AN EMPIRICAL COMPARISON OF PIE vs. LINEAR MENUS

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ABSTRACT

Menus are largely formatted in a linear fashion listing items from the top to bottom of the screen or window. *Pull down menus* are a common example of this format. Bitmapped computer displays, however, allow greater freedom in the placement, font, and general presentation of menus. A *pie menu* is a format where the items are placed along the circumference of a circle at equal radial distances from the center. Pie menus gain over traditional linear menus by reducing target seek time, lowering error rates by fixing the distance factor and increasing the target size in Fitts's Law, minimizing the drift distance after target selection, and are, in general, subjectively equivalent to the linear style.

KEYWORDS: menus, user interface, empirical studies, directional selection

INTRODUCTION

In presenting a list of choices to the user, most computer system designers have been limited, largely by the available hardware and software, to a linear format. The items are listed from top to bottom, sometimes with an index number for each to the item. Occasionally, the lists are multi-columned, have multiple items per line, or are even hierarchical (i.e. indented sub-choices), but for the most part lie in a strictly one dimensional structure. Many of these menus are static on the display screen or activated from mouse

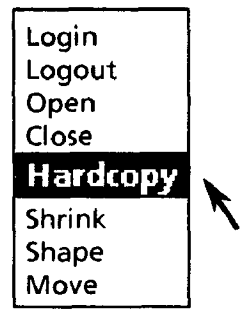

Figure 1: A typical linear menu

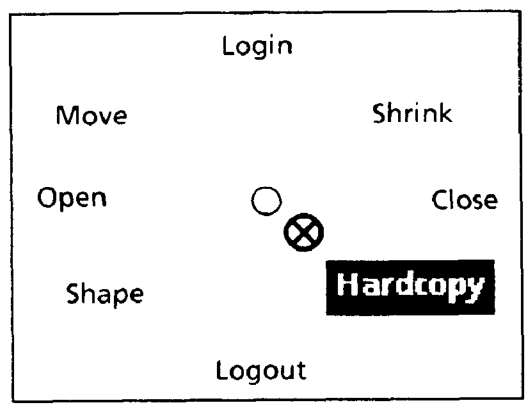

Figure 2: A crude pie menu

actions in two formats: pull-down (menu appears at a fixed label on screen when mouse directed) or pop-up (menu appears anywhere within a fixed area, occasionally the whole screen) [11]. Some systems have used the two dimensional nature of the computer display to the advantage of certain menu applications. Many flight simulation programs, for example, lay out directional headings in a typical compass format.

Item placement in menus has been an important research topic for many years. Menu organization is typically divided into three types [4]: alpha/numeric, categorical (functional), and random ordering. It is generally agreed that the performance of subjects (i.e. time to seek a target) with different placement styles converges with practice [2,10]. Further studies [9] revealed that a functional placement of items is supe-

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rior when the task domain is unambiguous to the user whereas an alphabetic organization can be useful in uncertain task descriptions. All of these studies have concentrated on the linear display format.

Has defaulting to a linear format (Figure 1) made some menus easier to use? Harder? By changing the menu format, can users find the item they seek faster? Is a particular menu format faster than other formats even with practice? What type of formats should be tested?

These are important questions for the designers of many systems. Software libraries of menu display routines are widely used as a default by programmers of many window systems and applications. Would it be worthwhile to present items in variable formats or perhaps in another fixed general format like the compass?

A pie menu [7] is a system facility for pop-up menus built into MIT's X windows [5] window management system, and Sun Microsystem's NeWS window system [6] and SunView window system. The pie menu interface supplies a standard library of functions that can be used by programmers to format and display menus in a circular format. The system is written in C and Forth and currently runs on a Sun Microsystems workstation. Items in the menu are placed at

