NotificationManager: Personal Boundary Management on Mobile Devices

Tom Gross[0000-0001-8353-7388] and Anna-Lena Mueller

Human-Computer Interaction Group, University of Bamberg, 96045 Bamberg, Germany
hci@uni-bamberg.de

Abstract. The growing use of mobile devices that are available everywhere can blur the boundaries between life domains work and life. The increasing number of notifications on smartphones leads to interruptions that might be unrelated to the current life domain and task and are therefore disruptive. Despite some tools there is a gap between the preferred and the actual separation of life domains. In this paper we show how concepts from the field of boundary management can be applied for notification management on mobile devices. We present a formal model of the semantic structure of life domains, which is based on the concepts of integration and segmentation from boundary theory. We introduce an app for the management of notifications on Android smartphones that leverages on this formal model. In a field study we evaluated the app with real-life notifications. The results show a significant reduction of the gap between actual and preferred boundary management.

Keywords: Boundary Management, Notifications, Formal Model, Android App.

1 Introduction

The increasing use of ubiquitous technologies makes the separation of life domains such as work and life more difficult. For instance, smartphones users are constantly reachable for their contacts independent of their personal as well as their contacts' current life domain. Boundary management has become relevant for research in human-computer interaction and computer-supported cooperative work [12, 34, 45, 59]. Current trends contribute to the blurring of boundaries between life domains—for instance, home office, and bring your own device.

Home office work increases the work-related communication outside of the confines of the employer. Employers often provide laptops and mobile devices to their employees allowing them to work from home and be reachable at home. Business smartphones make employees available for work anytime and anyplace. Dual-SIM smartphones can be equipped with private and business SIM cards in one device and make it unnecessary to carry two devices. Sales for dual-SIM smartphones increased by eight percent recently [9].

Bring your own device (BYOD) where employees use their private devices for business purposes is booming. BYOD leads to increased satisfaction and flexibility of employees [41, 57]. The development of rules and security standards for the use of employees' private devices is being researched, which will eventually make BYOD possible for more and more employees [4, 56]. Choose your own device (CYOD) is a related concept where the employees can choose the hardware on which they want to work and where the company pays and owns the hardware [7]. Often the employees are allowed to also use the hardware for private purposes.

Such trends bring advantages but also entail challenges. Users are often confronted with different life domains that blur on devices [23]. This makes the separation more difficult.

Overall the number of apps on mobile devices that push notifications to users is increasing. Notifications in general, and notifications from life domains and tasks that are currently not relevant to the respective user, can lead to disruptions and stress [36]. Interruptions and their negative consequences for users have been an important research topic of human-computer interaction [37]. Current research shows that blocking disruptions can have a positive effect on task focus and productivity [35]. However, the total blocking of notifications is often not possible, since it might mean that users might miss important and relevant information and that users might damage social connections [54].

In social science there is a great body of knowledge on boundary management—that is, how humans effectively establish borders between their life domains and how they efficiently organise passages between life domains. It is based on roles and tasks as a basis for structuring and organising life domains [8, 16, 31].

In this paper we show how essential insights of boundary management from social science can be transferred to the design of concepts for managing life domains with a smartphone app. As the literature on boundary management is multifarious domains [8, 16, 31], it is necessary to distil essential insights and to use them as input for requirements for our new concepts. We introduce a formal model on the semantic structure of life domains, which is based on the concept of integration and segmentation from boundary theory [8, 43]. Central building blocks of the formal model are life domains, persons, availability, interruptions, and notifications. The formal model served as the foundation of and Android app. The app was used in a multi-day field study with real users.

2 Background and Related Work

Modern technologies are a two-edged sword—they are disrupting and make boundary management necessary, but at the same time they offer support for boundary management [10, 16, 34]. Solutions from notification management reduce the number of disruptions caused by notifications on smartphones or other devices. Still, the boundary management in practice does not always life up to the requirements and needs of users, which can lead to conflicts between life domains, especially between work and life [55].

2.1 Notification Management

Notification management follows two paradigms: the automatic detection of opportune moments for the presentation of notifications based on users' current contexts, and the manual specification of user-defined rules for filtering notifications.

The paradigm of automatic detection of opportune moments is based on sensor data to infer on the user's context [20, 30, 61, 65]. Often machine learning is used to carve out the most relevant features from the sensor data in order to detect the user's context [13, 38, 50, 51, 53, 58]. Detecting breakpoints—that is, moments after a user has finished an activity or task and before they start a new one—is promising and has been vastly researched [21, 26, 27, 44, 46-48]. However, their disadvantages are that in general the users do not get any information as to how the system has detected the breakpoints, if and when the system presents notifications. Also, typically users are not in control as to incoming notifications. This reduces the users' acceptability of those systems [40]. Furthermore, these systems only consider measurable sensor data and not the internal state of the users.

The user-centred paradigm requires users to manually specify rules to filter incoming notifications. Users can decide on the relevancy of notifications and the timing and presentation depending on their respective use context and notification contents [3, 14, 29].

The receptivity of notifications for a recipient and therefore the relevance of the message causing the notification strongly depend on the contents of the message as well as the relation between message sender and recipient [11, 39, 40, 52, 60]. In the case of messages from a messenger app, which are the biggest share of daily notifications [52], it is often enough to see the name of the sender in order to infer the relevancy to the current situation [29].

A further factor that influences the personal receptivity of notifications is the relevancy of its contents for the task at hand [1, 18, 22, 62]. For instance, if a message notification is from a working colleague and relevant to the current task, it is more likely that the recipient has a stronger preference to see the notification and the message than for other notifications.

2.2 Boundary Management

The research on boundary management has also been dealing with interruptions—especially those caused by technical devices—in different life domains. A life domain is a conceptual category that originates from mental and physical boundaries around persons, things, and a part of the self (e.g., work, or family) [43].

Cross-domain interruptions have an origin outside of a person's current domain, whereas within-domain interruptions originate from within [2].

A person's interruptibility for cross-domain interruptions strongly depends on their boundary management style—that is, whether a person prefers to segment, or integrate life domains [31]. Segmentation refers to an inflexible and impermeable mental and physical boundary [16], and to the lack of a conceptual overlap between the life domains [31]. Integration refers to the opposite with neither clear boundaries between nor clear distinction of life domains' members, thoughts, and intellectual as well as emotional approaches [8]. The boundaries are flexible and permeable [16], conceptually, a continuum connects complete segmentation and complete integration, and humans can be on any position of this continuum.

Boundary work refers to the concreate tactics that a person applies for realising their boundary management style. Those tactics serve the maintenance of boundaries for segmentation, or alternatively the switching between life domains for integration [43].

