# Teaching an Old Mouse New Tricks: User-Centered Development of a Gesture Set for Touch-Enabled Computer Mice

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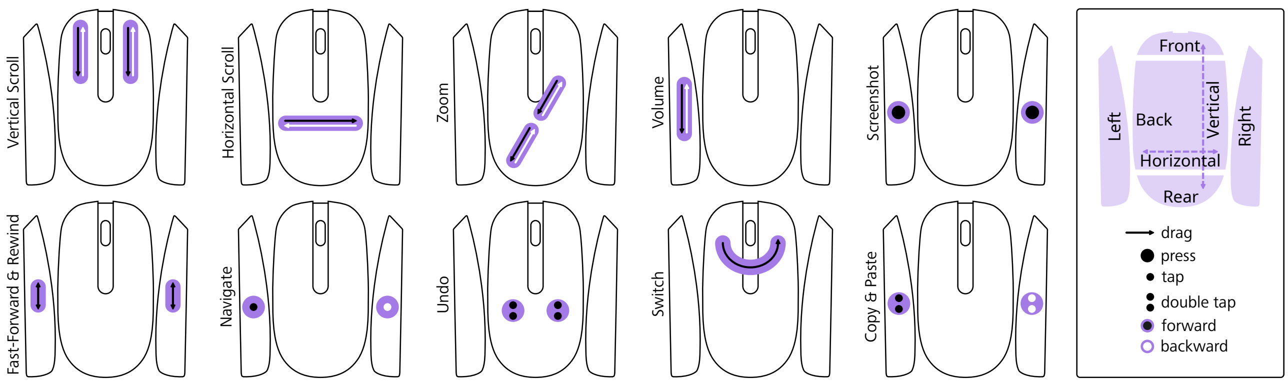


**Figure 1: User-defined gesture set for a multi-touch mouse. Operations were identified in a diary study, gestures were proposed in elicitation study. All illustrations assume right-handed mouse use.**

## Abstract

Touch-sensitive surfaces offer an intuitive and flexible form of interaction, for example through gesture input. Despite being the primary input modality for mobile devices, they hardly find application in desktop settings. At the same time, the computer mouse is still the most efficient and accurate input device for pointing. Consequently, keeping the unmatched functionality of a mouse but extending it with new input options via a touch-sensitive surface, is a promising approach. While research prototypes and niche products for multi-touch mice exist, the concept has not yet become established. In this work, we follow a user-centered approach towards touch interaction on computer mice. In a user study (n=12), we identified which areas on the mouse are suitable for touch input. Further, we explored potential usage scenarios in a diary study (n=11) and intuitive gestures in an elicitation study (n=10). We compile our findings into a gesture set which future research can build upon to implement touch interaction on computer mice.


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## CCS Concepts

• **Human-centered computing** → *Empirical studies in interaction design*; *Interaction devices*; **Gestural input**; • **Hardware** → *Emerging interfaces*; Sensor applications and deployments.

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## 1 Introduction

Gesture-based communication is highly efficient, learnable, and intuitive [25, 65]. Therefore, it is suitable for natural user interfaces in human-computer interaction [66, 73]. Consequently, touch interaction gained popularity and became a constant feature of our everyday lives in the form of smartphones and tablets, wearable touch devices, or touch displays in vehicles or on smart home objects. While these mobile devices are used for communication, entertainment and social media, as well as taking notes and pictures [13, 34], people still rely on laptop or desktop PCs for handling larger amounts of information or performing complex tasks, such as writing or proofreading texts, or administrative and confidential work [13, 34, 64]. In contrast to touchscreen-equipped mobile devices, gesture input is rarely used in desktop settings, where actions are commonly invoked through keyboard shortcuts and mouse-operated graphical menus [42].

For pointing tasks, the computer mouse is faster, more accurate, and less prone to errors than both, indirect touchpads and direct touch screens [28, 63]. Furthermore, the mouse is more ergonomic and causes less fatigue [46]. Consequently, it has been one of the most popular input devices for decades. Initially equipped with only one button [22], the mouse's appearance has changed over time: more buttons were introduced to allow for secondary input, and an added mouse wheel serves as dedicated input for scrolling through documents [14]. Even though those extensions of the mouse foster new ways for interaction, them requiring hardware modifications results in a chicken-and-egg problem: newly designed forms of interaction can only be established if enough users own the required hardware. On the other hand, the hardware only changes if there are applications using the new features. In contrast, touch interfaces are highly customizable, requiring only software adjustments to expand the range of possible input options.

To combine the unmatched pointing precision and efficiency of a computer mouse with the flexibility and intuitiveness of gesture input, several prototypes for touch-sensitive computer mice have been developed [7, 14, 69]. Such devices could circumvent the trade-off between pointing performance and variety in interaction, as well as reduce the need for time-consuming switches between mouse and keyboard [15]. However, only few of those products made it to the market (e.g., the *Apple Magic Mouse*).

Previous research has mainly focused on developing methods for tracking gestures and re-evaluating the design of the mouse [69]. However, a deep understanding of usage context and user needs is crucial for designing novel forms of interaction [9, 32]. To address this issue, we explored design spaces, potential use cases, and intuitive gestures for multi-touch mice, following a user-centered design process.

We used a computer mouse instrumented with a grid of capacitive touch sensors to identify regions touched during common mouse operations in a first user study ($n = 12$). We then conducted an experience sampling diary study ($n = 11$) to explore situations of high-frequent mouse usage and collect use cases for potential touch interaction. As a last step, we elicited intuitive gestures for emerged use cases ($n = 10$). We found evidence that touch-enabled computer mice could potentially improve desktop workflows in various usage scenarios, such as browsing, text production, or creative work, as well as general view control, such as scrolling, zooming, or switching between applications. From a technical standpoint, the sides and back of the mouse are promising candidates for being used as touch-sensitive regions. User-elicited gestures also use those regions, as well as the surface of the mouse buttons. Based on these findings, we derive a set of touch gestures for ten different operations that can be performed on the surface of a computer mouse (Figure 1). The proposed gesture set informs future design decisions for an enhanced mouse interaction and lays a foundation for developing new prototypes for touch-enabled computer mice.

## 2 Related Work

First prototypes for the computer mouse were developed in the 1960s and featured rotary encoders for movement tracking, as well as a single button for selection [22, 45]. During the 1980s and early 1990s, the design was slightly altered in several iterations [14] until converging to the modern design with two mouse buttons, a scroll wheel, and an optical movement sensor.

Over time, specialized mice adapted to specific applications have been developed. For example, gaming mice feature additional customizable buttons, ergonomic mice allow for a grip that reduces hand and arm strain, and 3D mice feature a jogwheel with multiple degrees of freedom, allowing for easier navigation in 3D viewports [14]. Additionally, several research projects have explored an extended scope of interaction for computer mice, for example rotation via a second mouse sensor [22, 44], tilt via a built-in gyroscope [6], pressure sensitivity through inflatable material [36], or enabling 3DOF interaction in general [23]. Nevertheless, the basic functionality of the computer mouse remained unchanged.

