

# Geolocation

## Predicting Location via Indoor Positioning Systems

### The Raw Data

```
file_offline <- file.path(data.dir, "offline.final.trace.txt")
file_online <- file.path(data.dir, "online.final.trace.txt")

raw_offline <- read_lines(file_offline)
raw_online <- read_lines(file_online)
```

### Sanity Check

```
# number of comment lines in the data
sum(substr(raw_offline, 1, 1) == "#")
```

```
[1] 5312
```

```
# total number of lines in the data
length(raw_offline)
```

```
[1] 151392
```

### Data Pre-processing

Generate read data function for preprocessing training and test data.

```
processLine <- function(x) {
  tokens <- strsplit(x, "[;=,]")[[1]]

  if(length(tokens) == 10)
    return(NULL)

  tmp <- matrix(tokens[-(1:10)], ncol = 4, byrow = T)
  cbind(matrix(tokens[c(2, 4, 6:8, 10)], nrow = nrow(tmp),
```

```

        ncol = 6, byrow = T), tmp)
}

validLines <- function(data) {
  substr(data, 1, 1) != "#"
}

roundOrientation <- function(angles) {
  refs = seq(0, by = 45, length = 9)
  q <- sapply(angles, function(o) which.min(abs(o - refs)))
  c(refs[1:8], 0)[q]
}

readData <- function(file, submacs = macs) {

  lines <- read_lines(file)

  valid_lines <- lines[ validLines(lines) ]

  processed_lines <- lapply(valid_lines, processLine)

  data <- as.data.table(do.call("rbind", processed_lines),
    stringsAsFactors = F)

  names(data) <- c("time", "scanMac", "posX", "posY", "posZ",
    "orientation", "mac", "signal",
    "channel", "type")

  numVars <- c("time", "posX", "posY", "posZ",
    "orientation", "signal")

  data[, (numVars) := lapply(.SD, as.numeric), .SDcols = numVars]

  data <- data[ data$type == 3, ]
  data[, type := NULL]

  data[, rawTime := time]
  data[, time := time/1000]
  class(data$time) = c("POSIXt", "POSIXct")

  # drop scanMac & posZ
  data[, `:=`(scanMac = NULL, posZ = NULL)]

  data$angle = roundOrientation(data$orientation)

```

```

data$channel = NULL

data$posXY <- paste(data$posX, data$posY, sep = "-")

return(data[mac %in% submacs])
}

```

## Test Pre-processor

```

lines <- processLine(raw_offline[4:20])
lines

```

	[,1]	[,2]	[,3]	[,4]	[,5]	[,6]
[1,]	"1139643118358"	"00:02:2D:21:0F:33"	"0.0"	"0.0"	"0.0"	"0.0"
[2,]	"1139643118358"	"00:02:2D:21:0F:33"	"0.0"	"0.0"	"0.0"	"0.0"
[3,]	"1139643118358"	"00:02:2D:21:0F:33"	"0.0"	"0.0"	"0.0"	"0.0"
[4,]	"1139643118358"	"00:02:2D:21:0F:33"	"0.0"	"0.0"	"0.0"	"0.0"
[5,]	"1139643118358"	"00:02:2D:21:0F:33"	"0.0"	"0.0"	"0.0"	"0.0"
[6,]	"1139643118358"	"00:02:2D:21:0F:33"	"0.0"	"0.0"	"0.0"	"0.0"
[7,]	"1139643118358"	"00:02:2D:21:0F:33"	"0.0"	"0.0"	"0.0"	"0.0"
[8,]	"1139643118358"	"00:02:2D:21:0F:33"	"0.0"	"0.0"	"0.0"	"0.0"
[9,]	"1139643118358"	"00:02:2D:21:0F:33"	"0.0"	"0.0"	"0.0"	"0.0"
[10,]	"1139643118358"	"00:02:2D:21:0F:33"	"0.0"	"0.0"	"0.0"	"0.0"
[11,]	"1139643118358"	"00:02:2D:21:0F:33"	"0.0"	"0.0"	"0.0"	"0.0"

	[,7]	[,8]	[,9]	[,10]
[1,]	"00:14:bf:b1:97:8a"	"-38"	"2437000000"	"3"
[2,]	"00:14:bf:b1:97:90"	"-56"	"2427000000"	"3"
[3,]	"00:0f:a3:39:e1:c0"	"-53"	"2462000000"	"3"
[4,]	"00:14:bf:b1:97:8d"	"-65"	"2442000000"	"3"
[5,]	"00:14:bf:b1:97:81"	"-65"	"2422000000"	"3"
[6,]	"00:14:bf:3b:c7:c6"	"-66"	"2432000000"	"3"
[7,]	"00:0f:a3:39:dd:cd"	"-75"	"2412000000"	"3"
[8,]	"00:0f:a3:39:e0:4b"	"-78"	"2462000000"	"3"
[9,]	"00:0f:a3:39:e2:10"	"-87"	"2437000000"	"3"
[10,]	"02:64:fb:68:52:e6"	"-88"	"2447000000"	"1"
[11,]	"02:00:42:55:31:00"	"-84"	"2457000000"	"1"

```
offline_valid <- raw_offline[validLines(raw_offline)]
```

```
head(offline_valid)
```

```

[1] "t=1139643118358;id=00:02:2D:21:0F:33;pos=0.0,0.0,0.0;degree=0.0;00:14:bf:b1:97:8a=-38,2437
[2] "t=1139643118744;id=00:02:2D:21:0F:33;pos=0.0,0.0,0.0;degree=0.0;00:14:bf:b1:97:8a=-38,2437
[3] "t=1139643119002;id=00:02:2D:21:0F:33;pos=0.0,0.0,0.0;degree=0.0;00:14:bf:b1:97:8a=-38,2437

```

```
[4] "t=1139643119263;id=00:02:2D:21:0F:33;pos=0.0,0.0,0.0;degree=0.0;00:14:bf:b1:97:8a=-38,2437
[5] "t=1139643119538;id=00:02:2D:21:0F:33;pos=0.0,0.0,0.0;degree=0.0;00:14:bf:b1:97:8a=-46,2437
[6] "t=1139643119818;id=00:02:2D:21:0F:33;pos=0.0,0.0,0.0;degree=0.0;00:14:bf:b1:97:8a=-37,2437
```

```
length(offline_valid)
```

```
[1] 146080
```

```
tmp <- lapply(offline_valid[1:17], processLine)
```

```
sapply(tmp, nrow)
```

```
[1] 11 10 10 11 9 10 9 9 10 11 11 9 9 9 8 10 14
```

## Dry Run

```
offline_test <- as.data.table(do.call("rbind", tmp))
```

```
offline_test
```

	V1	V2	V3	V4	V5	V6	V7	V8
1:	1139643118358	00:02:2D:21:0F:33	0.0	0.0	0.0	0.0	00:14:bf:b1:97:8a	-38
2:	1139643118358	00:02:2D:21:0F:33	0.0	0.0	0.0	0.0	00:14:bf:b1:97:90	-56
3:	1139643118358	00:02:2D:21:0F:33	0.0	0.0	0.0	0.0	00:0f:a3:39:e1:c0	-53
4:	1139643118358	00:02:2D:21:0F:33	0.0	0.0	0.0	0.0	00:14:bf:b1:97:8d	-65
5:	1139643118358	00:02:2D:21:0F:33	0.0	0.0	0.0	0.0	00:14:bf:b1:97:81	-65
---								
166:	1139643122647	00:02:2D:21:0F:33	0.0	0.0	0.0	0.0	00:0f:a3:39:e0:4b	-79
167:	1139643122647	00:02:2D:21:0F:33	0.0	0.0	0.0	0.0	00:0f:a3:39:e0:4b	-80
168:	1139643122647	00:02:2D:21:0F:33	0.0	0.0	0.0	0.0	00:0f:a3:39:e2:10	-83
169:	1139643122647	00:02:2D:21:0F:33	0.0	0.0	0.0	0.0	00:0f:a3:39:dd:cd	-65
170:	1139643122647	00:02:2D:21:0F:33	0.0	0.0	0.0	0.0	02:00:42:55:31:00	-84
	V9 V10							
1:	2437000000	3						
2:	2427000000	3						
3:	2462000000	3						
4:	2442000000	3						
5:	2422000000	3						
---								
166:	2462000000	3						
167:	2462000000	3						
168:	2437000000	3						
169:	2412000000	3						
170:	2457000000	1						

## Process

```
# Enter Debug Context

# options(error = recover, warn = 2)

offline_data <- lapply(offline_valid, processLine)
offline <- as.data.table(do.call("rbind", offline_data),
                        stringsAsFactors = F)

names(offline) <- c("time", "scanMac", "posX", "posY", "posZ",
                    "orientation", "mac", "signal",
                    "channel", "type")

numVars <- c("time", "posX", "posY", "posZ",
             "orientation", "signal")

dim(offline)

[1] 1181628      10

offline[, (numVars) := lapply(.SD, as.numeric), .SDcols = numVars]

offline <- offline[ offline$type == 3, ]
offline[, type := NULL]

offline[, rawTime := time]
offline[, time := time/1000]
class(offline$time) = c("POSIXt", "POSIXct")

# options(error = recover, warn = 1)
```

## Data Cleaning

```
summary(offline)
```

time		scanMac	posX
Min.	:2006-02-11 02:31:58	Length:978443	Min. : 0.00
1st Qu.	:2006-02-11 08:21:27	Class :character	1st Qu.: 2.00
Median	:2006-02-11 14:57:58	Mode :character	Median :12.00
Mean	:2006-02-16 09:57:37		Mean :13.52
3rd Qu.	:2006-02-19 09:52:40		3rd Qu.:23.00
Max.	:2006-03-09 15:41:10		Max. :33.00
posY	posZ	orientation	mac
Min. : 0.000	Min. :0	Min. : 0.0	Length:978443

1st Qu.: 3.000	1st Qu.:0	1st Qu.: 90.0	Class :character
Median : 6.000	Median :0	Median :180.0	Mode :character
Mean : 5.897	Mean :0	Mean :167.2	
3rd Qu.: 8.000	3rd Qu.:0	3rd Qu.:270.0	
Max. :13.000	Max. :0	Max. :359.9	

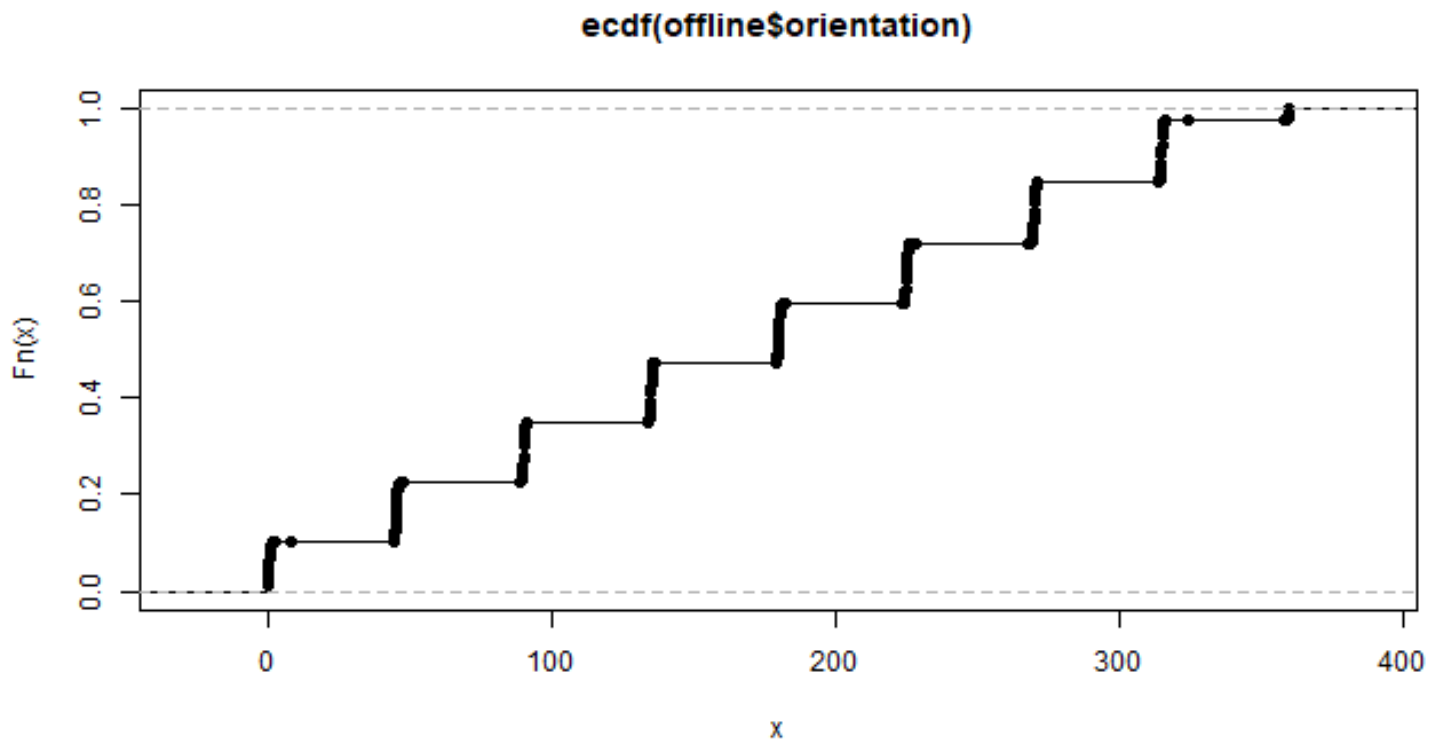
signal	channel	rawTime
Min. : -99.0	Length:978443	Min. :1.140e+12
1st Qu.: -69.0	Class :character	1st Qu.:1.140e+12
Median : -60.0	Mode :character	Median :1.140e+12
Mean : -61.7		Mean :1.140e+12
3rd Qu.: -53.0		3rd Qu.:1.140e+12
Max. : -25.0		Max. :1.142e+12

## Orientation Exploration

```
length(unique(outfile$orientation))
```

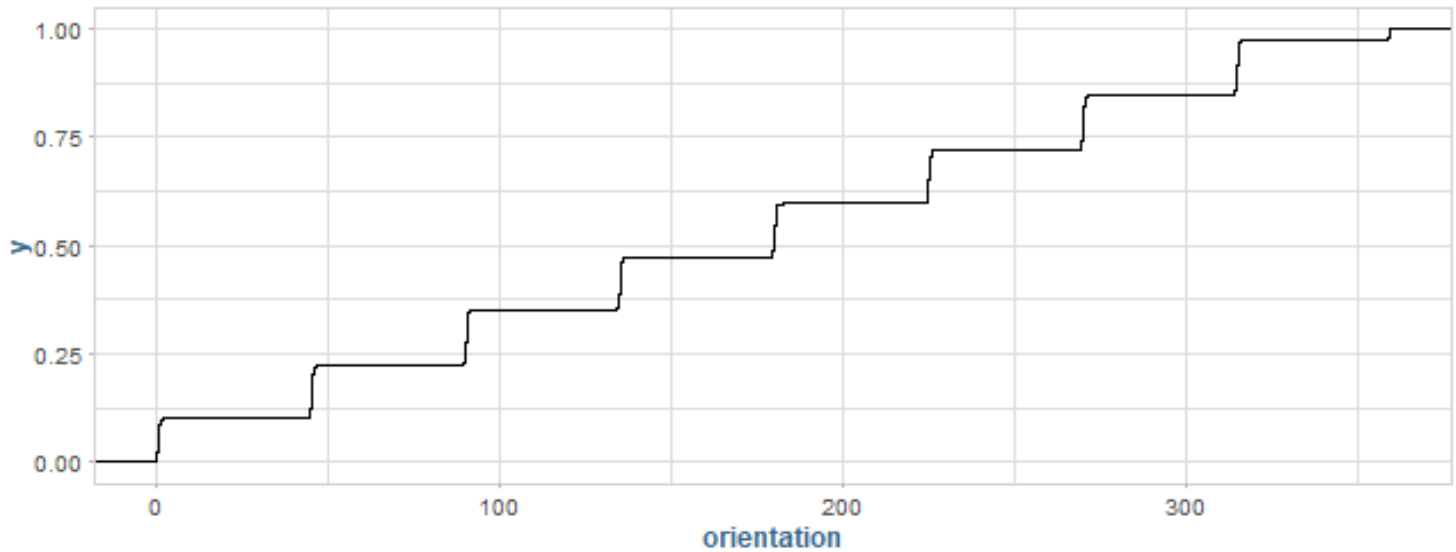
```
[1] 203
```

```
plot(ecdf(outfile$orientation))
```

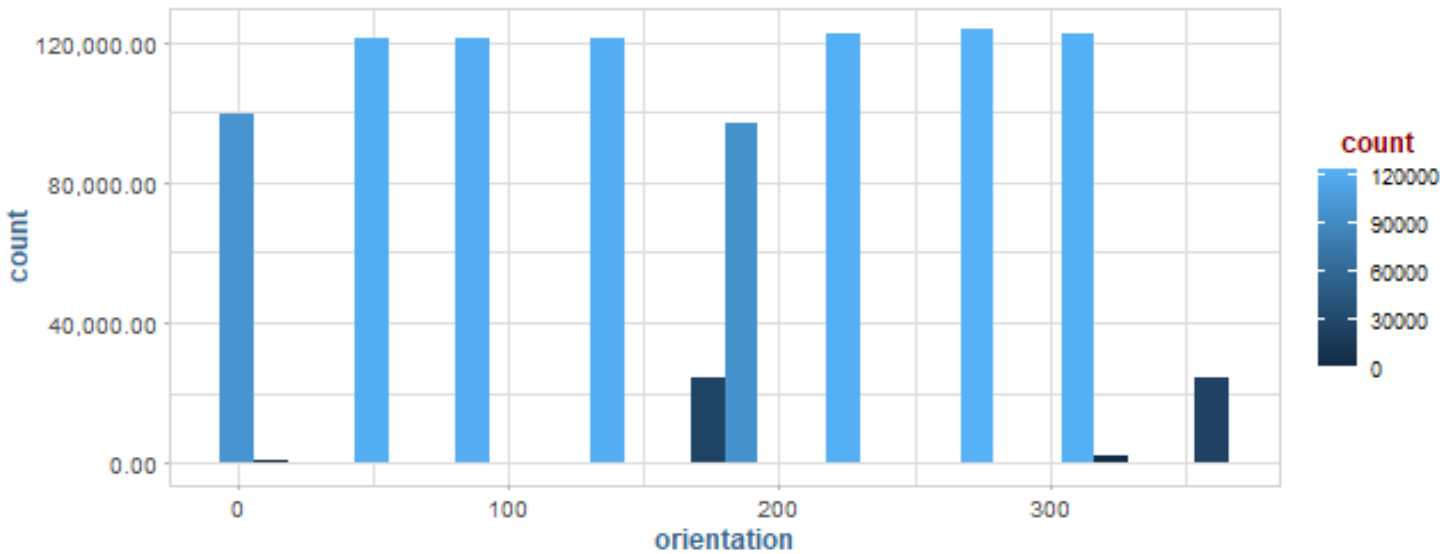


```
ggplot(outfile, aes(orientation)) +  
  stat_ecdf() +
```

```
labs("Orientation")
```

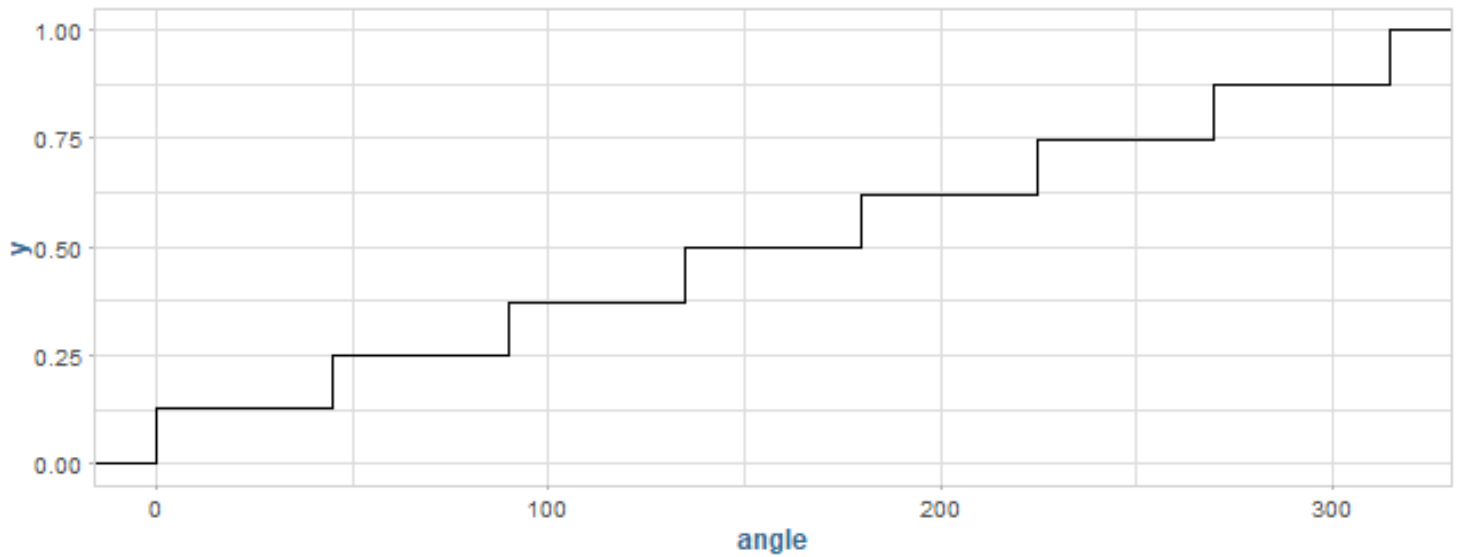


```
ggplot(offline, aes(orientation, fill = ..count..)) +  
  geom_histogram(bins = 30) +  
  scale_y_continuous(labels = comma) +  
  labs("Orientation Value Clusters")
```

