Exploring the Design Space of Bezel-initiated Gestures for Mobile Interaction

Wing Ho Andy Li
School of Creative Media
City University of Hong Kong
Hong Kong SAR
andy@onthewings.net

Kening Zhu
School of Creative Media
City University of Hong Kong
Hong Kong SAR
keninzhu@cityu.edu.hk

Hongbo Fu
School of Creative Media
City University of Hong Kong
Hong Kong SAR
fuplus@gmail.com

Abstract
Bezel enables useful gestures supplementary to primary surface gestures for mobile interaction. However, the existing works mainly focus on researcher-designed gestures, which utilized only a subset of the design space. In order to explore the design space, we present a modified elicitation study, during which the participants designed bezel-initiated gestures for four sets of tasks. Different from traditional elicitation studies, ours encourages participants to design new gestures. We do not focus on individual tasks or gestures, but perform a detailed analysis of the collected gestures as a whole, and provide findings which could benefit designers of bezel-initiated gestures.

Author Keywords
User study, design space, bezel-initiated gestures, mobile interaction

Introduction
Bezel-initiated surface gestures have been widely adopted in mobile interfaces. For example, on both iOS and Android, users can activate the notification list by swiping down from the top bezel of a mobile touch screen. A series of bezel-initiated gestures have been incorporated into Windows Phone, e.g., for switching between different applications. It has been reported that bezel-initiated

gestures are fast and preferred by users [2]. Such gestures are complementary to primary surface gestures, since the bezel-initiated nature makes them compatible with direct-touch-based interaction techniques. Although bezel-initiated gestures have already been part of modern mobile platforms, and have been proposed by a number of researchers on designing interaction techniques [2, 6, 15], the design space of such gestures is limitedly studied.

In this paper, we present the design and the results of a modified elicitation study, which explored the users' perception on the design space of bezel-initiated gestures. Our contribution is twofold. First, we introduce a modified elicitation study. Different from conventional elicitation studies, ours is more general to tasks, and is able to encourage participants to design new gestures. Second, by analyzing the results collected from our modified elicitation study, we provide insights to a number of unanswered questions about the bezel-initiated gesture design space: (1) What bezel-initiated gestures will users commonly design? (2) What features will users mainly use for gesture design? (3) What actions are more suitably referred by bezel-initiated gestures? Our study covers the user-defined gestures for a large set of mobile operations in two types of hand-held postures. All participants managed to design proper gestures for all operations, signaling the great potential of bezel-initiated gestures beyond the limited applications explored in the previous works. This is also confirmed by low agreement on the elicited gestures. The results also reveal a set of bezel-initiated gestures adopted by more than 25% of the participants. This gesture set suggests that most users tended to design their gestures in a multi-dimensional design space and utilized features like location, symbolic shape, direction, and speed. We also found that bezel-initiated gestures were intuitively applicable to navigation or abstract tasks. However, it is harder to use bezel-initiated gestures to specify action targets.

Related Work

Bezel-initiated Interaction

A number of research revealed the advantages of bezel-initiated gestures for mobile interaction. For example, Roth et al. [15] introduced *Bezel Swipe* for secondary actions like multi-target selection, copying and pasting. Bragdon et al. [2] found that bezel-initiated gestures, such as *Bezel Marks* and *Bezel Paths*, were more resistant to situational impairments than soft-button-based interfaces. Serrano et al. [17] presented *Bezel-Tap* and demonstrated the benefit of sequential gesture combinations. Bezel-initiated gestures have also been explored to address the limited thumb reach problem [8, 23, 7]. However, there is no suggestion on how to explore the design space and design bezel-initiated gestures in these works. It is not obvious whether initiating from the bezel would be a limiting design constraint to interaction designers or end users. Instead, our work is not about the design of a specific bezel-initiated gesture for a specific task but the exploration of the multi-dimensional gesture design space.

