Current Issues in Computing and Philosophy
A. Briggle et al. (Eds.)
IOS Press, 2008

On the Ecological/Representational Structure of Virtual Environments

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Abstract. This paper introduces an alternative view of virtual environments based on an analysis of two opposing views: the Traditional View and the Ecological View. The Traditional View argues for a representational view of perception and action susceptible of being mapped onto virtual settings. The Ecological View, which is inspired by Gibson's ecological approach to perception, considers that perception and action are inseparable, embodied processes that do not imply mental representations. The alternative view put forward here claims for an articulation of the opposing views, namely the Ecological/Representational view of virtual environments, providing the notion and levels of representation implied in perceptual and agentic processes is functionally defined.

Keywords. Virtual environments, ecological approach to perception, Gibson, affordances, perception/action

Introduction

Over the past 15 years, the growing development and multifarious applications of Virtual Reality Technologies have yielded a variety of desktop and immersive Virtual Environments (VEs), the implementation of which pervades different life domains ranging from everyday mobile communication, computer-based tasks, e-banking, collaborative learning, to specific uses in scientific research, medical care, and military industry among others. Such a rising development has brought about a bulk of literature coming from diverse disciplines and addressing different aspects of VEs. On the one hand, psychologists have studied people's perceptual, cognitive, affective, and behavioral responses to VEs and discussed the ecological validity of virtual reality as a research tool [1]. Sociologists and communication theorists have analyzed the impact of virtual communication and cyberculture on intersubjective practices and activities carried out in VEs [2]. Philosophers have examined the metaphysical and epistemological implications of VEs in terms of both their ontological status and their implications for people's perception and judgments of reality [3].

On the other hand, interdisciplinary research on VEs, mostly represented by the joint efforts of philosophers, psychologists, and cognitive scientists working on immersive environments, has focused on the phenomenon of *presence*, that is, the feeling of "being there" inside the VE. Investigations into the nature of presence in VEs have raised issues about the adaptive dimension of perception and action in virtual

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worlds, and have been principally driven by two trends. The first trend, which may be called the Traditional or Rationalistic View, considers presence as a subjective, inner state (i.e., feeling) originated from an agent's perceptual immersion in and interaction with an external, digitally reproduced world (i.e., a virtual environment). It has been argued that the theoretical versions composing this trend still convey the old-fashioned subject/object dichotomy, and further the claim that for agents to successfully perceive and act in VEs they have to recruit *mental representations* in order to bridge the subjective and objective sides of the virtual experience [4].

The second trend, which is known as the Ecological View, draws principally on Gibson's [5] ecological approach to perception and regards presence as a unified phenomenon, stemming from the very interaction between an agent and its environment. On this view, presence is an agent's awareness of his existence in the (virtual) world, a kind of awareness that is claimed to arise from the intertwining of the agent's "virtual perception" and "virtual action". The agent is said to directly perceive the action opportunities or "affordances" provided by the VE, and to do so he does not need to recruit whatever representations since the perceptual information required to act is already available in the very structure of the VE.

The debate opposing the defenders of each trend has mostly revolved around the explanatory advantages of one view over the other. Apart from some exceptions (see [6] and [7]), authors have paid little attention to the possibility of building bridges and working on the interfaces between their views. Yet on closer inspection, both views are complementary to each other to the extent that the ecological meaning of affordances can be soundly understood in representational terms. This certainly implies a re-examination of the concept and level of representation supposed to be implied in the perception of affordances as well as an elucidation of the reasons addressed by the defenders of the ecological view to rule out any representational features of perception.

In this spirit, my aim in this paper is twofold. First, I will argue that an ecological account of perception and action is not necessarily incompatible with a representational view of the mind. I will draw on three arguments coming from evolutionary studies and neuropsychological research to support this claim and defend an ecological/representational model of perception and action. Second, and by implementing the preceding claim, I will argue that VEs can be accurately accounted for within this model, and that such a model allows for a representational understanding of virtual and real affordances that is helpful for VE design.

