Project Proposal

Project Title: Using A Mathematical Model to Personalize Keyboard Layouts For Users Missing Digits

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Abstract

The overall aim of this project is to develop fifteen specially arranged keyboard layouts to allow users missing index and/or middle fingers to type on keyboards with less difficulty. In this project, the keyboards will be arranged using ergonomic criteria for typing speed and efficiency found in previous studies. In addition, a mathematical model will be created that will be used to analyze the latency time between keys, adjusted to consider the missing digit(s), to gauge the relative speed of the keyboard layout. In addition, it will analyze the key distances from the original Qwerty keyboard layout to show that the new layout is very similar. Analysis will ideally show that the new layouts are faster to type on while still maintaining similarity to Qwerty. As a result of rearranging the keyboard, typing speed and comfort should be improved for users. In addition, the new layouts' similarity to Qwerty will allow the user to retain most of their muscle memory, shortening the learning time. While the current focus is on users who are missing their index or middle fingers, the scope can be expanded in the future to accommodate other missing digits.

Thus, since many typists are trained to touch type on the Qwerty keyboard layout using all ten fingers, causing typing to become difficult and inefficient if one or more digits are lost. To combat this, the objective is to design alternate keyboard layouts optimized for combinations of commonly lost digits that will increase typing speed and comfort while also being easy to learn and adapt to quickly.

Background

Although keyboards are ever more common in the present age of technology and many assistive devices have been made to aid in computer use, one big component remains unchanged: the keyboard. Because keyboards assume the typist has full function of all fingers and both hands, they are not as accessible to those with hand injuries or disorders, such as those who are missing one or multiple digits. Thus, the goal of this project is to create custom layouts for the most common combinations of missing digits to increase typing speed and comfort for individuals who would like a solution.

The Target Audience

An estimated 45,000 finger amputations occur per year in the United States alone (Reid et al., 2019). This means that the number of Americans who are missing one or multiple digits is even higher. Currently, these people are forced to relearn how to type: a time-consuming task. If time is already being spent learning to type with fewer digits, why not instead spend that time learning a custom keyboard that accounts for those missing digits? If there is text-to-speech for the visually impaired and subtitles for the hard of hearing, accessibility for the keyboard should be implemented as well.

Although few studies show the impacts of finger loss on typing speed and comfort, there is anecdotal evidence on the internet to suggest that typing after a finger amputation is an issue. Looking through various forum websites such as Reddit, as well as personal blog pages, it is clear that many people struggle to reach their maximum typing speed after the loss of a finger. Furthermore, while there is technology that allows for accessible text input such as gesture typing on phones and speech-to-text, no comprehensive solutions for the physical keyboard currently exist. There has, however, been past research that provides typing data and specific ergonomic criteria to help reassign keyboard keys.

History of the keyboard

The Qwerty layout, denoted by the Q, W, E, R, T, and Y keys in the top row, is the de facto standard of keyboard layout in America and many other regions of the world (Harford et al., 2019). This layout was invented for the typewriter by Christopher Sholes in the 19th century and quickly became the status quo. Despite being the most common layout today, it was invented to make typing slower. This was because typewriters would frequently jam or print letters on top of each other if the keys were hit too fast (Harford et al., 2019). And so while Sholes successfully improved typing on the typewriter, but in turn, sacrificed the typing speed and comfort of the keyboard, also known as ergonomics. Despite working well for typewriters, the original reason for inventing the layout is no longer applicable to modern computers.

Because of this, many attempts have been made to optimize keyboard layouts using a variety of different methods today. Although these layouts have improved typing speed and comfort, only a small niche of enthusiasts commit to learning a new layout. For most people, the time and difficulty of learning a new layout may not offset the slight benefits of typing faster. This is exacerbated by the fact that most optimized keyboard layouts look completely different from the Qwerty layout, meaning that the learning curve is high. Even the most popular alternate layout, the Dvorak layout, looks nothing like Qwerty (*Figure 1*). If one were to learn an alternate layout, not only would they have to learn the new locations of the keys, but they would also have to undo years of muscle memory from typing on the Qwerty layout. However, if the learning curve was to be decreased, the pros might start to outweigh the cons. Specifically, focusing on those who are missing digits, and moving only the crucial keys, while keeping the rest of the keyboard the same could increase typing speed and comfort while only requiring a few weeks to learn.