User Elicitation Studies

Conducting user elicitation, or guessability studies, has been a popular way to conceptualize new interaction techniques. This methodology has been adopted to develop touch gestures for tabletops [22], motion and touch gestures for mobile devices [16, 3, 9], mid-air gestures for TVs [21, 10], and body gestures for games [18]. However, our focus is not to develop a gesture set that maps to specific referents. Gesture recall is not our main concern either. Our referents are mainly used as exemplar context for the experiment. Our work is

System
S1. App switch next
S2. App switch previous
S3. Back to previous state
S4. View notifications
Text editing
T5. Toggle upper/lower case
T6. Switch to number
T7. Switch to letter
T8. Select part of sentence
T9. Select all
T10. Delete selected item
T11. Cut selected item
T12. Copy selected item
T13. Paste selected item
T14. Undo
T15. Redo
Video playback
V16. Next video
V17. Previous video
V18. Play
V19. Pause
V20. Stop
V21. Brightness up
V22. Brightness down
V23. Volume up
V24. Volume down
V25. Mute
V26. Seeking
V27. Fast forward
V28. Backward
V29. Full screen
V30. Switch orientation
Web browsing
W31. Next tab
W32. Previous tab
W33. New tab
W34. Close tab
W35. Next page (history)
W36. Previous page (history)
W37. Open link in current tab
W38. Open link in new tab
W39. Activate address bar
W40. Open home page
W41. Add bookmark
W42. Select text
W43. Copy selected text

Table 1: Referents (tasks) used in our user elicitation study.

more similar to the work of Oh et al. [14], which is to find out the gestures preferred by the majority of the users and to understand how people perceive different properties of the gestures. Our work also helps investigate the guessability and intuitiveness of the researcher-designed bezel-initiated interactions, since user-defined gestures are found to have higher memorability [13] and are more preferred by end users [12].

Elicitation Study for Design Space Exploration

We propose a modified elicitation study to help explore the design space of bezel-initiated gestures. We applied priming, production, and game theory into the study. They are described in sections Gesture Design Space, Referents, and Participants' Objective, respectively.

Referents

To examine the potential of bezel-initiated gestures for various tasks, we selected four sets of referents (tasks), covering both actions and navigation-based referents [16], namely, *system*, *text editing*, *video playback*, and *web browsing*. There were in total 43 referents, as listed in Table 1. The gestures designed for the *system* referent set should be globally unique, while those for the rest of the referent sets were only required to be locally unique. For example, the gestures designed for *text editing* could be reused for *web browsing*.

We ensured the exploration of the design space by asking each participant to design a large number of unique gestures. Each participant was required to design at least 19 unique gestures (4 in *system* + 15 in *video playback* (largest group)). It is similar to the *production* technique [11], with the difference that we forced our participants to design large sets of gestures not for each referent but for the whole study.

Gesture Design Space

Since participants might not be fully aware of the capability of mobile devices, which would be an undesired limiting factor, we used the *priming* technique [11], which is to provide participants a list of detectable gesture dimensions to the participants, as summarized in Column *Design Space* in Table 2. Specifically, it included touch location, size, pressure, path length, path shape, movement direction, movement speed, and the number of fingers. Several gesture dimensions (e.g., the number of fingers) are under-explored in the context of bezel-initiated gestures. Note that this list was mainly for inspiration and thus not exclusive. Gestures could be designed by assigning different values to the properties. For example, various gestures could be initiated from different bezel edges, with one or multiple fingers. Sequential combination of gestures (i.e., a bezel-initiated gesture followed by one or more gestures, which were not necessarily initiated from the bezel) could lead to new compound bezel-initiated gestures.

Participants and Apparatus

We recruited 24 paid participants, with 10 male and 14 female, between the ages of 15-26 (mean=21.17, SD=2.75). All of them were frequent users of touch-based mobile devices. Each participant was asked to design a bezel-initiated gesture that represents each referent (Table 1) on a mobile phone. In order to study the effect of hand posture and avoid fatigue, we adopted a between-subject experimental design by equally splitting the participants into two groups of postures, namely, one-handed thumb-based posture and two-handed posture (one hand holding, the other hand operating). In the preliminary study we had conducted within-subject experiments where each participant designed gestures for both postures. However, it took 1.5-2 hours to complete

