Simulation as Attunement

Metastability, Coherence, and Embodied Orientation in Virtual Reality

Jose Hopkins B., Ksenia Fedorova

As immersive technologies continue to change, the question of what it means to *feel real* within virtual systems becomes increasingly urgent. Users often report moments of alignment, recognition, and clarity while engaging with virtual environments that are unstable and materially disjointed. This paradox lies at the heart of our inquiry: how does embodied coherence emerge under conditions of sensory and spatial instability?

We build on the argument that VR, MR and XR[1] do not function by delivering a total illusion,[2] but by enabling the body to *attune* to shifting condi-

1 We use the terms VR, MR and XR interchangeably throughout this paper. We echo Mark B. Hansen's claim that all virtual reality is in fact »mixed reality« because it is always experienced by and through the body, which always remains partially »outside«. As we focus on embodied processes rather than discrete technological categories, we decided to continue building on the theoretical current that argues that VR experiences are always situated in »real« physical space, and thus are always mixed reality (MR). See Mark B. Hansen (2006): Bodies in Code. Interfaces with Digital Media, New York: Routledge; and Liam Jarvis (2021): Immersive Embodiment. Theatres of Mislocalized Sensation, London: Palgrave Macmillan.

2 By »total illusion«, we refer to the idea that immersive systems (such as VR) aim to completely replace reality with a seamless, perceptually convincing simulation that the user accepts as continuous and self-contained. This view aligns with early »presence« theories in VR research, where success was measured by the degree to which users »forgot« the real world (Cf. Mel Slater/Sylvia Wilbur (1997): »A Framework for Immersive Virtual Environments (FIVE): Speculations on the Role of Presence in Virtual Environments«, in: Presence: Teleoperators and Virtual Environments 6/6, pp. 603–616). Our approach challenges this notion by emphasising that XR experiences are not total illusions to be believed, but modulations to be navigated. Even in the most »immersive« environments, the body remains partially outside simulation – proprioceptively,

tions, offering an opportunity to reconfigure one's inner sense of the self and to *modulate* its *coherence* within a fluctuating perceptual field. *Simulation*, in this context, is not a seamless reproduction or a model of reality – not a stable representational layer that precedes experience. It is a dynamic, co-emergent field of interaction, meaningful only through embodied engagement. More than an illusion, simulation functions as a regulatory force: a structure of sensory and affective modulation through which the body learns to feel itself aligned, even if only momentarily. The body is never entirely »inside« the simulation; it acts from within and without, participating in what we call *metastable interfacing* – a continuous oscillation between the actual and the virtual. By *metastability*, we do not refer to a property of the digital system or environment, but to the creative and responsive field that emerges through affective and proprioceptive modulation. It is not the system that is metastable, but the relation: a constantly negotiated state of readiness, reorientation and becoming.

Our central claim is that simulation operates as *attunement*: it does not mask instability but guides the body through it. In doing so, it enables coherence not as a given state, but as a felt achievement; enacted through orientation, recalibration, and movement across the shifting seams of XR experience.

1. Metastable Interfaces: Embodiment in Tension

Across multiple disciplines, there is growing acknowledgement of the body's flexibility and its relational openness to its environment. Thinkers in phenomenology (Maurice Merleau-Ponty), process philosophy (Erin Manning, Brian Massumi, Gilles Deleuze), embodied cognition (Francisco Varela, Alva Noë, Shaun Gallagher) post-phenomenology (Don Ihde, Ingrid Richardson), media theory (Mark. B. Hansen, Anna Munster, N. Katherine Hayles), body studies (Elizabeth Grosz), feminist new materialisms (Vicki Kirby, Karen Barad), among others, have all contributed to this conversation. While differing in emphasis, they broadly converge on the idea that the body and the feeling of embodiment are not fixed, enclosed objects, but flexible, open, and responsive processes entangled with their environment.

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affectively and materially. It is this ongoing negotiation rather than absorption that structures the experience.

One of the most influential empirical demonstrations of embodiment flexibility is the *rubber hand illusion,*[3] in which participants begin to feel ownership over a rubber hand when their real hand and a visible rubber one are stroked in synchrony. This experiment reveals how *proprioceptive coherence* – the felt unity of the body – can be manipulated, demonstrating that the body's somatic boundaries are susceptible to realignments through audiovisual and tactile stimuli. Proprioception (from Latin *propius,* »one's own«, »individual«, and *capio, cepi* – »to receive«, »to perceive«) is one of the sixth senses that is taken for granted the most since a particular organ does not represent it but the body as a whole. It is proprioception that is responsible for the body's feeling of its position and movement in space. Thus, the rubber hand is not a visual illusion but relies on the body's capacity to ›imagine‹ its potential positions and align towards them.

Similar experiments using VR technologies have replicated and expanded these findings,[4] showing how users come to feel that digital avatars, limbs, or full-body representations are their own. These experiments suggest that VR technologies produce (often lingering) transformations in the participant's *somatic self-perception* and *body schema,*[5]that is, the dynamic internal model of the body used to guide movement and interaction. These effects are especially significant because they counteract the initially device-related hermeticism of VR, which can make the user feel disembodied or artificially detached. Through sensory feedback loops, these systems progressively align the user's proprioceptive and affective experiences with the simulation.

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3 Matthew Botvinick/Jonathan Cohen (1998): »Rubber Hands ›Feel‹ Touch That Eyes See«, in: Nature 391/6669, p. 756.

4 Such as Julia Reinhard/Dominik Reinhardt/Mel Slater (2020): »Proprioceptive Drift and Embodiment«, in: Frontiers in Psychology 11, n.p.; Tabitha C. Peck/Sofia Seinfeld/Selene Aglioti/Mel Slater (2013): »Putting Yourself in the Skin of a Black Avatar Reduces Implicit Racial Bias«, in: Consciousness and Cognition 22/3, pp. 779–787; Domna Banakou/Parasuram D. Hanumanthu/Mel Slater (2013): »Illusory Ownership of a Virtual Child Body Causes Overestimation of Object Sizes and Implicit Attitude Changes«, in: Proceedings of the National Academy of Sciences 110/31, pp. 12846–12851.

