Introduction to R: Session 03

Holger Sennhenn-Reulen[a], Nordwestdeutsche Forstliche Versuchsanstalt (NW-FVA)

Oktober 26, 2021 (Version 0.1)

Contents

[a]Private webpage: uncertaintree.github.io

Data

Drought

Data basis: Fischer, R., Dobbertin, M., Granke, O., et al., 2006. The condition of forests in Europe. 2006 Executive report. UNECE, Hamburg.

```
bair <- c(.505, .648, .523, .426, .64, .5, .257, .866, .434, .368, .54, .923, .702,
          .615, 1.013, .807, .262, .887, 1.281, 1.125, .99, 1.2, .983, .697, .606,
          .718, .48, .822, .944, .77, 1.036, 1.23, .68, .985)
elev <- c(335, 460, 480, 515, 540, 650, 680, 715, 730, 835, 860, 960,
          1020, 1025, 1100, 1150, 1150, 1170, 1190, 1350, 1400, 1500, 1540,
          475, 480, 507.5, 580, 750, 780, 800, 1025, 1100, 1150, 1200)
species <- c("Spruce", "Spruce", "Spruce", "Spruce", "Spruce", "Spruce",
             "Spruce", "Spruce", "Spruce", "Spruce", "Spruce", "Spruce", "Spruce",
             "Spruce", "Spruce", "Spruce", "Spruce", "Spruce", "Spruce", "Spruce",
             "Spruce", "Spruce", "Spruce", "Beech", "Beech", "Beech", "Beech",
             "Beech", "Beech", "Beech", "Beech", "Beech", "Beech", "Beech")
drought <- data.frame(bair = bair,
                      elev = elev,
                      species = species)
summary(drought)
```

```
##       bair             elev          species
##  Min.   :0.2570   Min.   : 335.0   Beech :11
##  1st Qu.:0.5272   1st Qu.: 597.5   Spruce:23
##  Median :0.7100   Median : 847.5
##  Mean   :0.7489   Mean   : 888.3
##  3rd Qu.:0.9732   3rd Qu.:1150.0
##  Max.   :1.2810   Max.   :1540.0
```

For further context information, another source working on and interpereting this data (p. 202-203):

Matthias Dobbertin, Markus Neumann, Hans-Werner Schroeck, Chapter 10 - Tree Growth Measurements in Long-Term Forest Monitoring in Europe, Editor(s): Marco Ferretti, Richard Fischer, Developments in Environmental Science, Elsevier, Volume 12, 2013, Pages 183-204, https://doi.org/10.1016/B978-0-08-098222-9.00010-8

Frost

Data basis: Deutscher Wetterdienst, values shown here were generated over individual values by myself.

Direct download links for data basis (Stations Id 1691, Goettingen):

- historical data)
- recent data)

Some definitions:

- Budburst is estimated based on first day with degree days > 220 (begin counting on March, 20).
- End of 1st development stage is estimated based on first day with degree days > 320 (begin counting on March, 20).
- Definition frost event: $\min(\text{Temp}_{50\text{cm}}) < -1.95$řC

```
frost <- data.frame(year = 1947:2021,
                    n_frost = c(0, 0, 2, 0, 0, 0, 0, 0, 0, 0, 2, 0, 0, 0, 0, 1,
                                0, 0, 2, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
                                0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
                                2, 0, 0, 0, 0, 0, 0, 0, 0, 1, 2, 0, 0, 0, 0, 0,
                                3, 2, 0, 0, 0, 0, 0, 0, 1, 5, 0),
                    bud_burst = as.Date(c(-19230, -18867, -18503, -18127, -17758, -17408, -17034,
                                          -16661, -16293, -15929, -15566, -15202, -14847, -14475,
                                          -14121, -13744, -13384, -13017, -12647, -12291, -11917,
                                          -11563, -11191, -10821, -10462, -10092, -9720, -9361,
```

```
                                                -8997, -8635, -8261, -7896, -7530, -7164, -6808, -6436,
                                                -6078, -5705, -5347, -4981, -4619, -4254, -3883, -3524,
                                                -3145, -2788, -2437, -2060, -1694, -1322, -958, -602,
                                                -237, 124, 499, 864, 1222, 1592, 1957, 2321, 2681, 3055,
                                                3408, 3789, 4137, 4513, 4877, 5234, 5610, 5976, 6345,
                                                6691, 7074, 7435, 7812),
                                              origin = as.Date("2000-01-01")),
                    end_1st_dev_stage = as.Date(c(-19222, -18859, -18489, -18118, -17746, -17397,
                                                      -17026, -16650, -16280, -15921, -15552, -15192,
                                                      -14837, -14464, -14104, -13726, -13370, -13006,
                                                      -12633, -12281, -11905, -11545, -11180, -10808,
                                                      -10455, -10078, -9710, -9349, -8984, -8623, -8248,
                                                      -7886, -7521, -7151, -6799, -6427, -6068, -5691,
                                                      -5338, -4972, -4601, -4246, -3875, -3513, -3131,
                                                      -2780, -2426, -2050, -1679, -1311, -944, -594,
                                                      -225, 132, 510, 873, 1235, 1608, 1972, 2332, 2694,
                                                      3067, 3422, 3802, 4152, 4525, 4891, 5250, 5623,
                                                      5988, 6354, 6703, 7086, 7450, 7824),
                                                    origin = as.Date("2000-01-01")))
frost$may1st <- as.Date(paste0(frost$year, "-05-01"))
frost$bud_burst_days_since_may1st <- julian(frost$bud_burst, origin = as.Date("2000-01-01")) -
  julian(frost$may1st, origin = as.Date("2000-01-01"))
frost$end_1st_dev_stage_days_since_may1st <- julian(frost$end_1st_dev_stage,
                                                        origin = as.Date("2000-01-01")) -
  julian(frost$may1st, origin = as.Date("2000-01-01"))
summary(frost)
```

```
##       year         n_frost       bud_burst           end_1st_dev_stage
##  Min.   :1947   Min.   :0.00   Min.   :1947-05-09   Min.   :1947-05-17
##  1st Qu.:1966   1st Qu.:0.00   1st Qu.:1965-11-11   1st Qu.:1965-11-23
##  Median :1984   Median :0.00   Median :1984-05-19   Median :1984-06-02
##  Mean   :1984   Mean   :0.32   Mean   :1984-05-12   Mean   :1984-05-24
##  3rd Qu.:2002   3rd Qu.:0.00   3rd Qu.:2002-11-09   3rd Qu.:2002-11-20
##  Max.   :2021   Max.   :5.00   Max.   :2021-05-22   Max.   :2021-06-03
##      may1st           bud_burst_days_since_may1st
##  Min.   :1947-05-01   Min.   :-4.00
##  1st Qu.:1965-10-30   1st Qu.: 8.00
##  Median :1984-05-01   Median :11.00
##  Mean   :1984-04-30   Mean   :11.69
##  3rd Qu.:2002-10-30   3rd Qu.:16.00
##  Max.   :2021-05-01   Max.   :23.00
##  end_1st_dev_stage_days_since_may1st
##  Min.   : 8.00
##  1st Qu.:20.00
##  Median :24.00
##  Mean   :23.47
##  3rd Qu.:28.50
##  Max.   :36.00
```