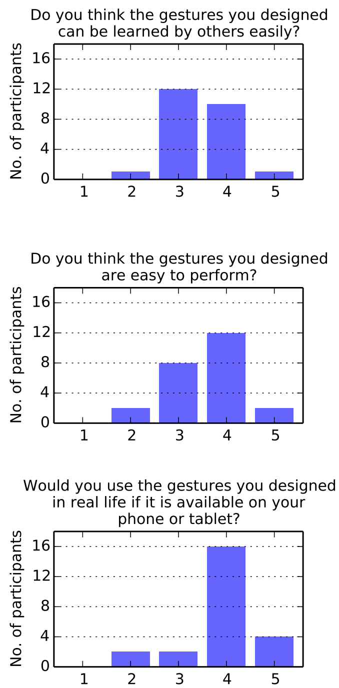

Figure 1: Participants' opinions on their designed gestures.

for each participant. We observed user fatigue affected the quality of gesture design. We also considered asking each participant to design gestures they feel comfortable performing with either of the two postures. However, it could lead to insufficient exploration of bezel-initiated gestures for one-handed posture, as it is easily expected that most of the designed gestures would be for two-handed posture, which is much more flexible.

We used Samsung Galaxy S III as the model phone for the experiment. We developed an Android app for data recording, with a static mock-up interface but no visual feedback so that participants would not be distracted or biased by any existing user interface.The Android app was remotely controlled by a PC software, which was responsible for navigating and displaying referents. The participants' hands were also videotaped.

Participants' Objective
We adopted a game-theory-based method into the study design similar to [5], which prevents participants to design random esoteric gestures. The participants were instructed to design gestures that could best match the design by other participants for the same referents. This strategy aligned with our research focus – to find out the commonly designed bezel-initiated gestures. It could potentially increase the agreement among the gestures designed by different participants.

Procedure
At the beginning of the study each participant was briefed on the purpose of the study and the definition of bezel-initiated gestures. They were informed about the gesture dimensions (Column *Design Space* in Table 2) and introduced to illustrating examples of gestures, at least one example per dimension. The dimensions were explained in a randomized order. We also emphasized the global uniqueness of the gesture set for the *system* referent set and the local uniqueness for the other three gesture sets. We took detailed notes during the study so that participants could easily check the already occupied gestures, which were also allowed to redesign at any point of the study.

The study began with the *system* referent set, the gestures in which would be globally accessible and affect the design of the other gestures, followed by the rest of the referent sets in a counterbalanced order.

At the end of the study each participant was asked to complete a questionnaire to collect their opinions on their designed gestures.

Results and Discussions
Figure 1 plots the post-study questionnaire results. Overall, the answers to all three questions were positive. The participants expressed that the gestures were easy to learn by others, easy to perform, and they wanted to use the gestures in real life.

Formulation of Bezel-initiated Gesture
We collected in total 24 (participants) $\times$ 43 (referents) $=$ 1,032 gestures, 547 of which were unique. All gestures formulated into *GestIT* expressions [20] for further analysis. We made use of the cardinal directions (N, E, S, W, NE, SE, SW, NW), rotation directions (CW, CCW), and shorthands of bezel (B) and corner (C) in the formulation. For example, B_N is the top bezel; C_{SW} is the bottom-left corner.

We defined some basic gestures:

$$\text{Tap} = (\text{Press} \gg \text{Move}^* \gg \text{Release})[\text{smallOffset}][\text{shortDuration}],$$
$$\text{Swipe} = (\text{Press} \gg \text{Move}^* \gg \text{Release})[\text{largeOffset}].$$

Bezel-initiated gestures were defined in the following format

$$\{\text{region}\}\{\text{gesture}\} = \{\text{gesture}\}[\text{from}\{\text{region}\}].$$

For example, a bezel swipe from the top bezel, in downward direction, would be

$$\text{B}_\text{N}\text{Swipe}[\text{dir}_\text{S}] = \text{Swipe}[\text{fromB}_\text{N}][\text{dir}_\text{S}].$$

Additionally, we defined

$$\text{Double}(\{\text{gesture}\}) = (\{\text{gesture}\} \gg \{\text{gesture}\})[\text{sameLocation}],$$
$$\text{TwoFinger}(\{\text{gesture}\}) = \{\text{gesture}\} \parallel \{\text{gesture}\}.$$

