Process Physics: Toward an Organismic, Neo-Whiteheadian Physics

Jeroen B. J. Van Dijk

Forthcoming in *Process Cosmology: Toward a Wider Science and a Deeper Philosophy*,

a collection of essays edited by Mw. Andrew Schwartz, Maria-Teresa Teixeira and Andrew Davis.

Expected in 2021.

Introduction

Over the last four hundred years, our physical sciences have known many glorious successes and have been a major factor in giving shape to our way of thinking about nature. Despite its many impressive achievements, however, our current mainstream physics also exhibits some bothersome deficiencies. Many specific examples can be given, but, on the whole, the main source of trouble for mainstream physics seems to be that so much of it follows from the arbitrarily drawn "object-subject boundary"—the measurement interface between "objective" system-to-be-observed and "subjective" observing system. In physics, this dividing line was first delineated explicitly by Galileo. As such, it enabled the later formulation of what we now like to think of as "laws of nature"—physical equations that basically result from various acts of approximation, neglect and simplification.[1]

[1] The very formulation of physical equations is made possible by the division of nature into object and subject. This "object-subject boundary," or "Galilean cut," separates the *quantifiable world* whose physical aspects can be *measured* objectively from the *non-quantifiable world* whose qualitative aspects are *experienced* subjectively. In this way, so-called "hard and objective" physical quantities, like location, size, and weight, were distinguished from "soft and subjective" qualitative aspects of observation, like the redness of red, the warmth of heat, and the hurtfulness of pain. Subsequently, the acts of approximation, neglect and simplification typically pertain to measurement information extracted from the object side (as raw experimental results are converted into well-refined empirical data). What is more, they are also applied to the outer-system environment (whose influences are typically neglected), the frequency of sampling, the statistical format for interpreting the measurement outcomes, and so on (see, for instance, Van Dijk 2017, pp. 76ff.)

As will be explained in more detail below, instead of revealing what our universe is all about, all these feats of idealization arguably only take us further away from a more clarifying account of nature. An alternative way of doing physics that does not start from this problematic object-subject boundary should therefore be very welcome.

From Contemporary Mainstream Physics to Process Physics

Because of all the aforementioned counts of abstraction, a strong case can be made that the "laws" of nature as we know them will actually never be able to give us a fundamental account of nature's most basic behavior. In fact, these "laws" should better be seen as *measurement phenomenologies*—data-compliant algorithms capable of closely following the changing states of measurement instruments, *not* the changes in nature itself.

An absolute necessity for putting together any measurement phenomenology is the "object-subject boundary." This division of nature into an "objective" system-to-be-observed and a system-observing subject side can thus be seen as one of the main preconditions for our contemporary mainstream physics. Because our current practice of physics relies so heavily on the long-established tradition of first isolating some system-to-be-observed from the rest of the universe, as if it were placed in a heavily sealed box, physicist Lee Smolin has indeed characterized it as "doing physics in a box" (see Table 2.1, first entry, left). Now, the most essential characteristic of "doing physics in a box" is arguably also its most problematic one, since the splitting up of nature into an observed target side and an observing subject side, actually *excludes* all aspects of subjectivity from the system-to-be-observed, and, by logical extension, also from nature as a whole.[2]

---

[2] Additionally, "doing physics in a box" leads us to commit the "cosmological fallacy." This is the mistake of trying to extrapolate local, law-like physical equations to the universe at large. Unfortunately, this leads to the

Mainstream Physics	Process Physics
1. Doing physics *in* a box	1. Doing physics *without* a box
2. Laws of nature and initial conditions	2. Routine of nature and initial randomness
3. Based on empirical data	3. Based on 'mutual informativeness'
4. Life-neglecting and mechanistic	4. Life-centric and organismic
5. Consciousness is epiphenomenal	5. Proto-subjectivity is a primordial aspect

Table 2.1 Mainstream physics versus Process Physics

In contrast, Reg Cahill's Process Physics may be characterized as "doing physics *without a box*" (see Table 2.1., first entry, right), in that it models nature as an ecological whole. That is, Process Physics doesn't draw any hypothetical boundaries between target world, subject world and their ambient environment. Instead, Process Physics starts out with a network of initially undifferentiated, orderless background patterns—a "void-like pre-space" or "pregeometric vacuum-like expanse"—in which newly developing foreground patterns will start to emerge through a process of self-organization. That is, from early patternlessness, this network of initially negligible background processuality manages to give rise to gradually actualizing foreground patterns through ubiquitous, system-intrinsic reciprocity. All this is achieved by way of a self-organizing relational network that (1) has no need for any a priori separation between subject and target side and (2) works on the basis of *including*, *not excluding*, all environmental aspects (Cahill and Klinger 1996; 2005; Cahill et al. 2000).

The second entry in Table 2.1 addresses another major problem of our current mainstream physics. That is, with the concepts of "laws of nature" and their "initial conditions," mainstream physics aims to offer a methodology through which, eventually, we'll be able to formulate a scientific account of all of nature—thus coming as close as

impossible task of moving the entire subject side *outside* the universe—including not only all measurement gear, but also the conscious observer behind the displays, switches and knobs of all this equipment. See Smolin 2013 pp. 46 and 80.

possible to the very origin of the universe itself. Unfortunately, however, the actual origin of the laws themselves necessarily remains a total mystery.[3] Process Physics, on the other hand, can avoid this problem by starting from a background of initially undifferentiated randomness that will gradually develop its own habit-establishing foreground patterning from initially stochastic primordial processuality—hence the expression "routine of nature" from "initial randomness."

As for the third entry of Table 2.1, mainstream physics typically deals with "information-for-us" in the form of empirical data, whereas the Process Physics model is all about "information-for-the-process-itself" in that all its activity patterns are "mutually informative" or "diaphoric" by making a difference to each other.

Another problematic feature of mainstream physics, as shown in entry 4 in Table 2.1, is that it tries to reduce all of nature to "inanimate bits of matter in motion," thus making it virtually impossible to explain how things like life, consciousness, and the qualitative feel of sensory experiences, could ever have come into existence. Such an explanation, after all, would require us to explain life in terms of non-life, sentience in terms of the non-sentient, and "internal" experiential qualities in terms of "external" physical quantities—a task that seems impossible by definition.

Again, Process Physics is not plagued by such difficulties, since it models nature as one giant integrated web of organismic relations. In the Process Physics model, object-like *and* subject-like features actually form complementary aspects of the one undivided whole which is the vast "routine-driven" network of relational activity patterns. That is, as the network evolves towards increasing complexity, it takes on the form of a large quantum foam system

[3] This is because the laws of nature as we know them are phenomenology-based abstractions of nature that are formulated from the external perspective of the subject side, rather than being entirely synonymous with the target-side of observation.

in which classical, matter-like behavior emerges through the internal interplay among activity patterns.

Moreover, the mutual informativeness among the system's relational activity patterns can be thought of as a form of proto-subjectivity.[4] As such, subjectivity is a naturally evolving, primordial feature, not just an accidental, later-arriving side-effect (Van Dijk 2017, p. 2). This brings us to the final entry in Table 2.1: Mainstream physics, because of its association with reductionistic materialism, typically treats conscious experience as an epiphenomenon or even as an entirely illusory by-product of physical brain activity. In Process Physics, however, subjectivity is a primordial, inherent aspect of nature (more details below).

From Outside to Inside the System-to-be-Observed

By telling ourselves that we are in fact outside of the system we are trying to observe, we are basically treating it as if all information, as if everything about it, has a separate objective existence independent from us as external observers. As will be explained in more detail, this is a result of what may be called "the embargo on subjectivity":

> Without being aware of it and without being rigorously systematic about it, we exclude the Subject of Cognizance from the domain of nature that we endeavor to understand. We step with our own person back into the part of an onlooker who does not belong to the world, which by this very procedure becomes an objective world. (Schrödinger 1958, p. 37f.)

