Portfolio Optimisation with Threshold Accepting

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This vignette provides the code for some of the examples from Gilli et al. [2011]. For more details, please see Chapter 13 of the book; the code in this vignette uses the scripts `exampleSquaredRets.R`, `exampleSquaredRets2.R` and `exampleRatio.R`.

We start by attaching the package. We will later on need the function `resample` (see `?sample`).

```
> require("NMOF")
> resample <- function(x, ...)
      x[sample.int(length(x), ...)]
> set.seed(112233)
```

1 Minimising squares

1.1 A first implementation

This problem serves as a benchmark: we wish to find a long-only portfolio w (weights) that minimises squared returns across all return scenarios. These scenarios are stored in a matrix R of size number of scenarions `ns` times number of assets `na`. More formally, we want to solve the following problem:

$$\min_{w} \ \Phi \tag{1}$$

$$w'\iota = 1\,,$$
$$0 \leq w_j \leq w_j^{\mathrm{sup}} \quad \text{for } j = 1, 2, \ldots, n_A\,.$$

We set w_j^{sup} to 5% for all assets. Φ is the squared return of the portfolio, $w'R'Rw$, which is similar to the portfolio return's variance. We have

$$\frac{1}{n_S} R'R = \mathrm{Cov}(R) + mm'$$

in which Cov is the variance–covariance matrix operator, which maps the columns of R into their variance–covariance matrix; m is a column vector that holds the column means of R, ie, $m' = \frac{1}{n_S}\iota' R$. For short time horizons, the mean of a column is small compared with the average squared return of the column. Hence, we ignore the matrix mm', and variance and squared returns become equivalent.

For testing purposes we use the matrix `fundData` for R.

```
> na <- dim(fundData)[2L]
> ns <- dim(fundData)[1L]
> winf <- 0.0; wsup <- 0.05
> data <- list(R = t(fundData),
               RR = crossprod(fundData),
               na = na,
               ns = ns,
               eps = 0.5/100,
               winf = winf,
               wsup = wsup,
               resample = resample)
```

The neighbourhood function automatically enforces the bugdet constraint.

```
> neighbour <- function(w, data){
      eps <- runif(1L) * data$eps
      toSell <- w > data$winf
```

```
    toBuy  <- w < data$wsup
    i <- data$resample(which(toSell), size = 1L)
    j <- data$resample(which(toBuy),  size = 1L)
    eps <- min(w[i] - data$winf, data$wsup - w[j], eps)
    w[i] <- w[i] - eps
    w[j] <- w[j] + eps
    w
}
```

The objective function.

```
> OF1 <- function(w, data) {
    Rw <- crossprod(data$R, w)
    crossprod(Rw)
}
> OF2 <- function(w, data) {
    aux <- crossprod(data$RR, w)
    crossprod(w, aux)
}
```

`OF2` uses $R'R$; thus, it does not depend on the number of scenarios. But this is only possible for this very specific problem.

We specify a random initial solution `w0` and define all settings in a list `algo`.

```
> w0 <- runif(na); w0 <- w0/sum(w0)
> algo <- list(x0 = w0,
               neighbour = neighbour,
               nS = 2000L,
               nT = 10L,
               nD = 5000L,
               q = 0.20,
               printBar = FALSE,
               printDetail = FALSE)
```

We can now run `TAopt`, first with `OF1` ...

```
> system.time(res <- TAopt(OF1,algo,data))
```

```
   user  system elapsed
  4.024   0.008   4.037
```

```
> 100 * sqrt(crossprod(fundData %*% res$xbest)/ns)
```

```
        [,1]
[1,] 0.33632
```

... and then with `OF2`.

```
> system.time(res <- TAopt(OF2,algo,data))
```

```
   user  system elapsed
  2.456   0.004   2.463
```

```
> 100*sqrt(crossprod(fundData %*% res$xbest)/ns)
```

```
        [,1]
[1,] 0.33672
```

Note that we have rescaled the results (see the book for details). Both results are similar, but `OF2` typically requires less time. We check the contraints.

```
> min(res$xbest) ## should not be smaller than data$winf
```

```
[1] 0
```

```
> max(res$xbest) ## should not be greater than data$wsup
```

```
[1] 0.05
```

```
> sum(res$xbest) ## should be one
```

```
[1] 1
```

The problem can actually be solved quadratic programming; we use the quadprog package [Turlach and Weingessel, 2011].

```
> if (require(quadprog, quietly = TRUE)) {
      covMatrix <- crossprod(fundData)
      A <- rep(1, na); a <- 1
      B <- rbind(-diag(na), diag(na))
      b <- rbind(array(-data$wsup, dim = c(na, 1L)),
                 array( data$winf, dim = c(na, 1L)))
      system.time({
          result <- solve.QP(Dmat = covMatrix,
                             dvec = rep(0,na),
                             Amat = t(rbind(A,B)),
                             bvec = rbind(a,b),
                             meq = 1L)
      })
      wqp <- result$solution

      cat("Compare results...\n")
      cat("QP:", 100 * sqrt( crossprod(fundData %*% wqp)/ns ),"\n")
      cat("TA:", 100 * sqrt( crossprod(fundData %*% res$xbest)/ns ) ,"\n")

      cat("Check constraints ...\n")
      cat("min weight:", min(wqp), "\n")
      cat("max weight:", max(wqp), "\n")
      cat("sum of weights:", sum(wqp), "\n")
  }
```

```
Compare results...
QP: 0.33612
TA: 0.33672
Check constraints ...
min weight: -1.1425e-16
max weight: 0.05
sum of weights: 1
```