Using the mouse to draw gestures is a simple way to introduce gesture interaction in mouse-based workflows. Software tools such as *StrokeIt*[1], *GestureSign*[2], or *QuickHotkeys*[3] allow for gesture input using mouse movement. A pre-defined set of unistroke gestures can be assigned to distinct actions, such as launching or switching applications, or controlling media playback. While this allows for high-level interaction using only the mouse, this method interferes with normal mouse use. To circumvent this Midas Touch problem, either a dedicated canvas for gesture input, or a clutch mechanism (e.g., a keyboard shortcut) is required.

### 2.1 (Multi-) Touch Computer Mouse

Laptop computers come with built-in touchpads as a substitute for the mouse in mobile settings. Even though they are proven to be less accurate and efficient for pointing compared to mice [28], a major advantage of touchpads is multi-touch support and therefore gesture input. Swipe and pinch gestures can be used to navigate within documents or switch between applications – similar to interaction paradigms used for touch screen devices. With the *Magic Trackpad* [1] , Apple even offers an external touchpad completely replacing the computer mouse.

To combine the advantage of fast and accurate pointing with gesture input, researchers and hardware manufacturers have experimented with extending computer mice with touch sensing. The *Fujitsu Takamisawa ScrollPad Mouse (1998)* combined the concept of a touchpad and a traditional mouse by integrating a scroll pad between the left and right mouse button [14]. Similarly, the *PadMouse* fully replaces the front part of the mouse by a touchpad [7]. This way, the interaction for pointing stays untouched, whereas the integrated touchpad allows for gesture-based input for scrolling documents or scaling objects. More recent products include the Microsoft *Surface Arc Mouse*[4], the Apple *Magic Mouse* [30], as well as two discontinued products by Logitech, the *Touch Mouse T620*[5]

[1]https://www.tcbmi.com/strokeit
[2]https://gesturesign.win/
[3]https://sourceforge.net/projects/quickhotkeys/
[4]microsoft.com/en-us/d/surface-arc-maus-schwarz/8nr554s5qxn7
[5]logitech.com/assets/46476/3/touch-mouse-t620.pdf

and *T630*[6]. All of those support gestures to extend the mouse's functionality beyond pointing, for example horizontal swiping for switching between applications or navigation, drag gestures with a single finger for scrolling, or double tapping for a middle click or opening the home menu. Even though the *Magic Mouse* uses a similar feature set as Apple's trackpad, inconsistencies regarding the gestures were criticized in a usability evaluation, along with low sensitivity, lack of haptic feedback when clicking, and the non-ergonomic design [40].

Besides commercial products, there is research on multi-touch mouse prototypes. Villar et al. [69] propose five different prototypes for computer mice with multi-touch gesture input. The *Orb Mouse* and *FTIR Mouse* track a user's fingers on the mouse surface with a built-in camera. The *Side Mouse* is operated with only the palm of the hand. This way, the user's fingers are free to perform gestures on the table's surface, which are tracked with a camera in the front of the device. The *Cap Mouse* is covered with a grid of $20 \times 10$ capacitive touch sensors, detecting the user's fingers on the device's surface. Even though the tracking resolution is significantly lower than with camera-based methods, capacitive sensors are not affected by varying lighting conditions. Lastly, the *Arty Mouse* consists of three components: the user's palm rests on the base body while thumb and index finger each control an extension. As each of those components are equipped with an optical mouse sensor, simple two finger gestures can be tracked. The prototypes were evaluated in a qualitative think-aloud user study with six participants. Interestingly, participants were on the one hand quite open for exotic form factors, while on the other hand having difficulties with novel forms of interaction, such as multi-touch gestures on the mouse's surface [69]. Consequently, further exploration is needed to not only implement and test prototypes but also to design interaction in a user-centered way.

Benko et al. [9] evaluated Villar et al.'s *Cap Mouse* [69] in a user study. They define four main challenges for multi-touch mice: interaction that requires a 1:1 *mapping* to the screen content is difficult because of the indirect touch interaction. *Selecting* objects to bring them into focus and providing *feedback* during interaction is important. Further, a clutching mechanism should be considered to *avoid accidental input*. Authors implemented four different input techniques to select and manipulate 2D objects, and to activate touch input when needed. Results show that due to incoherent mental models, multi-touch implementations were less efficient and intuitive compared to a mouse or touch screen. This indicates that interactions depending on manual activation, focus, and cursor position might not be suitable for a multi-touch extension [9].

Previous work has shown that keeping the look and feel of a traditional mouse is important for efficient use, if common mouse operations stay available. This ensures that participants are still familiar with the interaction technique [9]. Besides offering a solid grip and overcoming the Midas Touch problem, finding suitable use cases is a significant challenge in the context of multi-touch mice [9, 69]. As multi-touch mice are not yet established but promising, we need to further investigate how to benefit from this concept.

[6] logitech.com/assets/49426/5/ultrathin-touch-mouse-t630-quick-start-guide.pdf

## 2.2 Gesture-based Interaction

Gesture-based interaction can be classified by the the body part(s) used to articulating a gesture, as well as the sensor that detects a gesture [66]. For example, one can move a finger (body part) on a touchscreen (device), or perform a sign gesture with the whole hand (body part) which is captured by a camera (device). While we perform gestures, we are influenced by situational, cognitive, physical and system factors [79]. These factors should be taken into account when designing gesture-based interaction.

*Situational* factors include the environment in which a gesture is performed. Social acceptance plays an important role for gesture-based interaction when other people are around [48]. Gestures that attract attention due to unfamiliar movement or interference with ongoing communication, are less willingly executed [60].

*System* factors refer to the recognition of and feedback provided to a gesture entered. As there are different ways to perform a specific gesture, e.g. varying start and end points or movement direction, recognition algorithms should provide flexibility to some extent [4, 59, 67]. Since discoverability of a gesture is often an issue [66], providing feedback to users is crucial. Guidance during gesture entry helps recognize possible input options, and learn how to perform a gesture [3, 8, 20].

*Physical* factors consider whether a gesture is physically demanding, causes fatigue, or is accessible for physically impaired people. Therefore, quantifying effort and fatigue of a gesture improves the understanding of an interaction and how users experience it [33, 41]. When designing gesture-based interactions in particular, the impact of fatigue is often overlooked, as its negative effects may remain unnoticed due to short evaluation phases [62].

*Cognitive* factors address the learnability and memorability of a gesture. For example, stroke gestures are easier to remember than keyboard shortcuts for menu selection tasks [5]. However, when designed poorly, gesture-based interaction can result in significant usability problems [56]. To design gesture-based interaction in a way that makes it as natural as possible, the aforementioned properties must be considered. Gestures that follow a familiar or simple shape can be articulated faster and easier [51, 59, 68]. Additionally, memorability increases if the corresponding action is reflected in the gesture – for example, by using letters associated with a specific action [39, 61]. Utilizing familiar symbols, shapes, or letters also increases the discoverability of a gesture, which is a major challenge in gesture-based interaction. In contrast to physical or tangible user interfaces which offer clear affordance through their appearance [54, 55], in gesture-based interaction, available input options are not immediately recognizable. Developing gesture sets in a user-centered way might overcome this issue, since user-defined gestures have proven to be easier to remember than gestures defined by experts or designers [51, 52].

