LINEUp: List Navigation Using Edge Menu

Enhancing Touch Based Menus for Mobile Platforms

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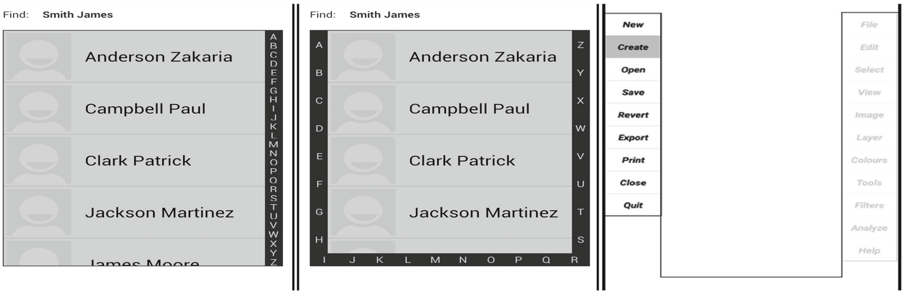

Abstract. Displaying and interacting with Cascaded Menus on mobile phones is challenging due to the limited screen real estate. In this paper, we propose the *Edge Menu* – U-shaped layout displayed along the edges of the screen. Through the use of transparency and minimum screen space, the Edge Menu can be overlaid on top of existing items on the screen. We evaluated the suitability of two versions of the Edge Menu: List and Nested Menus. We compared the performance of the Edge Menu to the traditional Linear Menu. We conducted three studies and revealed that Edge Menu can support the use of single hand and both hands, it outperforms the regular Linear Menu, and is in average 38.5% faster for Single hand usage, and 40% faster for Dual hands usage. Edge Menu using both hands is in average 7.4% faster than Edge Menu using Single hand. Finally, the Edge Menu in Nested Menus shown to be faster than Linear Menus in Nested Menus with 22%–36%.

Keywords: Cell phones · Edge Menus · Linear Menus
Nested Menus · Gestures · Mobile interaction · Menu techniques
Mobile phone menus

1 Introduction

Mobile phones are used today to perform various functions and are not limited to making voice calls only. Users are manipulating images and videos, writing

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documents, broadcasting events, and even creating and editing 3D models on mobile phones. The processing capabilities of some recent mobile phones is similar to that of laptops, which makes them suitable for performing any task. However, the limited screen real estate on mobile presents itself as the biggest obstacle against the utilization of the underlying hardware and sophisticated software applications. There is currently over 1 billion smartphones worldwide [2]. Hence, it is no exaggeration to claim that navigating through lists generally is one of the most frequently performed daily tasks.

In this paper, we describe our work aiming to enhance menu navigation on mobile phones. We conducted three studies. In the first two studies, we explored one of the regularly visited lists, Contacts' List. Since, calling a previously stored phone number in the Contacts' List is one of the most commonly performed daily tasks. Although the current design of the Contacts' List, in Android and in iPhone, seems adequate to most users, yet we believe it will be soon challenged by the rapidly increasing number of entries. As the current trend of merging social contacts with phone contacts in one list continues to spread, the average number of entries is expected to rise rapidly. A typical Internet user has about 600 social ties [16]. In Facebook, the mean number of friends among adult users is 338 and the median comes in at 200 friends [1]. At this rate, Contacts' Lists with several hundred entries, will gradually become the norm. At the moment, finding a contact can be done using speed dial, search by voice, search by typing name and using the menu. Each of these interaction techniques suits a specific context. For instance, while search by voice might be the fastest way to dial a contact, it requires the user to be in a relatively quite environment.

Moreover, many software applications have complex features which are organized into deeply Nested Menu structures. This renders them unusable on mobile screens - where the limited screen size would make the display of such menus impossible.

In our third study, we developed the Edge Menu as a proposed solution to this problem. The Edge Menu displays each level of a Nested Menu on one side of the screen and the user alternates between left and right edges while navigating in the menu using symmetric bi-manual interaction.

In this research, we aim to enhance menu navigation through the following contributions:

- Investigating the Edge Menu - U-shaped menu.
- A comparison is done between different Layout and Interaction techniques; Edge Menu and Linear Menu - Circular and Linear Scrolling.
- We did an extended evaluation for Edge Menus; using Nested Edge Menus.

2 Related Work

Menu Navigation is still an open topic that has many usability issues that need more investigation and research. Our work builds on strands of prior work: (1) Menus Design, (2) List Navigation task, (3) Contacts' List usage and (4) Edge Screen.

