# The Effect of Simple Borders on Icon Search


## ABSTRACT

As the use of graphical user interfaces expands into new areas, icons are becoming an increasingly important aspect of GUIs. Oddly, little research has been done into the the costs and benefits associated with using icons. One aspect of icons, icon borders, has been proposed as means of adding information to icons. Two experiments were conducted in which the potential cost in response time of using simple icon borders was investigated. It is concluded that simple icon borders do not influence user response time in locating a target icon, and hence, icon borders show promise as a potential means of conveying additional information to users.



### Keywords

Icons, icon search, file search, screen design


## INTRODUCTION

Icons are commonly used in the everyday environment, such as in traffic symbols and public facilities, and have even achieved a substantial amount of international standardization. In GUIs, icons have come to represent commands in most applications and objects in data management systems. This paper is primarily concerned with the use of icons to aid in the search of specific data files, a process which will be referred to as icon search. In this context, icons have been the focus of a relatively small body of research , the aim of which is to examine their potential of minimizing user errors and increasing the speed of making selections.

### Previous Research

Beyond desktop computers, the use of icons is becoming more widespread and increasingly important The technology once only associated with desktop computers is popping up in a variety of new locations, including mobile telephones, automobile navigation systems, kiosks, handheld computers, etc. However, the portability and size of all these new computer systems has put significant constraints on the viewable area available to the user, rendering many of the text-based interfaces commonly used on desktops ineffective. The task then for designers has been to get more information to the user in less space. Icons have been, and likely will continue to be, the preferred method in this respect.

The use of icons in all of these new applications has given rise to a number of interesting issues. One of the most prominent of which is determining the costs that are associated with the use of icons. These costs can be examined in terms of the time it takes a user to accomplish a task and the number of errors the user makes in the completion of the task. In this case, time and errors are only symptoms of a deeper issue—the amount and the effectiveness of the information represented by the icon. Ideally, the more information contained in the icon, the more effective the users utilization of the icon will be. However, there are some limitations and trade-offs associated with additional detail and information contained within the icon.

In GUIs, the information contained within the icon is often utilized by the user in one of two ways. In one manner, icons are simply used as a target for visual search. In this context, the icon conveys no interpretive meaning other than its association with a file or application, rather, the icon is simply a design that aids the user in icon search. Icons can also be used to convey information other than simple associative meanings. Houde and Salomon [5] offer an example of how this can be done using simple icon borders.

The basic premise behind Houde and Salomon's use of icon borders to convey information is that real world objects come in a variety of shapes and sizes, yet icons have become standardized to be one size and often one shape on the computer screen. Small alterations to simple pieces of the icon can give the user quite a bit more information. Some examples are provided in Figure 1.

If the file that an icon represents is a three-dimensional model, possibly created for engineering or architecture purposes, the addition of a few lines to create a three dimensional cube as a border could potentially give the user some information about the file the icon represents. Also, adding a few lines to the back of the icon border may help users differentiate from multiple-page and single-page documents. Finally, the folded corner of the icon border as a representation of documents is a current example of using icon borders to convey some simple information.


Figure 1. Examples of using icon borders to convey information.

Clearly there are opportunities to make icons more informative. However, as alluded to earlier, there is evidence that more information is not always advantageous to the user. Much of this evidence centers on a trade-off between the level of complexity in the icon and the effectiveness of the icons.

### Complexity trade-off, Clutter vs. Information

Some insight can be gained into the visual search process by examining response times as the number of objects in the display (also called the "set size") increases. If response times substantially increase as set size increases, the search can be termed a relatively inefficient one. This indicates a relatively serial search strategy, where items or groups of items must be examined individually or on a local level—features of the visual object that require such a search in order to be distinguished from other objects are termed local features. Conversely, if response times do not increase substantially as set size increases, the search can be termed as a relatively efficient one, also known as a preattentive search (vision does not need to shift to each object specifically, rather, the target can be located by examining the set as a whole). A large body of visual search literature has been devoted to defining the features of objects that lead to efficient search (termed global or basic features), such as color, size, curvature, etc. [11] The use of set size in inferring the efficiency of the process is particularly relevant in the experiments discussed in this paper. Much of the impetus for these studies is to investigate any potential costs associated with icon borders. The relative efficiency of the search with various icon borders provides an insight into the cost in time of searching for an icon. Additionally, an understanding of global and local features is key in understanding the trade-off involved in adding additional detail and complexity to icons.

