

# R handout: Integration and Transformation

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## 1. Monte Carlo Method

Suppose  $X$  is a random variable with a p.d.f.  $f$  and a c.d.f.  $F$  over a domain  $D$ . Also, we have a sample  $X_s = \{x_1, x_2, \dots, x_n\}$  from  $X$  with  $n$  observations.

$$E(X) = \int_D x f(x) dx \approx \bar{X} = \frac{1}{n} \sum_{i=1}^n x_i$$

Besides, because of Central Limit Theorem,  $\bar{X}$  asymptotically follows  $N(\mu, \frac{\sigma^2}{n})$  where  $\mu = E(X)$  is the mean of  $X$  and  $\sigma^2$  is the variance of  $X$ . So, when  $n \rightarrow \infty$ ,  $\bar{X} \rightarrow E(X)$ . Hence, intuitively, the result is more precise with a larger sample size.

## 2. Example. $Y = |X|$ where $X \sim N(0, 1)$ . Find out $E(Y)$

### (a) Direct Integration

As we know, the p.d.f. of  $Y$

$$f_Y(y) = 2\phi(y), y \geq 0$$

where  $\phi$  is the p.d.f. of the standard normal distribution.

- R code

```
# define the p.d.f. of Y
Y.pdf <- function(y) 2 * dnorm(y)

# define the integrand of the expectation of Y
E.Y <- function(y) y * Y.pdf(y)

# Integrate the integrand
integrate(E.Y, lower = 0, upper = Inf)
# Result: 0.7978846
```

(b) Monte Carlo Method with a transformation

Because

$$E(Y) = E(|X|) = \int_{-\infty}^{\infty} |x|\phi(x)dx \approx \frac{1}{n} \sum_{i=1}^n |x_i|$$

where  $n$  is the number of simulation and  $X_s = \{x_1, \dots, x_n\}$  is a sample from  $N(0, 1)$ .

- R code

```
# set seed to make this process repeatable
set.seed(12345)

# set the number of simulation
n <- 1000

# simulate a sample from the standard normal distribution
X.s <- rnorm(n)

# calculate the mean of the absolute values
mean(abs(X.s))

# Result: 0.7944
```

(c) Monte Carlo Method with another transformation

Because  $\exp(1)$  has a same domain as  $Y$ ,

$$E(Y) = \int_0^{\infty} y f_Y(y) dy = \int_0^{\infty} \frac{y f_Y(y)}{e^{-y}} e^{-y} dy = E\left(\frac{y f_Y(y)}{e^{-y}}\right) \approx \frac{1}{n} \sum_{i=1}^n \frac{y_i f_Y(y_i)}{e^{-y_i}}$$

where  $n$  is the number of simulation and  $Y_s = \{y_1, \dots, y_n\}$  is a sample from  $\exp(1)$ .

- R code

```
# set seed to make this process repeatable
set.seed(12345)

# set the number of simulation
n <- 1000

# define the p.d.f. of Y
Y.pdf <- function(y) 2 * dnorm(y)
```

```
# simulate a sample from the standard normal distribution
Y.s <- rexp(n)

# calculate the mean of the absolute values
mean(Y.s * Y.pdf(Y.s) / dexp(Y.s))
# Result: 0.7729
```

### 3. Summary: Steps of Monte Carlo Method

- (a) Check the domain
- (b) Simulate an appropriate sample over the domain
- (c) Calculate the mean via an appropriate transformation

### 4. Practice: suppose $Y = X^{-1}$ , where $X \sim \chi^2(10)$ . Use Monte Carlo Method to find $E(Y)$ .

Hint: You need to show the analytical part and the numerical part in R. Also, you may need to use *rchisq* and *help(rchisq)* in R