Hence, the rather hasty and not-so-well-thought-through exclusion of subjectivity from our target world of interest is probably what has caused most present-day physicists to think that

[4] In the most prominent modern account of consciousness, Giulio Tononi's Integrated Information Theory, the occurrence of mutually informative activity patterns is the core indicator of conscious experience. See Tononi 2008. And although Tononi's use of the concept of "mutual information" does require some adaptation to be compatible with that of Process Physics, there is certainly enough common ground to identify the "mutual informativeness" in Process Physics with subjectivity (see Van Dijk 2017, pp. 124-129, 171 and 177).

we are actually living in an entirely physical, hence absent-minded natural world (see Hunt 2014, p. 68). But looking at nature in this way will inevitably cause us to miss what has in fact been actively thrown out from the very start: the very phenomenon of subjective experience through which all observation—including all empirical observation—is made possible at all.

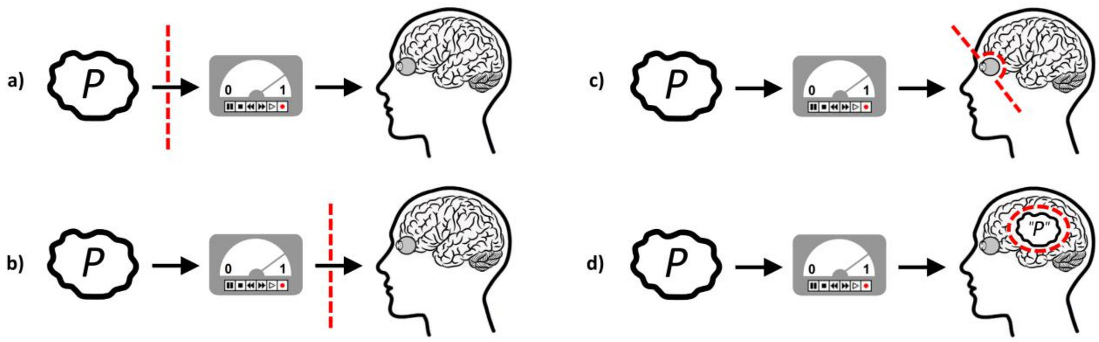

Figure 2.1: The "shifty split" between target and subject side

Mainstream physics and the info-computational approach to empirical observation

Mainstream physics starts by singling out some process of interest *P*, separate from the measuring instrument and the observer. But it is ultimately impossible to determine where the *actual* separation between the target and subject side is to be drawn. It can be drawn between process and measuring instrument (as in Fig. 2.1a), between instrument and observer (Fig. 2.1b), between the eyes and the brain (Fig. 2.1c), or even between the brain and the observer's thought of process *P* (Fig. 2.1d). But despite the ambiguity of this split, the method still managed to stand the test of time and has thus given us many empirically successful physical equations—since just after Galileo to the present day. It works so well, in fact, that it is often conveniently forgotten that our target of observation cannot be straightforwardly equated with what is found in observation and that "a natural system" is not the same as the sensory information and numerical data that are extracted from it. Because of the example given by Galileo and Newton, among many others, it basically became the main task of physics to turn observable aspects of nature into numbers. But this basic recipe for how physics should be done, turned out to give rise to the rather sloppy idea that empirical data could simply, without all too much objection, be equated with the "physical quantities" that they were actually thought to refer to.

Because of the success of this general methodology, we started looking at nature in an info-computational manner—as if the process of observation merely consisted of the act of extracting information from nature. As such, many fields and disciplines in science were framed as being essentially info-computational in their nature. This happened in genetics, in neuroscience, in artificial intelligence, and we even did it in physics and cosmology.[5]

All this has played a not-to-be-underestimated role in our thinking of nature and how we obtain our knowledge about it. In fact, all of the above has significantly shaped our thinking of observation. It motivated us to interpret the process of observation in an explicitly info-computational manner—as the mere registration of information. A hidden side-effect of this is that we all too easily forget that our concepts, categories, codings and names are not synonymous with whatever it is that they are meant to refer to. In fact, the desired synonymy between (1) sensory patterns, (2) our linguistic labels for these patterns, (3) raw empirical data, and (4) well-refined, empirically adequate algorithms typically do not come automatically without effort. This synonymy can only be achieved through a whole lot of pre-algorithmic interpretation, foregoing social convention, handshaking and subjective choice. All in all, the sincerely hoped-for one-on-one relation between these different levels

---

[5] The info-computational framework offered a convenient vocabulary for speaking of DNA as "the program code of life" and allowed us to start thinking of the brain as a very complex biological computer. As it was thought in the field of artificial intelligence, it should therefore be possible to model the brain by using digitally operating artificial neural networks. By looking at the universe as being a vast computational system, or a giant simulation, even physics and cosmology could be gathered under the same umbrella of info-computationalism. See Van Dijk 2017, pp. 83-86; 112-113.

of description can ultimately only be forced by us, conscious observers, through carefully considered, well-informed, but above all *subjective* decision-making—rather than through objective criteria.

It is because of the forgetfulness of this in mainstream physics that we started to think that there really exists such a thing as "electrons" separately from our conceptions and subjective sense-making of nature. But in reality, "electrons" do not exist separately and independently from our entire intellectual-technological context of use that enabled us to conceive of them at all.

Also, without realizing it, by welcoming the info-computational approach that came hand in hand with the Galilean-Newtonian paradigm of "doing physics in a box," we unfortunately allowed all kinds of associated, but not immediately apparent problems to come in and haunt us. As will become clearer as we continue, problems like the stripping away of subjectivity from our physical world picture, the bifurcation of nature (Whitehead 1920, pp. 27–30), the cosmological fallacy (Smolin 2008, p. 97; Rosen 2010, p. 72), the troublesome origination story behind the laws of nature (Smolin 2008, pp. 97–98; Van Dijk 2017, p. 8), and so on, are slowly but surely causing the first hairline cracks in the framework of exophysical-decompositional physics.[6]

From external "information-for-us" to internal "information-for-the-process-itself"

When it comes down to all of these problems, mainstream physics seems to have quite a significant blind spot that is mostly unnoticed. A good case can be made that this blind spot is more or less the result of a cognitive dissonance. It is, after all, a well-established tradition;

[6] In the exophysical-decompositional paradigm (i.e., the Cartesian-Newtonian scheme) we typically interpret nature in a nature-dissecting way by treating it as an entirely physical "real world out there" that exists as the sum total of law-governed physical constituents. See Van Dijk 2017, pp. 29–31.

we've always been trying to inform ourselves about nature by probing into target systems from the outside. Any problem resulting from that outside perspective, may well be experienced as too confusing, and as too inconsistent with this familiar outside perspective. In this case, it would probably be easier to just dismiss such problems as being irrelevant, less fundamental than the premises they were conflicting with; or as being valid only within an entirely different context of use. Yet still, in reality, we can only make sense of nature from the inside, as we are seamlessly embedded within it. Our current mode of doing physics in a box doesn't seem to have any suitable way of taking this into account.

The whole idea of mathematics being the objectively true language of nature is intimately tied in with this problematic external perspective as well. When we think that mathematics is fundamental and just lying "out there" in wait to be discovered, instead of just a highly useful and convenient tool invented by us to help us make sense of nature, we will be making a mistake similar to thinking that the names of the stars and their constellations are also waiting out there to be discovered.[7] In other words, trying to grasp the whole of nature in terms of mathematical language, or any other linguistic system or method of symbol manipulation, basically amounts to treating nature as fully synonymous with the names, categories, data and also the algorithms—all of these formulated within their own respective systems of expression. We should realize, therefore, that "nature as left unframed by our intellectual gaze" is actually an unlabeled and uncategorized place. It is not possible to observe nature as an objectively existing "real world out there" with its informational labels already in place—ready to be harvested. Instead, as Werner Heisenberg comments: "… we

[7] At the 2017 Whitehead Psychology Nexus conference in Fontarèches, France, John Pickering from Warwick University (UK) told me an entertaining anecdote about stars and their names that was originally written down by Lev Vygotsky who, in turn, got it from Wilhelm von Humboldt. See L. S. Vygotsky's "Thought and Word" in Rieber and Robinson 2013, p. 76.

have to remember that what we observe is not nature in itself but nature exposed to our method of questioning" (Heisenberg 1958, p. 58).

