

Package ‘FLSSS’

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Type Package

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Description Specialized solvers for combinatorial optimization problems in the Subset Sum family. These solvers differ from the mainstream in the options of (i) restricting subset size, (ii) bounding subset elements, (iii) mining real-value sets with predefined subset sum errors, and (iv) finding one or more subsets in limited time. A novel algorithm for mining the one-dimensional Subset Sum induced algorithms for the multi-Subset Sum and the multidimensional Subset Sum. The latter decomposes the problem in a novel approach, and the multi-threaded framework offers exact algorithms to the multidimensional Knapsack and the Generalized Assignment problems. Package updates include (a) renewed implementation of the multi-Subset Sum, multidimensional Knapsack and Generalized Assignment solvers; (b) availability of bounding solution space in the multidimensional Subset Sum; (c) fundamental data structure and architectural changes for enhanced cache locality and better chance of SIMD vectorization; (d) an option of mapping real-domain problems to the integer domain with user-controlled precision loss, and those integers are further zipped non-uniformly in 64-bit buffers. Arithmetic on compressed integers is done by bit-manipulation and the design has virtually zero speed lag relative to normal integers arithmetic. The consequent reduction in dimensionality may yield substantial acceleration. Compilation with g++ '-Ofast' is recommended. See package vignette (<arXiv:1612.04484v3>) for details. Functions prefixed with 'aux' (auxiliary) are or will be implementations of existing foundational or cutting-edge algorithms for solving optimization problems of interest.

License GPL-3

Encoding UTF-8

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ByteCompile true

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LinkingTo Rcpp, RcppParallel

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auxGAPbb	<i>Multithreaded generalized assignment problem solver via branch and bound</i>
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Description

Multithreaded exact solver for the generalized assignment problem via decomposition to binary knapsack problems (branch), and Lagrangian relaxation (bound).

Usage

```
auxGAPbb(
  cost,
  profitOrLoss,
  budget,
  maxCore = 7,
  tlimit = 60,
  ub = "MT",
  greedyBranching = TRUE,
  optim = "max",
  multithreadOn = "nodes",
  threadLoad = 32
)
```

Arguments

cost	A numeric matrix. Dimensionality = $N(\text{agents}) \times N(\text{tasks})$.
profitOrLoss	A numeric matrix of the same dimensionality of cost. Profit for maximum GAP. Loss for minimum GAP.
budget	A numeric vector. Size = $N(\text{agents})$.
maxCore	Maximal threads to invoke. No greater than the number of logical CPUs on machine.
tlimit	Return the best existing solution in tlimit seconds.
ub	Upper bound function. "MT" or "HS". See auxKnapsack01bb().
greedyBranching	If TRUE, branch and bound in a greedy manner. See Details.
optim	A string. optim = "max" ("min") solves the maximum (minimum) GAP.
multthreadOn	A string. The default multthreadOn = "nodes" multithreads over branching nodes. Internally, a single-threaded miner runs at first and stops once there are no less than maxCore * threadLoad latent trees stored in stack. The miner realizes those branches and distribute them to threads. Threads work on the subproblems sequentially and update the optimum supervised by a light mutex lock. Other values of multthreadOn assign threads to knapsack problems at each branching node, which is a historical remain and should always be avoided. It has overwhelming overheads because knapsack problems at those nodes are typically trivial.
threadLoad	An integer. Each thread is loaded with threadLoad sub-problems on average.

Details

A popular library of GAP instances can be found here: <https://github.com/WhateverLiu/gapInstances>. This algorithm is based on a foundational paper by Ross and Soland (1975) and is carefully engineered towards speed. Implementation highlights include (i) decomposition for multithreading; (ii) a new branching method (greedyBranching) that pushes all candidate branching variables at each node into stack instead of pushing only those that have the highest desirabilities and would not affect the subsequent branching after being pushed; (iii) the return of current best solutions in time; (iv) the capability of taking real costs and profits. greedyBranching may considerably lower the number of nodes having the same series of knapsack problems to solve, thus accelerate the convergence speed.

Value

A list of 5:

totalProfitOrLoss	Total profit or loss generated from the assignment.
agentCost	A numeric vector of total costs for each agent.
assignment	An integer vector. assignment[i] indexes the agent assigned to the ith task.
nodes	The number of branching nodes generated in mining.
bkpSolved	The number of binary knapsack problems solved in mining.

Note

The C++ implementation is fully independent and borrows no code from any commercial or open source.

Examples

```
# =====
# Data source: http://people.brunel.ac.uk/~mastjjb/jeb/orlib/gapinfo.html,
# gap1 c515-1, 5 agents 15 tasks. Parsed instances from the library can be
# found here: https://github.com/WhateverLiu/gapInstances
# =====
profit = c(17,21,22,18,24,15,20,18,19,18,16,22,24,24,16,23,16,21,16,17,16,19,
          25,18,21,17,15,25,17,24,16,20,16,25,24,16,17,19,19,18,20,16,17,21,
          24,19,19,22,22,20,16,19,17,21,19,25,23,25,25,25,18,19,15,15,21,25,
          16,16,23,15,22,17,19,22,24)
profit = t(matrix(profit, ncol = 5))
cost = c(8,15,14,23,8,16,8,25,9,17,25,15,10,8,24,15,7,23,22,11,11,12,10,17,16,
        7,16,10,18,22,21,20,6,22,24,10,24,9,21,14,11,14,11,19,16,20,11,8,14,
        9,5,6,19,19,7,6,6,13,9,18,8,13,13,13,10,20,25,16,16,17,10,10,5,12,23)
cost = t(matrix(cost, ncol = 5))
budget = c(36, 34, 38, 27, 33)

sol = FLSSS::auxGAPbb(cost, profit, budget, maxCore = 2, tlimit = 4,
                     ub = "MT", greedyBranching = TRUE, optim = "max")

# =====
# Data source: http://support.sas.com/documentation/cdl/en/ormpug/65554/HTML
# /default/viewer.htm#ormpug_decomp_examples02.htm, an example made by SAS
# corporation. 24 tasks assigned to 8 agents.
# =====
cost = t(matrix(c(
  8,18,22,5,11,11,22,11,17,22,11,20,13,13,7,22,15,22,24,8,8,24,18,8,24,14,11,
  15,24,8,10,15,19,25,6,13,10,25,19,24,13,12,5,18,10,24,8,5,22,22,21,22,13,
  16,21,5,25,13,12,9,24,6,22,24,11,21,11,14,12,10,20,6,13,8,19,12,19,18,10,21,
  5,9,11,9,22,8,12,13,9,25,19,24,22,6,19,14,25,16,13,5,11,8,7,8,25,20,24,20,11,
  6,10,10,6,22,10,10,13,21,5,19,19,19,5,11,22,24,18,11,6,13,24,24,22,6,22,5,14,
  6,16,11,6,8,18,10,24,10,9,10,6,15,7,13,20,8,7,9,24,9,21,9,11,19,10,5,23,20,5,
  21,6,9,9,5,12,10,16,15,19,18,20,18,16,21,11,12,22,16,21,25,7,14,16,10),
  ncol = 8))
profit = t(matrix(c(
  25,23,20,16,19,22,20,16,15,22,15,21,20,23,20,22,19,25,25,24,21,17,23,17,16,
  19,22,22,19,23,17,24,15,24,18,19,20,24,25,25,19,24,18,21,16,25,15,20,20,18,
  23,23,23,17,19,16,24,24,17,23,19,22,23,25,23,18,19,24,20,17,23,23,16,16,15,23,
  15,15,25,22,17,20,19,16,17,17,20,17,17,18,16,18,15,25,22,17,17,23,21,20,24,22,
  25,17,22,20,16,22,21,23,24,15,22,25,18,19,19,17,22,23,24,21,23,17,21,19,19,17,
  18,24,15,15,17,18,15,24,19,21,23,24,17,20,16,21,18,21,22,23,22,15,18,15,21,22,
  15,23,21,25,25,23,20,16,25,17,15,15,18,16,19,24,18,17,21,18,24,25,18,23,21,15,
  24,23,18,18,23,23,16,20,20,19,25,21), ncol = 8))
```

```

budget = c(36, 35, 38, 34, 32, 34, 31, 34)

# Intel CPU i7-4770 3.4GHz, g++ '-Ofast', 64-bit Windows 7:
system.time({sol = FLSSS::auxGAPbb(
  cost, profit, budget, maxCore = 2, tlimit = 4, ub = "MT",
  greedyBranching = FALSE, optim = "max"}})
# user system elapsed
# 0.02 0.00 0.01
# The elapsed time is about 1% of that reported by the SAS proc with 8
# threads, although its hardware configuration is unknown.

system.time({sol2 = FLSSS::auxGAPbb(
  cost, profit, budget, maxCore = 2, tlimit = 4, ub = "MT",
  greedyBranching = TRUE, optim = "max"}})
sol[c("nodes", "bkpSolved")] # 4526, 14671, can be different.
sol2[c("nodes", "bkpSolved")] # 4517, 13115, can be different.
# Greedy branching may lower the numbers of branching nodes and
# knapsack problems to solve.

# =====
# Play random numbers.
# =====
set.seed(22) # A nontrivial instance searched via changing random seeds.
             # RNG in R 3.5.1 for Windows.
Nagent = 20L; Ntask = 200L
cost = matrix(runif(Nagent * Ntask, 1e3, 1e6), nrow = Nagent)
profit = matrix(abs(rnorm(Nagent * Ntask, 1e6, 1e6)) + 1000, nrow = Nagent)
budget = apply(cost, 1, function(x) runif(1, min(x), sum(x) / 2))

# Intel CPU i7-4770 3.4GHz, g++ '-Ofast', 64-bit Windows 7.
system.time({sol1 = FLSSS::auxGAPbb(
  cost, profit, budget,
  maxCore = 1, multithreadOn = "KPs",
  tlimit = 3600, ub = "MT", greedyBranching = TRUE, optim = "max"}})
# user system elapsed
# 9.17 0.00 9.19

# Multithread knapsack problems at each branching node.
# This does not accelerate the speed at all because threading overheads
# are overwhelming.
system.time({sol2 = FLSSS::auxGAPbb(
  cost, profit, budget,
  maxCore = 7, multithreadOn = "KPs",
  tlimit = 3600, ub = "MT", greedyBranching = TRUE, optim = "max"}})
# user system elapsed
# 39.02 5.24 11.12

```

```
# Multithread nodes.
system.time({sol3 = FLSSS::auxGAPbb(
  cost, profit, budget,
  maxCore = 7, multithreadOn = "nodes", threadLoad = 32L,
  tlimit = 3600, ub = "MT", greedyBranching = TRUE, optim = "max"}})
# user system elapsed
# 14.62 0.00 2.13
```

 auxGAPbbDp

Multithreaded generalized assignment problem solver via a hybrid of branch-and-bound and dynamic programming.

