Opportunistic Nudges for Task Migration Between Personal Devices

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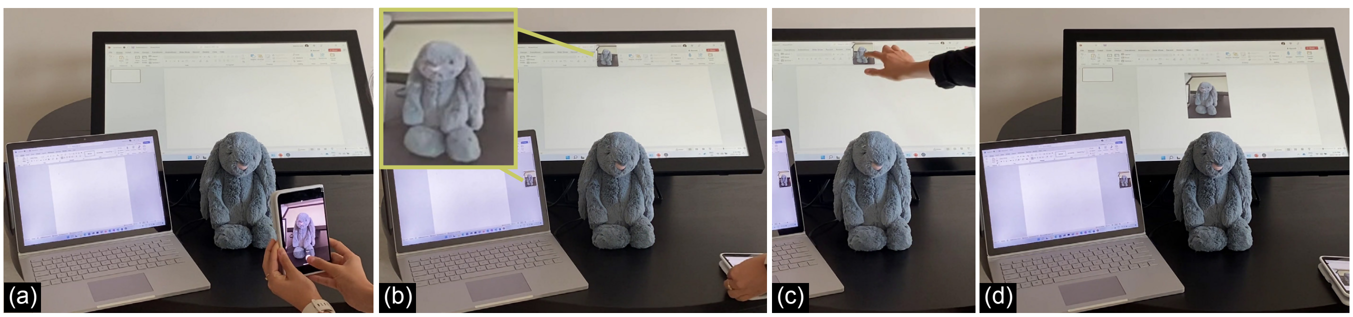

Figure 1: Opportunistic nudges enable lightweight migration between devices: (a) capturing a photo on a phone causes (b) a nudge to appear on nearby devices; (c) interacting with it on another device (d) shares content and migrates the task to that device.

ABSTRACT

Using multiple devices to exploit their strengths and mechanics for a task is referred to as "migration." However, re-establishing context upon moving from one device to another can be cumbersome. We propose opportunistic nudges as a way to more seamlessly share content between personal devices. Opportunistic nudges appear in the bezel when a device migration occurs and can be interacted with to quickly share files and applications. However, if the user ignores them, they automatically disappear after some time. We explore the design space of opportunistic nudges through rapid prototyping and develop a preliminary design space consisting of four stages. Focusing on six design parameters of the Visualization stage, we gather feedback on the concept through an exploratory user study. Results show that opportunistic nudges can be an effective way to reduce the transaction costs of sharing content between devices.

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CCS CONCEPTS

• **Human-centered computing** → **Interaction design**; **Interaction techniques**.

KEYWORDS

multi-device, cross-device computing, distributed user interfaces

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1 INTRODUCTION

Our daily activities with information technology rely on the capabilities and strengths of multiple devices. For example, capturing a photo or video on a phone but editing it on a laptop. Moving between devices for related tasks is referred to as *migration* [8, 40]. However, migrating to other devices can be cumbersome, especially when context needs to be re-established, like re-opening the same files or applications after switching to the new device. Yuan et al.'s exploration of multi-device usage patterns [40] revealed that re-establishing context within a personal device ecology is something users expect to "just work" without requiring much time or effort. In other words, migration should be a seamless experience where the devices are responsible for re-establishing context.

The possible need to migrate to another device can be sensed through hardware; picking up, moving, unlocking, or touching another personal device all suggest that the user's attention and focus is shifting away to another device. Some prior work has focused on technical systems to share files, applications, or panels between devices (e.g., [9–11, 17, 26, 36, 38]). Apple's Continuity features allow users to share documents, applications, device functionalities, and clipboards between their Apple devices [6]. However, prior work suggests that users are largely unaware of how such sharing capabilities work and how they can be leveraged to improve their workflows [8, 32]. Apple's Handoff Continuity feature, which allows users to re-open applications across devices, provides awareness of the possibility to migrate in the form of an icon in the Dock or App Switcher interface [5]. Providing awareness is limited to this specific feature, but there are other ways migration can occur between devices, and different ways awareness can be provided.

