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Title Statistical Package for Reliability Data Analysis

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Author Yili Hong, Yimeng Xie, and Zhibing Xu

Maintainer Yili Hong <yilihong@vt.edu>

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Description The Statistical Package for REliability Data Analysis (SPREDA) implements recently-developed statistical methods for the analysis of reliability data. Modern technological developments, such as sensors and smart chips, allow us to dynamically track product/system usage as well as other environmental variables, such as temperature and humidity. We refer to these variables as dynamic covariates. The package contains functions for the analysis of time-to-event data with dynamic covariates and degradation data with dynamic covariates. The package also contains functions that can be used for analyzing time-to-event data with right censoring, and with left truncation and right censoring. Financial support from NSF and DuPont are acknowledged.

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 SPREDA-package

Statistical Package for Reliability Data Analysis

Description

The Statistical Package for REliability Data Analysis (SPREDA) implements recently-developed statistical methods for the analysis of reliability data. Modern technological developments, such as sensors and smart chips, allow us to dynamically track product/system usage as well as other environmental variables, such as temperature and humidity. We refer to these variables as dynamic covariates. The package contains functions for the analysis of time-to-event data with dynamic covariates and degradation data with dynamic covariates. The package also contains functions that can be used for analyzing time-to-event data with right censoring, and with left truncation and right censoring. Financial support from NSF and DuPont are acknowledged.

Details

Package: SPREDA
 Type: Package
 Version: 1.1
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 License: GPL-2

Contains functions that are useful for the analysis of reliability data.

Author(s)

Yili Hong, Yimeng Xie, and Zhibing Xu
 Maintainer: Yili Hong <yilihong@vt.edu>

References

- Hong, Y., W. Q. Meeker, and J. D. McCalley (2009). Prediction of Remaining Life of Power Transformers Based on Left Truncated and Right Censored Lifetime Data. *The Annals of Applied Statistics*, Vol. 3, pp. 857-879.
- Hong, Y. and Meeker, W. Q. (2010), Field-Failure and Warranty Prediction Using Auxiliary Use-rate Data. *Technometrics*, Vol. 52, pp. 148-159.
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- Hong, Y., Y. Duan, W. Q. Meeker, D. L. Stanley, and X. Gu (2014), Statistical Methods for Degradation Data with Dynamic Covariates Information and an Application to Outdoor Weathering Data, *Technometrics*, DOI: 10.1080/00401706.2014.915891.
- Meeker, W. Q. and L. A. Escobar (1998). Statistical Methods for Reliability Data. *John Wiley & Sons*.
- Meeker, W. Q. and L. A. Escobar (2014). RSplida. <http://www.public.iastate.edu/~stat533/>.
- Xu, Z., Y. Hong, and R. Jin (2014), Nonlinear General Path Models for Degradation Data with Dynamic Covariates, submitted.

 ce.dat.prep

 Create an object for cumulative exposure

Description

Create a dataset with format that is suitable for analysis in the cumulative exposure model.

Usage

```
ce.dat.prep(xt.dat, failure.dat, ref_time = NULL)
```

Arguments

xt.dat	"data.frame" format object. The first and second columns are sample id and time, respectively. Other columns are dynamic covariates.
failure.dat	A "Surv" object. See Surv .
ref_time	Reference time for each sample. If not specified, ref_time is a vector of 0's.

Value

A list of failure.dat, xt.obj and aux.inf.

cls	<i>Mixed primal-dual bases algorithm for estimation of parameters with restriction.</i>
-----	---

Description

It is used to estimate the parameters which have restrictions on the domain based on mixed primal-dual bases algorithm.

Usage

```
cls(y, X)
```

Arguments

y	A vector for responses.
X	Matrix of covariates.

Value

y	A vector for responses;
x	Matrix of covariates;
betahat	Estimates of parameters;
yhat	Estimates of responses.

Author(s)

Yili Hong

References

Fraser, D. A. S. and H. Massam (1989), A mixed primal-dual bases algorithm for regression under inequality constraints. Application to concave regression. *Scandinavian Journal of Statistics*, Vol. 16, pp. 65-74.

