tum group – that are assigned to the links of the graphs, is the natural instantiation of this line of thought and might represent redundancy.

« 5 » Moving from such an intuitive approach we are led to ask a second relevant question: How can we encode the observer-system duality in those models of quantum gravity that are phrased within the language of graphs (spin-networks, Wilson loops or string-nets)? (Q2) If we take into account the authors' analysis in (§§15–17), it seems natural to argue that the individuation of an interface distinguishes two subsystems of the Hilbert space, and thus implies that the total set of degrees of freedom encloses both the observer that perceives and the perceived system. Nonetheless, redundancy would require, in order to let emerge the notion of spacetime that satisfies the Einstein equivalence principle, that a continuous group structure G could be consistently defined (§§15–17) for the spaces of actions, and that this G could be connected to the Lorentz group.

« 6 » As the authors point out in §33, a sizable amount of energy expenditure is required for the holographic encoding, which is roughly proportional to the number of bits involved at the interface and to thermal energy for each degree of freedom. This implies that the redundancy increases in proportion to the dimension of the Hilbert space at the boundary between the observer and the system. Thus, the simple system described by a binary code, namely the Hilbert space of spin 1/2 particle in the physicist's jargon, might already turn into an extremely complicated model to be solved. Nonetheless, at least from a theoretical perspective, we may ask what happens if the Hilbert space at the boundary is composed by N degrees of freedom whose internal degeneracy is described by the irreducible representation of a Lie group G. The main last question I propose is therefore: What is the nature of these degrees of freedom at the interface between the observer and the system and what is the internal degeneracy group, namely the redundancy, connected to these degrees of freedom? (Q3)

« 7 » The answer to Q3 amounts to the correct reconstruction of the boundary physical theory. We must indeed recover the relevant degrees of freedom at the interface, and consistently describe at the quantum(-gravitational) level the interactions these undergo. The role of the symmetries, to which are connected charges that may play the role of bits, is indeed very intertwined with this aspect, as emphasized in a series of studies by Hawking, Perry and Strominger — see, e.g., Hawking, Perry & Strominger (2016).

« 8 » I wish also to emphasize that the role of quantum gravity is not only crucial to determine the dimensionality of the boundary Hilbert space – this pertains to the total set constituted by the "observer" and the "system," and accounts for the description of their interaction – but is relevant as well to regularize the maximum amount of degrees of freedom that shall be considered while reckoning the exchange of bits and the flow of information through the membrane. This provides a set-up in which we can operationally accomplish calculations, avoiding infinities.

« 9 » I end this brief commentary by recalling the authors' suggestive remark (in §37) – part of common belief in the community of quantum gravity that has been growing in recent years – that with the relation between interface's perception and holographic encoding we may only actually be probing the tip of an iceberg. A deeper understanding of the emergent nature of spacetime might indeed arise from the development of a theory of quantum information gravity that many authors are currently developing in the literature.

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Authors' Response

Boundaries, Encodings and Paradox: What Models Can Tell Us About Experience

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> Upshot • Formal models lead beyond ordinary experience to abstractions such as black holes and quantum entanglement. Applying such models to experience itself makes it seem unfamiliar and even paradoxical. We suggest, however, that doing so also leads to insights. It shows, in particular, that the "view from nowhere" employed by the theorist is both essential and deeply paradoxical, and it suggests that experience has an unrecorded, non-reportable component in addition to its remembered, reportable component.

« 1 » We thank our commentators for their insightful criticism. While each of them chooses a different focus for their comments, the issues they raise overlap considerably. We highlight in what follows what we take to be the major issues, and attempt to show how they relate both to what we propose in the target article and to one another.

The "classical world" is the explanandum

« 2 » Constructivists, phenomenologists, and others who reject naive realism are faced with the task of explaining a sharable experience of a classical world – a world of "tables and chairs and dogs and cats and people" (**Eric Dietrich** §1). Even the "naturalized" sciences, however, face this challenge. This is obvious in the case of quantum theory, but even the classical theory of atom-based matter – the classical physics of the late 19th century – faces the problem of how clouds of atoms could appear to us to be tables or chairs. It is less obvious in the case of biology and psychology, but here it must be explained how agglomerations of cells – i.e., organisms – could self-assemble in ways that allow the experience of such things as tables and chairs as opposed to, say, just brightness and saltiness.

