Supporting Mobile Sensemaking Through Intentionally Uncertain Highlighting

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ABSTRACT

Patients researching medical diagnoses, scientist exploring new fields of literature, and students learning about new domains are all faced with the challenge of capturing information they find for later use. However, saving information is challenging on mobile devices, where the small screen and font sizes combined with the inaccuracy of finger based touch screens makes it time consuming and stressful for people to select and save text for future use. Furthermore, beyond the challenge of simply selecting a region of bounded text on a mobile device, in many learning and data exploration tasks the boundaries of what text may be relevant and useful later are themselves uncertain for the user. In contrast to previous approaches which focused on speeding up the selection process by making the identification of hard boundaries faster, we introduce the idea of intentionally supporting uncertain input in the context of saving information during complex reading and information exploration. We embody this idea in a system that uses force touch and fuzzy bounding boxes along with posthoc expandable context to support identifying and saving information in an intentionally uncertain way on mobile devices. In a two part user study we find that this approach reduced selection time and was preferred by participants over the default system text selection method.

Author Keywords

Annotation; copy-paste; saving; capture; information; sensemaking; highlighting.

ACM Classification Keywords

H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

INTRODUCTION

Patients researching medical diagnoses, scientist exploring new fields of literature, and students learning about new

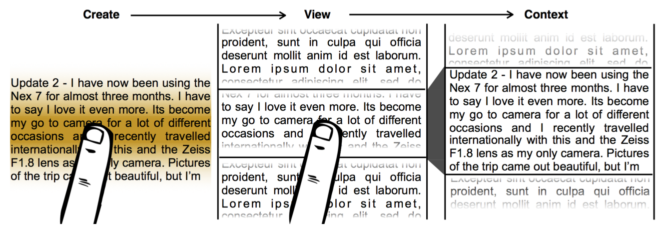

Figure 1. Highlighting with intentionally fuzzy boundary and a viewer that supports resolving uncertainty.

domains are all faced with the challenge of capturing information they find for later use [3]. Studies of information foraging [19] and active reading [17] have identified the importance of collecting snippets of information while exploring and reading from multiple sources for comparison, cross-referencing, and structuring [11, 1, 26, 12]. As reading and learning increasingly moves from handwritten notes and highlighted pages into web search and browsing, tools for supporting the curation and storage of online information have grown in popularity. For example, one well known tool for extracting snippets of information from web pages – Evernote Web Clipper – had over 4 million users on the Chrome desktop browser alone[1].

The need for reading and capturing information has expanded beyond the desk to domains where mobile devices are prevalent, such as in bed or at the kitchen table [1, 26]. Despite this need, identifying and saving snippets of textual information remains challenging on mobile devices. Small screens and font sizes combined with the inaccuracy of touch interfaces make selecting and saving text both time consuming and stressful. To understand the prevalence of text highlighting scenarios on mobile devices today, we conducted a survey with 153 participants (age 20-59, mean 32, 60% male, 76.5% from the U.S.) asking for their experiences with complex exploratory searches [15] on smartphones. Our results suggest that people frequently conduct complex searches either partly (70%) or completely (45%) on their phones. When asked about what makes these searches difficult, near half agreed that "*Selecting part of a webpage and save it*" is either moderately or extremely difficult, and 41% thought it would be valuable to have a better interface for it.

Approaches to improving capture interfaces have, to date, focused on improving the speed and accuracy of specifying

[1] http://chrome.google.com/webstore/

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the start and end boundaries of the selection area. Such approaches include using bezel or multi-push gestures [5, 21, 7], autocomplete [29], switching windows faster [4, 6], or leveraging the structure of the content to be copied [2, 10, 25]. These approaches are well suited for fast and simple copy-paste needs, such as copying an address from one application and pasting it in another.

