

20210515_CM2605_Coursework

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Question 1

a)

```
set.seed(17) #for reproducibility

#generate 10000 weight values for  $N(60, 3^2)$ 
weightKG <- rnorm(10000, mean = 60, sd = 3)

#generate 10000 height values for  $N(1.6, 0.1^2)$ 
heightM <- rnorm(10000, mean = 1.6, sd = 0.1)

#10000 BMI values
bmi <- weightKG / heightM ^ 2
bmi

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## [9321] 26.30217 24.87521 33.96523 21.41668 24.03866 29.68640 27.00613
22.67689
## [9329] 20.37948 24.37308 21.02592 24.75716 24.01861 20.37836 21.44679
23.82980
## [9337] 19.62032 22.31302 25.18226 23.91115 20.54636 22.49897 25.32591
24.10689
## [9345] 30.38526 25.16079 31.21207 17.86885 26.93997 23.87069 24.00978
20.00584
## [9353] 27.86756 20.49904 24.95774 17.65251 22.03634 22.24993 22.52015
22.84109
## [9361] 29.60942 26.22090 17.73878 26.38009 29.77645 22.40405 23.79314
26.66016
## [9369] 26.55981 27.37042 25.11521 24.47952 19.18092 18.89108 21.90633
28.83736
## [9377] 21.19009 21.60838 23.45584 23.93568 22.57215 31.72686 23.66092
20.49540
## [9385] 24.53214 20.77615 24.74946 22.72868 40.47640 22.65269 25.39502
24.66870
## [9393] 26.69070 20.79011 21.35851 23.49702 24.25071 17.81551 19.99706
22.42743
## [9401] 21.34737 24.17490 22.10594 23.54513 29.74559 24.92506 22.44375
26.24469
## [9409] 24.19700 20.09026 23.08372 22.66455 23.04034 26.58977 23.14834
30.04665
## [9417] 22.02835 21.31734 28.94769 27.55549 24.97615 23.84239 24.49225
30.63442
## [9425] 20.08415 23.90481 20.60197 28.87053 23.90164 25.36034 23.20517
27.53540
## [9433] 23.79597 22.91943 22.04987 18.00111 26.61919 22.17019 22.39025
23.32462
## [9441] 21.72232 16.65227 28.69799 21.60611 21.45451 22.99901 28.13694
20.40300
## [9449] 21.08097 25.65474 24.41471 21.94147 22.61628 28.10867 22.32217
29.36421
```



```
## [9457] 20.95170 21.31053 27.16440 21.20296 28.27451 19.82414 28.39345
22.46113
## [9465] 26.53487 30.32002 22.21133 21.95489 23.55407 21.03495 20.87517
25.09009
## [9473] 25.78407 24.14885 25.10847 22.49249 26.12679 24.32465 24.41206
25.77848
## [9481] 22.26518 26.26044 20.75154 26.08113 22.47984 25.78230 26.04969
22.46129
## [9489] 25.54951 23.47606 25.26607 24.51745 21.13429 30.29511 23.50319
20.81218
## [9497] 20.54642 21.12862 21.59877 18.28841 20.04766 21.93507 22.25607
22.61175
## [9505] 22.03783 22.48968 25.39917 23.50843 21.74621 27.43576 25.12376
21.10380
## [9513] 20.33209 26.43133 21.15918 24.15650 21.68359 22.51232 20.97342
26.27524
## [9521] 20.68272 24.96064 23.54127 27.21411 22.49238 28.89260 22.50659
22.74694
## [9529] 20.44538 21.07213 27.65881 19.26430 22.74283 27.82585 22.40963
31.80701
## [9537] 28.63080 20.41889 24.58415 18.10980 27.17699 24.71531 22.99000
26.11524
## [9545] 24.00805 24.38614 26.26927 30.37930 21.08789 20.18486 23.71222
21.44270
## [9553] 19.89289 22.28466 26.96105 25.60932 27.77717 26.11845 24.56421
22.16992
## [9561] 20.69907 19.66369 26.06107 22.00281 21.71497 23.46745 25.83604
24.53721
