DataHalo

A Customizable Notification Visualization System for Personalized and Longitudinal Interactions

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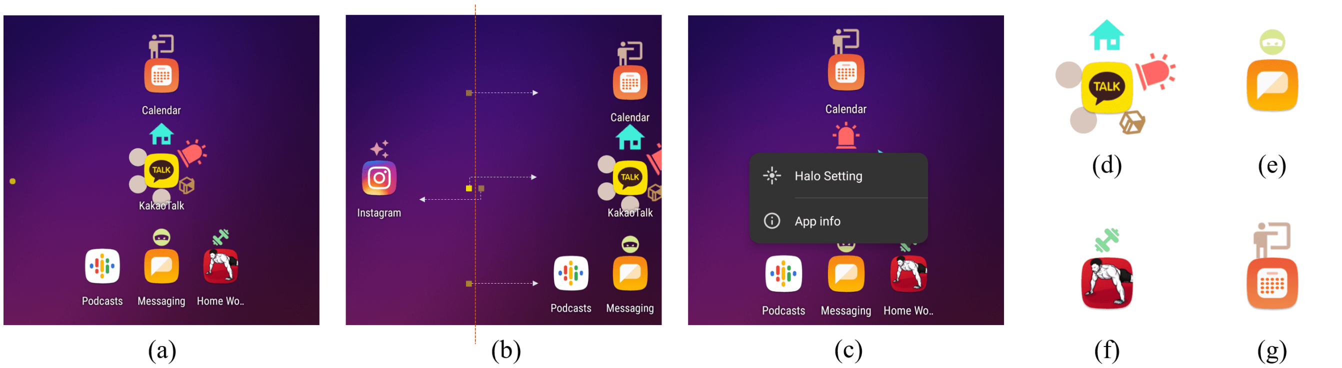

Figure 1: Visual interface of DataHalo: (a) DataHalo integrated with the smartphone home screen. Each app has its own *halo* visualization that extends a conventional app notification badge; (a-b) explanation of the side-lighting visualization. A dot on the left side in (a) provides users with a visual guidance for the unsighted notifications on the left home screen pages. Navigating to the left page, users can discover another *halo* activated; (c) entrance to the *halo* design interface triggered by a long touch; and (d-g) example *halos* with their source apps. Each graphical mark corresponds to a notification. For each designated app, users can customize data, mapping, and encoding rules for distinct marks.

ABSTRACT

People struggle with the overflow of smartphone notifications but often face two challenges: (1) prioritizing the informative notifications as they wish and (2) retaining the delivered information as long as they want to utilize it. In this paper, we present DataHalo, a customizable notification visualization system that represents notifications as prolonged ambient visualizations on the home screen. DataHalo supports keyword-based filtering and categorization, and draws graphical marks based on time-varying importance model to enable longitudinal interaction with the notifications. We evaluated DataHalo through a usability study (N = 17), from which we improved the interface. We then conducted a three-week deployment study (N = 12) to assess how people use DataHalo in their domestic contexts. Our study revealed that people generated various visualization settings for different kinds of apps. Drawing on both quantitative and qualitative findings, we discussed implications for supporting effective notification management through customizable ambient visualizations.

CCS CONCEPTS

• **Human-centered computing** → **User studies**; **Smartphones**; **Visualization systems and tools**.

KEYWORDS

smartphone notifications, ambient information visualization, personalization

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1 INTRODUCTION

People receive tremendous and diverse app notifications on their smartphones [9, 35]. However, modern smartphone operating systems have two main limitations in managing these notifications: First, people cannot prioritize the notifications from the same app according to *how informative they are*. For instance, it is challenging to filter out annoying notifications (e.g., advertisements) while maintaining only the informative ones sent from a messenger app. Second, it is limited to utilize the information delivered by notifications according to *when it becomes the most valuable for them* or *how long its informative value retains*. The content on the notification does not change throughout the lifespan (from post to removal), even though its importance may change over time. For example, a reminder notification of a meeting registered in a calendar app becomes more important until the schedule starts. However, the notification irreversibly disappears after a single tapping, forcing users to find workarounds if they need to access its information for a duration (e.g., leaving the notification untouched in the notification drawer).

Prior work on notification management [1, 29, 33, 34, 45] has focused on deterring unnecessary ones or delaying them until the user's opportune moment. Although their approach has successfully alleviated user distraction, it eventually limited the timeliness of notification as a side-effect. Moreover, few highlighted the necessity of providing a better conveyance method that makes the information more beneficial to the user's context. We point out (1) determining which notification is necessary should be more personalized, (2) delivering how the informative value changes can complement the loss of timeliness due to the delayed notification attendance, and (3) providing the enhanced information should be compatible with the acceptable level of user distraction.

To address these limitations, we designed and developed DataHalo (Figure 1), an Android home screen launcher embedded with fine-grained personalization capabilities of modeling and representing smartphone notifications. Regarding information modeling, people can define categorization rules for notifications from an app and how the importance of each category changes over time. For example, they can separate the daily messages from a messenger into multiple categories (e.g., the business contact and the message from one's beloved) and simply assign unique importance patterns (e.g., which reaches the highest peak before the user attendance but decays fast afterwards or whose importance sustains for several hours after the attendance). In terms of representation, people can create *ambient visualization* [38], called *halo*, which extends the current notification badges on the home screen. It incorporates animated graphical marks around an app icon to help people effectively glimpse the comprehensive notification status for the app (e.g., a heart pictograph for the message from one's beloved, a siren pictograph for the business contact). They can further specify *halo* to be more expressive by customizing the visual channels of the mark (i.e., size, position, color and animation) based on their acceptable level of distraction. As a result, people can conserve the timeliness of notifications without delaying or deterring them and grasp the notifications more coherently and persistently while making user-distraction controllable.

We evaluated DataHalo through a usability study (N = 17) followed by a deployment study (N = 12). From the usability study, we learned that participants could create personalized halos by understanding the core concepts of the dynamic importance and visualization construction. In addition, they positively responded to DataHalo's flexible configuration features. After addressing usability issues based on the feedback from the usability study, we conducted a three-week deployment study where participants installed and used DataHalo on their smartphones in the wild. The results suggested that DataHalo helped actualize the participants' diverse needs for better modeling, expressing, and consuming notification information. They agreed on the improved satisfaction of daily notification management and expected the DataHalo features to be accessible in their smartphone environment soon. Moreover, we analyzed patterns in the participants' DataHalo usage from three perspectives: (1) customization over time, (2) their design strategies to embody the personalized ambience, and (3) notification logs affected by halos. We discussed the importance of supporting smartphone users to reach their sweet spot of the user–notification interaction. We also suggested possible ways to improve the customization support for the future notification system. Our core contributions are: (1) we designed and implemented DataHalo, the first ambient notification visualization system that enables smartphone users to model, express, and consume the durational information with affordable user-distraction; (2) we evaluated DataHalo through usability and field deployment studies to understand how end-users achieve the satisfying user–notification interaction using DataHalo in the lab and in natural environment.

2 RELATED WORK

In this section, we cover the related work in the areas of (1) notification delivery mechanisms to minimize distraction, (2) supporting longitudinal interactions with notifications, and (3) visualizing personal data on ambient displays.

2.1 Notification Delivery Mechanisms to Minimize Distraction

The HCI community put intensive effort to collect and understand smartphone notifications (*c.f.*, NotificationLog [46]). A rich body of research has pointed out the negative aspects of notifications, particularly interrupting people's daily activities and causing stress [16, 23, 31, 35, 36, 42]. For example, Kushlev and colleagues found that interruptions caused by smartphone notifications could trigger higher levels of inattention and hyperactivity of people, which harms their mental well-being [18]. The HCI and UbiComp communities have explored ways to alleviate interruption and distraction primarily by delivering (1) only relevant notifications (2) at opportune moments. For example, there exist a line of research to understand people's mental modal on the relevance of notifications [1, 24, 41, 47]. Shirazi and colleagues found that smartphone users assess the importance of notifications by the category of the source app, the topic of the content, and the sender that triggered a notification (e.g., system, self, and family members) [41]. As a result of their in-situ study, Weber and colleagues [47] pointed out that the substantial portion of daily notifications was not important (38.91%) and not urgent (51.75%) for smartphone users. Users' assessment of notification was discrepant with the system-side priority, carved by app providers. Lin and colleagues also utilized people's rating of notification in four dimensions—importance, urgency, sender attractiveness, and content attractiveness—to analyze the seven types of notification attendance they suggested [24]. The highly-rated notifications tended to be handled faster than others regardless of the system-provided display order of notifications. These works call for a fine-grained and personalized approach for determining the relevance of individual notifications, even from a single app. However, major smartphone operating systems rarely support filtering out unnecessary notifications based on their content because users can suppress notifications as a whole, by an app, or by a channel that an app developer predefined.

Another line of research explored ways to deliver notifications at opportune moments to be interrupted. "Do Not Disturb" is the one primitive and straightforward method to specify when is *not* the opportune moment. Some systems incorporated automated prediction mechanisms for opportune moments. For example, Social Context-Aware smartphone Notification System (SCAN) delays notifications depending on the person's social context (e.g., presence of others) [33]. Mehrotra and colleagues proposed a data-driven mechanism for classifying notifications and delivering them at opportune moments based on the content of the notification and other contextual information such as location and surrounding sound [29]. The authors further extended the mechanism into a semi-automated notification control system called PrefMiner [28], which presents the data-driven rules in a human-readable form and allows people to manipulate them. Pielot and colleagues explored a machine learning approach to predict the opportune moment for engaging with a notification with a hundreds of features covering the data about the users and their contexts [34]. Cadvar and colleagues analyzed and modeled the association between the mobile app usage and the users' work load in a office setting [5] to study their responsiveness to a break-reminder notification. However, one common limitation of these systems is that the content on the deferred notifications is likely outdated because it is not updated since the notification was originally generated.

2.2 Supporting Longitudinal Interactions with Notifications

Smartphone notifications are often designed to be instant and ephemeral: Once a person taps on a notification to run the source app, it is discarded from the notification drawer/list. On the other hand, research has shown that people often interact with notifications in an opposed way. For example, Pielot and colleagues analyzed people's attendance to notifications by capturing the transition over the interaction stages (shown, seen, checked, consumed, and removed) over time [37]. They reported that not all seen or checked notifications are immediately consumed (i.e., tapping) or removed, and participants showed different patterns depending on the source app. Some people deliberately keep specific notifications on a drawer to leverage them (or badges on an app icon) as visual reminders [24]. However, people often lose notifications by unintentionally tapping on the list or the 'dismiss all' button. In this vein, we see numerous mobile apps that enable people to review past notifications, such as "Notification History" [32], which was downloaded over five million times from Google Play Store. Weber and colleagues found that managing the history of dismissed notifications could relieve the user's anxiety of losing important notifications due to careless actions [45].

People also *snooze* a notification when they want to be notified again later. However, the snoozing feature of both Android and iOS allows people to set only a fixed time interval; people often repetitively snooze a notification for a short term until they are ready to consume it. Weber and colleagues explored how people snooze notifications when provided with extended operations (e.g., snooze for time duration or snooze until specific time points) [45] and reported that it was necessary to provide personalized options that fit individuals' contexts and behaviors.

Previous works revealed the smartphone users' desire beyond the one-off interaction and the desire could be diverse based on individual users' smartphone environments (e.g., installed apps and their usages). However, to the best of our knowledge, few studies further explored what the specific scenarios are and how these scenarios could differ among people. Hence, we aimed to inquire about the day-to-day scenarios from people and understand what kinds of support they need. We also contemplated a novel method with which individuals can personalize the duration they reach informative notifications.

2.3 Visualizing Personal Data on Ambient Displays

Following the notion of calm computing, which utilizes the periphery of user-attention to convey information [48], researchers have incorporated *ambient* displays to visualize personal data in a longitudinal and less disruptive manner [26, 27, 38]. Such ambient visualization systems maintain information on a glanceable spot such as screen corners on the desktop (e.g., screen time [17]), phone screen background (e.g., sleep-related activities [3], physical activity [6–8]), smart wearable (e.g., physical activity [13]), physical environment (e.g., auditory activity data [43]), or dedicated devices other than ones for main tasks (e.g., a clock-like object visualizing time schedules [20, 21], a LCD display in the bedroom [19], a mobile system visualizing the communication via multiple smartphones [22]).

Unlike traditional information visualizations such as charts, ambient visualizations tend to involve abstract and artistic expressions to deliver the subtle change of data in an aesthetically pleasing manner [26, 38]. For example, Kandinsky system [11] was inspired by the abstract art of Kandinsky to visualize the text data like email. Skog and colleagues' work [44] was inspired by the abstract art of Mondrian to visualize the bus arrival information. Ubifit Garden visualized various aspects of physical activity using flowers and insects in a virtual garden on the phone screen [6–8]. Similarly, Info-Lotus visualized email notifications as decorative flowers on a peripheral region of the desktop screen [50].