1 Objectives of control structures.

'Automation' of the repetition of structurally identical commands.

- Repetition of a command – with parameter / quantities remaining the same or changing – with a predetermined or flexible number of repetitions.
- Conditional execution of various tasks.
- Generalization of tasks by defining functions.
- Combination of information in objects.

2 Logical comparisons.

Command	`TRUE` if:
`==`	Equality
`! =`	Inequality
`>, >=`	left side greater than (or equal to) the right side
`<, <=`	left side less than (or equal to) the right side
`% in%`	Is left side in vector on right side?

- `all ()` returns `TRUE` if all elements of the vector are `TRUE`.
- `any ()` returns `TRUE` if at least one element of the vector is `TRUE`.
- `is.na()` and `is.null()` return `TRUE` if the respective object (e.g. element of a vector) is `NA` or `NULL`.
- a logical value can be negated with a preceding `!` (e.g. `!TRUE` is`FALSE`)
- `which()` returns the index set (as an integer vector) if the logical comparison resulted in `TRUE`.

2.1 Exercises

```
is.na(drought$bair)
any(is.na(drought$bair))
drought$bair > 0
all(drought$bair > 0)
drought$bair > 1
any(drought$bair > 1)
all(drought$bair > 1)
which(drought$bair > 1)
drought$bair[which(drought$bair > 1)]
(tmp <- round(drought$bair, 1))
c(.8, 1.2) %in% tmp
c(.8, 1.2) %in% drought$bair
which(tmp %in% c(.8, 1.2))
drought$bair[which(tmp %in% c(.8, 1.2))]
tmp <- c(drought$bair[1:5], NA)
all(tmp > 0)
any(is.na(tmp))
which(is.na(tmp))
all(tmp[-which(is.na(tmp))] > 0)
mean(tmp)
mean(tmp, na.rm = T)
```

3 Conditional execution

3.1 'if-else'

Usage:

```
if (Condition) {
  ... ## Commands if Condition is TRUE
} else {
  ... ## Commands if Condition is FALSE
}
```

- TRUE or FALSE condition necessary.
- 'if-else'-sequences can be nested within one another.

Example together with the next topic.

3.2 'for'-loops

'for' loops often offer a simple and pragmatic way to complete steps in data management / preparation.

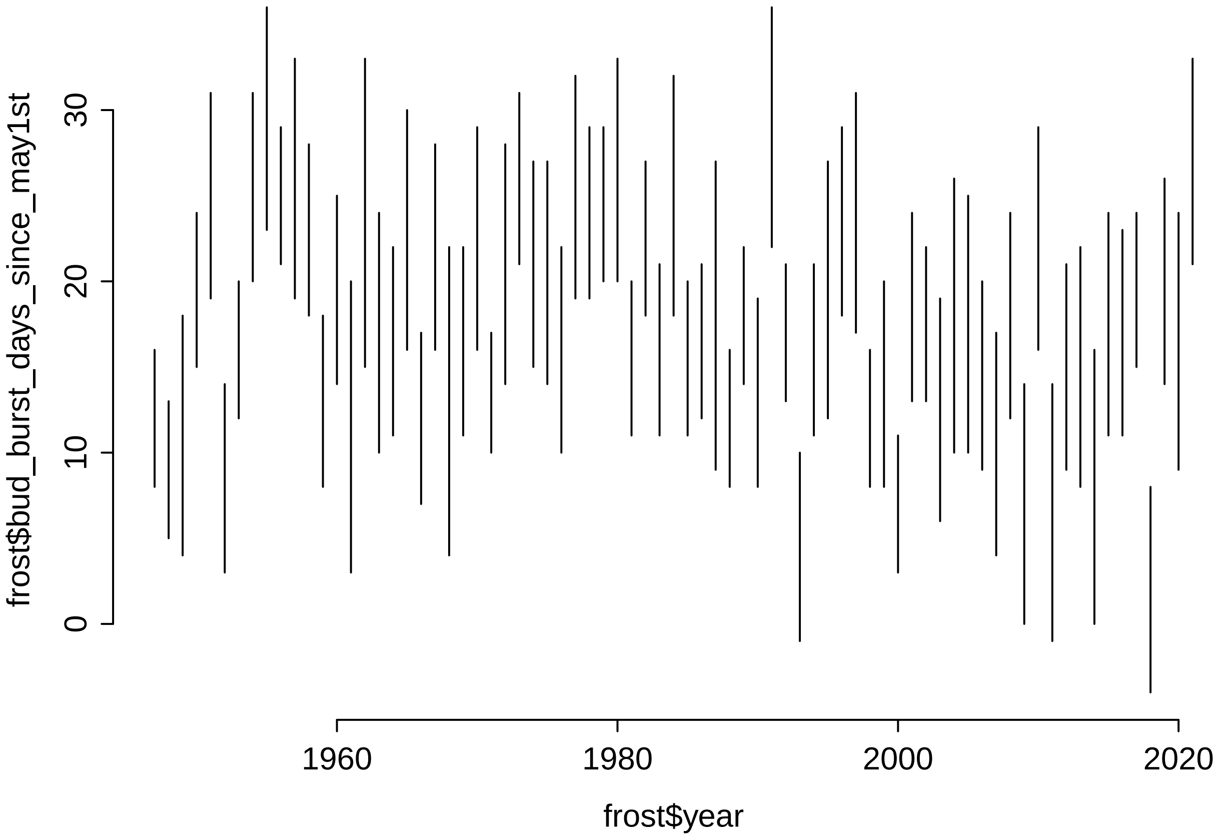
Usage:

```
for (index in vector) {
  ... index ... ## Command that in some form depend on index.
}
```

