Duality without Dualism

Timothy E. Eastman
Plasmas International, Silver Spring, Maryland

It is a matter of common sense that the world is composed of a multiplicity of discrete, separable objects. Indeed, this worldview of perceptual objects is practical and essential for everyday life. As the atomic theory of matter emerged, it was rather natural to assume that atoms were small-scale counterparts of everyday objects. Indeed, such a simplistic, philosophical atomism became an accepted part of the implicit metaphysics of classical physics. Similarly commonsensical is the basic distinction between mind and matter which, with Descartes, was elevated to a philosophical first principle.

Descartes' mind-matter distinction became the prime exemplar of dualism, the notion that certain concepts related in experience are not really related but belong to different categories, and that the apparent relationship of such dual pairs derives only from secondary connections. In contrast, the process-relational approach emphasizes a "duality without dualism" which affirms the fundamental connection of such concepts as being/becoming, mind/matter, and symmetry/asymmetry, but does so in a way that avoids a simplistic symmetry of the dualities.

In particular, contrasts are presented of the form "both A with respect to x and B with respect to y" instead of simple dualisms that set up some form of absolute "A versus B" opposition. In this way, a process framework grounds the "both-and" approach described below, which is embodied in the transition from classical to modern physics. By correlating various dualities in modern physics and philosophy, we demonstrate a new tool for testing certain philosophical claims and for suggesting new hypotheses of interest in physics. The nuanced correlates discussed by Whitehead and some process philosophers are closer to complementary pairs in modern physics than traditional dualisms.

Perceptual objects and particularism

The worldview of perceptual objects, with its discreteness and separability, has continued its imaginative hold up to the present day although many aspects of modern physics support a process-relational understanding of the world as Whitehead proposed (Jungerman 2000). In contrast to this process interpretation, it has been claimed that "field theories are radically reductionistic: the whole reality of a field in a given region is contained in its parts, that is to say, its points." (Howard 1989, 235) This common view of field theories is rationalized by assuming that the discreteness and separability of mathematical points can be simply mapped onto physical systems. A more technical statement of this claim is that "by modeling a physical ontology upon the ontology of the mathematical manifold, we take over as a criterion for the individuation of physical systems and states within field theories the mathematician's criterion for the individuation of mathematical points" (ibid., 236). Einstein presupposed the kind of separability indicated here and used it, along with a locality principle, as part of his strong attack on the completeness of quantum theory.

This paper was published as chapter two of *Physics and Whitehead: Quantum, Process and Experience*, ed. T. Eastman and H. Keeton, Albany: State University of New York Press, 2004, pp. 14-30 (Note: Table 1 is located at the end of this document).

Yutaka Tanaka demonstrates the construction of Bell's inequalities, applicable to certain quantum systems and their experimental testing, which have provided a definitive test of the assumptions of separability and locality. These assumptions together have now been shown conclusively as false (see papers in Cushing and McMullin 1989). This experimental disconfirmation of Bell's inequalities confirms quantum over classical prediction. Paul Teller refers to the assumption of ontological locality, employed in setting up Bell's inequalities, as particularism (Teller 1989, 215) and points out that this assumption allows "only one kind of locality: causal locality." In discussing the correlations revealed by the Bell inequality violations, Teller (1989, 222) states that recognizing 'relational holism' and avoiding particularism allows one to see "The correlation ... as simply a fact about the pair. This fact … need not itself be decomposable in terms of … more basic, nonrelational facts."

There are numerous historical and philosophical reasons to be skeptical of classical notions of separability and particularism as shown by Leclerc (1972, 1986) and to be skeptical of the non-relational, container view of space and time that is general linked with the worldview of classical physics (Capek 1974; Angel 1974).

Experience and dualities

Henry Stapp has shown how high-level consciousness or mind can be considered as an integral part of basic physical systems without assuming a simplistic reductionism or turning to mind-body dualism (Stapp 1993). One essential, non-reducible feature of quantum measurement is that of determining which question is posed (Stapp). As shown below, dualities are common in modern science but these are dualities that need not be interpreted as simple dualisms. Whitehead used experience-like features as a basic analogue for his treatment of actual entities and systems (Clayton). However, the use of this analogue is not "panpsychism" as so commonly supposed because Whitehead does not treat 'actual entities' as simply small-scale mental entities (psyches) that compose all large-scale mental entities. Instead, Whitehead's basic hypothesis is that some type of low-level experiencing (prehension) is ubiquitous and a basic metaphysical principle (Nobo). Griffin (1988) has shown why a better term is "pan-experientialism." The multi-level systems approach with emergence that has long been common in process approaches in considering the problem of high-level consciousness is now seen by many as a logical consequence of a nonlinear, dynamical treatment of living systems (Prigogine and Stengers 1984; Kaufmann 1993). On this basis, a Whiteheadian panexperientialism appears as a natural hypothesis for answering how Stapp's posing of the question to quantum systems is resolved more generally.