To explore these possibilities, we formalize the interface construct of *opportunistic nudges* as a way to share content and functionality across personal devices (Figure 1). They are *opportunistic* as they recognize that the user has performed an action that would likely lead to task migration. Opportunistic nudges may be considered a new type of notification as they provide awareness of an opportunity to share content when migrating devices, however, we believe *nudge* is more appropriate as they are designed to encourage users to share content across devices [37]. The nudging is done by automatically performing most of the steps needed to share content. Presenting the content right as the migration occurs lowers the transaction cost of sharing content, enabling immediate usability [23] of the shared content. By making sharing easy to access, we believe this will encourage users to use migration for more efficient cross-device task workflows. Opportunistic nudges are triggered by actions performed by the user that can be sensed, like picking up, moving, or tilting a device. They appear in the bezel of all devices within a personal device ecology and can take on different visual representations, like a gradient, icon, or thumbnail. When a nudge appears, the user can choose to interact with it to share content across devices. However, if they choose to ignore the nudge, it slides off the screen or fades away automatically after a few seconds.

We explore the design space of opportunistic nudges through rapid prototyping and a series of demonstration applications focused on four key scenarios: (1) capturing content on one device to be used on another; (2) ad hoc sharing of a device's screen during a meeting; (3) moving content to touch- or pen-enabled devices when such input is required; and (4) sharing text and image selections across devices through a shared clipboard. Through our exploration, we created a preliminary design space for opportunistic nudges and discuss core considerations for timing and animation, position and placement, and appearance. Using the key scenarios, we conducted an exploratory user study. Results show that opportunistic nudges are viewed positively due to their ability to eliminate steps for sharing content across devices and their ability to provide immediate visual feedback of sharing possibilities upon migrating devices. We contribute:

- a preliminary design space of cross-device opportunistic nudges that both organizes findings from related work and guides our prototyping to test and explore a range of nudging techniques and their interaction properties;
- implementation of a range of opportunistic nudge interaction and feedback techniques geared towards example scenarios such as content creation, ad hoc sharing, "pick up to mark up" content by leveraging specific input capabilities on another device at-hand, and sharing clipboard content;
- evaluation insights that demonstrate opportunistic nudges eliminate steps required to share content across devices, reducing the transaction costs of sharing; and that immediate feedback is desirable and highly sought after.

2 BACKGROUND AND RELATED WORK

Our work relates to challenges using multiple devices, micro-mobilities, notifications, and examples of visual nudges.

2.1 Challenges Using Multiple Devices

Migration involves using multiple devices to accomplish a task, such as reading an email on a phone but replying on a laptop [40]. However, re-establishing context, like re-opening files and applications after migrating to a new device, can be frustrating [27, 34]. *Migratory interfaces* [8] allow users to move applications [38], or panels [10, 17] across devices. Many techniques exist like "throwing" [11], portals [36], and trays [26], but they can be challenging to discover and use.

Apple's Continuity features synchronize application state and device input across devices, allowing users to resume tasks as they switch devices, and share functionalities across devices. These include: Handoff to re-open applications after switching devices [5]; Continuity Camera, Continuity Markup, Continuity Sketch, Universal Control, and Universal Clipboard to share camera, pen, mouse, and keyboard capabilities, as well as clipboard state [1–4, 7]. However, users are often unsure how Continuity features could be integrated into their existing workflows and many are unaware that such features exist [32]. Brudy et al. [8] identify awareness as an open challenge for multi-device interaction. Opportunistic nudges are a way to share applications, panels, files, clipboards, and device functionalities across multiple devices, but they expand upon Apple's Continuity features by providing visual feedback after a wider variety of sensed interactions. These properties can improve awareness of multi-device capabilities by visually communicating the potential sharing opportunities in the moment.