- New object `index` runs all elements in `vector`.
- `index` remains constant during `... index ...`
- `index` jumps to the next (if available) value of `vector` after running through `... index ...`.
- `index` takes each value of `vector` once.
- The number of iterations of `... index ...` is determined by the length of `vector`.

3.3 Example of a `for` loop

```
tmp1 <- frost$bud_burst_days_since_may1st
tmp2 <- frost$end_1st_dev_stage_days_since_may1st
days_since_may1st <- min(tmp1):max(tmp2)
rm(tmp1, tmp2)
par(mar = c(3, 3, .1, .1), mgp = c(2, .5, 0), tcl = -.3)
plot(frost$year, frost$bud_burst_days_since_may1st, type = "n",
     ylim = range(days_since_may1st), bty = "n")
for (index in 1:nrow(frost)) {
  tmp_x <- rep(frost$year[index], times = 2)
  tmp_y <- c(frost$bud_burst_days_since_may1st[index],
             frost$end_1st_dev_stage_days_since_may1st[index])
  lines(x = tmp_x, y = tmp_y)
}
```



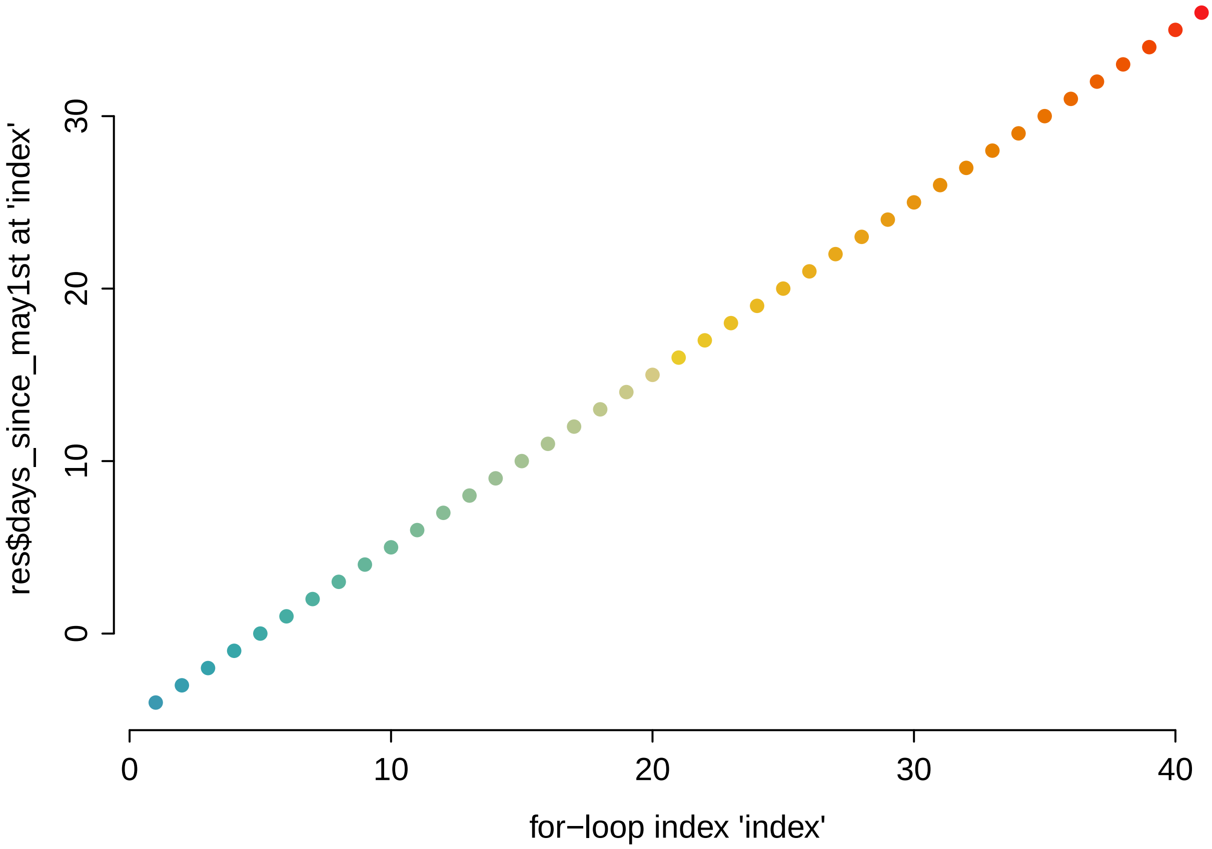
3.4 Example of a `for` loop with `if`

Preparations:

```
res <- data.frame(days_since_may1st = days_since_may1st,
                  n_at_risk = NA)
```