Taking this argument one step further, we may say that mathematical physics as we know it, instead of offering us a true and objective account of nature, is actually more like a figure of speech that aims to conform with the regularities that are found in this confrontation between nature and our method of questioning. What our mathematical physics offers us is not an objectively true physical account of nature. At best it merely offers us a reality exposed to the names, concepts and informational labels we impose on it (Thayer 2011, p. 148).

Now, if we decide to hang on to our familiar, but problematic subject-object boundary, we will not be able to overcome all the problems associated with it—especially the false synonymy between sensory patterns and our linguistic, numerical and algorithmically expressed labels for these patterns. Put differently, we would have to stick to our idealized, and thus necessarily incomplete, mathematics-based accounts of nature that aim to replicate experimentally obtained empirical data through info-computational, data-reproducing algorithms. Whereas these empirical data can be thought of as "information-for-us," the alternative is to attempt a modeling of nature in terms of "mutual informativeness." In short, such models revolve around internal "information-for-the-process-itself" in that all involved activity patterns are "mutually informative" in a process-relational, diaphoric sense as they are in fact participating in one vast integrated process in which all internal processuality is constantly involved in making a difference to all else, and vice versa.

As such, it can actually be seen as a modernized version of Gottfried Leibniz's relational monadology. As chance would have it, in his recent book, *Einstein's Unfinished Revolution*, Lee Smolin argued compellingly that such a monadology should be the way to go for foundational physics; at least, if it ever wanted to get out of the near-standstill situation that it has currently ended up in (Smolin 2019, pp. 241–272). And although Smolin was probably unaware of Process Physics when he wrote his book, it can definitely be read as an encouragement to take Cahill's work seriously.

Process Physics: How Does it Work?

But is Process Physics indeed capable of giving rise to such a mutually informative process-monadology—and, if so, how exactly? In Process Physics, higher-order activity patterns are seen as a natural outgrowth of the primordial background processuality from which they arise. As such, the start-up actualities in the Process Physics model basically get themselves up and going through an utterly relational process called "bootstrapping" (Cahill and Klinger 2005, p. 109). This is a process in which foreground patterns of higher-order complexity lift themselves into actuality from an initially latent background of practically negligible relational activity.[8] In other words, what can initially be thought of as an entirely vacant, void-like pre-space of homogeneous, patternless activity, manages to hoist itself to an upward level of patterned organization as its own fluctuating elevations coalesce to form an emergent network of higher-order relationships.

Without this co-creative, mutualistic bootstrapping process, any arbitrary elevation of connectivity would simply be swallowed, or be swept away, by its ambient background processuality. However, whenever this bootstrapping process turns out to have been effective from early beginnings onward, the Process Physics model can basically be thought of as evolving "foundations without foundations" (Chown 2000, p. 28; Van Dijk 2017, p. 146).

[8] In biology and neurobiology, such bootstrapping processes have also been put forward by others to explain the beginning of life as an autocatalytic process and the coming into actuality of higher-order consciousness. As such, early life and higher-order consciousness are thought to lift themselves into actuality from otherwise undifferentiated backgrounds, like a primordial soup of low-grade chemical activity or the "primordial chaos of sensations." Since Process Physics works according to the same principle, it can essentially be seen as through and through biocentric. See Kauffman 1995, p. 288; Edelman and Tononi 2000, 109, 173, 205; James (1890) 2007, pp. 288–289; Van Dijk 2017, p. 177.

When doing "physics in a box," the obligatory act of drawing the object-subject boundary will naturally elicit the question of what the actual "source of information" should be like. According to the Copenhagen interpretation of quantum mechanics, this question cannot be answered since the quantum mechanical formalism only pertains to measurement responses, whereas nature-in-itself is ultimately unknowable. Einstein's position, on the other hand, was that the actual source of information would simply have to be a subsystem of the objectively existing, entirely physical "real world out there"—capable of giving rise to hidden variables. This subsystem, just by changing the state of measurement instruments through a purely physical stimulus—thereby generating empirical data—would thus be able to inform us about what is going on in nature. This is also why he wouldn't allow for "spooky action at a distance"—a phenomenon we nowadays like to refer to as "nonlocality."[9]

However, as argued here, the preferred option is to follow the recipe of Process Physics. On that account, nature should be thought of in an informational way as consisting of relational "data in the wild."[10] These "raw givens of nature" are thus seen as "primordial discontinuities in the relational fabric of nature" (Floridi 2013, pp. 85–86). These discontinuities behave like initial "it-from-bit"-like actualities that are seamlessly embedded within the greater network of nature as a whole. And since they are so deeply interconnected with all the rest of nature, it is natural to think of these actualities as being engaged in a vast relational process in which all informs, or makes a difference to, all else within the network.

---

[9] There is still no explanation for nonlocality under our currently accepted physics theories. In Process Physics, however, nonlocality is an inherent aspect of the initially nondescript background ambience from which higher-order activity patterns are bootstrapped into actuality.

[10] The notion of information as it is used in Process Physics is quite reminiscent of John Archibald Wheeler's idea of "It from Bit." One of the key statements regarding Wheeler's informational view of nature was that nothing can exist unless it is observed (typically by a measuring sensor and an observer's sensory system). Process Physics, however, proposes a slightly more subtle process-relational interpretation of Wheeler's "It from Bit." That is, Process Physics holds that all actualities—considered as the "raw givens of nature"—are best thought of as forming a seamlessly interconnected whole in which everything "senses," and is "being sensed by," everything else. This can also be phrased in a Whiteheadian way as "all *prehends* all else" (and vice versa)—or, likewise, as "all *informs* all else" in an order of "difference-making mutual informativeness." So, considering all this, the "observation process" should best be thought of as having to do with "information for the process itself," rather than with "information for us." For the seminal papers on "It from Bit", see Wheeler 1980, pp. 132–154; Wheeler 1999, pp. 313–315.

To summarize, because of the bootstrapping effect, the Process Physics model can simply start out with random self-referential fluctuations (i.e., noisiness) that will naturally give rise to routine-driven network formation. Hence, instead of being based on the problematic notions of “laws of nature” and “initial conditions,” Process Physics revolves around “routine of nature” and “initial randomness.” This reflects the fact that the universe as a whole should be thought of as one unique, undivided process that is algorithmically incompressible (Chaitin 2007, p. 227; Ulanowicz 2009, pp. 121–122; Rosen 2010, p. 72; Van Dijk 2017, p. 148).

To be more precise, by definition, the complexity of nature-in-full goes beyond the capabilities of any conceivable regularity-seeking algorithm. After all, the very formulation of any formal algorithm as a so-called “law of nature,” necessarily requires us to dissect and oversimplify nature to the extent that it can serve as a target system for the candidate algorithm at hand. Because of these acts of simplification, we cannot realistically expect any one physical equation (or some small set of such equations) to be able to capture the whole of reality.

Therefore, the most logical alternative is to place our familiar way of “doing physics *in* a box” on the storage shelf for a while, and focus our attention on a way of “doing physics *without* a box”—like Process Physics. After all, one of the major assets of Process Physics is that it is based on a “routine of nature” that starts from “initial randomness.” Because of this, it can offer us a realistic alternative for the problematic concepts of “laws of nature” and “initial conditions.” As we are now starting to realize more and more, these concepts have caused us so much trouble primarily because of the problematic object-subject split. As John Stewart Bell already noticed, it is indeed this “shifty split” (Bell 1988; 1990, p. 34) that is a source of ongoing trouble. It has not only caused our celebrated laws of nature to have a necessarily unknown origin, but it also brought along problems like the cosmological fallacy

(Smolin 2013, p. 97; Rosen 2010, p. 72), the undesirable bifurcation of nature into "lifeless nature" and "nature alive" (Whitehead 1938, p. 173–232), the risk of the "fallacy of misplaced concreteness" (Whitehead 1978, pp. 7, 18), and the loose ends in the origination story of the physical entities whose behavior the laws of nature are supposed to be "governing" (Smolin 2013, pp. 97–98).