Design Space	Number of Users		Major specifications	Minor specifications
	one-handed	two-handed		
Location of touch	12	12	Individual bezel or corners. Side bezels (B_E or B_W). Any bezel. UI elements.	Specific part of bezel (Left/right part of B_N/B_S; top/bottom part of B_E/B_W).
Length of touch path	12	12	Swipe. Tap.	Short swipe.
Shape of touch path (bezel path)	11	11	Circle. Cross. Letters/Numbers. Arrows. Star. Square. Triangle.	Miscellaneous symbols. Scrabble. Chinese characters.
Direction of touch movement	12	12	N, E, S, W, NE, SE, SW, NW.	2-level bezel mark.
Speed of touch movement	9	9	Fast swipe. Slow swipe. Hold at location. Long tap.	
Number of fingers	0	11	Two-finger swipe.	Pinch/spread. Three-finger swipes. Two-finger swipe which the fingers are far from or close to each other.
Touch pressure	1	4	Heavy swipe. Light swipe.	Heavy press at location.
Touch size	1	1	Large swipe by palm or whole finger.	
Sequential combination	11	11	Double gesture. Swipe then tap. Tap then swipe.	Triple gesture. Tap then complex path.

Table 2: Usage of gesture design space.

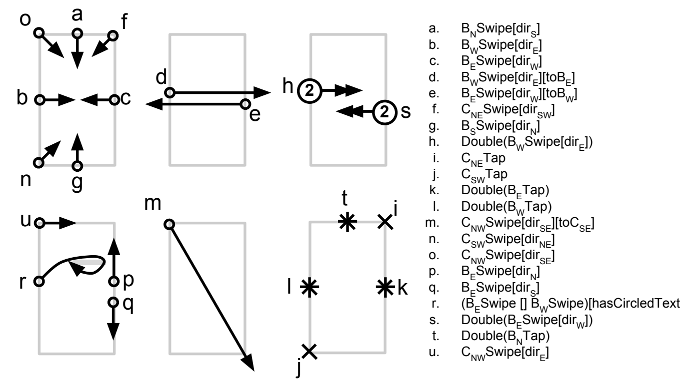

Figure 2: Commonly designed gestures by at least 25% of participants for one-handed thumb interaction, in order of decreasing number of users (a–u).

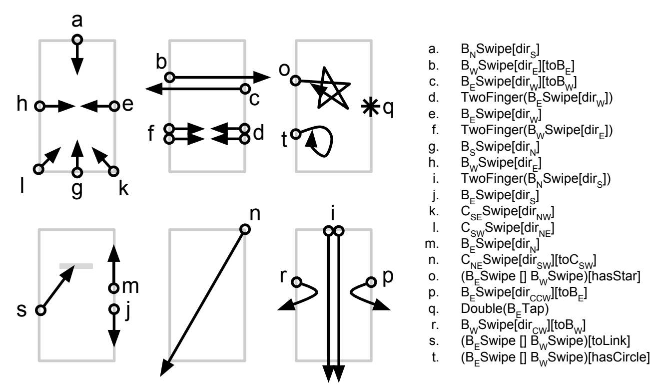

Figure 3: Commonly designed gestures by at least 25% of participants for two-handed posture, in order of decreasing number of users (a–t).

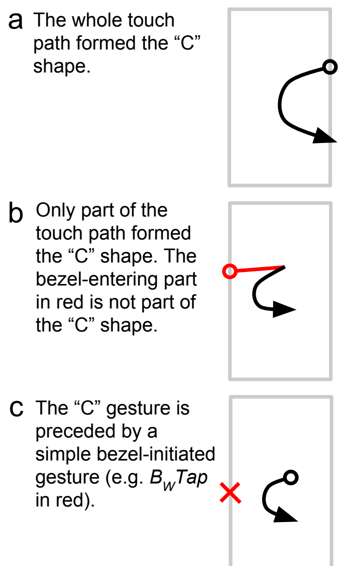

Figure 4: Three ways of performing a bezel-initiated C-shape gesture.