However, in many learning and exploration tasks, people are uncertain about which and how much information to save. Early in the process, before a user has a good sense of the topic space, they might save information that later turns out to be irrelevant, or they may be uncertain about how much information on a particular page may be needed in the future [12]. For example, a researcher might extract a particular finding from a paper early in their exploration process, only to realize later that they also need the author's statistical model from the following paragraph. Conversely, over-selecting text that does not prove to be useful later can lead to additional effort in sifting out useful information from extraneous chaff (for example, in the limit if the entire page was selected and saved then the user would have to do all the filtering again). Furthermore, forcing a user to choose hard selection boundaries requires them to carefully predict their future information need, which can involve high cognitive effort [24]. Indeed, in a pilot survey, we found 11 out of 19 participants had trouble in the past identifying how much text to highlight. Additionally, 13 out of 19 mentioned that they had needed to return to a document to read additional text in order to understand the selections they created in the past. These findings suggest that these considerations are commonly encountered. Adding to the challenge, interactions for gathering information while reading need to be quick and low effort, otherwise people tend not to capture information in the first place [16, 27, 9].

In this paper, we introduce and explore the concept of intentionally supporting uncertain input in the context of selecting and saving information during information exploration on mobile devices. We investigate the idea that in contrast to more defined selection tasks (such as copying an address or phone number), precise selection may not be the most appropriate interaction paradigm for complex learning and reading tasks. In doing so we build on previous approaches that support fuzzy input, encourage lower granularity selection (e.g., lines of text vs. characters), or defer action until later [22, 13, 27, 9, 12, 23] In contrast to approaches which take uncertain input and maintain its uncertainty to be resolved later (e.g., [23]) in which the user intention is certain but the input is not, we suggest that there are cases in which the user intention is itself uncertain and resolving user input is inappropriate. This approach frees us to consider alternate ways to support selecting and saving information, especially on mobile devices where selecting and saving can be challenging for users.

Specifically, we explore two ways in which we can design for intentionally uncertain input. One is to support uncertainty in the selection interface through a fuzzy bounding box. This allows a user to feel less stressed about exactly where the boundaries of their selection lie and may reduce the need for careful prediction of their future information need. Another way is to support uncertainty in retrieval by saving context around the selection area and surfacing it later. We explore the tradeoffs of these two approaches and their interaction through a controlled experimental study.

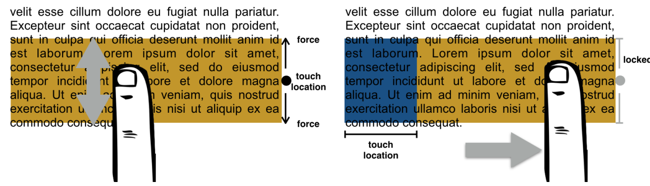

Figure 2. Selecting and saving text using force to set the selection area (left) then sliding right to lock it.

Furthermore, we introduce the idea of using pressure-sensitive touch as a new interaction approach for specifying selection boundaries. Pressure is particularly interesting as a modality because it has the potential to allow the fast selection of an area of interest while relaxing the cognitive and physical constraints of needing to specify exactly what should be saved. One potential drawback of such an approach is missing the information needed later due to inexact boundary selection, which motivated the idea of expandable context when reviewing snippets later.

In the rest of the paper, we will first describe the specific design of a system that embodies intentionally uncertain input in both selection (through pressure-sensitive touch selection) and retrieval of information. We then describe a two-part user study in which we investigate the performance of the two types of interfaces for a low-uncertainty task (targeted copy-paste) and a high-uncertainty task (exploratory search).

SYSTEM DESIGN

In this section, we introduce a new highlighting interaction that supports intentionally uncertain selection. Our aim with this technique is to reduce the stress and increase the efficiency of saving information for future use while exploring and learning new information. The explain this interaction, we break up the process of highlighting into three separate steps: initiating selection mode, indicating the start and end points, and saving the selected text. In the remainder of this section, we will give a high level overview of the proposed highlight interaction, and then discuss the different design options we explored for each step in the interaction.

Selection Interface

The proposed interaction is composed of three steps, which align with the above mentioned process (Figure 2):

1. Users initiate selection mode with a pressure (force) touch on the general area of interest.
2. Once selection mode is enabled, they then estimate the amount of context needed in the future by controlling their force while moving their fingers vertically to fine-tune the start and end points.
3. Finally, they swipe horizontally to confirm and save the information.