Technology plays an important role in executing the tactics. For instance, in asynchronous communication tools such as email users can maintain their segmentation by just reading sender names and subjects and decide if the person and contents fits into the current life domain [33].

In our approach, which we present in detail below, we leverage on the user-centred specification of life domains and the automatic adaptation of notifications from notification management. Users can specify of each of their life domain its permeability—that is, its interruptibility preferences for within-domain and cross-domain interruptions. Also it provides a categorisation for each notification, so users can make an easy choice whether to ready and reply to messages immediately or later after switching to a different life domain. Our approach and our implementation contribute a blueprint for a notification management approach that is based on users' interaction with the system and allows exploring users' preferences and behaviour, which is complementary to other approaches that automate the management of notifications.

3 Within-Domain and Cross-Domain Interruptibility

The multifarious nature of existing boundary management theories makes it very difficult to transfer the structure of life domains and their components directly into a system. Therefore, we introduce a formal model that distils relevant concepts into components and connections and dependencies that serve as a basis for a future system.

3.1 Fundamental Boundary Management Concepts

The main criterion for identifying concepts was their relevancy with respect to the effective management of boundaries and the efficient transitions across boundaries. We put a special focus on the factors that influence the interruptibility for notifications and their mutual connections.

In order to detect the interruptibility with respect to a specific notification it is first of all necessary to identify the life domain of the originator of the notification (mostly the sender of a message behind the notification). Assigning a life domain to a contact is not always unique (e.g., two working colleagues might also share a hobby, and so mutually be in the life domain work, but also leisure). In practice different techniques are used that make it possible to assign a single contact to multiple life domains—for instance, multiple address books [42], but also distinct domain-specific contact channels (e.g., using a contact's private email address in one life domain, and the work email address in another). The more the boundaries between life domains are blurring, the more difficult it gets to assign notifications to specific domains. The use of distinct contact channels has proofed helpful here [34]. Additionally, the interruptibility can depend on the person's current social context—that is, the other persons that are currently with the focal person and their life domain. The role and behaviour of a person as well as the expectations of others towards that person might change according to the current life domain, and so might their interruptibility [31].

3.2 Formal Modelling in Human-Computer Interaction

In human-computer interaction formal models have been developed for diverse purposes such as for modelling the problem domain, the interaction, or the system. Formal models provide great benefits when developing concepts and systems: they stimulate the developers to develop a very clear model of the world and force them to clarify all diverse aspects in detail. In discussions among developers they are a great vehicle to foster and focus discussions. As such models are widely used in computer science and mathematics and many other formal areas of research, they aim to provide—also in the HCI domain—a precise documentation of the concepts. They have similar purposes such as other representations (e.g., design patterns), but compared to other representations provide far more precision sometimes at the cost of effortless readability. Overall we belief that besides other models they provide considerable added value and the benefits by far outweigh the cost.

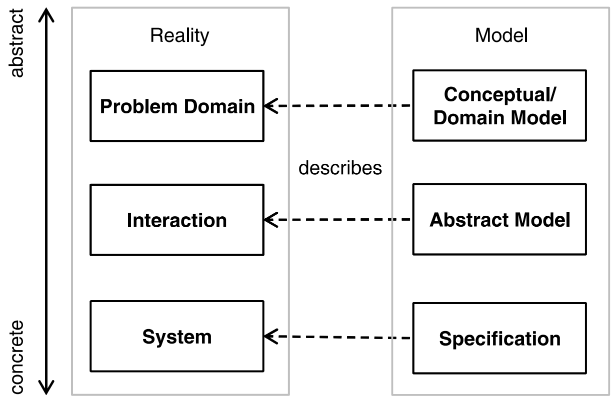

Fig. 1. Types of formal models.

Formal models have different levels of abstraction. Abstract formal models describe the problem without any relation to the system that is to be developed (e.g., DSML [28, 63]). Concrete models specify the structure of the systems (e.g., UML [6] or Z [64]). Between those abstract and those concrete models are models that describe the user interaction with the system without details of its implementation (e.g., PiE or

TAG [15, 49]). Figure 1**Error! Reference source not found.** summarises different types of formal models in human-computer interaction and the realms they model.

3.3 Formal Models of Interruptibility

In our conceptual model we describe the mental structure of humans concerning a specific domain. We completely separate this step from later interaction and application development. The advantage is that the model is independent and can be used in different systems, no matter how they are implemented or which architectures they use. What we are modelling is a problem domain that is not physically tangible and cannot be observed from outside. It describes a mental concept.

As we want to formally describe our understanding of a specific concept in real world instead of notating the functionality of a system in the first step, we do not use an implementation-related notation. Instead we decided to use simple set theory, basics of first-order logic and n-ary relations. Set theory allows explaining the possible assignment of instances to a set including constraints and particularities of this assignment as well as relations between the instances of objects in a concise manner with only a few simple and short formulas [5, 25]. The advantage of this approach is that we have a clear definition of our assumptions about users' mental concepts concerning their life domains [64].

Person. *P* is the set of all persons in the world. *P* cannot be empty ($P \neq \emptyset$). Persons have a name and several types of contact information (e.g., email addresses, phone numbers). Other attributes of humans are disregarded in our model. In the model we refer to one focal person who is the interruptee and element of P^I. As we only regard one focal person, P^I is a singleton. All other persons, the fellow persons, build the subset P^F.

$$P \coloneqq set\ of\ all\ persons$$
$$P \neq \emptyset$$
$$P \subseteq Name \times \mathfrak{P}(ContactInformation)$$
$$Focal\ Person\colon P^I \subseteq P$$
$$\#P^I = 1$$
$$Fellow\ Persons\colon P^F \coloneqq P - P^I$$

Domain. *D* is the set of all domains. *D* cannot be empty ($D \neq \emptyset$). A domain consists of the role a focal person has in the domain, the specific behaviours and rules imposed by the domain, its communication channels, its objects, the physical borders given by locations and times, and its channels used for communication. A validity timestamp makes it possible that domains can change over time. The foreground domain is an element of *D* and is the domain where the focal person is currently situated in. Background domains are all his/her other domains. The relation $owns$ specifies which person possesses the domain (i.e., the focal person).

$$D \coloneqq set\ of\ domains$$
$$D \neq \emptyset$$

$$Time: T = \mathbb{N}$$
$$D \subseteq Role \times \mathfrak{P}(Behaviour) \times \mathfrak{P}(Rule) \times \mathfrak{P}(Channel) \times \mathfrak{P}(Object) \times \mathfrak{P}(Location) \times \mathfrak{P}(Time) \times T$$
$$owns \subseteq P^I \times D$$
$$BackgroundDomains: D^B \subseteq D$$
$$ForegroundDomains: D^F \subseteq D$$
$$\#D^F = 1$$

