Revisiting Hybrid Input Devices for Immersive Analytics

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Abstract

Hybrid user interfaces offer a promising framework for analysts to leverage the strengths of heterogeneous environments, such as desktops and mixed reality, and transition fluidly between them. Especially for immersive analytics, which often blends 3D interaction spaces with traditional 2D workflows, such hybrid user interfaces can reduce cognitive workload and improve user experience. Prior work has combined desktop-based statistical analysis with an in-situ exploration of spatiotemporal data in mixed reality. However, switching between devices and input modalities in such combinations can disrupt users' flow. We revisit the concept of *hybrid input devices* that operate seamlessly across 2D and 3D contexts by leveraging the complementary strengths of heterogeneous input devices. We thereby propose a hypothetical hybrid input device that combines input from a mouse and a spatial controller, for which we present potential interaction techniques and discuss potential opportunities and challenges for immersive analytics.

Index Terms: Immersive Analytics, Mixed Reality, Cross Reality, Hybrid Interaction, Transitional Interfaces, Input Device

Immersive analytics (IA) explores how novel technologies such as mixed reality (MR) can support analytical reasoning and sensemaking [9]. While research often emphasizes analysis using 3D visualizations and spaces, data analysis still frequently involves 2D surfaces supporting visual analytics approaches. For example, prior work [18, 21, 30] demonstrates how a holistic analysis process can be distributed across desktop and MR environments to leverage their complementary strengths [33]. Yet, such asynchronous hybrid user interfaces [16, 19] introduce new challenges, as users must switch between distinct environments and interaction spaces.

While output components can be sufficiently emulated in one environment, this switching can be especially problematic for input devices, as their capabilities and physical affordances vary widely and are thus harder to simulate. In addition, prior work has shown that switching between input devices incurs significant transitioning costs [4, 12]. Alternatively, users could stick to one device with its limited input capabilities, for example, by using a desktop mouse for 3D input [1, 11] or an MR controller to point at a 2D surface.

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Yet, dedicated devices still offer distinct advantages: Desktop mice provide familiarity and high accuracy for 2D surfaces but struggle in spatial operations, such as 3D manipulations and selections. In contrast, MR controllers offer six degrees of freedom (6DoF) suitable for 3D manipulations in immersive environments, but are tiring [8] and less accurate due to hand jitter [3] and the Heisenberg effect of spatial interaction [6]. While this problem has been partially addressed by software-only solutions [35], we argue that a hardware-based approach offers greater potential to improve users' workflow, following the history of bespoke hardware for IA [13, 14].

We explore the concept of *hybrid cross-reality input devices* that combine the ergonomics and accuracy of 2D input devices with the spatial capabilities of 3D controllers. Such devices enable a seamless switch between 2D surfaces and 3D spaces, allowing for novel cross-dimensional interaction techniques. We illustrate our concept by describing a usage scenario in IA, discuss hybrid input devices, and present a hybrid cross-reality input device, for which we describe novel interaction techniques. We then discuss opportunities and challenges of hybrid cross-reality input devices.

1 Scenario

Although our concept of hybrid cross-reality input devices can be applicable to a wide range of IA scenarios, we base our scenario on prior work [18] in asynchronous hybrid user interfaces.

ReLive is a mixed-immersion analysis tool that combines a visual analytics approach on a desktop with IA in an MR environment (see Fig. 1). Researchers can use ReLive to analyze MR user studies by leveraging the complementary strengths of 2D and 3D visualizations [7, 29]: The desktop supports the analysis of aggregated data using computational notebooks, focusing on dense information displays that require precise mouse interaction. In contrast, the MR environment supports *in-situ* exploration of the data, allowing to *relive* a replication of the recorded study environment.

Using ReLive, researchers could thus make use of 2D surfaces and 3D spaces when analyzing an MR user study. For example, a researcher may start on a 2D surface to load in the data, create a computational notebook to aggregate and visualize the data, and identify outliers. Here, conventional devices such as keyboard and mouse offer ergonomic and precise input, allowing researchers to interact efficiently with dense data visualizations. For the investi-

Figure 1: ReLive combines a mixed reality environment for immersive analytics with a non-immersive desktop view for visual analytics.

