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## Great Problems Solved?

A careful analysis of their information content suggests solutions to a number of problems in physics, cosmology, psychology, biology, philosophy, and of course in metaphysics in particular.

In physics...

*Quantum Mechanics.* We offer a new interpretation in which the wave function is just abstract information about the probability of finding particles somewhere. We show that this information depends only on the wavelength of a particle and the boundary conditions of the experiment, such as the two slits in a wall and the detection screen beyond. Information exists in the form of standing waves, whether or not a particle is entering the apparatus. It depends only on whether one or two slits are open.

*Origin of Irreversibility.* The great problem in statistical mechanics is how we can explain macroscopic irreversibility (entropy increase) when microscopic collisions are thought to be reversible, even in quantum mechanics. We have shown that whenever microscopic collisions or other processes involve radiation, they are not reversible.<sup>1</sup> Outgoing spherical waves of radiation are the norm, but time-reversed incoming spherical waves are *never seen in nature*. Interactions of photons and electrons involve *ontological chance*, because the photon direction is random, as ALBERT EINSTEIN found in 1916. Every collision involving radiation erases the path information about the history of the particles that would have been needed for the collision to be time reversible.

*Entropy and the Second Law.* Abstract immaterial information is mathematically, phenomenologically, and experimentally related to the physical quantity in thermodynamics and statistical mechanics called the entropy. The second law of thermodynamics says that a closed system, left to itself, approaches a state of maximum entropy, or disorder. This change is "irreversible" without input of low-entropy free energy from outside the system.

The macroscopic irreversibility of the entropy law depends on microscopic irreversibility, as LUDWIG BOLTZMANN suspected.

1 See chapter 25 of *Great Problems in Philosophy and Physics*.



*Chance is Real.* Without chance and the generation of possibilities, no new information can come into the world. Without chance, there can be no *creativity*. Without the creation of new information, new ideas, the information content of the universe would be a constant - “nothing new under the sun.” In an eliminatively materialist and determinist world, there is but one possible future. Information philosophy shows that possibilities are real, if *metaphysical*, and chance is ontological.

The ultimate source of chance is the interaction of radiation and matter responsible for microscopic irreversibility.

*Laws of Nature Are Statistical.* With the exception of deep principles like conservation laws, symmetry considerations, and the constancy of light velocity, many laws of nature based on empirical evidence are in fact statistical laws. Microscopic atomic processes are governed by quantum physics, which is a *statistical* theory. These laws give us probabilities, not certainties. For material objects containing large numbers of atomic particles, the statistical uncertainty approaches zero and the laws are *adequately but only statistically deterministic*.

Quantum mechanical *probabilities* (the wave functions) evolve deterministically and continuously according to the Schrödinger equation, but the *actual* outcomes occur discontinuously and *statistically*. This may seem like a logical contradiction, but it's not.

The average value of *possible* particle positions moves according to classical mechanical laws, but the *actual* position where a particle is found is indeterminate (random), following quantum mechanical laws. “Determinism” is only an “adequate” *statistical determinism*.

*Actualizing a Possibility.* The existential status of possibilities is problematic, because they are not things, not physical material objects. They belong to the Platonic realm of ideas, an “ideal world” contrasted with the “material world.” The status of possibilities is a problem in metaphysics. Many metaphysicians today defend *necessitism*, especially the *necessity of identity*. The information philosopher and metaphysician defend *metaphysical possibilism*.



Note that the “possible worlds” of metaphysicians like DAVID LEWIS and the “many worlds” of physicists like HUGH EVERETT III are perfectly deterministic, each with only one possible future. Real possibilities mean there is more than one possible future.

***Collapse of the Wave Function.*** The paradigmatic example in physics of infinite possibilities realized as a single actuality is the so-called “collapse of the wave function” or “reduction of the wave packet.” Information philosophy provides a common-sense, intuitive picture of this process, so often taught as a deep mystery. RICHARD FEYNMAN called it “the only mystery in quantum mechanics.” Information philosophy hopes to *demytify* it.

The wave function is a complex quantity known as a probability amplitude which can interfere with itself. When it is squared it gives us a positive number that represents the probability of finding a particle somewhere. This tells us the specific possibilities of finding a particle in different places. When we make a measurement, we find the particle in one actual place. The possibilities of finding it anywhere else vanish. Nothing material “collapses” in the sense of moving from place to place. This is a perfect example of ambiguous words confusing us about what is really going on.

***The Two-Slit Experiment.*** Information philosophy simplifies this puzzling experiment by showing that the wave function is just *immaterial information* about where the particle may be found. Given the wavelength of the particle, the wave function is completely determined by the boundary conditions – the locations and size of the two slits and the distance to the screen. In the past, we have said that wave and particle are alternate descriptions, because we picture a wave between measurements and a particle when a measurement is made. But we were simply wrong to say “sometimes a wave, sometimes a particle.” These are two distinct aspects or properties.

