A Modular Smartphone for Lending

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ABSTRACT
We motivate, design, and prototype a modular smartphone designed to make temporary device lending trustworthy and convenient. The concept is that the phone can be separated into pieces, so a child, friend, or even stranger can begin an access-controlled interaction with one piece, while the owner retains another piece to continue their tasks and monitor activity. This is grounded in a survey capturing attitudes towards device lending, and an exploratory study probing how people might lend pieces of different kinds of modular smartphones. Design considerations are generated for a hardware form factor and software interface to support different lending scenarios. A functional prototype combining three smartphones into a single modular device is described and used to demonstrate a lending interaction design. A usability test validates the concept using the prototype.

Author Keywords
Smartphone, Lending smartphone, Modular smartphone

ACM Classification Keywords
H.5.2. Information Interfaces (e.g., HCI): Input devices

INTRODUCTION
People already lend their smartphones to people they trust [11,12]. Common reasons include entertaining a child with a game or video, letting a colleague make a phone call to avoid international roaming, or asking a passenger to update a GPS destination while driving [1]. The trouble is that it is difficult, or impossible, to control what content or functionality is shared while lending, and personal information can be accessed or destroyed intentionally or accidently [12]. This is why the related notions of *trust* and *convenience* are primary factors when lending a device [3,13].

Trust between the device owner (the *lender*) and the person borrowing the device (the *lendee*) strongly influences device lending [13]. For example, smartphone lenders will typically refuse to lend to people they do not know well, like strangers, even if the lending need is important, short, and harmless. At the other extreme, smartphone owners typically lend their device to close relatives or friends, regardless of the actual level of trust. Since an implicit level of trust is communicated by a choice to lend, or not to lend, owners feel social pressure to lend [8]. Issues of trust are magnified when the lender restricts lending duration [3] or they are not in close proximity of their device [8]. For a lendee, borrowing a device also has risks, like forgetting to sign out of accounts or deleting personal information before returning the device [8].

One method to increase trust is to use login profiles for lendees, such as a guest account [12]. However, setting up and configuring multiple profiles, as well as the process of signing out of the owner's account to sign into a guest account, takes time and mental effort. Primarily due to this inconvenience and effort, guest profiles are not used often or ignored entirely [3]. Researchers have suggested methods to configure access control at the moment of lending [9,12], or context-sensing access control [20], but these still require some manual interaction. More importantly, with current lending methods the owner must temporarily give up their phone. This is inconvenient because their task is interrupted and they may miss important notifications.

We believe issues of trust and convenience can be addressed using a modular smartphone designed for lending. Modular smartphones have been proposed to customize or upgrade functionality [5,14]. We extend this idea to a smartphone that has modules that can be easily detached and lent. For example, a small piece can be lent to a friend to make a phone call, or a medium piece lent to a child to play a game (Figure 1). Lending starts and ends with physical detachment and attachment of an access-controlled piece, the owner is not inconvenienced because they retain their phone, and our lending-specific interactions enable lendee monitoring and customizing access during the lending session.

The concept and implementation is motivated and guided by research investigating the closely related topic of *sharing* devices, an online survey about trust and convenience when lending current smartphones or future modular ones, and a lab study to evaluate different modular form factors and elucidate requirements for the device and lending interactions.

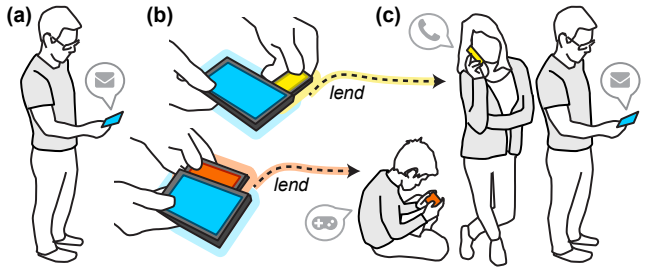

Figure 1. Modular smartphone for lending: (a) owner wishes to lend phone; (b) they slide out a module configured for limited access; (b) they hand it to their child to play a game, or to a friend to make a call, while they keep their phone.

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Based on this formative work, we built a functional hardware and software prototype to demonstrate how a lendable device could work and validate the design in a small usability study.

Our contributions are: (1) the concept of a modular smartphone designed for trustworthy and convenient device lending; (2) the results of our formative work, where we first motivate and validate the concept and then explore modular form factors for lending; and (3) an interaction design for device lending with a modular smartphone realized in a functional proof-of-concept hardware prototype.