Whitehead's philosophy is a type of general systems theory that he called a philosophy of organism.[1] Clayton shows how it frames an ecological perspective that arises naturally from a comprehensive event metaphysics. Although the basic elements of his system, actual entities, are generally treated as microscopic in scale, Whitehead never associates any particular size with actual entities. One problem with a simple microscopic interpretation is revealed by Nobo through detailed analysis of Whitehead's discussion of the two aspects of becoming: concrescence (microscopic in orientation) and transition (macroscopic in orientation). Tanaka addresses a second problem that emerges in quantum measurement theory wherein "an individual quantum event is not necessarily microscopic. The simultaneous correspondence of the EPR experiment shows us the individuality of a quantum process at long distances...the region of an individual quantum process may have an arbitrary size with respect to space-time coordinates." A. H. Johnson reports that Whitehead directly acknowledged an overemphasis on the micro-level in his works and recognized the need for a category of emergence so that nexus of actual entities can have emergent properties, both concepts being implicit in Whitehead's works and made explicit by Johnson (1983, 53). Nobo and Lango (2000) both develop details concerning how the enduring objects of our everyday life are constituted from societies or nexus of actual entities.

Relational holism

Alfred North Whitehead attacked various types of particularism and container views and introduced a comprehensive system of thought that replaces inert substance with relations, and expands upon a philosophy of organic, relational holism.[2] Related philosophical approaches have been introduced as systems theory (Laszlo 1972; Auyang 1998), hierarchy or complexity theory (Chandler, 1999), dialectical holism (Harris 1988), ecological perspectives (Nisbet 1991), evolutionary worldviews (Jantsch 1980), and varieties of holism in pragmatism and contextualism (Rescher 1999).

These various forms of relational holism are gaining in recognition for the following reasons:

1. Quantum theory is inconsistent with the classical notion of a philosophical atom (Leclerc, 1972) and "requires us to renounce objects." (Finkelstein 1996, 35).
2. A detailed analysis of parts and wholes in low-energy physics provides for "the rigorous establishment of emergence; that is, the exhibition of macroscopic properties radically different from those of the constituents." (Shimony 1987, 421)
3. Field theory, evolution, and systems concepts more generally illustrate how physical systems cannot be simple classical substances, sufficient unto themselves, but are constituted by their interactions and relations with other particle and field entities.
4. Experiments show the failure of Bell's inequality and thus explicitly deny the combined assumptions of separability and locality used to create the inequality. Leading theorists in philosophy of physics agree that 'particularism' is false and are seriously considering various types of relational holism as a viable metaphysical framework most compatible with the physics results. (Kitchener 1988; Cushing & McMullin 1989).
5. Einstein's relativity is a relational theory of space and time which is incompatible with the 'container' view held in association with classical physics and strongly associated with particularist and reductionist approaches. (Angel 1974; Capek 1961 1974)
6. The linguistic turn in philosophy is a wrong turn because "existence is not simply a matter of the satisfaction of a description" (Bradley 1998) as assumed for 'weak' theories of existence. In contrast, those who engage in the business of modern science and technology generally presume a strong theory of existence. Whitehead takes account of arguments made for the linguistic turn even while maintaining critical realism.

Table 1 orders those concepts which are common across all three conceptual systems under discussion here (classical, quantum, process) along with those that exhibit contrasts or that illustrate complementary aspects between the classical and quantum frameworks. Here, 'quantum' refers to modern physics broadly, exemplified especially by quantum theory and relativity theory.

