Assignment 4

Pranav Kasela 846965

Contents


```
require(GA)
require(ggplot2)
require(reshape2)
require(dplyr)
require(Rcpp)
```

Function definition

Initially the functions that were being using to calculate the makespan and fitness were the written in R, but one of the colleagues: *Federico Moiraghi*, was kind enough to provide his code compiled in C++ for the time function to speed up the process. Some parameters are modified in the function before reusing his code.

Since the time is > 0, the inverse of the makespan can be used as the fitness function for **GA** algorithm, since maximizing the fitness is equivalent to minimizing the makespan.

```
#-- Function before C++
makespan <- function(perm,distMatrix){
  n_jobs     <- ncol(distMatrix)
  n_machines <- nrow(distMatrix)
  dist       <- matrix(NA, nrow=n_machines, ncol=n_jobs)
  dist[1,]   <- cumsum(distMatrix[1,perm])
  dist[,1]   <- cumsum(distMatrix[,perm[1]])
  for (i in 2:n_machines){
    for (j in 2:n_jobs){
      dist[i,j] <- distMatrix[i,perm[j]] +
        max(dist[i,j-1],dist[i-1,j])
    }
  }
  makespan   <- dist[n_machines,n_jobs]
  return(makespan)
}

fitness <- function(perm,distMatrix){
  return(1/makespan(perm,distMatrix))
}
```

From hereon the time function used will be makespanCpp, while the fitness code will be fitnessCpp.

```
#-- function in C++
cppFunction('double fitnessCpp(NumericVector perm,
                           NumericMatrix distMatrix)
    {
        int nrow = distMatrix.nrow();
        int ncol = distMatrix.ncol();
        int norder = perm.size();
        NumericVector order(norder);
        for (int i = 0; i < norder; i++) order[i] = perm[i]-1;
        NumericMatrix time_matrix(nrow, norder);
        time_matrix[0] = distMatrix[nrow * order[0]];
        for (int r = 1; r < nrow; r++)
            time_matrix[r] = time_matrix[r - 1] +
            distMatrix[nrow * order[0] + r];
        for (int c = 1; c < norder; c++)
            time_matrix[nrow * c] = time_matrix[nrow * (c - 1)] +
            distMatrix[nrow * order[c]];
        for (int r = 1; r < nrow; r++)
            for (int c = 1; c < norder; c++)
                if (time_matrix[nrow * c + (r - 1)] > time_matrix[nrow * (c - 1) + r])
                    time_matrix[nrow * c + r] = time_matrix[nrow * c + (r - 1)] +
            distMatrix[nrow * order[c] + r];
        else
            time_matrix[nrow * c + r] = time_matrix[nrow * (c - 1) + r] +
            distMatrix[nrow * order[c] + r];
        return 1/time_matrix[nrow * norder - 1];
    }')

cppFunction('double makespanCpp(NumericVector perm,
                           NumericMatrix distMatrix)
    {
        int nrow = distMatrix.nrow();
        int ncol = distMatrix.ncol();
        int norder = perm.size();
        NumericVector order(norder);
        for (int i = 0; i < norder; i++) order[i] = perm[i]-1;
        NumericMatrix time_matrix(nrow, norder);
        time_matrix[0] = distMatrix[nrow * order[0]];
        for (int r = 1; r < nrow; r++)
            time_matrix[r] = time_matrix[r - 1] +
            distMatrix[nrow * order[0] + r];
        for (int c = 1; c < norder; c++)
            time_matrix[nrow * c] = time_matrix[nrow * (c - 1)] +
            distMatrix[nrow * order[c]];
        for (int r = 1; r < nrow; r++)
            for (int c = 1; c < norder; c++)
                if (time_matrix[nrow * c + (r - 1)] > time_matrix[nrow * (c - 1) + r])
                    time_matrix[nrow * c + r] = time_matrix[nrow * c + (r - 1)] +
            distMatrix[nrow * order[c] + r];
        else
            time_matrix[nrow * c + r] = time_matrix[nrow * (c - 1) + r] +
            distMatrix[nrow * order[c] + r];
        return time_matrix[nrow * norder - 1];
```

```
    }')
```

Table with 20 jobs for 5 machines for the performance checking

The testing of the functions are done with the smallest table available on the website. The algorithm used are the Genetic Algorithm from the R package and the Simulated Annealing that will be implemented manually to check their performance.