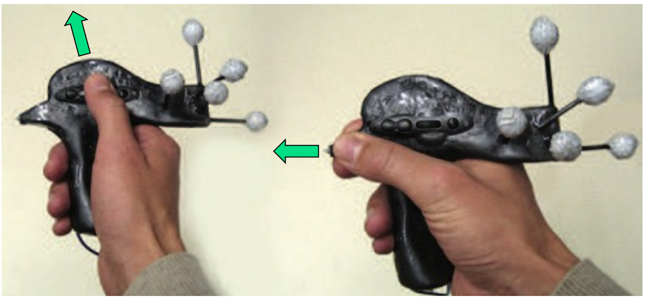

Figure 2: The *Eye of Ra* [5] is a hybrid input device combining 2D pen input with a 3D controller. Users can either grasp the device for 3D interaction (left) or for more precision (right).

gation of specific outliers, researchers can drag visualizations such as motion data from the 2D surface into the 3D space [27], automatically morphing them into their 3D representations [24, 28]. These 3D visualizations can reveal additional information, for example, through their environmental context [18] or by utilizing higher-dimensional data representations. In this environment, researchers may prefer an MR controller to leverage the increased degrees of freedom for manipulations or selections within 3D visualizations. In addition, researchers may need to frequently transition between 2D surfaces and the 3D space to triangulate their findings and leverage techniques such as linking and brushing.

2 Hybrid Input Devices

Our scenario demonstrates how a holistic analysis process could involve frequent switches between 2D surfaces and 3D spaces. While MR hardware can now sufficiently replicate the desktop environment within MR [30], switching between input devices, such as mouse and MR controller, still presents a major hurdle in fluidly switching between these environments [27, 30]. To address this challenge, we revisit the concept of *hybrid input devices* that can offer seamless interaction across both 2D and 3D environments. In the following, we first discuss prior work, develop a working definition, and outline key characteristics before introducing a hypothetical example of a hybrid input device.

2.1 Lightweight Literature Analysis

To gain an initial understanding of hybrid input devices, we conducted a lightweight literature analysis.

A survey on spatial interfaces for 3D visualizations by Besançon et al. [3] frames hybrid interaction as devices and interaction techniques that *"[recognize] the distinct advantages of different paradigms and devices"*. Building on *hybrid interaction* as umbrella term, we further differentiate between hybrid *interaction techniques* and hybrid *input devices*: Hybrid interaction techniques focus on software-based solutions to adapt existing input paradigms beyond their limitations, such as using mouse input for 3D selection [35]. In contrast, hybrid input devices explore novel hardware-based approaches that combine interaction paradigms in a single device. We focus on the latter.

While *hybrid input devices* have not been formally defined in prior work, LaViola [23] describes them as *"[combining] both discrete and continuous event generating devices to form a single device that is more flexible"*. However, this broad definition not only includes self-described hybrid input devices [5, 20, 22], but also encompasses many conventional devices that combine multiple input types, such as buttons and movement sensors, which can be found in most mice [23].

The concept of hybrid input devices that combine 2D and 3D input was also explored with commercial devices, such as the Logitech *"MX Air"*[1]. Given the lack of similar contemporary devices, we assume that such devices failed to present a compelling use case. Yet, with the increasing popularity of MR and increasing interaction complexity of IA, we see the need to revisit this concept: We see *hybrid input devices* that combine 2D and 3D input as the missing link in cross-reality applications such as IA, bridging the gap between spatial and conventional input paradigms and contributing towards fluid interaction [15].

2.2 Working Definition

Instead of using a broad definition encompassing virtually all conventional input devices, we see value in pursuing a narrow focus on hybrid input devices that primarily support interaction across heterogeneous environments [33], such as 2D surfaces and 3D spaces. Thus, we focus on devices such as the *Eye of Ra* [5] (see Fig. 2), which combine 2D and 3D interaction paradigms in a single device.

To differentiate our work from the broader terminology of hybrid input devices, we describe our concept as *hybrid cross-reality input devices*. We use the delimiter of *"cross-reality"* to emphasize our focus on devices that seamlessly work across the reality-virtuality continuum [26]. We thus propose the following definition:

> *Hybrid cross-reality input devices unify 2D and 3D input paradigms in a single input device.*

2.3 Potential Characteristics

We see the following characteristics as indicative of hybrid cross-reality input devices. While the broader concept of hybrid input devices may include a wide range of potential devices, such as keyboards with integrated touchpads, we intentionally focus on characteristics relevant to IA.