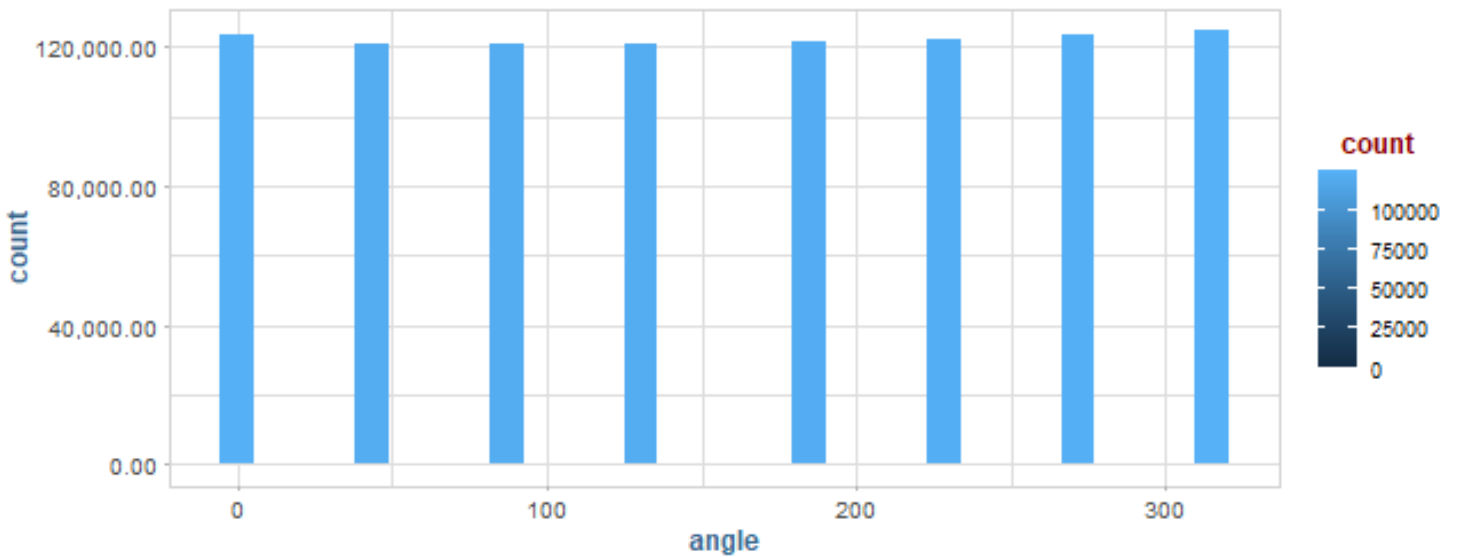


```
offline$angle <- roundOrientation(offline$orientation)
```

```
# angle = cleaned orientation column  
ggplot(offline, aes(angle)) +  
  stat_ecdf()
```

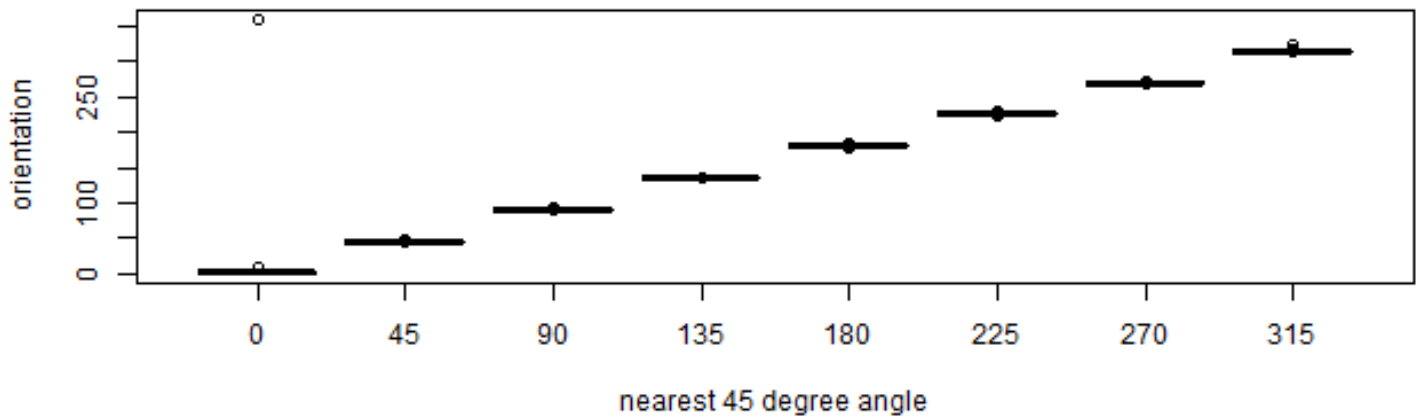


```
ggplot(offline, aes(angle, fill = ..count..)) +  
  geom_histogram(bins = 30) +  
  scale_y_continuous(labels = comma) +  
  labs("Cleaned Up Angles")
```

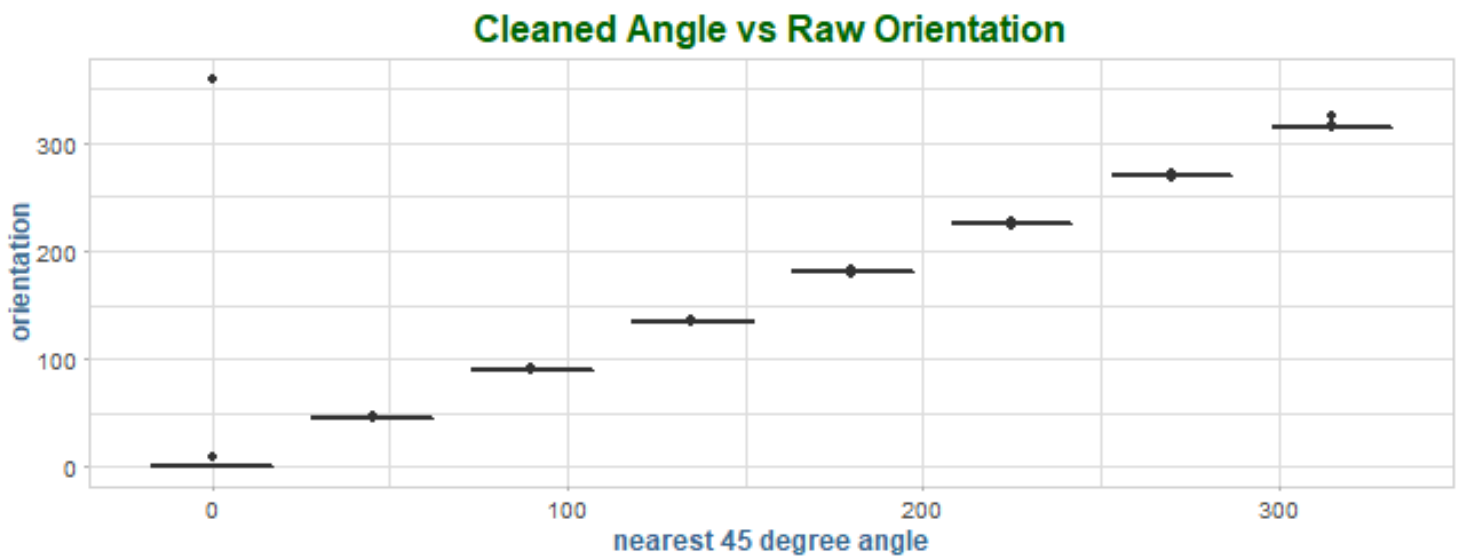


```
with(offline, boxplot(orientation ~ angle,  
  xlab = "nearest 45 degree angle",  
  ylab = "orientation"))
```





```
ggplot(offline, aes(angle, orientation, group = angle)) +
  geom_boxplot() +
  labs(title = "Cleaned Angle vs Raw Orientation",
       x = "nearest 45 degree angle",
       y = "orientation")
```



## MAC Address

```
c(length(unique(offline$mac)), length(unique(offline$channel)))
```

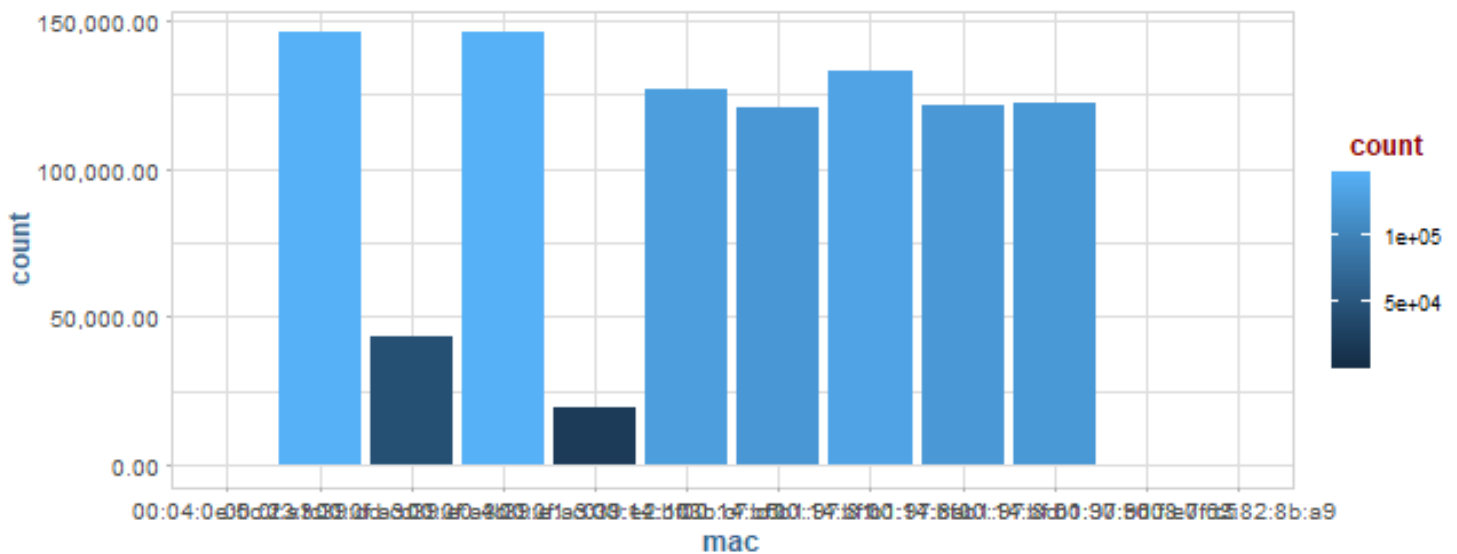
```
[1] 12 8
```

```
table(offline$mac)
```

```
00:04:0e:5c:23:fc 00:0f:a3:39:dd:cd 00:0f:a3:39:e0:4b 00:0f:a3:39:e1:c0
      418      145619      43508      145862
00:0f:a3:39:e2:10 00:14:bf:3b:c7:c6 00:14:bf:b1:97:81 00:14:bf:b1:97:8a
      19162      126529      120339      132962
00:14:bf:b1:97:8d 00:14:bf:b1:97:90 00:30:bd:f8:7f:c5 00:e0:63:82:8b:a9
      121325      122315      301      103
```

```
ggplot(offline, aes(mac, fill = ..count..)) +
  geom_histogram(stat = "count", bins = 30) +
  scale_y_continuous(labels = comma)
```

Warning: Ignoring unknown parameters: binwidth, bins, pad



```
# keep only the top 7 MAC address data points
```

```
dim(offline)
```

```
[1] 978443      11
```

```
offline_macs <- names(sort(table(offline$mac), decreasing = T)[1:7])
```

```
dim(offline)
```

```
[1] 978443      11
```

```
macChannel <- with(offline, table(mac, channel))
```

```
apply(macChannel, 1, function(x) sum(x > 0))
```

```
00:04:0e:5c:23:fc 00:0f:a3:39:dd:cd 00:0f:a3:39:e0:4b 00:0f:a3:39:e1:c0
```

```

      1      1      1      1
00:0f:a3:39:e2:10 00:14:bf:3b:c7:c6 00:14:bf:b1:97:81 00:14:bf:b1:97:8a
      1      1      1      1
00:14:bf:b1:97:8d 00:14:bf:b1:97:90 00:30:bd:f8:7f:c5 00:e0:63:82:8b:a9
      1      1      1      1

```

```

# mac and channel are 1:1, we can remove channel
#offline$channel := NULL

```

## Exploring the Position of the Hand-Held Device

```

locDF <- with(offline,
             by(offline, list(posX, posY), function(x) x))

```

```
length(locDF)
```

```
[1] 476
```

```
sum(sapply(locDF, is.null))
```

```
[1] 310
```

```
locDF <- locDF[ !sapply(locDF, is.null)]
```

```
length(locDF)
```

```
[1] 166
```

```
locCounts <- sapply(locDF, nrow)
```

```

locCounts <- sapply(locDF,
                  function(df)
                    c(df[1, c("posX", "posY")], count = nrow(df)))

```

```
class(locCounts)
```

```
[1] "matrix"
```

```
dim(locCounts)
```

```
[1] 3 166
```

```
locCounts[, 1:8]
```

```

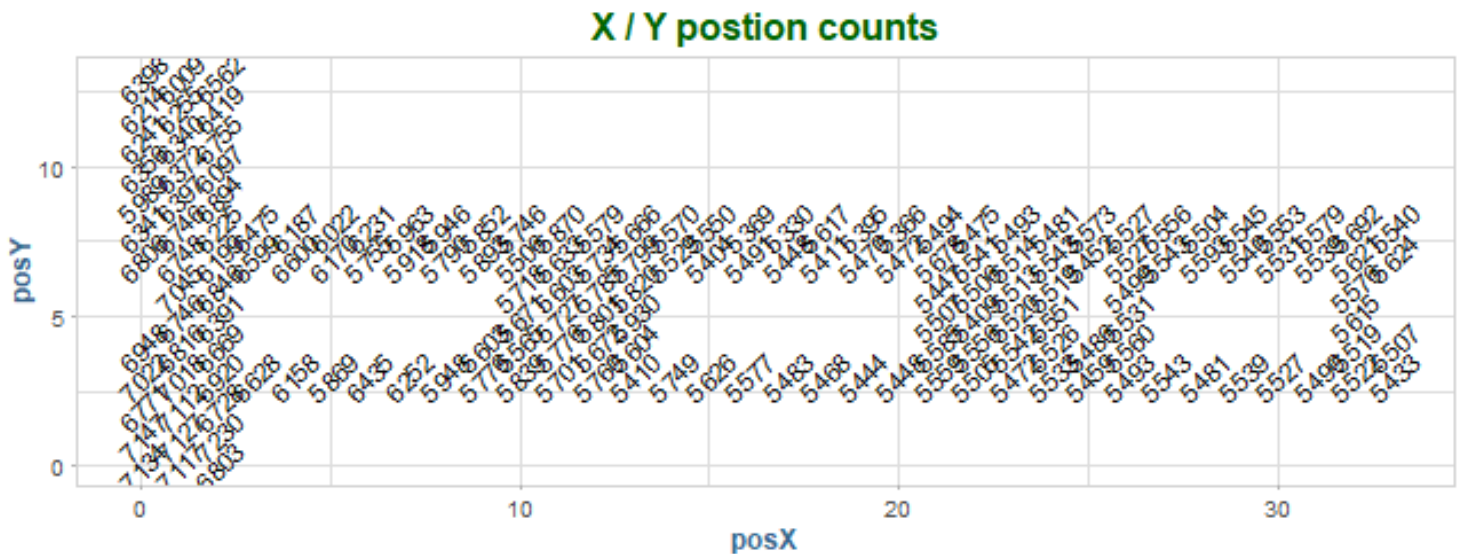
      [,1] [,2] [,3] [,4] [,5] [,6] [,7] [,8]
posX  0    1    2    0    1    2    0    1
posY  0    0    0    1    1    1    2    2
count 7134 7117 6803 7147 7127 7230 6771 7112

```

```
locCountsDF <- as.data.table(t(locCounts))

locCountsDF$posX <- unlist(locCountsDF$posX)
locCountsDF$posY <- unlist(locCountsDF$posY)

ggplot(locCountsDF, aes(posX, posY, label = count)) +
  geom_text(angle = 45) +
  labs(title = "X / Y position counts")
```

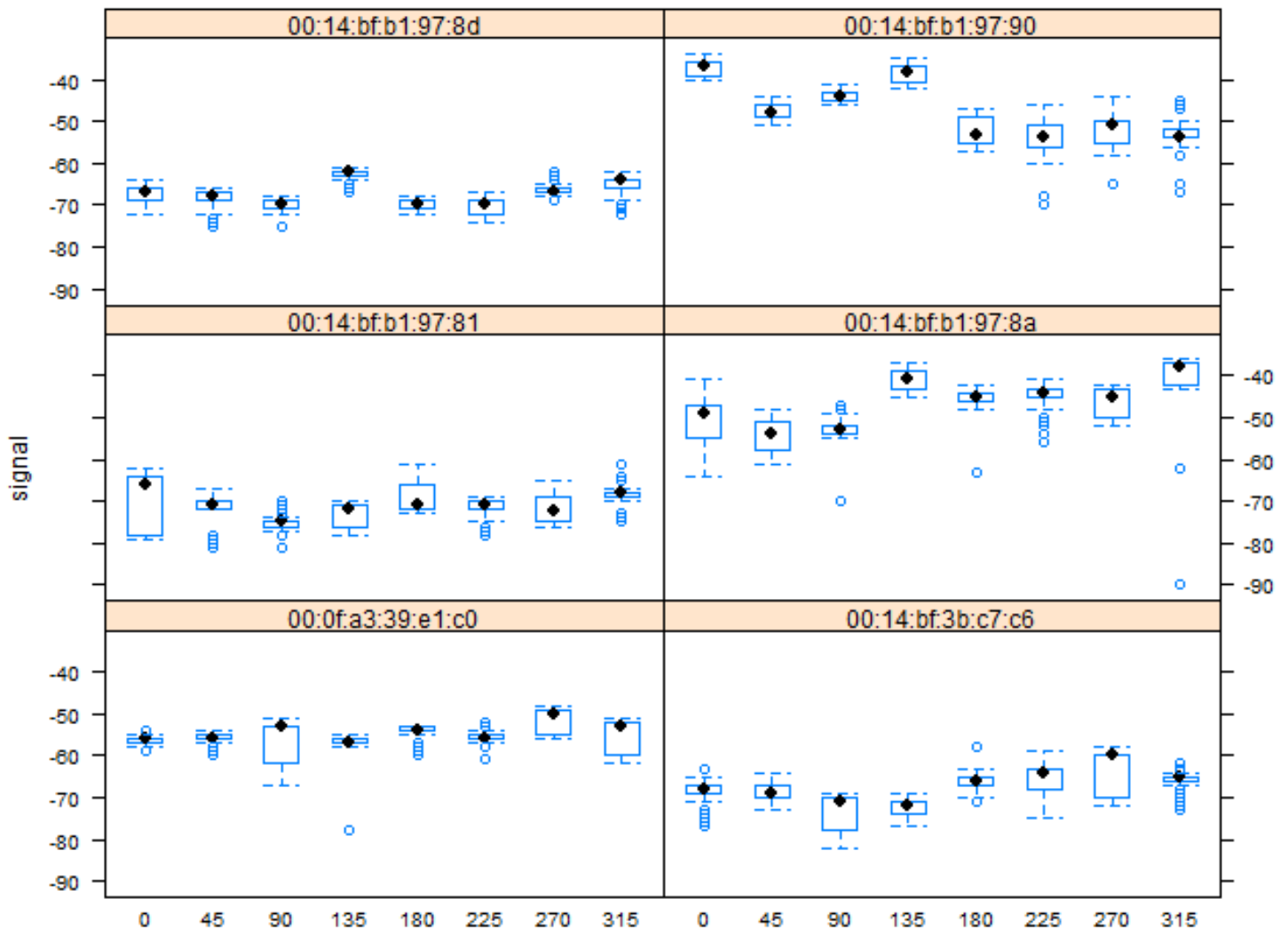


## Final Data Prep

```
offline <- readData(file_offline, offline_mac)
```

## Signal Strength

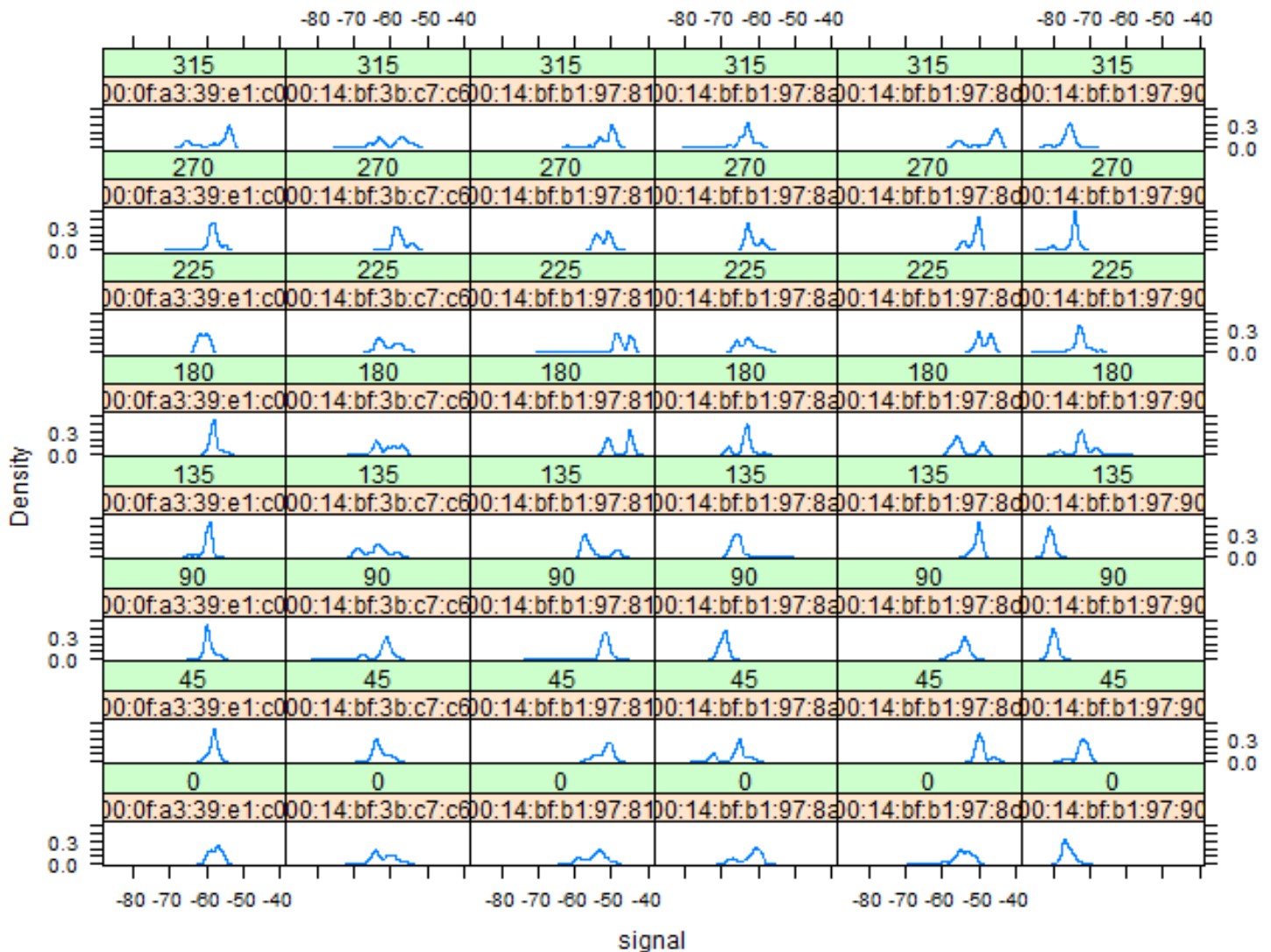
```
bwplot(signal ~ factor(angle) | mac, data = offline,
  subset = posX == 2 & posY == 12 &
    mac != "00:0f:a3:39:dd:cd",
  layout = c(2, 3))
```



```
summary(offline$signal)
```

Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
-98.00	-67.00	-59.00	-59.92	-53.00	-25.00

```
densityplot(~ signal | mac + factor(angle), data = offline,
  subset = posX == 24 & posY == 4 &
  mac != "00:0f:a3:39:dd:cd",
  bw = 0.5, plot.points = F)
```



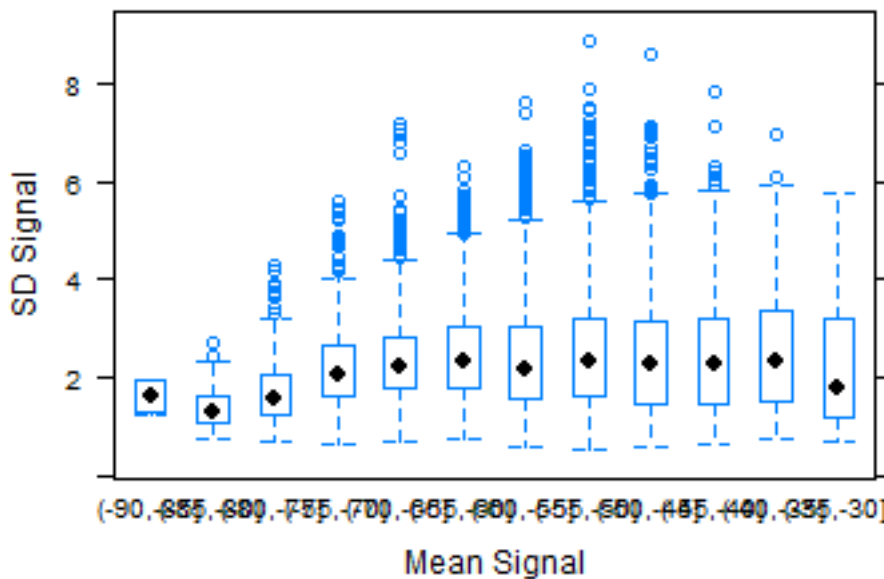
```
byLocAngleAP <- with(offline,
  by(offline, list(posXY, angle, mac),
    function(x) x))

signalSummary <-
  lapply(byLocAngleAP,
    function(oneLoc) {
      ans = oneLoc[1, ]
      ans$medSignal = median(oneLoc$signal)
      ans$avgSignal = mean(oneLoc$signal)
      ans$num = length(oneLoc$signal)
      ans$sdSignal = sd(oneLoc$signal)
      ans$iqrSignal = IQR(oneLoc$signal)
      ans
    })
```

```
offlineSummary <- do.call("rbind", signalSummary)

breaks <- seq(-90, -30, by = 5)

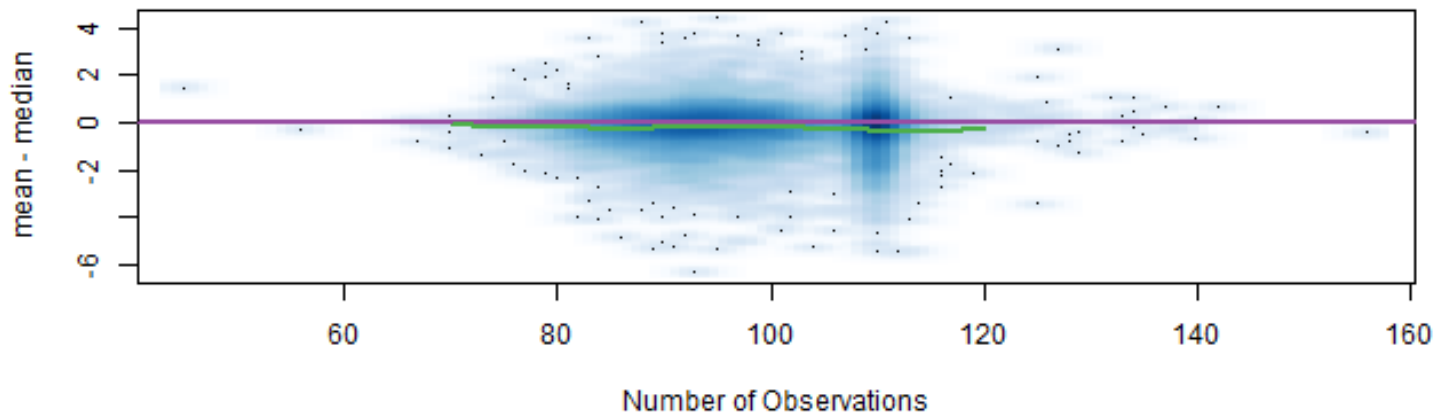
bwplot(sdSignal ~ cut(avgSignal, breaks = breaks),
      data = offlineSummary,
      subset = mac != "00:0f:a3:39:dd:cd",
      xlab = "Mean Signal", ylab = "SD Signal")
```



```
with(offlineSummary,
     smoothScatter((avgSignal - medSignal) ~ num,
                   xlab = "Number of Observations",
                   ylab = "mean - median"))
abline(h = 0, col = "#984ea3", lwd = 2)

lo.obj <- with(offlineSummary,
              loess(diff ~ num,
                    data = data.frame(diff = (avgSignal - medSignal),
                                       num = num)))

lo.obj.pr <- predict(lo.obj, newdata = data.frame(num = (70:120)))
lines(x = 70:120, y = lo.obj.pr, col = "#4daf4a", lwd = 2)
```



## Signal and Distance

```
subMacs <- names(sort(table(offline$mac), decreasing = T))[1:7]

surfaceSS <- function(data, mac, angle) {
  oneAPAngle <- subset(offlineSummary, mac == mac & angle == angle)

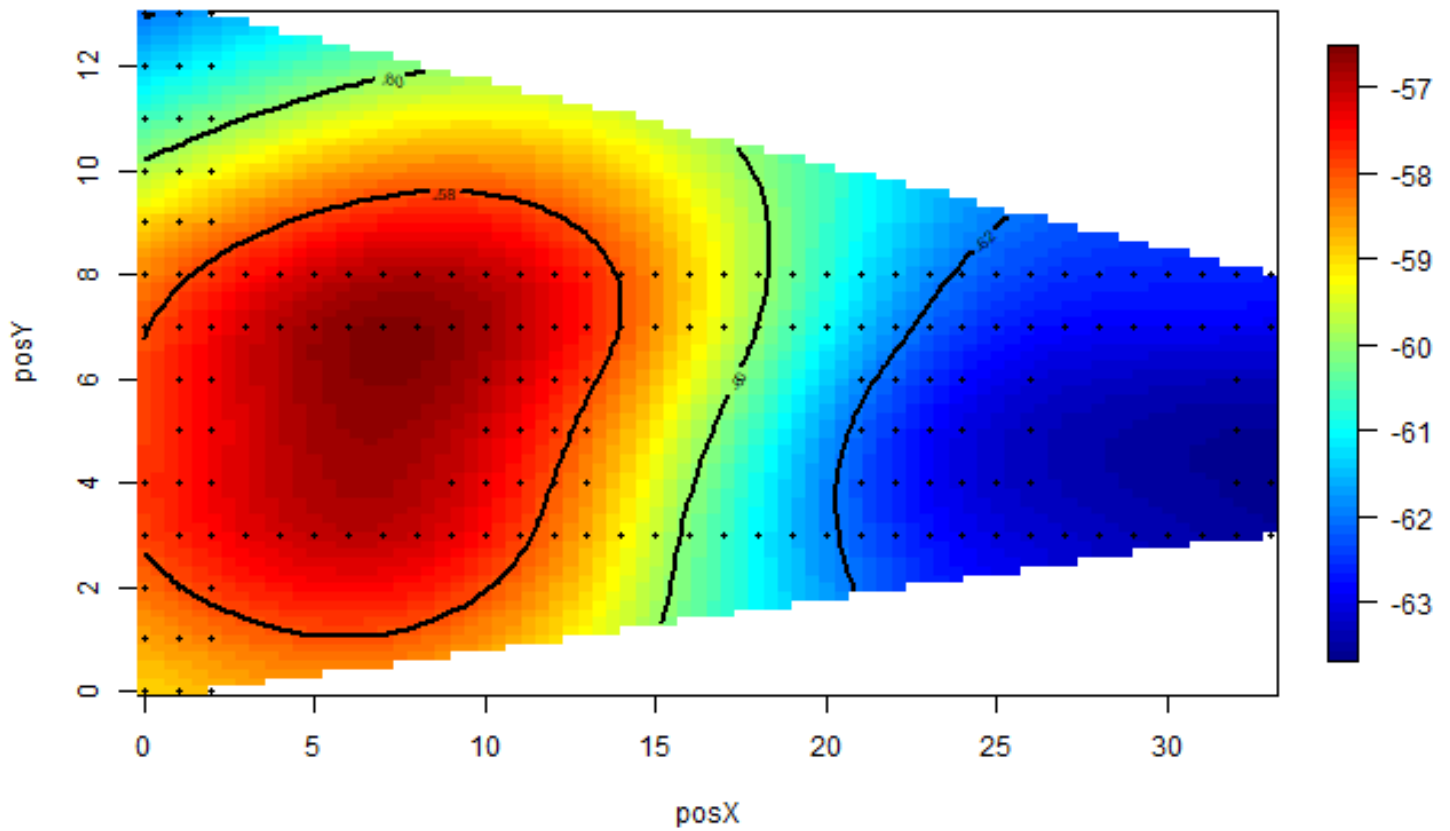
  smothSS <- Tps(oneAPAngle[, c("posX", "posY")],
                 oneAPAngle$avgSignal)

  vizSmooth <- predictSurface(smothSS)

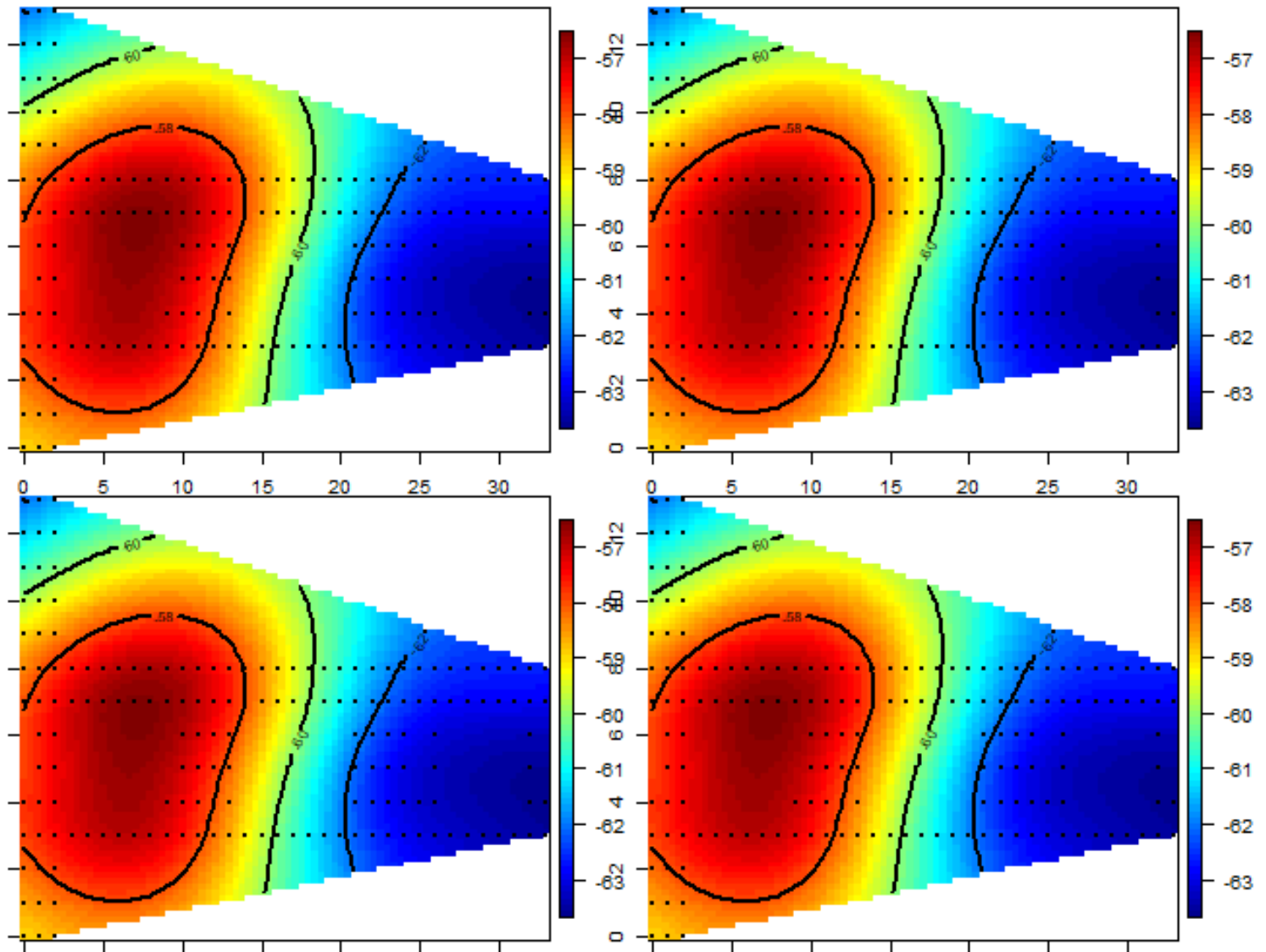
  plot.surface(vizSmooth, type = "C")
  points(oneAPAngle$posX, oneAPAngle$posY, pch=19, cex = 0.5)
}

surfaceSS(offlineSummary, subMacs[5], 0)
```





```
parCur <- par(mfrow = c(2,2), mar = rep(1, 4))  
mapply(surfaceSS, mac = subMacs[ rep(c(5, 1), each = 2)],  
        data = list(data = offlineSummary))
```



```
$`00:14:bf:b1:97:90`  
NULL
```

```
$`00:14:bf:b1:97:90`  
NULL
```

```
$`00:0f:a3:39:e1:c0`  
NULL
```

```
$`00:0f:a3:39:e1:c0`  
NULL
```

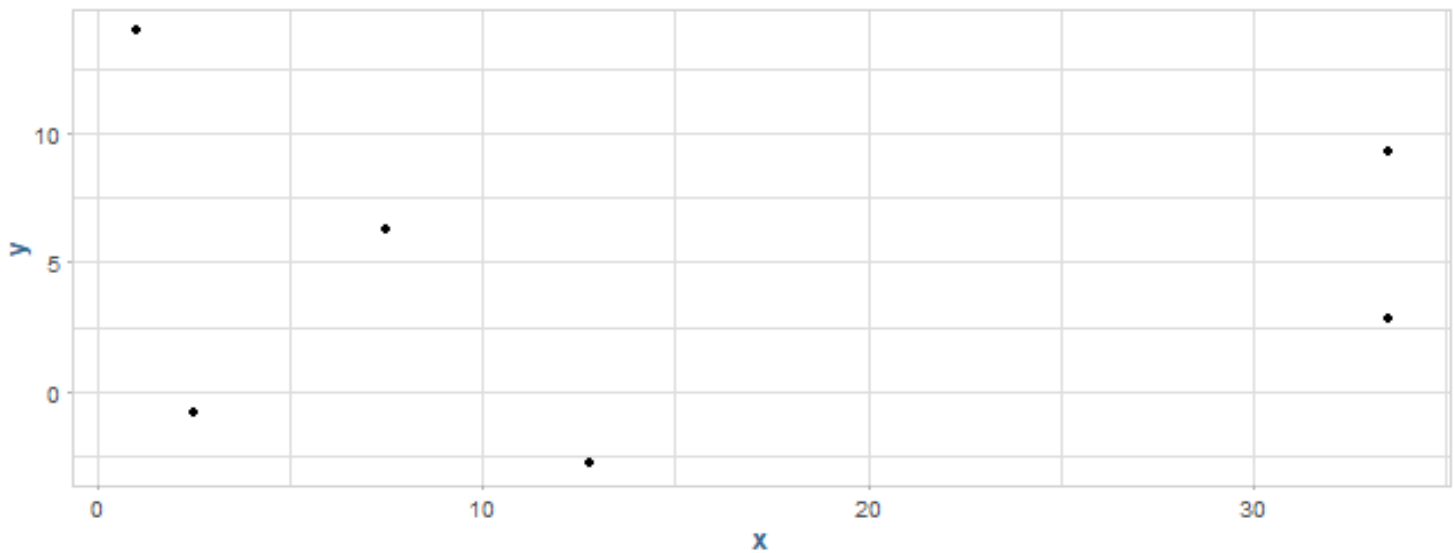
```
par(parCur)
```

Exclude one of two similar access points

```
offlineSummary <- subset(offlineSummary, mac != subMacs[2])
```

```
AP <- matrix( c( 7.5, 6.3, 2.5, -.8, 12.8, -2.8,  
               1, 14, 33.5, 9.3, 33.5, 2.8),  
             ncol = 2, byrow = T,  
             dimnames = list(subMacs[ -2 ], c("x", "y")) )
```

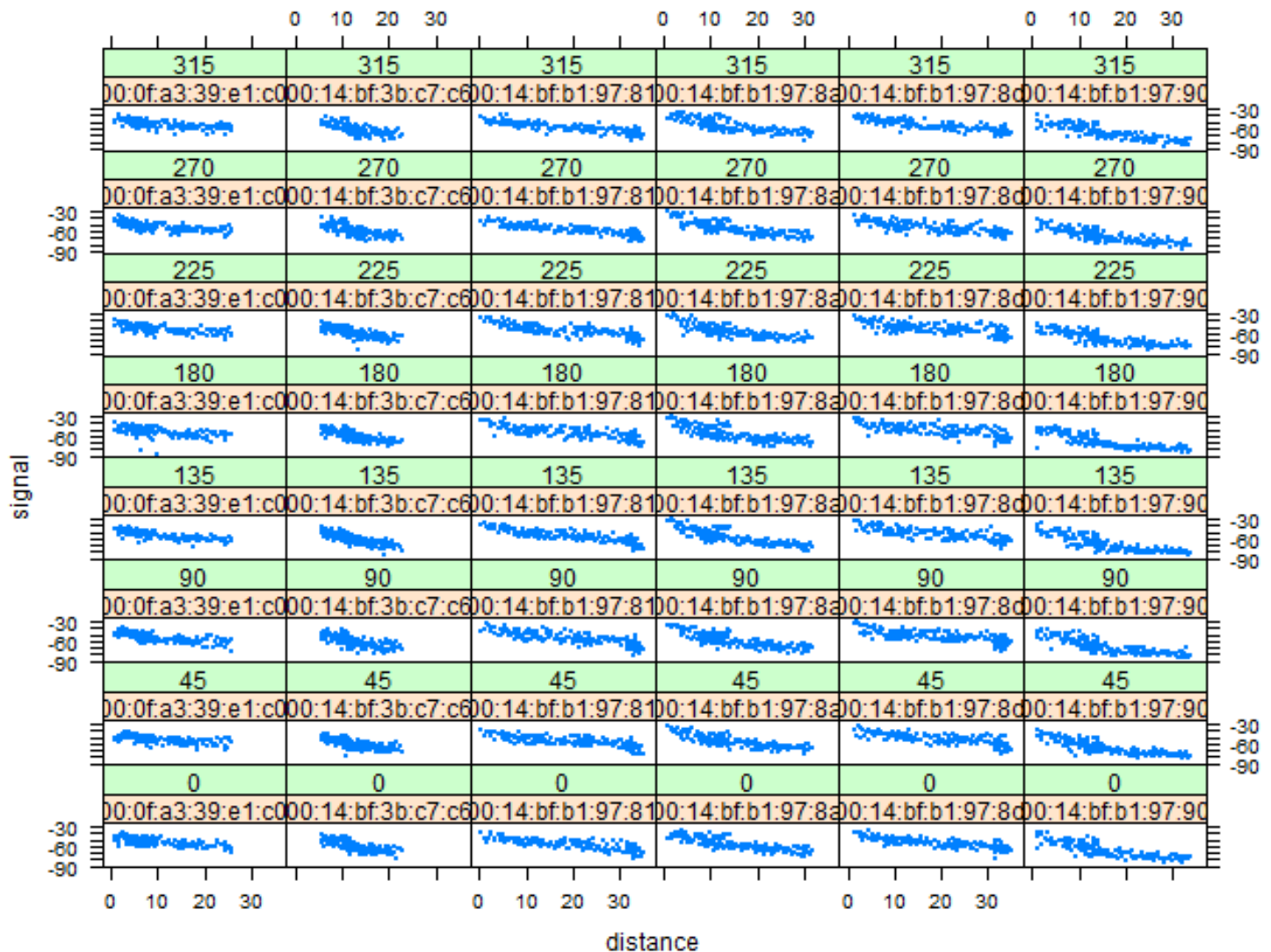
```
ggplot(data.table(mac = rownames(AP), AP), aes(x, y)) +  
  geom_point()
```



```
diffs <- offlineSummary[, c("posX", "posY")] - AP[offlineSummary$mac, ]
```

```
offlineSummary$dist <- sqrt(diffs[, 1]^2 + diffs[, 2]^2)
```

```
xyplot(signal ~ dist | factor(mac) + factor(angle),  
       data = offlineSummary, pch = 19, cex = 0.3,  
       xlab = "distance")
```



