SYSTEMS AND PROCESS METAPHYSICS

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Systems engage in various kinds of processes, so it might seem that a process metaphysics would be a natural approach to complex systems. Indeed it is, but systems are usually construed in terms of the interactions of parts that are not themselves modeled as systems or processes. The parts collectively form the stable base among which the system processes occur. Adopting a genuine process metaphysics, however, forces more fundamental changes in approaches to complex systems:

It overturns several standard conceptual and explanatory defaults, and
It enables posing and exploring new questions and explanatory frameworks.

A BRIEF HISTORY

Process conceptions of the world have had a presence in Western thought at least since Heraclitus, but have been dominated and overshadowed by substance and atomistic metaphysical frameworks at least since Empedocles and Democritus. In fact, Parmenides argued against Heraclitus that, far from everything being flux, change is not possible at all: in order for A to change into B, A would have to disappear into nothingness and B emerge out of nothingness. Nothingness does not exist, so change does not exist. The nothingness that Parmenides was denying perhaps has a contemporary parallel in the notion of the nothingness outside of the universe (vacuum is not nothingness in this sense). It is not clear that such a notion makes any sense, and this was roughly the Parmenidean point. Furthermore, for the ancient Greeks, to think about something or to refer to something was akin to pointing to it, and it is not possible to point at nothing. For a modern parallel to this, consider the difficulties that Russell or Fodor (and many others) have had accounting for representing nothing or something that is false [Hylton, 1990].

In any case, Parmenides' argument was taken very seriously, and both the substance and the atomistic metaphysical frameworks were proposed as responses. Empedocles' substances of earth, air, fire, and water were unchanging in themselves, thus satisfying the Parmenidean constraint, and Democritus' atoms were similarly unchanging wholes [Graham, 2006; Guthrie, 1965; Wright, 1997]. In both cases, apparent changes were accounted for in terms of changes in the mixtures and structural configurations of the underlying basic realities.

Plato and Aristotle also took these issues very seriously. Aristotle, in particular, developed a very sophisticated framework in which what he called earth, air, fire,

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and water could transform into each other [Gill, 1989], but there remained an underlying unchanging, thus Parmenidean satisfying, substrate of prime matter.[1]

These are the traditions that have dominated for over two millennia, and in many respects, still do. There is, however, a historical move away from substance models toward process models: almost every science has had an initial phase in which its basic phenomena were conceptualized in terms of some kind of substance — in which the central issues were to determine what kind of substance — but has moved beyond that to a recognition of those phenomena as processes. This shift is manifest in, for example, understanding fire in terms of phlogiston to understanding fire in terms of combustion, heat in terms of random kinetic motion rather than the substance caloric, life in terms of certain kinds of far from thermodynamic equilibrium processes rather than in terms of vital fluid, and so on. Sciences of the mind, arguably, have not yet made this transition [Bickhard, 2004] — I will have more to say about this below.

As mentioned, however, a thorough shift to a process metaphysical framework involves some deep and ramified conceptual changes in explanatory defaults and frameworks for questions. In this chapter, I will be outlining several of these.

1 THREE CONCEPTUAL SHIFTS

I begin with three basic consequences of substance frameworks, and their reversal in process approaches.

1.1 From stasis to change

The default for substances and Democritean "atoms" is stability. Change requires explanation, and there are no self-movers. This is reversed in a process view, with change always occurring, and it is the stabilities of organizations or patterns of process, if such should occur, that require explanation.

There are two basic categories of process stability. The first is what might be called energy well stabilities. These are process organizations that will remain stable so long as no above threshold energy impinges on them. Contemporary atoms would be a canonical example: they are constituted as organizations of process that can remain stable for cosmological time periods.

The second category of process stability is that of process organizations that are far from thermodynamic equilibrium. Unlike energy well stabilities, these require ongoing maintenance of their far from equilibrium conditions. Otherwise, they go to equilibrium and cease to exist.

Also in contrast to energy well stabilities, far from equilibrium stabilities cannot be isolated for significant periods of time. If an energy well stability is isolated, it goes to internal thermodynamic equilibrium and retains its stability. If a far from

[1] There are contemporary interpretations of Aristotle that do not attribute Prime Matter to him, but the assumption of an underlying unchanging substrate for change is maintained (e.g., [Gill, 1989, 2005]).

equilibrium process organization is isolated, it goes to equilibrium and ceases to exist.

Far from equilibrium processes can exhibit self-organization, in which pattern emerges as an intrinsic result of underlying processes. Such resultant self-organized patterns can be of fundamental importance in, for example, the self-organization of tissue differentiation in embryos.