Heterogeneous Input Paradigms with Adaptive Modes. Hybrid cross-reality input devices combine heterogeneous input paradigms such as direct pen input with 6DoF pointing [5], or indirect 2D pointing with indirect 3D manipulation techniques to support a broader range of interaction tasks within IA environments. By preserving the respective strengths of each modality, hybrid input devices can facilitate more expressive and contextually appropriate input than single-purpose alternatives. A key characteristic of such systems is their capacity for multiple modes of operation, enabling the device to adapt its functionality dynamically based on the user's context or task demands. For example, the Nintendo Switch 2 controllers[2] exemplify this flexibility: functioning as traditional gamepads when held, and as mouse-like devices when placed on a surface. This mode-switching capability illustrates how hybrid input devices can support fluid transitions between interaction styles, aligning with the diverse input requirements of IA workflows.

Seamless Transition. Hybrid cross-reality input devices should support seamless mode transitions instead of distinct switches, allowing users to remain focused on their task without spending cognitive or ergonomic efforts on the transition itself. These transitions should be designed to minimize disruption and support continuous, fluid interaction – which opens up a design space of novel interaction techniques.

Note that these are desirable characteristics that a hybrid cross-reality input device should strive towards in the context of IA. Given the exploratory nature of our work, these may not be complete or representative of the wider area of hybrid input devices.

[1] https://ifdesign.com/en/winner-ranking/project/mx-air/36413
[2] https://nintendo.com/gaming-systems/switch-2/

Figure 3: An initial prototype of the *"hybrid mouse"* could combine a desktop mouse with a Meta Quest 3 mixed reality controller, offering both indirect 2D pointing and spatial input.

2.4 Example: Hybrid Mouse

To illustrate our idea of hybrid cross-reality input devices, we describe a hypothetical hybrid input device called the *"hybrid mouse"* that combines the indirect pointing of a conventional computer mouse with the spatial input afforded by MR controller (see Fig. 3). While prior devices such as the *Eye of Ra* [5] and Logitech MX Air[1] are hybrid cross-reality input devices with heterogeneous input paradigms, they fall short of the seamless transition that we consider essential, as it has the potential to remove any mental barriers and thus open up possibilities for novel interaction techniques (see Sec. 3). To thus fluidly support both types of input, we envision that the hybrid mouse has the ergonomic form of an MR controller with a mouse sensor at its base. The hybrid mouse supports heterogeneous input paradigms with adaptive modes: It can be used as a desktop mouse for *mouse input*, or as an MR controller with 6DoF for *spatial input*. The hybrid mouse dynamically *switches modes* based on whether it is lifted or placed on a surface, thus supporting a seamless transition.

Mouse Input. When placed on a surface, the hybrid mouse operates like a conventional mouse, enabling indirect control of a cursor on a 2D surface, such as on a desktop monitor, by sliding the device across the surface. As the input is relative, the device supports clutching to allow users to reposition the device to a neutral position. In addition, the hybrid mouse offers familiar discrete inputs, such as buttons for left- and right-click, and input for scrolling, for example, using a scroll wheel or an integrated joystick.

Spatial Input. When lifted from a surface, the hybrid mouse can be used for spatial input, offering 6DoF suitable for 3D manipulation tasks. Similar to contemporary MR controllers, the device can be used for direct (e.g., grabbing objects) or indirect (e.g., using raycasting) 3D operations. To support these spatial interactions, the hybrid mouse must be ergonomically designed for easy gripping, while still providing access to essential controls, including buttons for discrete input and joysticks for fine-grained adjustments.

Mode Transitions. As hybrid cross-reality input devices are intended for use across heterogeneous environments, seamless transitioning between modes of operation and environments is a critical design consideration. Prior devices, such as the Eye of Ra [5], use a change in grip to switch between input modes (see Fig. 2). However, we argue that even such a minor hurdle could hinder interaction fluidity [15]. With the hybrid mouse, transitioning would occur simply by lifting the device or placing it back on a surface, thus eliminating the need for any explicit user action. For example, a distance sensor at the bottom of the device could detect a potential surface and trigger a switch between spatial and mouse input paradigm accordingly, while still supporting input paradigm specific activities (e.g., clutching).

3 Hybrid Interaction Techniques

We describe four potential interaction techniques enabled by the hybrid mouse that use the available capabilities of transitional workspaces (see Fig. 4). As our work extends well-established interaction techniques such as clutching, they need careful evaluation of their efficacy in real-world applications, which we consider outside the scope of this work. Additionally, we consider these interaction techniques an initial foundation for further exploration of interaction techniques enabled by the hybrid mouse.

