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A process algebra model of QED

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Abstract.
The process algebra approach to quantum mechanics posits a finite, discrete, determinate ontology of primitive events which are generated by processes (in the sense of Whitehead). In this ontology, primitive events serve as elements of an emergent space-time and of emergent fundamental particles and fields. Each process generates a set of primitive elements, using only local information, causally propagated as a discrete wave, forming a causal space termed a causal tapestry. Each causal tapestry forms a discrete and finite sampling of an emergent causal manifold (space-time) $\mathcal{M}$ and emergent wave function. Interactions between processes are described by a process algebra which possesses 8 commutative operations (sums and products) together with a non-commutative concatenation operator (transitions). The process algebra possesses a representation via nondeterministic combinatorial games. The process algebra connects to quantum mechanics through the set valued process and configuration space covering maps, which associate each causal tapestry with sets of wave functions over $\mathcal{M}$. Probabilities emerge from interactions between processes. The process algebra model has been shown to reproduce many features of the theory of non-relativistic scalar particles to a high degree of accuracy, without paradox or divergences. This paper extends the approach to a semi-classical form of quantum electrodynamics.

1. Process algebra

The goal of the process approach is to develop an emergent quantum mechanics which rests upon a model of reality that is discrete, finite, determinate (but not deterministic), and mostly non-contextual and local, in other words, as *realist* a reality as possible. The primitive elements of this ontology are *generated* by processes [1] and the usual entities of physics are emergent upon these primitives. The model reproduces the non-relativistic quantum mechanics (NRQM) of scalar particles to a high degree of accuracy and, it has been argued, without paradoxes [2, 3]. The present paper extends the model to a semi-classical version of quantum electrodynamics.

Formally, represent each primitive element as an *informon* $[n] < \mathbf{m}_n, \phi_n(\mathbf{z}), \Gamma_n, \mathbf{p}_n > \{G_n\}$, possessing *intrinsic* features (Γ_n-local process coupling constant; $\mathbf{p}_n$-vector of properties; G_n-causally ordered content set of *exclusively prior* informons, causally prior to n), and *extrinsic* features [interpretations by an observer] ($\mathbf{m}_n$-element of a causal space $\mathcal{M}$ [4]; $\phi_n(\mathbf{z})$-local contribution to a wave function in $\mathcal{H}(\mathcal{M})$, $\phi_n(\mathbf{m}_n) = \Gamma_n \hat{\phi}_n(\mathbf{m}_n) = \Gamma_n$). Moreover, $\Gamma_n = \sum_{k \in G_n} K(n,k)\Gamma_k$, for some propagator K. Each process generates R informons per each of N rounds, each of which is comprised of r short rounds, forming a *causal tapestry* $\mathcal{I}$, which embeds space-like into $\mathcal{M}$ while G_n-causal relations are preserved. $\mathcal{I}$ then becomes information for a new process generating a new tapestry. A process is *primitive* if $R = 1$. The informons of $\mathcal{I}$ generate, via an interpolation procedure [5], an emergent wave function on $\mathcal{M}$ of the form

$\Phi_{\mathcal{I}}(\mathbf{z}) = \sum_{n\in\mathcal{I}} \phi_n(\mathbf{z}) = \sum_{n\in\mathcal{I}}(\sum_{k\in G_n} K(n,k)\Gamma_k)\hat{\phi}_n(\mathbf{z})$. The physics plays out on the causal tapestry, independent of the interpretations. The wave function $\Phi_{\mathcal{I}}(\mathbf{z})$ represents a real discrete wave and a particular reality. In the case of NRQM it agrees closely with the usual NRQM wave function in the limit $N, r \to \infty$ and with Planck scale causal embeddings [2, 3].

Complex processes are formed from primitive processes using the process algebra which has 4 Abelian sums (sequential action of sub-processes, for states involving a single entity and superpositions), 4 Abelian products (simultaneous action of sub-processes, for states involving multiple entities), and concatenation which describes transitions between processes resulting from interactions with newly generated informons. Measurement is understood as an interaction between processes, triggered by the generation of individual informons and dependent upon their compatibility [6] (proportional to the local coupling constants), giving rise to an emergent contextual probability [7]. The process algebra possesses a useful heuristic representation as an algebra of non-deterministic combinatorial games [8]. Analysis requires the game tree [8], a heuristic and combinatorial tool (akin to configuration space) depicting all possible tapestries generated by the process, needed to generate set-valued process and configuration space covering maps, (defined on function space products (calculational) or co-products (ontological)) which link to NRQM [2, 3], enabling one to calculate correlations and measurement outcomes.

2. QED

A naive quantum electrodynamics is developed semi-classically following the idea of collective electrodynamics [9]. The local coupling constant is the local electrodynamic potential $(\phi_n, A_n^1, A_n^2, A_n^3)$. K is the classical electromagnetic propagator. A primitive process $\mathbb{P}_{\omega,\mathbf{k}}$ creates, sequentially, informons corresponding to a single photon of energy $E = \hbar\omega$ and momentum $\mathbf{p} = \hbar\mathbf{k}$. From a single informon, $\mathbb{P}_{\omega,\mathbf{k}}$ will generate a set of R informons embedding within a ball of radius Planck length in $\mathcal{M}$. Each of these nascent informons serves as a source during the next cycle of generation so the next generator takes the form $\hat{R}\mathbb{P}_{\omega,\mathbf{k}} = \overbrace{\mathbb{P}_{\omega,\mathbf{k}}\hat{\oplus}\cdots\hat{\oplus}\mathbb{P}_{\omega,\mathbf{k}}}^{R}$ where $\hat{\oplus}$ is the free sum which allows subprocesses to provide information to any other subprocess (the process analogue of superposition). A measurement will still always register single photons. Successive generations will result in the process $\hat{R}^n\mathbb{P}_{\omega,\mathbf{k}}$ as $n \to \infty$. The generated informons will spread out over an ever widening region of $\mathcal{M}$ giving the appearance of a discrete sampling of a field. The resulting (ontological) wave function will be

$$\Phi(\mathbf{z}) = \lim_{n\to\infty}\sum_{i=1}^{n}\Phi_i(\mathbf{z}) = \lim_{n\to\infty}\sum_{i=1}^{n}\sum_{k\in\mathcal{I}_i}(\phi_k, A_k^1, A_k^2, A_k^3)\hat{\phi}_k(\mathbf{z})$$

which gives an interpolation of the electrodynamic potential. Different plays of the process result in different $\Phi(\mathbf{z})$, expressed in the set-valued process covering map. Second quantization, needed for deriving the usual QED wave function, requires consideration of complex processes and the use of the more subtle and complicated configuration space process map.

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