2.1 Menus for Mobile

Several researchers have developed menus which attempt to speed up selection in large sets of items presented on a small cellphone screen. Kim et al. [22] developed a 3D Menu which utilizes the depth cue. The researchers' formal evaluation reveals that as the number of items gets larger and the task complexity is increased, the 2D organization of items is better. For a small number of items, the 3D Menu yields a better performance. Foster and Foxcroft [13] developed the Barrel Menu which consists of three horizontally rotating menu levels stacked vertically; the top level represents the main menu items. Selecting an item from a level is achieved by rotating the level left or right, resulting in the child elements of the current item being displayed in the menu level below. Francone et al. [14] developed the Wavelet Menu, which expands upon the initial Marking Menus by Kurtenbach and Buxton [21]. Bonnet and Appert [7] proposed the Swiss Army Menu which merges standard widgets, such as a font dialog, into a Radial Menu layout. Zhao et al. [35] used an Eyes-Free Menu with touch input and reactive auditory feedback.

2.2 List Navigation

Menus used in mobile phones are influenced by Linear Menus which were originally created for desktop graphical user interfaces (**GUI**). Such menus suit desktop environments, where large screen size can accommodate displaying more items. However, Linear Menus are not a good option for a mobile phone interface, as the screen is much smaller. Smartphone users are forced to do excessive scrolling to find an item in a Linear Menu since the screen can only display a handful of items at a time. Almost all menus are formatted in a linear manner, listing entries that are arranged from the top to the bottom of the screen. When presenting a list of items to the user, the available hardware and software have limited the computer system architecture to a linear format. Pull-Down Menus and Pop-Up Menus are a typical example of the linear arrangement. Most of these menus are either static on the screen or are activated from a specific mouse action [9].

2.3 Contacts' List

The Contacts' List has been the focus of several research works. Oulasvirta et al. [26] recommended augmenting each entry with contextual cues such as user location, availability of user, time spent in location, frequency of communication and physical proximity. Jung, Anttila and Blom [19] proposed three special category views: communication frequency, birthday date, and new contacts. This is meant to differentiate potentially important contacts from the rest. Bergman et al. [6] modified the Contacts' List to show unused contacts in smaller font at the bottom of the list. Plessas et al. [27] and Stefanis et al. [29] proposed using the call log data and a predictive algorithm for deciding which entries are most likely to be called at any specific time. Campbell et al. [24] utilized an

EEG signal to identify the user choice. Ankolekar et al. [4] created Friendlee, an application which utilized call log and social connections to enable faster access to the sub-social-network reachable via mobile phone, in addition to contacts.

2.4 Utilizing Screen Edge and Bezel

Apple Macintosh was the first to utilize the screen edge by fixating the menu bar at the top edge of the screen. Wobbrock developed the Edge Keyboard [32,34], where the character buttons are placed around the screen's perimeter, and could be stroked over or tapped like ordinary soft buttons. More recently, screen edge and bezel have attracted the attention of researchers to enable richer interactions on mobile. Li and Fu [23] developed the BezelCursor which is activated by performing a swipe from the bezel to the on-screen target. The BezelCusor supports swiping for command invocation as well as virtual pointing for target selection in one fluid action. Roth and Turner [28] utilized the iPhone bezel to create the Bezel Swipe. Crossing a specific area in the screen edge towards the inside activates a particular functionality. The user continues with the gesture to complete the desired operation. Chen et al. [10] utilized the bezel to enhance copy and paste. Based on Fitts' Law, nearer bigger targets are faster to reach to, compared to farther smaller ones. Thus, the target's size is an important parameter to take into consideration, because the larger the target is; the faster, easier and more efficient the target's selection is [11]. Jain and Balakrishnan [18] have proven the utility of bezel gestures in terms of efficiency and learnability. Hossain et al. [17] utilized the screen edges to display proxies of off-screen objects to facilitate their selection. Recently Samsung provided *Samsung Galaxy Edge* series, a mobile phone with a 3D melted glass that covered the curves of the mobile phone [3]. This design has a huge potential, which supports our research even more; seeking to prove that the Edge Menu Design is more usable than the regular Linear Menu.

In this work, we aim to evaluate the new Edge Menu design to enhance the navigation performance on smartphones. Namely we focus on three main research questions (**RQ**):

1. Does Edge Menu offer better User Experience than Linear Menu?
2. Does the kind of interaction influence the easiness of navigating through the menu list and reaching the user's target?
3. Will Nested Edge Menus speed up selection process while list navigation?

Menu Design and Interaction

Our main goal was to enable the quick selection of an entry in a list and speed up the navigation in a Nested Menu. While in previous works, researchers redefined the layout of the menu list totally, our strategy is to preserve the linear organization of entries and focus on speeding up the interaction.

To achieve this, we designed three user studies, for the first two studies we conducted two experiments that focus in Contacts' Lists. The main goal of any user is to speed up the selection process of the target name. Thus, selecting the first letter of both the first name and the last name is the most efficient technique to narrow down the Contacts' List as quickly as possible. Although not all users store the first and the last name of a contact, the same technique is applicable to contacts with just a single entry stored. In the latter case, the first two letters of the entry will be utilized in the search - this is further to be utilized in further studies.

