Desired Realities: Concept and Examples

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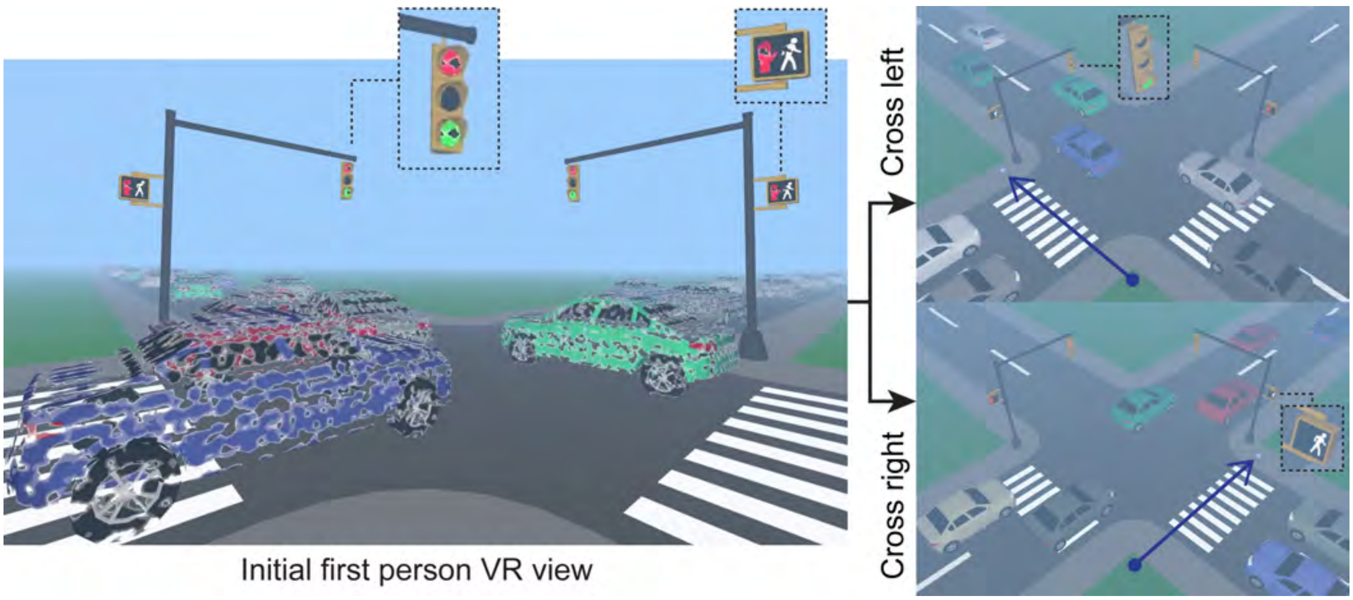

Figure 1: A minimal example of a Desired Reality. The user is standing at the corner of a virtual crossroad (left). Conventionally, whether the user can cross the desired direction when arriving at the crossroad at a random instance in time depends on an *observed* state of reality. In contrast, with a Desired Reality, observation does not lead to a collapse of possibilities into a single reality. Hence, green and red are equally possible for pedestrians and cars in all directions (see traffic lights and semi-visible cars). Depending on the side the user decides to cross the two possibilities collapse into a single reality (right).

Abstract

We introduce Desired Realities, a new type of reality that makes uncertainty a central part of immersive experiences and interactions. Previous works in different areas, such as touch input or text entry, aimed to hide uncertainties or let users disambiguate explicitly whenever the intended outcome of their action is ambiguous. In contrast, we suggest a post-hoc disambiguation approach. Whenever an action is uncertain, a Desired Reality application splits into multiple parallel universes, visibly co-existing in real-time inside the virtual environment. Users then simply ignore unintended universes and interact with their desired universe, retaining their agency without resorting to explicit error recovery. In this work, we present our concept as well as several illustrative examples.

CCS Concepts

• **Human-centered computing → Virtual reality**; *Mixed / augmented reality*; *User interface toolkits*.

