

# The Image of the Interface: How People Use Landmarks to Develop Spatial Memory of Commands in Graphical Interfaces

Md. Sami Uddin

Computer Science, University of Saskatchewan, Canada

Carl Gutwin

Computer Science, University of Saskatchewan, Canada

## ABSTRACT

Graphical User Interfaces present commands at particular locations, arranged in menus, toolbars, and ribbons. One hallmark of expertise with a GUI is that experts know the locations of commonly-used commands, such that they can find them quickly and without searching. Although GUIs have been studied for many years, however, there is still little known about how this spatial location memory develops, or how designers can make interfaces more memorable. One of the main ways that people remember locations in the real world is landmarks – so we carried out a study to investigate how users remember commands and navigate in four common applications (Word, Facebook, Reader, and Photoshop). Our study revealed that people strongly rely on landmarks that are readily available in the interface (e.g., layout, corners, and edges) to orient themselves and remember commands. We provide new evidence that landmarks can aid spatial memory and expertise development with an interface, and guidelines for designers to improve the memorability of future GUIs.

## CCS CONCEPTS

• **Human-centered computing** → Graphical user interfaces.

## KEYWORDS

Spatial memory, Commands, Landmarks, GUI, Memorability

### ACM Reference Format:

Md. Sami Uddin and Carl Gutwin. 2021. The Image of the Interface: How People Use Landmarks to Develop Spatial Memory of Commands in Graphical Interfaces. In *CHI Conference on Human Factors in Computing Systems (CHI '21)*, May 08–13, 2021, Yokohama, Japan. ACM, New York, NY, USA, 17 pages. <https://doi.org/10.1145/3411764.3445050>

## 1 INTRODUCTION

Graphical interfaces provide a visual two-dimensional representation of commands arranged in menus, toolbars, and ribbons, where each command appears at a specific location in the interface [42, 57]. In order to locate commands, novice users of those GUIs must perform a slow visual search among the icon-based commands [61], primarily because they have not memorized their locations. In contrast, frequent users of an application can easily find commands from memory without relying on visual search, even though many

Permission to make digital or hard copies of all or part of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. Copyrights for components of this work owned by others than the author(s) must be honored. Abstracting with credit is permitted. To copy otherwise, or republish, to post on servers or to redistribute to lists, requires prior specific permission and/or a fee. Request permissions from [permissions@acm.org](mailto:permissions@acm.org).

*CHI '21, May 08–13, 2021, Yokohama, Japan*

© 2021 Copyright held by the owner/author(s). Publication rights licensed to ACM.

ACM ISBN 978-1-4503-8096-6/21/05...\$15.00

<https://doi.org/10.1145/3411764.3445050>

commercial applications such as Adobe’s Photoshop or Microsoft’s Office suite have hundreds of commands in their interfaces [11]. For example, a frequent MS Word user knows that ‘Paste’ is located near the top-left corner of the interface, and that it is the leftmost item in the Home ribbon. Spatial memory is a powerful way to enable expert performance with GUIs [14, 28, 58]. One benefit of human memory with spatial locations is that people can quickly and accurately retrieve the locations of frequently-visited items from memory [53]. Even with a blank ribbon, Scarr et al. [57] showed that people could accurately recall ~30 commands (50% of the commands they used in MS Word) – indicating that users had developed strong spatial memory of those commands [61]. However, we do not precisely know how this spatial location memory is formed in GUIs.

One mechanism that helps people learn spatial locations in real life is the landmarks in an environment [17, 53, 63]. Landmarks help people to remember the places and locations they have visited earlier [45]. They also play a critical role in helping people move towards “survey knowledge” [63, 70] – that is, a mental map of an area (also called a *cognitive image* [35, 45, 72]). Landmarks provide spatial anchors in the mental map that help people remember object locations. Upon studying the cognitive images of three American cities back in 1960, Lynch [45] suggested that the citizens of a city develop a “mental image” of the city because of their spatial knowledge. He also identified five features of cities that can be considered landmarks [45, 78]: paths (obvious routes between places), edges (physical boundaries such as rivers), districts (obvious regions within the city), nodes (strategic points of interest such as intersections), and point landmarks (specific objects such as natural features, buildings, or monuments).

Landmarks are also present in GUI systems and can aid spatial learning [61]. Researchers have designed several GUIs [24, 30, 43, 62] that leverage the outer corners and bezels of small devices (e.g., tablets) as landmarks. Even a user’s own hands and fingers [27, 33, 34, 77, 79] have been used as landmarks to benefit spatial learning. However, there are only a few natural locations that can be used as landmarks in GUIs; in the absence of natural landmarks, artificially-created landmarks can also improve the performance of spatial tasks [23, 47, 68, 75, 76]. Artificial landmarking features are uncommon in GUIs, perhaps because of the risk of distraction [54, 64]. Still, frequent users are fluent in performing memory-based actions [57] – indicating that, over time, they have developed spatial images (i.e., mental maps) of the GUIs. It would be useful for designers to understand how this kind of expertise works – to know what landmarks are present in these GUIs that help develop spatial memory, and what designers can do to make GUIs more easily memorable.

In order to identify the role that landmarks play in building spatial memory of commands in current GUIs, we explored the

mental images that frequent users develop of the interfaces they use. Lynch [45] successfully demonstrated a method to elicit the cognitive images of a city from its inhabitants; to determine the images of GUIs that are in expert users' minds, we carried out a study adapting Lynch's [45] method to explore four conventional GUIs: Microsoft Word, Facebook, Adobe Acrobat Reader, and Adobe Photoshop.

Our study showed that frequent users of the four applications do have strong images of the GUIs in their minds, and they could easily recall the locations of commands using several types of landmarks. We found that, among the four GUIs, Word and Facebook were relatively more memorable (over 76% accuracy in verbal descriptions) than Reader and Photoshop (below 44% accuracy). Accuracy was even higher when participants carried out location pointing tasks on a sketch or a "washed-out" version of the UI (73% accuracy overall). We also found that people relied heavily on landmarks (e.g., GUI layout, command groups, internal and external corners, and icon visuals) to orient themselves to the GUIs and remember command locations – indicating that landmarks can aid in developing spatial memory of commands in GUIs.

Our work provides three contributions. First, to the best of our knowledge, we are first to show that frequent users of GUIs can develop vivid spatial images of GUIs, and we provide new evidence that landmarks readily available in GUIs can aid spatial memory and expertise development. Second, we identify four types of landmarks in GUIs that users can rely on to remember command locations correctly. Last, we provide guidelines for designers who want to make future GUIs more easily memorable.

## 2 BACKGROUND AND RELATED WORK

In the following sections, we review the psychological aspects of spatial memory and landmarks, then report how spatial memory and landmarks have been leveraged in GUIs.

### 2.1 Spatial Memory, Landmarks, and Cognitive Images

Spatial memory is a crucial human cognitive ability that allows learning and recalling the locations of objects and places in daily life [40, 53]. Human memory has long been studied in psychology [3, 4, 9, 17, 18], where researchers have looked at how spatial memory is developed [53, 69] and suggested that spatial learning in the real world greatly benefits from the landmarks in the environment [45, 63]. Landmarks are readily identifiable and stable features or objects in a space that are easily separable from their surroundings and that can provide a frame of reference for other locations [45]. Landmarks can be both natural and human-made: for example, in a city area, a park or a prominent building can be a landmark, allowing people to remember nearby locations. Landmarks can be divided into two categories based on their visibility: global and local [44, 67]. Global landmarks mainly provide orientation knowledge as they are visible from almost all regions of an environment, while due to limited visibility, local landmarks aid object locations recall in a specific area [36, 44].

Siegel et al. [63] suggested a model that described spatial memory as a combination of landmark, route, and survey knowledge.

After entering a new area, people naturally start learning the locations of objects with reference to other prominent objects (i.e., landmarks) [20, 25, 31] – which forms landmark knowledge [20]. Once people are familiar with the area, they begin to navigate between known landmarks and obtain route knowledge [70]. With further experience, people attain survey knowledge, where they have a complete understanding of the area along with its landmarks. Survey knowledge serves as a mental mapping of the items present in an environment – i.e., a cognitive image [35, 72]. This cognitive image provides people with the spatial information required to recall an item or perform navigation in that area.

Lynch [45], in his seminal work 'The Image of the City' investigated the cognitive images of three cities. He argued that the dwellers of a city collect and store distinct objects they come across during their daily lives in their memory, forming a coherent mental image of the city. He identified five categories of objects that make an urban area memorable [45]: *paths*, channels where a navigator can move; *edges*, channels denoting the boundary of a district; *districts*, 2D areas traceable from inside; *nodes*, crucial points of interest; and *point landmarks*, external elements that can be seen from a distance. In this paper, we follow Lynch's [45] methods to explore the cognitive images of four GUIs and determine what landmarks are present in GUIs and how they aid spatial users' memory development.

### 2.2 Leveraging Spatial Memory in GUIs

Spatial memory has long been exploited in GUIs to enable memory-based user actions [19, 55, 61] and to support users' transition from novice to expert [12, 41, 83]. For example, Scarr et al.'s CommandMap [57, 59] showed that spatially constant command placement in desktop UIs facilitated better command retrieval rate, even for real-world tasks [58]. The advantage arose because users could leverage spatial knowledge to recall the locations of commands from memory [13, 57, 75]. Other researchers have similarly shown that spatially-stable organizations that flatten command hierarchies to show all commands at once can improve revisitation efficiency compared to linear lists and menus [10, 28]. Research has also indicated that learning and recall performance can increase if command interfaces use meaningful icons [8].

Spatial memory can benefit touch and multi-touch interactions as well. For example, spatially stable command structures (i.e., each item in a cell) can improve selection speed in tablets [24, 29, 30, 74], in smartwatches [43], in smartphones [81, 82], and digital tables [77]. Even in large environments, spatial memory has been found to be useful (e.g., in VR [22], with wall displays [38], and large tables [39]). However, one basic question remains unanswered – what contributes to spatial memory development in standard GUIs that people commonly use.

### 2.3 Landmarks in Graphical Interfaces

There are two main categories of landmarks that researchers have exploited to aid spatial memory: natural and artificial. Natural landmarks in a GUI setting (e.g., screen corners) can offer support for spatial development [30, 75], and researchers have already leveraged the corners and bezels of small touch devices to place commands [30, 43, 62]. In larger settings, however, these real landmarks

become weaker, as locations are often far from the landmarks. In such cases, natural elements such as the users' own hands and fingers can offer spatial support. For example, systems by Hinckley et al. [33, 34], Gustafson et al.'s [27] Imaginary UIs, and Uddin et al.'s [74, 77] HandMark Menus use the non-dominant hand as a reference frame [79] for another hand to perform tasks efficiently. Yan et al. [80] showed that even the user's body could be a landmark.

In the absence of natural landmarks, digitally created visual objects can act as landmarks [75]. Vinson [78] and Sorrow et al. [65] suggested guidelines to design such landmarks, particularly for large environments. Mou et al. [48] leveraged the inter-object tie as a landmark in tabletops. Researchers used colour marks [1, 64], and random icons [76] in the scrollbar of a document reader to show that landmarks could improve within-document revisitation, even in very long documents [47]. Also, artificial landmarks have been found to be useful in VR [22, 23] and touch typing [68]. However, research suggested that overuse of landmarks might be distracting and can hamper performance [54, 64].

Surprisingly, standard GUIs do not explicitly use artificial landmarks, but even so, experts with a GUI can locate commands accurately from memory [57]. Therefore, we carried out a study to explore what landmarks exist in current GUIs.

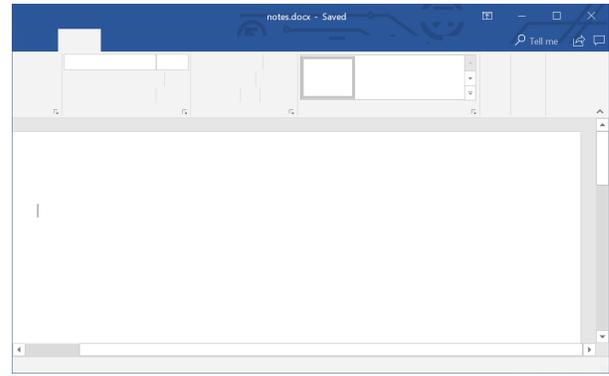
### 3 STUDY: THE IMAGE OF THE INTERFACE

To understand the role of landmarks in developing spatial memory of commands in regular GUIs, we carried out an interview study with users of four interfaces. The following sections present the GUIs used and methods followed in the study.