We explored three options for initiating text selection mode. One way is to use a simple touch gesture to start text selection, and swipe your finger across select text. This is analogous to using a highlighter pen to highlight text on papers. However, on a smartphone this may conflict with a number of gestures in reading mode, such as scrolling or canceling a tap on a hyperlink. The second option is to use the time dimension to initiate text selection to avoid conflicts with the reading mode gestures, such as tapping and holding at the same location for 500 milliseconds on iOS and Android devices. However, this will add an inherent cost to every highlight the user creates. 500 milliseconds might seem like a low cost if text selection is rarely needed. However, when people engage in complex sensemaking tasks, such as exploratory search, they often have the need to save pieces of information frequently in a short period of time [28]. The third option is to use the force dimension, which is beginning to appear in mass market products, to trigger text selection. This has the benefits of having no conflict with existing reading mode gestures and virtually no time delay. Consequently, we choose the third option for initiating our text selection phase.

In designing the interaction for the selection mode, we explored four options for indicating the start and the end points. The first option is to use two draggable handles for indicating the start and the end positions, and the second option is to use the initial touch location as the start point and the release location as the end point. Both approaches are used by many current touch systems, but both suffer from the inaccuracy of finger based touchscreens (minimal target area of 44 by 44 pixels) and the small font size (default of 17 points, or 34 pixels on iOS), making it difficult to physically pin-point the intended characters. Further, the finger view-blocking problem makes it difficult to for user to do fine-grained adjustments. To avoid having the users tap on exact words or characters, we instead chose the third option, which takes the touch coordinates as the center of the selection and uses the amount of force to determine the size of the selection. We explored two sub-options for adjusting selection range based on the amount of force. We first tested using force to adjust selection range at the character or word level. However, it was difficult to keep track of the start and the end points at the same time, especially near the beginning and the end of each line. The second option is to use force to adjust how many lines are selected. This way, the start and the end boundaries have the same vertical distance to the touch location, and was much easier to keep track of at the same time when adjusting the amount of force used. We tested mapping the same amount of force used to the same number of pixel height and number of lines highlighted according to the font size of the page. The second option made the system more consistent on pages with different font sizes, and also aligns better with our design goal of correlating force with the amount of context required by the user.

Finally, for saving the selection, we explored two options. The first is to have users quickly release their fingers from the touchscreen to save the selected text. Our pilot studies showed this option to be intuitive, and often what the users try first. However, in practice this approach proved challenging as it made capturing the right selection range ambiguous, since the force dimension is also used to control the range of the selection. Similarly, in our lab study some participants encountered similar issues with the built-in text selection, and often accidentally moved the handles when releasing their fingers from the screen. Instead, in our approach users move their finger horizontally across the screen and then release to save the selected text. By using a new dimension, we reduce the chance of accidentally changing the selected range when leaving the selection mode. To reduce the number of dimensions the users need to control, we lock the selection range (both the center location and the size) once the user begins to swipe their finger horizontally.

Previous work has shown conducting gestures in the force touched state can be laborious [14]. However, in our design, we only make use of the Y dimension movements during the selection mode, and we lock both the Y dimension and the force dimension when the user starts moving their fingers horizontally in the saving mode (Figure 2). User studies showed that participants were both able to efficiently create highlights using the proposed mechanisms, and prefer using the proposed interaction over the built-in text selection feature with draggable handles for highlighting information during a complex sensemaking task.

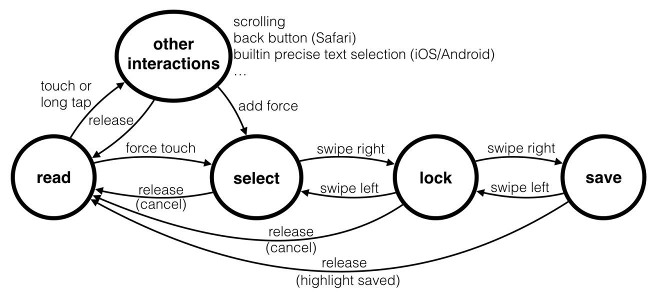

Figure 3. State transition diagram.

Figure 3 shows the states and transitions of the proposed interaction. Notice that the proposed interaction does not interfere with common reading interactions, such as vertical scrolling or horizontal swiping (backwards and forwards buttons in Safari). In addition, the proposed interaction can also co-exist with common precise text selection methods (both commercial and academic) that are initiated with long taps or edge taps [5]. We will discuss about supporting multiple selection methods in the discussion section.