## Nearest Neighbor Methods to Predict Location

```

macs <- unique(offlineSummary$mac)

online <- readData(file_online, submacs = macs)

length(unique(online$posXY))

[1] 60

tabonlineXYA = table(online$posXY, online$angle)
tabonlineXYA[1:6, ]

```

	0	45	90	135	180	225	270	315
0-0.05	0	0	0	593	0	0	0	0
0.15-9.42	0	0	606	0	0	0	0	0
0.31-11.09	0	0	0	0	0	573	0	0
0.47-8.2	590	0	0	0	0	0	0	0
0.78-10.94	586	0	0	0	0	0	0	0
0.93-11.69	0	0	0	0	583	0	0	0

```
keepVars <- c("posXY", "posX", "posY", "orientation", "angle")

byLoc <- with(online,
  by(online, list(posXY),
    function(x) {
      ans <- x[1, ..keepVars]
      avgSS <- tapply(x$signal, x$mac, mean)
      y = matrix(avgSS, nrow = 1, ncol = 6,
        dimnames = list(ans$posXY, names(avgSS)))
      cbind(ans, y)
    })
)

onlineSummary <- do.call("rbind", byLoc)

dim(onlineSummary)
```

```
[1] 60 11
```

```
names(onlineSummary)

[1] "posXY"          "posX"           "posY"
[4] "orientation"    "angle"          "00:0f:a3:39:e1:c0"
[7] "00:14:bf:3b:c7:c6" "00:14:bf:b1:97:81" "00:14:bf:b1:97:8a"
[10] "00:14:bf:b1:97:8d" "00:14:bf:b1:97:90"
```

## Choice of Orientation

```
reshapeSS <- function(data,
  varSignal = "signal",
  keepVars = c("posXY", "posX", "posY"),
  sampleAngle = F) {

  if(sampleAngle)
    data <- data[angle == sample(data$angle, size = 1), ]

  byLocation <- with(data,
    by(data, list(posXY),
      function(x) {
```

```

      ans <- x[1, ..keepVars]
      avgSS <- tapply(x$signal, x$mac, mean)
      y = matrix(avgSS, nrow = 1, dimnames = list(ans$posXY, names(avgSS)))
      cbind(ans, y)
    )))

newDataSS <- do.call("rbind", byLocation)

col_names <- colnames(newDataSS)
to_change <- !(col_names %in% keepVars)

n_cols <- length(col_names)
start <- length(keepVars)

colnames(newDataSS)[to_change] <- sapply(col_names[to_change], function(col) {
  n <- nchar(col)
  substr(col, n - 2, n)
})

newDataSS[, start:ncol(newDataSS)] <- round(newDataSS[, start:ncol(newDataSS)])

return(newDataSS)
}

selectTrain <- function(angleNewObs, signals, m) {

  refs <- seq(0, by = 45, length = 8)

  nearestAngle <- roundOrientation(angleNewObs)

  if( m %% 2 == 1) {
    angles <- seq(-45 * (m - 1) / 2, 45 * (m - 1) / 2, length = m)
  } else {
    m = m + 1
    angles <- seq(-45 * (m - 1) / 2, 45 * (m - 1) / 2, length = m)

    if( sign(angleNewObs - nearestAngle) >= 1)
      angles = angles[ -1 ]
    else
      angles = angles[ -m ]
  }

  angles <- angles + nearestAngle
  angles[angles < 0] = angles[ angles < 0] + 360

```

```

angles[angles > 360] = angles[ angles > 360 ] - 360

signals <- signals[angle %in% angles, ]

reshapeSS(signals, varSignal = "avgSignal")
}

findNN <- function(newSignal, trainSubset) {
  diffs <- apply(trainSubset[, 4:9], 1,
                 function(x) x - newSignal)
  dists <- apply(diffs, 2, function(x) sqrt(sum(x^2)))
  closest <- order(dists)
  return(trainSubset[closest, 1:3 ])
}

predXY <- function(newSignals, newAngles, trainData,
                  numAngles = 1, k = 3) {

  closeXY <- list(length = nrow(newSignals))

  for(i in 1:nrow(newSignals)) {
    trainSS <- selectTrain(newAngles[i], trainData, m = numAngles)
    closeXY[[i]] <- findNN(newSignal = as.numeric(newSignals[i, ]),
                          trainSS)
  }

  estXY <- lapply(closeXY, function(x)
                  sapply(x[, 2:3],
                        function(x) mean(x[1:k]))))
  estXY <- do.call("rbind", estXY)

  return(estXY)
}

estXYk1 <- predXY(newSignals = onlineSummary[, 6:11],
                  newAngles = onlineSummary[, 4],
                  offlineSummary, numAngles = 3, k = 1)

estXYk3 <- predXY(newSignals = onlineSummary[, 6:11],
                  newAngles = onlineSummary[, 4],
                  offlineSummary, numAngles = 3, k = 3)

calcError <- function(estXY, actualXY)
  sum( rowSums( (estXY - actualXY) ^ 2) )

```

```
actualXY <- onlineSummary[, c("posX", "posY")]
sapply(list(estXYk1, estXYk3), calcError, actualXY)
```

```
[1] 420.7603 388.1070
```

```
v <- 11;
```

```
permuteLocs <- sample(unique(offlineSummary$posXY))
permuteLocs <- matrix(permuteLocs, ncol = v,
                      nrow = floor(length(permuteLocs)/v))
```

```
Warning in matrix(permuteLocs, ncol = v, nrow = floor(length(permuteLocs)/v)):
data length [166] is not a sub-multiple or multiple of the number of rows [15]
```

```
onlineFold <- subset(offlineSummary, posXY %in% permuteLocs[, 1])
```

```
onlineCVSummary <- reshapeSS(offline,
                             keepVars = c("posXY", "posX", "posY", "angle"),
                             sampleAngle = T)
```

```
offlineFold <- subset(offlineSummary,
                     posXY %in% permuteLocs[, 1])
```

```
estFold <- predXY(newSignals = onlineFold[, 6:11],
                 newAngles = onlineFold[, 4],
                 offlineFold, numAngles = 3, k = 3)
```

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actualFold <- onlineFold[, c("posX", "posY")]
calcError(estFold, actualFold)
```

```
[1] 184352
```

```
K <- 20
err <- rep(0, K)

for(j in 1:v) {
  onlineFold <- subset(onlineCVSummary,
                      posXY %in% permuteLocs[, j])
  offlineFold <- subset(offlineSummary,
                      posXY %in% permuteLocs[, -j])

  actualFold <- onlineFold[, c("posX", "posY")]

  for(k in 1:K) {
    estFold <- predXY(newSignals = onlineFold[, 6:11],
                     newAngles = onlineFold[, 4],
                     offlineFold, numAngles = 3, k = k)
```



```

    err[k] <- err[k] + calcError(estFold, actualFold)
  }
}

```

```

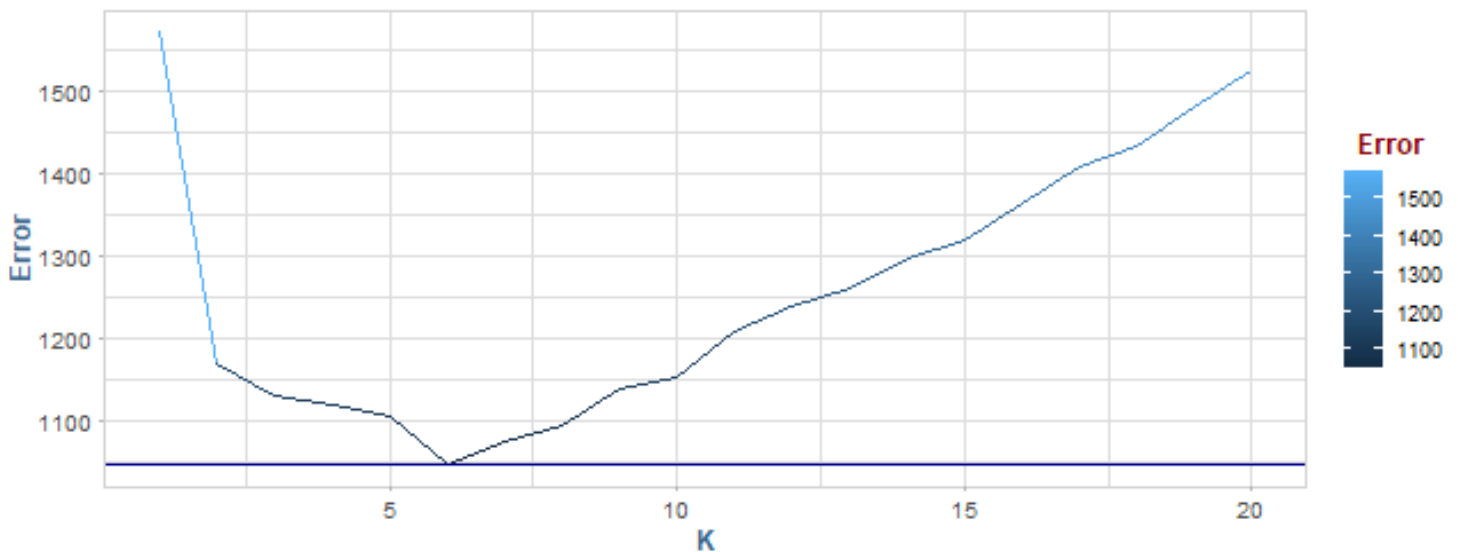
k_values <- data.table(K = 1:K, Error = err, Min = which.min(err))

```

```

ggplot(k_values, aes(K, Error)) +
  geom_line(aes(col = Error)) +
  geom_hline(data = k_values[K == Min], aes(yintercept = Error), col = "darkblue") +
  labs("K-NN Training Error")

```



```

estXYk5 <- predXY(newSignals = onlineSummary[, 6:11],
  newAngles = onlineSummary[, 4],
  offlineSummary, numAngles = 3, k = 5)

```

```

calcError(estXYk5, actualXY)

```

```

[1] 334.3683

```

```

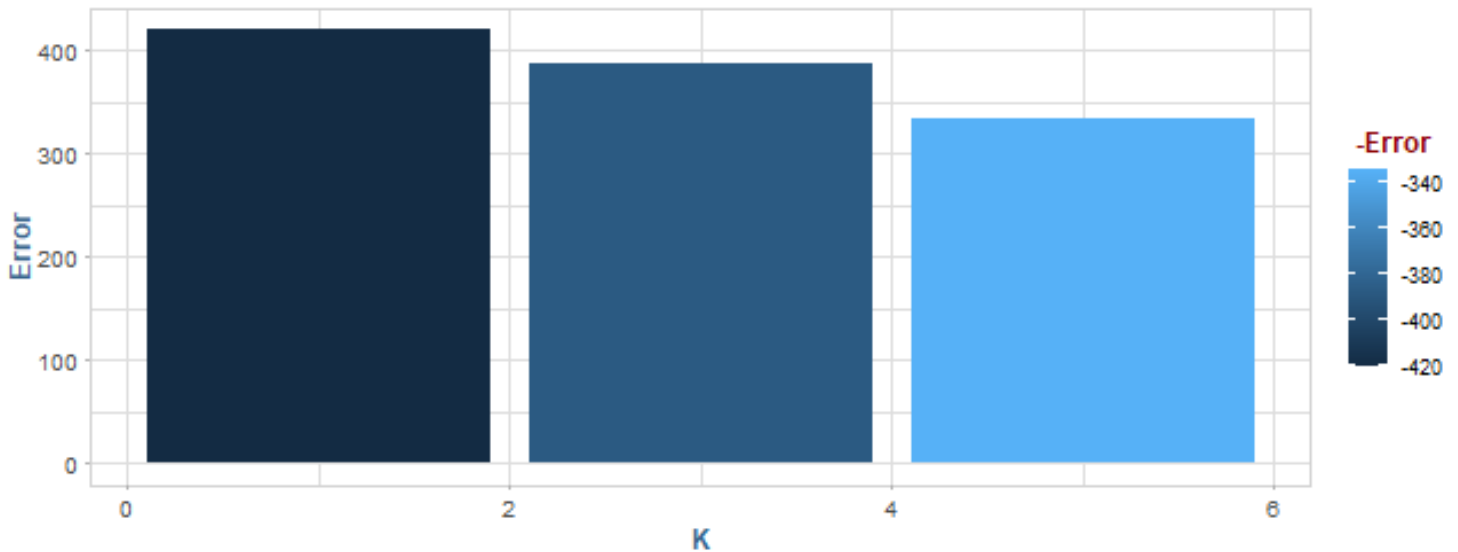
error_table <- data.table(K = c(1, 3, 5),
  Error = c(calcError(estXYk1, actualXY),
    calcError(estXYk3, actualXY),
    calcError(estXYk5, actualXY)))

```

```

ggplot(error_table, aes(K, Error, fill = -Error)) +
  geom_bar(stat = "identity")

```



## Further Analysis

### 1.)

Write the code to read the raw training data into the data structure in the first approach described in section 1.2. That is, the data structure is a data frame with a column for each MAC address that detected a signal. For the column name, use the last two characters of the MAC address, or some other unique identifier.

```
file <- file_offline

lines <- read_lines(file)

valid_lines <- lines[ validLines(lines) ]

parseLine <- function(line) {

  pairs <- strsplit(line, ";")
  tokens <- lapply(pairs, function(x)strsplit(x, "="))

  mat <- matrix(unlist(tokens), ncol = 2, byrow = T)

  colnames <- mat[, 1]
  values <- mat[, 2]

  dt <- data.table(t(values))
  colnames(dt) <- colnames

  dt
}
```

```
rows <- lapply(valid_lines, parseLine)
```

```
offline_alt <- rbindlist(rows, fill = T)
```

```
head(offline_alt)
```

	t	id	pos	degree	00:14:bf:b1:97:8a
1:	1139643118358	00:02:2D:21:0F:33	0.0,0.0,0.0	0.0	-38,2437000000,3
2:	1139643118744	00:02:2D:21:0F:33	0.0,0.0,0.0	0.0	-38,2437000000,3
3:	1139643119002	00:02:2D:21:0F:33	0.0,0.0,0.0	0.0	-38,2437000000,3
4:	1139643119263	00:02:2D:21:0F:33	0.0,0.0,0.0	0.0	-38,2437000000,3
5:	1139643119538	00:02:2D:21:0F:33	0.0,0.0,0.0	0.0	-46,2437000000,3
6:	1139643119818	00:02:2D:21:0F:33	0.0,0.0,0.0	0.0	-37,2437000000,3
	00:14:bf:b1:97:90	00:0f:a3:39:e1:c0	00:14:bf:b1:97:8d	00:14:bf:b1:97:81	
1:	-56,2427000000,3	-53,2462000000,3	-65,2442000000,3	-65,2422000000,3	
2:	-56,2427000000,3	-54,2462000000,3	-70,2442000000,3	-66,2422000000,3	
3:	-57,2427000000,3	-54,2462000000,3	-70,2442000000,3	-66,2422000000,3	
4:	-52,2427000000,3	-54,2462000000,3	-74,2442000000,3	-64,2422000000,3	
5:	-57,2427000000,3	-55,2462000000,3	<NA>	-66,2422000000,3	
6:	<NA>	-54,2462000000,3	-67,2442000000,3	-65,2422000000,3	
	00:14:bf:3b:c7:c6	00:0f:a3:39:dd:cd	00:0f:a3:39:e0:4b	00:0f:a3:39:e2:10	
1:	-66,2432000000,3	-75,2412000000,3	-78,2462000000,3	-87,2437000000,3	
2:	-67,2432000000,3	-73,2412000000,3	-79,2462000000,3	-83,2437000000,3	
3:	-69,2432000000,3	-65,2412000000,3	-78,2462000000,3	-83,2437000000,3	
4:	-68,2432000000,3	-78,2412000000,3	-78,2462000000,3	-83,2437000000,3	
5:	-67,2432000000,3	-66,2412000000,3	-80,2462000000,3	-83,2437000000,3	
6:	-67,2432000000,3	-67,2412000000,3	-79,2462000000,3	-89,2437000000,3	
	02:64:fb:68:52:e6	02:00:42:55:31:00	00:14:bf:3b:c7:c6	00:0f:a3:39:e0:4b	
1:	-88,2447000000,1	-84,2457000000,1	<NA>	<NA>	
2:	<NA>	-85,2457000000,1	<NA>	<NA>	
3:	-90,2447000000,1	<NA>	<NA>	<NA>	
4:	-87,2447000000,1	-84,2457000000,1	<NA>	<NA>	
5:	<NA>	-87,2457000000,1	<NA>	<NA>	
6:	-90,2447000000,1	-86,2457000000,1	<NA>	<NA>	
	00:0f:a3:39:e0:4b	00:0f:a3:39:e0:4b	00:0f:a3:39:dd:cd	00:14:bf:b1:97:90	
1:	<NA>	<NA>	<NA>	<NA>	
2:	<NA>	<NA>	<NA>	<NA>	
3:	<NA>	<NA>	<NA>	<NA>	
4:	<NA>	<NA>	<NA>	<NA>	
5:	<NA>	<NA>	<NA>	<NA>	
6:	<NA>	<NA>	<NA>	<NA>	
	00:14:bf:b1:97:8d	00:0f:a3:39:e0:4b	00:0f:a3:39:e0:4b	00:14:bf:b1:97:8a	
1:	<NA>	<NA>	<NA>	<NA>	
2:	<NA>	<NA>	<NA>	<NA>	

3:	<NA>	<NA>	<NA>	<NA>
4:	<NA>	<NA>	<NA>	<NA>
5:	<NA>	<NA>	<NA>	<NA>
6:	<NA>	<NA>	<NA>	<NA>
	00:04:0e:5c:23:fc	00:0f:a3:39:e2:10	00:04:0e:5c:23:fc	00:04:0e:5c:23:fc
1:	<NA>	<NA>	<NA>	<NA>
2:	<NA>	<NA>	<NA>	<NA>
3:	<NA>	<NA>	<NA>	<NA>
4:	<NA>	<NA>	<NA>	<NA>
5:	<NA>	<NA>	<NA>	<NA>
6:	<NA>	<NA>	<NA>	<NA>
	00:04:0e:5c:23:fc	00:0f:a3:39:e2:10	00:0f:a3:39:e2:10	00:0f:a3:39:e2:10
1:	<NA>	<NA>	<NA>	<NA>
2:	<NA>	<NA>	<NA>	<NA>
3:	<NA>	<NA>	<NA>	<NA>
4:	<NA>	<NA>	<NA>	<NA>
5:	<NA>	<NA>	<NA>	<NA>
6:	<NA>	<NA>	<NA>	<NA>
	00:04:0e:5c:23:fc	00:04:0e:5c:23:fc	02:64:fb:68:52:e6	00:0f:a3:39:e1:c0
1:	<NA>	<NA>	<NA>	<NA>
2:	<NA>	<NA>	<NA>	<NA>
3:	<NA>	<NA>	<NA>	<NA>
4:	<NA>	<NA>	<NA>	<NA>
5:	<NA>	<NA>	<NA>	<NA>
6:	<NA>	<NA>	<NA>	<NA>
	00:14:bf:b1:97:81	00:14:bf:b1:97:8d	00:14:bf:3b:c7:c6	02:64:fb:68:52:e6
1:	<NA>	<NA>	<NA>	<NA>
2:	<NA>	<NA>	<NA>	<NA>
3:	<NA>	<NA>	<NA>	<NA>
4:	<NA>	<NA>	<NA>	<NA>
5:	<NA>	<NA>	<NA>	<NA>
6:	<NA>	<NA>	<NA>	<NA>
	00:14:bf:3b:c7:c6	00:0f:a3:39:dd:cd	00:14:bf:b1:97:8a	00:0f:a3:39:e2:10
1:	<NA>	<NA>	<NA>	<NA>
2:	<NA>	<NA>	<NA>	<NA>
3:	<NA>	<NA>	<NA>	<NA>
4:	<NA>	<NA>	<NA>	<NA>
5:	<NA>	<NA>	<NA>	<NA>
6:	<NA>	<NA>	<NA>	<NA>
	02:64:fb:68:52:e6	00:14:bf:b1:97:81	00:14:bf:b1:97:81	00:30:bd:f8:7f:c5
1:	<NA>	<NA>	<NA>	<NA>
2:	<NA>	<NA>	<NA>	<NA>
3:	<NA>	<NA>	<NA>	<NA>
4:	<NA>	<NA>	<NA>	<NA>
5:	<NA>	<NA>	<NA>	<NA>

6:	<NA>	<NA>	<NA>	<NA>
	00:30:bd:f8:7f:c5	00:04:0e:5c:23:fc	00:0f:a3:39:e0:4b	00:30:bd:f8:7f:c5
1:	<NA>	<NA>	<NA>	<NA>
2:	<NA>	<NA>	<NA>	<NA>
3:	<NA>	<NA>	<NA>	<NA>
4:	<NA>	<NA>	<NA>	<NA>
5:	<NA>	<NA>	<NA>	<NA>
6:	<NA>	<NA>	<NA>	<NA>
	00:0f:a3:39:e0:4b	00:30:bd:f8:7f:c5	00:14:bf:b1:97:8a	00:14:bf:b1:97:90
1:	<NA>	<NA>	<NA>	<NA>
2:	<NA>	<NA>	<NA>	<NA>
3:	<NA>	<NA>	<NA>	<NA>
4:	<NA>	<NA>	<NA>	<NA>
5:	<NA>	<NA>	<NA>	<NA>
6:	<NA>	<NA>	<NA>	<NA>
	00:14:bf:3b:c7:c6	00:14:bf:b1:97:81	00:14:bf:b1:97:81	00:14:bf:3b:c7:c6
1:	<NA>	<NA>	<NA>	<NA>
2:	<NA>	<NA>	<NA>	<NA>
3:	<NA>	<NA>	<NA>	<NA>
4:	<NA>	<NA>	<NA>	<NA>
5:	<NA>	<NA>	<NA>	<NA>
6:	<NA>	<NA>	<NA>	<NA>
	00:0f:a3:39:e2:10	00:14:bf:b1:97:8a	00:e0:63:82:8b:a9	00:e0:63:82:8b:a9
1:	<NA>	<NA>	<NA>	<NA>
2:	<NA>	<NA>	<NA>	<NA>
3:	<NA>	<NA>	<NA>	<NA>
4:	<NA>	<NA>	<NA>	<NA>
5:	<NA>	<NA>	<NA>	<NA>
6:	<NA>	<NA>	<NA>	<NA>
	00:e0:63:82:8b:a9	00:0f:a3:39:e1:c0	02:37:fd:3b:54:b5	02:37:fd:3b:54:b5
1:	<NA>	<NA>	<NA>	<NA>
2:	<NA>	<NA>	<NA>	<NA>
3:	<NA>	<NA>	<NA>	<NA>
4:	<NA>	<NA>	<NA>	<NA>
5:	<NA>	<NA>	<NA>	<NA>
6:	<NA>	<NA>	<NA>	<NA>
	02:00:42:55:31:00	00:0f:a3:39:dd:cd	02:37:fd:3b:54:b5	00:0f:a3:39:dd:cd
1:	<NA>	<NA>	<NA>	<NA>
2:	<NA>	<NA>	<NA>	<NA>
3:	<NA>	<NA>	<NA>	<NA>
4:	<NA>	<NA>	<NA>	<NA>
5:	<NA>	<NA>	<NA>	<NA>
6:	<NA>	<NA>	<NA>	<NA>
	02:2e:58:22:f1:ac	02:2e:58:22:f1:ac	02:00:42:55:31:00	02:42:1c:4e:b5:c0
1:	<NA>	<NA>	<NA>	<NA>