Description

Multithreaded exact solver for the generalized assignment problem via decomposition to binary knapsack problems (branch), and Lagrangian relaxation (bound). Knapsack problems are solved via dynamic programming.

Usage

```
auxGAPbbDp(
  cost,
  profitOrLoss,
  budget,
  maxCore = 7L,
  tlimit = 60,
  greedyBranching = TRUE,
  optim = "max",
  multithreadOn = "nodes",
  threadLoad = 32
)
```

Arguments

cost	An integer matrix. Dimensionality = $N(\text{agents}) \times N(\text{tasks})$.
profitOrLoss	A numeric matrix of the same dimensionality of cost. Profit for maximum GAP. Loss for minimum GAP.
budget	An integer vector. Size = $N(\text{agents})$.
maxCore	Maximal threads to invoke. No greater than the number of logical CPUs on machine.
tlimit	Return the best existing solution in tlimit seconds.
greedyBranching	See greedyBranching in auxGAPbb().

optim	A string. optim = "max" ("min") solves the maximum (minimum) GAP.
multthreadOn	See multthreadOn in auxGAPbb().
threadLoad	See threadLoad in auxGAPbb().

Details

For instances with integral cost and budget of small magnitudes, knapsack problems from the decomposition could be solved faster via dynamic programming than branch and bound. See auxKnapsack01dp(). Implementation highlights include (i) only maxCore many lookup matrices exist in memory; (ii) a lookup matrix is recycled if it is sufficiently large to support solving the current knapsack problem, so as to minimize potential contentious memory allocations in multithreading. These management rules for economical memories propagate through all package functions. See more details in auxGAPbb().

Value

See Value of auxGAPbb().

Note

cost and budget are integers. The C++ implementation is fully independent and borrows no code from any commercial or open source.

Examples

```
# =====
# Data source: http://support.sas.com/documentation/cdl/en/ormpug/65554/HTML
# /default/viewer.htm#ormpug_decomp_examples02.htm, an example made by SAS
# corporation. 24 tasks assigned to 8 agents.
# =====
cost = t(matrix(as.integer(c(
  8,18,22,5,11,11,22,11,17,22,11,20,13,13,7,22,15,22,24,8,8,24,18,8,24,14,11,
  15,24,8,10,15,19,25,6,13,10,25,19,24,13,12,5,18,10,24,8,5,22,22,21,22,13,
  16,21,5,25,13,12,9,24,6,22,24,11,21,11,14,12,10,20,6,13,8,19,12,19,18,10,21,
  5,9,11,9,22,8,12,13,9,25,19,24,22,6,19,14,25,16,13,5,11,8,7,8,25,20,24,20,11,
  6,10,10,6,22,10,10,13,21,5,19,19,19,5,11,22,24,18,11,6,13,24,24,22,6,22,5,14,
  6,16,11,6,8,18,10,24,10,9,10,6,15,7,13,20,8,7,9,24,9,21,9,11,19,10,5,23,20,5,
  21,6,9,9,5,12,10,16,15,19,18,20,18,16,21,11,12,22,16,21,25,7,14,16,10)),
  ncol = 8))
profit = t(matrix(c(
  25,23,20,16,19,22,20,16,15,22,15,21,20,23,20,22,19,25,25,24,21,17,23,17,16,
  19,22,22,19,23,17,24,15,24,18,19,20,24,25,25,19,24,18,21,16,25,15,20,20,18,
  23,23,23,17,19,16,24,24,17,23,19,22,23,25,23,18,19,24,20,17,23,23,16,16,15,23,
  15,15,25,22,17,20,19,16,17,17,20,17,17,18,16,18,15,25,22,17,17,23,21,20,24,22,
  25,17,22,20,16,22,21,23,24,15,22,25,18,19,19,17,22,23,24,21,23,17,21,19,19,17,
  18,24,15,15,17,18,15,24,19,21,23,24,17,20,16,21,18,21,22,23,22,15,18,15,21,22,
  15,23,21,25,25,23,20,16,25,17,15,15,18,16,19,24,18,17,21,18,24,25,18,23,21,15,
  24,23,18,18,23,23,16,20,20,19,25,21), ncol = 8))
budget = as.integer(c(36, 35, 38, 34, 32, 34, 31, 34))
```

```

system.time({sol = FLSSS::auxGAPbbDp(
  cost, profit, budget,
  maxCore = 2, tlimit = 4, greedyBranching = TRUE, optim = "max"}})
sol[c("nodes", "bkpSolved")] # 2630, 8102

set.seed(8) # A nontrivial instance searched via changing random seeds.
# RNG in R 3.5.1 for Windows.
Nagent = 20L; Ntask = 200L
cost = matrix(as.integer(runif(Nagent * Ntask, 1, 50)), nrow = Nagent)
budget = as.integer(apply(cost, 1, function(x) runif(1, min(x), sum(x) / 2)))
profit = matrix(abs(rnorm(Nagent * Ntask, 1e6, 1e6)) + 1000, nrow = Nagent)

# Intel CPU i7-4770 3.4GHz, g++ '-Ofast', 64-bit Windows 7.
system.time({sol1 = FLSSS::auxGAPbb(
  cost, profit, budget,
  maxCore = 7, multithreadOn = "nodes",
  tlimit = 3600, greedyBranching = TRUE, optim = "max"}})
# user system elapsed
# 14.43 0.00 2.11

system.time({sol2 = FLSSS::auxGAPbbDp(
  cost, profit, budget,
  maxCore = 7, multithreadOn = "nodes",
  tlimit = 3600, greedyBranching = TRUE, optim = "max"}})
# user system elapsed
# 5.77 0.00 0.87
# Dynamic programming for solving knapsack problems could be faster
# for integral costs and budgets of small magnitudes.

```

 auxGAPga

Multithreaded generalized assignment problem solver via genetic algorithm

Description

A genetic algorithm with local heuristics for GAP.

Usage

```

auxGAPga(
  cost,
  profitOrLoss,
  budget,
  trials,

```



```

    populationSize,
    generations,
    randomSeed = NULL,
    maxCore = 7,
    optim = "max"
)

```

Arguments

cost	A numeric matrix. Dimensionality = N(agents) x N(tasks).
profitOrLoss	A numeric matrix of the same dimensionality of cost. Profit for maximum GAP. Loss for minimum GAP.
budget	A numeric vector. Size = N(agents).
trials	An integer. Number of trials, aka the number of population sets.
populationSize	An integer. Size of each population.
generations	An integer. As reproduction iterates, if there have been generations many children produced and accepted in population but no update on the current optimum, function quits.
randomSeed	An integer or NULL. randomSeed seeds the random number generator in R, generates trials many integers to seed the mt19937_64 (Mersenne Twister) engine for each trial.
maxCore	Maximal threads to invoke. No greater than the number of logical CPUs on machine. The algorithm multithreads over trials.
optim	A string. optim = "max" ("min") solves the maximum (minimum) GAP.

Details

This algorithm is based on a foundational paper by Chu and Beasley (1997) and is carefully engineered towards speed. Besides the standard cross-over and mutation operations, the algorithm applies two local heuristics for educating the new borns. The first is to randomly pick a task from each overloaded agent and reassign the task to the next budget-sufficient agent — if there is any. The second is to raise the total profit by reassigning another agent for each task — if the reassignment would not result in overload. The algorithm outperforms most peer metaheuristics such as variants of simulated annealing and tabu search (Osman), and is highly effective for large and hard instances.

Value

A list of 4:

totalProfitOrLoss	Total profit or loss generated from the assignment. Negative infinity if no solution found.
agentCost	A numeric vector of total costs for each agent. Empty if no solution found.
assignment	An integer vector. assignment[i] indexes the agent assigned to the ith task. Empty if no solution found.

populationInfo
A list of 3:

allGenes
An $N(\text{task}) \times (\text{populationSize} \times \text{trials})$ integer matrix recording genes in all population sets upon completion. Each column represents a gene, namely a tentative assignment.

allBudgetExceedance
A numeric vector of the size of $\text{populationSize} \times \text{trials}$. `allBudgetExceedance[i]` equals the total budget exceedance of tentative assignment `allGenes[, i]`.

allProfitOrLoss
A numeric vector of the size of `allBudgetExceedance`. `allProfitOrLoss[i]` equals the total profit or loss of tentative assignment `allGenes[, i]`.

Note

The C++ implementation is fully independent and borrows no code from any commercial or open source.