Intentionally Uncertain Boundary

We explored designing for uncertainty in two complementary ways: through a fuzzy boundary during highlighting, and through an expandable context during review. To explore uncertain input as a design consideration for highlighting, we introduced a fuzzy boundary in the selection mode (Figure 1). By intentionally hiding the hard boundaries from the user, we hope to free them from engaging in the difficult task of determining exactly how much context they will need when creating highlights, and postpone uncertainty resolution until the users review the saved information with a better idea of how much context they need. To achieve this, whenever the user creates a new highlight, the system will also save its surrounding text as context. To give users dynamic access to the context when reviewing, we made a simple highlight list interface that allows the users to use force touch gesture to expand the viewport and request for more context. The idea is that knowing they will have the chance to adjust the amount of context for each highlight during the review process, it will reduce both the cognitive stress and physical interaction load of creating highlights with exact boundaries.

USER STUDY

We conducted a two-part lab study to evaluate three highlighting methods for saving information during exploratory search for later use: force touch with hard boundary, force touch with fuzzy boundary, and system selection. The first part of the study tested the overall interaction workload without the cognitive demands of exploratory search, while the second part added simulated exploratory search behaviors. In the first part, individuals were given articles and asked to highlight random portions selected by the system for 20 minutes. In addition to collecting data, this served to train participants to use the three modes efficiently. In the second part of the study, participants were given a complex sensemaking task involving reading multiple articles and creating their own highlights. Afterwards, they reviewed their highlights using either an interface which showed expanded context around their initial selection or that only included their original selection, and wrote a short summary integrating the content of the articles.

We implemented the proposed technique on an iPhone 6s Plus running iOS 9.3.3 through a custom native app that uses the standard WebKit browser for the reader interface. Force touch highlighting was implemented in Javascript by accessing pressure sensor data through WebKit APIs and injected into the WebKit reader using Cocoa APIs.

Demographic

We recruited 24 participants from a local behavioral research participant pool. Participants ranged in age from 18 to 59. The majority of the participants were either undergraduate or graduate students, 11 female and 13 male. Participants were required to be fluent in English and use a smartphone as their main mobile phone. Based on self-reporting, 14 were Android users and 10 iPhone users.

Lab Study Part 1: Training and Interaction Cost

In the first part of the study, we evaluated the interaction cost of three highlighting methods: force touch with hard boundary, force touch with fuzzy boundary, and system selection. To remove the effects of prior knowledge and the cognitive demands associated with learning new information, the system marked random portions of article in red and asked participants to only highlight the red sentences without actually reading the article. Participants were required to highlight the sentences completely without highlighting surrounding sentences in order to proceed.

Before the study began, individuals filled out a pre-survey for demographic information and how they currently used text selection or highlighting on their smartphones. During the study, participants were given a minimum of 24 pages (8 for each mode) in random order. On each page there were four highlight targets (32 for each mode). We also randomized the font sizes (30px, 38px, 47px), page layout (with/without photos), and location and size of the targets (3-8 lines). If they finished highlighting the 24 pages under twenty minutes, more pages with random conditions were provided. Afterwards, participants filled out a NASA TLX survey for each highlight mode [8] to measure cognitive load.

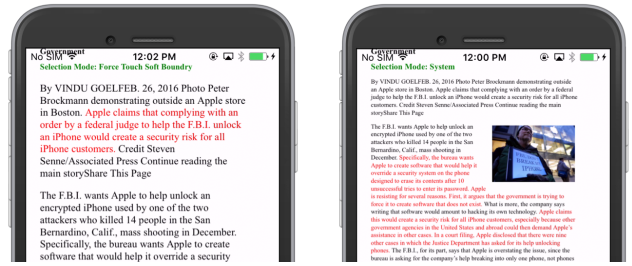

Figure 4. Examples from Part 1 of the lab study, where participants were asked to create highlights covering the red lines. Pages varied in conditions including font size and page layout.

