

Package ‘sMTL’

July 23, 2025

Title Sparse Multi-Task Learning

Version 0.1.0

Description Implements L0-constrained Multi-Task Learning and domain generalization algorithms. The algorithms are coded in Julia allowing for fast implementations of the coordinate descent and local combinatorial search algorithms. For more details, see a preprint of the paper: Loewinger et al., (2022) <[doi:10.48550/arXiv.2212.08697](https://doi.org/10.48550/arXiv.2212.08697)>.

URL <https://github.com/gloewing/sMTL>,
<https://rpubs.com/gloewinger/996629>

BugReports <https://github.com/gloewing/sMTL/issues>

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Depends R (>= 3.5.0)

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Imports glmnet, JuliaCall, JuliaConnectoR, caret, dplyr

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Suggests knitr, rmarkdown

NeedsCompilation no

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cv.smtl	<i>cv.smtl: cross-validation function</i>
---------	---

Description

cv.smtl: cross-validation function

Usage

```
cv.smtl(
  y,
  X,
  study = NA,
  grid = NA,
  nfolds = NA,
  commonSupp = FALSE,
  multiTask = TRUE,
  lambda_1 = TRUE,
  lambda_2 = FALSE,
  lambda_z = TRUE,
  maxIter = 2500,
  LocSrch_skip = 1,
  LocSrch_maxIter = 10,
  messageInd = FALSE,
  independent.regs = FALSE
)
```

Arguments

y	A numeric outcome vector or matrix (for multi-label problems)
X	A design (feature) matrix
study	An integer vector specifying the task ID
grid	A dataframe with column names "s", "lambda_1", "lambda_2" and "lambda_z" (if commonSupp = FALSE) with tuning values
nfolds	An integer specifying number of CV folds
commonSupp	A boolean specifying whether the task models should have the same support
multiTask	A boolean only used if study/task indices are provided: used to distinguish between a Multi-Task Learning Tuning (TRUE) or Domain Generalization Tuning (FALSE)
lambda_1	An optional boolean: if a grid is not provided, then set to TRUE if you want an automatic grid to be generated with non-zero values for this hyperparameter
lambda_2	An optional boolean: if a grid is not provided, then set to TRUE if you want an automatic grid to be generated with non-zero values for this hyperparameter
lambda_z	An optional boolean: if a grid is not provided, then set to TRUE if you want an automatic grid to be generated with non-zero values for this hyperparameter
maxIter	An integer specifying the maximum number of coordinate descent iterations
LocSrch_skip	An integer specifying whether to use local search at every tuning value (set to 1), every other value (set to 2), every third (set to 3),...
LocSrch_maxIter	An integer specifying the maximum number of local search iterations
messageInd	A boolean (verbose) of whether to print messages
independent.regs	A boolean of whether models are completely independent (only set to TRUE for benchmarks)

Value

A list

Examples

```
#####
##### simulate data
#####
set.seed(1) # fix the seed to get a reproducible result
K <- 4 # number of datasets
p <- 100 # covariate dimension
s <- 5 # support size
q <- 7 # size of subset of covariates that can be non-zero for any task
n_k <- 50 # task sample size
N <- n_k * p # full dataset samplesize
X <- matrix( rnorm(N * p), nrow = N, ncol=p) # full design matrix
B <- matrix(1 + rnorm(K * (p+1) ), nrow = p + 1, ncol = K) # betas before making sparse
```

```

Z <- matrix(0, nrow = p, ncol = K) # matrix of supports
y <- vector(length = N) # outcome vector

# randomly sample support to make betas sparse
for(j in 1:K) Z[1:q, j] <- sample( c( rep(1,s), rep(0, q - s) ), q, replace = FALSE )
B[-1,] <- B[-1,] * Z # make betas sparse and ensure all models have an intercept

task <- rep(1:K, each = n_k) # vector of task labels (indices)

# iterate through and make each task specific dataset
for(j in 1:K){
  indx <- which(task == j) # indices of task
  e <- rnorm(n_k)
  y[indx] <- B[1, j] + X[indx,] %*% B[-1,j] + e
}

colnames(B) <- paste0("beta_", 1:K)
rownames(B) <- paste0("X_", 1:(p+1))

print("Betas")
print(round(B[1:8,],2))

#####
# custom tuning grid
#####
grid <- data.frame(s = c(4, 4, 5, 5),
                  lambda_1 = c(0.01, 0.1, 0.01, 0.1),
                  lambda_2 = rep(0, 4),
                  lambda_z = c(0.01, 0.1, 0.01, 0.1))

#####
# cross validation with custom tuning grid
#####
## Not run:

if (identical(Sys.getenv("AUTO_JULIA_INSTALL"), "true")) { ## The examples are quite time consuming
## Do initiation for and automatic installation if necessary

  tn <- cv.smtl(y = y,
               X = X,
               study = task,
               commonSupp = FALSE,
               grid = grid,
               nfolds = 5,
               multiTask = FALSE)

  # model fitting
  mod <- smtl::smtl(y = y,
                  X = X,
                  study = task,
                  s = tn$best.1se$s,
                  commonSupp = TRUE,
                  lambda_1 = tn$best.1se$lambda_1,