2.2 Micro-Mobilities for Sharing

Micro-mobilities are movements done with a physical object to partially or fully show it to or conceal it from another person. In multi-device ecologies, micro-mobilities can be used to enable more nuanced sharing of content between people and their devices [30]. For example, Pass-Them-Around [28] leveraged spatial information

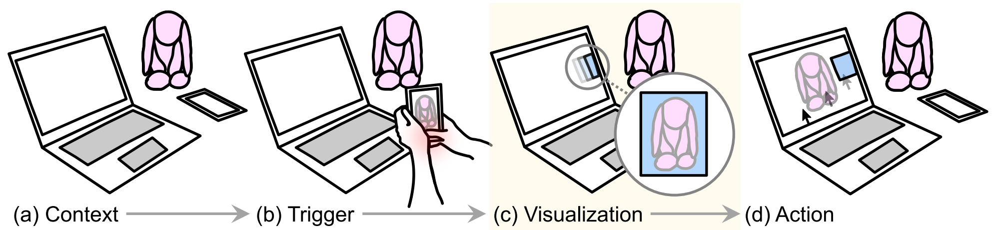


Figure 2: Opportunistic nudges consist of four stages: (a) the *Context* (e.g., two devices); (b) the *Trigger* (e.g., taking a photo); (c) the *Visualization* (e.g., a thumbnail of the photo); and (d) the *Action* (e.g., clicking the nudge and dragging to copy the photo to the laptop). Our work focuses on the *Visualization* stage.

and tilt to 'slide' images to devices arranged in a circle; and Tracko [25] allowed users to 'pour' content with their devices. AirConstellations [29] used proximity, device orientation, and movement to migrate windows and panels across a set of devices. Device grip and the order in which different users hold a device suggest properties related to sharing, like who owns the content being shared [39]. Opportunistic nudges leverage micro-mobilities as well as other techniques, like capturing content, to initiate more nuanced sharing across devices.

2.3 Interruptions with Notifications

Prior work on notifications shows that users are generally tolerant of some disruptions if notifications contain useful information [24]. Identifying the optimal times to show notifications is important to prevent excessive disruptions. Timing, content, and context can all impact how likely a user is to respond to a notification, which can be leveraged to issue notifications at opportune moments [31]. People may be more receptive to notifications when transitioning between physical tasks [22] or just after completing a task, like reading a text message [14]. Opportunistic nudges may have some interruption potential [23]. However, because they are presented when the user switches devices, a state of transition, they may be less disruptive than traditional notifications.

2.4 Other Opportunistic Nudges

There are some examples of nudges in existing products. Taking a screenshot on macOS or iOS causes the captured image to appear along the bezel as a thumbnail, which can be interacted with to open a photo editor. The Side-Channel menu [33] leveraged the tilt of a digital drawing board to show a menu of command shortcuts along the bezel of the device. Pre-touch sensing [20], grip [21], and pens [19] can surface menus to suit the context of use and assumed posture. All of these examples are opportunistic as they take advantage of sensed actions to appear at optimal moments, but they do not support migration as they are used on the same device.

When considering existing opportunistic nudges for device migration, AirConstellations [29] featured several examples of application windows 'spilling' over onto another device that appear as devices are re-positioned. The Tilt-to-Preview technique [30] used tilt to transfer files between side-by-side devices. Apple's Handoff feature nudges users to switch devices by displaying icons of applications that are open on other devices at the bottom of the screen (either in the Dock or App Switcher interface). With Conductor [18], small icons ("cues") appear along the left bezel of nearby devices, which can be touched to pull content to the current device.

These examples of existing opportunistic nudges feature several key properties: they display information in a context-aware manner; they typically appear along the bezel after a sensed contextual cue; interacting with the nudge simplifies migration; and they typically disappear automatically after some time. Our work formalizes these properties and identifies additional key design characteristics.

3 DESIGNING FOR OPPORTUNISTIC NUDGES

We created a rapid prototyping system to quickly explore different nudges and their design properties, and externalize different design scenarios [15]. The prototyping system is a Node.js application, built with the Electron framework. It consists of a control panel with several nudge-related parameters that can be adjusted. We created a server running on a virtual machine hosted on Azure. Using the server, we created a custom shared memory abstraction to synchronize data across devices. Note that we use images to mock up sharing panels and applications to quickly explore a wide variety of scenarios. Consolidating findings from related work, our rapid prototyping, and several group discussions, we create a preliminary design space for opportunistic nudges. Our design space has four stages: *Context*, *Trigger*, *Visualization*, and *Action*. We are primarily focused on characterizing the *Visualization* stage, in which there are six properties: TIMING, ANIMATION, WHICH DEVICE, SCREEN LOCATION, APPEARANCE, and STAGES. Although this design space is still a work-in-progress, it describes the basic structure of opportunistic nudges and provides consistent terminology that can be used and expanded upon in subsequent work.

