

AdvRes

```
#####Kalman filter

#Specifications of variables

t_total <- 10000
A <- 1
B <- 1
C <- 1
R <- 1^2
Q <- 5^2
Sigma_0 <- 10^2
mu_0 <- 50

kalman_filter <- function(A, B, C, R, Q, Sigma_0, mu_0, u, z) {
  # Arguments follow notation on the slides, Lecture SSM 1, slide 11, except for
  # all them are scalars and not matrices/vectors.
  #
  # Returns:
  # List:
  # $mu
  # $sigma
  t_total <- length(z)

  mu <- rep(NA, t_total)
  sigma <- rep(NA, t_total)

  mu[1] <- mu_0
  sigma[1] <- Sigma_0

  for (t in 2:t_total) {
    mu_bar <- A * mu[t-1] + B * u[t]
    sigma_bar <- A * sigma[t-1] * A + R

    K <- sigma_bar * C / (C * sigma_bar * C + Q)
    mu[t] <- mu_bar + K * (z[t] - C * mu_bar)
    sigma[t] <- (1 - K * C) * sigma_bar
  }
  return(list(mu = mu, sigma = sigma))
}

##Simulations
u <- rep(1, t_total) # actions (always 1)
x <- rep(NA, t_total) # hidden
z <- rep(NA, t_total) # observed
x[1] <- rnorm(1, mu_0, sqrt(Sigma_0))
z[1] <- rnorm(1, x[1], sqrt(Q))
for (t in 2:t_total) {
  x[t] <- rnorm(1, x[t-1] + B*u[t], sqrt(R))
}
```

```
z[t] <- rnorm(1, x[t], sqrt(Q))
}
```

Lab1

```
##Advanced Machine Learning lab 1
```

```
# source("http://bioconductor.org/biocLite.R")
# biocLite(c("graph", "RBGL", "Rgraphviz"))
#install.packages("gRain", dependencies=TRUE)
#install.packages("bnlearn")
#install.packages("gRbase")
#install.packages("gRain")
library(bnlearn)
```

```
## Warning: package 'bnlearn' was built under R version 3.3.3
```

```
##
```

```
## Attaching package: 'bnlearn'
```

```
## The following object is masked from 'package:stats':
```

```
##
```

```
##      sigma
```

```
library(gRain)
```

```
## Warning: package 'gRain' was built under R version 3.3.3
```

```
## Loading required package: gRbase
```

```
## Warning: package 'gRbase' was built under R version 3.3.3
```

```
##
```

```
## Attaching package: 'gRbase'
```

```
## The following objects are masked from 'package:bnlearn':
```

```
##
```

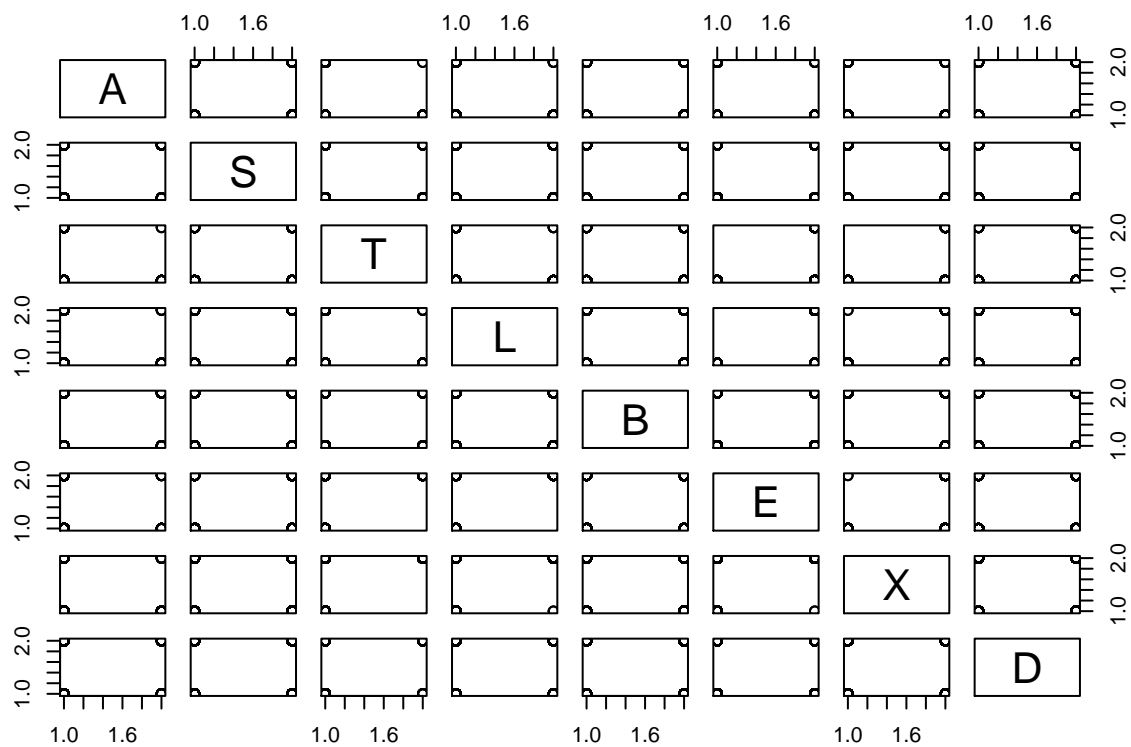
```
##      ancestors, children, parents
```

```
library(gRbase)
```

```
###1
```

```
data(asia)
```

```
plot(asia)
```

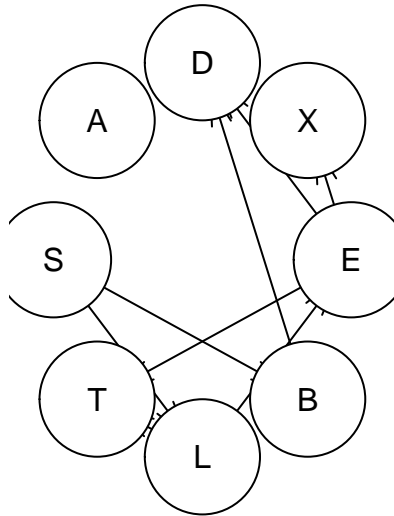


```
par(mfrow=c(1,2))

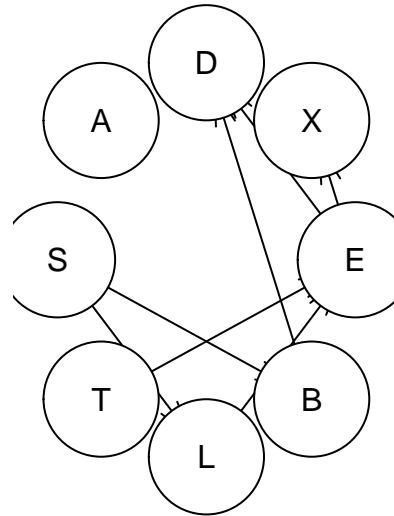
wl = matrix(c("E", "T"), ncol = 2, byrow = TRUE,
            dimnames = list(NULL, c("from", "to")))

plot(hc(asia, whitelist = wl), main = "HC with initial constraint")
plot(hc(asia, whitelist = NULL), main = "HC without constraint")
```

HC with initial constraint



HC without constraint



```
mygraph<-cpdag(hc(asia, whitelist = NULL, restart = 10))
cmygraph<-cpdag(hc(asia, whitelist = wl))
mygraph
```

```
##
## Bayesian network learned via Score-based methods
##
## model:
## [partially directed graph]
## nodes: 8
## arcs: 7
## undirected arcs: 2
## directed arcs: 5
## average markov blanket size: 2.25
## average neighbourhood size: 1.75
## average branching factor: 0.62
##
## learning algorithm: Hill-Climbing
## score: BIC (disc.)
## penalization coefficient: 4.258597
## tests used in the learning procedure: 257
## optimized: TRUE
```

```
cmygraph
```

```
##
## Bayesian network learned via Score-based methods
```

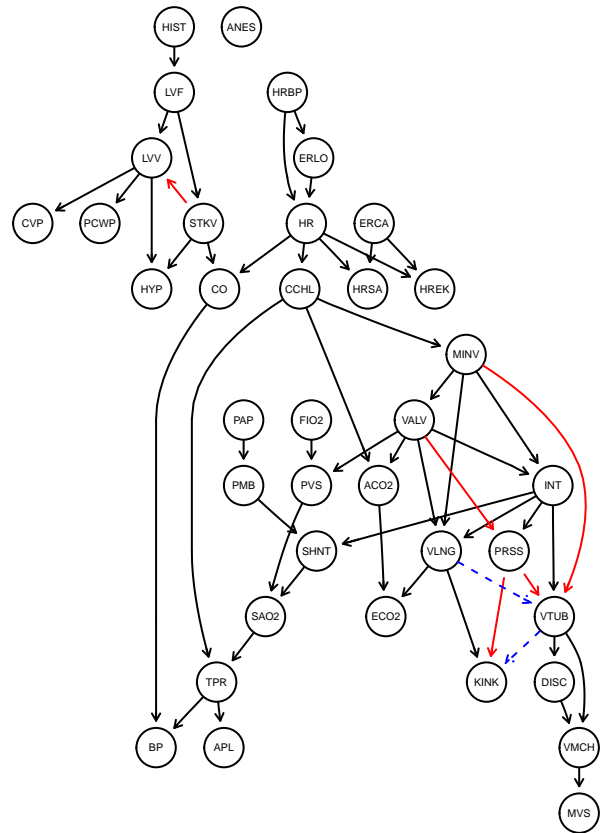
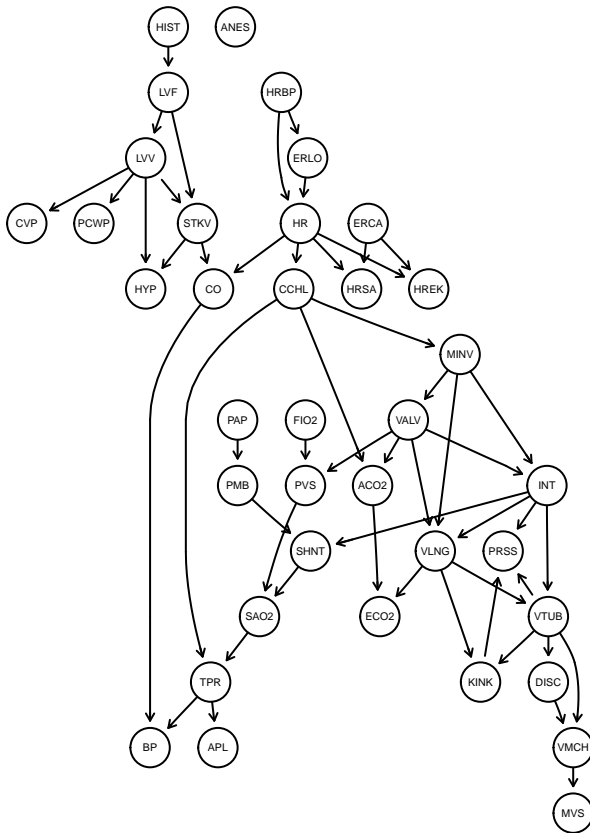
```

##
##  model:
##    [partially directed graph]
##  nodes:                        8
##  arcs:                         8
##    undirected arcs:           6
##    directed arcs:             2
##  average markov blanket size:  2.25
##  average neighbourhood size:   2.00
##  average branching factor:     0.25
##
##  learning algorithm:           Hill-Climbing
##  score:                        BIC (disc.)
##  penalization coefficient:     4.258597
##  tests used in the learning procedure: 82
##  optimized:                    TRUE
all.equal(mygraph, cmygraph)

## [1] "Different number of directed/undirected arcs"
#####Alternative
set.seed(12345)
countinue <- TRUE
while(countinue){
  hc1 <- hc(alarm, restart = 10)
  hc2 <- hc(alarm, restart = 10)
  continue <- ifelse(all.equal(vstructs(hc1), vstructs(hc2)) == TRUE, TRUE, FALSE)
  if (continue !=TRUE){
    par(mfrow = c(1,2))
    graphviz.compare(hc1, hc2)
    par(mfrow = c(1,1))
    break
  }
}

## Loading required namespace: Rgraphviz

```



```
###2
data("alarm")
n<-4
iss<- c(1,25,50,100)
mydag<-list()
par(mfrow=c(2,2))
for(i in 1:n){
  mydag[[i]]<- hc(alarm, restart = n,
                  score = "bde", iss = iss[i])
  plot(mydag[[i]], sub = paste0("iss = ", iss[i] ))
  print(alpha.star(mydag[[i]], alarm, debug = FALSE))
}
```

```
## [1] 6.241438
```

```
## [1] 7.459277
```

```
## [1] 10.35319
```



iss = 1



iss = 25



iss = 50



iss = 100

```
## [1] 16.62416
```

```
par(mfrow=c(1,1))
```

```
####3
```

```
data(learning.test)
```

```
pdag = iamb(learning.test)
```

```
pdag
```

```
##
```

```
## Bayesian network learned via Constraint-based methods
```

```
##
```

```
## model:
```

```
## [partially directed graph]
```

```
## nodes: 6
```

```
## arcs: 5
```

```
## undirected arcs: 1
```

```
## directed arcs: 4
```

```
## average markov blanket size: 2.33
```

```
## average neighbourhood size: 1.67
```

```
## average branching factor: 0.67
```

```
##
```

```
## learning algorithm: IAMB
```

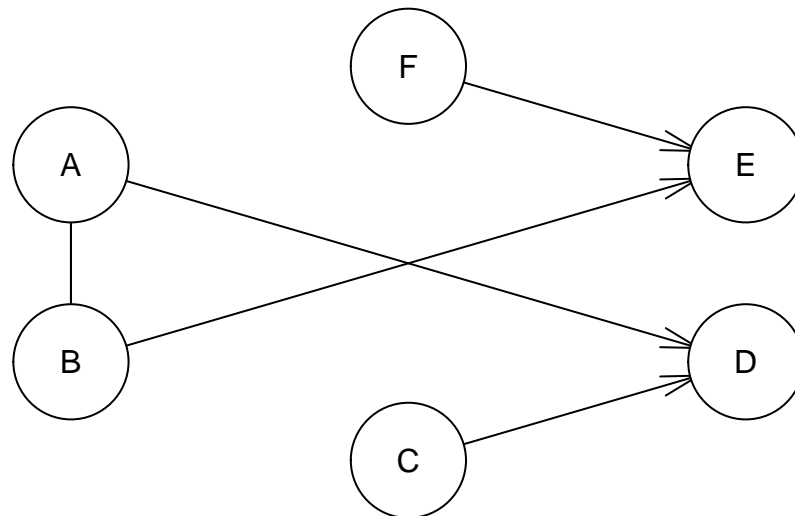
```
## conditional independence test: Mutual Information (disc.)
```

```
## alpha threshold: 0.05
```

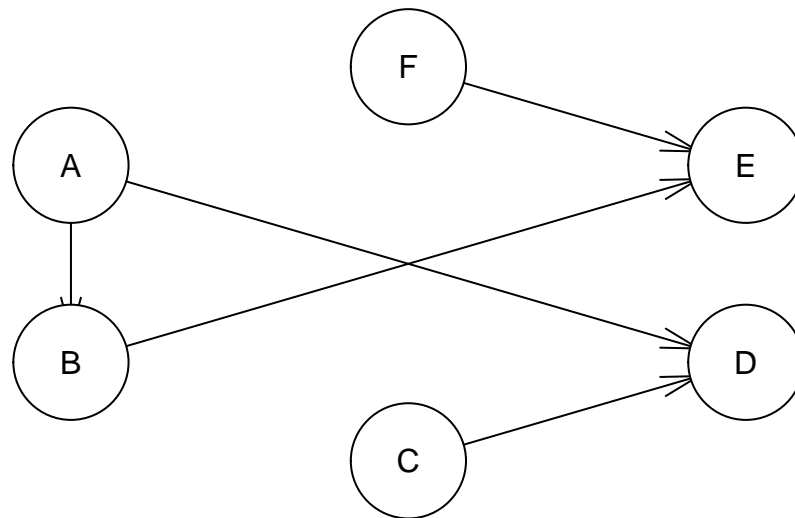
```
## tests used in the learning procedure: 94
```

```
## optimized: FALSE
```