```

```

        lambda_z = tn$best.1se$lambda_z)

#####
# cross validation with automatically generated grid
#####
tn <- cv.smtl(y = y,
             X = X,
             study = task,
             commonSupp = FALSE,
             lambda_1 = TRUE,
             lambda_w = FALSE,
             lambda_z = TRUE,
             nfolds = 5,
             multiTask = FALSE)

# model fitting
mod <- smtl::smtl(y = y,
                 X = X,
                 study = task,
                 s = tn$best.1se$s,
                 commonSupp = TRUE,
                 lambda_1 = tn$best.1se$lambda_1,
                 lambda_z = tn$best.1se$lambda_z)

print(round(mod$beta[1:8,],2))
}

## End(Not run)

```

grid.gen	<i>grid.gen: generate grid for cross-validation function. For internal package use only.</i>
----------	--

Description

grid.gen: generate grid for cross-validation function. For internal package use only.

Usage

```

grid.gen(
  y,
  p,
  study = NA,
  lambda_1 = TRUE,
  lambda_2 = FALSE,
  lambda_z = TRUE,
  commonSupp = FALSE,
  multiTask = TRUE
)

```

Arguments

y	A numeric vector or matrix of outcomes
p	An integer of covariate dimension
study	An integer vector of task IDs
lambda_1	A boolean
lambda_2	A boolean
lambda_z	A boolean
commonSupp	A boolean
multiTask	A boolean

Value

A dataframe

maxEigen	<i>maxEigen: maximum eigenvalue wrapper for Julia TSVD package. internal package use only</i>
----------	---

Description

maxEigen: maximum eigenvalue wrapper for Julia TSVD package. internal package use only

Usage

```
maxEigen(X, intercept = TRUE)
```

Arguments

X	A matrix.
intercept	A boolean.

Value

A numeric scalar of the maximum eigenvalue of provided matrix, X.

method_nm	<i>methods names: give name for printing. Internal package use only.</i>
-----------	--

Description

methods names: give name for printing. Internal package use only.

Usage

```
method_nm(method, multiLabel = TRUE)
```

Arguments

method	A string
multiLabel	A boolean

Value

A string indicating what type of multi-task learning problem is being fit.

multiTaskRmse	<i>multiTaskRmse: RMSE for multi-task problems (averaged across tasks)</i>
---------------	--

Description

multiTaskRmse: RMSE for multi-task problems (averaged across tasks)

Usage

```
multiTaskRmse(data, beta)
```

Arguments

data	A matrix including outcome vector/matrix and design matrix to test RMSE on
beta	A matrix of estimated beta coefficients where each task is in a different column

Value

Returns a scalar of average (across tasks) RMSE for predictions on data provided

multiTaskRmse_MT	<i>multiTaskRmse: calculate average (across tasks) RMSE for multi-label prediction problems</i>
------------------	---

Description

multiTaskRmse: calculate average (across tasks) RMSE for multi-label prediction problems