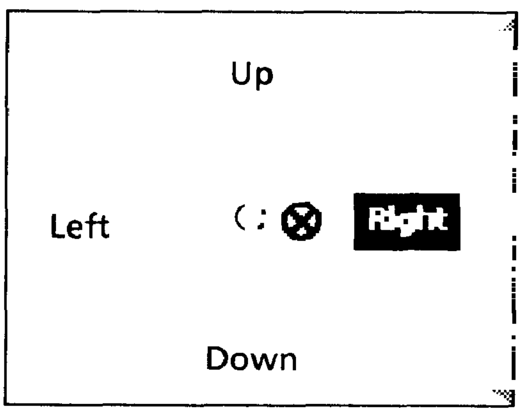

Figure 3: Pie menu activation region

equal radial distances along the circumference of a circle (Figure 2). The starting cursor position is at the center of the menu as opposed to being at the menu title or first item as in traditional pull-down menus. The cursor is under the control of a three button optical mouse on a fixed size moveable pad.

Imaginative menus formats are an inevitable future with the latest advances in window management systems. Window imaging systems using technology from laser printing protocol standards such as PostScript [1] and Interpress [12] will make it possible to display a large variety of non-rectangular shaped windows effectively on a bitmapped display. There are some obvious advantages to this organization for particular applications: compass directions, time, angular degrees, and diametrically opposed or orthogonal function names are some groupings of items that seem to fit well into the mold of the pie menu design. Alternatively, items with a sequential nature may not benefit and may in fact suffer from such a format. In addition, pie menus consume greater screen area and become polynomially larger than linear menus in both height and width with increased item size and number of items.

Distance to and size of the target are important factors that give pie menus the advantage over traditional linear menus. Even with linear menu initial cursor placement schemes where the cursor may initially be *in the middle* or *at the last item selected*, there remain target items at relatively great distances from the cursor location. Pie menus enjoy a two fold advantage because of their unique design: items are placed at equal radial distances from the center of the menu and the user need only move the cursor by a small amount in some direction for the system to recognize the intended selection. The advantages of decreased distance and increased target size can be seen as an effect on positioning time as parameters to Fitts's Law [3].

The distance to an item in any menu style can be defined as the minimum distance needed to highlight the item as selected. In both menu styles, this is defined by a region rather than a point. This region is typically of greater area than the actual target (Figure 3). Once the cursor has entered the region, the item is highlighted as feedback to the user.

Pie	*Linear*	*Unclassified*
North	First	Center
NE	Second	Bold
East	Third	Italic
SE	Fourth	Font
South	Fifth	Move
SW	Sixth	Copy
West	Seventh	Find
NW	Eighth	Undo

Table 1: Task groupings

EXPERIMENT

Introduction and hypothesis

This paper describes a controlled experiment to test two hypotheses: that pie menus decrease the seek time and error rates for menu items and that pie menus are especially useful in menu applications suited for a circular format, diametrically opposed item sets (e.g. open/close), directions (e.g. up/down) or even linear sets of items and conversely linear menus are useful for sets of linear items (e.g. one,two,three,etc.).

The experiment is a 2x3 randomized block design. Each cell is an element of the cross product of menu and task type. A typical pie task would be the compass example because it seems best suited functionally for pie menus. List of elements, like OPEN/CLOSE and UP/DOWN, whose meanings are antonyms are also classified as pie tasks. Lists, like numbers, letters and ordinals, are best suited for linear menus and are thus classified as linear tasks. Groups of menu items that have no relation to each other fall in the unclassified category. Table 1 shows an example of the groupings.

There are a total of 15 menus, a group of 5 for each task type. Subjects perform the experiment for all cells in the experiment matrix in random order in accordance with a randomized block design [8]. The subjects see each of the 15 menus four times, a total of twice in each menu format. Each cell in the experiment consists of 10 menus. Each subject therefore sees a total of 60 menus. Targets are uniformly distributed over the eight possible items.