The complexity trade-off in icon design is a factor as additional detail is added to an icon. On one hand, the addition of greater detail and complexity to the icon picture should give the user more information and help him or her locate the target icon quickly and effectively [1]. However, the global superiority effect, taken from the visual search literature, postulates that global features of figures can be selected and responded to considerably faster than local features [9]. Also, the addition of greater detail to icons, and hence, the addition of local features, adds to the number of features that the target shares with its distractors, and this will presumably slow down search. Lastly, the addition of local features adds to the general visual clutter of the display, making search for the target icon more difficult [1]. Thus, adding detail to icons should help the user by increasing the information contained in the icon, but additional detail may “hurt” the user by increasing the use of local features and adding visual clutter to the display. It is critical for the effective design of icons that a greater understanding of this trade-off is achieved.

The studies described in this paper delve into the complexity trade-off and icon search by investigating the costs associated with icon borders. Certainly, many of the basic concepts and ideas from the visual search literature are applicable to icon search. For example, as features shared between the target and distractors increases the more difficult the search becomes. Also, when search can be based on a distinction between basic features of the target and distractors, search is most efficient [9]. However, icon search is a deceptively simple process. What appears to be a simple point-and-click task is actually quite complex. And due to this complexity, icon search cannot be based solely on the visual search literature. Byrne [3] classified the factors of icon search that account for its greater complexity into three categories, general factors, graphic factors, and text factors. Each of these three classifications and the factors that make them up will be discussed to give a sense of the number of complex factors involved in icon search and why icon search demands a field of study of its own.

## General Factors

### Mixed Search

When searching for a target icon, the user must use two search processes, which may or may not be related. They must search the graphic picture of the icon and the text label below the icon representing the file name.

### Target Knowledge

While in visual search tasks the user knows exactly which object he or she is searching for, a green “X” for example, the users’ knowledge of the target is not always nearly so precise on every icon search. Users may not know the exact name of the file, or the exact picture of the icon, before they begin the search.

### Multiple Matches

It is common in icon search for the target icon to share its icon picture with other icons in the visual display. In this case, the user must use the semantic information provided by the icon label to distinguish the target icon from the other icons that share the same icon picture.

### Motor Task

In an applied setting, even after the user has identified the target icon, he or she must move the cursor to the icon and click on the icon with the input device, usually a mouse. The time it takes to complete this task is affected by the size of the icon, the distance that the cursor must be moved, and the quality of the mouse.

## Graphical Factors

### Size

It has been established in the visual search literature that objects can be preattentively distinguished based on varying sizes. In icon search, generally, all of the icons on the screen are roughly the same size, so little can be accomplished in terms of selecting particular icons. However, Jacko [6] showed that increasing the size of all of the icons decreases response times. Presumably, response times are decreased because features of the larger icons are more easily discernible. Increasing icon size is not an ideal solution to decrease response times however. There is a law of diminishing returns associated with continually increasing icon size—i.e. icons can only be so big before their increased size is no longer helpful, but rather adds to the visual clutter of the display [6].

### Color

Color has become a popular mode of differentiating icons among icon designers. However, caution should be exercised when using color. Despite its distinctiveness as a feature, the uncoordinated use of color can rapidly add visual clutter to the display.

### Display Shape

This was a larger field of study at the onset of the "computer era" than it is now. Bloomfield [2] found that users were quicker to locate objects when searching for them on a horizontal rectangularly shaped display than on other shapes of displays (square, vertical rectangle, etc.). Today, the shape of personal computer displays has become relatively standardized. However, this subject is likely to become a more prominent issue with the proliferation of computer technology in new places and devices.