The structure of the paper is as follows. The following section introduces and analyzes the basic source and assumptions of the Ecological View of VEs. The third section introduces the three arguments against an Ecological View that does not take into account representations in its explanation of perception and action. The fourth section capitalizes on and implements the outcomes of the preceding section to argue for an ecological/representational structure of VEs. The final section is devoted to some conclusions and issues for future research.

1. The Ecological View of VEs: Perception without Representations

Philosophical and psychological grounds for the Ecological View of VEs can be found in the papers by Flach & Holden [8], Zahorik & Jenison [4], Mantovani & Riva [9], Biocca [7], and Gross, Stanney, and Cohn [10] among others, issued in the journal

Presence. Although these authors have been typically concerned with finding appropriate ways of elucidating the ontological and epistemological nature of presence, that is, whether it is a subjective feeling or an objective state facilitated by technological displays, this concern only represents the tip of the iceberg. What is deeply implied in their views is the idea that a clear understanding of how perception and action are effectively interrelated in real environments must drive research on the design and implementation of VEs, and that this understanding cannot be gained by relying on traditional conceptions of perception and action. In order to provide suitable grounds for this enterprise, these authors draw on a common theoretical source and share a common methodological assumption. The common source often invoked by defenders of the Ecological View comes from Gibson's ecological approach to perception. This approach is posited as a non-rationalistic, situated framework suitable to understand the intertwining of perception and action in real environments. The common assumption implies that VEs are isomorphic to real environments to the extent that the perception/action dynamics of the former can be accurately modeled on the ecological structure of the latter. Let us consider the implications of the source and the assumption in some detail.

1.1. Gibson's Ecological View

According to Gibson's ecological approach to perception, perceiving is the direct process of picking up information from an already informationally rich environment. The nature of the information provided by the environment is not to be confused with proximal stimulation in the form of data sense, but rather to be viewed as action-guiding properties or dispositions of the objects inhabiting that environment. Such properties are what Gibson calls *affordances*, that is, specific invariants the perception of which is meant to support an organism's action. On Gibson's view, affordances are properties integrating both agent and environment into an embodied system, and the nature of this embodied relation entails the claim that to perceive the world is to co-perceive oneself.

Gibson's conception of perception as implying an intimate relation between exteroception and proprioception is meant to get rid of dualistic views in which the agent is thought to perceive or see the world through mentally processing raw data sense provided by the organs of its body. As he used to argue, agents do not see their environment with the eyes but with an embodied system composed of the "eyes-in-the-head-on-the-body-on-the-ground". This embodied system is conceived by Gibson as a functional unit that cannot be reduced to a juxtaposition of discrete anatomical parts. For Gibson, the idea that perception is the work of functional perceptual systems rules out any conception aimed at dividing perceptual experiences into subjective and objective dimensions. On his view, it is clear that the ecological complementarity between agent and world is not separable.

Furthermore, Gibson draws a clear distinction between perceptual senses and perceptual systems, attributing to the latter complex and functional operations that go beyond the mere registration of stimuli. A sense has just receptors whereas a system has organs that orient, explore, adjust, and come to equilibrium at a given level of subordinate or superordinate functioning. Perceptual senses are conceived as somewhat rigid mechanisms, grounded on a repertoire of innate sensations while the achievements of a perceptual system are susceptible to maturation and improving via learning.

Gibson's reluctance to ground perception on representations originates from his firm conviction that the pick up of relevant information is not filtered by an agent's mental models and processes, and that perceiving is an achievement of the whole individual, not an appearance in the theater of his consciousness. Perceiving in this sense concerns "keeping-in-touch" with the environment and provides the notions of situatedness, embodiment, and embeddedness with a full ecological meaning.

