

# Exercises for module 7

## Markov chain Monte Carlo methods

### Exercise 1

Consider the Metropolis-Hastings (MH) algorithm, assuming the target density is a standard normal:

$$\pi(x) = \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{1}{2}x^2\right).$$

Furthermore, assume that the proposals are normally distributed centred at the current value and with standard deviation  $\sigma$ :

$$q(x, y) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left(-\frac{1}{2\sigma^2}(y - x)^2\right).$$

1. Determine the acceptance probability.

The following is a pseudo code for implementing the MH algorithm:

```
choose initial value  $x^{(0)}$ 
for  $i = 1, \dots, n$  do
  generate proposal  $y \sim q(x^{(i-1)}, y)$ 
  generate  $u \sim \text{Unif}[0, 1]$ 
  calculate  $H(x^{(i-1)}, y) = (\pi(y)q(y, x^{(i-1)}))/(\pi(x^{(i-1)})q(x^{(i-1)}, y))$ 
  if  $u < H(x^{(i-1)}, y)$  then
    | set  $x^{(i)} = y$ 
  else
    | set  $x^{(i)} = x^{(i-1)}$ 
  end
end
```

2. Argue why in the MH algorithm the proposal  $y$  is accepted with probability  $\min\{1, H(x, y)\}$ .
3. Implement the code in R in such a way that it returns a realisation of the Markov chain. Make a trace plot and a histogram of the output. How large does  $n$  (i.e. the length of the chain) have to be for the histogram to look like a standard normal distribution. What effect does the value of  $\sigma$  have?
4. Use your code to estimate the probability  $P(X \leq -1)$ . The correct value is obtain in R by `pnorm(-1)`.
5. Assume now that the proposal kernel is

$$q(x, y) = \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{1}{2}y^2\right).$$

What is the interpretation of this proposal kernel? Find the resulting acceptance probability.