

# Repairing solutions

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## 1 Introduction

There are several approaches for including constraints into heuristics; see Chapter 12 of Gilli et al. [2011]. The notes in this vignette give examples for simple repair mechanisms. These can be called in DEopt, GAopt and PSopt through the repair function; in LSopt/TAopt, they could be included in the neighbourhood function.

```
> set.seed(112233)
> options(digits = 3)
```

## 2 Upper and lower limits

Suppose the solution  $x$  is to satisfy  $\text{all}(x \geq lo)$  and  $\text{all}(x \leq up)$ , with  $lo$  and  $up$  being vectors of  $\text{length}(x)$ .

### 2.1 Setting values to the boundaries

One strategy is to replace elements of  $x$  that violate a constraint with the boundary value. Such a repair function can be implemented very concisely. An example:

```
> up <- rep(1, 4L)
> lo <- rep(0, 4L)
> x <- rnorm(4L)
> x
```

```
[1] 2.127 -0.380 0.167 1.600
```

Three of the elements of  $x$  actually violate the constraints.

```
> repair1a <- function(x, up, lo)
+   pmin(up, pmax(lo, x))
> x
```

```
[1] 2.127 -0.380 0.167 1.600
```

```
> repair1a(x, up, lo)
```

```
[1] 1.000 0.000 0.167 1.000
```

We see that indeed all values greater than 1 are replaced with 1, and those smaller than 0 become 0. Two other possibilities that achieve the same result:

```
> repair1b <- function(x, up, lo) {
+   ii <- x > up
+   x[ii] <- up[ii]
+   ii <- x < lo
+   x[ii] <- lo[ii]
+ }
```

```

      x
    }
  > repair1c <- function(x, up, lo) {
    xadjU <- x - up
    xadjU <- xadjU + abs(xadjU)
    xadjL <- lo - x
    xadjL <- xadjL + abs(xadjL)
    x - (xadjU - xadjL)/2
  }

```

The function `repair1b` uses comparisons to replace only the relevant elements in `x`. The function `repair1c` uses the ‘trick’ that

$$\begin{aligned}
 \text{pmax}(x,y) &= \frac{x+y}{2} + \left| \frac{x-y}{2} \right|, \\
 \text{pmin}(x,y) &= \frac{x+y}{2} - \left| \frac{x-y}{2} \right|.
 \end{aligned}$$

```
> repair1a(x, up, lo)
```

```
[1] 1.000 0.000 0.167 1.000
```

```
> repair1b(x, up, lo)
```

```
[1] 1.000 0.000 0.167 1.000
```

```
> repair1c(x, up, lo)
```

```
[1] 1.000 0.000 0.167 1.000
```

```
> trials <- 5000L
```

```
> strials <- seq_len(trials)
```

```
> system.time(for(i in strials) y1 <- repair1a(x, up, lo))
```

```

  user  system elapsed
0.048   0.000   0.048

```

```
> system.time(for(i in strials) y2 <- repair1b(x, up, lo))
```

```

  user  system elapsed
0.013   0.001   0.013

```

```
> system.time(for(i in strials) y3 <- repair1c(x, up, lo))
```

```

  user  system elapsed
0.012   0.000   0.012

```

The third of these functions would also work on matrices if `up` or `lo` were scalars.

```
> X <- array(rnorm(25L), dim = c(5L, 5L))
```

```
> X
```

```

      [,1] [,2] [,3] [,4] [,5]
[1,] 0.1962 0.434 -2.155 -1.5881 -1.029
[2,] 0.2284 1.231 0.975 0.0682 1.818
[3,] -1.1492 0.580 -0.711 -0.4457 -1.315
[4,] -0.0712 0.246 0.628 1.4662 0.511
[5,] -0.5619 0.388 -0.136 -0.8412 1.337

```

```
> repair1c(X, up = 0.5, lo = -0.5)
```

```
      [,1] [,2] [,3] [,4] [,5]
[1,] 0.1962 0.434 -0.500 -0.5000 -0.5
[2,] 0.2284 0.500 0.500 0.0682 0.5
[3,] -0.5000 0.500 -0.500 -0.4457 -0.5
[4,] -0.0712 0.246 0.500 0.5000 0.5
[5,] -0.5000 0.388 -0.136 -0.5000 0.5
```

The speedup comes at a price, of course, since there is no checking (eg, for NA values) in `repair1b` and `repair1c`. We could also define new functions `pmin2` and `pmax2`.

```
> pmax2 <- function(x1, x2)
  ((x1 + x2) + abs(x1 - x2)) / 2
> pmin2 <- function(x1, x2)
  ((x1 + x2) - abs(x1 - x2)) / 2
```

