Process Structural Realism, Instance Ontology, and Societal Order

Joseph E. Earley, Sr.†
Department of Chemistry, Georgetown University
Washington, DC 20057

Published in "*Researching with Whitehead: System and Adventure*"
Franz Riffert and Hans-Joachim Sander, eds., Berlin: Alber, *2008, 190-211*.

Abstract

Whitehead's cosmology centers on the self-creation of *actual occasions* that perish as they come to be, but somehow do combine to constitute *societies* that are persistent agents and/or patients. "Instance Ontology" developed by D.W. Mertz concerns unification of *relata* into *facts of relatedness* by specific *intensions*. These two conceptual systems are similar in that they both avoid the substance-property distinction: they differ in their understanding of how basic units combine to constitute complex unities. "Process Structural Realism" (PSR) draws from both of these approaches in developing an account of how combinations of processes may produce ontologically significant coherences. When a group of processes achieves such closure that a set of states recurs continually, the effects of that coherence differ from what would occur in the absence of that closure. Such altered effectiveness is an attribute of the system as a whole, and would have consequences. This indicates that the network of processes, as a unit, has ontological significance. The closed network of processes, together with the conditions that prevail, constitute the form of definiteness of the coherence. That form continues to obtain as long as the coherence persists. Constituents contribute to, rather than share, that characteristic. Aspects of some recent research in systems biology, microeconomics, and social psychology illustrate the application of PSR.

(End of abstract)

† Mailing address: 502 W Broad St #501, Falls Church, VA 22046, USA. E-mail: earleyj@georgetown.edu.

Introduction

This paper briefly reviews how Alfred North Whitehead dealt with what he held to be a main problem of philosophy, reports on an alternative outlook called "Instance Ontology," then introduces "Process Structural Realism" (PSR), which draws on both of the approaches previously considered to provide an account of how processes may combine to yield ontologically significant coherences. Results of some recent research in systems biology, microeconomics, and social psychology illustrate application of PSR.

Whitehead recommended that readers pay careful attention to opening pages of scholarly works — for there authors might identify crucial assumptions. However, one widely accepted presupposition goes unmentioned, even in prefaces. That is the assumption that items that can be affirmed ("predicated")[1] of something else (i.e., "properties") — can cleanly be distinguished from what cannot be predicated (e.g., "substances"). Philosophical discussions generally start with presuppositions that specific entities (say x) exist and have specific properties (say P) — $(\exists x)\cdot P(x)$. Unfortunately, once one accepts that substance-property distinction, serious problems are unavoidable. Such difficulties surfaced in the recent revival of "structuralist" approaches (French 2003) in philosophy of science. Those theories — epistemological structural realism, ontological structural realism, and ("non-realist") constructive empiricism — emphasize "isomorphism" of structure between theoretical and natural entities, but van Fraassen (2006) recalled that, as early as 1920, Reichenbach had objected to that move. "The mathematical object of knowledge is uniquely determined by the axioms and definitions of mathematics. ….The physical object cannot be determined by axioms and definitions. It is a thing of the real world, not an object of the logical world of mathematics." How can a mathematical object (a "universal") relate to a (nonmathematical) natural entity? This problem is not new. John Locke (1690 VI 43) observed:

---

[1] Words used in technical senses will be enclosed in quotation marks on their first use. Unless stated otherwise, the sense meant will be that generally used elsewhere in this volume.

> [T]o… consider man, as he is in himself, and as he is really distinguished from others in his internal constitution, or real essence, that is, *by something he knows not what,* looks like trifling: and yet thus one must do who would speak of the supposed real essences and species of things, as thought to be made by nature.[2] (Emphasis added.)

Elsewhere in this volume, Rom Harré (forthcoming) holds that this issue is still relevant, both for chemistry and for process philosophy.

> The self-identity of things rests on their continuing to possess a modicum of `essential' attributes over time. However, if `process' is `continuous change' then how are we to account for self-identity? ….. In the end Whitehead's philosophy leaves us at the very same point as the ontology of contemporary chemistry leaves us, with a world sustained by something we know not what.

Towards a Process Ontology

Whitehead constructed central features of his cosmology with the problematic situation sketched out above clearly in mind. "All modern philosophy hinges round the difficulty of describing the world in terms of subject and predicate, substance and quality, particular and universal." (Whitehead [1929] 1978 49) A main feature of the strategy Whitehead used to deal with this challenge was rejection of the category of substance, as Locke had understood it. "'Actual entities' — also termed 'actual occasions'— are the final real things of which the world is made up." (Whitehead [1929] 1978 18) … "Actual entities perish, but do not change; they are what they are." (Whitehead [1929] 1978 35). Whiteheadian "actual occasions" are definitely not substances, they do not persist; they come to be and, as they do, they perish. "Process" for Whitehead is all of a single sort ─ self-creation of actual occasions.

If (as current science strongly suggests[3]) we reject the notion of a submicroscopic,

---

2 The sentence finishes…"if it be but only to make it understood, that there is no such thing signified by the general names which substances are called by."