## 2.3 Summary

Besides minor additions, such as the scroll-wheel, the design of a computer mouse has not noticeably changed over decades [14]. This underscores the unique capabilities of its concept. In desktop settings, it is still the most efficient and effective pointing device [28, 63]. However, touchpads enable a wider range of input options, such as intuitive and natural 2D touch gestures [5, 66, 73]. Thus, combining the unique performance strength of a computer mouse with touch gesture input is promising. However, this concept is not yet established and lacks in user-centered development [9, 51, 52]. To design a gesture set for a multi-touch enabled computer mouse with the user in mind, we identify following challenges: (1) suitable regions for touch interaction on the device need to be identified, so gesture input and mouse operation do not interfere with each other [9]; (2) use cases and usage scenarios for gesture input on a computer mouse need to be identified so the new form of interaction provides a practical benefit [32]; (3) touch gestures have to be elicited by users to maximize guessability and intuitiveness [51, 52].

## 3 Examining Mouse Usage

As a computer mouse is already covered by users' hands during interaction, parts of its surface can not be used for gesture input. For example, a tap gesture on the left mouse button would be hard to distinguish from a mouse click, leading to a Midas Touch problem. Additionally, touch interaction on certain areas could enforce a grip change to perform a gesture, interrupting primary interaction with the mouse. Therefore, we conducted a user study to find suitable regions for touch gestures on a computer mouse's surface.

### 3.1 Method

The study included ten tasks representing common mouse operations such as target selection and tunnel navigation, left, right, and double clicking, scrolling, drag & drop, as well as holding down the left, right, or middle mouse button. Tasks are further described and illustrated in Figure 3. Each participant completed all ten tasks in a random order.

While participants solved the tasks, we logged touch sensor data with an off-the-shelf computer mouse covered with a grid of capacitive sensors. This allows us to identify three types of areas: areas which are hardly touched during normal mouse usage, areas which are touched continuously, and areas with high activity, representing frequent changes between *touched* and *not touched*. We hypothesize that areas of low activity but high intensity in touch are the most suitable for touch gestures.

*3.1.1 Apparatus.* All tasks were implemented using PyQt6. Tasks were presented to participants on a *HP Pavillion x360* Laptop with Manjaro GNU/Linux and KDE Plasma, using an external 24" monitor in full-screen mode. For our touch sensitive mouse prototype (Figure 2), we attached 18 copper strips to the surface of a computer mouse[7]: 12 along the body, and 6 across. We used clear varnish as insulation between the layers. A *Bela Trill Craft*[8] uses the copper strips as capacitive sensors. Capacitance of each copper strip is measured at 172 Hz with a 12 Bit ADC and sent to a *BeageBoard Black* via I²C, which sends the data to the study computer via Wi-Fi. To derive a 2D representation of the mouse's surface from the individual strips' capacitance readings, we multiply the values of each row with those of each column, resulting in a matrix with 72 cells.

*3.1.2 Procedure.* We invited participants separately in our lab. After a short introduction and providing informed consent, participants filled out a demographic questionnaire containing additional questions regarding their typical mouse usage and their affinity for technology interaction on the ATI-S scale [72]. Participants then performed all ten tasks (see Figure 3) while interacting with the multi-touch mouse prototype. We expressly pointed out to participants that neither their performance nor the task completion times were subject of investigation, but that they should use the mouse as naturally as possible.

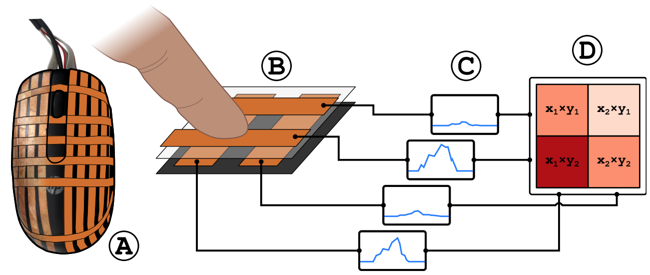


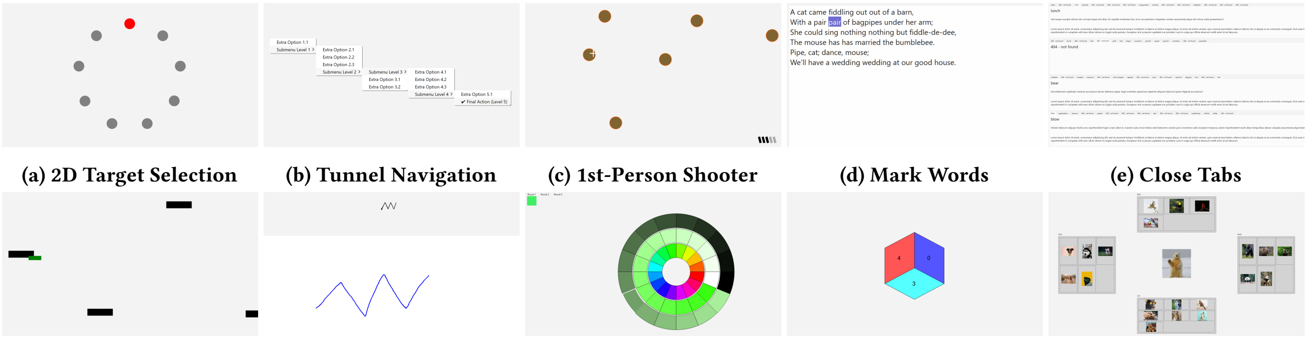

**Figure 2: Computer mouse instrumented with a grid of copper strips (A). Horizontal and vertical strips are separated with a layer of clear varnish (B). For touch sensing, we measure the capacitance of each copper strip (C). The closer the user's hand is to a strip, the higher its sensor reading. By multiplying sensor values from each row with those of each column, we derive a 2D matrix of sensor values, representing each node of the copper grid (D).**

*3.1.3 Participants.* We recruited 12 participants (7 women, 5 men) by convenience sampling. They were aged between 23 and 34 ($M = 27.42, SD = 3.20$) and all of them used the mouse with their right hand. Three of them typically do not use any other pointing device except the mouse, eight use a mouse often but they also use other alternative devices. The remaining participant only makes use of a mouse sometimes. ATI-S results indicate an overall high affinity for technology interaction ($M = 4.52, SD = 0.82$, *Cronbach's* $\alpha = 0.71$).

### 3.2 Results

Our dataset consists of time series data for all $12 \times 6$ sensor nodes, for each of 10 tasks and 12 participants. Thus, sensor values for a specific task and participant can be represented as a 3D tensor, with time as the third axis. We assume a region is suitable for gesture input if it is touched by users during mouse operation (= high *contact*), but the touch does not change over time (= low *activity*). We operationalize *contact* as a high average sensor value. *Activity* is operationalized as a high standard deviation of the derivative ($dt$) for each sensor value – representing many changes between being touched and not being touched. We calculate those values for each individual sensor position and each task, and aggregate resulting matrices over all participants. We then normalize the values for each task individually, mapping them to a range of $0 - 1$. By subtracting the resulting *activity* matrix from the corresponding *contact* matrix, we derive a matrix with values between -1 and 1, with positive values representing areas with high *contact* and low *activity*. Following our initial definition, we assume that those regions are most suitable for touch gestures.

