Conference contribution :

Robinson, S., Pearson, J., Jones, M., Joshi, A. & Ahire, S. (in press). *Better Together: Disaggregating Mobile Services for Emergent Users.* MobileHCI 2017,

Better Together: Disaggregating Mobile Services for Emergent Users

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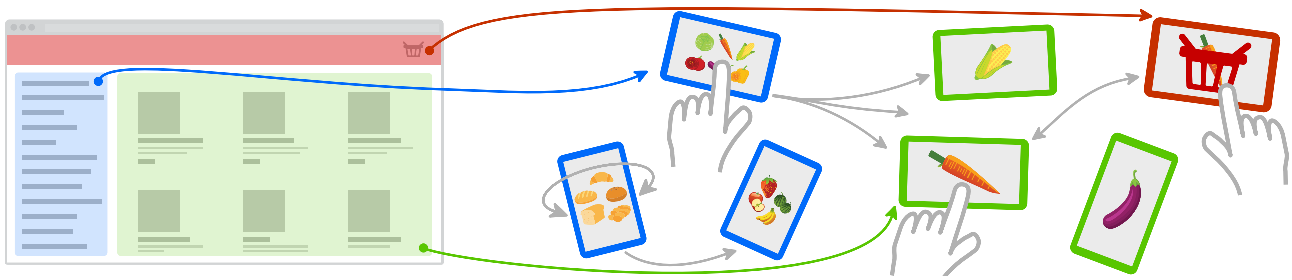


Figure 1. The *Better Together* concept, illustrating its use for disaggregating an existing service. Left: a shopping website on a laptop screen, with the familiar lists of categories and products, and a site-wide basket. Right: Better Together splits core components of a service onto separate phones—in this case there are seven—allowing them to be arranged according to users' preferences and interacted with independently. In the example shown, different phones are used for categories (highlighted in blue), products (green) and the basket (red) of the same shopping website. Users touch the screens to perform actions such as adding to (or removing from) the basket, or selecting a category to show; and, flip phones to switch to the next item or category.

ABSTRACT
Mainstream mobile interactions are focused around individual devices, with any collaboration happening via 'the cloud'. We carried out design workshops with emergent users, revealing opportunities for novel collocated collaborative interactions. In this paper we present *Better Together* – a framework for disaggregating services, splitting interaction elements over separate mobiles. This distribution supports both sharing of resources (such as screen real-estate, or mobile data); and, scaffolding of inclusive interaction in mixed groups (e.g., in terms of literacy or prior technology exposure). We developed two prototypes to explore the concept, trialling the first—collocated group-based shopping list making—with emergent users in South Africa and India. We deployed the second probe, which splits YouTube into its constituent parts across separate mobiles, in a longitudinal study with users in Kenya, South Africa and India. We describe the concept and design process, and report on the design's suitability for emergent users based on our results.

Author Keywords
Emergent users; mobile phones; device sharing; disaggregation; distributed interaction.

ACM Classification Keywords
H.5.2 User Interfaces: Input devices and strategies; H.5.3 Group and Organization Interfaces: Collaborative computing.

INTRODUCTION
Over the fifteen months between June 2015 and September 2016 we carried out a series of design workshops, studies and summit events with groups of people in Kenya, India and South Africa. In particular, we worked with so-called "emergent" users (as described by Devanuj and Joshi [7]) in order to understand how future mobile technologies might be developed or refined to more closely fit their everyday lives.

Emergent users are typically constrained by a range of factors that set apart their usage of technology when compared to mainstream, 'traditional' mobile device users. Key amongst these characteristics is limited access to resources. This constraint often means that emergent users have low mobile data allowances and little bandwidth, for example [1, 42]. Further, for many people, the sorts of benefits that are provided by access to additional devices beyond their primary mobile (such as the laptop or larger secondary screen that non-resource-constrained users take for granted) are often not available [11]. Finally, for those with lower textual or computational literacy, systems that are at their core designed primarily for English-speaking computer natives can be more difficult to use [28].

In all three of the locations we have been working in, one of the key desires that was surfaced was for people to be able to share access to resources that are on their own mobile device when they are together in groups. Rather than local file transfer (e.g., via Bluetooth, or widely used apps such as Zapya or SHAREit), or storage media sharing (e.g., via swapping memory cards [21, 34]), however, the emergent user groups we worked with identified an opportunity to collocate and combine individual mobiles to separate out shared tasks. Unlike previous work in this area, which has focused on device sharing by digital natives for productivity [15], enlarged viewing areas [22] or tangibility [30], our participants also saw a need for sharing resources and their own competencies to support richer mobile interactions. For example, some devices have particularly good cameras, while others offer a large storage capacity or a fast internet connection. The users we worked with sought to combine the best of these aspects, with the additional benefit of individual phone owners' expertise.

In response to this desire, we built the open source *Better Together* framework. Better Together is designed to disaggregate the components of complex services, allowing separate mobile phones to each represent and provide a single component of the overall interaction, as illustrated in Fig. 1. Our motivation for this design was twofold. Firstly, the approach enables resources to be conserved and combined within a group of users. For example, if only one member has access to mobile data, the group can come together to share and interact with a service on multiple devices, all using the same connection. Alternatively, if one device has a particularly large screen, this might be used to display video, while other phones become playback controls (repeated over multiple phones, where desired). Secondly, when there are a range of textual and computational literacies, by working together a group of people can help scaffold each other's competencies. For example, a more confident or experienced user might support those with lower education or technology expertise by using Better Together to collaboratively interact with their devices as a group (cf. [35]).

In the research presented here, then, we aim to explore whether this type of system might be appropriate and offer benefits for emergent users. First, we review related research to situate the work. We then summarise the workshop and summit interactions that led to the initial Better Together concept, and describe a technology probe centred around a shopping task which we built to demonstrate the interaction method. Following feedback from emergent users on this initial prototype, we refined the system and focused a second version around watching videos. We deployed this application for five weeks with a range of users, and we explore here the effectiveness of the system, and users' feedback. We conclude with a discussion of the benefits offered by systems such as this for emergent users, and suggest implications for future designs in this space.

BACKGROUND

Distributed or disaggregated interfaces

Distributed user interfaces (DUIs) are typically defined as those which allow separation of interaction over multiple devices or between multiple users. Early work in this area includes, for example Ishii's *TeamWorkStation* [15], which used cameras, handwriting input and display synchronisation between desktop workstations to link collaborators for communication and document editing. Also related is Bharat and Cardelli's *Migratory Applications* [5], which permitted applications to 'roam' between separate computers. Since this early work, there has been a significant amount of research into DUIs, as reviewed and categorised by Elmqvist [8].

