Package 'cgrcusum'

November 22, 2021

Title Continuous Time Generalized Rapid Response CUSUM

Version 0.1.0

Description Allows users to construct the Continuous Time Generalized Rapid Response CUSUM (CGR-CUSUM), Biswas & Kalbfleisch (2008) <doi:10.1002/sim.3296> CUSUM, Binary CUSUM and risk-adjusted funnel plot for survival data. These procedures can be used to monitor survival processes and detect problems in their quality.

License GPL (>= 3)

Encoding UTF-8

LazyData true

RoxygenNote 7.1.2

Suggests testthat (>= 3.0.0)

Config/testthat/edition 3

Imports ggplot2, survival

Depends R (>= 3.5.0)

Maintainer Daniel Gomon <d.gomon@math.leidenuniv.nl>

URL https://github.com/d-gomon/cgrcusum

NeedsCompilation no

Author Daniel Gomon [aut, cre] (<https://orcid.org/0000-0001-9011-3743>)

Repository CRAN

Date/Publication 2021-11-22 08:00:09 UTC

R topics documented:

`bercusum` *Risk-adjusted Bernoulli CUSUM*

Description

This function can be used to construct a risk-adjusted Bernoulli CUSUM chart on survival data. Specify one of the following combinations for the parameters:

- glmmod + theta
- p0 + theta
- p0 + p1

Usage

```
bercusum(data, followup, glmmod, theta, p0, p1, h, stoptime)
```

Arguments

`data`	`data.frame` containing the following named columns: • `entrytime` numeric - time of entry into study, • `survtime` numeric - time from entry until event, • `censorid` integer - (optional) censoring indicator (0 = right censored, 1 = observed),
`followup`	The followup time for every individual. At what time after entry do we consider the outcome?
`glmmod`	Generalized linear regression model used for risk-adjustment as produced by the function `glm`. Standard practice: `glm(as.formula(paste("(survtime <= followup) & (censorid == 1)~" ,paste(covariates,coll` `= data)`. Alternatively, a list containing: • $formula (~ covariates), • $coefficients (named vector specifying risk adjustment coefficients for covariates - names must be the same as in $formula and colnames of `data`).

`theta` e^θ is the odds ratio under the alternative hypothesis. Note that:

$$p_1 = \frac{p_0 e^\theta}{(1-p_0)(1+p_0 e^\theta)}$$

`p0` The baseline failure probability at entrytime + followup for individuals.

`p1` The alternative hypothesis failure probability at entrytime + followup for individuals.

`h` (optional) Control limit to be used for the procedure

`stoptime` (optional) Time after which the value of the chart should no longer be determined

Details

The Bernoulli CUSUM chart is given by:

$$S_n = \max(0, S_{n-1} + W_n)$$

with

$$W_n = X_n \ln\left(\frac{p_1(1-p_0)}{p_0(1-p_1)}\right) + \ln\left(\frac{1-p_1}{1-p_0}\right)$$

where X_n is the outcome of the n-th (chronological) subject in the data. Instead of displaying patient numbering on the x-axis, the time of outcome is displayed.

Value

An object of class `bercusum` containing:

- `CUSUM`: A `data.frame` containing:
  - $time (times at which chart is constructed),
  - $value (value of the chart at corresponding times),
  - $numobs (number of observations at corresponding times)
- `call`: the call used to obtain output
- `glmmod`: glm coefficients used for risk-adjustment, if specified
- `stopind`: indicator for whether the chart was stopped by the control limit

There are `plot` and `runlength` methods for "bercusum" objects.

Author(s)

Daniel Gomon

See Also

`plot.bercusum`, `runlength.bercusum`

Other qcchart: `bkcusum()`, `cgrcusum()`, `funnelplot()`

Examples

```
varsanalysis <- c("age", "sex", "BMI")
exprfitber <- as.formula(paste("(entrytime <= 365) & (censorid == 1)~",
 paste(varsanalysis, collapse='+')))
surgerydat$instance <- surgerydat$Hosp_num
glmmodber <- glm(exprfitber, data = surgerydat, family = binomial(link = "logit"))
bercus <- bercusum(data = subset(surgerydat, Hosp_num == 14), glmmod = glmmodber,
 followup = 100, theta = log(2))
plot(bercus)
```

---

bkcusum *Continuous time BK-CUSUM*

Description

This function performs the BK-CUSUM procedure based on the Biswas & Kalbfleisch (2008) CUSUM. For detection purposes, it is sufficient to only determine the value of the chart at the times of failure. This can be achieved by leaving `ctimes` empty.

