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Approximation of epidemic models by diffusion processes and statistical applications

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Joint work with Romain Guy¹,² and Elisabeta Vergu¹

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Abstract

Amongst various mathematical frameworks, multidimensional continuous-time Markov jump processes \((Z_t)\) on \(\mathbb{N}^d\) form a natural set-up for modeling SIR-like epidemics. We first extend the results of Ethier and Kurz (2005) on the approximation of density dependent processes by diffusion and Gaussian processes to general density time-dependent Markov processes on \(\mathbb{N}^d\). The normalization by the population size \(N\) of \((Z_t)\) leads, as \(N \to \infty\), to the solution of an ODE system. Recentering \((Z_t)\) yields a multidimensional Gaussian process. Another approximation leads to a time-dependent diffusion process with small diffusion coefficient \((\frac{1}{\sqrt{N}})\), close to the previous Gaussian process. For inference, we extend the results of Guy et al. (2012) on discretely observed diffusion processes with small diffusion coefficient to time-dependent diffusions. Consistent and asymptotically Gaussian estimates are obtained by means of a contrast process in two different asymptotics: fixed number \(n\) of observations (or equivalently \(\Delta\)) and \(N \to \infty\); \(n \to \infty\) and \(N \to \infty\) simultaneously. In the context of epidemics, \(n\) is usually fixed. Adding a correction term, we obtain better estimates non asymptotically (Guy et al. 2013). Finally, we simulated two Markov jump processes modeling SIR, SIRS epidemics in two different epidemic contexts (single and recurrent outbreaks) with different characteristics (variation of parameters \(R_0, N, n\)). We obtain that the estimators have good asymptotic properties and behave well for realistic numbers of observations and population sizes. Contrary to the majority of current inference techniques for partially observed processes which demand computer intensive simulations, our method, being mostly analytical, only requires the classical optimization steps.


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