In this paper we present a framework for distributing interfaces over multiple mobile devices, focusing on dynamic separation of discrete input or output components of an existing service. Our work, then, is similar to that of Melchior et al. [29], who created a toolkit for DUIs, demonstrating placing controls of a drawing application onto separate devices to those of the canvas, but focusing on single-user interaction. Rädle et al. [37] demonstrate a multi-user spatially-aware collaboration system that allows users to move their device into certain positions or orientations to change role (e.g., menu vs. main display). However, their technique uses image-based tracking, so is only able to support interaction in a specific work area.

Within DUI research there has been a particular focus on collaborative web browsing, with several previous works developing frameworks around analysis and segmentation of webpages for separation between devices (e.g., [10, 13, 25]). The key aim in these projects, however, has primarily been to support single user or master-slave interaction. More recent work such as that of Klokmose et al. [19] has explored how instant updating of shared documents or spaces can be beneficial – a feature also common in multiplayer games or commercial products such as Google Docs.[1] We see our work as a combination of the benefits of these interfaces, with conceptual links to zooming user interfaces [4] or focus plus context displays [3]. There are also similarities with previous work on multi-input devices, such as that of Myers et al. [32], who demonstrated using multiple (wired) PalmPilot devices connected to the same shared display for input, or Moraveji et al. [31], who explored the use of up to 32 individual mice with a single desktop computer in education-focused scenarios. In contrast to previous research, then, the focus of the Better Together design is on disaggregation of interfaces as flexibly as possible, without limiting layouts, areas, number of devices or duplication of components. As a result, we situate our work more closely to research in mobile collocated interaction.

Mobile collocated interaction

The field of mobile collocated interaction investigates the use of mobiles for collaboration in the same physical location [23]. A large amount of work in this area has focused on joining smaller screens together to create a single larger surface, often for photo sharing. Lucero et al. [22], for example, demonstrate how collocated photo sharing can be enhanced by creating a larger screen made up of individual participants' mobiles. More like our approach is that of Clawson et al. [6], who created a digital camera where photographs are automatically shared in realtime with other users in the same group. Turning to non-photo-focused techniques, previous work has explored ways to extend the tangibility of collocated interaction, aiming to fulfil Fitzmaurice et al.'s early vision of tangible 'handles' for virtual objects [9]. Many interaction techniques have been proposed to achieve this goal, but one of the most common is pinching devices together to expand their screen surface [24, 33]. Other research has investigated a variety of methods for achieving collocated media sharing between individual devices, ranging from broadcasting to other group members' phones [2] to picoprojection-focused item selection [12], proximity- [20] or height-based interactions [26] or physical gestures for 'tossing' media between devices [38].

Unlike the majority of this research, our design focuses on separation of discrete interface components onto different devices.

[1] See, e.g.: sleepingbeastgames.com/spaceteam; docs.google.com.

As a result, we see our work more as a generalised extension of research such as *Siftables* [30], which used custom-made mobile prototypes to create physical relationships between digital objects. Siftables consisted of small block-like devices with screens and sensors, and were used to explore tangible representations of media items and the relationships between them. One example of their usage in a similar way to our design is McMillan et al.'s technique for control of music playback [27]. In this project, the focus was around spatial arrangement for interaction, however, rather than user-driven component distribution. The system also required a separate webcam to drive actual music playback. In our work, we explore a similar class of scenario, but with off-the-shelf mobile devices, and a focus on the design's benefits for emergent users.

Collocated interactions for emergent users

While the systems and interactions we have reviewed are often appropriate for developed-world scenarios—such as collaborating on research papers, or multi-screen interaction with a shared projector—their benefits are as yet untested in more resource-constrained contexts. For the users we are focused on, who have previously been classified as "emergent" [7], there are often fewer of the core infrastructural elements that are required for these types of systems. Large-screen televisions, universal literacy, high-capacity data connections and a diverse ecology of devices are the foundation of many of the previous designs in this area. For many emergent users, these technologies simply are not available or affordable.

Previous work has shown the extent to which emergent users want to—and do—share digital media and interactions [39, 41]. The majority of the previous work in this area has explored audio-based sharing, however (e.g., [36]), with the exception of Jain et al.'s. featurephone-based multi-control display [16]. It is clear, however, that emergent users will increasingly own and use smartphones. Our work, then, aims to design for appropriate future-looking interactions in this area.

DEVELOPING THE BETTER TOGETHER CONCEPT

In this section we describe the process with which the Better Together concept was developed. This work, which has been conducted over the course of a year and a half, involves a diverse mix of participatory design, in-situ idea and scenario generation, summit engagement and prototype refinement. A more detailed discussion of the participatory and summit methodologies can be found in [17], discussing the benefits and limitations of the approach, and the additional ideas that were generated. In this paper we focus solely on those aspects that inspired and led to the Better Together design.

Phase One: Participatory design workshops

In our work, we consider the devices, services, content, interfaces and interactions that could transform uptake and benefits of new interactions within emergent user communities around the world. To this end, in June 2015 we held a series of participatory design workshops with a total of 49 emergent users in Bangalore, Cape Town and Nairobi. We asked emergent user participants to take part in two envisioning activities to stimulate thinking about future mobiles. In the first, participants sketched a picture of their ideal mobile device that they might own in the "far off future," defined as five-to-ten years ahead (based on the technique used in [18]). The second task involved a "magic thing" [14]; that is, an object that could be or do anything the user wanted in terms of how it helped them communicate with others, access content or provide information and answers to their needs. After the workshops, three researchers independently reflected on the materials and ideas participants created in order to identify themes, then came together to generate design concepts based on participants' insights.

Participants sketched and demonstrated a wide variety of future mobiles and interaction methods. A prominent theme was around the value of multiple devices used together. In their drawings, participants made it clear that future phones should be multi-purpose in both their digital and physical forms, with devices reconfigurable into different shapes and sizes. For example, one group from Bangalore proposed an interesting idea around splitting larger screens into smaller connected parts.

Participants used the magic thing activity to demonstrate the benefits of device ecologies – rather than carrying expensive mobiles that were suitable for every imaginable task, they sought to be able to access services as and when required, borrowing capabilities from others to help with this. Many participants also stressed how they would like to be able to use the phone to extend existing services and help others (such as those who are less practised with technology, or have lower textual literacy). Finally, while workshop participants were clear that they felt smartphones would be ubiquitous in five years' time, they saw data and access constraints as still being prevalent, suggesting that sharing of resources would be of considerable value in these contexts.