Concepts in Common

Concepts that are roughly common across the classical, quantum and process frameworks are listed in the first major row of the table. For each concept, related process phrases or terms are listed in the process column followed by contributors to this volume who provide more detail concerning that concept. Methodological (technique-based) reduction is common throughout just as it is an integral part of scientific method. Epistemological (knowledge-based) reduction fails in the quantum case because, as noted by Stapp, the physics alone does not specify which question is posed. The interconnectedness emphasized in process thought is now recognized as important in non-equilibrium, dissipative structures (Prigogine and Stengers 1984; Earley) and is common to all systems requiring long-range field interactions via the electromagnetic or gravitational fields, i.e., all macroscopic physical systems.

The temporal development of all complex systems, classical or quantum, is not predictable in absolute detail. Chew points out that approximation is an intrinsic part of all measurement although classical physics suggested erroneously that precision had no limit in principle. Unlimited specification of values or of states in classical physics has a counterpart in quantum physics in the specification of wave functions but, as shown by Born (1949), wave functions are associated with probability distributions and not with simply located states of objects as suggested in classical physics. In this way, quantum physics incorporates both probabilities and definiteness.

In so far as modern physics continues to seek a unified field theory with the presumption of one law or set of physical relationships, there is commonality in this sense between classical and modern physics. Methodologically, this emphasis on lawlike-behavior in physical systems is a key part of scientific metaphysics with the criteria of generality, coherence and consistency as discussed in detail by Riffert. However, Finkelstein points out that this emphasis on lawlike-behavior need not require ultimate reduction to a single set of physical relationships.

Contrasting Concepts

Numerous books emphasize contrasts between classical and modern physics. A pioneer in this genre is that of Milic Capek (1961). He documented how the worldview of classical physics included a container view of space and time within which space is a container for objects and a spatialized time is a container for events. In contrast, relativity theory is based on dynamic space-time relations even though Minkowski space-time diagrams [in which time and space are plotted along X and Y coordinates] can suggest a mere spatialization of time. Spatial and temporal relations are fundamentally linked via the Lorentz transformations in a symmetric but not fully equivalent way due to an imaginary coefficient for time in the geodesics (Bunge 1967). Classical physics treated all systems within some global, absolute coordinate frame. In contrast, relativity enables the basic physical relationships or laws, including Maxwell's laws of electromagnetism, to remain invariant in form between moving frames but at the expense of considering all systems as frame dependent. Whitehead was well versed in relativity theory (Whitehead 1922) and recognized the need for such frame dependence as early as 1905, independent of Einstein (Whitehead 1906). Further, Whitehead's 1905 Memoir "undertook the unification of geometry and physics by means of … symbolic logic … Not until 1916, in the General Theory of Relativity, did Einstein express the unification of geometry and physics." (Schmidt 1967, 4)

The temporal development of all classical systems is theoretically predictable in absolute detail. Thus, classical states, trajectories, systems and system evolution are treated as fully specifiable. As noted above, the unlimited precision of classical physics is incorrect both in principle and in practice. Modern physics has been built upon the recognition of fundamental limits that were denied in classical physics: relativity theory requires propagation velocity limits and quantum theory embodies Planck's constant limit to the specification of conjugate variables such as velocity and momentum. Finkelstein proposes to extend these limits even to the primary physical relationships themselves in a way reminiscent of Whitehead's discussion of cosmic epochs.

Classical physics presupposes a God's eye view of natural systems and an associated, unique global time. Relativity theory drops global time altogether and retains only local, frame-dependent times. Such local time is incorporated in Whitehead's local temporalism as discussed in detail by Hansen. One way to offset this loss of global time is to introduce two times in a model of historical reality as proposed by Chew. Local temporalism remains central but is then augmented by a measure of an actual occasion's total history.

Because of the particularism assumed in classical atomism, combined with unlimited specification of classical states and trajectories, a reductionist metaphysics is generally associated with classical physics. Nevertheless, Kant, Bergson and other philosophers tried to make some opening within the classical paradigm for consciousness and other wholistic features without resorting to any simple dualism. In contrast to the apparent reductionism of classical physics, quantum physics can have composite states which are not generally reducible to states of discrete constituents (Howard 1989, 253). Indeed, if one questions the reduction of fields to mere mathematical points, collisionless space plasmas represent a classical system within which the basic dynamics is reducible only to the scale of Debye screening spheres, which is roughly one kilometer in Earth's outer magnetosphere. There is no possible contiguity in Hume's sense in such a system, which is effectively without collisions because particle densities are only about 0.01 to 10 per cubic centimeter. The exchange of forces in such plasmas is without contact and mediated via electric and magnetic fields (Eastman 1993).