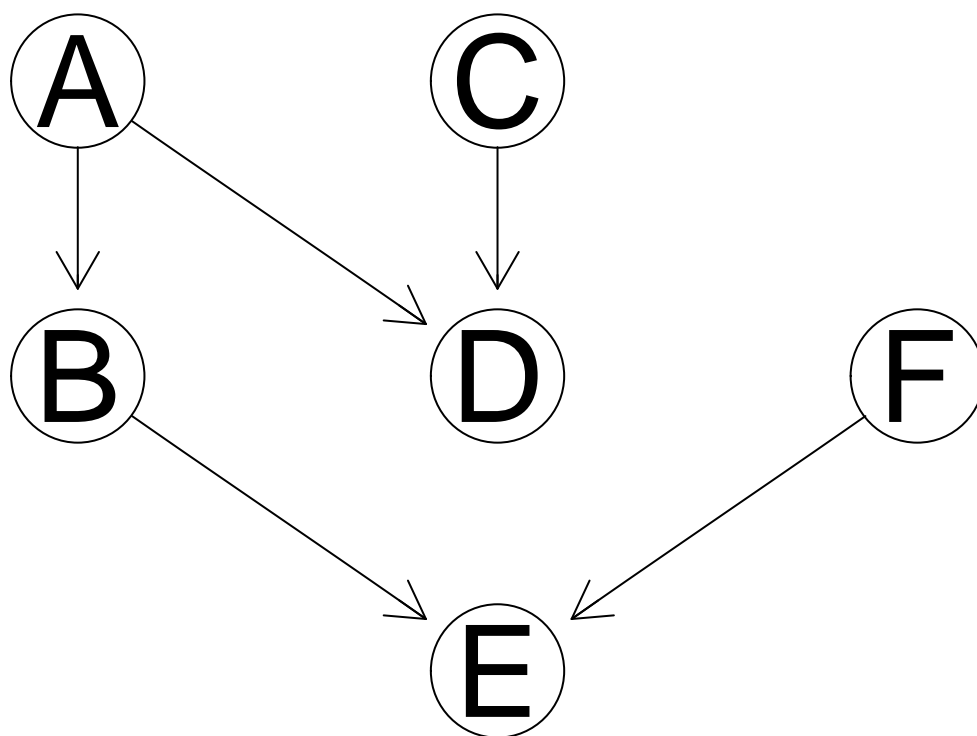
```
plot(pdag)
```



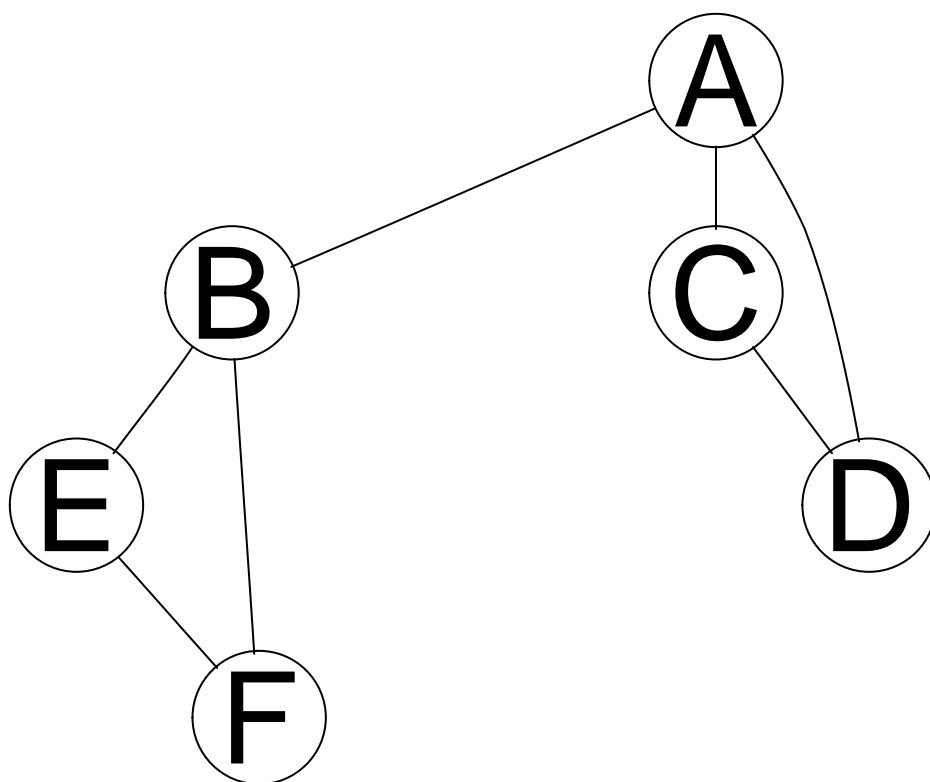
```
dag = set.arc(pdag, from = "B", to = "A")  
dag = pdag2dag(pdag, ordering = c("A", "B", "C", "D", "E", "F"))  
plot(dag)
```

```
fit = bn.fit(dag, learning.test)##It creates all conditional tables from one edge with another with his
LS<- as.grain(fit)## it creates LS
plot(LS)
```



```
MM<- compile(LS)##it triangulates and moralizes  
plot(MM)
```



```

basic<-querygrain(MM, nodes = c("A","E"))

#####
#####comparison of results for one change
## I want the conditional distribution of A, E given B = b

##Exact one
ChangeEvidence<-setEvidence(MM, c("B"), c("b"))
finalstate<-querygrain(ChangeEvidence, nodes = c("A","E"))

##Greedy algorithm
rsample<-cpdist(fit, nodes = c("A", "E"), evidence= (B=="b"), method = "ls")
condprob<-lapply(rsample, FUN = function(x){table(x)/length(x)})

res1<-cbind(A_LS= as.data.frame(finalstate)[1], A_Greedy= condprob$A,
            E_LS= as.data.frame(finalstate)[2], E_Greedy= condprob$E)
res1<-res1[,c(1,3,4,6)]
colnames(res1)<- c("A_LS", "A_Greedy", "E_LS", "E_Greedy" )
res1

##           A_LS  A_Greedy      E_LS  E_Greedy
## a 0.07394366 0.06838366 0.2611385 0.2690941
## b 0.64964789 0.63587922 0.2727394 0.2539964
## c 0.27640845 0.29573712 0.4661221 0.4769094

#####comparison of results for two changes
## I want the conditional distribution of A, E given B = b and F = b

```

```

ChangeEvidence2<-setEvidence(MM, c("B","F"), c("b", "b"))
finalstate2<-querygrain(ChangeEvidence2, nodes = c("A","E"))

res2<- list()
for(i in 1:4){
  ##Exact one
  ChangeEvidence2<-setEvidence(MM, c("B","F"), c("b", "b"))
  finalstate2<-querygrain(ChangeEvidence2, nodes = c("A","E"))
  ##Greedy algorithm
  rsample2<-cpdist(fit, nodes = c("A", "E"), evidence= (B=="b")&(F=="b"), method = "ls")
  condprob2<-lapply(rsample2, FUN = function(x){table(x)/length(x)})

  res2[[i]]<-cbind(A_LS= as.data.frame(finalstate2)[1], A_Approx= condprob2$A,
                    E_LS= as.data.frame(finalstate2)[2], E_Approx= condprob2$E)
  res2[[i]]<-res2[[i]][,c(1,3,4,6)]
}
res2

## [[1]]
##           A A_Approx.Freq           E E_Approx.Freq
## a 0.07394366    0.08362989 0.3167939    0.3256228
## b 0.64964789    0.64234875 0.3664122    0.3683274
## c 0.27640845    0.27402135 0.3167939    0.3060498
##
## [[2]]
##           A A_Approx.Freq           E E_Approx.Freq
## a 0.07394366    0.06010929 0.3167939    0.3333333
## b 0.64964789    0.65391621 0.3664122    0.3679417
## c 0.27640845    0.28597450 0.3167939    0.2987250
##
## [[3]]
##           A A_Approx.Freq           E E_Approx.Freq
## a 0.07394366    0.08791209 0.3167939    0.3150183
## b 0.64964789    0.64285714 0.3664122    0.3791209
## c 0.27640845    0.26923077 0.3167939    0.3058608
##
## [[4]]
##           A A_Approx.Freq           E E_Approx.Freq
## a 0.07394366    0.0752 0.3167939    0.2992
## b 0.64964789    0.6352 0.3664122    0.3840
## c 0.27640845    0.2896 0.3167939    0.3168

###WITHOUT EVIDENCE
## I want the conditional distribution of A, E

##Exact one
finalstate3<-querygrain(MM, nodes = c("A","E"))

#####comparison of results for two changes
## I want the conditional distribution of A, E given B = b and F = b, D=d
ChangeEvidence4<-setEvidence(MM, c("B","F","D", "A"), c("b", "b", "b", "b"))

```

```

finalstate4<-querygrain(ChangeEvidence4, nodes = c("A","E"))

i<-1
res5<- list()
for(i in 1:4){
  ##Exact one
  ChangeEvidence5<-setEvidence(MM, c("B","F","D", "C"), c("b", "b","b", "b"))
  finalstate5<-querygrain(ChangeEvidence5, nodes = c("A","E"))
  ##Greedy algorithm
  rsample5<-cpdist(fit, nodes = c("A", "E"), evidence= (B=="b")&(F=="b")&(D=="b")&(C=="b"), method = "L")
  condprob5<-lapply(rsample5, FUN = function(x){table(x)/length(x)})

  res5[[i]]<-cbind(A_LS= data.frame(finalstate5)[1], A_Approx= data.frame(condprob5$A),
                  E_LS= data.frame(finalstate5)[2], E_Approx= data.frame(condprob5$E))
  res5[[i]]<-res5[[i]][,c(1,3,4,6)]
}
res5

## [[1]]
##           A A_Approx.Freq           E E_Approx.Freq
## a 0.05115203    0.05882353 0.3167939    0.2941176
## b 0.23753656    0.17647059 0.3664122    0.3529412
## c 0.71131142    0.76470588 0.3167939    0.3529412
##
## [[2]]
##           A A_Approx.Freq           E E_Approx.Freq
## a 0.05115203    0.1052632 0.3167939    0.3157895
## b 0.23753656    0.1578947 0.3664122    0.4736842
## c 0.71131142    0.7368421 0.3167939    0.2105263
##
## [[3]]
##           A A_Approx.Freq           E E_Approx.Freq
## a 0.05115203    0.05882353 0.3167939    0.4117647
## b 0.23753656    0.05882353 0.3664122    0.2352941
## c 0.71131142    0.88235294 0.3167939    0.3529412
##
## [[4]]
##           A A_Approx.Freq           E E_Approx.Freq
## a 0.05115203    0.0000000 0.3167939    0.3809524
## b 0.23753656    0.0952381 0.3664122    0.3333333
## c 0.71131142    0.9047619 0.3167939    0.2857143

###4
burn_in<- c(1,100, 10000, 1000000)
every<-c(2,20,100, 200)

nodes<- LETTERS[1:5]
num <- 1000

checkingDags<- function(burnin, every, num, nodes){
  mymat<- matrix(ncol =length(burnin), nrow=length(every))
  for(i in 1:length(burnin)){

```

```

for(j in 1:length(every)){
  z<-random.graph(nodes = nodes, num = num, method = "ic-dag",
    every = every[j], burn.in =burnin[i])

  m<-unique(z)
  print(length(m))# This gives the proportion the number of repeated graphs out my

  dagGraph<-lapply(m, FUN= function(x){cpdag(x)})
  mymat[j,i]<- length(unique(dagGraph))/length(m)
}
}
return(mymat)
}

```

```

result<-checkingDags(burnin = burn_in, every = every, num = num, nodes = nodes)

```

```

## [1] 671
## [1] 977
## [1] 978
## [1] 985
## [1] 680
## [1] 985
## [1] 983
## [1] 979
## [1] 722
## [1] 983
## [1] 987
## [1] 981
## [1] 692
## [1] 975
## [1] 976
## [1] 981

```

```

colnames(result)<- paste0("burn in = " , burn_in)
rownames(result)<- paste0("every = " , every)
result

```

```

##          burn in = 1 burn in = 100 burn in = 10000 burn in = 1e+06
## every = 2      0.9195231      0.8955882      0.9030471      0.9089595
## every = 20     0.8802456      0.9055838      0.8870804      0.8769231
## every = 100    0.8905930      0.9094608      0.9047619      0.8903689
## every = 200    0.8812183      0.8968335      0.8858308      0.8970438

```

Lab2

```

#####Lab1

set.seed(12345)
#install.packages("HMM")
library(HMM)

##Question1
# Initialise HMM

```

```

states      <- as.character(1:10)
symbols     <- as.character(1:10)
startProbs  <- rep(0.1,10)
transProbs  <- diag(x = 0.5, 10)
transProbs[10,1]<- 0.5 #writing the ones left
emissionProbs <- diag(x = 0.2, 10)
emissionProbs[1,9:10]<-rep(0.2,2)
emissionProbs[2,10]<-rep(0.2,1)
emissionProbs[9,1]<-rep(0.2,1)
emissionProbs[10,1:2]<-rep(0.2,1)
for(i in 1:ncol(transProbs)){
  for(j in 1:nrow(transProbs)){
    if(j == i+1){
      transProbs[i,j]<-0.5
      emissionProbs[i,j]<-0.2}
    if(j == i+2){ emissionProbs[i,j]<-0.2}
    if(j == i-1){ emissionProbs[i,j]<-0.2}
    if(j == i-2){ emissionProbs[i,j]<-0.2}
  }}

myhmm = initHMM(States = states,
               Symbols = symbols,
               startProbs = startProbs,
               transProbs= transProbs,
               emissionProbs=emissionProbs)

##2
length<-100

my100sim<-simHMM(myhmm, length)

#3

myobs<-my100sim$observation # Taking just the real observations (Z)
###Filtering
filtering<-exp(forward(myhmm, observation=myobs))#A matrix containing the forward probabilities given o
marginalFilter<-apply(as.data.frame(filtering),2, FUN = function(x){prop.table(x)})##prop.table already

###Smoothing
smoothing<-posterior(myhmm, observation=myobs)

##Most probable path

Viterbi<-viterbi(myhmm, observation=myobs)

#4
mystates<-my100sim$states

smoothingMostProb  <- sapply(as.data.frame(smoothing), which.max)