Later, for the third study we ran an experiment to enhance the search in Nested Menus same way we aim to enhance One-Level Menus. Although redesigning menus might result in efficient interaction, yet our approach would enable the porting of existing applications to the mobile platforms with less effort. We formulated three guiding design goals;

– Support Dual-hands and Single-hand interaction
– Minimize finger travel distance
– Utilize screen edges

Although users prefer Single-hand interaction [20], two-handed input has proven quicker [22,25]. We anticipate that the overwhelming number of contacts might require the user to utilize two hands to reach the target entry faster. The second design goal was to minimize finger time travel distance on the screen. Fitts' Law teaches that movement time is inversely correlated with distance to target and to width of target [12]. The third design goal was to make use of the screen edges since user's fingers are often located there while holding the phone. Walker and Smelcer [31] and Froehlich et al. [15] have shown that utilizing an edge as a stopping barrier improves target acquisition time.

Our design effort yielded a menu fitted to the edges which makes it easily reachable using single hand and two hands. Two variations were developed to support the design goals. Since performance difference could be attributed to more than one factor, we opted for implementing simpler designs supporting only a single design goal for comparison purposes. In this paper our focus is to investigate if single and multi-level Edge Menu designs will work better than Linear Menu designs, with Single hand and Dual hands.

2.5 Layout Design

Linear Menu. Since Android based phones already have a Linear Menu used in the Contacts' List application, we were interested in using it as a baseline and to investigate the difference in performance between the different designs, (see Fig. 1). We implemented the Linear Menu in our system following the same interaction style as offered by Android OS. To support selecting both the first name and the last name, we extended the selection mechanism to accept two letters instead of one. Thus the user would need to tap twice for the two first letters. It is worth noting that in Android 2.2, the Contacts' List had a feature to select both first and last names. The user would start by selecting the first letter of the first name, then continue by swiping the finger horizontally for

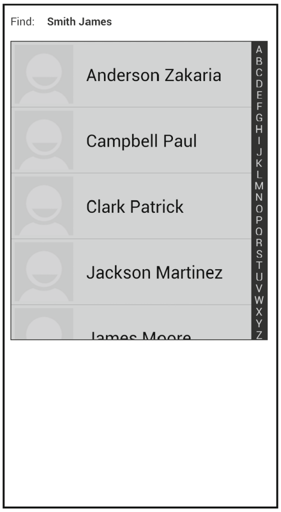

Fig. 1. Linear Menu with flicking support

Fig. 2. Edge Menu with flicking support

a short distance and next move vertically - either upward or downward - to select the first letter of the last name. Although this feature was dropped from later versions of Android, we felt it is more appropriate to utilize an interaction mechanism which supports selection of the first two letters to be comparable with our design.

Edge Menu. An Edge Menu consists of a U shaped panel fitted to the left, right and bottom edges of the screen, (see Figs. 2 and 10). For the purpose of the Contacts' List, the menu items are the alphabetical letters and for the purpose of the Nested Menu, the menu items are the default menu icons. We decided not to use the upper edge since it is the furthest away from the user's fingers. For the first study, we decided to use names with first and last names not first names only to make the study consistent, the later case will be supported in future studies. The user taps on the first letter of the first name followed by a tap on the first letter of the last name. This narrows down the choices for the user. Scrolling through the results is done by flicking up and down. This menu design was motivated by the first design goal which is to support both two handed and single handed interaction, and the third which is to use screen edges.

2.6 Interaction Design

Linear Menu with Wheel. This menu consists of two components: a linear list of alphabet letters placed in the right edge of the screen and a wheel for scrolling at the bottom (see Fig. 3). To select an entry, the user starts by choosing the first letter of the first name and next select the first letter of the second name from the menu. Next, the user scrolls through the narrowed down results using the wheel provided. Holding the phone in one hand, the wheel lies where the user would rest his thumb. This menu design was motivated by the second design goal to minimize finger travel distance. We speculated that the slowest part of the interaction is scrolling up and down to locate an entry. Since the user is unaware of the exact location of the contact, the employed flicking either overshoots or undershoots the location of the desired entry. Tu et al. [30] compared flicking to radial scrolling and found that radial scrolling led to shorter movement time than flicking for larger target distance. However, it was not clear if using the thumb is efficient since Wobbrock et al. [33] has reported that the index finger is generally faster. This menu design was motivated by the second design goal which is minimize travel distance but focused on the interaction with the narrowed down list.