Analysis on Gesture Design Space

A number of gestures were adopted by multiple participants, though sometimes for different tasks. It means that the participants agreed on the gestures but not necessarily the tasks they referred to. The gestures used by at least 25% participants with one-handed and two-handed postures are illustrated in Figures 2 and 3, respectively. They are within the top 10% of the most used gestures among the 547 unique gestures we collected. Many of them (e.g., Figure 2 (d;e;m), Figure 3 (r;p;i)) have never been used by existing works and could be used for designing new interaction techniques. We summarize the usage of gesture design space in Table 2 and give detailed discussions as follows.

Initiation location. 62% gestures were specified to be initiated from only one of the four bezels, while 15% gestures were from only one of the four corners. 13% gestures could be equally initiated from more than one bezel. 9% gestures were started from part of a bezel, e.g., the left/right part of the top bezel, or the bezel part adjacent to the keyboard area. Several participants with one-handed posture mentioned the limited thumb reach problem, i.e., the distant bezels (the top bezel and the side bezel that is at the opposite side of the holding hand) were hard to reach. They suggested that it would be better to have commonly used gestures initiated from the close bezels, or to allow gestures to be initiated from more than one bezel.

Length of touch path. 63% gestures were single swipes, and only 2% of them had length specified (*short* or *long*). 6% gestures were single taps. Others were multiple swipes/taps, or mix of both.

Shape of touch path. 120 unique shape-based gestures, including 11 unique characters (c, p, h, a, etc.) and 25 unique symbols (circle, cross, letters, arrows, etc.), were specified by the participants. The shapes of most touch pathes could be mapped to the semantic meanings of the referents. For example, 42% participants used a star symbol for *W41. Add bookmark*. Since bezel-initiated gestures have a constraint on touch starting point, it may affect the usability of bezel path gesture (shape-based). We recognized three patterns of performing such gestures in our study, as illustrated in Figure 4:

a The whole touch path formed the shape. The starting point had to be the outermost part of the shape, limiting the choice of activation bezel. For example, a C-shape gesture must be initiated from $B_E$when designed in this way. This pattern appeared in 46.32% of all shape-based gestures.

b Only part of the touch path formed the shape. The bezel-entering part of touch path was not part of the shape. In this way a C-shape gesture can be initiated from any bezel. It was used in 49.47% of all shape-based gestures.

c A simple bezel-initiated gesture was first used for activation, followed by a shape gesture, which was not necessarily bezel-initiated. It was used in 4.21% of all shape-based gestures.

Multi-finger gestures. 11 of the 12 participants using two-handed posture designed multi-finger gestures, which were 12% of all the designed gestures. Our finding was somewhat opposite to that of Wobbrock et al. [22] (i.e., "users rarely care about the number of fingers they employ"). This is possibly because the touch table they used had a larger form factor than our smartphone, making their users prefer arm movements to finger

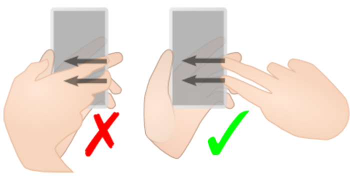

Figure 5: Performing *TwoFinger*(B_E*Swipe*[dir_W]), using an awkward posture (left) and a comfortable posture (right).

movements. Instead, multi-finger gestures are more natural to users when operating hand-held devices.

However, multi-finger bezel-initiated gestures might not always be intuitive to perform. A few participants with two-handed posture found that it was difficult to perform such gestures from the sides. They used an awkward posture to perform those gestures (Figure 5 left), and seemed not aware of an alternative but more comfortable posture (Figure 5 right). We suggest that when illustrating multi-finger bezel-initiated gestures to end users, it is better to demonstrate a comfortable posture since it may not be trivial to discover by themselves.

For participants using one-handed posture, which disallowed multi-finger gestures, we observed that they often adopted repeated gestures (e.g., *Double*(B_W*Swipe*[dir_E])) for tasks that multi-finger gestures (e.g., *TwoFinger*(B_W*Swipe*[dir_E])) were used for. It suggests that gesture designers may provide similar repeated gesture alternatives to multi-finger gestures, in order to support one-handed interaction.

