Ensemble self-reinforcement and strong memory effects for the anomalous transport of heterogeneous populations

Sergei Fedotov
Deparetment of Mathematics, The University Of Manchester, Manchester, United Kingdom

We present a random walk model that incorporates random transition probabilities among a heterogeneous population of random walkers, resulting in an effectively self-reinforcing random walk. The heterogeneity of the population leads to conditional transition probabilities that increase with the number of steps taken previously (self-reinforcement). We establish the connection between random walks with a heterogeneous ensemble and those with strong memory where the transition probability depends on the entire history of steps. We employ subordination, utilizing the fractional Poisson process to count the number of steps at a given time and the discrete random walk with self-reinforcement to determine the ensemble-averaged solution of the fractional master equation. We also find the exact solution for the variance which exhibits superdiffusion even as the fractional exponent tends to 1.

We discuss the applications of this random walk model for intracellular transport and stochastic endocytosis. Given that a heterogeneous population of random walkers emulates strong memory, this opens another avenue for modeling biological processes that display strong memory properties and yet are heterogeneous ensembles of inanimate objects, such as organelles and macromolecules. Might it be that nature has developed a mechanism such as an ensemble self-reinforcement that we demonstrate in this work as a proxy for strong memory? Such questions have plagued the field of intracellular transport for decades where brainless membrane-bound vesicles seemingly engage in random walks that appear to have correlations caused by strong memory effects.

Our finding also fits nicely with the emerging theory that, in biological processes, the first arrival times of a signal to a cell (or neuron) influence the subsequent system behavior far more than the average arrival times. With ensemble self-reinforcement, the cell can organize the movement of these particles such that it maintains the efficiency of transport and overcomes the trapping that occurs in the crowded cytoplasm. We hypothesize that ensemble self-reinforcement is a way that the cell efficiently transports vesicles in a heavily crowded intracellular environment, which has been shown to be subdiffusive. Moreover, this provides another mechanism through which seemingly unintelligent systems can exhibit strong memory.

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