5 For more information about this concept and its differences with body-image consult the text Shaun Gallagher (1986): »Body Image and Body Schema: A Conceptual Clarification«, in: The Journal of Mind and Behavior 7/4, pp. 541–554.

As Ingrid Richardson[6] observes in her work on mobile technologies, such experiences with technology articulate and transform what she calls the *technosoma*: a hybrid configuration of the sensing body, composed not only of organic matter but also of technological extensions and media environments.

These experimental and theoretical insights have been extended in the context of interactive media art and XR technologies by scholars such as Mark B. Hansen[7] and in our own work.[8] Rather than framing bodily reconfigurations as the substitution of old boundaries with new ones, this line of research invites us to approach the interface not merely as a point of connection, but as a relational condition, a structuring force that modulates how we sense, respond, and become in relation to XR media environments. The focus shifts not only to what the body becomes with these systems, but also how that becoming is orchestrated through the interplay of hybrid materialities and codifications. In this context, the concepts of *interface* and *metastability* provide a framework for analysing the affective and proprioceptive dynamics of user-system interaction.

For one of us, for Ksenia Fedorova, an interface – or interfacing – is a relational condition, not exclusive to digital systems, in which the body and the environment become entangled in a field of dynamic, processual, and affectively encoded exchanges. Drawing from thermodynamics and cybernetics, she argues that interfaces are not stable zones of interaction but »the process of entering into a dynamic framework of relations organised in a procedural structure.«[9] Echoing Johanna Drucker,[10] who argues that interfaces are not access points but events of subjectivity formation, Fedorova emphasises that interfaces not only connect but also transform and structure experiences; they are, in this sense, tactical. This procedural-relational framing shifts our attention away from interfaces as tools for representation or interaction to bodily fields – both affective and proprioceptive – that emerge through ongoing negotiation

6 Ingrid Richardson (2010): »The Hybrid Ontology of Mobile Gaming«, in: Convergence 16/4, pp. 419–430.

7 Mark B. Hansen (2004): New Philosophy for New Media, Cambridge, MA: MIT Press; Id.: Bodies in Code.

8 Ksenia Fedorova (2020): Tactics of Interfacing: Encoding Affect in Art and Technology, Cambridge, MA: MIT Press.

9 Ibid.

10 Johanna Drucker (2011): »Humanities Approaches to Interface Theory«, in: Culture Machine 12, n.p.

between the user and their media-created environment. This dynamic relationality finds a particularly rich expression in XR systems, where unstable yet patterned feedback conditions continually modulate the body's orientation.

But how does this relational and procedural understanding of interfacing actually manifest in the body's experience of XR? What kind of condition enables the body to remain open and in constant adaptation to its hybrid environment? Fedorova addresses this question through the term *metastability*, which she adapts from Gilbert Simondon.[11] She defines metastability as a dynamic equilibrium, one sustained not by isolated components but by the shifting relations among them. Unlike homeostasis, which implies self-regulation toward stability, metastability names a condition of oscillation, readiness to shift, and the system's potential for transformation through relational intensities. Scholars such as Erin Manning[12] have similarly drawn on this concept to explore bodily flexibility, emphasising that bodies are never fully enclosed or stable, but always in flux, always in a constant state of becoming through movement and relation. Fedorova positions metastability specifically within the process of digital interfacing, where perceptual and affective thresholds are continually recalibrated. As she writes, metastability is a »relational scenario for living through that state of confused boundaries and in constant (suspenseful) readiness to respond to changing conditions.«[13] In this light, *metastable interfacing* offers a powerful conceptual tool to describe how users in XR environments do not simply »access« a system but become with it, undergoing proprioceptive and affective transformations that are always in motion.

For Fedorova and Hansen, the embodied flexibility enabled, demanded or triggered by these metastable experiences is materialised through the user's proprioceptive capacities. Proprioception is not a self-contained system of internal feedback. Rather, it is relational and porous, shaped by external cues that are felt as internal. This understanding resonates strongly with the rubber hand illusion experiment, which manipulates the boundaries of *bodily coherence* –what users believe their body is and what it can feel like – by aligning audiovisual and tactile cues.

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11 Gilbert Simondon (1992): »The Genesis of the Individual«, in: Jonathan Crary/Sanford Kwinter (eds.), Incorporations, New York: Zone Books, pp. 297–319.

12 Erin Manning (2009): Relationscapes: Movement, Art, Philosophy, Cambridge, MA: MIT Press.

13 K. Fedorova: Tactics of Interfacing, p. 23.

A key aspect of this approach to proprioception is that it is *pre-* or *non-subjective*: it emerges not from a fixed *body-image*, but from a blurring of internal and external orientations of bodily self. This dynamic does not imply a total loss of bodily coherence. Instead, a sense of ownership persists, though not only as active control, but as an affective recomposition of how and where the body feels. In other words, a virtual avatar or limb may be felt as part of one's body not simply because it is controlled, but because it produces proprioceptive effects that transform the user's body schema. The body appears to absorb and expand into, or enfold with, the digital materiality.

In social VR (SVR) platforms such as *VRChat*, metastability manifests not only in proprioceptive experiences but also in existential and performative transformations. SVR platforms give people the opportunity to interact anonymously, primarily via avatars and text (although voice is also possible); they share experiences in the virtual environment, collectively building it or simply exploring and informally communicating with one another. As David Berliner and Maria Erofeeva[14] argue, users undergo shifts in how they perceive themselves and how they perform their identity, shifts that are intimately linked to proprioceptive alterations. Their ethnographic research reveals that avatars in *VRChat* are not merely symbolic representations, but become generative figures through which new or ›truer‹ versions of oneself can emerge.