See Also

[clme](#) and [deglmx](#)

Examples

```
y<-sort(rnorm(100, 10, 2))
x<-cbind(runif(100, 1, 3), sort(rnorm(100, 3, 1)))
res<-cls(y, x)
```

Coatingenv

Dynamic covariates for the coating data.

Description

A data frame with 36 observations and 9 variables.

Usage

```
data(Coatingenv)
```

Format

SPEC_NUM Observation id.
TIME Observation time for each id.
UVB a dynamic covariate.
UVA a dynamic covariate.
VIS a dynamic covariate.
TEMP a dynamic covariate.
RH a dynamic covariate.
UV a dynamic covariate.
GROUP Group for each id.

Source

Hong, Y., Y. Duan, W. Q. Meeker, D. L. Stanley, and X. Gu (2014), Statistical Methods for Degradation Data with Dynamic Covariates Information and an Application to Outdoor Weathering Data, *Technometrics*, DOI: 10.1080/00401706.2014.915891.

Coatingout

Dynamic covariates for coating data

Description

A data frame with 36 observations and 4 variables.

Usage

```
data(Coatingout)
```

Format

SPEC_NUM Observation id.
 TIME Observation time for each id.
 DAMAGE_Y Response for each id.
 GROUP Group for each id.

Source

Hong. Y., Y. Duan, W. Q. Meeker, D. L. Stanley, and X. Gu (2014), Statistical Methods for Degradation Data with Dynamic Covariates Information and an Application to Outdoor Weathering Data, *Technometrics*, DOI: 10.1080/00401706.2014.915891.

deglmx	<i>Functions for estimating parameters in the linear/nonlinear mixed models with dynamic covariates.</i>
--------	--

Description

Functions for estimating parameters in the linear/nonlinear mixed models with dynamic covariates. Those dynamic covariates will have restricted-shape effects such as monotonic increasing, decreasing or quadratic shape.

Usage

```
deglmx(fixed, data, dyn.data, id, time, random = NULL, linear = TRUE, ytrend,
splinetrend = NULL, splinetype = NULL, degree = NULL, knots = NULL,
weights = NULL, subset = NULL, start, maxiter = 10, method = "BFGS", ...)
```

Arguments

fixed	Formula with fixed effect.
data	Data with id, time, response, and fixed covariates.
dyn.data	Dynamic data with id, time, dynamic covariates.
id	The name of the id which is characters or string.
time	The name of time in the data or dyn.data which is characters or string.
random	The formula for random parts which should condition on the id.
linear	The index of linear or nonlinear.
ytrend	If ytrend=1 indicates the increasing trend of the response, if ytrend=-1 indicates the decreasing trend of the response.
splinetrend	They are a vector of trends of dynamic covariate effects. Define 1 as increasing trend and -1 as decreasing trend.
splinetype	They are a vector of the spline basis type which can be chosen among "Ms", "Is", and "Cs".

degree	The degree of the spline functions.
knots	The number of knots in the spline functions.
weights	Weights of the observation.
subset	Subset of the data.
start	The initial values for covariance and variance matrix.
maxiter	The maximum number of iteration in the optimization.
method	The method of optim function with "BFGS" as default. More details in optim .
...	Other items.

Value

The returned outputs belong to class of "deglmx". `list(type = type, fit = fit, dat = dat.obj, dyn.mat = cov.mat.tmp, ytrend = ytrend, dyncovnames = dyncovnames, dyn.data = dyn.data, beta.index = beta.index, call = mfun)`

type	Type of the model either linear mixed or nonlinear mixed models.
fit	The fitting results in the model including estimates, residuals, loglikelihood, and so on.
dat	The modified data.
dyn.mat	The spline basis functions.
ytrend	The indication of response trend either increasing (1) or decreasing (-1).
dyncovnames	Names of dynamic covariates in the model.
dyn.data	The modified dynamic data.
beta.index	Indications of parameters in the dyanmic covariates.
call	The call function in the model.

Note

For the nonlinear model, we currently only implement one specific nonlinear relationship.