Process Physics: "Routine of Nature"

Process Physics aims to avoid all these problems by resorting to "routine of nature," instead of "laws of nature." Accordingly, the Process Physics model operates on the basis of an iterative, habit-establishing update routine that *indexes* connection strengths in a relational matrix (see Table 2.2 and also Fig. 2.2 below). This relational matrix can be seen as a vast bookkeeping table that registers emergent connectivity within it. Although the relational strength between connectivity nodes is being indexed by a pre-sorted 2-dimensional *i*-by-*j* matrix, this, remarkably enough, does *not* impose any external order onto the system. This can in fact be explained as follows: Just as a list of home addresses does not tell us anything about which members within the community will grow closest to each other, the numerical labels (*i* and *j*) that are used to denote the "addresses" where the relational strengths are being indexed, do not tell us anything about which relations are being formed by the Process Physics model and how strong these relational connections can become. Furthermore, the initial patternlessness within the relational matrix ensures that there is no pre-given organization—no pre-imposed order (Van Dijk 2017, pp. 157–158).

node nrs.	1	2	3	4	5	6	$\rightarrow j$
1	0	$B_{12}(=-B_{21})$	$B_{13}(=-B_{31})$	$B_{14}(=-B_{41})$	$B_{15}(=-B_{51})$	$B_{16}(=-B_{61})$	
2	$B_{21}(=-B_{12})$	0	$B_{23}(=-B_{32})$	$B_{24}(=-B_{42})$	$B_{25}(=-B_{52})$	$B_{26}(=-B_{62})$	
3	$B_{31}(=-B_{13})$	$B_{32}(=-B_{23})$	0	$B_{34}(=-B_{43})$	$B_{35}(=-B_{53})$	$B_{36}(=-B_{63})$	
4	$B_{41}(=-B_{14})$	$B_{42}(=-B_{24})$	$B_{43}(=-B_{34})$	0	$B_{45}(=-B_{54})$	$B_{46}(=-B_{64})$	
5	$B_{51}(=-B_{15})$	$B_{52}(=-B_{25})$	$B_{53}(=-B_{35})$	$B_{54}(=-B_{45})$	0	$B_{56}(=-B_{65})$	
6	$B_{61}(=-B_{16})$	$B_{62}(=-B_{26})$	$B_{63}(=-B_{36})$	$B_{64}(=-B_{46})$	$B_{65}(=-B_{56})$	0	
$\downarrow$ i							.

Table 2.2: The indexical relation matrix. When nodes i and j are connected, they will be indexed as having a non-zero connection strength B_{ij}. Anti-symmetry (here indicated by matching background colors of the matrix cells) guarantees that the strength of any self-connection (B_{ii}) will always be zero. Positive or negative signs of the actual B_{ij} values depend on the direction of the arrows between nodes i and j (see Figure 1.2).

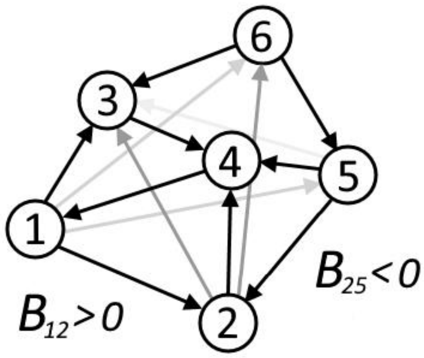

Figure 2.2: Schematic representation of interconnecting nodes: Connections between nodes i and j with arrows indicating non-zero connection strengths B_{ij}. The direction of the arrows determines the sign of the connection strengths; when nodes are thought to be (as yet) unconnected, the arrows are absent, indicating a connection strength B_{ij} = 0. Connection strengths indicated by "darkness" (with black arrows denoting high-strength connections and lighter-colored arrows implying weaker connectivity).

Unlike a carefully outlined map of the internet, for example, the Process Physics model does not depict a pre-configured, fixed infrastructure on which dynamic signal traffic can be shuttled from source to destination, or from one address to the next. Rather, in Process Physics, what we usually like to think of in terms of "infrastructure" and "signal traffic," is ultimately one integrated network of activity patterns. In order to make this work, the relational matrix has to start evolving from an initially patternless, pregeometric vacuum-like stage in which pattern formation gets going as an *internal*, self-organizing process—not by feeding *external* signals into a pre-configured infrastructure (such as the physical communication network of the internet). Accordingly, in the early stages of running the model, the relational matrix will indeed look smooth and uniform all over. But once it picks up pace, quite some variability in connection strength will start to emerge—just from the continual accumulation of "micro-impacts" delivered by the repetitive cycling of the self-referential noise factor in the iterative update routine (see Figure 2.3).

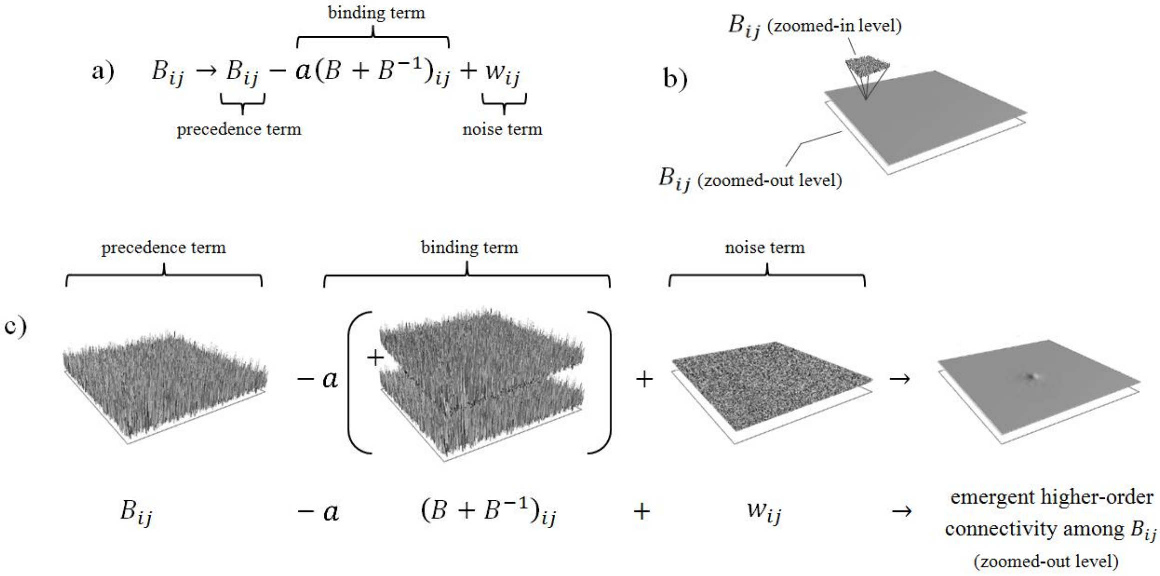

Figure. 2.3: Artistic visualization of the stochastic iteration routine (original images of noisy 3D surfaces: Bourke 1997): a) the here depicted noise-driven iterative routine can be subdivided into a precedence term, a binding term, and a noise term; b) At a coarse-grained level, the B_{ij} form a smooth and homogeneous 'indexing landscape' – this in line with the absence of connectivity. However, when zooming in onto a finer-grained level, the indexing landscape gives a much rougher and more spiky impression characteristic of randomness; c) The precedence, binding, and noise terms are visualized as 'indexing landscapes' thus forming a map of connection strengths.[11] Going through the iterations again and again will eventually lead to the formation of higher-order connectivity in a small region of the total indexing landscape.

