TMS 165/MSA350 Stochastic Calculus

Home Exercises on Numerical Methods

Througout this set of exercises $B = \{B(t)\}_{t \geq 0}$ denotes Brownian motion.

Task 1. It is not hard at all to find SDE for which the Euler (Euler-Maruyama) method collapses with a very high probability – one exemple would be the CKLS SDE (see Task 2 below) with a large γ coefficient. For such SDE it is usually the case that a so called implicit method works much better: With the notation of Section 1.2 in Stig Larsson's lecture notes, the so called fully implicit Euler method is given by $Y_0 = X_0$ and

$$Y_{n+1} = Y_n + \left(\mu(Y_{n+1}, t_{n+1}) - \left(\sigma \frac{\partial \sigma}{\partial x} \right)(Y_{n+1}, t_{n+1}) \right) \int_{t_n}^{t_{n+1}} ds + \sigma(Y_{n+1}, t_{n+1}) \int_{t_n}^{t_{n+1}} dB$$

for $n \geq 0$. Explain why this method does not take the simpler form

$$Y_0 = X_0 \quad \text{and} \quad Y_{n+1} = Y_n + \mu(Y_{n+1}, t_{n+1}) \int_{t_n}^{t_{n+1}} ds + \sigma(Y_{n+1}, t_{n+1}) \int_{t_n}^{t_{n+1}} dB \quad \text{for} \ n \geq 0.$$

Task 2. Demonstrate by means of simulations the fact that for the CKLS SDE

$$dX(t) = (\alpha + \beta X(t)) \, dt + \sigma X(t)^\gamma \, dB(t) \quad \text{for} \ t > 0, \quad X(0) = x_0,$$

with some choice of parameters $\alpha, \beta, \sigma, x_0 > 0$ and a large $\gamma > 1$ (e.g., $\gamma = 5$), the Euler method breaks down while the fully implicit Euler method works.

Task 3. Show by means of simulations of the SDE in Exercise 6 of Exercise session 4

$$dX(t) = \left(\sqrt{1 + X(t)^2} + \frac{X(t)}{2} \right) dt + \sqrt{1 + X(t)^2} \, dB(t) \quad \text{for} \ t > 0, \quad X(0) = 0,$$

that the Milstein method converges quicker than the Euler method. Are the conditions for convergence of the Euler method satisfied?

Task 4. Given constants $\mu \in \mathbb{R}$ and $\sigma > 0$, find the solution $f(x, t)$ to the PDE

$$\mu \frac{\partial f(x, t)}{\partial x} + \frac{\sigma^2}{2} \frac{\partial^2 f(x, t)}{\partial x^2} + \frac{\partial f(x, t)}{\partial t} = 0 \quad \text{for} \ t \in [0, T), \quad f(x, T) = x^2.$$

Task 5. Show that a solution $f(x, t)$ to the PDE

$$\mu(x, t) \frac{\partial f}{\partial x} + \frac{\sigma(x, t)^2}{2} \frac{\partial^2 f}{\partial x^2} + \gamma(x, t) \, f(x, t) + \frac{\partial f}{\partial t} = k(x, t) \quad \text{for} \ t \in [0, T), \quad f(x, T) = g(x),$$

must take the form (with obvious notation)

$$f(x, t) = \mathbf{E} \left\{ g(X(T)) \, e^{\int_t^T \gamma(X(s), s) \, ds} - \int_t^T k(X(s), s) \, e^{\int_t^s \gamma(X(r), r) \, dr} ds \ \bigg| \ X(t) = x \right\}.$$