RELATED WORK

In HCI research, the verbs *share* and *lend* are sometimes used interchangeably, but the definition reveal a distinction: *share* means "to partake of, use, experience, occupy, or enjoy with others" and *lend* means "to give for temporary use on condition that the same or its equivalent be returned" [27]. Our focus is on lending (and the complementary verb, to *borrow*). After discussing current device lending practices, we examine trust and convenience issues, and argue why a modular device form factor addresses these issues.

Current Device Lending Patterns

Despite smartphones and other devices containing personal information, lending is commonplace [11–13]. Karlson et al. found people shared their mobile phones more frequently than they initially believed, and this raised privacy concerns. Hendrick et al. [16] found multiple family members shared a single tablet for tasks like playing games and information seeking. Bødker and Christiansen [1] report that close friends and family members shared smartphones. Liu et al. [12] found common apps used by lendees included maps, web browser, music player, and games. Device lending is especially common in developing countries due to socio-economic conditions [17]. Steenson and Donner [23] found device lending is essential in these countries, and often organized around familial relationships.

Trust is a primary factor that influences lending [11,13,23]. Trust in a lendee translates into a willingness to share, from open sharing (full access) with close family members and friends, to more limited sharing with strangers (phone calls only) [11]. Since trust is implicitly communicated by the lender, they sometimes share more information than necessary to avoid harming established relationships [13]. Convenience is another contributing factor for lending a device [13], handing over your phone to a friend so they can check a map or play a game requires very little effort. Matthews et al. [13], identified six types of account sharing between family members: *borrowing, mutual use, setup, helping, broadcasting and accidental*. They found that convenience and trust influenced the characteristics of all six scenarios. Our lendable device focuses on supporting *trust* and *convenience* for scenarios like those described by Matthews et al.

Trust and Convenience Issues

Although trust is a factor when lending, the lender is at risk for security issues like loss of privacy (e.g. revealing sensitive information), malicious behavior (e.g., using device access to post on social networks), and accidental damage (e.g., deletion of data, changes in app settings) [1,8]. These issues can also occur for a lendee, they may forget to remove their information before returning the device, leaving their private information exposed to the lender [8]. Additionally, a lendee may find themselves in uncomfortable situations where they unintentionally view information (e.g. incoming messages from a spouse, personal photos) but still desire to respect the lender's privacy [8,9,12]. Liu et al. [12] found lenders were reluctant to lend apps with personal data, like photos, videos, or messaging. This is a primary reason why lenders keep in close proximity to their device and the lendee [1,8].

Most current mobile operating systems support multiple account profiles, or a guest mode. Using these to lend may decrease risk [8,13], but these mechanisms can be brittle and are underused in practice due to effort to configure them and switch between profiles [3]. For example, many families share a single profile on a desktop computer or tablet, despite the availability of multiple user accounts [7].

Alterative solutions have been proposed to manage security and privacy more easily for sharing and lending. *xShare* [12] provides a lender with custom access controls and a way to switch to guest mode in a user interface integrated into a lending workflow. *Treasurephone* [21] can automatically determine access control for a lendee based on application context. Our lendable smartphone also enables custom access control, a simple way to enter guest mode, and methods to leverage application context, but we accomplish this using physical manipulation of the lendable modules.

Modularity

Regardless of software improvements for lending, a lender will still be inconvenienced because they cannot access their information (e.g. time-sensitive notification) or their smartphone's functionality (e.g. make a phone call) while lending. Our approach is to lend only a piece of a phone using a modular design, so the lender is not inconvenienced.

Commercial modular smartphones like *Project Ara* [5], *Phoneblocks* [14], *Motorola Z* [6], and *LG G5* [25] use modularity as a way to customize or enhance device capabilities. For example, replacing a camera module to upgrade the lens and sensor, or adding a battery module when going on a long trip. Modular approaches have even been applied to fitness wristbands [26] and smartwatches [24]. We use a different approach with modularity, by creating modules that are self-contained and fully interactive so they can operate like simple smartphones, but under the control of a master phone.

Sharing content with interactive displays that can be attached and detached has been demonstrated on a larger tablet scale by *Codex* [10], a smart watch scale by *Doppio* [22], and an even smaller "block" scale by *Siftables* [15]. These systems demonstrate the feasibility of multiple interactive displays working independently or jointly, depending on physical connection. Doppio demonstrated the idea of separating one watch face to share photos with a friend. This was a primary inspiration for the concept of a lendable smartphone.

Interacting with Multi-Display Devices

Using multiple connected displays has shown a wide variety of interaction techniques. An early example is "pick and drop" which allowed a user to transfer digital items between wall-displays and a PDA [19]. Similarly, Dachselt et al. [4] used a "throwing" technique to place content onto a large display at different distances. Paay et. al [18] describe general approaches used in cross-device interaction techniques for large displays (*pinching*, *swiping*, *swinging* and *flicking*). Bragdon et al. highlighted the impact of multi-device interactions on co-located collaboration {Citation}. We build upon existing research work in multi-device interactions and apply their techniques in the context of a modular smartphone.