---

[11] Please note that the noise employed in the Process Physics model is Gaussian white noise (which is also used to model thermal noise). See Klinger 2005, p. 165.

To put it more graphically, with each single iteration the relational network is blanketed with random, growth-decay inducing increments. As the matrix runs through its update cycles again and again, each time it basically adds a layer of noise over all individual connection strengths within the matrix. The preceding connection strengths of all member nodes in the relation matrix are represented by B_{ij} (old) which is called the *precedence term*. The following two terms are the *binding term* or *cross-linkage term*[12] and the novelty-infusing *noise term.* At first sight, these two terms mostly seem to cancel each other out. However, in the longer run, there will be enough reactive low-grade activity patterns to enable the emergence of a complexly outward-branching network of higher-order process-structures.

"Landscape of Connection Strengths"

As the system goes through its iterations, the precedence term, the cross-linkage term, and the noise term will together give rise to a constantly fluctuating "landscape of connection strengths"—resulting from cumulative noise that gives rise to progressively correlating activity patterns. Some entries become large because of the cumulative effect of the iterative update routine.[13] These large connection strengths tend to hook up together to form islands of elevated connectivity (see figure 2.4). As the relational network has reached this stage, these islands with large-valued connections can be submitted to statistical analysis so that the global pattern to their behavior can be studied in more detail.

---

[12] This binding or cross-linkage term can be thought of as a realization of Mach's principle. See Klinger 2016, p. 168. In this principle, Ernst Mach claimed that local inertial effects are actually caused by the large-scale distribution of matter: "The inertial motion of a body is influenced by all the masses in the universe." Goenner 1995, p. 442. The binding term pays heed to Mach's principle as it links all activity patterns within the Process Physics model with each other.

[13] This cumulative effect works both ways: positively and negatively. Because the noise can *add to* as well as *subtract from* the gradually forming network of connectivity, it is strengthened and weakened in a dynamic, self-organizing way so that the system develops a growth-decay regime with all the hallmarks of Self-Organized Criticality.

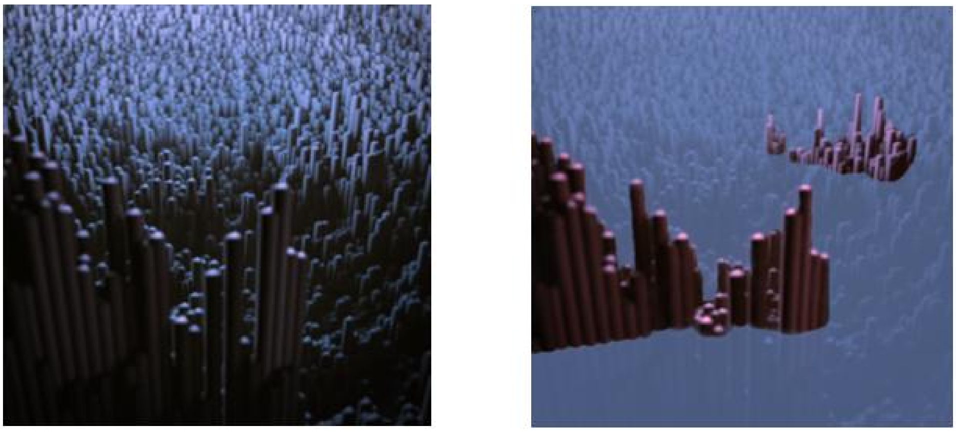

Figure 2.4: Landscape of connection strengths: Foreground patterns with elevated connectivity can be submitted to statistical analysis by choosing an appropriate lower threshold of connection strength below which no data will be taken into consideration. By changing the threshold different features of foreground and background activity patterns can be found, such as the "refresh rate," i.e., the rate at which lower-order connectivity nodes may renew the constituent components of higher-order process-structures.

This statistical analysis basically amounts to counting the total number of member nodes in those islands, after which one reference node can be chosen to see how many neighbors are nearest neighbors, how many are second nearest neighbors, how many are three connections away, and so on. Now, the distance-to-strength ratio for connectivity nodes tells us that the overwhelming majority is formed by weak, short-distance connections and only a minute fraction is made up by strong long-distance connections (see Table 2.3).

	low connection strength	**medium connection strength**	**high connection strength**
short-distance	massive majority	few	scarce
medium-distance	few	scarce	very, very scarce
long-distance	scarce	very, very scarce	extremely scarce

Table 2.3: The amount of connections arranged by distance and connection strength

In the islands of elevated connectivity this translates into short-distance, local connections being the most probable ones, which then automatically leads to tree-graph-like branching structures as displayed in figure 1.4. Since this will be the most probable configuration that will occur, the connectivity nodes within these branching structures will most likely organize themselves into a near-3-dimensional distribution relative to one another. That is, the branching structures will end up getting the same distance distribution among their nodes as uniformly arranged points in a three-dimensional space—thus forming what may be called "gebits" (geometry bits) (Cahill 2003a, pp. 24–28). This can be found because the amount of neighbors for our chosen reference node turns out to increase in proportion to the square of the number of steps away—something which is only seen to occur in three-dimensional spaces (Chown 2000, p. 28; Cahill 2003a, pp. 25-27).

Emergent 3D Network of Branching Structures and the Appearance of Matter

What eventually arises from the iterations of the stochastic update routine is in fact emergent three-dimensionality from initial non-connectivity. The different branching structures basically grow to become embeddable in 3D—as cell-like subnetworks. The 3-dimensional, cell-like distribution of activity patterns is illustrated in Figure 2.5 below. It needs to be stressed, however, that these visualizations are of course merely artistic impressions.

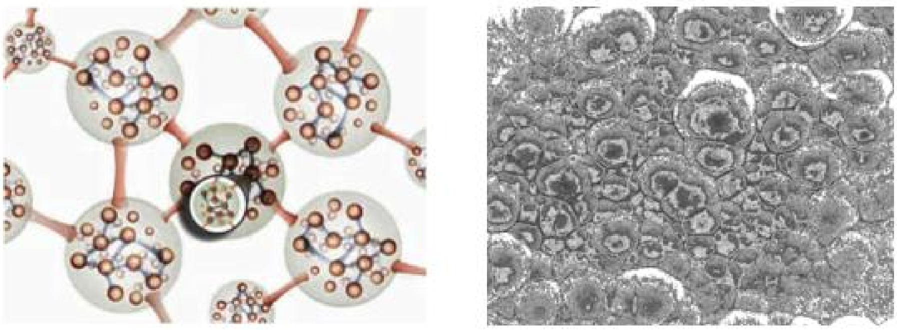

Figure 2.5: Emergent 3D-network of nodes with inner and outer branching structures: The illustration on the left-hand side shows fractal structuration with inner and outer connectivity of nodes (thus forming branching structures). The visualization on the right-hand side depicts the connectivity network as a flow system of Prigoginean dissipative structures (original image left: Cahill 2003a, p. 30; right: Cahill 2016, p. 7).

A rather interesting feature of these branching structures is that similar-sized ones are more likely to hook up together because they do not engulf each other—as larger-sized branching structures would do with any smaller filaments in their vicinity. Instead, among equals, they tend to grow together and form more durable connections.

Similar to what happens in the formation of neural pathways, the growth and decay of network connections occurs as earlier grown islands of connectivity and branching structures are being strengthened and weakened by the continuous addition of noisiness. As this goes on for long enough, each locality within the network will become so much correlated with the rest of the system that it can be thought of as having a local sense of how to contribute to system-preserving criticality. As such, we may say that there is an acquired dispositional preference—active within and among these branching structures—to reach out and connect among each other. This can be seen as a very primitive sense of choice—an inherent, rudimentary form of subjectivity that is ultimately both ecological and primordial.