Pilot study results

A pilot study of 16 subjects showed that users were approximately 15% faster with the pie menus and that errors were less frequent with pie menus. Statistically significant differences were found for item seek time but not task type. Subjects were split on their subjective preference of pie and linear menus. Some commented that they were able to visually isolate an item easier with linear menus and that it was hard to control the selection in pie menus because of the sensitivity of the pie menu selection mechanism. These subjects tended to be the most mouse naive of all whereas those who had heard of or seen a mouse/cursor controlled system but had not used one extensively tended to prefer pie menus. The most mouse naive users, while finding linear menus easier, tended to be better at pie menus and commented that with practice, they would probably be superior and in fact prefer the pie menus because of their speed and minimization of hand movement with the mouse. Not surprisingly, therefore, most of those preferring linear menus did not have a strong preference on the scaled subjective questionnaire.

Subjects

Subjects were volunteers from the University of Maryland Psychology Department Subject Pool. All 33 subjects were undergraduate students with little or no mouse experience. They were rewarded with 1 extra credit point for participating.

Materials

As stated, pie menus run on a Sun Microsystems Workstation as part of an enhanced version of MIT's X windows system. The screen is a 19-inch bitmapped high resolution black-and-white display. Cursor location is controlled by a three button optical mouse on a moveable mousepad made of a specially formatted reflective material.

Procedures and problems

Some changes were made from the pilot design of the experiment: a better distribution of menu targets and doubled number of menu trials, though the total number of menus remained constant.

The process of selecting items from a pop-up menu, regardless of format, can be characterized in three stages: invocation, browsing, and confirmation. To make a selection, the user invokes the menu by pressing a mouse button (*invocation*), continues to hold the mouse button down and moves to an item which is then highlighted (*browsing*) and releases the mouse button confirming the selection (*confirmation*).

The typical sequence of events for a subject is as follows:

- The target is displayed to the user in a fixed text window at the top of the screen. The cursor associated with the mouse is marked by a small hash mark "x" on the display screen.
- The user invokes the menu by pressing and holding any one of three mouse buttons. The menu appears with the cursor location unchanged (except near screen boundaries where the cursor must "jump away" to accomodate the menu). The cursor is located in the center or menu title region of pie and linear menus respectively.
- With the mouse button still depressed, the user moves the cursor with the mouse towards the textual target as indicated. Selections highlight as the cursor moves into distinct activation regions. As noted, the activations regions for pie menus are "pie" shaped sections that extend to the screen boundaries and are rectangular sections extending horizontally towards the screen boundaries for linear menus.
- Once selection is made, the user releases the mouse button to confirm the selection. The menu disappears from the display screen. The cursor remains at the screen position relative to the selection location. If the selection is correct, the process begins again with a new target and possibly a new menu style. Otherwise, if the selection is not the requested target, an audible "beep" tone is heard and the user attempts the task again.

Basically, the computer posts the target name at the top of the screen, the user invokes the current menu, moves to the target item, and confirms the selection by releasing the mouse button. This sequence, called a task, is repeated 60 times by each subject. Each subject saw 6 sequences of 10 menus each. In each ten menu sequence, the menu type was the same, either pie or linear, and since there are only 5 menus per task type, each menu appears twice in the sequence.

	Task type			
	Pie	Linear	Unclass.	Mean_{menu}
Using pie menus	2.20	2.18	2.40	2.26
Using linear menus	2.68	2.30	2.94	2.64
Mean_{task}	2.44	2.24	2.67	

Table 2: Target seek time (sec) means per cell, menu type, and task type

	F	$PR > F$
Menu type	16.23	0.0003
Task type	6.93	0.0030
Menu type X Task type	2.82	0.0750

Table 3: repeated measures analysis of variance results for target seek time

The 10 menu sequences correspond to the cells in the experiment table design. Each subject performed a sequence for all 6 cells in random order. 60 data points are collected per subject. A total of 33 subjects performed the experiment for a total of 1980 data points.

For each task, the time from the first mouse button down to the correct target selection is the seek time for the item. If the user selected the wrong item, the time is included in this interval. The number of errors made as well as the sub-interval times when errors are made is recorded during the experiment by the system. All subjects performed the test adequately and no person failed to finish the assignment.