STUDY 1: LENDING ATTITUDES AND PERCEPTIONS

To motivate and ground our work, we conducted a survey about lending trust and convenience with current smartphones and to probe the idea of a future modular phone. Our goal was to discover current perceptions and attitudes about how devices, scenarios, and social relationships affect lending and possible directions for modular lendable devices.

Study Method

We conducted a 15-minute online survey with United States residents using SurveyMonkey. Respondents were presented with three *lending scenarios*: lending to a close friend or family member; lending to a colleague like a co-worker or classmate; and lending to a stranger. For each scenario, they commented on trustworthiness, convenience, and lending frequency with two current lending methods in mind: handing over an unlocked smartphone; and logging out to activate a guest profile. At the end of survey, we introduced the idea of sharing a piece of a modular phone and asked for comments.

We used comics to demonstrate the techniques and scenarios, including the lendable modular smartphone concept (see Figure 2). The study explained it as containing a small piece equipped with a touchscreen that can be detached from the body of the smartphone for lending. Participants imagined keeping and using the small piece to control and monitor what the lendee does on the lent smartphone. They were informed that the lendable device does not reflect the final design and they should only focus on the high-level concept.

Results

We collected responses from 54 people, 29 male and 28 female, ranging from 25 to 75 years of age. Overall, qualitative findings confirm smartphone lending occurs in all three scenarios, but there are issues in current lending practices.

Confirming prior work, we found that device lending practices and willingness to lend either their smartphone or piece of a smartphone was linked to the relationship between the lender and lendee. In the scenarios where the lendee was either a colleague or stranger, using a modular design was more preferred than using the default unlocked state of a smartphone (Figure 2). One participant noted *"…I would probably "loan" it more frequently to friends and relatives"*. We also observed some unwillingness to share with strangers

Figure 2. Example of comic strip used to explain lending scenarios (lending a piece to a stranger shown).

at all, one participant commented *"… I wouldn't lend my phone to a stranger in any circumstance"*.

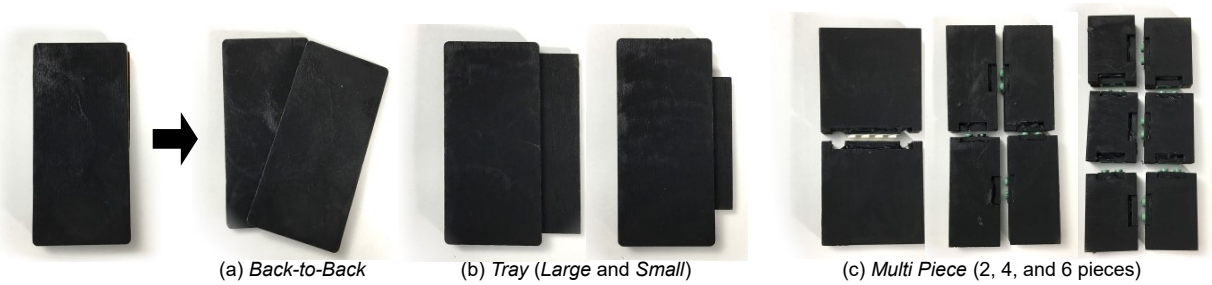
We also found that in scenarios where the lendee was a close friend or family member, participants preferred the unlocked (or all or nothing) approach compared to guest accounts and different profiles. This confirms previous work by Brush and Inkpen [3], Matthews et al. [13], and others [12,16]. Another participant based their opinion on personal experience "*I would never have occasion to lend my phone to anyone other than a close friend or family and then not for their use out of my presence*." This type of lending relies solely on the owners' trust in the lendee. This can be inconvenient for the lendee if they are outside of the trusted group. On the other hand, giving up the smartphone can be inconvenient for the owner as it may lead to missing phone calls or text messages. Participants saw the potential of a lendable smartphone addressing these issues, with one participant stating *"…it's a great idea to allow the use of the phone [during sharing]"*

Discussion

Our results confirm that users are forced to limit smartphone lending within a small group of highly trusted people, validating previous work and extending those results to current smartphone lending practices. Lending a device is inconvenient for both the lender and lendee. A modular smartphone has great potential to address these issues, with some participants noting *"...I like the idea better than handing over my phone"*. An important takeaway for modular device design is to ensure lenders have control over who they are sharing with and always maintain a level of control of their lent piece and their information. This was echoed by participants who stated *"...as long as my personal stuff was kept safe, I could see myself lending…"* and *"...for others, I would still want to be within eyesight [and control] my phone"*. An easy-to-use detachment technique is also important to ensure a positive overall user experience. Some participants noted concerns around a modular piece (or pieces) *"that could be easy to lose"* based on how they are attached and detached. We incorporate these principles into our design space and prototype designs described in later sections.