Participants often describe developing deep attachments to avatars that initially felt artificial. Over time, however, these avatars become like what some describe as a »second skin« or a mask, producing a sense of self-coherence that is not grounded solely in an experience of realism, but in affective familiarity, embodied consistency and identity authenticity. Importantly, this is not a passive transformation but an active, iterative process: many users design and test multiple avatars until they find one that resonates with who they feel they are or aspire to become. In this sense, metastability emerges not only as a state but as a technique – a practised, affectively charged and controlled negotiation through which users craft a coherent sense of self across material and symbolic registers. One participant, for instance, recounts how their long-term use of a cat-like avatar with femboy aesthetics began to merge with their psyche, bodily feelings and performative gestures. After extensive use, they report feeling the two (the avatar and themselves) had become one and the same, stating: »It's

14 David Berliner/Maria Erofeeva (2025): »Becoming Otter: Avatars and the Crafting of the Self in Social Virtual Reality«, in: Journal of Material Culture 30/4, pp. 414–438, https://doi.org/10.1177/13591835251377583.

like wearing a mask until it becomes your real face.«[15] Such experiences suggest that VR avatars do not simply extend the body; they restructure the conditions under which the self becomes experientially coherent.

Another aspect of Berliner and Erofeeva's research is how embodied transformation in *VRChat* can manifest as a quest for a »truer« or more »authentic« bodily identity. Several participants report feeling more themselves while »wearing« their avatars than without them. These reports suggest that identity is not only transformed but, in some cases, clarified or achieved through VR. For example, a transwoman whose gender journey predates her use of social VR emphasises how the platform has helped her alleviate her body dysmorphia: »Because in VR, your body is whatever you want it to be… I can look down and see an idealised version of me […] And it's not just for trans people. If you don't like something about your body, when you're in VR, it's not real. That body isn't there.«[16]

At the same time, other accounts suggest that behaviours and proprioceptive habits cultivated in VR bleed into offline life. One user, for instance, describes unconsciously reaching out to touch a friend's nose at school – a gesture native to *VRChat*'s social etiquette – and feeling instant embarrassment. Such instances resonate with previous VR studies, which have shown that virtual embodiment can alter users' behaviour and proprioception even after the experience ends.[17] These accounts reveal two distinct yet entangled phenomena: one of simulated self-realisation and another of performative and proprioceptive crossover. Both illustrate how metastable interfacing not only expands the user's sense of embodiment but also generates coherence across realities, blurring the lines between simulation and lived identity.

Therefore, we argue that these experiences are not simply the result of immersion; they emerge from a metastable interplay between bodily affect, memory, performativity, technique, and interfacing – a dynamic in which presence and coherence are not given but rather outcomes of repetition and attunement. The user does not become who they »truly are,« but instead who they can become in relation to the VR system's dynamic feedback and affordances.

15 Ibid., p. 20.

16 Ibid.

17 Such as D. Banakou/P. D. Hanumanthu/M. Slater: Illusory Ownership; T. C. Peck/S. Seinfeld/S. Aglioti/M. Slater: Putting Yourself in the Skin of a Black Avatar; J. Reinhard/D. Reinhardt/M. Slater: Proprioceptive Drift and Embodiment.

This process is shaped by ongoing proprioceptive recalibration and performative negotiation. What Berliner and Erofeeva describe is not the revelation of a stable identity, but a practice of self-crafting, in which affective attunements and sensorimotor learning converge to produce a subject who oscillates between feeling momentarily coherent yet never fully settled.

This brings us back to the question of what XR interfaces transform, and how they do so. When read alongside our own work and that of Berliner and Erofeeva, a generative tension emerges: between metastability, as a continual becoming, and simulation, as a staging ground for stable forms of self-expression. XR, in this sense, does not resolve identity; it negotiates it. The simulated body is not merely provisional or illusory; it is a site of potential subjectivity, where the suspension of self through proprioceptive reorganisation coexists with the performance of coherence through *affective orientation*.

2. Simulation as Regulatory Attunement for Embodied Coherence

How does coherence emerge in environments designed through disorientation? In XR systems, users are immersed in spaces where sensory cues, spatial relations and bodily expectations are unstable, fragmented or fluctuating. Rather than being continuous or predictable, experiences in these environments unfold with *metastable interfacing dynamics*. Yet, despite these conditions, users routinely report sensations of wholeness, coherence, and even bodily integration. This paradox invites a deeper question: how does the user come to feel aligned within experiences that actively disrupt sensory continuity? What enables a momentary sense of orientation amidst ongoing instability?

To address this, we turn to the concept of *simulation*. Traditionally, simulation is defined as the creation of a system or model that imitates or predicts the behaviour of real-world processes – often used in scientific and technological domains such as climate forecasting or aeronautics.[18] In media theory,

18 Stephan Hartmann (1996): »The World as a Process: Simulations in the Natural and Social Sciences«, in: Rainer Hegselmann/Ulrich Mueller/Klaus G. Troitzsch (eds.), Modelling and Simulation in the Social Sciences from the Philosophy of Science Point of View, Dordrecht: Springer, pp. 77–100; Paul Humphreys (2004): Extending Ourselves: Computational Science, Empiricism, and Scientific Method, Oxford: Oxford University Press.

especially following Jean Baudrillard,[19] simulation takes on a more critical dimension: a self-referential, hyperreal image or illusion that replaces reality. In VR theory, as David J. Chalmers[20] suggests, simulation fuses both these logics. Virtual realities are not mere illusions, he claims, but genuine realities in themselves – ontologically distinct yet experientially real, built through computational models that afford interaction, change, and subjective presence.

However, we want to shift the emphasis: from simulation as a descriptor for technical capacities to simulation as a body-system relational process. Our concern is not whether simulation mirrors, predicts or constructs a substitute for reality, but how it structures experience through bodily engagement. Simulation becomes meaningful not as a model either to be compared to an original or in its own conditions, but as a *regulatory field*: a dynamic interface in which coherence is felt, not found. It is not a preexisting structure into which users enter, but a relational ecology that emerges through calibration and feedback. Simulation, in this sense, is less a representational technology than an *affective technique*, one that modulates perception, orientation and coherence.

