

# Final Project 37810–Gibbs Sampling

October 28, 2015

```
Gibbs_<-function(x0,y0,iterations,B=5,burnIn=0)
## 5 parameters are needed in this function, with B=5 and burnIn=0 by default
{
  if(x0>0&& x0<B&&y0>0&&y0<B)
## to check whether the starting values are in the domain.
  {
    x<-c(x0,rep(NA,iterations-1))
## Initialize the Markov chain
    y<-c(y0,rep(NA,iterations-1))
## Initialize the Markov chain
    for(i in 1:(iterations-1))
    {
      x[i+1]<-(-log(1-runif(1)*(1-exp(-y[i]*B)))/y[i])
## use inverse transform sampling to draw sample from conditional distribution
## p(x^{i+1}|y^{i})
      y[i+1]<-(-log(1-runif(1)*(1-exp(-x[i+1]*B)))/x[i+1])
## use inverse transform sampling to draw sample from conditional distribution
## p(y^{i+1}|x^{i+1})
    }
    if(burnIn>0)
    {
      x<-x[-(1:burnIn)]
      y<-y[-(1:burnIn)]
      print(length(x))
## discard the first bunch of draws for the burn-in process
    }
    return(data.frame(x,y))
  }
  else
    stop("Initial values incorrect")
## print the information for incorrect starting values
}
```

To estimate the marginal distribution generated from the conditional distributions using Gibbs sampling, we first pick up the starting values for  $X$  and  $Y$ . Denote them as  $x_0$  and  $y_0$ . `iterations` stands for the number of draws we want to get from Gibbs sampling.  $B$  is the number given in the exercise, which is 5 here. `burnIn` is the number of draws we want to discard for the burn-in process, the default for `burnIn` is 0.

In this case, both the conditional distribution of  $X|Y$  and  $Y|X$  are truncated exponential distribution. The domains of both conditional pdf's are  $[0, B]$ . So the starting values should satisfy  $0 < x_0 < B$  and  $0 < y_0 < B$ . Therefore I put a restriction `if(x0>0&&x0<B&&y0>0&&y0<B)` on the input of starting values to check if they satisfy the requirement.

Since

$$p(x|y) \propto ye^{-yx}, 0 < x < B$$

$$p(y|x) \propto xe^{-yx}, 0 < y < B$$

Consider  $p(x|y)$  only. To get samples using inverse transform sampling, first we need to figure out the normalizing constant for the conditional pdf and then the inverse function of cdf.

The normalizing constant can be calculated using the formula  $c = \frac{1}{\int f(x|y) dx}$ , if  $p(x|y) \propto f(x|y)$ . In this case,  $f(x|y) = ye^{-yx}$ ,  $0 < x < B$ . Therefore  $c = \frac{1}{\int_0^B ye^{-yx} dx} = \frac{1}{1-e^{-By}}$ .

Then we start to calculate the cdf  $H(x|y)$  for  $X|Y$ .

We have

$$p(x|y) = \frac{ye^{-yx}}{1-e^{-By}}, 0 < x < B$$

Using the formula  $F(x) = \int_{-\infty}^x p(z) dz$ , we get the cdf of  $X|Y$ :

$$F(x|y) = \frac{1-e^{-xy}}{1-e^{-By}}, 0 < x < B$$

Then we can write down the inverse function of  $F(x|y)$ , Denote as  $F^{-1}(u|y)$ , where  $0 \leq u \leq 1$ .

We have:

$$F^{-1}(u|y) = -\frac{\log(1-u(1-e^{-By}))}{y}, 0 \leq u \leq 1$$

According to inverse transform sampling, to draw a sample from  $p(x|y)$ , we first generate  $u$  from  $Unif[0, 1]$ , then  $x = F^{-1}(u|y)$  is from the conditional distribution of  $X|Y$ .

We draw samples from  $p(y|x)$  using the same method.

Now we start generating samples from  $p(x,y)$ .