3 Early interpreters reached a consensus that these fundamental units of Whitehead's

elementary-particle level of description as fundamental, what criterion could identify the final real things? Whitehead's discussion of "concrescence" — the coming to be of each actual occasion — suggests a possibility. Each concrescence involves "ingression" of an "eternal object" — a "form of definiteness" that serves as a "subjective aim" to regulate whether "data" provided by the antecedent world are "prehended" positively (integrated into the concresent occasion) or negatively (excluded from the concrescence). A defining "eternal object" is a necessary feature of Whiteheadian actual occasions. Another important feature of each actual occasion is a contrast of aspects.

> In the analysis of actuality the antithesis between publicity and privacy obtrudes itself at every stage. There are elements only to be understood by reference to what is beyond the fact in question; and there are elements expressive of the immediate, private, personal, individuality of the fact in question. The former elements express the publicity of the world; the latter elements express the privacy of the individual.
>
> An actual entity considered with respect to the publicity of things is a 'superject'; namely, it arises from the publicity which it finds, and it adds itself to the publicity which it transmits. It is a moment of passage from decided public facts to a novel public fact. Public facts are, in their nature, coordinate.
>
> An actual entity considered in reference to the privacy of things is a subject; namely, it is a moment in the genesis of self-enjoyment. It consists of a purposed self-creation out of materials which are at hand in virtue of their publicity.

---

philosophy of organism were necessarily submicroscopic. However, the current scientific climate is much different from that of the first half of the twentieth century. In that period, much chemistry and physics was reductively unified in terms of a few sorts of elementary particles (protons, neutrons and electrons). In our own day, particles formerly considered elementary are known to be composite, and serious arguments are made (Laughlin 2005) that even basic physical laws are 'emergent' phenomena.

> Eternal objects have the same dual reference, an eternal object considered in reference to the publicity of things is a ‘universal;’ namely, in its own nature it refers to the general public facts of the world without any disclosure of the empirical details of its own implication in them. Its own nature as an entity requires ingression — positive or negative — in every actuality; but its nature does not disclose the private details of any actuality. (Whitehead [1929] 1978 289)

Even though actual occasions perish as they come to be, some combinations of actual entities (“societies with personal order”) do have careers through time. In Whitehead’s view, all enduring things are societies. “The Universe achieves its values by reason of its coordination into societies of societies, and societies of societies of societies.” (Whitehead [1933] 1967 206) Societies, not actual occasions, are the bearers of what we normally consider to be properties. Process ontology needs to deal with how a number of actual occasions can constitute a society that occupies time and interacts with the rest of the world in determinate ways — even though the constituent occasions do not persist.

A Burner Flame as a Society

Some kind of internal balance characterizes everything that persists. Ordinary “material” objects involve equilibration of attraction between components that tends to compact the entity, and repulsion that keeps parts separate (Earley forthcoming). At all temperatures, every part is in motion. Maintaining balance requires that all such motions be *oscillatory* — that a closed set of states of the composite occur repeatedly. Coherences often interact with others to bring about rearrangements of components and thereby to produce new types of order. Each such process is the coming-to-be of new coherences and the dissolution of old ones. Chemical reactions are especially well understood[4]

---

[4] If collision between molecules is sufficiently energetic, the collision complex may pass through a “transition state” that fragments to yield products other than the reactants. In any mixture, a myriad of such “reaction channels” are possible. Chemical changes occur through those reaction channels that have transition states of

examples of processes, but related interactions are ubiquitous (e.g., in biology, psychology, and economics). Normally, processes use up their components and gradually slow down. However, some continually get faster ─ because, for instance, they produce more of their reactants than they use up. Such "autocatalysis" often leads to explosions. However, if an autocatalytic process combines with interactions that can reduce the effectiveness of autocatalysis, a balance may be struck and oscillations in the amounts of the reactants then will persist over long times. (Earley 2006ab, 2003ab) Every "organism" (biological or other) involves many such "homeostatic" arrangements. This type of generation of long-lived coherence from several processes is an example of the genesis of societal order.

$$\begin{array}{l} \rightarrow CH_4 \\ \rightarrow \quad O_2 \end{array}$$

$$CH_4 + 2O_2 \rightarrow [several\ rapid\ steps] \rightarrow CO_2 + 2H_2O + heat$$

$$\begin{array}{l} CO_2 \rightarrow \\ H_2O \rightarrow \\ heat \rightarrow \end{array}$$

Scheme 1. A minimum set of processes that might be involved in a steady flame. The first two lines describe entry of fuel and oxidizer into the reaction zone. The last three lines describe the exit of products from the reaction zone[5].

Each steady flame is a persistent coherence of physical processes and chemical reactions (e.g., Scheme 1) — this is a "dissipative structure" (Kondepudi, 1998). We can consider a stable flame in a burner as a Whiteheadian society. The combustion reaction (like most chemical reactions) operates faster at higher temperatures. Since it produces heat[6] that increases the temperature of the reaction mixture, combustion is autocatalytic

---

lower energy. Chemical reactions are complicated but not mysterious.

