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A Convergent Interacting Particle Method for Computing Kpp Front Speeds in Random Flows

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Abstract : We aim to efficiently compute the spreading speeds of reaction-diffusion-advection (RDA) fronts in divergence-free random flows under the Kolmogorov-Petrovsky-Piskunov (KPP) nonlinearity. We study a stochastic interacting particle method (IPM) for the reduced principal eigenvalue (Lyapunov exponent) problem of an associated linear advection-diffusion operator with spatially random coefficients. The Fourier representation of the random advection field and the Feynman-Kac (FK) formula of the principal eigenvalue (Lyapunov exponent) form the foundation of our method implemented as a genetic evolution algorithm. The particles undergo advection-diffusion and mutation/selection through a fitness function originated in the FK semigroup. We analyze the convergence of the algorithm based on operator splitting and present numerical results on representative flows such as 2D cellular flow and 3D Arnold-Beltrami-Childress (ABC) flow under random perturbations. The 2D examples serve as a consistency check with semi-Lagrangian computation. The 3D results demonstrate that IPM, being mesh-free and self-adaptive, is simple to implement and efficient for computing front spreading speeds in the advection-dominated regime for high-dimensional random flows on unbounded domains where no truncation is needed.

Keywords : KPP front speeds, random flows, Feynman-Kac semigroups, interacting particle method, convergence analysis
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