This, by the way, is very much in line with Thomas Nagel's hope for a more comprehensive account of evolution that is "no longer exclusively materialist, but that retains the Darwinian structure" (Nagel 2012, p. 74) so that it will be able to extend the "reach" of evolution from the limited confines of the earth's biosphere to nature as a whole.

Next to this remarkable feature of proto-subjectivity, the Process Physics model also gives rise to matter-like behavior. To be more specific, certain activity patterns within the relational network will start to exhibit a kind of "tangled connectivity" within themselves, thus leading to durable, densely packed process-structures that the system cannot get rid of. Although these process-structures constantly get renewed on lower-order levels of organization, they maintain the same overall pattern higher up.

These process-structures can be thought of as "trapped information within the system" or as "overconnected space" (Cahill, 2005, p.16-17) that cannot be smoothened out in any way as the involved activity patterns more or less "got stuck" within themselves. On close enough scrutiny, therefore, this overconnectivity can be equated with matter as it bears all the hallmarks of physical stuff, like, for instance, object-like corporality, solidity, a highly long-lasting permanence, and a relative separateness from the environment.

Gravitation as a Process-Informational In-flow Effect

Now, what is perhaps of even more interest is that these overconnected "clusterings" of activity patterns (also called "topological defects") routinely swallow up the smaller "islands of connectivity" in their vicinity. Because of this, a distinct in-flow effect can be seen to occur:

> …because these defects have a different structure to space their gebit[14] refreshment / replacement rate will be different from that of space, and … the net effect of these different replication rates is that space will essentially flow into matter." (Cahill 2005, p. 17)

Remarkably, this dynamic in-flow effect has a striking resemblance with our well-known, but still not completely understood, phenomenon of gravity in nature. So, by interpreting gravity as the "ingestion" of relational information into higher-order patterns of overconnectivity, we can start to look at it in a different way: *not* as being caused by stiff, curved geometry, as Einstein would have it, but as the loss of relational information that takes place due to the dynamic in-flow process.

Recent developments in gravitational physics seem to point in a similar direction. During the last International Whitehead Conference in Ponta Delgada, for instance, Timothy Eastman reminded me that there may well be a Whiteheadian link between Process Physics and Erik Verlinde's work on an alternative theory of gravitation (See Eastman 2016, p. 226;

---

[14] As explained above, these "gebits" are connectivity nodes whose internal connectivity takes on an emergent 3D distribution among each other, thus serving as "bits of space geometry."

Bettinger 2015). Verlinde managed to draw quite some attention with his 2016 paper "Emergent Gravity and the Dark Universe" in which he claimed to have found an alternative theory of gravitation that had no need for any hypothetical dark matter. And it must indeed be said that, although he takes an entirely different approach than Process Physics,[15] some of Verlinde's conclusions are remarkably similar:

> In particular, it suggests that the microscopic constituents from which spacetime emerges should be thought of as basic units of quantum information whose short-range entanglement … provides the microscopic "bonds" or "glue" responsible for the connectivity of spacetime. (Verlinde 2016, p. 3)

In a nutshell, Verlinde takes gravity to be a side-effect of quantum interactions. Accordingly, what has become known as *dark matter*—the apparent "extra" gravity behind the high orbital speeds in spiral galaxies—should simply be seen as a byproduct of *dark energy*—the background energy that, in his view, is intimately tied in with the cosmic fabric of spacetime (Verlinde 2016, p. 5–7). Furthermore, similar to what follows from Process Physics, Verlinde also claims that our universe has a deeply informational essence, that it exhibits emergent gravity, and that dark matter is only an apparent phenomenon, not a real one.

It can be argued, however, that Verlinde's work does not reach the same depth as Cahill's. That is, since Verlinde associates information with matter and its location and

[15] The similarities between the work of Reg Cahill and Erik Verlinde make it more plausible that the idea of gravity as an in-flow effect does indeed point in the right direction. Long before Verlinde, however, Cahill already endorsed a (process-)informational universe—without any unexplained dark matter or dark energy and with an emergent process-space, rather than Verlinde's holographically emerging spacetime (encoded on an a priori 2-dimensional holographic screen; see Verlinde 2010, 6-7). Also, in stark contrast with Process Physics, Verlinde's work is still very much couched within the exophysical-decompositional paradigm. He interprets gravity to be an entropic force between matter in an informational universe, but he still proposes a law-like physical equation that merely offers us a measurement phenomenology. That is, it provides us with a law-like algorithm capable of reproducing the well-refined, state-of-the-art data of our cosmological observations. And as discussed in detail earlier in this paper, such law-like physical equations bring along a lot of foundational problems. Moreover, it first requires the hypothesis that gravity is an entropic force, after which the equation is supposed to prove what it implicitly already presumes. Such circularity is basically inherent in the very methodology of "doing physics in a box." Process Physics, on the other hand, models the processual informativeness of the system itself and thereby manages to go beyond mere phenomenal description while avoiding the above-mentioned vicious circularity due to its bootstrapping procedure which gives it "foundations without foundations," so to say.

movement within space (Verlinde 2010, pp. 2, 6), it cannot go beyond phenomenology. In other words, whereas his formula does indeed seem to offer an empirically adequate measurement phenomenology—i.e., a mathematical equation capable of closely keeping track of the observational data without any appeal to hypothetical dark matter—it does not offer a modeling of nature that goes all the way down. That is, by invoking Gerard ‘t Hooft’s holographic principle (’t Hooft 1993), Verlinde merely shifts the burden of explanation one level downward. Without thinking too much of it, he simply shoves it over to the 2-dimensional holographic screen on which he thinks that the fabric of spacetime, including the matter within it, is encoded. This, in my view, amounts to Whitehead’s fallacy of misplaced concreteness. That is, by looking at nature purely in terms of “information-for-us,” Verlinde just ends up positing yet another layer of abstraction in order to find a physical equation for our as yet unaccounted-for empirical data. However, Verlinde might better have taken John Archibald Wheeler’s advice that physics should avoid a potentially infinite regress of would-be elementary constituents and that it should reject any presupposed *n*-dimensional space or pre-existing time as well (Wheeler 1999, p. 310). But instead, by relying on the holographic principle, Verlinde already seems to presume what he aims to demonstrate, namely, that nature must consist of quantum-informational qubits hustling around on an underlying holographic screen. He doesn’t seem to realize, however, that this scheme simply equates “information-for-us” with “information-for-the-process-itself.” It synonymizes qubits (i.e., measurement phenomena) with the “sub-phenomenal existents” of nature itself, thus taking far too literally Wheeler’s mantra *It from Bit* (Wheeler 1999, p. 310n 22)

Process Physics, on the other hand, is capable of modeling its activity patterns “on the same level as nature itself,” so to say, thereby basically realizing a “beable-like” modeling (Bell, 1988, pp. 52–62, 173–180) instead of the “observable-based” modeling of our contemporary mainstream physics. On top of this crucial asset—which is made possible by its unique way of doing physics without a box—Process Physics manages to shed new light on many other features of nature as well. At the end of the day, the Process Physics network gives rise to not only matter-like behavior and a gravitational effect, but also to non-locality, emergent relativistic and inertial phenomena; inherent creative novelty; process-based temporality with open-ended evolution, and more (Cahill 2003a, pp. 111–115; Van Dijk 2017, p. 11).

Conclusion

Let's recap: Process Physics can be contrasted with our familiar way of doing physics in several ways. Whereas our contemporary mainstream physics can be characterized as a nature-dissecting, subjectivity-excluding way of "doing physics in a box," Process Physics can be considered a nondecompositional, subjectivity-including way of "doing physics *without* a box." It can be thought of that way since it revolves around habit-establishing "routine of nature" that leaves its marks in the "initial randomness," or "primordial chaos" from which the "nature-mimetic" modeling of Process Physics starts. In this way, it differs from doing physics in a box because the latter avails itself of "laws of nature" that start from "initial conditions." The problem with this method, however, is that the question of "why these laws and initial conditions?" will always remain unanswered because the laws and the starting conditions are axiomatic to the methodology which means that any meta-questions cannot be answered within the system itself.