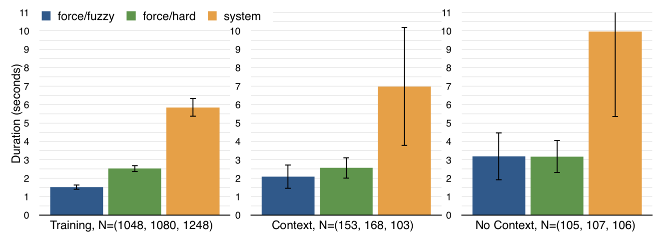

Figure 5. Average time spent creating highlights in each condition: training in part 1 (left), the context condition in part 2 of the study (middle), and the no context condition in part 3 of the study (right)

Results

Table 2 shows the pre-survey responses from 24 participants about their smartphone text selection habits and opinions. The results show that many users find it frustrating and time consuming to use the text selection feature, and they are unable to do it efficiently or frequently. However, 22 out of the 24 participants agree that they would copy or highlight text more often if it was easier to do so. This suggests a strong need for saving information for future use on smartphone devices, and the lack of an efficient method to fulfill this need.

When asked about the reasons for copying and pasting on their smartphones, 63% of the participants reported copying text for later use with note taking apps or emailing themselves, and 58% reported copying text to share information with friends via social networks, emails, or text messages. For none textual copying and pasting, 54% of the participants reported sharing URLs with friends, and 50% reported saving URLs for themselves. Finally, 21% of the participants reported to not use the copy and paste feature.

Based on 1048 samples for force highlight with fuzzy boundary, 1080 samples for force highlight with hard boundary, and 1248 samples for system selection, the average time to create highlights using the three modes were 1.80 seconds, 2.77 sec-

	Study 1			Study 2 (with context)			Study 2 (no context)		
	Hard	Fuzzy	System	Hard	Fuzzy	System	Hard	Fuzzy	System
Mental	7.43	6.10	9.05	6.78	5.89	8.33	7.50	5.90	10.50
Physical	7.57	6.00	9.05	8.11	5.56	10.22	6.10	3.90	9.20
Temporal	7.90	7.10	9.52	8.22	6.56	11.00	6.50	6.60	9.80
Performance	14.10	15.00	13.43	12.44	14.00	12.11	12.20	15.30	14.30
Effort	8.86	6.76	11.00	7.78	5.00	9.33	6.20	6.10	10.80
Frustration	7.43	5.19	11.52	7.00	4.00	11.00	5.10	4.80	8.90
Overall (0-100)	39.20	31.10	50.14	37.89	27.00	49.89	31.40	27.30	49.20

Table 1. Average NASA TLX scores for three highlighting modes from part 1 of the lab study: Targeted highlighting (left), reading and highlighting with an expandable viewer (middle), and without an expandable viewer (right). Higher numbers mean higher workload or higher performance.

Question	Mean	95% Conf. Int.
I find it frustrating to select text on my smartphone	5.71	[5.19, 6.23]
I find it time consuming to select text on my smartphone	5.50	[4.84, 6.16]
I can select text efficiently on my smartphone	3.17	[2.50, 3.83]
I often copy and paste text on my smartphone	3.92	[3.09, 4.74]
I often highlight text on my smartphone	3.17	[2.50, 3.83]
I would copy or highlight text more often if it was easier to do on my smartphone	5.79	[5.26, 6.32]

Table 2. Self-reported text selection and highlighting habits on a 7-point likert scale. A higher score indicates stronger agreement. N=24

onds, and 6.06 seconds, respectively (Figure 5). We analyzed these results using an ANOVA model, where duration was found to be significant different between the three conditions ($F(2,20) = 18.0$, $p < 0.001$). Using a Fisher LSD means difference test, we found the soft boundary selection mode was the fastest, with the hard boundary mode being slightly slower, and system selection being the slowest ($p < 0.001$). Note that these times reflect the constraint that users were not able to proceed without accurate highlighting. No significant differences were found on NASA TLX measures. In the next study, we look at how this new highlighting technique perform when users are actively engaged with the content through a complex sensemaking task.

Lab Study Part 2: Exploratory Information Seeking

In the second part of the study, individuals were asked to highlight important information while researching a new topic, and to write a short summary using the highlights they created. Half of the participants were given the reviewing interface in which they could expanding context surrounding their original highlights.