## [9569] 20.97141 22.06057 26.91324 20.76616 25.68152 23.43760 20.41318
23.17308
## [9577] 20.36188 26.78846 22.50674 20.60192 28.96720 27.43142 19.88297
24.00249
## [9585] 27.07731 21.60929 23.75705 23.71821 20.37705 18.10539 21.94256
25.14331
## [9593] 25.45020 21.68118 25.15743 26.59140 27.19628 21.70748 24.03861
21.30471
## [9601] 27.48657 22.51100 21.37165 19.13339 22.09759 21.20254 22.35657
21.24597
## [9609] 26.67836 20.72266 22.27419 24.24007 19.77299 21.58956 19.36675
29.39636
## [9617] 20.00895 26.55582 25.73486 24.99251 26.16173 20.35061 24.66868
18.75190
## [9625] 25.28056 21.68775 23.09863 23.04648 23.96459 27.53909 20.22931
20.50491
## [9633] 28.30333 23.80150 21.11981 25.39559 20.62782 21.34287 23.32507
21.88786
## [9641] 30.52486 29.01751 23.46769 21.94731 25.60322 22.64677 21.83105
24.41539
## [9649] 24.50026 33.07633 22.06013 26.84120 21.59824 17.76789 23.20369
19.10588
```

```
## [9657] 25.15324 19.38718 23.52008 24.58349 21.88866 24.47071 24.40027
22.54837
## [9665] 22.07192 24.51035 21.28152 21.27332 26.28189 21.31888 26.51661
21.35294
## [9673] 20.75404 26.13765 27.58937 22.01222 24.24035 22.37078 21.28724
28.54658
## [9681] 19.79607 23.97524 18.16537 25.04485 23.90032 19.03299 23.82838
26.66730
## [9689] 26.12125 20.04235 22.87997 20.30283 20.94533 27.75562 18.39151
25.01083
## [9697] 25.65319 20.13390 24.52941 21.27921 24.74605 21.51046 23.49372
26.19426
## [9705] 17.79340 22.15701 24.33171 21.20117 20.52675 20.54459 15.52637
23.86570
## [9713] 22.45861 26.23254 20.83700 22.90188 26.31566 27.73463 25.08341
21.40368
## [9721] 31.55959 20.78626 22.20215 21.08328 21.82339 36.11723 20.30257
29.43021
## [9729] 26.12935 21.28172 23.69439 22.42736 21.44911 27.04316 24.74668
26.62498
## [9737] 26.87143 21.33653 23.45399 21.75554 22.05949 20.05476 23.99391
26.74570
## [9745] 22.41949 19.83881 18.25039 25.32456 21.03883 21.05382 24.23366
16.40424
## [9753] 20.45225 24.29640 23.61600 16.07940 24.64393 27.14130 25.96101
26.00060
## [9761] 22.15061 26.74528 17.17990 19.97397 24.20393 17.03886 30.75600
21.69280
## [9769] 30.08752 22.63088 22.88227 20.43883 18.66325 19.88792 18.81088
23.82029
## [9777] 25.81245 24.07928 22.42703 21.84715 22.25293 29.87010 19.82338
21.62394
## [9785] 25.37982 25.18049 22.94432 30.61973 24.65613 24.80994 26.87736
19.42123
## [9793] 29.73001 25.34743 19.60939 39.09956 26.59166 36.37214 23.57637
25.82475
## [9801] 23.70222 22.47417 16.65634 30.60297 21.63812 19.42191 26.40477
21.00181
## [9809] 23.72772 21.96676 21.90579 22.78768 22.78840 25.38031 25.53798
20.56922
## [9817] 21.78472 25.26313 19.94693 26.61135 24.66274 34.06548 23.55459
25.92337
## [9825] 28.20313 29.30377 26.38176 29.94900 23.65688 22.88979 22.24562
25.99338
## [9833] 21.86215 22.03722 23.30293 30.86914 23.93705 25.28210 18.44003
23.17539
## [9841] 23.70777 21.44358 19.16646 22.78798 21.54686 25.03450 26.49572
20.50257
## [9849] 21.19732 20.10825 19.50608 27.86897 20.35245 25.55740 21.35123
28.52770
```