### Spatial Organization

On many modern computers it is possible for the user to organize the icons in the display to his or her liking. For example, they may be presented in a grid-like or staggered organization.

An additional perspective on the spatial organization of displays comes from Tullis [10]. He proposed four basic geometrical characteristics that may affect how well users are able to extract information from a display.

1. Overall density: the number of characters displayed, expressed as a percentage of the total spaces available;

2. Local density: the average number of characters in a five-degree visual angle around each character;

3. Grouping: the extent to which characters on the display form well defined perceptual groups;

4. Layout complexity: the extent to which the arrangement of items on the display follows a predictable visual scheme.

It was found that there is a high correlation between the geometrical characteristics of a display and the search time for an item on the display. Although these studies did not deal specifically with icons, it can be inferred that the visual spatial organization of the display is an important factor to be considered.

### Number of Objects

One of the most studied aspects of visual search, and applicable to icon search, is that of varying the number of distractors among which the target must be selected. Set size has been studied in such depth because of the inferences that can be drawn about the relative efficiency or inefficiency of the search.

### Form

One of the principal dimensions on which icons vary is that of their shape or form. As in the visual search literature, form is a very complex factor and contains a number of sub-dimensions, such as the level of detail in the icon and the meaningfulness of the form.

## Text Factors

### Icon labels

It has been previously noted that icon search relies on both a graphical search of the icon picture and a text search of the icon label before the target icon can be identified. One of the interesting aspects of icon labels is that they often are not made up of complete words. They may be abbreviated words, parts of words, strings of letters only meaningful to their creator, or even numbers or a combination of the above.

### Sorting

An additional source of complexity that must be dealt with before icon search is fully understood is the use of sorting features by users. On most GU's, icons may be arranged or sorted alphabetically according to their label, by the date that they were last modified, by the type of application that was used to create the document, or even by the type of document the icon represents.

Each of the factors just discussed is worthy of future research and individual examination. However, a study of icon borders provides an ideal focus of investigation for several reasons. First, icon borders are a key part of the overall form of an icon, which, as previously mentioned, is a primary dimension on which icons differ. Additionally, icon borders may help provide an insight into the complexity trade-off. In fact, one-half of the elements of the complexity trade-off—how borders can be used to convey information—has already been developed. However, the costs potentially associated with icon borders remain to be examined. Hence, the primary impetus for the following studies was to examine the potential costs of simple icon borders.

## EXPERIMENT ONE

The basic paradigm of the experiment is one borrowed from the visual search literature—locating a target among distractors. Succinctly put, the users' task was to locate a target icon among a set of distractor icons.

### Method

#### Design

The design of the experiment was intentionally kept relatively simple, although a certain level of complexity was necessary to examine the process. Three independent variables were manipulated, all of which were within-subjects factors.

The first of these factors, set size, had four levels, 6, 12, 18, or 24 icons.

A second within-subjects factor, target type, had three levels. The target icon to be searched for could be presented without a border (no-border condition), with a circle as a border (circle), or with a box as a border (square). Refer to Figure 2 for examples of each border type.


Figure 2. Some examples of icons with different borders. Note that these icons are identical to some of the icons used in the experiment. (The file names are selected randomly from a list.)

The final within-subjects factor was termed distractor type and was varied at two levels. In the matched condition, the distractors among which the user searched for the target, had borders matching that of the target—i.e. if the target icon had a square border, then all of the distractors would also have square borders. In the mixed condition, the borders of the distractors were varied—i.e. the user searched for the target among icons without borders and with circles and squares for borders. In this condition, each of three border types was randomly assigned to the distractors in the display.

Each block in the experiment thus consisted of 24 trials. Each independent variable was examined at each level of the other independent variables (4 x 3 x 2 = 24). The order of presentation was randomized.

The dependent variable being measured was the response time of the users—specifically, the time from when they clicked on the "Ready" button to indicate that they were finished examining the target icon to when they clicked on the target icon among the set of distractor icons.

One potential independent variable that was held constant in this experiment was the number of icons matching the target in the search display. On each trial one-third of the icons in the search display had the same pictorial icon. Thus, ultimately the user was forced to differentiate among the icons by the file name.