#### 3.1 Study Interfaces

The study concerned learning and recalling locations of commands in standard GUIs. We chose the interfaces of four popular desktop applications for our study: Microsoft Word, Facebook, Adobe Acrobat Reader, and Adobe Photoshop. We chose these four not only because many people use them frequently, but also because they provide variation in terms of the type of tasks carried out with the UI (e.g., photo editing, document processing, and social media), the number of commands (from a few to a few hundred), and the primary command arrangement (e.g., ribbons, menus, and toolbars). The versions of the applications that we studied are those from August 2018.

*Word* [84], a popular and well-known document processing application, arranges hundreds of commands in tab-based ribbon menus that usually appear at the top of the GUI. A large number of commands and the multiplexed ribbon menus create a unique challenge to remember command locations and navigate in the interface. *Facebook* [85], a popular social media platform, is a representative of complex web-based applications. Although it seems to have relatively few commands, Facebook utilizes the whole window to arrange its commands, which may make it more difficult to recall command locations. *Reader* [86], a well-known document viewing application, is the simplest interface among the four in terms of command number and arrangement. We were interested to see how people form location memory in a simple interface. Last, *Photoshop* [87], a popular photo editing and design application, uses a slightly



**Figure 1: Part of the washed-out image of the Home ribbon of Word interface used in the study.**

different layout than the other systems – a canvas for editing photos in the middle and commands around the left, top, and right of the UI. A large number of commands are visible in the UI, possibly making it difficult for users to learn and remember their locations.

#### 3.2 Study Method

Previous literature suggests that expert users of an interface can recall command locations from memory (without visual search) [30, 57] – indicating they may have developed a *cognitive mapping* [9] of those commands. As a result, they can easily visualize an image of the interface in their mind. We therefore planned to elicit and analyze users' interface-images to explore what helps people remember commands and navigate in GUIs. Kevin Lynch, in his seminal work 'The Image of the City' [45], successfully elicited images of a city from its inhabitants' minds and revealed how people develop spatial memory of a city. Even after 60 years, architects and urban planners rely on this method to evaluate the visual perception of urban spaces. Therefore, to explore users' mental images of GUIs, we designed an interview study that adapted the methods used by Lynch.

In preparation for the study, we conducted an initial inspection of the four interfaces to understand their layouts. The aim was to check the structures and the arrangements of the available commands and also to identify their appearance, perceptibility, and the available landmarks in the GUIs so that later we could validate participants' responses. The main study consisted of semi-structured interviews with a small sample of people who use the four interfaces frequently. We aimed to elicit the images of the GUIs from users' memory, so the interview involved users describing the interface layout, the available commands, and the locations of commands they frequently use, along with nearby commands. It also included tasks such as drawing sketches of the GUIs, and identifying command locations on the sketches and on washed-out images (see Figure 1). The study ended with users carrying out walkthroughs (i.e., step by step instructions) to locate commands.

**3.2.1 Interview Questionnaire and Tasks.** Our semi-structured interview included the following questions (adapted from Lynch [45]) and tasks:

**Table 1: Tasks used in walkthrough generation**

Word	Facebook	Reader	Photoshop
From Home ribbon, select insert an equation	From Home page, open friend list of a friend	Highlight texts in the document	Select brush and yellow colour
Change line spacing	Post a photo to own timeline	Add a signature to the document	Turn on the 2 <sup>nd</sup> layer
Insert a table	Delete that post	Fit a full page to the window	Add text in blue colour
Change the zoom level of the text.	Write a comment to a post in the News Feed	Go to a specific section of the document	Select all items, then use 'left alignment'

1. What image comes to your mind first when you think of or visualize the interface of \_\_\_?
2. Describe the interface of \_\_\_\_. What are the commands or tools available, and where are they located in the interface? [We asked for details when needed.]
3. Draw a sketch of the \_\_\_ interface, as if you are describing it to a person who has never seen it before. Try to cover the main features of the interface. [We took notes of the drawing sequence.]
4. Name 5 commands from this application that you frequently use or that you find most distinctive. They may be small or large, but should be commands that you can easily identify and remember.
5. (The following questions are repeated for each of the 5 commands that the participant provided)
  - a. Describe the location of \_\_ command in the interface. Picture yourself locating it and describe the path you would take and the items you would see to locate it.
  - b. How did you remember the location of the command? Did you use any landmarks for it? Also, if you were uncertain about the command's exact location, what strategy would you use to locate it?
  - c. Name the commands around <the chosen command>. You can describe the colour or shape of these items if you cannot recall exact names.
6. (Location pointing task: also repeated for the 5 commands that the participant provided)
  - a. Show the command's location in your sketch.
  - b. Point to the command's location in the washed-out image.
7. Walkthroughs for four imaginary tasks (Table 1) using real snapshots of the interfaces.

As in Figure 1, washed-out images of the GUIs were created by removing the commands from a screen snapshot, keeping the outline and boundaries intact. This was done to see whether people use structural features as landmarks to locate commands. For the walkthrough tasks, we showed participants actual snapshots (printed on A4 paper) of the GUI. For each system, we came up with four tasks (see Table 1) and asked the users to generate step-by-step instructions to locate the required commands to perform those tasks. In the Word interface, for example, one task was "Insert a table." We analyzed the answers to look for any mention of landmarks, spatial locations, or frames of reference, in order to determine what landmarks were used for locating commands and navigating within the interface.

**Table 2: Experience of participants per interface**

Interface	<1 year	1-3 years	4-6 years	7-9 years	9+ years
Word	0	0	0	2	3
Facebook	0	1	0	3	1
Reader	0	0	2	1	2
Photoshop	1	2	2	0	0

**3.2.2 Participants and Apparatus.** We recruited 20 people (5 women), 5 for each interface, ages 18-43 (mean 27.2) from a local university. Most of the participants were students (18), and two were working professionals. All were self-reported frequent users of the respective GUIs (daily or almost daily usage: 16; several times a week: 3), except for one who was only somewhat familiar with the Photoshop interface and used it about once a week. Table 2 summarizes their experience per interface: sixteen participants had been using these interfaces for over three years and one had less than one year of experience. Participants used these GUIs either on laptop or desktop computers (only one used Facebook on a smartphone). The study lasted about 60 minutes, and participants received a \$10 honorarium.

The visuals of the interfaces used in the study were snapshots captured from the versions available in August 2018, using a Windows 10 PC with a 21.5-inch monitor. Participants drew sketches of the interfaces using pencil and paper. The study was approved by our local Ethics Review Board.

**3.2.3 Procedure and Data Analysis.** Before the study, we carried out an initial inspection of the four GUIs, where we saw that the layouts of Word, Facebook, and Photoshop differed from each other – often having multiple tabs or pages. Therefore, we decided to examine commonly used tabs and commands in our interviews. For example, there were 11 tabs in the Word interface, each with a slightly different layout. Therefore, we limited our study in Word to the *Home* and *Insert* tabs only. Similarly, from Facebook, we chose the *Home* and *Profile* pages, and in Photoshop, we used Options bars (displaying additional tools for a tool selected in the left-side toolbar) for the *Move* and *Text* tools.

We ran a pilot study with four volunteers before the actual study to refine the questionnaires and tasks. During the study (carried out in a lab), participants first filled out a demographic questionnaire then proceeded to the interview. Each participant completed

the study for only one interface, and all the sessions were audio-recorded. Later, we collected images of the actual interfaces used by participants in their workspace to cross-check their descriptions (this step was optional for the participants). We set out to answer three main questions:

1. Do users develop images of an interface: that is, do they develop spatial memory of commands and interface features, and remember their locations?
2. How strong and accurate are the images of an interface: that is, how accurately can users remember the locations of commands?
3. How do people use landmarks to remember commands and navigate in an interface, and what are those landmarks?

Our analysis began by transcribing the recorded interview sessions. We carried out a reflexive thematic analysis [6, 7] in our study, particularly for the verbal descriptions and walkthrough tasks. Our study had several a priori goals, but we also wanted to be open to new ideas, so we coded the transcribed data using both deductive and open coding methods. While coding, we had some obvious a priori categories in mind – spatial references, landmark references, relative/absolute positioning, use of the overall frame of reference, difficulty in remembering a location, or ease of recalling a location. Then we generated potential themes for each of the four interfaces. For example, in Reader, we had codes, e.g., ‘abstract reference to the top’ and ‘vaguely pointing towards left;’ this resulted in ‘abstract direction’ as a potential theme. Additionally, we had ‘menu bar,’ ‘toolbar’ and ‘side panel’ as initial themes. Next, the first author used axial coding [15] to further refine the themes by checking their relations with the codes and discussed results regularly with other authors. The aforementioned potential themes, for instance, were merged into one theme, ‘interface layout’ for Reader. We repeated this hybrid deductive-inductive thematic analysis for the four interfaces to develop spatial images of the interfaces.

We also analyzed the sketches to check the sequences in which participants drew different elements and features of the interfaces. Furthermore, we analyzed and validated the accuracy of the verbal descriptions and pointing tasks by comparing them with actual interfaces (reported in Table 3).

## 4 FINDINGS

The following sections present an overview of the mental images of the four interfaces, review their clarity, and report on the landmarks that contributed to building the images.

### 4.1 Cognitive Images of the Four Interfaces

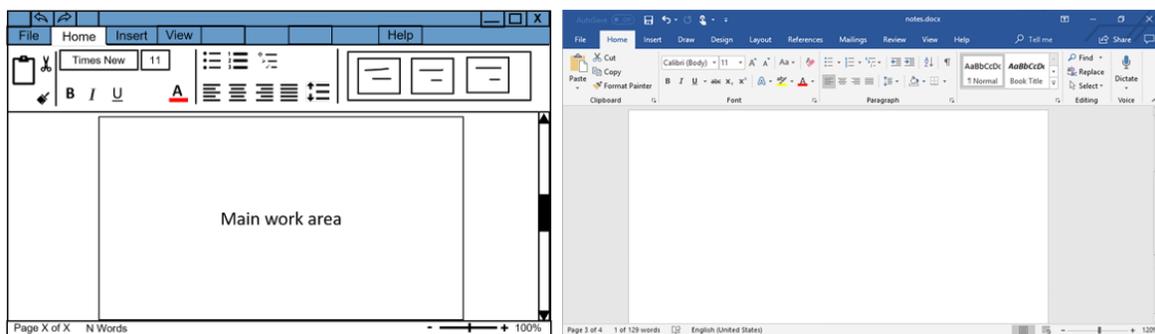
We assessed the accuracy and coverage of participants’ memory of the interfaces, using their verbal descriptions, their sketches of the interface, and their task walkthroughs. We found that people do develop images of the interfaces in their memory. The images we found are from a small population (although still reasonable [26]), and involve subjective responses; nevertheless, the data gathered from the study were rich and consistent enough to elicit meaningful, stable images of the four GUIs.

**4.1.1 Image of the Microsoft Word Interface.** The mental image of the Word interface contained both distinctive colour and structure: the “*blue colour menu*” at the top with a horizontal ribbon underneath and a “*white [coloured] page in the middle*” were two features everyone instantly remembered. To users, Word had “*lots of options [commands],*” yet was “*clean*” and “*organized*” because of its well-structured layout.

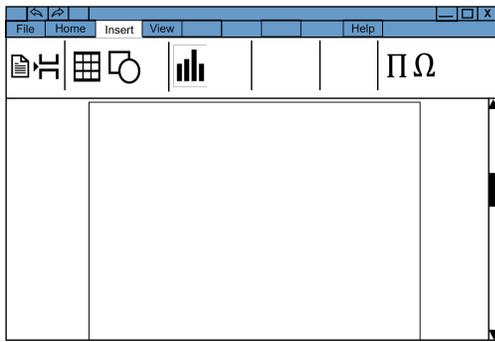
As shown in Figures 2 and 3, despite ambiguity in the name and order of tabs, everyone cited and drew a tabbed ribbon bar at the upper left corner. Although all interviewees knew the leftmost tabs (i.e., File, Home) and the rightmost (i.e., Help), surprisingly, none could recall the tabs from the middle (perhaps due to the serial-position effect [49]; further clarified in Discussion).