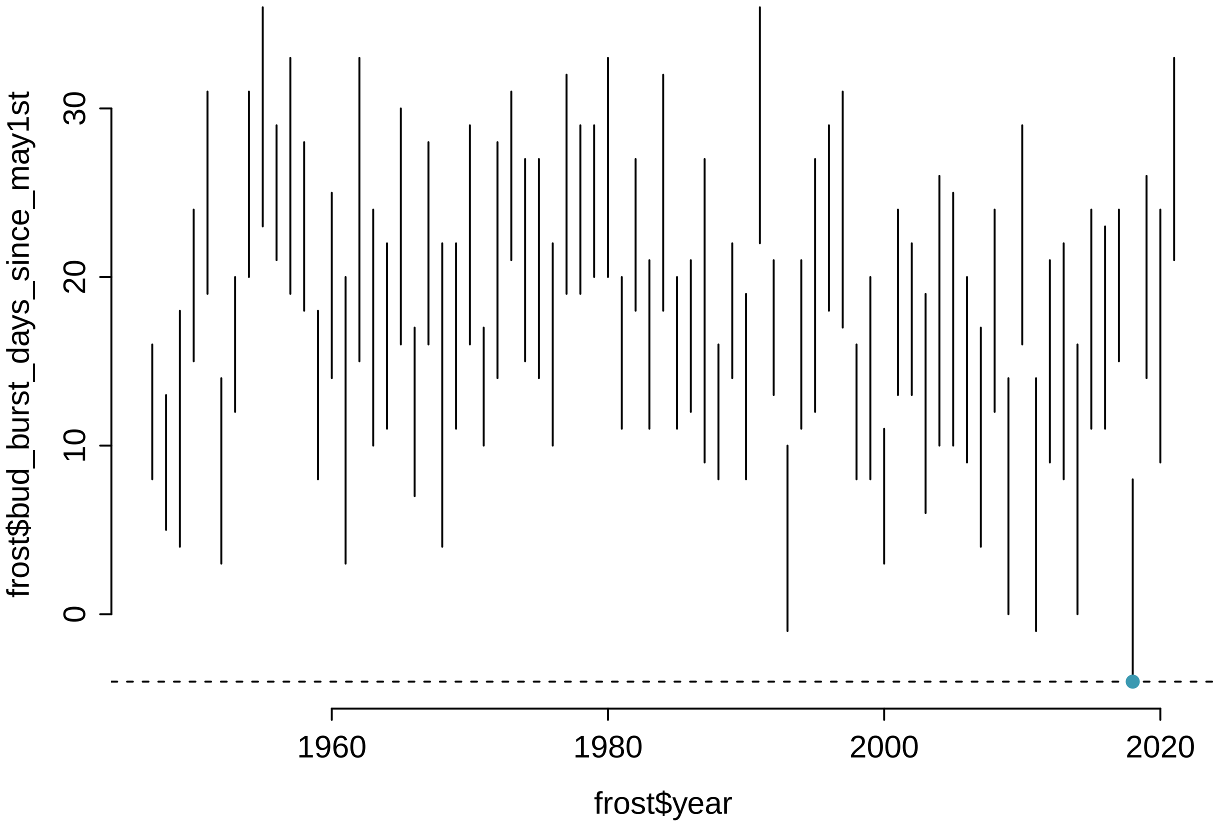
3.4.1 Illustrating the loop index:

```
paint <- colorspace::divergingx_hcl(n = nrow(res), pal = "Zissou")
par(mar = c(3, 3, .1, .1), mgp = c(2, .5, 0), tcl = -.3)
plot(1:nrow(res), res$days_since_may1st, col = paint, pch = 16, bty = "n",
     xlab = "for-loop index 'index'", ylab = "res$days_since_may1st at 'index'")
```



