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Case # 10-3164

Quantum-Inspired Simulative Data Interpretation: A Proposed Research Strategy

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July 22, 2010

1. Introduction

The main objective of this paper is to propose a quantum-inspired approach to extracting the maximum possible semantic value from sensor data, even when the quality and level of detail of that data varies widely. The approach has broader cognitive implications as well [1].

The approach is based on a pragmatic view of naturally occurring quantum systems, referred to in this paper as Wave Packet Network (WPN) theory. This pragmatic view of quantum mechanics interprets large classical systems as multi-scale networks of wave packets. Exchanges of information between pairs of WPN packets cause both packets to restructure ("collapse") in ways that restrict the sets of possible futures associated with each wave packet.

The premise of this paper is that well-designed emulations of WPN using modern simulation hardware could lead to a general model for exploiting sensor data. Available sensor data would "collapse" a set of simulated wave packets that represent the best current interpretation of the external world. It is postulated that WPN emulation will enable sensor processing that is more top-down, more linear in time, and more compatible with control systems due to its use of object-like packets to represent the world.

If a general theory of sensors can be developed using WPN analogies, and if the resulting analogies can be implemented efficiently on modern simulation hardware, the implications for designing intelligent and autonomous systems could be profound. For example, a general theory of sensors would enable more systematic and energy efficient design of sensors and processing for small robots. Efficient sensors would aid in the design of autonomous vehicles to support of a wide range of human activities. A general theory of how to maximize semantic value from sparse or variable-quality data would cut costs and make autonomous systems more robust, especially if it enables sensor processing that can adapt dynamically to changes in environment or sensor quality. Such capabilities would enable designs that rely on less costly sensors, and make it easier to function with degraded or damaged sensors.

WPN was developed by the author as a pragmatic way to map quantum concepts into the world of classical-time-based information processing [2]. However, WPN qualifies as a physical theory in its own right, one that suggests alternative views of how quantum mechanics relates to classical physics. For example, WPN packets with high rates of data exchange (collapses) approximate classical thermodynamic particles, and high levels of WPN data exchanges approximate thermodynamic heat.

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2. Background

As exemplified in particular by Nobel Laureate Richard Feynman's formulation of the theory of quantum electrodynamics (QED) [3], the most mathematically precise way to interpret any quantum experiment is as an integral of all of the possible histories by which a specified final outcome could have occurred. QED itself is a static theory that only calculates probabilities between specified preconditions and outcomes, but even before finishing it Feynman recognized the need for a more dynamic version that, like Schrödinger's non-relativistic wave equation, would enable wave functions to evolve over time [4].

Feynman's final QED theory accommodates such approximations of wave evolution through calculation of individual points in a cone-like four-dimensional spacetime volume. This cone can be interpreted from any observer frame as a series of three-dimensional slices that show the evolution of a wave function over time [5]. This approach provides a precise and relativistically accurate way to interpret Schrödinger's earlier concept of an evolving *wave packet*, that is, of a physically compact but expanding wave form. A QED wave packet then can be interpreted as an evolving representation of all the possible histories that could have arisen in classical space as outcomes of the original set of preconditions and their dynamics. In a QED wave packet the emphasis shifts subtly from the probability of a specific *outcome* occurring (the Schrödinger wave packet) to the probability of a specific spacetime *history* (or more precisely, a reduced set of histories) occurring.

A QED wave packet is reduced into a classical history if it is paired with information that ties it irreversibly to an outcome recorded somewhere in the classical world. While this "observer paradox" is the root of much philosophical speculation [6] [7] [8], Feynman observed that the only precondition that must be met for a particle to cease to behave under quantum rules is for it to leave this type of historical trace anywhere within the classical universe. The trace may be as small as a change in the state of a single atom or particle [9] [10], a view that if applied consistently makes the need for a conscious observer irrelevant.

The combination of QED wave packets and reduction via information recording provides a more uniform way to view the evolution of quantum and classical systems. Both resolve into bundles (wave packets) of potential histories that expand under quantum rules until recording events occur. Wave packets then "reset," generating both specific histories and preconditions for launching new packets. If wave packet collapse and information recording are accepted as physical events, the result is a discontinuous view of time in which the smoothness of QED applies only to the cone-like four dimensional spacetime regions that exist between collapse events. Classical history in this view becomes an interlinked network of smaller history units that emerge every time a wave packet collapses. Such collapse events can occur on nearly any scale, giving time a fractal structure. For example, intergalactic photons may remain quantum—go unrecorded in any historical record—for billions of years [11], while photons in a room usually rejoin classical history within nanoseconds. Molecules in solids are nearly classical, with very short rejoin half-lives.