This framing returns us to the questions of coherence in metastable systems, which aligns with broader philosophical accounts of perception and embodiment. Henri Bergson's notion of *qualitative multiplicity*[21] challenges the idea that experience is composed of discrete, stable units. Instead, he describes consciousness as a continuous yet heterogeneous flow: a lived synthesis that holds difference together without collapsing it. Coherence in this framework is not given but composed; it is not the product of cognitive clarity but of intuitive navigation through shifting states. Similarly, Timothy Morton's[22] ecological philosophy stresses the irreducibility and interdependence of systems, emphasising that beings are always entangled in relations they cannot fully perceive or control. These thinkers share the claim that coherence is not a property but a process – a felt resolution that emerges from complexity rather than despite it.

19 Cf. Jean Baudrillard (1994): Simulacra and Simulation, Ann Arbor: University of Michigan Press.

20 Cf. David J. Chalmers (2022): Reality+. Virtual Worlds and the Problems of Philosophy, New York: W. W. Norton & Company.

21 Cf. Henri Bergson (1912 [1903]): An Introduction to Metaphysics, New York: G. P. Putnam's Sons.

22 Cf. Timothy Morton (2016): Dark Ecology: For a Logic of Future Coexistence, New York: Columbia University Press.

We approach these dynamics through two interrelated concepts: *attunement*[23] and *orientation*.[24] Attunement, drawing from affect theory and process philosophy, refers to the body's ongoing responsiveness to its environment. So, the capacity to adjust, recalibrate, or synchronise in response to shifting conditions. It is not a passive reception, but a form of micro-negotiation between internal states and external cues. Erin Manning employs the concept of attunement to explain how the body »gets in tune« with the forces that bring about an event.[25] Orientation, meanwhile, refers to the directional force of these negotiations: how bodies are drawn toward or away from specific relational alignments, perceptual anchors, or rhythms. Sara Ahmed refers to how subjects are positioned in space and time by the objects, bodies, and environments they inhabit. Orientation is not only about physical direction, but about the affective and perceptual vectors that shape how we inhabit the world.

Placing the analysis of technology at the intersection of process philosophy, such as Bergson and Manning, and phenomenology, like Ahmed, allows us to discuss the virtual not as an opposite of the real, but as a potential yet to be activated (a thought elaborated extensively by Brian Massumi[26]). Whereas *VRChat* foregrounds the exploration of potential identities, these processes of becoming can also be understood as operating within a dynamic interplay between the actual and the virtual – not as endpoints along a continuum, but as

23 Cf. E. Manning: Relationscapes.

24 Cf. Sara Ahmed (2006): Queer Phenomenology: Orientations, Objects, Others, Durham: Duke University Press.

25 We want to thank Annette Urban and Manischa Partowi for pointing us to the discussion of *alignment* in Julia Reich/Manuel van der Veen (2023): »A Kind of Mixed, Intermediate Experience: On the Entanglement of Image and Bodies«, in: Yearbook of Moving Image Studies (Mixed Reality Images), Darmstadt: Büchner, pp. 92–114. Their notion of alignment offers a valuable account of how the viewer and the image-body become performatively synchronised within MR environments – a choreography through which perception and movement are co-constituted across real and virtual domains. While our argument resonates with this relational framing, we extend it through the concept of *attunement*, which foregrounds the affective and ecological dimensions of such coupling. Rather than describing spatial and movement synchronisation, attunement names an ongoing modulation through which the body sustains coherence under metastable and shifting conditions, emphasising that the coherence is not performed but felt.

26 Cf. Brian Massumi (2002): Parables for the Virtual: Movement, Affect, Sensation, Durham, NC: Duke University Press.

interwoven modes of embodiment and expression. Situations in XR environments have a more powerful psychological effect than traditional forms of art, such as literature, theatre, and cinema, which also involve elements of identification with the character and techniques that immerse the audience in the storyworld. In XR, not only the minds but also the very bodies of users are actively involved, contributing their states to the overall experience and its coherence. While participants in *VRChat* attune their avatars, i.e., their potential selves, to what feels »true« and authentic from within, it is also important to note that these gestures and movements are shaped by volumetric tracking systems, animation presets, and control regimes that mould how the body can express itself in virtual experiences. Yet, within these constraints, users still draft rhythms of coherence that feel experientially authentic.

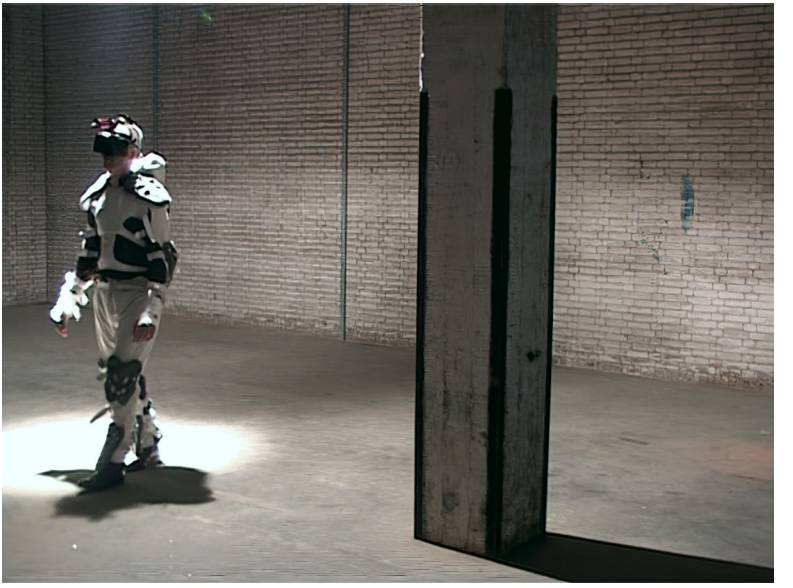

fig. 1: Marnix de Nijs: Exercise in Immersion 4, 2006-2007

Marnix de Nijs's *Exercise in Immersion 4* (2006-2007; hereafter *EI4*) offers a peculiar instantiation of the role of the body in XR and, with that, of simulation as attunement. Described as an »art-game,« the piece invites the users

into a hybrid installation where physical movement, responsive spatialisation, and gamified feedback become central. The setup is deceptively simple. Participants wear a custom-designed crash suit and a head-mounted display (HMD), navigating an expansive warehouse space equipped with motion tracking and pre-rendered visual overlays (fig. 1). All technical elements were made by the artist himself, reflecting the media art of the time and allowing greater creative control. Initially, the simulated environment closely resembles the physical warehouse. This 1:1 mapping mimics spatial alignment and fosters an expectation of stability.