Some systems self-organize in ways that result in making contributions to their own far from equilibrium stability — they contribute to their own maintenance, hence are (partly) *self maintaining*. A canonical example would be a candle flame: the flame organizes (and is constituted by) a flow of air that brings in fresh oxygen and gets rid of waste. The organization is driven, in standard conditions, by the maintenance of above combustion threshold temperature, which melts wax that can then percolate up the wick, and vaporizes wax in the wick which can then burn in the incoming air.

Still more complex systems can vary their activities in accordance with changes in their environment, or in their relationships with their environment, so that the condition of being self-maintaining is itself maintained: they are in this sense *recursively self-maintenant*. A canonical example would be a bacterium that can swim if it is headed up a sugar gradient and tumble if it is oriented down the gradient. The two activities make self maintenant contributions, but in differing circumstances.

Recursive self maintenance requires some sort of infrastructure for detecting relationships with the environment and for switching among available activities. Such infrastructure may itself be of energy well stability form, but in most living examples, it too is necessarily open system far from equilibrium process. It functions as infrastructure in virtue of cycling on slower time scales than processes such as detection and switching.

In complex living systems, the maintenance of infrastructure (metabolism) and the interactions with the environment that support overall self maintenance constitute *autonomy*. Autonomy, in this sense, is a graded phenomenon, with self maintenance and recursive self maintenance constituting the broadest and potentially simplest kinds. Autonomy is the property of being able to exploit the environment in the service of self maintenance — in the service of the stability of the far from equilibrium process organization [Bickhard, 2004; Christensen and Bickhard, 2002; Christensen and Hooker, 2000].

1.2 From unalterability to emergence

Empedoclean earth, air, fire, and water not only cannot change into one another, it is not possible to generate an emergent fifth substance. Reasonably so, since emergence was one of the phenomena that such a metaphysical framework was introduced in order to preclude.

Hume

A manifestation of this point that has been of fundamental historical importance is Hume's argument against the possibility of deriving norms from facts [Hume, 1978]. Hume argues that, if the premises of a valid reasoning contain only factual terms, then the conclusion can only involve factual terms. Therefore, no normative conclusions can validly be derived from factual premises.

The argument, as standardly rendered, is that any terms in the conclusion that are not already in the premises must have been introduced via definition, and the definitions must be in terms either of what is available in the premises or what has been previously defined in the course of the reasoning. In either case, any new terms in the conclusion can always be back-translated through their definitions, substituting the defining phrases or clauses for the defined terms, until all such new terms are eliminated in favor of those in the premises.

Since the premises, by assumption, contain only factual terms, via such a procedure any valid conclusion can also be stated in those same factual terms. Therefore, only factual conclusions can be validly derived from factual premises.

But Hume's argument depends on the assumption that definitions always permit back-translation, and this is false. In particular, implicit definition does not permit back-translation. Implicit definition has been on the scene for roughly a century, most forcefully introduced by Hilbert around the end of the 19^{th} century [Hilbert, 1971; Otero, 1970]. There has been a tendency to minimize or ignore it for various reasons, one of which is Beth's theorem which holds implicit definition and explicit definition to be of equal power [Doyle, 1985]. But Beth's theorem provides only an extensional equivalence of the two kinds of definition, and even that only in certain combinations of kinds of logic and classes of models [Kolaitis, 1990]. In general, implicit definition is often more powerful than explicit definition. For current purposes, it cannot be ignored [Bickhard, 2009a; in preparation; Hale and Wright, 2000; Quine, 1966; Shapiro, 1997; 2005] and it does not permit back-translation, so Hume's argument is unsound.

Note that Hume's argument, in its general form, precludes anything other than re-arrangements of terms already in the premises. In its general form, it precludes any kind of emergence, not just normativity. It is a manifestation of the restriction to combinatorics of a substance or atomistic metaphysical framework. But, because the argument is in fact invalid, this barrier to the metaphysical possibility of emergence is removed.

Jaegwon Kim

In modern form, this metaphysical block of emergence is perhaps most strongly argued for by Jaegwon Kim's argument that any higher level organization may well manifest its own particular properties of causal regularities, but that these will ultimately always and necessarily be causally epiphenomenal relative to the basic particles that are engaged in those processes. Particles are the only legitimate potential loci of causality; organization is the framework, the stage setting, in which the particles do their causal dance. Any manifestation of higher level organization is merely the working out of the particle interactions within that organization [Kim, 1991; 1998].