A test follows.

```
> x1 <- rnorm(100L)
> x2 <- rnorm(100L)
> t1 <- system.time(for (i in strials) z1 <- pmax(x1,x2) )
> t2 <- system.time(for (i in strials) z2 <- pmax2(x1,x2))
> t1[[3L]]/t2[[3L]] ## speedup
```

```
[1] 2.73
```

```
> all.equal(z1, z2)
```

```
[1] TRUE
```

```
> t1 <- system.time(for (i in strials) z1 <- pmin(x1,x2) )
> t2 <- system.time(for (i in strials) z2 <- pmin2(x1,x2))
> t1[[3L]]/t2[[3L]] ## speedup
```

```
[1] 2.8
```

```
> all.equal(z1, z2)
```

```
[1] TRUE
```

One downside of this repair mechanism is that a solution may quickly become stuck at the boundaries (but of course, in some cases this is exactly what we want).

## 2.2 Reflecting values into the feasible range

The function `repair2` reflects a value that is too large or too small around the boundary. It restricts the change in a variable `x[i]` to the range `up[i] - lo[i]`.

```
> repair2 <- function(x, up, lo) {
  done <- TRUE
  e <- sum(x - up + abs(x - up) + lo - x + abs(lo - x))
  if (e > 1e-12)
    done <- FALSE
  r <- up - lo
  while (!done) {
```

```

adjU <- x - up
adjU <- adjU + abs(adjU)
adjU <- adjU + r - abs(adjU - r)

adjL <- lo - x
adjL <- adjL + abs(adjL)
adjL <- adjL + r - abs(adjL - r)

x <- x - (adjU - adjL)/2
e <- sum(x - up + abs(x - up) + lo - x + abs(lo - x))
if (e < 1e-12)
  done <- TRUE
}
x
}
> x
[1] 2.127 -0.380 0.167 1.600

> repair2(x, up, lo)
[1] 0.873 0.380 0.167 0.600

> system.time(for (i in strials) y4 <- repair2(x,up,lo))
   user  system elapsed 
0.033   0.000   0.033

```

## 2.3 Adjusting a cardinality limit

Let  $x$  be a logical vector.

```

> T <- 20L
> x <- logical(T)
> x[runif(T) < 0.4] <- TRUE
> x
[1] FALSE TRUE TRUE FALSE TRUE TRUE FALSE FALSE FALSE FALSE FALSE
[12] FALSE TRUE TRUE FALSE FALSE TRUE FALSE FALSE TRUE

```

Suppose we want to impose a minimum and maximum cardinality,  $k_{\min}$  and  $k_{\max}$ .

```

> kmax <- 5L
> kmin <- 3L

```

We could use an approach like the following (for the definition of `resample`, see `?sample`):

```

> resample <- function(x, ...) x[sample.int(length(x), ...)]
> repairK <- function(x, kmax, kmin) {
  sx <- sum(x)
  if (sx > kmax) {
    i <- resample(which(x), sx - kmax)
    x[i] <- FALSE
  } else if (sx < kmin) {
    i <- resample(which(!x), kmin - sx)

```

```

        x[i] <- TRUE
    }
    x
}
> printK <- function(x)
  cat(paste(iffelse(x, "o", "."), collapse = ""),
      "-- cardinality", sum(x), "\n")

```

For kmax:

```

> for (i in 1:10) {
  if (i==1L) printK(x)
  x1 <- repairK(x, kmax, kmin)
  printK(x1)
}

```

```

.oo.oo.....oo..o..o -- cardinality 8
.oo.o.....oo..... -- cardinality 5
.o...o.....oo.....o -- cardinality 5
.o..o.....o...o..o -- cardinality 5
..o.oo.....o.....o -- cardinality 5
.o...o.....oo..o... -- cardinality 5
....oo.....oo..o... -- cardinality 5
.o..oo.....o.....o -- cardinality 5
.oo..o.....oo..... -- cardinality 5
.oo..o.....o...o..o -- cardinality 5
.oo..o.....o...o... -- cardinality 5

```

For kmin:

```

> x <- logical(T); x[10L] <- TRUE
> for (i in 1:10) {
  if (i==1L) printK(x)
  x1 <- repairK(x, kmax, kmin)
  printK(x1)
}

```

```

.....o..... -- cardinality 1
.....oo..o..... -- cardinality 3
o.....o.....o..... -- cardinality 3
...o.....o..o..... -- cardinality 3
.....o..o...o... -- cardinality 3
....o....oo..... -- cardinality 3
....o....oo..... -- cardinality 3
.....o.o.....o -- cardinality 3
.....o.o..o..... -- cardinality 3
.....o...o...o..... -- cardinality 3
....o....o...o..... -- cardinality 3

```

## References

Manfred Gilli, Dietmar Maringer, and Enrico Schumann. *Numerical Methods and Optimization in Finance*. Elsevier/Academic Press, 2011. URL <http://enricoschumann.net/NMOF>.