This work expands the line of research in the ambient visualization of personal data in two dimensions. First, DataHalo is the first ambient visualization system for smartphone notifications. We leverage the smartphone's home screen, particularly the surrounding region of each app icon, for visualizing notifications encoded to the animated symbols (i.e., graphical marks). By doing so, we aimed to facilitate people to quickly get the comprehensive status of the notifications of the apps of interest without manually browsing the notification drawers. Second, DataHalo enables people to customize the visual encoding between the graphical marks and various aspects of notifications. Through a series of usability and deployment studies, we aimed to empirically understand people's design perspectives, which has been pointed out by Huang et al. [14] as an important design challenge of personal data visualization.

3 DATAHALO

To enable fine-grained control over incoming notifications, we designed and developed DataHalo, a notification visualization system that represents notifications as ambient visualizations based on user-defined rules. In this section, we describe our design rationale and the DataHalo app along with the implementation details.

3.1 Design Rationales

DR1: Support personalized categorization of notifications. Prior literature suggests that people have individualized assessment on the relevance of notifications [1, 24, 41], which is not well supported by existing smartphone operating systems. As such, we aimed to allow people to categorize notifications based on the intrinsic information. In addition, considering the diversity of mobile apps [9], the categorization method should be applicable to any apps. As a result, we enabled people to define categorization rules by an app, based on keywords in the textual information of the notification (e.g., sender and content).

DR2: Support longitudinal interactions with notifications. Although the existing notification drawers (usually) dismiss a notification upon attendance, prior literature suggests that attendance proceeds longitudinally and people often want to retain notifications even after attendance [24, 37, 45]. As such, we allowed people to customize how long the notifications should be accessible and how the relevance of the information should change by elapsed time and user interaction, which we call the 'importance model' as a whole. Because the Android system did not allow much flexibility on the design of notification drawers for developers, we incorporated dedicated 'Notification History' views inside a companion app where people can access past notifications regardless of the status of the notification drawer.

To effectively display notifications according to the importance model, we incorporated ambient visualization on the home screen by representing each notification as graphical marks (See Figure 1). With marks, we can visualize the varying importance of a notification through visual properties such as color and size. We chose the home screen as an ambient display for two main reasons: (1) We can display the graphical marks for notifications in close proximity to icon of the source app; and (2) app icons tend to be arranged according to the frequency of the attendance so the notification visualizations for frequently used apps are likely to be exposed more pre-attentively.

DR3: Facilitate lay individuals to customize the visual encoding. Our target audience is the general public who uses smartphones and might not be familiar with information visualization. Therefore, we followed the bottom-up, or constructive design paradigm [15], in which (1) an individual data item is assigned to a unit graphical mark without aggregation, (2) the user-defined visual grammar specifies the presentation of marks, and (3) the marks are assembled based on user-defined rules to construct the final visual representation. This bottom-up approach is known to be more accessible to lay individuals [30]. We mapped each notification element with a mark, assuming that the number of marks around each source app would not be many considering the average number of daily notifications [41]. In addition, we enabled people to choose the marks that can best depict the paired notification category. For example, one can assign a heart icon for notifications regarding messages from their significant other. By allowing personalized visual encoding, we expected people to easily catch the comprehensive trend of the current notifications at a glimpse.

3.2 System Components

We built DataHalo upon Rootless Pixel Launcher [49], an open-source launcher on Android that allows us to customize the home screen. The DataHalo system consists of two main components: (1) A halo configuration page that can be accessed via a context menu (See Figure 1c) of the installed app icons either on the home screen or the app drawer and (2) halo visualizations on the home screen. In its back-end, DataHalo includes (1) a new data structure of enhanced notifications and its periodic update logic, (2) an enhanced notification manager based on Android *NotificationListenerService*, and (3) a manager of users' *halo* design specifications.

3.2.1 *Halo Configuration.*

Figure 2 describes the pipeline for halo configuration of an app (in this case, Kakaotalk, a messenger app that is widely used in South Korea). Here, people can configure halo visualizations for the app by defining categorization rules, importance model, and visual encoding. The **Notifications** tab (Figure 2a, top) lists the notifications that are currently being manged by DataHalo, regardless of their status on the notification drawer, in the order of their current importance. On the **Filters** tab (Figure 2b, top), people can define a global filter for notifications that they want to see as halos (DR1). For example, people may filter out notifications for advertisement messages, which are likely to include an "[AD]" prefix in their text, by adding "AD" to the 'Block-List' (See Figure 2b); the notifications filtered out do not affect the visualization pipeline. On the **Notification Categories** tab (Figure 2c, top), people can define *virtual* categories with keyword-based rules applied to the textual information of notifications (e.g., sender, title, and content; DR1). According to these categorization rules, DataHalo automatically categorizes the incoming notifications of the app. The notifications unhandled by the categories people created belong to a special virtual category, "Remainder". For each virtual category, people can assign independent importance model and visual encoding. On the **Importance Models** tab (Figure 2d, top), people can define how the importance of the notification should change over time, before and after people attend it (i.e., tap on the notification; DR2). First, people can set the **initial importance** between 0.0 and 1.0 and the **target importance** to pursue until attendance. They can set the duration for the pursuit before attendance to the notification ("Before attendance" in Figure 2d, top) and if the notification is not attended after the importance reaches the target, the importance value remains the same. Second, people can set the **saturation importance** and the duration for the pursuit after attendance to the notification ("After attendance" in Figure 2d, top). Once people attend the notification, its importance moves to the saturation value for the duration. Since the initial delivery, a notification persists in the (DataHalo) system for the **lifespan** duration people set. By default, the importance model behaves identical to the ordinary notification; the importance value does not change

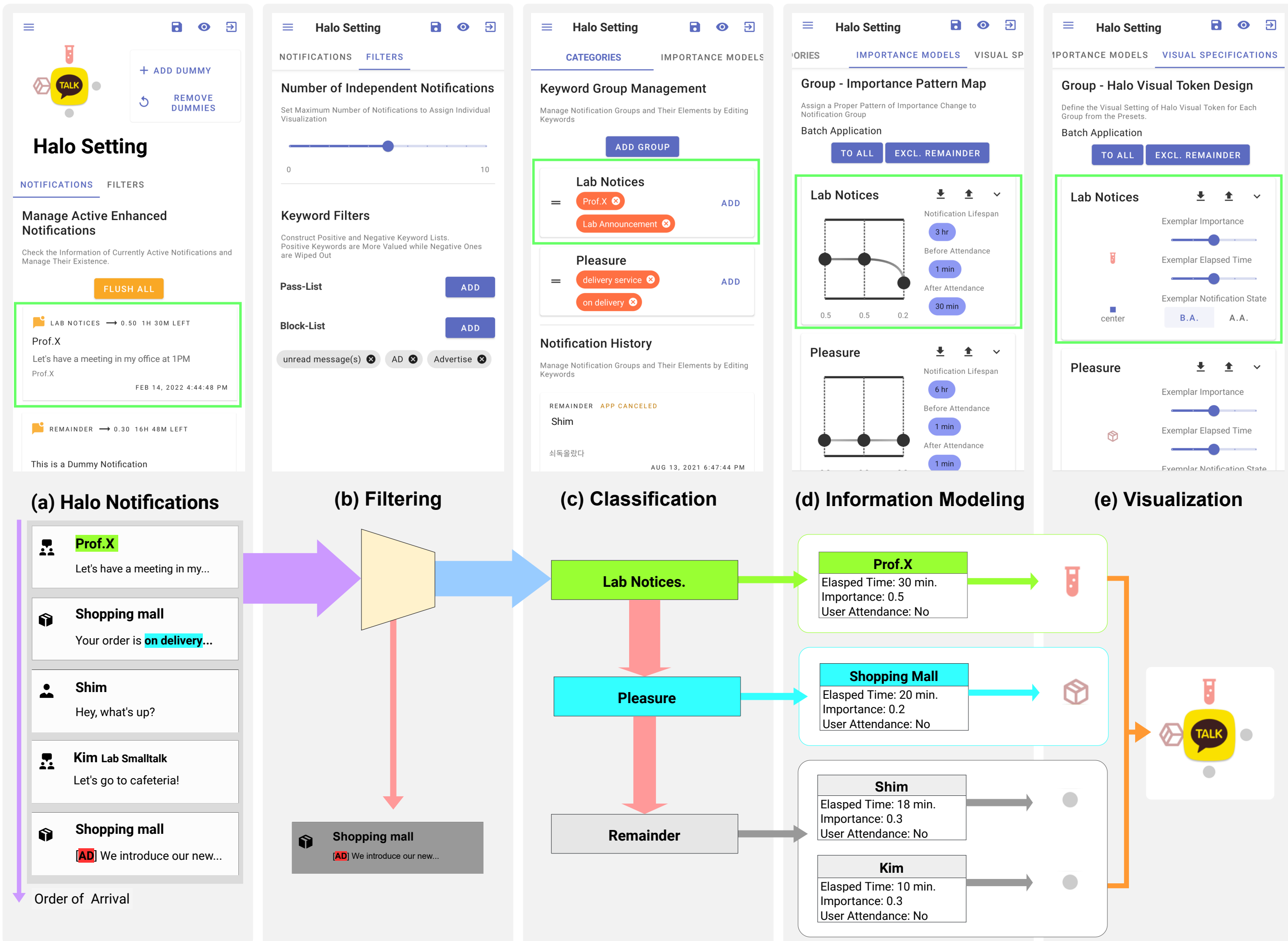


Figure 2: The main tabs of the halo configuration page (top) and the underlying pipeline of the visualization construction (bottom).

until the attendance (**initial** importance = **target** importance = 0.3); it disappears just after the attendance (**target** importance = 0.0). For novice users, we included a set of preset importance models, based on the implications from the usability study (Section 4.5).

3.2.2 Halo Visualization. Each notification that passed the global filter (See Figure 2b) is represented as a graphical mark around the source app icon on the home screen (DR2, DR3). People can configure how marks will look for each virtual category and encode importance/time variables or constants to visual properties of the mark. The system sorts the notifications by importance and draw them in clockwise order, starting from the top. If people do not customize the visual encoding of the virtual category, its default graphical mark is a static gray circle (See the mark of the Remainder category in Figure 2d and e).

On the **Visual Specifications** tab (Figure 2e, top), people can configure the visual encoding of each virtual category (DR3). DataHalo supports modification of five visual properties: (1) shape, (2) color, (3) animation, (4) size, and (5) distance from the center. As a shape of the graphical mark, people can choose one from a set of icons, upload a custom image, or use a text for the name of the category. For animation, people can combine four types of looped animations (blink, scale, rotate, jitter) to make the mark more attractive. Beside setting a constant value for the properties, people can encode importance, a ratio of elapsed time since delivery to lifespan, and a binary status of attendance to any of color, animation, and size. For example, one can configure a graphical mark for depicting a visual metaphor of sunrise; its color changes from red to yellow over time; its distance from the center becomes greater as importance increases. For novice users, we included a set of preset graphical marks with the visual encoding configured, based on the implications from the usability study (Section 4.5).

The discoverability of the halo visualization could be sub-optimal as users cannot easily glance at the visualization if it is not located on the first page of the home screen. To overcome this problem, we introduced a side-lighting visualization (Figure 1a-b). Each graphical mark provides a navigational cue that one or more activated halos exist if the user moves along the designated direction. Its brightness is proportional to the sum of the existing informative values of the activated halos along the direction.

3.3 Interacting with DataHalo

Here we describe DataHalo's interactions with a usage scenario of Han, a graduate student who wants to better manage text messages, from a messenger app called KakaoTalk, regarding important notices from his laboratory and his advisor. Han receives about a hundred of notifications per day from KakaoTalk, about incoming messages from friends and group chat rooms. Not to be distracted, Han has sustained the smartphone notification feedback silent for most of the day and checked the smartphone for about every 2-3 hours. Skimming a pile of notifications, Han often dismissed them in bulk by tapping "dismiss all" in the notification drawer. Meanwhile, Han occasionally dismissed and forgot important or urgent messages about his research and school. Hence, Han runs DataHalo to manage the KakaoTalk notifications by emphasizing ones related to his school. In particular, he wants to easily distinguish the lab notices from other KakaoTalk messages, and maintain them for several hours as a visual reminder even if he dismisses the notifications on the drawer by mistake.

Defining Global Filter and Virtual Category. Han long-presses the KakaoTalk icon on the home screen and opens the Halo Configuration page via a context menu. He first configures a global filter to exclude unnecessary advertisement spams (Figure 2b). To separate notification regarding his school, Han decides to capture the direct messages from his advisor and ones from the group chat room with his colleagues. On the **Notification Categories** tab, he adds a new virtual category named "Lab Notices" and appends two keywords, "Prof.X", his advisor's name, and "Lab Announcement", the name of the group chat room (Figure 2c).

Importance Modeling. Now Han turns to the importance modeling for the Lab Notices category. He wants to retain the halos as low importance, but for a long period even after he attends the notifications. Han opens the **Importance Models** tab and sets the **lifespan** to be *3 hours*, which is longer than the usual period that he checks his phone (Figure 2d). To keep the low importance throughout the lifespan, Han sets both the **initial** and **target** importance to be 0.5, but the **saturation** importance to be 0.2 as he wants to lower the importance after he checks the notification.