But, from the perspective of a process metaphysics, everything is process, and process is inherently organized. Furthermore, process has whatever causal powers that it does in part in virtue of its organization. In a process view, organization cannot be delegitimated as a potential locus of causality without eliminating causality from the universe.

But, if organization is a legitimate potential locus of non-epiphenomenal causality, then it is at least metaphysically possible that higher level organization, including that of brains, can exhibit interesting, important, and non-epiphenomenal emergences, such as, perhaps, various kinds of mental phenomena [Beckermann, Flohr, Kim, 1992; Bickhard, 2000; 2004; 2009a; in preparation; Teller, 1992].

In any case, the fundamental block against emergence that is inherent in substance frameworks is eliminated.

1.3 From a split metaphysics to potential integration

Positing a metaphysical realm of substances or atoms induces a fundamental split in the overall metaphysics of the world. In particular, the realm of substances or atoms is a realm that might be held to involve fact, cause, and other physicalistic properties and phenomena, but it excludes such phenomena as normativity, intentionality, and modality into a second metaphysical realm. It induces a split metaphysics.

Given such a split, there are only three basic possibilities — though, of course, unbounded potential variations on the three. One could posit some version of the two realms as fundamental, and attempt to account for the world in terms of them. Aristotle's substance and form, Descartes' two kinds of substances, Kant's two realms, and the realm of fact and science distinct from that of modality and normativity of analytic philosophy are examples. Or, one could attempt to account for everything in terms of the "mental" side of the split, yielding idealisms, such as for Hegel, Green, and Bradley. Or, finally, one could attempt to account for everything in terms of the physical realm, such as Hobbes, Hume (on many interpretations), Quine, and much of contemporary science and philosophy.

It might be tempting to try to account for the whole range of phenomena in terms of some kind of emergence of normative and mental phenomena out of non-normative phenomena, but emergence is excluded by the metaphysical frameworks that induce the split in the first place.

Adopting a process metaphysics, however, reverses the exclusion of emergence, and opens the possibility that normativity, intentionality, and other phenomena might be modeled as natural emergents in the world. This integrative program is, in fact, being pursued in contemporary work [Bickhard, 2004; 2009a; 2009b; in preparation].

2 SOME FURTHER CONSEQUENCES

The default of stasis, preclusion of emergence, and split into substance and normative realms are three of the most important consequences of the adoption of a substance or particle metaphysics — consequences that are undone by a shift to a process metaphysics. But they are not the only ones.

2.1 Barriers to further questioning

It makes no internal sense to ask why Empedoclean earth, air, fire, and water have the properties that they do, nor why they have the relationships among themselves, nor where they came from, and so on. They constitute a ground of metaphysics with which much can be done, but about which there is little that can be meaningfully questioned — at least from within that framework itself.

That has certainly not prevented such questioning, but the questions are necessarily of the metaphysical framework itself, not questions within that framework. This kind of barrier to further questioning is a further consequence that is reversed by the shift to a process framework. In general, it does make sense to ask of a process why it has the properties that it does or the relationships to other processes or where it came from. The possibility that the process in question is emergent from others by itself legitimates such questions as questions within the process metaphysical framework. Answers may or may not be discoverable, but there is no metaphysical barrier to asking the questions and seeking for answers.

2.2 Determinism and predictability

A process view lends itself naturally to consideration of chaotic dynamics, and, thus, to consideration of the differentiation between determinism and predictability that chaotic phenomena introduce: chaotic phenomena are fully deterministic, but cannot in principle be predicted into a far future, given any finite resolution of system state.

It should be noted, however, that this is a claim about the determinism and prediction of specific dynamic trajectories in full detail. Chaotic dynamics may well be predictable in more general senses, such as if the space of possible dynamic trajectories is organized into a few attractor basins, with, perhaps, chaotic attractors in those basins. Even in such a case, predictions about what the attractor possibilities are might be accurate.

2.3 Process physics

As mentioned, most sciences have made a historical shift from substance frameworks to process views of their subject matter. Sciences of mentality are delayed in this respect, possibly because the mental is the primary realm that encounters the split of normativity and intentionality from the rest of the world.

But the shift to process has also occurred in fundamental physics, so a shift to a metaphysics of process is consistent with and lends itself to consideration of this property of contemporary physics. In particular, according to quantum field theory, there are no particles. Everything is organizations of quantum field processes, and particle-like phenomena are results of the quantization of quantum field processes [Cao, 1999; Clifton, 1988; Halvorson and Clifton; 2002; Huggett, 2000; Kuhlmann, Lyre, Wayne, 2002; Weinberg, 1977]. This is akin to the quantization of the number of waves in a guitar string, and similarly gives no basis for assuming particles — there are no guitar sound particles, and no quantum field particles either. Everything is stable (or not so stable) organizations of processes.