3.1 Stages (Figure 2)

1. *Context* refers to the context of use before the nudge is displayed to users such as the number of devices in a personal device ecology, their sizes, their distances from each other, and situational factors like location [12, 30, 35].
2. *Trigger* refers to initiating the display of a nudge [16], much like connection actions that initiate cross-device sharing [23]. For opportunistic nudges, this is through a sensed device property. We define two types of triggers: *discrete* triggers (e.g., turning a device on/off, docking/undocking a pen) and *continuous* triggers (e.g., device tilt, distance between two devices). Continuous triggers may allow for more nuanced sharing, similar to micro-mobilities [30]. Triggers can be further categorized into four groups (Table 1).

Table 1: Groups of triggers that can be sensed from devices.

Group	Explanation	Example
Adding or removing a device	Changing the number of devices present.	A device powers on/off.
Repositioning relative to others	Changing the distance, position, or rotation relative to others.	Moving a device closer to another.
Repositioning relative to itself	Changing the orientation of a device relative to itself.	Tilting or rotating a device.
Input and interaction	Interacting with the main user interface of a device.	Using a keyboard or touchscreen.

3. *Visualization* refers to the nudge appearing. We discuss this in detail in the following section.
4. *Action* refers to interactions the user can perform with the nudge after it appears, like tapping or dragging to move content, or inking directly on the nudge to quickly sign a document. These may serve as ways to accept content that has been shared [23].

3.2 Visualization Properties

Six properties characterize key characteristics for the nudge *Visualization*. They relate to (1) how the nudge appears on the screen; (2) where it appears; and (3) how it looks.

3.2.1 How the Nudge Appears (Figure 3).

- TIMING describes how long the nudge takes to (1) appear onto the screen; (2) stay on the screen in its neutral state; and (3) disappear if there is no interaction. All three together make up the full duration to interact with the nudge.
- ANIMATION describes how the nudge appears onto and disappears from the screen. Fading in and out may be less distracting, but sliding in and out may be better mapped to the motion dynamics of certain triggers.

The TIMING and ANIMATION is subject to a Goldilocks Effect: the ANIMATION should be captivating enough to grab the user's attention but not too captivating that it becomes annoying or disruptive. Similarly, the nudge should persist long enough for the user to interact with it, but not so long that it becomes distracting or annoying if the user does not want to interact with it. Prior work suggests that fading on the screen quickly (500ms), persisting for a few seconds (3s) and then slowly fading out (3s) strikes the best balance [33].

3.2.2 Where the Nudge Appears (Figure 4).

- WHICH DEVICE is on which device the nudge is placed. There are two types of devices during a migration: a *source* device, which is the device that contains the application, panel, or file that is shared through the nudge; and one or more *target* devices, which are devices that will receive shared content [17].

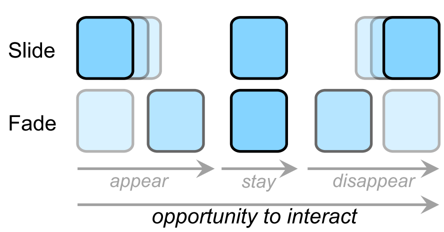


Figure 3: Three stages of TIMING make up the opportunity to interact. The ANIMATION can be mapped to motion dynamics of the trigger.

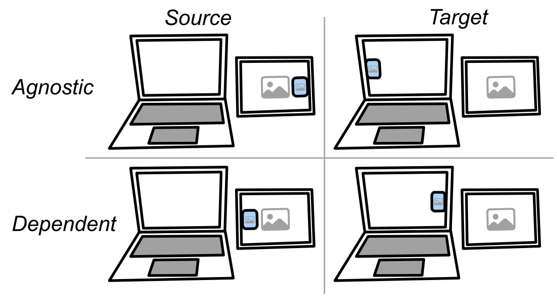


Figure 4: Combining WHICH DEVICE and SCREEN LOCATION creates several possibilities for where along the bezel a nudge should be placed.