3.4.2 An iteration 'by hand':

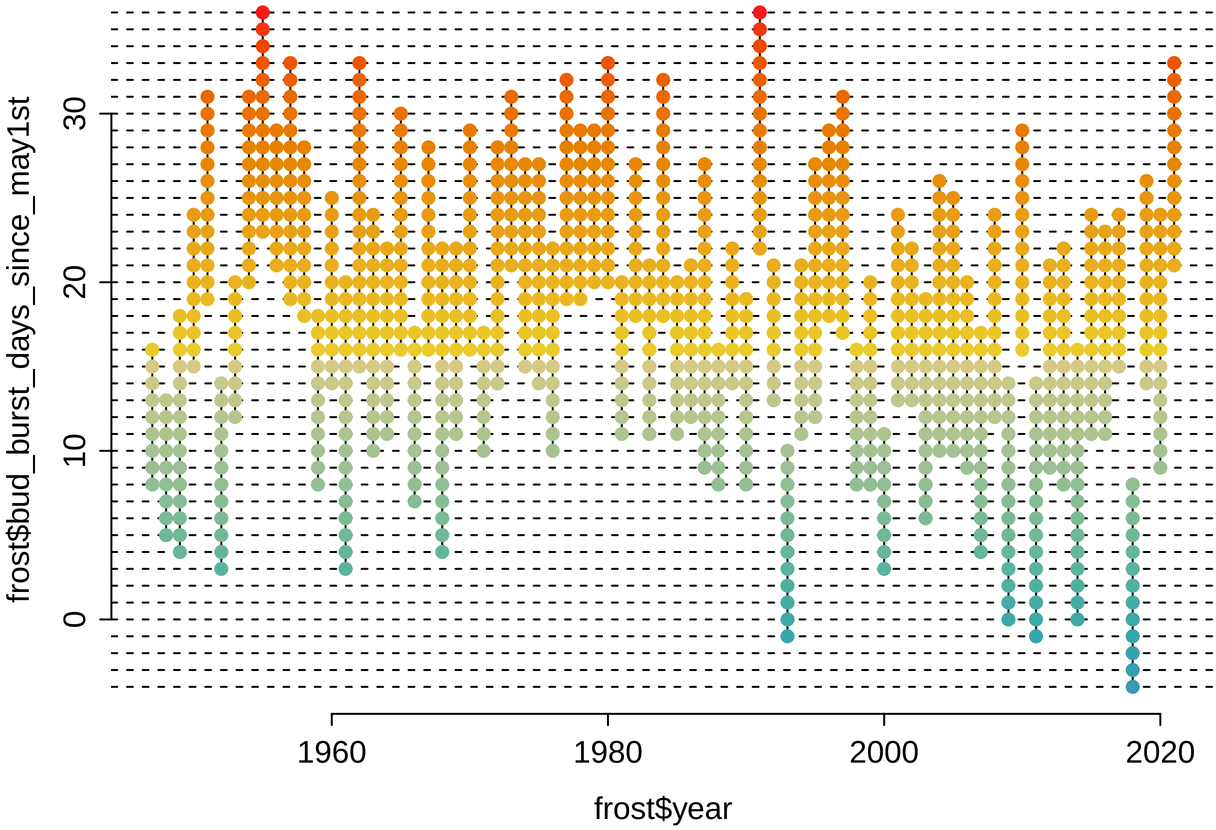
```
par(mar = c(3, 3, .1, .1), mgp = c(2, .5, 0), tcl = -.3)
plot(frost$year, frost$bud_burst_days_since_may1st, type = "n",
     ylim = range(days_since_may1st), bty = "n")
for (index in 1:nrow(frost)) { ## here, the uninteresting loop
  tmp_x <- rep(frost$year[index], times = 2)
  tmp_y <- c(frost$bud_burst_days_since_may1st[index],
             frost$end_1st_dev_stage_days_since_may1st[index])
  lines(x = tmp_x, y = tmp_y)
}
index <- 1
abline(h = res$days_since_may1st[index], lty = 2)
## boolean 1 and 2:
bool1 <- frost$bud_burst_days_since_may1st <= days_since_may1st[index]
bool2 <- frost$end_1st_dev_stage_days_since_may1st >= days_since_may1st[index]
which_true <- which(bool1 & bool2)
points(frost$year[which_true], days_since_may1st[index], col = paint[index], pch = 16)
```




```
res$n_at_risk[index] <- length(which_true)
rm(index)
```

3.4.3 A 'full' loop:

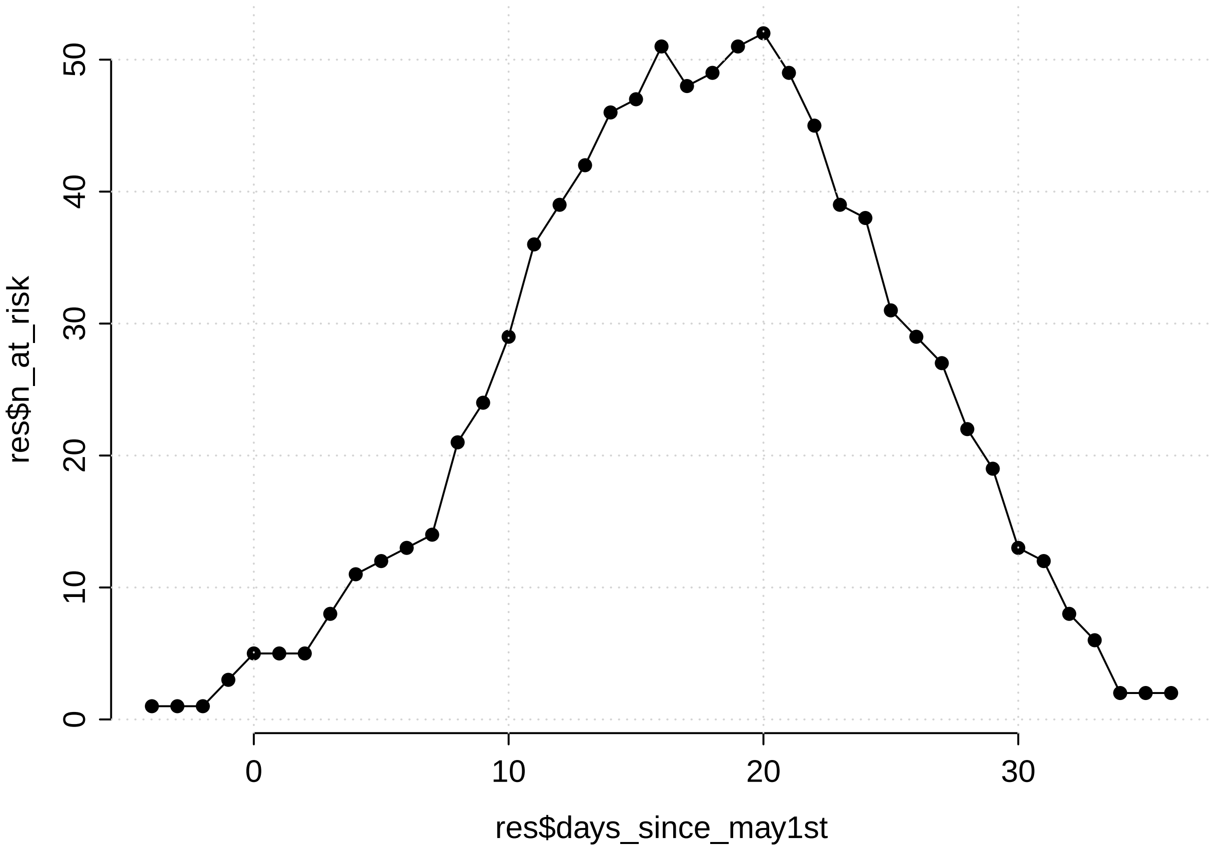
```
par(mar = c(3, 3, .1, .1), mgp = c(2, .5, 0), tcl = -.3)
plot(frost$year, frost$bud_burst_days_since_may1st, type = "n",
     ylim = range(days_since_may1st), bty = "n")
for (index in 1:nrow(frost)) { ## here, the uninteresting loop
  tmp_x <- rep(frost$year[index], times = 2)
  tmp_y <- c(frost$bud_burst_days_since_may1st[index],
             frost$end_1st_dev_stage_days_since_may1st[index])
  lines(x = tmp_x, y = tmp_y)
}
for (index in 1:nrow(res)) { ## here, the interesting loop
  abline(h = res$days_since_may1st[index], lty = 2)
  bool1 <- frost$bud_burst_days_since_may1st <= days_since_may1st[index]
  bool2 <- frost$end_1st_dev_stage_days_since_may1st >= days_since_may1st[index]
  ## if any ... else ...
  if (any(bool1 & bool2)) {
    which_true <- which(bool1 & bool2)
    points(frost$year[which_true],
           rep(days_since_may1st[index], times = length(which_true)),
           col = paint[index], pch = 16)
    res$n_at_risk[index] <- length(which_true)
  } else {
    res$n_at_risk[index] <- 0
  }
}
```




```
head(res, n = 10)
```

```
##    days_since_may1st n_at_risk
## 1                 -4         1
## 2                 -3         1
## 3                 -2         1
## 4                 -1         3
## 5                  0         5
## 6                  1         5
## 7                  2         5
## 8                  3         8
## 9                  4        11
## 10                 5        12
```

```
par(mar = c(3, 3, .1, .1), mgp = c(2, .5, 0), tcl = -.3)
plot(res$days_since_may1st, res$n_at_risk, type = "o", pch = 16, bty = "n")
grid()
```




```
## Plot f?r (21.1,26.9] und (26.9,51] erstellt.
```