The most consistent element in the images was the ribbon, showing commands of a tab in groups isolated by vertical lines. However, we found contrasting images of the two ribbons: *Home* and *Insert*. The *Home* ribbon was the most striking of the two images. Everyone understood the two separate areas of this ribbon: the left half crowded with three groups of commands, and a large rectangular area, ‘Styles’ covering almost all the right half (see Figure 2). As one Word user described:

“All the tabs are at the top. In Home [ribbon], there are type of fonts [. . .]. Then to the right of it, there are bullet points options. [. . .] After that, there is a large box, styles.”



**Figure 2: Images of MS Word’s Home interface. Left: image reconstructed combining all participants’ descriptions and sketches, right: a snapshot of the actual interface.**



**Figure 3: Image of MS Word’s Insert ribbon interface reconstructed from all interviews (description and sketch).**

Users also remembered the edges and boundaries of these groups, including their uniquely shaped icons (e.g., 4 out of 5 people described *“a box for the Font Name at the left”*). They correctly recalled at least 20 of the 38 items from *Home*. Interestingly, we observed that participants first visualized the meaning of a command in their minds as they referred to the visual appearances (e.g., shape, or colour) of the corresponding icon while describing any command’s location. For example, *“a painting brush”* was mentioned for the ‘Format painter’ command.

The *Insert* ribbon (see Figure 3), in contrast, had a slightly unclear image to the users, primarily because of the similarity in appearance among its commands and layout. This tab arranges nearly 32 icons, each with an upright rectangle icon, into ten groups, making it hard for users to identify the edges and boundaries of each group. As a result, users could name only 11 commands in this ribbon and were uncertain about their locations. However, 4/5 users correctly remembered the *“Equation and Symbol [commands] at far-right.”*

Besides the ribbon, several items also consistently appeared in the cognitive images. For example, 3/5 people drew the ‘Quick Access Toolbar’ at the top-left corner; and everyone cited the correct locations of Pages, Word Count, and Zoom Level at the bottom (see Figure 2).

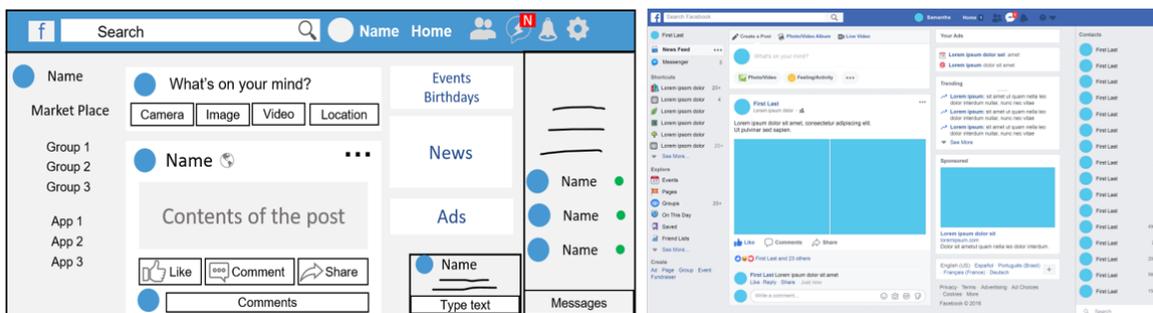
Overall, it appeared that the easy-to-recognize boundaries of command groups, uniqueness of the icon appearance, and icons’ meaning helped users to construct the cognitive image of the Word interface.

**4.1.2 Image of the Facebook Interface.** A large number of commands in the Facebook UI and their distributed placement (often repeated – for example, the Messenger icon appears at three locations) contribute to a less clear image; participants visualized this UI in several different ways (e.g., a *“blue and white”* GUI, *“lots of images,”* *“News Feeds,”* or *“notifications”*). However, participants also recognized the structured layout with clear sections and meaningful commands that allowed them to form vivid spatial images of the *Home* and *Profile* pages (see Figures 4 and 5).

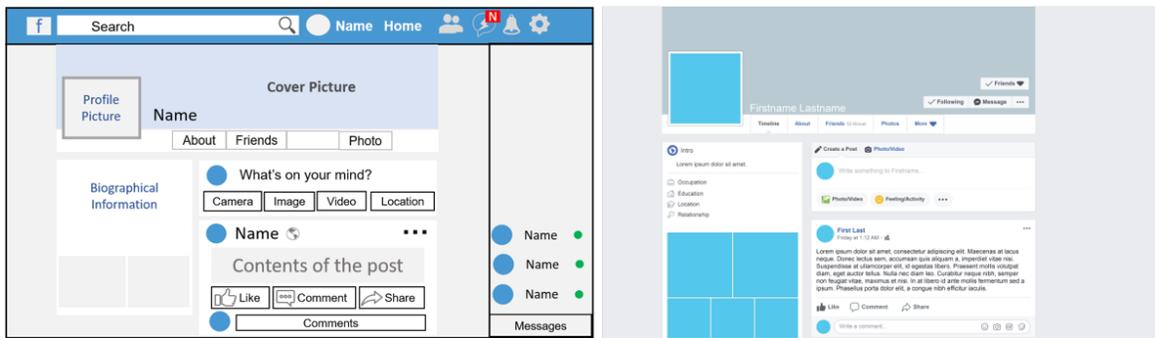
We found that the three separate areas of the *Home* page appeared in all sketches and descriptions with clear boundaries (see Figure 4). The News Feed (NF), the widest among the three, sat in the middle, showing ‘posts’ in a scrollable stack, each with *“a unique box [a rectangular card showing all the elements of a post].”* All users identified the very first box as an *“area to create a new post with texts, photos, and videos.”* Two users even quoted the text, *“What’s on your mind?”* that usually appears inside that box. The rest of the boxes, displaying posts, had around 12 items in the layout, and everyone recalled (i.e., described and drew) at least 8 items at the correct locations. All stated that the left side’s area held links to Groups and Apps; however, 3 out of the 5 users only vaguely recalled the contents as they seemed similar and lacked clear boundaries. The area at right, in contrast, held the *“Events, News, and Ads”* in vertically isolated areas that all participants identified correctly. Also, everyone mentioned the *“chat area at the bottom-right”* with correct details. One participant reported:

*“Chat option is in the right-hand side of the screen. Normally it is hidden [collapsible menu] at the bottom, but clicking on it will show a list of people with green dots [availability] beside them.”*

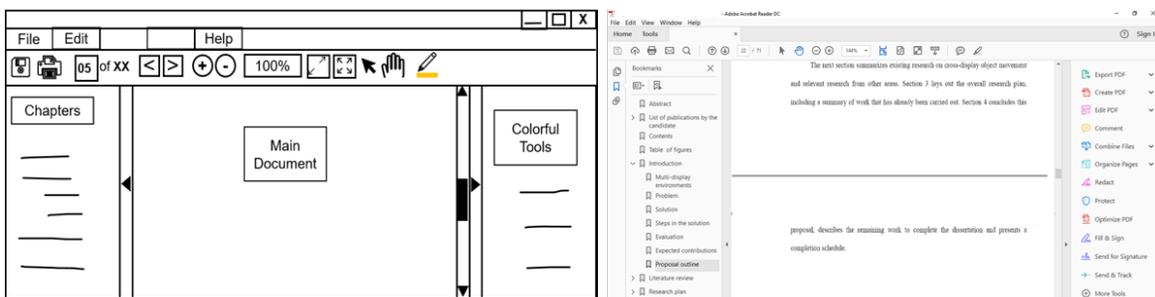
The mental images of the *Profile* page, on the contrary, had a large Cover Photo (CP) at the top, including a square Profile Photo (PP) at its bottom left (interestingly, one drew it as a circle), and a tabbed menu underneath the CP (see Figure 5). Though all reported these elements correctly, surprisingly, none recalled the five tabs correctly. The rest of the space was divided into two vertical areas, and almost all (4/5) noted that the large area at the right showed *“posts in boxes,”* similar to NF. We found that only two out of five users correctly recalled the sections for biographical information, photos, and friends located at the left, possibly because of their similar appearance (all appear in equal-sized rectangles).



**Figure 4: Images of Facebook’s Home page. Left: image reconstructed combining all participants’ descriptions and sketches, right: a snapshot of the actual interface.**



**Figure 5: Images of Facebook's Profile page. Left: image reconstructed combining all participants' descriptions and sketches, right: a snapshot of the actual interface.**



**Figure 6: Images of Adobe Acrobat Reader interface. Left: image reconstructed combining all participants' descriptions and sketches, right: a snapshot of the actual interface.**

There was, however, a vivid area in the topmost part of the two pages: the blue menu bar. As expected, all five users recognized a horizontal bar with two unique areas: a search box at the left and a few items at the right. The mental images were accurate: four users recalled at least 8 of the 10 items with the proper shape and order. Again, we observed a tendency among the users to describe the visual appearances of the command-icons along with their locations, similar to Word. One stated, “*There is a bubble [icon for Messenger] at the left to the bell [icon for Notifications].*” Another user said, “*a thumbs-up at the bottom left corner,*” when describing the ‘Like’ command.

**4.1.3 Image of the Adobe Acrobat Reader Interface.** The task of ‘reading a PDF’ is so prominent in Reader that everyone remembered it first, even before recalling other items: the “*red logo,*” “*colourful,*” yet “*annoying sidebar.*” We found consistency in the mental images that included a PDF document pane in the middle and commands around its three sides, a toolbar above the PDF document, and two side panels. Surprisingly, despite being the simplest GUI among the four, participants struggled more to recall command locations in Reader, possibly because of the linear placement of commands in the toolbar (see Figure 6) without clear grouping.

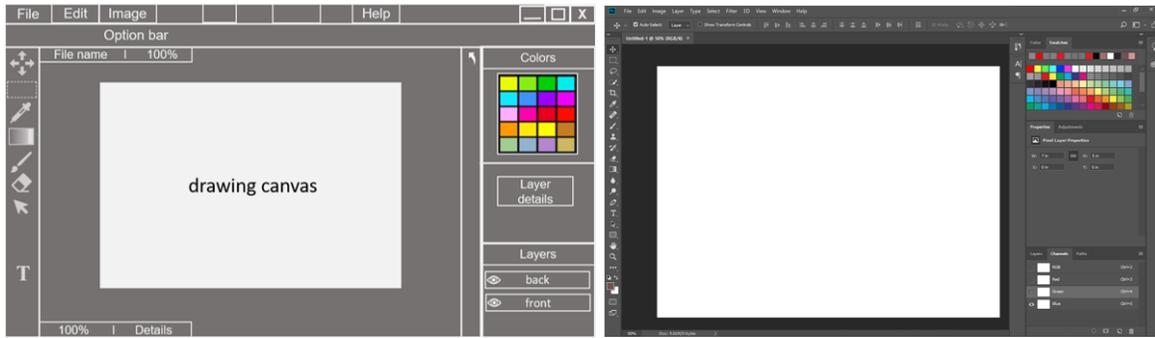
As seen in Figure 6, all users mentioned the tabbed menu at the top, but similar to Word and Facebook, none could exactly recall exact names and order. They were, however, unanimous that a horizontal toolbar was present just above the PDF. Interestingly, though nearly all (4/5) users could name at least 12 of the 19 commands

linearly placed in the toolbar, they could not precisely remember their locations. Also, despite uncertainty in the direction (i.e., vertical or horizontal), all knew the “*two arrows [icons for Next page and Previous page]*” to navigate pages, and three people were confident that a “*small square for page number*” was beside those arrows. However, four of five users recalled the Highlight tool precisely at “*far down the right*” and described the visual appearance of its icon, portraying a “*pen slightly tilted with colour below it, usually yellow.*”

Apart from the toolbar, two side panels always appeared in all the images, but most users (3/5) kept those hidden to make room for the PDF. Though users could imagine the “*Table of Contents*” in the panel at the left, none recalled the “*colourful*” tools accurately from the panel at the right.