Touch pressure & size. *Touch pressure* and *touch size* were seldom used. We suspect that the participants were less familiar with them, since they had not been commonly used in existing mobile applications.

Mode-switching. Nine participants overcame the bezel-initiation constraint for some of the gestures by prefixing regular (non-bezel-initiated) gestures with bezel taps/swipes. Here the bezel-initiated gestures served more as a mode-switching mechanism, similar to *Bezel-Tap* by Serrano et al. [17]. Two participants, one from each of the two posture groups, used this method to design gestures extensively.

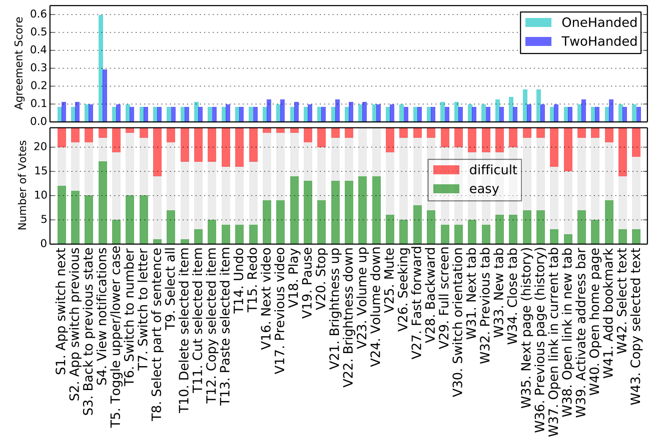

Figure 6: Analysis on referents. S1-S4: System (context-independent). T5-T15: Text editing. V16-V30: Video playback. W31-W43: Web browsing. Top: Gesture agreement score. Bottom: Number of easy/difficult votes.

Analysis on Referent

To compute the agreement score for each referent, we used an equation similar to the one used for computing Simpson's index of diversity in Biology [19]. The score could be interpreted as the probability that two randomly chosen participants used the same gestures. There was generally low consensus on assigning bezel-initiated gestures to referents even when participants thought the assignment was easy. Figure 6 plots the agreement scores and the subjective ratings on the difficulty of gesture design for each referent. The agreement scores of all referents except *S4. View notification* were rather low. The mean agreement scores of the gestures were 0.11 (one-handed) and 0.10 (two-handed). Although we did not have a very large number of participants, but even if the agreement scores of gestures get doubled, they would be still low (~ 0.2). This indicates that bezel-initiated gestures tend to be highly personalized and demand user-dependent training to get familiar with gestures by system designers.

We performed Wilcoxon rank-sum test on agreement scores of the two postures and found no significant difference ($z = -0.29$, $p = 0.78$). For two-handed interaction, the number of *easy* votes was positively correlated to the agreement score (Spearman's $\rho = 0.63$, $p < 0.001$). Similarly, the number of *difficult* votes was negatively correlated to the agreement score (Spearman's $\rho = -0.47$, $p < 0.002$). However, the correlations were not significant for one-handed interaction (*easy*: Spearman's $\rho = -0.01$, $p = 0.96$; *difficult*: Spearman's $\rho = -0.20$, $p = 0.20$).

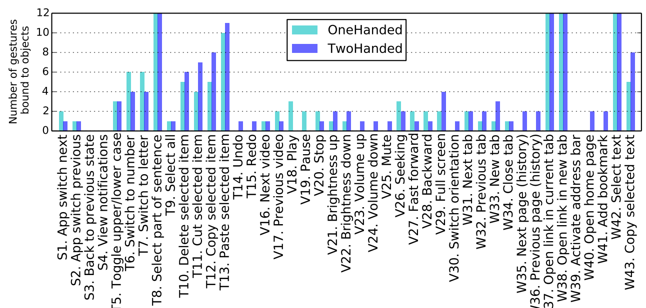

Figure 7: Number of gestures bound to objects.

We observed the effect of legacy bias [11]. *S4. View notification*, for which most of the participants used $B_N Swipe[dir_S]$, had the highest agreement score. Most of them conveyed that they preferred the one commonly adopted in the current mobile systems for consistency. The participants also tended to convert existing popular gestures to bezel-initiated ones. For example, for *previous video* the designed gesture was often $B_W Swipe[dir_E]$, similar to Apple OSX Finder's *Cover Flow*, which uses a simple swipe-right gesture.