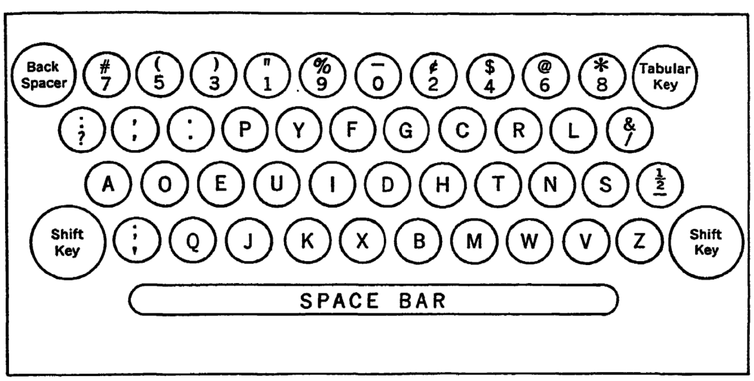

Figure 1: The Dvorak keyboard layout, created by August Dvorak (Dvorak et al. 1936). Despite being one of the most popular alternate keyboard layouts, only two letters remain in their original Qwerty locations: A and M. This not only goes to demonstrate the inefficiency of Qwerty but also how different other keyboard layouts are.

Previous Studies

Although no literature has been published specifically regarding the effects of finger loss on typing performance, there has been a plethora of previous literature regarding the keyboard assignment problem (KAP), a combinatorial problem regarding the optimal arrangement of the letters on the keyboard (Light & Anderson, 1993).

A wide range of strategies have been employed to optimize the physical keyboard layout: from manual rearrangement to computer algorithms, virtually every method has been tested. For example, the Dvorak keyboard, created by August Dvorak was optimized by analyzing touch typing, while Onsorodi & Korhan (2020) used a genetic algorithm to search for an optimal solution. However, the efficacy of these solutions varies due to the sheer size of the solution space: 26! = 403,291,461,126,605,635,584,000,000 possible different keyboard layouts. Despite there being no conclusive evidence for the “best” keyboard layout, lots of data have been recorded and analyzed. For example, the book by Dvorak et al. (1936) outlined eleven key principles to follow when creating new keyboard layouts, focusing on ergonomic principles. In addition, Shieh & Lin (1999) quantified and concluded these ergonomic principles, while Bi & Zhai (2016) investigated how important similarity to the Qwerty keyboard is to learning a layout quickly. Finally, İşeri & Ekşioğlu (2015) measured digraph times, or the time it takes to type a pair of keys, to provide a way to analyze the speed of a keyboard layout.

These studies and criteria will be taken into account when working on this project to ensure that the new layout will be easy to learn and also ergonomically appropriate. In particular, The criteria by Dvorak et al. (1936), the conclusions by Shieh & Lin (1999) on finger dexterity and ideal key placement, the findings by Bi & Zhai (2016) on learnability due to similarity to Qwerty, as well as the touch typing principles (Figure 2) will be focused on when rearranging the keyboard. Then, the digraph times found by İşeri & Ekşioğlu (2015) will be used to analyze typing speed of the keyboard.