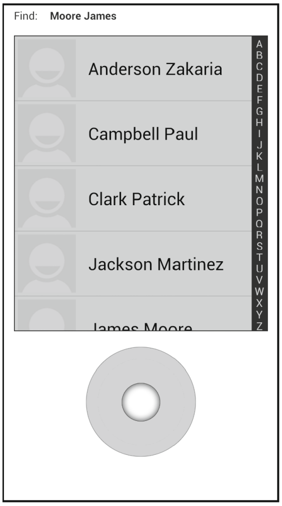

Fig. 3. Linear Menu with radial control for scrolling

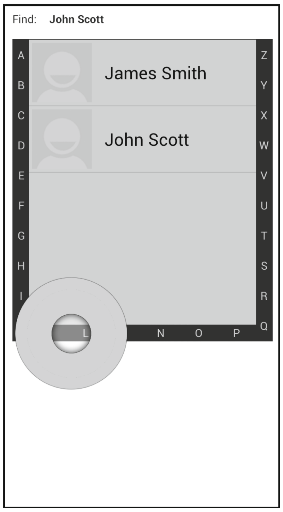

Fig. 4. Edge Menu with radial control for scrolling

Edge Menu with Wheel. This design is similar to the Edge Menu but augmented with a wheel for scrolling through the results list (see Fig. 4). After choosing the first letter, a wheel is displayed in proximity to the last position of the user's finger. The user scrolls through the list of contacts by moving the finger in a circular motion on the wheel - following the same interaction style as in the Linear Menu with wheel. Clockwise movement causes scrolling down and anti-clockwise movement signals scrolling up. The speed of the rotation governs how fast the scrolling of names occurs. The user does not have to maintain his finger within the wheel border as any radial movement above or close to it, activates the scrolling. Finally, the user taps on the desired contact. This menu design attempts to support the three stated design goals.

2.7 Pre Study: Observing Mobile Holding Position

We observed people in public areas, while holding their mobile phones, to observe the most common, comfortable position to hold their mobile phones. After observing many samples of people, almost all people grabbed their phones in a position where the phone's back rests on the users' palms (see Fig. 5).

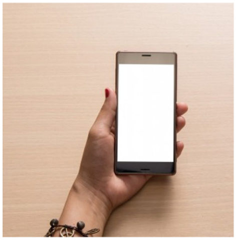

Fig. 5. Most habitual holding position of a cellphone

3 Study I: Evaluating Edge Menus Layout and Interaction Techniques

To answer **RQ** and to test our hypothesis of whether using Edge Menu instead of Linear Menu improves the user's performance or not? We started 3 studies sequentially.

Our goal with the evaluation was to find which menu is most efficient while working with a large-size list. A secondary goal was to understand the importance of our design goals and decide which is most relevant for future design efforts.

3.1 Design

We applied a repeated-measures design, where all participants were exposed to all conditions. An application displaying the menus and measuring user performance was implemented. The study has two independent variables, specifically the menu type with four levels; *Linear Menu*, *Edge Menu*, *Linear Menu with Wheel* and *Edge Menu with Wheel*, and the list size with three levels; *201 entries*, *300 entries* and *600 entries*; and two dependent variables the mean execution time and error rate. The latter is defined as the percentage of trials with an incorrect selection of a target name. The mean execution time, is defined as the time between the display of a target name to the participant and the participant tapping on that name in the Contacts' List. The order of the conditions was counter-balanced to avoid any learning effects. The study time was around 60–120 min plus 3 min for the training trials.

3.2 Apparatus

Our experimental setup consisted of a Samsung S3 device with a 4.8 in. (1280 × 720) display running Android 4.0.

3.3 Participants and Procedure

We recruited 36 participants (18 females) and (18 males) with an average age of 26 years ($SD = 2.27$) using university mailing lists. Four of the participants were left-handed. None of the participants had any previous experience using Edge Menus. After arriving in the lab and welcoming the participants, they signed a consent form and received an explanation of the purpose of the study.

We equally divided the participants to 3 groups each with 12 participants. First group was tested using 201 contacts; we divided them accordingly to 3 blocks, each having 67 trials. Thus each participant performed 804 trials: (4 menus × 67 trials × 3 blocks). The total number of trials in the experiment was *9648* (12 participants × 804 trials).

Second group was tested using 300 contacts; we divided them accordingly to 3 blocks, each having 100 trials. Thus each participant performed 1200 trials: (4 menus × 100 trials × 3 blocks). The total number of trials in the experiment was *14400* (12 participants × 1200 trials).

Finally, the Third group was tested using 600 contacts; we divided them accordingly to 3 blocks, each having 200 trials. Thus each participant performed 2400 trials: (4 menus × 200 trials × 3 blocks). The total number of trials in the experiment was *28800* (12 participants × 2400 trials).

The target names were carefully selected to ensure that the user will need to navigate in the Contacts' List before reaching the required name. The alphabet was divided into 3 sets: the first set contained names starting with letters A to I, second set contained names starting with letters J to Q, and the last set contained names starting with letters R to Z, (see Fig. 6). Each block contained an equal number of names from the three sets. Names were not repeated between blocks to avoid learning effects. In this experiment a large Contact's List size was chosen to evaluate the difference in performance since the user has to scroll through many target names.

In this experiment we asked the participants to use only single hand while performing the experiment. Hence, the user uses only one hand to hold the mobile phone and experiments the Edge Menu and Linear Menu likely.