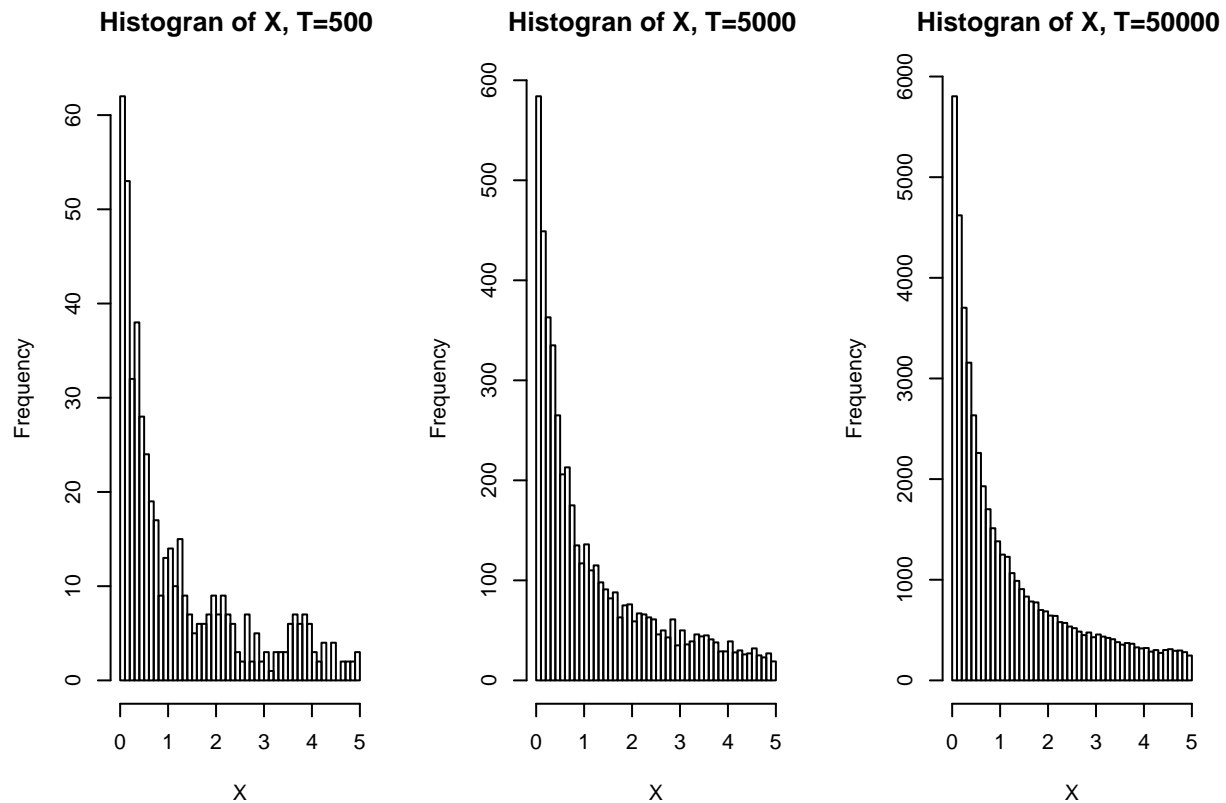
Here I start Gibbs sampling with  $x_0$  and  $y_0$ , draw a value  $x^{(1)}$  from the full conditional  $p(x|y_0)$  using inverse transform sampling. Then use the updated  $x^{(1)}$  to draw a sample from  $p(y|x^{(1)})$ .

To get more samples using Gibbs sampling, continually use the most updated values of  $x$  and  $y$  when generating samples from conditional distribution. To be more specific, generate  $x^{(i+1)}$  from  $p(x|y^{(i)})$  and  $y^{(i+1)}$  from  $p(y|x^{(i+1)})$ . Repeat it for  $n = \text{iterations}$  times.

For the burn-in process, discard the first  $m = \text{burnIn}$  samples from the Markov chain to reduce the influence of starting values on the Markov chain.

For  $B = 5$  and sample size  $T = 500, 5000, 50000$ , to see the histogram of values for  $x$  generated from Gibbs sampling, We have:

```
par(mfrow=c(1,3))
x<-Gibbs_(1,2,50000,B=5,burnIn=0)
hist(x[1:500,1],breaks=60, main="Histogram of X, T=500 ",xlab="X")
hist(x[1:5000,1],breaks=60, main="Histogram of X, T=5000 ",xlab="X")
hist(x[1:50000,1],breaks=60, main="Histogram of X, T=50000 ",xlab="X")
```



Here I picked up the starting values arbitrarily.

The plots above shows that as  $T$  increases, the histogram tend to be more smooth.

Use the mean of the generated samples to estimate the expectation of  $X$ .

```
set.seed(123)
mean_500<-c()
mean_5000<-c()
mean_50000<-c()
for(i in 1:10)
{
  x<-Gibbs_(1,2,50000,B=5,burnIn=0)
  mean_500<-c(mean_500,mean(x[1:500,1]))
  mean_5000<-c(mean_5000,mean(x[1:5000,1]))
  mean_50000<-c(mean_50000,mean(x[1:50000,1]))
}
mean_500

## [1] 1.323771 1.392163 1.425209 1.300402 1.319226 1.200004 1.389191
## [8] 1.305194 1.360014 1.357299

mean_5000

## [1] 1.266212 1.263367 1.264459 1.280466 1.269729 1.280995 1.252972
## [8] 1.279271 1.254663 1.296133
```

```
mean_50000
```

```
## [1] 1.259416 1.272679 1.266894 1.275371 1.269562 1.270537 1.267437  
## [8] 1.267778 1.261333 1.262746
```

```
c(var(mean_500),var(mean_5000),var(mean_50000))
```

```
## [1] 0.0040109521 0.0001785322 0.0000253901
```

As we can see, the mean is around 1.26, as sample size  $T$  increases, the variance of the estimator also decreases.