Keywords

Input uncertainty, Multiverse interaction, Virtual Reality

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1 Introduction

Immersive worlds in Virtual Reality (VR), regardless of whether they simulate real environments or are fully fictional, conventionally obey most of the laws of physical reality. However, designers of virtual environments, in particular VR environments, may choose to ignore specific laws of physics (e.g., picking up and placing virtual objects that float in mid-air) or provide unrealistic capabilities to the user (e.g., "superpowers" [9, 12, 26, 27]). Selectively ignoring certain constraints of the physical world while retaining a sense of a cohesive reality can also enhance human collaboration, e.g., across space [22, 23, 25, 39, 42], across different virtual realities [40], or across time [7, 11]. In this context, an often overlooked fundamental aspect of existence is the **effect of observing reality itself**. In physical reality, humans are aware of the many possible outcomes of real events—before or even without experiencing them. However, we are used to a *single* reality once we *observe* it. This understanding is also grounded in quantum mechanics, which holds that observing physical entities leads to a collapse of all possibilities into a single experienced reality, while other possibilities that *could have been* are deferred to a parallel universe [3, 21, 31], or simply cease to exist. This fundamental aspect of reality is mostly unquestioned and unaltered—even in fully fictional artificial realities such as VR.

In this work, we explore what happens if we challenge the assumption that observation (by users) leads to a collapse into a single reality. As an alternative trigger for reality collapse, we use **desire**—implicitly expressed through the actions a user performs when presented with multiple possibilities. Figure 1 shows a minimal example of what we call a **Desired Reality**. The example argues that, before arriving at a crossroad (i.e., before observing it) and without prior knowledge, any direction could have a green light for cars or pedestrians, i.e., we can imagine multiple possibilities. Conventionally, a single direction has green light when observing the crossroad upon arrival, so one of the possibilities turns into reality. With a Desired Reality, however, observation is not enough. Only when the user expresses a desire by crossing in one direction, all traffic lights adjust accordingly, as the user must have green. Generalizing from this simple example, this work proposes the novel Desired Realities concept. We implemented several illustrative examples that showcase our concept across several VR application aspects, namely, physics, menus, and gestures.

2 Related work

2.1 Uncertain or ambiguous input

Conventionally, the goal of systems that deal with uncertain input is to resolve ambiguities as quickly as possible, i.e., during or right after the ambiguous action [13, 34]. This means that ambiguity is either hidden from the user or they can explicitly select different options, such as word suggestions when using text input [37]. For instance, Mankoff et al. [20] focus on explicitly resolving ambiguities after the uncertain input (pen input in their case) and investigate different ways of displaying and explicitly selecting the correct input afterwards. Similarly, Zhu et al. [44] hide ambiguity and resolve it internally using Bayesian methods.

In addition to individual algorithms, researchers developed frameworks for resolving different types uncertain input, primarily for 2D user interfaces and 2D gestures [6, 17, 18]. In particular, the motivation of Schwarz et al. [33] is very similar to ours. They aim to resolve uncertainties not as quickly as possible but during the direct follow-up interaction (in their case within a 2D UI context). Later work by Schwarz et al. [35] introduced an architecture to handle and visualize uncertainty in 2D user interfaces.

Overall, previous toolkits for uncertain input were specifically designed for 2D user interfaces, meaning that they focus on typical UI widgets and components. Our work generalizes from uncertain menu input and also connects it with other aspects of applications like physics and 3D interaction.

Multimodality. Input based on different modalities such as gaze and speech is useful as a natural, complementary input. Bolt's 'Put-that-there' approach [4] utilizes multiple modalities at once. However, some modalities can be error prone when used in isolation [15, 19]. Hence, researchers combined multiple modalities for disambiguation [1, 38, 43], e.g., using finite state machines [5].

To resolve an ambiguous action, our aim is to use interactions that are separated from the ambiguous action, which is conceptually similar to multimodal approaches. However, we take into account *follow-up actions* using the same modality instead of simultaneous actions using different modalities.