Usage

```
multiTaskRmse_MT(data, K = NA, beta)
```

Arguments

data	A matrix including outcome vector/matrix and design matrix to test RMSE on
K	An integer of number of studies/tasks
beta	A matrix of estimated beta coefficients where each task is in a different column

Value

Returns a scalar of average (across tasks) RMSE for predictions on data provided

predict	<i>predict: predict on smtl model object</i>
---------	--

Description

predict: predict on smtl model object

Usage

```
predict(model, X, lambda_1 = NA, lambda_2 = NA, lambda_z = NA, stack = FALSE)
```

Arguments

model	An sMTL model object returned from the smtl() function
X	A matrix of deatures
lambda_1	A optional numeric scalar specifying which lambda_1 to use for prediction. Only needed if the model object is fit on a path (multiple hyperparameter values)
lambda_2	A optional numeric scalar specifying which lambda_2 to use for prediction. Only needed if the model object is fit on a path (multiple hyperparameter values)

lambda_z	A optional numeric scalar specifying which lambda_2 to use for prediction. Only needed if the model object is fit on a path (multiple hyperparameter values)
stack	An optional boolean specifying whether to calculate and apply stacking weights (only for Domain Generalization problems).

Value

A matrix of task-specific predictions for multi-task/multi-label or for Domain Generalization problems, average and multi-study stacking predictions.

Examples

```
#####
##### First Time Loading, Julia is Installed and Julia Path is Known #####
#####
# fit model
## Not run:

if (identical(Sys.getenv("AUTO_JULIA_INSTALL"), "true")) { ## The examples are quite time consuming
## Do initiation for and automatic installation if necessary
mod <- smtl(y = y,
            X = X,
            study = task,
            s = 5,
            commonSupp = FALSE,
            lambda_1 = c(0.1, 0.2, 0.3),
            lambda_z = c(0.01, 0.05, 0.1))

# make predictions
preds <- SMTL::predict.smtl(model = mod,
                             X = X,
                             lambda_1 = 0.1,
                             lambda_z = 0.01) }

## End(Not run)
```

reName_cv

reName_cv: rename output from CV. For internal package use only.

Description

reName_cv: rename output from CV. For internal package use only.

Usage

```
reName_cv(x)
```

Arguments

x A list (S3 class) supplied from internal sMTL functions

Value

A list (S3 class) with elements renamed.

best A list (S3 class) with hyperparameters that achieve lowest average RMSE.

best.1se A list (S3 class) with hyperparameters associated with lowest sparsity level within 1 standard deviation of hyperparameters that achieve lowest average RMSE.

lambda_1 Numeric hyperparameter for L2 (ridge penalty).

lambda_2 Numeric hyperparameter for betabar penalty.

rho Integer specifying sparsity level (s).

rhoScale	<i>rhoScale: scale lambda_z depending on magnitude. For internal package use only.</i>
----------	--

Description

rhoScale: scale lambda_z depending on magnitude. For internal package use only.

Usage

```
rhoScale(K, p, rhoVec, itrs = 10000)
```

Arguments

K An integer - number of tasks

p An integer - dimension of covariates

rhoVec A vector of integers

itrs An integer

Value

A matrix or dataframe with lambda_z hyperparameter scaled appropriately depending on sparsity level.

seReturn	<i>seReturn: find smallest rho within 1 se of smallest cv error. For internal package use.</i>
----------	--

Description

seReturn: find smallest rho within 1 se of smallest cv error. For internal package use.