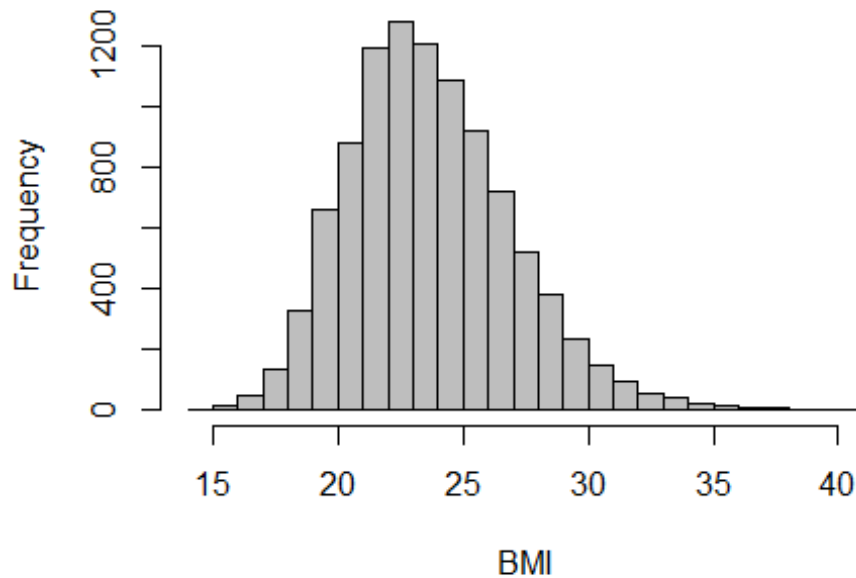
```
## [9857] 21.60129 27.57325 20.39832 25.23129 23.40720 25.62360 22.54441
24.56194
## [9865] 25.63373 27.12349 26.90154 17.83217 23.79240 26.53524 22.00269
26.81300
## [9873] 22.30382 25.56919 25.12060 22.35397 19.86372 24.44207 28.57267
20.85574
## [9881] 31.00908 26.21182 25.26049 19.19725 20.97578 20.18124 25.46627
20.37300
## [9889] 26.00178 17.93663 20.75026 22.98029 33.69126 23.56079 24.59916
16.27191
## [9897] 24.02388 27.99626 25.46069 22.46405 22.71739 24.94563 25.63040
23.76105
## [9905] 22.87649 23.45310 30.42351 26.68349 31.74474 21.70994 21.35584
17.23613
## [9913] 28.97773 29.60564 25.54175 25.72371 19.42870 18.65322 28.32049
28.50635
## [9921] 27.69167 26.58540 19.86233 22.84792 28.99959 26.22755 20.29545
27.75739
## [9929] 23.54315 22.50879 21.93603 22.74400 24.65361 24.16634 21.44965
24.85012
## [9937] 21.19696 20.48271 19.81511 23.23957 20.44659 23.94852 23.40771
19.55639
## [9945] 26.44052 20.96442 25.09970 19.69407 20.69375 24.44999 22.01254
27.18628
## [9953] 26.94038 21.13976 24.09367 23.74197 31.06996 27.45779 22.87322
17.64784
## [9961] 30.92034 28.48493 24.08854 21.77785 23.49172 23.01636 21.35777
19.51675
## [9969] 28.40595 19.07690 19.14034 26.84269 17.64773 19.39138 24.85792
22.95768
## [9977] 20.53262 21.80981 24.52853 31.43836 26.62775 20.01942 28.36953
24.32860
## [9985] 31.78971 24.22418 20.75191 21.37591 22.41320 26.81710 18.55915
20.41974
## [9993] 23.84557 25.37780 22.61538 25.54724 18.17356 19.15708 23.04074
24.93492
```