Meaningful reference to objects at all scales is presumed in classical physics. In contrast, our everyday world of perceptual objects has no counterpart in quantum microphysics. Discrete self-identical objects, the essence of the classical notion of substance, are replaced with interacting wave-particle entities. Finkelstein points out that Bohr talked about 'no object' physics. In his major work *Quantum Relativity*, Finkelstein (1996) systematically develops a new conception of act and process to supplant objects. Relativity theory makes reference to events and clocks but contains no fundamental reference to objects (Schmidt 1967, 30). Objects and substances may be considered as derivative notions in modern physics and need not be treated as primary concepts as they were in classical physics.

Complementary dualities in both physics and philosophy

Modern physics comprises many complementary pairs or dualities and a number of these are correlated with dualities in philosophy. Further, the transition from classical to modern physics can be illustrated as the movement from one to both poles of various dualities as shown in Table 2. The basic form of this transition is from 'A' only to 'A plus B' where A-B are complementary pairs. The worldview of classical physics tended to make A terms exclusive or ultimate in some way that is now recognized as misleading or incomplete. Just as classical physics can be considered as a limiting case of quantum and relativity physics, its 'A' characterizations can be considered as a limit or subset of more complete A-B complementary pairs. The quantum and process views construct a more inclusive duality in each case that treats 'A' only as a type of classical limit analogous to how Newton's equations can be retrieved as a classical limit to equations for quantum dynamics.

This explicit recognition of dualities is becoming increasingly understood as an integral part of modern physics (Witten 1997). The corresponding both-and approach cuts through most of the alleged puzzles that are so much a part of the current genre of physics popularizations. Many of these "puzzles" depend on the comparison of a confirmed physics result with a presupposition linked to the worldview of perceptual objects or, effectively, of classical physics. For example, the insistence on identifying a simply-located particle going through one slit or the other in a two-slit quantum experiment depends on treating particles only as traditional philosophical atoms and not as quantum wave-particle entities. When properly constructed, the puzzle dissolves.

Table 2. Movement from one to both poles simultaneously of various dualities in the transition from classical to modern physics.

Classical Physics	Modern Physics
Substance only; materialism	both substance and event-oriented descriptions
External relations only	both external and internal relations
Continuity only; no ultimate discreteness	both continuity and quantization
Symmetry only	both symmetry and asymmetry
Space only; time spatialized	both space and time; coupled space-time metric
Determinism only	both predictability/determination and Indetermination[3]
Particles only	both particles and waves
Parts only	both parts and wholes[4]
External only (source for order)	both external and internal sources of order; self-organization[5]
Efficient cause only	both efficient cause and other types[6]

Although the 'both-and' and duality themes of process thought are emphasized here, we wish to avoid another simplistic reduction. Dualities are often enclosed in triadicities encouraging us, with Peirce, to "think in trichotomies not mere dichotomies, the latter being crude and misleading by themselves."[7] Similarly, the complementary pairs of modern physics often point beyond themselves to higher levels of abstraction or other (meta)physically contructed solutions.

Dualities of various types permeate philosophy and undergird Plato's dialogical method. Table 3 lists many such dualities adapted from a list by Charles Hartshorne who discusses a technique for relating the terms of each dual pair.[8] This list of philosophical dualities shows how many important topics lend themselves to a dual or complementary construction and that these dualities are often not merely symmetric in character.

Table 3. Dualities in Philosophy

relative	absolute
dependent	independent
internally related	externally related
experience, subject	things experienced, object
whole, inclusive	constituent, included
effect, conditioned	cause, condition
later, successor	earlier, predecessor
becoming	being
temporal	atemporal
concrete	abstract
particular	universal
actual	possible
contingent	necessary
finite	infinite
discrete	continuous
complex	simple
asymmetry	symmetry