Examples

```
# =====
# A trivial instance
# =====
profit = c(17,21,22,18,24,15,20,18,19,18,16,22,24,24,16,23,16,21,16,17,16,19,
          25,18,21,17,15,25,17,24,16,20,16,25,24,16,17,19,19,18,20,16,17,21,
          24,19,19,22,22,20,16,19,17,21,19,25,23,25,25,25,18,19,15,15,21,25,
          16,16,23,15,22,17,19,22,24)
profit = t(matrix(profit, ncol = 5))
cost = c(8,15,14,23,8,16,8,25,9,17,25,15,10,8,24,15,7,23,22,11,11,12,10,17,16,
        7,16,10,18,22,21,20,6,22,24,10,24,9,21,14,11,14,11,19,16,20,11,8,14,
        9,5,6,19,19,7,6,6,13,9,18,8,13,13,13,10,20,25,16,16,17,10,10,5,12,23)
cost = t(matrix(cost, ncol = 5))
budget = c(36, 34, 38, 27, 33)

Nagent = 5L; Ntask = 15L
rst = FLSSS::auxGAPga(
  cost, profit, budget, trials = 2, populationSize = 100, generations = 10000,
  randomSeed = 42, maxCore = 2, optim = "max")

# =====
# A relatively hard instance.
# =====
# Download gapInstances.Rdata from
# https://github.com/WhateverLiu/gapInstances. Load it in R.

cost = gapC[[3]]$cost
loss = gapC[[3]]$loss
budget = gapC[[3]]$budget
# Intel CPU i7-4770 3.4GHz, g++ '-Ofast', 64-bit Windows 7.
system.time({rst = FLSSS::auxGAPga(cost, loss, budget, trials = 7,
```

```

        randomSeed = 42, populationSize = 100, generations = 500000,
        optim = "min", maxCore = 7)})
rst$totalProfitOrLoss # 1416
# user system elapsed
# 69.24  0.17  11.61
# The known optimum equals 1402 as the total loss.

```

auxKnapsack01bb

Multithreaded binary knapsack problem solver via branch and bound

Description

Given items' weights and values, concurrently solve 0-1 knapsack problems to optimality via branch and bound for multiple knapsacks of different capacities.

Usage

```

auxKnapsack01bb(
  weight,
  value,
  caps,
  itemNcaps = integer(0),
  maxCore = 7L,
  tlimit = 60,
  ub = "MT",
  simplify = TRUE
)

```

Arguments

weight	A numeric vector.
value	A numeric vector. The size equals that of weight.
caps	A numeric vector of knapsack capacities.
itemNcaps	An integer vector of upper bounds on the number of selected items. <code>itemNcaps[i]</code> corresponds to instance <code>caps[i]</code> . Empty <code>itemNcaps</code> implies no size restriction.
maxCore	Maximal threads to invoke. No greater than the number of logical CPUs on machine.
tlimit	Return the best existing solution in <code>tlimit</code> seconds.
ub	Upper bound function.
simplify	If <code>length(caps) == 1</code> , simplify the output.

Details

The algorithm takes the Horowitz-Sahni (1974) and the Martello-Toth (1977) upper bound functions and is carefully engineered towards speed. Implementation highlights include (i) an extra option of upper bounding the number of selected items, which only adds trivial overhead; (ii) the return of existing best solutions in time; (iii) the capability of taking numeric weights and values.

Value

A list of 2:

maxValue: a numeric vector. maxValue[i] equals the sum of values of items selected for capacity caps[i].

selection: a list of integer vectors. selection[i] indexes the items selected for capacity caps[i].

Note

The function is not to solve the 0-1 multiple knapsack problem. The C++ implementation is fully independent and borrows no code from any open or commercial source.

Examples

```
set.seed(42)
weight = runif(100, min = 1e3, max = 1e6)
value = weight ^ 0.5 * 100 # Higher correlation between item weights and values
                        # typically implies a harder knapsack problem.
caps = runif(10, min(weight), sum(weight))
rst = FLS::auxKnapsack01bb(weight, value, caps, maxCore = 2, tlimit = 2)
str(rst)
```

auxKnapsack01dp

Multithreaded binary knapsack problem solver via dynamic programming

Description

Given items' weights and values, concurrently solve 0-1 knapsack problems to optimality via dynamic programming for multiple knapsacks of different capacities.

Usage

```
auxKnapsack01dp(
  weight,
  value,
  caps,
  maxCore = 7L,
  tlimit = 60,
  simplify = TRUE
)
```

Arguments

weight	An integer vector.
value	A numeric vector. The size equals that of weight.
caps	An integer vector of knapsack capacities.

maxCore	Maximal threads to invoke. No greater than the number of logical CPUs on machine.
tlimit	Return the best existing solution in tlimit seconds.
simplify	If length(caps) == 1, simplify the output.

Details

Implementation highlights include (i) lookup matrix is only of space complexity $O(N * [\max(C) - \min(W)])$, where N = the number of items, $\max(C)$ = maximal knapsack capacity, $\min(W)$ = minimum item weight; (ii) threads read and write the same lookup matrix and thus accelerate each other; (iii) the return of existing best solutions in time.

Value

A list of 3:

maxValue: a numeric vector. maxValue[i] equals the sum of values of items selected for capacity caps[i].

selection: a list of integer vectors. selection[i] indexes the items selected for capacity caps[i].

lookupTable: a numeric matrix.

Note

The function is not to solve the 0-1 multiple knapsack problem. weight and caps are integers. Be cautioned that dynamic programming is not suitable for problems with weights or capacities of high magnitudes due to its space complexity. Otherwise it could outperform branch-and-bound especially for large instances with highly correlated item weights and values.

Examples

```
set.seed(42)
weight = sample(10L : 100L, 600L, replace = TRUE) # Dynamic programming
                                                # solution requires integer
                                                # weights.
value = weight ^ 0.5 * 100 # Higher correlation between item weights and values
                           # typically implies a harder knapsack problem.
caps = as.integer(runif(10, min(weight), 600L))
system.time({rstDp = FLSS::auxKnapsack01dp(
  weight, value, caps, maxCore = 2, tlimit = 4)})
system.time({rstBb = FLSS::auxKnapsack01bb(
  weight, value, caps, maxCore = 2, tlimit = 4)})
# Dynamic programming can be faster than branch-and-bound for integer weights
# and capacity of small magnitudes.
```

FLSSS

*One-dimensional Subset Sum given error threshold***Description**

Given subset size `len`, sorted superset `v`, subset sum `target` and error `ME`, find at least `solutionNeed` index (integer) vector(s) `x`, such that $target - ME \leq \text{sum}(v[x]) \leq target + ME$. To mine subsets that sum in a given range, set `target` to the midpoint and `ME` to half of the range width.

Usage

```
FLSSS(
  len,
  v,
  target,
  ME,
  solutionNeed = 1L,
  LB = 1L : len,
  UB = (length(v) - len + 1L) : length(v),
  viaConjugate = FALSE,
  tlimit = 60,
  useBiSrchInFB = FALSE,
  useFloat = FALSE
)
```

Arguments

<code>len</code>	An integer as the subset size: $0 \leq len < \text{length}(v)$. If <code>len == 0</code> , <code>FLSSS()</code> mines subsets without size restriction. <code>len <- 0</code> would be most likely slower than looping <code>len</code> over $1 : (\text{length}(v) - 1)$. See Details.
<code>v</code>	A sorted numeric vector, the superset. <code>v</code> can be negative and nonunique.
<code>target</code>	A numeric value, the subset sum target.
<code>ME</code>	A positive numeric value, the error threshold.
<code>solutionNeed</code>	An integer, the least number of solutions wanted. If the function returns fewer solutions, either <code>tlimit</code> is up or less than <code>solutionNeed</code> solutions exist. The function may also return more than <code>solutionNeed</code> solutions.
<code>LB</code>	An integer vector of size <code>len</code> as the lower bounds of the solution space: for any solution <code>x</code> , $LB[i] \leq x[i]$. Custom <code>LB</code> should be no less than $1L : len$ element-wisely. Every element in <code>v</code> should be within the range enclosed by <code>LB</code> and <code>UB</code> .
<code>UB</code>	An integer vector of size <code>len</code> as the upper bounds of the solution space: for any solution <code>x</code> , $x[i] \leq UB[i]$. Custom <code>UB</code> should be no greater than $(\text{length}(v) - len + 1L) : \text{length}(v)$ element-wisely. Every element in <code>v</code> should be within the range enclosed by <code>LB</code> and <code>UB</code> .

<code>viaConjugate</code>	A boolean value. If TRUE, FLSSS() mines subsets of size $\text{length}(v) - \text{len}$ that sum to $\text{sum}(v) - \text{target}$ with the same ME. Let x be the integer vector indexing a qualified subset. FLSSS() returns $(1L : \text{length}(v))[-x]$. Simulations show that FLSSS() often finds the first qualified conjugate subset faster if len is much less than $\text{length}(v) / 2$.
<code>tlimit</code>	A numeric value. Enforce function to return in <code>tlimit</code> seconds.
<code>useBiSrchInFB</code>	A boolean value. If TRUE, the function performs binary search for index bounds in the auxiliary triangle matrix of continuous sequence sums. This argument is mainly for research. Simulations show binary search has no major advantage over linear search due to caching mechanisms. The advantage may be pronounced if $\text{length}(v)$ is substantial (> 10000) while len is small (< 5).
<code>useFloat</code>	A boolean value. If TRUE, convert data to single-precision floats. This argument is mainly for research. <code>useFloat = TRUE</code> is highly unrecommended.

Details

If $\text{len} == 0$, FLSSS() would (1) reset len to $\text{length}(v)$, (2) pad len zeros at the beginning of v and sort v , (3) search for size- len subsets, and (4) for an index vector that represents a subset, erases elements pointing to zeros in v . See the [package documentation](#) for more details.

Value

A list of index vectors.