Assigned Persons. The relation $isAssignedTo$ shows the fellow persons that a focal person assigns to life domains (e.g., one's family members in the domain family). The set $P_{d,p,t}$ is defined as the subset of P containing all persons that are assigned to one domain *d* belonging to focal person *p* at time *t*. Fig. 2 shows an example on how a graph accompanies our model containing the defined subsets.

$$isAssignedTo \subseteq P^F \times T \times D$$
$$P_{d,p,t} \subseteq P^F$$
$$P_{d,p,t} \coloneqq \{q \in P^F : owns(p,d) \wedge isAssignedTo(q,t,d)\}$$

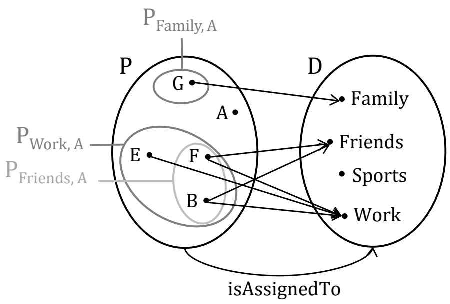

Fig. 2. Example of focal person A's life domains and assigned fellow persons at a given moment t_i.

Current Situation. The relation $situatedIn$ shows the relationship between persons and domains depending on time t. At one point in time, persons can be physically situated in one of the focal person's domains. $S_{d,t}$ is defined as the subset of persons that is located in the same domain *d* at time *t* (see example in Fig. 3).

$$situatedIn \subseteq P \times T \times D$$
$$\forall p \forall t \forall d \left(\left(p \in P^I \wedge t \in T \wedge d \in D \wedge situatedIn(p,t,d) \right) \rightarrow d \in D^F \right)$$
$$S_{d,t} \subseteq P$$
$$S_{d,t} \coloneqq \{p \in P: situatedIn(p,t,d)\}$$

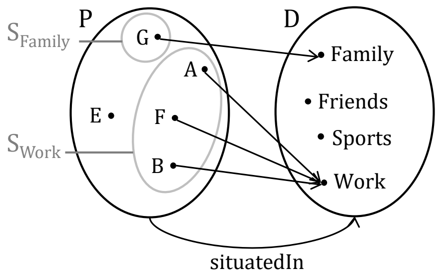

Fig. 3. Example of life domains and persons' current situation at a given moment t_i.

Availability. Availability is the relation that describes the readiness of the focal person for interruptions by a fellow person. The availability depends on the focal person's preferences, the domain of the interruption, the currently active domain where the focal person is located in, the time, the persons situated in the currently active domain (e.g., availability can differ if the individual in the current domain is alone, together with domain members, or together with domain non-members), and the communication channel of the interruption.

$$Availability: A \subseteq P^I \times D \times D^F \times T \times \mathfrak{P}(P^F) \times Channel$$

Interruption. Interruptions relate to the person that is interrupted, the person that is interrupting, the time of occurrence, the channel of the interruption, and the content of the interruption.

$$Interruption: I \subseteq P^F \times P^I \times T \times Channel \times Content$$

Interruptions' Domain. The relation $refersTo$ maps cross-domain interruptions to the concerned domain. We assume that for each interruption from a known person, there exists a unique domain the interruption refers to (even if the interrupter and the interruptee share multiple domains), which can be determined using the sender, the channel and the content of the interruption.

$$refersTo \subseteq I \times D$$
$$\forall i \forall p \forall t$$
$$\big(i \in I \land p \in P^F \land t \in T \land \exists! d \big(d \in D \land assignedTo(p,t,d) \land refersTo(i,d)\big)\big)$$

Notification. According to the availability for a certain domain, the notification of an interruption can differ. The attributes of notifications are the presentation modality (e.g., visual, auditory), the concrete layout of a notification (e.g., type of sound), and the timing (e.g., immediately or diverted to a later point in time).

$$Notification: N \subseteq Modality \times Layout \times Timing$$

Those are the entities we defined in our model. If an interruption appears, we can conclude the focal person's current availability for this interruption and an appropriate notification can be chosen to present to the focal person.

The model is formal and therefore concise—with only a few statements we describe all relevant concepts. The formal model can be used for later system related notations in order to specify the implementation of the entities of the formal model. The structure of the formal model can alternatively be represented in other forms such as UML. However, in UML diverse structural models would be needed for cover all the information of the formal model.

4 NotificationManager

We built the *NotificationManager* Android app for managing notifications according to these entities of the formal model. While the formal model was developed thoroughly and based on many years of experience with developing such systems, we still wanted to verify it through the implementation of a real system. Fig. 2 depicts how the entities of the formal model were transferred into a UML class diagram and how the classes of the NotificationManager are embedded into the Android operating system.

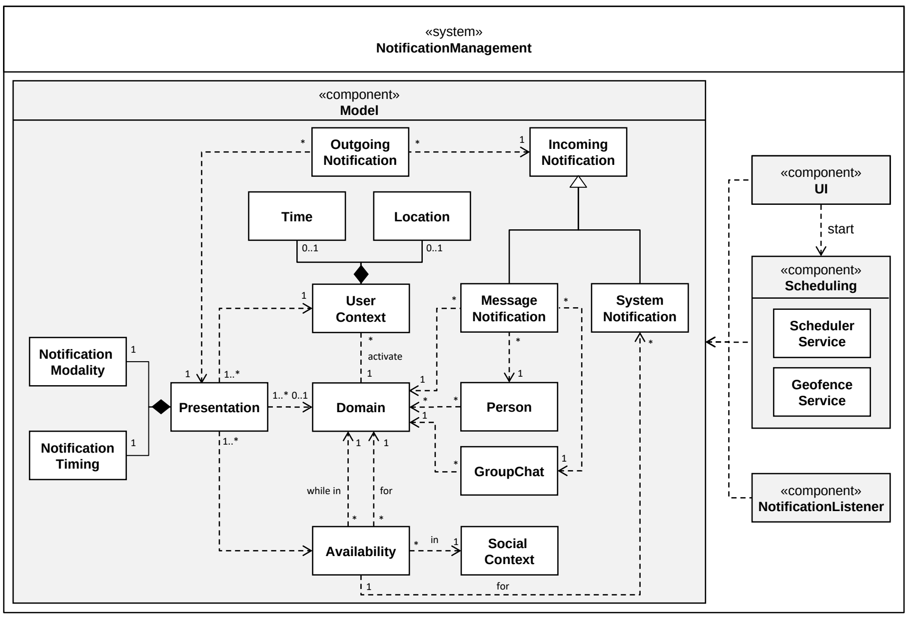

Fig. 4. NotificationManager as UML Class Diagram (simplified; without attributes and methods).

