

Symmetrical Reality: Toward a Unified Framework for Physical and Virtual Reality

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ABSTRACT

In this paper, we review the background of physical reality, virtual reality, and some traditional mixed forms of them. Based on the current knowledge, we propose a new unified concept called symmetrical reality to describe the physical and virtual world in a unified perspective. Under the framework of symmetrical reality, the traditional virtual reality, augmented reality, inverse virtual reality, and inverse augmented reality can be interpreted using a unified presentation. We analyze the characteristics of symmetrical reality from two different observation locations (*i.e.*, from the physical world and from the virtual world), where all other forms of physical and virtual reality can be treated as special cases of symmetrical reality.

Index Terms: Human-centered computing—Human computer interaction (HCI)—Interaction paradigms—Mixed/augmented reality

1 INTRODUCTION

It has been a long time since the first concept of virtual reality (VR) was proposed. Actually, that is the very beginning for our physical world to embrace the virtual world (or the digital world). As of now, we have heard a lot of concepts about various kinds of forms that represent the combination of the physical world and the virtual world, such as virtual reality, mixed reality (MR) [6], augmented reality (AR) [2], inverse virtual reality (IVR) [8], and inverse augmented reality (IAR) [9]. Each form has its specific application field, but all of these forms share a common framework.

Symmetrical Reality (SR) is to unify all of the existing forms about the combination of the physical world and the virtual world. Symmetrical reality is defined regarding two crucial attributes: *Object* and *Interaction*. For *Object*, the ratio between the virtual elements and the physical elements determines the existing style of symmetrical reality. For example, if all elements are virtual, SR appears to be virtual reality, and if both virtual parts and physical parts exist, SR appears to be the mixed reality. For *Interaction*, two kinds of actors should be considered. If the actor is located in the physical world, SR appears to be the traditional virtual reality or augmented reality. Conversely, if the actor is located in the virtual world, SR appears to be the inverse virtual reality or inverse augmented reality.

We all know that there is still some undiscovered matter of our world. Inspired by the physical concept of the parallel world [1], the virtual world might be kind of similar to a parallel world of the physical world. If we consider the physical world as a combination of the humans and the environment, the virtual world should also be composed of the similar two components, *i.e.*, the virtual agents and the virtual environment. Since the physical environment can evolve by itself and humans are fully autonomous individuals, it is expected that the virtual environment and the virtual agent should also possess the capability of evolving automatically. Artificial intelligence can be used to make the virtual environment more intelligent [4], and the virtual world, including virtual agents, can even evolve by itself. Hence the virtual environment and the virtual agent can be treated as two kinds of agents [5], *i.e.*, the character agent and the virtual environment agent. Here we notice that the virtual world is created by humans, but it can grow according to its own rules without direct

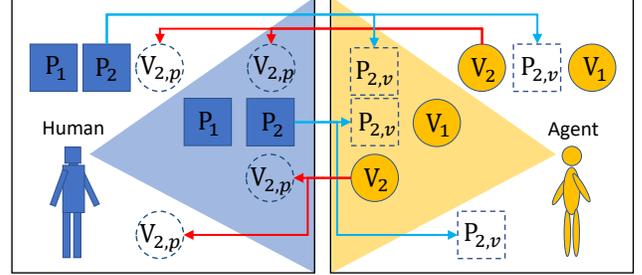


Figure 1: Basic structure of symmetrical reality. (Left) The physical world is represented by blue elements. The physical human can sense a part of P_1, P_2 and $V_{2,p}$. (Right) The virtual world is represented by orange elements. The virtual agent can sense a part of V_1, V_2 and $P_{2,v}$.

intervention from the physical world, though the physical world can still send some signals to the virtual world.