Examples

```
# =====
# Example I: play random numbers.
# =====
rm(list = ls()); gc()
subsetSize = 200L
supersetSize = 1000L
superset = 10000 * sort(rnorm(supersetSize) ^ 3 + 2 * runif(supersetSize) ^ 2 +
  3 * rgamma(supersetSize, 5, 1) + 4)
subsetSum = runif(1, sum(superset[1L : subsetSize]), sum(superset[(supersetSize -
  subsetSize + 1L) : supersetSize]))
subsetSumError = 1e-3

# Mine 3 subsets
rst1 = FLSSS::FLSSS(len = subsetSize, v = superset, target = subsetSum,
  ME = subsetSumError, solutionNeed = 3, tlimit = 4)

# Mine 3 subsets via solving the conjugate problem
rst2 = FLSSS::FLSSS(len = subsetSize, v = superset, target = subsetSum,
  ME = subsetSumError, solutionNeed = 3, tlimit = 4,
  viaConjugate = TRUE)
```

```

# Verify uniqueness
cat("rst1 number of solutions =",
    length(unique(lapply(rst1, function(x) sort(x))))), "\n")
cat("rst2 number of solutions =",
    length(unique(lapply(rst2, function(x) sort(x))))), "\n")

# Verify solutions
if(length(rst1) > 0)
  all(unlist(lapply(rst1, function(x)
    abs(sum(superset[x]) - subsetSum) <= subsetSumError)))
if(length(rst2) > 0)
  all(unlist(lapply(rst2, function(x)
    abs(sum(superset[x]) - subsetSum) <= subsetSumError)))

# Mine 3 subsets in bounded solution space.
# Make up the lower and upper bounds for the solution space:
tmp = sort(sample(1L : supersetSize, subsetSize))
tmp2 = sort(sample(1L : supersetSize, subsetSize))
lowerBounds = pmin(tmp, tmp2)
upperBounds = pmax(tmp, tmp2)
rm(tmp, tmp2)

# 'FLSSS()' does not work if there are elements not under the hood of
# lowerBounds + upperBounds. Exclude those elements:
remainIndex = unique(unlist(apply(cbind(lowerBounds, upperBounds), 1,
  function(x) x[1] : x[2])))
lowerBounds = match(lowerBounds, remainIndex)
upperBounds = match(upperBounds, remainIndex)
superset = superset[remainIndex]

# Plant a subset sum:
solution = integer(subsetSize)
solution[1] = sample(lowerBounds[1] : upperBounds[1], 1)
for(i in 2L : subsetSize)
{
  l = max(lowerBounds[i], solution[i - 1] + 1L)
  u = upperBounds[i]
  if(l == u) solution[i] = u
  else solution[i] = sample(l : u, 1)
}
subsetSum = sum(superset[solution])
subsetSumError = abs(subsetSum) * 0.01 # relative error within 1%
rm(solution)

rst3 = FLSSS::FLSSS(len = subsetSize, v = superset, target = subsetSum,
  ME = subsetSumError, solutionNeed = 2, tlimit = 4,
  LB = lowerBounds, UB = upperBounds, viaConjugate = TRUE)

```



```

print(length(rst3))

# Verify solutions
if(length(rst3) > 0)
  cat(all(unlist(lapply(rst3, function(x)
    abs(sum(superset[x]) - subsetSum) <= subsetSumError))), "\n")

# =====
# Example II: mine a real-world dataset.
# =====
rm(list = ls()); gc()
superset = c(
  -1119924501, -793412295, -496234747, -213654767, 16818148, 26267601, 26557292,
  27340260, 28343800, 32036573, 32847411, 34570996, 34574989, 43633028,
  44003100, 47724096, 51905122, 52691025, 53600924, 56874435, 58207678,
  60225777, 60639161, 60888288, 60890325, 61742932, 63780621, 63786876,
  65167464, 66224357, 67198760, 69366452, 71163068, 72338751, 72960793,
  73197629, 76148392, 77779087, 78308432, 81196763, 82741805, 85315243,
  86446883, 87820032, 89819002, 90604146, 93761290, 97920291, 98315039,
  310120088, -441403864, -548143111, -645883459, -149110919, 305170449, -248934805,
  -1108320430, -527806318, -192539936, -1005074405, -101557770, -156782742, -285384687,
  -418917176, 80346546, -273215446, -552291568, 86824498, -95392618, -707778486)
superset = sort(superset)
subsetSum = 139254953
subsetSumError = 0.1

# Find a subset of size 10.
subsetSize = 10L
rst = FLSSS::FLSSS(len = subsetSize, v = superset, target = subsetSum,
  ME = subsetSumError, solutionNeed = 1, tlimit = 4)
# Verify:
all(unlist(lapply(rst, function(x)
  abs(sum(superset[x]) - subsetSum) <= subsetSumError)))

# Find a subset without size specification.
rst = FLSSS::FLSSS(len = 0, v = superset, target = subsetSum,
  ME = subsetSumError, solutionNeed = 1, tlimit = 4)
# Verify:
all(unlist(lapply(rst, function(x)
  abs(sum(superset[x]) - subsetSum) <= subsetSumError)))

# Find a subset via looping subset size over 2L : (length(v)).
for(len in 2L : length(superset))
{
  rst = FLSSS::FLSSS(len = subsetSize, v = superset, target = subsetSum,

```

```

        ME = subsetSumError, solutionNeed = 1, tlimit = 4)
    if(length(rst) > 0) break
}
# Verify:
all(unlist(lapply(rst, function(x)
  abs(sum(superset[x]) - subsetSum) <= subsetSumError)))

# Find as many qualified subsets as possible in 2 seconds
rst = FLSSS::FLSSS(len = subsetSize, v = superset, target = subsetSum,
  ME = subsetSumError, solutionNeed = 999999L, tlimit = 2)
cat("Number of solutions =", length(rst), "\n")

# Verify:
all(unlist(lapply(rst, function(x)
  abs(sum(superset[x]) - subsetSum) <= subsetSumError)))

# =====
# Example III: solve a special knapsack problem.
# Given the knapsack's capacity, the number of categories, the number of items in each
# category, select the least number of items to fulfill at least 95% of the knapsack's
# capacity.
# =====
rm(list = ls()); gc()
capacity = 361
categories = LETTERS[1L : 10L] # A, B, ..., J, 10 categories
categoryMasses = round(runif(length(categories)) * 20 + 1)
categoryItems = sample(1L : 20L, length(categories))

itemLabel = unlist(mapply(function(x, i) rep(i, x), categoryItems, categories))
itemMasses = unlist(mapply(function(x, i) rep(x, i), categoryMasses, categoryItems))
vorder = order(itemMasses)
itemLabel = itemLabel[vorder]

superset = itemMasses[vorder]
rate = 0.95
subsetSum = (capacity * rate + capacity) / 2
subsetSumError = capacity - subsetSum
for(subsetSize in 1L : length(itemMasses))
{
  rst = FLSSS::FLSSS(len = subsetSize, v = superset, target = subsetSum,
    ME = subsetSumError, solutionNeed = 1, tlimit = 4)
  if(length(rst) > 0) break
}

# There may exist no qualified subsets. One can lower 'rate' until a solution

```

```

# shows up.
if(length(rst) == 0L)
{
  cat("No solutions. Please lower rate and rerun.\n")
} else
{
  cat("A solution:\n")
  print(table(itemLabel[rst[[1]]]))
}

rm(list = ls()); gc()

```

FLSSSmultiset

Multi-Subset Sum given error threshold

Description

Find a subset of a given size for each of multiple supersets such that all the subsets sum in a given range.

Usage

```

FLSSSmultiset(
  len,
  buckets,
  target,
  ME,
  solutionNeed = 1L,
  tlimit = 60,
  useBiSrchInFB = FALSE,
  useFloat = FALSE
)

```

Arguments

len	A positive integer vector as the subset sizes for the supersets.
buckets	A list of the supersets. buckets[[i]] is an unsorted numeric vector of size len[i].
target	See target in FLSSS().
ME	See ME in FLSSS().
solutionNeed	See solutionNeed in FLSSS().
tlimit	See tlimit in FLSSS().
useBiSrchInFB	See useBiSrchInFB in FLSSS().
useFloat	See useFloat in FLSSS().

Value

A list of solutions. Each solution is a list of index vectors. Assume X is a solution. $X[[i]]$ indexes the subset of superset buckets $[[i]]$.

Examples

```
rm(list = ls()); gc()
Nsupersets = 30L
supersetSizes = sample(5L : 20L, Nsupersets, replace = TRUE)
subsetSizes = sapply(supersetSizes, function(x) sample(1L : x, 1))

# Create supersets at random:
supersets = lapply(supersetSizes, function(n)
{
  1000 * (rnorm(n) ^ 3 + 2 * runif(n) ^ 2 + 3 * rgamma(n, 5, 1) + 4)
}))
str(supersets) # see the structure

# Give a subset sum
solution = mapply(function(n, l) sample(1L : n, l), supersetSizes, subsetSizes)
str(solution) # See structure
subsetsSum = sum(mapply(function(x, s) sum(x[s]), supersets, solution, SIMPLIFY = TRUE))
subsetsSumError = abs(subsetsSum) * 1e-7 # relative error within 0.00001%
rm(solution)

# Mine subsets:
rst = FLSS::FLSSMultiset(len = subsetSizes, buckets = supersets, target = subsetsSum,
  ME = subsetsSumError, solutionNeed = 3, tlimit = 4)
cat("Number of solutions =", length(rst), "\n")

# Verify:
ver = all(unlist(lapply(rst, function(sol)
{
  S = sum(unlist(mapply(function(x, y) sum(x[y]), supersets, sol)))
  abs(S - subsetsSum) <= subsetsSumError
}))))
cat("All subsets are qualified:", ver)
```

Description

Given a number of agents and a number of tasks. An agent can finish a task with certain cost and profit. An agent also has a budget. Assign tasks to agents such that each agent costs no more than its budget while the total profit is maximized.

Usage

```
GAP(
  maxCore = 7L,
  agentsCosts,
  agentsProfits,
  agentsBudgets,
  heuristic = FALSE,
  tlimit = 60,
  threadLoad = 8L,
  verbose = TRUE
)
```

Arguments

<code>maxCore</code>	Maximal threads to invoke. Ideally <code>maxCore</code> should not surpass the total logical processors on machine.
<code>agentsCosts</code>	A numeric matrix. <code>agentsCosts[i, j]</code> is the cost for agent <code>i</code> to finish task <code>j</code> .
<code>agentsProfits</code>	A numeric matrix. <code>agentsProfits[i, j]</code> is the profit from agent <code>i</code> finishing task <code>j</code> .
<code>agentsBudgets</code>	A numeric vector. <code>agentsBudgets[i]</code> is agent <code>i</code> 's budget.
<code>heuristic</code>	A boolean value. If <code>TRUE</code> , the function returns once it has found a solution whose sum of ranks of the profits becomes no less than that of the optimal. See <code>heuristic</code> in <code>mmKnapsack()</code> .
<code>tlimit</code>	A numeric value. Enforce function to return in <code>tlimit</code> seconds.
<code>threadLoad</code>	See <code>avgThreadLoad</code> in <code>mFLSSspar()</code> .
<code>verbose</code>	If <code>TRUE</code> , function prints progress.