```

```
FilteringMostProb <- sapply(as.data.frame(marginalFilter),which.max)
Viterbi
```

```
## [1] "8" "9" "10" "1" "1" "1" "1" "1" "2" "2" "3" "3" "3" "3"
## [15] "3" "4" "4" "4" "4" "5" "6" "7" "8" "9" "10" "1" "1" "1"
## [29] "1" "1" "2" "3" "3" "3" "4" "4" "4" "5" "5" "6" "7" "8"
## [43] "9" "10" "1" "1" "1" "1" "2" "3" "4" "4" "4" "5" "6" "7"
## [57] "7" "8" "8" "8" "9" "10" "10" "10" "10" "1" "1" "1" "1" "2"
## [71] "2" "2" "3" "3" "3" "3" "3" "4" "5" "6" "7" "8" "8" "8"
## [85] "8" "8" "9" "10" "1" "1" "1" "1" "1" "1" "1" "1" "1" "1"
## [99] "2" "2"
```

```
smoothingresult <-table(mystates == smoothingMostProb)
Filteringresult <-table(mystates == FilteringMostProb)
Viterbiresult <-table(mystates == Viterbi)
```

```
ResultTable <-cbind(smoothingresult, Filteringresult, Viterbiresult)
```

```
###5
```

```
Comparingsimulations<-function(HMM, length){
```

```
  ResultTable<-list()
```

```
  FilterEntropy<-list()
```

```
  library(entropy)
```

```
  for(i in 1:length(length)){
```

```
    my100sim <-simHMM(myhmm, length[i])
```

```
    myobs <-my100sim$observation # Taking just the real observations (Z)
```

```
    ###Filtering
```

```
    filtering <-exp(forward(myhmm, observation=myobs))#A matrix containing the forward prob
```

```
    marginalFilter <-apply(as.data.frame(filtering),2, FUN = function(x){prop.table(x)}##prop.
```

```
    ###Smoothing
```

```
    smoothing <-posterior(myhmm, observation=myobs)
```

```
    #Getting just the Z states for different models
```

```
    mystates <-my100sim$states
```

```
    smoothingMostProb <- sapply(as.data.frame(smoothing), which.max)
```

```
    FilteringMostProb <- sapply(as.data.frame(marginalFilter),which.max)
```

```
    smoothingresult <-table(mystates == smoothingMostProb)
```

```
    Filteringresult <-table(mystates == FilteringMostProb)
```

```
    Viterbi <-viterbi(myhmm, observation=myobs)##Most probable path
```

```
    Viterbiresult <-table(mystates == Viterbi)
```

```
    ResultTable[[i]] <-cbind(smoothingresult, Filteringresult, Viterbiresult)/length[i]
```

```
    FilterEntropy[[i]] <- apply(marginalFilter,2,entropy.empirical)
```

```
  }
```

```
  return(list(PercentageSim=ResultTable, Entropy=FilterEntropy))
```

```
}
```



```

length <-rep(100,5)
myhmm = initHMM(States = states,
                Symbols = symbols,
                startProbs = startProbs,
                transProbs= transProbs,
                emissionProbs=emissionProbs)

Simulations<-Comparingsimulations(myhmm, length = length)

##
## Attaching package: 'entropy'

## The following object is masked from 'package:bnlearn':
##
##      discretize
Simulations$PercentageSim

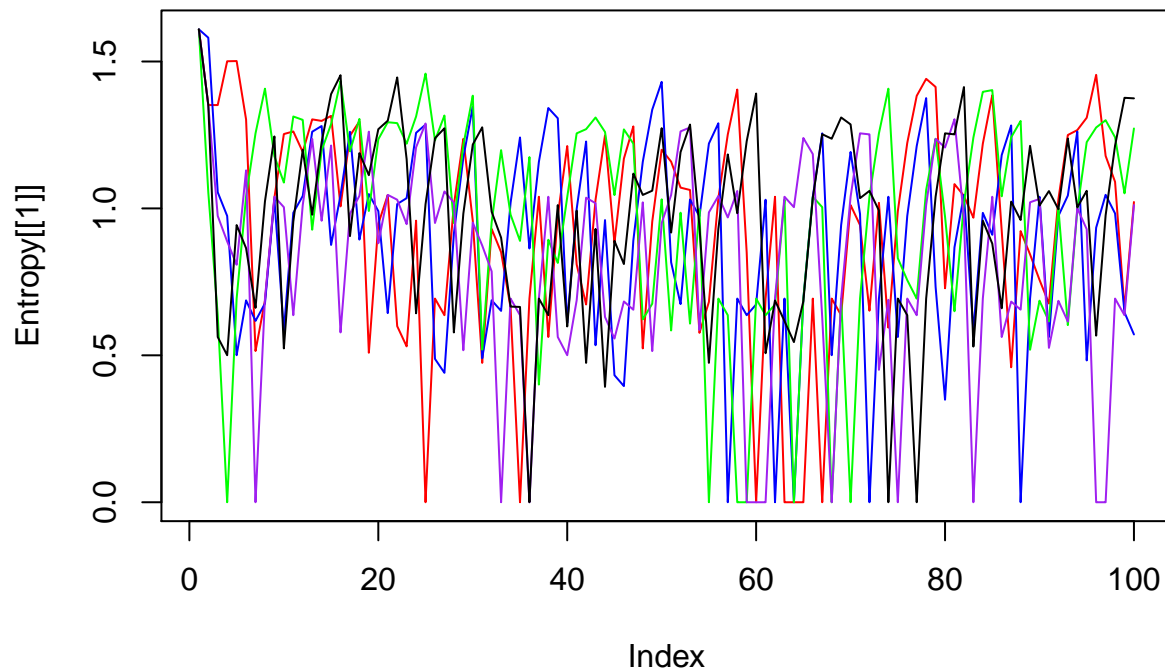
## [[1]]
##      smoothingresult Filteringresult Viterbiresult
## FALSE              0.32              0.54              0.39
## TRUE               0.68              0.46              0.61
##
## [[2]]
##      smoothingresult Filteringresult Viterbiresult
## FALSE              0.23              0.51              0.35
## TRUE               0.77              0.49              0.65
##
## [[3]]
##      smoothingresult Filteringresult Viterbiresult
## FALSE              0.42              0.51              0.44
## TRUE               0.58              0.49              0.56
##
## [[4]]
##      smoothingresult Filteringresult Viterbiresult
## FALSE              0.2              0.4              0.35
## TRUE               0.8              0.6              0.65
##
## [[5]]
##      smoothingresult Filteringresult Viterbiresult
## FALSE              0.36              0.46              0.61
## TRUE               0.64              0.54              0.39

#6
#install.packages("entropy")

Entropy<-Simulations$Entropy

plot(Entropy[[1]], col = "red", type = "l")
lines(Entropy[[2]], col = "blue")
lines(Entropy[[3]], col = "green")
lines(Entropy[[4]], col = "purple")
lines(Entropy[[5]], col = "black")

```



```
##7
likelihood<-posterior(myhmm, myobs)
prior<-transProbs
result<-prior%%likelihood[,100]
```

Lab3

```
##Advanced ML lab 3
library("mvtnorm")

##1a
x <- c(0.4)
y <- c(0.719)
xStar <- seq(-1,1,length=200)
sigma_f<-1
l<-0.3
hyperParam<- c(sigma_f, l)
sigmaNoise<- 0.1
nSim <- 100

###Calculating K from y and x, that are two vector inputs
GaussianKernel<- function(x1,x2, sigma_f =sigma_f, l=1){
  n1<- length(x1)
  n2<- length(x2)
  K<- matrix(NA, n1, n2)
```

```

for(i in 1:n2){
  K[,i]<- sigma_f^2*exp(-0.5*((x1-x2[i])/l)^2 )
}
return(K)
}

GaussianKernel(c(1,4), c(3,1), sigma = 2, l=1)

##           [,1]      [,2]
## [1,] 0.5413411 4.00000000
## [2,] 2.4261226 0.04443599

GaussianKernel(c(1,4), c(3,1), sigma = 2, l=2)

##           [,1]      [,2]
## [1,] 2.426123 4.00000
## [2,] 3.529988 1.29861

GaussianKernel(c(1,4), c(3,1), sigma = 2, l=3)

##           [,1]      [,2]
## [1,] 3.202950 4.000000
## [2,] 3.783838 2.426123

GaussianKernel(c(1,4), c(3,1), sigma = 2, l=4)

##           [,1]      [,2]
## [1,] 3.529988 4.000000
## [2,] 3.876933 3.019358

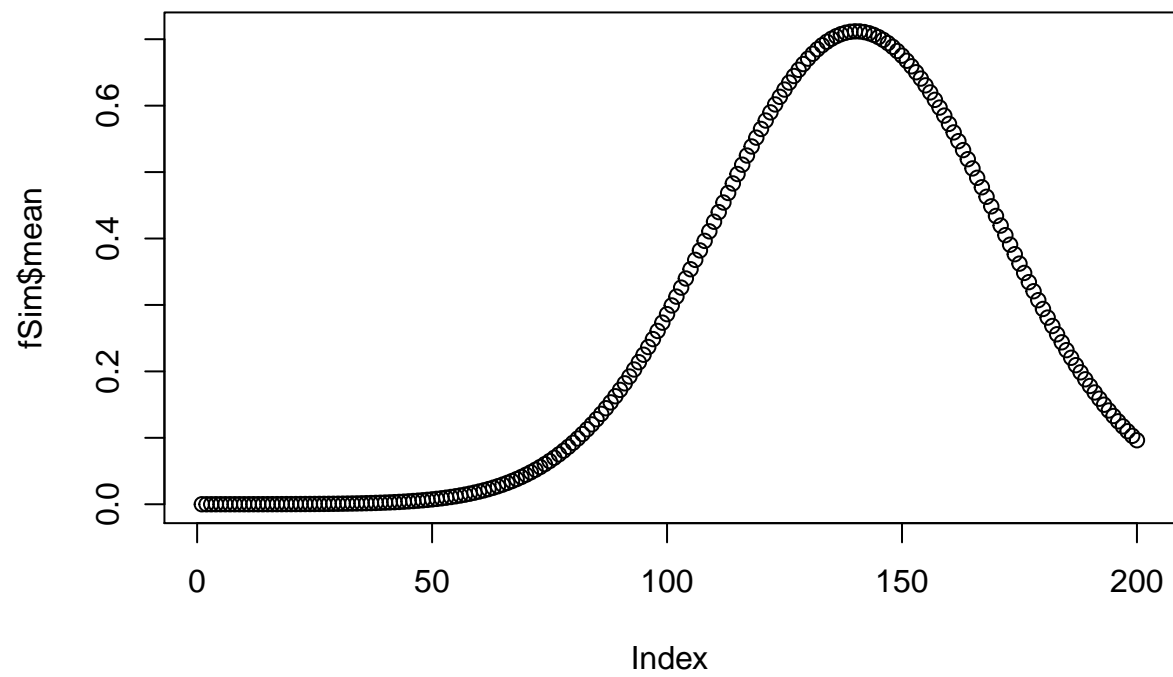
SimGP <- function(K,x,y, xStar, nSim, sigmaNoise, ...){
  # Simulates nSim realizations (function) form a Gaussian process with mean m(x) and covariance K(x,x'
# over a grid of inputs (x)
  n <- length(xStar)
  #if (is.numeric(m)) meanVector <- rep(0,n) else meanVector <- m(xStar)

  covMat <- K(x, x,...)
  covMatdiff2<- K(x, xStar,...)
  covMatStar<- K(xStar, xStar,...)
  L<-t(chol(covMat+ (sigmaNoise^2)*diag(dim(covMat)[2])))
  alpha<- solve(t(L),solve(L,y))
  fStar<- t(covMatdiff2)%*%alpha
  v<-solve(L,covMatdiff2)
  covfStar <- covMatStar-t(v)%*%v
  return(list(mean=fStar, covfStar= diag(covfStar)))
}

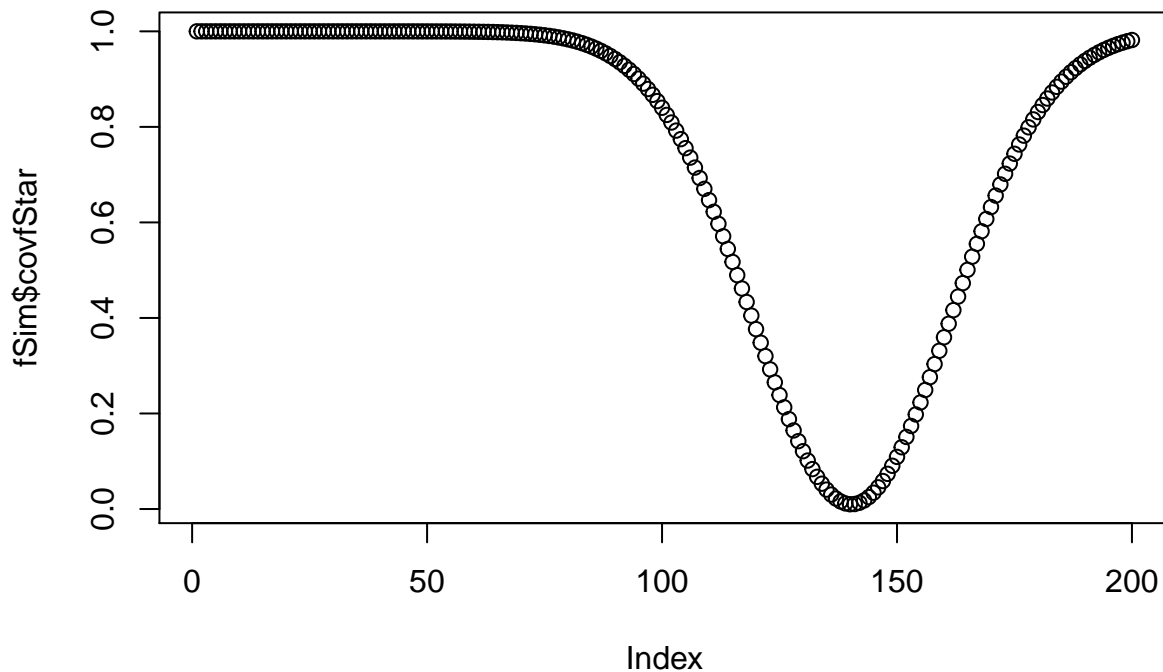
##b
fSim <- SimGP(y=y, xStar = xStar, x= x, K=GaussianKernel, nSim = nSim, sigma_f =sigma_f, l=1, sigmaNoise=sigmaNoise)

plot(fSim$mean)

```

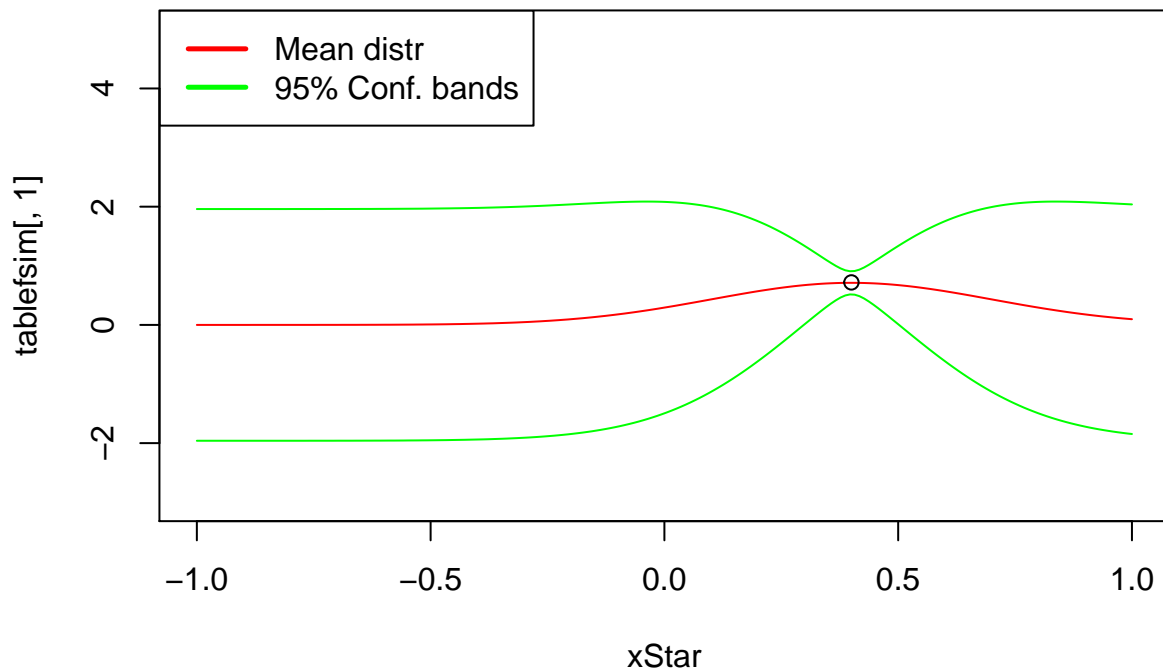


```
plot(fSim$covfStar)
```



```
tablefsim<-cbind(mean = fSim$mean, low= fSim$mean-1.96*sqrt(fSim$covfStar),high= fSim$mean+1.96*sqrt(fS
plot(x= xStar,y = tablefsim[,1], col = "red", type = "l", ylim = c(-3,5), main = "1 data prior")
lines(x= xStar, y =tablefsim[,2], col ="green")
lines(x= xStar, y = tablefsim[,3], col = "green")
points(x = x, y = y)
legend("topleft", # places a legend at the appropriate place
      c("Mean distr ", "95% Conf. bands"), # puts text in the legend
      lty=c(1,1), # gives the legend appropriate symbols (lines)
      lwd=c(2.5,2.5),col=c("Red","Green")) # gives the legend lines the correct color and width
```