Visual Encoding. To configure visual encoding for the category, Han opens the **Visual Specification** tab. He first sets the **shape** of the symbol to be a *test tube* icon, indicating a "laboratory." To make the symbol noticeable, he configures the **color** to gradually changes from *yellow* to *red* over time, and assigns a *blink* **animation** to be played until attendance. Finally, Han encodes the *current importance value* to the **distance from the center of app** so that the symbol would move closer to the app icon as the importance decreases. The resulting appearance of Han's halos for KakaoTalk and its dynamic change based on the visual encoding is described in Figure 3.

4 USABILITY STUDY

To assess the feasibility of the personalization features provided by DataHalo and identify usability issues, we conducted a usability study. The study was approved by the institutional review board.

4.1 Study Procedure

At the beginning of each session, we conducted a semi-structured interview asking about participants' usual patterns and strategies of (1) configuring notification feedback, (2) dealing with notifications stacked in the status bar, and (3) managing app icons on the home screen. The interview took about five to ten minutes.

After a short introduction of DataHalo, we installed the DataHalo launcher on participants' smartphones and had a ten-minute tutorial. In the tutorial, we provided them with a short material describing the interface and example usages of DataHalo. We then proceeded to two *halo design tasks* (task 1 and task 2). For each task, participants designed an alternative notification method of a selected app by reflecting on their daily inconveniences. For task 1, participants chose their most frequently used messenger because messenger apps are the most significant source of notifications smartphone users receive. For task 2, participants freely chose any other app freely. During the task, we encouraged participants to think aloud; they were also free to ask questions or request technical support. We also recommended that they try all the customization capabilities to collect holistic feedback.

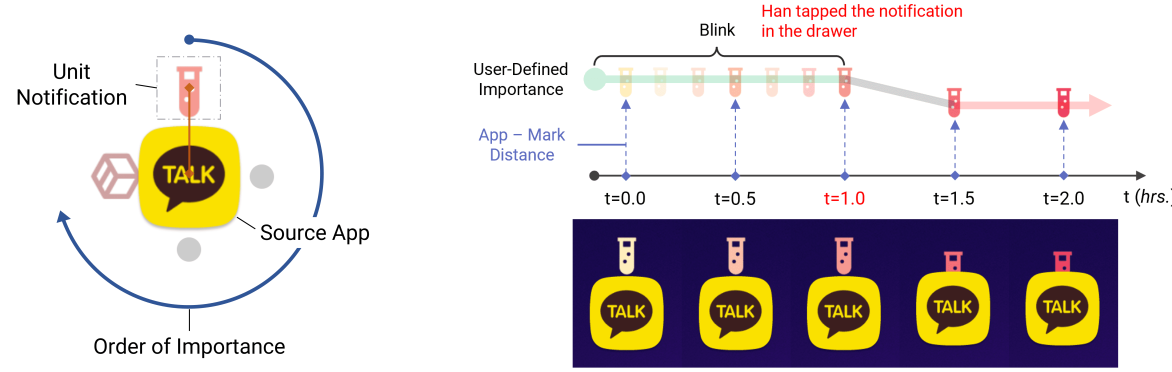
After completing the tasks, we had a ten-minute interview covering (1) participants' strategies to set up satisfying halos and (2) suggestions to improve the usability of DataHalo. The whole process took about an hour. We rewarded participants with 10,000 KRW (equivalent to 8.50 USD). We audio-recorded both the interviews and the design tasks, logged their halo settings during the design task, and collected the System Usability Scale (SUS).

4.2 Participants

From a local university, we recruited 17 participants (U01–17; 4 women and 13 men) who have used smartphones for at least a year and are currently using Android smartphones with version 8.0 Oreo or later. We employed opportunity sampling by recruiting participants through an online forum for university students and faculty members. All participants were undergraduate or graduate students in their 20-30s.

4.3 Analysis

Two researchers transcribed the audio recordings from the interviews and the halo design tasks. We then categorized participants' responses in terms of the following topics: (1) the usefulness of DataHalo, (2) the assessment on the halo representation, and (3) the feedback about the customization capabilities. Based on the topics, we investigated 32 completed halo settings (Task 1: 17, Task 2: 15; we excluded two because of incomplete logging) that illustrated how participants categorized notifications, modeled the importance, mapped data variables to visual channels, and encoded graphical marks of the halo visualization for a selected app; we utilized the results to triangulate the interview findings. We graded the collected SUS data according to the traditional school grade [2].



(a) The halo visualization Han created.

(b) The change of graphical mark by time and Han's attendance.

Figure 3: Han's halo visualization and its change based on visual encoding.

4.4 Result

4.4.1 App Selection & Virtual Category Creation. In the first halo design task of a messenger app, 15 out of 17 participants chose KakaoTalk, and the rest (U03, U09) chose the default text messaging app. They thought of diverse virtual categories that curated communication with people of interest (e.g., family, one's beloved, advisor, personal fitness trainer) and that subscribed to their topic of interest (e.g., lab meeting, payment & shipping information of product, a favorite sports team). In the second task, they chose apps from 10 distinct categories: secondary messenger, email, social media, financing, video streaming, movie ticketing, language learning, food delivery, game, and paid survey. We elaborated on all the virtual categories authored during the second task with the reason for creation in Appendix A.

4.4.2 Visual Design of Graphical Marks. Figure 4 presents examples of the *halos* created by participants. Participants were motivated to combine multiple visual properties to create desired graphical marks. Shape and color were the most popular properties they customized. Pictograph was the most preferred option to encode the shape of a graphical mark; the provided icon set was broad and attractive enough to delineate their intention. U16 worried that images (e.g., portraits of her intimates) or text might easily expose the notification content to somebody in reduced-privacy situations such as shoulder surfing. When choosing the color, participants considered the followings: (1) to highlight the urgency of information, (2) to tell apart distinct virtual categories quickly, and (3) to reflect their color tastes.

4.4.3 Usefulness of DataHalo & Customization Fatigue. Participants' reactions to DataHalo were generally positive. The average SUS of DataHalo was in the range of OK and GOOD. After usage, they all agreed that DataHalo could successfully support their demand for personalized notification management for various apps. In addition, the flexibility of DataHalo also encouraged participants to rethink the value of previously ignored notifications. For example, U09 had deactivated most app notifications except phone calls and text messages since she felt overwhelmed by unnecessary notifications. After completing her design task for the food delivery app, however, she expressed her desire to reactivate more app notifications on DataHalo. On the other hand, they expressed the fatigue of configuration from scratch. Compared to editing virtual categories, they struggled with configuring the importance model and visual encoding, which needed the support of the experimenter.

4.5 Implications and Design Improvements

Despite the promising results from the usability study, we thought it would be crucial to relieve the user's customization fatigue not to demotivate usage of DataHalo in the wild. We improved the customization flow of the importance model (Figure 5a) and visual setting (Figure 5b) of a virtual category by modifying predefined or user-created examples. First, we added a set of predefined examples for importance models and visual encodings to alleviate the burden of initial customization. People could quickly start customization by choosing an exemplar importance model and visual setting from the gallery. After completing the customization, people could choose to register the results to the gallery. Then, they can easily reuse these new presets when customizing other virtual categories across different apps.

5 DEPLOYMENT STUDY

With the improved interface, we conducted a field deployment study to explore the commonalities and differences among people's personalization strategies for better notification management, emerging in the real-world context. The study was approved by the institutional review board.

5.1 Study Design

Pre-study session. We met each participant on Zoom. We first conducted a semi-structured interview inquiring about daily experiences related to notifications. The questions were identical to those of the pre-study interview of our usability study. Participants then had an exercise of designing a halo for the KakaoTalk app where they (1) created a virtual category to manage the study announcements from the experimenter, (2) set an importance model, and (3) specified a visual setting of a graphical mark. Finally, they

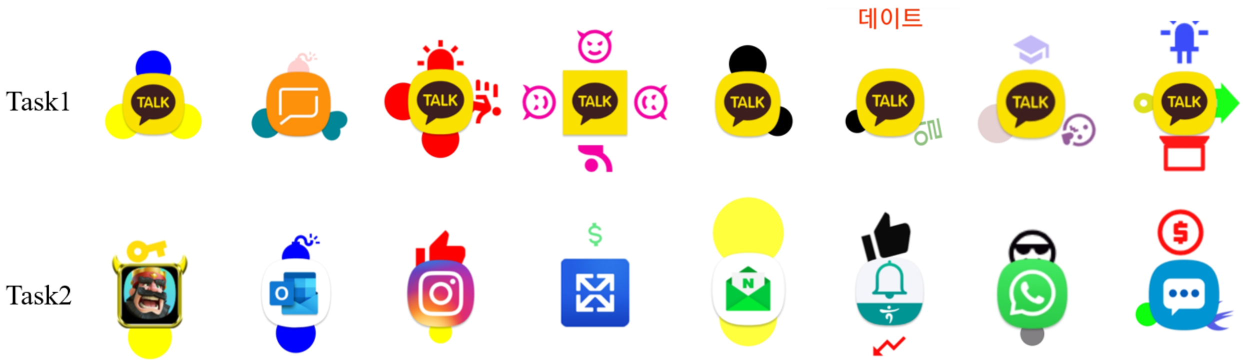
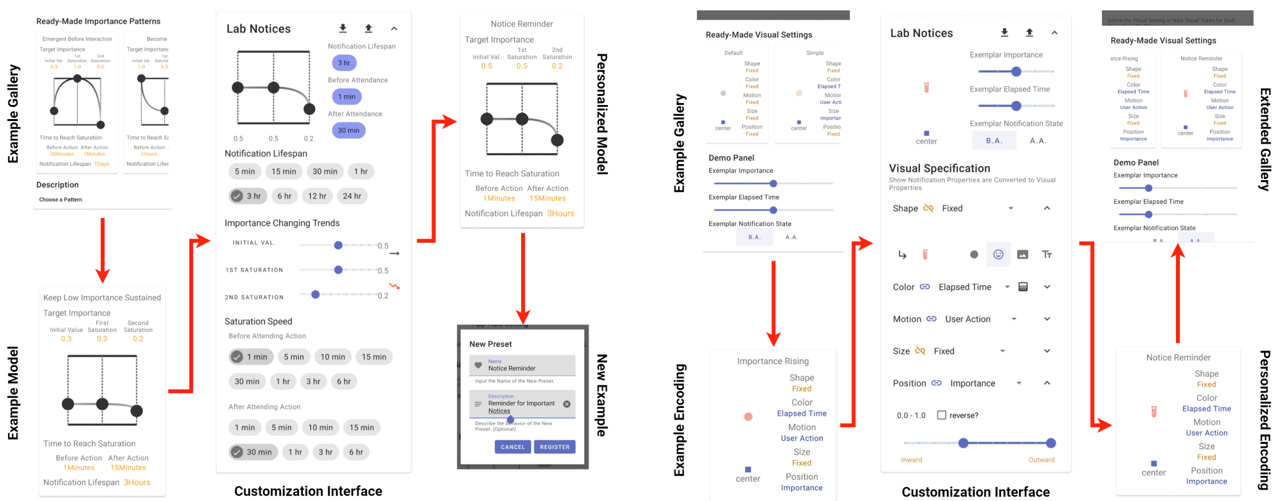


Figure 4: Examples of app halos created by participants during the usability study. In the end of each halo design task, we captured the preview from the halo configuration page.



(a) The flow of importance modeling **(b) The flow of visual encoding**

Figure 5: Customization of the importance model and visual encoding by example.

responded to the set of apps that they currently planned to manage halo during the usage.

Deployment. Participants immediately started using DataHalo. For the following 3 weeks, we communicated with participants via the 1-to-1 chat room of KakaoTalk. Participants were free to ask questions or request technical support. We sent announcements such as app updates and weekly summaries of their DataHalo usage. The content of the weekly summary consisted of (1) an initial usage plan summarized from the participants' pre-study interview responses, (2) a list of apps for which they currently manage halo, (3) the most frequently edited halo, and (4) the accumulated number of app notifications influenced by their halo settings; we sent three in total per participant. If some participants did not utilize DataHalo since they received the last week's summary, we added a sentence, "*Do you satisfy with the current settings of DataHalo? If not, how about creating a new halo or adjusting the existing halos for better notification management?*" to the summary of this week.

Debriefing. After three weeks of usage, participants had an exit session for about an hour. We asked participants about (1) the experience of using DataHalo's capabilities of managing notifications, (2) halo design goals and strategies for the apps they customized. We also collected the System Usability Scale (SUS) and a 7-point Likert scale questionnaire (Appendix B) inquiring the user experience of notification management before and after using DataHalo. Both the feasibility of core capabilities and their influence on improving the experience of notification management were positively assessed. We rewarded them 50,000 KRW (equivalent to 44 USD) for their complete participation. If participants hoped to continue using DataHalo launcher, they could voluntarily use more.

5.2 Participants

We employed opportunity sampling by recruiting participants through the two most active online communities for students and alumni of a local university. We advertised our study with an introductory material. The requirements were primarily identical to those of the formative lab study, except for additional conditions: (1) they should be available for a video conference and (2) we log the usage of DataHalo and the part of the information from their daily notifications (specified in Section 5.3).