We observed that some participants encountered difficulty in binding gestures to objects during the study. A large number of such gestures were complex, though at the end simpler gestures emerged (e.g., Figures 2 (r) and 3 (s)). Specifically, referents T8, W37, W38, and W42 requires gestures bound to target objects. We performed Fisher's exact test and confirmed that the percentage of participants voting those referents as easy to design gestures for (9.38%) was significantly lower ($p < 0.001$) than the percentage of participants voting other referents as easy to design for (37.00%). Similarly, the percentage of participants voted those referents as difficult to design gestures for (38.54%) was significantly higher ($p < 0.001$) than the percentage of participants voting other referents as difficult to design for (14.67%). We speculate that the participants focused too much on satisfying the bezel-initiated constraint but did not immediately realize they could specify the release location. As shown in Figure 7, despite of the difficulty, all participants still managed to bind gestures to action objects, even for referents that were not necessary to explicitly specify target objects, e.g. for *T10. Delete selected item*, where the item to be selected was supposed to be pre-selected. For referents T10, T11, T12, T13, and W43, a large number of gestures were bound to the selected texts. For referents T6 and T7, gestures were bound to the keyboard. It suggests that when there is an obvious action object, people would prefer the gesture bound to it. However, it is not easy to design such bezel-initiate gestures.

Conclusion and Future Work

In this work we explored the design space of bezel-initiated gestures through a modified elicitation study. Our elicitation study incorporated the priming and production techniques to reduce legacy bias and encourage participants to design new gestures. Game theory was used to prevent participants designing random esoteric gestures. Collected gestures are formulated into GestIT expressions and analyzed as a whole. We provided answers to the three research questions mentioned in the introduction section: (1) We found out the commonly designed bezel-initiated gestures for one-handed and two-handed postures, as illustrated in Figures 2 and 3, respectively. (2) We found that the participants were able to design bezel-initiated gestures making use of most of the dimensions in the proposed design space. As detailed in Table 2, the participants mainly utilized location, symbolic shape, direction, and speed, but utilized less touch pressure, touch size, and bezel mark. (3) The results also revealed that bezel-initiated gestures were intuitively applicable to navigation or abstract tasks but it was harder when there was a need to specify target objects. In addition, we provided several suggestions: Commonly used gestures should be initiated from the near bezels, or to allow gestures to be initiated from more than one bezel. Multi-finger gestures were popular among participants and could be explored more, but they might be hard to perform without demonstrations using comfortable postures. Repeated gestures can be provided as alternatives to multi-finger gestures, in order to support one-handed interaction. For individual tasks, designers may convert existing popular gestures to bezel-initiated ones. Whenever there is an obvious action object, bind the gesture to it. These findings will help researchers and designers to develop new interaction techniques by making use of the common user-defined bezel-initiated gestures. Existing bezel-based techniques can be extended and improved by exploring the unused design space.

We also revealed some interesting properties of bezel-initiated gestures that can be further studied, but are out-of-scope of this paper. For the three patterns of performing shape-based gestures, there were fewer occurrences of (c) using simple bezel-initiated gesture to precede a shape gesture. We are not sure whether it was a result of preference or some participants simply did not come up with the pattern. As the participants in our study were mostly young adults with solid touch-screen usage experience, it needs more studies to verify whether children, elderlies, and novice touch-screen users would produce similar results. In addition, it would be interesting to replicate the study in the context of eye-free interaction or in a distractive environment, since bezel gestures are known to be effective in these areas [2, 6]. Another possible direction is to investigate how to ease the difficulty of designing bezel-initiated gestures that bind to an object. Using embodied allegories [4, 1] is a potential method.

References

[1] Bakker, S., Antle, A. N., and Van Den Hoven, E. Embodied metaphors in tangible interaction design. *Personal Ubiquitous Comput. 16*, 4 (Apr. 2012), 433–449.