[5] If either reactant is in excess, or combustion is incomplete, additional lines would indicate exit of other system components.

[6] Combustion of methane (the complicated central process in Scheme 1) gives off heat because atoms adhere together more strongly in the products than in the reactants.

(goes faster as it proceeds). Diffusion of heat out of the system can control that autocatalysis (Scott 1994 16-17). Scheme 1 suggests that, in favorable cases, input of reactants and exit of products might just balance the combustion reaction, to yield a steady flame. So long as fuel and oxidizer enter, and combustion products escape, the flame may persist in (more or less) the same shape, and may function (as signal or source of heat) in yet other coherences. Steady flames demonstrate an important type of social order.

Consider Whitehead's formal definition of a society:

> A nexus enjoys 'social order' where (i) there is a common element of form illustrated in the definiteness of each of its included actual entities, and (ii) this common element of form arises in each member of the nexus by reason of the conditions imposed on it by its prehensions of some other members of the nexus, and (iii) these prehensions impose that condition of reproduction by reason of their inclusion of positive feelings of that common form. Such a nexus is called a 'society', and the common form is the 'defining characteristic' of the society. The notion of 'defining characteristic' is allied to the Aristotelian notion of 'substantial form.' ….
> A nexus enjoys 'personal order' when (α) it is a society and (β) when the genetic relatedness of its members orders those members 'serially.' (Whitehead [1929] 1978 34)

Societal Order: Public Aspects

The "Eleatic Principle" (also known as "Alexander's Dictum") specifies:

> …. everything that we postulate to exist should make some sort of contribution to the causal/nomic order of the world. (Armstrong 2004 37).

Merricks (2001) proposed an important clarification of that principle:

The significant chemical potential energy of a methane-oxygen mixture is a *relational* property.

> … every material object not only has causal powers, but has non-redundant causal powers. …For material objects to be is to have non-redundant causal powers.

This Extended Eleatic Principle (hereafter called the EEP) asserts that each ontologically significant entity must exert causal influence that is not reducible to the causal powers of the components. Process ontology should clarify the relationship between public and private aspects of coherences that have ontological significance. A burner flame has effects quite different from an un-ignited stream of oxygenated methane: the flame fulfills the EEP. Why does this happen? The steady flame functions as a reliable source of heat because the network of chemical and chemical processes has reached an appropriate *closure*, so that a cyclical set of states continually recurs.

Societal Order: Private Aspects

If a flame is a Whiteheadian society, what would be the component actual occasions? Perhaps the dioxygen and methane molecules might be the components of the flame. However, an adequate account of that flame would also need to involve the structures of the low-energy transition states and the ultimate products. It is not clear that there is any "common element of form" shared by all those molecular species. A better move might be to consider that the constituents of the flame are the fluxes of molecules into and out of the burner, and the chemical reactions that comprise the mechanism of the combustion. It is the combination of these dynamic processes that yields the overall stability of the flame. If processes (rather than molecules) are constituents of the flame then those constituents all contribute, in diverse ways, to the balance that accounts for the stability of the flame society. In the achievement of closure of processes that constitutes the flame, a form of definiteness — an eternal object — has appeared.[7] Successive realizations of that closure would be the actual occasions that constitute the society. The balance of processes would be a common element of form shared by all those occasions.

[7] Elsewhere (Earley 2006b), I proposed that each such closure represent a mathematical "group."

All these occasions exemplify the same form of definiteness, as required by Whitehead's definition of a society with personal order. (To ask where one occasion ends and another begins would be "misplaced concreteness" of a high order.) Whitehead's definition of societal organization is an adequate and applicable account of the personal order that grounds a society's persistence through time, but it is not adequate with respect to the achievement of satisfaction of each of the society's constituent successive occasions. Each succeeding occasion requires that many agents (each themselves societies with personal order) function (each one in a different way) in achieving the coherence of the occasion. Those constituent societies *contribute to* the form of definiteness of the societal unity of the concrescent occasion: they do not *share* that form.

Instance Ontology

Donald W. Mertz (1996, 1999, 2003, 2004ab, 2005) revived an ancient philosophical approach which avoids the substance-property distinction in a way that resembles Whitehead's, but differs significantly. Like Whitehead's "Philosophy of Organism," Mertz's "Instance Ontology" operates with a single ontological category. Whitehead calls his *final real things* actual entities or actual occasions: Mertz uses alternative designations — "property instance," "state of affairs," "fact of relationship"— for his basic ontological category. Each such property-instance corresponds to a formula.

$$:R^n_i\,(a_1, a_2, \ldots , a_n)$$

The leading colon distinguishes a fact (a state of affairs) from a corresponding "proposition," $R^n_i\,(a_1, a_2, \ldots , a_n)$ — a statement that the fact exists. Superscript n pertains to the number ($1 \leq n$) of "relata" which the fact involves. When $n = 1$, the relation is "monadic" rather than "polyadic," and corresponds to a "property". [8] Relata are