Usage

```
bkcusum(data, theta, coxphmod, cbaseh, ctimes, h, stoptime, C, pb = FALSE)
```

Arguments

`data`	`data.frame` containing the following named columns: • `entrytime` numeric - time of entry into study, • `survtime` numeric - time from entry until event, • `censorid` integer - (optional) censoring indicator (0 = right censored, 1 = observed), and optionally additional covariates used for risk-adjustment.
`theta`	expected ln(hazard ratio) θ
`coxphmod`	(optional) a cox proportional hazards regression model as produced by the function `coxph()`. Standard practice: `coxph(Surv(survtime,censorid) ~ covariates,data = data)`. Alternatively, a list with: • $formula (~ covariates) • $coefficients (named vector specifying risk adjustment coefficients for covariates - names must be the same as in $formula and colnames of `data`).
`cbaseh`	a function which returns the non risk-adjusted cumulative baseline hazard $H_0(t)$. If `cbaseh` is missing but `coxphmod` has been specified as a survival object, this baseline hazard rate will be determined using the provided `coxphmod`.
`ctimes`	(optional) vector of construction times at which the value of the chart should be determined. When not specified, the chart is constructed at all failure times.

h	(optional) value of the control limit. The chart will only be constructed until the value of the control limit has been reached or surpassed.
stoptime	(optional) time after which the value of the chart should no longer be determined. Default = max(failure time). Useful when ctimes has not been specified.
C	(optional) a numeric value indicating how long after entering the study patients should no longer influence the value of the chart. This is equivalent to right-censoring every observation at time entrytime + C.
pb	(optional) boolean indicating whether a progress bar should be shown. Default = FALSE

Details

The BK-CUSUM can be used to test the hypothesis of an instant change of fixed size e^θ in the subject specific hazard rate from $h_i(t)$ to $h_i(t)e^\theta$. The parameter C can be used to ignore information provided by subjects C time units after their entry into the study. The BK-CUSUM is constructed as:

$$G(t) = \max_{0 \leq k \leq t} \left(\theta N(k,t) - \left(e^\theta - 1\right) \Lambda(k,t) \right)$$

with θ the ln(expected hazard ratio) and

$$N(k,t) = N(t) - N(k)$$

with $N(t)$ the counting process of all failures at time t and

$$\Lambda(k,t) = \Lambda(t) - \Lambda(k)$$

the with $\Lambda(t)$ the summed cumulative intensity of all subjects at time t.

Value

An object of class "bkcusum" containing:

- BK: list containing
  - $time (times at which chart is constructed),
  - $value (value of the chart at corresponding times),
- stopind: indicator for whether the chart was stopped by the control limit
- call: the call used to obtain output

There are plot and runlength methods for "bkcusum" objects.

Author(s)

Daniel Gomon

References

Biswas P. and Kalbfleisch J.D. (2008), A risk-adjusted CUSUM in continuous time based on the Cox Model, doi: 10.1002/sim.3216

See Also

plot.bkcusum, runlength.bkcusum

Other qcchart: bercusum(), cgrcusum(), funnelplot()

Examples

```
require(survival)
tdat <- subset(surgerydat, Hosp_num == 14)
tcbaseh <- function(t) chaz_exp(t, lambda = 0.01)
varsanalysis <- c("age", "sex", "BMI")
exprfit <- as.formula(paste("Surv(survtime, censorid) ~" ,paste(varsanalysis, collapse='+')))
tcoxmod <- coxph(exprfit, data= surgerydat)
#Alternatively, cbaseh can be left empty when specifying coxphmod through coxph()
bk <- bkcusum(data = tdat, theta = log(2), coxphmod = tcoxmod, cbaseh = tcbaseh, pb = TRUE)
plot(bk)
```

---

calc_risk *Calculate the Cox risk associated with the covariates of the individual*

Description

This function can be used to calculate the risk associated with the covariates of an individual under a specified Cox PH model.

Usage

```
calc_risk(data, coxphmod = NULL)
```

Arguments

data	data frame containing the covariates to be used for risk-adjustment as named columns.
coxphmod	(optional) a cox proportional hazards model generated using coxph() or a list containing: • $formula (~ covariates), • $coefficients (named vector specifying risk adjustment coefficients for covariates - names must be the same as in $formula and data colnames).