We decided for Android as the platform, because it enables intercepting and modifying notifications. With notifications we refer to the information snippets shown in the status bar and the notification drawer of Android (esp. version 7). .

The app allows users to configure their life domains and the interruptibility in each of them for within-domain and cross-domain interruptions. Furthermore, it provides meta-information on notifications (esp. the life domain of their origin) in order to help users in deciding whether to read a notification immediately or later.

For notifications created by the NotificationManager, the standard behaviour of Android notifications was adapted as much as possible. Notifications are kept in the drawer until the user either accesses the notification or opens the NotificationManager app to see all received notifications in the Notification Log. In the current implementation of the NotificationManager, all notifications are kept persistently in a local database. A clean up mechanism for old notifications after a specific amount of time could be easily integrated.

Users can set up their life domains consisting of a name and an icon and assign contacts, group chats, locations, and times to them. Contacts represent persons and all their information can simply be picked from the smartphone's address book. Communication channels that are currently supported by the NotificationManager are phone calls, SMS, email, messages from messengers (e.g., WhatsApp, Telegram), and social media (e.g., Facebook). Users can either assign a contact with all their communication channels to one domain, or have more fine-grained assignments with a high degree of segmentation by associating a contact's distinct communication channels to life domains (e.g., one contact's office phone number to work domain and private phone to family domain). Group chats can facilitate the communication with all contacts of a specific life domain. Times can be specified as intervals with a start time and end time for each individual day of the week (e.g., 9-17h from Monday to Friday for work).

In order to balance the users' wish for fine-grained specifications versus user effort the app supports multiple modes to specify one's interruptibility and presentation of notifications. In the simple mode we distinguish available from not-available. If the user is available, all notifications are shown in the notification drawer. If the user is not-available no notifications are shown in the drawer, but users can open the respective app to see the notifications later. In the advanced mode we distinguish three levels of interruptibility (high, middle, and low) for all with-in and cross-domain notifications. In the app high interruptibility is green, middle is yellow, and low is red (cf. Fig. 5 left side). Users can specify their preferences for the intensity of the presentation of the notifications for each level. All three levels offer default notification intensities that can be changed according to the user's will. When the user first starts the app it does not have life domains, but it already filters according to notifications related to their contacts in the Android address book, notifications from unknown persons, and notifications from the system.

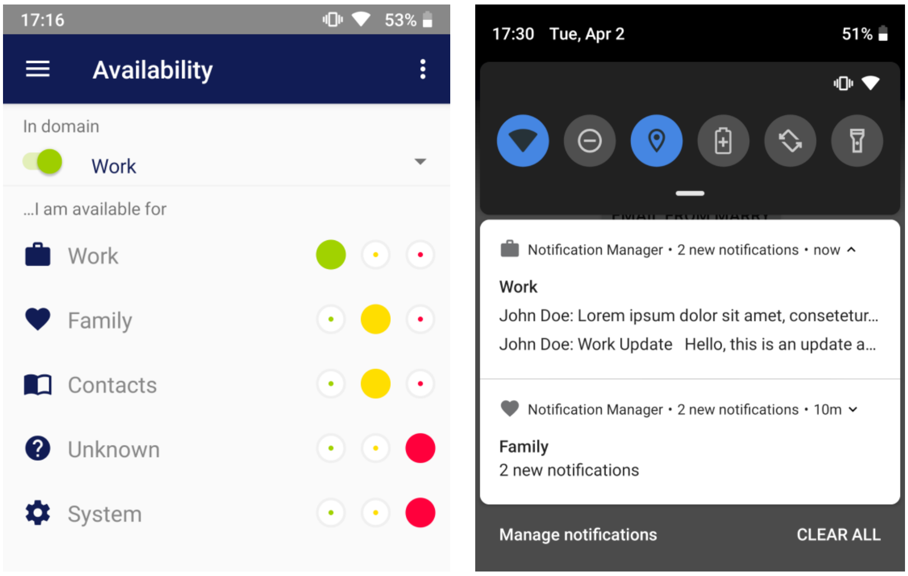

Fig. 5. Specification dialog for cross-domain notifications in the domain work (left side); executive summary of notifications according to life domains in the notification drawer (right side).

Notifications can be completely suppressed and hidden, or they can be presented in an executive summary that the NotificationManager generates in real-time. Summaries can be compiled according to diverse criteria—both semantics and time. For instance, users can get one summary across all their life domains or a summary for each life domain. Summaries can be presented on an hourly basis, or once a day at a specific time. The NotificationManager suppresses all individual notifications to keep disruption to a minimum. Yet, via the summaries users rest assured that they do not miss notifications. Furthermore, all notifications, those presented and those not presented, are collected in a notification log inside the application, so no information gets lost and the user can browse through the logs and the individual notifications they contain when they please. Logs are ordered by domain and time so previous notifications can easily be found again.

Whereas in standard Android notifications in the drawer carry the icon of the respective app (e.g., WhatsApp), in the NotificationManager they carry the icon of the respective life domain for better priorisation of the user (cf. Figure 5, right side).

Users can also specify the modality of the presentation (e.g., sound, vibration, LED lights). The number of options and level of detail depends on the hardware capabilities of the respective smartphone (e.g., some smartphones feature LED lights with multiple colours, in which case colours can express semantics, such as life domains).

The NotificationManager provides options for automatically activating a life domain and its interruptibility settings—for instance, when entering a specified location, or during specific time intervals (via the *Google Geofencing API* and the *JobScheduler* in the background). The system then automatically compares the current life domain, checks the interruptibility levels for all other life domains, and adapts the presentations accordingly.

The application was implemented for Android SDK 28 and runs on Android 7.0 or higher. The system configuration as well as the notifications are stored in a SQLite database. For capturing and modifying the original notifications we implemented a `Notification Listener Service`. It was developed using Android Studio 3.3.1 on MacOS X Version 10.11.6. For testing we used a Samsung Galaxy Note 8 with Android 8 and a Nokia 6 with Android 9.

5 Evaluation

A field study was carried out to find out if users can effectively and efficiently organise their life domains with the NotificationManager.

Before the main study we conducted a pilot-test with our prototype, our study procedure, and our questionnaires. We decided to use the participants' own devices to test the application on a variety of smartphones and Android OS versions. In this pilot-study ten participants used the application for two days and revealed some usability and functionality issues, which were fixed before our main user study started. Also the process of introducing the participants to the application and the questionnaires, which the participants had to fill in, were checked and slightly revised. The main field study then was much longer—participants used the app for one week.