- SCREEN LOCATION is the location of the nudge on the screen. Locations that are *device-agnostic* have no dependencies related to other devices (e.g., always appearing in the top right corner), but locations that are *device-dependent* will cause the nudge to appear closest to nearby source or target devices (e.g., appearing along the left bezel of the target device if the source device is to the left).

Placing a nudge on the source device can serve as a 'confirmation' and be beneficial when sharing content with devices that are further away. But placing the nudge on target devices may make more sense when target devices are nearby, so the content can immediately be interacted with on the device the user intends to use next. A device-agnostic SCREEN LOCATION can make it easier and faster for people to interact with nudges and can be optimized to better suit the layout of other applications. In contrast, a device-dependent SCREEN LOCATION can better convey which device is the source or target device when there are more than two devices in the device ecology.

3.2.3 How the Nudge Looks (Figure 5).

- APPEARANCE is the visual style of the nudge, like a gradient 'glow' effect, and other representations of the content (e.g., icon, thumbnail, or entire files, menu items, or applications).
- STAGES is the number of APPEARANCES the nudge will transition between; for example, starting with an ambient glow and then displaying a thumbnail. Transitioning between stages occurs as the user continues to perform the trigger-mapped action, meaning multi-stage nudges are only compatible with continuous triggers.

Some APPEARANCES are not ideal for smaller devices (e.g., thumbnails or entire menus and applications), and similarly, others are ideal in public spaces where privacy is a concern. Having multiple STAGES can act as feedforward, providing additional awareness of the possibility for migrating but requires more time and effort from the user.

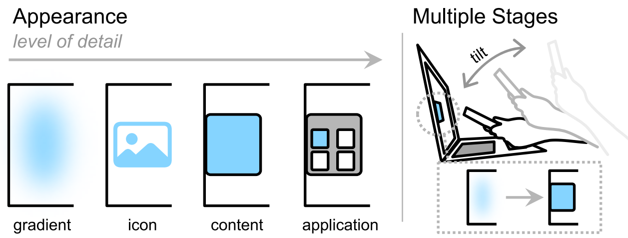


Figure 5: Different APPEARANCES convey more or less detail and may be suitable for *Contexts*. Multiple APPEARANCES can be used when there are multiple STAGES, acting as feedforward for a continuous *Trigger*.

4 EXEMPLAR SCENARIOS

We explored four common and compelling scenarios for using opportunistic nudges. All represent cases where people would want to migrate devices or use multiple devices at once, and were created using our rapid prototyping system.

4.1 Content Creation

This scenario is focused on moving content that was captured on one device onto another for additional processing. Once someone captures content on one device, they move this source device closer to another target device to *Trigger* a nudge to appear with a fade ANIMATION. The nudge is placed on the target device (WHICH DEVICE) and the SCREEN LOCATION is dependent on that of the source device. There are two STAGES and therefore two APPEARANCES: a gradient glow when the source device is further away, and a thumbnail or application when the source device is closer to the target device. The user can perform an *Action* on the nudge, like a drag and drop to move content to the target device. The *Trigger* could also be pressing a button to capture content, a binary trigger. The captured content appears right away on the target device, without a preliminary gradient visualization (i.e., single STAGE and APPEARANCE). This could be beneficial in cases where the user is working in creativity applications like video or photo editing software on their laptop and needs to capture media in the spur of the moment with their phone (Figure 6a).

4.2 Ad Hoc Sharing

This scenario is focused on sharing content on one device onto another device during a meeting for others to view. To *Trigger* the nudge, the user tilts the source device forward, toward the target device. Tilt is mapped to the nudge ANIMATION, meaning the nudge slides up or down to reveal more or less of itself for larger and smaller tilt angles. The nudge can either be the source or target device, depending on how close the devices are (WHICH DEVICE), and the SCREEN LOCATION is dependent on that of the source device when placed on the target device. The nudge appears in one STAGE and its APPEARANCE is a thumbnail image. The user can perform a drag *Action* to share content with the target device. This could be useful during an in-person or remote meeting, when an attendee wants to share brainstorming artifacts, notes, sketches, or other annotations on their tablet with their collaborators in the moment (Figure 6b).