Details

The subject specific increased risk is given by:

$$e^{\beta Z_i}$$

with β the Cox coefficients and Z_i the covariates of subject i.

Value

A vector of nrow(data) specifying the increased risk of failure for each subject.

Author(s)

Daniel Gomon

See Also

Other utils: exp_hazards, gen_arriv_times(), gen_surv_times(), runlength()

Examples

```
crdat <- data.frame(age = rnorm(10, 40, 5), BMI = rnorm(10, 24, 3))
crlist <- list(formula = as.formula("~age + BMI"), coefficients = c("age"= 0.02, "BMI"= 0.009))
calc_risk(crdat, crlist)
```

---

cgrcusum *Continuous time Generalized Rapid response CUSUM (CGR-CUSUM)*

Description

This function performs the CGR-CUSUM procedure described in ARTICLE UNDER REVIEW FOR PUBLICATION. For detection purposes, it is sufficient to only determine the value of the chart at the times of failure. This can be achieved by leaving ctimes empty.

Usage

```
cgrcusum(
  data,
  coxphmod,
  cbaseh,
  ctimes,
  h,
  stoptime,
  C,
  pb = FALSE,
  cmethod = "memory2"
)
```

Arguments

data	data.frame containing the following named columns: • entrytime numeric - time of entry into study, • survtime numeric - time from entry until event,

- `censorid` integer - (optional) censoring indicator (0 = right censored, 1 = observed),

and optionally additional covariates used for risk-adjustment.

`coxphmod` (optional) a cox proportional hazards regression model as produced by the function `coxph()`. Standard practice:
`coxph(Surv(survtime,censorid) ~ covariates,data = data)`.
Alternatively, a list with:

- $formula (~ covariates)
- $coefficients (named vector specifying risk adjustment coefficients for covariates - names must be the same as in $formula and colnames of `data`).

`cbaseh` a function which returns the non risk-adjusted cumulative baseline hazard $H_0(t)$. If `cbaseh` is missing but `coxphmod` has been specified as a survival object, this baseline hazard rate will be determined using the provided `coxphmod`.

`ctimes` (optional) vector of construction times at which the value of the chart should be determined. When not specified, the chart is constructed at all failure times.

`h` (optional) value of the control limit. The chart will only be constructed until the value of the control limit has been reached or surpassed.

`stoptime` (optional) time after which the value of the chart should no longer be determined. Default = max(failure time). Useful when ctimes has not been specified.

`C` (optional) a numeric value indicating how long after entering the study patients should no longer influence the value of the chart. This is equivalent to right-censoring every observation at time `entrytime` + C.

`pb` (optional) boolean indicating whether a progress bar should be shown. Default = FALSE

`cmethod` One of the following:

- "memory2" (default) Matrix formulation of the problem (faster for high volume/long time construction - less RAM than "memory")
- "CPU" Calculates the value of the CGR-CUSUM for every time point from scratch. Recommended for small data volume (lower initialization time).
- "memory" (outdated) Matrix formulation of the problem (faster for high volume/long time construction - may require much RAM)

Details

The CGR-CUSUM can be used to test for a change of unknown positive fixed size θ in the subject-specific hazard rate from $h_i(t)$ to $h_i(t)e^{\theta}$ starting from some unknown patient ν. The starting time of the first patient which had an increase in failure rate as well as the estimated increase in the hazard rate are also given in the output. The CGR-CUSUM is determined as:

$$\max_{1\leq\nu\leq n}\left(\hat{\theta}_{\geq\nu}(t)N_{\geq\nu}(t)-\left(\exp\left(\hat{\theta}_{\geq\nu}(t)\right)-1\right)\Lambda_{\geq\nu}(t)\right)$$

with

$$N(\geq\nu)(t)=\sum_{i\geq\nu}N_i(t)$$

with $N_i(t)$ the counting process for the failure at time t of subject i and

$$\Lambda_{\geq\nu}(t) = \sum_{i\geq\nu} \Lambda_i(t)$$

the with $\Lambda_i(t)$ the cumulative intensity of subject i at time t.

Value

An object of class "cgrcusum" containing:

- `CGR`: a data.frame with named columns:
  - $time (time of construction),
  - $value (value of the chart at $time),
  - $exp_theta_t (value of MLE e^{θ_t}),
  - $S_nu (time from which patients are considered for constructing the chart)
- `call`: Contains the `call` used to obtain output;
- `stopind`: (only if h specified) Boolean indicating whether the chart was stopped by the provided value of h;
- h: Specified value for the control limit;

There are `plot` and `runlength` methods for "cgrcusum" objects.

