Post-Post-it: A Spatial Ideation System in VR for Overcoming Limitations of Physical Post-it Notes

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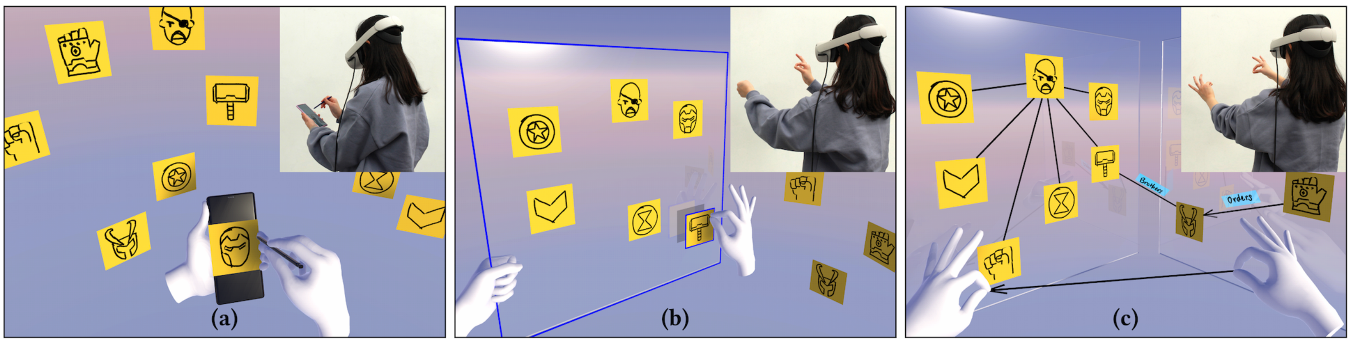

Figure 1: In our VR system, *Post-Post-it*, the user ideates for problem-solving by (a) writing on Post-it notes using a motion-tracked smartphone and a stylus. Using lifelike one- and two-hand gestures, the user can (b) organize individual notes and layers of notes at desired positions and orientations in 3D space, and (c) express relationships between notes with links.

ABSTRACT

Post-it notes are great problem-solving tools. However, physical Post-it notes have limitations: surfaces for attaching them can run out; rearranging them can be labor-intensive; documenting and storing them can be cumbersome. We present *Post-Post-it*, a novel VR interaction system that overcomes these physical limitations. We derived design requirements from a formative study involving a problem-solving meeting using Post-it notes. Then, through physical prototyping, using physical materials such as Post-it notes, transparent acrylic panels, and masking tape, we designed a set of lifelike VR interactions based on hand gestures that the user can perform easily and intuitively. With our system, the user can create and place Post-it notes in an immersive space that is large enough to ideate freely, quickly move, copy, or delete many Post-it notes at once, and easily manage the results.

CCS CONCEPTS

• **Human-centered computing → Interaction techniques**.

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KEYWORDS

Post-it note, layer, link, virtual reality, bimanual hand gesture

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1 INTRODUCTION

Post-it notes, accidentally created during the development of adhesives at 3M in the 1960s [10], are of suitable size to hold a small piece of information, can be attached quickly to surfaces of various objects, and can be detached and reattached easily and repeatedly without leaving a trace. Thanks to these characteristics, they are useful for quick memos, emphases in documents, and to-do reminders, and have become widely established as essential household and office supplies loved by many.

Post-it notes are also prolific problem-solving tools. Several motivated individuals gathered in front of a large wall with stacks of Post-it notes in their hands can quickly collect many pieces of information and ideas in a short time, effectively organize them, visualize complex relationships among them, and efficiently plan their course of action [10]. However, physical notes present problems (Figure 2).

First, the size of the surface to which notes can be attached is limited, so if several people are actively using the notes, the space can run out quickly (Figure 2a). In such a case, the scramble to make more room may interrupt the flow of the meeting.

Second, rearranging notes can be labor-intensive (Figure 2b). To change the arrangement of existing notes or add new notes among them, all notes in the vicinity must be detached and reattached one by one. The more notes there are, the more difficult this task is, and the more reluctant people become to organize notes in new ways.