2.2 Multiverse simulations

In the context of our work, we interpret anything that runs in multiple instances with a similar start condition as a 'multiverse' (or 'parallel universes'). Given this terminology, several previous works have explored the use of multiverses to simulate variations of the starting conditions. For instance, in the context of statistical analysis, researchers provided tools for running multiple instances of statistical tests to improve robustness, reproducibility, and transparency [14, 16]. The 'multiverse analysis' by Dragicevic et al. [10] enables readers to switch between multiple possible statistical tests within the document, i.e., rendering the document with different test results based on the same data depending on the chosen test. Sarma et al. [29] run multiple instances of data analyses tasks in *R* while reducing redundant data and processing. Similar concepts can be applied to other types of analysis or simulation, while accounting for uncertainty [30]. Schindler et al. [32] let analysts control multiple data flow scenarios in a multiverse for a comparative analysis of time-dependent data, e.g., to deal with uncertainty in flood simulations [41]. Multiverses can even represent real world entities, such as physical entities in multiversal digital twins [8, 28].

Overall, multiverses—even though often not referred to as such—have been used in many different contexts and in different forms, but have rarely been used as an integral part of the user experience, i.e., visualized, and resolved inside a real-time 3D environment.

3 Illustrative examples

To illustrate our concept, we implemented several examples, showcasing Desired Realities across various aspects of real-time applications such as physics, menus, and gestures.

Crossroad

(Demonstrates: *minimal application logic*)

The *Crossroad* example, seen in Figure 1, represents a minimal instance of a Desired Reality. The user is at the corner of a virtual crossroad. Depending on which side the user chooses to cross (thereby expressing a desire), the respective reality becomes crisp (i.e., fully existing without alternative versions in other universes). As opposed to the subsequent examples, this minimal example features only two concurrent universes, both of which are presented to the user from the start.