–>

3.5 'while'-loops.

'while' loops are used less often in data management / preparation, but are more likely to be found in 'computationally intensive' applications (e.g. for optimizations).

Nutzung:

```
index <- k ## 'k' here has to be smaller than 'K' in next line.
while (index < K){
  ...
  index <- index + 1
}
```

- ... und die darauf folgende Zeile wird so lange wiederholt wie die Bedingung TRUE ist (also solange hier k<K)
- flexible Anzahl an Wiederholungen.
- stoppt unmittelbar nachdem die Bedingung nicht mehr eingehalten wird.
- kann auch als eine 'for'-Schleife umgeschrieben werden.
- The commands that '... stands for, and the following line, are repeated as long as the condition is TRUE (i.e. here as long as k<K).
- flexible number of repetitions.
- stops immediately after the condition is no longer met.

Example 1

```
accepted <- 0
table(frost$n_frost > .5)
```

```
##
## FALSE  TRUE
##    63    12
```

```r
sum(frost$n_frost > .5)
```

```
## [1] 12
```

```r
P <- NULL
n_iter <- 0
while (accepted < 1000) {
  p <- rbeta(n = 1, shape1 = 1/3, shape2 = 1/3)
  y_tilde <- sample(x = c(TRUE, FALSE), size = nrow(frost), replace = T,
                    prob = c(p, 1 - p))
  if (sum(y_tilde) == sum(frost$n_frost > .5)) {
    accepted <- accepted + 1
    P <- c(P, p)
  }
  n_iter <- n_iter + 1
}
length(P)
```

```
## [1] 1000
```

```r
n_iter
```

```
## [1] 109936
```

```r
length(P) / n_iter
```

```
## [1] 0.009096201
```

```r
summary(P)
```

```
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.06084 0.13054 0.16213 0.16313 0.19376 0.28682
```