GA algorithm (from the GA package)

```
#This is the pre-test given in the assignment
time_matrix <- matrix(c(29,30,27,2,37,62,21,6,95,59,70,82,
                 85,11,62,80,65,55,67,57),nrow = 4) #used once to test and never again

time_matrix <- as.matrix(read.csv("j20-m5",sep=" ",header = FALSE))
n_jobs <- ncol(time_matrix)


time_taken_GA_20_5 <- microbenchmark::microbenchmark(
  GA.fit <- ga(type = "permutation",
    fitness = fitnessCpp,
    distMatrix = time_matrix,
    lower = 1,
    upper = n_jobs,
    popSize = 600,
    maxiter = 10000,
    run = 300,
    pmutation = 0.2,
    keepBest = TRUE,
    monitor = NULL,
    seed = 1234),
times = 1
)

summary(GA.fit)
```

```
## -- Genetic Algorithm -------------------
##
## GA settings:
## Type                  =  permutation
## Population size       =  600
## Number of generations =  10000
## Elitism               =  30
## Crossover probability =  0.8
## Mutation probability  =  0.2
##
## GA results:
## Iterations             = 359
## Fitness function value = 0.00077101
## Solutions =
##       x1 x2 x3 x4 x5 x6 x7 x8 x9 x10  ...  x19 x20
```

```
## [1,]  15 11  9 14  5  7  1  3 19  4        10  20
## [2,]  15  6 11 14  7 17  9  5  8  1        10  20
## [3,]   1 17 15 14 19  9 16  6 11 13        10  20
## [4,]  15 11  9 14  5  8  7 17  1  3        10  20
## [5,]  15 14 19  1  3  9  4 17  5 16        10  20
## [6,]  15  6 11 14  5  8  7 17  1 19        10  20
## [7,]  15 11  9 14  5  7  1  8  6 19        10  20
## [8,]  15  9 14  5  1  6 19  4  7 16        10  20
## [9,]   1  9  4 19 15 17 14 16  5  3        10  20
## [10,] 15 17 14  4  9  3  1 19  5 16        10  20
##  ...
## [29,] 15  6 11  9  7 17  1 19 14  5        10  20
## [30,] 15  6 11 17 14  9  1  7  8  3        10  20
```

```
makespanCpp(GA.fit@solution[1,],time_matrix) #best time
```

```
## [1] 1297
```

```
out <- plot(GA.fit, main = "GA progression")
```

```
melt(out[,c(1:3,5)],id.var="iter") %>%
  mutate(inv.value=1/value) -> df1

ggplot(df1, aes(x = iter, y = inv.value,
                group = variable, colour = variable)) +
  xlab("Generation") + ylab("Makespan") +
  geom_line(aes(lty = variable)) +
  scale_colour_brewer(palette = "Set1") +
  labs(title = "GA Progression with 20 jobs in 5 machines")
```

The **GA** algoritm finds the best solution as 1297, with an initial population of 600, a mutation probability of 20% and a crossover probability of 80%. An initial trend of improvement can be seen

SA algorithm (manually implemented)

The change that has been made the SA algorithm is the swapJobs function, in this case since the permutation will be done on a lot of elements (=number of jobs) - If the number of the jobs is greater than 10, the swap will be done on a random number of elements between 2 and 5; - If the number of jobs is smaller or equal to 10, the swap will be done on 2 elements.