By assuming a radical position against mentalistic explanations of perception, Gibson argues that the term "representation" is misleading. For him, there is no literal re-presentation (as in a photograph) of an earlier optic array perceived in the environment; only some of its invariants can be preserved, but that is all. His dissatisfaction with philosophical and psychological approaches to representation targeted conceptualizations of representation as "pictures in the head", which are supposed to tie—in a rather obscure way—the objective (sensory) and subjective (mental) contents of experience. A major flaw in this view has been often addressed, namely that it leads to metaphysical perplexities like a surreptitious "inner eye" or "homunculus" whose function is to verify the consistency between the object and its corresponding 'picture', and guarantee the appropriate matching between objective and subjective experiential contents. However, beyond his rejection of pictorialist accounts of representation, Gibson's negative attitude towards representational accounts of perception and action in general is but a symptom of his deep skepticism about the explanatory promises of cognitive and computational models of the mind championed by several of his contemporary colleagues.

1.2. The Isomorphism between Real Environments and VEs

As stated above, the common assumption of the Ecological View is that VEs are isomorphic to real environments to the extent that the perception/action dynamics of the former can be modeled on the ecological structure of the latter. This assumption implies that (a) "virtual perception" and "virtual action" are inherently related via "virtual affordances", and (b) agents navigating through VEs *directly* perceive the action opportunities furnished by virtual objects and virtual agents. It should be noted here that, though the isomorphism between real environments and VEs is *mutatis mutandis* structurally and functionally valid, it is nonetheless partial. This is so because, to date, some real-world affordances cannot be mapped onto their virtual counterparts. For example, a virtual fruit affords, say, "grasp-ability", manipulability, "throw-ability", but not edibility. Equally, a virtual glass of water affords "reach-ability" and "break-ability", but not "drink-ability". However, these extreme cases of technological irreproducibility of affordances do not undermine the basic assumption of the Ecological View since the essentials of perception and action in real environments can be reliably applied to VEs.

This reliability or ecological validity of VEs is largely contingent on designers' accurate understanding of the nature of affordances. For a VE to be meaningful in the ecological sense, programmers and software developers have to provide users with sensible relations between actions, affects and effects, no matter whether the VE is designed for psychological therapies, collaborative learning, or even video games in which agents can fly, resuscitate, clone themselves, or metamorphose into other creatures. Such relations represent a design commitment to provide a satisfacing compromise between virtual events, available actions, and users' expectations. Furthermore, designers of VEs must be aware that the meaning of virtual actions is not just a construct of the user's mind. Sufficient and clearly detectable physical, semantic, and cultural information has to be provided by the very structure of the objects and agents inhabiting a given VE in order to afford users the possibility of choosing between alternate patterns of action marked by explicit degrees of freedom.

Defenders of the Ecological View of VEs consider Gibson's ecological approach to perception as a compelling framework for disposing of representations and validating a direct, embodied account of perception and action in VEs. Animated by this ecological impetus, they claim that the Traditional View is inadequate because of its artificial separation between objective (sensory information) and subjective (cognitive processing) dimensions of perceptual experiences, thus conveying the idea of an agent interacting in a distal, disincarnated way with his (real and/or virtual) surroundings.

Nevertheless, it is necessary to consider that in view of recent functional accounts of perception and action originated from evolutionary, psychological, and neurophysiological perspectives, Gibson's ecological approach needs some critical scrutiny in order to test its basic tenets and concepts for theoretical accuracy and explanatory power. The outcomes of such a scrutiny will certainly have an impact on the way the Ecological View conceives of the structure of VEs. In the following section, three arguments coming from the aforementioned perspectives will be analyzed.

2. Three Arguments for the Need of Representations

Recent evolutionary, psychological, and neurophysiological research on cognition, has delivered interesting models for understanding perception and action in accurate representational ways. For the most part, these models aim at articulating preceding and, to some extent, competing views of perception/action into a theoretical framework that allows for cognitive and embodied explanations of the interactions between agents and their environment. Here, we will briefly examine three arguments in favor of mental representations advanced by these models.

2.1. The Environmental Complexity Thesis

By adopting an adaptationist and pragmatic view on the evolution of cognition, Godfrey-Smith has argued that the complexity of the environment drives the need for agents to develop complex cognitive resources and capabilities. His basic claim is condensed in the *Environmental Complexity Thesis*: 'The function of cognition is to enable the agent to deal with environmental complexity' [11]. This thesis implies two causally interrelated corollaries concerning the relations between agent and environment: a) the more complex the environment, the more elaborate is the behavioral repertoire required to deal with the environment, and b) the more elaborate the behavioral repertoire, the more complex are the cognitive capabilities and mental representations needed.