1 data prior



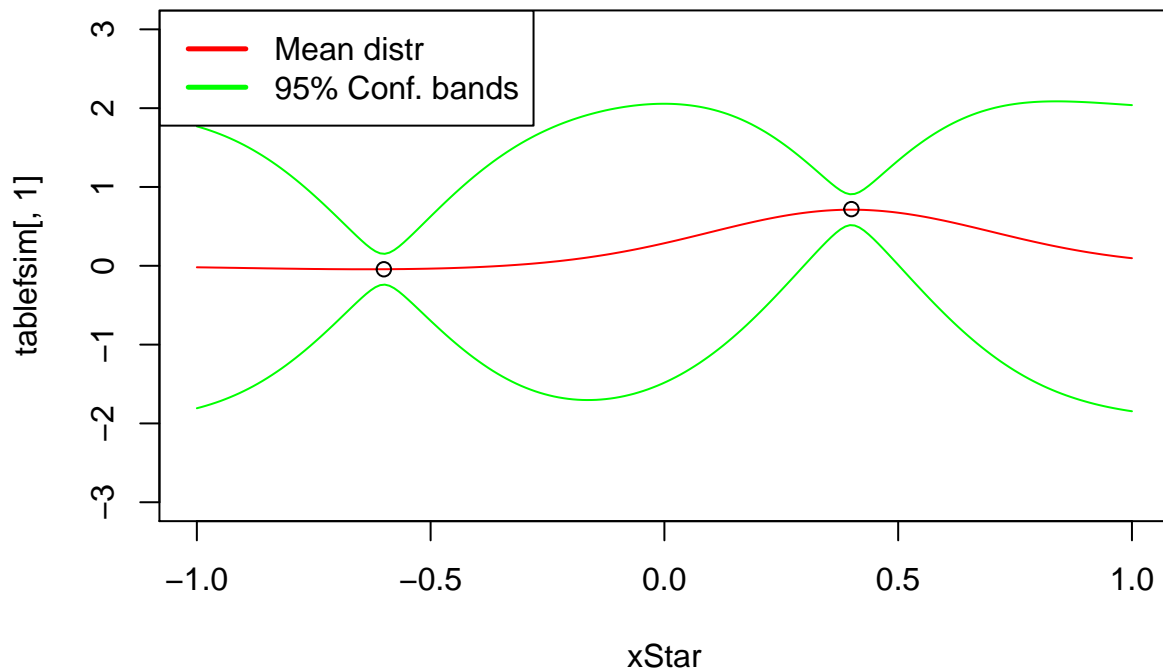
```
##c
```

```
x<-c(x,-0.6)
y<-c(y, -0.044)
```

```
fSim <- SimGP(y=y, xStar = xStar, x= x, K=GaussianKernel, nSim = nSim, sigma_f =sigma_f, l=1, sigmaNois
```

```
tablefsim<-cbind(mean = fSim$mean, low= fSim$mean-1.96*sqrt(fSim$covfStar),high= fSim$mean+1.96*sqrt(fS
plot(x= xStar,y = tablefsim[,1], col = "red", type = "l", ylim = c(-3,3), main = "2 data prior")
lines(x= xStar, y =tablefsim[,2], col ="green")
lines(x= xStar, y = tablefsim[,3], col = "green")
points(x = x, y = y)
legend("topleft", # places a legend at the appropriate place
      c("Mean distr ", "95% Conf. bands"), # puts text in the legend
      lty=c(1,1), # gives the legend appropriate symbols (lines)
      lwd=c(2.5,2.5),col=c("Red","Green")) # gives the legend lines the correct color and width
```

2 data prior

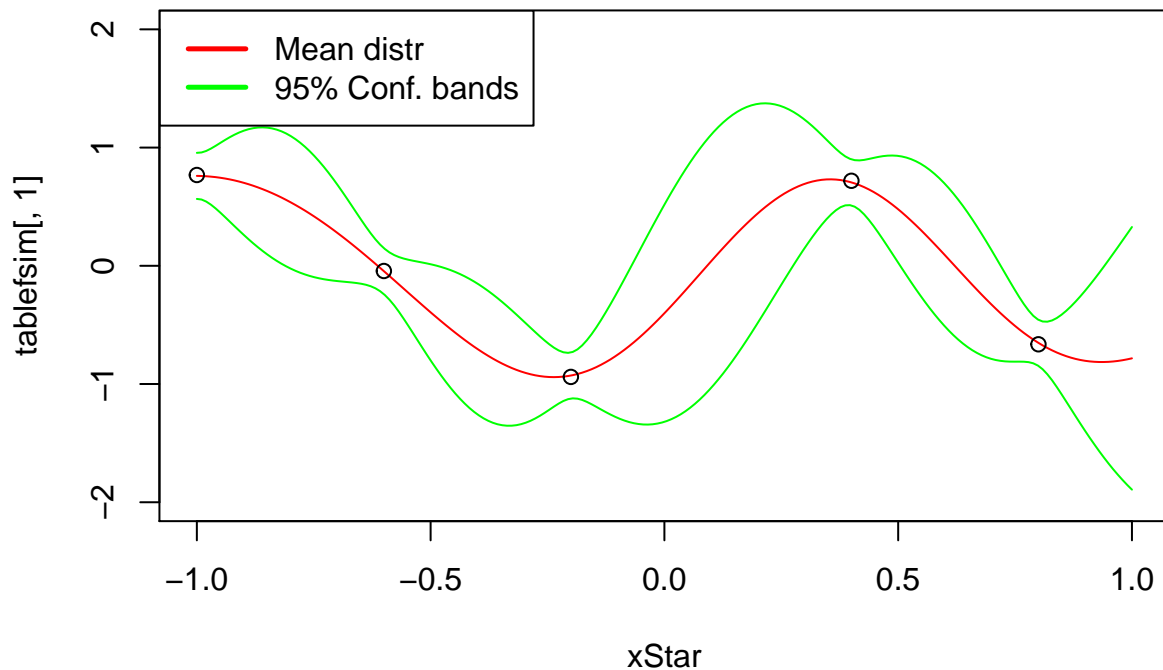


```
###d
x<- c(-1.0,-0.6,-0.2,0.4,0.8)
y<- c(0.768,-0.044,-0.940,0.719, -0.664)

fSim <- SimGP(y=y, xStar = xStar, x= x, K=GaussianKernel, nSim = nSim, sigma_f =sigma_f, l=1, sigmaNoise=0.1)

tablefsim<-cbind(mean = fSim$mean, low= fSim$mean-1.96*sqrt(fSim$covfStar),high= fSim$mean+1.96*sqrt(fSim$covfStar))
plot(x= xStar,y = tablefsim[,1], col = "red", type = "l", main = "5 data prior, l = 0.3", ylim = c(-2,2))
lines(x= xStar, y =tablefsim[,2], col ="green")
points(x = x, y = y)
lines(x= xStar, y = tablefsim[,3], col = "green")
legend("topleft", # places a legend at the appropriate place
      c("Mean distr ", "95% Conf. bands"), # puts text in the legend
      lty=c(1,1), # gives the legend appropriate symbols (lines)
      lwd=c(2.5,2.5),col=c("Red","Green")) # gives the legend lines the correct color and width
```

5 data prior, $l = 0.3$



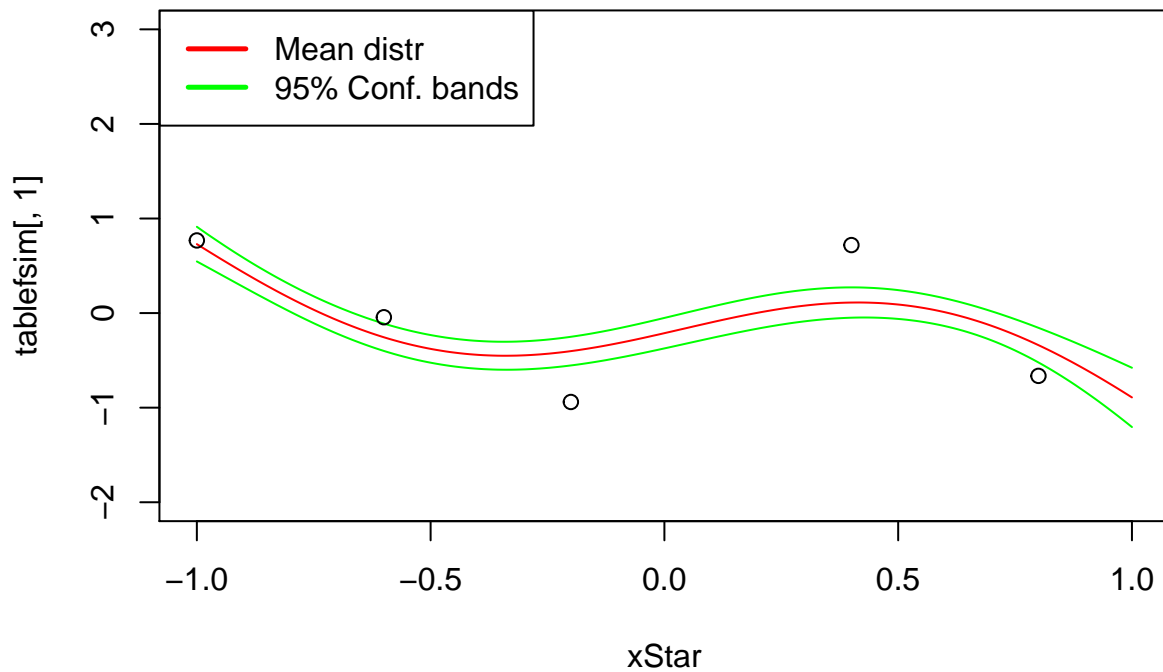
```
###e

sigma_f<-1
l<-1
hyperParam<- c(sigma_f, l)

fSim <- SimGP(y=y, xStar = xStar, x= x, K=GaussianKernel, nSim = nSim, sigma_f =sigma_f, l=l, sigmaNois

tablefsim<-cbind(mean = fSim$mean, low= fSim$mean-1.96*sqrt(fSim$covfStar),high= fSim$mean+1.96*sqrt(fS
plot(x= xStar,y = tablefsim[,1], col = "red", type = "l", ylim = c(-2,3), main = "5 prior l = 1")
lines(x= xStar, y =tablefsim[,2], col ="green")
lines(x= xStar, y = tablefsim[,3], col = "green")
points(x = x, y = y)
legend("topleft", # places a legend at the appropriate place
      c("Mean distr ", "95% Conf. bands"), # puts text in the legend
      lty=c(1,1), # gives the legend appropriate symbols (lines)
      lwd=c(2.5,2.5),col=c("Red","Green")) # gives the legend lines the correct color and width
```


5 prior l = 1



```
#####2
#
#
#
# plot(xStar, fSim[1,], type="l", ylim = c(-3,3))
# for (i in 2:dim(fSim)[1]) {
#   lines(xStar, fSim[i,], type="l")
# }
# lines(xStar, MeanFunc(xStar), col = "red", lwd = 3)
#
#
# # Plotting using manipulate package
# #install.packages("manipulate")
# library(manipulate)
#
# plotGPPrior <- function(sigma_f, l, nSim=20){
#   fSim <- SimGP(y=y, xStar = xStar, x= x, K=GaussianKernel, nSim = nSim, sigma_f =sigma_f, l=l, sigma.
#   plot(xStar, fSim[1,], type="l", ylim = c(-3,3), ylab="f(x)", xlab="x")
#   for (i in 2:nSim) {
#     lines(xStar, fSim[i,], type="l")
#   }
#   title(paste('length scale =',l,', sigma_f =',sigma_f))
# }
#
#
# manipulate(
#   plotGPPrior(sigma_f, l, nSim = 20),
```

```

#   sigma_f = slider(0, 2, step=0.1, initial = 1, label = "SigmaF"),
#   l = slider(0, 2, step=0.1, initial = 1, label = "Length scale, l")
# )
#

###2

library(kernlab)
Data<- read.csv("https://github.com/STIMALiU/AdvMLCourse/raw/master/GaussianProcess/Code/TempTullinge.csv",
               sep = ";")

TData<-data.frame(time = 1:2190, date = Data$date, day = rep(1:365,6), temp = Data$temp)
GaussKernel<- function(sigmaF , ell){
  rval <- function(x,y, sigma_f = sigmaF, l = ell){
    n1 <- length(x)
    n2 <- length(y)
    K <- matrix(NA,n1,n2)
    for (i in 1:n2){
      K[,i] <- sigma_f^2*exp(-0.5*( (x-y[i])/l)^2 )
    }
    return(K)
  }
  class(rval) <- "kernel"
  return(rval)
}

SmallData<- TData[seq(1, nrow(TData), 5), ]
sigma_f<-2
l<-1
X<-matrix(c(1,3,4), ncol = 1)
XStar<-matrix(c(2,3,4), ncol = 1)

GaussianKernel2 <- GaussKernel(sigmaF = sigma_f, ell = l)
cov_matrix <- kernelMatrix(kernel = GaussianKernel2, x=X, y = XStar)

x1<-1
x2<-2

K<-GaussianKernel2(x=x1,y= x2)
##b
sigma_f<-20
l <-0.2

x<-SmallData$time
x_prime<- seq(1,365,1)
GaussianKernel3<-GaussKernel(sigmaF = sigma_f, ell = l)
K<-kernelMatrix(GaussianKernel3, x,x_prime)

mylm<-lm(temp~time+ I(time^2), SmallData)
sigma_2_n<-var(mylm$residuals)

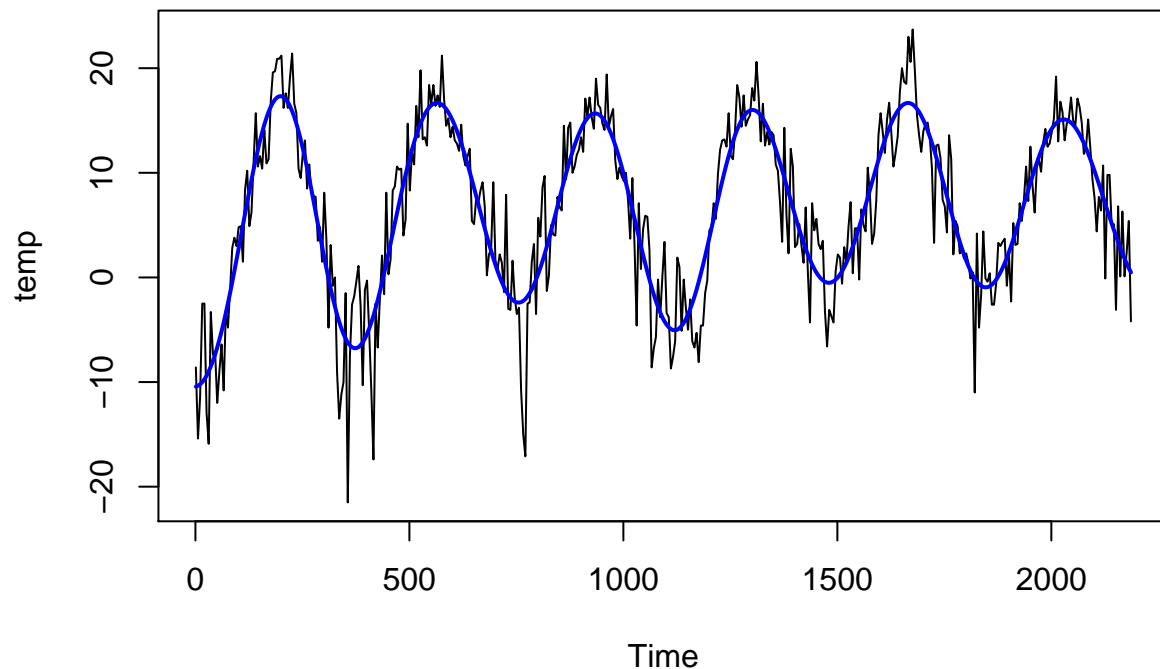
```

```
GPfit <- gausspr(temp ~ time, data = SmallData ,
  kernel = GaussianKernel3,
  kpar = list(sigma = sigma_f, ell = 1), var = sigma_2_n)

myrange<-range(SmallData$time)
Xgrid<- myrange[1]:myrange[2]
meanPred<-predict(GPfit, SmallData)
length(meanPred)
```

```
## [1] 438
```

```
plot(x = SmallData$time, SmallData$temp, type = "l",
  xlab = "Time", ylab = "temp")
lines(SmallData$time, meanPred, col="blue", lwd = 2)
```



```
##c
```