Phase 2: Summit Event

The insights and ideas created by participants in the design workshops were used as input to a summit we held later in the same week. We invited a range of stakeholders including an interdisciplinary mix of industry, NGO and academic researchers, developers and designers to this event. Summit attendees built on participants' ideas to propose a series of potential future devices, platforms and services. Several brainstorming and ideation activities were used during the event to stimulate discussion, culminating in a set of scenarios, one of which was the potential use of multiple phones together.

Phase 3: Revisiting Emergent Users

After the summit event, we revisited the original emergent user groups. We showed the concept scenario (and others), and asked participants to think about combining the features of multiple phones. This was done via an interactive exercise in which participants used sticky notes to design display surfaces and distributed interfaces, imagining that each piece of paper was a separate phone. The discussion around the designs ranged from the benefits of different positions and configurations to what could be done on that bigger surface (e.g., what interactions might be used, what they would view or share, and who might use the combined devices). All of this activity took place over a two-week period, at the end of which a series of detailed design ideas and scenarios had been generated.

After this second set of participatory design workshops, it was clear that participants saw benefits in combining multiple

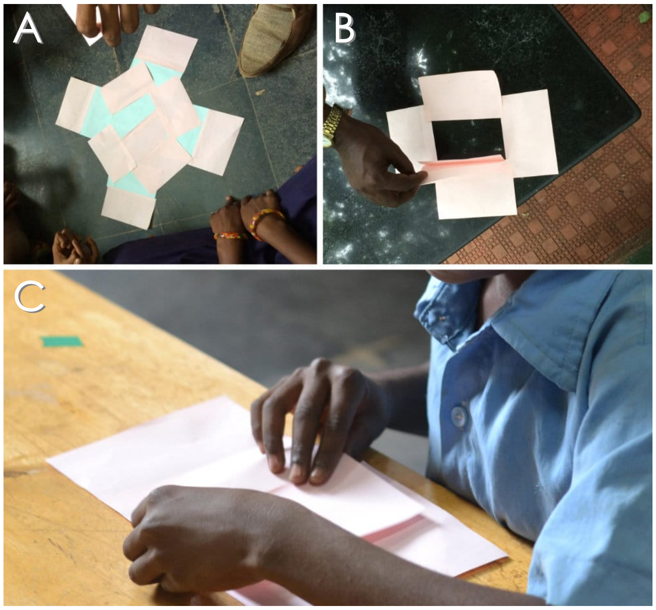


Figure 2. Distributed interfaces created in our participatory design workshops. A: A flower-shaped design for collaborative music-making. The centre phones—each represented by a sticky note—act as a speaker, while the petals can be touched to play different musical instruments. B: A similar shape, this time for group gameplay. Each player has their own personal controls (outer phones), while the centre screen is for shared content. C: A book-shaped creation in use – flip phones to turn the pages.

mobiles into a single system. Importantly, this was not just seen as a method for enlarging displays (as demonstrated by much of the previous work in this area), but also as a way to split interfaces into separate components. For example, one group created a design modelled after a flower, where the petals represented different musical instruments and the centre phones acted as a speaker (see Fig. 2 (A)). A similar shape was demonstrated for playing games, with one device per person for controls and individual information, and a central screen for joint content (Fig. 2, (B)). Another group created a rectangular layout (Fig. 2 (C)), laid out in the shape of a book. Navigation was achieved by flipping phones (e.g., turning pages), ending up with a stack of phones when reaching the end of the content. Finally, one assembly had mobiles laid-out on the ground with a separate device propped upright. Participants described how the devices would act like a desktop computer, with the largest mobile becoming the screen, while others were the keyboard, mouse and other interaction peripherals.

Many groups stressed the benefits of sharing resources. These ranged from battery life—if some phones had solar panels, they could combine to create a group power source—to data connections or memory (which would improve a phone's ability to play advanced games). Some more nuanced views of this aspect were articulated – one group, for example, talked about a shared data connection as a WiFi hotspot that helped sustain a community of togetherness by requiring all members to be present in order for any individual to be able to access the internet. Finally, several groups highlighted potential privacy issues, wanting to make sure that putting devices together did not cause content (such as private messages) to, in the words of one participant, 'leak' from one mobile to another.

Phase 4: The Better Together Framework

We built upon the insights from the first three phases to develop and refine the core idea of disaggregating services at a component level. Our ultimate goal was to create a framework that allowed individual phones to act as any part of any service, with no limits on the layout, number of components, or number of phones that a component could be displayed on (e.g., component duplication should be allowed).

The framework we elaborate in the rest of this paper was developed to meet emergent user needs. Firstly, its collaborative nature aims to support learning and inclusion (a need mentioned in the first workshops). In the second set of workshops with emergent users, our participants highlighted the value of splitting up an interface into components; and, the value in sharing diverse resources – from data connections to screens. We also sought to address comments from previous studies around difficulties with menus and standard presentations [28]; accommodation of mixed literacies and education levels [35]; sharing of scarce or costly resources [21]; and, allocation of screen real-estate to make tricky tasks more manageable.

To elaborate the framework we created two prototypes. The first, described in the next section, built directly on insights from these workshops. Its design separates out service components onto different phones, uses touch for interaction between components, and employs tangible gestures for other functions on individual devices. The second prototype consolidates the idea, taking a more extensible, platform-based approach, aiming to allow any service to be adapted for interaction over multiple phones. In the rest of this paper we present and discuss the two prototypes, and report on several studies of their effectiveness and usability with emergent users.

PROTOTYPE 1: SHOPPING TOGETHER

We created an initial probe around the Better Together concept in order to test its suitability and effectiveness, and prototype the interaction methods with emergent users. This first version, developed as an Android app, simulated a simple shopping list task, with components separated onto individual devices. This task was suggested by local researchers and endorsed by participants during studies. Their motivation was twofold: firstly, participants often made lists in groups of 3–5 on their phones or paper for one person to then go shopping. Secondly, participants did not currently shop online, but wanted to – they noted, though, that not everyone in their communities was tech-savvy or literate, and were keen for us to explore a way that might help mixed groups in future interactions.

Figure 3 illustrates the prototype, with seven phones connected together. Each one can represent any of the three standard components of a typical shopping system: a basket, categories (or filters), and products. In the example shown, one phone acts as the shopping basket (upper right in Fig. 3 (A)), while three others show categories of products (left), and three further phones show results (centre). Figure 1 illustrates the interaction flow of the system, which lets users complete a shared shopping list creation task across multiple phones, with each phone able to represent any single component of the overall system. The accompanying video figure demonstrates the system in use.