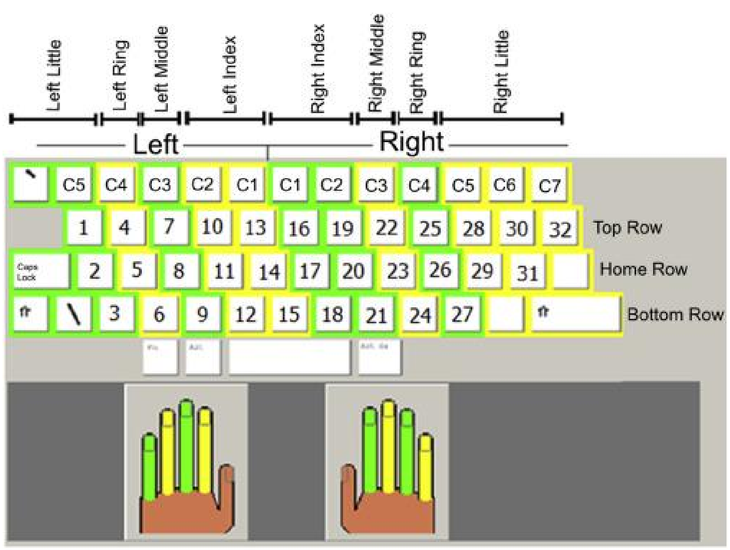

Figure 2: A visual representation of touch typing (İşeri & Ekşioğlu 2015). Because touch typing is a style of typing where each finger is assigned its column, finger movement is predictable and easier to analyze.

Methodology

The goal of this project is to engineer specific layouts for touch typists missing digits. Since the index and middle finger are the digits that are most frequently injured (Saraf & Tiwari, 2007). This project will focus on these specific situations where the index and/or middle fingers on either hand are missing, meaning fifteen different layouts will be created. However, an extension might be considered in the future.

The long-term goal is to create a computerized mathematical model of the keyboard while accounting for criteria that define optimal key placement. By quantifying how optimal each key location and letter placement is, the model keyboard can be used to analyze which combination of rearrangements proves to be not only the most efficient and comfortable for the user but also the easiest to learn. The rationale is that a mathematical model can be expanded in the future as more research and extensions are done.

The three main goals of this project are:

1) To develop 15 personalized keyboard layouts to account for all combinations of hands missing index and middle fingers.
2) To show that typing on the newly engineered keyboard layouts will increase the user's typing speed (words per minute) as well as comfort after reaching full mastery.
3) To show that adapting to the keyboard will not require extensive retraining and a long period of practice.

Firstly, it will be assumed that the user is a touch typist. Touch typing is a style of typing where the locations of the keys are memorized, and the typist does not need to look at the keyboard to type. In addition, a touch typist often uses the same fingers for specific keys. Since a touch typist always uses the same finger to type the same key, this allows typing patterns to be discerned since there is a methodology to typing. In addition, the majority of the past studies, including Dvorak et al. (1936), Shieh & Lin (1999), and İşeri & Ekşioğlu (2015) focused on touch typing, this project will as well.

Because of this assumption, if a user is missing a specific finger, for example, the middle finger on the left hand, a specific column can be identified as problematic for the user to reach. Though the user would be able to reach these keys using other fingers, for the sake of clarity, they will be called "inaccessible" from here forward. From there, the frequency of each letter (*Figure 3*) can be utilized to rank each key: 1 being the most frequent and 26 being the least frequent. Common punctuation such as commas and periods will be taken into account as well. This is important to note because if a commonly used letter, such as "e", is located in the inaccessible column, the user must spend more time reaching with another finger to hit that key, decreasing comfort and typing speed.