[7]HP Optical Mouse, Model 672662-001
[8]https://eu.shop.bela.io/collections/trill/products/trill-craft




**(a) 2D Target Selection** **(b) Tunnel Navigation** **(c) 1st-Person Shooter** **(d) Mark Words** **(e) Close Tabs**

**(f) Scrolling** **(g) Drawing** **(h) Radial Menu** **(i) Rotating** **(j) Drag & Drop**

**Figure 3: Participants performed ten tasks requiring all typical mouse operations: pointing in a Fitts' Law task [24, 43], a Steering Law task [2] and a simple 2D 1st-person shooter game. Double clicks to mark words in a text, close tabs by pressing the middle mouse button, and scrolling to move a character in another simple 2D game. Drawing a set of unistroke shapes [77] on a canvas by holding the left mouse button, navigating through a radial color picker menu by holding the right mouse button, and rotating a 3D cube by holding the middle mouse button. Lastly, images should be sorted by drag & drop.**

We visualized *contact*, *activity*, and the combined matrix by mapping all sensor coordinates to an unwrapped 2D representation of the mouse (Figure 4, a–c). We then generated a Voronoi diagram[9] to extend those points to 2D regions, approximating each sensor's area. Especially the sides of the mouse, as well as the palm region on the left hand side seem suitable for gestures. Mouse buttons are not suitable due to high activity and the rear of the mouse is not suitable because there is not a lot of contact.

## 4 Finding Use Cases

To get insights into typical mouse usage, we conducted a one-week diary study. Multiple times per day during computer use, we asked participants in which situation they might benefit from a touch extension on their computer mouse. This way, we can determine potential *usage scenarios* (high-level, e.g., web browsing or gaming) and *operations* (low-level, e.g., pointing or scrolling) for multi-touch mouse interaction in a user-centered way.

### 4.1 Method

Our diary study [37] included five workdays and the weekend to get insights into diverse usage contexts. Participants provided information about their current mouse usage in a short online survey multiple times per day. They were asked to answer the survey whenever they noticed that they could benefit from a multi-touch mouse. Furthermore, in situations with above-average mouse usage, the survey was displayed automatically, following an experience sampling approach [12, 18, 27]. As mouse usage is highly dependent on person and task, and there are no rigorous studies on average mouse usage, we approximated a threshold using anecdotal data from several blog posts [10, 11, 58]. Via a tray icon, participants could disable the automatic display of the questionnaire for periods they did not want to be disturbed.

The survey included questions about current mouse use, what software was operated, and whether a touch-sensitive mouse could support ongoing activities. Participants could include a screenshot of their current screen to clarify their statements [16]. After the diary study, we interviewed each participant. We asked how reasonable they would assess a touch-extension for computer mice, as well as their willingness to use them, on a 5-point Likert scale each. To gain qualitative insights, we asked participants about suitable and unsuitable usage contexts, as well as advantages and disadvantages of a multitouch-mouse.

*4.1.1 Procedure.* First, participants were introduced to the study's objective and procedure, gave informed consent and completed a short demographic questionnaire including questions regarding their mouse usage and the ATI-S scale [72]. Afterward, they were guided on how to install and use the experience sampling program. Participants used their computer mouse as they would normally do over seven days, while being asked to answer our survey at least 3 to 5 times a day. As the seven days passed by, we invited each participant for a post-study interview.

*4.1.2 Participants.* We recruited 11 participants (4 women, 7 men) through personal contacts and a university mailing list. They were aged between 21 and 26 ($M = 23.82$, $SD = 1.40$). Results of the ATI-S indicate a high affinity for technology interaction ($M = 4.07$, $SD = 1.53$, *Cronbach's* $\alpha = 0.85$). Five participants stated they solely use a mouse for pointing tasks on their computer, 5 use it regularly, and one sometimes, but in combination with other devices. Three participants use a mouse with two buttons and a scroll wheel. Eight participants typically use a mouse with additional buttons, such as a gaming mouse. Participants use a mouse for surfing and web research (10), office work (8), gaming (8), design and creative work (6), and programming or data analysis (4).

### 4.2 Results

We analyzed all qualitative data following the method for qualitative content analysis by Mayring [47]. We coded written answers, provided screenshots, and notes taken during the post-study interview before combining the codes into broader categories.

[9]https://shapely.readthedocs.io/en/latest/reference/shapely.voronoi_polygons.html

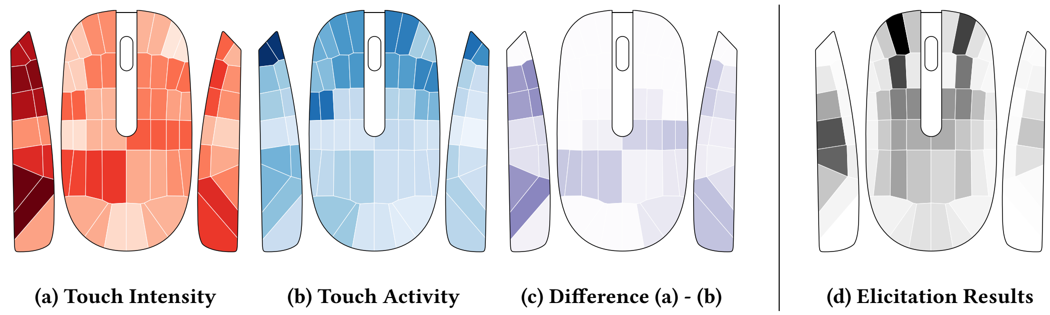



**Figure 4: Distribution of touch (a, normalized mean sensor values) and activity (b, normalized standard deviation of time derivative for sensor values) on the mouse surface. We assume that those regions that are touched but with low activity are most suitable for gestures from a technical point of view. Those regions are depicted in (c). In our elicitation study (Section 5), participants frequently performed gestures in the regions marked in (d).**

*4.2.1 Usage Scenarios and Operations.* Overall, the questionnaire was opened 175 times. In 122 cases, participants stated that a touch extension would be beneficial for the task they were currently working on. Most suitable scenarios were stated to be *web search and browsing* (30), *working with documents or text production* (28), and *creative work* (26). Less popular but still noticeably were *multimedia and entertainment* (13) and *gaming* (12).

Participants further suggested concrete operations for a multi-touch mouse. In the following, we focus on operations that were mentioned at least three times. The remaining operations can be clustered into four categories: view control and switching views, shortcuts, and multimedia. Scrolling vertically (8) or horizontally (8), as well as zooming (8) were most frequently mentioned for the *view control* category. Moving the cursor was suggested three times. *Switching views* includes switching between applications (5), tabs (5), or monitors (3). Additionally, participants wished for replacing *shortcuts* with touch gestures. Deleting, cutting, and capturing screenshots were mentioned three times each. Undo was requested four times and copy & paste six times. The *multimedia* category included pause/play (3), fast-forward and rewind (3), changing audio volume (4), and navigating through images or objects (5).