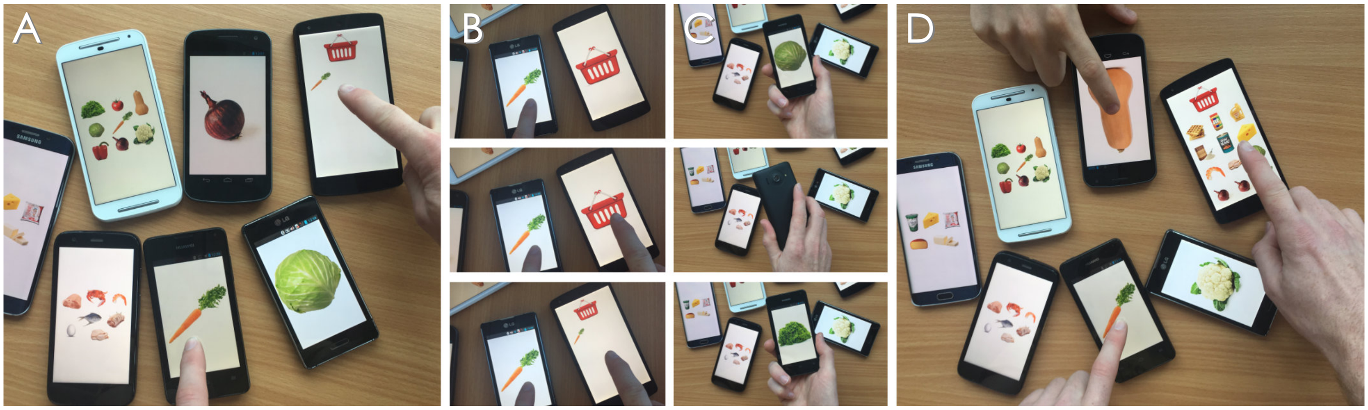


Figure 3. Better Together for shopping. A: Categories, products and the shopping basket are represented on different devices – here there are three categories (left), three products (centre) and one shopping basket. B: Touching an item followed by the basket adds the item to the order. C: Flip phones over to switch to the next category or product. D: Interactions can be combined – here, two items are being added to the basket at the same time.

Users interact with the system by touching the screen or gesturing with any of the phones. Touching a product (e.g., the carrot in Fig. 3 (A)), and then touching the basket will add one of that product to the basket. Items visually appear in the basket as soon as they are added. Touching the basket again while still touching a product will place a further item into the basket, and so on. Multiple items can be interacted with simultaneously – for example, touching the carrot and squash in Fig. 3 (D) at the same time and then touching the basket will add one of each to the order. Reversing this interaction sequence—touching the basket before the product—will remove the selected items.

As the number of products or categories that can be displayed simultaneously is limited by the number of phones assigned to that particular component of the interface, it is necessary to be able to change their display to show more of the available items. Rather than add further touch gestures, we employed the flip metaphor suggested by workshop participants in their book-style design. Physically flipping over a phone that is displaying products or categories, then, displays the next in the list (Fig. 3 (C)). Flipping the basket completes the order.

The prototype was created to directly support the distributed interface concepts and requirements articulated by emergent users in our participatory design workshops. As such, each connected phone represents and behaves as a discrete component of the overall system (as illustrated in Fig. 1). The touch and flip interactions were directly inspired by participants' designs, and are used to reduce the need for prior smartphone experience, or knowledge of existing touchscreen interaction methods. All of the system's interfaces are as text-free as possible, using imagery and icons to represent actions. While this version of the system was configured to use seven specific phones for simplicity during experiments, synchronisation between phones is managed entirely using Bluetooth to avoid using data connection allowances (see the second prototype, later, for a more flexible and extensible version of the system).

We chose shopping as the focus of this prototype for two reasons. Firstly, it is clear that people often plan what they intend to buy before going shopping [40], so we wanted participants to imagine it as an alternative to their current method of list-making, in a planning sense (e.g., completing the shopping task offline, so no data connection or credit card are required). Secondly, and more forward-looking, our view is that in the near future these users will want to shop online. Our goal, then, is to explore appropriate interface and interaction techniques now, preemptively satisfying future needs.

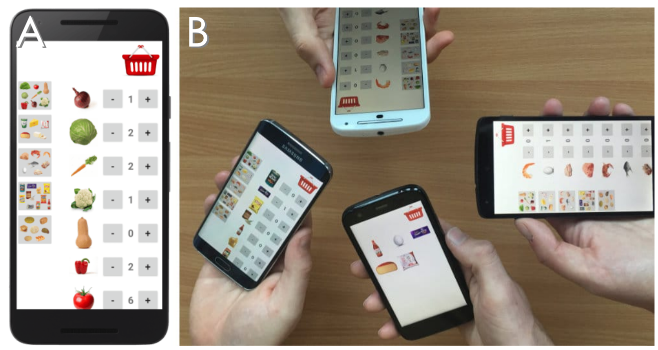


Figure 4. The two comparison systems used for the Better Together shopping study. A: Standard, which mimics a traditional shopping app. The $+$ and $-$ buttons are used to add or remove items from the list, a view of which is toggled via the basket icon. B: the Synchronised system's interaction is identical to that of the Standard system, but items are placed into a shared basket (shown on the frontmost phone, and viewable on any connected device by toggling the basket icon).

IN-SITU EXPLORATORY STUDY

In order to explore the potential for disaggregated user interfaces of this form, we conducted an exploratory study in two locations: Mumbai, India, and Langa township, Cape Town, South Africa. We recruited 24 emergent user participants for each experiment in six groups of four, giving a total of 48 participants. In Mumbai ages ranged from 16 to 46 (12M, 12F); participants in Langa were aged from 19 to 50, (6M, 18F).

Systems

As our interest was in the viability of the distributed interface interaction technique for emergent users in comparison to existing approaches, we chose to test the Better Together prototype against two other potential ways of shopping together. We developed two further Android applications to be used as control systems during the study (illustrated in Fig. 4).

Figure 5. A group using the Better Together prototype in the lab study. Participants sat around a table, and were asked to add the items on their personal list to a group shopping basket using each of the three systems in turn. There were a wide range of interaction techniques and phone layouts used – here, for example, participants have grouped the phones into categories and products, and are collaborating to add items to the basket. The categories (coloured in blue), products (green) and basket (red) have been highlighted in the image for clarity.

The first comparison system, *Standard*, was modelled directly on what we saw as the current method for completing a shopping task in a group. That is, Standard was a normal shopping app (simplified for the study), used on a single phone. Its interface displayed a shopping basket and lists of categories and products (see Fig. 4 (A)). Selecting a category displays the products in that group, and touching the plus or minus buttons will add or remove the selected product from the basket. Selecting the basket displays the current list of items.