But this alignment quickly begins to slip. As the participant moves through space, the visuals in the HMD start to deviate from the warehouse's architectural reality. Abstract, shifting geometries gradually replace familiar structures. Visual landmarks disappear. Gravity fluctuates. The longer the user moves, the more the environment disorients them. The key is not fidelity, but progressive dislocation – a slow, deliberate drift between visual expectation and proprioceptive feedback.

This growing discrepancy does not break the simulation; it intensifies it. The user's challenge is not to remain immersed in a coherent illusion, but to recalibrate and re-orient in real time. Movement becomes both exploratory and tactical, guided not by visual continuity but by the shifting sensorium of cues. It is motivated by visual elements—referred to as ›bionts‹—that float in space and guide users in avoiding collisions with physical structures that are no longer visible in the headset (figs. 2–3). These bionts were semi-autonomous, slime-like agents that the user collected throughout the experience, much like Pac-Man. Once collected, these bionts swarm around the user, acting as perceptual extensions: they alert the player to spatial obstacles, buffer against collisions, and function as indicators of relational proximity. Their presence effectively scaffolds a relational awareness between the user's body and the hybrid space, enhancing orientation even as the environment slips into abstraction. Importantly, the experience is designed to »fail.« When a participant collides with a wall or a pillar, the visual environment is momentarily re-synchronised with the original warehouse. This moment of realignment is not a return to immersion as coherence but an apparent »reset« that demonstrates how simulation works as a process of rhythmic punctuation between consistency and chaos. The bionts not merely guide; they modulate the body's sense of proximity and relational coherence, shaping an ecology of feedback among the user, the system, and the semi-autonomous agent. Furthermore, their presence, as well as the strategy of taking participants out of their comfort zone, is typical

of De Nijs' work and speaks to the specificity of this project as an artwork. It is both the creative choices, the playful element, and the counterintuitive motivation approach that make this work an open-ended experiment, enabling unique experiences and new observations about the capacities of the body-mind to modulate and re-align.

fig. 2: Marnix de Nijs: Exercise in Immersion 4, 2006-2007

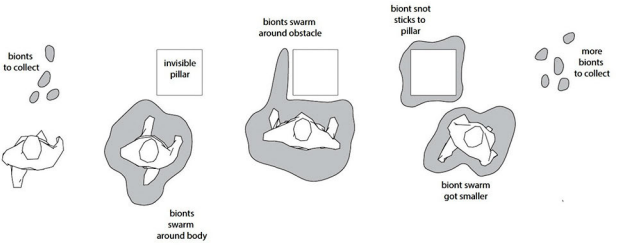

fig. 3: Marnix de Nijs: Exercise in Immersion 4, 2006-2007

Simulation, from the Latin *simulatio*, meaning ›imitation‹, ›pretence‹, or ›representation‹, and *simulare*, ›to make like‹, has long been understood through two dominant traditions. The first treats simulation as representation – a visual or perceptual imitation of the real. In this tradition, most commonly associated with Baudrillard, simulation – unlike *mimesis*, which works as a copy of reality – is the creation of a seamless illusion that conceals the absence of reality behind its image. The second, more technical tradition defined simulation as modelling – the construction of systems (physical, computational, or conceptual) that mimic or predict the behaviour of real-world processes.[27] David J. Chalmers notes that simulations do not necessarily replicate an existing process, but they can be used to create novel processes in their own right.[28] From engineering to medicine to art, simulation enables controlled experimentation by abstracting and formalising the dynamics of the target system.

These traditions persist in XR discourse. Many VR applications aim to replicate reality with high fidelity, while others use simulation to model possible experiences, environments, and identities. Chalmers, in *Reality+*, engages both. He suggests that virtual environments are not merely illusions or models; they are real realities in their own right – ontologically valid spaces that support agency, interaction, and experience. For Chalmers, simulations are real because they instantiate systems with consistent causal dynamics, regardless of whether those dynamics resemble the physical world.

We do not reject this ontological framing. However, our focus lies elsewhere: not on what simulation is in its technical capacities, but how it is lived. We shift the attention from simulation as a technological system to simulation as an embodied relation. That is, simulation becomes meaningful not because it represents or predicts a world, but because it modulates orientation; it structures how bodies move, feel, and become in dynamic relation to fluctuating environments.

Simulation, in this view, is not a model into which the user steps and manipulates to get coherent results. It is a *regulatory field*: a dynamic interface that is co-constituted through action and sensation. It does not precede experience as a fully formed structure; it is felt and enacted through metastable interfacing – a process of continuous calibration between the body and the system. In this sense, simulation is not only what appears in the headset or in the coding

27 Cf. S. Hartmann: The World as a Process.

28 Cf. D. J. Chalmers: Reality+.

processes; it is what emerges in the rhythm of interaction. Coherence is not found but practised.

This ongoing calibration is best understood through Gilles Deleuze's notion of *modulation*,[29] which shifts the emphasis from disciplinary control to continuous affective adjustment. Applied to VR experiences, modulation is not the total elimination of control or disciplinary mechanisms by technological affordances, but rather their reconfiguration as a dynamic, responsive force – one that adapts, tunes, and reshapes how bodies interact with systems. In simulation, modulation makes coherence possible: not through the imposition of structure, but through its relational ecology, which attunes the user's sensorium through shifting gradients of affect and orientation. Ahmed's concept of *orientation*[30] furthers this view, suggesting that bodies are not merely in space, but are continually shaped by what they are drawn toward or repelled from. Manning's work on proprioception extends this further: movement and sensation do not originate solely in the body, but co-emerge with the environments that modulate them.[31] Simulation as attunement, then, is not passive reception of cues, but a field of modulation that enables coherence to be enacted – not once, but again and again, across changing conditions.