Value

A list of size nine.

<code>assignedAgents</code>	is a 2-column data frame, the mining result. The 1st column is task indexes. The 2nd column is agent indexes.
<code>assignmentProfit</code>	is the profit resulted from such assignment.
<code>assignmentCosts</code>	is a numeric vector. <code>Value\$assignmentCosts[i]</code> is the cost of agent <code>i</code> .
<code>agentsBudgets</code>	is a numeric vector. <code>Value\$agentsBudgets[i]</code> shows the budget of agent <code>i</code> .
<code>unconstrainedMaxProfit</code>	is the would-be maximal profit if agents had infinite budgets.
<code>FLSSsolution</code>	is the solution from mining the corresponding multidimensional Subset Sum problem.
<code>FLSSvec</code>	is the multidimensional vector (a matrix) going into the multidimensional Subset Sum miner.

MAXmat is the subset sum targets' upper bounds going into the multidimensional Subset Sum miner.
 foreShadowFLSSSvec is the multidimensional vector before comonotonization.

Examples

```
# =====
# Play random numbers
# =====
rm(list = ls()); gc()
agents = 5L
tasks = 12L
costs = t(as.data.frame(lapply(1L : agents, function(x) runif(tasks) * 1000)))
budgets = apply(costs, 1, function(x) runif(1, min(x), sum(x)))
profits = t(as.data.frame(lapply(1L : agents, function(x)
  abs(rnorm(tasks) + runif(1, 0, 4)) * 10000)))

# A dirty function for examining the result's integrity. The function takes in
# the task-agent assignment, the profit or cost matrix M, and calculates the cost
# or profit generated by each agent. 'assignment' is a 2-column data
# frame, first column task, second column agent.
agentCostsOrProfits <- function(assignment, M)
{
  n = ncol(M) * nrow(M)
  M2 = matrix(numeric(n), ncol = tasks)
  for(i in 1L : nrow(assignment))
  {
    x = as.integer(assignment[i, ])
    M2[x[2], x[1]] = M[x[2], x[1]]
  }
  apply(M2, 1, function(x) sum(x))
}

dimnames(costs) = NULL
dimnames(profits) = NULL
names(budgets) = NULL

rst = FLSSS::GAP(maxCore = 7L, agentsCosts = costs, agentsProfits = profits,
  agentsBudgets = budgets, heuristic = FALSE, tlimit = 60,
  threadLoad = 8L, verbose = TRUE)
# Function also saves the assignment costs and profits
rst$assignedAgents
rst$assignmentProfit
rst$assignmentCosts

# Examine rst$assignmentCosts
if(sum(rst$assignedAgents) > 0) # all zeros mean the function has not found a solution.
  agentCostsOrProfits(rst$assignedAgents, costs)
```

```

# Should equal rst$assignmentCosts and not surpass budgets

# Examine rst$assignmentProfits
if(sum(rst$assignedAgents) > 0)
  sum(agentCostsOrProfits(rst$assignedAgents, profits))
# Should equal rst$assignmentProfit

# =====
# Test case P03 from
# https://people.sc.fsu.edu/~jburkardt/datasets/generalized_assignment/
# =====
agents = 3L
tasks = 8L
profits = t(matrix(c(
27, 12, 12, 16, 24, 31, 41, 13,
14, 5, 37, 9, 36, 25, 1, 34,
34, 34, 20, 9, 19, 19, 3, 34), ncol = agents))
costs = t(matrix(c(
21, 13, 9, 5, 7, 15, 5, 24,
20, 8, 18, 25, 6, 6, 9, 6,
16, 16, 18, 24, 11, 11, 16, 18), ncol = agents))
budgets = c(26, 25, 34)

rst = FLSSS::GAP(maxCore = 2L, agentsCosts = costs, agentsProfits = profits,
                agentsBudgets = budgets, heuristic = FALSE, tlimit = 2,
                threadLoad = 8L, verbose = TRUE)
agentCostsOrProfits(rst$assignedAgents, costs)
# Should equal rst$assignmentCosts and not surpass budgets

knownOptSolution = as.integer(c(3, 3, 1, 1, 2, 2, 1, 2))
knownOptSolution = data.frame(task = 1L : tasks, agent = knownOptSolution)

# Total profit from knownOptSolution:
sum(agentCostsOrProfits(knownOptSolution, profits))
# Total profit from FLSSS::GAP():
rst$assignmentProfit

```

mFLSSSpar

Multithreaded multidimensional Subset Sum given error thresholds

Description

The multidimensional version of FLSSS().

Usage

```
mFLSSSpar(
  maxCore = 7L,
  len,
  mV,
  mTarget,
  mME,
  solutionNeed = 1L,
  tlimit = 60,
  dl = ncol(mV),
  du = ncol(mV),
  useBiSrchInFB = FALSE,
  avgThreadLoad = 8L
)
```

Arguments

maxCore	Maximal threads to invoke. Ideally maxCore should not surpass the total logical processors on machine.
len	An integer as the subset size. See len in FLSSS().
mV	A data frame or a matrix as the multidimensional set, columns as dimensions.
mTarget	A numeric vector of size ncol(mV) as the subset sum.
mME	A numeric vector of size ncol(mV) as the subset sum error thresholds.
solutionNeed	See solutionNeed in FLSSS().
tlimit	See tlimit in FLSSS().
dl	An integer no greater than ncol(mV). Let sol be the index vector of a solution. Let dls <- 1L : dl. The following is true: colSums(mV[sol, dls]) >= mTarget[dls] - mME[dls].
du	An integer no greater than ncol(mV). Let sol be the index vector of a solution. Let dus <- (ncol(mV) - du + 1) : ncol(mV). The following is true: colSums(mV[sol, dus]) <= mTarget[dus] + mME[dus].
useBiSrchInFB	See useBiSrchInFB in FLSSS().
avgThreadLoad	If mV is comonotonic, mFLSSSpar() warms up with a breadth-first search and then spawns at least B branches for parallelization. B equals the first power-of-two integer no less than avgThreadLoad * maxCore.

Value

A list of index vectors.

Examples

```
rm(list = ls()); gc()
subsetSize = 7L
supersetSize = 60L
```



```

dimension = 5L # dimensionality

# Create a superset at random:
N = supersetSize * dimension
superset = matrix(1000 * (rnorm(N) ^ 3 + 2 * runif(N) ^ 2 +
  3 * rgamma(N, 5, 1) + 4), ncol = dimension)
rm(N)

# Plant a subset sum:
solution = sample(1L : supersetSize, subsetSize)
subsetSum = colSums(superset[solution, ])
subsetSumError = abs(subsetSum) * 0.01 # relative error within 1%
rm(solution)

# Mine subsets, dimensions fully bounded
rst = FLSSS::mFLSSSpar(maxCore = 2, len = subsetSize, mV = superset,
  mTarget = subsetSum, mME = subsetSumError,
  solutionNeed = 2, dl = ncol(superset), du = ncol(superset),
  tlimit = 2, useBiSrchInFB = FALSE, avgThreadLoad = 8L)

# Verify:
cat("Number of solutions = ", length(rst), "\n")
if(length(rst) > 0)
{
  cat("Solutions unique: ")
  cat(length(unique(lapply(rst, function(x) sort(x)))) == length(rst), "\n")
  cat("Solutions correct: ")
  cat(all(unlist(lapply(rst, function(x)
    abs(colSums(superset[x, ]) - subsetSum) <= subsetSumError))), "\n")
} else
{
  cat("No solutions exist or timer ended too soon.\n")
}

# Mine subsets, the first 3 dimensions lower bounded,
# the last 4 dimension upper bounded
rst = FLSSS::mFLSSSpar(maxCore = 2, len = subsetSize, mV = superset,
  mTarget = subsetSum, mME = subsetSumError,
  solutionNeed = 2, dl = 3L, du = 4L,
  tlimit = 2, useBiSrchInFB = FALSE, avgThreadLoad = 8L)

# Verify:
cat("Number of solutions = ", length(rst), "\n")
if(length(rst) > 0)
{

```

```

cat("Solutions unique: ")
cat(length(unique(lapply(rst, function(x) sort(x)))) == length(rst), "\n")
cat("Solutions correct: ")
cat(all(unlist(lapply(rst, function(x)
{
  lowerBoundedDim = 1L : 3L
  lowerBounded = all(colSums(superset[x, lowerBoundedDim]) >=
    subsetSum[lowerBoundedDim] - subsetSumError[lowerBoundedDim])

  upperBoundedDim = (ncol(superset) - 3L) : ncol(superset)
  upperBounded = all(colSums(superset[x, upperBoundedDim]) <=
    subsetSum[upperBoundedDim] + subsetSumError[upperBoundedDim])

  lowerBounded & upperBounded
}))), "\n")
} else
{
  cat("No solutions exist or timer ended too soon.\n")
}

```

mFLSSSparImposeBounds *Multithreaded multidimensional Subset Sum in bounded solution space given error thresholds*

Description

For comparison, function mFLSSSpar() puts no bounds on the solution space so it sorts mV internally in a special order for mining acceleration.