3.4 Results

We analyzed the Mean Execution Time. Data from the practice trials was not used in the analysis. A univariate repeated measures ANOVA was carried out on the remaining data. Significant main effect was found for menu type. Mauchley's test indicated that the assumption of sphericity had been violated, therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity $F(2.79, 30.68) = 82.758$. $p < .0001$ Post-hoc analyses were carried out to compare means for menu type. Four statistically significant groups were detected

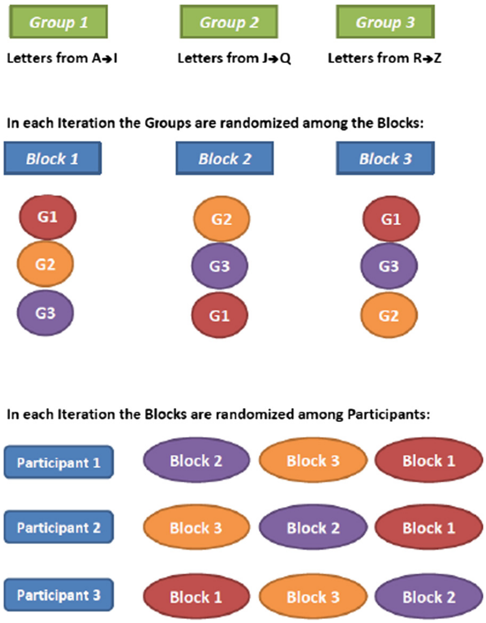

Fig. 6. An explanation of each trial's arrangement

from the analysis, namely: Linear Menu and Linear Menu with wheel, Edge Menu and Edge menu with wheel. Thus, Linear Menu and Linear Menu with Wheel performance was similar, but together they were statistically different from the other three groups. The fastest performance was accomplished using Edge menu ($\mu = 5.5$ s, $\sigma = 0.15$), followed by Edge menu with wheel ($\mu = 5.9$ s,

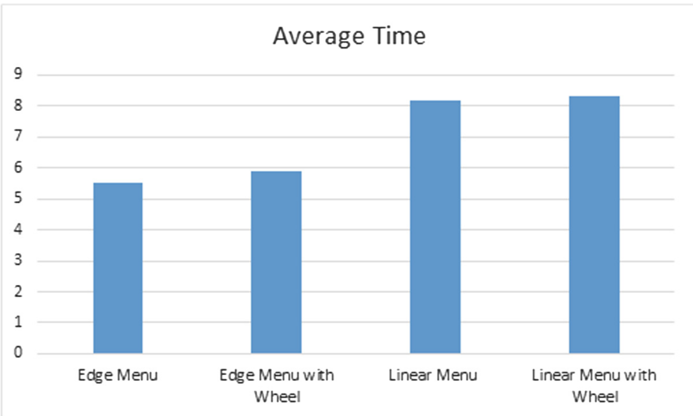

Fig. 7. Study I: mean execution time

Table 1. Mean execution time for the four layouts using Single hand

Layout	(Mean::SD)	
Edge Menu	5.5 s	0.15
Edge Menu with Wheel	5.9 s	0.21
Linear Menu	8.2 s	0.93
Linear Menu with Wheel	8.3 s	0.88

$\sigma = 0.21$). Third came the Linear Menu ($\mu = 8.2$, $\sigma = 0.93$) and Linear Menu with wheel ($\mu = 8.3$ s, $\sigma = 0.88$) (refer to Table 1 and Fig. 7 for the results). Participants' errors in response were very few (2%). There was no significant difference between the different menu types.

3.5 Discussion

In conclusion, the U-shaped Edge Menu revealed better results than the regular Linear Menu; regardless the interaction technique used (circular or linear).

In addition to that, since the Edge Menu design spreads out the letters on three sides of the screen; left, right and bottom, this creates an opportunity for the user to use either one of his hands to interact or his two hands if the first letter of the first name and that of the last name reside in different sides. Although, it is not guaranteed to always have such an allocation. Consequently, half the Contacts' List entries were names whose first letters were residing in the same side and the other half were names whose first letters were residing in different sides. Therefore in Study II we aim to explore dual hand interaction as informed by the subjective measures from the participants (questionnaire).

3.6 Post Study: Questionnaire

It was really important to collect the subjective view of participants towards the design in general after finishing the first study and before doing any further research.

After the Participants finished the Experiment, a questionnaire was distributed among them. They were all satisfied by the experience and the options offered to them. However, the major comment we received was, that the participants will be more satisfied by the Edge Menu, if they were able to use both of their hands while navigating. Based on the information collected by the questionnaire, we carried the second study, enabling the participants to use both of their hands while navigating through the list.

4 Study II: Dual vs. Single Handed Interaction

After proving that the Edge Menu outperforms the Linear Menu, while maintaining the same testing environment and conditions. It was time to prove that the Edge Menu can perform even better when using both hands, since the menu items are distributed along both screen edges (see Fig. 8). In this experiment the user was asked to use both of his hands while trying the new Edge Menu design using linear scrolling only. The circular scrolling technique was eliminated in this study since it wasn't proven that it is better than the normal linear technique. We investigated different lengths of lists - different numbers of contacts - to make sure that our study will almost fit most of the applications. The Experiment Design, Apparatus and Task were similar to that of Study I.