Godfrey-Smith understands environmental complexity in terms of 'heterogeneity'. This means that environments can be varied, diverse, changing, and offering the agent opportunities to face a lot of different states. Yet the notion of heterogeneity underlying environmental complexity is not an all-or-nothing condition: any environment can be heterogeneous in some respects, and homogeneous in others. The complexity of a given environment can be assessed in different states at different times, rather than the same state all the time. Different states represent changes in the environment, changes that largely amount to what Gibson refers to as *environmental events*: modifications or transformations of the environment's objects, surfaces, and layout that impose constraints on the organism's perceptual and agentic activities. Furthermore, Godfrey-Smith considers that the complexity properties of environments are to be regarded as objective, agent-independent properties of which only a few will be relevant to any given agent. Whether a specific kind of complexity matters or is relevant to an agent will depend on what the agent is like: on its physiology, cognitive endowment, needs, and habits.

Furthermore, the objective status of complexity properties as well as their agent-relative relevance implies that for agents to track and deal with complexity properties, they also need to develop a kind of complexity, namely *cognitive flexibility*. Cognitive flexibility is seen as an agent's adaptive response to challenging conditions of their environments, a kind of adaptation produced by evolution to enable agents to perceive what environmental invariants persist, and what have either changed or gone out of existence, in order to regulate their behaviors and seize environmental 'opportunities' in successful ways. Cognitive flexibility also implies that agents possess and develop complex representational architectures that can be constantly improved given the agent's potential to learn. This latter point shares with Gibson's notion of a perceptual system the idea that perceiving is a process open to improvement given the susceptibility of perceptual systems to maturation and learning.

2.2. The Evolution of Decoupled Representations

In an adaptationist spirit similar to that of Godfrey-Smith's, Sterelny has provided an evolutionary explanation of the consequences of different informational environments on the evolution of cognitive systems [12]. His baseline for developing his claims is that organisms have mechanisms that mediate specific adaptive responses to features of their environment by registering specific environmental signals telling them of the presence of those features. Yet although the signals of informationally rich features of the environment can be accurately perceived by an organism, this may not be always the case.

Sterelny points out that agents living in complex and changing environments can develop robust tracking systems. Unlike simple detection systems, robust tracking emerges as a flexible adaptive response to the informational structure of a given environment. When considered from an informational perspective, environments can be of three kinds: *transparent*, *translucent*, or *opaque*. Transparent environments are so stable that they allow for adaptive responses by using reliable specific cues. Yet if the ecologically relevant features of the environment map in complex ways onto the cues an agent can detect, this agent is living in a translucent environment. In order to cope adaptively with a translucent environment, an agent has to develop functionally flexible ways of perceiving salient features enabling it to discriminate a functional category (e.g., food, shelter, mates, etc.) via multiple perceptual channels (e.g., vision, smell, auditions, etc.). Finally, if the environment becomes so unstable that even functional flexibility in tracking salient features is bound to misfire, then the agent is living in an informationally opaque environment. To be sure, environments are typically heterogeneous in that they are transparent with respect to some features, translucent with respect to others and even opaque with regard to still others. In a clearly ecological spirit, Sterelny claims that the epistemic character of an environment is the result of an organisms adapting to its physical circumstances, tuning its perceptual channels to pick up information that the world provides for free.

To supply an explanation of how agents adapt and evolve in complex environments, Sterelny has postulated the evolution of *decoupled representations*. According to him, decoupled representations are "internal cognitive states which (a) function to track features of the environment, and (b) are not tightly coupled functionally to specific types of response" [12]. Decoupled representations are thus conceived as 'fuel for success' since they constitute a flexible information database that enables the agent to carry out perceptual and agentic activities without being tied to specific behaviors. Moreover, decoupled representations evolve along with response breadth, which means that decoupling is a matter of degree, developing from an increasing flexibility in the use of information agents pick up.