[8] Mertz denies that relationships derive from the (monadic) properties of *individual* relata. Concerning professional basketball players, some say that Yao Ming is taller than Shaquille O'Neal because *Yao* is seven feet five inches (2.26 meters) tall while *Shaq* stands only seven feet one inch (2.16 meters). From an Instance Ontology perspective, what counts is that *Yao's height* is greater than *Shaq's height*.

individuals — property instances, "intensions," or "complexes." The list *(a_1, a_2,… , a_n)* specifies the relata for a particular instance designated by a subscript *(i* in this case). The order of relata is important: "Mary loves John" is not the same state of affairs as "John loves Mary." R^n_i is the "intension" of the relationship (what connects the *n* relata in a particular fact). Closely related intensions (R^n_j, R^n_k, R^n_l, …) may occur in similar property instances involving other relata. The various intensions R^n_i, R^n_j, R^n_k, R^n_l, … may all be exemplifications of a "relation-type," $R.^n$ Relation-types correspond to "universals," and to Whitehead's "eternal objects." Only one intension R^n_i of the type R^n involves a particular list of relata *(a_1, a_2, …, a_n).* Each property instance, like each Whiteheadian actual entity, is unique and unrepeatable. Each property instance is "continuously simple" in the sense that analysis of that relation instance into intension and relata is "conceptual" rather than having ontological implications (Mertz 2004a). What exists is each particular fact of relationship. If we trip over something heavy, rectangular, and red, we may identify it as "a red brick," but that linguistically convenient separation into substance and property is (in Mertz's view) a *mental* distinction, not an *ontological* one. In a heap of bricks, there is indeed a sharing of universals (heavy, rectangular, made of clay, red) but those are shared between red-brick-instances, rather than between red brick-substances. By recognition of intension-types (universals), Mertz's approach qualifies as a realism[9].

Each state of affairs corresponds to unification of its relata.

> [E]ach relation, insofar as it obtains among an *n*-tuple of relata (i.e., is an *ontic (material) predicate*), is a cause of unity of itself with and among each of its *n* subjects, where this unity is conditioned or delimited by a specific *n*-adic content of intension, R^n … and by its compatibility with each of the *n* subjects. (Mertz 2003 130)

The ontology of property instances provides a way of dealing with compound individuals

[9] Instance Ontology is a type of "particularism." "Trope theory" (Trettin 2004) is a "nominalist" particularism that does not recognize universals.

that are produced by *complementary* activities of diverse individuals.

> The unity in a fact is a plural one — the relata are both connected via an instance of R^n and yet by the same agency held in an identity-saving distinctness from each other and the relation. (Mertz 2003 130).

This makes the relata $(a_1, a_2, \ldots, a_n)$ — together with the intension — into a unified whole rather than a mere list, set, or mereological fusion. Relation instances may be relata in other relation instances. Such "horizontal" composition yields complexes. Similarly, complexes (as unified wholes) can serve as relata in "vertical" types of composition.

Mertz specifically denies a widely held principle:

> **The Unity-by-the-Unit Thesis, U.** All elements making up a plural whole must share a *single unifier* as the constituent cause of their collective unity and hence of the existence of the resultant whole. (Mertz 2003 132)

As Mertz points out, a steel chain may be an effective unity even though each link connects only to at most two other links. So long as every link holds to its neighbors, the chain does not need a cable threaded through all the links in order to achieve integrity. A chain of many links has no unifying agent other than the links themselves. There is no need for "something, one knows not what." In virtue of achieved integrity, sturdy chains may be working parts of larger plural unities. Gilbert Simondon ([1964] 1992 300) pointed out that philosophers generally take constituted individuals as given. He recommends that we should try to: "… understand the individual from the process of individuation rather than the process of individuation by means of the individual." Anticipating this point, Whitehead makes the achievement of individuality by each actual occasion a focus of his system. Mertz does not appear to have dealt with the process of individuation yet.

Process Structural Realism (PSR)

Whitehead's definition of a society requires that all constituent occasions *share* an element of form. This seems to be statement of what Mertz called The Unity-by-the-Unit Thesis U. This principle would lead to the awkward interpretation that the constituent occasions of a flame society must be successive realizations of the network of relationships that defines the flame. It seems better to use an alternative interpretation, that a society (such as a flame) is a plural unity in which diverse components (molecules, fluxes, etc.) contribute to (rather than share) a defining characteristic[10] of the society. A specific closure of n agents, $:C^n{}_i$ say (a determinate instance of the relation-type "closure," C^n) would unify constituent processes (including fluxes from and to the outside world) and thereby ground the external relations of the coherence, as well as individuate that coherence as the occasion that it is. Successor[11] members of the same society $:C^n{}_j$, $:C^n{}_k$, $:C^n{}_l$ … would inherit from predecessors the same non-mysterious intension-type C^n. Perhaps this is the 'something we know not what' sought by Locke, and by Harré.