Author(s)

Yili Hong

References

Hong, Y., Y. Duan, W. Q. Meeker, D. L. Stanley, and X. Gu (2014), Statistical Methods for Degradation Data with Dynamic Covariates Information and an Application to Outdoor Weathering Data, *Technometrics*, DOI: 10.1080/00401706.2014.915891.

Examples

```
data(Coatingenv)
data(Coatingout)
```

```
fit=deglmx(DAMAGE_Y~UV+RH+TEMP, data=Coatingout, dyn.data=Coatingenv,
           id="SPEC_NUM", time="TIME", random=~TIME|SPEC_NUM, linear=TRUE, ytrend=-1,
           splinetrend=c(-1, -1, -1), splinetype=c("Is", "Cs", "Is"), degree=c( 3, 3, 3),
           knots=c(4, 4, 4), weights=NULL, subset=NULL, start=c(0.017,0.0013,-0.404,0.0176),
           maxiter=10, method='BFGS')
```

```
fit=deglmx(DAMAGE_Y~G/(1+exp(-log(UV+RH+TEMP)/H)), data=Coatingout, dyn.data=Coatingenv,
           id="SPEC_NUM", time="TIME", random=~G+H|SPEC_NUM, linear=FALSE, ytrend=-1,
           splinetrend=c(1, 1, 1), splinetype=c("Is", "Cs", "Is"), degree=c( 3, 3, 3),
           knots=c(4, 4, 4), weights=NULL, subset=NULL, start=c(0.1, 0.1, -0.5, 0.01),
           maxiter=4)
```

i.spline.x

i_spline basis

Description

Create the *i*_th splines basis for I_splines basis or C_splines basis

Usage

```
i.spline.x(xx, tt, i, k, delta = 1e-04, Cs = F)
```

Arguments

xx	values of of covariate
tt	values of knot sequence of the covariate
i	I_th splines basis
k	degree of the spline
delta	the length of the spans to split the range of covariate
Cs	indicator of whether the creation of C_splines basis is needed

Details

Creation of the *i*_th splines basis for I_splines basis or C_splines basis

Value

i.spline.x returns a vector of *i*_th splines basis for covariate values *xx* in knots *i* and degree *k*

Author(s)

Yili Hong

References

Hong. Y., Y. Duan, W. Q. Meeker, D. L. Stanley, and X. Gu (2014), Statistical Methods for Degradation Data with Dynamic Covariates Information and an Application to Outdoor Weathering Data, *Technometrics*, DOI: 10.1080/00401706.2014.915891.

See Also[m.spline.x](#)**Examples**

```
i.spline.x(xx=runif(20), tt=c(0, 0, 0, 0.3, 0.6, 0.8, 1, 1, 1 ), i=3, k=3,
delta = 1e-04, Cs = FALSE)
i.spline.x(xx=runif(20), tt=c(0, 0, 0, 0.3, 0.6, 0.8, 1, 1, 1 ), i=3, k=3,
delta = 1e-04, Cs = TRUE)
```

kaplan.meier.location *Kaplan-Meier Location*

Description

Calculate the location of Kaplan-Meier estimator.

Usage

```
kaplan.meier.location(fit)
```

Arguments

fit [survfit](#) object.

Value

xloc, yloc x, y locations.

Author(s)

Yili Hong

Examples

```
require(survival)
fit <- survfit(Surv(time, status) ~ x, data = aml)
kaplan.meier.location(fit)
```

Description

Fit parametric models (based on log-location-scale family of distributions) to right censored and/or left truncated data, with (dynamic) covariates.