STUDY 2: LENDABLE SMARTPHONE DESIGN

The goal of this lab study is to evaluate modular designs and develop design considerations for lending interactions.



(a) *Back-to-Back* (b) *Tray* (*Large* and *Small*) (c) *Multi Piece* (2, 4, and 6 pieces)

Figure 3. Six mockups for a lendable smartphone: each is painted wood with Lego embedded bricks for attaching.

Twelve people participated (ages 20 to 35) in this exploratory study using physical mockups of different form factors.

Form Factor Mock-ups

We created six physical mockups to explore module *size*, module *amount*, and module *detachment techniques*. The wood mockups are similar in size to an iPhone 5S (123.8 x 58.6 x 8.6 mm). The mockups were used to physically demonstrate the concept of lending through modularity and to guide discussion and trigger ideas during the interviews. Three classes of form factors were explored (see Figure 3):

Back-to-Back — Two identical modules are attached back-to-back (each 124 × 58 × 5 mm). Lego bricks were embedded into the pieces to enable attaching and detaching. Each module resembles a very thin full-size phone.

Multi Piece (2, 4, and 6 piece variations) —Smaller identical pieces, each with the same thickness, attach to form a full-size phone. The *Multi-2* mockup splits in half lengthwise, each 62 × 58 × 10 mm. The *Multi-4* mockup splits into four pieces, each 62 × 30 × 10 mm. The *Multi-6* mockup splits into six pieces, each 41 × 29 × 10 mm. Embedded LEGO bricks enable attaching and detaching. The idea for 4 and 6 pieces was to enable sharing with multiple people or used together to create different module sizes.

Tray (Small and Large) — Inspired by SIM-card trays, an internal piece is slid out of the side cavity of a full-size phone. The internal piece in the *Tray-Large* mockup was 110 x 53 x 3 mm, but only 80 x 40 x 3 mm in the *Tray-Small* mockup. With the tray form factor, the main phone retains its full size, and the two modules are different sizes.

Protocol

We began by asking the participant about current device lending habits considering the scenarios from Study 1: lending to family members and close friends; lending to co-workers and classmates; and lending to strangers. Next, we explained they would manipulate different prototype form factor of modular smart phones built for lending. They were told to imagine each piece was capable of common tasks like viewing a map, making a phone call, playing games, etc.

Then, prototypes were shown one at time in counterbalanced order. For each, the participant was asked for overall impression, and to describe how they might use the prototype based on their own device lending experience. After all prototypes were examined, we led a semi-structured interview to compare all prototypes regarding how the different form factors could be used for lending, how each prototype impacted trust and convenience, and for ideas about alternative or refined designs. Finally, the participant ranked the prototypes considering trust and convenience and provided explanations. Each one-hour session was video and audio recorded with comments transcribed and placed into thematic groups.

Results

The value of the overall concept was demonstrated by comments like *"…I would definitely be more encouraged to share my phone with this"* [P2], and "… *I like the control that I have …*" [P4]. For the combined trust and convenience ranking, 41% of the participants selected Tray-Large for their top choice, followed by Back-to-Back (24%), Tray-Small (19%), Multi-2 (10%), Multi-6 (4%), and Multi-4 (2%). Mockups with large pieces were also perceived to be more useful for lending since they were comparable to a full phone. We identified the following themes from observations and comments:

(T1) Retaining a Piece Increases Trust — Regardless of prototype, participants said lending felt more trustworthy because they kept a piece of their phone, particularly when lending to strangers. For example, *"I wouldn't mind as much to give a piece to a stranger, now that I can control and not worry as much"* [P12]. Several participants described previous experiences lending a phone to strangers. They found it untrustworthy and inconvenient, but noted circumstances can make lending to a stranger necessary. For example, one participant described being a stranger needing to lend a phone, "*my phone died and I needed to make a call… [I] was lucky to find someone to let me use their phone"* [P3]. All participants said a modular design made lending to strangers more likely, for example, *"I would be more inclined to share with a stranger now that I can control everything"* [P6].

(T2) Controlling Trust by Piece Size — In all interviews, comments suggest a connection between level of trust and the size of the lent piece. The more trust there was in the lendee, the larger the piece. A typical comment: *"… I may just give my entire phone to a family member because it's easier, but for a stranger or someone I don't trust, they're getting a small piece …"* [P11].