5.1 Participants

In the main user study 15 participants were invited by personal contact to use the application for one week. From those 15 in the beginning we excluded 4 due to technical issues. The remaining 11 participants were between 23 and 47 years old (M = 33.55, SD = 8.32). 5 of them were female and 6 male. 8 participants stated to use their smartphone for both private and for work communication, 3 stated that they use it only for private communication. 9 participants were employees, 1 was self-employed, and 1 was student. 2 participants said they use their smartphone 10-25 times a day, 5 participants 26-50 times a day, and 4 participants 50+ times a day.

5.2 Procedure

After being briefed and signing a consent form**,** each participant received a detailed introduction including a video demonstration of the app and individual guidance. We used pre-task and post-task questionnaires, all of which contained questions about both the separation of work from life, and life from work. Before usage, they filled in an online pre-task-questionnaire measuring the users' preferred and actual segmentation and asking for additional demographical data and information about their smartphone usage behaviour. In a post-task questionnaire the users again answered questions concerning actual segmentation to measure changes of behaviour. Additionally, we did post-task interviews via telephone or personal contact to get informal feedback on the participants' boundary management, but also the usability and stability of the app. The participants had only some minor usability issues and reported on small bugs.

The task for the participants was that they could configure and use the NotificationManager as they liked, but we recommended using a minimum of two domains (work, and life). All participants had at least the two domains work and life. Some participants added also other domains (e.g., for specific hobbies, especially if they involved groups of people and communication with them, such as a sports club, or a big band). The post-task questionnaire was—for comparability reasons—standardised and asked questions about the two core domains work and life.

5.3 Measures

Since we were interested in the influence of the app use on the actual boundary management behaviour (eventually even during the week of use in our study), we asked for the actual segmentation before and after the use of the app. We assumed that preferences do not change in such a short time, so we measured preferred segmentation only in the pre-task questionnaire.

We measured preferred boundary management style using Kreiner *et al.*'s scale for preferred segmentation of the work domain from life domain (PSWL) [32]. As the items only refer to one direction—separating work issues from life—we adapted them for the other direction—separating life issues from work (PSLW). For measuring actual segmentation we used Powell et al.'s scale and again replicated those items in the other direction (ASWL, ASLW) [55].

Finally, we added a specific question about the communication behaviour from Kossek et al. [31]. The participants were asked to rate the statements on a seven-item Likert scale (1 = "strongly disagree", 7 = "strongly agree").

5.4 Results

The results show that for participants there is a discrepancy between the preferred segmentation and the actual segmentation of their life domains (cf. Fig. 6). The results confirm that this discrepancy shrank during the use of the NotificationManager. We also found that the participants' segmentations were not symmetrical between their work and life domains.

Starting with the latter we found that preferred segmentation of work from life PSWL was stronger ($M = 6.11$, $SD = 0.95$) that that for life from work **(**PSLW) ($M = 4.48$, $SD = 1.18$) that is based on a Wilcoxon signed rank test statistically significant ($p < .01$). The actual segmentation of work from life (ASWL) was also stronger ($M = 4.07$, $SD = 1.56$) than that for life from work (ASLW) ($M = 3.66$, $SD = 1.60$), but is based on a Wilcoxon signed rank test not statistically significant ($p = .237$). In the post-task results, the distance between actual segmentation of work from life (ASWL) ($M = 5.25$, $SD = 1.23$) and life from work (ASLW) ($M = 4.57$, $SD = 1.45$) increased, but is based on a Wilcoxon signed rank test not statistically significant ($p = .153$).

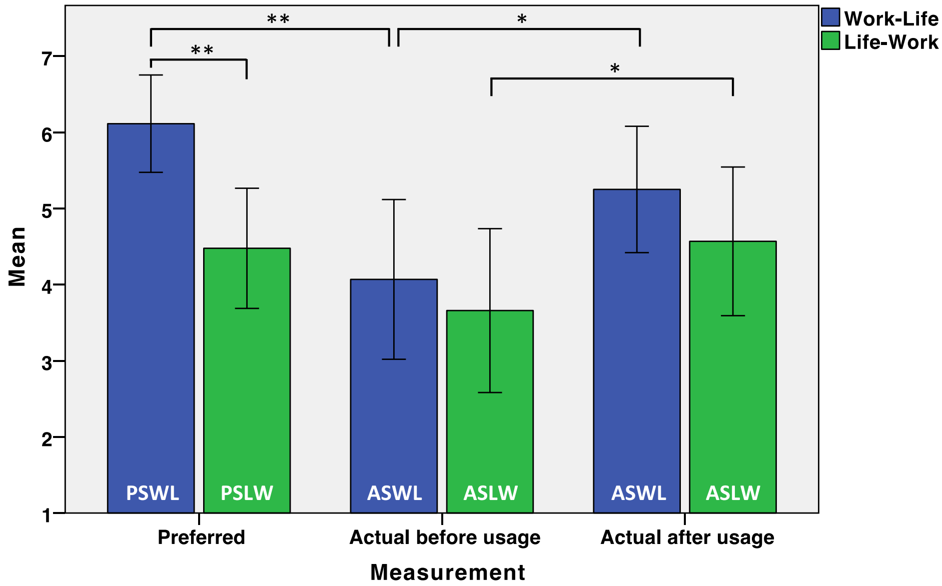

Fig. 6. Results of all comparisons of Work-Life (WL) versus Life-Work (LW) for preferred, actual pre-task, and actual post-task segmentation with * for a significance of $p < .05$ and ** for $p < .01$.

We compared preferred and actual segmentation from the pre-task questionnaire using a Wilcoxon signed rank test on the preferred and actual values. The results revealed that there is a statistical difference between PSWL and ASWL in our sample with $p < .01$. In contrast, regarding the other direction, the difference between PSLW and ASLW is smaller and not significant with $p = .185$.

In order to evaluate whether our app improves boundary management we tested if the discrepancy or delta between preferred and actual segmentation decreased throughout the use of our app (i.e., from the pre-task to the post-task). The pre-task delta between preferred and actual segmentation of work from life (PSWL-ASWL) is ($M = 2.05$, $SD = 1.60$) and more than twice as large as the post-task delta ($M = 0.86$, $SD = 1.60$) and the results are according to a Wilcoxon test statistically significant ($p < .05$). The pre-task delta between preferred and actual segmentation of life from work (PSLW – ASLW) is ($M = 0.82$, $SD = 1.86$) disappeared during post-task ($M = –0.09$, $SD = 1.69$) and the results are according to a Wilcoxon test statistically significant ($p < .05$).

5.5 Discussion

The statistical evaluation revealed a significant difference for preferred segmentation between the directions work from life and life from work. This confirms that borders between domains are configured differently depending on the direction of crossing. Such asymmetrical preferences have been found in the boundary management literature before. However, to the best of our knowledge, they have not been shown in the practical use of tools yet. After usage, the distance was greater compared to the pre-task values and thus more asymmetric than before, but not significantly.