The algorithm, since it's computationally easy to compute, will be done 5 time, to avoid heavy dependencies from it's probabistic nature.

```
swapJobs <- function(perm){
    perm <- as.numeric(perm)
    n <- length(perm)
    if(n>10)
      n_change <- min(sample(2:ceiling(n/5),1),5) #no more than 5 changes at a time
    else
      n_change <- 2
    change <- sort(sample.int(n,n_change))
    newperm <- replace(perm,change,perm[sort(change,decreasing = TRUE)])
    return(as.numeric(newperm))
}

SA <- function(tour, distMatrix, maxIterNoChange = 2000, T_ini = 50, T_min = 1){
  path <- tour
```

```
  n <- length(path)
  tmin <- T_min    # minimum temperature
  alpha <- 0.999  # update factor
  T <- T_ini
  tini <- T_ini   # starting temperature
  dist <- makespanCpp(path, distMatrix)
  bestLength <- dist
  traceBest <- c(dist)
  traceCurrentLength <- c(dist)
  iterNoChange = 0
  while(T >= tmin){        # if the temperature is not at its minimum
    iterNoChange = iterNoChange+1
    newpath <- swapJobs(path) #swap
    dist_new <- makespanCpp(newpath, distMatrix)
    if(dist_new <= bestLength){
      path <- newpath
      dist <- dist_new
      bestLength <- dist
      iterNoChange <- 0
    }
    else {

      if (exp((dist-dist_new)/T)>runif(1, 0, 1)){
        dist <- dist_new
        path <- newpath
        iterNoChange <- 0
      }

    }
    traceBest <- append(traceBest, bestLength)
    traceCurrentLength <- append(traceCurrentLength, dist)
    T <- T*alpha # the temperature is updated
    if(iterNoChange >= maxIterNoChange){ break}
  }
  res = list(route=path, traceBest = traceBest, trace = traceCurrentLength)
  return(res)
}


start <- as.numeric(sample(1:n_jobs,n_jobs)) #start randomly
best_res   <- SA(start, time_matrix, maxIterNoChange = 10000)

for (i in 1:4){
  start <- as.numeric(sample(1:n_jobs,n_jobs)) #start randomly
  res   <- SA(start, time_matrix, maxIterNoChange = 10000)
  if (tail(res$traceBest,1) < tail(best_res$traceBest,1))
    best_res <- res
}
tail(best_res$traceBest,1) #best value found
```

```
## [1] 1297
```

When trying with the 100x20 table, the **GA** algorithm finished in approximately 5 minutes, while **SA** algorithm finished in a few seconds giving more or less the same result (GA best makespan was 6557 while

SA best makespan was 6594). The result for the 100x20 table is not provided here for the simplicity of the report.

Final Results using 500 jobs with 20 machines.

```
time_matrix <- as.matrix(read.csv("j500-m20",sep=" ",header = FALSE))
n_jobs <- ncol(time_matrix)

time_taken_GA_500_20 <- microbenchmark::microbenchmark(
  GA.fit <- ga(type = "permutation",
    fitness = fitnessCpp,
    distMatrix = time_matrix,
    lower = 1,
    upper = n_jobs,
    popSize = 300,
    maxiter = 10000,
    run = 100,
    pmutation = 0.2,
    keepBest = TRUE,
    monitor = NULL,
    seed = 1234),
times = 1
)

makespanCpp(GA.fit@solution[1,],time_matrix) #best time
```

```
## [1] 28361
```

```
out <- plot(GA.fit, main = "GA progression")
```

```
melt(out[,c(1:3,5)],id.var="iter") %>%
  mutate(inv.value=1/value) -> df1

ggplot(df1, aes(x = iter, y = inv.value,
                group = variable, colour = variable)) +
  xlab("Generation") + ylab("Makespan") +
  geom_line(aes(lty = variable)) +
  scale_colour_brewer(palette = "Set1") +
  labs(title = "GA Progression with 500 jobs in 20 machines")
```