The Western intellectual bias is very different from that of Chinese culture. Chinese scholars David Hall and Roger Ames distinguish two modes of thinking. 'Correlative' or 'analogical' thinking, the dominant mode in classical Chinese culture, "seeks to account for states of affairs by appeal to correlative procedures rather than by determining agencies or principles."(Hall and Ames 1995, xviii) It accepts no priority of permanence over process and presumes no ultimate agency responsible for the general order of things. Causal thinking, the dominant Western mode, tends to assert a priority of being over becoming and to see the cosmos as a single-ordered world and as the consequence of some primordial agency. Hall and Ames argue that correlative thinking is dominant in Chinese culture whereas causal thinking is recessive. In turn, causal thinking is dominant for the West whereas correlative thinking is recessive. The Western tendency to convert certain dualities into either a dualism or a univocal prioritization of one pole over the other is also offset by correlative thinking. "In a correlative sensibility such as we find within the Chinese tradition, terms are clustered with opposing or complementary alter-terms. Classical Chinese may be uncongenial to the development of univocal propositions for this reason." (ibid., 230)

With the philosophical dualities of Table 3 as both motivation and a basis of comparison, I now consider in Table 4 various dualities in modern science as exemplified by quantum and relativity theory.

Table 4. Dualities in Physics

field	source/matter	field theories
wave	particle	Bohr's complementarity
momentum	position	principle (Wilkins)
magnetic	electric	gauge theories (Witten)
discreteness	continuity	topology (Geroch, p. 142)
actuality	possibility	quantum properties (Bub)
non-linear	linear	both classical and quantum
final act/absorption	initial act/emission	quantum actions
synthetic	analytic	geometry[9]
asymmetry	symmetry	linear mappings (Geroch,p.116)
episystem	system	quantum system cut
nonlocal	local	quantum levels

Some of the physics dualities are direct correlates to those in the philosophy list (discreteness-continuity; actuality-possibility; synthetic-analytic; asymmetry-symmetry; and final act-initial act, associated with successor-predecessor). These dualities have a structure that is similar in both physics and philosophy. For example, an analysis of asymmetry and symmetry in physics yields the same result as applying Hartshorne's interpretive rules for dual pairs in philosophy.[7] Rosen states this result as follows. "Asymmetry is a necessary condition for symmetry. For every symmetry there is an asymmetry tucked away somewhere in the world."

Shimon Malin argues that the collapse of quantum states in quantum physics enforces a balance between actuality and potentiality, and between complexity and simplicity. The actuality-possibility duality is often debated in interpretations of modern science. One apparently explicit way in which this duality enters is in an analysis of the uniqueness theorem for quantum measurement theory. As stated by Bub (1997, 239) "Classically, only the actual properties are time-indexed; quantum-mechanically, both the actual properties and the possible properties are time-indexed ... there is nothing inherently strange about the notions of possibility or actuality in quantum mechanics."

Classical physics is often quoted as superior to quantum physics at the macroscopic scale, which is often regarded as simply linear. However, Finkelstein (1996, 388) points out that "classical non-linearity is a simplification of the quantum non-linearity inherent in the many-system kinematics of the composite system whose classical limit we take."

The final act-initial act pair in Table 4 is discussed in depth by Finkelstein. "Initial and final actions taken together are collectively called external (or terminal) actions ... The duality between initial and final modes, between before and after the fact, is the most important symmetry of quantum theory ... Often we call initial actions 'creation operations' and final actions 'annihilation operations.' There is no need, however, to imagine creation from nothing or annihilation to nothing. These are acts of an experimenter with a large reservoir of quanta from which to draw and in which to deposit. Some use the terms 'emission' and 'absorption' which have more appropriate associations." (ibid. 14; see also 17,40, 47, 48).

The philosophical pairing of whole-constituent has two related physics entries, episystem-system and nonlocal-local. In quantum physics, episystem is defined as follows: "What acts on the system we will call the episystem. The episystem consists of everything playing a significant part in the experiment that is not part of the system, including the experimenter, the apparatus, the recording system, and an entropy dump. We call this division of an experiment into system and episystem, the system cut … An action vector does not describe a state of being of the system but an action of the episystem on the system." (ibid., 16). The system cut "is permeable and movable." (ibid., p. 395).

Applying Hartshorne's interpretive rules for dual pairs to episystem-system results in the proposition that an episystem necessitates some system; whereas a system necessitates only that there be some episystem or other, yet which particular episystem is contingent. The unavoidable yet contingent presence of an episystem is widely recognized in quantum physics and is a central part of the argument by Stapp that necessarily a question must be posed to quantum systems although there is some contingency in both details about the episystem and the answer that nature gives to any particular question.