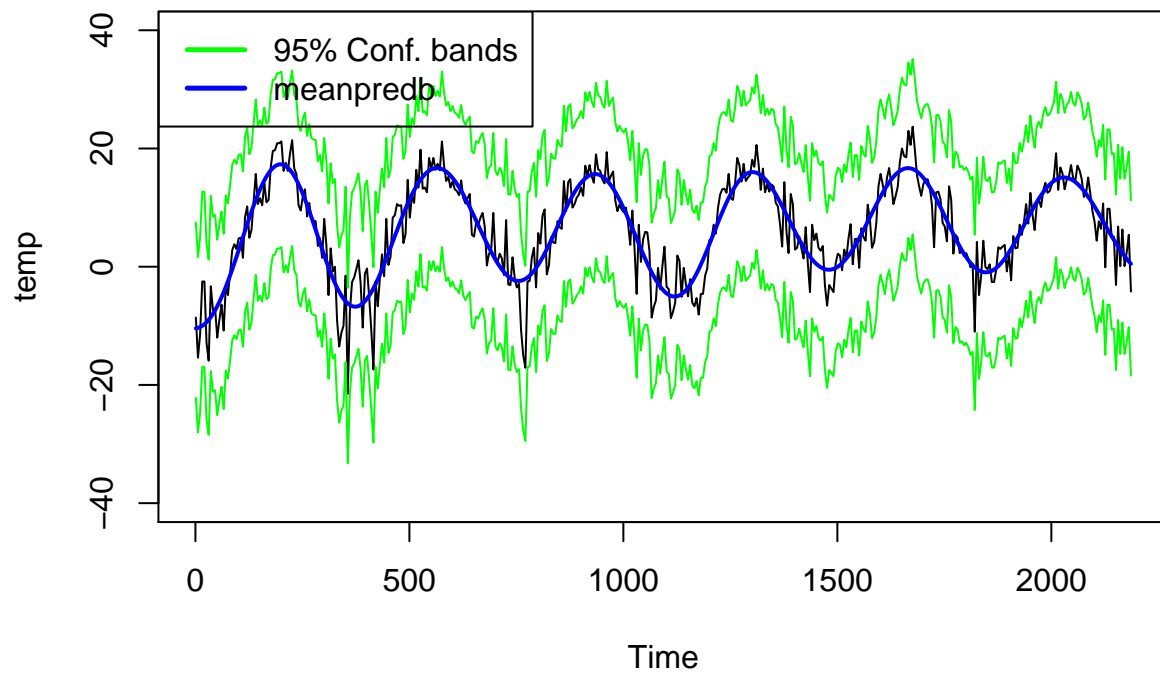
```
fSim <- SimGP(y=SmallData$temp, xStar = SmallData$time, x= SmallData$time,
  K=GaussianKernel3, nSim = nSim,
  sigma_f =sigma_f, l=1,
  sigmaNoise = sqrt(sigma_2_n ))
```

```
tablefsim<-cbind(mean = fSim$mean, low= fSim$mean-1.96*sqrt(fSim$covfStar),high= fSim$mean+1.96*sqrt(fS
plot(x = SmallData$time, SmallData$temp, type = "l",
  xlab = "Time", ylab = "temp", ylim= c(-40,40))
lines(SmallData$time, meanPred, col="blue", lwd = 2)
```

```

lines(x= SmallData$time, y =tablefsim[,2], col ="green")
lines(x= SmallData$time, y = tablefsim[,3], col = "green")
legend("topleft", # places a legend at the appropriate place
      c( "95% Conf. bands", "meanpredb"), # puts text in the legend
      lty=c(1,1), # gives the legend appropriate symbols (lines)
      lwd=c(2.5,2.5),col=c("Green", "blue")) # gives the legend lines the correct color and width

```



```

####d

mylm<-lm(temp~day+ I(day^2), SmallData)
sigma_2_n<-var(mylm$residuals)
sigma_f<-20
l <- 1.2

GaussianKernel4<-GaussKernel(sigmaF = sigma_f, ell = 1)

GPfit <- gausspr(temp ~ day, data = SmallData ,
                 kernel = GaussianKernel4,
                 kpar = list(sigma = sigma_f, ell = 1), var = sigma_2_n)

meanPred2<-predict(GPfit, SmallData)

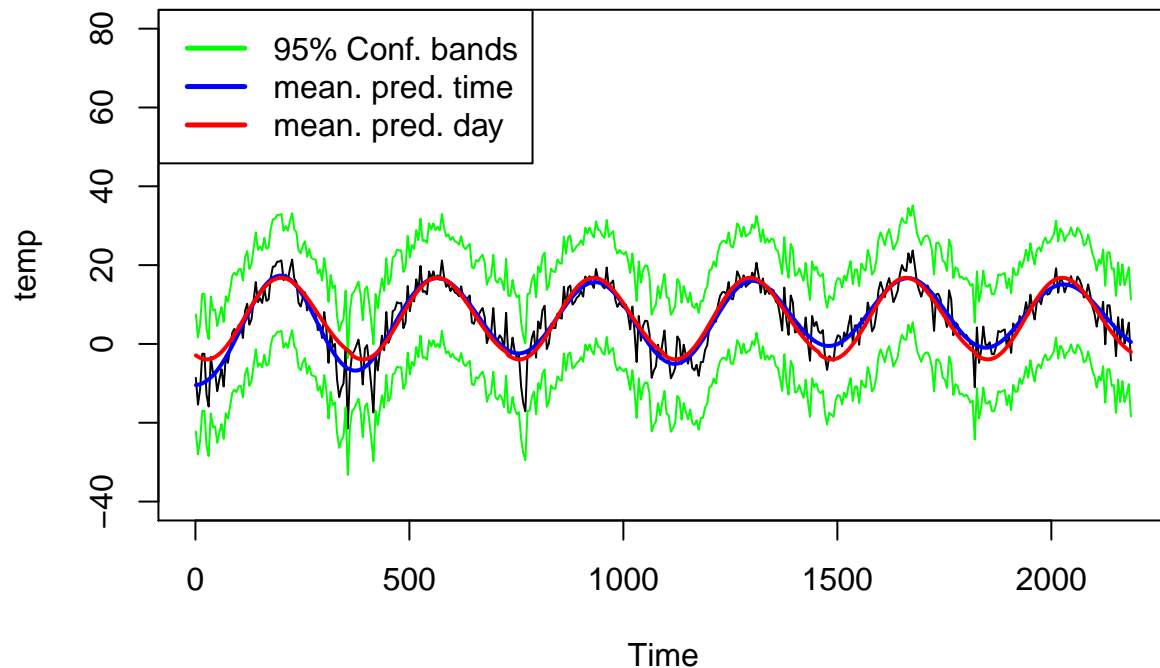
```

```

plot(x = SmallData$time, SmallData$temp, type = "l",
     xlab = "Time", ylab = "temp", ylim= c(-40,80))
lines(SmallData$time, meanPred, col="blue", lwd = 2)
lines(x= SmallData$time, y =tablefsim[,2], col = "green")
lines(x= SmallData$time, y = tablefsim[,3], col = "green")
lines(SmallData$time, meanPred2, col="red", lwd = 2)

legend("topleft", # places a legend at the appropriate place
      c( "95% Conf. bands", "mean. pred. time", "mean. pred. day"), # puts text in the legend
      lty=c(1,1), # gives the legend appropriate symbols (lines)
      lwd=c(2.5,2.5),col=c("Green", "blue", "red")) # gives the legend lines the correct color and wid

```



```

##e

periodicKernel<- function(sigmaF, ell1, ell2, di){
  rval<-function(x1,x2, sigma_f =sigmaF, l_1=ell1, l_2=ell2, d=di){

    K<-  sigma_f^2*exp((-2*sin(pi*abs(x1-x2)/d)**2)/l_1^2)*exp((-1/2*abs(x1-x2)**2)/l_2^2)

  }
  class(rval) <- "kernel"
  return(rval)
}
sigma_f<-20
l_1<- 1
l_2<-10

```

```

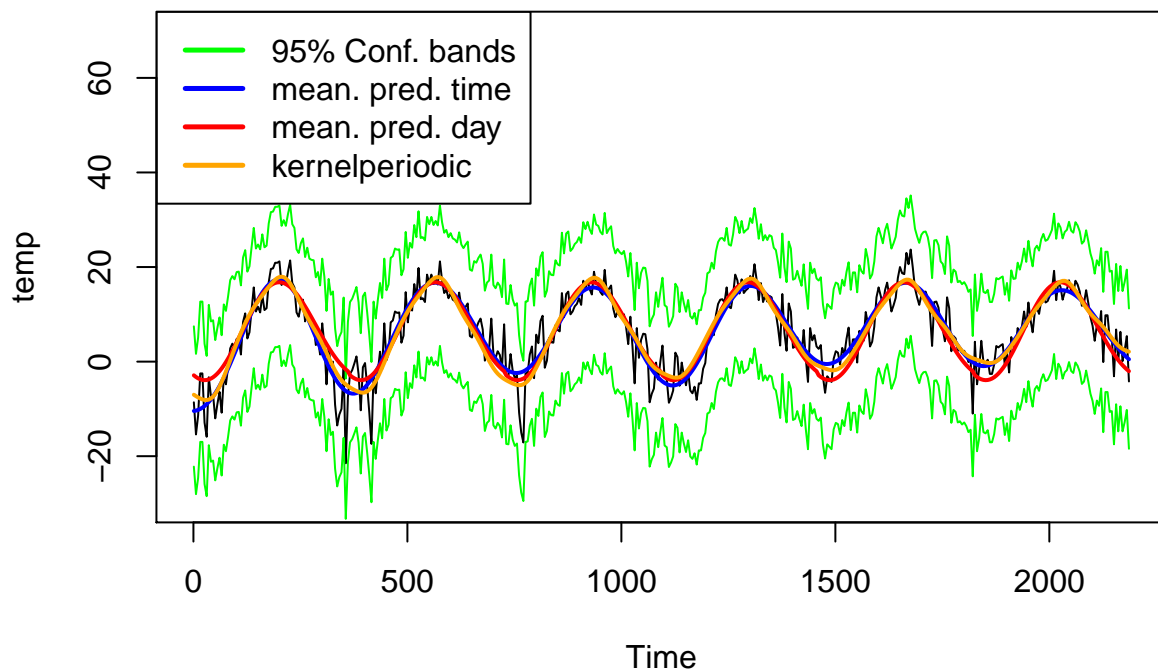
d <- 365/sd(SmallData$time)
periodicKernel5<-periodicKernel(sigmaF=sigma_f, ell1=l_1, ell2=l_2, di=d)

GPfit <- gausspr(temp ~ time, data = SmallData ,
                 kernel = periodicKernel5,
                 kpar = list(sigma = sigma_f, ell = 1), var = sigma_2_n)

meanPred3<-predict(GPfit, SmallData)

plot(x = SmallData$time, SmallData$temp, type = "l",
     xlab = "Time", ylab = "temp", ylim= c(-30,70))
lines(SmallData$time, meanPred, col="blue", lwd = 2)
lines(x= SmallData$time, y =tablefsim[,2], col="green")
lines(x= SmallData$time, y = tablefsim[,3], col = "green")
lines(SmallData$time, meanPred2, col="red", lwd = 2)
lines(SmallData$time, meanPred3, col="orange", lwd = 2)
legend("topleft", # places a legend at the appropriate place
      c( "95% Conf. bands", "mean. pred. time", "mean. pred. day", "kernelperiodic"), # puts text in t
      lty=c(1,1), # gives the legend appropriate symbols (lines)
      lwd=c(2.5,2.5),col=c("Green", "blue", "red", "orange")) # gives the legend lines the correct col

```



```
##3
```

```

data <- read.csv("https://github.com/STIMALiU/AdvMLCourse/raw/master/GaussianProcess/Code/banknoteFraud
names(data) <- c("varWave", "skewWave", "kurtWave", "entropyWave", "fraud")