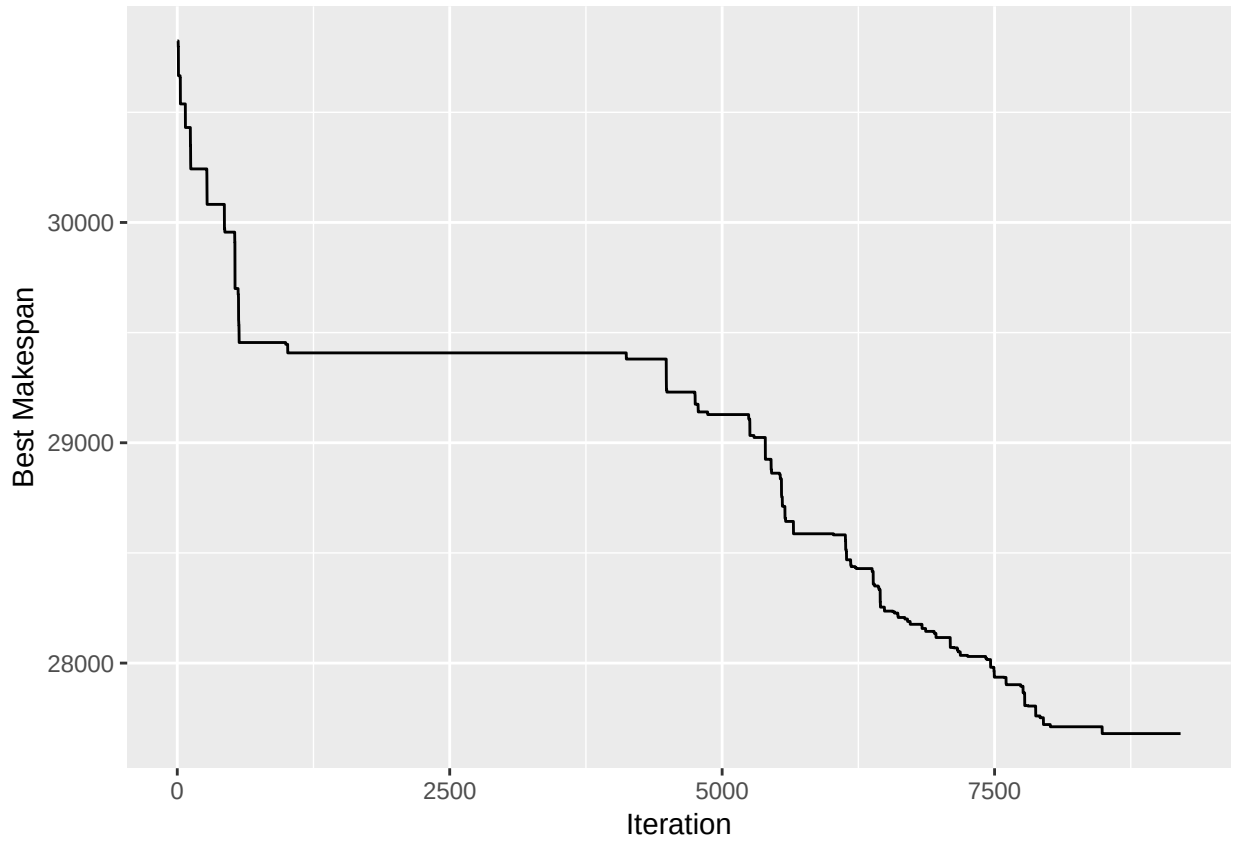
The **SA** algorithm solution is better than the one given by the **GA** algorithm.

```
start <- as.numeric(sample(1:n_jobs,n_jobs)) #start randomly
best_res   <- SA(start, time_matrix, maxIterNoChange = 30000,
                 T_ini = 10000,T_min = 1)

for (i in 1:4){
  start <- as.numeric(sample(1:n_jobs,n_jobs)) #start randomly
  res   <- SA(start, time_matrix, maxIterNoChange = 30000,
              T_ini = 10000,T_min = 1)
  if (tail(res$traceBest,1) < tail(best_res$traceBest,1))
    best_res <- res
}
tail(best_res$traceBest,1) #best value found
```

```
## [1] 27680
```

```
ggplot(data = data.frame(iteration=1:length(best_res$traceBest),
                         optimal=best_res$traceBest),
       aes(iteration,optimal)) +
  geom_line() +
  xlab("Iteration") + ylab("Best Makespan") +
  scale_colour_brewer(palette = "Set1")
```