**4.1.4 Image of the Adobe Photoshop Interface.** Participants visualized Photoshop as a “*black-themed*” GUI consisting of “*lots of tools.*” Similar to Reader and Word, a large canvas at the middle occupied a significant part of all images, providing a strong anchor for three nearby areas: the Tool Panel at left, the Options Bar at the top, and a Side Panel at right (see Figure 7). Overall, it was evident that everyone remembered the overall layout of Photoshop; however, the linear presentation of commands without a clear sense of division made the interface less memorable.

The Tool Panel was strongly visible in all the cognitive images; however, we found ambiguity in the name and order of commands. Though all recognized this vertical panel, participants could only



**Figure 7: Images of Adobe Photoshop interface. Left: reconstructed combining all participants’ descriptions and sketches, right: a snapshot of the actual interface.**

name about 10 of the 23 tools, and only vaguely recalled their locations. However, similar to the previous three GUIs, users referred to the visual appearances of commands while attempting to recall their locations. As one said regarding the ‘eraser’ tool:

“It [the eraser command] is at the left side panel, kind of in the middle and looks like a physical eraser, [placed] in angle [slightly tilted] with a shadow [underneath].”

We found the Options Bar located above the canvas even less memorable, as its tools (and layout) change based on the item selected in the left panel. Only two people mentioned that “it shows additional tools,” and surprisingly, none correctly recalled any tool from that panel. The right-hand panel, however, was more vivid because of the three clear sections. Almost all (4/5) users correctly recalled the two sections: Colors at the top and Layers at the bottom. One user correctly remembered the History tool beside the right panel.

In summary, we found that users developed images of all the interfaces in their minds, but the memorability of the interfaces varied: people could recall the locations of commands more reliably in Word and Facebook than Reader and Photoshop (reported in Table 3). Despite the differences, it was evident that users developed spatial memory of commands in all the four GUIs, especially in areas having clear frames of reference such as corners and edges in the GUI environment, and command groups with easily identifiable boundaries – i.e., areas with landmarks.

## 4.2 Accuracy of the Cognitive Images

We analyzed the location data collected from the study to assess the images’ accuracy (Table 3). Participants were asked to verbally describe locations and nearby commands of five commands they frequently used. For the verbal description and nearby commands, when users accurately described an item’s location in a GUI and at least one adjacent item respectively, we treated it as *correct* (e.g., in Word, “Symbol is at the right edge of the list, in the Insert ribbon”), otherwise *incorrect*. However, when they misdescribed a location but were close or used a general direction (e.g., “at the top”), we noted it as *partially correct*. For the sketch and washed-out images, *correct* indicates that the pointing gesture was within 10mm, with larger errors marked as *incorrect*.

We report the number of events (e.g., correct, partly correct, or incorrect) for the four tasks across all the participants (percentages denoted in brackets) in Table 3. Overall, locations for both Facebook and Word were more accurate (at least 76%) than Reader and Photoshop (less than 64%). In participants’ verbal descriptions, 90 of the 100 locations were nearly correct or correct. For Word and Facebook, people were more accurate (over 76%) than for Reader and Photoshop (below 44%). For nearby commands, among 100 cases, over 57 were correctly recalled. Again, Reader and Photoshop had lower accuracy (less than 36% correct responses).

However, total accuracy improved in both the sketch and the washed-out interfaces (over 73% accuracy), because the available layout outlines, group borders, and shapes provided better landmarks to recall commands. The accuracy of pointing to command locations in Word and Facebook was at or above 84% correct, while

**Table 3: Results (in frequencies; percentages denoted in brackets) of the four tasks used in the study**

GUIs	Verbal Descriptions			Nearby Commands			Sketch		Washed-out	
	Correct	Partly Correct	Incorrect	Correct	Incorrect	No Reply	Correct	Incorrect	Correct	Incorrect
Word	19(76%)	5(20%)	1(4%)	19(76%)	6(24%)	0(0)	21(84%)	4(16%)	21(84%)	4(16%)
Facebook	23(92%)	1(4%)	1(4%)	21(84%)	4(16%)	0(0)	24(96%)	1(4%)	24(96%)	1(4%)
Reader	10(40%)	12(48%)	3(12%)	8(32%)	14(56%)	3(12%)	13(52%)	12(48%)	13(52%)	12(48%)
Photoshop	11(44%)	9(36%)	5(20%)	9(36%)	13(52%)	3(12%)	15(60%)	10(40%)	16(64%)	9(36%)
Total	63(63%)	27(27%)	10(10%)	57(57%)	37 (37%)	6(6%)	73(73%)	27(27%)	74(74%)	26(26%)

**Table 4: Types of landmarks present in the interfaces and their functions**

Type of landmark	Example	Function
Interface Layout	Structure of a GUI containing commands and other elements: toolbar, ribbon, side panels, etc.	Provides an abstract location information of commands and other elements.
Command Group	Font and paragraph groups in Word's Home tab. A card displaying a post in Facebook's News Feed.	Provides an absolute location information of a command relative to other commands of the group.
Corner and Edge	Corners and edges of a GUI window, or a group (Facebook's card).	Provide a clear frame of reference for the location of a command.
Icon Visual Appearance	Format painter icon looks like a "painting brush".	Create memory anchors for a command by encoding its location information to its visual appearance.

Reader and Photoshop had below 64% accuracy, suggesting their weaker support in developing spatial memory of commands (discussed further below). Overall, these results are an indication that we successfully elicited the GUI images from users' minds.

### 4.3 Landmarks in the Graphical Interfaces

Although the individual spatial images of the four interfaces seemed sparse and varied in layout and number of commands, clear patterns emerged when we analyzed them together. Based on Lynch's notion of landmarks [45], we looked for unique, stable, always-visible features and structural elements (e.g., layout) in GUIs, including elements from both inside (e.g., groups) and outside (e.g., device corners) the interfaces that participants used as landmarks to remember the locations of commands in the four GUIs. There are, of course, other factors (e.g., subjective cognitive ability) that can influence the formation of interfaces' spatial images; here, we mainly focus on the role that landmarks play.

We identified four different landmark types from our data (see Table 4). Although these landmarks acted together to form the spatial images, for simplicity, we present them separately. The following sections present these landmarks and report how users employed them to recall commands.

**4.3.1 Interface Layout.** The layout is the overall structure of an interface that arranges commands in menus, toolbars, and panels, placing them around the main work area. Users traverse through different parts of a GUI's layout in order to interact with its commands. It allows users to form a birds-eye-view image of the interface, helping users remember the locations of commands and navigate to them. Therefore, an interface's layout can act as a "reference frame" type of landmark. However, layouts do not reveal too many details about the locations of commands and other elements, because each region of a layout usually contains several commands. We found that all participants understood the unique layouts of the four GUIs and used them as general a reference frame for remembering relative locations of commands. As a result, even participants who were uncertain about the location of some commands had a clear idea of how the elements were laid out in the interfaces. For example, one Word user said:

"All the tools [commands] are located at the top and grouped into several tabs such as File, Home based

on item category [the ribbon toolbar]. Items related to texts [editing] are in the left [Home tab]."

From our analyses of the sketches and interviews, it was evident that the layout of an interface came to users' minds first when they tried to visualize any command. Similar to the *paths* described by Lynch [45, 78], the layout connected different regions of an interface, providing routes for users to navigate through the GUI easily. During the sketch task, 17 out of the 20 users drew the layout first and then they placed commands in different parts of the layout, allowing users to visualize the complete picture of an interface. A Facebook user described the Home page:

"It has three separate areas with the ratio 20:60:20. The left area shows the 'Groups' [...], middle one displays the posts, images, and videos; and the right side is for events and news updates."

Computer applications are primarily designed for specific tasks (e.g., *Word* for writing documents, *Photoshop* for editing images). Users observe and interact with the commands of an interface while performing the task at a specific area in its layout – the main workspace. We found this large area of an interface's layout (e.g., "a blank white page" for *Word*) serving as the primary point of focus in our four GUIs, forming a vital landmark [65] that all participants referred to remember commands and others areas of the interfaces. One user recalled various parts of the Photoshop interface using the main workspace as a landmark:

"There is a big canvas in the middle, where we can draw or edit. On its left, there are some useful tools for the work. It has some tools in a menu at the top as well. In the right, there is a panel of colours and layers."

We also found that in the walkthrough task, 15 of the 20 users relied heavily on this central area of an interface's layout to describe locations of commands and other areas, and interestingly, it was the starting point of their narration. For example, when we asked people to describe step by step how to search for something on Facebook, a user replied:

"You see the large area in the middle [News Feed] with lots of posts and pictures? Right above it, there is a blue bar with a white box in its middle. You can type there whatever you want to find."

Our analyses further revealed that people used general spatial directions – a widely used real-life reference frame – inside an interface’s layout to provide coarse location knowledge of commands. For example, one Word user said, “*The Bulleted List command is located at the top [of the layout].*” This answer, although under-specified, is not incorrect – it pointed to the vicinity of the actual location and eventually helped the user to find the command. The majority (14/20) of the users (across all interfaces) used terms like “*towards the left*” or “*to the bottom*” area of the layouts in their responses to recall the locations of a few commands vaguely (partly-correct responses in Table 3), mostly for interfaces (e.g., Reader and Photoshop) and particular areas of Word (e.g., the Insert ribbon) that lacked adequate landmarks. One Photoshop user even mentally divided the Tool Panel into four quarters and used them as references: “*a quarter down from the top*” and “*3 quarters down.*”

**4.3.2 Command Group.** Graphical interfaces usually arrange commands into several tabs or sections based on utility or similarity [71, 88], and even within an individual tab/section, sub-groupings of commands with specific areas are evident. These semantically divided groups can help users find commands, particularly when they are novices. However, expert users can recall the locations of commands using the *visual* representations of the grouping as landmarks (rather than the semantics). We found that the users in our study relied on the visual command groups when visualizing an interface. One Word user described the Home ribbon using the grouping feature as a landmark:

“In the Home [ribbon], there are types of fonts, change size and **B**, *I*, U [icons for Bold, Italic and Underline]. Then right to it [that group], there are bullet-point and alignment options. After that, there is a large box for styles [another group].”

Usually, UI groups are denoted with clear borders (e.g., vertical lines in Word and boxes in Facebook) that most users (15/20) drew in the sketches. Similar to Lynch’s concept of a *district* [45, 78], users could even cognitively go inside a group having distinct features and layouts, and visualize its commands accurately. For example, each post on Facebook appeared as a group in a rectangular box that everyone recalled clearly. As one user said:

“It [each card/box in the News Feed] shows an image in a circle and [post creator’s] name at the top left. [...] Below, there are buttons for Like, Comment and Share. After that, it has other people’s comments.”

Our analyses showed that in at least 76% of cases, users correctly recalled nearby commands for both Word and Facebook, compared to less than 36% for both Reader and Photoshop (see Table 3). These differences are not due to different experiences with the UIs, as all of our users were highly experienced (see Table 2). One reason specific to Reader could be that people do not use commands as often in Reader as they do in Word – people mostly just scroll and read, so they might have less familiarity with the commands (this is certainly not the case for Photoshop). A further reason that is related to the design of the GUIs is that the linear placement of commands with no group-based arrangement in Reader and Photoshop reduced memorability. Our results indicate that the clear and easily separable command grouping served as a reliable

landmark in painting vivid spatial images of the interfaces, and the absence of landmarks made GUIs (at least parts of them) less memorable.

Interestingly, we further noticed that when users identified a command from a group, they could quickly recall its nearby commands. Also, 17 of the 20 people used the relative association among the commands to devise informal groups and used the location of a distinctive command as an anchor to recall the locations of adjacent commands. One Facebook user said, “[...] *a bubble [icon for Messenger] at the left to the bell [icon for notification].*” Similarly, to describe the location of the page navigation arrows in Reader, one user relied on relative position:

“In the menu, there is a small box with a number on it [page number]. The two arrows [for navigating pages: previous and next] are right next to it.”

In both cases, the references were accurate, but to find the actual locations, users must locate those anchor commands first, or else the landmarks become invalid.