Usage

```
Lifedata.MLE(formula, data, xt.dat = NULL, dist, method = "BFGS",
subset, truncation, na.action, weights, ref_time = NULL, starts = NULL, ...)
```

Arguments

formula	A formula object, which has a Surv object on the left of ~ and covariates on the right.
data	A data frame used to evaluate variables in the formula, subset and weights arguments.
xt.dat	A data frame contains dynamic covariates. The first and second columns must be sample id and time. If specified, cumulative exposure model will be used to fit the data.
dist	Distribution used in the model. Can be "weibull", "lognormal", "loglogistic", "frechet".
method	Default is "BFGS". This function calls optim to do optimization. Other options can be found in optim .
subset	This is an optional argument that specifies the subset of observations to be used in the fitting procedure.
truncation	An optional data frame contains truncation time and indicators.
na.action	Indicates what to be done when data contain missing values.
weights	An optional vector of weights for each observation.
ref_time	An optional vector of reference time (start time) of dynamic covariates. If it is NULL, ref_time is a vector of 0's.
starts	Initial values for parameters.
...	Further arguments can be passed to optim .

Details

The default method for choosing start values can sometimes failed, the user may need to try several start values to make the function work.

Value

This function returns an object of class "Lifedata.MLE". An "Lifedata.MLE" object is a list of

call	Called function.
formula	Formula argument in the input.
coef	Vector of coefficients.
vov	Variance-covariance matrix of coef.
min	-loglikelihood evaluated at coef.
surv	Survival probabilities.
dat	Dataset used to fit the model.

Author(s)

Yili Hong

References

Yili Hong and William Q. Meeker. Field-Failure Predictions Based on Failure-Time Data With Dynamic Covariate Information. *Technometrics*, **55**(2), 135–149, 2013.

See Also

[Surv](#), [optim](#), [summary.Lifedata.MLE](#). See `methods(class="Lifedata.MLE")` for all the functions related to "Lifedata.MLE" object.

Examples

```
#####
### right censored data
data(shock)
res1=Lifedata.MLE(Surv(Distance, Censor)~1, data=shock, dist="weibull")
res1
summary(res1)

res2=Lifedata.MLE(Surv(Distance, Censor)~1, data=shock, dist="lognormal")
res2
summary(res2)

#####
### left truncated right censoring data
data(testdata)
test=Lifedata.MLE(Surv(truncation.age, age, failure)~1, data=testdata,dist="weibull",
method="Nelder-Mead", subset=(group=="MC_Old"))
summary(test)

#####
### dynamix covariates
data(Prod2.xt.dat)
```

```
data(Prod2.fai.dat)

test=Lifedata.MLE(Surv(failure.time, delta)~1, data=Prod2.fai.dat,xt.dat=Prod2.xt.dat,
starts=c(12, 3.5, log(2)), dist="weibull")
summary(test)
```

lifetime.mle

*Calculate MLE for Lifetime Distribution***Description**

Calculate MLE for samples from lifetime distribution, e.g., Weibull distribution. The observations can be complete or censored.

Usage

```
lifetime.mle(dat, minusloglik, starts, method = "BFGS", hessian = TRUE,...)
```

Arguments

dat	First column contains event times, second column contains event indicators.
minusloglik	-loglikelihood.
starts	Initial values for parameters.
method	Default is "BFGS". This function call optim to do optimization. Other options can be found in optim .
hessian	A logical value. If TRUE, hessian matrix will be returned. Default is TRUE.
...	Further arguments can be passed to optim .

Value

A list of

call	Called function.
coef	The best minimizer found.
vov	Variance-covariance matrix of coef.
min	-loglikelihood evaluated at coef.
dat	Dataset used.
minusloglik	-loglikelihood function.

Author(s)

Yili Hong

See Also[optim](#)**Examples**

```
#censored samples from Weibull distribution
dat=cbind(c(1.1,2,3.6,4,5.3,7,7,7), c(1,1,1,1,1,0,0,0))
res=lifetime.mle(dat, minusloglik=minusloglik.sev, starts=c(0,1))
res$coef #return \eqn{u, log(\sigma)}
```

m.spline.x	<i>M_splines basis</i>
------------	------------------------

Description

Creation of M_splines basis

Usage

```
m.spline.x(x, tt, i, k)
```

Arguments

x	a value of the covariate
tt	values of knot sequence of the covariate
i	the i_th M_spline function
k	degree of the spline

Value

m.spline.x returns a value of M_spline basis value for x in i_th spline degree of k

Author(s)

Yili Hong

References

Hong. Y., Y. Duan, W. Q. Meeker, D. L. Stanley, and X. Gu (2014), Statistical Methods for Degradation Data with Dynamic Covariates Information and an Application to Outdoor Weathering Data, *Technometrics*, DOI: 10.1080/00401706.2014.915891.