#### Procedures

Users were initially given some instructions as to how to perform the task, then were given one block of practice trials to develop some familiarity with the task and with the mouse used to point and click on the target icon.

Each trial had two stages. On the initial screen of the first stage, users were presented with a target icon and a corresponding file name. After 1500 milliseconds, a button labeled "Ready" appeared in the lower right corner of the screen. Users could move the mouse and click on the button whenever they felt they had sufficiently examined the icon and were ready to move on to the next stage of the trial.

Immediately after clicking on the Ready button, the users were presented with a screen that contained a number of icons (6, 12, 18, or 24), one of which was the target icon. The user's task was to identify the target icon and click on it as quickly as possible. Clicking on an icon brought them to the first stage of the succeeding trial. Response time was measured from the time they clicked on the ready button to the time they clicked on an icon in the distractor set.

The location of the target icon was randomly selected for each trial. Also randomly selected were the file names for the icons. The distractor file names and the target file names were randomly selected without replacement from a list of 750 names until the list was exhausted. At which time, the list was recycled.

Each user completed four blocks of trials in addition to the practice block for a total of 120 trials.

#### Users

The users in the experiment were 25 undergraduate students at Rice University who were participating in order to meet a requirement for a psychology course. Although some variation with regard to computer experience was expected, users in this population are generally familiar with computer use.

#### Apparatus / Materials

The experiment was conducted on Apple Macintosh iMac personal computers.

The icons used in the experiment were standard Macintosh sized icons (32 pixels by 32 pixels). They were subjectively designed as arbitrary shapes by the experimenters. An effort was made to design the icons so that they did not represent any specific well-known shape or object. Additionally, they were created entirely in grayscale—none of the icons contained any color other than white, black, and shades of gray.

### Results

When the user did not correctly identify the target icon the trial was considered an error and removed. Outliers were also removed when the response time was more than three standard deviations from the 5% trimmed mean of the user for the corresponding set size. In total, less than 5% of the trials were removed due to errors and outliers. For statistical tests, where response times had been removed as errors or outliers, they were replaced with the user's grand mean.

Figure 3 provides a graphical summary of the data. Examination of the data provided evidence for some interesting patterns, described below.

One interesting pattern in the data is a reliable effect of set size, $F(3, 72) = 117.89$, $p < 0.001$. It took users an average of 1422 ms to locate and click on the target icon in the smallest distractor set size. For each additional six icons added to the distractor set, the users took approximately one-half second longer to locate the target icon. This consistent increase in response time across set sizes is confirmed by a reliable linear effect of set size, $F(1, 24) = 168.55$, $p < 0.001$.

Another interesting result observed in the data is the lack of any reliable effect, $F(2, 48) = 1.66$, $p = 0.20$, or interaction involving border-type. Hence, no evidence is provided to support the hypothesis that the type of border affects the icon search.

Whether the distractor borders matched the target border or were a mixed set of the three different border types did not significantly affect the users' performance on the task. No evidence was found for an effect of distractor-type, $F(1,24) = 1.48$, $p = 0.24$, nor for any interactions involving distrator-type.

### Discussion of Experiment One

The results of Experiment1 provide some insights into the costs associated with simple icon borders. First, the cost in time of a search for a target icon is a linear function of the number of icons in the display. Also, the lack of any evidence for simple icon borders affecting icon search response times is an interesting result, and it suggests that simple icon borders have the potential to break the complexity trade-off—i.e. a means of getting information to some users through increased icon detail at virtually no cost to those users who do not take advantage of it. However, before drawing definitive conclusions, there should be some additional examination of the process. Specifically, there should be an examination of whether such a result can be found across other types of icons. This was the motivation for a second icon search study.