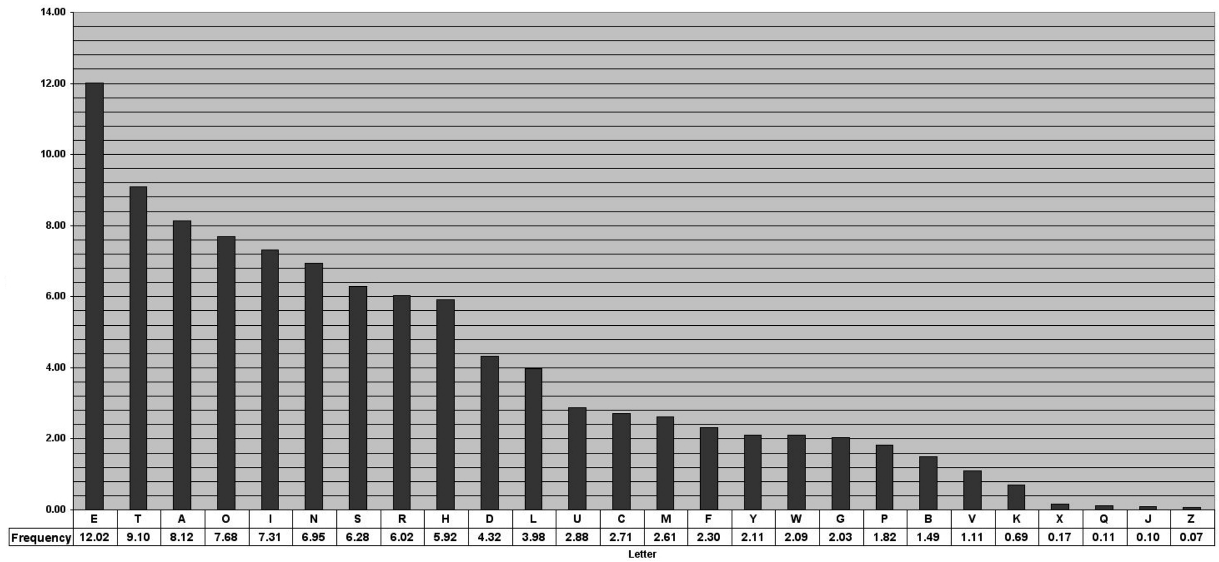

Figure 3: A chart from Cornell University detailing the frequency of letters in the English dictionary based on a sample of 40,000 words (*Frequency Table*, n.d.).

From here, each location on the keyboard will be given an accessibility score, independent of the letter that currently resides there. This score will be given based on the findings of Dvorak et al. (1936) and Shieh & Lin (1999). For example, Shieh & Lin (1999) concluded that the tapping load for each finger should directly correspond to the dexterity of that finger. They also found that the index was the most dexterous finger, followed by the middle, ring, and then pinky finger. This means that ideally, the less dexterous remote fingers (ring and pinky) should type the less commonly-occurring letters such as “q”, “x”, or “z”. Inversely, the strongest fingers (index and middle) should type the more commonly-occurring letters such as “e”, “t”, or “a”. In addition, Dvorak et al. (1936) concluded that typing in the home row (middle row) should be maximized, and movement to other rows should be minimized. Consecutive keys should be typed with alternating hands or fingers as much as possible and reaching for keys should be minimized.

From here, the frequently used characters that are inaccessible will be swapped with less frequently used characters. This would be done while taking to account the distance the key is moved and the accessibility score of the new location. This is because although it isn’t ideal for a commonly-occurring letter such as “e” to be located in an inaccessible column, it also isn’t ideal for it to be typed with a less dexterous finger such as the pinky finger.

The result should be a keyboard that has moved the inaccessible keys and swapped them with the less frequently used keys, while also accounting for travel distance and similarity to Qwerty. By balancing all of these factors, ideally, the keyboards will be arranged in a way that increases typing speed and comfort while not sacrificing learnability.

In the end, the keyboard will be analyzed using a computerized version of the model and then it will output a script that can be used to physically reassign the keys. Although the issue of the letters on the keyboard not matching the layout itself exists, this problem can be overcome by using tricks such as tape or custom keycaps to switch the letters around as well.

The script outputted will be an AutoHotkey script. This software was chosen because it can not only run quietly in the background, but it is also easily downloaded and thus accessible to anyone who has a computer. This accessibility helps ensure that as many people can be benefitted from this project as possible.

Materials
For this project, the following equipment will be used:

Java 8

- ❖ the language for coding the mathematical model and performing the theoretical analyses

Eclipse IDE 2022-09

- ❖ the environment for coding in Java

AutoHotkey

- ❖ the script writing program for the keyboard reassignment script

Ethical Considerations
Because this project will be performed *in silico* using data from previous studies, there are no ethical issues to be addressed.

Data Analysis

After the new keyboard layouts are created, they will be compared to the Qwerty layout in terms of interkey stroke times (digraph times) and similarity. İşeri & Ekşioğlu (2015) conducted a study where they measured the number of digraphs (pairs of keys) that could be typed in a 30-second interval of time and then calculated digraph times based on this data. They did this by assuming that the digraph times for each pair of keys were independent of the letters on those keys. This means that if the time it took to hit "f" then "r" is 226 milliseconds (ms), then even if those keys were changed to, for example, "q" and "u", the digraph time would remain 226 ms because the positions did not change, only the letters. They also made the assumption that hit direction did not matter, meaning that typing "f" then "r" would have the same time as "r" then "f". They calculated these times for all possible digraph combinations on the keyboard, and this data will be used to analyze the efficacy of the keyboard.