2.3. The Theory of Event Coding

The basic claim of the Theory of Event Coding (TEC) advanced by Hommel et al. [13], is that perception, attention, intention, and action share, or operate on, a common representational domain. This theory draws on both cognitive and ecological views of perception and action, and attempts to articulate theoretically and empirically the central tenets of each view.

Unlike most theories that assume a functional dichotomy between perceptual codes and action codes, the TEC denies that perceiving a stimulus and planning a voluntary action are distinct processes operating on completely different codes. For Hommel et al., perception and action are equivalent insofar as they are alternative ways of internally representing interactions between ecological events and the perceiver/agent. Several claims can be distilled from TEC. First, perceiving is seen as a process of actively acquiring information about the perceiver/environment relationship, a process that implies allocating cognitive resources (e.g., attention, memory) to salient features of the environment. Second, the process of perceiving presupposes and affords active behavior, and action in turn affords perceptual information. Third, to the extent that environmental actions can be considered as coming into being by anticipating their distal effects, perceived events and their consequent affordances are coded and stored together in one common representational domain. Fourth, the functional equivalence between perceptual and action codes stems from the fact that both kinds of code refer to external events: the codes representing the intended action features are already activated in the course of perceiving the stimulus, so underlying the perception/action dynamic relation.

Furthermore, TEC posits that feature codes—that is, the codes that represent the distal features of an event—are not specific to a particular stimulus or response, but register information from various sensory systems and modulate various motor systems. In a line similar to the evolution of decoupled representations put forward by Sterelny, TEC considers that salient features of the environment can be perceived through more than one sensory modality and it is the common coding of perception/action that integrates this information. Interestingly, TEC also claims that the dimensions feature codes refer to need not always be properties like color or shape, but can also be as complex as 'edibility', 'graspability' or 'sit-on-ableness" in a Gibsonian sense.

Although essentially conceived as a cognitive model for perception and action applicable to behavioral data, TEC also find support in recent neuroanatomical and neurophysiological evidence for brain modules shared by perception and action planning. For instance, the discovery of mirror neurons has provided support for the functional overlapping of perceptual and action-related codes. Mirror neurons discharge during the performance of goal-directed actions and the perception of actions performed by others [14]. These neurons have been identified in the ventral premotor and posterior parietal cortices of monkeys, and a number of functional neuroimaging studies with humans documented the selective recruitment of homologous cortical regions that implement perception/action representations in human premotor and parietal cortices.

Taken together, these three arguments speak in favor of a representational view of perception and action (and, by extension, of the mind) which is overtly compatible with the central tenets of Gibson's ecological view. The next section will be devoted both to an articulation of the representational with the ecological view of perception/action and to a targeting of relevant implications of this articulation for the Ecological View of VEs.

3. Redefining the Ecological/Representational Structure of VEs

Recall that the core assumption of the Ecological View of VEs is intended to support the claim that agents can engage in purposeful perceptions and interactions inside VEs in as much the same way as they do in real environments. For the defenders of this view, Gibson's ecological conception of perception has proven to be a suitable theoretical means both to map real perception and action onto virtual experiences and to explain the advantages of this view for the design and implementation of VEs. On this view, agents are said to navigate through VEs by engaging their perceptual systems and agentic capacities in a direct way, without being bound to draw on mental representations of virtual objects and/or virtual agents.

Yet as we have seen in the preceding section, the story about the ecology of perception/action without representation is far from being uncontroversial. The point is not that the Ecological View of VEs is fundamentally flawed or false; rather, it is that its common source and core assumption are in need of some conceptual and methodological fine-tuning. The arguments introduced above provide us with cogent reasons to carry out such a fine-tuning, and suggest that an ecological view of perception and action is compatible with a representational view of the mind, provided the concept of representation is understood in a functional, non-'pictures-in-the-head' sense.