That is to say, when a group of processes achieves such closure that a set of states of affairs recurs continually, the effect of that coherence on the world differs from what would occur in the absence of that closure. (Earley 2003c, also the Appendix of this paper). Such altered effectiveness is an attribute of the system as a whole, and would have consequences. This indicates that the network of processes, as a unit, fulfills the EEP, and therefore has ontological significance. Whenever a network of processes generates continual return to a limited set of states of affairs, the system may function as a "whole"— with respect to appropriate interaction partners. The balance achieved by the processes provides the form of definiteness of a unified agent. The causal powers of such coherent aggregates are indeed just the powers of the "constituents acting in concert" (Merricks 2001). However, the components act in concert in the specific way they do *only because of* their inclusion in the closed set of interactions that defines the coherence. This renders the causal powers of the coherence defined by that closure non-redundant, and hence the coherence, as a unit, is ontologically significant. The form of definiteness

---

10 On this basis, the flame society would a fact of relatedness, involving as relata the concentrations of reactants and products, and rate parameters for each of the relevant processes (e.g., those in Scheme 1). Rate parameters for each process implicitly include information on transition states and forcing functions for that process.

11 To hold that each member occasion of a persistent society exists only at an instant (a temporal point) is the error of "simple location." (Whitehead [1925] 1967)

that provides internal coherence (a private aspect) also grounds external efficacy (a public aspect) of the societal aggregation. The closure is a *structural* feature of the coherence — possibly, but not necessarily, apparent in spatial structuring. One can show[12] that every such coherence is the representation of a mathematical "group" or "semi-group." What is fundamental is achievement of effective coherence — the level of size on which that achievement occurs is irrelevant. Combinations of processes produce effects that are not simply attributable to the constituents. Whenever that efficacy is relevant,[13] non-redundant causality warrants recognition of those coherences as ontologically significant. This ontology is a variety of structural realism — related to Ontological Structural Realism (OSR) (French 2003). It is also a kind of process philosophy. The designation "Process Structural Realism" (PSR) seems appropriate. How would this approach work out in practice? We consider four system-types, two from biology and two from the social sciences.

Partial Networks of Biochemical Reactions as "Oscillophores"

There has been a recent increase in interest in 'systems biology' — quantitative modeling of complex networks of biological interactions. Complicated systems of interactions abound at all biological levels — molecular, organismic, and ecological. Sets of interactions that return repeatedly to the same sequence of states (a closed "trajectory" in appropriate "state space") are of special interest. Oscillating interaction networks have been studied extensively in non-biological contexts (e.g., Eiswirth 1991)[14] but constraints peculiar to biological systems require special attention. Typically, networks of interaction that are of biological interest involve tens or hundreds of interacting species and

---

12 This involves Cayley's theorem. (Earley 2006b)

13 Whether or not coherence is ontologically significant depends on the detailed characteristics of entities with which that coherence interacts (Earley 2003c).

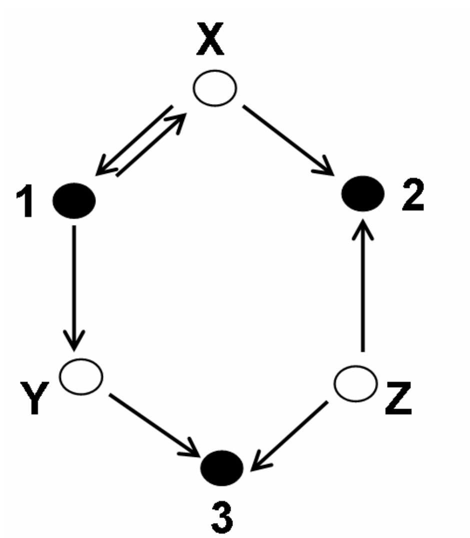
14 Such studies consider "direct" autocatalysis in which a single reaction produces tow or three copies of one of the reactants. In biological systems, "indirect" or "network" autocatalysis (e.g., Scheme 2) predominates.

correspondingly large numbers of interactions. Fortunately, much can be learned (Goldstein 2004) by studying "sub-networks"— structural motifs that occur as parts of larger networks. Some specific patterns of connection ("topologies") internal to partial networks can lead to sustained oscillations when they are included in larger sets of interactions in biological systems. When imbedded in larger systems, some sub-networks are carriers of oscillatory behavior ("oscillophores"). Scheme 2 represents three reactions (dark circles) involving only three biochemical (molecular) agents (open circles). In the first reaction, species X produces Y, but with concomitant reformation of X. In the second and third reactions, species Z removes X and Y from the system.[15] For appropriate parameters, this partial network (as a unit) can display autocatalysis, and thereby "destabilize" a larger network of which it is a part. Such instability is a necessary (but not sufficient) condition for oscillation.

1) $X \rightarrow \frac{1}{2}(X + Y)$

2) $X + Z \rightarrow$

3) $Y + Z \rightarrow$



Scheme 2. Two representations of a oscillophore of minimum size. Open circles corespond to molecular species, filled circles corespond to processes, including exit from the system

[15] A product inhibition pathway in certain (phosphofructokinase) enzymatic reactions fits this pattern.