#b)

#Empirical distribution histogram of BMI

```
hist(bmi, breaks = 25, main = "Histogram of BMI distribution", xlab = "BMI",
col = "grey")
```

Histogram of BMI distribution



c)

```
#c)
#approximate mean
meanBMI = mean(bmi)

#variance
varianceBMI = var(bmi)

meanBMI
## [1] 23.6793

varianceBMI
## [1] 10.64996

#d)
#P(BMI >= 25)
sumOfValuesGreaterThan25 = sum(bmi >= 25)
probGreaterThan25 = sumOfValuesGreaterThan25 / length(bmi)
probGreaterThan25
## [1] 0.3152
```

Question 2

a)

```
set.seed(17)

probPlayer1WinsPlayer1Serves = 0.55
probPlayer1WinsPlayer2Serves = 0.40

#Function to start game with rule A
startA = function(){

  player1Score = 0
  player2Score = 0

  # Game continues until one player reaches a score of 2
  while (player1Score < 2 && player2Score < 2){

    if (player1Score == player2Score){
      # Player 1 serves when scores are tied(0,0)

      probWin = probPlayer1WinsPlayer1Serves
    }
    else if (player1Score > player2Score){
      # Player 1 serves after winning 1st point(1,0)

      probWin = probPlayer1WinsPlayer1Serves
    }
    else{
      # Player 2 serves after winning 1st point(0,1)

      probWin = probPlayer1WinsPlayer2Serves
    }

    # Randomly determine who wins the point
    if (runif(1) < probWin){

      player1Score = player1Score+1 # Player 1 wins the point
    }
    else{

      player2Score = player2Score+1 # Player 2 wins the point
    }
  }
}
```

```

    #Return TRUE if player 1 won the game, FALSE otherwise
    return((player1Score == 2))
}

#Function to start game with rule B
startB = function(){

    player1Score = 0
    player2Score = 0

    while (player1Score < 2 && player2Score < 2){

        if (player1Score == player2Score){
            # Player1 serves when scores are tied(0,0)

            probWin = probPlayer1WinsPlayer1Serves

        }
        else if (player1Score > player2Score){
            # Player2 serves after losing 1st point(1,0)

            probWin = probPlayer1WinsPlayer2Serves

        }
        else{
            # Player1 serves after losing 1st point(0,1)

            probWin = probPlayer1WinsPlayer1Serves

        }

        # Randomly determine who wins the point
        if (runif(1) < probWin){

            player1Score = player1Score+1 # Player 1 wins the point
        }
        else{

            player2Score = player2Score+1 # Player 2 wins the point
        }
    }
    return((player1Score == 2)) # Return TRUE if player 1 won the game, FALSE otherwise
}

#Simulate the game 1000 times
set.seed(17)

```

```
gamesA = replicate(1000, startA())
gamesB = replicate(1000, startB())
```

a) 1.Estimate the winning probability of Player 1 under service rule A

```
probWinA = sum(gamesA) / length(gamesA)
probWinA
```

```
## [1] 0.538
```

a) 2.Estimate the winning probability of Player 1 under service rule B

```
probWinB = sum(gamesB) / length(gamesB)
probWinB
```

```
## [1] 0.534
```

#b)

```
simulateGame = function(rule){

  #set initial score to 0
  score = c(0,0)

  #start the game -player1 is serving
  server = 1

  #play the game until 1 player is reaching 2 points
  while (max(score) < 2) {

    # Finding the probability of server winning a point
    if (rule == 'A'){

      if (score[server] == 0){
        prob = probPlayer1WinsPlayer1Serves
      }
      else{
        prob = probPlayer1WinsPlayer2Serves
      }
    }
    else{

      if(score[server]==0){
        prob = probPlayer1WinsPlayer2Serves
      }
      else{
        prob = probPlayer1WinsPlayer1Serves
      }
    }

    #simulate whether the server wins the point
    if(runif(1) < prob){
```

```
#server wins a point
score[server] = score[server]+1
}
else{

#server losses a point
server = 3-server
}
}
#return length of the game
return(sum(score))
}

set.seed(17)
gamesA = replicate(1000, simulateGame('A'))
gamesB = replicate(1000, simulateGame('B'))
```