We know, of course, that contemporary physics is incomplete and has to be wrong in crucial respects. But a return to a substance or particle framework is precluded by the empirical confirmation of multiple non-localities, and dynamic space-time and vacuum effects. Such phenomena are not consistent with the local independence and fixedness of particles and substances.

2.4 Thermodynamics

Thermodynamics does not require a process metaphysics, but a process framework puts thermodynamic considerations at the center of metaphysical issues. The distinction between energy well forms of stability and far from equilibrium forms of stability, for example, is an explicitly thermodynamic distinction. Elsewhere, it is argued that these distinctions underlie the basic emergences of normative biological function, intentionality, and other normative phenomena.

2.5 Historicity

'indexbiosphere Taking a process view permits new kinds of explorations of, for example, self-organization. If processes of self-organization are temporally extended, they may manifest powerful dependencies of later organization on earlier organization. That is, they may manifest powerful historicities.

The self-organization of the biosphere, maintained in a far from equilibrium condition for billions of years by the sun, with natural selection constituting the local processes by which that self-organization is driven, is a primary realm, though certainly not the only realm, of such historicity. Macro-evolution is constrained and enabled by multifarious such historistic dependencies, including various kinds of individuation and encapsulization, reproductive modularizations, ecosystem interdependencies, and so on [Bickhard, in preparation; Bickhard and Campbell, 2003].

3 CHALLENGES

A process metaphysics puts many traditional assumptions into question. It is not always clear that the questions any longer make any sense, and often certain that neither they nor possible answers can be understood in traditional ways. A central class of these have to do with issues of boundaries and individuation.

3.1 Boundaries and individuation

Boundaries

In conjunction with thermodynamic considerations, a process metaphysics overturns standard assumptions about the individuation of entities in terms of boundaries. For open, far from equilibrium systems in particular, it is not clear what form such questions or their answers should take.

For example, what are the boundaries of a whirlpool or a hurricane? Or a candle flame? The candle flame is an interesting first focus: here we find various kinds of phase changes, such as between the region that engages in combustion and the region that feeds and cleans up after that combustion. It might seem that this is similar to the phase change boundary that individuates a rock, but note that a rock also has a co-extensive boundary at which it can be isolated, and also a co-extensive boundary at which it can be pushed. A candle flame has no clear boundary at which it can be isolated, though a distant boundary might permit it to continue for a time, and it has no boundary at which it can be pushed at all.

In many cases, it makes good sense to ask why there are any boundaries at all, and how the ones that do appear can be explained. In general, boundaries are put into question within a process framework in the same sense in which stability is put into question.

In the biological realm, boundary and individuation questions take the forms of: Why are there cells? Organisms? Species? Ecosystems? What creates and what maintains such boundaries? What different kinds of boundaries are there? Do they always, necessarily, exist? Such questions tend strongly to evoke classic canonical examples in which the answers might appear to be clear, but single organisms of fully sexually reproducing and sexually isolated species are far from the whole story.

How many individuals are there, for example, in a field of crabgrass, in which some rooted clumps of grass are still connected to others via runners, and some have had their generating runners decay? How many individuals in a clone of birch trees? How many species of bacteria that engage in horizontal gene transfer? Or species that maintain stable hybrid zones? And so on? What counts as a second instance of an autocatalytic process, rather than just a further spread of the autocatalytic cycling into broader regions? Or how many fires are there when what appear to be two brush fires merge, or one fire splits? The point, simply, is that boundaries and individuations are not inherent to process, so any boundaries that do exist, or are at least posited, must be explained in terms of their natures, origins, and forms of maintenance.

Individuation

If not in terms of an underlying substance with clear and unique entity-boundaries, how can processes be individuated?[2] What remains of the notion of an entity?

Subject to the basic conservations, processes occur in regions of space-time.[3] Trajectories along which conservations are maintained constitutes a major class of (partially) individuated processes. Quantum and field phenomena render this only a partial identification in terms of point trajectories because the relevant conservation honoring processes may not be locatable at particular points. Instead, they may be spread out through regions which themselves have at best broad and non-distinct boundaries.

This class of process individuations illustrates some general principles of individuation: 1) individuation is in terms of types of patterns or organizations of processes that satisfy some (set of) criteria, and 2) instances of the relevant types are commonly differentiated in terms of location, though, as was discussed above, that criterion isn't always clear: it's essentially a boundary-dependent notion.