Usage

```
seReturn(x)
```

Arguments

x	dataframe
---	-----------

Value

Returns a dataframe that includes summary statistics to choose the best sparsity level (s) according to the 1-standard deviation rule.

smtl	<i>smtl: make model-fitting function</i>
------	--

Description

smtl: make model-fitting function

Usage

```
smtl(
  y,
  X,
  study = NA,
  s,
  commonSupp = FALSE,
  warmStart = TRUE,
  lambda_1 = 0,
  lambda_2 = 0,
  lambda_z = 0,
  scale = TRUE,
  maxIter = 10000,
  LocSrch_maxIter = 50,
  messageInd = TRUE,
  model = TRUE,
  independent.regs = FALSE
)
```

Arguments

<code>y</code>	A numeric outcome vector (for multi-task/domain generalization problems) or a numeric outcome matrix (for multi-label problems)
<code>X</code>	A matrix of covariates
<code>study</code>	A vector of integers specifying task (or study/domain) ID. This should be set to NA for Multi-Label problems, but is required for Multi-Task and Domain Generalization problems.
<code>s</code>	An integer specifying the sparsity level
<code>commonSupp</code>	A boolean specifying whether to constrain solutions to have a common support
<code>warmStart</code>	A boolean specifying whether a warm start model is fit internally before the final model. Warm starts improve solution quality but will be slower.
<code>lambda_1</code>	A numeric vector of ridge penalty hyperparameter values
<code>lambda_2</code>	A numeric vector of betaBar (to borrow strength across coefficient values) penalty hyperparameter values
<code>lambda_z</code>	A numeric vector zBar (to borrow strength across coefficient supports) penalty hyperparameter values
<code>scale</code>	A boolean specifying whether to center and scale covariates before model fitting (either way coefficient estimates are returned on original scale before centering/scaling)
<code>maxIter</code>	An integer specifying the maximum number of coordinate descent iterations before
<code>LocSrch_maxIter</code>	An integer specifying the number of maximum local search iterations
<code>messageInd</code>	A boolean specifying whether to include messages (verbose)
<code>model</code>	A boolean indicating whether to return design matrix and outcome vector
<code>independent.regs</code>	A boolean specifying whether to fit independent regressions (instead of multi-task). This ensures there is NO information sharing via active sets or penalties

Value

A list (object of S3 class).

<code>beta</code>	Matrix with coefficient estimates where column <code>j</code> are estimates from task <code>j</code> .
<code>reg_type</code>	String specifying whether model is "multiStudy" denoting that there is a separate design matrix for each task, "multiLabel" where the design matrix is the same across tasks and "L0" indicating a single-task regression.
<code>K</code>	Integer that indicates number of tasks.
<code>s</code>	An integer that indicates sparsity level.
<code>commonSupp</code>	Boolean indicating of supports are common across tasks.
<code>warmStart</code>	A Boolean indicating whether to fit a MTL model as a warm start.
<code>grid</code>	A dataframe including grid of hyperparameters that model is fit on.

maxIter An integer specifying the maximum number of iterations of block CD.

LocSrch_maxIter An integer specify the maximum number of iterations of local search.

independent.regs A boolean indicating whether to make each task independent of each other (no shared active sets).

AS_multiplier An integer specifying the active set multiplier.

X_train A Matrix: the design matrix (row concatenated across tasks).

y_train The outcome vector or matrix.

Examples

```
## Not run:

if (identical(Sys.getenv("AUTO_JULIA_INSTALL"), "true")) { ## The examples are quite time consuming
## Do initiation for and automatic installation if necessary

# load package
library(sMTL)
smtl_setup()

#####
#### simulate data
#####
set.seed(1) # fix the seed to get a reproducible result
K <- 4 # number of datasets
p <- 100 # covariate dimension
s <- 5 # support size
q <- 7 # size of subset of covariates that can be non-zero for any task
n_k <- 50 # task sample size
N <- n_k * p # full dataset samplesize
X <- matrix( rnorm(N * p), nrow = N, ncol=p) # full design matrix
B <- matrix(1 + rnorm(K * (p+1) ), nrow = p + 1, ncol = K) # betas before making sparse
Z <- matrix(0, nrow = p, ncol = K) # matrix of supports
y <- vector(length = N) # outcome vector

# randomly sample support to make betas sparse
for(j in 1:K)     Z[1:q, j] <- sample( c( rep(1,s), rep(0, q - s) ), q, replace = FALSE )
B[-1,] <- B[-1,] * Z # make betas sparse and ensure all models have an intercept

task <- rep(1:K, each = n_k) # vector of task labels (indices)

# iterate through and make each task specific dataset
for(j in 1:K){
  indx <- which(task == j) # indices of task
  e <- rnorm(n_k)
  y[indx] <- B[1, j] + X[indx,] %*% B[-1,j] + e
}
colnames(B) <- paste0("beta_", 1:K)
rownames(B) <- paste0("X_", 1:(p+1))
```

```

print("Betas")
print(round(B[1:8,],2))

#####
##### fit Multi-Task Learning Model for Heterogeneous Support
#####

mod <- smtl::smtl(y = y,
                  X = X,
                  study = task,
                  s = 5,
                  commonSupp = FALSE,
                  lambda_1 = 0.001,
                  lambda_2 = 0,
                  lambda_z = 0.25)

print(round(mod$beta[1:8,],2))

# make predictions
preds <- smtl::predict(model = mod, X = X[1:5,])

#####
##### fit Multi-Task Learning Model for Common Support
#####

library(smtl)
smtl::smtl_setup(path = "/Applications/Julia-1.5.app/Contents/Resources/julia/bin")
mod <- smtl::smtl(y = y,
                  X = X,
                  study = task,
                  s = 5,
                  commonSupp = TRUE,
                  lambda_1 = 0.001,
                  lambda_2 = 0.5)

print(round(mod$beta[1:8,],2))
}

## End(Not run)