1.Estimate the expected length of a game under service rule A

```
mean(gamesA)
## [1] 2.451
```

2.Estimate the expected length of a game under service rule B

```
mean(gamesB)
## [1] 2.269
```

c)

According to the outcomes of the simulation, Player 1 has the following winning chances when serving according to Rules A and B:

Rule A: 0.538

Rule B: 0.534

Under service rule A, when the server is the winner of the previous point, Player 1 has a slightly better winning chance.

Outcomes for the expected length of the game for Rule A and Rule B are as follows:

Rule A: 2.451

Rule B: 2.269

So, games played according to rule B are typically shorter than games played according to rule A.

Overall, according to the findings, we can say that service rule B is more competitive for Player 1 because it gives them a lower chance of winning and short lengthy games.

d)

Assumptions:

The game is played under the same conditions.

Both players are equally talented. Since their personal abilities are not considered here.

Question 3

a) Simulate five realizations of the random walk $\{S_n, n \geq 1\}$.

```
# Initializing number of steps in the random walk
numSteps = 100

# Assigning the probability of going to right (1/2)
probRight = 0.5

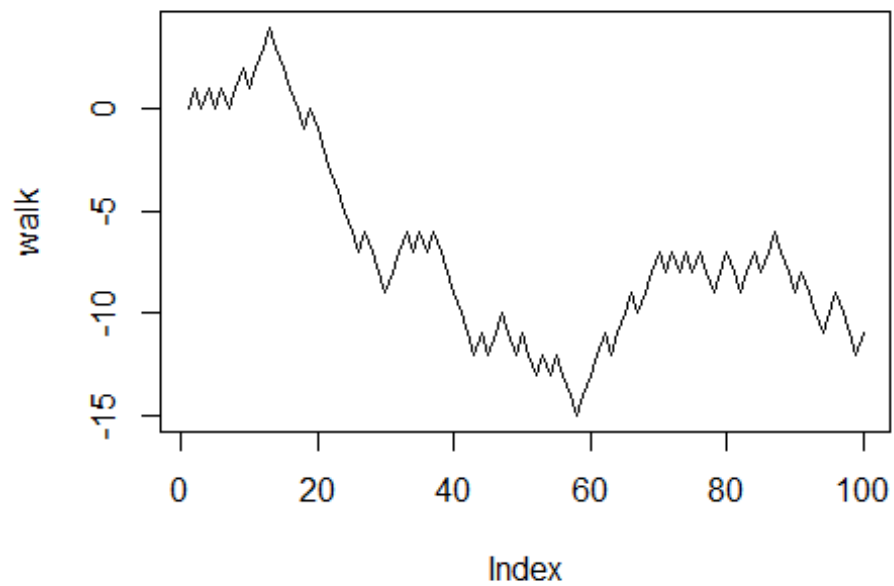
# Executing 5 realizations of the random walk
set.seed(17)
for (i in 1:5) {

  #Initializing the random walk to zero
  walk = rep(0, numSteps)

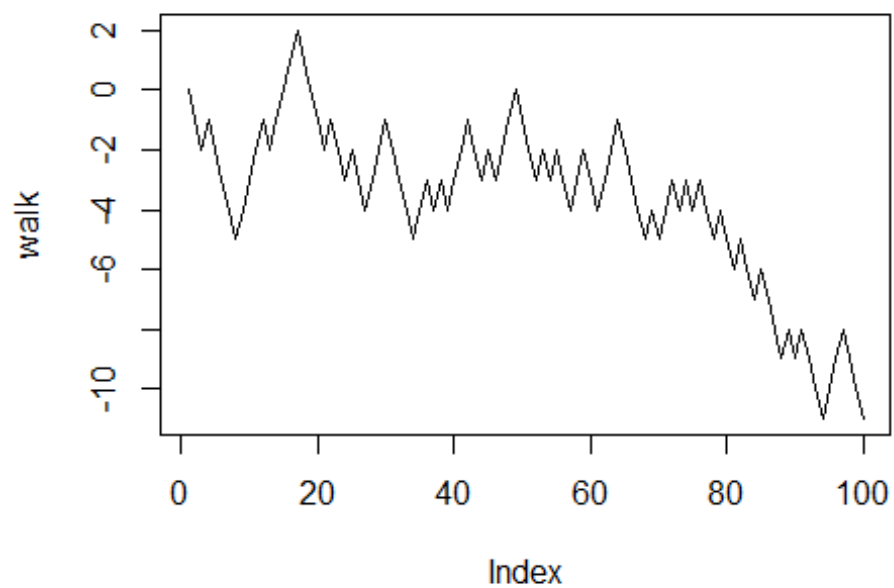
  #Simulating each step of random walk
  for (j in 2 : numSteps) {
    step = sample(c(-1, 1), size = 1, prob = c(probRight, 1 - probRight))
    walk[j] = walk[j-1] + step
  }

  #Plot the random walk
  plot(walk, type = "l", main = paste0("Random Walk ", i))
}
```