First, participants completed a pre-survey about their experiences and opinions about saving information for future use on mobile devices. Before they started on the main task, individuals were given six highlights we created from the Planet Habitability entry from Wikipedia and asked to write a short summary of the six highlights in five minutes. This was to ensure the participants in the context condition were aware that they could resolve uncertainty when reviewing their highlights when they wrote the summary. Finally for the main task, participants were given three pages to read, each containing two Amazon reviews for a different camera. Participants were told they had 15 minutes to read and highlight each source, and all three sources were of similar length, so they should spend roughly five minutes on each page. Each page required the participants to use a different method to create highlights; both the pages and modes were given in random order. After 15 minutes, participants were given 10 minutes to review their highlights, rank the three cameras, and explain their reasoning. The instructions were as follows:

> "You have a friend who is looking to buy a new camera for taking pictures of his/her young kids at birthday parties. Using the highlights you saved, rank the three cameras, and write a short summary to explain to your friend how and why you ranked them this way."

After writing the summary, individuals answered a NASA TLX survey for each highlight mode according to when they were created their own highlights on the camera articles, as well as a questionnaire about the three highlighting modes and highlighting information in general.

Results

A total of 19 individuals participated in the part 2 of the study, where 10 of them were given the highlight review interface with that supports expanding viewport for more context, and 9 of them were given a highlight review interface with static viewports. All of the 19 individuals also participated in part 1 of the study, and had twenty minutes training of the three highlighting modes. Using a 7-point likert scale, user reported strong preference over having a uncertain input for highlighting during the complex sensemaking task of ranking digital cameras. On average, participants agrees (5.89/7.00) that the force mode with fuzzy boundary makes it less stressful comparing to force mode with hard boundary and the system selection mode, and find (5.32/7.00) using the force touch with fuzzy boundary mode to be fun (Table 3). When asked about which of the three highlighting mode they would use in the future if they need to read articles and learn new things on their phone, 15 of the 19 participants chose force touch with fuzzy boundary, 4 chose force touch with hard boundary, and 0 chose the system selection feature. In both conditions, only two participants chose the force highlighting mode with hard boundary, suggesting that even without the a way to resolve uncertainty when reviewing the saved information,

Question	Mean	95% Conf. Int.
Soft boundary makes it less stressful to create highlights comparing to the other two modes	5.89	[5.25, 6.54]
Hard boundary (force and system) makes it less stressful to highlight comparing soft boundary	3.00	[2.25, 3.75]
Using the system selection mode for highlighting makes it less stressful to create highlights	2.05	[1.51, 2.60]
Its fun to use the force touch with hard boundary mode to create highlights	3.58	[2.77, 4.39]
Its fun to use the force touch with soft boundary mode to create highlights	5.32	[4.61, 6.02]

Table 3. Survey question about certain and uncertain boundary using a 7-point likert scale. A higher score indicates stronger agreement. N=19

some participants still prefer uncertain input while selecting and saving information. Below are representative quotes from participants about the soft boundary force touch interface:

> "The soft boundary took a bit of getting used to, but once I got the hang of it it made things go a lot faster. It took away the pressure of getting the exact lines right, and let my intuition take over about how much needed to be highlighted "

> "The soft boundary is my favorite, because it is the least physically taxing, least mentally taxing and if I'm going to highlight in an article it just has to be generally around what I want not perfect, so this was my favorite."

> "I hated how exact you had to be with the hard boundary. It was just a huge pain. The soft boundary is so much better. I never realized how much I hated the generic copy and paste mechanisms. "

We also asked the participants to fill out a NASA TLX survey for each of the three modes after writing the summary. To understand the workload effects, we utilized a generalized linear model to evaluate the differences between context vs no context, and the different modes of highlighting. In the results of the model, context was not found to be a significant factor ($F(1, 17) = 0.07$, $p = 0.789$), however the highlighting mode was ($F(2, 17) = 11.25$, $p < 0.01$). Additionally, was no interaction effect between the level of context provided and the highlighting condition ($F(2, 17) = 0.29$, $p = 0.749$). In order to understand the difference between the three highlighting modes, we ran a Fisher LSD means difference test, and found both the force touch soft ($t(17) = 4.66$, $p < 0.01$) and the force touch hard ($t(17) = 3.10$, $p < 0.01$) conditions to be significantly easier at $p < 0.01$ than the system selection feature. There was no difference ($t(17) = -1.56$, $p = 0.128$) between the two force touch highlighting conditions.