« 3 » We agree with Dietrich (§14) that the *experience* of a classical world is ineluctable. When we open our eyes, we see bounded objects with definite shapes, sizes and locations; when we open our ears we hear tones with definite loudness and pitch. Our goal is to explain why we have such experiences. Dietrich suggests that the experience of a classical world is ineluctable because there is an ontologically real classical world, one with a "mind-independent spacetime" that is "filled with mind-independent objects" (§2). We "visit" this world by opening our eyes and ears. According to Dietrich (§12), an utterly differently structured quantum world that we can access (since the 1920s) only via our thoughts can be considered to be equally real, and there may be other equally real worlds with yet different structures that we cannot access at this time. From a constructivist perspective, these "worlds" are all constructs, one of our perceptual systems and the other(s) of our theoretical imaginations. Why the former should provide compelling experimental evidence for the latter remains a mystery. Why we can only express our theories – even to ourselves, in thoughts – using classical symbols is also mysterious.

« 4 » We attempt to address these questions by appealing to a specific mechanism: holographic encoding on an interface that employs spacetime as an error-correcting code. We (each) see a classical world, in our view, because we (each) have this kind of interface. The "objects" – including objects of thought – that our interfaces present to us are eigenforms. As Heinz von Foerster (1976) emphasized, eigenforms and the corresponding eigenbehaviors are (at least approximate) fixed points of multiply repeated (ideally infinitely repeated) perception-action loops (cf. Louis Kauffman's commentary). Eigenform and eigenbehavior must be classically correlated across these repetitions; hence the process of repetition, whether it is conscious or not, constitutes a *memory*. It is this memory of classical correlation that confers classicality on the "classical world" of our interface-encoded experience.

« 5 » If we are correct, the "classical world" is not a world at all, but is *only* an experience. The classical-world experience is ineluctable because the interface that encodes it is the only interface we have; as Ernst von Glasersfeld puts it, summarizing three millennia of philosophical empiricism, "it is impossible to compare our image of reality with a reality outside" (Glasersfeld 1981: 89). When we imaginatively construct theories of what lies beyond the interface, we construct and express them using symbols and diagrams that our interfaces allow: classical symbols and diagrams that have definite arrangements and shapes. Such symbols and diagrams are, like our percepts, eigenforms, fixed points that are only recognizable through repeated use. We have no choice in our use of *classical* symbols and diagrams, as our experiences of theory construction and our experiences of our constructed theories are *experiences* and so are encoded on our interfaces. The classical symbols and diagrams that we use to express our theories make use of redundancy in space and time; hence they enable error correction.

« 6 » What we have called the classical world*view*, on the other hand, is an assumption that the classical world of our experience is not just encoded on our interfaces, but also exists beyond them as an ontologically real structure comprising a multitude of well-defined, bounded, time-persistent macroscopic objects. We see tables and chairs, in this worldview, because tables and chairs (not just clouds of atoms) are out there, bouncing light into our eyes. Perception is (mostly) veridical because the interfaces through which we have perceptual experiences are (mostly) transparent. The world, on this worldview, is not a black box at all, but rather a (mostly) white one. What you see is what you get. Dietrich argues (§3, §12) that this world/worldview distinction is illegitimate without empirical evidence that our model is correct. We disagree: the classical worldview is an explicit philosophical claim or, more commonly, an implicit and perhaps innate assumption that can be (and in point of fact is) made independently of whether the classical world that it postulates actually has the ontological status that the classical worldview claims it to have. On the other hand, we agree with Dietrich that there is a deep issue here: stating this distinction is making a *statement*, and making any particular statement is a classical act. If the classical worldview is rejected, the status of statements is cast into doubt; it is unclear how anyone could speak one particular sentence or think one particular thought. Memory and communication both become paradoxical. Any non-classical theory seems to require, as Niels Bohr argued, a classical metatheory just to support *language*. Here a dialetheic world (Dietrich §12) seems inescapable (Dietrich & Fields 2015).