Some researchers have proposed related works belonging to the proposed SR framework. For example, the concept of “dual reality” [3] refers to building the reflected virtual and physical world, which is similar to the mutually mirrored world [8] regarding the structure. However, the former one does not consider a self-learning ability of the virtual agent when compared to the later one. In addition, Roo *et al.* [7] proposed the “one reality” system, which contained a 6-level mixture of virtual and real contents ranging from purely physical to purely virtual world, which is also a human-centered framework. The above contents are discussing the *Object* attribute of SR, and the other attribute called *Interaction* is more significant under this framework. We emphasize the equivalent interaction between the physical world and the virtual world. Milgram *et al.* [6] analyzed the concepts of AR, MR, and VR, which treated the human as the absolute center of the whole framework. However, the proposed SR can extend the prior framework by adding the virtual agent-centered part [9]. Therefore, the proposed SR break the current frontier by considering a two-center symmetrical world structure and the symmetrical interaction style between the physical and virtual world. In this paper, we proposed the framework of symmetrical reality to unify the current concepts related to physical and virtual reality.

2 THEORY OF SYMMETRICAL REALITY

The typical structure of SR is shown in Fig. 1. All solid squares (P_1, P_2) denote physical objects in the physical world, and all empty squares ($P_{2,v}$) denote the virtual correspondences of the physical objects. Symmetrically, all solid circles (V_1, V_2) denote virtual objects in the virtual world, and all empty circles ($V_{2,p}$) denote the physical correspondences of the virtual objects.

Let W_p denote the set of objects that exist in the physical world, including the virtual-to-physical mapping objects of some virtual objects, W_v denote the set of objects that exist in the virtual world, including the physical-to-virtual mapping objects of some physical objects, then we have

$$\begin{cases} W_p = P_1 \cup P_2 \cup V_{2,p} \\ W_v = V_1 \cup V_2 \cup P_{2,v} \end{cases}, \quad (1)$$

where P_1 denote the set of physical objects that are not sensed by the physical human, P_2 the set of physical objects that has been sensed by the physical human, $V_{2,p}$ the set of the virtual-to-physical mapping objects that are originally located in the virtual world. Similarly, we

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can know the definitions of V_1 , V_2 and $P_{2,v}$ by replacing “physical” with “virtual”. Let W_{SR} denote the set of objects in symmetrical reality, then

$$W_{SR} = W_p \cup W_v \cup H_p \cup H_v, \quad (2)$$

where H_p and H_v denote the set of physical humans and the set of virtual humans (or virtual agent), respectively. The physical humans are not treated as general physical objects, because they have independent minds and they can be observers of the SR system. The same thing happens to the virtual humans.

We define an operation “ \star ” on the set W_{SR} . For two given sets a and b , which are subsets of W_{SR} , $a \star b$ denote the status that a and b coexist in one system. Since in an SR system, the physical human and the virtual human both have the ability to observe the outer environment, we can define the observation function for both of them. Let $F_{H_p}(\cdot)$ denote the observation function of the physical human, and $F_{H_v}(\cdot)$ denote the observation function of the virtual human. The input of the functions can be any subset of W_{SR} , and the output of the functions are the observed part of the input set. For example, if there are input sets I, I_1, I_2 , we have the following rules: $F_{H_p}(I) = [I; \alpha]$ and $F_{H_p}(I_1 \cup I_2) = [I_1; \alpha_1] \star [I_2; \alpha_2]$, which means that the percentage of I, I_1, I_2 being observed is $\alpha, \alpha_1, \alpha_2$, respectively. There should be

$$\begin{aligned} F_{H_p}(W_p) &= F_{H_p}(P_1 \cup P_2 \cup V_{2,p}) \\ &= [P_1; \alpha_1] \star [P_2; \alpha_2] \star [V_{2,p}; \alpha_3], \end{aligned} \quad (3)$$

and

$$\begin{aligned} F_{H_v}(W_v) &= F_{H_v}(V_1 \cup V_2 \cup P_{2,v}) \\ &= [V_1; \beta_1] \star [V_2; \beta_2] \star [P_{2,v}; \beta_3], \end{aligned} \quad (4)$$

where $\alpha_1, \alpha_2, \text{ and } \alpha_3$ indicate the ratio by which the $P_1, P_2, \text{ and } V_{2,p}$ are observed by the physical human, and $\beta_1, \beta_2, \text{ and } \beta_3$ indicate the ratio by which the $V_1, V_2, \text{ and } P_{2,v}$ are observed by the virtual human. The model of the proposed SR framework can be represented as:

$$\begin{aligned} \mathcal{M}_{SR} &= F_{H_p}(W_{SR}) \star F_{H_v}(W_{SR}) \\ &= F_{H_p}(W_p \cup W_v \cup H_p \cup H_v) \star F_{H_v}(W_p \cup W_v \cup H_p \cup H_v) \\ &= F_{H_p}(W_p \cup H_p) \star F_{H_v}(W_v \cup H_p) \\ &= F_{H_p}(P_1 \cup P_2 \cup V_{2,p} \cup H_p) \star F_{H_v}(V_1 \cup V_2 \cup P_{2,v} \cup H_p) \\ &= [P_1; \alpha_1] \star [P_2; \alpha_2] \star [V_{2,p}; \alpha_3] \star [H_p; \alpha_4] \star [V_1; \beta_1] \star [V_2; \beta_2] \\ &\quad \star [P_{2,v}; \beta_3] \star [H_p; \beta_4], \end{aligned} \quad (5)$$

where we hold an assumption that the physical human cannot sense the W_v and the virtual human cannot sense the W_p . In Eq. 5, to simplify the discussion, we also assume that the physical human does not sense himself/herself, and the virtual human does not sense itself, either.

3 SPECIAL CASES OF SYMMETRICAL REALITY

According to Eq. 5, if we set the parameters to different values, the SR will converge to different special cases, as shown in Table 1. In this table, all parameters can range from 0 to 1. For example, if α_1 equals 0, it means P_1 cannot be sensed by the physical human at all; if α_1 is a greater than 0, it means P_1 can be sensed by the physical human. Note that the parameters only determine the ratio that the objects are sensed by physical or virtual humans. No matter what values the parameters are, all physical and virtual objects, including the mapping relations between the physical and the virtual world, always exist in the symmetrical reality.

Table 1: Parameter configuration of typical modes of the combination of the virtual world and the physical world. The bottom row indicates that all parameters can range from 0 to 1 in SR, while some parameters cannot be 0 in other modes.

Mode	α_1	α_2	α_3	α_4	β_1	β_2	β_3	β_4
VR	0	0	(0,1]	(0,1]	0	0	0	0
AR	(0,1]	(0,1]	(0,1]	(0,1]	0	0	0	0
IVR	0	0	0	0	0	0	(0,1]	(0,1]
IAR	0	0	0	0	(0,1]	(0,1]	(0,1]	(0,1]
SR	[0,1]	[0,1]	[0,1]	[0,1]	[0,1]	[0,1]	[0,1]	[0,1]

Virtual Reality: Physical Human’s Perspective Virtual reality is a paradigm which treats the physical human as the center of the whole system. In a VR system, the human need to wear a kind of device (e.g., the immersive head-mounted display) to experience the virtual vision and even other virtual feelings.

Augmented Reality: Physical Human’s Perspective Similar to VR, augmented reality [2] is a paradigm which also treats the physical human as the center of the whole system. Different from a VR system, the AR system can provide the human with a scene that mixed both the virtual and the real elements. Another concept called mixed reality is similar to the above structure, but it emphasizes the high fusion of the virtual and the real elements.

Inverse Virtual Reality: Virtual Agent’s Perspective Inverse virtual reality [8] is a paradigm which treats the virtual agent (or virtual human) as the center of the whole system. In an IVR system, the virtual agent, which may be created by humans but can develop by itself, acts as a physical human regarding the living habits. Hence it could also sense all things in the physical world (e.g., the physical objects, and the physical human, etc.) that surrounds it.

Inverse Augmented Reality: Virtual Agent’s Perspective Similar to IVR, inverse augmented reality [9] is a paradigm which also treats the virtual agent (or virtual human) as the center of the whole system. Different from an IVR system, the IAR system can provide the virtual agent a mixed scene of the world. Specifically, all the physical elements become virtual, while all the virtual elements become kind of “real” because the virtual agent itself is exactly a virtual object.

4 CONCLUSION AND FUTURE WORK

Symmetrical reality is a unified concept of the combination of the virtual world and the real world. We derive the formulation of SR in the perspective of set theory, which may provide some insight for understanding and designing various systems that bridge the virtual world and the real world. Especially, the artificial intelligence is assumed to construct the mind of the virtual agent in the virtual world. The understanding of SR should be helpful in the future exploration about mixed space of the virtuality and the reality, where the human intelligence and the artificial intelligence coexist.

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