(T3) Lender's Trust Is Visible — Several participants noted they would feel awkward lending a smaller piece since this implied *"less access to their device"* [P5]. When lending to family members or close friends, there was a potential to harm a relationship [11,13]. For example, *"a smaller piece, or interacting in a manner that restricts them access, feels*

like I am hiding something … and I don't want them to know I'm hiding anything …" [P9]. When lending to strangers, obvious lack of trust was no issue: *"I don't really care what they think, they're not really gonna see me again"* [P12].

(T4) Monitoring Usage — Participants felt it was useful to have a sense of *"seeing what the other person was seeing"* [P9]. For example, one participant said when a lendee was viewing photos, they wanted *"to be able to see the exact same photo as them, almost like a screen share"* [P2].

(T5) Sharing Other Content — Modularity also made participants willing to lend for accessing content previously found to be hard to share conveniently [16]. One participant noted *"It's difficult to share the Gmail app or Facebook app because I have to do all this work to log out"* and later followed with *"I could easily just hand them this and they'd login to their account and I don't have to log out of mine"* [P7].

(T6) Keeping a Complete Phone — Many participants noted the *Tray* and *Back-to-Back* designs were more convenient because the lender retains a complete device, "*… this sim design is cool because I still feel like I actually have a phone in my hands while someone is using part of it …"* [P11]. With other mockups, participants typically felt there was an *"incomplete device for myself and the other person"* [P12].

(T7) Master and Slave — The relationship between the pieces was also highlighted as important. Participants suggested a *"master and slave"* [P2] analogy. For the *Tray* designs, the main and secondary pieces had clear physical differences, *"… this bigger one is definitely the one I feel like I keep, and the thinner one inside I give …"* [P1]. With other designs participants noted there was no distinction between a master piece and the remaining piece(s).

(T8) Form Factor — All participants suggested designs merging different aspects of the mockups. For example, several suggested merging the *Tray* designs with the *Multi-Piece* concept. One participant said this flexibility would enable them to *"choose to give them a full piece or small pieces and still keep my phone … it would be less awkward sometimes"* [P8]. Several participants preferring sliding techniques of the *Tray* designs because *"… it feels less flimsy than breaking apart a device and is way easier to do"* [P4]. Combining aspects of sliding and different sized pieces ultimately proved to be the most common suggestion amongst participants. For nearly all participants, aspect ratio of the content on a piece played a factor in their mockup preference. Non-standard aspect ratios like *Multi-2* and *Multi-6* were disliked, for example: *"… I don't like the odd size of this [Multi-2], as I feel it's odd for me and the person I'm giving it too …"* [P10].

DESIGN CONSIDERATIONS

Primarily based on our study results, we generated design considerations for a lendable modular smartphone. Related survey results and study themes are noted when applicable.

Shape and Size of Modules — The shape of modules should at minimum, maintain a similar aspect ratio of the main piece (T8). Larger pieces are preferred for more trustworthy lendees, and smaller pieces for those less trustworthy or who need only limited functionality like making a calls (T2). Multiple modules of different sizes make an explicit choice of trust level possible (T1, T8).

Modularity Mechanism — The techniques to attach and detach modules affects perceived convenience (Study 1, T8). A sliding mechanism is preferred over a "breaking apart" mechanism since the lender retains fully functional (T6) pieces that could be lost even when not lending or the mental effort required to reassemble similar sized pieces (T8).

Software Interface and Interaction

A lending interaction begins by physically detaching a module, but a user interface for both the lender and lendee is required to monitor and fine tune the lending session.

Tight Integration — The concept of lending can be integrated into the operating system. The interaction design should support lending without any modifications to current apps, but app developers should also be provided with enhanced APIs to allow more nuanced control of lending content in their specific app (T5).

Simple and Configurable — Users should be able to lend with minimal or no explicit interaction beyond removing the modular piece (T7,T8) (in contrast to existing methods [8,9]). If desired, there should be fine-grained access control when beginning to lend, or during a lending session. This control should consider the type of content (T5) (after [12]).

Lending Modes — There are different ways to lend a piece to support different lending scenarios [15, 18] and different levels of trust in the lendee (T1,T2). For example the lending mode could restrict the lendee to a single app, grant the lendee access to multiple apps (e.g. phone, browser [12]), enable the lendee to have full access to the piece, or even enable the lendee to view what the lender is doing (e.g. to give directions or share photos).

Lender and Lendee Control — The lender should feel in control of the lending session and by default, they should retain full phone functionality (T6). The interaction should enable real-time monitoring at different levels (T4), for example, lendee screen mirroring or a summary status of lendee activity. The lendee should have a way to request more access and feel confident any personal data they may view or generate will not be seen by the lender (T5).