Eighteen people initially applied, and four withdrew during the pre-study session; one dropped because of the compatibility issue with the open source launcher, and the rest resigned because three weeks were too long for them to participate. We also screened out two applicants because they did not utilize DataHalo during the deployment despite our additional reminders. Of the final 12 participants (six males and six females; we call them P01-P12 in the following), 11 participants were in their 20s, and one was in her 40s. Seven participants were undergraduate students, 4 were graduate students, and 1 was a full-time employee. They utilized ten different Android smartphones from two manufacturers (9 Samsung models and a single Xiaomi model); the distribution was consistent with the market share of Android smartphones in South Korea, where Samsung occupied 91% [40]. We sent 2-3 messages per week to each of them, including the announcements and the weekly summaries. After completing participation, four participants (P02, P03, P05, P07) hoped to continue using DataHalo. We monitored their extra usage for about three more weeks.

5.3 Technical Specification of Remote Study

Both pre- and post-study sessions were video conferences remotely held through Zoom and recorded for interview analysis. We utilized Android TeamViewer QuickSupport app for screen sharing and remote technical support. During the deployment, we used the open chat feature of KakaoTalk to communicate with participants; it did not require any personal information and was easily accessible for most South Koreans. We offered participants an exclusive invitation to install DataHalo via Firebase App Tester for Android. They could receive notifications about app updates and install the latest version from the tool. We monitored the app distribution from the Firebase console and kept participants up to date with DataHalo; we contacted them if they did not install the necessary update. There were five updates to improve (1) app crashes reported by Firebase Crashlytics, (2) device compatibility issues regarding the screen resolution & aspect ratio, and (3) log transfers during the bad data connection (e.g., flight mode).

To understand (1) how participants utilized DataHalo and (2) how the usage affected their interaction with daily notifications, we logged **halo setting logs** and **notification logs**. The halo setting log, the latest configuration of a halo of an app, consisted of (1) virtual categories and their keyword elements, (2) parameter settings of user-defined importance models, and (3) visual encoding results of user-defined visual settings. A notification log was generated when it ended its informative lifespan based on its importance model. Each notification log included information about (1) the identification of the virtual category (e.g., user-id, app name, virtual category label), (2) Android notification channel (e.g., channel name and system importance), and (3) user interaction (e.g., post time, interaction time, the system flag about the reason of notification removal, and lifespan). We did not log and transmit the sensitive part of notification contents (e.g., title, subtitle, text, and image) outside participants' smartphones. DataHalo sent a stack of halo setting logs and notification logs to Firebase Realtime Database (RTDB) [12] hourly.

5.4 Data Analysis

We analyzed transcriptions of the pre and post-study interviews, halo setting logs, and notification logs. In the following, we elaborated on our analytic approach in detail.

5.4.1 Data Preprocessing. We transcribed the responses of the semi-structured interview. Regarding the interview of the pre-study session, we grouped the transcriptions according to the topics describing their current notification management: (1) filtering, (2) feedback setting, (3) attending, and (4) accessing information in a longitudinal manner. We also categorized the responses about the current home screen management: app shortcuts and their layout.

Regarding the interview of the post-study session, we summarized the transcriptions into a table that listed the participants' considerations during each app halo customization from the following perspectives: (1) their high-level motivation of app choice, (2) notification filtering & categorization, (3) importance modeling, and (4) visual encoding; we named the table as **halo design table** in the following. The table consisted of 91 cases of app halos; it included 205 design scenarios of the graphical mark applied to each virtual category.

Regarding the collected halo setting logs, we reconstructed the temporal events of DataHalo customization; we denoted the data as **halo customization events** in the following. Halo customization events consisted of following properties: (1) *participant_id*, (2) *timestamp*, (3) *target_app*, (4) *app_category* provided by Google Play Store, and (5) the halo configuration at that time.

Regarding the collected notification logs, we first applied the following filters to obtain the notifications of interest with which participants actually interacted.

(1) Filter out the notifications from the Android system (e.g., charging state)
(2) Filter out the notifications not clearable by users (e.g., media control of music/video players accessible in the notification drawer)
(3) Filter out the notifications not removed by users (e.g., a summary notification of unread messages in KakaoTalk; it repeats post and removal by app whenever the number of unread messages changes.)

Among the filtered notifications of interest, we separated ones from the apps for which participants managed custom halos; we named these notifications as **halo notifications** in the following.

5.4.2 App-Level Customization Analysis. First, we aimed to understand the participants' DataHalo usage in app level: choice of apps and customization over time. We labeled the halo customization events based on (1) customization type (i.e., creation or edit) and (2) weeks (i.e., first week, second week, third week, and extra weeks). We then investigated halo creation and edits over time by app category and participant. Finally, we reviewed the adjacent edit events and the halo design table to understand why participants repeatedly edited app halos over time.

5.4.3 Virtual Category-Level Design Analysis. Next, we aimed to understand the design motivations and choices underlying participants' halo designs. Because the virtual category was the unit of notification management in DataHalo, we drilled down into virtual category-level analysis. The analysis proceeded in two steps. First, we derived the high-level **design motivations**. We analyzed 205 graphical mark design scenarios in the halo design table referring to (1) our design considerations, (2) the major findings from the usability study, (3) user–notification interaction patterns summarized from the interview results of the pre-study session, and (4) design dimensions or evaluation criteria of ambient information visualization [25, 27, 38]. Next, we derived participants' **customization choices** regarding these motivations. We reviewed the last halo customization events of 91 app halos, which included the final configuration of 205 virtual categories. For each virtual category, we compared the corresponding motivation described in halo design table with the relevant part of the halo configuration; we validated if the configuration could output the graphical mark that behaves as participants described. If two data were consistent, we labeled the pair of description and configuration. we iteratively refined and grouped similar labels, and named the final set of labels as choices.

5.4.4 Halo Notification Analysis. We also aimed to understand the similarities and differences between the virtual categories made by participants the notification channels carved by app providers. We first investigated the volume of halo notifications by participant and app category. We then compared (1) the category and (2) the importance of notification carved by the system (i.e., notification channel and channel importance of the Android System) to those defined by participants (i.e., virtual category and user-defined importance).

6 RESULT

In this section, we start with a brief summary of the conventional user–notification interaction before using DataHalo. Next, we present the result of analysis on (1) app-level usage, (2) virtual category-level design, and (3) halo notifications. Finally, we report the usability of DataHalo and its contribution to a better user experience of notification management.

6.1 Notification Management and Attendance before Using DataHalo

Most participants (9 out of 12) have struggled to control the volume of app notifications. They decided to disable the advertisements when installing an app or block all the notifications of some apps (e.g., messengers, social apps) later in the usage. To avoid being distracted, most (except P01) preferred less noticeable feedback (i.e., vibration or silence) over the sound as a default feedback method regardless of their spatial or eventual context. It led participants to frequently attend a stacked list of notifications in the drawer when they visited the smartphone home screen. Most (except P08) frequently experienced the need to access some notices for a longer duration when attending notifications. They kept the notification untouched in the drawer or manually duplicated the content using other services (e.g., calendars, image capture). Most participants (except P11) preferred to locate the frequently used app shortcuts on the first page of the home screen, where they could access the apps quickly. Other criteria (e.g., proximity among the apps with similar features, comfortable area for touch, and aesthetics) also influenced their home screen layout. Participants eventually placed some useful apps on the subsequent pages, and they thought the badges of these apps were less effective; they could not glimpse the badges immediately.

6.2 App-level Usage of DataHalo

6.2.1 Overview. In total, participants managed 91 halos of 55 different Android apps from 19 app categories provided by Google Play Store (Figure 6a). On average, participants have created 7.58 app halos ($min = 3, median = 7, max = 15$). After the creation, participants edited their app halos 188 times in total. They edited the app halos 15.67 times on average ($min = 5, median = 14.5, max = 33$) during the usage (Figure 6b). The edit count per app halo was 2.07 times on average ($min = 0, median = 1, max = 18$). 51 out of 91 app halos have been edited by participants at least one additional time after creation; these apps covered 14 out of 19 categories.

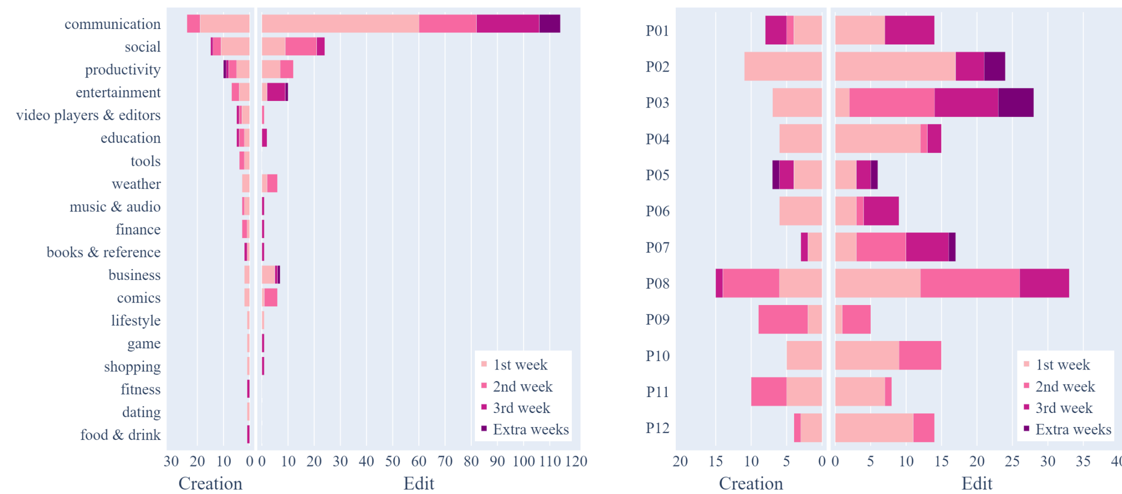
The major categories, where the number of the created app halos was more than five, included the following apps.

(1) **Communication** (24): KakaoTalk (12; instant messaging app), Messages (6), etc.
(2) **Social** (15): Instagram (5; social media), Between (2; relationship app for couple), EveryTime (2; community app for university students), etc.
(3) **Productivity** (10): Calendar (5), Email (3), etc.
(4) **Entertainment** (7): KakaoPage (3; web comic & novel service), Netflix (2; video-on-demand service), etc.

The communication category accounted for 61% (114) of total edits, and KakaoTalk (94) mainly contributed to the result. Participants edited KakaoTalk 7.83 times on average ($min = 2, median = 7, max = 18$).

6.2.2 Halo Creations & Edits over Weeks. Overall, halo creation and edits decreased in a different pattern over time. Most participants completed the creation of halos during the first two weeks. Of the 91 app halos, participants created 67% (61) in the first week, 24% (22) in the second week, and 8% (7) in the third week. The rest, 1% (1), occurred during the extra usage of four participants. The number of halo edits also decreased over time, but the speed was slower than that of creation. Of the 188 edit events, 46% (87) occurred in the first week of usage, 26% (49) in the seconds week, and 22% (42) in the third week; the rest 5% (10) occurred during the extra usage. Figure 6b supports the difference. Five participants (P02, P03, P04, P06, and P10) completed halo creation in the first week but continued editing afterward. P02 and P03 had consistently edited app halos of messenger, email, and webtoon services even during the voluntary extra usage to adjust the change. Their primary reason for the edit was to newly create the virtual category or refine the existing ones because new communication partners or webtoons of interest appeared.

6.2.3 Halo Edits for New Notifications of Interest. Participants became constantly motivated to manage notifications of new interests within an app halo; the motivation originated from themselves (e.g., P03's need to curate messages from her intimates) or their surroundings (e.g., P11's need for a subscription to the confirmed COVID-19



(a) Halo creation and edit events by app category. **(b) Halo creation and edit events by participant.**

Figure 6: Halo creation and edit events collected during the deployment. The color encodes the week the event occurred. We aggregated the events according to app category provided by Google Play Store.

cases that occurred on campus). They either created a new virtual category or expanded the keyword-based rules of the existing ones to reflect the new interests; the choice depended on how definite/flexible they conceptualized the virtual category. Participants managed specific virtual categories because they could control notifications finely, especially using various graphical marks. For example, P03 started with a virtual category for curating messenger notifications sent from a friend. Finding the customization helpful and joyful, she created four new virtual categories by person and assigned distinct images to them. On the other hand, participants could also finish editing faster by adding new keywords to the virtual category of broader concepts.

6.2.4 Halo Edits for Improvements for Current Category. Participants edited halos when they faced a critical but unseen notification that the current category could not successfully classify. They experienced both the user-side and the app provider-side issues while improving the keyword-based rules of their virtual categories.

When initially building a virtual category, participants skimmed the recent app notifications from the notification drawer or the notification history in our halo configuration page. When the relevant app notifications users could reach were too small, the initial keyword-based rules needed improvements to actualize their goal. For the apps triggering notifications frequently (e.g., messenger app), participants could realize the problem and complement the rules. However, P09, who created a virtual category that subscribed to an irregularly updated podcast, needed a long time until she received the new notification.