*4.2.2 Post-Study Interview.* In a post-study questionnaire, participants rated both, the reasonability of a multi-touch mouse, and their willingness to use one, on a 5-point scale. Nine participants strongly agreed (3) or agreed (6) that they assess a multi-touch extension on a mouse as reasonable. The remaining two participants were unsure. Six participants strongly agreed that they would use such a mouse. Two participants agreed and three were unsure.

We then conducted a short, semi-structured interview, asking participants to reflect on their mouse usage during the study, as well as their general opinion on a multi-touch mouse. As suitable contexts, participants mentioned creativity software due to its great number of different tools and shortcuts (9). On the other hand, gaming was explicitly described as unsuitable six times. As general advantages of a multi-touch mouse, participants could imagine intuitive (4) and efficient (4) interaction and an increased range of functionalities (2). Furthermore, they liked that it might reduce the need for switching between mouse, touchpad, and keyboard (3), or replace the 'out-dated' scroll wheel (2). The problem of having to carry an additional device if a mouse is used together with a laptop on the go, still remains and a touch extension would not offer any incentive for four participants to take the mouse with them. Also, participants were afraid of a high learning curve (2) in comparison to a traditional mouse. However, the main disadvantage was seen in the Midas Touch problem (8).

## 5 Finding Gestures

First introduced by Nielsen in 2004 [53] and popularized by Wobbrock et al. [76], elicitation studies have found their way in human-computer interaction and served for designing interaction in various contexts [70, 71]. They are commonly used to involve end users in the design process of gesture-based interaction. To find intuitive gesture sets for novel forms of interaction, a referent – a specific action with a defined start and end state – is presented to participants. Participants then produce and propose their own gesture which feels natural and matches the referent.

### 5.1 Method

We conducted an elicitation study to explore gestures suitable for performing different operations with a multi-touch mouse. We selected referents by consolidating the most popular operations suggested by participants of our diary study (Section 4.2.1). Thus, we ended up with the following ten referents: SWITCH, VERTICAL and HORIZONTAL SCROLL, ZOOM, COPY & PASTE, UNDO, taking a SCREENSHOT, NAVIGATE through images or objects, adjusting audio VOLUME, and FAST-FORWARD & REWIND.

To counteract legacy bias, participants were asked to propose two gestures for each referent [19, 50]. The referents were presented as a 'before and after' visualization instead of an animated one to avoid imitation bias [74]. This was implemented as a simple slide show with one slide for each referent. To reduce carry-over and sequence effects, we balanced the order of referents in a Latin square.

*5.1.1 Procedure.* First, each participant was introduced to the study's objective and gave informed consent. Afterward, they provided demographic information including questions on their usage of a computer mouse and the ATI-S scale [72]. For each referent, participants could take as much time as they wished to explore different gestures. When they decided on their two preferred gestures, they could start a video recording to capture those gestures. After recording a gesture, participants rated whether the proposed gesture is *easy to perform*, and a *good match* for the given purpose, on a 7-point Likert scale [76]. As in the diary study, we conducted semi-structured interviews at the end (see section 4).

*5.1.2 Participants.* Ten participants (2 women, 7 men, 1 diverse) were recruited via personal contacts and a university mailing list. They were between 20 and 36 years old ($M = 24.70, SD = 4.45$) and tended to have a high affinity for technology interaction as measured by the ATI-S ($M = 4.40, SD = 1.35$, *Cronbach's* $\alpha = 0.82$). They use a mouse for tasks such as design and creative work (9), surfing and web research (8), office tasks (7), and gaming (6). Seven participants primarily use a mouse for pointing, input devices by two use it in combination with other pointing devices, and one participant never uses a mouse in their routine.

## 5.2 Results: Gesture Elicitation

We analyzed video recordings of the 200 proposed gestures, annotating gesture type, movement path, fingers used, and location of the gesture on the mouse. Afterward, we calculated the Max-Consensus and Consensus-Distinct-Ratio and assessed participants' ratings of their gestures for quantitative analysis.

*5.2.1 Gesture Type.* Overall, 11 distinct gesture types were performed. Most commonly performed gestures were vertical (65) and horizontal (47) swipes. Other swipe gestures occurred 3 times. 29 gestures were classified as long presses and 15 gestures as double taps. Single taps (11) and triple taps (6) occurred less frequently. A pinch and circle gesture were proposed once each. Some gestures were combinations of gesture types. Six gestures combined spreading and pinching fingers. We observed a tap together with a swipe four times, a vertical swipe together with a double tap three times and a horizontal and vertical swipe in one gesture two times. Other combinations were suggested once each (7).

*5.2.2 Movement Path.* We assigned movement paths to all swipe, pinch, and spread gestures. 54 gestures used vertical[10] movement and 42 gesture used horizontal movement. Moving only downwards was assigned to 12 gestures, upwards to only one. Similarly, we observed a movement to the left side four times but only once to the right side. Seven gestures followed a diagonal path and one gesture a counterclockwise one. Less popular were combinations of different movement directions within one gesture. We observed nine distinct combinations, but each of them occurred only once. Regarding gestures combining movement with a tap or press, four gestures include a movement downwards, one gesture a sequence of up and down, and one gesture a diagonal movement.

*5.2.3 Finger Usage.* All participants used their right hand to operate the mouse. If gestures were articulated using only one finger (92), thumb and index finger were used most frequently (38 each) compared to the middle finger (10), ring finger (3), and pinky (3).

From 91 two-finger gestures total, 59 used the index and middle finger. The thumb was combined with the index finger twelve times, with the pinky nine times, with the ring finger seven times, and only once with the middle finger. Only three gestures combine the index and ring finger. Three fingers were combined in eleven proposed gestures. The most popular finger combination was index, middle, and ring finger (8). The remaining three gestures made use of the thumb, index, and middle finger. One gesture made use of a combination of the thumb, index, middle, and ring finger. There were no gestures using three or five fingers. However, some gestures included the palm – as the only active part (4) or in combination with the thumb and pinky (1).

*5.2.4 Region on the Mouse.* The most popular region on the mouse to perform a touch gesture was the back of the mouse (61). Sixteen were performed on the left mouse button and eight on the right one. The left side of the mouse was chosen 26 times, whereas the right side was chosen only six times. Touching the mouse in the front (5) or in the rear end (3) was not as popular. Some gestures used multiple areas of the mouse. Touching both mouse buttons (35) or both sides of the mouse (16) were the most frequently observed options. Another three area combinations with the left side of the mouse were proposed: together with the area of the left button (4), the back of the mouse (3), or both buttons (2). We observed ten further combinations which, however, were only proposed once.

Based on the video recordings, we annotated elicited gestures on a 2D representation of the mouse's surface. By aggregating those annotations and mapping them to a discrete grid, we derived a map of most prevalent areas envisioned for interaction. This allows us to compare them with regions suitable for touch input emerged from our task-based user study (see Figure 4d).