Third, documenting and storing notes can be cumbersome (Figure 2c). Much time and effort are spent in converting the arrangement of hundreds of notes into digital diagrams before sharing or embedding them elsewhere. Moreover, important notes can easily be lost during this process.

These problems are unavoidable with physical Post-it notes. Therefore, in this study, we propose *Post-Post-it*, a novel spatial interaction system for creating and managing Post-it notes that uses virtual reality (VR) to overcome these physical limitations (Figure 1). In our system, the user can utilize the immersive space of VR that is large enough to ideate freely, quickly move, copy, or delete multiple notes at once with simple gestures, and no extra steps are needed to digitize the notes. In addition, using our system is as easy and intuitive as manipulating physical notes in physical space, and does not involve complicated menus, buttons, or widgets.

Figure 2: Post-it notes are prolific problem-solving tools, but they are not without their inconveniences. (a) First, the surface on which to attach notes can run out. (b) Second, rearranging them can be labor-intensive. (c) Third, documenting and storing them can be cumbersome.

2 RELATED WORK

Klemmer et al. recognized that Post-it notes are actively used to record and communicate ideas in design practice, and developed *The Designers' Outpost* [6]. In their system, when the user writes on a physical note and attaches it to an interactive wall, the system digitizes the note. The user then manipulates the graph of data represented by the notes, while utilizing the note as the physical handle to those data. In *Affinity Lens* [11], when the user prints digital data and augmented reality (AR) markers on Post-it notes and arranges them on a wall in a desired layout, relevant insights are visualized in real time in a smartphone-based AR. Although we do not use physical Post-it notes directly, we have been inspired by these approaches that respect the physicality of the paper notes.

There have also been attempts to completely digitalize Post-it notes. Jensen et al. proposed a system that emulates the physical process of writing on a Post-it note. In their system, the user writes on a hand-held mobile device and transfers the note to a large touch display using a tap gesture [5]. Wu et al. proposed a technique for creating a Post-it note on a motion-tracked mobile device and placing it in the AR space using a pinch gesture [12]. These studies have shown that a motion-tracked mobile device capable of touch and pen input can complement VR experiences [13]. However, while proposing a number of interesting component techniques, these studies have not provided a complete set of functionalities needed to facilitate full-scale Post-it meetings in VR spaces.

Although it does not feature Post-it notes directly, *BumpTop* [1] represents data as tiles and sheets of paper subject to the laws of physics and lets the user organize them into many useful 3D layouts using rich mouse gestures. *SpaceTop* [7] lets the user create, place, and browse documents in a volume of 3D space that is visible through a transparent 2D screen, using keyboard, touch, and hand gesture inputs. Finally, *Spatial* [9] is a remote collaboration platform that allows meeting attendees to share 2D documents, 2D images, and 3D models in VR. *Spatial* is a commercial platform launched by the two researchers who developed *BumpTop* and *SpaceTop*, but has not yet implemented the physics-based interactions or the rich set of gestures seen in these two systems. By bringing them to VR, our research may contribute to enhancing the usability of such a platform.

3 FORMATIVE STUDY

Straker consolidated a number of widely used problem-solving tools, such as brainstorming, affinity diagrams, mind maps, and flowcharts, into 6 simple but effective tools using Post-it notes [10]. To gain a firsthand understanding of the conveniences and inconveniences of using many physical notes in a problem-solving setting and derive the requirements that our system should satisfy, we conducted a problem-solving meeting using these 6 tools (Figure 3). The topic of the meeting was *"How to improve online video conferencing."* 4 participants (aged 22-31 years, all majoring in Industrial Design), including the authors, conducted the meeting. It lasted 9 hours over 4 days, and a total of 189 notes were used.

3.1 6 Problem-Solving Tools Using Post-its

First, post-up (PU) is used to discover and collect many problems related to a specific situation within a short time. Each person holds a stack of Post-it notes, writes one problem per sheet, and freely attaches it to the workspace. In our meeting, participants posted problems such as *"Forget to turn mic on/off"* and *"Don't know if people are paying attention"* when asked about problems of video conferencing (Figure 3a).

Second, bottom-up tree (BUT) is used to organize problems into larger categories. Notes are grouped by attaching similar notes closer together. In our meeting, participants categorized problems of video conferencing as *"Face and Vision," "Voice and Sound," "Installation," "Multi-screen," "Security," "Teacher and Student," "Social,"* and *"Health"* (Figure 3b).