Author(s)

Daniel Gomon

See Also

`plot.cgrcusum`, `runlength.cgrcusum`

Other qcchart: `bercusum()`, `bkcusum()`, `funnelplot()`

Examples

```
require(survival)
tdat <- subset(surgerydat, Hosp_num == 1)
tcbaseh <- function(t) chaz_exp(t, lambda = 0.01)
varsanalysis <- c("age", "sex", "BMI")
exprfit <- as.formula(paste("Surv(survtime, censorid) ~" ,paste(varsanalysis, collapse='+')))
tcoxmod <- coxph(exprfit, data= surgerydat)
#Alternatively, cbaseh can be left empty when specifying coxphmod through coxph()
cgr <- cgrcusum(data = tdat, coxphmod = tcoxmod, cbaseh = tcbaseh, pb = TRUE)
plot(cgr)
```

`cgr_helper` *Continuous time Generalized Rapid response CUSUM (CGR-CUSUM) helper - single time point*

Description

This function calculates the value of the CGR-CUSUM at one specified timepoint

Usage

```
cgr_helper(data, ctime, coxphmod, cbaseh, displaypb = FALSE)
```

Arguments

`data`	data frame containing the following named columns: `entrytime` (numeric - time of entry into study), `survtime` (numeric - time from entry until event), `censorid` (integer - censoring indicator: 0 - right censored, 1 - observed), `cause` (factor - cause of event - competing risks).
`ctime`	construction time (single) at which the value of the chart should be determined.
`coxphmod`	a cox proportional hazards regression model as produced by the function `coxph`. Obtained using: `coxph(Surv(survtime,censorid) ~ covariates,data = data)`. Alternatively, a list with $formula (~ covariates) and $coefficients (named vector specifying risk adjustment coefficients for covariates - names must be the same as in $formula and colnames).
`cbaseh`	a function which returns the non risk-adjusted cumulative baseline hazard $h_0(t)$. If `cbaseh` is missing but `coxphmod` has been specified as a survival object, this baseline hazard rate will be determined using the provided `coxphmod`.
`displaypb`	(optional) boolean indicating whether a progress bar should be displayed

Value

A list containing the following:

- $val value of CGR-CUSUM at specified time point
- $theta value at corresponding time of the MLE $\hat{\theta}_t$
- $starttime time from which individuals contribute to the chart S_ν

Author(s)

Daniel Gomon

See Also

`bkcusum`, `bercusum` (step 2)

Examples

```
#TO-DO
```

`cgr_helper_mat` *Continuous time Generalized Rapid response CUSUM (CGR-CUSUM) helper - matrix formulation of the problem*

Description

This function calculates the value of the CGR-CUSUM using a matrix formulation of the problem

Usage

```
cgr_helper_mat(data, ctimes, coxphmod, cbaseh, displaypb = FALSE)
```

Arguments

`data`	`data.frame` containing the following named columns: • `entrytime` numeric - time of entry into study, • `otime` numeric - time from entry until event, • `censorid` integer - (optional) censoring indicator (0 = right censored, 1 = observed), and optionally additional covariates used for risk-adjustment.
`ctimes`	(optional) vector of construction times at which the value of the chart should be determined. When not specified, the chart is constructed at all failure times.
`coxphmod`	(optional) a cox proportional hazards regression model as produced by the function `coxph()`. Standard practice: `coxph(Surv(survtime,censorid) ~ covariates,data = data)`. Alternatively, a list with: • $formula (~ covariates) • $coefficients (named vector specifying risk adjustment coefficients for covariates - names must be the same as in $formula and colnames of `data`).
`cbaseh`	a function which returns the non risk-adjusted cumulative baseline hazard $H_0(t)$. If `cbaseh` is missing but `coxphmod` has been specified as a survival object, this baseline hazard rate will be determined using the provided `coxphmod`.
`displaypb`	boolean Display a progress bar?