```

2:      <NA>      <NA>      <NA>      <NA>
3:      <NA>      <NA>      <NA>      <NA>
4:      <NA>      <NA>      <NA>      <NA>
5:      <NA>      <NA>      <NA>      <NA>
6:      <NA>      <NA>      <NA>      <NA>
  00:14:bf:b1:97:8a 00:14:bf:b1:97:90 02:0a:3d:06:94:88 00:0f:a3:39:dd:cd
1:      <NA>      <NA>      <NA>      <NA>
2:      <NA>      <NA>      <NA>      <NA>
3:      <NA>      <NA>      <NA>      <NA>
4:      <NA>      <NA>      <NA>      <NA>
5:      <NA>      <NA>      <NA>      <NA>
6:      <NA>      <NA>      <NA>      <NA>
  02:5c:e0:50:49:de 02:5c:e0:50:49:de 00:0f:a3:39:dd:cd 00:0f:a3:39:dd:cd
1:      <NA>      <NA>      <NA>      <NA>
2:      <NA>      <NA>      <NA>      <NA>
3:      <NA>      <NA>      <NA>      <NA>
4:      <NA>      <NA>      <NA>      <NA>
5:      <NA>      <NA>      <NA>      <NA>
6:      <NA>      <NA>      <NA>      <NA>
  02:4f:99:43:30:cd 02:5c:e0:50:49:de 02:b7:00:bb:a9:35 02:b7:00:bb:a9:35
1:      <NA>      <NA>      <NA>      <NA>
2:      <NA>      <NA>      <NA>      <NA>
3:      <NA>      <NA>      <NA>      <NA>
4:      <NA>      <NA>      <NA>      <NA>
5:      <NA>      <NA>      <NA>      <NA>
6:      <NA>      <NA>      <NA>      <NA>
  00:14:bf:b1:97:90
1:      <NA>
2:      <NA>
3:      <NA>
4:      <NA>
5:      <NA>
6:      <NA>

```

## 2.)

Compare the size of two data structures: the data frame created in Section 1.2 and the data frame created in the previous problem.

- Which uses less memory?

```
object.size(offline)
```

```
69549552 bytes
```

```
object.size(offline_alt)
```

114691968 bytes

- What are the dimensions of each?

```
dim(offline)
```

```
[1] 914951      9
```

```
dim(offline_alt)
```

```
[1] 146080     90
```

- How might this change with different numbers of devices in the building?

*Columns will expand out drastically with more devices.*

- Different number of signals from the less commonly detected devices?

*The more devices we have the more the columns in the alternative approach will be filled with NAs, thus bloating the object size significantly.*

### 3.)

Compare the total time it takes to read the raw data and create the data frame, for the two approaches described in Section 1.2.

```
file <- file_offline

fn_read_data <- function(file, processFun, sample = F, samp.size = 100 ) {
  start_time <- Sys.time()

  lines <- read_lines(file)
  valid_lines <- lines[ validLines(lines) ]

  n <- length(valid_lines)

  if(sample) {
    samp <- sample(n, samp.size, replace = F)

    valid_lines <- valid_lines[samp]
  }

  res <- processFun(valid_lines) # throw away

  return(Sys.time() - start_time)
}
```

```
fn_read_data(file_offline, processLine)
```

Time difference of 3.260024 secs

```
fn_read_data(file_offline, parseLine)
```

Time difference of 35.59798 secs

Do this for different size subsets of the data (chosen at random) and draw a curve of the time against input size for each of the approaches.

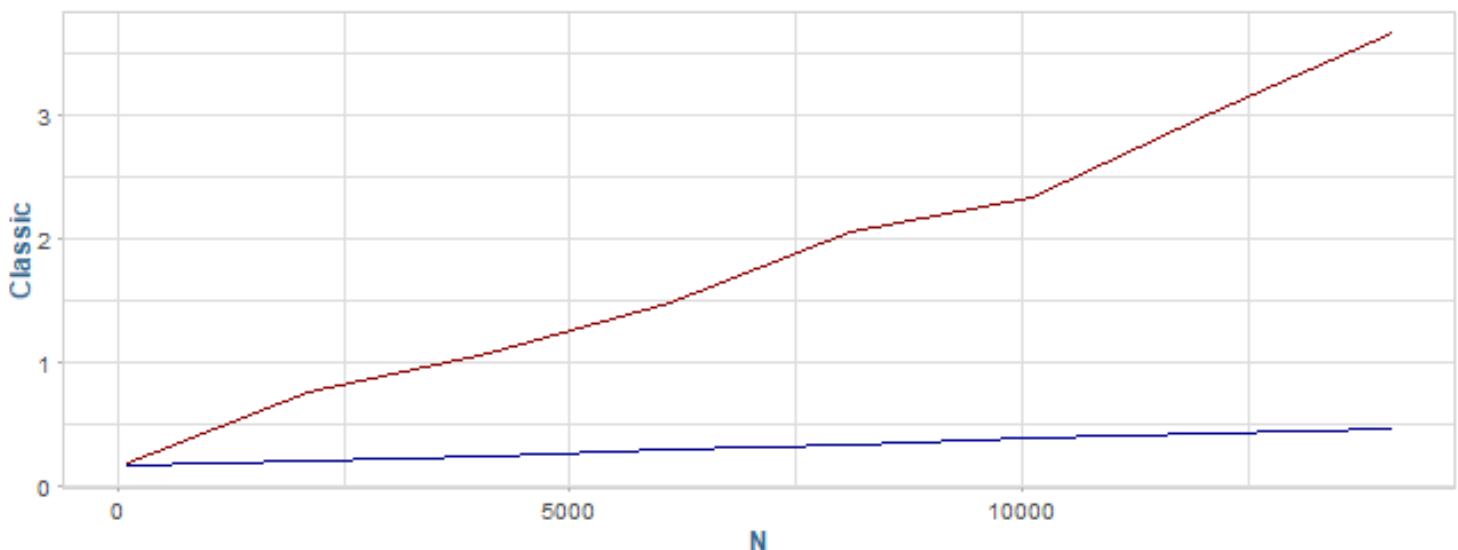
```
sample_sizes <- seq( from = 100, to = 15000, by = 2000)

times_classic <- sapply(sample_sizes, function(samp) {
  fn_read_data(file_offline, processLine, sample = T, samp.size = samp)
})

times_alt <- sapply(sample_sizes, function(samp) {
  fn_read_data(file_offline, parseLine, sample = T, samp.size = samp)
})

results <- data.table(N = sample_sizes, Classic = times_classic, alt = times_alt)

ggplot(results) +
  geom_line(aes(N, Classic), col = "darkblue") +
  geom_line(aes(N, alt), col = "darkred")
```



Also, comment on the memory and speed for the two approaches.

*The alt approach is substantially worse in all aspects.*



#### 4.)

Examine the time variable in the offline data. Any change over time in the characteristics of the signal caused by, e.g., reduced battery power in the measuring devices as time goes by, or measurements taken on different days may be made by different people with different levels of accuracy. Also, examination of time can give insights into how the experiment was carried out.

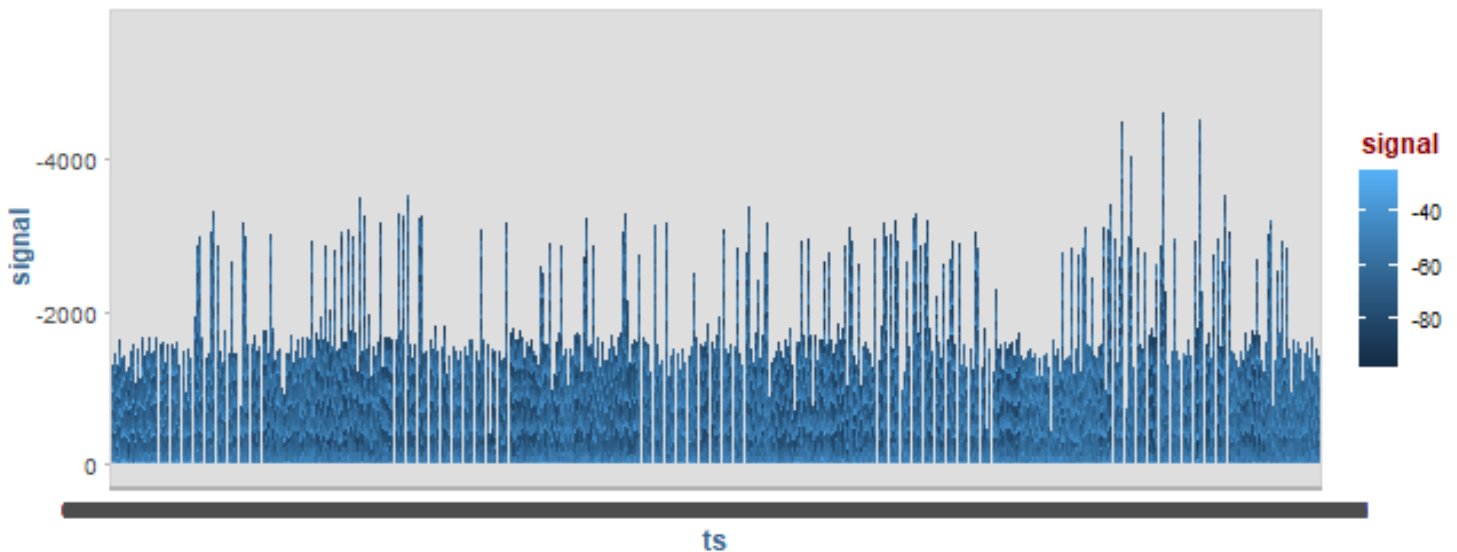
Were the positions close to each other measured at similar times?

Do you see any change in the signal strength variable or mean over time?

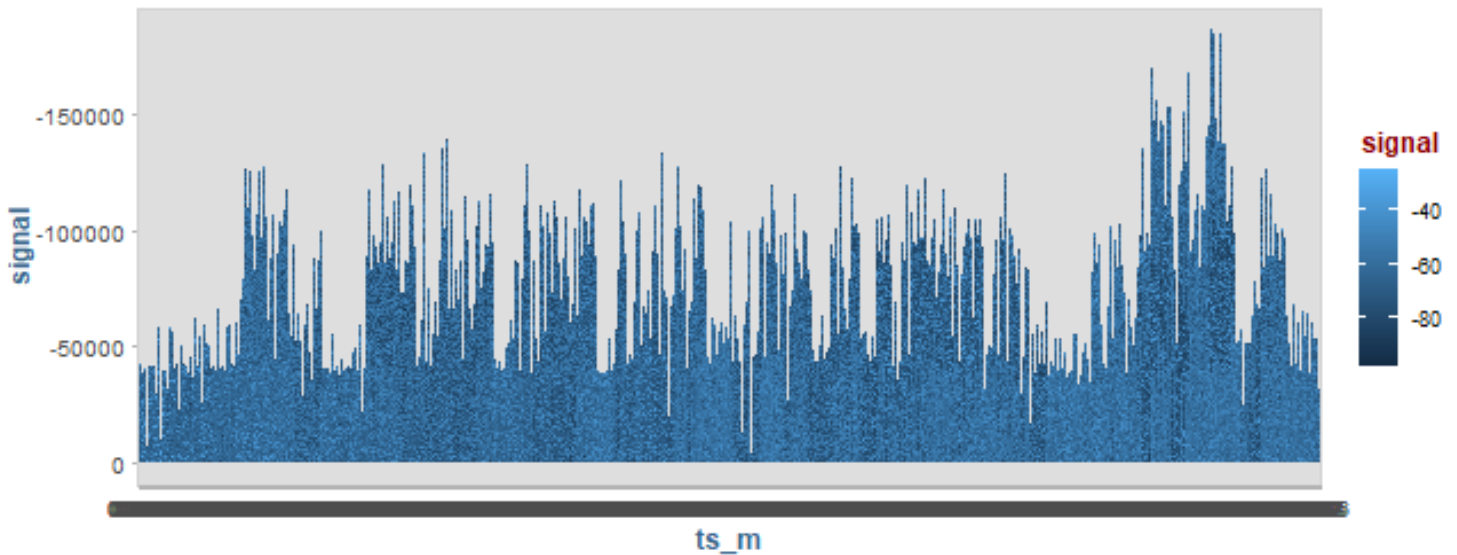
Try controlling for other variables that might affect this relationship.

```
offline_copy <- offline
offline_copy$ts <- strptime(offset_copy$time, format="%H:%M:%S")
offline_copy$ts_m <- strptime(offset_copy$time, format="%H:%M")
offline_copy$ts_h <- strptime(offset_copy$time, format="%H")
```

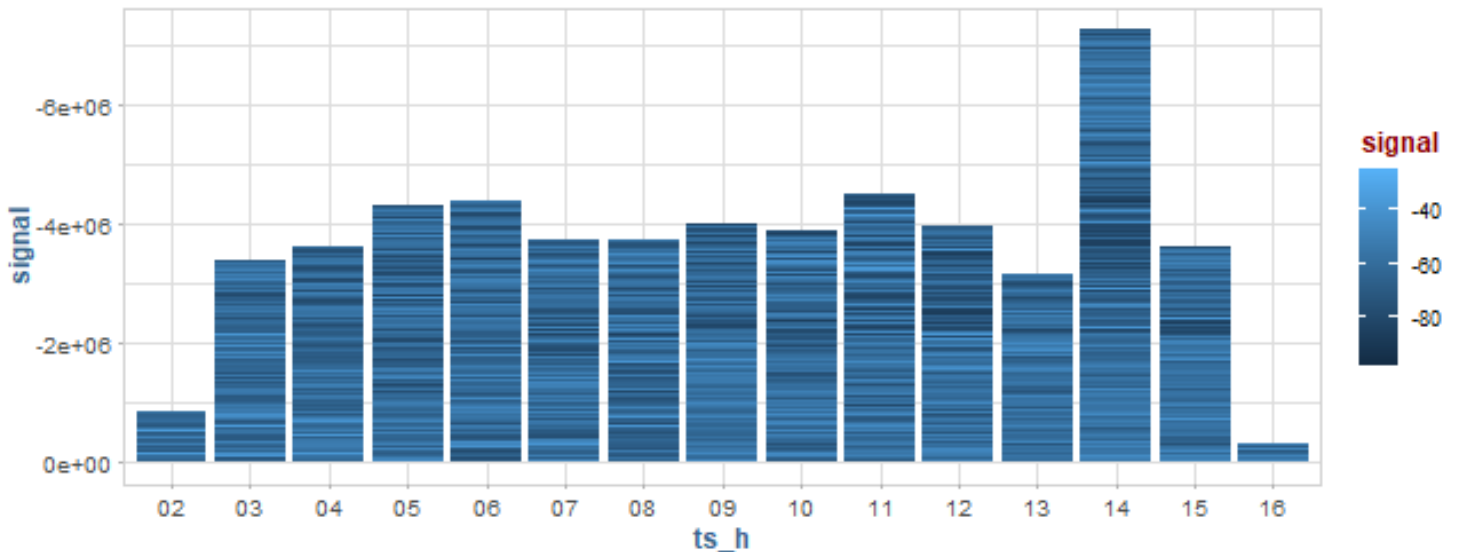
```
ggplot(offset_copy, aes(ts, signal, fill = signal)) +
  geom_bar(stat = "identity") +
  scale_y_reverse()
```



```
ggplot(offset_copy, aes(ts_m, signal, fill = signal)) +
  geom_bar(stat = "identity") +
  scale_y_reverse()
```



```
ggplot(offline_copy, aes(ts_h, signal, fill = signal)) +
  geom_bar(stat = "identity") +
  scale_y_reverse()
```



## 5.)

Write the `readData` function described in Section 1.3.4. The arguments to this function are the file name and the MAC address to retain, `subKMacs`. Determine whether these parameters should have default values or not. The return value is data frame described in section 1.3. Use the `findGlobals()` function available in *codetools* to check that the function is not relying on any global variables.

```
readData <- function(file, submacs = macs) {
```

```

lines <- read_lines(file)

valid_lines <- lines[ validLines(lines) ]

processed_lines <- lapply(valid_lines, processLine)

data <- as.data.table(do.call("rbind", processed_lines),
                      stringsAsFactors = F)

names(data) <- c("time", "scanMac", "posX", "posY", "posZ",
                 "orientation", "mac", "signal",
                 "channel", "type")

numVars <- c("time", "posX", "posY", "posZ",
             "orientation", "signal")

data[, (numVars) := lapply(.SD, as.numeric), .SDcols = numVars]

data <- data[ data$type == 3, ]
data[, type := NULL]

data[, rawTime := time]
data[, time := time/1000]
class(data$time) = c("POSIXt", "POSIXct")

# drop scanMac & posZ
data[, `:=`(scanMac = NULL, posZ = NULL)]

data$angle = roundOrientation(data$orientation)

data$channel = NULL

data$posXY <- paste(data$posX, data$posY, sep = "-")

return(data[mac %in% submacs])
}

```

## 6.)

In section 1.4.1 we calculated measures of center and location for the signal strenghts at each location x angle x access point combination (see fig 1.9 for example).

Another possible summary statistic we can calculate is the Kolmogorov-Smirnov test-statistic for normality. If the signal strenghts are roughly normal, then we expect the p-values to have a uniform distribution. This

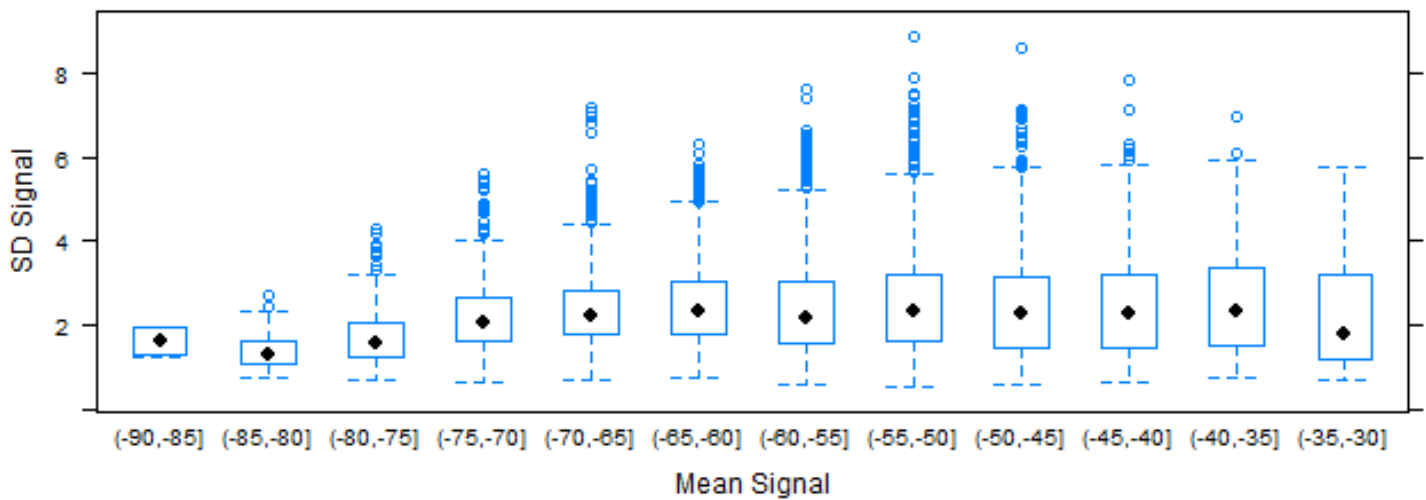
leads to about 5% of the p-values for the 8000 tests to fall below 0.05.