Other problems of our current mainstream physics are: (1) it cannot go beyond its measurement phenomenology (it models empirical data, rather than nature itself); (2) it is life-neglecting (as it basically thinks of nature as an entirely physical, insentient world); (3) it is based on mechanistic and deterministic modeling methodologies (due to its dependence on "regularity-backtracking" algorithms). Process Physics has been shown to circumvent these problems by setting up a self-organizing network of mutually informative activity patterns that evolve from initial randomness to higher-order complexity as even the slightest fluctuations within the system make a non-negligible difference to all else.

In this way, the Process Physics model evolves, firstly, from a pregeometric pre-space where there is initially no manifest patterning, towards an early universe with emergent three-dimensionality and a relatively uniform distribution of matter. In the long enough run, then, this will eventually take on the shape of a rich, complex neural-network-like cosmic web in which life is a natural outgrowth of the system's earliest organismic activity patterns.

Hence, from this we can derive that nature should be treated as an entirely processual and undivided whole. Some may argue that several interpretations of quantum mechanics (e.g., the Copenhagen interpretation and David Bohm's holistic "pilot wave" interpretation) have already taken significant steps in the direction of undivided wholeness as well. Moreover, Jesse Bettinger's noteworthy attempt to give a Whiteheadian interpretation of Verlinde's work seems to aim for the same goal (Bettinger, 2015). A fully complete turn towards universal processuality and undivided wholeness, however, should not just be made by means of interpretation. Adding a holistic interpretation as a mere "aftermath extension" to an earlier formulated mathematical equation is like trying to glue nature back together into one, whereas it should not have been broken down to pieces in the first place (Van Dijk 2017, pp. 63, 100,189).

Hence, in my opinion, this turn towards holism should be made by setting up a nonexophysical-nondecompositional physics—a way of "doing physics without a box"—so that nature isn't unduly dissected into system-to-be-observed, its designated subject system, and their supposedly negligible surroundings. And now, with Reg Cahill's Process Physics, it looks as if such a nondecompositional way of doing physics—one that does not fall in the trap of these problematic dissections—has finally arrived.

By setting up a modeling method that is based on “routine of nature” and “initial, system-wide randomness,” instead of “laws of nature” and “initial conditions,” Process Physics offers a realistic alternative to the currently dominant way of doing physics which simply resorts to cutting up nature into pieces and then trying to “stitch” them together again through interpretation, while hoping that nothing got lost during this whole “surgical procedure.”

Fortunately, however, by modeling nature without first decomposing it into all kinds of oversimplified constituents, Process Physics manages to avoid all the problems caused by taking on an external, nature-dissecting perspective onto our natural world. In so doing, Process Physics circumvents many of the problems that contemporary mainstream physics has to face—problems like the explanatory gap between mind and brain (Velmans 2009, pp. 306–313), the systematic neglect of lived subjectivity in the physical sciences, the bifurcation of nature (Whitehead 1938, 173–232) the cosmological fallacy (Smolin 2013, p. 97; Rosen 2010, p. 72), the troublesome origination story behind the laws of nature (Smolin 2013, pp. 97–98; Van Dijk 2017, p. 8), the physicist’s fallacy (Van Dijk 2017, p. 175), and so on.

The history of science has known many attempts to solve these and other problems, but up to now a real breakthrough solution has never been found. It’s only natural, therefore, that any newly proposed modeling of nature that promises a final cure will be looked at with great skepticism. So, there’s definitely a downside to proposing, as Process Physics does, such a radical rethinking of our way of doing physics: It will typically lead to a lot of initial misunderstanding.

On the upside, however, the introduction of Process Physics does not at all mean that we should as soon as possible get rid of doing physics in a box. On the contrary: Although Process Physics primarily deals with foundational physics, it can also be applied to all kinds of practical problems relating to physics and engineering, like getting our GPS-devices to work properly (Cahill 2003b), or finding a new framework for developing bio-analogous quantum computers (Cahill 2002). But in order to get these practical applications up and running, Process Physics has to rely on quantitative analyses, physical equations and other conventional physics methodologies. Furthermore, Process Physics needs our conventional physics to judge it against previously acquired insights and our well-tried and tested way of doing physics in a box is suitably equipped to do just that. On the other hand, insights from Process Physics may very well be applied in our familiar nature-dissecting physics as well, so that we eventually end up with a "binocular physics" (Van Dijk 2017, p. 99–100), which should ideally give us the best of both worlds.

The interplay between Process Physics and Verlinde's gravitational physics is in fact an excellent example of such "binocularity." It gives us two different angles on the same phenomenon of gravity: On the one hand, the Process Physics method gives us a view from within, thus providing us with a sense of how nature works based on what happens *inside* the process itself. On the other hand, Verlinde's gravitational physics offers us an external view—as seen by a faraway observer located *outside* the actual phenomena of interest.

As has become clear from our discussion above, such an outward perspective typically comes with a considerable amount of abstraction and simplifying idealization. In the spirit of binocular physics, however, we should keep an open mind and try to compare the differences and similarities between Verlinde's Emergent Gravity and Cahill's Process Physics without prejudice. After all, a two-eyed view should arguably add more depth and texture to our understanding of hitherto insufficiently understood phenomena like gravity. Such an approach could very well lead to creative new solutions or telling clues as to how nature might hang together as a whole. A major insight that can arguably be gained by way of this binocular approach, then, is that gravity—although it may perhaps be explained as an entropic force when looking at distant gravitational phenomena *from the outside*—should really be thought of as a system-intrinsic in-flow effect (Cahill 2003a, pp. 12, 37).

On top of all this, there are still some further conclusions that may be drawn:

- Nature should best be seen as a unique, habit-establishing and noise-driven totality. This makes it impossible to wrap it up into algorithm-based laws of nature. This means, that nature should in fact be thought of as a lawless whole that is essentially unfit to be compressed into lawful algorithms.

- Mutual informativeness, not empirical data, is central to Process Physics. Elevating data-compliant algorithms to the status of laws of nature basically amounts to treating nature as synonymous with the empirical data that we extract from it through observation. This, however, may lure us into thinking that our laws of nature are in fact eternal, objective truths that existed even before the earliest beginnings of our universe and that these laws were actually responsible for calling nature into existence. But because this line of reasoning brings along more problems[16] than it solves, it is far better to opt for the alternative solution of routine-driven self-organization that Process Physics has to offer.

- Process Physics is an utterly ecological physics in that there is no presumed separation between target world, subject side and their entire ambient environment. The Process Physics model does not *neglect*, but *includes* all environmental activity patterns. Next to this, it turns out that primordial subjectivity—in the form of system-wide mutual informativeness and the dispositional preference of connectivity nodes to hook up with kindred ones—naturally emerges in the Process Physics model as an early, deeply embedded aspect of its self-organizing network of connectivity.

[16] These involve problems like the absence of a proper origination story of the laws and initial conditions themselves, cosmological fallacy, physicist's fallacy, bifurcation of nature, the explanatory gap between mind and brain, as mentioned above.

- This finding of primordial subjectivity suggests that nature is much more mind-like than we usually like to admit in the physical sciences. That is, from its earliest of beginnings our universe exhibits proto-subjectivity in the sense that even its most initial activity patterns have a dispositional preference of how to connect among each other.
- Process Physics is life-centric and organismic in that the relational activity patterns within the Process Physics model are seamlessly interconnected, integrated endo-processes of the greater omni-process which is the connectivity network as a whole. Both foreground and background patterns of connectivity are constantly engaged in giving shape to each other's further evolution. All activity patterns participate in the greater embedding process of self-organizing habit formation, while this overarching process itself will in turn modulate the future development of all activity patterns that participate in it. Furthermore, the Process Physics model is capable of going beyond the mechanicism and determinism of mainstream physics through the activity of its stochastic update routine which constantly infuses the relational network with creative novelty. Also, because an embryonic form of subjectivity is a natural consequence of the Process Physics methodology, and because the habit-establishing update routine of Process Physics spontaneously steers its patterns of connectivity towards a neural-network-like organization, it can also be considered to have a natural propensity to develop in the direction of further bio-analogous pattern formation.