**4.3.3 Corners and Edges.** The corners and edges available both outside and inside digital interfaces are an obvious set of landmarks [30, 75] that we found people explicitly brought up in the study.

**Corners.** GUIs usually appear inside physical screens having four clear corners. These external corners are always visible to computer users and can substantially aid spatial learning and navigation for the commands appearing near those locations [69, 75] (though only useful when a GUI is maximized on the screen), similar to Lynch’s [45] *point landmarks* in cities. Also, the corners of a GUI window can provide a strong landmarking facility. In our study, we saw users strongly relying on these landmarks to recall commands correctly in all four interfaces. For example, everyone drew the ‘Close,’ ‘Maximize,’ and ‘Minimize’ commands at the top-right corner of all the sketches. All of the Word users recalled that “*zoom level is at the bottom-right corner,*” and the “*number of pages is at the bottom-left [corner].*” All the Facebook users mentioned that “*Messenger is at the bottom right corner.*” Even in Photoshop, where the mental images were less accurate, almost all (4/5) users correctly recalled the ‘Magnification status’ in the bottom-left corner of the window (see Figure 7).

Corners, on the other hand, are also available inside GUIs. These internal corners, however, are not as prominent as external corners, but exist within the layout of an interface as well as in clearly marked command groups. Similar to external corners, internal corners can provide stable anchors for commands located near them. In the study, 13 of 20 users explicitly referred to these landmarks while remembering commands. For example, a Facebook user said, “*The Like [button] is at the bottom-left part of the box [displaying the post] (see Figures 4 and 5).*” Another user made use of internal corners in the walkthrough task while describing the way to delete a post:

“Look at the middle [in News Feed]; a box is showing the post [you want to delete]. Go to the top right corner of the box; there are three dots [icon for options].”

**Edges.** Similar to corners, external screen bezels and edges have spatial features (i.e., they are stable and easily visible) that help users in developing memory of commands [62, 75]. Following Lynch’s



Figure 8: A snapshot of MS Word’s Insert ribbon.

[45] definition of edges in physical spaces, we found that the four external bezels (when a window was maximized), as well as the edges of the GUI window, provided spatial anchors for the commands located near them, at least at an abstract level. However, in our study, users did not differentiate between the bezels of the actual screen and the window of a GUI. References to these landmarks, e.g., “near the right-side” or “at the top-side,” repeatedly appeared in our analyses, especially for the Photoshop and Reader interfaces. These landmarks, however, did not refer to a specific command or an absolute location; instead, they pointed to a *command group* of a particular GUI region. In other words, these edges served as “signposts,” providing abstract directional information for other elements in GUIs. For example, one Reader user said: “There are some commands at the right [near the bezel].” Another Photoshop user relied on this landmark to correctly visualize the Tool Panel:

“[The] most important items are at the left side [near the left bezel] of the screen.”

Internal edges, in contrast, provided explicit references to the specific locations of commands. The internal edges refer to the boundary of a command group, or the starting and ending points of a linear command group. Strong dependence on the internal edges was apparent among users in our analyses. For example, as seen in Figure 8, one Word user said,

“The ‘Insert Symbol’ is at the right end of the Insert Tab. Not to the far right, but at the end of that list.”

Although participants used internal edges less frequently than corners, they made use of these landmarks to visualize at least part of the horizontal tabbed menu bar correctly in all GUIs. We also found that participants faced more difficulty recalling locations, particularly in the middle of the menu bars where edges were weakly marked. For instance, while sketching the Reader interface, most of the users (3/5) drew the menu bar with 4-5 blank tabs, but only wrote ‘File’ in the first tab and ‘Help’ in the last (see Figure 6).

**4.3.4 Icon Visual Appearance.** Graphical interfaces use two-dimensional icons to portray the underlying meaning of the corresponding commands visually. Shape, size, and colour are three visual attributes that make icons meaningful [50], and usually, novice users rely on these features to find an icon (i.e., a command) in a GUI [11, 61]. Although these visual features do not provide any information about a command’s location, interestingly, we found that participants frequently referred to them while recalling any command’s location. In most cases, participants imagined the visual appearance of an icon first before describing its location – indicating, people might have encoded icons’ spatial information into its visual features. For example, one Word user recalled ‘Insert table’ as “a square icon with a couple of rows and columns located in the left part of the Insert [ribbon].” Another cited ‘Line spacing’ command using the visual features and meaning of its icon as a referencing mechanism – landmark:

“[. . .] two up and down arrows with two/three lines [icon for Line spacing], near the centre of the Home ribbon, beside the Alignment [commands].”

We also observed that all participants could clearly visualize the shape of an icon while recalling it. The shapes were clear enough in users’ minds that they drew those shapes accurately in the sketches, even though they were often incorrect about their locations. For example, although people rarely recalled tools from the Insert ribbon in Word, nearly all users (4/5) identified the exact location of the ‘Insert Symbol’ as a “round Greek letter at the end.” Also, a user drew a hand to represent the ‘Pan’ tool of Reader (see Figure 6). All Facebook users drew a thumbs-up for the ‘Like’ button and a circle at the top-left corner of a post that usually shows the image of the post creator (see Figure 4). Often these shapes resemble real-life objects that people recognized and exploited to remember commands. For example, one Photoshop user mentioned the “dropper we use in the chemistry lab” while recalling the ‘Colour Picker.’

In addition to shape, we found that the colour of a command was another prominent feature that users often used a landmark. Colour has a unique ability to make one icon easily separable from others [46, 65], and we saw that people recognized it and used it as a reference point to recall those items, along with other features. All the Facebook users, for instance, mentioned:

“[There is] a blue bar at the top [of the interface]. [It has] a long and white colour rectangular box [search bar] with a magnifying tool.”

Three of them also mentioned changes in the icons – e.g., one user remembered “a number in a little red box” when a notification is received (see Figure 4). Sometimes two visual features act together to make the images more vivid. One participant described the ‘Font Color’ command in Word as “a big ‘A’ and a red colour line under it.”

Our analyses indicated that the size of commands in an interface also provided clues for spatial memory. We saw that users recognized the size differences in some commands, and later that helped them to identify commands correctly. For example, in the Home ribbon of Word, there were two small but differently-sized boxes in the Font group, and almost all users (4/5) correctly identified the relatively large one as the ‘Font Name’ command because of its size.

Overall, we found that the frequent users of these four GUIs developed spatial memory of commands by exploiting the available landmarks in the interfaces, and that they heavily relied on those landmarks to retrieve the command locations from memory.

#### 4.4 Ambiguities in the Cognitive Images

The individual spatial images of an interface overlapped and collectively formed a ‘composite image’ [45] of the interface. However, in our analyses, we observed some uncertainties in the images, at

least in some parts of them, at two levels: individual images and composite images.

**4.4.1 Ambiguities in Individual Images.** Individual-level ambiguities occurred in isolated images and did not influence the composite cognitive image of an interface. For example, we found confusion among Facebook users with the location of the ‘Messenger’ command – it appeared at two locations: at the bottom-right and top-right. Interestingly, both were correct. Messenger does appear at two locations, as mentioned by the users. So, when we asked about its location, three users reported only one (either top or bottom), and two mentioned both locations. In another instance, although the ‘Profile Photo’ command in Facebook is squared-shaped and appeared at the bottom-left part of the Cover Photo, one user drew it as a circle and placed it in the middle. The same user mentioned a ‘Market place’ option in the top-left part of the News Feed, whereas it was absent in other (4/5) images. A probable reason could be that when companies redesign their UIs, it may confuse users’ mental images and break their landmarks (elaborated in Discussion).

Similar events occurred in Word images as well. For example, although most users mentioned the ‘Font Color’ icon (a big ‘A’) was in the bottom-right corner of the ‘Fonts’ group in the Home ribbon, interestingly, one user recalled it at the middle bottom-centre area (perhaps different screen size was responsible; discussed further below).

**4.4.2 Ambiguities in Composite Images.** We noticed some uncertainties were consistent in most of the mental images, irrespective of individual differences. There were certain areas in the interface images that were less memorable among the users. For example, the tabbed menu bar in Word, Reader, Photoshop, and Facebook (Profile Page) interfaces was one place where all users struggled. Although everyone recognized the menu with linearly placed commands, surprisingly, none could recall the names of tabs and their order accurately (could be due to the serial-position effect [18, 49]), except for the first and last tabs (see Figures 2, 3, 6, and 7). As one Word user said:

“I know there are several tabs after Home and Insert that I often use, but seriously, I cannot remember their names! I have even used it this morning.”

Apart from the tabbed menus, there were certain general areas in the composite cognitive images of individual interfaces where most users faced difficulty in recalling commands accurately: the Insert ribbon in Word, Reader’s toolbar, and Photoshop’s tool panel (left-side). Although everyone in our study knew where those menus and toolbars were located and could name some of their commands, they could not recall the locations of those commands accurately. As a result, one Photoshop user described the tool panel and toolbar vaguely:

“On the left-hand side of the image [main workspace], there are some tools [tool panel] for work. [And] like other apps, there is a menu [toolbar] at the top part of the screen.”

Overall, despite these minor ambiguities, the mental images we elicited were vivid and accurate enough to identify available landmarks in them. We detected four landmarks that supported users to develop spatial memory of commands and found that

people heavily relied on those landmarks to recall the commands later.

## 5 DISCUSSION

The key findings of our study are:

1. Frequent users of graphical interfaces do develop vivid spatial images of those GUIs in their minds, and we were able to successfully evoke those images;
2. Users rely heavily on landmarks to familiarize themselves with GUIs and remember the locations of commands;
3. We identified four different landmarks that aid in developing spatial memory of the interfaces.

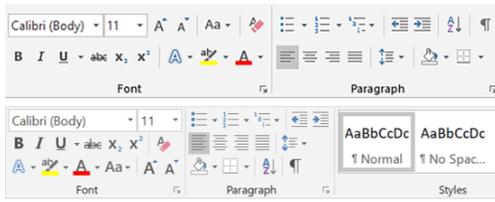
The following sections reveal more insights into our findings and present future directions, along with design implications.

### 5.1 Interpreting the Results

**5.1.1 Reliability of the Interfaces’ Images.** The images of the interfaces we generated from the study were rich in information, revealing how people perceived the visual forms of those GUIs and leveraged the landmarks readily available in a GUI environment to form spatial memory of commands. Although we interviewed only 20 people (5 people for each of the four GUIs), we believe the following two reasons indicate that our evoked interface images were of good quality. First, the images of the GUIs people had in mind were the collection of experiences they had with those GUIs [32]. Since our participants were reasonably experienced and frequent users of those four GUIs (see Table 2), they could compose vivid and detailed images of the GUIs [63]. In our analyses, we found several statements that only an experienced person could share. For example, one Reader user described the ‘Search’ command as “A blank white box with ‘Find’ and a magnifying glass pops up at the top-right part.” Another Word user recalled, “Temporary tabs will appear if you select a table or an image!”

Second, we compared these evoked images to their real counterparts to check their accuracy (see Table 3). Also, we reviewed snapshots of the GUIs from participants’ workstations (an optional part of the study) that participants sent after the study. Although the images did not cover everything that appeared in the actual interfaces, we found that they included the basic structures and visual features along with the frequently used commands. Overall, we managed to elicit clear images of the four interfaces, stable enough to be treated as the ‘public images’ [45] of the respective GUIs.

**5.1.2 Icons’ Visual Appearances Acted as Landmarks.** Among the four landmarks we identified, although the visual appearance of a command did not disclose any spatial information, interestingly, everyone actively referred to it while recalling its location. One of the main reasons for this finding can be explained by the stages of learning (cognitive, associative, and autonomous) [2, 21] and forming spatial memory [63]. Users in a new GUI, particularly novices (i.e., those at the *cognitive stage*), find an icon/command using visual features that represent its meaning, often attaching personal stories or experiences to its visuals [8, 16] as part of the development of landmark knowledge [20]. After locating a command, they encode the location information along with its visual appearance



**Figure 9: Snapshots of MS Word’s Home ribbon from two differently-sized screens. Top: 22-inch desktop, Bottom: 13.1-inch laptop.**

(obtaining route knowledge [70]) and eventually progress to the *associative stage*. When users become experts (i.e., the *autonomous stage*), they can simply recall the location of commands from their memory, using their acquired survey knowledge [63]. Since the visual appearance of a command was involved at the very early stage of learning to recall its location, participants in our study might have imagined that appearance first – indicating visual appearance was a potential landmark.