The case of *EI4* complicates standard accounts of immersive VR, which often prioritise »seamless immersion« and perceptual continuity. In other words, VR experiences tend to avoid a coherence mismatch between what the user sees and feels in space, thereby avoiding potential physical collisions. This phenomenon is a familiar experience for habitual VR users who adapt their living rooms for VR play or use. However, for *EI4*, these collisions do not »break immersion,« they are not treated as interruptions but as integral parts of the simulation. We suggest that, besides complicating the boundaries between »real« and »virtual« materialities and ontologies, it also materialises that coherence in XR is not given by realism or consistency, but rather by attunement capacities to new patterns and rhythms. So, attuning to the experience as a simulation here works as a regulatory force that orients the body towards readjusting to new logics, thereby existing in coherence within these constantly changing, metastable relations.

Collision in *EI4* exemplifies simulation as attunement, as a way that structures the ways users feel coherence. Rather than presenting the XR experience

29 Gilles Deleuze (1992): »Postscript on the Societies of Control«, in: October 59, pp. 3–7.

30 Cf. S. Ahmed: Queer Phenomenology.

31 Cf. E. Manning: Relationscapes.

as a seamless world, *EI4* operated through a cycle of rupture and orientation. The user does not become part of a stable or predictable reality – at least not at the beginning. They practice coherence by continuously attuning to the simulation, not only to the »new« logics of digitality but also to their ambivalence and their reformulation of »preexisting« ones. Coherence here is not a property of the environment, but an emergent feeling that the changing forces of VR are transforming the world the user metastably becomes with.

In XR environments, we argue, simulation is modulation. It not only presents an immersive image of the world, but it also orchestrates the conditions of attunement. Even when environments are fragmented, unstable, or unfamiliar, the simulation guides the user toward momentary coherence through the regulation of cues and perceptual rhythms. Coherence in this sense is not the goal of simulation, but its effect – a felt outcome that emerges through patterned instability. So, if simulation is not a representational layer but a regulatory ecological force, then its central operation lies in how it orients the bodily feelings. We propose that simulation in XR functions not as a visual or cognitive illusion, but as a system that attunes the user toward momentary coherence.

This is what we mean by simulation as attunement, not the reproduction of a stable environment, but the dynamic calibration of the user's sensorium to patterns of instability. Simulation creates rhythms, thresholds and resistances, not to resolve instabilities, but to allow the body to learn how to navigate them. The user is not attuning to a fully realised world, but rather attuning into the simulation itself – a field of forces, where coherence emerges through adjustments.

This view shifts the emphasis from fidelity to feedback. Simulation, as we understand it here, operates by modulating tensions – between visual and proprioceptive perception, between prediction and response, and between coherence and disorientation. The role of the user is not to detect whether the world is »realistic,« but to develop rhythms of action within it. The simulation, in turn, becomes a kind of training field for these rhythms. It is a space where the user's orientation is always slightly off-balance, but never outside the possibility of temporary alignment.

Importantly, attunement is not reducible to interactivity or immersion. It is not a feature of the software, but a relational achievement – a process that unfolds over time between the user and the MR environment. Affective attunement does not guarantee clarity or stability; instead, it enables coherence to be felt amidst difference.

The logic of simulation as attunement in *EI4* resonates with the social and identity-oriented practices of users in *VRChat*. As Berliner and Erofeeva[32] show, users on social VR platforms often describe a transformation of their sense of self. We suggest that this attunement does not solely emerge from inhabiting an alternate world, but rather from learning to perform in coherence. Their ethnographic research demonstrates how avatars are not merely visual representations, but sites of sensory alteration and learning. Over time, avatars become what one participant describes as a »second skin,« a phenomenon that emerges not solely through immersion but through repeated, embodied negotiation of form, posture, movement, and interaction.

This dynamic mirrors the logic of *EI4* in a different modality. Where *EI4* »trains« the user to recalibrate spatial and proprioceptive orientation under destabilised conditions, *VRChat* users recalibrate affective and performative orientations within unstable and unfamiliar avatar bodies. In both cases, simulation is not a container, but a structuring becoming, one that, through attunement with it, allows coherence to emerge as a felt structure.

The metastable oscillations between logics and materialities are not only processes of coherence and breakdowns; these movements are compositional elements oriented by the affective forces of simulation. In other words, the simulation's »success« lies in its ability to guide the user through misalignments, not in its capacity to hide them. So, XR as simulation becomes an affective infrastructure through which bodies learn to feel situated, even under conditions of constant transformation.

3. Haptics in VR

To specify the effects of embodiment in VR, it is helpful to focus on a sense that foregrounds the body's physicality: the haptic sense. It is through haptic sensations evoked by movement, gesture, and touch, or through skin sensations, that the body manifests its presence. But more than any other modality, haptics grounds the body not only in space, but in relational orientation. If, as we have argued, simulation in XR operates less as representational fidelity and more as attunement, then haptics becomes a critical site where that attunement is enacted, felt and regulated. This raises important questions: Is it possible to adequately transmit a haptic sensation and the associated sense of

32 Cf. D. Berliner/M. Erofeeva: Becoming Otter.

intimacy? What does the simulation of a haptic sensation do to the sense of the self and the borders of the self? In what follows, we aim to explore how touch, gesture, and movement function not only as immersive techniques but also as relational practices of bodily orientation within metastable environments.