One generalization of conserved quantity individuations are patterns of process organization that tend to recur for reasons other than basic conservations. Unsupported rocks tend to roll down hillsides, and sufficient quantities of U-235 in close proximity tend to explode. Such processes, of course, honor conservations, but are more restricted. In terms of dynamic landscapes, conserved quantity processes have unbounded "attractor basins" — all processes honor them — while more restricted kinds of process will have varying regions of attraction of prior processes that will enter such patterns: processes that remove support to rocks on hillsides will lie in the roll-down-hill attractor region, and so on. Note that the sense in which such kinds of processes have attractor basins is not the same as for the usual usage of the term: in particular, once on the way in the "attracting" process, the ongoing processes may remain in that attracting type only so long as is involved in its reaching a natural completion — reaching the bottom of the hill, or dissipation of the explosion. The "attractor" in such cases may attract, but the dynamics do not necessarily remain in or on the attracting pattern for indefinite lengths of time.

In spite of their possible short temporal extent, process types with attractor basins nevertheless exemplify a special kind of stability or persistence: a recurrence persistence. *Instances* of these types may not have much temporal persistence, but the *types* of process patterns may persist in multiple recurrences of instances of the type. Recurrences of such types will be probable insofar as their attractor basins are large relative to the relevant space of possible process organizations. In the physical realm, electrons of high energy level will tend to emit photons and thereby fall to lower energy levels; in the biological realm, individual bacteria may or may not last long, but the types tend to persist via recurrence — in this case, via a historistic process of reproduction.

[2]For an approach toward a general process ontology, see [Seibt, 2004; 2009].

[3]I set aside here issues concerning, for example, the unboundedness of a quantum field, various quantum non-localities, and the possibility that space and time are in some sense emergents.

It may also be the case, of course, that instances of a process type may exhibit some form of persistence in themselves. In such cases, the attracting process trajectories exhibit some sort of closure, such that, once entered on such a trajectory, a process will tend to remain on it (or *at it*, in the case of a point attractor). A very important subclass of kinds of instance-persistences are those composed of intertwined trajectories of simpler instances, perhaps conservation instances, for which the topological knot formed by that intertwining is relatively persistent. This category is subdivided with respect to whether or not the "simpler" instances remain associated with the instance of the dynamic topological knot, or instead if the knot persists, but the constituent simpler instances change.

A first special subclass of these, then, are those topological knot patterns of process for which the process instances that make them up are stable not just as instances in themselves, but also in their *relationships to the knot.* That is, for which the constituting instances are stable *parts* of the overall process patterns. A major kind of this case are those for which the stability of the knot pattern is maintained by being in an energy well, as discussed earlier (e.g., quark and electron field processes in an atom; atoms in a molecule, etc.). These constitute the canonical examples of *cohesive* process patterns [Collier, 1988].[4]

On the other hand, there will also be relatively persistent topological knots of process that are stable qua knot, but for which the relationships with the process instances that constitute the knot are not stable. Far from thermodynamic equilibrium self-organized process patterns are canonical examples of this type. The constituent instances of atoms and molecules that make up such a process — e.g., a candle flame — are continually changing, and are *necessarily* continually changing.

A further interesting class of topological knot persistences are those in which the form of the dynamic topological knot or twist (pattern) will itself change over time, but it remains a descendent *as an instance* of some original persistent knot of processes. In general, this will occur when there is a spatio-temporal continuity from earlier instance to later instance. Here we find continuities through growth, development, evolution, and so on.

Spatio-temporal continuity, however, is not conceptually required so long as there is a dynamically real sense of dependent derivation. In such cases, the distinction between type of process pattern and instance of process pattern becomes unclear, or at least crossed: *whale* as a type has individual whales as instances, but *the whale* as an instance of a species (arguably) does not. In general, to the extent that the dependence derivational relation becomes increasingly informational, the distinction between instance and type becomes at best complex, and in some ways blurred [Griesemer, 2005]. What are the type-instance rela-

[4]Another subtype would be stabilities that result from mechanical connections that may be weaker than the energy well stability, and perhaps only exist in certain directions or forms, such as something hanging on a hook: the stability of the relationship is only with respect to the direction of potential falling, and is weak in an upward direction. In general, energy well stabilities do not necessarily have isotropic strengths: e.g., layers of graphite are much stronger within a layer than between layers.

tionships involved in a range of artifacts that are in part manufactured through identical or similar processes, and in part copied from one manufacturing firm to another, or partially copied within a firm from earlier patterns/instances, such as generations of automobile types? Primarily informational derivation tends to abstract dynamic patterns from constituted instances, and thereby collapse the pattern-instance distinction. It is because of this collapse that biological species are better understood as spatially distributed single instances of complex dynamic and changing processes — individuals — than as types of which single organisms are instances [Ghiselin, 1974; 1987; 1997; Hull, 1976].