Circadian Rhythms

Many biological organisms display cyclical variations in characteristics (e.g., body temperature) with a period of approximately twenty-four hours. These "circadian" rhythms are one of the most studied aspects of systems biology. Remarkably, circadian oscillations maintain approximately 24-hour periods under wide variations in external conditions and gross changes in the internal states of the animals displaying them. Clearly, mechanisms underlying these oscillatory changes must be insensitive to variations in parameters. This characteristic is called "robustness." Robustness would be an evolutionary advantage, by allowing organisms to function well in changing circumstances. However, it is not clear how this feature might have originated through biological evolution. One suggestive observation is that circadian rhythms typically result from complex combinations of several different oscillatory networks, rather than from single oscillatory mechanisms, such as the relatively simple ones studied by physical chemists, or the minimum oscillophores just considered. Perhaps there is some connection between evolutionarily valuable robustness and mechanistic complexity.

To understand the evolutionary origin of robustness of circadian rhythms, Andreas Wagner (2005) considered a simple mechanism that is relevant for some circadian oscillations. In this model, a nucleic acid (mRNA, designated R) serves as a template for production of a protein (P) that (after a delay) produces a second protein (P′). The second protein interacts with the nucleic acid in a way that *decreases* the rate of production of P. (This is "product inhibition".) The investigator considered all possible interactions of two distinct but similar oscillators of this class. The three components of the first oscillator are R_1, P_1 and P_1'. The second oscillator involves corresponding substances, R_2, P_2, and P_2'. Wagner restricted his attention to the interaction of P_1' with R_1, R_2 and P_2', and the corresponding interactions of P_2'. Each of these six interactions was allowed one of three characteristics — inhibitory, catalytic, or absent (decreasing, increasing, or having no influence on, the overall reaction rate). Those (3^6) combinations of possibilities give rise to 729 interaction topologies. The detailed behavior of each topology depends on a number of parameters (between 10 and 16, depending on the topology). Only 201 of those topologies gave rise to circadian oscillations for at least one set of the values of relevant parameters. (5000 random combinations were tested). The majority of topologies that yielded circadian oscillation did so for only a small number of parameter sets — that is, those topologies were not robust. In contrast, about 5% of the 729 topologies yielded oscillations for many sets of parameter values, demonstrating significant robustness. The topology in which both systems (1 and 2) oscillate independently was one order of magnitude less robust than the most robust 5% of the coupled topologies. Since more robust topologies would have an evolutionary advantage, significant increase in robustness provided by coupling of oscillatory mechanisms is a sufficient explanation of persistence of mechanistic complexity that natural circadian rhythms display. In the system modeled, more robust topologies resembled each other closely; paths involving only single alterations in topology connected them all. This indicates that ordinary evolutionary development could reach all robust topologies. There is no evidence that the origin of complicated mechanisms (and therefore robust topologies) would present an evolutionary problem.

Complex Coherence

Psychiatrist Murray Bowen (Bowen 1991, Kerr 1989) held that people begin life as reactive components of "family systems:" "differentiation" toward formation of an autonomous "self" may occur during maturation of an individual, but is often inadequate, and is never fully achieved. Deficiencies in differentiation lead to individual and family pathologies. In social psychology, Rom Harré (2003) developed "positioning theory" which holds that agents develop in and through "conversation" with others.

> … discursive practices constitute the speakers and hearers and yet at the same time in certain ways is a resource through which speakers and hearers can negotiate new positions. A subject position is a possibility in new forms of talk: position is what is created in and through talk as the speakers and hearers take themselves up as persons. …(Davies 1991)

Partial integrations of processes that involve scarce resources are major features of the modern world. These large-scale economic systems provide the basis for survival of over 6.5 billion humans (3/1/2006 estimate). Standard economics[16] assumes that individuals choose among courses of action, based on accurate information and because of preferences ("utility" functions) that are self-interested and predetermined. That is to say, the agents recognized by standard economics are pre-constituted and pre-individuated — the $(\exists x)\cdot P(x)$ assumption applies. Social interactions are all "contractual." This is the model of "economic man." This approach has clarified important aspects of economic behavior, but has deficiencies (e.g. Drucker 1939) that are now widely recognized (Brooks 2006). A new approach to microeconomics (Bowles 2003) treats utility functions as developed over time, under the influence of non-contractual social arrangements ("institutions") and controlled by intrinsic limitations on individual reasoning power ("bounded" rationality) and scarcity of relevant information. This amounts to considering that economic agents *emerge from* the interactions in which those agents engage, as Bowen, Harré and others describe. Camerer (2006) reviewed recent experiments (most used "game theory") testing the applicability of the standard economic model. The main findings were that some situations provide agents with incentives to *do the opposite* of what other agents are doing. (This is strategic "substitutability"). In such cases, the model of economic man applies reasonably well. In other situations, incentives favor agents *matching* strategies employed by others— then the economic man model does not apply. In the latter case (called strategic "complementarity"), highly coordinated action of agents can arise from factors not considered important in standard economics. The cases in which the model of economic man does not apply are similar to the biochemical oscillophores in that autocatalytic[17] processes can destabilize systems, possibly — but by no means necessarily — leading to yet higher levels of integration if suitable controls emerge. Each of these diverse examples illustrate how ontologically significant coherence can arise from process.