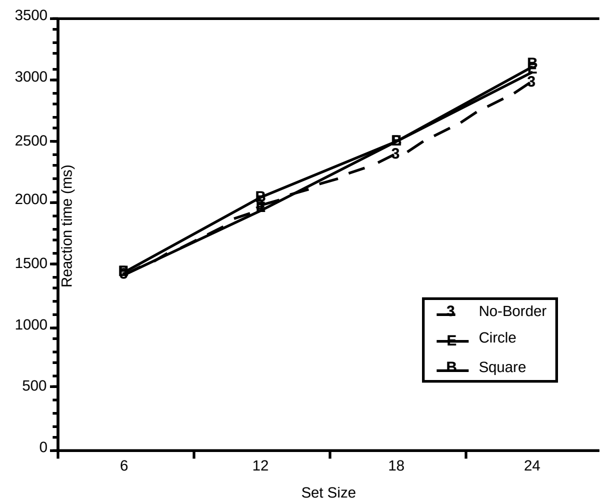


Figure 3. Plot of mean response times by set size and border type.

## EXPERIMENT TWO

The experiment was designed to investigate the effect of simple icon borders on a broader range of icons (relative to Experiment1). The range of icons examined varied according to their relative quality—defined here as their distinctiveness from other icons.

### Method

#### Design

The design of the experiment was very similar to that of the first experiment. The basic paradigm was not changed, but one independent variable, termed icon quality, was added, and the independent variable of distractor-type (mixed or matched conditions) was removed. The other independent variables, set size and target type, were not changed.

The within-subjects factor that was added to the design, icon quality, had three levels. Icons were designed that varied in their level of distinctiveness. On one end of the spectrum were icons of “good” quality. These icons were designed to be easily distinguishable from other icons based on the basic visual (“pop-out”) features of color and shape (specifically curvature). Icons in the good quality set were one of six colors (red, blue, green, yellow, brown, or black) and one of two shapes (circle or triangle). Examples are shown in Figure 4. On the other end of the quality spectrum were icons that were not easily distinguishable (referred to as “poor” quality icons). They were designed to be distinguishable in a set of two icons, but quite indistinguishable in a large distractor set. The icons designed to be representative of the area in between these two ends of the spectrum, “fair” quality icons, were the icons used in the first experiment.

The within-subjects factor of distractor type was removed from the analysis. The first experiment found no evidence of an effect or interaction involving distractor type so this factor was not considered further.

Each block in the experiment thus consisted of 36 trials. Each independent variable was examined at each level of the other independent variables (4 x 3 x 3 = 36).

As in the first experiment, the dependent variable being measured was the response time of the users—specifically, the time from when they clicked on a button to indicate that they were finished examining the target icon to when they clicked on the target icon among the set of distractor icons.

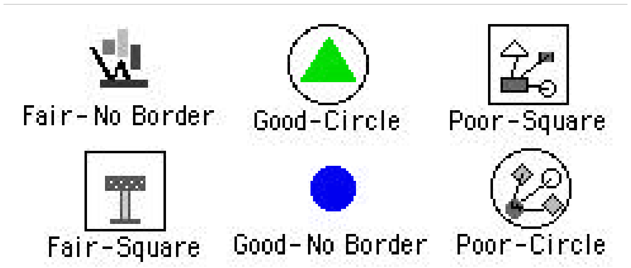


Figure 4. Examples of icons of good, fair, and poor quality used in the experiment. The good quality icons were each a single solid color, whereas the fair and poor quality icons were drawn in grayscale.

### Procedures

The task is nearly identical to that performed in the first experiment. The only changes being the addition of the icon quality factor, the removal of the distractor type variable, and thus an increase in the number of trials in each of the five blocks. Each user completed four blocks of trials in addition to the practice block for a total of 180 trials. The paradigm of the presentation of the target icon and the search among distractor icons remained exactly the same, however.

### Users

The users in the experiment were 20 undergraduate students at Rice University who were participating in order to meet a requirement for a psychology course. Although some variation with regard to computer experience was expected, users in this population are generally familiar with computer use.

### Apparatus

The experiment was conducted on Apple Macintosh iMac personal computers.

## Results

User errors and outliers were removed from the data according to the same procedure as Experiment 1. In total, less than 5% of the trials were replaced due to errors and outliers. For statistical tests, where response times had been removed as errors or outliers, they were replaced with the user's grand mean.