Nonlocal-local pairs naturally emerge in quantum physics and resolve the meaning of action. The action principle is the key variational principal of physics. However, in classical physics, there is no reason why a particle's motion should be affected by values of the action on paths it does not take. In contrast, "Quantum physics is kinematically nonlocal though dynamically local. Quanta only act where they are, but most initial and final actions, even sharp ones, do not determine where they are" (Finkelstein 1996, 372).

Dualities without dualism. As we have seen, there is substantial correspondence between many duality pairs in philosophy and physics. In those cases where the correspondence is most clear, the physics results may have important philosophical implication. Where the physics pairings have less clear counterparts in the philosophy list, for example with gauge theory dualities, those cases should be fruitful areas of study. For example, the magnetic-electric pair and other such pairings in gauge theory are deeply linked to symmetry principles and are closely related to the asymmetry-symmetry pairing. Philosophical analysis of these cases, such as the application of Hartshorne's interpretive rules, points to the need for transcending simple symmetry and recognizing symmetry breaking, a key result of modern physics (Witten 1997).

Finding a balance. The process-relational tradition has occasionally opted for the Heraclitean extreme that 'all is change.' However, Whitehead and most recent process philosophers have worked towards a middle ground in which

> "being and becoming, permanence and change must claim coequal footing in any metaphysical interpretation of the real, because both are equally insistent aspects of experience." (Kraus 1979, 1)

References

Angel, Roger B., 1974 1980. *Relativity, the theory and its philosophy*. Oxford: Oxford University Press.

Auyang, Sunny Y. 1998. *Foundations of Complex Systems Theories*, Cambridge: Cambridge University Press.

Barbour, Ian. 1990. *Religion in an Age of Science: The Gifford Lectures 1989-1991, Volume 1,* San Francisco: Harper.

Born, Max. 1949. *Natural Philosophy of Cause and Chance*. Oxford: Oxford University Press.

Bradley, James. 2002. The speculative generalization of the function: A key to Whitehead. *Tijdschrift voor filosofie,* Leuven, Belgium, forthcoming.

Bub, Jeffrey. 1997. *Interpreting the Quantum World*. Cambridge: Cambridge University Press.

Bunge, Mario. 1967. *Foundations of Physics*. New York: Springer-Verlag.
Capek, Milic. 1961. *Philosophical Impact of Contemporary Physics*. Princeton: D. Van Nostrand.
Capek, Milic. 1971. *Bergson and modern physics. A reinterpretation and re-evaluation*. Dordrecht: Reidel.
Chandler, Jerry L.R. 1999. Semiotics of complex systems and emergence within a simple cell. *Semiotica* 125, no. 1/3, 87-105.
Cushing, James T. and Ernan McMullin, eds. 1989. *Philosophical Consequences of Quantum Theory: Reflections on Bell's Theorem*. Notre Dame: University of Notre Dame Press.
Eastman, Timothy E. "Micro- to macroscale perspectives on space plasmas." *Phys. Fluids B* 5 (7): 2671-2675 (1993).
Finkelstein, David R. 1996. *Quantum Relativity: A Synthesis of the Ideas of Einstein and Heisenberg*. Berlin: Springer-Verlag.
Geroch, Robert. 1985. *Mathematical Physics*. Chicago: University of Chicago Press.
Griffin, David Ray, ed. 1988. *The Reenchantment of Science: Postmodern proposals*, Albany: State University of New York Press.
Hall, David L. and Roger T. Ames. 1995. *Anticipating China: Thinking through the Narratives of Chinese and Western Culture*, Albany: State University of New York Press.
Harris, Errol E. 1988. Contemporary physics and dialectical holism, In *The World View of Contemporary Physics: Does it need a new metaphysics?* Edited by R. F. Kitchener. Albany: State University of New York Press.
Hartshorne, Charles. 1970. *Creative Synthesis and Philosophic Method*. La Salle: Open Court.
Hartshorne, Charles. 1997. *The Zero Fallacy and Other Essays in Neoclassical Philosophy*. La Salle: Open Court.
Howard, Don. 1989. Holism, separability, and the metaphysical implications of the Bell experiments. In *Philosophical Consequences of Quantum Theory: Reflections on Bell's Theorem*. Edited by J. T. Cushing and E. McMullin. Notre Dame: University of Notre Dame Press.
Jantsch, Erich. 1980. *The Self-organizing Universe: Scientific and human implications of the emerging paradigm of evolution*. Oxford: Pergamon Press.
Johnson, A. H. 1983. *Whitehead and His Philosophy*, Lanham: University Press of America.
Jungerman, John A. 2000. *World in Process: Creativity and interconnection in the new physics*. Albany: State University of New York Press.
Kauffman, Stuart A. 1993. *The Origin of Order: Self-organization and selection in evolution*. Oxford: Oxford University Press.
Kitchener, Richard F. ed. 1988. *The World View of Contemporary Physics: Does it need a new metaphysics?* Albany: State University of New York Press.
Kraus, Elizabeth M. 1979. *The Metaphysics of Experience: A companion to Whitehead's Process and Reality*. New York: Fordham University Press.
Lango, John W. Whitehead's category of nexus of actual entities. *Process Studies* 29 (1): 16-42 (spring-summer 2000).
Laszlo, Ervini. 1972. *Introduction to Systems Philosophy: Toward a New Paradigm of Contemporary Thought*. New York: Gordon and Breach.
Lawrie, Ian D. 1990. *A Unified Grand Tour of Theoretical Physics*. Bristol: Adam Hilger.
Leclerc, Ivor. 1986. *The Nature of Physical Existence*, Lanham: University Press of America. (originally published by George Allen & Unwin Ltd, London, 1972).