The second comparison system, *Synchronised*, took what we regarded as the most direct method of extending the traditional shopping app approach to allow for multi-person use. That is, Synchronised links a single shopping basket over a group of phones (one phone per person), with all devices sharing a single list of items to purchase – an approach that is currently used by several online shopping websites.[2] Interaction here is identical to the Standard system for browsing products, but the basket displays all items from all users who are using the system concurrently (as illustrated in Fig. 4 (B)).

The final system was our Better Together prototype. Here, interaction was exactly as described in the previous section, with three phones assigned as categories, three as products, and one as the shopping basket, as shown in Figs. 1 and 3.

All three systems were preloaded with the same set of products and categories (though we localised the product images used). Prior to the study we generated three random subsets of products to be used as the shopping list during the study, each divided into four separate lists (one per participant). Each system automatically tracked interactions and recorded the items added to or removed from the shopping basket during the task.

Procedure

Participants took part in the study in groups of four people (see Fig. 5 for a typical group arrangement). After an IRB-approved informed consent procedure, we began each session by gathering demographics and recording the type of mobile phone owned by participants (if any). Participants were also asked about their current use of online shopping, followed by an exploration of any group-based tasks that they currently undertook, and the collaboration methods they had used.

Following this, participants performed a simulated shopping list task on each of the three systems (Better Together, Standard and Synchronised). The aim was to simulate a group coming together to generate a combined shopping basket, with each participant having their own selection of products to add to the group purchase. To begin, a researcher demonstrated one of the prototypes, then gave each participant a list of items to add (see Fig. 5). Participants then used the system to compile the given basket of items. After finishing the task, the process was repeated with the remaining two systems. The order of systems was balanced between groups (Latin square), with each group using the same product lists in the same order to allow comparison. During the tasks we timed (from the start to when the group declared the task complete), video recorded and observed participants' usage of the system, paying particular attention to the collaboration and interaction behaviours used.

After the task, participants discussed the advantages and disadvantages of each of the three systems as a group. Each session took around 45 min, and participants were each given ₹200 (Mumbai) or R150 (Langa) as a token of our appreciation.

Design outcomes

We expected three interaction outcomes given the design of the Better Together system:

- In terms of behaviour, the observed patterns of use will be more inclusive and interactive than the comparison systems.
- In terms of accuracy, the final group shopping baskets generated will be as accurate (compared to the given lists) as the comparison systems.
- In terms of time, the system will likely be slower than the alternative methods, due to its display of a lower number of products and categories, and its requirement for coordination across devices.

Results

All participants could relate to group-based tasks, with all except two reporting previous experience when planning events, travel or social groups, amongst other activities. Only four of the 48 participants had previously shopped online.

Demographics and previous experience

All participants in Mumbai owned or had access to either a basic phone (4 people), featurephone (7) or smartphone (13). Six participants had no touchscreen experience, and seven less than one year (often via a family member or friend). The remainder had 1–2 years of touchscreen experience, but only two participants had data-plans, with one other person having intermittent access to data. The majority of participants had either no (4 people) or a very basic level of English literacy (13). Most participants rated their literacy in their native language (Marathi or Hindi) as good (14 people) or excellent (6), and the remainder had either no or a basic level of literacy.

[2]See, for example: instacart.com or mouser.com.

All participants in the Langa study owned a mobile phone, and their touchscreen experience ranged from none (4 people) to less than one year (6) to 2–4 years (14). In total, there were two basic phones, 13 featurephones and 9 smartphones. Despite data plans being relatively costly in South Africa, half of the participants said they bought data whenever possible, or had a data-plan. The majority of participants rated their level of English literacy as good (10 people) or excellent (12), with the remainder (2) having a basic level of English. All except one rated their native language literacy (isiXhosa) as good (5 people) or excellent (18).

Observations and feedback

It was apparent throughout the task that there were clear differences in how participants interacted with each of the three systems. Turning first to Better Together, usage of this system was clearly a collaborative experience. In all groups there was discussion and conversation throughout the task about which products were required, and the categories in which they might be found. Participants generally helped each other find products, and flipped phones near to them where necessary to reveal further items for others' lists. The overall interaction with phones was collaborative – for example, adding items to the basket was achieved most often by one person touching a product and another touching the basket. There was no use of the ability for multiple people to add items to the basket at the same time by touching multiple phones at once, however. In this sense, there was a tendency to use the system in a linear, turn-taking manner, but people worked together to find the correct items to add in most cases.

There was also evidence of scaffolding competencies with the Better Together system – people with lower education levels or technology experience were supported and encouraged by others (e.g., *"you touch that one and I'll touch this one"*). Participants with touchscreens helped those who had not used touchscreens before by pointing to the right phones or items and showing how they were used. It was rare for groups to rearrange the layout of the phones. The main exception to this was in three groups who chose to move the basket phone amongst themselves when individuals wanted to add items.

When using the Standard comparison system, the most common interaction method was for one participant to take charge, handling all of the interaction with the phone themselves. This person then asked each of the other participants in turn to relay the list of items they needed, either optimising (by asking, e.g., *"does anyone else need carrots?"*) or simply moving around one-by-one. Turning to the Synchronised approach, this system was, on the whole, a difficult experience for participants. The shared basket notion proved to be a confusing concept, in particular because every group member's items appeared in all phones' baskets at the same time. This confusion was exacerbated by the individualised interaction behaviour that the system encouraged. Participants each had their own phone, and focused solely on this device. As a result, interaction was in complete silence for the majority of the time, with the occasional exception of a participant exclaiming that there was an item in the basket that they had not added (i.e., from another person), and which in some cases they attempted to correct.

