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First-passage time for PDifMPs: an Exact simulation approach for time-varying thresholds

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Piecewise Diffusion Markov Processes (PDifMPs) are valuable for modelling systems where continuous dynamics are interrupted by sudden shifts and/or changes in drift and diffusion. The first-passage time (FPT) in such models plays a central role in understanding when a process first reaches a critical boundary. In many systems, time-dependent thresholds provide a flexible framework for reflecting evolving conditions, making them essential for realistic modelling. We propose a hybrid exact simulation scheme for computing the FPT of PDifMPs to time-dependent thresholds. Exact methods traditionally exist for pure diffusions, using Brownian motion as an auxiliary process and accepting sampled paths with a probability weight. Between jumps, the PDifMP evolves as a diffusion, allowing us to apply the exact method within each inter-jump interval. The main challenge arises when no threshold crossing is detected in an interval: We then need the value of the process at the jump time, and for that, we introduce an approach to simulate a conditionally constrained auxiliary process and derive the corresponding acceptance probability. Furthermore, we prove the convergence of the method and illustrate it using numerical examples.

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