Individuation and boundaries: Summary

Issues of individuation, thus, become varied and complex within a process metaphysics. Simple assumptions of bounded substances constituting entities simply do not apply, and certainly do not suffice, for the complexities actually encountered in the world. Note, in this regard, that very little about boundaries has been relevant to the discussion of individuation. We have individuation in terms of topological patterns that exhibit dynamically relevant properties, with persistence of various kinds being among the important such properties. Boundaries, should they exist, will be created within and by those topological patterns, and, when they do exist, can be of multifarious kinds and forms.[5]

A process metaphysics raises basic metaphysical issues about unity, individuation, and boundaries. They are (multiple kinds of) temporal phenomena of (some) processes — not inherent characteristics of what it is to exist.

3.2 Supervenience

A final topic that I will consider is that of supervenience. The intuition of supervenience is that higher level phenomena cannot differ unless their supporting lower level phenomena also differ. There may be something correct in this intuition, but a process metaphysics puts at least standard ways of construing supervenience into question too.

Most commonly, a supervenience base — that upon which some higher level phenomena are supposed to be supervenient — is defined in terms of the particles and their properties, and perhaps the relations among them, that are the mereological constituents of the supervenient system [Kim, 1991; 1998]. Within a particle framework, and so long as the canonical examples considered are energy well stabilities, this might appear to make sense.

But at least three considerations overturn such an approach. First, local versions of supervenience cannot handle relational phenomena — e.g., the longest pencil in the box may lose the status of being longest pencil even though nothing about the pencil itself changes. Just put a longer pencil into the box. Being the longest pencil in the box is not often of crucial importance, but other relational phenomena

[5]Including, for example, fractal boundaries.

are. Being in a far from equilibrium relation to the environment, for example, is a relational kind of property that similarly cannot be construed as being locally supervenient. And it is a property of fundamental importance to much of our worlds — including, not insignificantly, ourselves.

A second consideration is that far from equilibrium process organizations, such as a candle flame, require ongoing exchanges with that environment in order to maintain their far from equilibrium conditions. There is no fixed set of particles, even within a nominally particle view, that mereologically constitutes the flame.

A third, related consideration is the point made above about boundaries. Issues of boundary are not clear with respect to processes, and not all processes have clear boundaries of several differentiable sorts — and, if they do have two or more of them, they are not necessarily co-extensive. But, if boundaries are not clear, then what could constitute a supervenience base is also not clear.

Supervenience is an example of a contemporary notion that has been rendered in particle terms, and that cannot be simply translated into a process metaphysical framework [Bickhard, 2000; 2004]. More generally, a process framework puts many classical metaphysical assumptions into question.

4 CONCLUSION

A hurricane or a candle flame illustrates a number of changes forced by a shift to a process metaphysical framework. They are roughly constituted as a twist or knot in the topology of the flow of ongoing process. Note that the point here is not just that the hurricane or flame is *dependent on* such process organization, but that they are *constituted in* such process organization.

As such, they have no inherent boundaries, individuations, supervenience bases, and so on. They are not entities in any classical sense. Questions about such properties — their existence, emergence, nature, maintenance, etc. — cannot be taken for granted, as is (or appears to be) the case within a particle framework. Instead, questions about such phenomena become legitimate and important *scientific* questions, questions that are not well motivated by a substance or particle metaphysics. Such questions take on an especially central importance in realms of science that address inherently far from equilibrium phenomena, such as biology and studies of the brain and mind. These are the realms in which the limitations and failures of classical substance and particle presuppositions are most damaging.

Conversely, a process metaphysics maintains the historical trend in science toward process. It is consistent with contemporary foundational physics, and integrates thermodynamics in a central and natural way. It makes emergence a genuine metaphysical possibility, and, in particular, it renders normative emergence a class of phenomena that are scientifically addressable. It requires changes, such as the shift to a default of change rather than stasis, and it raises multiple questions about properties that have historically often been presupposed, such as individuations and boundaries. But it is arguably the only framework that offers a viable orientation for the scientific future.