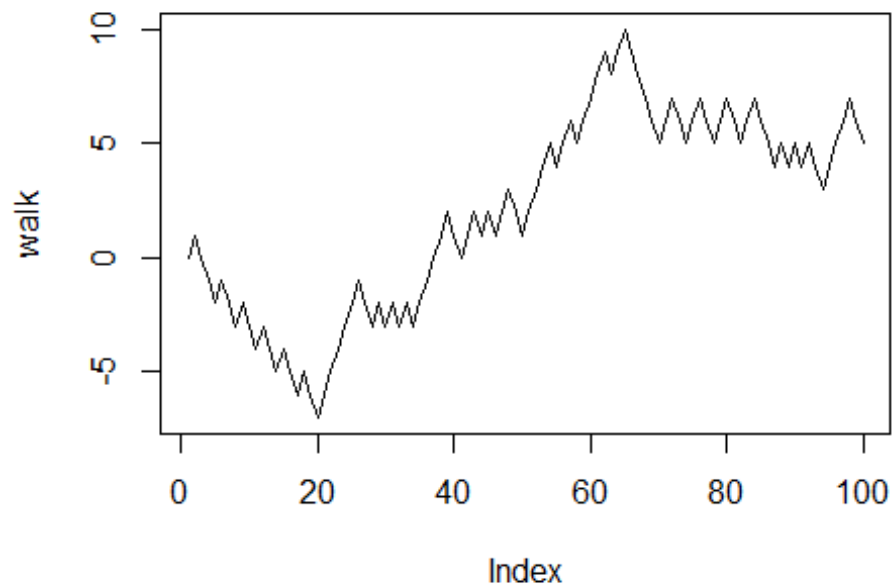
Random Walk 1



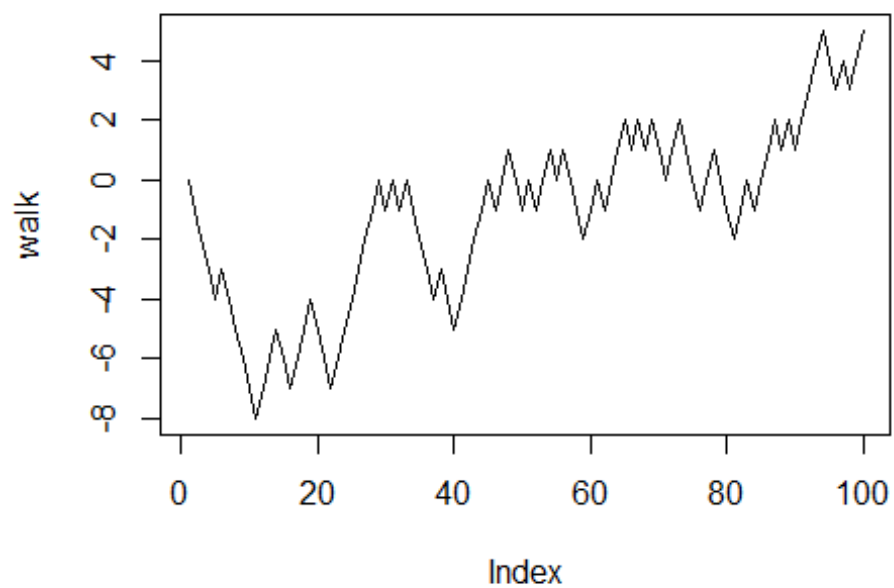
Random Walk 2



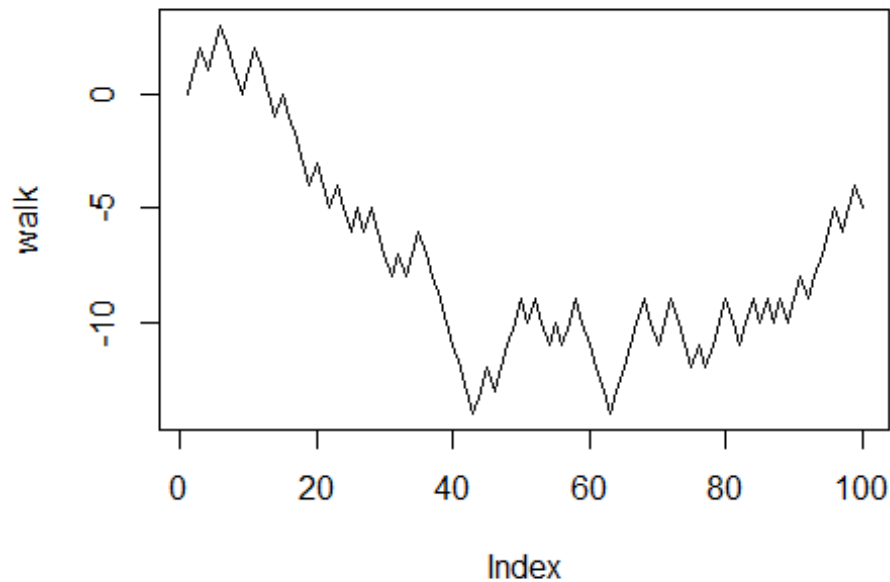
Random Walk 3



Random Walk 4



Random Walk 5



b) Discuss the aspects of the random variable S_n as n tends to infinity.

The central limit theorem (CLT) is a fundamental theorem in probability theory that states that the sum of a large number of independent and identically distributed random variables will be approximately normally distributed, regardless of the distribution of the individual random variables.

In the case of a random walk, S_n is the sum of n independent and identically distributed random variables, each with two possible values (+1 or -1) and equal probability of occurrence. As n increases, the CLT implies that S_n will approach a normal distribution, with mean 0 and variance $n/4$.

This means that as n increases, the distribution of the random walk becomes more and more spread out, and the probability of the walker returning to the starting point decreases. This is because the variance of the distribution is proportional to n , while the mean remains at 0. Therefore, as n increases, the distribution becomes wider, and the probability of the walker returning to the starting point becomes smaller.