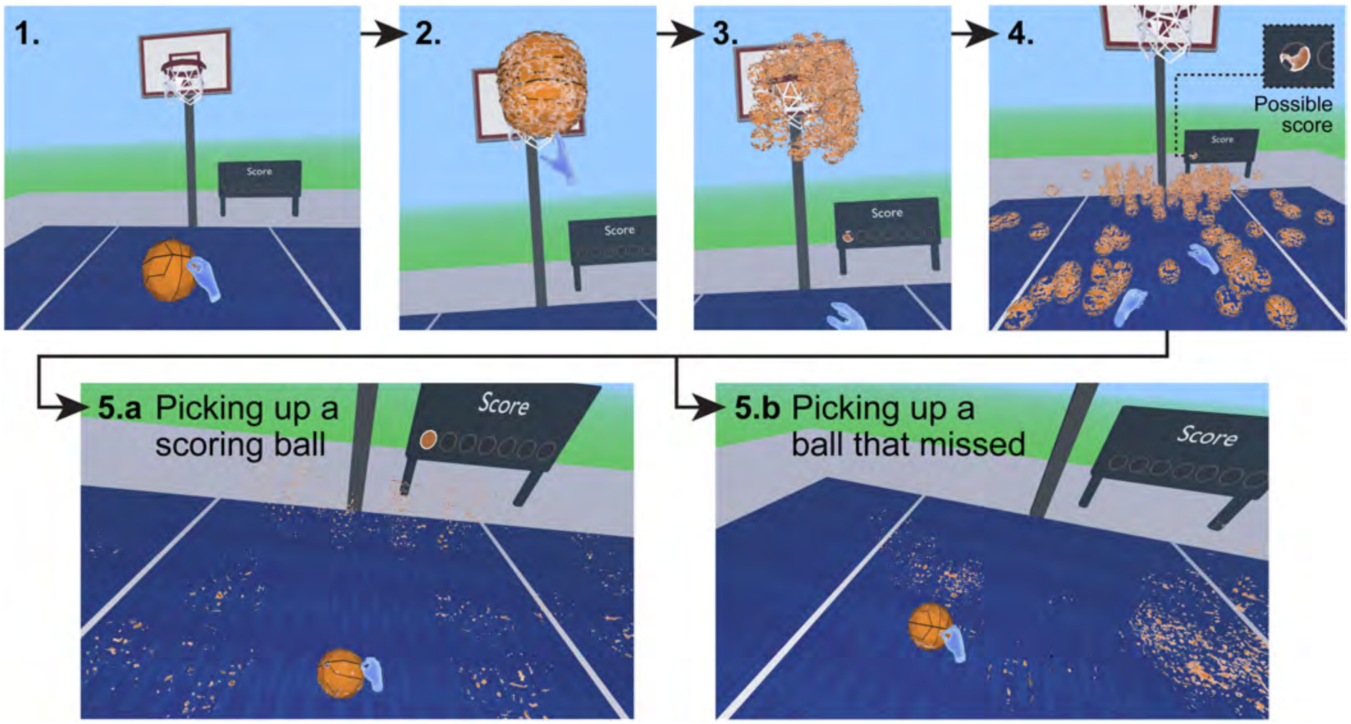

Figure 2: Simple example of a physics-based Desired Reality. 1) The user stands on a virtual basketball field and holds a ball. 2) When thrown towards the basket, the single crisp ball splits into multiple possible balls, each with slightly different movement parameters, leading to different trajectories. 3) Only few balls go through the basket. 4) Scoring and not scoring are both possible at this point (see semi-visible point on score display). 5) Whether or not the user scored (see score displays in a and b) depends on whether they pick up a ball whose trajectory previously went through the basket. In both cases, all other balls are impossible and hence dissolve.

Basketball throw

(Demonstrates: *physics, retrocausality*)

Our second example involves splitting a crisp object into many similar possible objects (Figure 2). The user picks up a basketball (Figure 2.1) and throws it towards a basket (Figure 2.2). When throwing, multiple possible basketballs (150 in this example) are spawned, each with slightly different movement parameters, leading to different trajectories. Some of those balls pass through the basket (Figure 2.3), which means that it is *possible* but not certain that the user scored (indicated by a semi-filled score on the scoreboard in Figure 2.4). When the user picks up a basketball, this ball becomes crisp, and all other balls vanish (Figure 2.5). If the user picks up a ball that has passed through the basket, the score becomes fully crisp (Figure 2.5a). Otherwise, it disappears (Figure 2.5b). This way of affecting the earlier scoring event by picking up a ball (a later event) can be seen as retrocausal.

Sorcery

(Demonstrates: *uncertain gestures, sequences of possible actions*)

Our approach can also handle nested uncertainties. In the following, we demonstrate a slightly more complex *Sorcery* example, which revolves around gestural interaction sequences (Figure 3). The user stands at a sorcerer's desk (Figure 3.1). On the desk are four objects: two potions (red and blue), a green magic wand for summoning plants, and a red magic wand for summoning creatures. The user wants to spawn a specific magical entity. First, the user performs a quick pinching motion with the right hand to pick up a wand. However, the blue potion and the two wands are so close to each other that the system cannot reliably determine which of the three objects the user meant to pick up. Therefore, all three are superimposed in the user's hand (Figure 3.2). The user stretches the right arm forward (Figure 3.3). This gesture is typical for using a magic wand, which implies that the user wanted to pick up one of the wands and *not* the potion. Hence, the potion is now crisp and back at its original location on the table, as it retroactively was never actually picked up (Figure 3.3 bottom). The two wands summon different entities, but based on the same gesture, namely, a circular motion (Figure 3.4), i.e., this gesture still does not lead to a disambiguation of the wands. The red wand has an additional function: Pointing towards a surface with a short dwelling time spawns a small creature attached to that surface. Since the user sketched the imaginary circle somewhat slowly, the system does not yet know whether it was a circular gesture or a pointing gesture. Therefore, in total three possible entities are spawned: a plant, a creature in mid-air (Figure 3.4 center), and a creature attached to the wall (Figure 3.4 top). The user now pinches with the left hand within the