RESULTS AND DISCUSSION

A repeated measures analysis of variance was performed on the data. Table 2 shows the means per cell, per row, and per column. Table 3 displays the repeated measures ANOVA results. A Tukey analysis reveals that there is a statistical significant difference ($P < 0.01$) between overall menu type performance and task type performance in target seek times. Pie tasks and linear tasks did not significantly differ from each other, but both organizations are an improvement over the unclassified menu tasks. Slight statistical significant difference ($P = 0.075$) between cells in the experiment design is also observed. No other interaction was observed to be significant.

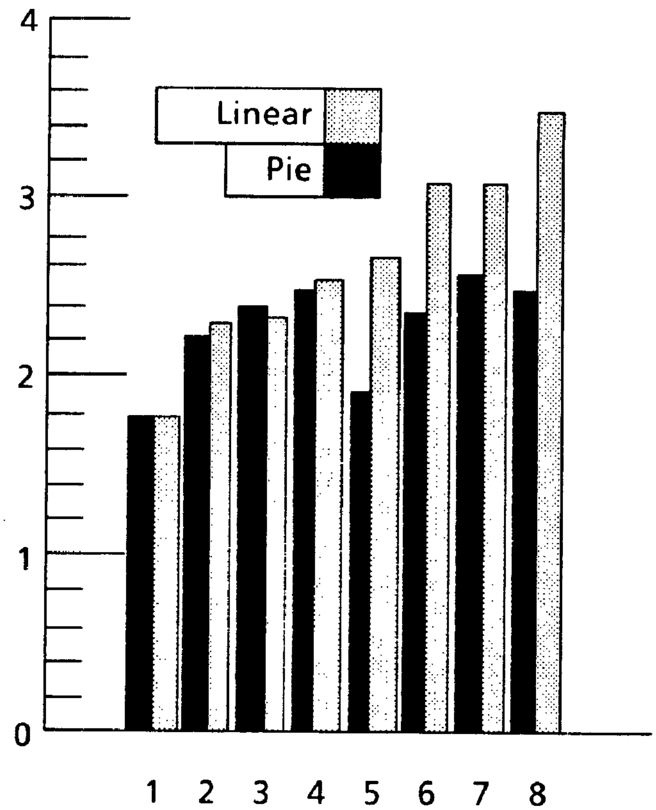

Figure 4: Target location (x) vs. seek time (y) in seconds

The statistically significant difference between menu type performance is the central result of this study. The task type difference reiterates earlier study results [2,9] that showed that some organization is helpful. Furthermore, the slight interaction between menu types and task types tends to confirm the hypothesis that certain task groupings perform well with particular menu formats. The reason for a lack of strong correlation is evident in the lower mean for pie menus even on linearly grouped tasks.

Figure 4 displays the target location by item plotted against the mean seektime. The mean seektime across target location for pie menus is fairly constant. As expected for linear menus, the mean seek time increases proportionally to the distance of the target from the initial cursor location. Analysis of seektime vs. number of menus seen shows that no strict convergence occurs between the two menu styles, though mean seektimes did decrease for both pie and linear menus with practice.

With error times removed from the results (measuring time from menu invocation to *first correct* choice), the menu styles compared relatively the same as the comparison which includes error times because of the error rates.

An analysis of seek time based on Fitts's Law $T = K_0 + K log_2(D/S + 0.5)$ where T = time to position cursor using mouse (seek time), K_0 = constant time to adjust grasp on mouse, K = constant normalization factor (positioning device dependent), S = size of target in $pixels_2$, D = distance in screen pixels, helps explain our results because the ratio of the distance (D) to target size (S) is smaller for pie menus. The fixed target distance and increased size of targets for pie menus decreases the mean positioning time as compared with linear menus. In our experiment, the activation region for an item constitutes the target. All subjects were informed of the fact that their target was not necessarily the text, but the region containing the text target item. This was clearly understood by all participants. The font size for text items in both