For the Extra point, NEH algorithm for the suboptimal solution

```
insert_at <- function(x,pos,val){
  "inserts at a given position (pos) the value (val) in the array x"
  if (pos==1)
    return(c(val,x))
  len <- length(x)
  if (pos==(len+1))
    return(c(x,val))
  return(c(x[1:pos-1],val,x[pos:len]))
}

NEH <- function(distMatrix,fun.obj,REPORT=0){
  sum <- rbind(colSums(distMatrix),1:ncol(distMatrix))
  sum_order <- as.numeric(sum[2,order(sum[1,])])

  job <- sum_order[1] #the job that takes less time in all machines

  for (i in 2:ncol(distMatrix)){
    temp_ris <- lapply(1:(length(job)+1), function(x) {
                          temp_job = insert_at(job,x,sum_order[i])
                          t <- fun.obj(1:(length(job)+1),distMatrix[,temp_job])
                          return(list(temp_job=temp_job, t=t))
                      })
    t <- unlist(lapply(temp_ris, '[[','t'))
```

```
    job <- lapply(temp_ris, '[[','temp_job')[[which.min(t)]]
    if(REPORT!=0 && i%%REPORT==0)
      print(paste0("Done ",as.character(i)," jobs"))
  }
  return(list(sol   = job,
              value = fun.obj(job,distMatrix) ))
}
```

```
time_taken_NEH_500_20 <- microbenchmark::microbenchmark(
  ris <- NEH(distMatrix = time_matrix, fun.obj = makespanCpp),
times = 1
)

ris$value
```

```
## [1] 26936
```

```
#ris$sol
```

```
SA(ris$sol,time_matrix,maxIterNoChange = 10000,T_ini = 10,T_min = 1)
```

```
## $route
##   [1] 485 183  10 475 157 176 326 288  46 169  31  51 166 203 135 494 378
##  [18] 207 303 487 104 186 275 362 108 421 355 283 248 100 484  56 201 337
##  [35]  96 460 285  29 373  97  36  48 270 358 254 145 429 499 256  81 225
##  [52] 418  78 286  87 252 229 220  76 441 305 129 223 146 102 213  74 120
##  [69] 344 404 444  15 474 296 356 149 397  68 193 150 500 243 301 142 319
##  [86] 371 446  11 384 402 442 455 124 412 114   2  44  63 492  38 329 479
## [103] 461 405 163 302 450 281  14 289 264 438 401 192  65 407  85 433 369
## [120] 247 443  19 291  23  34 440 208 251  13 379 282 178 482 389 478  86
## [137] 352 312 159  25 341 436 315 314  49 180 468 388 128  55 347 240 342
## [154] 354 423 143 255 134 382 457 308 141 377  21 107 428 339  27 198 374
## [171] 189  99 392 349 237  28 413  16 214 453 151 140 219   1 325 411 336
## [188] 470 139 263 161 221  61 451 267 381 332 257 330   8 249 498 121  37
## [205] 304 196  26  18 238  83  57 122  88 398  62 269 268 298  22 424 233
## [222] 113 184  79 119  95 278 393 165  59 473 416 306 245 400 321 408 493
## [239] 331 241  80 299  24 297   7 177  41 432 236 365  70 370 462 217 110
## [256] 162 447 153 191 181 160  84 215 335 276 338 230  73 272 258 224 360
## [273] 477  53 350 261 399 190 194 295  60 259  91 480 395 188 168 116 242
## [290]   5 202 340 287 167 131  52 394  72 483 222 496 469 422  58 144 231
## [307] 410 154 476  33 174  92 437  69 324 127 449 328 182 123 253  50 372
## [324] 171 172  75  45 216  94 101  40 458 246 218 490  67   4 106 434 126
## [341] 132 197 467  20 497  47 456 152 205 125 227 173 368 293 148  98 232
## [358] 310 206 234  54 376 179 495 415 385 431 380 472 117 130 435 327 486
## [375]  42 452 417 320 226 345 489 481 459 147 409 235 209 109 204   9  71
## [392] 274 364 396 280 105   3  32 158 318 390 322 195  77 187 448 406 307
## [409]  39 244 112 133 309 425 491 351 391 439 115 323 403 212 313 427 317
## [426]  43 387 239 156  90 164 353  12 316 359 292 170 488 200 137 273 185
## [443] 386 279 346 284  35  17 471 414 260 111 375 210 175  30 445 419 290
## [460] 383 366   6 228 265 426 334 250 311  64 211  82  89 277 138 361 136
## [477] 199  93 155 103  66 343 271 367 266 357 454 420 463 333 348 430 118
## [494] 466 363 294 465 464 262 300
##
## $traceBest
##    [1] 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936
```

```