Value

A matrix with 4 named columns:

- $time time at which the value of the CGR-CUSUM was determined
- $value value at corresponding time of the CGR-CUSUM
- $exp_theta_t value at corresponding time of the MLE $\hat{\theta}_t$
- $S_nu time from which individuals contribute to the chart S_ν

Author(s)

Daniel Gomon

See Also

cgrcusum

Examples

```
## Not run:
require(survival)
tdat <- subset(surgerydat, Hosp_num == 1)
tdat$otime <- tdat$entrytime + tdat$survtime
tcbaseh <- function(t) chaz_exp(t, lambda = 0.01)
varsanalysis <- c("age", "sex", "BMI")
exprfit <- as.formula(paste("Surv(survtime, censorid) ~" ,paste(varsanalysis, collapse='+')))
tcoxmod <- coxph(exprfit, data= surgerydat)
#Alternatively, cbaseh can be left empty when specifying coxphmod through coxph()
cgrv1 <- cgr_helper_mat(data = tdat, ctimes = unique(tdat$entrytime + tdat$survtime),
                        coxphmod = tcoxmod, cbaseh = tcbaseh, displaypb = TRUE)

## End(Not run)
```

---

cgr_helper_mat_2 *Continuous time Generalized Rapid response CUSUM (CGR-CUSUM) helper - matrix formulation of the problem - version 2*

Description

This function calculates the value of the CGR-CUSUM using a matrix formulation of the problem - this can require a lot of available RAM.

Usage

```
cgr_helper_mat_2(data, ctimes, coxphmod, cbaseh, displaypb = FALSE)
```

Arguments

data	data.frame containing the following named columns: • entrytime numeric - time of entry into study, • otime numeric - time from entry until event, • censorid integer - (optional) censoring indicator (0 = right censored, 1 = observed), and optionally additional covariates used for risk-adjustment.
ctimes	(optional) vector of construction times at which the value of the chart should be determined. When not specified, the chart is constructed at all failure times.

coxphmod	(optional) a cox proportional hazards regression model as produced by the function coxph(). Standard practice: coxph(Surv(survtime,censorid) ~ covariates,data = data). Alternatively, a list with: • $formula (~ covariates) • $coefficients (named vector specifying risk adjustment coefficients for covariates - names must be the same as in $formula and colnames of data).
cbaseh	a function which returns the non risk-adjusted cumulative baseline hazard $H_0(t)$. If cbaseh is missing but coxphmod has been specified as a survival object, this baseline hazard rate will be determined using the provided coxphmod.
displaypb	boolean Display a progress bar?

Value

A matrix with 4 named columns:

- $time time at which the value of the CGR-CUSUM was determined
- $value value at corresponding time of the CGR-CUSUM
- $exp_theta_t value at corresponding time of the MLE $\hat{\theta}_t$
- $S_nu time from which individuals contribute to the chart S_ν

Author(s)

Daniel Gomon

See Also

cgrcusum

Examples

```
## Not run:
require(survival)
tdat <- subset(surgerydat, Hosp_num == 1)
tdat$otime <- tdat$entrytime + tdat$survtime
tcbaseh <- function(t) chaz_exp(t, lambda = 0.01)
varsanalysis <- c("age", "sex", "BMI")
exprfit <- as.formula(paste("Surv(survtime, censorid) ~" ,paste(varsanalysis, collapse='+')))
tcoxmod <- coxph(exprfit, data= surgerydat)
#Alternatively, cbaseh can be left empty when specifying coxphmod through coxph()
cgr2 <- cgr_helper_mat_2(data = tdat, ctimes = unique(tdat$entrytime + tdat$survtime),
                         coxphmod = tcoxmod, cbaseh = tcbaseh, displaypb = TRUE)

## End(Not run)
```

`cgr_helper_mat_3` *Continuous time Generalized Rapid response CUSUM (CGR-CUSUM) helper - matrix formulation of the problem - version 3*

Description

This function calculates the value of the CGR-CUSUM using a matrix formulation of the problem - reduce calculations by specifying control limit.

Usage

```
cgr_helper_mat_3(data, ctimes, coxphmod, cbaseh, h, displaypb = FALSE)
```

Arguments

`data`	`data.frame` containing the following named columns: • `entrytime` numeric - time of entry into study, • `otime` numeric - time from entry until event, • `censorid` integer - (optional) censoring indicator (0 = right censored, 1 = observed), and optionally additional covariates used for risk-adjustment.
`ctimes`	(optional) vector of construction times at which the value of the chart should be determined. When not specified, the chart is constructed at all failure times.
`coxphmod`	(optional) a cox proportional hazards regression model as produced by the function `coxph()`. Standard practice: `coxph(Surv(survtime,censorid) ~ covariates,data = data)`. Alternatively, a list with: • $formula (~ covariates) • $coefficients (named vector specifying risk adjustment coefficients for covariates - names must be the same as in $formula and colnames of `data`).
`cbaseh`	a function which returns the non risk-adjusted cumulative baseline hazard $H_0(t)$. If `cbaseh` is missing but `coxphmod` has been specified as a survival object, this baseline hazard rate will be determined using the provided `coxphmod`.
`h`	(optional) value of the control limit. The chart will only be constructed until the value of the control limit has been reached or surpassed.
`displaypb`	boolean Display a progress bar?