```
signalSummary <-
  lapply(byLocAngleAP,
    function(oneLoc) {
      ans = oneLoc[1, ]
      ans$medSignal = median(oneLoc$signal)
      ans$avgSignal = mean(oneLoc$signal)
      ans$num = length(oneLoc$signal)
      ans$sdSignal = sd(oneLoc$signal)
      ans$iqrSignal = IQR(oneLoc$signal)
      ans
    })

offlineSigSummary <- do.call("rbind", signalSummary)

breaks <- seq(-90, -30, by = 5)

bwplot(sdSignal ~ cut(avgSignal, breaks = breaks),
  data = offlineSummary,
  subset = mac != "00:0f:a3:39:dd:cd",
  xlab = "Mean Signal", ylab = "SD Signal")
```



```
by_pos_angle_mac <- offlineSigSummary[, .(AvgSignal = mean(signal)), by = list(mac, angle, posX)]

with(by_pos_angle_mac, ks.test(AvgSignal, "pnorm")) # Kolmogorov-Smirnov test-statistic
```

Warning in ks.test(AvgSignal, "pnorm"): ties should not be present for the Kolmogorov-Smirnov test

One-sample Kolmogorov-Smirnov test

```
data: AvgSignal
D = 1, p-value < 2.2e-16
alternative hypothesis: two-sided
by_pos_angle <- offlineSigSummary[, .(AvgSignal = mean(signal)), by = list(angle, posXY)]
with(by_pos_angle, ks.test(AvgSignal, "pnorm")) # Kolmogorov-Smirnov test-statistic
```

Warning in ks.test(AvgSignal, "pnorm"): ties should not be present for the Kolmogorov-Smirnov test

One-sample Kolmogorov-Smirnov test

```
data: AvgSignal
D = 1, p-value < 2.2e-16
alternative hypothesis: two-sided
by_mac <- offline[, .(AvgSignal = mean(signal)), by = list(mac)]
with(by_mac, ks.test(AvgSignal, "pnorm")) # Kolmogorov-Smirnov test-statistic
```

One-sample Kolmogorov-Smirnov test

```
data: AvgSignal
D = 1, p-value < 2.2e-16
alternative hypothesis: two-sided
```

## 7.)

Write the `surfaceSS()` function that creates plots such as those in Figure 1.10. This function takes 3 arguments: data for the offline summary data frame, `mac` and `angle`. The parameters `mac` and `angle` are used to specify which MAC address and angle are to be selected from the data for smoothing and plotting.

```
reshapeSS <- function(data,
                      varSignal = "signal",
                      keepVars = c("posXY", "posX", "posY"),
                      sampleAngle = F) {

  if(sampleAngle)
    data <- data[angle == sample(data$angle, size = 1), ]

  byLocation <- with(data,
                    by(data, list(posXY),
```

```

    function(x) {
      ans <- x[1, ..keepVars]
      avgSS <- tapply(x$signal, x$mac, mean)
      y = matrix(avgSS, nrow = 1, dimnames = list(ans$posXY, names(avgSS)))
      cbind(ans, y)
    })

newDataSS <- do.call("rbind", byLocation)

col_names <- colnames(newDataSS)
to_change <- !(col_names %in% keepVars)

n_cols <- length(col_names)
start <- length(keepVars)

colnames(newDataSS)[to_change] <- sapply(col_names[to_change], function(col) {
  n <- nchar(col)
  substr(col, n - 2, n)
})

newDataSS[, start:ncol(newDataSS)] <- round(newDataSS[, start:ncol(newDataSS)])

return(newDataSS)
}

```

## 8.)

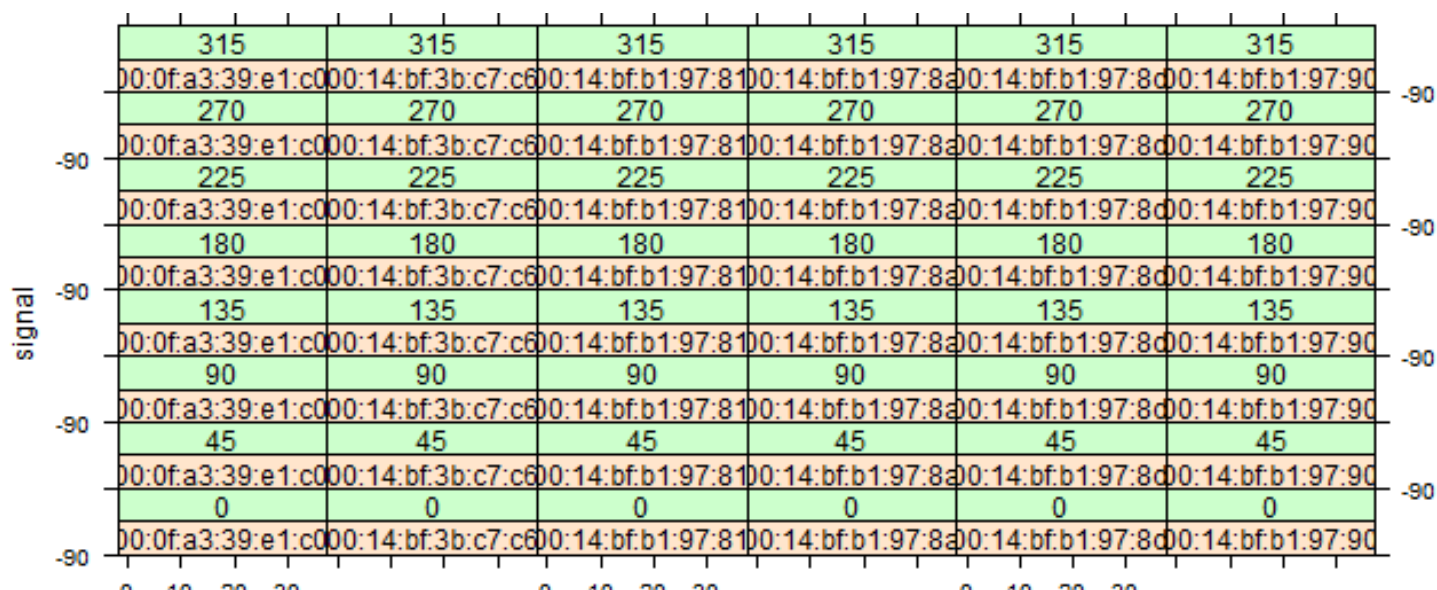
Consider the scatter plots in Figure 1.11. There appear to be curvature in the signal strength-distance relationship. Does a log transformation improve this relationship, i.e., make it linear?

```

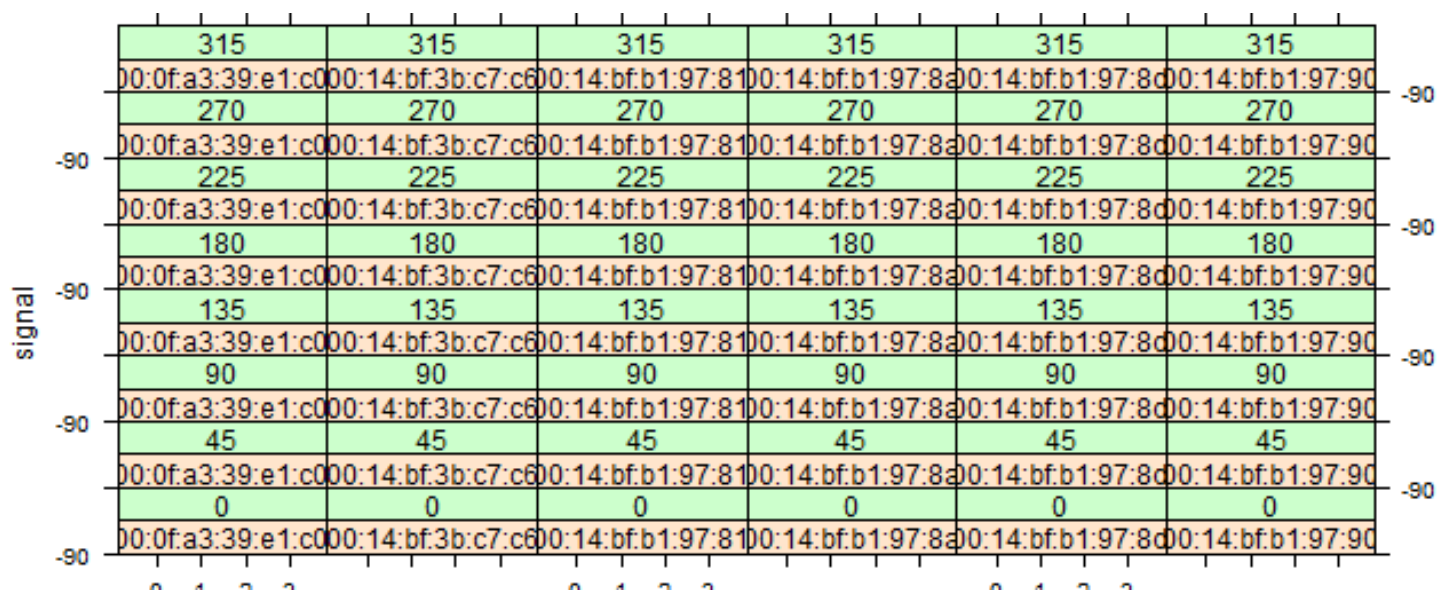
offlineSummary$dist <- sqrt(diffs[, 1]^2 + diffs[, 2]^2)
offlineSummary$log_dist <- log(offlineSummary$dist)

xyplot(signal ~ dist | factor(mac) + factor(angle),
  data = offlineSummary, pch = 19, cex = 0.3,
  xlab = "distance")

```

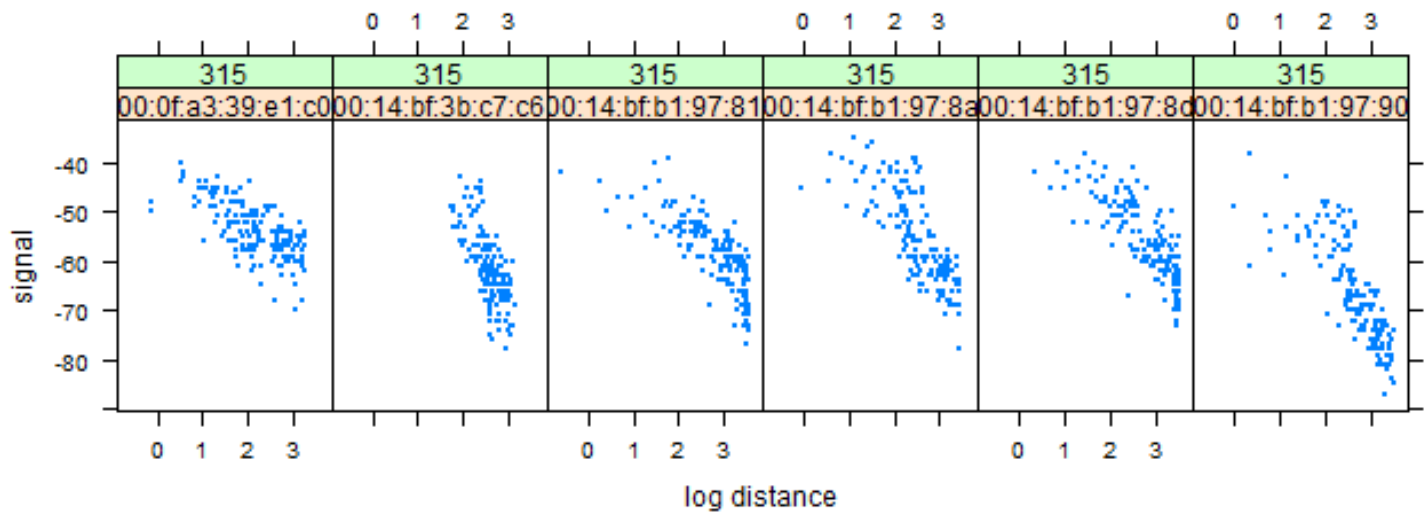


```
xyplot(signal ~ log_dist | factor(mac) + factor(angle),
  data = offlineSummary, pch = 19, cex = 0.3,
  xlab = "log distance")
```

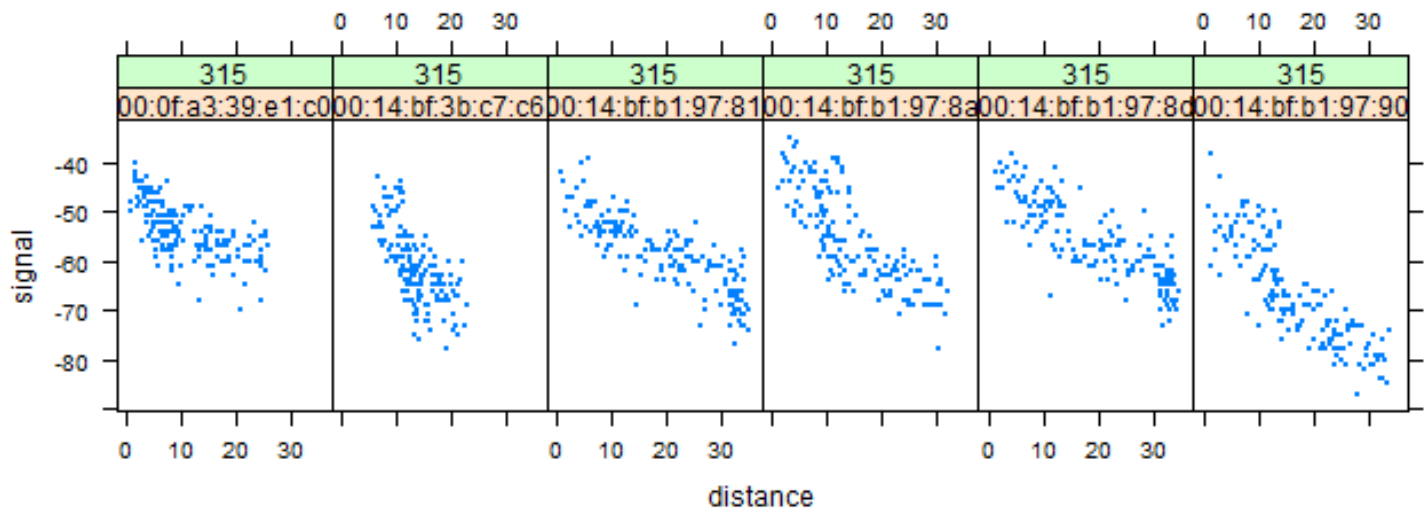


```
xyplot(signal ~ log_dist | factor(mac) + factor(angle),
  data = offlineSummary[angle == 315], pch = 19, cex = 0.3,
  xlab = "log distance")
```





```
xyplot(signal ~ dist | factor(mac) + factor(angle),
  data = offlineSummary[angle == 315], pch = 19, cex = 0.3,
  xlab = "distance")
```



*The log transform removes a bit of the curvature, but not a great deal.*

## 9.)

The floor plan for the building (see Figure 1.1) shows 65 access points. However, the data contain 7 access points with roughly the expected number of signals (166 locations x 8 orientations x 100 replications = 146,080 measurements).

With the signal strength seen in the heat maps of Figure 1.10), we matched the access points to the corresponding MAC addresses. However, two of the MAC addresses seem to be for the same access



point 00:0f:a3:39:e1:c0 and to eliminate the 00:0f:a3:39:dd:cd address.

Conduct a more thorough data analysis into these two MAC addresses. Did we make the correct decision? Does swapping out the one we kept for the one we discarded improve the prediction?

```
subMacs <- names(sort(table(offline$mac), decreasing = T)) # all sub macs

angles <- seq(0, by = 45, length = 8) # all angles

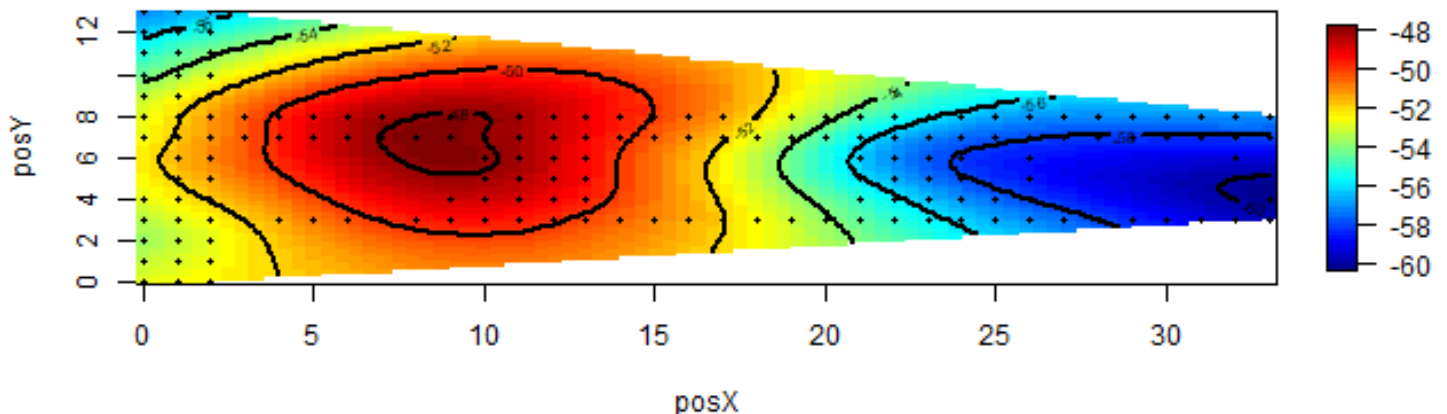
surfaceSS <- function(data, filter_mac, filter_angle) {
  oneAPAngle <- data[mac == filter_mac & angle == filter_angle]

  smothSS <- Tps(oneAPAngle[, c("posX", "posY")],
                 oneAPAngle$avgSignal)

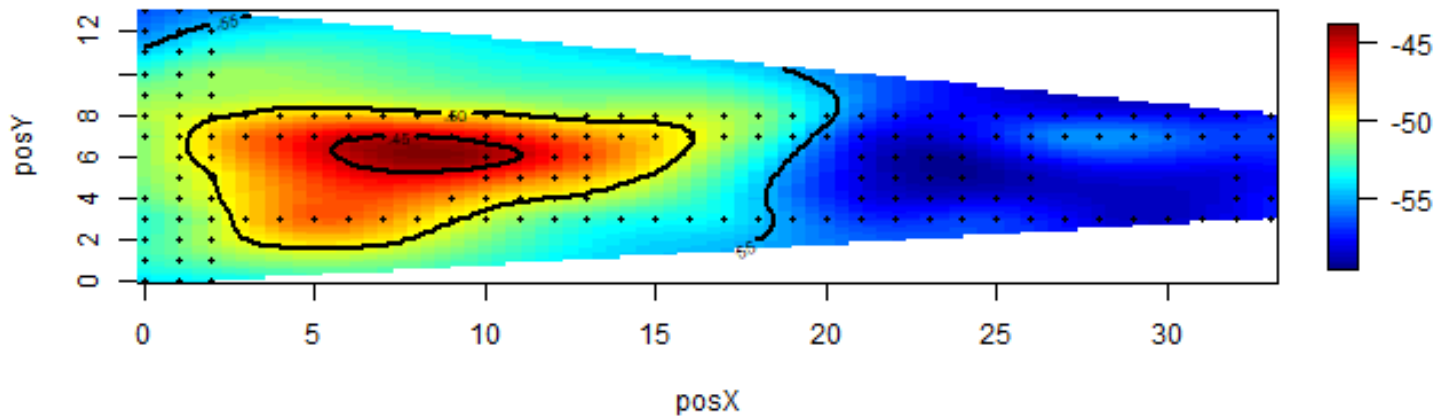
  vizSmooth <- predictSurface(smothSS)