Hybrid Input. 6DoF devices outperform mouse input for basic manipulation tasks in 3D [34]. Still, mouse input can be more accurate for placing objects in 3D [2], especially as our biomechanical constraints may cause translations to be accompanied by unintentional rotation during spatial operations [17]. Using the hybrid mouse, we can fluidly switch between fine-grained mouse interaction or efficient 6DoF input, depending on the required level of precision. For example, 3D manipulations for positioning visualizations may be achieved by first coarsely positioning the visualization using *spatial input* with its 6DoF, followed by fine-grained adjustments using *mouse input* (see Fig. 4 a).

This approach also extends to interactions on large or spatially distributed 2D surfaces. For example, moving an object between 2D surfaces may require clutching operations to reach the target: The user may briefly use *spatial input* to position an item coarsely via mid-air pointing, then return to *mouse input* for fine adjustment.

Cross-Dimension Drag and Drop. Immersive workspaces require frequent transitions between 2D and 3D, such as dragging visualizations and data from a 2D surface to its surrounding 3D environment [11, 27, 32]. Using the hybrid mouse, this transition can be made truly seamless: Users can start dragging using *mouse input*, then lift the device to utilize *spatial input* while holding the button to perform a *cross-dimension drag-and-drop* operation (see Fig. 4 b). Conversely, users can also grab an object with *spatial input*, then put the hybrid mouse down for *mouse input*, thereby transforming the 3D object back to its 2D representation on a 2D surface. This procedure does not require items to be dragged outside of the bounds of the 2D surface; instead, the hybrid mouse can be lifted as soon as the 2D item is dragged, regardless of its position to transform it to 3D and vice versa, thereby avoiding potential errors due to proximity with other 2D surfaces.

Gaze-Based Clutching. Because the hybrid mouse provides relative input when using *mouse input*, users must perform clutching operations by slightly lifting the device, resetting it to a neutral position, and then putting it down again. This works for conventional mice, as the sensor does not report any movement while in the air. Unlike conventional mice, however, the hybrid mouse is also tracked in space, allowing the detection and usage of clutching as an implicit form of input. With eye-tracking prevalent in new MR headsets, the hybrid mouse could therefore combine this with clutching to position the cursor: Once the clutching ends or *mouse input* is used (i.e., the hybrid mouse is put down), the cursor jumps to the user's current gaze location. While this can help to position the cursor on a single 2D surface, we also see the potential in switching between multiple 2D surfaces (e.g., multiple visualization dashboards [31]), which may be arbitrarily arranged in the MR environment (see Fig. 4 c).

Stamping. Similarly to clutching, the process of lifting the hybrid mouse when using *mouse input* can serve as an explicit interaction technique. Unlike clutching, this technique refers to a rapid vertical motion, akin to *stamping* a document: lifting the device briefly and returning it to the table without horizontal movement (see Fig. 4 d). This can be mapped to deliberate commands such as "undo", providing a quick yet intentional interaction method.

Due to the higher physical effort involved in comparison to conventional inputs such as button clicks, *stamping* may be suited for