Third, swap sort (SS) is used to prioritize among categories of problems. Notes are arranged into a column, then sequentially compared from first to last and reshuffled according to perceived importance. In our meeting, based on the questions *"Which problems are more urgent?"* and *"Which problems can be solved with a good interface design?"* the category of problems chosen as the top priority was *"Social"* (Figure 3c).

Fourth, information map (IM) is used to identify and visualize correlational or causal relationships among problems. Similar notes are placed closer together, and lines and arrows are drawn between them. In our meeting, participants found many such relationships within the *"Social"* category, e.g. *"Lack of eye contact"* and *"Can turn off the camera"* led to *"Easy to become distracted"* (Figure 3d).

Fifth, top-down tree (TDT) is used to break down a larger problem into smaller problems that are easier to solve, through a process of elaboration. In our meeting, tackling the problem that *"People interrupt each other,"* participants generated two ideas, *"Let people know when they can speak"* and *"Let people know that others want to speak."* Then, they further generated many more ideas that would help achieve each of them (Figure 3e).

Sixth, action map (AM) is used to decide on a course of action. One action is written per note, and arrows are drawn between notes to indicate the order of execution, success conditions, and repetitions. In our meeting, participants determined that they should *"Find ways to visualize speaking time"* and conduct a *"User study to analyze distribution of speaking time"* (Figure 3f).

3.2 Design Requirements

We videotaped and analyzed the participants' use of Post-it notes during the problem-solving meeting. In contrast to using a couple of notes for memos, emphases, and reminders, solving a real problem required hundreds of notes to be arranged in a large workspace.

For this to happen in a smooth and uninterrupted manner, we found that it should be easy to manipulate not only individual notes, but also large quantities of notes. In addition, for relevant insights to be drawn from the notes, it should be easy to organize these notes into meaningful groups and relationships.

From these findings, we derived 9 design requirements (DR) that our system should satisfy, and indicated which of the 6 problem-solving tools each requirement applies to (Table 1).

4 PHYSICAL PROTOTYPING

In exploring a harmonious set of lifelike VR interactions that emulates natural interactions with physical Post-it notes and satisfies the design requirements derived from the formative study, we conducted several iterative rounds of physical prototyping using physical materials. Among them, the prototype that led to the final system design is presented (Figure 4).

For the Post-it notes, we used the most widely used size (3 in × 3 in) and color (yellow; R: 255, G: 212, B: 45). A stack of notes provided a hard flat surface to comfortably write against. It was natural to hold the stack with the non-dominant hand (NDH) and write with the dominant hand (DH) (Figure 4a), in accordance with the kinematic chain model [4].

Figure 3: Straker suggested 6 problem-solving tools using Post-it notes [10]. (a) Post-up (PU) is used to collect many problems. (b) Bottom-up tree (BUT) is used to organize problems into categories. (c) Swap sort (SS) is used to prioritize among categories. (d) Information map (IM) is used to identify and visualize relationships. (e) Top-down tree (TDT) is used to break down a large problem. (f) Action map (AM) is used to plan a course of action.

Table 1: By analyzing the usage patterns of Post-it notes in 6 problem-solving tools, we derived 9 design requirements.

Design requirements (DR)	6 problem-solving tools using Post-it notes					
	PU	BUT	SS	IM	TDT	AM
DR1: Easily write on a Post-it note.	✓				✓	✓
DR2: Easily throw away or bring back a Post-it note.	✓				✓	✓
DR3: Easily copy a Post-it note.		✓				✓
DR4: Easily attach, detach, and reattach a Post-it note.	✓	✓	✓	✓	✓	✓
DR5: Easily group many Post-it notes.		✓		✓	✓	
DR6: Easily relocate many Post-it notes at once.		✓		✓	✓	
DR7: Easily align many Post-it notes horizontally or vertically.			✓		✓	✓
DR8: Easily connect or disconnect non-directionally between two Post-it notes.				✓		
DR9: Easily connect or disconnect directionally between two Post-it notes.				✓	✓	✓

In addition, we used transparent acrylic panels (500 mm × 500 mm × 5 mm) to make notes appear as floating in the air. It was natural to use an index-finger pinch gesture to remove a note from the stack, and then move and attach it to a surface (Figure 4b).