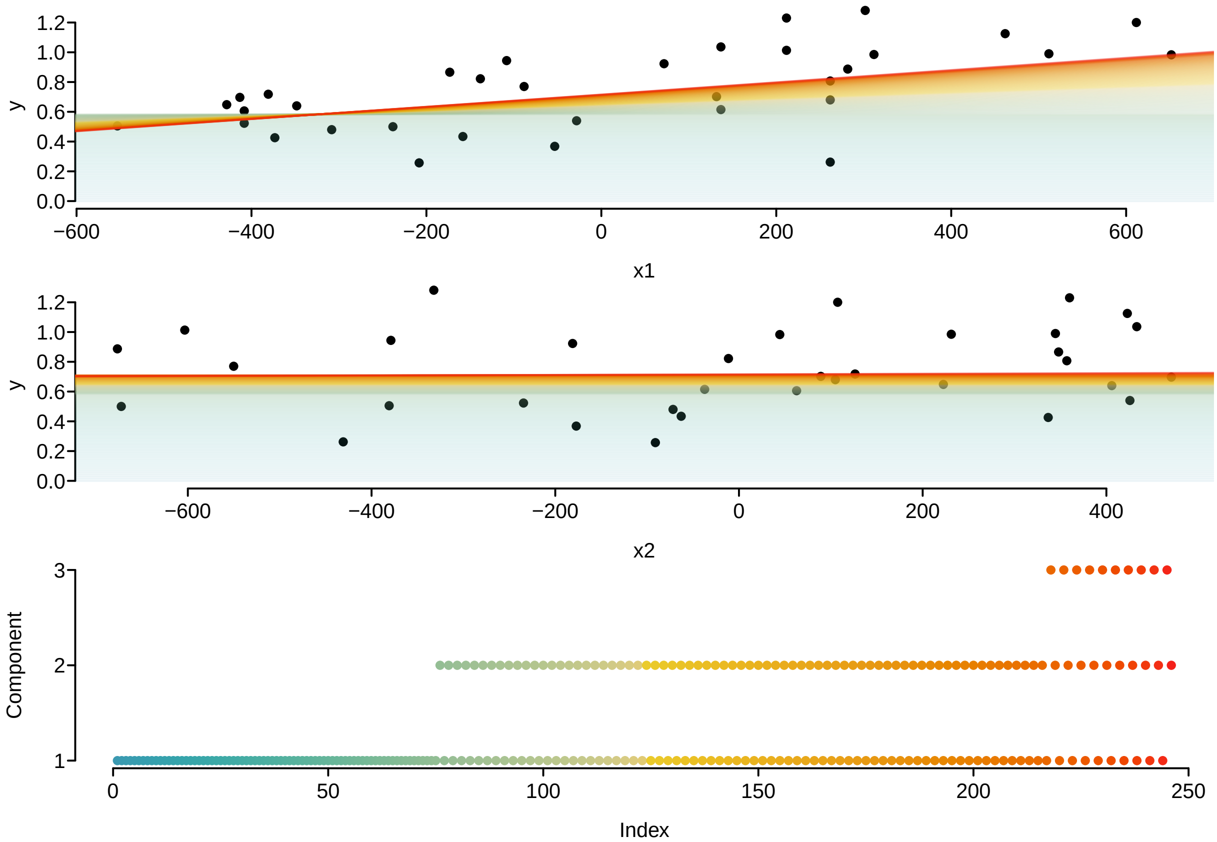
Example 2

```r
set.seed(123)
x1 <- drought$elev - mean(drought$elev)
x2 <- runif(nrow(drought), min = min(x1), max = max(x1))
x2 <- x2 - mean(x2)
y <- drought$bair#  - mean(drought$bair)
f_y_work <- function(y, x1, x2, b0, b1, b2){-1 * (-2*y + 2*(b0 + b1*x1 + b2*x2))}
b0 <- 0
b1 <- 0
b2 <- 0
krit_diff <- 1 ## Initialisierung irgendwie so dass Bedingung am Anfang wahr ist.
krit_alt <- sqrt(mean(c(y - (b0 + b1*x1 + b2*x2))^2))
component <- NULL
while (krit_diff > 0.0001) { ## Beginn der while-Schleife.
  y_work <- f_y_work(y = y, x1 = x1, x2 = x2,
                     b0 = b0[length(b0)], b1 = b1[length(b1)],
                     b2 = b2[length(b2)])
  lm_b0 <- lm(y_work ~ 1)
  lm_b1 <- lm(y_work ~ -1 + x1)
  lm_b2 <- lm(y_work ~ -1 + x2)
  krit_b0 <- mean(lm_b0$residuals^2)
  krit_b1 <- mean(lm_b1$residuals^2)
  krit_b2 <- mean(lm_b2$residuals^2)
  selected <- which.min(c(krit_b0, krit_b1, krit_b2))
  update_weight <- rep(0, 3)
  update_weight[selected] <- .01
  b0 <- c(b0, b0[length(b0)] + update_weight[1] * coef(lm_b0))
```

```
  b1 <- c(b1, b1[length(b1)] + update_weight[2] * coef(lm_b1))
  b2 <- c(b2, b2[length(b2)] + update_weight[3] * coef(lm_b2))
  component <- c(component, selected)
  krit_neu <- sqrt(mean(c(y - (b0[length(b0)] +
                               b1[length(b1)] * x1 +
                               b2[length(b2)] * x2))^2))
  krit_diff <- krit_alt - krit_neu ## Update!
  krit_alt <- krit_neu
} ## Ende der while-Schleife.
table(component)
```

```
## component
##   1   2   3
## 155  81  10
```

```
par(mfrow = c(3, 1), mar = c(3, 3, 0, 0), las = 1, oma = c(0, 0, 0, 0),
    mgp = c(2, .4, 0), tcl = -.3)
paint <- colorspace::divergingx_hcl(n = length(b0), pal = "Zissou")
paint_a <- colorspace::divergingx_hcl(n = length(b0), pal = "Zissou", alpha = .1)
plot(x1, y, pch = 16, bty = "n", las = 1, ylim = range(c(0, y)), bty = "n")
for (index in 1:length(b0)) {
  abline(a = b0[index], b = b1[index], col = paint_a[index])
}
plot(x2, y, pch = 16, bty = "n", las = 1, ylim = range(c(0, y)), bty = "n")
for (index in 1:length(b0)) {
  abline(a = b0[index], b = b2[index], col = paint_a[index])
}
plot(as.numeric(as.factor(component)), yaxt = "n", ylab = "Component",
     col = paint, pch = 16, bty = "n")
axis(2, at = 1:length(unique(component)), labels = levels(as.factor(component)),
     las = 1)
```



3.6 'apply'-commands

An 'apply'-command applies the same function to each of the elements of a data object.

Usage:

```
apply(X, MARGIN, FUN, ...) ## For matrix X: Result is a list.
lapply(X, FUN, ...) ## For list X: Result is a list.
sapply(X, FUN, ...) ## For list X: Result is a vector or another
                    ## Data object that the result might be 'simplified' to.
```

- apply applies function (specified by FUNCTION) to each element of the respective dimension (defined with argument MARGIN) of X.
- MARGIN equals 1 for line-by-line, and 2 for column-wise execution.
- ... for further arguments to FUNCTION (same for every element ofX!).
- For lists X, MARGIN cannot be selected because lists only have one dimension.