***Nonlocality and Entanglement.*** When one particle decays into two particles that separate from a central point with equal and opposite velocities, ALBERT EINSTEIN saw that a measurement of one particle’s position instantly tells us where the other particle is (assuming there has been no interaction with the environment).



We know because of the conservation laws for energy, momentum, angular momentum, and particle spin. This allows us to calculate the second particle's position. But this is not "action at a distance," as Einstein feared. We call it "knowledge at a distance." It is central to demystifying the puzzle of entanglement, where two particles are described with a single wave function.

For reasons that we can not yet comprehend, Einstein introduced a false *asymmetry* into a symmetric situation. This asymmetry has confused the interpreters of quantum mechanics for decades.<sup>2</sup>

Two entangled particles resulting from an irreversible single particle decay are described by a two-particle wave function that cannot be separated into a product of single-particle wave functions. When they are "measured" in the rest frame of the original particle decay, their positions are determined simultaneously. The original rest frame is a "special frame." Other moving frames may make one particle's measurement *appear* to be before the other, contributing to the "mystery" of entanglement.

*Reconciling Quantum Mechanics and Special Relativity.* As we saw on page 204 above, Einstein assumed that the entangled particles can be separated and measured independently. But they cannot separate without some interaction that *decoheres* the two-particle wave function into the product of two single-particle wave functions. The first measurement or interaction with anything external instantly locates the particles in a spacelike separation that satisfies the conservation laws, for example equidistant from the origin, with spins that add up to the original spin. Before that measurement, the particles could have been anywhere the two-particle wave function was non-zero (the essence of nonlocality), but wherever they were they must have been satisfying the conservation laws.

Nothing moves faster than light in the collapse of the two-particle wave function, reconciling quantum mechanics and relativity.

In cosmology...

*The Expanding Universe.* Expansion creates more phase space per particle, more possible ways to arrange material, more room for information structures. The increase in positive entropy (disorder) does not mean a decrease in negative entropy (potential informa-

2 See our forthcoming book *My God, He Plays Dice! How Albert Einstein Invented Most of Quantum Mechanics*.



tion). Both entropy and information, both disorder and order, have been increasing since the beginning of the universe. Today's information structures, the galaxies, stars, and planets, including our Sun and our Earth, emerged. Information about them did not exist at the origin of the universe, as many philosophers and theologians have thought.

*The Cosmic Creation Process.* Information philosophy explains the creation and *emergence* of new information in the universe as a two-step process beginning with an *irreversible* quantum event (in which possibilities become actualized) and ending with some positive entropy carried away from the resulting low-entropy information structure, to satisfy the second law of thermodynamics.

This process underlies the creation of every single bit of information, whether the formation of a hydrogen atom from a proton and electron, a complex physical measurement like discovering the Higgs boson, or the creation of a new idea in a human mind.

*The Universe is Open.* It began in a state of total disorder, with the maximum entropy possible for the initial conditions, some 13.75 billion years ago. How then can the universe today contain such rich information structures as galaxies, stars, and planets like Earth, with its rich biological information-processing systems? Why isn't the universe still in thermal equilibrium?

*This is the fundamental question of information philosophy.*

Our answer is that the maximum entropy of the early universe was tiny compared to the maximum possible entropy today, as a result of the expansion of the universe. And because the universe has not had time to reach its potential maximum of disorder, new information (negative entropy) has been and is now being created.

*The Arrow of Time.* The expansion of the universe is the fundamental *arrow of time*. It enables untold numbers of irreversible microscopic events, each of which has an arrow in the same time direction. The so-called radiation arrow is the fact of only outgoing spherical waves. Incoming spherical waves are never seen in nature.

*Negative Entropy has Value.* The source for all potential information can serve us as a basis for *objective value*. It is the *sine qua non* of anything interesting and useful in the universe.





In psychology ...

*The Experience Recorder and Reproducer.* The extraordinarily sophisticated connection between words and objects is made in human minds, mediated by the brain's *experience recorder and reproducer* (ERR). Words stimulate neurons to start firing and to play back relevant experiences that include the objects. The neuroscientist DONALD HEBB famously said that "neurons that fire together get wired together." Our ERR model says neurons that were wired together by old experiences will fire together again when a new experience resembles the old in any way, instantly providing guidance to deal with the new.

*Mind-Body Problem.* Since experiences are stored as immaterial information embodied in the neurons of the brain, information philosophy agrees that the *mind is software in the brain hardware*. But how can immaterial ideas move the material body? A specific example of the mind causing an action, while not itself being caused by antecedent events is the following. Faced with a decision of what to do next, the mind considers several possible alternatives, at least some of which are creatively invented based on random ideas that just "come to mind." Other possible alternatives might be familiar options, even habits, that have frequently been done in earlier similar situations.

All these mental alternatives show up as "neural correlates" - brain neurons firing. When the alternatives are evaluated and one is selected, the selected action results in still other neurons firing, some of which connect to the motor cortex that signals muscles to move the body. Apart from the occasional indeterministic generation of creative new alternative ideas, this whole causal process is adequately determined and it is downwardly causal. Mental events are causing physical body events.