Question 4

a) Simulate 5 possible beer purchases for 10 weeks by assuming that he bought beer brand A for first week.

```
#Define transition probability matrix P
P = matrix(c(0.1, 0.2, 0.7,
             0.2, 0.4, 0.4,
             0.1, 0.3, 0.6),
           nrow = 3, ncol = 3,
           byrow = TRUE,
           dimnames = list(c("A", "B", "C"), c("A", "B", "C")))

#Loop over 5 sequences of beer purchases for 10 weeks each
for (i in 1:5) {
  #Define initial state as "A"
  initialState = "A"

  #Initialize the sequence with the first week's purchase
  beerPurchases = c(initialState)

  #Simulate the rest of the purchases for each week
  for (j in 2:10) {

    #Get the transition probabilities from the current state
    transitionProbs = P[which(rownames(P) == initialState), ]

    # Sample the next state based on the transition probabilities
    nextState <- sample(x = rownames(P), size = 1, prob = transitionProbs)

    # Update the current state
    initialState <- nextState

    # Add the next purchase to the sequence
    beerPurchases <- c(beerPurchases, initialState)
  }

  # Print the sequence
  cat("Possible beer purchase", i, "=", paste(beerPurchases, collapse = " "),
      "\n")
}

## Possible beer purchase 1 = A C C A C B A C C C
## Possible beer purchase 2 = A C C A C A C C B C
## Possible beer purchase 3 = A C C A C B B A C C
## Possible beer purchase 4 = A B C C C B A C C C
## Possible beer purchase 5 = A C B A B A A B C C
```

b) Find the probability that he purchases beer brand A in first week and again buy the same brand in fifth week

```
#b)
#Define transition probability matrix
P = matrix(c(0.1, 0.2, 0.7, 0.2, 0.4, 0.4, 0.1, 0.3, 0.6), nrow = 3, ncol =
3, byrow = TRUE)

#Compute fourth power of transition probability matrix
P4 = P %**% P %**% P %**% P

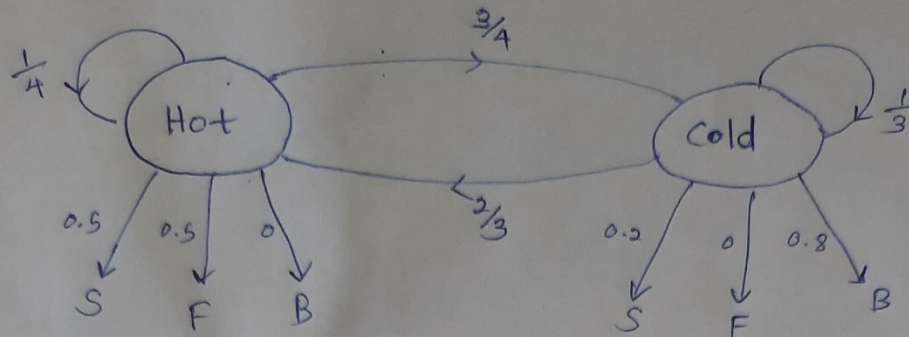
#Extract probability of transitioning from state A to state A after four
steps
probAtoA = P4[1, 1]
probAtoA

## [1] 0.1319
```

Question 5

S = Sandals F = Flip-flop B = Boots

a.)



State space of HMM :-

$$X = \{ \text{Hot, cold} \}$$

Signal :-

$$S = \{ S, F, B \}$$

b.)

$$P = \begin{matrix} & \begin{matrix} \text{Hot} & \text{Cold} \end{matrix} \\ \begin{matrix} \text{Hot} \\ \text{Cold} \end{matrix} & \begin{bmatrix} \frac{1}{4} & \frac{3}{4} \\ \frac{2}{3} & \frac{1}{3} \end{bmatrix} \end{matrix}$$

c) $P(S | \text{cold}) = 0.2$

Prob. of wearing sandals tomorrow

$$\begin{aligned}
 & \begin{matrix} \text{cold} \rightarrow \frac{1}{3} \times 0.2 = \frac{1}{15} \\ \text{hot} \rightarrow \frac{2}{3} \times 0.5 = \frac{1}{3} \end{matrix} \\
 & \underline{\hspace{10em}} \\
 & = \frac{1}{15} + \frac{1}{3} = \frac{6}{15} = \frac{2}{5}
 \end{aligned}$$

$$\text{Final Probability} = 0.2 \times \frac{2}{5} = \frac{1}{5} \times \frac{2}{5} = \frac{2}{25} = 0.08$$