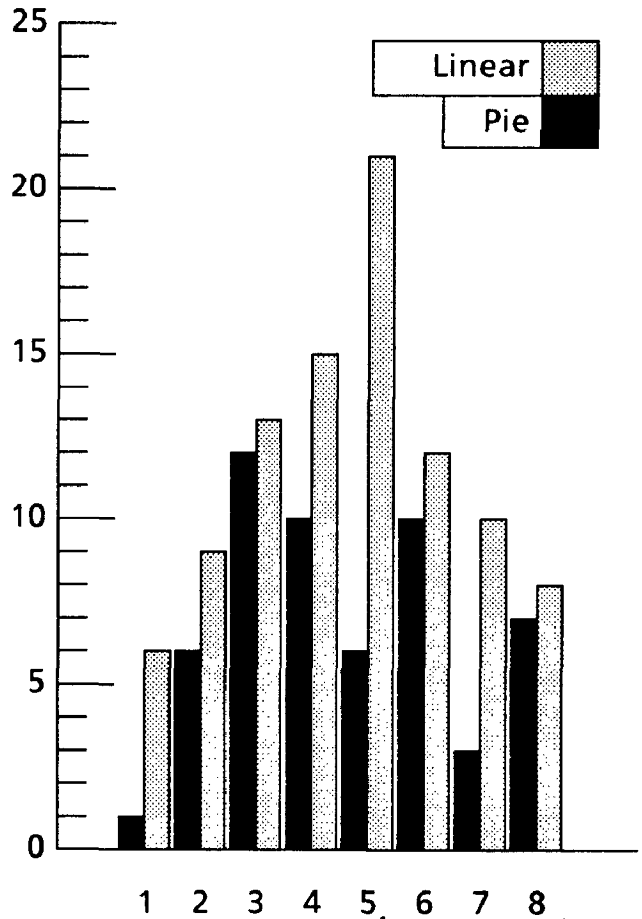

Figure 5: Target location (x) vs. number of errors (y)

menu styles was the same, yet the target region size for pie menus ($3500-6000 pixels^2$) was on the order of 2-3 times the size of linear menu activation region sizes ($1000-2000 pixels^2$). The distance from the center of a pie menu to an activation region is 10 pixels while the distance in linear menus varied from 13-200 pixels.

Figure 5 displays the target location plotted against the total number of errors across all subjects. Pie and linear menus seem to suffer from a similar phenomenon - errors are made more often on items in the central

	Task type			
	Pie	Linear	Unclass.	$Mean_{menu}$
Using pie menus	0.45	0.60	0.60	0.55
Using linear menus	0.88	0.73	1.24	0.95
$Mean_{task}$	0.66	0.66	0.92	

Table 4: number of errors means per cell, menu type, and task type (all observations including no errors)

region of the menu display. These are the items with the most interaction with neighboring items [2].

Repeated measure analysis of variance results on the error rates show marginally statistically significant differences ($P = 0.087$) between pie and linear menus (Tables 4 and 5). No other statistically significant differences were observed.

Subjective results obtained in the pilot study repeated themselves in the experiment. Subjects were split on preferring one menu type over another but those who preferred linear menus had no strong conviction in this direction and most agreed that with further practice

	F	$PR > F$
Menu type	3.12	0.0869
Task type	0.93	0.4066
Menu type X Task type	1.34	0.2773

Table 5: repeated measures analysis of variance results for number of errors

they might prefer the pie menu structure. Those who preferred pie menus generally felt fairly confident in their assessment and this is reflected in the questionnaires.

One subject complained of having a problem with *menu drift* which is the phenomenon which occurs as the result of the cursor relocating to the relative screen location of the last selected target. With linear menus, this tends to "drift" the cursor towards the bottom of the screen. This may explain the higher error rate for linear menus, but the same problem occurs to a lesser degree with pie menus. This, in fact, we believe to be another positive feature of pie menus: the cursor drift distance is minimized. Most subjects had no problems coping with drift in either menu style. One area of further research is measuring the extent and effect of this problem.

CONCLUSIONS

What does this mean? Should we program pie menus into our bitmapped window systems tomorrow and expect a 15-20% increase in productivity since users can select items slightly faster with pie menus. Pie menus seem promising, but more experiments are needed before issuing a strong recommendation.