Another reason could be the recognizability and memorability of icons. People can recognize and locate commands more effectively when the icons representing the commands portray accurate meaning [5, 8]. Research also suggests that some icons or images are more easily memorable than others [37, 56, 66], perhaps because of personal experience [16] or the presence of landmarks – an avenue we will explore in future. In our analyses, we saw that users could make use of three landmark types (GUI layout, command group, and corner and edge) to reach the vicinity of a command’s location; however, it could be the visual appearance of the command that they imagined in their minds (and used as an anchor) to reach its actual location.

**5.1.3 Ambiguities in the Images of the GUIs.** Some degree of differences in individual images of the GUIs were inevitable; in fact, these contrasts made the composite images more informative. However, we observed some unexpected distortions in both individual and composite images of the GUIs (reported in section 4.4). Four main reasons could account for these confusions – first, the difference in screens’ sizes forces an interface to rearrange its elements. As shown in Figure 9, Word rearranges all the items under a group from a two-row layout (Figure 9 top) to a three-row layout (bottom) layout when the window is resized from large to small. As a result, two people coming from these two different instances would produce two slightly different images of the same GUI: ‘Font Color’ command (letter ‘A’ with a red line underneath) at the bottom-right corner in Font group (Figure 9 top) in one image, and the bottom-centre in another (bottom).

Second, interfaces often change over time because of updates that add or remove items and alter layouts [89], which, in most cases, do not reach all users at once [90]. These changes force users to adjust their images and could lead to some ambiguities in the individual images of a GUI. However, we noticed that users were aware of these temporal changes of the spatial images: as one Facebook user said, “There is a ‘Market Place’ at the left side of the News Feed, under my name. It was not there before!” Still, modification of the interfaces over time is inevitable, but care should be taken that it does not

force users to shift the image of an interface that was developed over a long period.

Third, the lack of adequate landmarks in certain regions of the GUIs could have contributed to the uncertainties found in their composite images. For example, the tabbed toolbars in all the images were unclear, along with Word’s Insert ribbon, Reader’s toolbar, and Photoshop’s tool panel. However, a common trend we noticed in those areas that the commands were linearly placed without arranging icons in clear groups or with easily distinguishable boundaries. As a result, people could not associate those commands to memory anchors, and later struggled while retrieving the locations from memory. A potential solution to this problem is using artificial landmarks [75, 78] in those areas to improve memorability.

Last, our participants differed in several ways: ages ranged from 18 to 43; we had both men and women users; participants varied in terms of both the total time using the GUIs and the weekly frequency; and users’ backgrounds also varied. These demographic differences may have led to some ambiguities in learning and remembering command locations in GUIs. For example, due to extensive usage, a professional Photoshop user described an aspect of the GUI (“Left side panel can be customized based on your need”) that other users did not know about. Research also suggests that people’s ability to recognize and successfully employ landmarks to recall locations and navigate an environment can vary depending on age and gender [20, 44]. The small sample size in our study has prevented us from investigating landmark usage in GUIs based on participants’ age and gender – an avenue we plan to explore in the future.

## 5.2 Generalizing the Results and Design Implications

Our study reveals that the readily available landmarks in a GUI help users orient themselves to its commands and can aid them in developing spatial memory of the interface. The benefit of landmarks in building spatial memory of commands and expertise with GUIs is not unknown – in fact, several HCI researchers have already demonstrated the potential of landmarks through prototypes with either external objects (e.g., hands) or strategically created items (e.g., images and colour blocks) [22, 23, 47, 73, 75, 76]. Our work fundamentally differs from these previous studies in that we specifically focused on expertise development in standard GUIs present in the real life and which were not augmented with landmarks. To the best of our knowledge, this is the first work that explored the basic questions of what contributes to the development of expertise in standard GUIs, and what role landmarks play in this expertise.

Our findings help to explain why frequent users of a GUI, empowered by the developed vivid spatial images of the interface, can recall command locations easily from their memory; our results agree with existing research findings [11, 28, 57, 75]. However, we also encountered several instances (about 27% in all tasks) where even our expert users struggled to recall command locations accurately – indicating some regions in the GUIs (e.g., tabbed menu bar; see section 4.4) did not provide enough cues for memory (i.e., landmarks) to build a clear spatial memory. Therefore, designers of GUIs should consider including more landmarks in an interface to support better recall, even for experts.

- **Implication 1:** Include landmarks in GUIs to support better recall.

This implication appears to contradict a widely practiced usability heuristic – ‘recognition rather than recall’ [51, 91]. We acknowledge that recognition is a vital part of spatial memory development [53, 69], and particularly novice users rely on recognition (i.e., visual search) to find the location of a command. However, when novices begin transitioning to experts, they tend to recall locations from memory. After becoming experts, the goal is a quick recall than a slow recognition [11]. Therefore, interfaces should be designed in a way that would facilitate both recognition and recall, so that they can support the user’s transition from novice to expert [12, 60].

- **Implication 2:** Interfaces should facilitate both recognition and recall.

In addition, results indicate four different types of landmarks that help users learn and recall the locations of commands in GUIs. Interestingly, the landmarks we identified (e.g., GUI layout, command group, and corners) are already present in the GUI environment, and designers include them in GUIs as a part of standard design (e.g., Gestalt principles) [71, 88] and usability practices such as Nielsen’s design heuristics [51, 52, 91], but not as landmarks. The novelty of our findings is that we have discovered an additional value of these already-existing design elements – i.e., their value as landmarks. Therefore, designers can consider using those GUI elements and features (e.g., the visuals of icons) as potential landmarks in order to design more easily memorable GUIs, and incorporate the idea of landmarks in current design practices.

- **Implication 3:** Incorporate the ‘idea of landmarks’ in existing design practices.

Another interesting finding is the use of icons’ visuals as landmarks to remember commands. Although the value of visual appearance to differentiate and remember commands is known [5, 8], no other work has provided evidence of using visuals as a promising spatial referencing mechanism (i.e., landmark) that can help users to develop spatial memory for commands and later enable memory-based recall. However, further research is needed to understand more about how the appearance of an icon can represent spatial information or how designers can exploit it to design more memorable GUIs. Besides these four landmarks, designers can consider other useful landmarks [65, 75, 78] (e.g., images, colour blocks), but care should be taken so that they do not become distracting [54].

- **Implication 4:** GUI layout, command group, corners and edges, and visuals of icons can be useful landmarks.

### 5.3 Limitations and Future Work

We see three main limitations in our study that prevent us from generalizing the findings more broadly. First, the sample size we used was small, though reasonable enough to generate stable trends [26] that created the basis for our analyses. Second, the cognitive images that users provided to us could be influenced by their subjective experiences (which is inevitable in qualitative studies [45] but should be followed up with a larger-scale study). Nevertheless, we believe the users’ vivid images enabled us to see a reasonably complete picture of an interface. Last, we limited our investigation

only to desktop interfaces involving command selections, while landmarks can be valuable in other spatial tasks (e.g., interaction with 1D documents: video and text [1, 10, 76], results sets in visual workspaces, or big-data visualization systems); this choice was made for simplicity and to avoid introducing an additional variable. We plan to investigate spatial learning in alternate structured visual information in future. Despite this limitation, the four interfaces we chose were diverse, and the data we gathered showed this diversity.

There are several ways we can continue our research in the future. First, people use GUIs in multiple platforms that often vary in size, which can force users to deploy multiple instances of the same GUI. We plan to carry out a large-scale study to generate public images of GUIs in users’ native environments: desktops, smartphones, and VR and AR. Second, data-driven or adaptable interfaces often place frequently used commands in convenient locations, but in doing so, they may complicate the natural process of developing spatial memory [57] (particularly if a recency metric is used rather than frequency). We plan to investigate this issue in future (e.g., what frequent users remember about areas that have dynamic content). Third, since spatial images of interfaces change over time, we plan to investigate the temporal progression of interfaces images. Fourth, random or excessive use of landmarks in GUIs may have an adverse effect on spatial memory – so we plan to find an optimal number of landmarks to maximize spatial benefits. Last, future studies will compare different landmarks to determine their strengths and weaknesses.

## 6 CONCLUSION

Graphical interfaces display a large number of commands at specific locations through menus and toolbars, but frequent users of these systems can quickly find commands because they already know the locations. In order to figure out how people develop this spatial location memory, we carried out a study with frequent users of four standard GUIs: Word, Facebook, Reader, and Photoshop. Our study revealed that people rely heavily on landmarks readily available in the GUI environment to orient themselves to the GUI, and that these landmarks help frequent users to develop vivid cognitive images of the interfaces. We identify four landmark types that people use in regular GUIs to remember the locations of commands: the layout of an interface provides a high-level reference frame for the objects present in the interface; a clear and unique command grouping is a landmark providing spatial support to recall commands from the group; the corners and edges present in a GUI (both inside and outside) serve as landmarks for nearby commands; and the visual appearance of a command acts as a reliable memory anchor for remembering its location. This work provides new evidence that landmarks can benefit spatial learning and expertise development in graphical interfaces, and provides design guidelines that can help make GUIs more easily memorable.

## ACKNOWLEDGMENTS

This work was supported by the Natural Sciences and Engineering Research Council of Canada (NSERC). We also thank the anonymous reviewers and committee members for their valuable comments and suggestions.