Let us begin by noting that representations can be considered to enter the ecological view of perception/action at a functional level as the basis of an agent's cognitive schema of individuation. Such a schema corresponds to a set of evolved representational capacities, contingent on the agent's cognitive endowment and allowing it to adaptively perceive and deal with its environment in terms of meaningful arrays of perceptual invariants. The adaptive perception of these arrays implies that affordances have a representational dimension anchored in the intrinsically normative character of action opportunities (physical regularities of the environment or social rules of a group). Moreover, this schema of individuation is not conceived as a purely conceptual template to be stamped on the world, but rather as an active mechanism assembling perceptual and action-related codes to enable the agent to be aware of both his situation in the environment and the opportunities furnished by objects and other agents. Far from being a mere reductionist strategy, the fact that cognitive and neuroanatomical evidence lends support to the emergence and operations of this schema of individuation gives us reliable arguments to defend an ecological/representational view of perception and action, in which both the whole acting subject and his embodied brain activity play crucial roles in picking up of invariants and having meaningful perceptual experiences.

Now, as far as the Ecological View of VEs is concerned, this fine-tuning of its common source has two basic implications for the common assumption. First, to the extent that humans have not naturally evolved in technologically reproduced virtual settings, it is reasonable to expect that they capitalize on their natural representational abilities to perceive and act in VEs. Second, apart from being representational at a functional level (given that they are experienced by recruiting cognitive capacities), VEs are also representational at an epistemic level, namely as deliverers of knowledge representations.

VEs provide agents with three kinds of knowledge representations: analogical, propositional, and procedural [15]. Analogical representations preserve properties of objects and events in an intrinsic manner and keep their same inherent constraints. In this sense, an icon on the computer screen, a labyrinth in a video game, a virtual fruit, or even an avatar, all are analogical representations. They are ontological reproductions or simulations of real objects and events, and are designed to functionally keep the latter's physical attributes and action opportunities. Propositional representations preserve the structure of objects and events extrinsically. When navigating through a given VE, linguistic indications such as "Enter Here", "Members Only", "User Name", or "Password" provide users with information relevant to carry out specific patterns of action. Here objects and events are extrinsically, linguistically coded to afford clear perceptual and active engagement. Finally, procedural representations provide users with specific rules to accomplish particular actions within the VE. These representations can take the form of a set of instructions to sign up for a given website, to master an avatar's movements, or to find a way out of a virtual maze.

It is clear that an appropriate understanding of these representational issues is crucial for a meaningful design and implementation of VEs. For the way the functional and epistemic levels of representation are brought inside a given VE determines its entire epistemic structure. The essential difference between real and virtual settings rests on a platitude worth recalling: VEs are artificially reproduced worlds whose entire affordance-related and epistemic structure is largely a matter of designers' intentions and goals. In this sense, it is up to VE developers to draw on an ecological/representational understanding of perception and action in order to realize that their design of virtual worlds can be as much transparent, translucent or opaque as their real counterparts.

4. Conclusions

We have seen that, despite the claims of the Ecological View of VEs, a representational account of perception and action, either in real or virtual environments, is compatible with an embodied, ecological conception such as that championed by Gibson. This compatibility resides in the fact that, *pace* Gibson, not any representational account of perception necessarily implies a pictorial conception of representation or a dualistic view of perceptual experiences. Arguments from evolutionary, cognitive, and neuroanatomical studies have proven to be helpful to elucidate a functional, representational model of perception and action, and to favor an ecological/representational explanation of the structure of VEs, without having to betray the ecological, and certainly theoretical valuable, view of embodied perception. Accounts of cognition and environmental complexity, decoupled representations, and common coding for perception and action, have yielded compelling reasons for arguing that perceptual and agentic processes can be ecological as well as representational.

The implications of this for the design of VEs have been explored. The ecological/representational analysis of VEs provided here, makes clear that for meaningful use of VEs, users draw on their natural cognitive, representational endowment to accurately track structural and functional correspondences between real and virtual worlds. This point has been argued to be useful for VE designers, since it is their understanding of how affordances and significant features are perceived and engaged in that will make a VE epistemically transparent, translucent or opaque.

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