P03 explained the “advertisement cop” issue caused by app providers while managing the keyword composition of virtual categories. When she tried to subscribe to notifications about the arrival of new short pants for the fashion app, she found that her keywords failed to hit these notifications. Their notification text, colloquial expression written by a copywriter, changed frequently and utilized synonyms or indirect expressions so that the current keywords became quickly outdated.

We could observe a primitive use case where a participant utilized the app-provided notification control method and DataHalo at the same time. P07 utilized the structured notification features provided by his blog app; he could figure out what notifications the app would trigger easier than looking up the list of the received notifications. He disabled the unnecessary notifications from the app-provided menu and moved to halo customization. Because he thought all the notifications the app triggered were informative, he did not create any virtual category and just edited the graphical mark of the Remainder category. P09 also commented on unifying the app-specific methods of Kakaotalk into the DataHalo interface. She came up with the idea while filtering and categorizing diverse notifications, but did not take action; she felt the app-provided features added another complexity.

6.2.5 Null Halo and Removal from Home Screen. Participants disabled halo visualization for 11 apps in total. They either hid all the graphical marks in the halo configuration setting or removed the halo from the home screen. As a result of the former approach, participants got a “null halo”; they chose it when app notifications were useless, but they wanted to use the app on the home screen. For example, P08 set null halos for the app store, web browser, gallery, and banking apps to maintain his home screen neatly. Participants chose the latter when they decided not to use an app on the home screen. For example, P05 had become indifferent to the matching service provided by the dating app, so he blocked all the notifications and finally dropped the app from the home screen. P01 had removed the halo for the webtoon app, although subscriptions she made were still valuable for her; she worried her halo visualization, which highlighted the update for her favorite webtoons, might disturb her concentration during the midterm period.

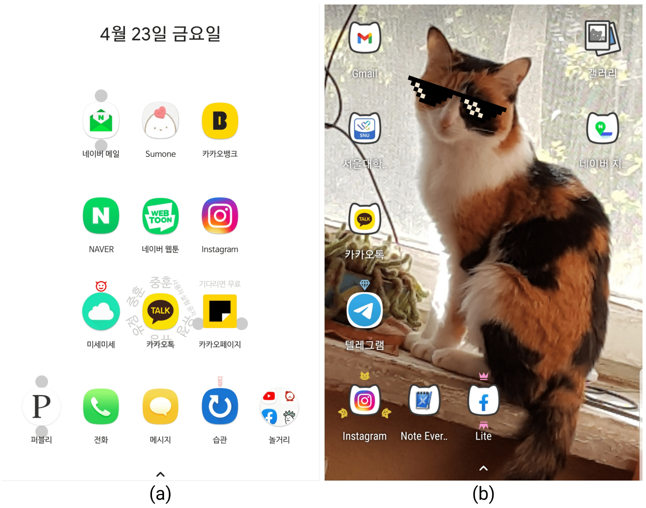


Figure 7: Personal difference in usage of DataHalo. (a) P02 pursued pragmatism while (b) P06 valued aesthetic experience. Upon P06's request of not disclosing the photo of her favorite cat directly, we masked its face with a sunglasses.

6.2.6 *Contrasting Use Cases of DataHalo.*

We present use cases of P02 and P06 that indicate the diversity of DataHalo usage. P02 (Figure 7a) was one of the most passionate users of DataHalo according to the number of halos and the total number of virtual categories she created. She managed 42 virtual categories (31 user-created and 11 Remainder categories) in total for 11 halos. The app halo of KakaoTalk even included ten virtual categories. She tried to control the notifications of her interest as sophisticated as possible. Because P02 attached the highest priority on the discernibility of multiple graphical marks, she frequently presented the name of virtual categories directly (i.e., text) or assigned unique pictographs to different virtual categories. Her home screen wallpaper was also solid white, supporting her design goal of extensive and effective notification management.

On the other hand, P06 (Figure 7b) created a minimal number of categories. She created only three custom categories in total while managing six halos. Besides two communication apps (KakaoTalk and Telegram), P06 was not motivated to classify notifications. Instead, she made a great effort to design a home screen that reflected her aesthetic preference. First, she laid out halos where they did not occlude the image of her favorite cat on the wallpaper. Second, she decorated halos by selecting pictographs irrelevant to the app or notification but visually satisfying (e.g., cat for Instagram and crown for Facebook).

6.3 Participants' Design Motivations and Choices

As a result of the virtual category-level design analysis, we derived participants' five **design motivations** (**M1-5**) and corresponding **design choices** (see Figure 8), consisting of an app-level and four virtual-category-level motivations. We provide an exhaustive list of the virtual category-level scenarios in the supplementary material.

6.3.1 ***M1.*** *Control the Scalability Issue of App Notification Control.*

Participants left 54% of the apps (49 out of 91 apps) **as-is** when they had no desire to filter. For 34% (31) of them, participants mixed various features, including Pass-List, Block-List, and the maximum number of visualized marks, to **selectively control**. Participants tried the selective control for 17 of 24 communication apps and 4 of 15 social apps. Lastly, participants **blocked** notifications of 12% (11) of the apps by setting zero to the number of visualized marks.

6.3.2 ***M2.*** *Classify Notifications based on User-defined Schema.*

Participants prioritized **self-organized events**, which involved scheduled events, to-dos, or daily goals created and registered by themselves. Their **curated communications** focused on senders of interest who communicate with them via messenger, email, and social apps. **Personal subscriptions** covered diverse topics of interest. The notifications participants **did not want to categorize** belonged to the Remainder category. However, some of them naturally covered the notifications of interest (Figure 9a); some apps (e.g., to-do app) triggered only the notifications that the user organized; P07 filtered the blog app notifications using app-provided features so that he could subscribe to notifications of interests from the Remainder category.

6.3.3 ***M3.*** *Respond to Notifications according to Urgency and Persistence.*

Participants wanted to **recognize** the useful but non-critical notifications in the same way they used to; they left the default importance model untouched. They wanted to **react** immediately to urgent notifications by imposing high initial and target importance values but a zero saturation importance to the category. They wanted to **remind** themselves of persistently helpful notifications by setting the long lifespan and keeping the saturation importance non-zero. They **disregarded** unnecessary notifications by setting the initial, target, and saturation importance to zero or the lowest value within the app. Figure 9b indicates that participants chose more diverse responding approaches for the user-created virtual category, while they thought that the recognition was enough for the notifications of the Remainder category.

6.3.4 ***M4.*** *Control the Complexity of Visual Information Conveyed through Marks.*

Participants expected the graphical mark to behave similarly to the dot-shaped notification badge by which they could only guess if any notification **exists**; they left the default visual encoding untouched. Participants made the graphical mark **identifiable** by assigning a distinct combination of visual properties (e.g., shape, color) to the default encoding. Participants additionally wanted to track the **change of information state** by configuring a more complex visual encoding, starting from our predefined examples. In terms of visual variables, the most preferred visual encoding was the following:

- *user_checked* → *shape* (i.e., the shape changes after the user attends to notification.)
- *elapsed_time* → *color* (i.e., the color changes over time.)
- *user_checked* → *motion* (i.e., the motion changes after the user attends to notification.)
- *importance_value* → *size* (i.e., the size is proportional to the current importance.)
- *importance_value* → *position*. (i.e., the position is proportional to the current importance.)

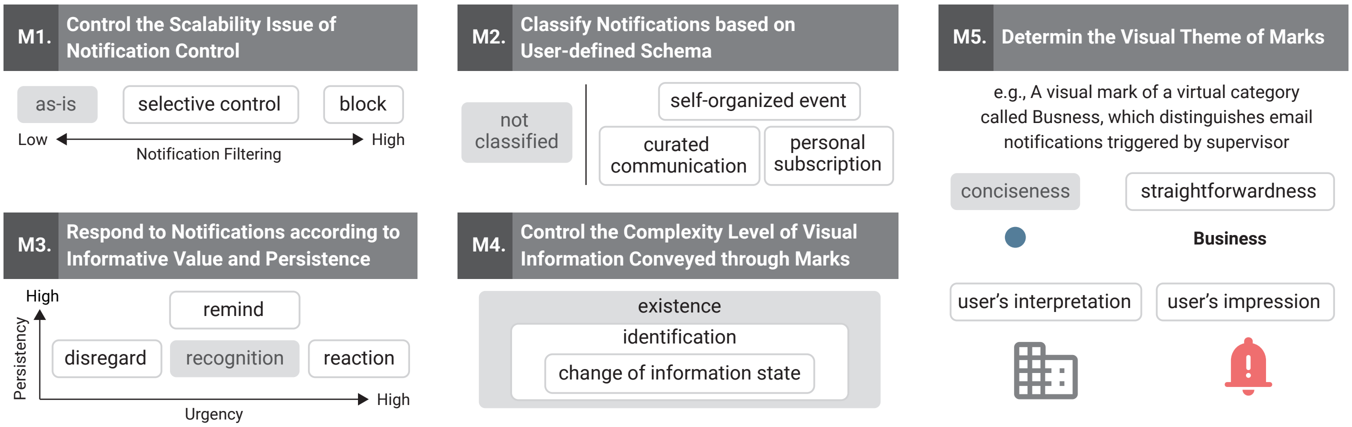


Figure 8: An app-level design motivation (M1) and four virtual category-level design motivations (M2-5) with corresponding choices. For each design motivation, the grey-colored design choice implies that user had the minimal motivation to customize their interaction with notifications of a designated virtual category.

Participants tended to configure the more complex visual encoding for the user-created virtual categories (Figure 9c). However, P06 managed the category "non-urgent group chats" in her messenger and assigned an unidentifiable graphical mark to disregard the targeted messages.

*6.3.5 **M5.** Determine the Visual Theme of Marks.* Participants pursued **conciseness** by utilizing the default graphical mark (i.e., circle) as-is or with color change. They pursued **straightforwardness** by presenting the name of the virtual category directly. Participants wanted to **represented their interpretation** of the category (e.g., a pictograph of the office building). Participants were motivated to express **their impression** to the mark (e.g., a bomb-shaped icon to express the negative and pressing moods). Figure 9d indicates that participants applied diverse visual themes to the user-created virtual categories, while they generally favored concise graphical marks for the Remainder category. We also observed the individual difference regarding the preferred theme of the mark. We revisit P02 and P06's usage in Section 6.2.6. 43% (18 out of 42) of the graphical marks created by P02 highlighted straightforwardness, while P06 created 56% (5 out of 9) of the marks emphasizing her impression.

6.4 Virtual Category-Level Design Strategies

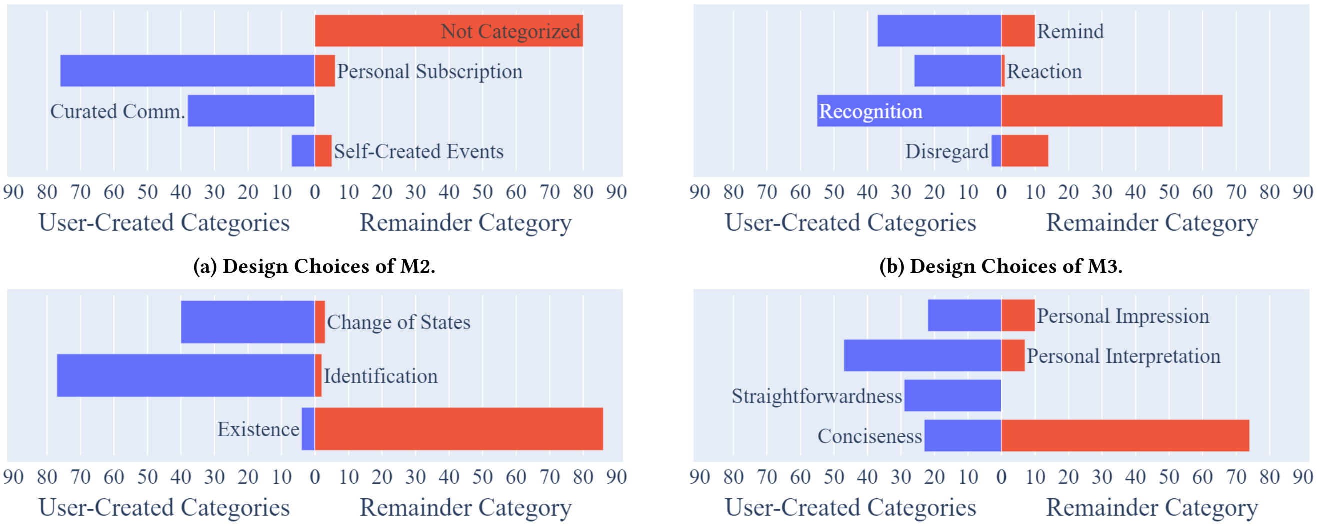
We denoted a combination of the design choices along the five design motivations participant made for a virtual category as its virtual category-level **design strategy**. In the following, We further describe the commonalities and diversities among the participants' halo designs by comparing their design strategies. We listed the selected design strategies that were (1) frequently adopted and (2) widely shared among participants in Appendix C.