```

```

data[,5] <- as.factor(data[,5])
set.seed(111)
SelectTraining <- sample(1:dim(data)[1], size = 1000, replace = FALSE)
model<-gausspr(fraud~varWave+skewWave, data = data[SelectTraining,])

## Using automatic sigma estimation (sigest) for RBF or laplace kernel
##Part III
data<- data
predictionfunction<- function(data, rows){
  prediction<-predict(model,data[rows,])
  confusionMat<-table(pred=prediction, true = data[rows,5]) # confusion matrix
  Accuracy<-sum(diag(confusionMat))/sum(confusionMat)
  print(confusionMat)
  print(as.numeric(Accuracy))
}

predictionfunction(data = data, rows = SelectTraining)

##      true
## pred   0   1
##      0 512  24
##      1  44 420
## [1] 0.932

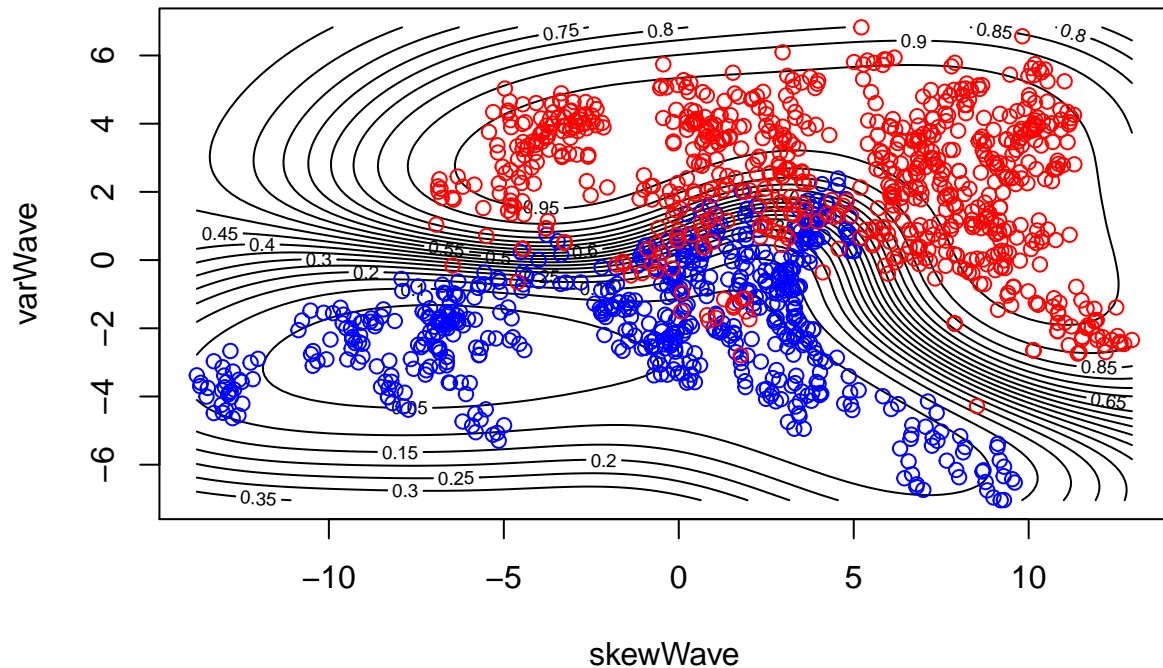
##contour
library(AtmRay)

## Warning: package 'AtmRay' was built under R version 3.3.3
x1 <- seq(min(data[, "varWave"]),max(data[, "varWave"]),length=100)
x2 <- seq(min(data[, "skewWave"]),max(data[, "skewWave"]),length=100)
gridPoints <- meshgrid(x1, x2)
gridPoints <- cbind(c(gridPoints$x), c(gridPoints$y))

gridPoints <- data.frame(gridPoints)
names(gridPoints) <- c("varWave", "skewWave")
#####
probPreds <- predict(model, gridPoints, type="probabilities")
# Plotting for Prob(setosa)
contour(x2,x1,matrix(probPreds[,1],100), 20, xlab = "skewWave", ylab = "varWave", main = "Prob(varWave,
points(data[data[,5]==1,"skewWave"],data[data[,5]==1,"varWave"],col="blue")
points(data[data[,5]==0,"skewWave"],data[data[,5]==0,"varWave"],col="red")

```

Prob(varWave, Skewwave) is not fraud(red), fraud(blue)



```
###b
```

```
test<-setdiff( 1:dim(data)[1], SelectTraining)
probPreds<-predictionfunction(data = data, rows = test)
```

```
##      true
## pred  0   1
##    0 191   9
##    1  15 157
## [1] 0.9354839
```

```
#c
```

```
model<-gausspr(fraud~., data = data[SelectTraining,])
```

```
## Using automatic sigma estimation (sigest) for RBF or laplace kernel
```

```
#train
```

```
predictionfunction(data = data, rows = SelectTraining)
```

```
##      true
## pred  0   1
##    0 552   0
##    1   4 444
## [1] 0.996
```

```
#test
```

```
predictionfunction(data = data, rows = test)
```



```
##      true
## pred  0   1
##      0 205   0
##      1   1 166
## [1] 0.9973118
```

Lab4

```
#####
#####1
set.seed(12345)
#####Generating model
#initial model
p1<-runif(1,0,100)

# Transition

sd_T<-1
sd_E<-50

Transition<- function(n,p0, sd_2){
  z<- integer(n)
  z[1]<-p0
  for(i in 2:n){
    p<- sample(c(z[i-1]+2,z[i-1],z[i-1]+1),1)
    z[i]<-rnorm(1,p,sqrt(sd_2))
  }
  return(z)
}
myZ<-Transition(100, p0= p1, sd_2= sd_T**2)
##Emission model

Emission<- function(vectorz, sd_2){
  n<- length(vectorz)
  x<- integer(n)
  for(i in 1:n){
    p<- sample(c(vectorz[i]-1,vectorz[i],vectorz[i]+1),1)
    x[i]<-rnorm(1,p,sqrt(sd_2))
  }
  return(x)
}
x_t<- Emission(myZ, sd_2 = sd_E**2)

#####
weights<- rep(0.01,100)
X<-runif(100,0,100)
calculatprob<- function(simulations, init_weights, grid, sd_E, sd_T, x_t= x_t){
  n<- length(grid)
  parameters<- matrix( ncol = n,nrow = simulations)
  newweights<- matrix(ncol = n,nrow = simulations)

  newweights[1,]<-init_weights/sum(init_weights)
```

```

parameters[1,]<-sample(x =grid,size = n, replace=TRUE, prob = newweighth[1,])
### sample(dnorm(parameters[1,],grid) Left that
xt<- integer(100)
for(i in 2:simulations){

  for(j in 1:simulations){
    xt[j]<-Transition(2,parameters[i-1,j],sd_T)[2]
  }
  newweighth[i,]<-dnorm(x_t[i-1], xt, sqrt(sd_E))/sum(dnorm(x_t[i-1], xt,sqrt(sd_E)))
  parameters[i,]<-sample(xt, size =n, replace=TRUE, prob = newweighth[i,])

}
result<- list(parameters = parameters, weights=newweighth)
return(result)
}
sd_2T<-1
sd_2E<-1

trial<-calculationprob(simulations =100, init_weights = weights, grid= X,
                        sd_T = sd_T, sd_E = sd_E,x_t= x_t)
parameter_est<-trial$parameters
parameter_est

```

##		[,1]	[,2]	[,3]	[,4]	[,5]	[,6]
##	[1,]	32.982907	1.440976	92.277439	7.980915	50.615597	98.471387
##	[2,]	1.816412	1.549527	1.549527	2.443120	1.816412	1.816412
##	[3,]	11.787982	11.787982	11.787982	11.787982	11.787982	11.787982
##	[4,]	15.952391	15.952391	16.336434	15.227336	14.438412	15.952391
##	[5,]	17.118250	20.409466	19.233179	20.409466	19.599645	19.232895
##	[6,]	21.584083	21.828535	22.344629	23.259423	24.027784	20.445090
##	[7,]	24.463288	25.819961	23.416190	23.843451	24.165383	27.430718
##	[8,]	29.575487	28.721945	27.700789	30.805639	27.755357	28.002756
##	[9,]	32.661883	33.161700	30.999578	30.366266	32.971866	33.297542
##	[10,]	35.423282	36.210795	31.498000	33.910229	37.356663	33.910229
##	[11,]	39.253764	33.845322	38.011704	40.420160	36.007824	41.782526
##	[12,]	40.695834	41.217928	40.735086	36.473441	36.881589	38.826780
##	[13,]	44.103691	44.441574	43.429181	44.189971	44.189971	44.821268
##	[14,]	43.696016	42.504049	43.100383	42.396364	44.104831	42.137329
##	[15,]	47.272931	42.836247	44.862925	47.179485	46.769675	45.239815
##	[16,]	48.338930	47.618157	48.475706	48.096101	49.459915	48.146835
##	[17,]	54.303371	52.430107	47.600782	51.229319	49.892177	48.607875
##	[18,]	56.861521	56.944712	56.944712	56.861521	56.944712	56.861521
##	[19,]	57.582874	61.710484	61.310798	61.710484	61.310798	58.537452
##	[20,]	63.603754	64.385631	62.641059	64.982317	63.981180	64.076548
##	[21,]	65.294289	64.389182	67.555519	65.098378	62.875809	62.932463
##	[22,]	68.285267	70.063239	67.812266	69.558319	69.804422	69.985727
##	[23,]	71.271918	72.538398	71.946222	73.622092	69.609270	71.557067
##	[24,]	78.958021	75.008497	78.958021	78.958021	76.159287	78.958021
##	[25,]	78.716232	80.937980	82.569873	81.322147	80.604741	76.740595
##	[26,]	80.395136	85.709330	83.792575	84.939449	83.740131	85.709330
##	[27,]	86.261565	88.048146	87.191076	86.299401	85.556568	86.055523
##	[28,]	90.473130	89.107406	89.532008	90.587386	90.628026	89.954031
##	[29,]	94.020790	90.400019	93.051317	91.158811	93.083534	92.290152
##	[30,]	97.841061	94.101442	97.742396	93.888559	96.173127	94.529866

##	[31,]	96.458748	97.609566	96.458748	95.247694	93.791036	96.327344
##	[32,]	93.689034	93.749370	93.588125	94.560488	93.749370	94.986108
##	[33,]	96.341044	96.144484	98.901118	94.702873	95.018556	96.867271
##	[34,]	95.731035	97.928883	98.208762	96.716581	96.884918	96.801298
##	[35,]	97.869922	97.910683	97.910683	97.468414	97.869922	95.111824
##	[36,]	99.004962	95.484009	96.870554	99.145480	96.195102	102.294980
##	[37,]	101.820305	101.119671	96.427840	103.431608	97.990700	102.163518
##	[38,]	98.157507	98.157507	100.942319	99.063006	96.986158	98.157507
##	[39,]	103.667129	103.202700	102.149659	97.525991	105.163085	100.571516
##	[40,]	95.377631	96.603397	95.511754	95.511754	95.377631	96.133194
##	[41,]	98.568481	96.315011	98.179062	98.568481	95.176517	96.649738
##	[42,]	96.071050	93.535698	98.055360	96.193426	93.535698	97.086118
##	[43,]	93.260462	93.721606	94.775253	93.896404	93.896404	92.221338
##	[44,]	101.514963	101.514963	101.514963	101.514963	100.855991	100.855991
##	[45,]	102.429958	99.658748	100.139641	100.606013	101.874376	103.908178
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##	[47,]	96.862140	97.473947	97.473947	96.862140	95.586172	95.586172
##	[48,]	101.557375	101.910141	101.862891	102.218469	102.218469	101.910141
##	[49,]	102.901179	105.776528	103.192428	103.622377	105.647349	105.017256
##	[50,]	107.513697	108.135378	107.282376	105.018595	107.308450	108.180475
##	[51,]	110.661784	109.011090	110.224373	108.662850	107.481789	110.224373
##	[52,]	114.937628	114.937628	114.937628	114.937628	114.152864	113.754175
##	[53,]	114.690641	115.571483	115.524693	114.981307	116.453821	114.745025
##	[54,]	117.036774	117.417252	118.709113	118.709113	118.469316	117.810582
##	[55,]	116.823291	121.606969	122.020186	117.962650	117.203642	120.487286
##	[56,]	125.336382	124.578294	124.508245	123.529692	125.336382	124.199218
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##	[67,]	140.671606	138.275700	138.802424	138.325438	135.161880	137.378222
##	[68,]	139.097766	142.149225	144.268002	144.965491	144.037403	144.965491
##	[69,]	145.332665	140.793423	138.760737	143.926202	141.232630	140.793423
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##	[71,]	145.285632	145.285632	145.041348	145.041348	145.285632	145.393813
##	[72,]	146.986757	150.045510	147.464726	147.699653	149.089085	151.066414
##	[73,]	148.004396	144.023396	148.390146	148.239330	152.521409	150.667845
##	[74,]	149.149273	150.798617	150.358053	151.041317	149.149273	148.719346
##	[75,]	145.868869	145.868869	150.020770	146.818119	146.818119	145.868869
##	[76,]	147.163611	145.624418	147.030767	146.667521	145.214194	145.487440
##	[77,]	147.312349	147.830821	146.699011	145.228565	148.445309	146.066305
##	[78,]	149.428178	149.639217	147.696894	147.723099	152.654013	150.984666
##	[79,]	152.146022	155.656064	151.046746	148.247517	148.337080	149.274243
##	[80,]	151.720228	155.156558	153.035022	153.745738	154.806620	154.806620
##	[81,]	152.845385	147.832358	150.016067	150.588838	147.832358	147.832358
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##	[83,]	148.367368	148.833540	148.286063	148.346780	151.806086	149.419927
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##      [,7]      [,8]      [,9]      [,10]     [,11]     [,12]
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## [2,]   1.816412   1.816412   2.44312   2.44312   2.44312   1.549527
## [3,]  11.787982  11.787982  11.78798  11.78798  11.78798  10.092643
## [4,]  16.336434  15.227336  16.33643  16.33643  15.95239  16.336434
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##	[38,]	98.157507	96.218728	98.54093	96.21873	98.54093	96.878876
##	[39,]	99.235002	105.163085	103.09250	98.79760	100.30230	100.984449
##	[40,]	95.511754	95.818814	96.73199	96.60340	95.37763	96.133194
##	[41,]	95.922895	97.616601	97.79320	98.44968	97.94773	99.814401
##	[42,]	93.535698	96.796838	96.79684	96.96943	95.63642	96.969427
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##	[44,]	97.212684	101.514963	101.51496	98.85968	98.49326	100.855991
##	[45,]	97.927670	97.927670	100.59771	99.65875	102.08147	101.446525
##	[46,]	97.735091	99.918957	98.77920	100.73394	98.46155	97.735091
##	[47,]	97.071828	95.586172	97.66089	95.58617	95.58617	95.586172
##	[48,]	101.557375	99.581643	100.77968	101.55737	100.03530	100.894871
##	[49,]	105.522809	105.647349	104.90015	105.77653	102.29253	102.260320
##	[50,]	108.041640	107.513902	107.60600	107.50029	106.33699	104.767782
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##	[61,]	129.619269	135.442042	135.30220	134.45273	133.90374	137.268578
##	[62,]	127.624753	127.624753	127.62475	127.62475	127.62475	127.624753
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## [24,] 78.958021  76.986738  76.986738  71.746806  78.95802  77.20162
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##	[25,]	82.569873	82.569873	82.569873	81.139477	81.139477	79.375783
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##	[32,]	93.640210	93.749370	93.689034	93.588125	93.640210	93.588125
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##	[63,]	126.703852	127.744483	127.768830	128.092104	127.992253	129.659055
##	[64,]	132.365975	131.199746	129.665702	132.467122	132.283873	128.983435
##	[65,]	131.883913	129.686855	129.098208	133.717125	138.418307	131.116226
##	[66,]	139.323788	135.864590	138.147880	136.899684	139.283413	139.283413
##	[67,]	142.247541	141.028990	140.356819	140.926634	140.169270	137.653200
##	[68,]	144.207140	144.798225	140.685130	144.965491	142.912338	144.798225
##	[69,]	139.310903	142.071274	138.760737	145.904838	142.598798	140.793423
##	[70,]	148.926564	148.926564	148.926564	148.926564	148.926564	148.744380
##	[71,]	144.667710	145.393813	144.667710	145.041348	144.667710	145.041348
##	[72,]	147.869405	150.013439	147.699653	147.780517	147.415860	146.050277
##	[73,]	147.300128	144.023396	148.621311	149.648364	146.836336	148.084545
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##	[79,]	153.305116	149.051266	150.126948	149.986641	149.032738	152.489101
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##	[81,]	147.832358	150.016067	147.832358	147.832358	150.588838	150.861804
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##	[83,]	146.580413	148.221510	149.570368	147.648173	147.199232	146.522190
##	[84,]	153.630088	150.619680	152.146060	152.231133	153.638362	147.680173
##	[85,]	150.136563	155.895817	155.619739	150.933633	146.935564	152.948667
##	[86,]	157.934057	153.135482	154.740494	153.935887	151.353237	156.321037