We found that the transparent panel was also suitable as a layer capable of collecting and carrying several notes at once. When holding and moving a transparent panel, it was natural to perform grab gestures on the sides of the panel, due to the panel being considerably larger and heavier than a note (Figure 4c).

To create a link between two spatially positioned notes, instead of drawing a line with a pen, which is only possible on a physical surface such as a whiteboard, we used masking tape (10-mm wide). It was natural to pinch both ends of the tape to attach it to the notes while pulling the ends to keep it straight (Figure 4d).

An unwanted note could be crumpled into a small ball with a grab gesture, which could be easily tossed into the trash bin (Figure 4e). Moreover, in case of a mistake, the crumpled note could be picked up and flattened, and its content could be viewed again. When a link was no longer needed, it was natural to grab and pull it to tear both ends off of the attached notes (Figure 4f).

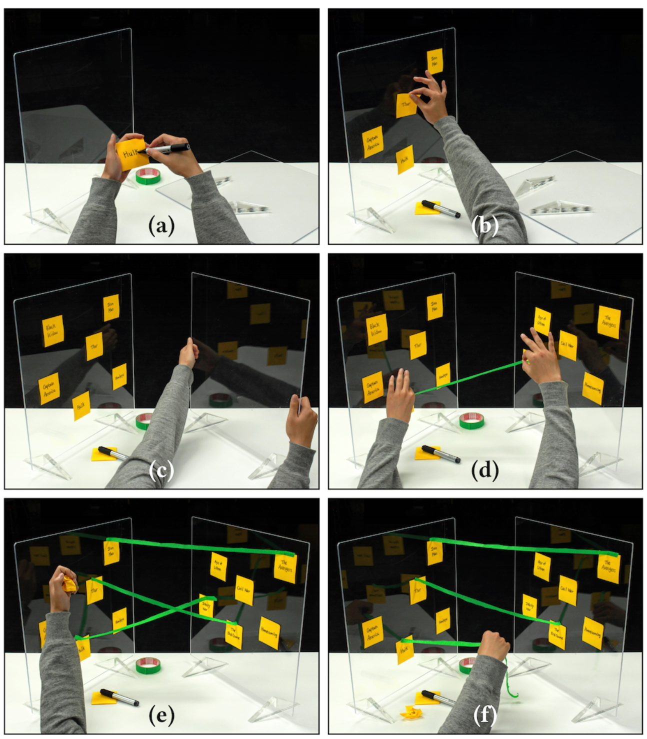

Figure 4: We explored lifelike interactions through prototyping with physical materials. (a) Holding a stack of Post-it notes with the non-dominant hand (NDH) and writing with the dominant hand (DH). (b) Pinching and attaching a note to a transparent acrylic panel and "floating it in the air." (c) Grabbing and moving the transparent acrylic panel, a kind of layer. (d) Linking notes with masking tape by pinching both ends. (e) Grabbing and crumpling an unwanted note. (f) Grabbing and tearing off an unwanted link.

5 POST-POST-IT

In this section, we introduce component interactions of our system, consisting of note, layer, link, and mixed interactions. These interactions reflect the design requirements derived from the formative study and the physical metaphors derived from the physical prototyping. For convenience, the right hand is shown as the DH and the left as the NDH, but roles of hands are interchangeable.

5.1 Note Interactions

The user writes on a note as if writing on the top of a stack of Post-it notes (DR1), in accordance with the kinematic chain model [4], and places a note in the air with a pinch gesture (Figure 5) [12]. The user also deletes a note as if crumpling it with a grab gesture, and restores the deleted note as if uncrumpling it with a two-hand pinch gesture (DR2) (Figure 6) [1].

5.2 Layer Interactions

The user creates, resizes, moves (Figure 7), and deletes a layer (Figure 8) with one- and two-hand grab gestures as if handling a transparent acrylic panel of considerable size and weight.

5.3 Link Interactions

With a two-hand pinch gesture that resembles holding a segment of masking tape [2], the user creates a non-directional link (DR8) and a directional link (DR9) (Figure 9). The user attaches it to a pair of notes as if attaching a segment of masking tape, and also deletes a link as if tearing the tape away from the attached notes with a grab gesture (DR8, DR9) (Figure 10).