*5.2.5 Gesture Variety and Consensus.* To identify the *variety* of elicited gestures, we determined how many distinct gestures were proposed for each referent. We first visualized and categorized all gestures of our elicitation study based on the video recordings. This allowed us to identify which gestures are distinct and which are the same. We assumed that gestures are the same for a given referent if the area on the mouse, the type of gesture, the movement path, and the number of fingers involved are the same. Since the focus was on the gesture itself, we did not distinguish which finger or part of the hand was used. Similar to established gesture interaction, e.g., a pinch-to-zoom gesture does not require the movement of the thumb and index finger, but of any two fingers.

Overall, the variety is high ($M = 15.30, SD = 3.51$, Table 1). The referent VERTICAL SCROLL resulted in the smallest gesture variation. The total of 20 proposed gestures shows only seven distinct ones. As all participants proposed two gestures for each referent, the smallest possible variety is two. On the other hand, the referents SWITCH and COPY & PASTE were the greatest in variety with 20, which is the maximum of distinct gestures.

The *consensus* between participants' proposed gestures is oftentimes quantified by calculating the Agreement Rate [71]. However, this measure is not applicable as we followed the *production principle* by Morris et al. [50], and thus each participant suggested two distinct gestures. Therefore, a different metric has to be used [49]: calculating the Max-Consensus (MC) and the Consensus-Distinct Ratio (CDR) for each referent. The MC indicates the guessability of a gesture, the CDR, on the other hand, measures the diversity of apparently intuitive gestures. For the MC, the most frequently proposed gesture for each referent is identified – the MC is now the percentage of participants who proposed this gesture. To calculate

[10] The terms for movement directions are visualized in the legend of Figure 1.

the CDR, we counted distinct gestures for a referent that were proposed at least two times and divided this number by the number of all distinct gestures for the given referent [49]. Values for variety, MC, and CDR for all referents are listed in Table 1.

*5.2.6 Ratings.* Participants' ratings of *good match* and *easy to perform* tend to be positive in general. As shown in Figure 5, gestures for VERTICAL SCROLL received the most positive *good match* ratings, whereas those for SWITCH received the most negative ones. Gestures for the referent UNDO were rated as *easiest to perform* and the ones for ZOOM the hardest. Interestingly, gestures which do not match their purpose are still assessed as easy to perform.

## 5.3 Results: Post-Study Interview

After getting familiar with the concept of a multi-touch mouse during the elicitation process, participants rated its reasonability on a 5-point scale. Only two participants disagreed with the statement that a touch extension is reasonable. The remaining eight participants either agreed (6) or strongly agreed (2). Eight agreed that they would use a multi-touch mouse, two of them strongly. One participant was unsure and one was inclined not to use it. This indicates an overall positive assessment of the concept of a multi-touch mouse.

As suitable fields of application, participants mentioned software for creative (5) or office work (5) and web browsing (5). In contrast, gaming (7) was most frequently cited as an inappropriate usage scenario. Participants saw potential for a more efficient workflow (5) less switching between mouse and keyboard (5). Other mentioned advantages include increased functionality (4), intuitive use (3), room for personalization (2), one-hand operation (2), and accessibility (2). However, a high learning curve for complex and new gestures (4) and unintentional input due to unreliable detection (2) or the Midas Touch problem (7) left participants skeptical. When asking participants whether a touch extension would change their willingness to use a computer mouse, four participants expected an increased usage, while four did not expect any change. The other two were unsure but added that they would not buy but use it or want to try it out in practice before giving an assessment.

# 6 Gesture Set

We compile the findings of all three studies in a gesture set. It includes gestures for potential use cases we found in our diary study. The gestures are mainly user-defined as a result of our elicitation study (Section 5.2.5) with consideration of suitable regions we found in our study on mouse usage.

To do so, we proceeded as follows for each referent: First, we identified the gesture that was proposed most frequently. If this gesture was also the most popular for another referent, we assigned the gesture to the referent for which it was proposed more often. For the other one, we proceeded with the second most frequently proposed gesture. In case of a tie, we based our decision on both the findings of our first study investigating suitable regions for touch events and participants' ratings in terms of *good match* and *easy to perform*. We chose the gesture with the highest rating over these three criteria for the final gesture set. The final gesture set is depicted in Figure 1 and listed in Table 2. Additionally, a complete list of gestures proposed at least twice can be found in Table 3.

# 7 Discussion

In both, the diary study and the elicitation study, participants found the concept of a multi-touch mouse suitable for their workflows and stated to be willing to use it. Even if it might not be suitable for gaming, participants saw advantages in various fields, mainly for creative work, general view control, and replacing keyboard shortcuts or media keys. That switching between keyboard and mouse might be required less often was valued to increase efficiency [15]. Further, gesture input was attributed to be fast and intuitive. Thus, when selecting appropriate gestures that do not entail a high learning curve or familiarization phase, and overcome the Midas Touch problem, the concept of multi-touch mice seems promising.

## 7.1 Regions Suitable for Touch

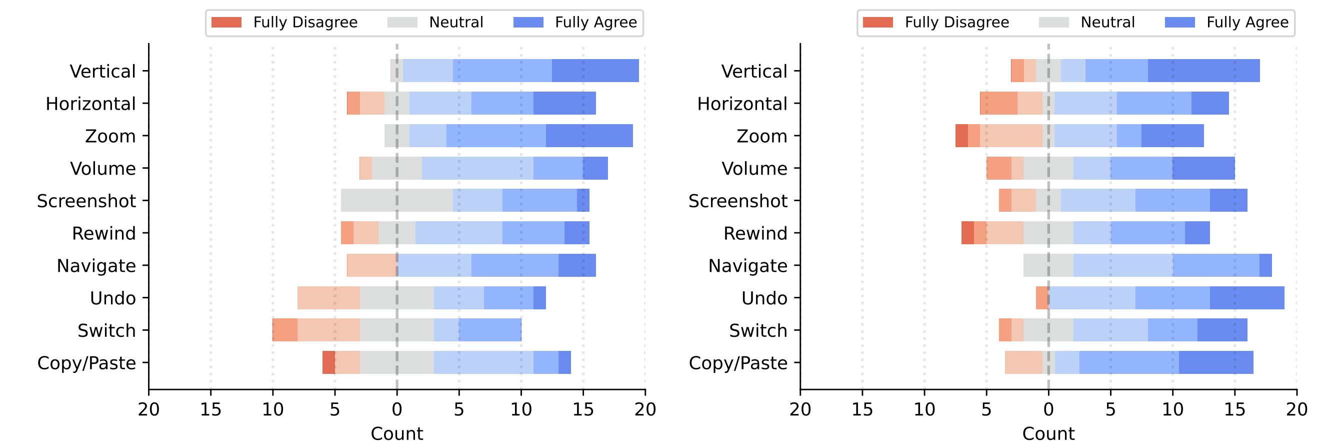
Due to its high efficiency and accuracy for pointing [28, 63], performing gestures on the mouse should not interfere with its normal use and vice versa. Therefore, we first investigated regions touched on a computer mouse during different tasks. As clutching mechanisms slow down interaction [9], we instead identified regions that will not conflict with mouse operation. We assume that suitable regions for gesture input are those being touched during normal use, as this avoids the need for grip changes. At the same time, gesture-enabled regions should be touched passively to avoid accidental touch input when operating the mouse. Results of our first user study indicate that these areas might be the left and right side of the mouse as well as in the center of the back of the mouse.