« 7 » While we do not, as Dietrich points out, have direct empirical evidence for our model, there is plentiful (albeit indirect) evidence for holography as a mechanism (see, e.g., Antonino Marcianò's commentary). Many would argue, moreover, that the mounting evidence for quantum effects at macroscopic scales demonstrates empirically that the classical worldview is wrong. As Dietrich emphasizes, accepting this argument requires the acceptance of another deep paradox. Experiments, in particular, require time-persistent observers and apparatuses that interact while remaining separable in the physicist's sense of having independently characterizable states. Joint states of interacting systems are not, however, separable under the unitary evolution prescribed by quantum theory. This paradox can be stated starkly: local decoherence requires global coherence, i.e., global entanglement. From a global quantum-theoretic perspective, both decoherence and the classical world it produces are epiphenomenal.

« 8 » Dietrich also points out (§14) that we have offered no theory of how human beings can formulate, within their classical interfaces, theories of the non-classical. This is a fair challenge that we hope someday to accept.

Consciousness is fundamental, but architecture must be fundamental too

« 9 » Both Dietrich (§13) and Urban Kordeš (§10) suggest that we are trying to explain phenomenal consciousness, or are at any rate not taking it to be fundamental. We were perhaps not sufficiently clear that we take phenomenal consciousness to be fundamental and irreducible, and simply assume that conscious agents have it. However, we also assume that conscious agents have an architecture in addition to consciousness. The structure and content of phenomenal consciousness (i.e., experience) alone is, we claim, insufficient to explain itself, e.g., insufficient to explain the structure and content of the experienced classical world.

« 10 » Kordeš specifically argues that our distinction between the experience space *X* and the space *G* of available actions is a mistake; *G*, Kordeš suggests, should be a subset, presumably a proper one, of *X*. "Being autonomous," he claims, "means that the agent chooses from the options the agent itself constructs rather than from pre-given options" (§11). Placing *G* within *X* results, however, in an agent aware of every available action and of every choice of action. No actions by such an agent can be "automatic" as psychologists such as John Bargh and Tanya Chartrand (1999) use this term. Genuine autonomy, moreover, requires that the agent be able to actually perform whatever action is chosen. This is possible only if the world never interferes to prevent a chosen action. The conscious agent (CA) formalism separates *G* from *X* not just to enable automaticity, but also to take the evident ability of the world to interfere with our desires into account. The best argument for the existence of a world independent of your own mind is, as The Rolling Stones explain it, "you can't always get what you want."

« 11 » Postulating an architecture is, by its very nature, going beyond "lived experience" to the realm of theoretical models. We fully agree with Kordeš that pretending to "eyes of God" that "[see] all agents, their actions and interactions" (§13) is a mistake, but we nonetheless regard an ability to build, consider, and derive predictions from theoretical models as an essential adjunct to phenomenology. The formalism and diagrams of von Foerster, for example, compose such a model, as do those of Karl Friston or Wojciech Zurek or indeed of any other author who claims to explain or predict any experience of any observer. Kordeš is no exception. "By renouncing the view from nowhere, consciousness appears everywhere" (Kordeš §15) may well be a report of first-person experience, but saying *how this happens* requires a model. For many, moreover, consciousness appears everywhere only *from* a theoretical, view-from-nowhere perspective, one from which the futility of attempts to make consciousness "emerge" from something else becomes evident.

« 12 » Consciousness appears everywhere in the CA framework via a postulate: conscious realism (see §9 in our target article). This postulate is not as radical as it seems. Two CAs defined to have the same "world" set *W* can be taken to represent two "points of view" on *W*. If, however, *W* is reconceptualized as simply the *information channel* via which the agents interact, its degrees of freedom can be subsumed into the perception and action maps of the agents to produce the interacting-agent configuration shown in Figure 1c of our target article. From the perspective of either agent, the "world" is indistinguishable from the other agent. René Descartes realized this in his *Meditations*, stating that nothing in his experience could prove that he was not interacting with an "evil demon" that synthesized his every percept. The currently fashionable idea that we (each) live in a computer simulation constructed by some advanced race, maybe even our own descendants (Bostrom 2003), updates Descartes. The simulation is, in this view, the channel by which the aliens, or maybe our grand^{n}-children, toy with us.