3.6.1 Exercises

```
apply(drought, MARGIN = 2, FUN = function(x){sum(is.na(x))})
```

```
##    bair    elev species
##       0       0       0
```

```
apply(drought[, 1:2], MARGIN = 2, FUN = mean)
```

```
##        bair        elev
##   0.7489118 888.3088235
```

```
apply(drought[, 1:2], MARGIN = 1, FUN = mean)
```

```
##  [1] 167.7525 230.3240 240.2615 257.7130 270.3200 325.2500 340.1285 357.9330
##  [9] 365.2170 417.6840 430.2700 480.4615 510.3510 512.8075 550.5065 575.4035
## [17] 575.1310 585.4435 595.6405 675.5625 700.4950 750.6000 770.4915 237.8485
## [25] 240.3030 254.1090 290.2400 375.4110 390.4720 400.3850 513.0180 550.6150
## [33] 575.3400 600.4925
```

```
apply(frost, MARGIN = 2, FUN = function(x){sum(is.na(x))})
```

```
##                             year                          n_frost
##                                0                                0
##                        bud_burst                end_1st_dev_stage
##                                0                                0
##                          may1st         bud_burst_days_since_may1st
##                                0                                0
## end_1st_dev_stage_days_since_may1st
##                                0
```

```
apply(frost[, c(1:2, 6:7)], MARGIN = 2, FUN = mean)
```

```
##                             year                          n_frost
##                       1984.00000                          0.32000
##      bud_burst_days_since_may1st end_1st_dev_stage_days_since_may1st
##                         11.69333                         23.46667
```

```
lapply(frost[, c(1:2, 6:7)], FUN = mean)
```

```
## $year
## [1] 1984
##
## $n_frost
## [1] 0.32
##
## $bud_burst_days_since_may1st
## [1] 11.69333
##
```

```
## $end_1st_dev_stage_days_since_may1st
## [1] 23.46667
```

```
sapply(frost[, c(1:2, 6:7)], FUN = mean)
```

```
##                          year                          n_frost
##                    1984.00000                          0.32000
##      bud_burst_days_since_may1st end_1st_dev_stage_days_since_may1st
##                      11.69333                         23.46667
```

3.7 Programming-'Workflow'.

- Use loops as often as possible ('upwards!'), but avoid loops as often as necessary ('downwards'), because (very roughly (!) said):
  - Loops read and write to the main memory in each iteration →.
  - Vectorized programming reads and writes only once: many functions take vectors as arguments and are therefore (often) faster.
- For clearer code:
  - vectorizing conditions:

```
result <- content1 * logical_comparison1 +
          content2 * logical_comparison2 + ...
```

- Use an `apply` command if you want the function to do the same on every element.
- But:
  - Loops are easy and whoever masters them is already a king: It is better if R-Code gets something right slowly than quickly wrong!
  - Loops cannot be avoided in iterative processes!
  - Avoiding 'if-else' is not worth it under complex conditions!

4 Define your own functions.

Why should I be able to define my own functions?

- Functions generalize command sequences and make it easier and easier to try something out under many different argument values / dates / ....
- Functions keep the workspace clean (see next section on environments).
- Functions facilitate the reproducibility of analyzes.
- Functions make it easier for other users to access your work.
- As can be seen from the `apply()` examples, it is very often necessary to be able to write your own little helper functions. Also for your own **orientation**: Always comment on the processes and steps in your code and in your functions to make it easier to understand the motivation and ideas behind it later.

```
name <- function(arg1, arg2, arg3 = TRUE, arg4 = 2, ...){
  content
  return(result)
}
```

- The general rules for naming objects also apply to function arguments.
- Arguments can have preset values (here `arg3` and`arg4`)
- The last argument `...` (optional) is a special argument and can be used to pass unspecified arguments to function calls.
- Arguments changed by `content` and objects created are in their own local environment.
- The result is returned to the global environment with `return(result)`.

4.1 Naming conventions for arguments.

Argument name	Inhalt
`data`	Dataframe
`x, y, z`	Vectors (most often with numerical elements)
`n`	Sample size
`formula`	Formula object
...	...

- Use function and argument names that are based on existing R functions.
- Make arguments as self-explanatory as possible by name.

4.2 `content` and`result`.

The `content` block:

- Should make it possible to carry out many similar – but different – calculations and therefore define as few objects as possible to 'fixed values': alternatively, always try to define arguments with default values.
- Falls back on the higher-level environment (or environments, if necessary) if it cannot find an object in the local environment (this is known as *scoping*).

The `result` object:

- Can be of any possible R object class (vector, list, data set, function (a function that itself returns a function is called *closure*), ...).
- Is generated by calling the function and stored in the global environment.
- All other objects are no longer 'visible' from the global environment.

4.3 Examples

4.3.1 Environments and Scoping

```
rm(list = ls())
ls()
```

```
## character(0)
```

```
f <- function(x){
  y <- 2
  print(ls())
  y <- y + z ## f wird nach z in der ?bergeordneten Umgebung (hier global) suchen.
  print(ls())
  return(x + y)
}
x <- 1; z <- 3
f(x = x) ## f wird z finden:
```

```
## [1] "x" "y"
## [1] "x" "y"
```

```
## [1] 6
```

```
## -> obwohl wir es nicht explizit als Argument in die lokale Umgebung
##    von f übergeben haben.
y ## Von der übergeordneten Umgebung aus können wir nicht auf y zurückgreifen.
```

```
## Error in eval(expr, envir, enclos): Objekt 'y' nicht gefunden
```

4.3.2 Closure

```
power <- function(exponent){
  return(function(x){
    return(x ^ exponent)})
}
square <- power(2)
square(2)
```

```
## [1] 4
```

```
square(4)
```

```
## [1] 16
```

```
cube <- power(3)
cube(2)
```

```
## [1] 8
```

```
cube(4)
```

```
## [1] 64
```