Between preferred and actual segmentation, a significant difference could only be found for segmentation of work from life but not for life from work. Thus, our participants seemed to be more satisfied with the separation of life issues from work and need more support in separating work from life. After using our app, the distance between preferred and actual segmentation decreased significantly for both directions. This is an indication that our application successfully supports users to get closer to their boundary management preferences.

6 Conclusions

We showed how insights from boundary management literature in social science can be used to reduce the burden of users of smartphones with the increasing number of notifications on their technical devices. In a multi-day field test we could demonstrate that the NotificationManger app helps users to reduce the gap between preferred and actual segmentation of their life domains and to experience fewer disruptions.

The app suppresses and hides notifications, but this was accepted by the users since the configuration mechanisms are transparent and understandable.

In future work the app could be extended. The participants of the study provided some stimuli for further development of functionality for the NotificationManager. The configuration effort could be reduced by repeatedly asking short questions about their preferences and adapting the system behaviour accordingly.

The experience sampling method [17, 19] could be used to better understand the user behaviour and to optimise the default settings of the NotificationManager in order to minimise the configuration effort.

Another possibility is to include the senders of messages—they might add subjects and urgencies to their messages which can be fed into the algorithms for assigning notifications to life domains and forms of presentation [24].

Acknowledgements

We thank the participants of the study as well as the members of the Cooperative Media Lab at the University of Bamberg.

References

1. Addas, S. and Pinsonneault, A. The Many Faces of Information Technology Interruptions: A Taxonomy and Preliminary Investigation of Their Performance Effects. Information Systems Journal 25, 3 (May 2015). pp. 231-273.
2. Ashforth, B.E., Kreiner, G.E. and Fugate, M. All in a Day's Work: Boundaries and Micro Role Transitions. Academy of Management Review 25, 3 (July 2000). pp. 472-491.

3. Auda, J., Weber, D., Voit, A. and Schneegass, S. Understanding User Preferences towards Rule-Based Notification Deferral. In Extended Abstracts of the Conference on Human Factors in Computing Systems - CHI 2018 (Apr. 21-26, Montreal, Canada). ACM, N.Y., 2018. pp. LBW548:1-6.
4. Baillette, P., Barlette, Y. and Leclercq-Vandelannoitte, A. Bring Your Own Device in Organisations: Extending the Reversed IT Adoption Logic to Security Paradoxes for CEOs and End Users. International Journal of Information Management 43 (Dec. 2018). pp. 76-84.
5. Barker-Plummer, D., Barwise, J. and Etchemendy, J. Language, Proof, and Logic. CSLI Publications, Stanford, CA, 2011.
6. Booch, G., Rumbaugh, J. and Jacobson, I. The Unified Modelling Language uwser Guido. Pearson, Englewood Cliffs, NJ, 2005.
7. Brodin, M. BYOD vs. CYOD - What is the Difference? In Proceedings of the 9th IADIS International Conference on Information Systems - IS 2016 (Apr. 9-11, Vilamoura, Portugal). IADIS Press, 2016. pp. 55-62.
8. Campbell Clark, S. Work/Family Border Theory: A New Theory of Work/Family Balance. Human Relations 53, 6 (June 2000). pp. 747-770.
9. Canalys. Smartphone Shipment Fall 6.3% in Europe in Q1 2018. https://www.canalys.com/newsroom/smartphone-shipments-fall-63-europe-q1-2018, 2020. (Accessed 4/3/2020).
10. Cecchinato, M.E., Cox, A.L. and Bird, J. Working 9-5? Professional Differences in Email and Boundary Management Practices. In Proceedings of the Conference on Human Factors in Computing Systems - CHI 2015 (Apr. 18-23, Seoul, Republic of Korea). ACM, N.Y., 2015. pp. 3989-3998.
11. Chen, K.-Y., Lee, H.-P., Lin, C.-H. and Chang, Y.-J. Who Matters: A Closer Look at Interpersonal Relationship in Mobile Interruptibility. In Adjunct Proceedings of the ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the ACM International Symposium on Wearable Computer – UbiComp 2017 (Sept. 11-15, Maui, HI, USA). ACM, N.Y., 2017. pp. 910-915.
12. Ciolfi, L. and Lockley, E. From Work to Life and Back Again: Examining the Digitally-Mediated Work/Life Practices of a Group of Knowledge Workers. Computer Supported Cooperative Work: The Journal of Collaborative Computing (JCSCW) 27, 3-6 (May 2018). pp. 803-839.
13. Corno, F., De Russis, L. and Montanaro, T. A Context and User Aware Smart Notification System. In Proceedings of the IEEE 2nd World Forum on Internet of Things - WF-IoT 2015 (Dec. 14–16, Milan, Italy). IEEE Computer Society Press, Los Alamitos, 2015. pp. 645-651.
14. De Russis, L. and Roffarello, A.M. On the Benefit of Adding User Preferences to Notification Delivery. In Extended Abstracts of the Conference on Human Factors in Computing Systems - CHI 2017 (May 6-11, Denver, CO). ACM, N.Y., 2017. pp. 1561-1568.
15. Dix, A.J. Formal Methods for Interactive Systems. Academic Press, Chestnut Hill, MA, 1991.
16. Duxbury, L., Higgins, C., Smart, R. and Stevenson, M. Mobile Technology and Boundary Permeability. British Journal of Management 25 (2014). pp. 570-588.
17. Fetter, M. and Gross, T. PRIMIExperience: Experience Sampling via Instant Messaging. In Proceedings of the ACM 2011 Conference on Computer-Supported Cooperative Work - CSCW 2011 (Mar. 19-23, Hangzhou, China). ACM, N.Y., 2011. pp. 629-632.
18. Fetter, M., Mueller, A.-L., Vasilyev, P., Barth, L.M. and Gross, T. Towards a Better Understanding of Availability and Interruptibility with Mobile Availability Probes. In Pro-