4.1 Design

This study has 2 independent variables, specifically the menu type with two levels; *Linear Menu* and *Edge Menu* and the list size with three levels; *201 entries*, *300 entries* and *600 entries*, and 2 dependent variables the error rate and mean execution time. The distribution of the blocks throughout the trial was same as of the First Study, (see Fig. 6). In each trial, the participant is instructed to locate and press on a specific contact name. Thus, simulating the typical interaction that occurs while calling a number.

4.2 Participants and Procedure

Similar to the first study, We recruited 36 participants (18 females) and (18 males) with an average age of 25 years ($SD = 2.24$) using university mailing lists. Six of the participants were left-handed. None of the participants had any previous experience using Edge Menus. After arriving in the lab and welcoming the participants, they signed a consent form and received an explanation of the purpose of the study.

We equally divided the participants to 3 groups each with 12 participants. First group was tested using 201 contacts; we divided them accordingly to 3 blocks, each having 67 trials. Thus each participant performed 402 trials: (2 menus × 67 trials × 3 blocks). The total number of trials in the experiment was *4824* (12 participants × 402 trials).

Fig. 8. Study setup - user while performing a trial

Second group was tested using 300 contacts; we divided them accordingly to 3 blocks, each having 100 trials. Thus each participant performed 600 trials: (2 menus × 100 trials × 3 blocks). The total number of trials in the experiment was *7200* (12 participants × 600 trials).

Finally, the Third group was tested using 600 contacts; we divided them accordingly to 3 blocks, each having 200 trials. Thus each participant performed 1200 trials: (2 menus × 200 trials × 3 blocks). The total number of trials in the experiment was *14400* (12 participants × 1200 trials).

4.3 Results

A paired samples t-test using the execution time of the Edge Menu and that of Linear Menu for each level of the Contacts' List size (201 - 300 - 600) was performed. The results were very promising. For the 201 Contacts level, The fastest performance was accomplished using Edge Menu, Edge Menu had statistically significant lower execution time (5.15 s) compared to Linear Menu (7.75 s), $t(11) = 4.083$, $p < .05$.

Table 2. Mean execution time for the two layouts using Dual hands

Layout	201 contacts	300 contacts	600 contacts
Edge Menu	5.15 s	5.11 s	5.6 s
Linear Menu	7.75 s	8.5 s	8.7 s

Also, for the 300 contacts, Edge Menu had statistically significant lower execution time (5.11 s) compared to Linear Menu (8.5 s), $t(11) = 6.811$, $p < .05$. Finally, for the 600 Contacts level, the fastest performance was accomplished using Edge Menu, Edge Menu had statistically significant lower execution time (5.6 s) compared to Linear Menu (8.7 s), $t(11) = 6.534$, $p < .05$.

Interestingly, results showed that for the 201 contacts, Edge Menu outperformed Linear Menu with 33.54%. Similarly, for the 300 contacts, Edge Menu outperformed Linear Menu with 39.88%. Finally, for the 600 contacts, Edge Menu outperformed Linear Menu with 35.63%. Impressively, results have shown slight improvement in performance of the users while using the Edge Menu with both hands than Edge Menu with Single hand. The average performance of the 2 menu types with different number of trials (201 - 300 - 600 Contacts) have been recorded (refer to Table 2 and Fig. 9 for the results).

4.4 Discussion

After performing the second study, it was proven that the Edge Menu outperforms Linear Menu, specially the Dual Edge Menu, and is worth for usage and for further research. This was the initial exploration but of course our study is for

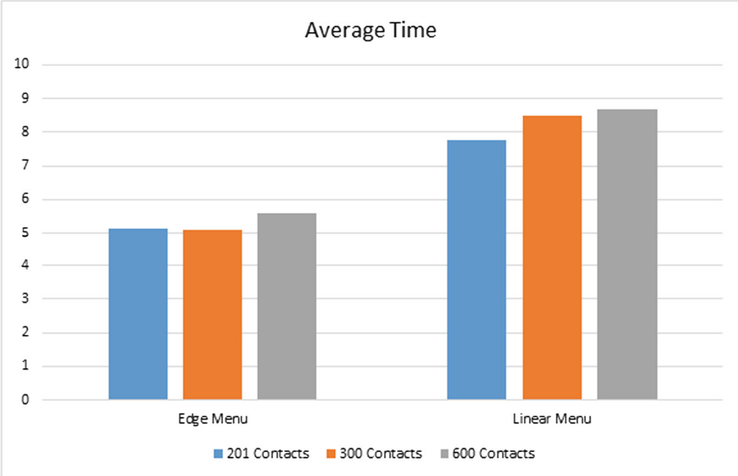

Fig. 9. Study II: mean execution time

limited use case and we envision that this could be extended for wider application than the Contacts' List. Therefor, we investigated the extension of the U-shaped Edge Menu via Nested Menus to allow more content navigation/display.