The interface is a boundary in state space, not spacetime

« 13 » Kauffman and Konrad Werner both wonder how the interface is defined, a question that is present but implicit for both Dietrich and Kordeš. Kauffman asks, in particular, (Q2) whether we require the interface to be a "physical surface," later attributing to us the notion that "the fundamental source of the epistemic boundary is spacetime itself" (§7). The word "physical" here is ambiguous; physicists often use it to mean merely "consistently describable in the language of physics," ruling out as "unphysical" only situations with mathematical descriptions that are self-contradictory or meaningless. We can, however, state categorically that we do not require the interface to be a boundary in spacetime, and we apologize if anything in our text suggests this. We regard spacetime as a way of encoding information on an interface, one that may or may not be used, but that provides the benefit of some level of error correction. Human experience and thus the (typical) human interface employs spacetime to advantage for encoding percepts, some concepts (e.g., those of geometry), and much of what we imagine, but other kinds of observers may have interfaces that do not employ spacetime, or that employ spacetimes with more or fewer dimensions or even different geometries from ours. Encodings of some kinds of human experience, e.g., of emotions or epistemic feelings, tend to employ time but not space. Nothing requires or even suggests a common encoding across the entire interface.

« 14 » The notions of open and closed boundaries of classical mereotopology are motivated by the characteristics of ordinary objects occupying continuous, locally Euclidean spacetime. Hence it is unsurprising that, as Werner shows, they are of little use in understanding the kind of interface proposed here. Werner rejects, in particular, our characterization of observer (or "perceiver") and environment ("outside world") as mereotopologically neither open nor closed (Werner §5). If either is open, its complement must be closed (Smith 1996). Observer and environment are, however, on this model entirely equivalent and interchangeable; this is why we draw them symmetrically and prefer the neutral "Alice" and "Bob" nomenclature to the connotation-laden "observer" and "environment." Nothing motivates any structural distinction between the two; hence there is no justification for a mereotopological distinction. Given that they interact, we are left with the situation that Werner (§4) labels "1B*pw*": both systems are closed and they share a boundary. While the boundary is shared, however, the systems cannot both be closed: observer and environment together compose the entire universe, which, as Barry Smith (1996) points out, is boundaryless and hence not mereotopologically closed (it is, however, closed in the physicist's sense of not interacting with anything). This situation is rendered even more paradoxical by noting that observer and environment each appears fully embedded in the other when viewed from their own perspective.

« 15 » Kauffman remarks that "the most generally applicable epistemic boundary is any distinction whatsoever" (§6). The distinctions between red and green or between happy and sad are examples. Any property that supports such a distinction (what physicists call a "degree of freedom") can be thought of as a component of the *state* of a system. The boundaries in which we are interested are boundaries in the abstract state space (as Kauffman §7 points out, this is a

Hilbert space in quantum theory) of the universe. Observer and environment are distinguished as subsystems by the states that they can occupy. The epistemic boundary between them – the boundary by which *we*, as theorists, distinguish them – is their shared interface. The states on this boundary are available to encode experiences; they implement the respective spaces ***X*** of observer and environment in the CA formalism. *What is encoded* on the interface at any instant of either system-relative time depends on how the two systems are interacting at that time. The interaction need not involve spatial degrees of freedom, as **Kauffman** makes clear in his discussion of entanglement (§7).

All boundaries encode experience, but all boundaries can be erased

« 16 » **Kauffman**'s remark that "any distinction whatsoever" creates an epistemic boundary is, however, even more powerful than this. It implies, when taken seriously, that every possible boundary in state space encodes experience. Every system is an observer; likewise, every system is an observed environment. Every state corresponds to an experience on some interface. The universe is, therefore, filled with experiencers and filled with experience. In this sense, contra **Kordeš** (§17), the abstract space in which agents live is indeed a space of phenomenal experience. Each agent, however, experiences only what is encoded on its own interface. Sensations, thoughts, feelings, imaginations, the experiences of deciding or doing, all are encoded on the interface. All are eigenforms. Each agent's internal, "bulk" states are experientially inaccessible to it, even though each of them is on the interface of and hence encodes accessible experience for *some* agent. To see this in the simpler arena of spacetime, think of the constant experiences of your own neurons (of which Cook 2008 provides a compelling description), all of which are inaccessible to you.