---

[16] Neoclassical or 'Walrasian' economics

[17] Indirect (network) autocatalysis can obtain even when the model of economic man is applicable.

Applications of PSR

At the end of the paper that questioned how mathematical objects might apply to things of the natural world, van Frassen (2006) pointed out that every investigation has some particular interest. Every investigator (scientist or not) has a specific point of view – and that effectively reduces the intrinsic complexity of the natural world and enables observations (necessarily partial) to constitute a "data model." Such models are mathematical objects rather than natural ones. Judgments of isomorphism between theoretical models and data models are appropriate.

Whitehead was sensitive to the inherent complexity of nature.

> However we fix a determinate entity, there is always a narrower determination of something which is presupposed in our first choice. Also there is always a wider determination into which our first choice fades by transition beyond itself. The general aspect of nature is that of evolutionary expansiveness. (Whitehead [1925] 1967 93)

This short survey identified four levels of dynamic structure: biochemical oscillophores, robust circadian rhythms in individual organisms, human selves emerging through conversation, and economic integrations. Many levels of integration intervene between the pair from systems biology and the set of two from social science. Similarly, there are many levels of structure at lower[18] (and higher) levels of complexity. However, at each of the four levels considered —and, I propose, at all of the other levels as well — closure of networks of processes provides good warrant for recognition of individual coherences with non-redundant causality as items of ontological significance. Individuals on any one level are composed of individuals of lower levels. Those lower-level individuals contribute in diverse ways to the realization of the closure of relationships that defines and individuates the more-complex coherence. It is not clear that the form of definiteness of the more complex individual is a component of those lower level entities. Composite coherences at any level contribute (both directly and through intermediate complexes) to coherences at higher levels of complexity. Higher levels of complexity control

[18] Chemists leave the less complex levels to physicists. (Laughlin 2005)

environments in which lower level coherences must continually renew themselves. Failure of closure at any level sometimes occurs, with consequences both up and down the scale of complexity. (Please see the Appendix.)

> The endurance of an entity represents the attainment of a limited aesthetic success, though if we look beyond it to its external effects, it may represent an aesthetic failure. Even within itself, it may represent the conflict between a lower success and a higher failure. The conflict is the presage of disruption. (Whitehead [1925] 1967 94)

Process Structural Realism, as a structuralism, emphasizes[19] the central importance of self-restoring networks of relationships (structures). As realism, it recognizes universals as necessary constituents of states of affairs. As process philosophy, it holds that closure of networks of processes defines individuals — and processes are all self-creation of individual dynamic coherences.

Acknowledgement

I thank Rom Harré and D.W. Mertz for helpful comments on earlier versions of this paper.

---

[19] PSR is open to the possibility that there may be closed cycles of relationships without other non-relational relata (French 2003, Mertz 2003 154-157), but does not require that to be the case.

References

Armstrong, David M. (2004). *Truth and Truthmakers*. Cambridge: Cambridge U. Press.

Bowen, Murray (1991). “Diversity from Unity” in *Individuality and Cooperative Action*, Joseph Earley, ed.. Washington: Georgetown University Press.

Bowles, Samuel (2004). *Microeconomics*. Princeton: Princeton University Press.

Brooks, David (2006). “Questions of Culture.” *New York Times*, February 19, 12 WK.

Camerer, Colin and Ernst Fehr (2006). “When Does ‘Economic Man’ Dominate Social Behavior?” *Science, 311(6 Jan),* 47-52.

Davies, Bronwyn and Rom Harré (1991). “Positioning: The Discursive Production of Selves.” *Journal for the Theory of Social Behaviour, 20*(1), 43-63.

Drucker, Peter (1939). *The end of economic man***.** New York: John Day.

Earley, Joseph E. (forthcoming). “Ontologically Significant Aggregation: Process Structural Realism (PSR)” in *The Handbook of Whiteheadian Process Thought*, Michel Weber, ed.. Frankfurt: Ontos Verlag, forthcoming (2006?).

— (2006a). “Chemical ‘Substances’ that are not ‘Chemical Substances.’” *Philosophy of Science*, 2006, in press.

— (2006b). "Some Philosophical Implications of Chemical Symmetry" in *Philosophy of Chemistry: Synthesis of a New Discipline,* Davis Baird and Eric Scerri, eds.. Dordrecht: Springer, 207-220.

— (2003a). "Constraints on the Origin of Coherence in Far-from-equilibrium Chemical Systems" in *Physics and Whitehead: Quantum, Process and Experience,* Timothy E. Eastman and Hank Keeton, eds.. Albany: State U. of New York Press, 63-73.

— (2003b). "How Dynamic Aggregates May Achieve Effective Integration." *Advances in Complex Systems, 6*, 115-126.

Eiswirth, Marcus A. Freund, and John Ross (1991). *J. Adv. Chem. Phys., 190*, 127: *J. Phys. Chem., 95*, 1294.

Harré, H. Rom (forthcoming). “Process and Structure in Chemistry.” *This volume*.