[2] Bragdon, A., Nelson, E., Li, Y., and Hinckley, K. Experimental analysis of touch-screen gesture designs in mobile environments. In *CHI '11* (2011), 403–412.

[3] Buchanan, S., Floyd, B., Holderness, W., and LaViola, J. J. Towards user-defined multi-touch gestures for 3d objects. In *ITS '13*, ACM (2013), 231–240.

[4] Cafaro, F., Lyons, L., Kang, R., Radinsky, J.,

Roberts, J., and Vogt, K. Framed guessability: Using embodied allegories to increase user agreement on gesture sets. In *TEI '14*, ACM (2013), 197–204.

[5] Chen, X., Saparov, A., Pang, B., and Funkhouser, T. Schelling points on 3d surface meshes. *ACM Trans. Graph. 31*, 4 (2012), 29:1–29:12.

[6] Jain, M., and Balakrishnan, R. User learning and performance with bezel menus. In *CHI '12* (2012), 2221–2230.

[7] Kim, S., Yu, J., and Lee, G. Interaction techniques for unreachable objects on the touchscreen. In *OzCHI '12*, ACM (New York, NY, USA, 2012), 295–298.

[8] Li, W. H. A., Fu, H., and Zhu, K. Bezelcursor: Bezel-initiated cursor for one-handed target acquisition on mobile touch screens. *International Journal of Mobile Human Computer Interaction* (2015), Accepted for publication.

[9] Liang, H.-N., Williams, C., Semegen, M., Stuerzlinger, W., and Irani, P. User-defined surface+motion gestures for 3d manipulation of objects at a distance through a mobile device. In *APCHI '12*, ACM (New York, NY, USA, 2012), 299–308.

[10] Morris, M. R. Web on the wall: Insights from a multimodal interaction elicitation study. In *ITS '12* (2012), 95–104.

[11] Morris, M. R., Danielescu, A., Drucker, S., Fisher, D., Lee, B., schraefel, m. c., and Wobbrock, J. O. Reducing legacy bias in gesture elicitation studies. *interactions 21*, 3 (May 2014), 40–45.

[12] Morris, M. R., Wobbrock, J. O., and Wilson, A. D. Understanding users' preferences for surface gestures. In *GI '10* (2010), 261–268.

[13] Nacenta, M. A., Kamber, Y., Qiang, Y., and Kristensson, P. O. Memorability of pre-designed and user-defined gesture sets. In *CHI '13* (2013), 1099–1108.

[14] Oh, U., and Findlater, L. The challenges and potential of end-user gesture customization. In *CHI '13* (2013), 1129–1138.

[15] Roth, V., and Turner, T. Bezel swipe: Conflict-free scrolling and multiple selection on mobile touch screen devices. In *CHI '09* (2009), 1523–1526.

[16] Ruiz, J., Li, Y., and Lank, E. User-defined motion gestures for mobile interaction. In *CHI '11* (2011), 197–206.

[17] Serrano, M., Lecolinet, E., and Guiard, Y. Bezel-tap gestures: Quick activation of commands from sleep mode on tablets. In *CHI '13* (2013), 3027–3036.

[18] Silpasuwanchai, C., and Ren, X. Jump and shoot!: Prioritizing primary and alternative body gestures for intense gameplay. In *CHI '14* (2014), 951–954.

[19] Simpson, E. H. Measurement of diversity. *Nature* (1949).

[20] Spano, L. D., Cisternino, A., Paternò, F., and Fenu, G. GestIT: A declarative and compositional framework for multiplatform gesture definition. In *EICS '13* (2013), 187–196.

[21] Vatavu, R.-D., and Zaiti, I.-A. Leap gestures for tv: Insights from an elicitation study. In *TVX '14*, ACM (2014), 131–138.

[22] Wobbrock, J. O., Morris, M. R., and Wilson, A. D. User-defined gestures for surface computing. In *CHI '09* (2009), 1083–1092.

[23] Yu, N.-H., Huang, D.-Y., Hsu, J.-J., and Hung, Y.-P. Rapid selection of hard-to-access targets by thumb on mobile touch-screens. In *MobileHCI '13*, ACM (2013), 400–403.