## REFERENCES

- [1] Jason Alexander, Andy Cockburn, Stephen Fitchett, Carl Gutwin, and Saul Greenberg. 2009. Revisiting read wear: analysis, design, and evaluation of a footprints scrollbar. In Proceedings of the SIGCHI conference on Human Factors in Computing Systems - CHI '09, ACM, New York, NY, USA, 1665–1674. DOI: <https://doi.org/10.1145/1518701.1518957>
- [2] John Robert Anderson. 2000. Learning and memory: An integrated approach, 2nd ed. John Wiley & Sons Inc, Hoboken, NJ, US.
- [3] Alan D. Baddeley. 1990. Human memory: theory and practice. Hove, [England]: Lawrence Erlbaum.
- [4] Alan D. Baddeley. 1999. Essentials of human memory. Psychology Press, Hove England.
- [5] Meera Blattner, Denise Sumikawa, and Robert Greenberg. 1989. Earcons and Icons: Their Structure and Common Design Principles. *Human-Computer Interact.* 4, 1 (March 1989), 11–44. DOI: [https://doi.org/10.1207/s15327051hci0401\\_1](https://doi.org/10.1207/s15327051hci0401_1)
- [6] Virginia Braun and Victoria Clarke. 2006. Using thematic analysis in psychology. *Qual. Res. Psychol.* 3, 2 (January 2006), 77–101. DOI: <https://doi.org/10.1191/1478088706qp0630a>
- [7] Virginia Braun and Victoria Clarke. 2019. Reflecting on reflexive thematic analysis. *Qualitative Research in Sport, Exercise and Health* 11, 589–597. DOI: <https://doi.org/10.1080/2159676X.2019.1628806>
- [8] Febi Chajadi, Md. Sami Uddin, and Carl Gutwin. 2020. Effects of Visual Distinctiveness on Learning and Retrieval in Icon Toolbars. In Proceedings of the 46th Graphics Interface Conference, GI 2020, Toronto, ON, Canada, 11.
- [9] William G Chase. 1986. Visual information processing. In *Handbook of perception and human performance*, Vol. 2: Cognitive processes and performance. John Wiley & Sons, Oxford, England, England, 1–71.
- [10] Andy Cockburn, Carl Gutwin, and Jason Alexander. 2006. Faster document navigation with space-filling thumbnails. In Proceedings of the SIGCHI conference on Human Factors in computing systems - CHI '06, ACM, New York, NY, USA, 1–10. DOI: <https://doi.org/10.1145/1124772.1124774>
- [11] Andy Cockburn, Carl Gutwin, and Saul Greenberg. 2007. A predictive model of menu performance. In Proceedings of the SIGCHI conference on Human factors in computing systems - CHI '07, ACM Press, New York, NY, USA, 627–636. DOI: <https://doi.org/10.1145/1240624.1240723>
- [12] Andy Cockburn, Carl Gutwin, Joey Scarr, and Sylvain Malacria. 2014. Supporting Novice to Expert Transitions in User Interfaces. *ACM Comput. Surv.* 47, 2 (November 2014), 1–36. DOI: <https://doi.org/10.1145/2659796>
- [13] Andy Cockburn, Per Ola Kristensson, Jason Alexander, and Shumin Zhai. 2007. Hard lessons: effort-inducing interfaces benefit spatial learning. In Proceedings of the SIGCHI conference on Human factors in computing systems - CHI '07, ACM Press, New York, New York, USA, New York, USA, 1571–1580. DOI: <https://doi.org/10.1145/1240624.1240863>
- [14] Andy Cockburn and Bruce McKenzie. 2002. Evaluating the effectiveness of spatial memory in 2D and 3D physical and virtual environments. In Conference on Human Factors in Computing Systems - Proceedings, Association for Computing Machinery (ACM), New York, New York, USA, 203–210. DOI: <https://doi.org/10.1145/503376.503413>
- [15] Juliet Corbin and Anselm Strauss. 2014. Basics of qualitative research: Techniques and procedures for developing grounded theory (4th ed.). Sage publications. Retrieved from <https://us.sagepub.com/en-us/nam/basics-of-qualitative-research/book235578>
- [16] Helen M. Couclelis, Reginald G. Golledge, Nathan D. Gale, and Waldo R. Tobler. 1987. Exploring the anchor-point hypothesis of spatial cognition. *J. Environ. Psychol.* 7, 2 (June 1987), 99–122. DOI: [https://doi.org/10.1016/S0272-4944\(87\)80020-8](https://doi.org/10.1016/S0272-4944(87)80020-8)
- [17] Fergus I.M. Craik and Robert S. Lockhart. 1972. Levels of processing: A framework for memory research. *J. Verbal Learning Verbal Behav.* 11, 6 (December 1972), 671–684. DOI: [https://doi.org/10.1016/S0022-5371\(72\)80001-X](https://doi.org/10.1016/S0022-5371(72)80001-X)
- [18] James Deese and Roger A Kaufman. 1957. Serial effects in recall of unorganized and sequentially organized verbal material. *J. Exp. Psychol.* 54, 3 (September 1957), 180–7.
- [19] Brian D. Ehret. 2002. Learning where to look: location learning in graphical user interfaces. In Proceedings of the SIGCHI conference on Human factors in computing systems - CHI '02, ACM, New York, NY, USA, 211–218. DOI: <https://doi.org/10.1145/503376.503414>
- [20] Gary W. Evans. 1980. Environmental cognition. *Psychol. Bull.* 88, 2 (September 1980), 259–287. DOI: <https://doi.org/10.1037/0033-2909.88.2.259>
- [21] Paul M Fitts and Michael I Posner. 1967. Human performance. Brooks/Cole, Oxford, England.
- [22] BoYu Gao, Byungmoon Kim, Jee-In Kim, and HyungSeok Kim. 2019. Amphitheater Layout with Egocentric Distance-Based Item Sizing and Landmarks for Browsing in Virtual Reality. *Int. J. Human-Computer Interact.* 35, 10 (June 2019), 831–845. DOI: <https://doi.org/10.1080/10447318.2018.1498654>
- [23] BoYu Gao, HyungSeok Kim, Byungmoon Kim, and Jee-In Kim. 2018. Artificial Landmarks to Facilitate Spatial Learning and Recalling for Curved Visual Wall Layout in Virtual Reality. In 2018 IEEE International Conference on Big Data and Smart Computing (BigComp), IEEE, 475–482. DOI: <https://doi.org/10.1109/BigComp.2018.00076>
- [24] Varun Gaur, Md. Sami Uddin, and Carl Gutwin. 2018. Multiplexing spatial memory: increasing the capacity of FastTap menus with multiple tabs. In Proceedings of the 20th International Conference on Human-Computer Interaction with Mobile Devices and Services - MobileHCI '18, ACM Press, New York, New York, USA, 1–13. DOI: <https://doi.org/10.1145/3229434.3229482>
- [25] Reginald G. Golledge, Terence R. Smith, James W. Pellegrino, Sally Doherty, and Sandra P. Marshall. 1985. A conceptual model and empirical analysis of children's acquisition of spatial knowledge. *J. Environ. Psychol.* 5, 2 (June 1985), 125–152. DOI: [https://doi.org/10.1016/S0272-4944\(85\)80014-1](https://doi.org/10.1016/S0272-4944(85)80014-1)
- [26] Greg Guest, Arwen Bunce, and Laura Johnson. 2006. How Many Interviews Are Enough? An Experiment with Data Saturation and Variability. *Field methods* 18, 1 (February 2006), 59–82. DOI: <https://doi.org/10.1177/1525822X05279903>
- [27] Sean Gustafson, Daniel Bierwirth, and Patrick Baudisch. 2010. Imaginary interfaces: spatial interaction with empty hands and without visual feedback. In Proceedings of the 23rd annual ACM symposium on User interface software and technology - UIST '10, ACM Press, New York, New York, USA, 3–12. DOI: <https://doi.org/10.1145/1866029.1866033>
- [28] Carl Gutwin and Andy Cockburn. 2006. Improving list revisitation with ListMaps. In Proceedings of the working conference on Advanced Visual Interfaces - AVI '06, ACM, New York, NY, USA, 396–403. DOI: <https://doi.org/10.1145/1133265.1133347>
- [29] Carl Gutwin, Andy Cockburn, and Benjamin Lafreniere. 2015. Testing the rehearsal hypothesis with two FastTap interfaces. In Proceedings of the 41st Graphics Interface Conference - GI '15, Canadian Information Processing Society, 223–231. Retrieved May 23, 2018 from <https://dl.acm.org/citation.cfm?id=2788930>
- [30] Carl Gutwin, Andy Cockburn, Joey Scarr, Sylvain Malacria, and Scott C. Olson. 2014. Faster command selection on tablets with FastTap. In Proceedings of the ACM conference on Human factors in computing systems - CHI '14, ACM Press, New York, New York, USA, 2617–2626. DOI: <https://doi.org/10.1145/2556288.2557136>
- [31] Lynn Hasher and Rose T. Zacks. 1979. Automatic and effortful processes in memory. *J. Exp. Psychol. Gen.* 108, 3 (1979), 356–388. DOI: <https://doi.org/10.1037/0096-3445.108.3.356>
- [32] Mary Hegarty, Daniel R Montello, Anthony E Richardson, Toru Ishikawa, and Kristin Lovelace. 2006. Spatial abilities at different scales: Individual differences in aptitude-test performance and spatial-layout learning. *Intelligence* 34, 2 (March 2006), 151–176. DOI: <https://doi.org/10.1016/j.intell.2005.09.005>
- [33] Ken Hincley, Randy Pausch, and Dennis Proffitt. 1997. Attention and visual feedback: the bimanual frame of reference. In Proceedings of the 1997 symposium on Interactive 3D graphics - SI3D '97, ACM Press, New York, New York, USA, New York, USA, 121–126. DOI: <https://doi.org/10.1145/253284.253318>
- [34] Ken Hincley, Randy Pausch, Dennis Proffitt, James Patten, and Neal Kassell. 1997. Cooperative bimanual action. In Proceedings of the SIGCHI conference on Human factors in computing systems - CHI '97, ACM Press, New York, New York, USA, 27–34. DOI: <https://doi.org/10.1145/258549.258571>
- [35] Stephen Hirtle. 2009. Cognitive Maps. In *Handbook of Research on Geoinformatics*. IGI Global, 58–64. DOI: <https://doi.org/10.4018/978-1-59140-995-3.ch008>
- [36] Rebecca Hurlebaus, Kai Basten, Hanspeter A. Mallot, and Jan M. Wiener. 2008. Route learning strategies in a virtual cluttered environment. In *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, Springer Berlin Heidelberg, Berlin, Heidelberg, 104–120. DOI: [https://doi.org/10.1007/978-3-540-87601-4\\_10](https://doi.org/10.1007/978-3-540-87601-4_10)
- [37] Phillip Isola, Devi Parikh, Antonio Torralba, and Aude Oliva. 2011. Understanding the Intrinsic Memorability of Images. In Proceedings of the 24th International Conference on Neural Information Processing Systems, Curran Associates, Inc., Granada, Spain, 2429–2437.
- [38] Yvonne Jansen, Jonas Schjerlund, and Kasper Hornbæk. 2019. Effects of Locomotion and Visual Overview on Spatial Memory when Interacting with Wall Displays. In Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems - CHI '19, ACM Press, New York, New York, USA, New York, USA, 1–12. DOI: <https://doi.org/10.1145/3290605.3300521>
- [39] Nikhita Joshi and Daniel Vogel. 2019. An Evaluation of Touch Input at the Edge of a Table. In Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems - CHI '19, ACM Press, New York, New York, USA, 1–12. DOI: <https://doi.org/10.1145/3290605.3300476>
- [40] Roy P.C Kessels, L Jaap Kappelle, Edward H.F de Haan, and Albert Postma. 2002. Lateralization of spatial-memory processes: evidence on spatial span, maze learning, and memory for object locations. *Neuropsychologia* 40, 8 (January 2002), 1465–1473. DOI: [https://doi.org/10.1016/S0028-3932\(01\)00199-3](https://doi.org/10.1016/S0028-3932(01)00199-3)
- [41] Gordon Kurtenbach and William Buxton. 1994. User learning and performance with marking menus. In Proceedings of the SIGCHI conference on Human factors in computing systems celebrating interdependence - CHI '94, ACM Press, New York, New York, USA, 258–264. DOI: <https://doi.org/10.1145/191666.191759>
- [42] Gordon Kurtenbach, Abigail Sellen, and William Buxton. 1993. An Empirical Evaluation of Some Articulatory and Cognitive Aspects of Marking Menus. *Human-Computer Interact.* 8, 1 (March 1993), 1–23. DOI: [https://doi.org/10.1207/s15327051hci0801\\_1](https://doi.org/10.1207/s15327051hci0801_1)