See Also[i.spline.x](#)**Examples**

```
m.spline.x(x=0.3, tt=c(0, 0, 0, 0.3, 0.6, 0.8, 1, 1, 1 ), i=2, k=3)
```

MIC.splines.basis *Splines basis functions*

Description

Creation splines basis for M_splines, I_splines and C_splines

Usage

```
MIC.splines.basis(x, df = NULL, knots = NULL, boundary.knots = NULL,
type = "Ms", degree = 3, delta = 0.01, eq.alloc = F)
```

Arguments

x	values of covariate
df	number of splines needed which is equal to knots+degree
knots	number of knots needed which does not include the number of knots at the beginning
boundary.knots	the values of boundary knots, which are usually the minimum and maximum of covariate
type	types of splines basis needed, which can be Ms Is or Cs
degree	degree of the splines function
delta	the length of the spans to split the range of covariate
eq.alloc	indicators of whether the knots are equally allocated

Value

list(mat=mat,x=x, df=df, knots=knots,boundary.knots=boundary.knots, type=type,degree=degree,delta=delta)

mat	it is a matrix of splines basis
x	the input of covariate
df	the input of number of splines needed
knots	the input of number of knots needed not including the boundary
boundary.knots	the values of boundary knots
type	type of splines function which can be MS IS or Cs
degree	degree of the splines functions
delta	the length of the spans to split the range of covariate

Author(s)

Yili Hong

References

Hong, Y., Y. Duan, W. Q. Meeker, D. L. Stanley, and X. Gu (2014), Statistical Methods for Degradation Data with Dynamic Covariates Information and an Application to Outdoor Weathering Data, *Technometrics*, DOI: 10.1080/00401706.2014.915891.

See Also

[i.spline.x](#), [m.spline.x](#)

Examples

```
MIC.splines.basis(x=runif(20), df = NULL, knots = 3, boundary.knots = NULL,  
  type = "Ms", degree = 4, delta = 0.01, eq.alloc = FALSE)
```

plev

The Standard Largest Extreme Value Distribution

Description

The cdf, pdf, quantile function, and random number generation for the standard largest extreme value distribution.

Usage

```
plev(z)  
dlev(z)  
qlev(p)  
rlev(n)
```

Arguments

<code>z</code>	Vector of values where the cdf or pdf to be evaluated.
<code>p</code>	Vector of probabilities where the quantile function to be evaluated.
<code>n</code>	Number of random samples. If input is a vector, then the number generated is the length of it.

Value

`plev` returns cdf, `dlev` returns pdf, `qlev` returns quantiles, and `rlev` returns random samples.

Author(s)

Yili Hong

See Also

[psev](#), [dsev](#), [qsev](#), [rsev](#).

Examples

```
plev(c(2,3))
dlev(c(2,3))
qllev(0.1)
rlev(10)
```

```
plotdeglmx
```

```
Plot function for the class of "deglmx".
```

Description

Plots of dynamic covariates and fitting of the model in the class of "deglmx".

Usage

```
plotdeglmx(x, type)
```

Arguments

x	The fitting results of class "deglmx".
type	If type=1, plot the spline effect plot. If type=2, plot the fitting plots. If type is missing, plot all of them.

Author(s)

Yili Hong

See Also

[deglmx](#)

Examples

```
data(Coatingenv)
data(Coatingout)

fit=deglmx(DAMAGE_Y~UV+RH+TEMP, data=Coatingout, dyn.data=Coatingenv,
           id="SPEC_NUM", time="TIME", random=~TIME|SPEC_NUM, linear=TRUE, ytrend=-1,
           splinetrend=c(-1, -1, -1), splinetype=c("Is", "Cs", "Is"), degree=c( 3, 3, 3),
           knots=c(4, 4, 4),weights=NULL, subset=NULL,start=c(0.017,0.0013,-0.404,0.0176),
           maxiter=10, method='BFGS')
plotdeglmx(x=fit)
plotdeglmx(x=fit, type=1)
plotdeglmx(x=fit, type=1)
```

Prod2.fai.dat	<i>Dataset of failure information of Product 2.</i>
---------------	---

Description

A data frame with 1800 observations and 3 variables.