Participants saw advantages in all three of the systems. In particular, Better Together was seen as being useful for helping others, or for training. Participants liked the separation of the different elements of the design: *"this one is the best – everyone can do a lot of work together,"* and *"I can see where the item is going – it is going from this place to this other place."* They also found the collaborative interaction to be more enjoyable than the other systems: *"very playful and friendly."* Some aspects were not liked, however – in particular, the flipping phone metaphor was seen as unnecessary, and something that could be more easily achieved by swiping. One participant felt that if *"everybody wants to touch"* at the same time then there could be a need for more formal organisation. Turning to the Standard system, many participants used their familiarity with existing shopping techniques to their advantage. Their comments about effectiveness reflected this: *"we already knew how to do it; one person just took all of the lists and did everything."* The Synchronised approach was seen as a logical extension of the Standard system: *"we all understand better because we have our own screens"*; and, *"we all had control."* However, participants acknowledged that the shared basket could be confusing: *"I kept seeing what other people were putting and kept thinking I shouldn't put that in."*

Accuracy and time taken

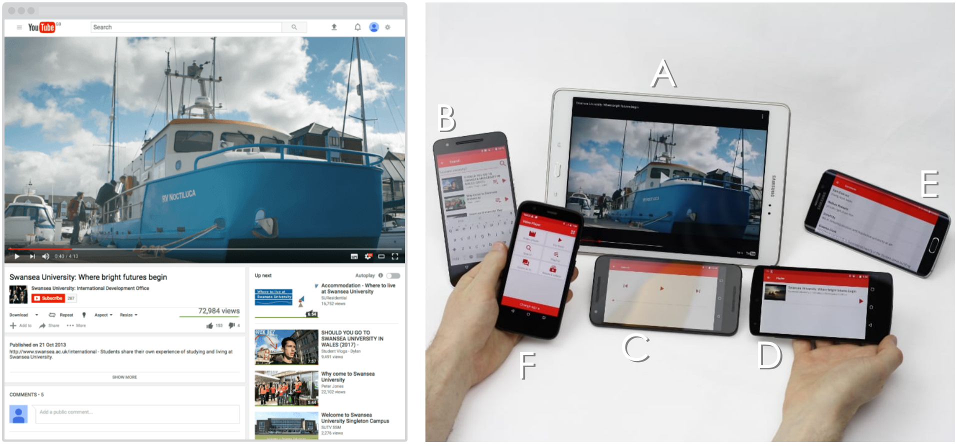
Better Together was the most accurate of the three systems. Ten of the twelve groups' lists were correct, with the remaining groups missing one and two items, respectively. That is, out of the 255 items that we asked participants to add to their shopping baskets, in total over all groups, 252 (98.8 %) were correct when using the Better Together system. For Standard, similarly, ten groups' lists were correct, and two (different) groups had errors (5 items were missing; 2 extra items not on the lists were included, giving an overall accuracy of 97.3 %).

The accuracy of the Synchronised comparison system was far lower. None of the groups successfully added all of the correct items on their lists. The most accurate group completed the task with one extra item and one missing item; the least successful group had nine missing items and five extra items. Overall, the accuracy of the Synchronised system was 85.1 %

As expected, participants took longer to complete the task using Better Together than the comparison systems. Better Together took 3 min 38 s on average (s.d. 1 min 9 s), with Standard taking 2 min 5 s (s.d. 51 s), and Synchronised taking 2 min 8 s (s.d. 1 min 11 s). A repeated measures ANOVA of the timings shows this difference to be statistically significant ($F = 18.11, p < 0.001$). Post-hoc analysis (Bonferroni correction) also shows that Better Together is significantly slower than both Standard ($p = 0.001$) and Synchronised ($p = 0.003$). As discussed previously, we suggest that this difference is caused by the Better Together system showing fewer items at once, requiring participants to switch between products and categories more often using the flip gesture.

Discussion and design implications

It was interesting to see the range of techniques for solving the same task with the three systems used in the study. The traditional shopping approach on a single phone (Standard) led to one person taking charge, while the logical extension



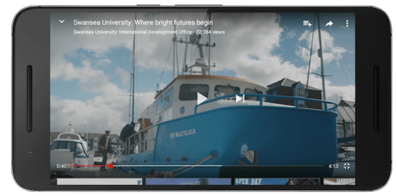


Figure 6. Left: YouTube on a large screen. When the same page is opened on a mobile (above), features are hidden, simplified, or only accessible by switching modes.

Centre: Better Together lets users choose components as appropriate. Here, video playback is shown on the largest screen (A), while others are used for search (B), playback controls (C), playlist (D) and comments (E), or other components (F).

of individual shopping baskets to a multi-phone design (Synchronised) was confusing, and led to a high number of errors. Better Together was seen as a beneficial collaborative and shared approach. It was clear that participants worked together to achieve their goal, helping each other to complete the task, especially when some group members were less educated or had lower technology exposure. While the shopping task in this study was simulated, perhaps in a real situation, the disaggregated interface might allow for more inclusive decisions.

In terms of accuracy, Better Together was as good as the current method of shopping together (Standard). Some aspects of the design were seen as overly simplified – for example, flipping to change items. However, it was clear that overall Better Together was seen as valuable, and worth further investigation. As such, we decided to adapt a second service to use the Better Together framework, this time focusing on participant-driven usage (rather than specific tasks). After consulting with research project partners about suitable regularly-used services, we chose to disaggregate YouTube for collaborative video watching. This was chosen as a trade-off between opportunities for collaborative use, the need for internet access, and a service that potential participants already actively used.

PROTOTYPE 2: WATCHING TOGETHER

We created a second prototype using the Better Together framework in order to explore everyday usage of distributed interfaces by emergent users. Our aim here was to produce a deployment-quality probe that was suitable for use over a prolonged period on participants' own devices. This application of the framework came directly from the participants who took part in evaluating the earlier shopping prototype.

Figure 6 (centre) demonstrates the application in use. This prototype, again implemented as an Android app, splits the component parts of YouTube onto separate devices. In this example, then, the device with the largest and highest-quality screen has been chosen to play the video (A). Search can be split over two phones, with one displaying the input and results (B) and another providing the keyboard (not shown). Other phones show controls for the video (C), the current playlist (D), comments (D), and related videos (not shown). As in the first prototype, any component can be displayed on any device, including duplicates if desired (F), and all interactions are synchronised over each of the connected devices. For example, selecting a playlist item will update the video, as well as the controls, related videos and comments. The accompanying video figure illustrates interaction with the prototype.

As this prototype is intended to be used in self-driven manner by participants, it must be able to flexibly add and remove devices from a group. That is, it must be possible for participants to join and manage their own Better Together video sessions with anyone else who has the app. We achieved this by adding a short setup process to connect and synchronise devices at the start of a session. When the app is opened, one user in the group displays a QR code on their phone's screen. Any others who would like to join use the app on their own phone to scan this code. This action initiates a background Bluetooth connection, which is then used for all future communication between devices. Once the devices are synchronised in this way, users are then given a choice of interface components to use on their device. Figure 6 (F) shows the available options. Any component can be used on any phone, and the choice of component can be changed at any time.

As with the first Better Together prototype, we endeavoured to provide the features and benefits originally specified by emergent users in our participatory design workshops. As the application is used to stream videos, however, it was not possible to remove the need for internet access. When WiFi is available this requirement is not an issue; however, requiring the use of multiple users' data connections could be problematic. We addressed this by sharing a single data connection amongst all users in a group. As a result, only one member of each group will incur data costs while watching videos. This same connection is used to download comments and related videos, and any other content (note that the connection is not shared outside of the Better Together app). Because of the inherent flexibility of the system, each person can then take turns to use their own data connection when necessary.