The rubber hand illusion, De Nijs' work and some of the experiences in *VRChat* all have haptic sensation in their core. One of the most elusive senses, the haptic sense (from Greek *haptós*, meaning palpable) encompasses phenomena of touch and tactility, as well as other somatic sensations that extend beyond the body's surface, such as kinaesthesia, the sense of balance, and proprioception. More than any other, the haptic sense is grounded in the body as a whole. It is impossible to feel space without first being aware of the starting point for that orientation – one's own body. Although it seems that one is primarily exposed to the virtual space through vision, the haptic sense immediately comes into play as the beholder or their avatar begins to move or is touched.

As proposed above, we see simulation not as a replication of sensations of touch and movement in an imagined reality to be attuned to, but rather as a means of attuning to the sensations of touch and movement themselves. The very technique of simulation regulates bodily engagement. It organises the emergence of proprioception toward fleeting but felt coherence, generating a relational field through which touch-like self-orientation becomes possible. The effect becomes ever more salient if the body is activated in a direct physical sense, not only through vision, i.e., via the neurological connections within the brain that trigger sensations of movement or touch felt purely in the brain, rather than on the skin or within muscles.

While the above-discussed cases involve elements of haptics, it plays an even more prominent role in projects driven by dance and choreography. Such projects typically feature a pre-recorded dancer who guides the user through the space and interacts with them, for example, by looking directly into the user's eyes, stretching their arms to reach out to the user's hands, gesturing an invitation to follow, or simply allowing them to be observed closely. Below are examples of just two creative projects in which an audience member is involved in dance, either through simple gestures that explore the pre-recorded dance freely or by moving together with both on- and off-screen partners.

Dust (2016–17) by Andrej Boleslavský and Mária Júdová is a 4-minute immersive experience that places the user in a space filled with tiny floating particles (fig. 4). It is possible to see the real-time simulations of one's arms and legs as well as another human figure, who explores this peculiar space through dance, as if inviting the user to do the same. Volumetric recordings of dancers

and photogrammetric imagery of the building create the aesthetic effect of a porous space, where there are no clear borders between objects, and the contours appear to flicker. The metaphor of dust here stands for the invisible particles that make up our planet, the »stardust« that once became Earth. According to the authors, the audience was invited to take the perspective of such a particle and to come extremely close to the dancers, to watch them from unusual angles (not possible in real life), and even to step ›inside‹ the dancers' bodies. The permeability of bodies in this virtual environment prompts one to recalibrate and reattune the borders of one's own body through active gestures and movement. The vibrating space and oscillating shapes epitomise here, quite literally, the sense of metastability. While the audience member can still feel solid ground under their feet, the visual field welcomes movements that challenge the solidity of matter.

fig. 4: Andrej Boleslavský and Mária Júdová: Dust, 2016

Another example of a VR experience involving dance is *Eve 3.0* (2024) by Margherita Bergamo Meneghini (fig. 5).[33] Instead of only witnessing dance

33 We thank Tingyu Li for bringing Margherita Bergamo's work to our attention, as well as Berghamo herself for presenting this project in Leiden in December 2024.

within the VR, the audience is encouraged to participate in actual dance, synchronising the movements of the figures within the headset with the movement of one's own body. The experience begins with you, the audience member, sitting in a chair or on a bench in a park within the VR story. There is a group of teenagers dancing under a big tree, and at one point, one girl comes to you to pick up her forgotten notebook from your hands. As it happens, you feel someone's hands take yours and invite you to stand up and move with them. This episode is part of a more complex story that involves teenagers stealing the diary and teasing its author. The viewer must take a stance in this social dynamic. It is thus a hybrid performance that happens both in VR and in real life. The authors describe it as a collective dance that is designed to make one »reflect on common and widespread extreme states of consciousness such as addiction, anxiety, depression, obsession, jealousy and paranoia.«[34] These affects are not depicted precisely but rather through an abstract language of dance. This form of allusion to the potential of VR to let us live through various behavioural scenarios is worth noting: the story allows us to recognise particular psychological states at the cognitive level, but the choreography immerses the very body in at least one of them at a time, letting one experience them intuitively and on a more subtle subconscious level.

What interests us in this work is the role of the haptic component in the blending of realities and the psychological effects that this conversion may entail. Active bodily participation in the story necessitates tuning in to the character whose position you are taking – someone to help return the intimate records – the diary – to a safe environment in a joint dance. You thus have to find coherence between your physical body, your usual habitual self and the role you are temporarily given to play. This happens here through alignment of simulation – as you see your own arms in the space of the story, filled with other, virtual characters, – and direct sensation of touch. Thus, touch, as in the rubber hand illusion, once again calls for proprioceptive alignment and the matching of the actual and potential realities.

34 Margherita Bergamo Meneghini (2024): »Eve 3.0«, in: compagnievoix.com. Online: https://compagnievoix.com/en/projects/creation/eve-3 (last access: 13.10.2025).

fig. 5: Margherita Bergamo Meneghini, Veronica Boniotti, John Desnoyers-Stewart, and Daniel González-Franco: Eve 3.0, 2023

In media studies, the simulation of haptics and touch has been continuously seen as one of the next frontiers.[35] Unlike vision or hearing, haptics operates on a deeper, more subtle physical level. An overview of the issues and already available hardware is beyond the scope of this text. Instead, the aforementioned projects aim to draw attention to the distinction between imagined and real sensations of touch, as well as to the role of movement and gesture within the same haptic continuum, yet without direct skin sensation. All these haptic elements require bodily activity, necessitating awareness of one's presence and active engagement.

In the history of philosophy, from Aristotle to Merleau-Ponty, touch has been associated with immediacy and indivisibility, as it enables one to feel the connection with the world, which is as close as the surface of one's body. It is, however, worth noting an aspect brought up by Jean-Luc Nancy: that touch also implies separation – an »originary spacing,« *partage*, or »division,« »sharing out« between the two touching parties.[36] Touch is not only contact but also the

35 Cf. David Parisi/Mark Paterson/Jason Archer (2017): Haptic Media Studies, London: Routledge.

36 Jacques Derrida (2005): On Touching: Jean-Luc Nancy, Stanford: Stanford University Press, p. 156.

»in-between« that enables it. Through touch and the haptic sense more generally, we can modulate our connectedness to the world and the ways it impacts us.