« 17 » Expanding one's (theoretical) perspective to the entire universe considered as a whole, however, produces not **Kauffman**'s hoped-for abduction but **Dietrich**'s dialetheic paradox. As described in §7 of our target article, both classical and quantum physics allow inter-system boundaries to be moved or erased arbitrarily without affecting joint-system dynamics (e.g., Zanardi 2001; Dugíc & Jekníc-Dugíc 2008; Harshman & Ranade 2011); this constancy of whole-system dynamics under arbitrary decomposition has been termed "decompositional equivalence" (Fields 2016b). Within the CA formalism, decompositional equivalence is implemented by the arbitrary composability of Markov processes. The universe as a whole has no "outer" boundary; decompositional equivalence allows the erasing of any "inner" boundaries as well. Hence the universe can be considered to be filled with observers and experiences as described above, but the boundaries defining these observers can also be erased with no effect. In the CA formalism, the universe can be considered to be a CA or any combination of CAs, but it can also be considered to be a single set *W* mapped to itself. If any distinction creates a boundary, such a boundaryless system can make no distinctions. With no boundary to serve as an interface and no ability to make distinctions, the universe has no experience space *X* and no experiences. It has no point of view, on itself or on anything else. John Wheeler's well-known statement (**Kauffman** §3) is, therefore, misleading. The universe is composed of observer-participants, but is, when viewed as a boundaryless whole, itself neither an observer nor a participant.

« 18 » Taking actions into account deepens the above paradox. Boundaries encode not just experiences but actions: the perceptions of each agent are the actions of its environment and vice versa. The actions of agents drive the evolution of the universe; the dynamics of a universe entirely composed of agents is nothing beyond the combination of all of their actions. Yet from the (theoretical) perspective of the entire universe, none of the boundaries matters. Decompositional equivalence allows the erasing of all boundaries with no effect. From the perspective of the whole universe, there is no spacetime (indeed no classical information) and nothing is happening. The universe is in a pure entangled state. That this fixed point exists is the physical content of the Wheeler-DeWitt equation.

« 19 » The paradox posed by the "universal view" is, however, deeper still. The boundary erasure allowed by decompositional equivalence erases all interfaces and hence all encoded experience. From the (theoretical) perspective of the entire universe, consciousness and its contents are, like decoherence, epiphenomenal. Decompositional equivalence renders a universe filled with awareness and a universe containing no awareness indistinguishable from a (theoretical) perspective that stands "outside" of it. The "view from nowhere," even when adopted via an abstract model, is inherently paradoxical.

Experience is both classical and non-classical

« 20 » A partial resolution of this paradox of disappearing awareness may come from an unlikely corner. **Marcianò** focuses on a particular system for which the state-space boundary corresponds to a spatial boundary, the black hole, and asks (Q1) how our approach might deal with the paradox that black holes appear to destroy information whenever they gain energy, in violation of quantum theory's requirement of unitarity and hence information conservation. As **Marcianò** points out, one answer to this paradox is to recognize that black holes are only apparently classical objects; they are entangled with the rest of the universe by "soft" photons and possibly other "quantum hair" (see Strominger 2017 for a recent elaboration of this view).

« 21 » As all systems smaller than the universe as a whole are observers in our approach, black holes are observers. Indeed, they are *ideal* observers: all information (particles or waves) that contacts their surfaces is both fully absorbed and holographically encoded. Black holes are also ideal actors: they constantly alter the states of their environments by emitting Hawking radiation. These observations and actions are classical: they can be observed by (i.e., can encode information on the interface of) an external observer. When the situation is viewed quantum-mechanically, however, on the two sides of a black hole's boundary are simply quantum states, which to preserve unitarity must be entangled. The correlations that implement this entanglement cross the boundary; they are the soft quantum hairs. In Andrew Strominger's formalism, these soft hairs are the decohering environment for the Hawking radiation; the latter is detectable by us only because the soft hairs are there. The soft hairs themselves, however, are not detectable; they carry zero energy and hence cannot encode classical bits on an interface.