  plot.surface(vizSmooth, type = "C")
  points(oneAPAngle$posX, oneAPAngle$posY, pch=19, cex = 0.5)
}
```

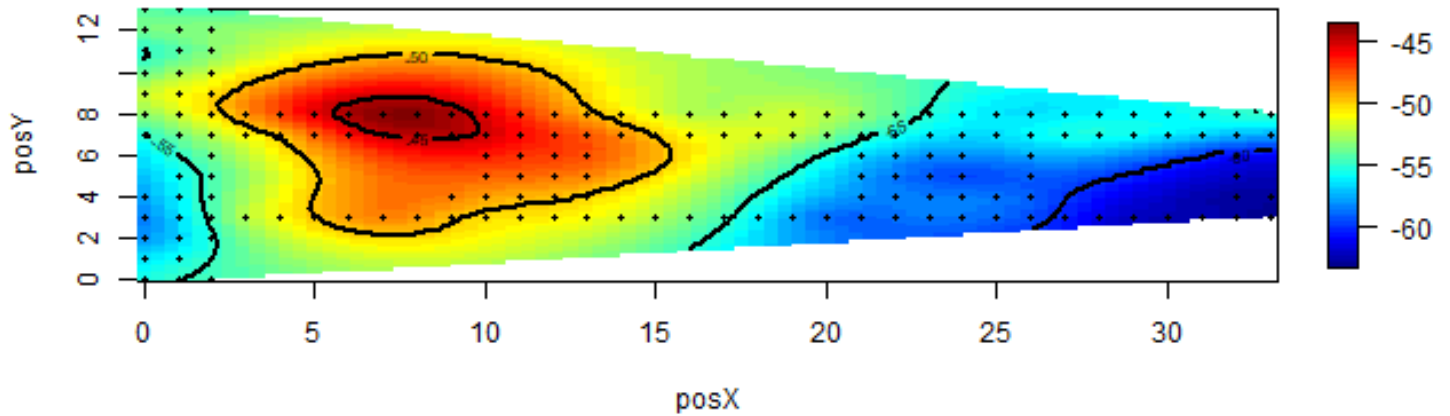
```
surfaceSS(offlineSummary, subMacs[1], angles[1])
```



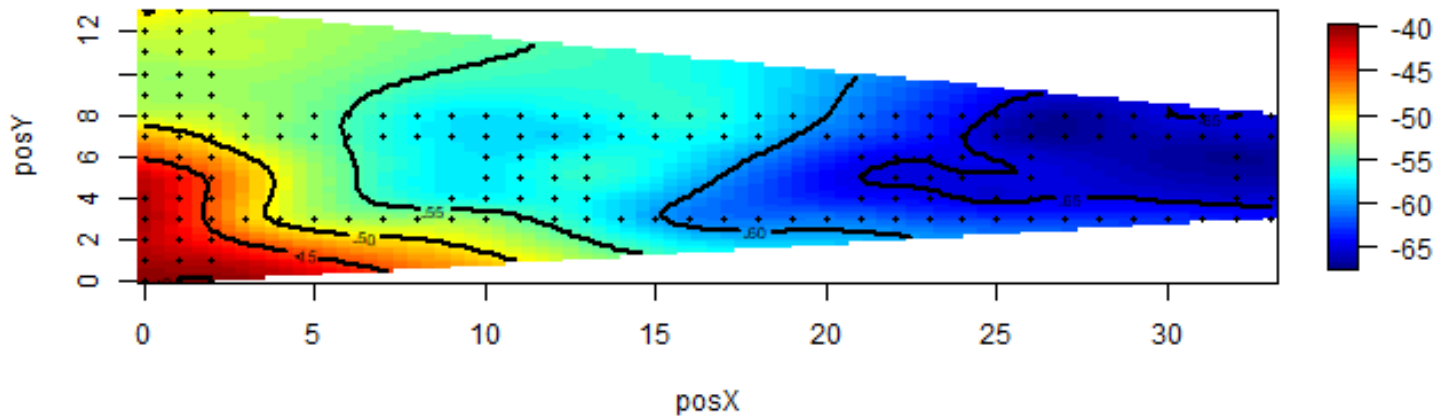
```
surfaceSS(offlineSummary, subMacs[1], angles[5])
```



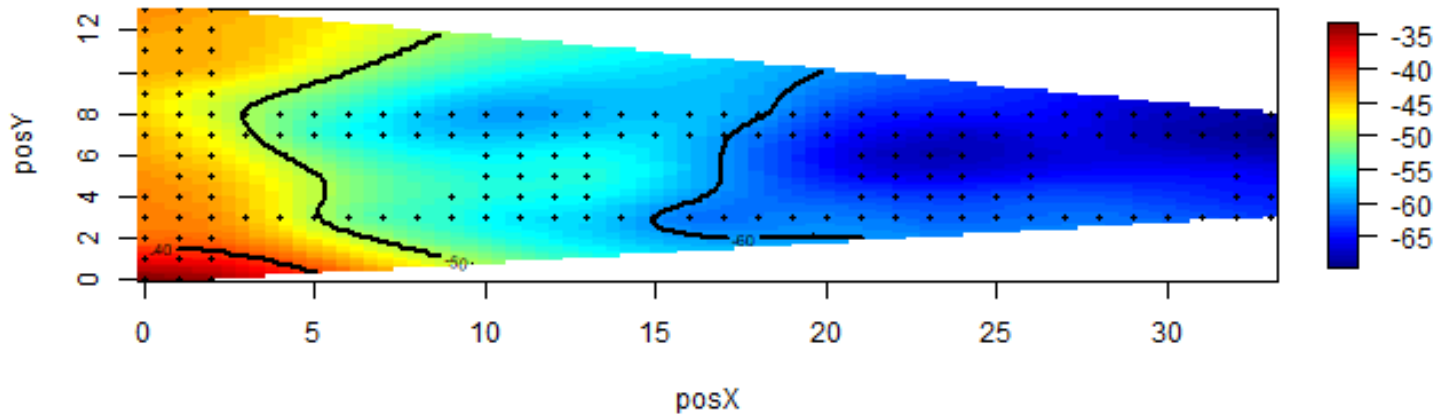
```
surfaceSS(offlineSummary, subMacs[1], angles[7])
```



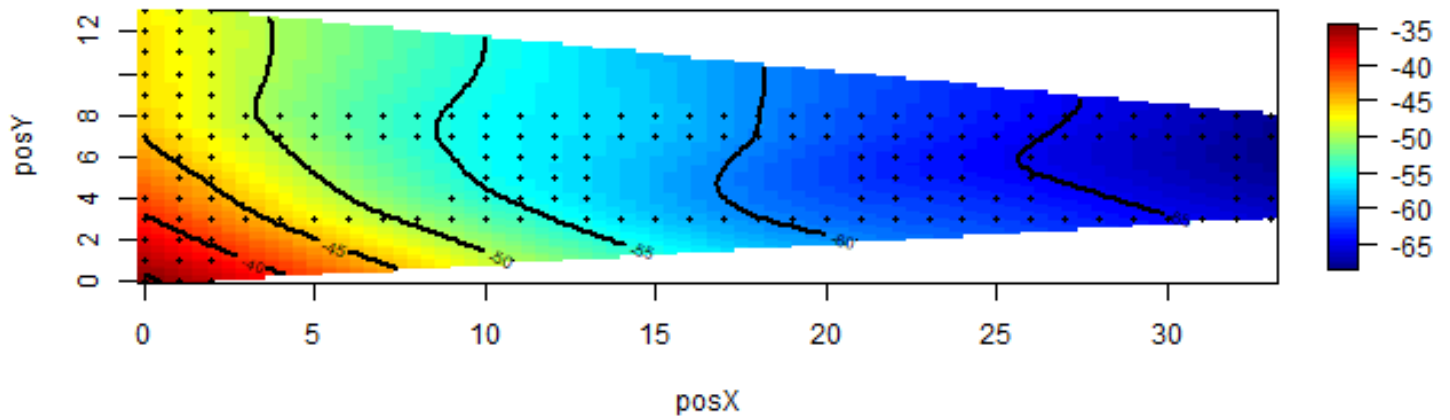
```
surfaceSS(offlineSummary, subMacs[3], angles[2])
```



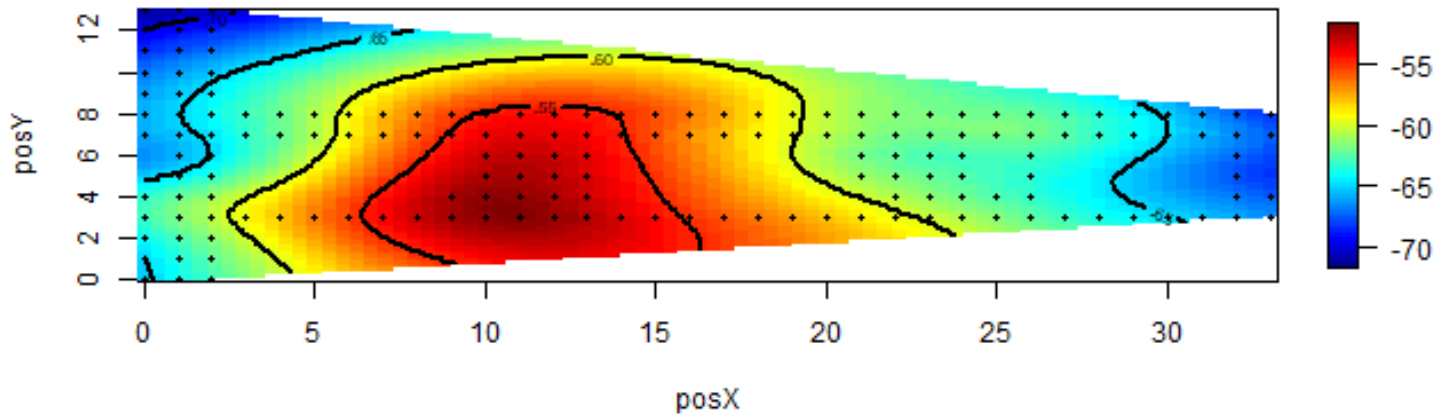
```
surfaceSS(offlineSummary, subMacs[3], angles[5])
```



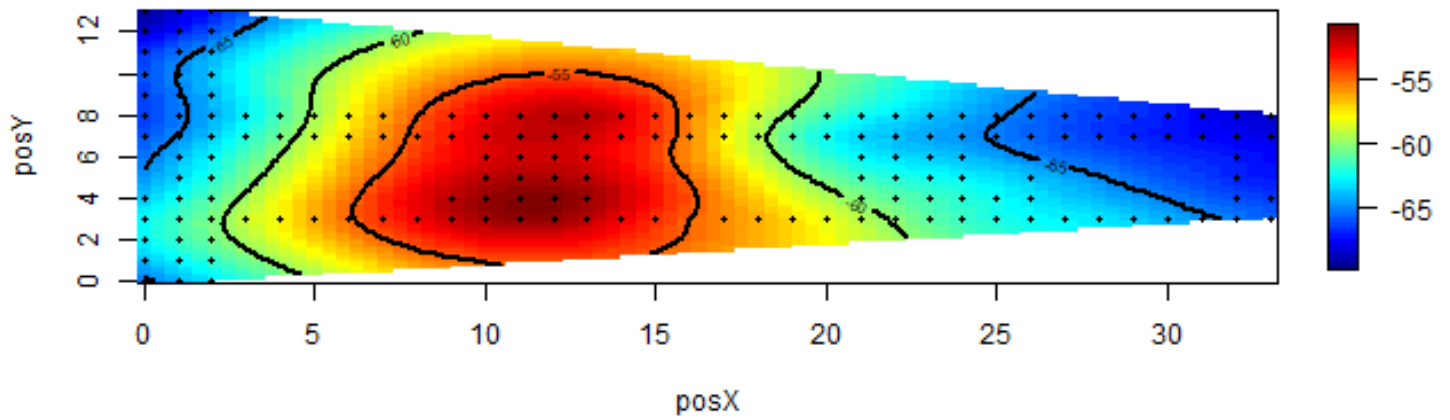
```
surfaceSS(offlineSummary, subMacs[3], angles[7])
```



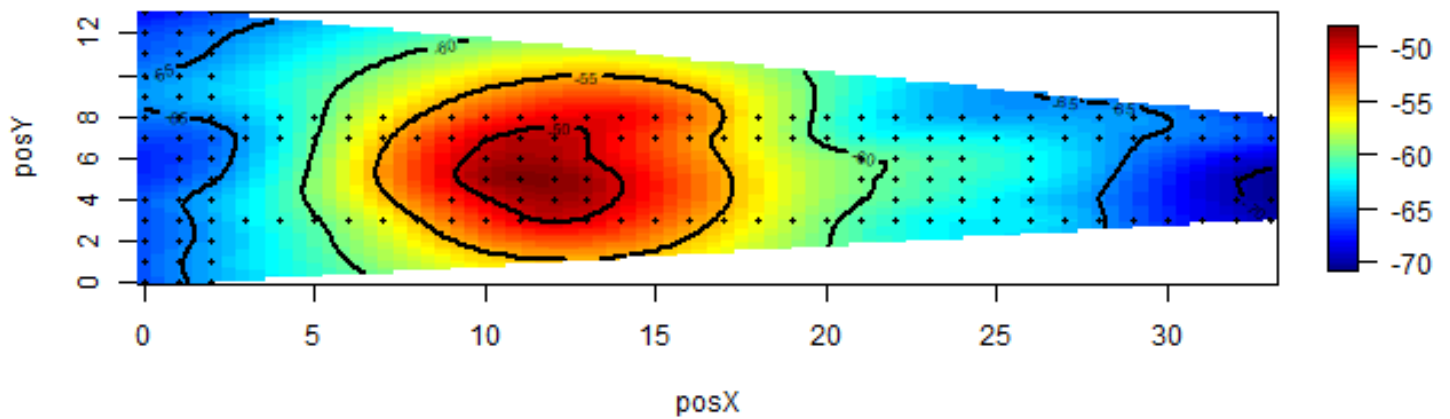
```
surfaceSS(offlineSummary, subMacs[4], angles[2])
```



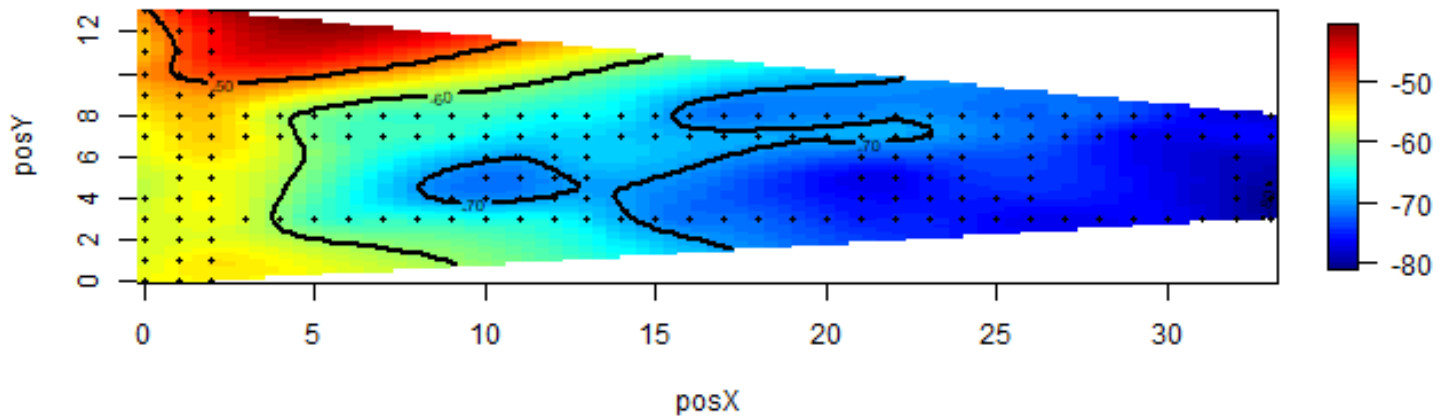
```
surfaceSS(offlineSummary, subMacs[4], angles[5])
```



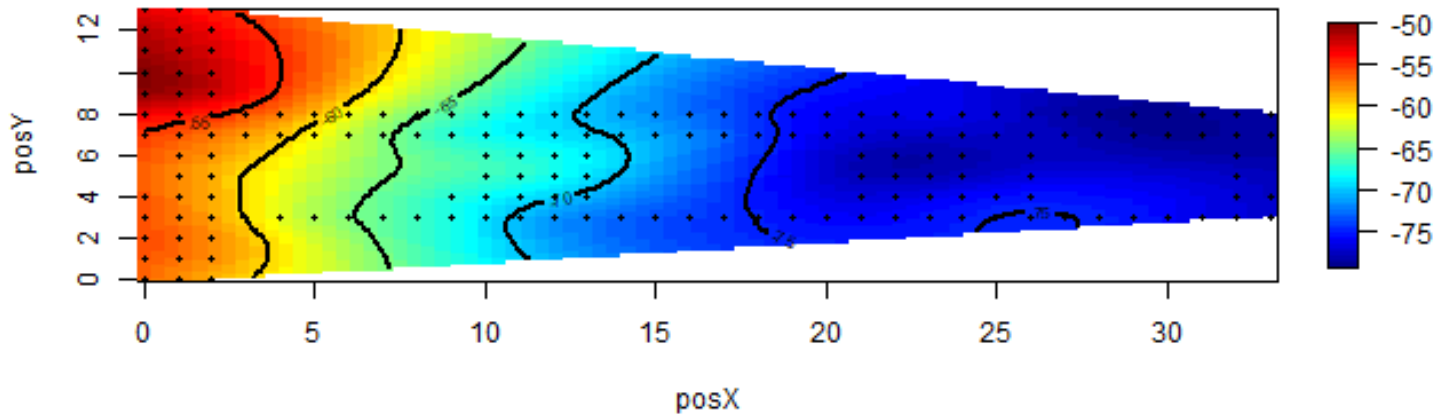
```
surfaceSS(offlineSummary, subMacs[4], angles[7])
```



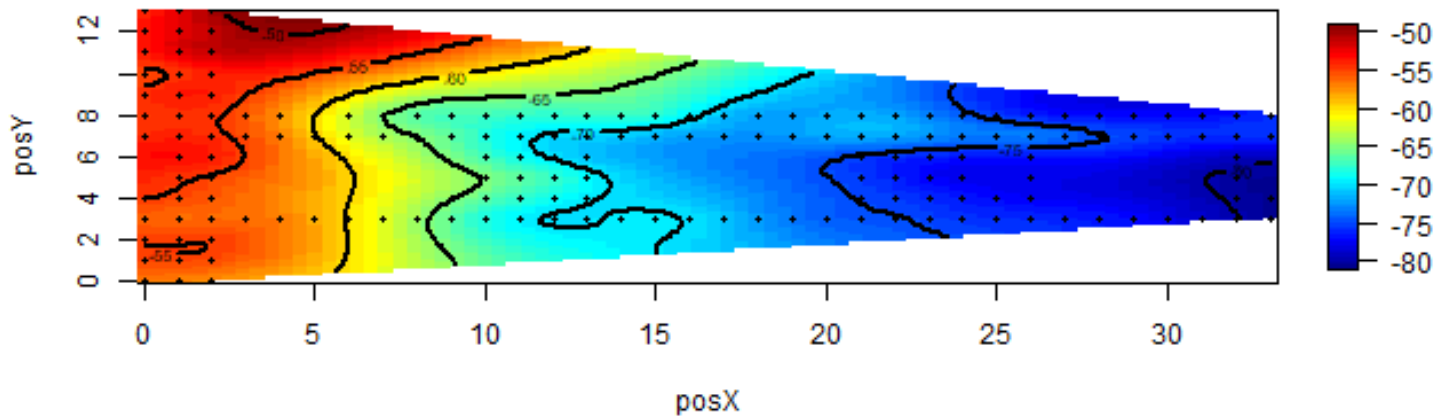
```
surfaceSS(offlineSummary, subMacs[5], angles[2])
```



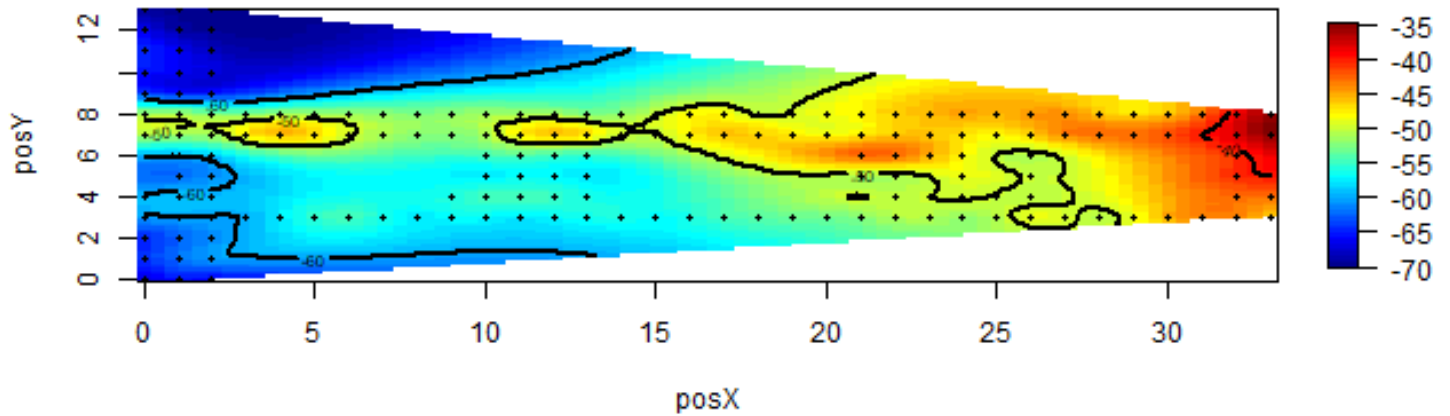
```
surfaceSS(offlineSummary, subMacs[5], angles[5])
```



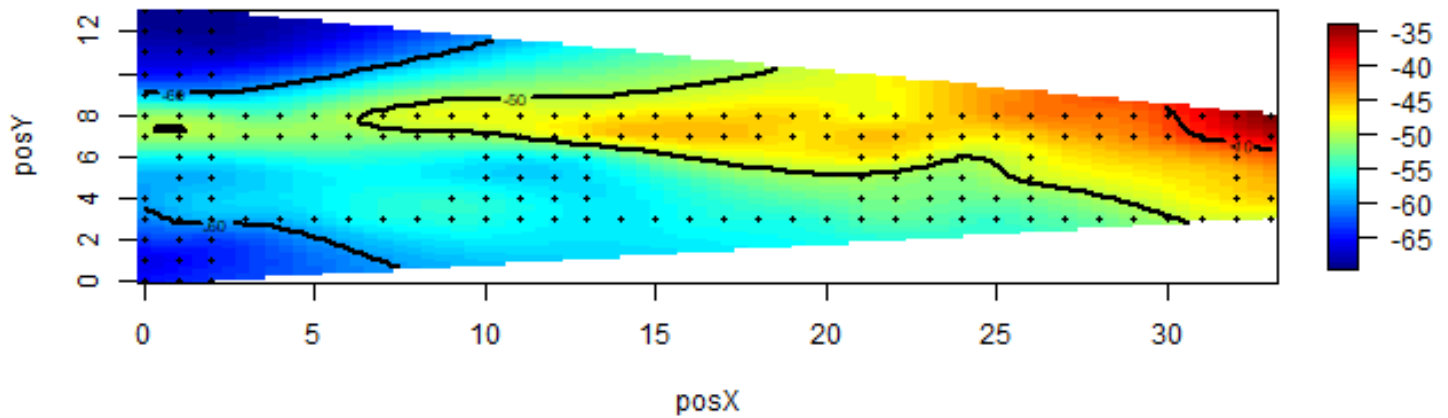
```
surfaceSS(offlineSummary, subMacs[5], angles[7])
```



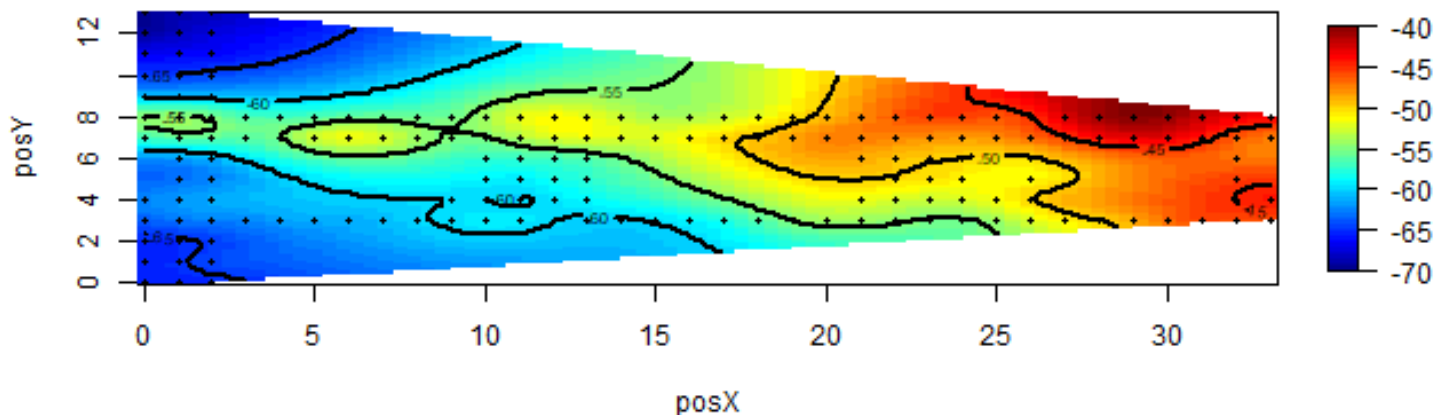
```
surfaceSS(offlineSummary, subMacs[6], angles[2])
```



```
surfaceSS(offlineSummary, subMacs[6], angles[5])
```



```
surfaceSS(offlineSummary, subMacs[6], angles[7])
```



## 10.)

Write the `selectTrain()` function described in Section 1.5.2. This function has 3 parameters: `angleNewObs`, the angle of the new observation, `signals`, the training data, i.e., data in the format of `offlineSummary`; and `m`, the number of angles to include from signals.

The function returns a data frame that matches `trainSS`, i.e., `selectTrain()` calls `reshapeSS()`.