In this pragmatic view, quantum physics becomes the subset of physics for which information recording events occur only occasionally. Classical physics represents the other extreme, that of systems for which recording events occur rapidly and at near-atomic levels of detail. Between these two extremes are the physics of everyday existence, which counterintuitively include many intermediate scales of data recording. Such everyday intermediate situations include photons delocalized over large areas, and reflective effects in metal that are caused by delocalized electrons with high but classically unavailable thermal energies.

The relevance of the above summary of quantum theory to sensor interpretation is that these naturally occurring, multi-scale networks of quantum wave packets exploit available status information with remarkable (and likely maximal) efficiency to "decide" both what has happened in the past and what could happen in the future. Both of these results—knowledge of the past and estimation of the near future—are fundamental to the design of efficient systems for gathering and interpreting sensor data. The premise of this paper is that quantum wave-packet networks are the most fundamental example of a general class of algorithms in which networks of evolving state packets provide an optimal overall structure for capturing, reconciling, and interpreting both the past history of dynamic systems, and the future paths down which they are most likely to evolve.

When applied to sensor networks, this premise becomes an assertion that if the predictive abilities of quantum wave packets can be emulated well by using modern simulation hardware, new algorithms for maximizing the extraction of semantic value from sensor data may become possible. The emulations would both track past status information and use this information to estimate likely future events.

When emulated in hardware, wave packets would be replaced by *simulation packets* that model the evolution of external objects. Just as quantum packet evolution is guided by the conservation laws of physics, simulation packets would focus on various "conserved properties" of external world objects, such as their tendency to persist as units and to behave in certain predictable ways. As a scene is analyzed, higher-level packets that predict the behavior of entire suites of pixels would replace simpler pixel-level packets, a process that corresponds to the simplification of using rigid classical objects to stand in for many bundled quantum objects. Quantum collapse becomes *simulation collapse*, in which ranges of uncertainty in the predictions of a simulation packet are reduced by applying new sensor data. Even quantum entanglement [12] has an analog in *packet correlations*, where data that updates one packet must also update a "distant" packet with a shared history. Packet correlations need to be minimized, since there is no efficient way to emulate them in classical computers [13].

This overall strategy of quantum-inspired *simulative data interpretation* analyzes sensor data not by attempting to interpret it only in its raw form—which can be very costly computationally—but by looking at how sensed data matches internal estimates of how the external system is most likely to have evolved. Closely matching data can be reduced quickly into simple updates of parameters such as position and velocity, with no need for full image analysis.

The ability to match sensor inputs based on predictions of behavior derived from past data makes it easier to match partial images to known simulation packets, which in turn enables use of this data to update simulation status. In fact, a single-pixel "hit" can in certain cases be used reliably to perform major updates to a packet, since that single pixel may have very high semantic value if it falls in a well-defined estimate of a likely future. This feature of simulative data interpretation has intriguing similarities to the mathematical field of compressive sensing [14], in which under the right conditions of prior knowledge it becomes possible to extract very high levels of "meaning" from individual pixels. This may indicate an underlying mathematical connection. For example, simulative data interpretation may provide a way by which the basis sets of compressive sensing can be updated dynamically.

3. Risks and Challenges

The fundamental premise of using networks of simulation packets to capture and evolve predictions about sensor data seems strong enough from an algorithmic and information theory perspective to keep overall risks fairly low. The highest risks instead emerge from two premises implied by this framework.

The first major risk is whether sufficiently detailed and efficient simulations can be performed in real-time on cost-effective computer or simulation hardware. Most forms of simulation are computationally expensive, so a poor choice of platforms or algorithms could easily erase any overall benefits from using predictive simulations. A factor that helps offset this risk is the emergence in recent years of powerful low-cost simulation platforms in response to a strong global market for online immersive gaming.

The second major risk is whether the right mathematical algorithms can be found for implementing fast, easy-to-update simulation packets. These algorithms would need to calculate collections of future histories that are in some sense “sums” of all possible future histories. They would also need to “reset” easily based on new data. Both of these goals are very different from those typically imposed on simulation systems. Quantum theory should provide some insights on how to implement the required algorithms, but additional cross-disciplinary insights may also be needed from topics such as neurology.

Both risks are non-trivial, but likely not insurmountable.