ceedings of the 16th European Conference on Computer-Supported Cooperative Work - Exploratory Papers - ECSCW 2018 (June 4-8, Nancy, France). Reports of the European Society for Socially Embedded Technologies, EUSSET, Siegen, Germany, 2018. pp. 14:1-18.
19. Fetter, M., Schirmer, M. and Gross, T. CAESSA: Visual Authoring of Context-Aware Experience Sampling Studies. In Extended Abstracts of the Conference on Human Factors in Computing Systems - CHI 2011 (May 7-12, Vancouver, Canada). ACM, N.Y., 2011. pp. 2341-2346.
20. Fetter, M., Seifert, J. and Gross, T. Predicting Selective Availability for Instant Messaging. In Proceedings of the 13th IFIP TC.13 International Conference on Human-Computer Interaction - INTERACT 2011 (Sept. 5-9, Lisbon, Portugal). Springer-Verlag, Heidelberg, 2011. pp. 503-520.
21. Fischer, J.E., Greenhalgh, C. and Benford, S. Investigating Episodes of Mobile Phone Activity as Indicators of Opportune Moments to Deliver Notifications. In Proceedings of the 13th International Conference on Human-Computer Interaction with Mobile Devices and Services - MobileHCI 2011 (Aug. 30-Sept. 2, Stockholm, Sweden). ACM, N.Y., 2011. pp. 181-190.
22. Fischer, J.E., Yee, N., Bellotti, V., Good, N., Benford, S. and Greenhalgh, C. Effects of Content and Time of Delivery on Receptivity of Mobile Interruptions. In Proceedings of the 12th International Conference on Human-Computer Interaction with Mobile Devices and Services - MobileHCI 2010 (Sept. 7-10, Lisbon, Portugal). ACM, N.Y., 2010. pp. 103-112.
23. Fleck, R., Cox, A.L. and Robinson, R.A.V. Balancing Boundaries: Using Multiple Devices to Manage Work-Life Balance. In Proceedings of the Conference on Human Factors in Computing Systems - CHI 2015 (Apr. 18-23, Seoul, Republic of Korea). ACM, N.Y., 2015. pp. 3985-3988.
24. Grandhi, S.A. and Jones, Q. Knock, knock! Who's There? Putting the User in Control of Managing Interruptions. International Journal of Human-Computer Studies 79 (July 2015). pp. 35-50.
25. Halmos, P.R. Naive Set Theory. D. Van Nostrand Company, Inc., Princeton, NJ, 1960.
26. Ho, J. and Intille, S. Using Context-Aware Computing to Reduce the Perceived Burden of Interruptions from Mobile Devices. In Proceedings of the Conference on Human Factors in Computing Systems - CHI 2005 (Apr. 2-7, Portland, OR). ACM, N.Y., 2005. pp. 909-918.
27. Iqbal, S.T. and Bailey, B.P. Effects of Intelligent Notification Management on Users and Their Tasks. In Proceedings of the Conference on Human Factors in Computing Systems - CHI 2008 (Apr. 5-10, Florence, Italy). ACM, N.Y., 2008. pp. 93-102.
28. Kelly, S. and Tolvanen, J.-P. Domain-Specific Modelling: Enabling Full Code Generation. Wiley, N.Y., 2008.
29. Kerber, F., Hirtz, C., Gehring, S., Loechtefeld, M. and Krueger, A. Managing Smartwatch Notifications through Filtering and Ambient Illumination. In Adjunct Proceedings of the 18th International Conference on Human-Computer Interaction with Mobile Devices and Services - MobileHCI 2016 (Sept. 6-9, Florence, Italy). ACM, N.Y., 2016. pp. 918-923.
30. Kern, N. and Schiele, B. Context-Aware Notification for Wearable Computing. In Proceedings of the Seventh IEEE International Symposium on Wearable Computers - ISWC 2003 (Oct. 21-23, White Plains, NY). IEEE Computer Society Press, Los Alamitos, 2003. pp. 223-230.
31. Kossek, E.E., Ruderman, M.N., Braddy, P.W. and Hannum, K.M. Work-Nonwork Boundary Management Profiles: A Person-Centred Approach. Journal of Vocational Behavior 81 (Aug. 2012). pp. 112-128.

32. Kreiner, G.E. Consequences of Work-Home Segmentation and Integration: A Person-Environment Fit Perspective. Journal of Organisational Behaviour 27, 4 (May 2006). pp. 485-507.
33. Kreiner, G.E., Hollensbe, E.C. and Sheep, M.L. Balancing Borders and Bridges: Negotiating the Work-Home Interface via Boundary Work Tactics. Academy of Management Journal 52, 4 (2009). pp. 704-730.
34. Lim, H., Arawjo, I., Xie, Y., Khojasteh, N. and Fussell, S. Distraction or Life Saver?: The Role of Technology in Undergraduate Students' Boundary Management Strategies. Proceedings of the ACM on Human-Computer Interaction 1, 68 (Nov. 2017). pp. 68:1-68:18.
35. Mark, G., Czerwinski, M. and Iqbal, S.T. Effects of Individual Differences in Blocking Workplace Distractions. In Proceedings of the Conference on Human Factors in Computing Systems - CHI 2018 (Apr. 21-26, Montreal, Canada). ACM, N.Y., 2018. pp. 92:1-12.
36. Mark, G., Gudith, D. and Klocke, U. The Cost of Interrupted Work: More Speed and Stress. In Proceedings of the Conference on Human Factors in Computing Systems - CHI 2008 (Apr. 5-10, Florence, Italy). ACM, N.Y., 2008. pp. 107-116.
37. McFarlane, D.C. and Latorella, K.A. The Scope and Importance of Human Interruption in Human-Computer Interaction Design. Human-Computer Interaction 17, 1 (2002). pp. 1-61.
38. Mehrotra, A., Hendley, R. and Musolesi, M. PrefMiner: Mining User's Preferences for Intelligent Mobile Notification Management. In Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing - UbiComp 2016 (Sept. 12–16, Heidelberg, Germany). ACM, N.Y., 2016. pp. 1223-1234.
39. Mehrotra, A. and Musolesi, M. Designing Content-Driven Intelligent Notification Mechanisms for Mobile Applications. In Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing - UbiComp 2015 (Sept. 7-11 Osaka, Japan). ACM, N.Y., 2015. pp. 813-824.
40. Mehrotra, A., Pejovic, V., Vermeulen, J., Hendley, R. and Musolesi, M. My Phone and Me: Understanding People's Receptivity to Mobile Notifications. In Proceedings of the Conference on Human Factors in Computing Systems - CHI 2016 (May 7-12, San Jose, CA). ACM, N.Y., 2016. pp. 1021-1032.
41. Niehaves, B., Koeffer, S. and Ortbach, K. The Effect of Private IT Use on Work Performance - Towards an IT Consumerisation Theory. In Proceedings of the 11th International Conference on Wirtschaftsinformatik - WI 2013 (Feb. 27-Mar. 1, Leipzig, Germany). Merkur Druck- & Kopierzentrum, Leipzig, 2013. pp. 39-53.
42. Nippert-Eng, C. Calendars and Keys: The Classification of "Home" and "Work". Sociological Forum 11, 3 (Sept. 1996). pp. 563-582.
43. Nippert-Eng, C. Home and Work: Negotiating Boundaries through Everyday Life. University of Chicago Press, Chicago, 1996.
44. Obuchi, M., Sasaki, W., Okoshi, T., Nakazawa, J. and Tokuda, H. Investigating Interruptibility at Activity Breakpoints using Smartphone Activity Recognition API. In Adjunct Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing - UbiComp 2016 (Sept. 12-16, Heidelberg, Germany). ACM, N.Y., 2016. pp. 1602-1607.
45. Oemig, C. and Gross, T. Impacts of Disruption on Secondary Task Knowledge: Recovery Modes and Social Nuances. In Mensch & Computer - 19. Fachuebergreifende Konferenz fuer interaktive und kooperative Medien - M&C 2019 (Sept. 8-11, Hamburg, Germany). ACM, N.Y., 2019. pp. 815-818.
46. Okoshi, T., Nakazawa, J. and Tokuda, H. Attelia: Sensing User's Attention Status on Smart Phones. In Adjunct Proceedings of the International Jiont Conference on Pervasive and