##   [12] 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936
##   [23] 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936
##   [34] 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936
##   [45] 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936
##   [56] 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936
##   [67] 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936
##   [78] 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936
##   [89] 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936
##  [100] 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936
##  [111] 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936
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##  [177] 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936
##  [188] 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936
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##  [232] 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936
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##  [364] 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936
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##  [441] 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936
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##  [485] 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936
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##  [573] 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936
##  [584] 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936
##  [595] 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936
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##  [606] 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936
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##  [628] 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936
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##  [650] 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936
##  [661] 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936
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##  [815] 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936
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##  [848] 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936
##  [859] 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936
##  [870] 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936
##  [881] 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936
##  [892] 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936
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##  [914] 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936
##  [925] 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936
##  [936] 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936 26936
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## [1728] 26950 26950 26950 26950 26950 26950 26950 26950 26950 26950 26950
## [1739] 26950 26950 26950 26950 26950 26950 26950 26950 26950 26950 26950
## [1750] 26950 26950 26950 26950 26950 26950 26950 26950 26950 26950 26950
## [1761] 26950 26950 26950 26950 26950 26950 26950 26950 26950 26950 26950
## [1772] 26950 26950 26950 26950 26950 26950 26950 26950 26950 26950 26950
## [1783] 26950 26950 26950 26950 26950 26950 26950 26950 26950 26950 26950
## [1794] 26950 26950 26950 26950 26950 26950 26950 26950 26950 26950 26950
## [1805] 26950 26950 26950 26950 26950 26950 26950 26950 26950 26950 26950
## [1816] 26950 26950 26950 26950 26950 26950 26950 26950 26950 26950 26950
## [1827] 26950 26950 26950 26950 26950 26950 26950 26950 26950 26950 26950
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## [1838] 26950 26950 26950 26950 26950 26950 26950 26950 26950 26950 26950
## [1849] 26950 26950 26950 26950 26950 26950 26950 26950 26950 26950 26950
## [1860] 26950 26950 26950 26950 26950 26950 26950 26950 26950 26950 26950
## [1871] 26950 26950 26950 26950 26950 26950 26950 26950 26950 26950 26950
## [1882] 26950 26950 26950 26950 26950 26950 26950 26950 26950 26950 26950
## [1893] 26950 26950 26950 26950 26950 26950 26950 26950 26950 26950 26950
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