5.4 Mixed Interactions

The user creates a layer out of multiple notes (DR5) or snaps a note onto a layer (DR4) (Figure 11). The user slides around one or more notes (DR6) or aligns them horizontally or vertically (DR7) within a layer (Figure 12). The user also relocates many notes at once by using the layer as if it were a sieve (DR5, DR6) and copies notes by using the layer as if it were a silkscreen (DR3) (Figure 13).

6 IMPLEMENTATION

For implementation, we used an Oculus Quest 2, a VR device capable of tracking hand motion and gesture and a Galaxy Note 10+, a smartphone capable of receiving stylus input. The smartphone's built-in DepthVision, together with Android's ARCore SDK, enabled precise estimation of the pose of the smartphone in 3D space. Our VR application was written with the Unity 3D game engine. A Node.js WebSocket server facilitated real-time data transfer between the devices.

Using our implementation, we enacted a user scenario whereby we summarize the plot of *The Avengers* (Figure 1), in which many Marvel characters establish allegiance to different teams (Figure 1b), as well as friendly or hostile relationships with one another over time (Figure 1c). This fictional material was ideal for showcasing the complete set of interactions of our system in a short time, and for demonstrating that our interactive system closely emulates our physical prototype, in full compliance with the design requirements we aimed to satisfy in our formative study.

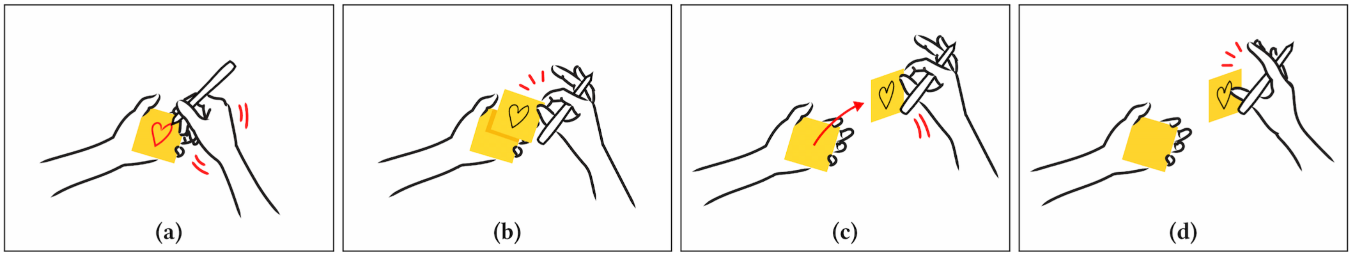

Figure 5: Note creation and placement. (a) The user holds a stack of notes in the NDH and the stylus in the DH, and writes on the uppermost note. (b) When the user pinches near the note, it attaches to the hand. (c) After moving the note to the desired position and orientation, (d) the user unpinches to place the note.

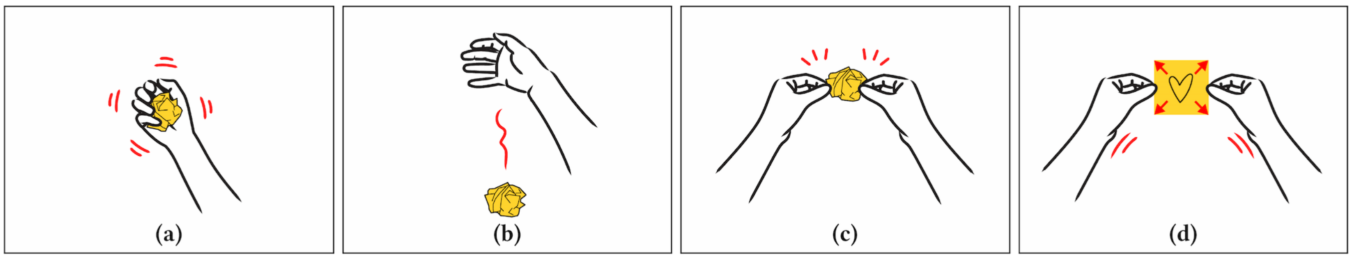

Figure 6: Note deletion and recovery. (a) When the user grabs an unwanted note, the note is crumpled. (b) When the user releases the crumpled note, it falls to the floor. (c) After picking up a crumpled note by pinching it with one hand, pinching and (d) pulling it sideways with another hand uncrumples and restores the note.