In *Dust* and *Eve 3.0*, touch is both simulated and physical. It is reasonable to assume that the authors deliberately sought to highlight this tension between the two, emphasising the significance of the irreproducible inner experience of direct physical sensations. The tension between realities resonates with the conflict between connectivity and distance in touch, as highlighted by Nancy.

Just as in the case of the other examples explored in the earlier sections, simulation in *Dust* and *Eve 3.0* asks us to find oneself anew not only in the reality of the storyworld, but in the physical reality of one's own body and one's own self. Going through the pre-choreographed and improvised movements, you literally perform this coherence, integrating, in a metastable condition, the elements of not only one imagined and physical self but also its multiple *potential* versions.

4. Conflict and Tension: Discovery vs. Becoming

This understanding of simulation as attunement allows us to revisit the tension at the heart of XR embodiment: the pull between metastability, as a continual becoming, and simulation as a site for apparent stability and self-expression. If metastability describes the body's readiness to transform – its openness to new orientations and relational compositions – simulation offers, paradoxically, a scaffold for coherence. Even as it destabilises sensory input or alters spatial logic, simulation provides sufficient rhythmic, affective, and perceptual consistency to allow a subject-user to emerge. In *VRChat*, this might take the form of stable identity performances through avatar use; in *EI4*, it's the body learning to find proprioceptive rhythm within an environment that continually shifts.

Crucially, these are not mutually exclusive processes. The user becomes coherent not by escaping instability, but by learning to inhabit it – by attuning to simulation's modulated cues and treating them as provisional grounds for action. Simulation, then, is not the opposite of becoming – it is what allows becoming to be *felt* as coherent. The user does not become coherent by overcoming instability, but by tactically navigating it. And it is precisely this lived contradiction that defines the experiential power of VR today.

Returning to Jean-Luc Nancy's idea of touch helps illuminate this paradox. For Nancy, touch always implies partition or spacing, a shared distance that both connects and separates. Touch is not fusion, but partition; not collapse but a relational tension held across difference. Touch is not a chaotic combination; it presumes that the touching elements remain distinct, that a gap persists even in contact. In this light, coherence in XR – the »harmonious« touch between materially different elements – is constantly haunted by distance. The body senses and becomes with both contact and separation.

This insight reframes our tension. Simulation may scaffold a felt coherence, but it cannot erase the spacing between body and code, subject and avatar, expectations and sensation. That gap – that collision – is not a flaw; it is what materialises coherence. It demonstrates that coherence is not a given, but a practice – something to be modulated, felt, and continuously re-achieved. So, simulation is not a representation; it is an attunement. Instability is not noise, but the condition through which simulation orients the user. In other words, it is what demonstrates that coherence is a technique, something to be practised rather than assumed. Simulation does not erase differences; it re-orients through them.

Thus, the tension between metastability and coherent performance is not structured as a binary opposition. These are not endpoints along a spectrum from chaos to order. They are coextensive dynamics in the process of *embodying with* XR technologies. It is a process that is neither fully chaotic nor metastable, nor the representation of preexisting structures. The system and the body are not in a completely unstructured fusion, nor do they remain as completely discrete and pre-structured elements. XR does not guarantee wholeness; it modulates the terms through which coherence is possible. So, this tension is not to be resolved, but it is integral to the felt coherence. XR does not deliver self without gaps; it offers a site for the »spacing of coherence« – a coherence that is always already partial, always touched by difference, always attentive to the spacing that makes the relation possible.

The cases we have examined make this tension palpable. For instance, in *Exercise in Immersion 4*, the user's body navigates a simulation built on rupture – collisions, resets, and drifting alignments – where coherence is achieved not through fidelity but through rhythmic recalibration. In *VRChat*, users engage in parallel practices of identity attunement: crafting avatars, gestures, and social expressions until a »second skin« begins to feel authentic, even as its limits remain permeable. In both instances, the biological and the digital never fully fuse, though they may *feel* aligned momentarily. It is this irreducible spacing –

Nancy's original distance – that underpins the possibility of coherence. Similarly, in *Dust* and *Eve 3*, active body movement helps to increase the effect of being close and yet remaining apart. Although moments of tactile and gestural alignment blur the boundary between the virtual and the physical – especially in *Eve 3*, when another person physically holds the user's hands – there remains a persistent sense of separation, a lingering »gap« that materialises disbelief or unreality, even within moments of intimacy. This way, simulation does not erase difference but stages it, offering a patterned field where bodies and selves practice alignment within instability. XR does not deliver a seamless self; it provides a site of coherence that is always partial, always touched by difference, and made livable through attunement.

Conclusion: Simulation as Practice

Reframing simulation as attunement invites a shift in how we conceptualise XR; not as a domain striving for realism, but as a site of affective, bodily practice. Coherence, as we have argued, is not the outcome of seamless representation, but the product of a modulation: a rhythm the body learns to inhabit. The simulation is not just what appears in the headset, but the patterned conditions that guide bodily orientation and self-making. One literally forges one's identity, as in *VRChat*, or discovers one's potential as a participant of a collective dance, as in *Eve 3*.

This perspective holds practical stakes. For artists and XR designers, it suggests that immersion need not hinge on fidelity or continuity. Disorientation, rhythmic breakage, and sensorial misalignment are mattering tools; not disruptions to overcome but textures to work with. Designing for attunement rather than illusion foregrounds the body's role in the construction of experience.

For media theorists, curators, and educators, this reframing also reshapes evaluative criteria. The critical question is no longer how accurately XR mirrors »reality«, but how it scaffolds new modes of relationality. Simulation, in this view, becomes a technique of perception, a way of composing the body across affective, proprioceptive, and technical fields of difference.

To treat simulation as attunement is not only to describe what XR does, but to ask how it might feel otherwise, and what new rhythms of coherence we might learn to inhabit.

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