A summary of the data, collapsed across the icon quality variable, provides results quite similar to those in first experiment. (Refer to Figure 5.) Response times range from approximately 1500 ms for the smallest set size of six icons, and increase by 400 to 500 milliseconds for each additional six icons added to the distractor set, up to about 3000 ms for a set size of twenty-four icons. As in the first experiment, there is a significant effect of set size ,$F(3,57) = 210.45$, $p < 0.001$. Also, there is a reliable linear effect of set size, $F(1,19) = 426.36$, $p < 0.001$. Additionally, as in the first experiment, there is not a main effect of border type, $F(2,38) = 0.46$, $p = 0.63$.

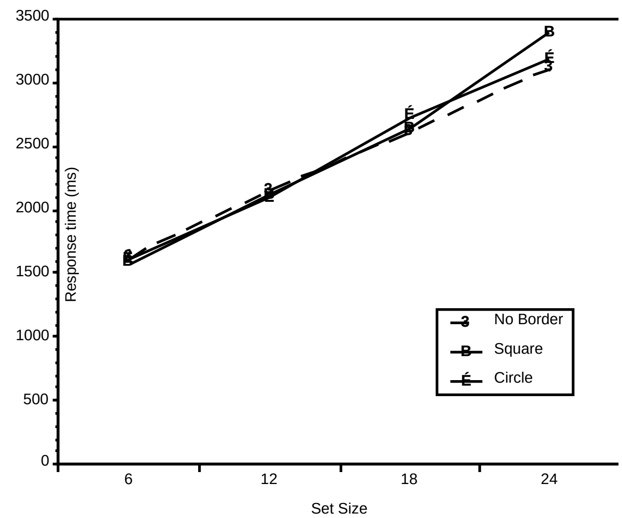


Figure 5. Mean response times by set size and border type.

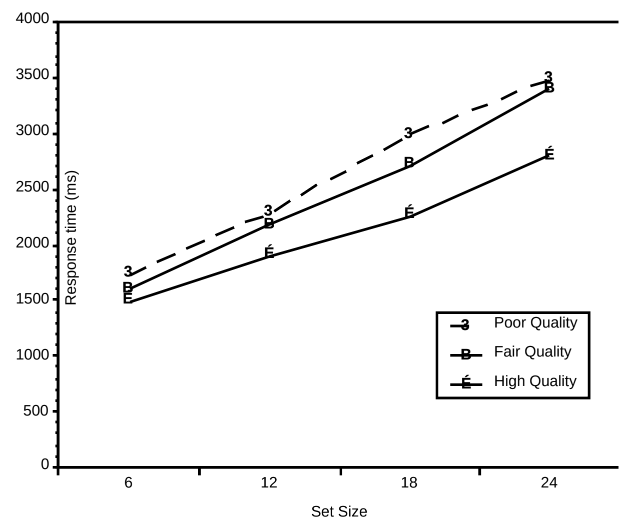


Figure 6. Mean response times by set size and icon quality, illustrating a main effect of icon quality.

In Figure 6, mean response times are presented as a function of set size and icon quality. Here, it is evident that as icon quality decreases (good to fair to poor), response times increase. This is confirmed by a significant main effect of quality, $F(2,38) = 52.14$, $p < 0.001$. Also, not only are the three qualities significantly different, but the slopes of the lines appear to be different, as confirmed by a reliable quality by set size interaction, $F(6,14) = 5.20$, $p < 0.01$.

In Figure 7, mean response times are presented across icon quality and target border type. This chart once again displays the main effect of icon quality—as quality decreases, response times increase. Here again, there is no effect of border type, and no interactions involving border type. Also, the difference in response times across the different icon qualities is relatively consistent, leading to a reliable linear effect of icon quality, $F(1,19) = 103.06$, $p < 0.001$. One key aspect to note from this chart is the relatively large effect of icon quality. Any potential effects of border type would be far outweighed by the main effect of quality.