Swapping Roles — The lender should be able to choose any piece to act as the master piece (T7). For example, the largest piece could be lent, and the smallest piece retained by the lender for simple monitoring and control. This is especially useful in *broadcasting lending scenarios* [13], where the primary piece is required to view content like video or play complex games. The ability to swap roles helps overcome social awkwardness in situations where the lendee feels they should be trusted, but the lender has some reservations (T3).

LENDABLE SMARTPHONE PROTOTYPE

Based on our design considerations, we built a hardware and software prototype to demonstrate and evaluate a lendable modular smartphone. This helped us more effectively explore the design space, and through several iterations of case

designs, devices, software, and sensors, we learned valuable design and technical lessons for future hardware designs.

The phone has three modules to enable lending (Figure 4): a large phone, a medium phone, and a small phone. This design is a hybrid of the two Study 2 mockups: the medium and small pieces slide into the large piece like the *Tray* mockup and the large and medium pieces are complete phones like *Back-to-Back* mockup.

The large module is the *primary* piece. It is the only visible piece when not lending, and is the default piece retained by the lender. The medium module is a *secondary* for lending. It is a fully functional, self-contained smartphone with restricted access during lending. It is designed primarily to be lent to a trusted lendee (e.g. child, family member, close friend), but this role can be swapped with the large piece. The small piece is designed for lendees with less trust (e.g. a stranger) who typically require less functionality (e.g. strictly making a phone call). After technical details, we describe how it is used to support lending interactions.

Hardware

The prototype (Figure 4) uses a Google Nexus 6P (5.7") as the *large* piece, a Nexus 4 (4.7") as the *medium* piece, and a custom Android phone (2.4") for the *small* piece.

Each component is placed into a custom-designed 3D printed resin housing. The housing for the medium piece with the Nexus 4 (13.9 × 7.3 × 1.4 cm) contains a hidden NFC tag placed on its back. Similarly, the housing for the small piece (9.5 × 5.1 × 1.7 cm) uses an NFC placed on its back. Lastly, the housing for the large piece, with the Nexus 6P (19.4 × 9.6 × 3 cm) uses a guided railing designed into the case, that allows for the Tray pieces to easily slide or be detached. The complete prototype is thicker and larger than we envision for a real device, however, it is effective and necessary for validating and demonstrating the lendable smart phone concept.

The detection of attachment of both the small and large pieces to the main piece is accomplished with the built-in NFC capabilities of the Nexus 6P. This method was accurate for detecting different configurations, as the placement of the NFC tags allowed us to detect distinct changes of state.

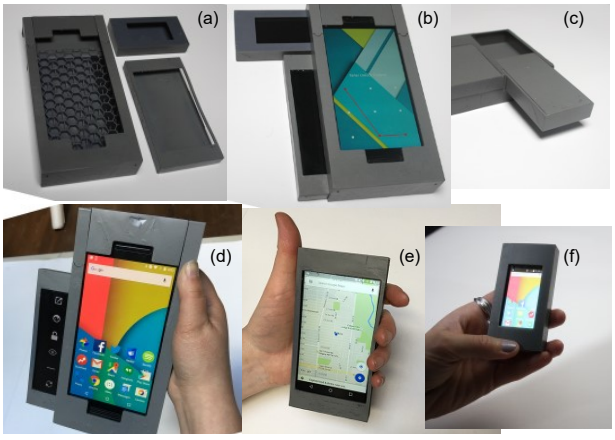


Figure 4. Hardware prototype: (a) 3D printed housings; (b) form factor showing medium and small pieces half slid out; (c) sliding mechanism; (d) large piece with medium piece half slid; (e) detached medium piece; (f) detached small piece.

Software

The Nexus 6P, Nexus 4, and smaller phone all run custom Android software that passes lending state to a server via WiFi. Combined with the NFC state detection of the Nexus 6, the server determines the current lending configuration and updates the larger, medium and smaller piece. Although our prototype uses an external server to accelerate development and software design iteration, a commercial version would use the large piece as the server.

INTERACTION DESIGN

There are four types of lending interactions: starting a lending session: monitoring activity, requesting and responding, and ending the session.

Starting a Lending Session

Each lending session begins with the physical action of sliding out the medium or small piece. When partially slid out, a default lending mode is selected and a lending menu is displayed on the visible part of the piece. Using the menu, the lender can select a different lending mode, configure the currently selected lending mode, or swap roles so the large piece will be lent instead (the four lending modes explained below). Using the menu is optional — if the piece is slid out without using the menu, the default lending mode is activated and the lending session begins immediately.

This partial sliding state is designed to increase convenience and trust. A full slide is like the current practice of handing over an unlocked phone, but in our system, the piece will automatically be in a restricted lending mode. A half-slide integrates customized access control into the physical landing action. This is more convenient than manually entering a guest mode on current devices, and is more trustworthy because the lender is more likely to fine-tune access.