We implemented this second version of the Better Together framework as an extensible framework. The core connection, synchronisation and communication aspects are entirely separated from the service that is being disaggregated. As a result, we imagine using the technique to split many other services in this way. The small size of mobile screens often necessitates removing, hiding or truncating interface components, making interaction manageable in the available space, but adding complexity and extra mode switches (Fig. 6, right). Larger screen sizes are more able to display the full experience, but are less flexible and portable (Fig. 6, left). As shown in Fig. 6 (centre), the Better Together approach brings the features and benefits of the larger screen to the mobile, preserving the flexibility of the mobile experience via its component-focused design.

LONGITUDINAL DEPLOYMENT

We deployed the Better Together YouTube prototype in three resource-constrained locations over a period of five-weeks. Our goal was to explore how well the component disaggregation approach worked in a more natural, everyday environment, and whether participants saw value in its ability to share resources. We recruited 48 users from areas in and around, Mumbai, Langa and Nairobi (16 in each location). Participants from these regions took part in friendship groups of four people, with groups from a range of different social, educational and technological backgrounds. We specifically recruited participants from Mumbai and Langa who could be classed as “emergent,” whereas in Nairobi we selected participants who were less emergent, but still resource-constrained in terms of their internet access and disposable income. In order to be eligible to take part in the study, all participants had to own their own Android phone (i.e., we did not hand out devices). As a trade-off between participant privacy and depth of analysis, the app was set up to report each time a video was played, but no other information was automatically collected.

Procedure

Participants were asked to attend a total of four study sessions in their groups over the five-week period. The initial session began with an IRB-approved informed consent procedure, followed by a short interview gathering demographics and general phone usage patterns, as in the lab study described above. We then demonstrated the Better Together app to each member of the group, showing examples of how it disaggregates each of the elements of a typical YouTube video. Following this, we installed the app on participants’ own phones (via the Play Store), demonstrated the device connection process (i.e., QR scanning), and allowed them to experiment with the application until they were comfortable with its use. Participants were explicitly told that the application would report when a video was opened, and that no further information (such as identifiable video information or timings) was gathered. We relied on participants’ reporting and feedback to evaluate their usage of the system, rather than tracking behaviour directly.

We asked participants to use the Better Together application in their groups at least three times per week for the duration of the deployment. We also scheduled follow-up meetings at weeks 1, 3 and 5 after the initial session for reporting back and problem solving. In each of these meetings, participants were asked to discuss their usage of the system, and provide feedback about its suitability and any issues they had encountered. In the final meeting, we also asked participants to rate the system’s ease of use and other aspects of its video viewing interaction (such as its usefulness for watching videos in groups), followed by a group discussion about the general experience.

Participants were given ₹500 (Mumbai), R200 (Langa) or Ksh1000 (Nairobi) at the end of each of the four meeting sessions. In addition, because the app uses an internet connection to play videos, we provided participants with an airtime credit of 1 GB per month in order to ensure that, were they not able to access WiFi, the application would still be usable.

Results

Demographics and previous experience

Participants in Mumbai were aged from 20 to 46 (6M, 10F) and were all employed as housekeepers. Of the 16 participants taking part in this region, 14 had access to data only when they could afford it, whereas the remaining two had none. Participants owned a range of smartphones, with around half being well-known international brands and others from local Indian or Chinese manufacturers. Two participants had less than a year of touchscreen experience, with the rest having up to two (6 people) or more than three years (8). All but two participants had previously watched online videos, and all had watched videos in groups before, but only ever on a phone, and primarily sourced via direct sharing between phones. When asked about problems with group video watching, the two key issues raised were the viewing angle and insufficient audio volume.

Of the 16 Langa-based participants (13M, 3F aged 18 to 50), 11 were students, with the remainder employed locally or currently searching for a job. All participants had smartphones made by well-known brands, and touchscreen experience ranged from less than one year (1 person), to two years (3), to at least three years (12). All except one participant had watched videos online previously, and all had watched videos in groups. The primary way of watching videos together was by gathering around one phone, but four had also viewed on a computer screen. Issues with watching together were similar to those in Mumbai, with other problems mentioned including having control of what is being watched, and choosing videos.

Participants in Nairobi were aged from 18 to 24 (7M, 9F), and the majority were students (15 people), with one person unemployed. There were a similar range of smartphone brands to those in Mumbai, but in Nairobi most participants had regular access to data. All except one routinely purchased data bundles (either on a daily or weekly basis), however, all participants said that they always ran out of data before the end of this time period. All participants had at least two (1 person) or three (15) years touchscreen experience. All except three participants watched videos in groups, primarily on laptop screens, with the main issues being around the visibility of the screen and use of data.

Usage and feedback

Usage logs show that there were a total of 356 recorded Better Together YouTube sessions across the three sites over the five-week study period. Table 1 shows the distribution of these over the three regions: over half were in Mumbai, with participants in Langa showing the least engagement. Although we only asked participants to use the system three times per week, many voluntarily exceeded this number, suggesting an increased level of commitment for the study. On average, then, there were 10.4 video sessions per group per week in Mumbai, 2.2 per group per week in Langa and 5.3 in Nairobi.

	Total sessions	Average sessions per group, per week	Ease of use (out of 10)
Mumbai	208	10.4	6.3
Langa	43	2.2	4.6
Nairobi	105	5.3	7.1

Table 1. Usage data from the longitudinal deployment of the Better Together system. There were a total of 356 sessions, with participants in Mumbai making most use of the system over the five-week period.

It was clear from interviews that there was a large amount of enjoyment while using the system. Several groups also mentioned specific advantages of its component disaggregation. For example, one group of Nairobi participants related how they had chosen devices to use based on their capabilities: *"when watching [videos], my phone was the screen because it had the bigger screen."* Other groups spoke about related benefits, such as being able to see individual interface components that are hidden in the standard mobile single screen view (cf. Fig. 6), and the ability to search without closing or minimising the currently played video. There were also positive comments relating to the app's sharing of data – an expensive commodity in many emergent user areas: *"[the app] saves on bundles, only one phone uses bundles – and it also brings about togetherness"*. Other participants commented on its similarity with the control separation of traditional televisions: *"it's fun because it's like having a TV – there's a screen and a remote control"* while others saw more specific usage scenarios for the system in other situations: *"it won't really work for people who aren't friends but will definitely work for school projects"*.