— and Fathali M. Moghaddam, eds. (2003). *The self and others: positioning individuals and groups in personal, political, and cultural contexts.* Westport, Conn.: Praeger.

Kerr, Michael and Murray Bowen (1988). *Family Evaluation: An Approach Based on Bowen Theory*. New York: Norton.

French, Stephen and James Ladyman (2003). "Remodeling Structural Realism: Quantum Physics and the Metaphysics of Structure." *Synthese, 136*: 31-56.

Goldstein, Boris G. Ermakov, J. Centelles, H. Westerhoff and M. Cascante (2004). "What makes biochemical networks tick? A graphical tool for the identification of oscillophores." *European Journal of Biochemistry*, *271*, 3877-3887.

Kondepudi, Dilip and Ilya Prigogine (1998). *Modern Thermodynamics: From Heat Engines to Dissipative Structures.* New York: Wiley..

Laughlin, Robert B. (2005). *A Different Universe: Reinventing Physics from the Bottom Down*. New York: Basic.

Locke, John (1690). *An Essay Concerning Human Understanding*. http://www.rbjones.com/rbjpub/philos/classics/locke/.htm ctb3c06

Merricks, Trenton (2001). *Objects and Persons*. New York: Oxford U. Press.

Mertz, Donald W. (1996). *Moderate Realism and Its Logic*. New Haven: Yale U. Press.

— (1999). "The Logic of Instance Ontology." *Journal of Philosophical Logic, 28*: 81-111.

— (2003). "An Instance Ontology for Structures: Their Definition, Identity, and Indiscernibility. *Metaphysica* , 127-164

— (2004a). "The Nature and Necessity of Composite Simples, E.g., Ontic Predicates." *Metaphysica*, 89-133.

— (2004b). "Objects as Hierarchical Structures: A Comprehensive Ontology." *Relations and Predicates*, Herbert Hochberg and Kevin Mulligan (Eds.), Frankfurt: Ontos Verlag.

Scott, Stephen (1994). *Oscillations, waves and chaos in chemical kinetics.* Oxford: Oxford University Press.

Simondon, Gilbert ([1964] 1992). “The Genesis of the Individual,” Jonathan Crary and Sanford Kwinter, trans., in *Incorporations,* Jonathan Crary and Sanford Kwinter, eds., New York: Zone (MIT Press).

Trettin, Käthe, (2004). “Tropes and Relations” in *Relations and Predicates*, Herbert Hochberg and Kevin Mulligan (Eds.). Frankfurt: Ontos Verlag.

Van Fraassen, Bas C. (2006). “Representation: the Problem for Structuralism” *Philosophy of Science*, in press. http://philsci-archive.pitt.edu/archive/00002498/01/PSA04Structure-FIN-SM.pdf

Wagner, Andreas (2005). Circuit topology and the evolution of robustness in two-gene circadian oscillators. *Proceedings of the National Academy of Science (USA)102(33),* 11775-11780.

Whitehead, Alfred ([1925] 1967). *Science and the Modern World*. New York: Macmillian.

— ([1933] 1967). *Adventures of Ideas*. New York: Macmillian.

— ([1929] 1978). *Process and Reality* (Corrected Edition, David Griffin and Donald Sherburne, editors). New York: Free Press.

Appendix

Suppose we have a set of several agents (x_1, x_2 , x_3 , …. x_i) — let's call them "X, the set of *x*s". Each *x* may interact with other *x*s, and with itself. Also, consider an appropriate test agent *y* that has some property *F* when the *x*s do not interact in a significant way. If the *x*s do interact so as to generate a closed set of states that continually recur over a more or less extended period of time – indicated *X I*, then *y* may have different (other than *F*) properties (~*F*) due to interaction between *y* and *X*, the set of xs. If the latter condition prevails, it is legitimate to conclude that an emergent entity *z* exists, and the xs are parts of *z.*

If P is the part relation, I indicates that the set of xs interact to yield closed set of states, and *y* is an agent that, in the absence of significant interaction among the xs, has property *F* then:

$$(\exists x_1 \ldots \exists x_i) \in X \,.\left[\left\{\sim\ X\ I \supset \left(\exists y \left(F\left(y\right)\right)\right)\right\}\right]$$

$$(\exists x_1 \ldots \exists x_i) \in X \,.\left[\left\{X\ I \,.\left(\exists y \left(\sim\ F\left(y\right)\right)\right)\right\} \supset\ \exists z\left(X P z\right)\right]$$

The symbol *z* refers to an emergent entity of which the xs are parts. It is legitimate to speak of the emergence of a new entity *z*, if and only if certain agents (the xs in this case) interact in such a way that some (any) test entity (*y*) suffers a change in its properties (*F* becomes ~*F*) due to the closure of that interaction (XI). If such closure does occur, then the xs are correctly considered as parts of the emergent entity *z* — that is, XPz. Any such *z* might interact with other agents, of similar or different sorts, to generate yet larger emergent entities, say, one of the ws. Also, each and every one of the xs, is itself an emergent entity made up of components, perhaps the us. Every one of these integrations can fail to persist, with consequences both for its constituents and for coherences of which it may be a component.