4.3 Pick Up to Mark Up

This scenario is focused on moving documents or applications to another device when specific input capabilities are required but unavailable on the source device. Picking up the target device will *Trigger* the nudge to appear with a fade ANIMATION in a single STAGE. The nudge is placed on the target device (WHICH DEVICE) and its SCREEN LOCATION is dependent on that of the source device. The APPEARANCE resembles the entire document 'spilling' over the edge of the screen [29]. The user *Actions* include pulling the document out to reveal a smaller 'preview' of the document in the bezel, or pulling it to the center of the screen to reveal the full-sized document. This could be useful for quick inking activity, like reading a document on a laptop but signing it on a tablet, or to share tablet inking activities with a large display that is further away during a meeting (Figure 6c).

4.4 Sharing Clipboard Content

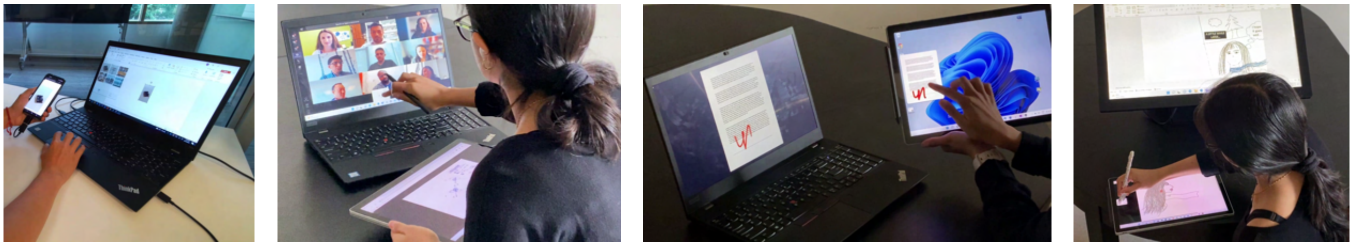
This scenario is focused on sharing clipboard content across multiple devices. The nudge will *Trigger* after issuing a copy command with a keyboard shortcut or by pressing a UI element. The nudge ANIMATION is a fade, and will appear in a single STAGE. The APPEARANCE is a small thumbnail preview of the copied content. We consider when the nudge is placed on both the source and target devices (WHICH DEVICE), but the SCREEN LOCATION is agnostic of that of the source device. This could be useful when merging smaller sketches created on a tablet when on the go with a larger, stationary drawing board; or when copying links or passwords across devices [40].

5 STUDY

We conducted an exploratory study based on first impressions to gather feedback on opportunistic nudges and to better understand user preferences of different *Visualization* properties. We recruited 7 participants within our organization (4 men, 3 women) across the following age ranges: 18-29 (2), 30-39 (3), 40-49 (1), 50-59 (1). All participants were screened for owning at least 2 devices. To have a wider range of *Situations*, *Triggers* and *Visualizations*, we tested multiple variations of opportunistic nudges for some scenarios (Appendix A.1). We set up multiple stations within a large room. Each station was focused around one exemplar scenario or variation. Each station involved pairs of devices varying in their form-factor and placement in the room. For the Content Creation variations, the participant watched three videos of the variations on a large screen due to technical constraints.

5.1 Procedure

The participant tried each scenario and variation and the order was randomized. The experimenter did not demonstrate or explain in order to observe first impressions; rather, the experimenter instructed participants to pick a device or start completing an action as they would normally and probed them to talk aloud as to what they noticed what they thought was happening. The experimenter then worked with the participant to customize the nudge design using PowerPoint. After setting a parameter (e.g., nudge size), the experimenter replayed the nudge experience multiple times, allowing



(a) Content Creation (b) Ad Hoc Sharing (c) Pick Up to Mark Up (d) Sharing Clipboard Content

Figure 6: Prototyped scenarios: (a) content shared through device proximity; (b) ad hoc sharing with tilt; (c) sharing documents and applications when a touch- or pen-enabled device is picked up; and (d) sharing clipboard content after a copy command.

the participant to iteratively adjust their design. The entire study lasted around 90 minutes. Participants received $40.