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BIBLIOGRAPHY

[Beckermann *et al.*, 1992] A. Beckermann, H. Flohr, and J. Kim. *Emergence or Reduction? Essays on the Prospects of Nonreductive Physicalism*. Berlin, Walter de Gruyter, 1992.

[Bickhard, 2000] M. H. Bickhard. Emergence. In P. B. Andersen, C. Emmeche, N. O. Finnemann, P. V. Christiansen, eds., *Downward Causation*, pp. 322-348. Aarhus, Denmark: University of Aarhus Press, 2000.

[Bickhard, 2003] M. H. Bickhard. Variations in Variation and Selection: The Ubiquity of the Variation-and-Selective Retention Ratchet in Emergent Organizational Complexity, Part II: Quantum Field Theory. *Foundations of Science, 8*(3), 283-293, 2003.

[Bickhard, 2004] M. H. Bickhard. Process and Emergence: Normative Function and Representation. *Axiomathes — An International Journal in Ontology and Cognitive Systems, 14*, 135-169, 2004. Reprinted from: M. H. Bickhard. Process and Emergence: Normative Function and Representation. In J. Seibt, ed., *Process Theories: Crossdisciplinary Studies in Dynamic Categories.* (121-155). Dordrecht: Kluwer Academic, 2003.

[Bickhard, 2009a] M. H. Bickhard. The interactivist model. *Synthese* 166(3), 547-591, 2009a.

[Bickhard, 2009b] M. H. Bickhard. Interactivism. In J. Symons, P. Calvo, eds., *The Routledge Companion to Philosophy of Psychology*, pp. 346-359. London: Routledge, 2009.

[Bickhard, forthcoming] M. H. Bickhard. Interactive Knowing: The Metaphysics of Intentionality. In R. Poli, J. Seibt, and J. Symons, eds., *Theory and Applications of Ontology.* Dordrecht: Kluwer, forthcoming.

[Bickhard, in preparation] M. H. Bickhard. *The Whole Person: Toward a Naturalism of Persons — Contributions to an Ontological Psychology.* In preparation.

[Bickhard and Campbell, 2003] M. H. Bickhard and D. T. Campbell. Variations in Variation and Selection: The Ubiquity of the Variation-and-Selective Retention Ratchet in Emergent Organizational Complexity. *Foundations of Science, 8*(3), 215-282, 2003.

[Campbell, 1974] D. T. Campbell. Evolutionary Epistemology. In P. A. Schilpp, ed., *The Philosophy of Karl Popper*, pp. 413-463. LaSalle, IL: Open Court, 1974.

[Campbell, 1992] R. J. Campbell. *Truth and Historicity.* Oxford, Oxford University Press, 1992.

[Cao, 1999] T. Y. Cao. *Conceptual Foundations of Quantum Field Theory.* Cambridge: U. of Cambridge Press, 1999.

[Christensen and Bickhard, 2002] W. D. Christensen, M. H. Bickhard. The Process Dynamics of Normative Function. *Monist, 85*(1), 3-28, 2002.

[Christensen and Hooker, 2000] W. D. Christensen, C. A. Hooker. An Interactivist-Constructivist Approach to Intelligence: Self-Directed Anticipative Learning. *Philosophical Psychology, 13*(1), 5-45, 2000.

[Clifton, 1996] R. Clifton. *Perspectives on Quantum Reality.* Kluwer Academic, 1996.

[Collier, 1988] J. Collier. Supervenience and Reduction in Biological Hierarchies. In M. Matthen and B. Linsky, eds., *Philosophy and Biology: Supplementary Volume 14 of the Canadian Journal of Philosophy*, pp. 209-234. Calgary: University of Calgary Press, 1988.

[Doyle, 1985] J. Doyle. Circumscription and Implicit Definability. *Journal of Automated Reasoning, 1*, 391-405, 1985.

[Ghiselin, 1974] M. T. Ghiselin. A Radical Solution to the Species Problem. *Systematic Zoology, 23*, 536-544, 1974.

[Ghiselin, 1987] M. T. Ghiselin. Species Concepts, Individuality, and Objectivity. *Biology and Philosophy, 2*, 127-144, 1987.

[Ghiselin, 1997] M. T. Ghiselin. *Metaphysics and the Origin of Species*. SUNY, 1997.

[Gill, 1989] M-L. Gill. *Aristotle on Substance*. Princeton, Princeton University Press, 1989.

[Gill, 2005] M. L. Gill. Aristotle's Metaphysics Reconsidered. *Journal of the History of Philosophy, 43*(3), 223-251, 2005.