5 Study III: Evaluating Nested U-Edge Menus

In this Study we extend our design to include Nested Menus. Our goal with the evaluation was to find which menu is most efficient while working with a large-size list. A secondary goal was to understand the importance of our design goals and decide which is most relevant for future design efforts.

5.1 Design

The goal of this study is to compare the performance of the Edge Menu to a standard Linear Menu, on mobile, in the case of navigating a Nested Menu structure. We measured two dependent variables; execution time and error rate. The latter is defined as the percentage of trials with an incorrect selection of an item. The Execution Time is defined as the time between the communication of a menu item to the participant till tapping on that target. There were two independent variables; *Menu-Type* and *Menu-Depth*. *Menu-Type* had two levels; *Linear Menu* and *Edge Menu*. *Menu-Depth* had four levels; *Depth-2*, *Depth-3*, *Depth-4* and *Depth-5* - representing Nested Menus with different depths.

5.2 Apparatus

Our experimental setup consisted of a Samsung S3 device with a 4.8 in. (1280 × 720) display running Android 4.0.

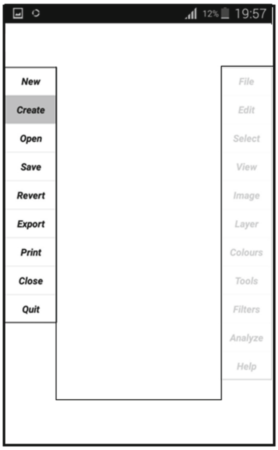

Fig. 10. Nested Edge Menu. Each level of a Nested Menu is displayed on one side of the screen.

5.3 Participants and Procedure

Eleven unpaid university students, six males and five females, performed the experiment (age $\mu = 21.5$).

In each trial, the participant is provided with a target menu item along with the path to follow to reach to that menu item. The participant task is to navigate through the menu, (see Fig. 10) and click on the specified menu item.

At the beginning of the experiment, the task was explained to the participant. Before using each of the two designs, an explanation of the menu and the interaction was provided and some practice trials were executed. We instructed participants to use a specific hand posture with each menu type. In the Edge Menu, the participant was asked to hold the phone using two hands and use the thumbs to select. Meanwhile, in the Linear Menu, the user holds the phone with one hand and uses the thumb of that hand to perform the interaction. The study duration was around 50 min.

The experiment was divided into 3 blocks, each having 20 trials. The total number of trials in the experiment was; (11 Participants $\times$ 2 Menus $\times$ 4 Depths $\times$ 20 Trials $\times$ 3 Blocks = 5,280 trials.

5.4 Results

Error Rate was very small (less than 2%), thus was not included in the analysis. Since we wanted to compare the performance of the Edge Menu to the Linear Menu at every nesting level, we conducted a paired samples t-test using the execution time of the Edge Menu and that of Linear Menu at each Menu-Depth. For Depth-5, Edge Menu had statistically significant lower execution time (3.88 s) compared to Linear Menu (6.1 s), $t(10) = 3.3$, $p < .05$. Similar results were found

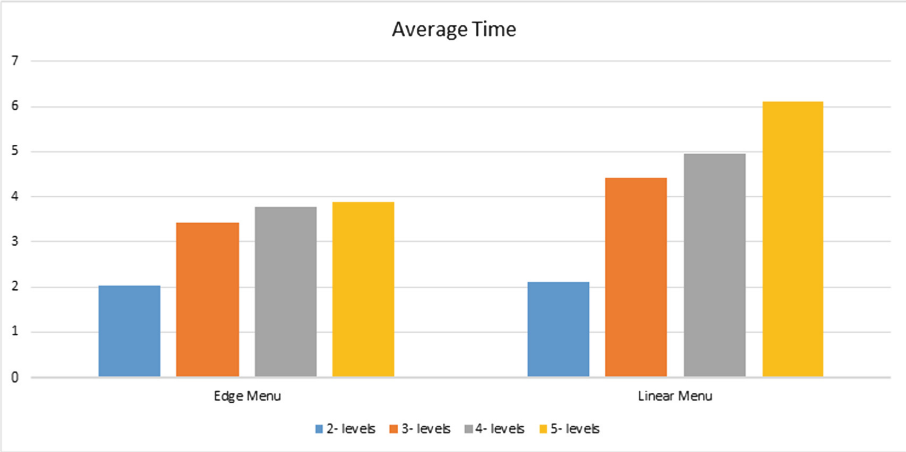

Fig. 11. Study III: mean execution time

Table 3. Mean execution time for the two layouts using Nested Menus

Layout	Depth-2	Depth-3	Depth-4	Depth-5
Edge Menu	3.4 s	3.4 s	3.77 s	3.88 s
Linear Menu	3.5 s	4.42 s	4.95 s	6.1 s

for Depth-4, where Edge Menu mean execution time was (3.77 s) while Linear Menu was (4.95 s), $t(10) = 2.9$, $p < .05$. For Depth-3, Edge Menu mean was (3.4 s) while Linear Menu was (4.42 s), $t(10) = 3.4$, $p < .05$. In Depth-2, there was no statistical significance between the two menus (refer to Table 3 and Fig. 11 for the results).