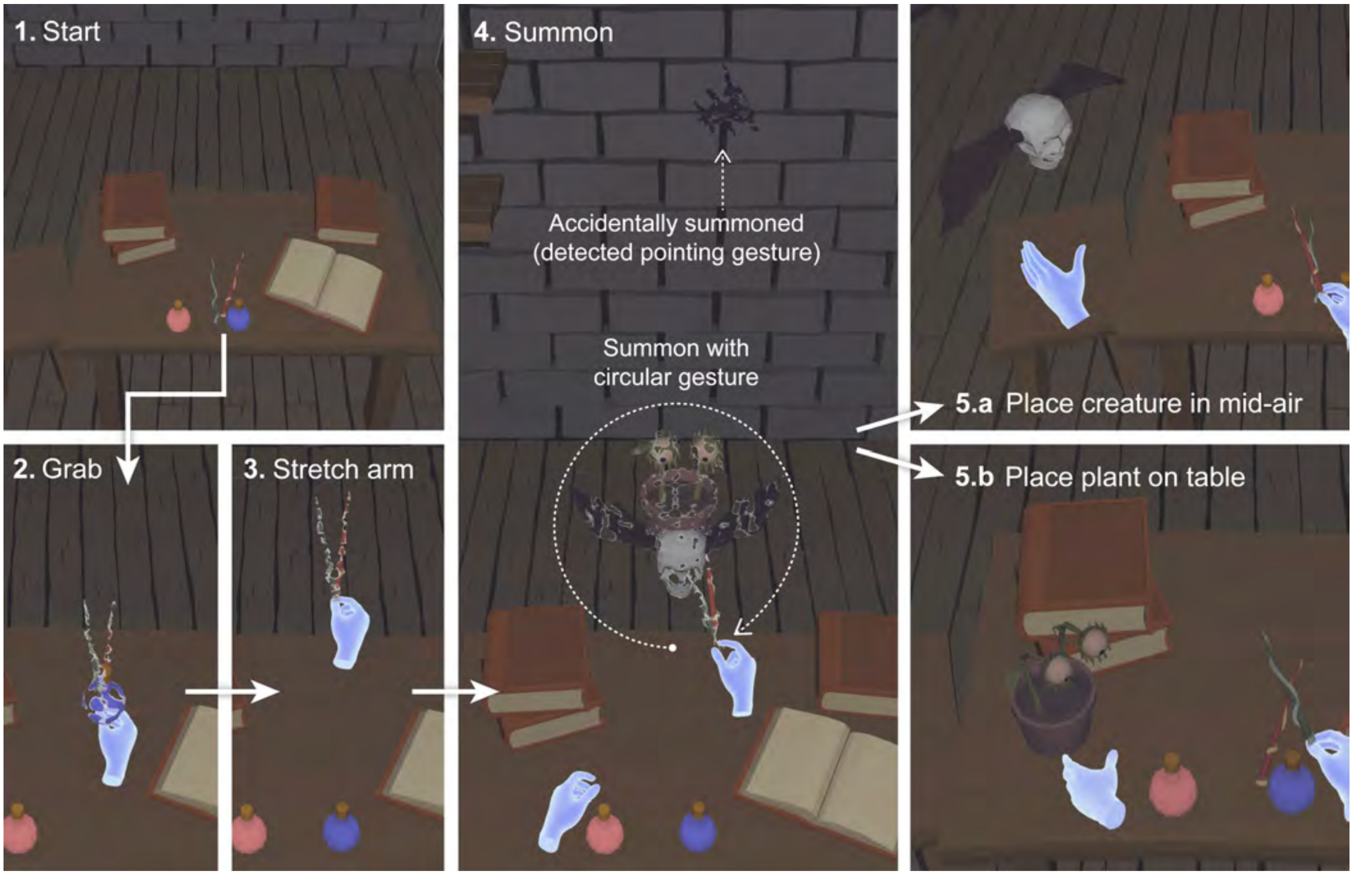

Figure 3: Example of a sequence of different types of gestures and actions. The user wants to summon a magical entity. 1) The user stands in front of a table with two magic wands and two potions. The red wand is for summoning creatures and the green one for plants, both using a circular motion gesture. The red wand can additionally summon creatures by pointing at surfaces for a few seconds. 2) The user wants to grab a magic wand, but because of input uncertainty, the other wand and one potion are grabbed as well. 3 & 4) The user simply continues with a magic wand gesture for summoning the intended creature. Besides the intended entity, two additional unintended entities are summoned due to a misclassified additional gesture and the possible alternative wand. 5) The user simply ignores the unintended entities and interacts with the intended entity by placing it in the air (a) or on the table (b).

region of the plant and the flying creature. This gesture implies that the creature on the wall was not intended (no follow-up with the wand in that location), and it vanishes. Still, both magic wands are possible, as their interactions are still identical so far. Therefore, the existence of the wands and magical entities depends on one last action. If the user releases the pinch in the air—an action that does not make sense for the plant—the creature becomes crisp and only the red wand is held (Figure 3.5.a). In contrast, when the pinch is released close to a surface, the plant turns crisp and only the green wand is held (Figure 3.5.b). After this final step, no more ambiguities remain, i.e., all objects and the magical entity are crisp.