Participants also made suggestions for improvements to the viewing together aspect of the system. For example, one clear recommendation in all three study locations was that the application should also be able to control a video's accompanying audio with more granularity. That is, participants requested that the playback controls should be able to adjust the volume of the video, and audio should be capable of being split or duplicated over multiple phones if required.

While there were no issues with participants understanding the system concept and its operation, during the first week of the study several groups experienced minor technical problems related to connecting phones together. These issues were primarily caused by the variety of Android devices and versions in use over the three locations. Some participants had very old phones that struggled to scan QR codes, while others had devices that used bespoke versions of Android which did not support standard APIs. There were also issues with the speed of setting up the initial Bluetooth connection. This concern was flagged in the first interim session, after which we updated the app to alleviate these problems and refine the connection process. Feedback regarding the connection process had improved significantly by the second interim meeting.

Suggested improvements to the disaggregation aspect of the app included one from Langa where participants had tried using the system with more than the four original group members, and saw the need for duplication of components: *"it's more difficult to see the video so it would be better to have two screens to watch,"* and *"there should be a tiny screen on everyone's device so they don't have to watch from the main screen"*. Participants had also thought of uses beyond those we intended – for example, one participant borrowed a second phone to use as a remote control for his own: *"I used it to entertain my younger sister while she watched cartoons and I controlled it with a different phone"*.

Other discussions touched on the challenges of choosing videos together: *"we all have different tastes, so everyone had to compromise and take turns to select a video for everyone to be happy,"* but also related the positive aspects of the situation: *"using YouTube as a group is fun because there are people to laugh and talk to while you're watching a video"*. There were also comments about modifications to the design to allow single person viewing, which is not currently supported. A Nairobi group, for instance, talked about the possibility of searching for videos independently, then watching them using the Better Together system in a group later. In general, participants in Langa were less likely to watch videos together, and one participant even actively refuted the suggestion: *"the application is not for me – I don't [watch videos with] friends and I enjoy being alone"*. There were also comments about the group video experience – participants who did watch videos in groups would like to combine the benefits of individual watching with those of the Better Together approach: *"the app forces people to work together – it's fun and entertaining but can be problematic if interests are too different"*.

In the final week of the study period we focused on evaluating the entire experience over the preceding five weeks. The ratings given for ease of use of the system are shown in Table 1. Participants in Mumbai and Nairobi rated the app higher than those in Langa. The Langa users had experienced connection problems more often than those in the other locations, and this affected their experience of the app. Overall, however, the majority of participants felt that the app was beneficial when they did want to collaboratively watch videos.

DISCUSSION AND CONCLUSIONS

Better Together was designed for and in collaboration with emergent users, who often experience a range of resource constraints. The main benefits of the approach include:

- The ability to share resources (such as data connections, storage space, larger or higher resolution screens);
- Providing a reconfigurable interaction area to perform tasks, reducing the need for expensive secondary screens; and,
- Facilitating and scaffolding help for people who are less technologically savvy, or have lower levels of literacy.

We conducted an exploratory study of the technique to see how the approach might work, using a collaborative shopping task as an example. When compared to two other mainstream methods of group-based digital shopping list-making, Better Together was more accurate, and well received by emergent user participants, though slightly slower (as we anticipated).

Our follow-up study focusing on YouTube as an example use-case further supported these findings, demonstrating that a system that facilitates the disaggregation and sharing of services and resources is seen as valuable by emergent users.

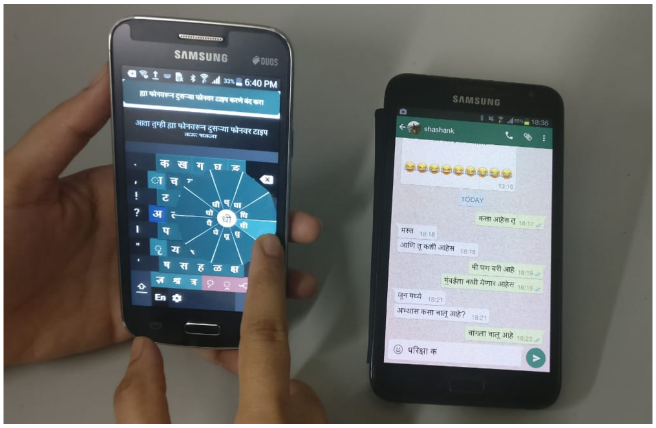


Figure 7. The Swarachakra Marathi keyboard with the Better Together framework integrated to provide seamless multi-device connectivity. Typing on one phone (left) inputs text on the other (right). The remote keyboard can be used for text entry in any app.

Participants found the conservation of data packages particularly beneficial, as well as the ability to use whichever available screen was most appropriate for watching videos. The separation and duplication of components was also seen as a benefit, especially for promoting group collaboration.

Turning to future work, there are several aspects of the Better Together system that we did not investigate in this research. For example, we did not ask users how they monitored data usage, or how they decided which participant's data would be used, and at what point this negotiation took place. There are also improvements that could be made to the system. For example, in the current version, swapping between devices interrupts the services that are being used (e.g., video playback). Participants in our studies also suggested valuable improvements to the design, which we intend to focus on in future releases of the design as the Better Together open source toolkit.

Better Together open source toolkit

Since undertaking this research, we have further developed the original and refined Better Together prototypes into an open source plugin-based toolkit. Better Together is available on Google Play as a standalone app,[3] to which plugins can be added to locally disaggregate any service over multiple devices using a simple message-based API. The Android source code, API documentation and examples are available at the toolkit website, released under the Apache 2.0 license.[4,5]

We have also worked to integrate the framework with other existing applications and services. For example, the popular Swarachakra keyboard,[6] used by nearly two million people for input in Indic languages, has recently integrated the Better Together framework to allow using one phone as a remote input device for another (see Fig. 7). We have also released versions of the example systems used during our studies as plugins for the Better Together framework.

[3] Better Together on Google Play: bettertogethertoolkit.org/app.
[4] Toolkit website and further information: bettertogethertoolkit.org.
[5] Open source code: github.com/reshaping-the-future/better-together.
[6] Swarachakra on Google Play: bettertogethertoolkit.org/keyboard.

We developed Better Together as an open source and extensible system to which any existing service can be added for disaggregation. Our aim now, then, is to extend other services using the technique, and continue to deploy the framework with emergent users.

ACKNOWLEDGMENTS

We would like to thank Minah Radebe, Sharon Wangari, Francis Mwangi, Frankline Mogoi and Debjani Roy for their help in conducting user studies. This research was funded by EPSRC grant EP/J000604/2, with additional toolkit deployment work supported by EPSRC grant EP/K504002/1.

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