Ubiquitous Computing – UbiComp 2014 (Sept. 13-17, Seattle, WA). ACM, N.Y., 2014. pp. 139-142.

47. Okoshi, T., Ramos, J., Nozaki, H., Nakazawa, J., Dey, A.K. and Tokuda, H. Reducing Users' Perceived Mental Effort due to Interruptive Notifications in Multi-Device Mobile Environments. In Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing - UbiComp 2015 (Sept. 7-11 Osaka, Japan). ACM, N.Y., 2015. pp. 475-486.
48. Park, Y. and Jex, S.M. Work-Home Boundary Management Using Communication and Information Technology. International Journal of Stress Management 18, 2 (May 2011). pp. 133-152.
49. Payne, S.J. and Green, T.R.G. Task-Action Grammars: A Model of the Mental Representation of Task Languages. Human-Computer Interaction 2, 2 (June 1986). pp. 93-133.
50. Pejovic, V. and Musolesi, M. InterruptMe: Designing Intelligent Prompting Mechanisms for Pervasive Applications. In Proceedings of the International Joint Conference on Pervasive and Ubiquitous Computing – UbiComp 2014 (Sept. 13-17, Seattle, WA). ACM, N.Y., 2014. pp. 897-908.
51. Pielot, M., Cardoso, B., Katevas, K., Serra, J., Matic, A. and Oliver, N. Beyond Interruptibility: Predicting Opportune Moments to Engage Mobile Phone Users. Proceedings of the ACM on Interactive, Mobile, Wearable, and Ubiquitous Technolologies - UbiComp 2017 1, 3 (Sept. 2017). pp. 91:1-91:25.
52. Pielot, M., Church, K. and Oliveira Patres, R. An In-Situ Study of Mobile Phone Notifications. In Proceedings of the 16th International Conference on Human-Computer Interaction with Mobile Devices and Services - MobileHCI 2014 (Sept. 23-26, Toronto, Canada). ACM, N.Y., 2014. pp. 233-242.
53. Pielot, M., Dingler, T., San Pedro, J. and Oliver, N. When Attention is not Scarce - Detecting Boredom from Mobile Phone Usage. In Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing - UbiComp 2015 (Sept. 7–11 Osaka, Japan). ACM, N.Y., 2015. pp. 825-836.
54. Pielot, M. and Rello, L. Productive, Anxious, Lonely - 24 Hours Without Push Notifications. In Proceedings of the 19th International Conference on Human-Computer Interaction with Mobile Devices and Services - MobileHCI 2017 (Sept. 4-7, Vienna, Austria). ACM, N.Y., 2017. pp. 11:1-11:11.
55. Powell, G.N. and Greenhaus, J.H. Sex, Gender, and the Work-to-Family Interface: Exploring Negative and Positive Interdependencies. Academy of Management Journal 53, 3 (June 2010). pp. 513-534.
56. Ratchford, M.M. BYOD: A Security Policy Evaluation Model. In Proceedings of the 14th Conference on Information Technology - Next Generations - ITNG 2017 (Apr. 10-12, Las Vegas). Springer-Verlag, Heidelberg, 2017. pp. 215-220.
57. Romer, H. Best Practices for BYOD Security. Computer Fraud & Security 2014, 1 (Jan. 2014). pp. 13-15.
58. Schulze, F. and Groh, G. Conversational Context Helps Improve Mobile Notification Management. In Proceedings of the 18th International Conference on Human-Computer Interaction with Mobile Devices and Services - MobileHCI 2016 (Sept. 6-9, Florence, Italy). ACM, N.Y., 2016. pp. 518-528.
59. Schuss, M. and Gross, T. Availability and Boundary Management: An Exploratory Study. In Extended Abstracts of the Conference on Human Factors in Computing Systems - CHI 2019 (May 4-9, Glasgow, Scotland, UK). ACM, N.Y., 2019. pp. LBW 1215:1-4.
60. Shirazi, A.S., Henze, N., Dingler, T., Pielot, M., Weber, D. and Schmidt, A. Large-Scale Assessment of Mobile Notifications. In Proceedings of the Conference on Human Factors

in Computing Systems - CHI 2014 (Apr. 26-May 1, Toronto, Canada). ACM, N.Y., 2014. pp. 3055-3064.
61. Siewiorek, D., Smailagic, A., Furukawa, J., Krause, A., Moraveji, N., Reiger, K., Shaffer, J. and Wong, F.L. SenSay: A Context-Aware Mobile Phone. In Proceedings of the Seventh IEEE International Symposium on Wearable Computers - ISWC 2003 (Oct. 21-23, White Plains, NY). IEEE Computer Society Press, Los Alamitos, 2003. pp. 248-249.
62. Speier, C., Valacich, J.S. and Vessey, I. The Influence of Task Interruption on Individual Decision Making: An Information Overload Perspective. Decision Sciences 30, 2 (Spring 1999). pp. 337-360.
63. Van Mierlo, S., van Tendeloo, Y., Meyers, B. and Vangheluwe, H. Domain-Specific Modelling for Human-Computer Interaction. In Weyers, B., Bowen, J., Dix, A. and Palanque, P., eds. The Handbook of Formal Methods in Human-Computer Interaction. Springer-Verlag, Heidelberg, 2017. pp. 435-462.
64. Woodcock, J. and Davies, J. Using Z: Specification Refinement, and Proof. Prentice Hall, Englewood Cliffs, NJ, 1996.
65. Yuan, F., Gao, X. and Lindqvist, J. How Busy Are You? Predicting the Interruptibility Intensity of Mobile Users. In Proceedings of the Conference on Human Factors in Computing Systems - CHI 2017 (May 6-11, Denver, CO). ACM, N.Y., 2017. pp. 5346-5360.