Settings menu

(Demonstrates: *uncertain menu input*)

We implemented a minimal example akin to a probabilistic 2D user interface in which two buttons right next to each other summon two different pop-up menus in mid-air (Figure 4). If there is no uncertainty (i.e., the user clearly presses one of the buttons), then an ordinary crisp menu interaction is used (black arrows in Figure 4). If it is uncertain which of the two buttons was pressed (e.g., due to tracking inaccuracies or imprecise movements by the user), our system superimposes both possible menus. One menu features buttons, and the other one features sliders. The user continues to interact with the intended menu while ignoring the other one, i.e., the user either presses buttons or moves sliders as they normally would. The type of interaction (pointing gesture for a button press versus pinch gesture for a slider) can be used to discriminate post-hoc which menu the user intended to open. Hence, the desired menu becomes crisp, while the other menu vanishes (Figure 4.C.2). A consequence of our concept is that menu elements of competing universes must have distinct input methods when being superimposed. We will discuss those and other implications in the remainder of this work.

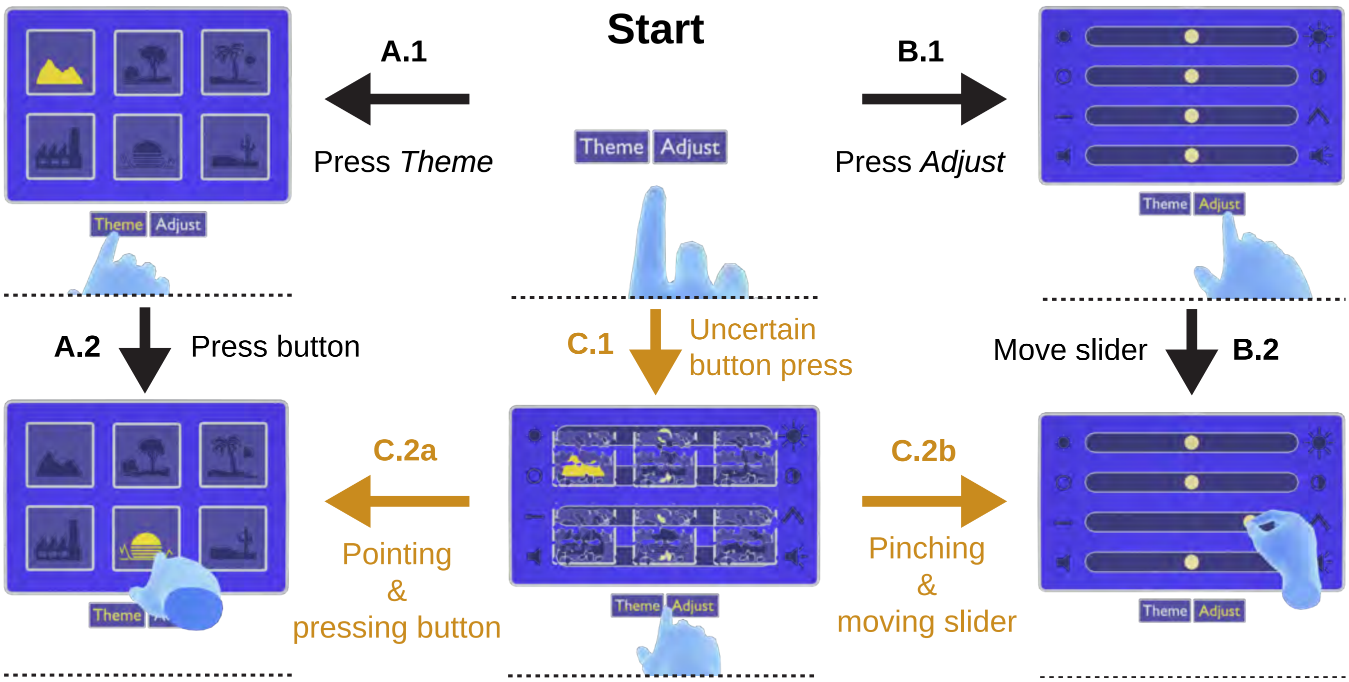

Figure 4: Minimal example of crisp (black arrows) versus uncertain (gold arrows) menu interaction (camera kept static and background removed for clarity). Start) Two buttons summon two different menus. If the button presses are clear, the respective menu is opened and used in a crisp way (A & B paths). A) Pressing 'Theme' opens a menu with buttons, and the user presses one of them. B) Pressing 'Adjust' opens a menu with sliders, and the user moves one of them. C) Due to inaccuracies (either by tracking inaccuracies or the user not aiming precisely) it is not certain, which menu the user wanted to summon. Hence, both menus are possible (C.1). Depending on the user's action—pointing for button presses versus pinching for sliders (C.2a or C.2b, respectively)—our system can resolve post-hoc which menu the user wanted to open. Even with the uncertainty, the amount of actions is the same as with crisp interaction.

3.1 Summary and implications of examples

In all examples, instead of hiding ambiguous input and presenting a single outcome, users retain their agency when resolving uncertainty without significantly changing how they would act in a universe. Due to the post-hoc interpretation, a single universe emerges simply by acting as if only this one universe existed. One implication of such *acting in the desired universe* (while ignoring unintended ones) is that false positives do not necessarily require error recovery by the user—as they simply continue interacting inside the true positive universe. Users can navigate into their desired reality *implicitly* instead of choosing options *explicitly*.