6.4.1 Explanation of Terminology by Example. Figure 10 describes the relationship between the design motivations, the design choices, the virtual category-level strategy, and the graphical mark with a halo of Loop Habit Tracker created by P02. It was a self-tracking app where she registered her daily goals and monitored their achievement. Although the app could send notifications that remind her of daily goals, they easily disappeared when "dismissing all" from the drawer. So, she decided to manage a virtual category called "Supplements" that reminded her of a daily goal to take nutritional supplements. Our design motivations (**M1–5**) provide the five viewpoints of P02's design scenario. Next, our design choices regarding these motivations give a detailed explanation of her customization behaviors. Finally, the resultant virtual category-level design strategy —M1: as-is, M2: self-organized event, M3: remind, M4: identification, M5: personal interpretation— comes out; it enables the scenario-to-scenario comparison with other virtual categories made by P02 and by other participants.

6.4.2 No Intersection between Design Strategies of User-Created Category and Remainder Category. We could observe 74 unique design strategies from the 205 virtual category-level design scenarios; 50 of them were for the user-created virtual categories (118 out of 205); 24 of them were for the 87 Remainder categories. There was no intersection between two sets of unique strategies, indicating that participants posed distinct design approaches based on whether they were actively involved in category creation.

6.4.3 Individual Differences of Design Strategies Applied to User-Created Category. Participants tended to reuse the same design strategies multiple times for similar virtual categories in the same app or across apps. 58% (7 out of 12) of participants reused their design strategies. For example, P02 repeated her three design strategies nine, eight, and five times, respectively. Individual design strategies hardly overlapped among participants. 1.61 Participants shared the same design strategy on average ($median = 1, max = 4, std = 1.60$). Only 26% (13 out of 50) of the design strategies were shared by two or more participants. The most widely shared strategy, used by four participants, was to subscribe to the experiment notices (Section 3.3) provided as an exercise; all participants initially utilized the same setting, but eight participants changed the strategies by further customization during their usage.

6.4.4 Homogeneity of Design Strategies Applied to Remainder Category. As illustrated in Figure 9, design strategies for the Remainder



(a) Design Choices of M2. (b) Design Choices of M3.

(c) Design Choices of M4. (d) Design Choices of M5.

Figure 9: Distribution of design choices for the user-created virtual category and the Remainder category.

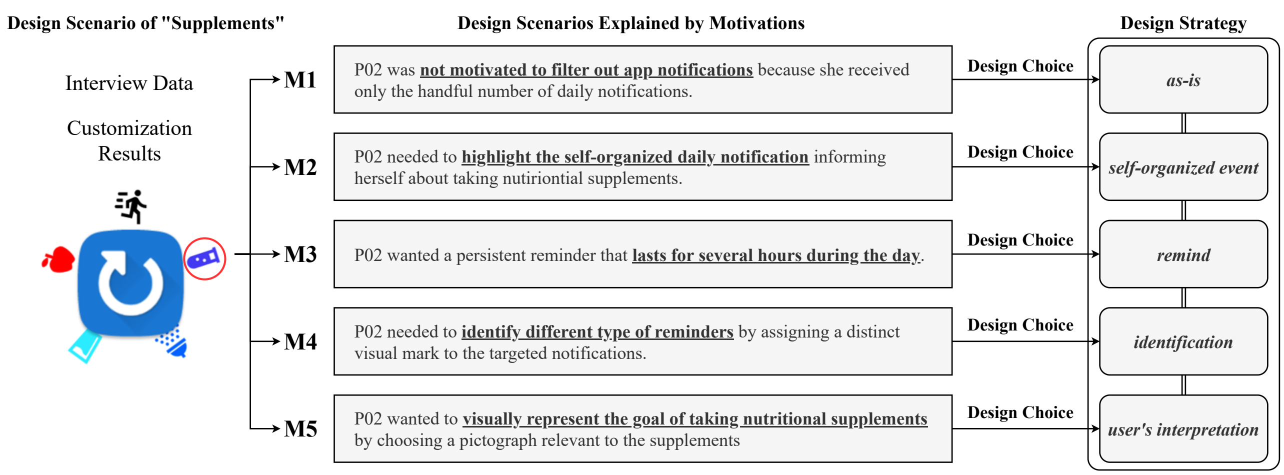


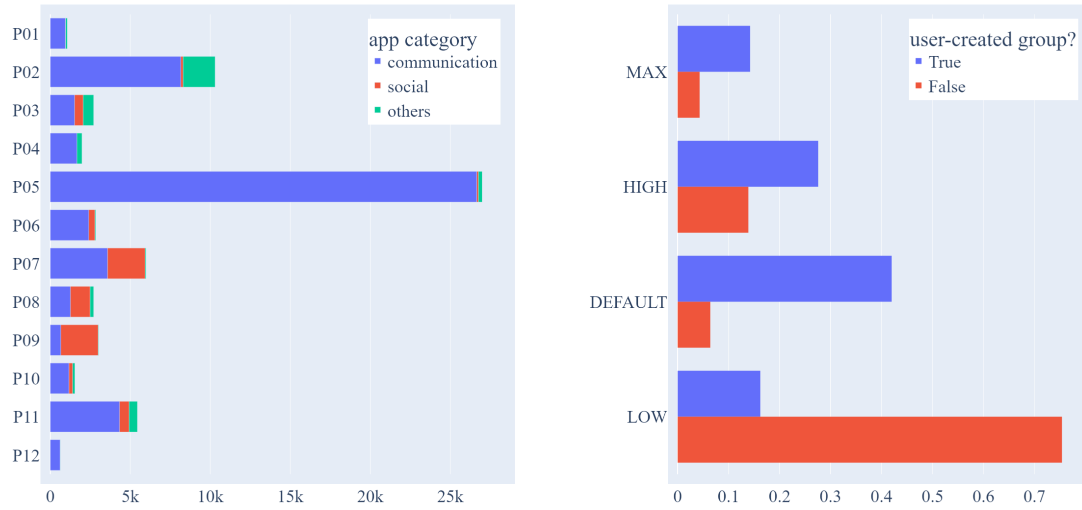
Figure 10: Relationship between design motivations, choices, virtual category-level design strategy, and graphical mark of P02's Loop Habit Tracker.

category were more homogeneous than those for the user-created category: The two most frequent strategies took up 55% (48 out of 87) of usage. These two were identical except for the choice of **M1**. They corresponded to the default configuration of the Remainder category; participants did not customize because they focused on managing the categories they created.

6.5 Halo Notification Analysis

6.5.1 Overview. Of the 1,088,368 total notification logs collected, we filtered 114,316 notifications of interest. Of the 114,316 notifications of interest, halo notifications occupied 65,200. The communication category was prevailing in halo notifications (52,995 out of 65,200); KakaoTalk dominated this category (51,023 out of 52,995). The second most frequent app category was social (7,910 out of 65,200). Therefore, these two categories, related to communication among users, were the primary source (93%) of halo notifications. On average, participants received 5433.3 halo notifications ($min = 627, median = 2,773, max = 26,992$, Figure 11a).

6.5.2 Comparative Analysis on Virtual Categories and Android Notification Channels. At a high level, we found some commonalities between the notification importance imposed by the user's information schema and one provided by the channel structure of the current notification system. We observed a significant difference in the distribution of notification's channel importance (Figure 11b) based on whether it belongs to the user-created virtual category or



(a) Halo notifications by participant.

(b) Distribution of Android channel importance by type of virtual category.

Figure 11: The result of halo notification analysis.

the Remainder category (i.e., not classified by user schema). Similarly, notifications that belonged to user-created categories also had higher channel importance than the Remainder categories. It coincided with the observation from the halo design table; all but one participant imposed a higher or equal importance value to the virtual category they created than the Remainder category automatically generated.

However, the detailed investigation contrasted the schema of virtual categories with Android notification channels. Virtual categories frequently accommodated heterogeneous notification channels. 41% (39 out of 94) of virtual categories included two or more distinct notification channels ($min = 1, max = 9, mean = 1.54$). For example, the "announcement" category created by P01 for KakaoTalk assigned a higher informative value to the designated notifications. However, the halo notifications showed that the notifications from two different Android notification channels, "New Message" and "Notification without Feedback", were classified into her "announcement" category. These channels assigned contrasting system importance ("New Message" ⟶ *IMPORTANCE MAX*, "Notification without Feedback" ⟶ *IMPORTANCE LOW*) to notifications, which shows a discrepancy with user motivation.

Moreover, the categorization based on notification channels was not specific enough to cover the user's schema. 38% (31 out of 82) of Android notification channels involved two or more virtual categories($min = 1, max = 8, mean = 1.77$). For example, P02 managed five virtual categories for MiseMise, a weather app specialized in forecasting air pollution, to subscribe to five-graded fine-dust alarms. On the other hand, the logs indicated that its app provider labeled all the differently-graded alarms with a single Android notification channel called "MiseMise Alarm". In addition, channel importance itself could not effectively differentiate virtual categories. For example, four different virtual categories created by P11 for KakaoTalk involved the identical channel importance, *IMPORTANCE DEFAULT*, although she applied distinct importance models to all of them.

6.6 Usability and User Experience

6.6.1 Usability Feedback. Compared with the prior result of the formative study, there was no significant increase in the score of the System Usability Scale (SUS). The score was in the range of OK-GOOD again [2]. However, the subsequent inquiry revealed that the fatigue of customization, the main usability issue of the early prototype, has been successfully alleviated.

6.6.2 User Experience of New Notification Management. Regarding the 7-point UX questionnaire (Appendix B), the distribution of responses for every question was left-skewed (Figure 12). All participants agreed that these capabilities provided a better experience of notification management: (1) notification categorization, (2) prioritization of information, (3) longitudinal interaction, and (4) delivery in a favorable visual form. Participants who favored managing aesthetic halos (P01, P03, P06, P10) especially loved the capability of personalizing graphical marks for the notifications of interest. For example, P10 responded that she voluntarily had a brainstorming session of decorating halos with her friend for about an hour. She thought DataHalo could appeal to her peers interested in decorating their smartphone home screen.

As a result, all participants responded that their user–notification interaction improved overall during the deployment. They hoped to use the full version of DataHalo from the app store soon. On the other hand, the launcher-related usability issues resulted in less positive responses to Q7, "Continue to Use". Many participants wanted to continue using the DataHalo capabilities in their original launcher (e.g., One-UI). P4 also mentioned that he wanted to use

DataHalo with ‘NotiStar’, a notification management service provided by the One-UI launcher; it supported the global search over the notifications that can harmonize with our app-specific method.

7 DISCUSSION

7.1 Customization Support towards the Personalized Ambience

Our studies revealed diverse perspectives on the satisfactory user–notification interaction among participants. In the casual context [39], participants used DataHalo for a broad range of purposes not limited to obtaining analytic insights from notification information; some wanted to decorate their home screen prettier, while others carefully chose graphical marks that implied their emotion. In designing halos, participants reflected their personal preferences (e.g., aesthetic taste) and usage contexts (e.g., app usage, home screen management), producing highly personalized and unique ambient displays. This suggests the potential of DataHalo's customizability in supporting individualized notification management. Although participants generated highly individualized halos, they also tended to apply the same design strategies for multiple virtual categories they created. To streamline such a unified but individualized halo configuration, a future version of DataHalo may support global customization across multiple apps. This could lower the burden of people who want to repeat similar design strategies for virtual categories across multiple apps.

7.2 The Ease of Adaptation to Trace the Moving Sweet Spot of User Experience

Another important lesson of our deployment study was the change of personal ‘sweet spot’ in the user experience over time. Participants added, edited, and even removed halos during usage, similar to personal information trackers [10]. Although participants determined most of the app halos during the first two weeks of usage, they constantly edited halo configurations for extended periods; their sweet spot (i.e., well-personalized setting at a specific time) needed to be updated to adjust the changes originated from themselves and their surroundings. The result indicated that the customization capabilities should be more accessible for people to keep up with the shift of sweet spots. DataHalo successfully exploited the accustomed interaction methods of the home screen, app icons, and notification badges. Users could intuitively organize an apt information display that adapts to their desire. For instance, they could include or exclude information sources by placing and removing app icons on the home screen. Plus, they could quickly access the halo customization interface of a target app thanks to the context menu triggered by directly manipulating its icon. Likewise, our design study provides an example of integrating novel ideas into widely known interfaces and interaction methods by concinnously extending their underlying semantics.

7.3 Generalizability beyond Culture and Population

Since we conducted the study in South Korea, some halo design patterns may be subject to regional characteristics of app usage, given that halo creations and edits were active for *communication* and *social* apps. Especially, KaKaoTalk, a communication app most South Koreans use (over 40 million [4]), is more than a messenger. It incorporates various platform services such as shopping, so many commercial chatbots also send messages (e.g., advertisement, invoice, and delivery) to people. Receiving both chat and non-chat messages makes KaKaoTalk a notification-intensive communication app. Most participants needed to curate notifications from this app and subscribe to only useful ones with distinct longitudinal interactions. Because (1) DataHalo successfully covered a case of a notification-intensive app that triggered diverse information and (2) our analysis drilled down into the virtual category level, we believe our findings also apply to notification management of other apps in other regions.