Usage

```

mFLSSSparImposeBounds(
  maxCore = 7L,
  len,
  mV,
  mTarget,
  mME,
  LB = 1L : len,
  UB = (nrow(mV) - len + 1L) : nrow(mV),
  solutionNeed = 1L,
  tlimit = 60,
  dl = ncol(mV),
  du = ncol(mV),
  targetsOrder = NULL,
  useBiSrchInFB = FALSE,
  avgThreadLoad = 8L
)

```

Arguments

maxCore	See maxCore in mFLSSSpar().
len	See len in mFLSSSpar().
mV	See mV in mFLSSSpar().
mTarget	See mTarget in mFLSSSpar().
mME	See mME in mFLSSSpar().
LB	See LB in FLSSS().
UB	See UB in FLSSS().
solutionNeed	See solutionNeed in mFLSSSpar().
tlimit	See tlimit in mFLSSSpar().
d1	See d1 in mFLSSSpar().
du	See du in mFLSSSpar().
targetsOrder	This argument is mainly for research and unrecommended for use. Depending on the structure of mV, mFLSSSpar() or mFLSSSparImposeBounds() would break the mining task into a collection of no more than $len * (nrow(mV) - len) + 1$ independent subtasks. Threads work on these subtasks, sequentially coordinated by an atomic counter [1]. Different subtasks have different probabilities of yielding a qualified subset, thus the order of subtasks matters to the mining speed. targetsOrder is an index vector of size $len * (nrow(mV) - len) + 1$ for ordering the subtasks. targetsOrder <- NULL makes a special order, and is implicitly the choice in mFLSSSpar(). This order is empirically optimal based on simulations. See the package documentation for details.
useBiSrchInFB	See useBiSrchInFB in mFLSSSpar().
avgThreadLoad	See avgThreadLoad in mFLSSSpar().

Value

A list of index vectors.

References

[1] Atomic template class in [Intel TBB](#). An atomic counter is used to coordinate heterogeneous subtasks to avoid idle threads. The atomic operation overhead is negligible compared to the time cost of the lightest subtask.

Examples

```
rm(list = ls()); gc()
subsetSize = 7L
supersetSize = 60L
dimension = 5L # dimensionality

# Create a supertset at random:
```

```

N = supersetSize * dimension
superset = matrix(1000 * (rnorm(N) ^ 3 + 2 * runif(N) ^ 2 +
                        3 * rgamma(N, 5, 1) + 4), ncol = dimension)
rm(N)

# Make up the lower and upper bounds for the solution space:
tmp = sort(sample(1L : supersetSize, subsetSize))
tmp2 = sort(sample(1L : supersetSize, subsetSize))
lowerBounds = pmin(tmp, tmp2)
upperBounds = pmax(tmp, tmp2)
rm(tmp, tmp2)

# Exclude elements not covered by 'lowerBounds' and 'upperBounds':
remainIndex = unique(unlist(apply(cbind(lowerBounds, upperBounds), 1,
                                function(x) x[1] : x[2])))

lowerBounds = match(lowerBounds, remainIndex)
upperBounds = match(upperBounds, remainIndex)
superset = superset[remainIndex, ]

# Plant a subset sum:
solution = apply(rbind(lowerBounds, upperBounds), 2, function(x)
  sample(x[1] : x[2], 1))
subsetSum = colSums(superset[solution, ])
subsetSumError = abs(subsetSum) * 0.01 # relative error within 1%
rm(solution)

rst = FLSSS::mFLSSSparImposeBounds(
  maxCore = 2L, len = subsetSize, mV = superset, mTarget = subsetSum,
  mME = subsetSumError, LB = lowerBounds, UB = upperBounds,
  solutionNeed = 1, tlimit = 2, dl = ncol(superset), du = ncol(superset),
  targetsOrder = NULL, useBiSrchInFB = FALSE, avgThreadLoad = 8L)

# Verify:
cat("Number of solutions = ", length(rst), "\n")
if(length(rst) > 0)
{
  cat("Solutions unique: ")
  cat(length(unique(lapply(rst, function(x) sort(x)))) == length(rst), "\n")
  cat("Solution in bounded space: ")
  cat(all(unlist(lapply(rst, function(x)
    sort(x) <= upperBounds & sort(x) >= lowerBounds))), "\n")
  cat("Solutions correct: ")
  cat(all(unlist(lapply(rst, function(x)
    abs(colSums(superset[x, ]) - subsetSum) <= subsetSumError))), "\n")
} else
{
  cat("No solutions exist or timer ended too soon.\n")
}

```

mFLSSSparImposeBoundsIntegerized

An advanced version of mFLSSSparImposeBounds()

Description

See the description of mFLSSSparIntegerized().

Usage

```
mFLSSSparImposeBoundsIntegerized(
  maxCore = 7L,
  len,
  mV,
  mTarget,
  mME,
  LB = 1L:len,
  UB = (nrow(mV) - len + 1L) : nrow(mV),
  solutionNeed = 1L,
  precisionLevel = integer(ncol(mV)),
  returnBeforeMining = FALSE,
  tlimit = 60,
  dl = ncol(mV),
  du = ncol(mV),
  targetsOrder = NULL,
  useBiSrchInFB = FALSE,
  avgThreadLoad = 8L,
  verbose = TRUE)
```

Arguments

maxCore	See maxCore in mFLSSSpar().
len	See len in mFLSSSpar().
mV	See mV in mFLSSSpar().
mTarget	See mTarget in mFLSSSpar().
mME	See mME in mFLSSSpar().
LB	See LB in FLSSS().
UB	See UB in FLSSS().
solutionNeed	See solutionNeed in mFLSSSpar().
precisionLevel	See precisionLevel in mFLSSSparIntegerized().
returnBeforeMining	See returnBeforeMining in mFLSSSparIntegerized().

tlimit See tlimit in mFLSSSpar().
 dl See dl in mFLSSSpar().
 du See dl in mFLSSSpar().
 targetsOrder See targetsOrder in mFLSSSparImposeBounds().
 useBiSrchInFB See useBiSrchInFB in mFLSSSpar().
 avgThreadLoad See avgThreadLoad in mFLSSSpar().
 verbose If TRUE, prints mining progress.

Value

See Value in mFLSSSparIntegerized().

Note

32-bit architecture unsupported.

Examples

```

if(.Machine$sizeof.pointer == 8L){
# =====
# 64-bit architecture required.
# =====
rm(list = ls()); gc()
subsetSize = 7L
supersetSize = 60L
dimension = 5L # dimensionality

# Create a superset at random:
N = supersetSize * dimension
superset = matrix(1000 * (rnorm(N) ^ 3 + 2 * runif(N) ^ 2 +
3 * rgamma(N, 5, 1) + 4), ncol = dimension)
rm(N)

# Make up the lower and upper bounds for the solution space:
tmp = sort(sample(1L : supersetSize, subsetSize))
tmp2 = sort(sample(1L : supersetSize, subsetSize))
lowerBounds = pmin(tmp, tmp2)
upperBounds = pmax(tmp, tmp2)
rm(tmp, tmp2)

# 'mFLSSSparImposeBoundsIntegerized()' does not work if there are elements not
# under the hood of 'lowerBounds' + 'upperBounds'. Exclude these elements first:
remainIndex = unique(unlist(
  apply(cbind(lowerBounds, upperBounds), 1, function(x) x[1] : x[2])))
lowerBounds = match(lowerBounds, remainIndex)
upperBounds = match(upperBounds, remainIndex)
superset = superset[remainIndex, ]

```

```

# Plant a subset sum:
solution = integer(subsetSize)
solution[1] = sample(lowerBounds[1] : upperBounds[1], 1)
for(i in 2L : subsetSize)
{
  l = max(lowerBounds[i], solution[i - 1] + 1L)
  u = upperBounds[i]
  if(l == u) solution[i] = u
  else solution[i] = sample(l : u, 1)
}
subsetSum = colSums(superset[solution, ])
subsetSumError = abs(subsetSum) * 0.01 # relative error within 1%
rm(solution)

system.time({rst = FLSSS::mFLSSSparImposeBoundsIntegerized(
  maxCore = 2L, len = subsetSize, mV = superset, mTarget = subsetSum,
  mME = subsetSumError, LB = lowerBounds, UB = upperBounds,
  solutionNeed = 1, tlimit = 3, dl = ncol(superset), du = ncol(superset),
  targetsOrder = NULL, useBiSrchInFB = FALSE, avgThreadLoad = 8L)})

# Compare the time cost of 'mFLSSSparImposeBoundsIntegerized()' and
# 'mFLSSSparImposeBounds()'. The speed advantage of 'mFLSSSparIntegerized()'
# may not be pronounced for toy examples.
system.time(FLSSS::mFLSSSparImposeBounds(
  maxCore = 2L, len = subsetSize, mV = superset, mTarget = subsetSum,
  mME = subsetSumError, LB = lowerBounds, UB = upperBounds,
  solutionNeed = 1, tlimit = 2, dl = ncol(superset), du = ncol(superset),
  targetsOrder = NULL, useBiSrchInFB = FALSE, avgThreadLoad = 8L))

# Verify:
cat("Number of solutions = ", length(rst$solution), "\n")
if(length(rst$solution) > 0)
{
  cat("Solutions unique: ")
  cat(length(unique(lapply(rst$solution, function(x)
    sort(x)))) == length(rst$solution), "\n")
  cat("Solution in bounded space: ")
  cat(all(unlist(lapply(rst$solution, function(x)
    sort(x) <= upperBounds & sort(x) >= lowerBounds))), "\n")

  cat("Solutions correct regarding integerized data: ")
  cat(all(unlist(lapply(rst$solution, function(x)
    abs(colSums(rst$INT$mV[x, ]) - rst$INT$mTarget) <= rst$INT$mME))), "\n")

  cat("Solutions correct regarding original data: ")
  boolean = all(unlist(lapply(rst$solution, function(x)

```

```

    abs(colSums(superset[x, ] - subsetSum) <= subsetSumError)))
cat(boolean, "\n")
if(!boolean)
{
  cat("The given error threshold relative to subset sum:\n")
  givenRelaErr = round(abs(subsetSumError / subsetSum), 5)
  cat(givenRelaErr, "\n")

  cat("Solution subset sum relative error:\n")
  tmp = lapply(rst$solution, function(x)
  {
    err = round(abs(colSums(superset[x, ]) / subsetSum -1), 5)
    for(i in 1L : length(err))
    {
      if(givenRelaErr[i] < err[i]) message(paste0(err[i], " "), appendLF = FALSE)
      else cat(err[i], "")
    }
    cat("\n")
  })
  cat("Integerization caused the errors. Future versions of")
  cat("'mFLSSSparIntegerized()' would have a parameter of precision level.\n")
}
} else
{
  cat("No solutions exist or timer ended too soon.\n")
}

# =====
# =====
}

```

mFLSSSparIntegerized *An advanced version of* mFLSSSpar()

Description

This function maps a real-value multidimensional Subset Sum problem to the integer domain with minimal precision loss. Those integers are further compressed in 64-bit buffers for dimension reduction and SWAR (SIMD within a register) that could lead to substantial acceleration.