The examples showcased different types of uncertain input and ambiguous system states. The uncertainties used in the *Settings menu* example and the *Sorcery* example could arise due to inaccurate tracking or imprecise movements of the user, especially within potentially cluttered environments and with hard-to-reach targets. For the sake of clarity, the targets in both examples were directly in front of the user. However, in practice, the targets to press or pick up could also be in the periphery or even outside the field of view [36], which means that movements can be challenging to track or that users rely on proprioception. Other forms of ambiguity can result from performative actions (*Basketball throw* example) or be a deliberate part of the experience (*Crossroad* example).

4 State machine perspective

Many VR use cases or processes of physical reality can be expressed by a state machine, describing a current state of the user and the environment, with transitions to other states triggered by the user's actions. Figure 5 visualizes the difference between conventional realities[1] and our Desired Realities concept from a state machine perspective. As an example, the sequence of actions in Figure 5.A could represent a walkthrough of a conventional *universe version* of our *Sorcery* example, which could go as follows: The user wants to pick up a wand to summon a flying creature, but the pinch is detected closer to the potion due to inaccuracies, which means that the user needs to put down the potion again (actions 1 and 2 in Figure 5.A.1). As a next action, the user picks up the wrong wand, but does not realize it until a magic plant is summoned, which means the user has to remove the plan and drop the wand (actions 3–6 in Figure 5.A.2). Eventually, the user picks up the correct wand and performs the correct circular gesture to summon the intended flying creature (actions 7 and 8 in Figure 5.A.3).

In contrast, in a Desired Reality (Figure 5.B), a single action leads to multiple state transitions, letting users interact with multiple states at once, meaning a multiverse walkthrough of the *Sorcery*

[1]With "conventional realities", we refer to both, physical reality as well as artificial realities heavily inspired by it, including VR.