Although digraph times can be used, one major limitation is that there is no data for when fingers have to move to different columns that they are not assigned to. This is because fingers will stay in their columns for touch typing, but the circumstance changes when digits are lost. Because of this, some assumptions need to be made. These assumptions are typing a digraph with one finger when it was originally typed with alternating fingers increases the digraph time by around 50 ms. Then, changing columns adds an additional 10 ms. Finally, each finger adds an additional period of time based on the dexterity of the finger. These would be an added 5 ms for the middle finger, 11 ms for the ring finger, and 22 ms for the index and pinky fingers. These values were estimated by analyzing the data gathered by İşeri & Ekşioğlu (2015).

From this, the times for the most common digraph can be added and calculated for the optimized and the Qwerty keyboard. Each time can be multiplied by the frequency of each digraph and then summed together. In the end, since the frequently used keys will be moved to more optimal locations, the sum of digraph times for the optimized layout should be lower than the sum of times for the Qwerty layout, showing that the new layout will increase typing speed and, thus, comfort.

Finally, to show that the keyboard is relatively easy to learn, the distance of each key from its original to its new location will be averaged. This will show how similar the new keyboard is to the Qwerty keyboard. For example, if the letter “t” was switched with the letter “r”, the distance would be one key length. This average would be taken — once for just the keys that have been moved, and once for the whole keyboard — to find a general sense of how similar the optimized layout is to the Qwerty layout. The average for the whole keyboard should be less than 1 key length because only a few keys are being switched around. As for the average of the keys that have moved, there should ideally be less than a 3-key length difference.

The end result will be keyboards that will increase typing speed without sacrificing learnability for users missing index and middle fingers.

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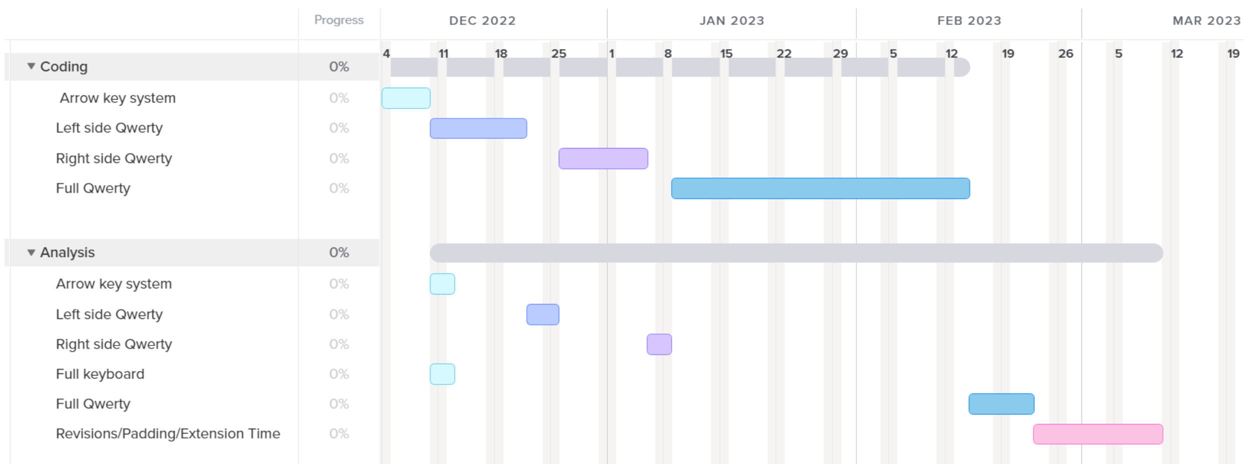
Timeline



First, a small-scale model will be developed and computerized, before expanding to each side of the Qwerty keyboard and finally combining to create the final layouts.