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##      [,55]      [,56]      [,57]      [,58]      [,59]      [,60]
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## [3,]  11.78798  10.092643  11.787982  11.787982  11.787982  11.787982
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## [5,]  18.37796  16.989917  19.104758  19.485639  16.031866  20.409466
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## [28,] 90.62803  90.473130  90.587386  90.040075  90.628026  90.628026
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## [31,] 97.89944  97.609566  99.944519  97.364692  98.500440 100.061538
## [32,] 93.58812  93.640210  94.986108  93.640210  93.749370  93.749370
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##	[40,]	95.37763	95.377631	95.511754	95.511754	98.901805	95.818814
##	[41,]	98.76121	96.529948	97.141187	97.251195	98.717703	96.953479
##	[42,]	94.39271	94.252962	93.535698	93.535698	94.252962	94.392706
##	[43,]	94.83675	93.439045	92.221338	92.385551	98.724627	94.566511
##	[44,]	101.51496	100.585997	100.585997	100.497542	101.514963	100.855991
##	[45,]	101.97397	104.335657	103.264809	102.168214	102.136836	100.130339
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##	[51,]	107.46027	107.640570	109.911669	108.069949	106.150717	109.911669
##	[52,]	114.93763	114.937628	114.937628	114.152864	114.937628	114.937628
##	[53,]	115.93197	114.996686	118.506379	113.448945	116.458803	115.433010
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##	[61,]	135.44204	135.302200	132.980348	135.258038	135.258038	130.976401
##	[62,]	127.62475	127.624753	130.290840	127.624753	127.624753	127.624753
##	[63,]	127.07664	129.445460	128.175966	128.812991	127.691894	128.080415
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##	[80,]	155.37125	154.378813	151.944581	153.451934	158.189174	149.773604
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##	[82,]	148.44848	148.541796	153.143922	149.177065	147.517044	150.790597
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##	[17,]	52.430107	50.525804	54.30337	50.80801	50.902410	50.808011
##	[18,]	56.861521	56.861521	56.94471	56.86152	56.066552	56.944712
##	[19,]	59.649253	61.710484	57.23005	56.65042	58.912904	56.592908
##	[20,]	63.815450	63.815450	63.60375	63.68677	59.351527	59.911099
##	[21,]	66.191368	66.972966	65.21782	66.85646	64.576528	66.457877
##	[22,]	69.097369	70.599845	70.06324	69.80442	69.970524	69.985727
##	[23,]	71.910989	72.646636	71.51884	68.93567	71.268889	68.677501
##	[24,]	78.958021	78.958021	78.95802	76.79924	78.958021	76.986738
##	[25,]	82.569873	82.569873	82.56987	79.60359	78.897694	80.937980
##	[26,]	84.939449	85.788712	82.56841	83.75759	84.802640	82.885266
##	[27,]	83.768410	81.812129	88.18933	84.99942	86.320852	86.148449
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##      [,79]      [,80]      [,81]      [,82]      [,83]      [,84]
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## [2,]  2.44312  1.549527  1.549527  2.44312  1.549527  2.44312
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##	[15,]	43.63232	47.702575	45.954513	45.25922	48.178704	48.17870
##	[16,]	48.07981	48.655565	48.552294	49.03296	48.964572	47.77704
##	[17,]	50.25045	51.760941	50.337392	50.41786	54.303371	49.83878
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##	[19,]	59.64925	60.570397	61.710484	61.71048	58.571274	59.67431
##	[20,]	64.84348	64.843483	62.718984	62.08908	64.843483	64.84348
##	[21,]	67.25949	64.571814	68.090923	66.55927	66.972966	62.87581
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##	[80,]	158.18917	150.738114	153.451934	156.09758	152.220795	155.37125
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##		[,85]	[,86]	[,87]	[,88]	[,89]	[,90]
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##	[13,]	44.821268	44.189971	44.10369	44.85374	44.189971	44.821268
##	[14,]	44.356776	43.335840	40.79433	40.79433	44.983471	42.160387
##	[15,]	44.497245	46.659558	46.84928	46.36390	46.086728	46.141897
##	[16,]	49.610004	47.391670	47.07126	47.71444	50.283734	49.138838
##	[17,]	52.285966	51.336069	54.30337	50.80801	50.738298	51.287100
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##	[19,]	58.099599	61.310798	57.49272	61.71048	59.625296	61.310798
##	[20,]	64.076548	62.537435	62.42482	59.04651	63.243855	64.076548

##	[21,]	66.457877	63.409490	66.45788	66.90254	65.090457	64.131610
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##	[25,]	80.061572	80.937980	80.06157	81.13948	80.335587	82.569873
##	[26,]	83.940593	85.709330	84.80264	85.70933	85.788712	85.709330
##	[27,]	86.956201	85.535734	84.70967	87.92485	85.398593	85.556568
##	[28,]	90.587386	90.587386	90.58739	89.54335	89.394810	90.033781
##	[29,]	93.463226	92.317114	93.58396	90.69687	92.317114	93.583957
##	[30,]	96.173127	95.356182	94.10144	95.43910	92.524131	94.808812
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##	[32,]	93.588125	94.738615	93.58812	93.64021	93.749370	93.640210
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##	[34,]	96.800573	98.240524	96.01006	93.89029	93.816097	94.494133
##	[35,]	97.460064	100.486042	97.46841	96.44228	97.024248	96.531072
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##	[37,]	101.820305	99.615407	100.90105	98.39819	101.212654	101.827957
##	[38,]	99.063006	99.876232	101.06430	98.15751	97.751315	99.063006
##	[39,]	102.149659	99.012827	100.42480	100.57152	105.163085	103.202700
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##	[41,]	96.953780	98.057916	98.05792	95.58902	98.717703	98.761207
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##	[43,]	93.956555	93.871019	92.22134	92.38555	93.439045	93.896404
##	[44,]	100.585997	100.497542	101.51496	100.58600	101.514963	101.514963
##	[45,]	101.051742	101.401785	100.46814	100.79618	101.642618	102.473470
##	[46,]	98.860603	97.735091	100.14303	98.86060	97.735091	97.735091
##	[47,]	98.567569	98.664232	95.58617	98.28308	95.586172	95.586172
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##	[52,]	113.936126	114.937628	114.93763	114.93763	114.937628	114.937628
##	[53,]	116.818740	116.402461	115.47414	113.73511	116.402461	114.808857
##	[54,]	116.496411	117.149209	115.95574	117.72992	116.346598	119.144650
##	[55,]	118.844576	118.493770	122.79319	122.28848	119.861874	120.331663
##	[56,]	123.804750	125.282037	121.79889	125.33638	124.732063	125.282037
##	[57,]	125.468755	128.074493	127.45419	125.66074	125.894233	127.774382
##	[58,]	129.017011	124.256294	129.64469	130.10615	129.644693	126.948036
##	[59,]	130.030420	125.595052	124.81577	128.81903	127.650979	126.317167
##	[60,]	132.615626	130.961733	132.87331	129.23747	128.092887	129.749807
##	[61,]	133.002800	133.050659	137.26858	133.95277	135.442042	135.221781
##	[62,]	127.624753	127.624753	127.62475	130.65474	127.624753	130.214221
##	[63,]	127.224134	129.206108	127.48055	126.71557	130.511147	128.085885
##	[64,]	131.818095	131.514847	129.17728	132.46712	132.365975	128.681502
##	[65,]	131.498003	130.755595	133.74487	131.88391	131.438361	132.615164
##	[66,]	139.323788	139.323788	139.32379	139.28341	135.864590	139.323788
##	[67,]	140.926634	140.659218	137.37822	138.85999	140.671606	140.062971
##	[68,]	144.207140	144.037403	142.20357	143.89808	144.037403	138.753020
##	[69,]	138.760737	141.866893	141.86689	141.23263	141.148772	138.760737
##	[70,]	148.926564	148.926564	148.74438	148.92656	145.832629	148.926564
##	[71,]	147.181219	145.432211	144.66771	148.53469	145.041348	144.667710
##	[72,]	151.066414	151.066414	145.66855	147.78052	145.483025	145.668554
##	[73,]	148.588491	150.445037	147.77791	148.66670	148.363661	144.023396
##	[74,]	151.041317	149.510598	150.82249	150.37662	151.041317	152.946618

##	[75,]	146.818119	148.242306	145.86887	147.34479	146.818119	148.153977
##	[76,]	145.225751	144.707884	146.87545	145.63680	147.920334	147.163611
##	[77,]	146.854639	145.032979	145.85449	143.81721	146.944258	147.830821
##	[78,]	147.066958	150.166887	149.36993	149.03971	146.350734	149.495831
##	[79,]	148.868625	148.819554	148.81955	151.28062	154.986185	148.650980
##	[80,]	150.995205	151.607666	152.89589	155.82036	154.878221	153.832822
##	[81,]	147.832358	151.414733	147.83236	147.83236	147.832358	147.832358
##	[82,]	146.150240	151.866754	149.74649	152.84305	154.412353	151.990335
##	[83,]	148.882573	146.580413	150.16342	148.83354	145.817380	148.221510
##	[84,]	150.864335	153.351302	151.46029	150.72034	150.269223	151.702492
##	[85,]	152.166695	151.648738	151.76913	153.37750	154.225732	153.441692
##	[86,]	152.428647	153.935887	153.13548	154.88342	157.270021	151.349002
##	[87,]	157.995220	156.394733	154.26589	153.20793	157.538241	153.282255
##	[88,]	147.198329	152.749395	152.28175	147.19833	147.198329	151.144421
##	[89,]	146.124351	146.223397	146.30413	145.89292	146.223397	146.480800
##	[90,]	151.805131	149.179767	149.77539	148.74649	151.805131	151.619145
##	[91,]	155.140667	153.774622	155.14067	155.14067	155.140667	153.639053
##	[92,]	155.214247	154.423763	152.21123	156.43150	154.477630	155.178106
##	[93,]	158.578455	159.174161	157.24339	157.65882	159.361826	159.174161
##	[94,]	160.326613	158.023872	158.02387	158.29993	161.281685	161.281685
##	[95,]	163.344277	164.158706	164.76684	164.28197	164.766840	161.750725
##	[96,]	167.938460	167.504039	168.62190	168.62190	166.088208	168.621901
##	[97,]	169.642836	169.076587	168.37077	169.96324	168.470971	165.704895
##	[98,]	172.829197	174.224274	173.35393	172.68280	172.367777	174.224274
##	[99,]	175.241454	176.185250	175.24145	174.41835	177.383342	175.637768
##	[100,]	178.687146	180.667670	177.81323	178.25715	177.043196	177.759048
##		[,91]	[,92]	[,93]	[,94]	[,95]	[,96]
##	[1,]	14.50309	42.029006	14.503087	22.69474	6.435620	69.92631
##	[2,]	2.44312	1.816412	4.977181	2.44312	1.816412	2.44312
##	[3,]	11.78798	11.787982	11.787982	11.78798	11.787982	11.78798
##	[4,]	16.33643	15.227336	15.952391	13.97374	13.414322	15.95239
##	[5,]	18.86059	19.485639	18.888649	20.40947	20.409466	20.38605
##	[6,]	23.25942	21.527277	22.581213	22.64684	22.993515	23.25942
##	[7,]	24.16538	26.881844	24.555488	23.64496	26.987147	26.98715
##	[8,]	30.80564	30.805639	29.575487	30.80564	27.690655	29.03989
##	[9,]	31.11553	33.297542	29.473429	34.60134	33.520644	33.80253
##	[10,]	37.76992	37.769921	33.687888	33.93049	37.356663	36.13850
##	[11,]	38.00410	39.360768	38.323076	37.44336	37.110912	39.36077
##	[12,]	38.78200	36.785772	41.574197	38.58963	40.735086	38.93413
##	[13,]	44.10369	44.441574	44.103691	44.82127	43.294479	42.40079
##	[14,]	42.17159	40.794332	42.171586	44.25477	42.504049	44.12636
##	[15,]	44.78121	42.060610	48.178704	44.51585	44.222392	47.27293
##	[16,]	49.95688	50.283734	49.516351	47.06845	49.373425	47.30972
##	[17,]	54.30337	54.303371	50.293724	51.64186	50.902410	51.11730
##	[18,]	56.16964	56.030039	56.861521	56.86152	56.861521	56.94471
##	[19,]	59.19708	57.568305	60.049267	61.71048	57.582874	58.48012
##	[20,]	64.84348	64.843483	62.718984	63.93741	64.385631	63.98118
##	[21,]	68.09092	66.972966	66.670901	68.09092	66.902541	64.57181
##	[22,]	68.82483	69.292059	65.918005	69.55832	69.985727	67.17503
##	[23,]	71.94622	70.890207	68.947515	73.62209	71.518839	68.67750
##	[24,]	77.20162	78.958021	76.986738	74.66316	75.973393	78.95802
##	[25,]	80.37219	80.937980	82.569873	79.61089	79.089479	79.44355
##	[26,]	84.15129	85.788712	85.709330	85.78871	84.802640	83.35600
##	[27,]	88.41876	86.055523	86.737443	85.20407	86.653743	86.72408