DISCUSSION

We investigated the idea of interfaces that support intentionally uncertain input in the context of complex reading and sensemaking tasks, where precise input may be undesirable because it mismatches the high level of uncertainty in users' understanding of the topic space, leading to stress and poorer selections. To do so we developed a system in which users could highlight information on a mobile phone using force touch, and manipulated whether the boundary was hard or soft. We also manipulated whether when they reviewed their highlights they could query for additional context around their highlights. Through a two-part user study we discovered that participants strongly preferred the force touch interaction technique with the soft, fuzzy boundary over the hard line boundary and over the default system selection with hard character boundary. We also found that both force touch highlighting approaches resulted in significantly faster selection speeds than the default system text selection.

While the force touch approach showed benefits in terms of speed, ease of use, and user preference, we also consider the drawbacks of such a solution. We initially hypothesized that people would not like the fuzzy force touch approach if they could not query for additional context later. However, only one participant mentioned this as a negative:

> "I did like the Soft Boundary better because I found it a lot less frustrating, but in the end, I think it is not as practical as the Hard Boundary just because of the accuracy level. It didn't take as much work, but I was also worried if I was able to include everything I wanted to include in the highlight."

Instead, it seemed that most users appeared to adjust for the soft boundary, for example by oversampling the selected text, and were not bothered even when they were not able to adjust context posthoc. This suggests that the soft boundary interface may be useful even with existing review interfaces that do not support posthoc adjustment, but also lead to concerns that the proposed technique promotes mass highlighting, which past work has suggested to have negative effects on learning [18]. By examining the highlights participants created in the second part of the study, we found the proportion of highlighted words did not significantly differ across conditions with absolute numbers trending against the hypothesis: On average, participants highlighted 27% of the camera reviews under the force touch with hard boundary condition, 20% with the system selection, and 19% with force touch with fuzzy boundary, suggesting the fuzzy boundary did not encourage mass highlighting. We analyzed these the highlighted information proportions with a generalized linear model, and did not find the highlighting condition ($F(2,13) = 2.39$, $p = 0.111$), context condition ($F(1,13) = 0.51$, $p = 0.487$), nor their interaction ($F(2,13) = 0.38$, $p = 0.687$) to cause any significant variation in the amount of text highlighted.

Another non-optimal case for this approach is when the task is a strict copy-paste task in which hard boundaries are important, for example copying a telephone number or an address. Therefore, supporting both scenarios the same devices seems crucial for the proposed technique to be practical, and past work has also pointed to benefits of supporting both fine-grained and coarse-grained manipulations with fully-engaged interactions and casual interactions [20]. We believe there are at least two possible interaction paradigms for supporting multiple selection interactions at the same time that can be explored in future work: 1. *Independent sets*. The proposed method does not conflict with many existing academic and commercial techniques (e.g,. edges of a screen[5] or long taps) which do not currently make use of the pressure dimension. Thus each method could be implemented and the user could choose which to use given their current need. 2. *Sequential sets*. The two approaches could be combined by performing a fuzzy selection first and then allowing the users to switch to a precise selection mode to further adjust the boundaries (e.g., using force to select an area including an address, which brings up optional handles to trim off text around the address).

A final limitation we will discuss is the size of the selection area, which is currently fixed to a maximum limit. One participant mentioned this as a concern, stating:

"I really liked both of the force touch modes but at times I felt that the maximum force touch highlight box size was not large enough."

Informally, we noticed that we were able to select reasonably accurately when testing the system with larger size selections than explored in the study. However, it is possible that with a sufficiently large selection jittering from finger tremors or inaccuracy may become problematic. Exploring smoothing and transformation functions from the pressure input to match human cognitive expectations and physical capabilities is a fruitful area of future work. Furthermore, there is an interesting edge case when the selection consists of the entire screen, and whether users consider this a phase transition that should mean the entire page should be saved or simply the highlighted area. Appropriately addressing this concern is something that future work will be need to answer.

Although we have focused here on the particular use case of highlighting information on mobile devices, it is possible that the idea of supporting intentionally uncertain input may have broader implications. The most obvious inference is for information exploration on desktops: although mice or pens as pointing devices make selecting much easier, the cognitive uncertainty of where the boundaries should be drawn remains. There may be other kinds of tasks in which uncertain input may be supported better as well. For example, many applications and operating systems require files and folders to be named as soon as they are created, which can lead to inconsistencies between the name generated early on and what the contents of the file and folder end up being later, with resulting problems in refinding and organizing that information. More generally, we believe that uncertainty in user input should in the future be treated as a design feature, not only a limitation.

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