Monitoring Activity

The lender monitors lendee activity using a persistent lending system notification. Activity includes current app lendee is using and events like when the lendee opens a new app. The lender can expand the notification icon to view a realtime view of exactly what is on the lendee's screen. From the expanded notification, the lender may access a more detailed summary and log of all apps the lendee has used and customize lending settings. These settings are also available through a standard system menu, so lending parameters may be configured anytime.

Monitoring activity is designed to increase trust: the lender can be confident the lendee is not doing anything malicious. Although the realtime view is reasonable for many lending scenarios (e.g. a parent lending to their child to play an online game), we acknowledge it may be invasive when lending to a colleague (e.g. so they can send a private text). We imagine lendee's could be notified when the lender wishes to monitor their screen, and have the option to deny or postpone access.

Figure 5. Interaction design flows showing lender interactions on blue line and lendee interactions on orange line. Refer to text for detailed explanation and see the accompanying video for demonstrations of these interactions.

Requesting and Responding

Depending on the lending mode, the lendee may request additional permissions. For example, requesting access to another app by tapping on the app icon. This request triggers a notification on the lender's piece with option to grant or deny the request. This request and respond system is designed to make lending sessions flexible. Consider a scenario where a parent lends a piece to their child with access restricted to an educational game. After playing the game for a while, the child can request access to another game or a video app.

Ending the Lending Session

The lendee ends their session by tapping a persistent notification. This warns them if any personal data will be lost (e.g. photos taken that are still uploading to the cloud) and verifies all personal information will be cleared. The full lending session ends when the lent piece is slid back into the housing.

Lending Modes

These lending interactions are used to select and configure different lending modes: app lending; guest lending; full-access lending; and screen sharing. These modes are designed to support lending scenarios described in our previous two studies, applications typically shared during lending [12], and the taxonomy described by Matthews et al. [13].

App Lending — This mode supports lendees who only need access to a single app like a map or instant messaging (*borrowing* [13] scenarios). Selecting the app for the app lending mode may be accomplished in two ways. If the lender slides out a piece while an app is open on the large piece, that app is selected for app lending mode. Alternatively, the lender can half-slide the piece, select app lending and pick the app to share. Regardless of method, completing the slide will begin a lending session with a generic version of the selected app (without any lender settings or personal information). With apps like a map, the lendee is ready to navigate. For apps like instant messaging, the lendee must sign-in to the messaging service before reading or sending texts. During the lending session, the lendee may request access to another app. The request is sent for the lender to approve or deny.

Guest Lending — This mode supports lendees who need access to a set of standard apps. By default, we guest mode provides access to common apps used during lending [12]: browser, phone, camera, and maps. Guest mode may be selected in three ways. If the lender slides out a piece with no apps open, guest lending mode is selected by default. Or, the lender can use the half slide menu to select guest mode. Finally, if a piece is slid out when the large piece is locked, guest mode is selected and the half-slide menu only provides the option to swap pieces (other lending modes may not be selected). All apps in guest mode are generic versions, no lender settings or personal information. This lending mode is useful for scenarios involving ad hoc temporary lending (*borrowing* [13]), such as a user needing to borrow a phone in an emergency, and also prevents *accidental* [13] situations where a lendee accesses a lenders private information. This is also ideal for lending scenarios where a parent wants to lend their phone to their child to monitor and keep them occupied, but also prevent unnecessary applications from being purchased or installed. Several participants in Study 2 stated this to be the "killer app" for guest mode lending.

Screen Sharing — The lender may want *help* [13] from a lendee, such as configuring an email account or sorting locally stored photos. Or, the lender may want to share their view with others, such as showing photos from a vacation, sharing a humorous video, or going over a presentation before a meeting. To support these lending situations, a one-way screen sharing mode streams a view of the lender's piece to the lendee's piece. For help scenarios, the lender and lendee can physically exchange pieces, so the lendee has full access to the phone while the lender monitors their actions. For example, a lender who is less technically adept could be helped by a family member or friend to configure settings, install applications, or demonstrate how to accomplish tasks.

Full Access Lending — A lender may choose to allow the lent piece full application access with all available functionality This is useful for scenarios involving *mutual-use* [13], such as when a device is equally shared by a married couple. Full access is selected explicitly using the lending menu.

Small Piece Lending

The lending menu and role swapping behaviours are different for the medium and small piece. The small piece lending menu presents fewer lending modes, chosen as suitable for the smaller piece, and the app sharing mode defaults to certain apps like phone dialing, as suggested in our studies. Given the relationship between trust and size, this functionality is thus better suited for the smaller piece, while the larger piece can be used for more trusted lendees. Therefore, we treat the secondary small piece as a touchscreen headset.

