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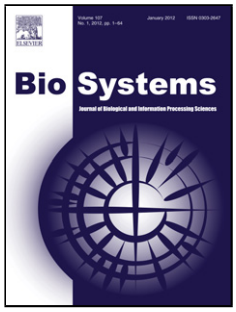

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Fast Bayesian parameter estimation for stochastic logistic growth models

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Abstract

The transition density of a stochastic, logistic population growth model with multiplicative intrinsic noise is analytically intractable. Inferring model parameter values by fitting such stochastic differential equation (SDE) models to data therefore requires relatively slow numerical simulation. Where such simulation is prohibitively slow, an alternative is to use model approximations which do have an analytically tractable transition density, enabling fast inference. We introduce two such approximations, with either multiplicative or additive intrinsic noise, each derived from the linear noise approximation (LNA) of a logistic growth SDE. After Bayesian inference we find that our fast LNA models, using Kalman filter recursion for computation of marginal likelihoods, give similar posterior distributions to slow, arbitrarily exact models. We also demonstrate that simulations from our LNA models better describe the characteristics of the stochastic logistic growth models than a related approach. Finally, we demonstrate that our LNA model with additive intrinsic noise and measurement error best describes an example set of longitudinal observations of microbial population size taken from a typical, genome-wide screening experiment.

***Keywords*: Kalman Filter; Linear Noise Approximation; Logistic; Population Growth; Stochastic Modelling;**

1 Introduction

Stochastic models simultaneously describe dynamics and noise or heterogeneity in real systems (Chen et al., 2010). For example, stochastic models are increasingly recognised as necessary tools for understanding the behaviour of complex biological systems (Wilkinson, 2011, 2009) and are also used to capture uncertainty in financial market behaviour (Kijima, 2013; Koller, 2012). Many such models are written as continuous stochastic differential equations (SDEs) which often do not have analytical solutions and are slow to evaluate numerically compared to their deterministic counterparts. Simulation speed is often a particularly critical issue when inferring model parameter values by comparing simulated output with observed data (Hurn et al., 2007).

For SDE models where no explicit expression for the transition density is available, it is possible to infer parameter values by simulating a latent process using a data augmentation approach (Golightly and Wilkinson, 2005). However, this method is computationally intensive and not practical for all applications. When fast inference for SDEs is important, for example for real-time

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