« 22 » The interfaces of black holes, our ideal observers, are thus more complicated than is depicted in Figure 3 of our target article. Not only do they encode classical information; they are also a locus of quantum correlation. The former cannot happen without the latter. If the encoded classical information is the content of *recallable, reportable, classical* experience, the kind of experience that can be remembered or put into a sentence, then it is natural to regard the boundary-crossing non-classical correlations as a kind of ineffable, non-classical experience that can be neither remembered nor reported. Without this ineffable experience, recallable, reportable experience could not occur.

« 23 » If all of the boundaries in the universe are erased, the classical, reportable experience disappears. It is, as noted earlier, epiphenomenal from a whole-universe perspective. The *non-classical experience*, however, remains. The quantum correlations that implement this non-classical experience constitute the universal entangled state, the fixed point of the universe's timeless evolution. Hence Kauffman's abduction can be partially recovered: the universe remains filled with ineffable, non-classical experience even when all observer–system boundaries have been removed. Perhaps Kauffman's "places of ambiguity" (§4) point to this non-classical experience as surely as do Dietrich's dialetheia. William James's (1892) "fringe" of consciousness similarly seems to point here.

"What is it like?" is not one question but two

« 24 » Kordeš (§14) introduces the traditional distinction between what consciousness *does* and what it *is like*, suggesting that we may address the former but can say nothing about the latter. We disagree, for we claim that "what is it like?" is two distinct questions. One asks what *sorts of experiences* might we expect a system to have, while the other asks what each of those experiences is like for each system that has it. The first of these questions can be answered, maybe not in all cases, but in some. We can expect bacteria, for example, to experience saltiness and expect humans to experience time-persistent objects located in 3D space. We can expect both to experience the difference between well-being and its absence (Peil Kauffman 2015). What these experiences are like for each individual experiencer, however, remains unanswerable. It remains unanswerable, we would argue, even from a first-person perspective. What is the experience of green like? It is like green! Even elaborating, saying that green is more like cyan than red, contributes nothing to capturing in non-experiential terms the experience of greenness. Remembering and then describing the greenness makes it, if anything, less immediate and vivid. Forcing experience into language, even first-person language, distances it.

« 25 » Holography provides a mechanism for rendering experience classical. Beyond that, answering the "what sorts of experiences?" question requires the investigation and modeling of the particular interfaces of particular kinds of systems – e.g., particular kinds of organisms – or even particular individuals. It requires us to take Werner's questions (§14) about the structures of sensory and cognitive systems seriously. Such questions inevitably lead to the field station, the laboratory, or the clinic. It is, once again, a fair challenge to ask how and even if such investigations can be fully and adequately described within a purely constructivist framework. We doubt it.

« 26 » Framed in Marcianò's terms, "what sorts of experiences?" becomes a mathematical question about the formal structures of model interfaces. Given an observer-environment pair, for example, what group structures characterize their interface (Q3)? We have addressed this question from the reverse direction, showing that an interface with a given group structure imposes that structure on the experienced world (Hoffman, Singh & Prakash 2015 and current work). For a finite interface and hence a finite classical experience space X, such groups are finite; hence they can at best approximate continuous group transformations, e.g., those of the Lorentz group (Q2). Whether the CA formalism can replicate the graph structures employed by physicists while maintaining its intended interpretation is a topic of ongoing investigation.

« 27 » Kauffman raises a general question about encoded experiences: what does it mean to say that the informational redundancy enabled by spacetime or any other group structure corrects errors (Q1)? As Kauffman notes, an experience *per se* simply is what it is; there is no sense in calling it an "error." The errors that are corrected, in our view, are errors of association between experiences and actions. Depth perception, for example, enables accurate grasping; disrupting depth perception introduces errors. In some cases, experience-action associations are mediated by intervening experiences. An accurate representation of the time between a current sensory experience and a remembered experience – as encoded in an experience of recall happening now – may be required to choose an appropriate action, e.g., whether to hurry to avoid being late. It is errors of this sort that can decrease fitness, and in extreme cases send fitness toward zero, stopping further input. For an organism, no action is repeated *ad infinitum* and no eigenform is stable forever. In a universe where you cannot always get what you want, you are better off having an interface that gets you what you need.

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