This lack of an effect involving target border is very clear at lower set sizes. However, at the largest set size of 24 icons, the data become quite a bit muddier, particularly for poor quality icons. Here again it is important to note that even at these large set sizes, where target border type may begin to have an effect on response times, this effect would be far outweighed by the relatively larger effects of set size and icon quality.

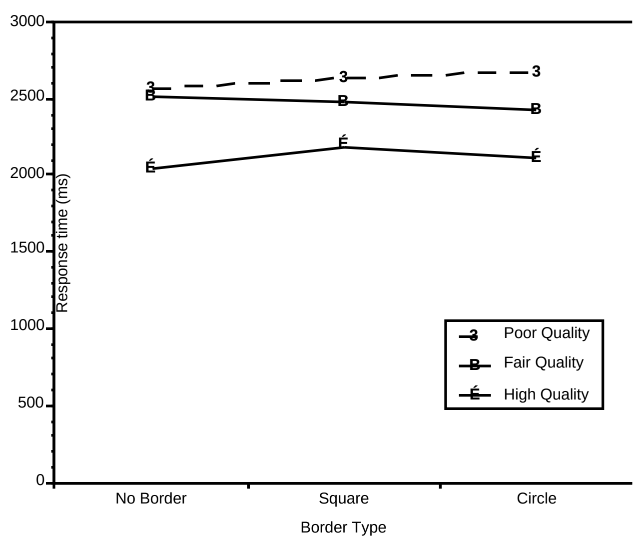


Figure 7. Response times by icon quality and border type.

### Discussion of Experiment Two

Experiment 2 confirmed that users' response times to selecting target icons is unaffected by simple icon borders. While the data do not definitively rule out a small effect of borders at large set sizes, the potential effect was far outweighed in magnitude by the effects of set size and icon quality. These results confirm the findings of Experiment1, but further generalize them across a broader range of icons varying in quality.

Additionally, the two most prominent effects produced in Experiment 2 are those of set size and icon quality. As in Experiment 1, Exeriment 2 produced a very consistent effect of set size. It took users approximately 1500 milliseconds to locate and click on the target icon in a set of six icons. For each additional six icons that were added to the distractor set, response times increased by approximately 500 milliseconds. The mean response times involved are likely specific to the icons that were used. However, the linear relationship between set size and response time is an important one to note. Second, an effect of icon quality was also produced, indicating that the quality of the icons has a significant effect on user response time.

## GENERAL DISCUSSION

The conclusion that simple icon borders do not affect icon search suggests that methods of adding information to icons through borders, such as those suggested by Houde and Salomon [5], are quite promising. The reason being that the cost of presenting this information to the user may be trivial. For the purposes of search, users are able to ignore borders, and thus, this set of experiments indicates that the presence of borders will not adversely "harm" users in terms of response time.

This concept of using icon borders to convey information at no cost to the user can also be discussed from the perspective of how users employ icons. From this perspective, the users' utilization of icons was discussed as belonging to two categories—simple targets to guide visual search or more complex symbols conveying interpretive meaning. The results of these experiments indicate that borders provide a means for increasing the interpretive content of the icon without altering its use as a target to guide search.

These conclusions may not apply to any and all icon borders. Certainly, as borders become more extravagant and move beyond the very simple shapes used in these experiments, they may become more visually demanding of the users' time and interest [4]. However, the conclusions drawn here should be leveraged to suggest that the judicious use of icon borders is unlikely to cost more in time than what could potentially be saved if the information is effectively used. In comparison to the effects of set size and icon quality on search time, any effect of icon borders is likely to be trivial. Thus, if an icon designer can use icon borders to transmit some information, it is likely worth the effort to try it, because the effect of the additional detail on search time, if any, will be minute.

The experiments discussed in this paper were designed to investigate the potential for using simple borders with icons. In examining this potential, both the costs and the benefits of using icon borders must be investigated. Both of the experiments that were conducted provided no evidence that simple icon borders have a significant effect on the primary cost involved in icon search—users' search times. However, there is still a need to examine in greater depth the benefits associated with using icon borders. The experiments in this paper provide the foundation and impetus for such future studies into the potential of simple icon borders.

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