5.5 Discussion

In this experiment, the enhancement in performance due to Edge Menu was not the same at every menu-depth. In Depth-5, Edge Menu caused a decrease of 36% in execution time, while in Depth-4, it caused a decrease of 24%, and in Depth-3, the decrease was 22.6%. Thus in conclusion, the gain in performance increases as the number of levels in the menu increases. We believe that this is because at the first levels of the menu, the user has almost the same step counts. However, as we go deeper the step counts from the beginning of the trial increases and the user needs to interact more. Therefor, at this point the difference between the Edge Menu results and Linear Menu results are really significant.

6 Summary

In the three studies, our results revealed that Edge Menu is faster, and yields better performance than the Linear Menu. In the two variations of the Edge

Menu, the user utilized both hands to simultaneously enter the first letters, which is an example of a symmetric bi-manual task [5,8]. Using the two hands outperforms using a Single hand since the time to position a Single hand on the next target is eliminated. When unifying the testing conditions in the first experiment, using Single hand while testing both Edge Menu and Linear Menu. Results showed that Edge Menu outperformed Linear Menu by 32.93%. Similarly, the Edge Menu with wheel outperformed Linear Menu with wheel by 28.92%. In the second experiment, in an attempt to enhance the Edge Menu performance even more and meet the most comfortable position while holding the mobile phone, the user was asked to use both of his hands while testing the Edge Menu. Results showed that for the 201 contacts, Edge Menu outperformed Linear Menu with 33.54%. Also, for the 300 contacts, Edge Menu outperformed Linear Menu with 39.88%. For the 600 contacts, Edge Menu outperformed Linear Menu with 35.63%. Interestingly, results have shown slight improvement in Edge Menu using both hands than Edge Menu using Single hand. In the third study, the Edge Menu showed a remarkable decrease in the execution time, 36%, 24% and 22.6% for Depth-5, Depth-4 and Depth-3. We believe that the menu's icons size contributed to the positive results demonstrated by the Edge Menu. Spreading out the menu items, across the edge of the screen gives more space to each item. Each icon activation area along the sides in the Edge Menu was 1.5x as large as the activation area in the Linear Menu. Our results agree with previous works that larger activation areas yields faster performance [11] (Fig. 12 and Table 4).

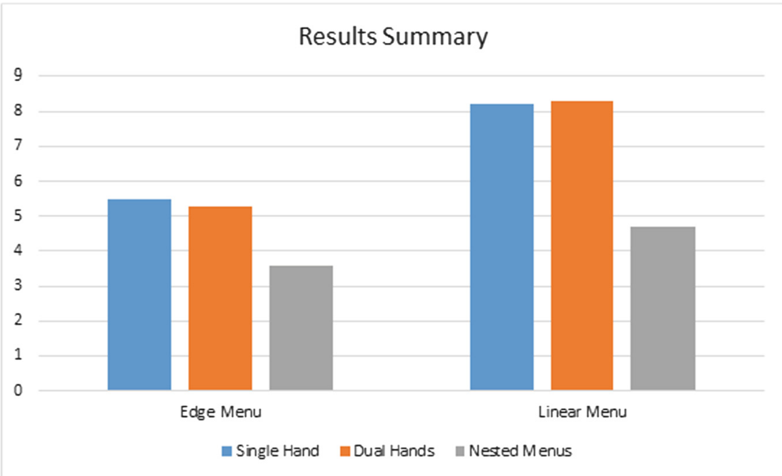

Fig. 12. Average results summary

Table 4. Summary of the 3 studies' results

Layout	Single hand	Dual hands	Nested menus
Edge Menu	5.5 s	5.28 s	3.6 s
Linear Menu	8.2 s	8.3 s (Single)	4.7 s

7 Limitations and Future Work

There were several limitations we explored through designing the 3 studies, most of which have been resolved during performing the experiments. The main challenge was supporting different lists' sizes, this we were able to resolve in the second study by running the experiment on different Contact's List size. Only few of the limitations were left for future research. The main goal would be creating a platform that allows application designers to integrate/convert their work directly with the Edge Menu. We believe that the source code and research done in this paper should be available for other researchers in an open source library, to help out researchers to add their ideas.

8 Conclusion

We developed the Edge Menu which is a U shaped menu fitted to the left, right and bottom edges of a mobile screen. An Edge Menu is superior to a Linear Menu by 23% to 40%. However, further research is required to enable the Edge Menu to support greater set of items - for example, languages with longer alphabet. While our findings suggest that the two variations of the Edge Menu will yield better performance in a larger list, this still needs to be verified using a formal study. The work explored the practicality and feasibility of Edge Menu design. Based on our user studies and experiments, it is proven that the Edge Menu yields better performance than the regular Linear Menu. By these results, encouraging software developers and application designers to start integrating Edge Menu with their designs instead of Linear Menu, and explore the capabilities offered by this relatively new design.

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