[Graham, 2006] D. W. Graham. *Explaining the Cosmos.* Princeton, NJ: Princeton University Press, 2006.

[Griesemer, 2005] J. R. Griesemer. The Informational Gene and the Substantial Body: On the Generalization of Evolutionary Theory by Abstraction. In M. R. Jones and N. Cartwright, eds., *Idealization XII: Correcting the Model, Idealization and Abstraction in the Sciences*, pp. 59–115. Poznan Studies in the Philosophy of the Sciences and Humanities: Vol. 86, Amsterdam: Rodopi, 2005.

[Guthrie, 1965] W. K. C. Guthrie. *A History of Greek Philosophy vol. II: The Presocratic Tradition from Parmenides to Democritus.* Cambridge: Cambridge University Press, 1965.

[Hale and Wright, 2000] B. Hale and C. Wright. Implicit Definition and the A Priori. In P. Boghossian and C. Peacocke, eds., *New Essays on the A Priori*, pp. 286-319. Oxford: Oxford University Press, 2000.

[Halvorson and Clifton, 2002] H. Halvorson, R. Clifton. No Place for Particles in Relativistic Quantum Theories? *Philosophy of Science, 69*(1), 1-28, 2002.

[Hilbert, 1971] D. Hilbert. *The Foundations of Geometry.* La Salle: Open Court, 1971.

[Hooker, 1995] C. A. Hooker. *Reason, Regulation and Realism: Toward a Naturalistic, Regulatory Systems Theory of Reason.* Albany, N.Y.: State University of New York Press, 1995.

[Huggett, 2000] N. Huggett. Philosophical Foundations of Quantum Field Theory. *The British Journal for the Philosophy of Science, 51*(supplement), 617-637, 2000.

[Hull, 1976] D. L. Hull. Are Species Really Individuals? *Systematic Zoology, 25*, 174-191, 1976.

[Hume, 1978] D. Hume. *A Treatise of Human Nature.* Index by L. A. Selby-Bigge; Notes by P. H. Nidditch. Oxford, Oxford University press, 1978.

[Hylton, 1990] P. Hylton. *Russell, Idealism, and the Emergence of Analytic Philosophy.* Oxford: Oxford University Press, 1990.

[Kim, 1991] J. Kim. Epiphenomenal and Supervenient Causation. In D. M. Rosenthal, ed., *The Nature of Mind*, pp. 257-265. Oxford University Press, 1991.

[Kim, 1998] J. Kim. 1998). *Mind in a Physical World.* MIT, 1998.

[Kolaitis, 1990] Ph. G. Kolaitis. Implicit Definability on Finite Structures and Unambiguous Computations. In *Proc. 5th IEEE LICS*, 168-180, 1990.

[Kuhlmann *et al.*, 2002] M. Kuhlmann, H. Lyre, and A. Wayne. *Ontological Aspects of Quantum Field Theory.* River Edge, NJ: World Scientific, 2002.

[Otero, 1970] M. H. Otero. Gergonne on Implicit Definition. *Philosophy and Phenomenological Research, 30*(4), 596-599, 1970.

[Quine, 1966] W. V. O. Quine. Implicit Definition Sustained. In W. V. O. Quine, ed., *The Ways of Paradox*, pp. 195-198. New York: Random House, 1966.

[Seibt, 2004] J. Seibt. *General Processes: A Study in Ontological Theory Construction.* Habilitations-Thesis, University of Kanstanz, Germany, 2004.

[Seibt, 2009] J. Seibt. Forms of Emergent Interaction in General Process Theory. *Synthese, 166*(3), 479-512, 2009.

[Shapiro, 1997] . Shapiro. *Philosophy of Mathematics: Structure and Ontology.* Oxford, 1997.

[Shapiro, 2005] S. Shapiro. *The Oxford Handbook of Philosophy of Mathematics and Logic.* Oxford: Oxford University Press, 2005.

[Teller, 1992] P. Teller. A Contemporary Look at Emergence. In A. Beckermann, H. Flohr, and J. Kim, eds., *Emergence or Reduction? Essays on the Prospects of Nonreductive Physicalism*, pp. 139-153. Berlin: Walter de Gruyter, 1992.

[Weinberg, 1977] S. Weinberg. The Search for Unity, Notes for a History of Quantum Field Theory. *Daedalus, 106*(4), 17-35, 1977.

[Wright, 1997] M. R. Wright. Empedocles. In C. C. W. Taylor, ed., *From the Beginning to Plato*, pp. 175-207. Routledge 1997.