References

Bell, John Stewart. 1988. *Speakable and Unspeakable in Quantum Mechanics*. Cambridge: Cambridge University Press.

Bell, John Stewart. 1990. Against 'Measurement.' *Physics World*: 33–40.

Bettinger, Jesse. 2015. *The Founding of an Event-Ontology: Verlinde's Emergent Gravity and Whitehead's Actual Entities*. PhD Dissertation. Claremont Graduate University.

Bourke, Paul. 1997. Online Gallery of Noise Frequency Spectra. http://paulbourke.net/fractals/noise/. Accessed and edited 10 July 2016.

Cahill, Reginald T. 2002. Synthetic Quantum Systems. arXiv:physics/0209064v1

Cahill, Reginald T. 2003a. Process Physics: From Information Theory to Quantum Space and Matter. *Process Studies Supplements* 5: 1–131.

Cahill, Reginald T. 2003b. Quantum Foam In-Flow Theory of Gravity and the Global Positioning System (GPS). arXiv:physics/0309016

Cahill, Reginald T. 2005. Process Physics: Self-Referential Information and Experiential Reality. *Conference on Quantum Physics, Process Philosophy, and Matters of Religious Concern*. Claremont, CA: Center for Process Studies (September 28–October 2).

Cahill, Reginald T. 2016. Guide to Dynamical Space and Emergent Quantum Gravity: Experiments and Theory. https://vixra.org/pdf/1603.0389v3.pdf. Accessed 25 October 2020.

Cahill, Reginald T., and Christopher M. Klinger. 1996. Pregeometric Modelling of the Spacetime Phenomenology. *Physics Letters A*., 223.5: 313–319.

Cahill, Reginald T., and Christopher M. Klinger. 2000. Self-Referential Noise and the Synthesis of Three-Dimensional Space. *General Relativity and Gravitation* 32.3: 529–540.

Cahill, Reginald T., and Christopher M. Klinger. 2000. Self-Referential Noise as a Fundamental Aspect of Reality. *Proceedings of the 2nd International Conference on Unsolved Problems of Noise and Fluctuations*. New York: American Institute of Physics.

Cahill, Reginald T., and Christopher M. Klinger. 2005. Bootstrap Universe from Self-Referential Noise. *Progress in Physics* 2: 108–112.

Cahill, Reginald T., Christopher M. Klinger, and Kirsty Kitto. 2000. Process Physics: Modelling Reality as Self-Organising Information. *The Physicist* 37.6: 191–195.

Chaitin, Gregory J. 2007. Leibniz, Information, Math & Physics. In Chaitin, Gregory J. *Thinking about Gödel and Turing: Essays on Complexity, 1970-2007*, 227-240. Singapore: World Scientific.

Chown, Marcus. 2000. Random Reality. *New Scientist*: 25–28.

Eastman, Timothy E. 2016. On Process Physics. In *Physics and Speculative Philosophy: Potentiality in Modern Science*, ed. Timothy Eastman, Michael Epperson, and David Ray Griffin. 221–230. Berlin: Ontos Verlag.

Edelman, Gerald, and Giulio Tononi. 2000. *Consciousness: How Matter Becomes Imagination*. London: Allen Lane.

Floridi, Luciano. 2013. *The Philosophy of Information*. Oxford: Oxford University Press.

Goenner, Hubert F. M. 1995. Mach's Principle and Theories of Gravitation. In *Principle: From Newton's Bucket to Quantum Gravity* (*Einstein Studies*, *Vol. 6*), ed. Julian Barbour and Herbert Pfister, 442–457. Boston: Birkhauser.

Heisenberg, Werner. 1958. *Physics and Philosophy: The Revolution in Modern Science*. New York: Harper & Row, Publishers.

't Hooft, Gerard. 1993. Dimensional reduction in quantum gravity. *Conference on Highlights of Particle and Condensed Matter Physics (SALAMFEST)*. *Conf. Proc. C* 930308: 284–296.

Hunt, Tam. 2014. *Eco, Ego, Eros: Essays in Philosophy, Spirituality and Science*. Santa Barbara: Aramis Press.

James, William. 2007. *The Principles of Psychology*, *Vol. 1* (1890). New York: Cosimo Classics.

Kauffman, Stuart. 1995. *At Home in the Universe: The Search for the Laws of Self-Organization and Complexity*. Oxford: Oxford University Press.

Klinger, Christopher M. 2005. *Process Physics: Bootstrapping Reality from The Limitations of Logic*. PhD-dissertation. School of Chemistry, Physics, and Earth Sciences. Faculty of Science and Engineering. Adelaide: Flinders University. (Also available as a book, published in Saarbrucken: VDM Verlag, 2010.)

Klinger, Christopher M. 2016. On the Foundations of Process Physics. In *Physics and Speculative Philosophy: Potentiality in Modern Physics*, ed. Timothy E. Eastman, Michael Epperson, and David Ray Griffin, 143–176. Boston: Walter de Gruyter.

Nagel, Thomas. 2012. *Mind and Cosmos: Why the materialist neo-Darwinian conception of nature is almost certainly false*. Oxford: Oxford University Press.

Rosen, Joe. 2010. *Lawless Universe: Science and the Hunt for Reality*. Baltimore: Johns Hopkins University Press.

Schrödinger, Erwin. 1958. *Mind and Matter.* Cambridge: Cambridge University Press.

Smolin, Lee. 2013. *Time Reborn: From the Crisis of Physics to the Future of the Universe*. London: Allen Lane.

Smolin, Lee. 2019. *Einstein's Unfinished Revolution: The Search for What Lies Beyond the Quantum*. New York, Penguin Press.

Thayer, Lee. 2011. *Explaining Things: Inventing Ourselves and Our Worlds*. Bloomington, IN: Xlibris Corporation.

Tononi, Giulio. 2008. Consciousness as Integrated Information: A Provisional Manifesto. *Biological Bulletin* 215: 216-242.

Van Dijk, Jeroen B. J. 2017. Process Physics, Time, and Consciousness: Nature as an Internally Meaningful, Habit-Establishing Process. *Process Studies Supplements* 24.

Velmans, Max. 2009. *Understanding Consciousness (2nd edition)*. London and New York: Routledge.

Verlinde, Erik P. 2016. Emergent Gravity and the Dark Universe. https://arxiv.org/abs/1611.02269. Accessed 14 March 2018.

Verlinde, Erik P. 2010. On the Origin of Gravity and the Laws of Newton. https://arxiv.org/abs/1001.0785. Accessed 14 March 2018.

Vygotsky, Lev S. 2013. Thought and Word. In *The Essential Vygotsky*, ed. Robert W. Rieber, David K. Robinson, 65–110. New York: Springer Science & Business Media.

Wheeler, John Archibald. 1980. Law without Law. In *Structure in Science and Art*, ed. P. Medawar and J. Shelley, 132–154. Amsterdam: Elsevier.

Wheeler, John Archibald 1990. "Information, Physics, Quantum: The Search for Links." In *Feynman and Computation: Exploring the Limits of Computers*, ed. Anthony Hey, and Richard P. Feynman, 309–336. Cambridge, MA: Perseus Books.

Whitehead, Alfred North. 1920. *The Concept of Nature*. Cambridge: Cambridge University Press.

Whitehead, Alfred North. 1938. *Modes of Thought*. New York: Macmillan.

Whitehead, Alfred North.1978. *Process and Reality: An Essay in Cosmology*. Corrected edition, David Ray Griffin and Donald Sherburne. New York: Free Press.

Ulanowicz, Robert. 2009. *The Third Window: Natural Life beyond Newton and Darwin*. West Conshohocken, PA: Templeton Foundation Press.