```

smtl_setup

smtl_setup: setup Julia path and/or install Julia or Julia packages using functions based on external package JuliaCall::julia_setup().

Description

smtl_setup: setup Julia path and/or install Julia or Julia packages using functions based on external package JuliaCall::julia_setup().

Usage

```
smtl_setup(path = NULL, installJulia = FALSE, installPackages = FALSE)
```

Arguments

```
path          A string
installJulia  A boolean.
installPackages
              A boolean.
```

Value

A message indicating either Julia language or package installation status or the path of Julia Binary on your computer. See vignette if you have problems specifying the path of Julia binary correctly.

Examples

```
## Not run:

if (identical(Sys.getenv("AUTO_JULIA_INSTALL"), "true")) { ## The examples are quite time consuming
## Do initiation for and automatic installation if necessary
#####
# First Time Loading, Julia is Installed and Julia Path is Known
#####
smtl_setup(path = "/Applications/Julia-1.5.app/Contents/Resources/julia/bin",
            installJulia = FALSE,
            installPackages = FALSE)

#####
# If you have run smtl_setup() before, then path specification shouldn't be necessary
#####
smtl_setup(path = NULL, installJulia = FALSE, installPackages = FALSE)

#####
##### First Time Loading, Julia is Not Installed #####
#####
smtl_setup(path = NULL, installJulia = TRUE, installPackages = FALSE)

#####
##### First Time Loading, Julia is Installed But Packages NEED INSTALLATION #####
#####
smtl_setup(path = "/Applications/Julia-1.5.app/Contents/Resources/julia/bin",
            installJulia = TRUE,
            installPackages = TRUE)

}

## End(Not run)
```

sparseCV	<i>sparseCV: cross-validation functions. For internal package use only.</i>
----------	---

Description

sparseCV: cross-validation functions. For internal package use only.

Usage

```
sparseCV(
  data,
  tune.grid,
  hoso = "hoso",
  method = "L0",
  nfolds = "K",
  juliaFnPath = NA,
  messageInd = FALSE,
  LSitr = 50,
  LSspc = 1,
  maxIter = 2500
)
```

Arguments

data	Matrix with outcome and design matrix
tune.grid	A data.frame of tuning values
hoso	String specifying tuning type
method	String specifying regression method
nfolds	String or integer specifying number of folds
juliaFnPath	String specifying path to Julia binary
messageInd	Boolean for message printing
LSitr	Integer specifying do <LSitr> local search iterations on parameter values where we do actually do LS; NA does no local search
LSspc	Integer specifying number of hyperparameters to conduct local search: conduct local search every <LSspc>^th iteration. NA does no local search
maxIter	Integer specifying max iterations of coordinate descent

Value

A list (S3 class) with elements used for cross validation.

best	A dataframe with the hyperparameters associated with the best prediction performance and summary statistics of performance.
best.1se	A dataframe including optimal hyperparameters according to 1-standard deviation rule.

rmse	A dataframe with prediction performance for hyperparamters in tuning grid for all folds.
avg	A dataframe with average performance at each of the hyperparameters in tuning grid (averaged across tasks).

sparseCV_MT	<i>sparseCV_MT: internal cross-validation functions. For internal package use only.</i>
-------------	---

Description

sparseCV_MT: internal cross-validation functions. For internal package use only.