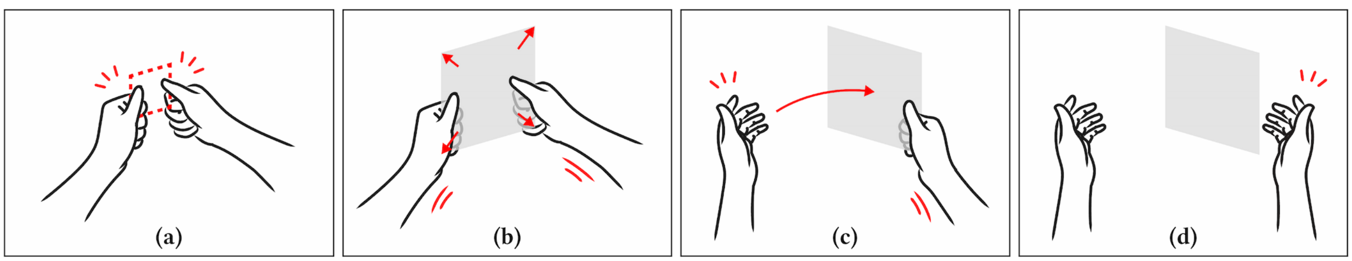

Figure 7: Layer creation, resizing, and placement. (a) By bringing the hands close together, grabbing, and moving the hands as if spreading a parchment, (b) the user creates and resizes a layer. (c) The user grabs and moves the layer with one or two hands, and (d) releases the layer to place it at the desired position and orientation.

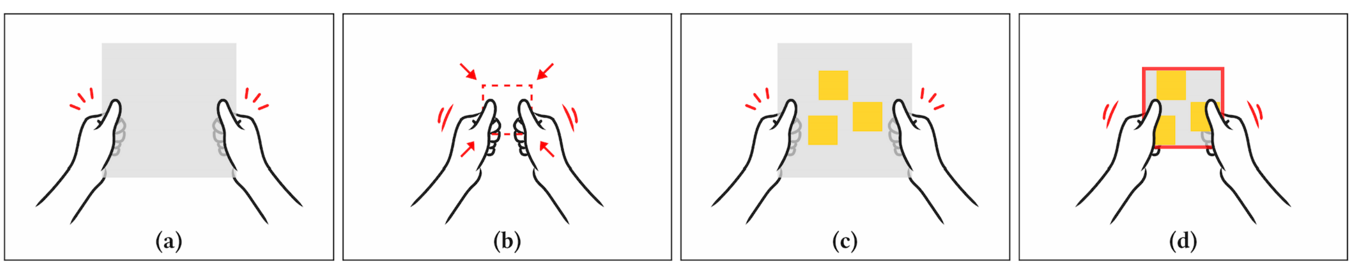

Figure 8: Layer deletion. (a) The user grabs both sides of the layer and reduces the space between the hands to decrease the layer size. (b) When the layer's size falls below a certain threshold, the layer is deleted. (c) However, if there are notes attached to the layer, (d) the layer's size is constrained by the bounds of the notes.