Value

A matrix with 4 named columns:

- $time time at which the value of the CGR-CUSUM was determined
- $value value at corresponding time of the CGR-CUSUM
- $exp_theta_t value at corresponding time of the MLE $\hat{\theta}_t$
- $S_nu time from which individuals contribute to the chart S_ν

Author(s)

Daniel Gomon

See Also

cgrcusum

Examples

```
## Not run:
require(survival)
tdat <- subset(surgerydat, Hosp_num == 1)
tdat$otime <- tdat$entrytime + tdat$survtime
tcbaseh <- function(t) chaz_exp(t, lambda = 0.01)
varsanalysis <- c("age", "sex", "BMI")
exprfit <- as.formula(paste("Surv(survtime, censorid) ~" ,paste(varsanalysis, collapse='+')))
tcoxmod <- coxph(exprfit, data= surgerydat)
#Alternatively, cbaseh can be left empty when specifying coxphmod through coxph()
cgr3 <- cgr_helper_mat_3(data = tdat, ctimes = unique(tdat$entrytime + tdat$survtime),
                         coxphmod = tcoxmod, cbaseh = tcbaseh, displaypb = TRUE)

## End(Not run)
```

---

exp_hazards *Exponential hazard, cumulative hazard and inverse cumulative hazard*

Description

Functions which return the hazard, cumulative hazard and inverse cumulative hazard at time t for an exponential distribution with parameter lambda and true hazard ratio mu.

Usage

```
haz_exp(t, lambda)

chaz_exp(t, lambda, mu = log(1))

inv_chaz_exp(t, lambda, mu = log(1))
```

Arguments

t	time of evaluation.
lambda	parameter of the exponential distribution.
mu	(optional) true excess hazard rate μ.

Details

The hazard function of an exponential distribution is given by:

$$h(\lambda) = \lambda$$

The cumulative hazard (with true hazard ratio μ) is given by:

$$H(\lambda, \mu) = \lambda t e^{\mu}$$

The inverse cumulative hazard (with true hazard ratio μ) by:

$$H^{-1}(\lambda, \mu) = \frac{t}{\lambda e^{\mu}}$$

Value

Value of specified function at time t.

See Also

Other utils: `calc_risk()`, `gen_arriv_times()`, `gen_surv_times()`, `runlength()`

`funnelplot` *Risk-adjusted funnel plot*

Description

This function can be used to construct a risk-adjusted funnel plot.

Usage

```
funnelplot(data, ctime, p0, glmmod, followup, conflev = c(0.95, 0.99))
```

Arguments

`data`	`data.frame` containing the following named columns: • `entrytime` numeric - time of entry into study, • `survtime` numeric - time from entry until event, • `censorid` integer - (optional) censoring indicator (0 = right censored, 1 = observed), • `instance` integer or character - indicating which instance (f.e. hospital) the observation belongs to and optionally additional covariates used for risk-adjustment.
`ctime`	construction time at which the funnel plot should be determined. Constructed over whole data when not specified
`p0`	The baseline failure probability at entrytime + followup for individuals. If not specified, average failure proportion over whole data is used instead.

`glmmod` a generalized linear regression model as produced by the function `glm()`. Standard practice:
`glm(as.formula(paste("(survtime <= followup) & (censorid == 1)~" ,paste(covariates,coll`
`= data)`.
Alternatively, a list with:

- $formula (~ covariates)
- $coefficients (named vector specifying risk adjustment coefficients for covariates - names must be the same as in $formula and colnames of `data`).

`followup` The followup time for every individual. At what time after subject entry do we consider the outcome?

`conflev` A vector of confidence levels of interest. Default is c(0.95, 0.99).