Leclerc, Ivor. 1986. *The Philosophy of Nature.* Washington, DC: The Catholic University of America Press.
Nisbet, E. G. 1991. *Leaving Eden: To protect and manage the Earth*. Cambridge: Cambridge University Press.
Nobo, Jorge Luis. 1986. *Whitehead's Metaphysics of Extension and Solidarity*, Albany: State University of New York Press.
Prigogine, Ilya, and Isabelle Stengers. 1984. *Order out of Chaos: Man's new dialogue with nature*. New York: Bantam Books.
Rescher, Nicholas. "On situating process philosophy." *Process Studies* 28 (1-2): 37-42 (spring-summer 1999).
Rosen, Joe. 1995. *Symmetry in Science: An introduction to the general theory*, Berlin: Springer-Verlag.
Schmidt, Paul F. 1967. *Perception and Cosmology in Whitehead's Philosophy*. New Brunswick: Rutgers University Press.
Shimony, 1987. *The methodology of synthesis: Parts and wholes in low-energy physics. In Kelvin's Baltimore Lectures and Modern Theoretical Physics: Historical and Philosophical Perspectives.* Edited by R. Kargon and P. Achinstein. Cambridge: The MIT Press, 399-424.
Stapp, Henry P. 1993. *Mind, Matter, and Quantum Mechanics*. Berlin: Springer-Verlag.
Teller, Paul. 1989. Relativity, relational holism, and the Bell inequalities. In *Philosophical Consequences of Quantum Theory*. Edited by J. T. Cushing and E. McMullin. Notre Dame: University of Notre Dame Press, 208-223.
Whitehead, Alfred North. On mathematical concepts of the material world. *Philosophical Trans. of the Royal Society of London A* 205: 465-525 (1906).
Whitehead, Alfred North. 1922. *The Principle of Relativity, with Applications to Physical Science*. Cambridge: Cambridge University Press.
Wilkins, M. H. F. 1987. Complementarity and the union of opposities. In *Quantum Implications: Essays in Honour of David Bohm*. Edited by B. J. Hiley and F. D. Peat. London: Routledge & Kegan Paul Ltd., 338-360.
Wilson, Edward O. 1998. *Consilience: The Unity of Knowledge*. New York: Knopf.
Witten, Edward. Duality, spacetime and quantum mechanics. *Physics Today* 28-33 (May 1997).

Notes

1. The famous general systems theory of Ervin Laszlo was inspired by Whitehead's philosophy. "I found … that the organic synthesis of Whitehead can be updated by the synthesis of a general systems theory, replacing the notion of 'organism' and its Platonic correlates with the concept of a dynamic, self-sustaining 'system' discriminated against the background of a changing natural environment." [Ervin Laszlo, *Introduction to Systems Philosophy : Toward a New Paradigm of Contemporary Thought* (New York : Gordon and Breach, 1972), viii] However, his systems theory is classical whereas Whitehead's philosophy of organism has clear quantum aspects [private communication, David Finkelstein, 3-29-02].
2. The term 'holism' is taken broadly here to suggest systems with significant interdependence and emergence, yet with hierarchical organization that provides for relative independence of components. A view that emphasizes discrete, independent elements without relations is here called a "particularism."