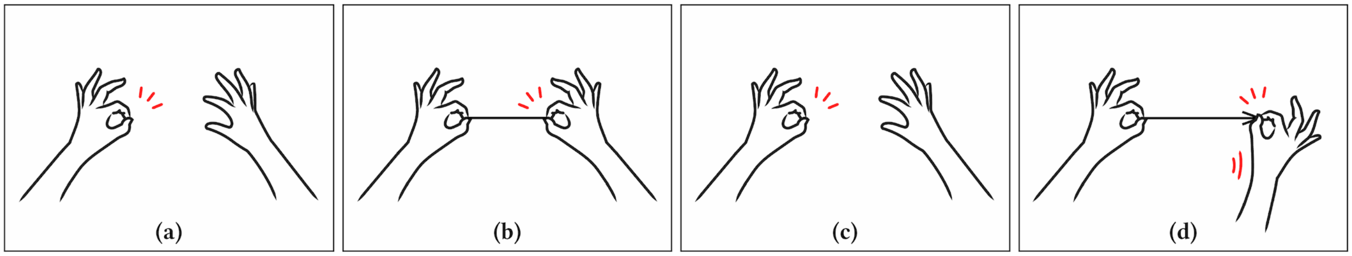

Figure 9: Non-directional and directional link creation. The user creates a non-directional link by (a) pinching the air with one hand, then (b) pinching the air with the other hand. Similarly, the user creates a directional link by (c) pinching the air with one hand, then (d) pinching the air with the other hand, while simultaneously moving the other hand in the direction of the arrowhead. Note that the trajectories of the thumb and index finger of the second hand trace the shape of the arrowhead.

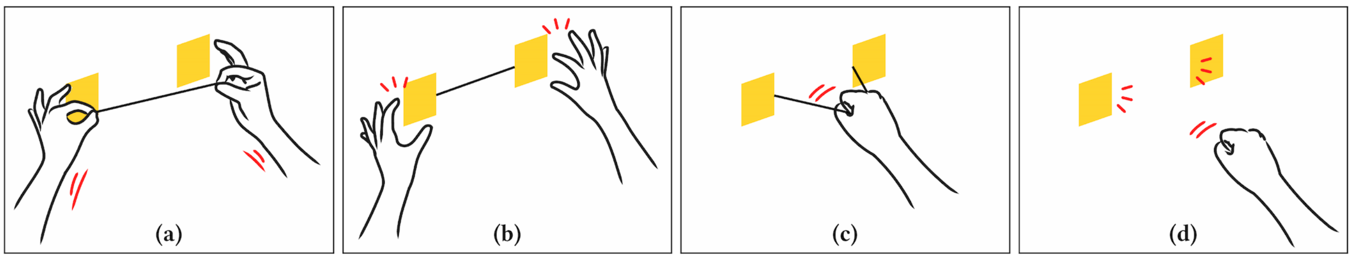

Figure 10: Link attachment and deletion. (a) The user places each of the two ends of the link near a desired note, and (b) unpinches to connect them with a link. The user deletes the link by (c) grabbing the link and then (d) pulling the hand away to a sufficient distance from the attached notes to tear the link from them.

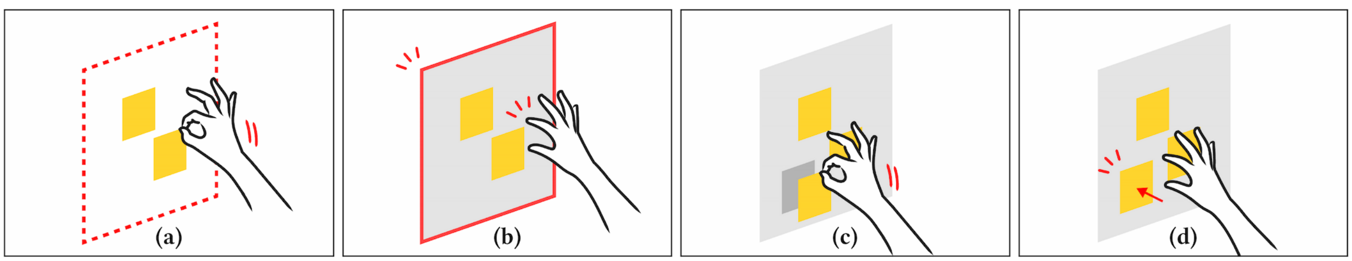

Figure 11: Layer inference and snapping. (a) When a note is placed close to another and the two are nearly coplanar, (b) a layer containing the two notes is automatically created. (c) When the user brings a note closer to a layer, a shadow is cast on the layer as feedforward, and (d) when the user releases it, it snaps onto the corresponding position on the layer.