These areas also were popular when asking users for intuitive gestures to perform on the surface of a mouse. In our elicitation study, most gestures were performed on the back of the mouse, despite requiring a grip change in three cases (horizontal scroll, zoom, undo). The right side was not chosen as often as the left side for gesture input, but gestures that used both sides, consecutively or at the same time, were frequently suggested. In contrast, the *Magic Mouse* [30] and the *Cap Mouse* [9, 69] rely solely on the front half of the mouse, with the former even neglecting input on the sides. Following our findings, we suggest designers to consider the side and back of the mouse as interactive regions, as those areas were oftentimes suggested by participants and should be comparatively easy to track gestures on. However, further investigation is required to quantify to which degree grip changes for touch gestures on the back of the mouse impact user performance.

Contrary to our recommendation of suitable regions for touch input, performing gestures on the mouse buttons was popular in the elicitation study. This could lead to accidental activation of touch gestures when operating the mouse [9, 29]. However, proposed gestures often include simultaneous finger movement on both mouse buttons. This might be less prone to false positive detections during normal mouse use as both mouse buttons are hardly ever pressed at the same time. Another way to distinguish between gesture input on the mouse buttons and normal mouse use would be to add a temporal heuristic: when, for example, a tap gesture on the left mouse button is detected, the system could wait for a specified amount of time. If no mouse click event arrives at the operating system during this time frame, the gesture is processed – otherwise, it is likely to be a false positive detection resulting from a mouse click and the gesture should be discarded. Even though this method would

**Table 1: Variety, Max-Consensus (MC), and Consens-Distinct-Ratio (CDR) for each referent in descending MC order. For each referent, *Variety* is the number of distinct gesture proposed. *MC* shows how many participants agreed on the most popular gesture. *CDR* indicates to what extent participants agreed on the different gestures proposed.**

| | VERTICAL SCROLL | HORIZONTAL SCROLL | ZOOM | VOLUME | SCREENSHOT | FAST-FORWARD & REWIND | NAVIGATE | UNDO | SWITCH | COPY & PASTE |
|---|---|---|---|---|---|---|---|---|---|---|
| variety | 7 | 11 | 12 | 15 | 16 | 14 | 14 | 18 | 20 | 20 |
| MC | 0.6 | 0.6 | 0.5 | 0.4 | 0.4 | 0.3 | 0.3 | 0.2 | - | - |
| CDR | 0.57 | 0.27 | 0.25 | 0.20 | 0.13 | 0.36 | 0.36 | 0.11 | - | - |




(a) "The gesture I picked is a good match for its intended purpose."

(b) "The gesture I picked is easy to perform."

**Figure 5: Participants rated gestures they proposed during the elicitation study. Results for a gesture being a *good match* to its referent (a) and a gesture being *easy to perform* (b) on 7-point Likert scales ranging from 'fully disagree' to 'fully agree'.**

introduce additional latency to gesture input, the typical latency of a mouse event (below 10 ms for modern mice [75]) is lower than the temporal perception threshold for tapping on touch-sensitive buttons (20 ms [35] to 40 ms [57]).

## 7.2 Gesture Set: Ratings and Agreement

In our elicitation study, participants suggested gestures similar to those commonly found on mobile devices. Tap and drag gestures were suggested most frequently, mainly using one or two fingers. This goes in line with a Villarreal-Narvaez et al. [70], who found that those types of gestures are generally among the most popular in elicitation studies. Three-finger gestures were rarely proposed.

Wobbrock et al. observed high ratings for frequently proposed gestures [77]. Similarly, in our study, for gestures with clear real-world correspondences, such as dragging to scroll or pinch/spread to zoom, both, consensus between participants and their ratings of the gestures, were comparatively high [49]. Such gestures were also similar to gestures used in other domains: The most frequently suggested gesture for vertical scrolling and zooming correspond to those commonly used on laptop trackpads and mobile devices' touch screens. Despite a high consensus and high ratings for being a good match, participants found pinch gestures for zooming hard to perform. We assume this could be caused by the curved surface, the different grip, and the small form factor of the mouse. Even if a gesture is well-known and people are familiar with that, it is not necessarily suitable for every context and input device. However, finding gestures that work consistently across different devices would be especially beneficial [21].

Previous studies have found that gestures are most intuitive if they are metaphors to real-world actions [26, 31]. For more abstract referents, such as switching between applications and copy & paste, we could not find a consensus in the elicitation study. Likewise, Le et al. reported medium or low ratings in their elicitation study for these referents [38]. Wobbrock et al. [76] made similar observations, with more complex referents leading to lower agreement scores. Notably, compared to other tasks such as scrolling, zooming, or adjusting audio volume, there are no good real-world counterparts to switching between applications or copy & paste. Smartphone operating systems also offer alternatives to gesture input for switching between applications (a virtual button instead of a bottom-up swipe) and copy & paste (a context menu item instead of long-pressing selected text), indicating that gesture input alone is not sufficient for those operations.

Even though elicitation studies are susceptible for legacy bias, this is not always a disadvantage: it reveals which gestures share interaction metaphors and are therefore guessable and high in agreement [50]. Interestingly, we did not always observe a transfer of gestures from other domains to multi-touch mice, especially for

**Table 2: Descriptions for gestures in our final gesture set, compiled from user-elicited gestures, suitable regions for interaction, and implications from previous research. Similarities to already existing gesture sets are described if applicable.**

| | |
|---|---|
| VERTICAL SCROLL | dragging upwards and downwards with two fingers along the left and right mouse button<br>(Similar to laptop touchpads.) |
| HORIZONTAL SCROLL | dragging horizontally with one finger on the back<br>(In line with *Magic Mouse*, *Logitech T620*, and *Logitech T630*, smartphones and tablets, similar to laptop touchpads.) |
| ZOOM | pinch-to-zoom on the back<br>(Equivalent to zooming on mobile devices.) |
| VOLUME | dragging vertically on the left side<br>(Similar to operating volume buttons on the side of a phone.) |
| SCREENSHOT | pressing the left and right side simultaneously<br>(Similar to capturing a screenshot on a phone by pressing volume and power button simultaneously.) |
| FAST-FORWARD & REWIND | short drag vertically on the left side (fast-forward) and right side (rewind) |
| NAVIGATE | tapping the left side (navigate back) and the right side (navigate forth)<br>(For back and forth navigation, Wobbrock et al. [76] and Morris et al. [51] suggest a simple swipe gesture, similar to common touch screen interaction. This gesture or a modified version of it was also proposed in our elicitation study but is in conflict with the gesture proposed to scroll horizontally.) |
| UNDO | double-tapping with two fingers on the back<br>(According to our results, also Wobbrock et al. [76] and Morris et al. [51] found no overall consensus for that referent. However, their suggestions include mainly swipe gestures whereas the majority of gestures proposed in our elicitation study were taps.) |
| SWITCH | drawing a semicircle behind the mouse wheel<br>(Similar to gesture on Android. However, the *Magic Mouse* and *Logitech* mice use multi-finger swipes.) |
| COPY & PASTE | double-tapping the left side (copy) and the right side (paste)<br>(Gesture proposed for copy & paste in previous work were complex [38, 51, 76] and no consensus could be found in our study. Thus, there might be no intuitive gesture for that action.) |

more abstract referents. For example, switching between applications is initiated with a three-finger swipe on laptop touchpads or a bottom-up swipe on Android and iOS. Participants did not suggest such gestures during the elicitation process. Villar et al. [69] observed similar behavior when evaluating their *Cap Mouse*: Participants did not use the common pinch-to-zoom gesture on the mouse surface. At this point, we can not tell if this is because of the gesture being inconvenient to perform due to the mouse's form factor, or if there is a mismatch between mental models for touch screens or touchpads and interacting on a mouse.