##	[28,]	89.05053	90.628026	90.040075	89.87737	89.107406	90.62803
##	[29,]	92.53848	94.020790	91.747223	92.82367	91.016489	91.18705
##	[30,]	93.44507	90.789369	94.758002	94.77265	97.841061	94.92594
##	[31,]	97.49194	97.049966	99.368900	97.63054	99.944519	100.21707
##	[32,]	93.64021	93.689034	93.689034	93.58812	93.588125	93.74937
##	[33,]	96.38650	96.110747	97.043487	96.82034	96.431891	95.67682
##	[34,]	95.57279	93.816097	93.890293	94.49413	98.781873	95.53354
##	[35,]	96.52953	97.976405	96.776213	98.12617	96.949212	94.98065
##	[36,]	96.40190	96.668687	95.484009	99.93763	99.241848	100.15347
##	[37,]	102.54445	98.997700	99.215369	99.61541	99.615407	101.00983
##	[38,]	100.68579	100.737736	99.063006	99.10647	98.540934	100.69404
##	[39,]	102.80134	102.719836	100.746824	103.26724	100.984449	100.47339
##	[40,]	95.37763	96.133194	95.818814	95.37763	95.377631	95.51175
##	[41,]	95.78508	98.730213	98.761207	97.94773	96.354389	96.32538
##	[42,]	98.66620	94.392706	93.535698	96.07105	95.999261	96.30639
##	[43,]	93.85997	94.836747	93.123814	95.02421	98.661468	93.87256
##	[44,]	101.51496	100.855991	100.677515	100.67751	100.677515	100.85599
##	[45,]	104.06326	101.712035	102.886640	103.90818	101.895983	101.45951
##	[46,]	102.45311	97.735091	99.018559	98.06688	98.580619	99.01856
##	[47,]	96.86214	96.862140	98.675029	96.75637	97.071828	95.58617
##	[48,]	99.58164	101.862891	100.035303	101.24831	101.910141	101.86289
##	[49,]	104.50172	103.608171	103.029151	105.64735	102.779579	105.52281
##	[50,]	105.40363	107.605998	107.886388	105.33161	106.615042	106.59187
##	[51,]	109.91167	110.606360	111.374609	108.13823	102.620536	107.99488
##	[52,]	114.93763	114.937628	113.936126	114.93763	114.937628	114.93763
##	[53,]	116.87129	114.407316	117.614164	116.72575	115.438132	116.06676
##	[54,]	117.36745	117.729916	120.862578	119.30872	118.431000	117.87140
##	[55,]	118.63872	121.664710	120.493541	120.67936	121.623599	121.05030
##	[56,]	125.33638	124.199218	123.590599	124.73206	125.336382	125.28204
##	[57,]	124.75671	127.169425	127.223868	127.24649	126.108205	125.54759
##	[58,]	126.77048	127.094098	126.259939	126.55885	127.443604	129.59029
##	[59,]	124.84389	123.275070	128.378290	129.87817	125.390933	126.59311
##	[60,]	130.96173	126.549470	134.054568	132.68066	127.001021	129.28016
##	[61,]	133.95277	133.952771	137.268578	128.04211	136.294489	135.22178
##	[62,]	127.62475	127.624753	130.290840	127.62475	127.624753	127.62475
##	[63,]	129.08245	127.076638	129.616518	127.69189	127.580229	127.58616
##	[64,]	129.83949	133.334059	132.792580	128.93169	128.562186	134.28524
##	[65,]	130.93835	128.583631	134.103440	132.61516	131.608968	131.07840
##	[66,]	139.28341	139.323788	139.283413	138.14788	139.323788	135.22054
##	[67,]	138.80242	140.397101	137.378222	140.67161	140.659218	141.07172
##	[68,]	144.79822	142.443588	143.776114	144.03740	142.149225	142.93532
##	[69,]	140.38028	139.310903	141.415631	140.38028	140.793423	142.54162
##	[70,]	148.74438	148.744380	148.926564	148.92656	148.926564	146.41065
##	[71,]	145.39381	145.285632	144.667710	145.66537	145.285632	144.66771
##	[72,]	147.50016	150.045510	147.780517	146.34636	147.260738	151.06641
##	[73,]	148.00440	148.239330	149.482898	146.08181	148.215005	149.63505
##	[74,]	152.05995	154.472173	152.680067	149.32420	149.510598	150.55346
##	[75,]	148.15398	146.818119	145.868869	145.86887	145.868869	147.34479
##	[76,]	144.15698	144.243756	145.214194	145.63680	148.319016	147.16438
##	[77,]	148.93848	146.316373	147.196609	149.00220	148.878836	145.82551
##	[78,]	153.39245	149.013521	150.205635	151.32727	153.392447	150.08833
##	[79,]	154.37667	149.673317	152.446962	149.15922	153.305116	149.12809
##	[80,]	153.80426	152.402449	151.782263	152.64252	151.143178	153.03502
##	[81,]	147.83236	150.016067	150.158828	151.25552	149.576843	149.57684

```

## [82,] 148.97596 147.759538 147.580796 150.40515 150.558858 151.97868
## [83,] 149.46795 149.467953 149.902367 146.52219 149.392213 148.22151
## [84,] 150.86434 153.367700 153.623808 149.48138 149.764794 153.63836
## [85,] 153.39213 154.702322 151.269466 155.46859 152.541095 151.87689
## [86,] 156.71046 153.259239 156.207235 155.54516 155.872482 153.46396
## [87,] 156.21923 151.432118 157.066302 151.40337 151.875918 152.43425
## [88,] 147.19833 147.198329 147.198329 147.19833 149.911396 149.46946
## [89,] 148.35998 146.124351 148.102599 147.54486 146.844622 146.12435
## [90,] 149.99073 149.775391 149.585943 148.34397 151.805131 151.80513
## [91,] 155.16173 153.774622 155.140667 154.01056 155.161732 153.63905
## [92,] 155.17126 155.382123 156.086030 155.24943 155.178106 153.49087
## [93,] 158.18520 158.642909 157.728655 158.80343 160.802902 158.64291
## [94,] 156.45290 157.014224 161.000884 161.15468 157.746268 160.46856
## [95,] 162.68703 164.626795 164.766840 163.34428 163.043401 160.76943
## [96,] 168.40837 168.621901 167.380341 168.40837 167.088059 167.93846
## [97,] 164.40227 168.443075 167.386324 168.16935 169.207407 168.18287
## [98,] 173.35393 170.315078 169.612420 169.02405 171.607518 174.22427
## [99,] 173.34155 174.723902 174.468353 173.67545 173.621459 170.51025
## [100,] 177.72051 180.667670 177.388669 177.57882 178.687146 176.99401
##      [,97]      [,98]      [,99]      [,100]
## [1,]   8.689466   67.08718   94.44209   94.442093
## [2,]   1.816412    2.44312    2.44312    1.549527
## [3,]  11.787982  11.78798   11.78798   11.787982
## [4,]  16.336434  15.95239   16.33643   15.952391
## [5,]  17.487718  20.38605   18.37761   16.610165
## [6,]  22.646835  21.21457   22.64684   20.740700
## [7,]  24.499177  24.32293   27.04919   26.216877
## [8,]  30.805639  30.80564   30.80564   30.805639
## [9,]  33.260550  33.29754   32.32248   33.161700
## [10,] 35.322563  36.69101   37.76992   37.863623
## [11,] 36.613126  39.58113   36.01123   36.580725
## [12,] 38.187386  39.96001   39.40398   38.714272
## [13,] 44.821268  44.10369   42.19796   43.035466
## [14,] 43.412584  43.96780   43.24401   42.844131
## [15,] 46.849278  44.16267   46.02641   48.178704
## [16,] 47.895785  49.03296   49.45992   48.453409
## [17,] 51.884162  50.22388   50.93497   49.974226
## [18,] 55.729615  56.86152   56.45049   56.030039
## [19,] 60.570397  60.57040   59.64925   58.537452
## [20,] 63.981180  62.42482   64.38563   64.843483
## [21,] 66.857776  66.12156   65.09838   65.098378
## [22,] 68.133809  69.80442   67.03588   70.063239
## [23,] 70.570520  72.64664   70.81517   71.263595
## [24,] 78.958021  76.79924   76.98674   78.958021
## [25,] 80.604741  82.56987   79.44355   79.801566
## [26,] 84.017320  83.00202   85.78871   84.135864
## [27,] 87.191076  85.53876   88.18933   85.557660
## [28,] 89.532008  90.62803   90.04007   89.954031
## [29,] 92.273568  92.15893   94.44468   93.463226
## [30,] 95.022537  92.42588   95.43910   93.444935
## [31,] 93.799298 100.10554   97.04997   99.944519
## [32,] 94.738615  93.58812   93.64021   93.749370
## [33,] 96.431891  98.31936   94.89573   95.235505
## [34,] 93.816097  96.19237   95.73103   93.890293

```



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## [35,] 97.869922 97.40184 96.52953 93.359136
## [36,] 99.195719 97.66663 96.91010 97.786612
## [37,] 101.538889 99.24039 99.97144 103.576650
## [38,] 96.218728 102.12465 96.98616 101.145203
## [39,] 100.302304 102.80134 97.65502 101.831137
## [40,] 95.818814 95.37763 95.51175 95.818814
## [41,] 96.529948 96.95348 98.76121 97.117134
## [42,] 94.252962 96.20267 94.25296 96.444711
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## [51,] 106.230865 107.99488 109.08456 105.849174
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## [61,] 135.610295 133.05066 137.26858 135.221781
## [62,] 127.624753 127.62475 127.62475 127.624753
## [63,] 129.659055 127.40982 127.01652 130.842365
## [64,] 131.514847 133.64527 131.84594 132.792580
## [65,] 130.318349 129.63302 131.51170 131.434293
## [66,] 134.939264 139.28341 139.28341 139.323788
## [67,] 136.150598 142.09712 137.60054 138.899720
## [68,] 140.548422 144.79822 143.35006 143.776114
## [69,] 139.310903 138.76074 145.60185 141.530806
## [70,] 148.926564 148.74438 148.74438 148.744380
## [71,] 146.518360 144.66771 145.28563 145.041348
## [72,] 146.210933 144.28155 147.97007 146.986757
## [73,] 149.000105 145.94288 147.10565 147.169736
## [74,] 152.419035 148.82243 155.66014 147.267140
## [75,] 145.868869 149.06200 151.15503 145.868869
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## [82,] 151.170118 151.86675 148.44848 151.926556
## [83,] 147.567457 149.90237 147.19923 149.176120
## [84,] 151.453558 152.14606 151.59687 148.847733
## [85,] 155.619739 154.70232 153.44169 155.619739
## [86,] 156.837363 154.91834 154.33840 152.178920
## [87,] 153.466828 155.08247 151.56957 153.461518
## [88,] 147.198329 150.86964 147.19833 147.198329

```

```

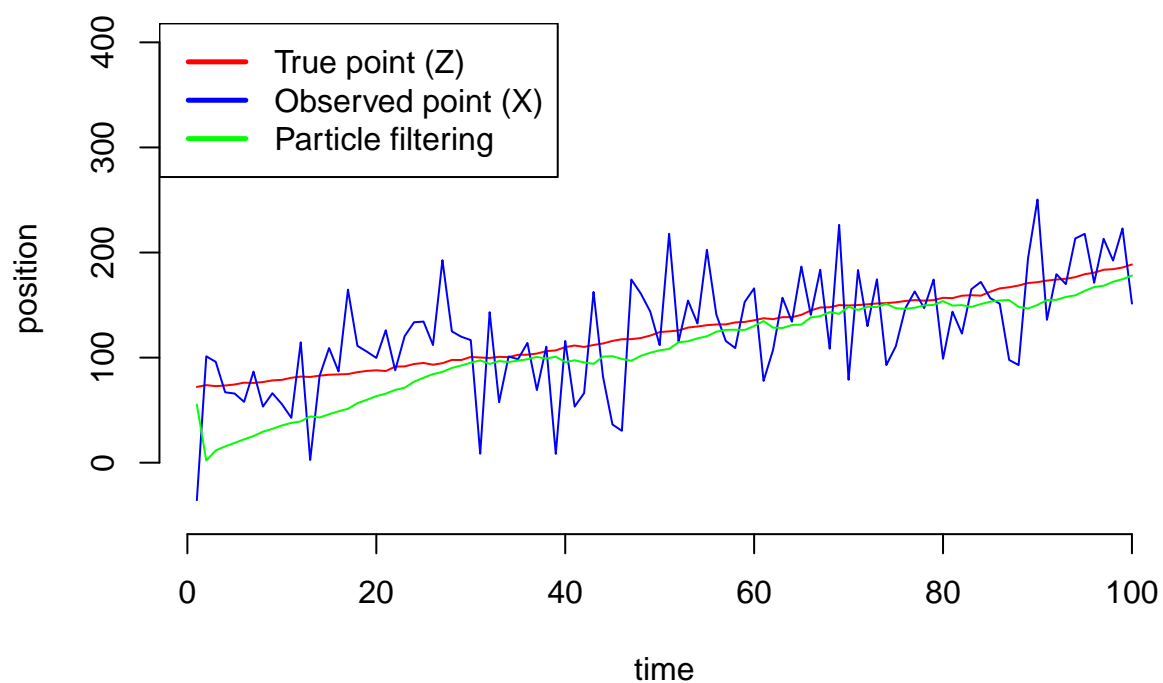
## [89,] 146.624513 147.57728 149.05644 145.892920
## [90,] 149.789218 151.61915 150.02235 151.619145
## [91,] 155.161732 155.14067 153.77462 155.140667
## [92,] 152.211231 153.84531 156.15709 156.044547
## [93,] 158.766788 157.79179 159.17416 158.578455
## [94,] 158.777204 159.66430 160.46856 161.000884
## [95,] 163.781759 162.19646 164.76684 163.254591
## [96,] 165.393872 168.62190 165.45905 168.408368
## [97,] 168.588573 168.61153 168.37467 170.649235
## [98,] 172.829197 171.82917 173.22312 171.347082
## [99,] 176.663924 175.88239 176.87569 175.938897
## [100,] 176.548219 180.66767 180.66767 176.390298

plotting<- function(Z=myZ, X=x_t , particle= trial$parameters){
  n<-1:length(Z)
  for(i in n){
    plot(0, xlim= c(1,300), ylim = c(0,150 ),bty='n',pch='',ylab='sep representation for clearness',xlab='time',
    points(y = 20, x = Z[i], col ="red")
    points(y = 30, x = X[i], col ="blue")
    points(y =rep(40, 100), x = particle[i,], col = "green")
    legend("topleft", # places a legend at the appropriate place
    c("True point (Z) ", "Estimated point (X)", "Particle filtering"), # puts text in the legend
    lty=c(1,1), # gives the legend appropriate symbols (lines)
    lwd=c(2.5,2.5),col=c("Red"," blue", "Green")) # gives the legend lines the correct color and width
    Sys.sleep(0.2)
  }
}
par(mfrow=c(1,1))
#plotting()

par(mfrow=c(1,1))
plot(0, xlim= c(1,100), ylim = c(-50,400),
     bty='n',pch='',ylab='position',xlab='time', main = paste0("Values for sd = ", sd_E))
lines(x = 1:100, y = myZ, col ="red")
lines(x = 1:100, y = x_t, col ="blue")
lines(x =1:100, y = apply(trial$parameters,1,mean), col = "green")
legend("topleft", # places a legend at the appropriate place
     c("True point (Z) ", "Observed point (X)", "Particle filtering"), # puts text in the legend
     lty=c(1,1), # gives the legend appropriate symbols (lines)
     lwd=c(2.5,2.5),col=c("Red"," blue", "Green")) # gives the legend lines the correct color and width

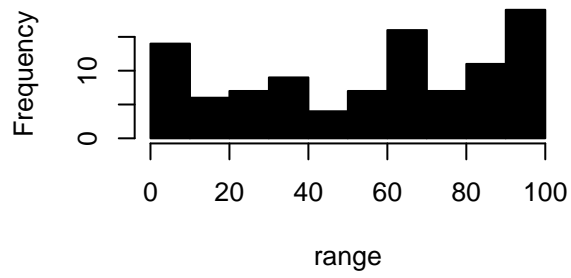
```

Values for $sd = 50$

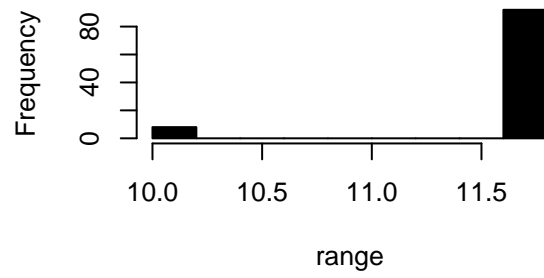


```
par(mfrow=c(2,2))
hist(trial$parameters[1,], main= "Initial distribution of numbers", xlab = "range", col = "black")
hist(trial$parameters[3,], main= "3rd distribution of numbers", xlab = "range", col = "black")
hist(trial$parameters[50,], main= "50th distribution of numbers", xlab = "range", col = "black")
hist(trial$parameters[100,], main= "Final distribution of numbers", xlab = "range", col = "black")
```

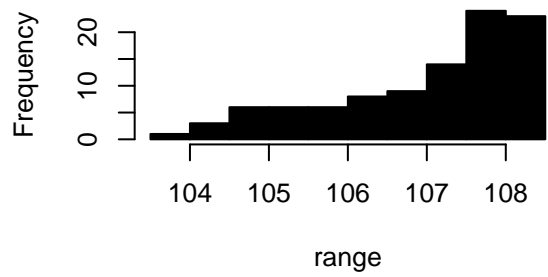
Initial distribution of numbers



3rd distribution of numbers



50th distribution of numbers



Final distribution of numbers