When swapping the master role to the medium piece, access to all apps, data, and functionality are swapped. When swapping the master role to the small piece, master piece functionality is focused on what is possible with the small screen: monitoring lendee activity, handling lendee access requests, and providing the lender with basic application functionality like notifications, texting, and calling.

While several of the lending modes and their associated scenarios are inspired by the broad taxonomy of Matthews et al. [13] and our prior studies, focusing on a specific lending scenario, like lending to occupy a child, could have design implications. For hardware, this could mean a simpler design for the small piece, or only a small piece. For software, this could mean a simplified user interface for young children.

STUDY 3: USABILITY AND USER FEEDBACK

To gain some preliminary feedback on the prototype and elicit discussion on the topic of modular, lendable devices, we conducted a small usability study with five participants (27 to 45 years of age, 2 female, all recruited by email). The 1-hour session began with the experimenter demonstrating the prototype, then the participant used it to perform lending tasks. The 8 tasks were all based on the scenarios described in our exploratory study: lending to a close friend or family member; lending to a colleague like a co-worker or classmate; and lending to a stranger. Each task was evaluated with

the participant as both lender and lendee, with the experimenter playing the alternate role.

Result

The concept was generally well received with positive feedback on the lending interactions in different social scenarios. As a lender, all participants felt that they must give a larger piece to lendees they trust, or who perceive they should be trusted confirming our earlier results. However, trustworthiness with respect to lender information was mentioned frequently, as the distinct modes, application requests, and continuous monitoring resulted in participants feeling more secure with their data, and thus more trustworthy of others when lending the medium piece and even the primary large piece (when swapped with the small piece).

We observed that participants familiar with the Android operating system (4 of 5), appreciated the integration of lending notifications and monitoring. The remaining participant struggled initially with the software techniques due to their unfamiliarity with the android operating system, however, the interaction techniques given the scenarios was well understood. All participants commented on the large size of the prototype, and felt a smaller size would be more convenient. Some participants expressed interest in a device with only the medium piece, but also noted lending it to strangers would be less comfortable.

Comment from several participants relate to the cost benefit of carrying a modular phone. One interesting idea to address this is to make modularity optional. For example, designing the main piece to be a fully functioning lightweight and thin phone without any modules, but when necessary, enabling modular pieces to be attached when lending scenarios are expected (such as travelling with a child).

LIMITATIONS AND FUTURE WORK

We discuss limitations with future research directions.

Technical Feasibility — With further engineering efforts, the size and thickness can be reduced. Entirely custom enclosures could be used to replace the combination of stock smartphones enclosures and 3D printed cases. The smartphones would also be replaced with secondary thin-displays, acting only as clients, while a "core" module could be thicker and more powerful to drive the clients. We believe that using technology readily available today, it is possible to create a lendable, modular smartphone with a similar thickness as Project Ara [5] (9.7 mm).

Battery Life — Other engineering improvements like a better battery size strategy should be explored. Since the medium and small pieces are not intended for all-day use, they could have small batteries that are charged when attached to the large piece. This would reduce the overall weight and thickness and reduce cost. Strategies such as using thin-secondary client displays would also reduce power battery demand.

Alternative Designs — Increased modularity on the large piece, like the *Multi-Piece* designs from Study 2, would be beneficial. Although we focused on a single prototype design, participants mentioned multi-user device lending scenarios that could benefit from alternate designs, particularly with multi-player mobile gaming. Future research should focus on exploring new device lending interactions that could be enabled by multi-user scenarios.

Other Sharing Influencers — Our concept primarily focused on *trustworthiness* and *convenience*, we did not fully explore other aspects such as cultural context, or older populations who may view device lending in a different manner [6].

Lending Content — We primarily focused on lending applications, with less focus on the techniques for lending content within applications. For example, a lender may also wish to share an album of photos in the photo application on the lent piece instead of a blank photos app. We also did not fully implement and explore how lendee information would be erased (or saved) when the lending session ends.

Evaluation — Understanding usability in real-world usage scenarios are necessary to identify issues not revealed in our usability study. We also did not fully explore the usability of the small piece which has more restricted capabilities.

CONCLUSION

Our work introduces the concept of a modular smartphone, designed to address issues with trust and convenience by lending only modular pieces of the device. The results of our formative studies provided additional motivation for the idea, and justifications for design choices. A proof-of-concept hardware prototype demonstrated how lending interactions can be used for common lending scenarios. Our concept may appear far-fetched at first, but we hope to have convinced the reader that there is some need and our modular strategy could be made practical. Perhaps more important, we hope our work will inspire other new ideas for future devices tailored to different needs of users, and their family, friends, and fellow citizens.

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