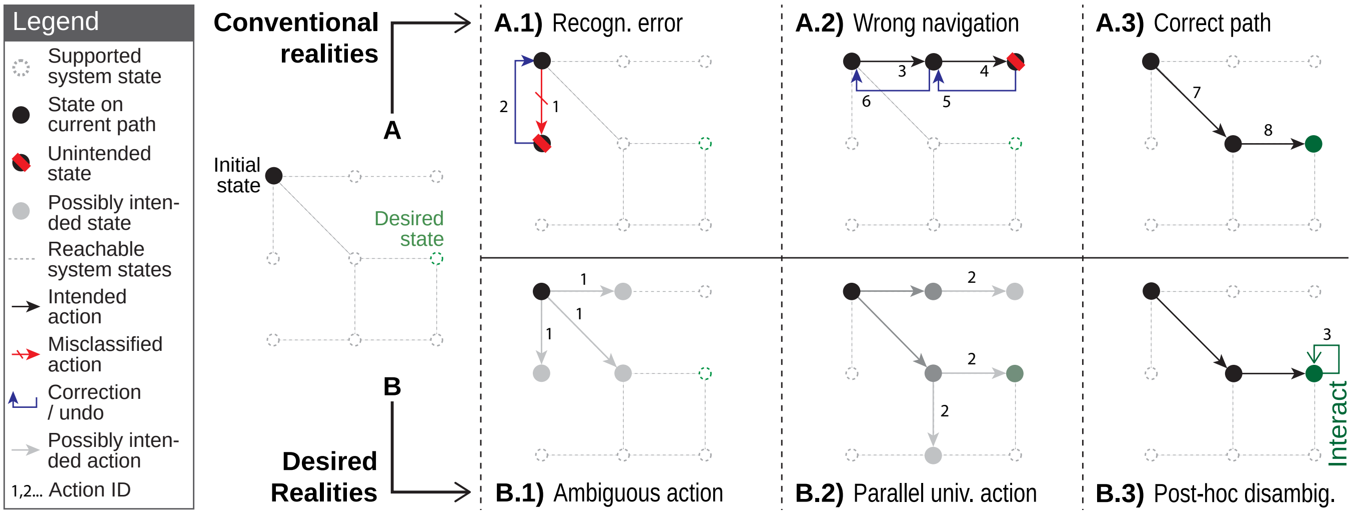

Figure 5: Comparison of state transitions in conventional realities (virtual and real) versus our Desired Realities concept with an abstraction of an example state machine. Conventionally, virtual *system states* (UI, physics and so on) are heavily inspired by physical reality. This does not only include realism but also how we understand getting from an initial state to a desired state—namely changing the environment through actions, including going back and forth (correcting mistakes) until we reach the desired outcome. Desired Realities disregards such constraints from physical reality and suggests an interplay of ambiguous actions and acting in a multiverse as if the desired state has been reached all along—until said state becomes real.

example from a state machine perspective would go as follows: Action 1 in Figure 5.B.1 represents how the user possibly picks up a potion (action 1 down), a plant wand (action 1 right), or a creature wand (action 1 down-right). The potion is quickly discarded because of the follow-up magic wand gestures in action 2 in Figure 5.B.1. Action 2 also represents how the plant wand summons a plant in parallel, independent of the two competing summoned creatures of the creature wand. Through follow-up interaction (action 3: placing the flying creature in mid-air), a single path becomes crisp.

5 Conclusion and future work

We presented Desired Realities, a multiverse concept in which users implicitly choose their experienced reality through their actions. When presented with multiple possibilities, users simply act as if only their desired reality is active while ignoring other possibilities, which yields many challenges and opportunities for future research.

5.1 Implications for menu design

When designing multiverse menus, not only the menu layout but also the overlap of menu elements must be taken into account. Resolving button presses post-hoc enables designers to use smaller buttons. However, closely spaced buttons should spawn menu elements suited for superposition (as in our *Settings menu* example with buttons and sliders). This yields the opportunity of extending automatic UI optimization methods [2, 24] to *multiverse menu optimization*. With multiverse menus, the objective functions additionally need to take overlay-compatibility into account when arranging buttons. UI design considerations can also be combined with interaction in the virtual environment. For instance, a multiverse painting application could have a toolbar in which tools are arranged with an automatic method that favors neighborhood of buttons with dissimilar follow-up interactions, so that an uncertain selection can be resolved easily in a post-hoc manner (e.g., movements typically differ between a brush and a flood fill tool).

5.2 Human factors

We anticipate that parameters such as number of feasible competing possibilities vary with the use case. While many possibilities can be spawned for similar universes (e.g., basketballs), the manageable number of competing possibilities is likely much lower when they are semantically different (for instance, spawning different menus). Furthermore, we anticipate that care must be taken in terms of novice versus expert usage. For instance, a novice using an application for the first time may prefer seeing all functionalities in a crisp way (even at the cost of error recovery) before they learn to navigate through the application using only visual hints that represent possibilities. A multiverse would hence allow expert users to navigate applications faster, where a loss of accuracy due to faster movements is then made up for with lenience for false positives when using post-hoc disambiguation. In other cases, a novice user could benefit from observing the possibilities in a feedforward style. Understanding these individual usage aspects (novice versus expert, semantic similarity of universes, and more) will require multiple dedicated empirical research undertakings.

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