and application designers. Most of participants concerned on the different representations or availability of application features when applications run on different device types. Interestingly, some participants pointed out the discrepancies in UIs and interaction strategies that they encounter when using devices from different platforms. For example, there are different ways to command the same functionality (e.g. closing an application) depending on the Operating Systems (e.g. Apple iOS and Microsoft Windows) and hardware platforms (tablet and laptop). What should be the ideal UI in this case when the shift of device happens that minimally disrupts the consistency of interaction? Would "ideal" UI and interaction strategy be the one that the user most familiar with, or could we extract a set of device-/OS-independent, generic design principles that can guide the designers for this?

Design Support for Changes in Device Composite. Consistency and continuity, known as essential properties for a seamless shifting the user interaction from one device to another [5, 6], can be achieved by distributing the UI elements and interaction resources based on the user's task and devices use [30]. However, it would be unrealistic to distribute and redistribute them to all devices in an ever-evolving computing environment when devices frequently join or leave. Rather, an informative shift mechanism is desirable to handle potential usability issues and proposing a suitable UI and interaction strategy for the user's consideration. It is important to allow the end-users deciding what to use (P2).

TABLE I. USER PERCEPTION: USING DEVICES BELONG TO OTHERS

Group	Borrowing from		Lending to
	People's devices	***Public devices***	***People's devices***
1	Unlikely	Possibly	No
2	Possibly	Yes	Possibly
3	Probably	Yes	Probably

Smart Shifting Cues. Participants commented that signaling available devices or "willing" devices (e.g. devices that their owners have indicated the willingness for collaboration) in the right context and at the right time would be desirable. Some participants suggested a smart device shifting when detecting a change in a user context, for example, picking up the phone and leaving the room would automatically trigger the shift of content to the phone (P9), walking near a device with larger screen size would suggest the user to output the game s/he is playing to the larger screen device, or the prompt requesting for input/output assistance should pop-up on the screen of the device that is closest to the user (P14).

Situational Feedback in Device Composite Shift. Participants pointed out that when collaborating in a small group of people, it is fairly easy to be aware of anyone joining or leaving the group (thus their devices join or leave the device composite), hence no feedback is needed. Some participants suggested that depending on its consequences, connecting/disconnecting devices in the device composite should be used as one of the key factors for whether or not to alert the users.

Informative Environment for Spontaneous Shift. Spontaneous communication mechanisms (section II.B), once implemented, will become useful when the end-users can be notified or informed not only the availability of such devices around them but also other usage implications including the changed interaction strategy and expected time/effort/errors saved by engaging in this shift of device composite. Considering such trade-offs against the hassle of the changing was one of the typical statements of the participants. Some participants were concerned about how they would recognize their friends' devices in a dense-device environment. Participants supported the idea that it should be able to manage their preference details of their devices' social circle locally (on each device) and remotely (e.g. using web interface).

VII. CONCLUSION

Apart from the planned device usage to support the tasks, opportunistic changes in task-centric device usage happen anytime. Usability issues are bound to emerge when the user spontaneously combines different devices for a task or changes from one device composite to another. While an increasing number of studies addresses multi-device situations as the impending pervasive computing and communication scenario, majority of them focus on the enabling back-end technology for such a vision. Our paper attempts at complementing this vision by starting a systematic exploration of the implications in terms of interactivity, usability and user experience.

Anticipating more widespread multi-device and cross-device uses in the coming years, we expect that the study of shifting between different device composites will become a very significant factor in determining the overall user experience. The benefits from the enhanced usability obtained from these shifts will be worthwhile only when the users are aware of the possible shifts, the shifts are transparent and the interaction with the newly added devices blends well with the rest of the interactivity.

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