Usage

```

mFLSSSparIntegerized(
  maxCore = 7L,
  len,
  mV,
  mTarget,
  mME,

```



```

solutionNeed = 1L,
precisionLevel = integer(ncol(mV)),
returnBeforeMining = FALSE,
tlimit = 60,
dl = ncol(mV),
du = ncol(mV),
useBiSrchInFB = FALSE,
avgThreadLoad = 8L,
verbose = TRUE
)

```

Arguments

maxCore	See maxCore in mFLSSSpar().
len	See len in mFLSSSpar().
mV	See mV in mFLSSSpar().
mTarget	See mTarget in mFLSSSpar().
mME	See mME in mFLSSSpar().
solutionNeed	See solutionNeed in mFLSSSpar().
precisionLevel	An integer vector of size equal to the dimensionality of mV. This argument controls the precision of real-to-integer conversion. If precisionLevel[i] = 0, mV[,i] is shifted, scaled and rounded to the nearest integers such that the maximum becomes no less than nrow(mV) * 8. If precisionLevel[i] > 0, e.g. precisionLevel[i] = 1000, mV[,i] is shifted, scaled and rounded to the nearest integers such that the maximum becomes no less than 1000. If precisionLevel[i] = -1, mV[,i] is shifted, scaled and rounded to the nearest integers such that ranks of elements stay the same. The shift operator contributes no precision loss. It only lowers the number of bits used for storing integers.
returnBeforeMining	A boolean value. If TRUE, function returns the integerized mV, mTarget and mME.
tlimit	See tlimit in mFLSSSpar().
dl	See dl in mFLSSSpar().
du	See du in mFLSSSpar().
useBiSrchInFB	See useBiSrchInFB in mFLSSSpar().
avgThreadLoad	See avgThreadLoad in mFLSSSpar().
verbose	If TRUE, prints mining progress.

Value

A list of two.

Value\$solution is a list of solution index vectors.

Value\$INT is a list of three.

Value\$INT\$mV is the integerized superset.
 Value\$INT\$mTarget is the integerized subset sum.
 Value\$INT\$mME is the integerized subset sum error threshold.
 Value\$INT\$compressedDim is the dimensionality after integerization.

Note

32-bit architecture unsupported.

Examples

```

if(.Machine$sizeof.pointer == 8L){
# =====
# 64-bit architecture required.
# =====
rm(list = ls()); gc()
subsetSize = 7L
supersetSize = 60L
dimension = 5L # dimensionality

# Create a superset at random:
N = supersetSize * dimension
superset = matrix(1000 * (rnorm(N) ^ 3 + 2 * runif(N) ^ 2 + 3 * rgamma(N, 5, 1) + 4),
                  ncol = dimension)
rm(N)

# Plant a subset sum:
solution = sample(1L : supersetSize, subsetSize)
subsetSum = colSums(superset[solution, ])
subsetSumError = abs(subsetSum) * 0.01 # relative error within 1%
rm(solution)

# Mine subsets, dimensions fully bounded
system.time({rst = FLSSS::mFLSSSparIntegerized(
  maxCore = 2, len = subsetSize, mV = superset, mTarget = subsetSum,
  mME = subsetSumError, solutionNeed = 2, dl = ncol(superset),
  du = ncol(superset), tlimit = 2, useBiSrchInFB = FALSE, avgThreadLoad = 8L)})

# Compare the time cost of 'mFLSSSparIntegerized()' and 'mFLSSSpar()'. The
# speed advantage of 'mFLSSSparIntegerized()' may not be pronounced for toy
# examples.
system.time(FLSSS::mFLSSSpar(
  maxCore = 2, len = subsetSize, mV = superset, mTarget = subsetSum,
  mME = subsetSumError, solutionNeed = 2, dl = ncol(superset),
  du = ncol(superset), tlimit = 2, useBiSrchInFB = FALSE, avgThreadLoad = 8L))

```

```

# Verify:
cat("Number of solutions = ", length(rst$solution), "\n")
if(length(rst$solution) > 0)
{
  cat("Solutions unique: ")
  cat(length(unique(lapply(rst$solution, function(x)
    sort(x)))) == length(rst$solution), "\n")

  cat("Solutions correct regarding integerized data: ")
  cat(all(unlist(lapply(rst$solution, function(x)
    abs(colSums(rst$INT$mV[x, ] - rst$INT$mTarget) <= rst$INT$mME))), "\n")

  cat("Solutions correct regarding original data: ")
  boolean = all(unlist(lapply(rst$solution, function(x)
    abs(colSums(superset[x, ] - subsetSum) <= subsetSumError)))
  cat(boolean, "\n")
  if(!boolean)
  {
    cat("The given error threshold relative to subset sum:\n")
    givenRelaErr = round(abs(subsetSumError / subsetSum), 5)
    cat(givenRelaErr, "\n")

    cat("Solution subset sum relative error:\n")
    tmp = lapply(rst$solution, function(x)
    {
      err = round(abs(colSums(superset[x, ] / subsetSum -1), 5)
      for(i in 1L : length(err))
      {
        if(givenRelaErr[i] < err[i]) message(paste0(err[i], " "), appendLF = FALSE)
        else cat(err[i], "")
      }
      cat("\n")
    })
    cat("Integerization caused the errors. Future versions of")
    cat("'mFLSSSparIntegerized()' would have a parameter of precision level.\n")
  }
} else
{
  cat("No solutions exist or time ended too soon.\n")
}

# Mine subsets, the first 3 dimensions lower bounded,
# the last 4 dimension upper bounded
rst = FLSSS::mFLSSSparIntegerized(
  maxCore = 2, len = subsetSize, mV = superset, mTarget = subsetSum,
  mME = subsetSumError, solutionNeed = 2, dl = 3L, du = 4L, tlimit = 2,
  useBiSrchInFB = FALSE, avgThreadLoad = 8L)

```

```

# Verify:
cat("Number of solutions = ", length(rst$solution), "\n")
if(length(rst$solution) > 0)
{
  cat("Solutions unique: ")
  cat(length(unique(lapply(rst$solution, function(x)
    sort(x)))) == length(rst$solution), "\n")

  cat("Solutions correct regarding integerized data: ")
  cat(all(unlist(lapply(rst$solution, function(x)
    {
      lowerBoundedDim = 1L : 3L
      lowerBounded = all(colSums(rst$INT$mV[x, lowerBoundedDim]) >=
        rst$INT$mTarget[lowerBoundedDim] - rst$INT$mME[lowerBoundedDim])

      upperBoundedDim = (ncol(rst$INT$mV) - 3L) : ncol(rst$INT$mV)
      upperBounded = all(colSums(rst$INT$mV[x, upperBoundedDim]) <=
        rst$INT$mTarget[upperBoundedDim] + rst$INT$mME[upperBoundedDim])

      lowerBounded & upperBounded
    }))), "\n")
} else
{
  cat("No solutions exist or timer ended too soon.\n")
}
# =====
# =====
}

```

mmKnapsack

Multithreaded multidimensional Knapsack problem solver

Description

Given a set of items characterized by a profit attribute and multiple cost attributes, `mmKnapsack()` seeks a subset that maximizes the total profit while the subset sum in each cost dimension is upper bounded. The function applies to the 0-1 Knapsack problem. For the bounded or unbounded Knapsack problem, one can replicate items as needed and turn the problem into 0-1 Knapsack. Profits and costs should be nonnegative. Negative values in data can be neutralized by shifting and scaling.

Usage

```

mmKnapsack(
  maxCore = 7L,
  len,

```

```

  itemsProfits,
  itemsCosts,
  capacities,
  heuristic = FALSE,
  tlimit = 60,
  useBiSrchInFB = FALSE,
  threadLoad = 8L,
  verbose = TRUE
)

```

Arguments

maxCore	Maximal threads to invoke. Ideally maxCore should not surpass the total logical processors on machine.
len	An integer as the subset size. See len in FLSSS().
itemsProfits	A nonnegative numeric vector of size equal to the number of items.
itemsCosts	A nonnegative numeric matrix. Number of rows equals number of items. Number of columns equals number of cost dimensions.
capacities	A numeric vector of size equal to the number of cost dimensions. capacities[i] upper-bounds the total cost in itemsCosts[, i].
heuristic	A boolean value. If TRUE, the function returns once it has found a solution whose sum of ranks of the profits is no less than that of the optimal. See Examples.
tlimit	A numeric value. Enforce function to return in tlimit seconds.
useBiSrchInFB	See useBiSrchInFB in FLSSS().
threadLoad	See avgThreadLoad in mFLSSSpar().
verbose	If TRUE, function prints progress.

Value

If no solution, an empty list, otherwise a list of five:

solution	The optimal solution.
selectionCosts	Solution costs.
budgets	Knapsack capacities.
selectionProfit	Solution total profit.
unconstrainedMaxProfit	Maximal profit given infinite budgets.