7.4 Implications for Better Personalization Support

7.4.1 Integrating User Schema and Android Notification Channels. There was a discrepancy between the categorizations for app notifications that participants implemented using DataHalo and Android notification channels defined by app providers. This gap implies the necessity of the user's participation in modeling the notification information of an app. Furthermore, P03's “advertisement cop” issue revealed the potential incompleteness of inductive methods provided by DataHalo. The exhaustive information for the app notifications from the app provider can supplement the quality of keyword-based rules that relies on people's observable range of notifications at the time. Combining the user's schema and the app-specific control methods could lower the burden of filter and categorizing notifications. However, this approach is not currently viable due to the limited access to Android's notification information. Therefore, future work may consider integrating the notification channel structure of Android with the visualization pipeline of DataHalo.

7.4.2 Semi-automated Tuning of Importance Model. Despite our efforts to alleviate the user's burden of customization by providing more intuitive examples and user interfaces for visual summary and reuse, some participants also reported the learning cost of tuning parameters for predefined models. To tackle this issue, we expect to utilize the set of design motivations and strategies as a source of questions (e.g., “What type of information you classified?”, “How do you want to respond to this notification?”) and options (e.g., “Personal subscription,” “I want to remind the notification for a while”). Based on the similar design choices in the collected patterns, DataHalo could suggest more sophisticated initial parameters than those of example patterns. In the long run, these parameters could be further adjusted based on user statistics computed by collected notification logs (e.g., the number of notifications and average interaction delay). This semi-automated tuning of the importance model would effectively resolve the remaining usability issues and possibly adapt to the temporal change of the personal sweet spot we mentioned above.

7.5 Limitations and Future Work

Our method currently focuses on extending the notification badge to visualize the notification information enhanced by smartphone users. The user–notification interaction would further improve if

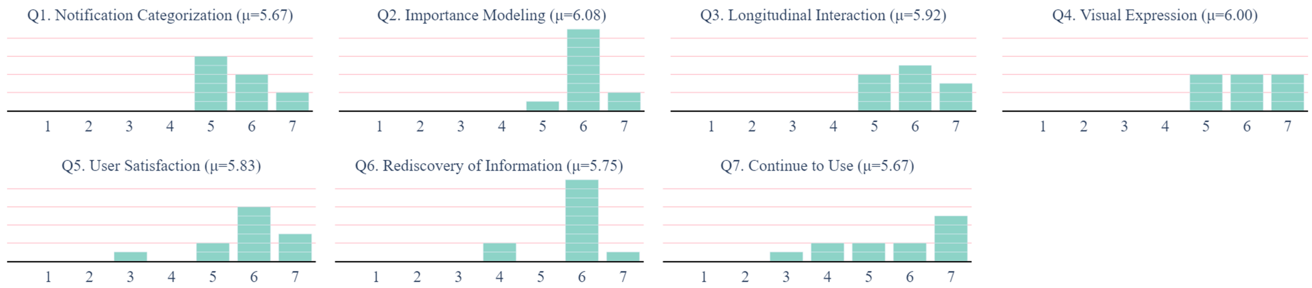


Figure 12: The result of 7-point Likert scale questionnaire about the UX of DataHalo.

the enhanced information could affect other visual components, such as the status bar & notification drawer, and even supports the smooth interplay with the halo visualization. For example, the notification drawer could support an alternative attendance method, such as pinning the halo notifications for the lifespan according to their importance models. It would provide users with intuitive access to individual notifications across app halos. Moreover, we could apply the halo visualization to other smartphone displays (e.g., Always On Display) or wearable devices. This approach would increase the accessibility of the enhanced notification information further but needs to tackle the battery consumption issue and the higher threat of privacy leaks.

Our weekly report of DataHalo usage might have influenced participants to promote their usage, especially for halo customization events, although we rewarded them identically regardless of usage. We believe the future version of DataHalo should incorporate features that consistently motivate people to find a better way to personalize their user–notification interaction.

8 CONCLUSION

To resolve significant interaction problems between smartphone users and notification, we suggested a novel notification visualization system called DataHalo. It empowers people (1) to construct the personal information model that categorizes and prioritizes notifications and (2) to create ambient visualization, halo, that longitudinally delivers valuable information on the home screen. We prototyped this system on an open-source Android launcher and conducted a lab study ($N = 17$) to validate the usefulness and improve usability. We then conducted a three-week deployment study ($N = 12$) to explore how people use DataHalo in a realistic context. Participants agreed that our methods were feasible and that DataHalo could improve the quality of their user–notification interaction. In addition, we derived people's design strategies from analyzing the interview data, the notification logs, and the customization logs. Based on the result, we discussed design implications for supporting effective notification management through customizable ambient visualizations.

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REFERENCES

[1] Jonas Auda, Dominik Weber, Alexandra Voit, and Stefan Schneegass. 2018. Understanding User Preferences Towards Rule-based Notification Deferral. In *Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems* (Montreal QC, Canada) *(CHI EA '18)*. ACM, New York, NY, USA, Article LBW584, 6 pages. https://doi.org/10.1145/3170427.3188688

[2] Aaron Bangor, Philip Kortum, and James Miller. 2009. Determining What Individual SUS Scores Mean: Adding an Adjective Rating Scale. *J. Usability Studies* 4, 3 (May 2009), 114–123. http://dl.acm.org/citation.cfm?id=2835587.2835589

[3] Jared S. Bauer, Sunny Consolvo, Benjamin Greenstein, Jonathan Schooler, Eric Wu, Nathaniel F. Watson, and Julie Kientz. 2012. ShutEye: Encouraging Awareness of Healthy Sleep Recommendations with a Mobile, Peripheral Display. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Austin, Texas, USA) *(CHI '12)*. ACM, New York, NY, USA, 1401–1410. https://doi.org/10.1145/2207676.2208600

[4] Pulse (by Maeil Business News Korea. 2020. KakaoTalk in its 10th year has nearly all S. Korean population connected. https://pulsenews.co.kr/view.php?year=2020&no=218180 Last accessed 12 December 2022.

[5] Seyma Kucukozer Cavdar, Tugba Taskaya-Temizel, Mirco Musolesi, and Peter Tino. 2020. A Multi-Perspective Analysis of Social Context and Personal Factors in Office Settings for the Design of an Effective Mobile Notification System. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.* 4, 1, Article 15 (mar 2020), 38 pages. https://doi.org/10.1145/3381000

[6] Sunny Consolvo, Predrag Klasnja, David W. McDonald, Daniel Avrahami, Jon Froehlich, Louis LeGrand, Ryan Libby, Keith Mosher, and James A. Landay. 2008. Flowers or a Robot Army?: Encouraging Awareness & Activity with Personal, Mobile Displays. In *Proceedings of the 10th International Conference on Ubiquitous Computing* (Seoul, Korea) *(UbiComp '08)*. ACM, New York, NY, USA, 54–63. https://doi.org/10.1145/1409635.1409644

[7] Sunny Consolvo, Predrag Klasnja, David W. McDonald, and James A. Landay. 2014. Designing for Healthy Lifestyles: Design Considerations for Mobile Technologies to Encourage Consumer Health and Wellness. *Found. Trends Hum.-Comput. Interact.* 6, 3–4 (apr 2014), 167–315. https://doi.org/10.1561/1100000040

[8] Sunny Consolvo, David W. McDonald, Tammy Toscos, Mike Y. Chen, Jon Froehlich, Beverly Harrison, Predrag Klasnja, Anthony LaMarca, Louis LeGrand, Ryan Libby, Ian Smith, and James A. Landay. 2008. Activity Sensing in the Wild: A Field Trial of Ubifit Garden. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Florence, Italy) *(CHI '08)*. ACM, New York, NY, USA, 1797–1806. https://doi.org/10.1145/1357054.1357335

[9] data.ai. 2019. 2017 Retrospective: A Monumental Year for the App Economy. https://www.data.ai/en/insights/market-data/app-annie-2017-retrospective/. Last accessed 15 August 2022.

[10] Daniel A. Epstein, An Ping, James Fogarty, and Sean A. Munson. 2015. A Lived Informatics Model of Personal Informatics. In *Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing* (Osaka, Japan) *(UbiComp '15)*. Association for Computing Machinery, New York, NY, USA, 731–742. https://doi.org/10.1145/2750858.2804250

[11] James Fogarty, Jodi Forlizzi, and Scott E. Hudson. 2001. Aesthetic Information Collages: Generating Decorative Displays That Contain Information. In *Proceedings of the 14th Annual ACM Symposium on User Interface Software and Technology* (Orlando, Florida) *(UIST '01)*. ACM, New York, NY, USA, 141–150. https://doi.org/10.1145/502348.502369

[12] Google. 2021. Firebase Realtime Database. https://firebase.google.com/docs/database. Last accessed 15 August 2021.

[13] Rúben Gouveia, Fábio Pereira, Evangelos Karapanos, Sean A. Munson, and Marc Hassenzahl. 2016. Exploring the Design Space of Glanceable Feedback for Physical Activity Trackers. In *Proceedings of the 2016 ACM International Joint Conference*

on Pervasive and Ubiquitous Computing (Heidelberg, Germany) *(UbiComp '16)*. Association for Computing Machinery, New York, NY, USA, 144–155. https://doi.org/10.1145/2971648.2971754

[14] Dandan Huang, Melanie Tory, Bon Adriel Aseniero, Lyn Bartram, Scott Bateman, Sheelagh Carpendale, Anthony Tang, and Robert Woodbury. 2015. Personal Visualization and Personal Visual Analytics. *IEEE Transactions on Visualization and Computer Graphics* 21, 3 (March 2015), 420–433. https://doi.org/10.1109/TVCG.2014.2359887

[15] Samuel Huron, Sheelagh Carpendale, Alice Thudt, Anthony Tang, and Michael Mauerer. 2014. Constructive Visualization. In *Proceedings of the 2014 Conference on Designing Interactive Systems* (Vancouver, BC, Canada) *(DIS '14)*. Association for Computing Machinery, New York, NY, USA, 433–442. https://doi.org/10.1145/2598510.2598566

[16] Minhyung Kim, Inyeop Kim, and Uichin Lee. 2021. Beneficial Neglect: Instant Message Notification Handling Behaviors and Academic Performance. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.* 5, 1, Article 18 (mar 2021), 26 pages. https://doi.org/10.1145/3448089

[17] Young-Ho Kim, Jae Ho Jeon, Eun Kyoung Choe, Bongshin Lee, KwonHyun Kim, and Jinwook Seo. 2016. TimeAware: Leveraging Framing Effects to Enhance Personal Productivity. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (Santa Clara, California, USA) *(CHI '16)*. ACM, New York, NY, USA, 272–283. https://doi.org/10.1145/2858036.2858428

[18] Kostadin Kushlev, Jason Proulx, and Elizabeth W. Dunn. 2016. "Silence Your Phones": Smartphone Notifications Increase Inattention and Hyperactivity Symptoms. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (San Jose, California, USA) *(CHI '16)*. Association for Computing Machinery, New York, NY, USA, 1011–1020. https://doi.org/10.1145/2858036.2858359

[19] Jan Kučera, James Scott, Nicholas Chen, Patrick Olivier, and Steve Hodges. 2017. Towards Calm Displays: Matching Ambient Illumination in Bedrooms. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.* 1, 2, Article 16 (jun 2017), 21 pages. https://doi.org/10.1145/3090081

[20] Kyung-Ryong Lee, Geon-il Goh, and Young-Woo Park. 2017. Quietto: An Interactive Timepiece Molded in Concrete and Milled Wood. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (Denver, Colorado, USA) *(CHI '17)*. Association for Computing Machinery, New York, NY, USA, 2988–2992. https://doi.org/10.1145/3025453.3025670

[21] Kyung-Ryong Lee, Somi Ju, Temirlan Dzhoroev, Geonil Goh, Moon-Hwan Lee, and Young-Woo Park. 2020. *DayClo: An Everyday Table Clock Providing Interaction with Personal Schedule Data for Self-Reflection*. Association for Computing Machinery, New York, NY, USA, 1793–1806. https://doi.org/10.1145/3357236.3395439

[22] Moon-Hwan Lee, Yea-Kyung Row, Oosung Son, Uichin Lee, Jaejeung Kim, Jungi Jeong, Seungryoul Maeng, and Tek-Jin Nam. 2018. Flower-Pop: Facilitating Casual Group Conversations With Multiple Mobile Devices. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.* 1, 4, Article 150 (jan 2018), 24 pages. https://doi.org/10.1145/3161170

[23] Yu-Kang Lee, Chun-Tuan Chang, You Lin, and Zhao-Hong Cheng. 2014. The dark side of smartphone usage: Psychological traits, compulsive behavior and technostress. *Computers in Human Behavior* 31 (2014), 373–383. https://doi.org/10.1016/j.chb.2013.10.047

[24] Tzu-Chieh Lin, Yu-Shao Su, Emily Helen Yang, Yun Han Chen, Hao-Ping Lee, and Yung-Ju Chang. 2021. "Put It on the Top, I'll Read It Later": Investigating Users' Desired Display Order for Smartphone Notifications. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. Association for Computing Machinery, New York, NY, USA, Article 520, 13 pages. https://doi.org/10.1145/3411764.3445384