4. Topics for Expansion and Exploration

The theme of this initial paper is that the pragmatic quantum theory of Wave Packet Networks also suggests viable paths by which modern computer and simulation hardware could be used to support faster, more efficient, and more robust sensors and sensor algorithms. The full development of such simulative approaches would require exploration and development far beyond the scope of this initial paper. Examples of possible candidate topics for future expansion and exploration of WPN ideas include:

- *Assessment of the limits of the WPN analogy.* The use of an analogy to quantum mechanics immediately suggests there could be limits to its applicability to any general theory of sensors. In particular, the existence of objects and conserved quantities is fundamental to how quantum wave packets evolve, so similar constraints should apply to simulative data interpretation. This aspect of the analogy may prove to be more a useful design guide than a limitation, however, since it suggests that the most vital feature of a good simulation packet will be its ability to capture those properties of an external entity that are most likely to remain invariant as future data arrives. Entanglements (packet correlations) are more clearly an example of a limit, since entanglement cannot be simulated efficiently in classical computers.

- *Assessment of broader information theory implications of Wave Packet Network concepts.* If Wave Packet Networks do exist in phenomena as fundamental as the quantum evolution of systems over time, it implies that the mathematical roots of the pragmatically inspired WPN approach may run deeper than they might seem, given such mundane origins. Possible links to the mathematics of compressed sensing have already been mentioned. More broadly, since WPN deals with issues of how to extract maximum semantic content from complex networks, even when those data exchanges vary widely in quality and level of detail, it is possible that a networked simulation framework could support development of a network-level superset of information theory. Such a network-level information theory would focus more on maximizing and validating the extraction of semantic content than on the transfer of messages per se, and would replace passive data storage concepts with active simulations of how past events lead to future predictions. Static data would simply become the simplest possible form of such a past-future simulation.

- *Development of a general theory of how to maximize extraction of semantic value from sensor data.* Based on insights from both WPN and information theory, it should be possible to develop a general theory of how to maximize extraction of semantic content from sensor data in any given situation. The result would be a General Sensor Theory that could be used to guide and optimize the design of cost-effective sensor systems.

- *Application of General Sensor Theory to available hardware.* Given its WPN origins, a careful assessment of relevant off-the-shelf capabilities could prove vital for applying a new theory of sensors effectively. Examples of products likely to be relevant when applying sensor theory to sensor design include simulation hardware, software, algorithms, and new generations of fast, powerful Field Programmable Gate Arrays (FPGAs).

- *Assessment of implications for other domains, including biology and neurology.* If wave packet networks have deep roots in physics, they may well have connections to other domains such as biology and neurology. WPN could provide insights, for example, into how biological systems manage to achieve nearly linear time when categorizing and processing sensor data.

5. Multi-Disciplinary Aspects of WPN

Any future work on WPN will unavoidably need to be multi-disciplinary. Quantum theory must be understood not just in terms of equations and applications, but also at the deeper level of how it applies to the evolution of systems over time. Aspects of fractal geometries emerge from the spectrum of frequencies at which packets are updated. This is true not just in WPN, but also in networks of simulation packets for which some bits of sensor data will have far broader impacts than others. Mathematical considerations must include assessments of whether and how quantum frameworks apply to classical simulations. The possibility that simulative data interpretation could have relevance to dynamic updating of the basis sets used in compressive sensing has already been mentioned.

Biological considerations include assessing whether constructs comparable to WPN packets and data exchanges exist within neurological systems. If they do, a general theory of sensing derived from WPN might provide new insights or interpretations of structures within advanced neurological systems. Conversely, if WPN-like structures can be identified in biology or neurology, such examples might well provide insights on how to make computer-based sensors more efficient.

Finally, the inherently classification-focused use of wave packets very likely can be generalized upwards to the broader topic of how to construct highly intelligent systems that can interpret and manipulate the external world.

6. Conclusions

The potential of Wave Packet Networks as an inspiration for constructing new types of simulation-based sensors and processing systems appears solid. The WPN approach simultaneously both preserves data and keeps that data structured in ways that makes it more immediately useful for interpreting new data. It is robust in handling incomplete data, and automatically provides intelligent classifications of that data. The WPN model also has potential as a unifying model that may apply across a diverse range of disciplines. It is a model worth examining.

Appendix A. References

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[10] Feynman, R.P.: The Feynman Lectures on Physics. Addison Wesley (1964). See: Vol. III Ch 3-4, Identical particles, near start of *recorded* version (not in printed version). Key quote: "... if there is a physical situation in which it is impossible to tell which way it

happened, it *always* interferes; it *never* fails." (Feynman's emphasis). See discussion at: http://en.wikipedia.org/wiki/Symmetry#Consequences_of_quantum_symmetry

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[12] Bell, J.S.: Speakable and Unspeakable in Quantum Mechanics, 2nd ed. Cambridge University Press (2004). See especially: Paper 16, Bertlmann's socks and the nature of reality, 139-158. This is a readable explanation of Bell's discovery that "spooky action at a distance," or entanglement, has measurable experimental implications.

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