3. The term ‘determination’ is used here to denote the predictability of causal order as practiced in science whereas ‘determinism’ is a metaphysical claim requiring philosophical argument. Science is neutral with respect to the philosophical question of determinism.
4. Macroscopic processes emerge in collisionless space plasmas where “the large-scale dynamics are immune from the details of microphysics.” In turn, some systems such as superfluids exhibiting Bose-Einstein condensation have a close coupling of micro- to macroscale, and there are other systems that fill in between these two extremes” (E. Siregar, S. Ghosh, and M. L. Goldstein. Nonlinear entropy production operators for magnetohydrodynamic plasmas. *Phys. Plasmas* 2 (5): 1481 (May 1995); see also T. E. Eastman, Micro- to macroscale perspectives on space plasmas. *Physics of Fluids B (Plasma Physics)* 5: 2671 (1993).
5. For an in-depth study of non-linear systems, self-organization and their application to biological systems and evolution, see Stuart A. Kauffman, *At Home in the Universe: The Search for Laws of Self-Organization and Complexity*. (Oxford: Oxford University Press, 1995).
6. Mario Bunge, *Causality: The Place of the Causal Principle in Modern Science* (Cambridge: Harvard University Press, 1959).
7. These dualities in philosophy listed in Table 3 are adapted from the table of Metaphysical Contraries in Charles Hartshorne, *Creative Synthesis* (1970) VI: 100-101. Hartshorne’s interpretive rules for dual pairs are located on these same pages. In Table 3, the dual pair asymmetry/symmetry is added based on Rosen’s analysis.
8. Charles S. Peirce, the great American philosopher and originator of pragmatism, considered triads as much more adequate than dyads or tetrads as intellectual instruments. Hartshorne associates his r-terms (left column) with Peirce’s Seconds and Thirds and his a-terms (right column) with Peirce’s Firsts (Charles Hartshorne, *Creative Synthesis* (1970) VI: 100.
9. “The qualitative (coordinate-free) and quantitative (coordinate-based) formulations of geometry are traditionally called synthetic and analytic geometry. Analogously, one may speak of synthetic and analytic quantum theory.” (Finkelstein, *Quantum Relativity* (1996) p. 186.

	Classical	Quantum	Process	Contributor
Concepts in Common	long-range order	long-range order	interconnectedness	Jungerman
	unpredictable evolution(praxis)	unpredictable evolution (praxis)	future as open	Jungerman
	'state' - definite values	'state' - definite probability values	probabilities and definiteness	Malin
	laws as absolute	laws as absolute (one law)	generality, coherence, consistency	Chew, Riffert
	methedological and epistemological reduction	methedological	methedological reduction	Riffert, Stapp
Contrasting Concepts	space, time separation	space-time relations	interactive relatedness	Hansen, Chew
	predictable evolution (theory)	unpredictable evolution (theory)	innovation/novelty	Jungerman
	state, trajectories	no state, non-unique trajectories	creative advance	Finkelstein
	objects	no 'object' physics	act, process	Finkelstein, Chew
	laws as absolute	laws as habits	cosmic epochs	Finkelstein
	absolute system	relative systems	interactive relatedness	Chew
	no experiential aspect	experiential aspect	experience as paradigm	Stapp
	no intrinsic limits	fundamental limits	limits, approximation	Chew
	global time	local time	local temporalism	Hansen
	reductionist	not reductionist	not reductionist	Finkelstein
Complementary Concepts	symmetry	both symmetry/asymmetry	dualities without dualism	Rosen
	space only; time spatialized	both space/time	becoming and being	Hansen
	particles only	both particles/waves	actual entities	Chew
	determinism only	both prediction/determination and indeterminism	subjective aim	Finkelstein
	continuity only	both continuity and quantization	coordinate and genetic anayses.	Tanaka
	order only	both order/disorder,novelty	innovation/novelty	Jungerman
	external relations	both external/internal relations	relations as fundamental	Earley
	substance/objects only	both substance and process/events	subject/object, process	Tanaka, Finkelstein,Malin
	global time	both global/local time	historical reality	Chew

Table 1. Classical, quantum, and process concepts are ordered here by those concepts which are common across all three conceptual systems along with those that exhibit contrasts or that illustrate complementary aspects between classical and quantum frameworks. Contributors to this volume that address each concept are listed at the right.