[25] Jennifer Mankoff, Anind K. Dey, Gary Hsieh, Julie Kientz, Scott Lederer, and Morgan Ames. 2003. Heuristic Evaluation of Ambient Displays. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Ft. Lauderdale, Florida, USA) *(CHI '03)*. ACM, New York, NY, USA, 169–176. https://doi.org/10.1145/642611.642642

[26] Tara Matthews. 2006. Designing and Evaluating Glanceable Peripheral Displays. In *Proceedings of the 6th Conference on Designing Interactive Systems* (University Park, PA, USA) *(DIS '06)*. Association for Computing Machinery, New York, NY, USA, 343–345. https://doi.org/10.1145/1142405.1142457

[27] Tara Matthews, Tye Rattenbury, and Scott Carter. 2007. Defining, Designing, and Evaluating Peripheral Displays: An Analysis Using Activity Theory. *Hum.-Comput. Interact.* 22, 1 (May 2007), 221–261. http://dl.acm.org/citation.cfm?id=1466595.1466602

[28] Abhinav Mehrotra, Robert Hendley, and Mirco Musolesi. 2016. PrefMiner: Mining User's Preferences for Intelligent Mobile Notification Management. In *Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing* (Heidelberg, Germany) *(UbiComp '16)*. Association for Computing Machinery, New York, NY, USA, 1223–1234. https://doi.org/10.1145/2971648.2971747

[29] Abhinav Mehrotra, Mirco Musolesi, Robert Hendley, and Veljko Pejovic. 2015. Designing Content-Driven Intelligent Notification Mechanisms for Mobile Applications. In *Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing* (Osaka, Japan) *(UbiComp '15)*. Association for Computing Machinery, New York, NY, USA, 813–824. https://doi.org/10.1145/2750858.2807544

[30] Gonzalo Gabriel Méndez, Uta Hinrichs, and Miguel A. Nacenta. 2017. Bottom-up vs. Top-down: Trade-Offs in Efficiency, Understanding, Freedom and Creativity with InfoVis Tools. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (Denver, Colorado, USA) *(CHI '17)*. Association for Computing Machinery, New York, NY, USA, 841–852. https://doi.org/10.1145/3025453.3025942

[31] Carol Moser, Sarita Y. Schoenebeck, and Katharina Reinecke. 2016. Technology at the Table: Attitudes About Mobile Phone Use at Mealtimes. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (San Jose, California, USA) *(CHI '16)*. ACM, New York, NY, USA, 1881–1892. https://doi.org/10.1145/2858036.2858357

[32] mydloch's dev team. 2021. Notification History. https://play.google.com/store/apps/details?id=com.myd.android.nhistory2. Last accessed 15 August 2022.

[33] Chunjong Park, Junsung Lim, Juho Kim, Sung-Ju Lee, and Dongman Lee. 2017. Don'T Bother Me. I'm Socializing!: A Breakpoint-Based Smartphone Notification System. In *Proceedings of the 2017 ACM Conference on Computer Supported Cooperative Work and Social Computing* (Portland, Oregon, USA) *(CSCW '17)*. ACM, New York, NY, USA, 541–554. https://doi.org/10.1145/2998181.2998189

[34] Martin Pielot, Bruno Cardoso, Kleomenis Katevas, Joan Serrà, Aleksandar Matic, and Nuria Oliver. 2017. Beyond Interruptibility: Predicting Opportune Moments to Engage Mobile Phone Users. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.* 1, 3, Article 91 (sep 2017), 25 pages. https://doi.org/10.1145/3130956

[35] Martin Pielot, Karen Church, and Rodrigo de Oliveira. 2014. An In-situ Study of Mobile Phone Notifications. In *Proceedings of the 16th International Conference on Human-computer Interaction with Mobile Devices & Services* (Toronto, ON, Canada) *(MobileHCI '14)*. ACM, New York, NY, USA, 233–242. https://doi.org/10.1145/2628363.2628364

[36] Martin Pielot and Luz Rello. 2017. Productive, Anxious, Lonely: 24 Hours Without Push Notifications. In *Proceedings of the 19th International Conference on Human-Computer Interaction with Mobile Devices and Services* (Vienna, Austria) *(MobileHCI '17)*. ACM, New York, NY, USA, Article 11, 11 pages. https://doi.org/10.1145/3098279.3098526

[37] Martin Pielot, Amalia Vradi, and Souneil Park. 2018. Dismissed!: A Detailed Exploration of How Mobile Phone Users Handle Push Notifications. In *Proceedings of the 20th International Conference on Human-Computer Interaction with Mobile Devices and Services* (Barcelona, Spain) *(MobileHCI '18)*. ACM, New York, NY, USA, Article 3, 11 pages. https://doi.org/10.1145/3229434.3229445

[38] Zachary Pousman and John Stasko. 2006. A Taxonomy of Ambient Information Systems: Four Patterns of Design. In *Proceedings of the Working Conference on Advanced Visual Interfaces* (Venezia, Italy) *(AVI '06)*. ACM, New York, NY, USA, 67–74. https://doi.org/10.1145/1133265.1133277

[39] Zachary Pousman, John Stasko, and Michael Mateas. 2007. Casual Information Visualization: Depictions of Data in Everyday Life. *IEEE Transactions on Visualization and Computer Graphics* 13, 6 (Nov 2007), 1145–1152. https://doi.org/10.1109/TVCG.2007.70541

[40] Counterpoint Research. 2022. Smartphone Market Share of South Korea in 2021 (in Korean). https://korea.counterpointresearch.com/2022. Last accessed 21 June 2022.

[41] Alireza Sahami Shirazi, Niels Henze, Tilman Dingler, Martin Pielot, Dominik Weber, and Albrecht Schmidt. 2014. Large-scale Assessment of Mobile Notifications. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Toronto, Ontario, Canada) *(CHI '14)*. ACM, New York, NY, USA, 3055–3064. https://doi.org/10.1145/2556288.2557189

[42] In-geon Shin, Jin-min Seok, and Youn-kyung Lim. 2018. Too Close and Crowded: Understanding Stress on Mobile Instant Messengers Based on Proxemics. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (Montreal QC, Canada) *(CHI '18)*. ACM, New York, NY, USA, Article 615, 12 pages. https://doi.org/10.1145/3173574.3174189

[43] Tobias Skog. 2004. Activity Wallpaper: Ambient Visualization of Activity Information. In *Proceedings of the 5th Conference on Designing Interactive Systems: Processes, Practices, Methods, and Techniques* (Cambridge, MA, USA) *(DIS '04)*. Association for Computing Machinery, New York, NY, USA, 325–328. https://doi.org/10.1145/1013115.1013171

[44] Tobias Skog, Sara Ljungblad, and Lars Erik Holmquist. 2003. Between Aesthetics and Utility: Designing Ambient Information Visualizations. In *Proceedings of the Ninth Annual IEEE Conference on Information Visualization* (Seattle, Washington) *(INFOVIS'03)*. IEEE Computer Society, Washington, DC, USA, 233–240. http://dl.acm.org/citation.cfm?id=1947368.1947410

[45] Dominik Weber, Alexandra Voit, Jonas Auda, Stefan Schneegass, and Niels Henze. 2018. Snooze!: Investigating the User-defined Deferral of Mobile Notifications. In *Proceedings of the 20th International Conference on Human-Computer Interaction with Mobile Devices and Services* (Barcelona, Spain) *(MobileHCI '18)*. ACM, New York, NY, USA, Article 2, 13 pages. https://doi.org/10.1145/3229434.3229436

[46] Dominik Weber, Alexandra Voit, and Niels Henze. 2018. Notification Log: An Open-Source Framework for Notification Research on Mobile Devices. In *Proceedings of the 2018 ACM International Joint Conference and 2018 International Symposium on Pervasive and Ubiquitous Computing and Wearable Computers*

(Singapore, Singapore) *(UbiComp '18)*. Association for Computing Machinery, New York, NY, USA, 1271–1278. https://doi.org/10.1145/3267305.3274118

[47] Dominik Weber, Alexandra Voit, Gisela Kollotzek, and Niels Henze. 2019. Annotif: A System for Annotating Mobile Notifcations in User Studies. In *Proceedings of the 18th International Conference on Mobile and Ubiquitous Multimedia* (Pisa, Italy) *(MUM '19)*. Association for Computing Machinery, New York, NY, USA, Article 24, 12 pages. https://doi.org/10.1145/3365610.3365611

[48] Mark Weiser and John Seely Brown. 1996. Designing Calm Technology. *POWERGRID JOURNAL* 1 (1996).

[49] Amir Zaidi. 2019. Rootless Pixel Launcher. https://github.com/amirzaidi/Launcher3.

[50] Leizhong Zhang, Nan Tu, and Dave Vronay. 2005. Info-lotus: A Peripheral Visualization for Email Notification. In *CHI '05 Extended Abstracts on Human Factors in Computing Systems* (Portland, OR, USA) *(CHI EA '05)*. ACM, New York, NY, USA, 1901–1904. https://doi.org/10.1145/1056808.1057051

A USABILITY STUDY: VIRTUAL CATEGORIES DURING THE TASK 2

Table 1: Smartphone applications that the usability study participants chose for the second halo design task and virtual categories they created.

	App	Description	Virtual Category / Reason of Creation
U01	Facebook	Social media	**Notice** - to subscribe to announcements from several Facebook pages **Social** - to curate the notice about other user's reactions (e.g., Like, Comment)
U02	Messages	Messenger	**Church** - to curate messages related to religious activity **Private Tutoring** - to curate messages sent by tutee
U03	Youtube	Video streaming	**[Youtuber_Name]** - to subscribe to the updates of the Youtube channel
U04	Kakao Story	Social media	**Story** - to subscribe to the story updates of social feeds
U05	Bank Salad	Financing	**Coffee** - to subscribe to the purchase history of coffee **Chicken** - to subscribe to the purchase history of fried chicken
U06	Megabox	Movie ticketing	**Event** - to subscribe to the notice of discount events
U07	Gmail	Email	**Shopping** - to subscribe to information letters from shopping mall **Major** - to subscribe to mails sent by the university faculty **Payment** - to subscribe to mails notifying purchase cancellations
U08	Cake	Language learning	**Untitled** - to subscribe to the notice of encouraging user to study English
U09	BaeMin	Food delivery	**Coupon** - to subscribe to the notice of discount events
U10	Clash Royale	Game	**Chest** - to subscribe to the arrival of free game items
U11	Outlook	Email	**Babymind** - to subscribe to the email informing the update of github storage **Lab** - to subscribe the email sent by lab people
U12	Instagram	Social media	**Notice** - to curate the notice about user's reaction
U13	PanelPower	Paid survey	**Survey** - to subscribe to the notice about new paid survey
U14	Naver Mail	Email	**University** - to subscribe to mails sent by faculty
U15	Hana Bank	Financing	**Deposit** - to subscribe to the notice informing the event of account deposit
U16	WhatsApp	Messenger	**[User_id]** - to curate the messages sent by the user
U17	Messages	Messenger	**Financial Service** - to subscribe to the messages sent by bank

B DEPLOYMENT STUDY: POST-STUDY QUESTIONNAIRE

Table 2: Questions for inquiring the user experience during the DataHalo usage.

Types	Questions
Q1. Notification Categorization	I could better categorize the information delivered by notifications of interest.
Q2. Importance Modeling	I could better prioritize notifications based on my information assessment.
Q3. Longitudinal Interaction	I could keep in touch with the longitudinal information as long as I wanted.
Q4. Visual Expression	I could access the useful information with my preferable visual representations
Q5. User Satisfaction	DataHalo provided more satisfactory experience of notification management to me.
Q6. Rediscovery of Information	I became more interested in the informative values of my daily notifications.
Q7. Continue to Use	If possible, I hope to continue using the personalization capabilities of DataHalo.

C DEPLOYMENT STUDY: POPULAR DESIGN STRATEGIES

Table 3: Frequent and widely used design strategies among participants. *#P* stands for the number of participants who shared the strategy and *Freq.* stands for the total frequency of the strategy.

Notification Control	Information Category	User Response	Information Complexity	Emphasis on Presentation	#P (Freq.)	Example Usage
User-defined virtual category						
selective	personal subscription	remind	change of states	user's impression	4 (4)	To subscribe DataHalo study announcement via instant messenger
as-is	personal subscription	recognition	identification	user's interpretation	3 (6)	To subscribe the withdrawl and deposit events of one's account via bank app
selective	curated communication	reaction	change of states	user's impression	3 (3)	To prioritize the chat with one's beloved via instant messenger
selective	curated communication	recognition	identification	raw information	2 (10)	To distinguish a large number (e.g., 9) of notification groups in the instant messenger with group labels
as-is	self-organized events	remind	identification	user's interpretation	1 (5)	To remind daily goals (e.g., taking a multivitamin tablet) registered in self tracking app
"Remainder" category						
selective	unclassified	recognition	existence	no emphasis	12 (26)	To simply visualize the remaining notifications unhandled by user created groups
block	unclassified	disregard	existence	no emphasis	4 (10)	To deactivate app halo for entire notifications (no user created groups)