## 7.3 Limitations and Future Work

During the elicitation study, we observed that similar gestures were proposed for different referents. Therefore, referent order could have influenced our results: If a participant has proposed a gesture for a certain referent before, they might not propose the same gesture later for another referent, even if it would be more suitable then. This is an inherent problem of open elicitation studies [17, 78], which can not entirely be prevented with counterbalancing. Consequently, a closed elicitation study, where participants have to assign gestures of a fixed set to given referents, can help to identify even better matches between use case and interaction. Additionally, a two step process of open and then closed elicitation [71] would allow researchers to curate the gesture set in between, taking into consideration external factors, such as technical limitations of the tracking infrastructure.

For more abstract referents, such as switching between applications or copy & paste, there was low agreement between elicited gestures. Contrarily, participants rated those gestures comparatively easy to use. As there was no option to skip a referent, participants might have just proposed a very simple gesture to continue the study in some cases. This is an inherent limitation of the procedure commonly used in elicitation studies, as there is no mechanism to check whether gesture input is even suitable for certain actions.

For referents with low agreement between elicited gestures, we had to resort to different selection criteria, such as user ratings, active region, and findings from related work. Even though a larger sample might increase the probability of finding consensus in proposed gestures, it is also possible that gesture input might not be the ideal form of interaction for those actions.

We tried to minimize conflicts between gesture input and normal mouse use by avoiding highly active regions on the mouse for our gesture set. However, our approach to determining the suitability of a region for gesture input is purely heuristic. Implementing a gesture recognizer for multi-touch mice is an important next step to validate our findings in real-world settings. This way, one could investigate whether focusing on low-activity regions actually improves detection. Furthermore, a fully functional prototype also allows for evaluating mouse gestures in the field. This way, practicability, learnability, and required effort to perform gestures could be measured in realistic usage scenarios. To quantify improvements offered by our gesture set for multi-touch mice, a task-based user study will allow for comparing it to related technology, like the *Magic Mouse*, or the software tool *StrokeIt*. This will provide further insights to inform design recommendations for future development.

# 8 Conclusion

In this work, we explored the potential touch gestures added to a computer mouse while keeping its functionality, since it is unmatched in accuracy and precision. In a user-centered approach, we first identified regions suitable for touch interaction by analyzing typical grip behavior and activity during mouse operation. Assuming that regions being touched continuously and with low variation are most suitable for gesture input, we infer that the sides and the back of the mouse are the most promising areas. As a next step, we conducted a 7-days diary study to gather real-life insights in what people usually use their mouse for and in which situations they might benefit from touch input on a computer mouse. Users see advantage in using mouse gestures for actions which are typically entered via the touchpad or keyboard shortcuts, as the necessity to switch between mouse, touchpad, and keyboard would be reduced. Examples include scrolling and zooming, copy & paste, or changing the volume. In a last step, we conducted an elicitation study to identify intuitive gestures for emerged use cases. We compiled the findings of all three studies, as well as implications from earlier research, into a gesture set for multi-touch mouse interaction.

From qualitative feedback we collected in our studies, we know that the willingness to use a multi-touch mouse is high. Potential lies in increased efficiency and a higher range of functionality. Thus, we conclude that this is a reasonable approach for extending the most popular pointing device and is worth investigating further.

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**Table 3: Overview of gestures proposed at least two times in our elicitation study.**

| referent | # fingers | gesture description | region on mouse | count | good match (mean) | easy to perform (mean) |
|---|---|---|---|---|---|---|
| vertical scroll | two | vertical drag | left and right mouse button | 6 | 6.33 | 5.50 |
| vertical scroll | one | vertical drag | left mouse button | 5 | 6.20 | 6.40 |
| vertical scroll | one | vertical drag | left side of the mouse | 4 | 5.75 | 7.00 |
| vertical scroll | one | vertical drag | center of back of the mouse | 2 | 6.00 | 6.00 |
| horizontal scroll | one | horizontal drag | back of the mouse | 6 | 5.67 | 4.50 |
| horizontal scroll | two | horizontal drag | back of the mouse | 4 | 6.25 | 4.75 |
| horizontal scroll | one | vertical drag | left side of the mouse | 2 | 3.50 | 6.00 |
| zoom | two | pinch-to-zoom | back of the mouse | 5 | 6.40 | 3.40 |
| zoom | two | vertical drag | back of the mouse | 4 | 6.50 | 6.00 |
| zoom | one | vertical drag | left mouse button | 2 | 4.50 | 7.00 |
| volume | one | vertical drag | left side of the mouse | 4 | 5.75 | 6.50 |
| volume | one | vertical drag | right side of the mouse | 2 | 6.00 | 5.50 |
| volume | one | horizontal drag | right mouse button | 2 | 5.00 | 6.00 |
| screenshot | two | press | left and right side of the mouse | 4 | 5.25 | 5.75 |
| screenshot | one | vertical drag | back of the mouse | 2 | 4.00 | 5.50 |
| fast-forward & rewind | one | horizontal drag | back of the mouse | 3 | 6.00 | 6.33 |
| fast-forward & rewind | one | horizontal drag | mouse buttons | 2 | 3.50 | 4.00 |
| fast-forward & rewind | one | vertical drag | left side of the mouse | 2 | 5.00 | 5.00 |
| fast-forward & rewind | one | vertical short drag | left (fast-forward) and right (rewind) side of the mouse | 2 | 4.00 | 4.00 |
| fast-forward & rewind | one | press | left (rewind) and right (fast-forward) mouse button | 2 | 6.00 | 5.00 |
| navigate | one | tap | left and right side of the mouse | 3 | 6.00 | 5.00 |
| navigate | two | drag | back of the mouse | 2 | 5.50 | 4.00 |
| navigate | one | tap | back of the mouse | 2 | 3.00 | 6.00 |
| navigate | one | drag | left side towards back of the mouse | 2 | 5.50 | 5.50 |
| navigate | one | drag | back of the mouse | 2 | 5.50 | 6.00 |
| undo | two | double-tap | back of the mouse | 2 | 5.00 | 6.00 |
| undo | one | press | right mouse button | 2 | 5.00 | 5.00 |