Usage

```
sparseCV_MT(
  data,
  tune.grid,
  hoso = "hoso",
  method = "L0",
  nfolds = "K",
  juliaFnPath = NA,
  messageInd = FALSE,
  LSitr = 50,
  LSspc = 1,
  maxIter = 2500
)
```

Arguments

data	Matrix with outcome and design matrix
tune.grid	A data.frame of tuning values
hoso	String specifying tuning type
method	String specifying regression method
nfolds	String or integer specifying number of folds
juliaFnPath	String specifying path to Julia binary
messageInd	Boolean for message printing
LSitr	Integer specifying do <LSitr> local search iterations on parameter values where we do actually do LS; NA does no local search
LSspc	Integer specifying number of hyperparameters to conduct local search: conduct local search every <LSspc>^th iteration. NA does no local search
maxIter	Integer specifying max iterations of coordinate descent

Value

A list (S3 class) with elements used for cross validation.

<code>best</code>	A dataframe with the hyperparameters associated with the best prediction performance and summary statistics of performance.
<code>best.1se</code>	A dataframe including optimal hyperparameters according to 1-standard deviation rule.
<code>rmse</code>	A dataframe with prediction performance for hyperparameters in tuning grid for all folds.
<code>avg</code>	A dataframe with average performance at each of the hyperparameters in tuning grid (averaged across tasks).

<code>sparseL0Tn_iht</code>	<i>sparseCV_L0: cross-validation functions. For internal package use only.</i>
-----------------------------	--

Description

`sparseCV_L0`: cross-validation functions. For internal package use only.

Usage

```
sparseL0Tn_iht(
  data,
  tune.grid,
  hoso = "hoso",
  nfolds = "K",
  juliaFnPath = "/Users/gabeloewinger/Desktop/Research Final/Sparse Multi-Study/",
  trainingStudy = NA,
  messageInd = FALSE,
  LSitr = 50,
  LSspc = 1,
  maxIter = 2500
)
```

Arguments

<code>data</code>	Matrix with outcome and design matrix
<code>tune.grid</code>	A data.frame of tuning values
<code>hoso</code>	String specifying tuning type
<code>nfolds</code>	String or integer specifying number of folds
<code>juliaFnPath</code>	String specifying path to Julia binary
<code>trainingStudy</code>	Integer specifying index of training study
<code>messageInd</code>	Boolean for message printing

LSitr	Integer specifying do <LSitr> local search iterations on parameter values where we do actually do LS; NA does no local search
LSspc	Integer specifying number of hyperparameters to conduct local search: conduct local search every <LSspc>^th iteration. NA does no local search
maxIter	Integer specifying max iterations of coordinate descent

Value

A list (S3 class) with elements used for cross validation.

best	A dataframe with the hyperparameters associated with the best prediction performance and summary statistics of performance.
best.1se	A dataframe including optimal hyperparameters according to 1-standard deviation rule.
rmse	A dataframe with prediction performance for hyperparamters in tuning grid for all folds.
avg	A dataframe with average performance at each of the hyperparameters in tuning grid (averaged across tasks).

tuneZscale	<i>tuneZscale: scale lambda_z depending on magnitude. For internal package use only.</i>
------------	--

Description

tuneZscale: scale lambda_z depending on magnitude. For internal package use only.

Usage

```
tuneZscale(tune.grid, rhoScale)
```

Arguments

tune.grid	A dataframe
rhoScale	A dataframe

Value

A dataframe that includes tuning grid with the lambda_z hyperparameter re-scaled appropriately for sparsity levels (s).

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