```
reshapeSS <- function(data,
  varSignal = "signal",
  keepVars = c("posXY", "posX", "posY"),
  sampleAngle = F) {
```



```

if(sampleAngle)
  data <- data[angle == sample(data$angle, size = 1), ]

byLocation <- with(data,
  by(data, list(posXY),
    function(x) {
      ans <- x[1, ..keepVars]
      avgSS <- tapply(x$signal, x$mac, mean)
      y = matrix(avgSS, nrow = 1, dimnames = list(ans$posXY, names(avgSS)))
      cbind(ans, y)
    })

newDataSS <- do.call("rbind", byLocation)

col_names <- colnames(newDataSS)
to_change <- !(col_names %in% keepVars)

n_cols <- length(col_names)
start <- length(keepVars)

colnames(newDataSS)[to_change] <- sapply(col_names[to_change], function(col) {
  n <- nchar(col)
  substr(col, n - 2, n)
})

newDataSS[, start:ncol(newDataSS)] <- round(newDataSS[, start:ncol(newDataSS)])

return(newDataSS)
}

```

## 11.)

We use Euclidean distance to find the distance between the signal strength vectors. However, Euclidean distance is not robust in that it is sensitive to outliers. Consider other metrics such as the  $L_1$  distance, i.e., the absolute value of the difference. Modify the findNN() functions in sections 1.5.3 to use this alternative distance.

```

findNN_l1 <- function(newSignal, trainSubset) {
  diffs <- apply(trainSubset[, 4:9], 1,
    function(x) abs(x - newSignal))
  dists <- apply(diffs, 2, function(x) sum(x))
  closest <- order(dists)
  return(trainSubset[closest, 1:3 ])
}

```

```
predXY_l1 <- function(newSignals, newAngles, trainData,
                      numAngles = 1, k = 3) {

  closeXY <- list(length = nrow(newSignals))

  for(i in 1:nrow(newSignals)) {
    trainSS <- selectTrain(newAngles[i], trainData, m = numAngles)

    closeXY[[i]] =
      findNN_l1(newSignal = as.numeric(newSignals[i, ]), trainSS)
  }

  estXY = lapply(closeXY,
                  function(x) sapply(x[, 2:3],
                                     function(x) mean(x[1:k]))))

  estXY <- do.call("rbind", estXY)

  return(estXY)
}

estXYk1_l1 <- predXY_l1(newSignals = onlineSummary[, 6:11],
                       newAngles = onlineSummary[, 4],
                       offlineSummary, numAngles = 3, k = 1)

estXYk3_l1 <- predXY_l1(newSignals = onlineSummary[, 6:11],
                       newAngles = onlineSummary[, 4],
                       offlineSummary, numAngles = 3, k = 3)

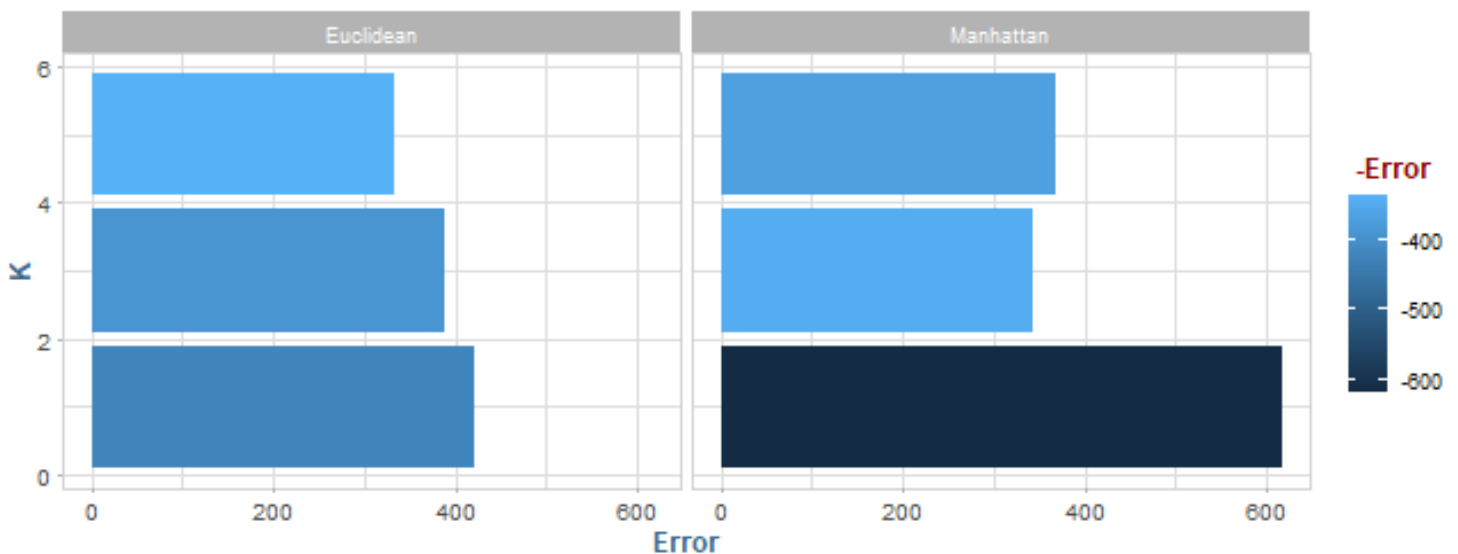
estXYk5_l1 <- predXY_l1(newSignals = onlineSummary[, 6:11],
                       newAngles = onlineSummary[, 4],
                       offlineSummary, numAngles = 3, k = 5)

error_table <- data.table(K = c(1, 3, 5),
                          Error = c(calcError(estXYk1, actualXY),
                                     calcError(estXYk3, actualXY),
                                     calcError(estXYk5, actualXY)),
                          Method = "Euclidean")

error_table_l1 <- data.table(K = c(1, 3, 5),
                             Error = c(calcError(estXYk1_l1, actualXY),
                                         calcError(estXYk3_l1, actualXY),
                                         calcError(estXYk5_l1, actualXY)),
                             Method = "Manhattan")
```

```
errors_combined <- rbind(error_table, error_table_l1)

ggplot(errors_combined) +
  geom_bar(aes(K, Error, fill = -Error), stat = "identity") +
  facet_wrap(~Method) +
  coord_flip()
```



Does it improve predictions?

*Euclidean seems to perform better.*

## 12.)

To predict location, we use the  $k$  nearest neighbors to a set of signal strengths. We average the known  $(x, y)$  values for these neighbors. However, a better predictor might be a weighted average, where the weights are inversely proportional to the “distance” (in signal strength) from the test observation. This allows us to include the  $k$  points that are close, but to differentiate between them by how close they actually are.

The weights might be:

$$\frac{1/d_i}{\sum_{i=1}^k 1/d_i}$$

for the  $i$ -th closest neighboring observation where  $d_i$  is the distance from our new test point to this reference point (in signal strength space).

Implement this alternative prediction method.

```
predXY_weighted <- function(newSignals, newAngles, trainData,
                             numAngles = 1, k = 3) {
```

```
closeXY <- list(length = nrow(newSignals))

for(i in 1:nrow(newSignals)) {
  trainSS <- selectTrain(newAngles[i], trainData, m = numAngles)

  closeXY[[i]] =
    findNN(newSignal = as.numeric(newSignals[i, ]), trainSS)
}

estXY = lapply(closeXY,
  function(x) sapply(x[, 2:3],
    function(x) {
      points <- x[1:k]

      if(k > 1) {
        weights <- points/sum(points)

        return(sum(points * weights))
      } else {
        return(points)
      }
    })
))

estXY <- do.call("rbind", estXY)

return(estXY)
}

estXYk10 <- predXY(newSignals = onlineSummary[, 6:11],
  newAngles = onlineSummary[, 4],
  offlineSummary, numAngles = 3, k = 10)

estXYk1_weighted <- predXY_weighted(newSignals = onlineSummary[, 6:11],
  newAngles = onlineSummary[, 4],
  offlineSummary, numAngles = 3, k = 1)

estXYk3_weighted <- predXY_weighted(newSignals = onlineSummary[, 6:11],
  newAngles = onlineSummary[, 4],
  offlineSummary, numAngles = 3, k = 3)

estXYk5_weighted <- predXY_weighted(newSignals = onlineSummary[, 6:11],
  newAngles = onlineSummary[, 4],
  offlineSummary, numAngles = 3, k = 5)
```

```

estXYk10_weighted <- predXY_weighted(newSignals = onlineSummary[, 6:11],
  newAngles = onlineSummary[, 4],
  offlineSummary, numAngles = 3, k = 10)

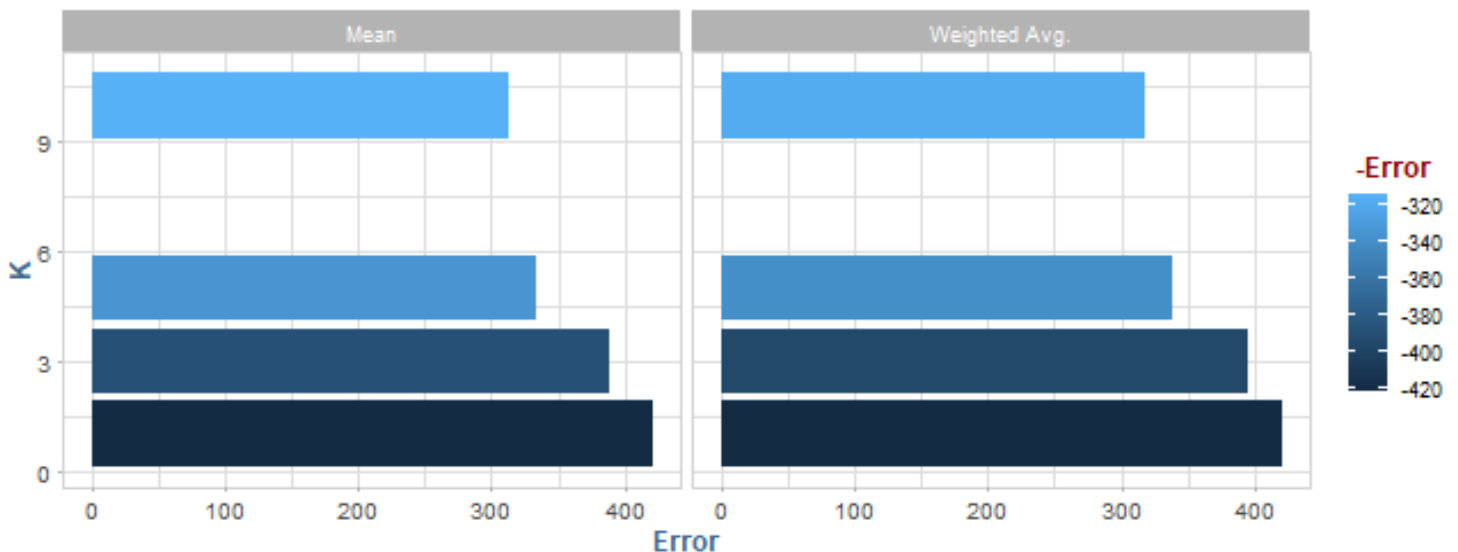
error_table <- data.table(K = c(1, 3, 5, 10),
  Error = c(calcError(estXYk1, actualXY),
    calcError(estXYk3, actualXY),
    calcError(estXYk5, actualXY),
    calcError(estXYk10, actualXY)),
  Method = "Mean")

error_table_weighted <- data.table(K = c(1, 3, 5, 10),
  Error = c(calcError(estXYk1_weighted, actualXY),
    calcError(estXYk3_weighted, actualXY),
    calcError(estXYk5_weighted, actualXY),
    calcError(estXYk10_weighted, actualXY)),
  Method = "Weighted Avg.")

errors_combined <- rbind(error_table, error_table_weighted)

ggplot(errors_combined) +
  geom_bar(aes(K, Error, fill = -Error), stat = "identity") +
  facet_wrap(~Method) +
  coord_flip()

```



```
errors_combined
```

```

      K   Error      Method
1:  1 420.7603        Mean

```

```

2:  3 388.1070      Mean
3:  5 334.3683      Mean
4: 10 313.7643      Mean
5:  1 420.7603 Weighted Avg.
6:  3 395.4816 Weighted Avg.
7:  5 339.1897 Weighted Avg.
8: 10 317.5429 Weighted Avg.

```

Does this improve the predictions?

*The weighted avg approach is of course identical in the base case ( $k=1$ ), however, it performs slightly worse than the simple average in the  $k=3$  and  $k=5$  cases. I even upped  $k$  to 10 (the best CV  $k$ ), and we still see simple average beats the weighted approach.*

### 13.)

In Section 1.5.4 we used cross-validation to choose  $k$ , the number of neighbors. Another parameter to choose is the number of angles at which the signal strength was measured.

Use cross-validation to select this value.

Also, consider  $N + K$  cross-validation pairs.

```

v <- 11 # n-folds
N <- 8  # num angles
K <- 20 # also choose k

nk_err <- matrix(rep(0, N * K), nrow = N, ncol = K)

for(j in 1:v) {
  onlineFold <- subset(onlineCVSummary,
                      posXY %in% permuteLocs[, j])
  offlineFold <- subset(offlineSummary,
                      posXY %in% permuteLocs[, -j])

  actualFold <- onlineFold[, c("posX", "posY")]

  for(k in 1:K) {
    for(n in 1:N) {
      estFold <- predXY(newSignals = onlineFold[, 6:11],
                      newAngles = onlineFold[, 4],
                      offlineFold, numAngles = n, k = k)

      nk_err[n, k] <- calcError(estFold, actualFold)
    }
  }
}

```

```
nk_err
```

```

      [,1]  [,2]      [,3]      [,4]  [,5]      [,6]      [,7]      [,8]
[1,]  243 131.75 155.22222 171.5000 133.68 131.69444 145.4694 158.98438
[2,]  124 132.25 130.44444 137.0625 154.72 147.69444 153.1837 140.23438
[3,]   98  89.75  84.77778 110.1250 107.72 103.63889 107.4490 114.76562
[4,]   75  75.75  96.88889  90.3125  97.92 110.83333 101.3265 105.10938
[5,]  109 111.50 108.11111  96.2500 108.96 113.61111 109.8367 106.64062
[6,]  101 125.00  89.44444  97.3125  93.60 106.66667 110.2857 118.04688
[7,]  116 122.00  98.11111  95.6875  90.96  88.77778  91.2449  84.98438
[8,]  110 100.50 106.44444  97.2500  91.92  77.72222  76.5102  73.46875
      [,9]  [,10]      [,11]      [,12]      [,13]      [,14]      [,15]
[1,] 161.27160 162.86 191.06612 189.69444 184.04734 207.59694 223.98222
[2,] 153.43210 156.08 145.76860 154.59028 158.75740 151.03571 144.70222
[3,] 125.93827 127.67 141.49587 144.04861 142.16568 145.32653 134.76000
[4,]  98.75309  97.05  95.21488  96.46528  99.91716 100.30102  97.49333
[5,] 115.59259 103.46 111.12397 111.84028 108.62722 111.52041 116.48444
[6,] 122.87654 117.23 108.31405  99.39583  97.60355 104.08673 101.77778
[7,]  92.33333  91.11  98.20661 100.03472 107.43195 111.39286 108.93778
[8,]  77.33333  85.84  91.79339  89.93750  92.21302  99.57653 100.27556
      [,16]  [,17]      [,18]      [,19]      [,20]
[1,] 224.36328 227.20415 241.6852 253.1690 251.6275
[2,] 140.67188 140.39100 143.0957 148.4848 151.7100
[3,] 136.67969 139.11073 145.9136 150.4211 156.7925
[4,]  99.60156 100.42215 109.2346 117.2659 120.1900
[5,] 122.67578 133.21453 131.3611 137.0748 135.1500
[6,] 104.01172  96.75087 104.3395 105.3241 113.4675
[7,] 106.63672 111.77509 111.6512 119.2659 117.5775
[8,] 101.25391 108.59170 117.9660 122.1468 117.9175

```

```
which(nk_err == min(nk_err), arr.ind = TRUE)
```

```

      row col
[1,]    8   8

```

```
head(order(nk_err))
```

```
[1] 64  4 12 56 72 48
```

```

# 1, 6
# 1, 5
# 1, 7
# 4, 8

```

```
n_take <- 20
```

```
cv_results <- data.table(nk_err)[, 1:n_take]
```

```

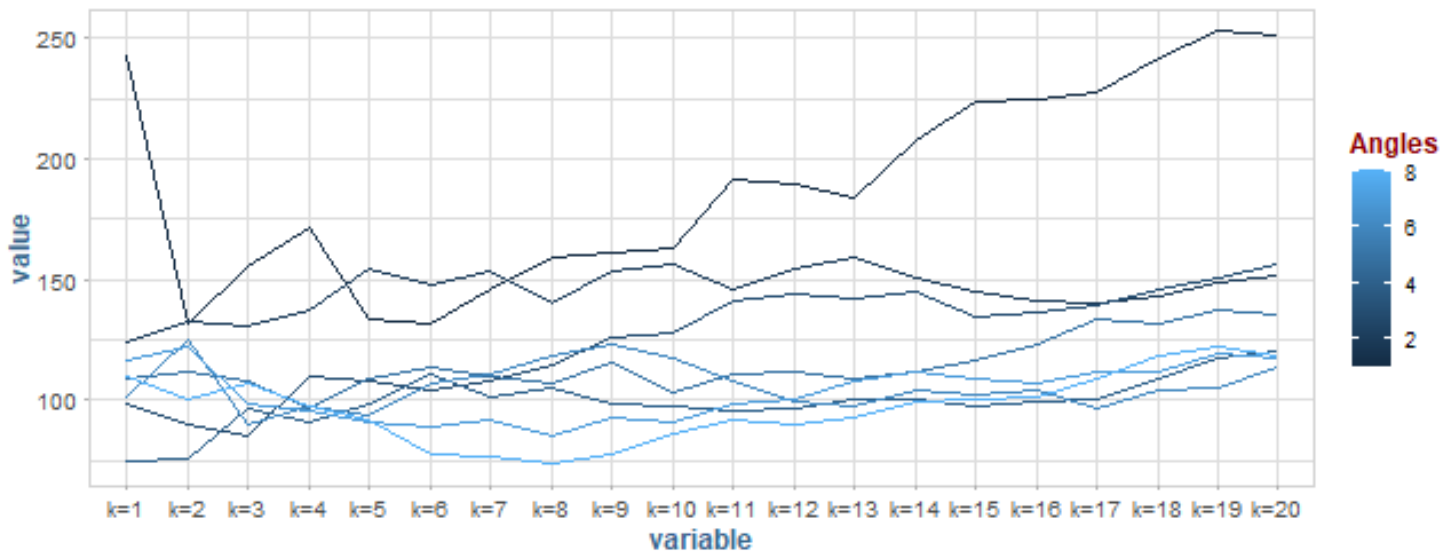
colnames(cv_results) <- sapply(1:n_take, function(x) {paste0("k=", x)})
cv_results[, Angles := .I]

min_cv <- which(nk_err == min(nk_err), arr.ind = TRUE)

cv_results_flat <- melt(cv_results, id.vars = "Angles")

ggplot(cv_results_flat, aes(variable, value, group = Angles)) +
  geom_line(aes(col = Angles)) +
  labs("K, N Cross-Validation Results")

```



The cross-validation of both N and K yield the optimal N at 1 and K at 6. 4 of the top 5 CV results have  $N=1$ .