Examples

```

# =====
# Play random numbers
# =====
rm(list = ls()); gc()
subsetSize = 6

```

```

supersetSize = 60
NcostsAttr = 4

# Make up costs for each item.
costs = abs(6 * (rnorm(supersetSize * NcostsAttr) ^ 3 +
                 2 * runif(supersetSize * NcostsAttr) ^ 2 +
                 3 * rgamma(supersetSize * NcostsAttr, 5, 1) + 4))
costs = matrix(costs, ncol = NcostsAttr)

# Make up cost limits.
budgets = apply(costs, 2, function(x)
{
  x = sort(x)
  Min = sum(x[1L : subsetSize])
  Max = sum(x[(supersetSize - subsetSize + 1L) : supersetSize])
  runif(1, Min, Max)
})

# Make up item profits.
gains = rnorm(supersetSize) ^ 2 * 10000 + 100

rst1 = FLSSS::mmKnapsack(
  maxCore = 2L, len = subsetSize, itemsProfits = gains, itemsCosts = costs,
  capacities = budgets, heuristic = FALSE, tlimit = 60, useBiSrchInFB = FALSE,
  threadLoad = 4L, verbose = TRUE)

# Let 'x' be the solution given 'heuristic = TRUE'. The sum of ranks of the
# profits subsetted by 'x' would be no less than that of the optimal solution.
rst2 = FLSSS::mmKnapsack(
  maxCore = 2L, len = subsetSize, itemsProfits = gains, itemsCosts = costs,
  capacities = budgets, heuristic = TRUE, tlimit = 60, useBiSrchInFB = FALSE,
  threadLoad = 4L, verbose = TRUE)

# Exam difference in total profits given by the heuristic and the optimal:
cat(length(rst1$solution)); cat(length(rst2$solution)) # See if solution exists.
if(length(rst1$solution) > 0 & length(rst2$solution) > 0)
  sum(gains[rst2$solution]) / sum(gains[rst1$solution])

# =====
# Test case P08 from
# https://people.sc.fsu.edu/~jburkardt/datasets/knapsack_01/knapsack_01.html
# =====
rm(list = ls()); gc()

```

```

costs = matrix(c(382745, 799601, 909247, 729069, 467902, 44328, 34610, 698150,
                823460, 903959, 853665, 551830, 610856, 670702, 488960, 951111,
                323046, 446298, 931161, 31385, 496951, 264724, 224916, 169684),
              ncol = 1)

gains = c( 825594, 1677009, 1676628, 1523970, 943972, 97426, 69666, 1296457,
          1679693, 1902996, 1844992, 1049289, 1252836, 1319836, 953277, 2067538,
          675367, 853655, 1826027, 65731, 901489, 577243, 466257, 369261)

budgets = 6404180

# 'mmKnapsack()' is designed for the multidimensional Knapsack and may not
# be ideal for one-dimensional 0-1 Knapsack regarding computing speed.
# 'len = 0' causes substantial deceleration. Looping 'len' over possible
# values is recommended if 'len' is ungiven.
rst1 = FLSS::mmKnapsack(
  maxCore = 2L, len = 12L, itemsProfits = gains, itemsCosts = costs,
  capacities = budgets, heuristic = FALSE, tlimit = 2, threadLoad = 4L,
  verbose = TRUE)
rst1 = sort(rst1$solution)

cat("Correct solution:\n1 2 4 5 6 10 11 13 16 22 23 24\nFLSS solution =\n")
cat(rst1, "\n")

# =====
# Test case P07 from
# https://people.sc.fsu.edu/~jburkardt/datasets/knapsack_01/knapsack_01.html
# =====
costs = matrix(c(70, 73, 77, 80, 82, 87, 90, 94, 98, 106, 110, 113, 115, 118, 120),
              ncol = 1)

gains = c(135, 139, 149, 150, 156, 163, 173, 184, 192, 201, 210, 214, 221, 229, 240)

budgets = 750

rst2 = FLSS::mmKnapsack(
  maxCore = 2L, len = 8L, itemsProfits = gains, itemsCosts = costs,
  capacities = budgets, heuristic = FALSE, tlimit = 2,
  threadLoad = 4L, verbose = TRUE)
rst2 = sort(rst2$solution)

cat("Correct solution:\n1 3 5 7 8 9 14 15\nFLSS solution =\n")

```

```
cat(rst2, "\n")
```

mmKnapsackIntegerized *An advanced version of mmKnapsack()*

Description

See the description of mFLSSSparIntegerized().

Usage

```
mmKnapsackIntegerized(
  maxCore = 7L,
  len,
  itemsProfits,
  itemsCosts,
  capacities,
  heuristic = FALSE,
  precisionLevel = integer(length(capacities)),
  returnBeforeMining = FALSE,
  tlimit = 60,
  useBiSrchInFB = FALSE,
  threadLoad = 8L,
  verbose = TRUE
)
```

Arguments

maxCore	See maxCore in mmKnapsack().
len	See len in mmKnapsack().
itemsProfits	See itemsProfits in mmKnapsack().
itemsCosts	See itemsCosts in mmKnapsack().
capacities	See capacities in mmKnapsack().
heuristic	See heuristic in mmKnapsack().
precisionLevel	See precisionLevel in mFLSSSparIntegerized().
returnBeforeMining	See returnBeforeMining in mFLSSSparIntegerized().
tlimit	See tlimit in mmKnapsack().
useBiSrchInFB	See useBiSrchInFB in FLSSS().
threadLoad	See avgThreadLoad in mFLSSSpar().
verbose	If TRUE, function prints progress.

Value

A list of six:

solution	The optimal solution.
selectionCosts	Solution costs.
budgets	Knapsack capacities.
selectionProfit	Solution total profit.
unconstrainedMaxProfit	Maximal profit given infinite budgets.
INT	A list of four:
INT\$mV	The integerized superset.
INT\$mTarget	The integerized subset sum.
INT\$mME	The integerized subset sum error threshold.
INT\$compressedDim	The dimensionality after integerization.

Note

32-bit architecture unsupported.

Examples

```

if(.Machine$sizeof.pointer == 8L){
# =====
# 64-bit architecture required.
# =====
# =====
# Play random numbers
# =====
rm(list = ls()); gc()
subsetSize = 6
supersetSize = 60
NcostsAttr = 4

# Make up costs for each item.
costs = abs(6 * (rnorm(supersetSize * NcostsAttr) ^ 3 +
  2 * runif(supersetSize * NcostsAttr) ^ 2 +
  3 * rgamma(supersetSize * NcostsAttr, 5, 1) + 4))
costs = matrix(costs, ncol = NcostsAttr)

# Make up cost limits.
budgets = apply(costs, 2, function(x)
{
  x = sort(x)
  Min = sum(x[1L : subsetSize])

```

```

    Max = sum(x[(supersetSize - subsetSize + 1L) : supersetSize])
    runif(1, Min, Max)
  })

# Make up item profits.
gains = rnorm(supersetSize) ^ 2 * 10000 + 100

rst1 = FLSSS::mmKnapsackIntegerized(
  maxCore = 2L, len = subsetSize, itemsProfits = gains, itemsCosts = costs,
  capacities = budgets, heuristic = FALSE, tlimit = 2, useBiSrchInFB = FALSE,
  threadLoad = 4L, verbose = TRUE)

# Examine if 'mmKnapsackIntegerized()' gives the same solution as 'mmKnapsack()'.
rst2 = FLSSS::mmKnapsack(
  maxCore = 2L, len = subsetSize, itemsProfits = gains, itemsCosts = costs,
  capacities = budgets, heuristic = FALSE, tlimit = 2, useBiSrchInFB = FALSE,
  threadLoad = 4L, verbose = TRUE)
# Possible differences in solutions are due to real-integer conversion

# Let 'x' be the solution given 'heuristic = T'. The sum of ranks of the
# profits subsetted by 'x' would be no less than that of the optimal solution.
rst3 = FLSSS::mmKnapsackIntegerized(
  maxCore = 2L, len = subsetSize, itemsProfits = gains, itemsCosts = costs,
  capacities = budgets, heuristic = TRUE, tlimit = 2, useBiSrchInFB = FALSE,
  threadLoad = 4L, verbose = TRUE)

# Exam difference in total profits given by the heuristic and the optimal:
if(length(rst3$solution) > 0 & length(rst1$solution) > 0)
  sum(gains[rst3$solution]) / sum(gains[rst1$solution])

# =====
# Test case P08 from
# https://people.sc.fsu.edu/~jburkardt/datasets/knapsack_01/knapsack_01.html
# =====
costs = matrix(c(382745, 799601, 909247, 729069, 467902, 44328, 34610, 698150,
                823460, 903959, 853665, 551830, 610856, 670702, 488960, 951111,
                323046, 446298, 931161, 31385, 496951, 264724, 224916, 169684),
              ncol = 1)

gains = c( 825594, 1677009, 1676628, 1523970, 943972, 97426, 69666, 1296457,
          1679693, 1902996, 1844992, 1049289, 1252836, 1319836, 953277, 2067538,

```

```
675367, 853655, 1826027, 65731, 901489, 577243, 466257, 369261)
```

```
budgets = 6404180
```

```
# 'mmKnapsackIntegerized()' is designed for the multidimensional Knapsack
# and may not be ideal for one-dimensional 0-1 Knapsack regarding computing speed.
# 'len = 0' would cause severe deceleration. Looping 'len' over possible
# values is recommended if 'len' is ungiven.
rst = FLSS::mmKnapsackIntegerized(
  maxCore = 2L, len = 12L, itemsProfits = gains, itemsCosts = costs,
  capacities = budgets, heuristic = FALSE, tlimit = 2, threadLoad = 4L, verbose = TRUE)
rst = sort(rst$solution)
```

```
cat("Correct solution:\n1 2 4 5 6 10 11 13 16 22 23 24\nFLSS solution =\n")
cat(rst, "\n")
# The difference is due to rounding errors in real-integer conversion. The default
# 'precisionLevel' shifts, scales and rounds 'itemCosts' such that its
# maximal element is no less than 8 times the number of items.
```

```
# Increase the precision level
rst = FLSS::mmKnapsackIntegerized(
  maxCore = 2L, len = 12L, itemsProfits = gains, itemsCosts = costs,
  capacities = budgets, heuristic = FALSE, precisionLevel = rep(500L, 1),
  tlimit = 2, threadLoad = 4L, verbose = TRUE)
# 'precisionLevel = 500' shifts, scales and rounds 'itemCosts' such that its
# maximal element is no less than 500.
rst = sort(rst$solution)
cat("Correct solution:\n1 2 4 5 6 10 11 13 16 22 23 24\nFLSS solution =\n")
cat(rst, "\n")
}
# =====
# =====
```

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