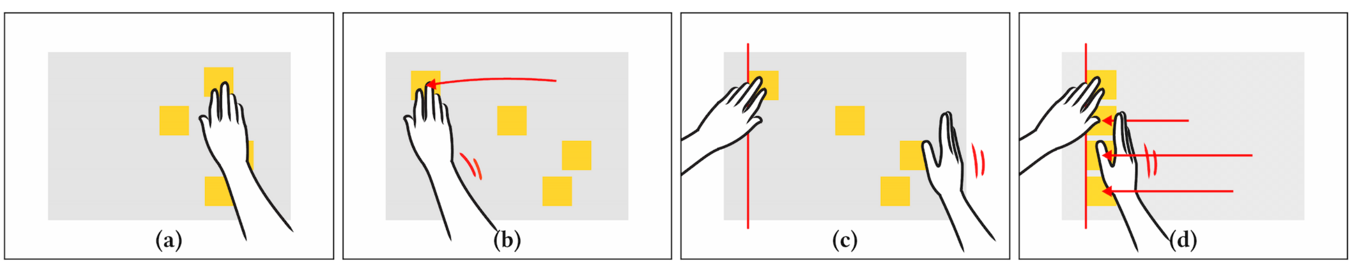

Figure 12: Note adjustment and alignment within a layer. The user moves around any note that belongs to a layer (a) by touching it and (b) sliding it across the surface of the layer. The user aligns notes (c) by touching a note to set the reference of alignment with the NDH and (d) simultaneously sweeping multiple notes to it with the DH. Here, the direction of sweeping (e.g. horizontal) determines the direction of alignment (e.g. vertical).

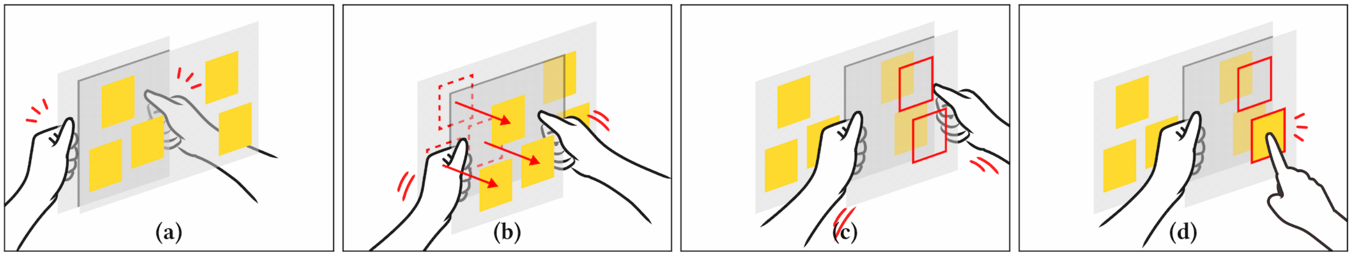

Figure 13: Bulk note transfer and duplication. As if using a "sieve," (a) first, the user holds the destination layer behind the origin layer. (b) Then, as the user pulls the destination layer in through the origin layer, notes within the intersecting region of the two layers are transferred to the destination layer in bulk. As if using a "silkscreen," (c) first, the user holds the destination layer in front of the origin layer, wherein notes on the overlapping region are projected forward. (d) Then, when the user touches on the desired projections, the corresponding notes are copied.

7 CONCLUSION & FUTURE WORK

Post-it notes can be used not only as simple tools for memos, emphases, or reminders, but also as more powerful tools for solving complex problems. However, physical Post-it notes have limitations: surfaces for attaching them can run out; rearranging them can be labor-intensive; documenting and storing them can be cumbersome. In this study, we focused on overcoming these limitations by completely reinterpreting the Post-it note as a novel system of VR interactions.

We derived the design requirements of our system through a formative study that involved an actual problem-solving meeting using physical Post-it notes, designed a set of harmonious and lifelike interactions by emulating a physical prototype built using physical materials, and implemented our system using the latest off-the-shelf technologies.

We found that the resulting system may be used to solve a real-life problem, wherein many Post-it notes are placed, arranged, and connected to assist the complex thought process involved. By building on the strengths of physical Post-it notes, while eliminating their weaknesses, we hope to have proposed and shown the viability of the VR *Post-Post-it* notes as alternatives to physical Post-it notes in the offices of the future.

The limitation of this study is that it does not yet support multiple users. Thus, future work should focus on accommodating social cues among collaborators [3], utilizing more physically accurate visual feedback [8], and evaluating quantitative task performances of the component interactions and qualitative usability of the entire system through formal user studies.

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