Usage

```
data(Prod2.fai.dat)
```

Format

failure.time a numeric vector
delta a numeric vector
ce a numeric vector

Source

Hong, Y. and W. Q. Meeker (2013). Field-Failure Predictions Based on Failure-Time Data With Dynamic Covariate Information. *Technometrics*, **55**(2), 135–149.

Prod2.xt.dat	<i>Dataset of covariate information of Produce 2.</i>
--------------	---

Description

A data frame with 80552 observations and 3 variables.

Usage

```
data(Prod2.xt.dat)
```

Format

id a numeric vector of sample ids.
time a numeric vector of time.
x1 a numeric vector of dynamic covariate x1.

Source

Yili Hong and William Q. Meeker. Field-Failure Predictions Based on Failure-Time Data With Dynamic Covariate Information. *Technometrics*, **55**(2), 135–149, 2013.

psev

The Standard Smallest Extreme Value Distribution

Description

The cdf, pdf, quantile function, and random number generation for the standard smallest extreme value distribution.

Usage

```
psev(z)
dsev(z)
qsev(p)
rsev(n)
```

Arguments

z	Vector of values where the cdf or pdf to be evaluated.
p	Vector of probabilities where the quantile function to be evaluated.
n	Number of random samples. If input is a vector, then the number generated is the length of it.

Value

psev returns cdf, dsev returns pdf, qsev returns quantiles, and rsev returns random samples.

Author(s)

Yili Hong

See Also

[plev](#), [dlev](#), [qlev](#), [rlev](#).

Examples

```
psev(c(2,3))
dsev(c(2,3))
qsev(0.1)
rsev(10)
```

shock

Shock Absorber Failure Data

Description

A data frame with 38 observations and 3 variables.

Usage

```
data(shock)
```

Format

Distance a numeric vector

Mode a factor with levels Censored Mode1 Mode2

Censor a numeric vector

Source

Meeker, W. Q. and L. A. Escobar. Statistical Methods for Reliability Data. *John Wiley & Sons*, 1998.

summary.Lifedata.MLE *Summaries of "Lifedata.MLE" Object*

Description

These functions summaries a "Lifedata.MLE" object.

Usage

```
## S3 method for class 'Lifedata.MLE'  
summary(object, ...)
```

Arguments

object A "Lifedata.MLE" object.

... Additional arguments.

Value

summary.Lifedata.MLE returns an object of class "summary.Lifedata.MLE", which is a list of

call	Component from obj.
coef	Vector of coefficients.
vcov	Variance-covariance matrix of coef
coefmat	Matrix contains mean, sd, 95% lower CI and 95% upper CI of coefficients.
min	Component from obj.
surv	Component from obj.
dat	Component from obj.
ori.coef	coef component in obj.
ori.vcov	vcov component in obj.

See Also

[Lifedata.MLE](#)

testdata	<i>Testdata</i>
----------	-----------------

Description

This dataset involves left truncation and right censoring.

Usage

```
data(testdata)
```

Format

A data frame with 710 observations on the following 9 variables.

age a numeric vector
 failure a numeric vector
 manufacture.year a numeric vector
 manufacturer a factor with levels MA MB MC MD ME Other
 cooling a factor with levels FIFE NIFE NINE Unknown
 insulation a factor with levels d55 d65
 truncation a numeric vector
 truncation.age a numeric vector
 group a factor with levels MA_New MB_Old MC.ME.Other_New MC_Old MD_Old ME_Old Other_Old

Source

Hong, Y., W. Q. Meeker, and J. D. McCalley. Prediction of Remaining Life of Power Transformers Based on Left Truncated and Right Censored Lifetime Data . *The Annals of Applied Statistics*, **3**(2), 857–879, 2009.

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