5.2 Results

Overall, opportunistic nudges were positively received. Participants valued the way opportunistic nudges bridged multiple devices together, e.g., *"I want this. It is already there [on the other device] like it just should be"* (P1). This is encouraging, as it suggests that the nudging technique would be successful at encouraging people to take advantage of the strengths of multiple devices. Some participants noted that they had very established setups for some of these scenarios, such as sending themselves files and snippets over cloud storage or through messaging applications. But multiple participants commented on the uncertainty of their existing methods, e.g., *"I do not know when it is gonna be there, so I wait, I am just waiting because it may arrive soon but sometimes [it doesn't]"* (P5), which aligns with prior work [8, 32]. As such, opportunistic nudges were valued for the immediate visual feedback they provided, e.g., *"we are used to [having] immediate feedback when we work, do things on computers and this is what I would expect"* (P1).

5.2.1 Nudge Design in PowerPoint. Participants commented on several key factors and for some properties, their designs converged. For ANIMATION, all participants used a slide animation and for POSITION, five participants believed it should be device agnostic, which may have been preferred as participants would have been familiar with these mechanics from native device notifications. For WHICH DEVICE, the preferences were more varied. Three participants wanted the nudge to appear on the device they are interacting with or holding, regardless of whether it was the source or target. Another three participants thought it depended on either the task or the type of devices being used. For APPEARANCE, five participants preferred a thumbnail image. Six participants preferred nudges with multiple STAGES.

5.2.2 Summary. Our conclusion from participant feedback is that most attractive qualities of opportunistic nudges were **(1) eliminating steps** for migration and **(2) providing immediate visual feedback** after switching devices. Weaker aspects mostly focused on the design of the nudges. Nudge design can be optimized based on participant feedback, like focusing on sliding ANIMATIONS, device agnostic POSITIONS, and thumbnail APPEARANCES with multiple STAGES, enabled by continuous *Triggers*.

6 DISCUSSION

Our work shows that opportunistic nudges are a promising way to provide awareness of how multiple devices can work together. Our preliminary design space outlines key considerations for opportunistic nudges and provides terminology that can be used. Feedback from participants suggests that they are valuable. That said, this is a preliminary investigation, and more work is needed to further understand other elements of design, such as identifying key characteristics for the *Context*, *Trigger*, and *Action* stages. In addition, reflecting on the preliminary design space may lead to additional characteristics to consider [13].

Nudges could facilitate sharing between devices owned by multiple people. This has additional implications for privacy, which would impact the design of the nudge; the nudge would likely have to always be shown on the source device, and additional information of the target device, like who the device belongs to, would have to be represented in the nudge as well. Other forms of context could be used as well to suggest sharing content between devices, like the user's history of using applications and devices, or their personal calendar. Authoring tools could allow users to map a wide variety of triggers to multi-device experiences [16]; users could use these additional forms of context to form "routines" for device migration, much like Amazon Alexa Routines. Our current study was limited in the number of participants, scenarios, and time spent using opportunistic nudges, so a longitudinal study with a wider range of tasks and more participants could reveal more benefits and design challenges. Opportunistic nudges could also be compared to other visual prompts, like standard operating system notifications, to better understand public perceptions.

7 CONCLUSION

We presented *opportunistic nudges* as a way to share content between devices upon migration. Through rapid prototyping, we created a design space consisting of four stages and six factors and implement multiple design variations focused around four key scenarios. We gathered feedback on the concept and design of opportunistic nudges and found that they were positively received as they eliminate steps for migration and provide immediate visual feedback.

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A APPENDIX

A.1 Scenarios Tested

- **Content Creation**: revealing a glow and then a photo thumbnail with proximity; revealing a photo thumbnail the moment the photo is captured; and revealing the entire photos gallery when a photo is captured.
- **Ad Hoc Sharing**: sharing from a tablet with a nearby laptop during a remote meeting; and sharing from a tablet with a large display further away during an in-person meeting.
- **Pick Up to Mark Up**: sharing a document as a smaller preview; sharing a full-sized document; and sharing a whiteboard application during an in-person meeting.
- **Sharing Clipboard Content**: sharing an image selection from one tablet to another.