First, this experiment only addresses fixed length menus, in particular, menus consisting of 8 items - no more, no less. Secondly, there remains the problem of increased screen real estate usage. In one trial a subject complained because the pie menu obscured his view of the target prompt message. Finally, the questionnaire showed that the subjects were almost evenly divided between pie and linear menus in subjective satisfaction. Many found it difficult to "home in on" a particular item because of the unusual activation region characteristics of the pie menu.

One assumption of this study concerns the use of a mouse/cursor control device and the use of pop-up style menus (as opposed to menus invoked from a fixed screen location or permanent menus). Certainly, pie menus can and in fact have been incorporated to use keyed input [7] and fixed "pull-down" style presentation (the pie menu becomes a *semicircle* menu). These variations are areas for further research.

One continuing issue with pie menus is the limit on the number of items that can be placed in a circular format before the size of the menu window is impractical. Perhaps, like the limiting factors in linear menus concerning their lengths, pie menus reach a similar "breaking point" beyond which other menu styles would be more useful. Hierarchical organization, arbitrarily shaped windows (Figure 6), numeric item assignment and other menu refinements as well as further analysis is contained in [7]. Pie menus offer a novel alternative worthy of further exploration.

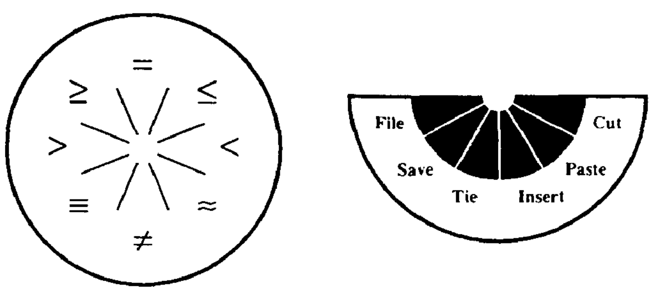

Figure 6: Advanced "pie" menus

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REFERENCES

[1] Adobe Systems Inc. *Postscript Reference Manual*, Palo Alto, Calif., 1985.

[2] Card, S.K. User perceptual mechanisms in the search of computer command menus, In *Proceedings - Human Factors in Computer Systems 1982* (Gaithersburg, Md., Mar. 15-17). ACM, New York, 1982, pp. 190-196.

[3] Card, S.K., Moran, T.P., and Newell, A. *The Psychology of Human-Computer Interaction*, Lawrence Erlbaum, London, 1983.

[4] Dray, S.M., Ogden, W.G., and Vestewig, R.E. Measuring performance with a menu-selection human computer interface *Proceedings of the Human Factors Society: 25th Annual Meeting 1981* (Rochester, N.Y., Oct. 12-16). Human Factors Society, Santa Monica, Calif., 1981, pp. 746-748.

[5] Gettys, J. and Newman, R., *X Windows*. MIT, 1985.

[6] Gosling, J. *NeWS: A Definitive Approach to Window Systems* Sun Microsystems Corp., Mountain View, Calif., 1986.

[7] Hopkins, D., Callahan, J., and Weiser, M. Pies: Implementation, Evaluation and Application of Circular Menus. University of Maryland Computer Science Department Technical Report, 1988.

[8] Kirk, R. *Experimental Design: Procedures for the Behavioral Sciences*. Brooks-Cole, Belmont, Calif., 1968.

[9] McDonald, J.E., Stone, J.D., and Liebelt, L.S. Searching for items in menus: The effects of organization and type of target. *Proceeding of the Human Factors Society: 27th Annual Meeting 1983* (Norfolk, Virginia, Oct. 10-14). Human Factors Society, Santa Monica, Calif., 1983, pp. 834-837.

[10] Perlman, G. Making the right choices with menus. *INTERACT '84, First IFIP International Conference on Human Computer Interaction*. North-Holland, Amsterdam, 1984, pp. 291-295.

[11] Shneiderman, B. *Designing the User Interface*, Addison-Wesley, Reading, Mass., 1987.

[12] Xerox Corporation, *Interpress Electronic Printing Standard*. Stamford, Conn., 1984.