1.2 Updating

Here we implement the updating of the objective function as described in Gilli et al. [2011].

```
> neighbourU <- function(sol, data){
      wn <- sol$w
      toSell <- wn > data$winf
      toBuy  <- wn < data$wsup
      i <- data$resample(which(toSell), size = 1L)
      j <- data$resample(which(toBuy), size = 1L)
      eps <- runif(1) * data$eps
      eps <- min(wn[i] - data$winf, data$wsup - wn[j], eps)
      wn[i] <- wn[i] - eps
      wn[j] <- wn[j] + eps
      Rw <- sol$Rw + data$R[,c(i,j)] %*% c(-eps,eps)
      list(w = wn, Rw = Rw)
```

```
 }
> OF <- function(sol, data)
     crossprod(sol$Rw)
```

Prepare the data list (we reuse several items used before).

```
> data <- list(R = fundData, na = na, ns = ns,
              eps = 0.5/100, winf = winf, wsup = wsup,
              resample = resample)
```

We start, again, with a random solution, and also use the same number of iterations as before.

```
> w0 <- runif(data$na); w0 <- w0/sum(w0)
> x0 <- list(w = w0, Rw = fundData %*% w0)
> algo <- list(x0 = x0,
              neighbour = neighbourU,
              nS = 2000L,
              nT = 10L,
              nD = 5000L,
              q = 0.20,
              printBar = FALSE,
              printDetail = FALSE)
> system.time(res2 <- TAopt(OF, algo, data))
```

```
   user  system elapsed
  1.980   0.020   2.002
```

```
> 100*sqrt(crossprod(fundData %*% res2$xbest$w)/ns)
```

```
        [,1]
[1,] 0.33673
```

This should be faster, and we arrive at the same solution as before.

1.3 Redundant assets

We duplicate the last column of fundData.

```
> fundData <- cbind(fundData, fundData[, 200L])
```

Thus, while the dimension increases, the column rank stays unchanged.

```
> dim(fundData)
```

```
[1] 500 201
```

```
> qr(fundData)$rank
```

```
[1] 200
```

```
> qr(cov(fundData))$rank
```

```
[1] 200
```

Checking the weight of the last asset (which was zero), we know that the solution to our model must be unchanged, too.

```
> if (require(quadprog, quietly = TRUE))
     wqp[200L]
```

```
[1] 1.104e-16
```

We redo our example.

```
> na <- dim(fundData)[2L]
> ns <- dim(fundData)[1L]
> winf <- 0.0; wsup <- 0.05
> data <- list(R = fundData, na = na, ns = ns,
              eps = 0.5/100, winf = winf, wsup = wsup,
              resample = resample)
>
```

But a number of QP solvers have problems with such cases.

```
> if (require(quadprog, quietly = TRUE)) {
     covMatrix <- crossprod(fundData)
     A <- rep(1, na); a <- 1
     B <- rbind(-diag(na), diag(na))
     b <- rbind(array(-data$wsup, dim = c(na, 1L)),
                array( data$winf, dim = c(na, 1L)))
     cat(try(result <- solve.QP(Dmat = covMatrix,
                                dvec = rep(0,na),
                                Amat = t(rbind(A,B)),
                                bvec = rbind(a,b),
                                meq = 1L)
               ))
 }
```

```
Error in solve.QP(Dmat = covMatrix, dvec = rep(0, na), Amat = t(rbind(A,  :
  matrix D in quadratic function is not positive definite!
```

But TA can handle this case.

```
> w0 <- runif(data$na); w0 <- w0/sum(w0)
> x0 <- list(w = w0, Rw = fundData %*% w0)
> algo <- list(x0 = x0,
              neighbour = neighbourU,
              nS = 2000L,
              nT = 10L,
              nD = 5000L,
              q = 0.20,
              printBar = FALSE,
              printDetail = FALSE)
> system.time(res3 <- TAopt(OF, algo, data))
```

```
   user  system elapsed
  1.960   0.012   1.979
```

```
> 100*sqrt(crossprod(fundData %*% res3$xbest$w)/ns)
```

```
        [,1]
[1,] 0.33715
```

Final check: weights for asset 200 and its twin, asset 201.

```
> res3$xbest$w[200:201]
```

```
[1] 0 0
```

See Gilli et al. [2011, Section 13.2.5] for a discussion of rank-deficiency and its (computational and empirical) consequences for such problems.

References

Manfred Gilli, Dietmar Maringer, and Enrico Schumann. *Numerical Methods and Optimization in Finance*. Elsevier, 2011.

Berwin A. Turlach and Andreas Weingessel. *quadprog: Functions to solve Quadratic Programming Problems.*, 2011. R package version 1.5-4 (S original by Berwin A. Turlach; R port by Andreas Weingessel.).