- [43] Benjamin Lafreniere, Carl Gutwin, Andy Cockburn, and Tovi Grossman. 2016. Faster Command Selection on Touchscreen Watches. In Proceedings of the ACM Conference on Human Factors in Computing Systems - CHI '16, ACM Press, New York, New York, USA, 4663–4674. DOI: <https://doi.org/10.1145/2858036.2858166>
- [44] Chin-Teng Teng Lin, Teng-Yi Yi Huang, Wen-Jing Jing Lin, Shu-Yen Yen Chang, Yin-Hung Hung Lin, Li-Wei Wei Ko, Daisy L. Hung, and Erik C. Chang. 2012. Gender differences in wayfinding in virtual environments with global or local landmarks. *J. Environ. Psychol.* 32, 2 (June 2012), 89–96. DOI: <https://doi.org/10.1016/j.jenvp.2011.12.004>
- [45] Kevin Lynch. 1960. *The image of the city*. MIT Press.
- [46] Aristides Mairena, Carl Gutwin, and Andy Cockburn. 2019. Peripheral Notifications in Large Displays: Effects of Feature Combination and Task Interference. In Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems - CHI '19, ACM Press, New York, New York, USA, 1–12. DOI: <https://doi.org/10.1145/3290605.3300870>
- [47] Ehsan Sotoodeh Mollashahi, Md. Sami Uddin, and Carl Gutwin. 2018. Improving revisitation in long documents with two-level artificial-landmark scrollbars. In Proceedings of the 2018 International Conference on Advanced Visual Interfaces, ACM, New York, NY, USA, 1–9. DOI: <https://doi.org/10.1145/3206505.3206554>
- [48] Weimin Mou, Chengli Xiao, and Timothy P. McNamara. 2008. Reference directions and reference objects in spatial memory of a briefly viewed layout. *Cognition* 108, 1 (July 2008), 136–154. DOI: <https://doi.org/10.1016/j.cognition.2008.02.004>
- [49] Bennet B. Murdock. 1962. The serial position effect of free recall. *J. Exp. Psychol.* 64, 5 (November 1962), 482–488. DOI: <https://doi.org/10.1037/h0045106>
- [50] Annie Wy Ng and Alan Hs Chan. 2009. What makes an icon effective? In AIP Conference Proceedings, AIP, 104–114. DOI: <https://doi.org/10.1063/1.3078113>
- [51] Jakob Nielsen. 1993. *Usability Engineering*. Morgan Kaufmann Publishers Inc., San Francisco, CA, USA.
- [52] Jakob Nielsen. 1994. Enhancing the explanatory power of usability heuristics. In Proceedings of the SIGCHI conference on Human factors in computing systems celebrating interdependence - CHI '94 (CHI '94), ACM Press, New York, New York, USA, 152–158. DOI: <https://doi.org/10.1145/191666.191729>
- [53] Albert Postma and Edward H.F. De Haan. 1996. What was where? Memory for object locations. *Q. J. Exp. Psychol. A.* 49, 1 (February 1996), 178–99. DOI: <https://doi.org/10.1080/173755605>
- [54] Philip Quinn, Andy Cockburn, Indratmo, and Carl Gutwin. 2008. An investigation of dynamic landmarking functions. In Proceedings of the working conference on Advanced visual interfaces - AVI '08, ACM Press, New York, New York, USA, New York, USA, 322. DOI: <https://doi.org/10.1145/1385569.1385623>
- [55] George Robertson, Mary Czerwinski, Kevin Larson, Daniel C. Robbins, David Thiel, and Maarten van Dantzich. 1998. Data mountain: using spatial memory for document management. In Proceedings of the ACM symposium on User interface software and technology - UIST '98, ACM Press, New York, New York, USA, 153–162. DOI: <https://doi.org/10.1145/288392.288596>
- [56] Irvin Rock and Phima Engelstein. 1959. A Study of Memory for Visual Form. *Am. J. Psychol.* 72, 2 (June 1959), 229. DOI: <https://doi.org/10.2307/1419366>
- [57] Joey Scarr, Andy Cockburn, Carl Gutwin, and Andrea Bunt. 2012. Improving command selection with CommandMaps. In Proceedings of the SIGCHI conference on Human Factors in Computing Systems - CHI '12, ACM, New York, NY, USA, 257–266. DOI: <https://doi.org/10.1145/2207676.2207713>
- [58] Joey Scarr, Andy Cockburn, Carl Gutwin, Andrea Bunt, Jared E. Cechanowicz, Joey Scarr, Andy Cockburn, Carl Gutwin, Andrea Bunt, and Jared E. Cechanowicz. 2014. The usability of CommandMaps in realistic tasks. In Proceedings of the 32nd annual ACM conference on Human factors in computing systems - CHI '14, ACM Press, New York, New York, USA, 2241–2250. DOI: <https://doi.org/10.1145/2556288.2556976>
- [59] Joey Scarr, Andy Cockburn, Carl Gutwin, and Sylvain Malacria. 2013. Testing the robustness and performance of spatially consistent interfaces. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, ACM, 3139–3148. DOI: <https://doi.org/10.1145/2470654.2466430>
- [60] Joey Scarr, Andy Cockburn, Carl Gutwin, and Philip Quinn. 2011. Dips and ceilings: understanding and supporting transitions to expertise in user interfaces. In Proceedings of the 2011 annual conference on Human factors in computing systems - CHI '11, ACM Press, New York, New York, USA, 2741–2750. DOI: <https://doi.org/10.1145/1978942.1979348>
- [61] Joseph Laurence Scarr. 2014. Understanding and Exploiting Spatial Memory in the Design of Efficient Command Selection Interfaces. University of Canterbury. Retrieved August 25, 2016 from <http://ir.canterbury.ac.nz/handle/10092/9326>
- [62] Katherine Schramm, Carl Gutwin, and Andy Cockburn. 2016. Supporting Transitions to Expertise in Hidden Toolbars. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems - CHI '16, ACM, New York, NY, USA, 4687–4698. DOI: <https://doi.org/10.1145/2858036.2858412>
- [63] Alexander W. Siegel and Sheldon H. White. 1975. The Development of Spatial Representations of Large-Scale Environments. *Adv. Child Dev. Behav.* 10, (January 1975), 9–55. DOI: [https://doi.org/10.1016/S0065-2407\(08\)60007-5](https://doi.org/10.1016/S0065-2407(08)60007-5)
- [64] Amy Skopik and Carl Gutwin. 2005. Improving revisitation in fisheye views with visit wear. In Proceedings of the SIGCHI conference on Human factors in computing systems - CHI '05, ACM Press, New York, New York, USA, 771–780. DOI: <https://doi.org/10.1145/1054972.1055079>
- [65] Molly E. Sorrows and Stephen C. Hirtle. 1999. The Nature of Landmarks for Real and Electronic Spaces. In *Spatial Information Theory. Cognitive and Computational Foundations of Geographic Information Science*. Springer Berlin Heidelberg, 37–50. DOI: [https://doi.org/10.1007/3-540-48384-5\\_3](https://doi.org/10.1007/3-540-48384-5_3)
- [66] Lionel Standing. 1973. Learning 10,000 pictures. *Q. J. Exp. Psychol.* 25, 2 (May 1973), 207–22. DOI: <https://doi.org/10.1080/14640747308400340>
- [67] Sibylle D. Steck and Hanspeter A. Mallot. 2000. The Role of Global and Local Landmarks in Virtual Environment Navigation. *Presence Teleoperators Virtual Environ.* 9, 1 (February 2000), 69–83. DOI: <https://doi.org/10.1162/105474600566628>
- [68] Ke Sun, Chun Yu, and Yuanchun Shi. 2019. Exploring Low-Occlusion Qwerty Soft Keyboard Using Spatial Landmarks. *ACM Trans. Comput. Interact.* 26, 4 (June 2019), 1–33. DOI: <https://doi.org/10.1145/3318141>
- [69] Perry W. Thorndyke and Sarah E. Goldin. 1983. Spatial Learning and Reasoning Skill. In *Spatial Orientation*. Springer US, Boston, MA, MA, 195–217. DOI: [https://doi.org/10.1007/978-1-4615-9325-6\\_9](https://doi.org/10.1007/978-1-4615-9325-6_9)
- [70] Perry W. Thorndyke and Barbara Hayes-Roth. 1982. Differences in spatial knowledge acquired from maps and navigation. *Cogn. Psychol.* 14, 4 (October 1982), 560–589. DOI: [https://doi.org/10.1016/0010-0285\(82\)90019-6](https://doi.org/10.1016/0010-0285(82)90019-6)
- [71] Dejan Todorovic. 2008. Gestalt principles. *Scholarpedia* 3, 12 (2008), 5345. DOI: <https://doi.org/10.4249/scholarpedia.5345>
- [72] Edward C. Tolman. 1948. Cognitive maps in rats and men. *Psychol. Rev.* 55, 4 (1948), 189–208. DOI: <https://doi.org/10.1037/h0061626>
- [73] Md. Sami Uddin. 2016. Use of Landmarks to Design Large and Efficient Command Interfaces. In Proceedings of the 2016 ACM Companion on Interactive Surfaces and Spaces - ISS Companion '16, ACM Press, New York, New York, USA, 13–17. DOI: <https://doi.org/10.1145/3009939.3009942>
- [74] Md. Sami Uddin and Carl Gutwin. 2016. Rapid Command Selection on Multi-Touch Tablets with Single-Handed HandMark Menus. In Proceedings of the 2016 ACM International Conference on Interactive Surfaces and Spaces, ACM, New York, NY, USA, 205–214. DOI: <https://doi.org/10.1145/2992154.2992172>
- [75] Md. Sami Uddin, Carl Gutwin, and Andy Cockburn. 2017. The Effects of Artificial Landmarks on Learning and Performance in Spatial-Memory Interfaces. In Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems, ACM, New York, NY, USA, 3843–3855. DOI: <https://doi.org/10.1145/3025453.3025497>
- [76] Md. Sami Uddin, Carl Gutwin, and Alix Goguy. 2017. Using artificial landmarks to improve revisitation performance and spatial learning in linear control widgets. In Proceedings of the 5th Symposium on Spatial User Interaction, ACM, New York, NY, USA, 48–57. DOI: <https://doi.org/10.1145/3131277.3132184>
- [77] Md. Sami Uddin, Carl Gutwin, and Benjamin Lafreniere. 2016. HandMark Menus: Rapid Command Selection and Large Command Sets on Multi-Touch Displays. In Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems, ACM, New York, NY, USA, 5836–5848. DOI: <https://doi.org/10.1145/2858036.2858211>
- [78] Norman G. Vinson. 1999. Design guidelines for landmarks to support navigation in virtual environments. In Proceedings of the SIGCHI conference on Human factors in computing systems the CHI is the limit - CHI '99, ACM Press, New York, New York, USA, 278–285. DOI: <https://doi.org/10.1145/302979.303062>
- [79] Haijun Xia, Ken Hinckley, Michel Pahud, Xiao Tu, and Bill Buxton. 2017. Writ-Large: Ink Unleashed by Unified Scope, Action, & Zoom. In Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems - CHI '17, ACM Press, New York, New York, USA, New York, USA, 3227–3240. DOI: <https://doi.org/10.1145/3025453.3025664>
- [80] Yukang Yan, Chun Yu, Xiaojun Ma, Shuai Huang, Hasan Iqbal, and Yuanchun Shi. 2018. Eyes-Free Target Acquisition in Interaction Space around the Body for Virtual Reality. In Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems - CHI '18, ACM Press, New York, New York, USA, New York, USA, 1–13. DOI: <https://doi.org/10.1145/3173574.3173616>
- [81] Shumin Zhai and Per-Ola Kristensson. 2003. Shorthand writing on stylus keyboard. In Proceedings of the conference on Human factors in computing systems - CHI '03, ACM Press, New York, New York, USA, 97–104. DOI: <https://doi.org/10.1145/642611.642630>
- [82] Jingjie Zheng, Xiaojun Bi, Kun Li, Yang Li, and Shumin Zhai. 2018. M3 Gesture Menu: Design and Experimental Analyses of Marking Menus for Touchscreen Mobile Interaction. In Proceedings of the Conference on Human Factors in Computing Systems - CHI '18, ACM Press, New York, NY, USA, 1–14. DOI: <https://doi.org/10.1145/3173574.3173823>
- [83] Jingjie Zheng, Blaine Lewis, Jeff Avery, and Daniel Vogel. 2018. FingerArc and FingerChord: Supporting Novice to Expert Transitions with Guided Finger-Aware Shortcuts. In The 31st Annual ACM Symposium on User Interface Software and Technology - UIST '18, ACM Press, New York, New York, USA, 347–363. DOI: <https://doi.org/10.1145/3242587.3242589>
- [84] Microsoft Word. Retrieved August 10, 2018 from <https://www.products.office.com/word>
- [85] Facebook. Retrieved August 10, 2018 from <https://www.facebook.com/>
- [86] Adobe Acrobat Reader. Retrieved August 10, 2018 from <https://acrobat.adobe.com/us/en/acrobat/pdf-reader.html>

- [87] Adobe Photoshop. Retrieved August 10, 2018 from <https://www.adobe.com/products/photoshop.html>
- [88] What are Gestalt Principles? | Interaction Design Foundation. Retrieved September 6, 2020 from <https://www.interaction-design.org/literature/topics/gestalt-principles>
- [89] Facebook's old web design will disappear in September - The Verge. Retrieved September 12, 2020 from <https://www.theverge.com/2020/8/21/21395079/facebook-new-design-default-september-classic-interface-disappearing>
- [90] New Facebook Design not showing up for me, is there anything I can do?: facebook. Retrieved September 12, 2020 from [https://www.reddit.com/t/facebook/comments/g07zmv/new\\_facebook\\_design\\_not\\_showing\\_up\\_for\\_me\\_is/](https://www.reddit.com/t/facebook/comments/g07zmv/new_facebook_design_not_showing_up_for_me_is/)
- [91] 10 Heuristics for User Interface Design: Article by Jakob Nielsen. Retrieved September 6, 2020 from <https://www.nngroup.com/articles/ten-usability-heuristics/>