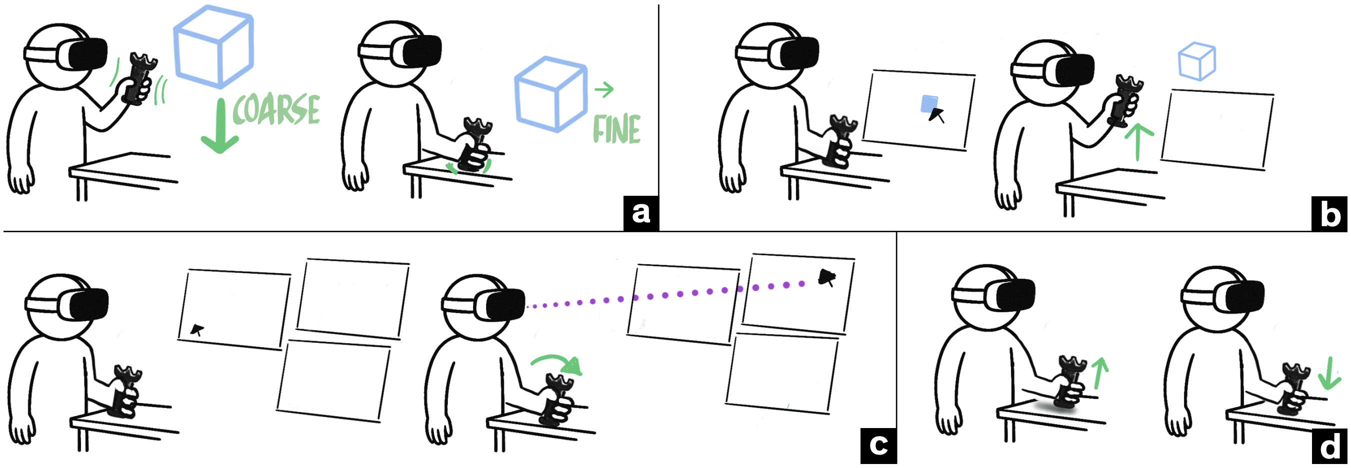

Figure 4: Our hybrid mouse concept opens up opportunities for novel interaction techniques, such as (a) *hybrid input*, (b) *cross-dimension drag and drop*, (c) *gaze-based clutching*, or (d) *stamping*. The sketches show a possible design of the hybrid mouse, combining characteristics of contemporary MR controllers and conventional mice into a unified slanted hardware design, including potential tracking capabilities on top.

deliberate actions where accidental input should be avoided. However, implementation of this technique requires careful considerations regarding detection thresholds (e.g., time and movement) to avoid ambiguities with clutching detection. In addition, lifting or putting down the hybrid mouse may cause movement of the 2D cursor (cf. [6]), which could limit its practical application.

4 Opportunities and Challenges

We discuss opportunities and challenges relating to the design, implementation, and evaluation of hybrid cross-reality input devices.

Device Combinations and Interaction Techniques. Our hybrid interaction techniques offer only a small glimpse into the broader design space enabled by the concept of hybrid cross-reality input devices. Different device combinations could unlock a wider range of techniques, opening new possibilities for interacting with data visualizations in IA. However, validating their efficacy poses a challenge, as we not only need to consider their trade-off between efficacy and ergonomics, but also compare this hardware-based approach against software-based compensation mechanisms [35].

Hardware Design. While such devices can be prototyped using 3D printers and off-the-shelf hardware solutions, developing new input devices also means competing against decades of industrial research and refinement, as well as manufacturing methods that are beyond the scope of many research papers. In addition, there is a plethora of different commercial input devices to address a wide range of user needs, addressing minutiae such as weight, form, and tactile feedback. As a result, directly evaluating novel hybrid cross-reality input devices against well-established and familiar input hardware can be challenging.

Trade-offs and Compromises. Designing hybrid cross-reality input devices involves multiple trade-offs and compromises. For our *hybrid mouse*, for example, factors such as grip and form factor must be balanced between supporting either spatial input (e.g., more vertical design for grip) or mouse input (e.g., horizontal design for performance). Likewise, while a mouse wheel could be more appropriate for mouse usage, a joystick may be necessary for spatial interactions. Adding both could provide the optimal experience in either mode, yet result in an overcomplicated design and require a grip change, introducing friction when switching.

Evaluation. The increasing complexity of hybrid cross-reality input devices can present a challenge in their evaluation. While traditional input methods like mouse interaction can be assessed using established models such as Fitts' Law, hybrid devices may require adapted or entirely new evaluation methods, such as a hybrid Fitts' Law task that measures pointing speed between targets on 2D surfaces and in 3D spaces. These methods also need to account for ergonomics across different modes of operation and the transitioning costs between different modes on cognitive load. For example, evaluating the ergonomics of hybrid cross-reality input devices needs to not only consider endurance and recovery metrics [25], but also the extent of physical support available during use [10].

5 Conclusion

Immersive analytics workflows increasingly involve a transition between 2D surfaces and 3D spaces. To address the diverse interaction demands of such heterogeneous environments, we revisit the concept of *hybrid input devices*. We propose hybrid cross-reality input devices, which unify heterogeneous input paradigms into a single device, thereby working seamlessly across 2D and 3D interaction spaces. We illustrate our concept through a hypothetical device that merges a conventional mouse with a mixed reality controller: When placed on a surface, it offers indirect 2D input; when lifted, it provides spatial input with six degrees of freedom. With this concept, we aim to provide a foundation for exploring novel hardware that better supports the increasing complexity of immersive analytics workflows.

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