*The Two-stage Model of Free Will.* Since every free act creates information, free will events are intimately related to events of cosmic creation, because they both begin with the generation of *alternative possibilities* for action, and they both end with one possibility being *actualized*. You can think of your thoughts as free, your actions as willed. You can think of both as cosmic events bringing new information into the universe.



***Determinism is an illusion.*** Determinism has had a long and successful history in philosophy and physics, but it is an unwarranted assumption, not supported by the evidence. The material world is quantum mechanical, and ontological chance is the result of quantum indeterminacy. An *adequate* and *statistical* determinism does *appear* when macroscopic objects contain large numbers of microscopic particles so that quantum events can be averaged over. But every free event shows that the universe is not *pre-determined*.

In philosophy...

***Knowledge is an isomorphism.*** Information *represents* a concept or an object better than an imprecise description in language. Information is the *form* in all concrete objects as well as the *content* in non-existent, merely possible, *abstract entities*. Knowledge is an *information structure* in a mind that is a partial *isomorphism* (a mapping) of an information structure in the external world. Information philosophy is the ultimate *correspondence* theory.

***Beyond Logic and Language.*** But there is no isomorphism, no information in common, no necessary connection, between *words and objects*. Although language is an excellent tool for human communication, its arbitrary and ambiguous nature makes it ill-suited to represent the world directly. Language does not picture reality. It is not the best tool for solving philosophical problems.

The teachable elements of information philosophy are not words or concepts, but *dynamical models of information structures*. They go far beyond logic and language as a *representation* of the fundamental nature of reality. They “write” directly into our mental experience recorders. By contrast, words must be *interpreted* in terms of earlier experiences. Without words and related experiences previously recorded in your mental experience recorder, you could not comprehend spoken or written words. They would be mere noise, with no meaning. Compare these two representations of a cat.

CAT



Linguistic and picture/model representations compared.





Compared to a spoken or printed word, a photograph or a moving picture with sound can be seen and mostly understood by human beings, independent of their native tongue.

Computer animated dynamical models can incorporate all the laws of nature, from the differential equations of quantum physics to the myriad processes of biology. At their best, such simulations are not only our most accurate knowledge of the physical world, they may be the best teaching tools ever devised. We can transfer knowledge non-verbally to coming generations and most of the world's population via the Internet and ubiquitous smartphones.

A dynamic information model of an information structure in the world is presented immediately to the mind as a look-alike and act-alike simulation, which is experienced for itself, not mediated through arbitrary and ambiguous words.

*Axioms of Identity.* We propose three axioms of identity, with which many puzzles are solved about the persistence of objects.

*Id1. Everything is identical to everything else in some respects.*

*Id2. Everything is different from everything else in some other respects.*

*Id3. Everything is identical to itself in all respects at each instant of time, but different in some respects from itself at any other time.*

We can rewrite these axioms in terms of information.

*I1. Any two things have some information in common.*

*I2. Any two things have some different information.*

*I3. The identity of anything over time is changing because the information in it (and about it) is changing with time.*

In biology...

*Origin of Life* Because of microscopic irreversibility, the paths of material particles do not always tell us where they have been in the past, though some determinist physicists think so. Cosmological and geological objects have an evolutionary history. And so does biology. Matter and energy (with low entropy) flows through living things, maintaining their dynamical information structures and much of their history.



To discover the origin of life, it will be easier to work backwards in time through the history of biological evolution than to start from physics and chemistry, which know little of preserving information.

**Information in Biology.** Despite many controversies about the role of information in biology over the past several decades, we can now show that the creation and communication of information is not only necessary to understand biology, but that biology is a proper, if tiny, subset of information creation in the material universe, including the evolution of human minds and the abstract ideas created or discovered by our minds that constitutes our knowledge.

As biosemioticians have long claimed, biocommunications use arbitrary codes and symbols that are precursors to human language.

**Evolution.** Material information creation, in the form of planets, stars, and galaxies, went on for perhaps ten billion years before biological "agents" formed. At some time between three and four billion years ago, processes appeared that replicated macromolecules, multiplying their information. Perfect replication does not produce *new* information, only copies of pre-existing information. Copying *errors* and genetic mutations provided the random changes needed for evolution by variation and natural selection.

Some two billion years ago, multicellular biological agents began to communicate with their component parts and with one another, processing and sharing information.

With the appearance of living things, agency, purpose, meaning, and values entered the universe.

This is not a teleological purpose, a "telos" that pre-existed life. It is what COLIN PITTENDRIGH, JACQUES MONOD, and ERNST MAYR suggested we call teleonomy, a "built-in" purpose. Aristotle called it "entelechy," which means "having a purpose within."

The goal for information philosophy is to write a new story of biological evolution as the growth of information processing and communication, connecting it back into cosmological evolution as the creation of information structures, and illustrating the total dependence of biology on cosmological sources of negative entropy (potential information).