Value

An object of class "funnelplot" containing:

- `data`: A `data.frame` containing:
  - $instance instance number
  - $observed observed number of failures at instance
  - $expected expected (risk-adjusted) number of failures at instance
  - $numtotal total number of individuals considered at this instance
  - $p (risk-adjusted) proportion of failure at instance
  - $conflevels worse/normal/better performance than expected at this confidence level
- `call`: the call used to obtain output
- `plotdata`: data used for plotting confidence intervals
- `conflev`: specified confidence level(s)

There are `plot` and `summary` methods for "funnelplot" objects.

Author(s)

Daniel Gomon

See Also

`plot.funnelplot`, `summary.funnelplot`

Other qcchart: `bercusum()`, `bkcusum()`, `cgrcusum()`

Examples

```
varsanalysis <- c("age", "sex", "BMI")
exprfitfunnel <- as.formula(paste("(entrytime <= 365) & (censorid == 1)~",
 paste(varsanalysis, collapse='+')))
surgerydat$instance <- surgerydat$Hosp_num
glmmodfun <- glm(exprfitfunnel, data = surgerydat, family = binomial(link = "logit"))
funnel <- funnelplot(data = surgerydat, ctime = 3*365, glmmod = glmmodfun, followup = 100)
plot(funnel)
```

`gen_arriv_times` *Generate arrival times according to a Poisson point process*

Description

This function can be used to generate arrival times for a Poisson point process with rate psi up until time t.

Usage

```
gen_arriv_times(psi, t)
```

Arguments

`psi`	rate of the arrival process.
`t`	time until which arrivals should be generated.

Details

Exponential(ψ) interarrival times.

Value

A vector of arrival times up until time t.

Author(s)

Daniel Gomon

See Also

Other utils: `calc_risk()`, `exp_hazards`, `gen_surv_times()`, `runlength()`

Examples

```
gen_arriv_times(psi = 0.3, t = 5)
```

gen_surv_times *Generate survival times*

Description

Generate survival times according to hazard rate $h(t)\exp(\mu)$ with $h(t)$ the hazard rate associated with the specified inverse cumulative hazard rate `invchaz` and μ the specified true hazard ratio `mu`. See Bender et al. (2005).

Usage

```
gen_surv_times(invchaz, mu = log(1), data, coxphmod = NULL)
```

Arguments

`invchaz`	the inverse cumulative (baseline) hazard rate to be used for generating survival times. Must take vector inputs!
`mu`	the true hazard ratio used to generate survival times.
`data`	an integer number of survival times to generate or (in combination with coxphmod): a `data.frame` containing subject covariates in named columns.
`coxphmod`	(optional) a cox proportional hazards regression model as produced by the function `coxph()`. Standard practice: `coxph(Surv(survtime,censorid) ~ covariates,data = data)`. Alternatively, a list with: • $formula (~ covariates) • $coefficients (named vector specifying risk adjustment coefficients for covariates - names must be the same as in $formula and colnames of `data`).

Details

Sometimes it is desirable to generate survival times from an increased hazard rate

$$h(t,\mu) = h_0(t)e^{\mu}$$

with h_0 the baseline hazard rate. We call e^{μ} the true hazard ratio.

Value

A vector of survival times from subject entry time.

Author(s)

Daniel Gomon

References

Bender, R., Augustin, T., & Blettner, M. (2005). Generating survival times to simulate Cox proportional hazards models. Statistics in medicine, 24(11), 1713-1723. doi: 10.1002/sim.2059

See Also

Other utils: calc_risk(), exp_hazards, gen_arriv_times(), runlength()

Examples

```
gen_surv_times(invchaz = function(t) inv_chaz_exp(t, lambda = 0.01), data = 5)
```

`plot.cgrcusum` *Plot a quality control chart*

Description

Plot a 'cgrcusum', 'bkcusum', 'bercusum' or 'funnelplot' chart.

Usage

```
## S3 method for class 'cgrcusum'
plot(x, h, ...)

## S3 method for class 'bkcusum'
plot(x, h, ...)

## S3 method for class 'funnelplot'
plot(x, percentage = TRUE, ...)

## S3 method for class 'bercusum'
plot(x, h = x$h, ...)
```

Arguments

x	chart to plot
h	control limit to display for 'cgrcusum', 'bkcusum' or 'bercusum'
...	further plotting parameters
percentage	Should output be shown in percentages?

Value

A plot of the associated chart is displayed in the current graphics device.

Methods (by class)

- cgrcusum: Plot a CGR-CUSUM
- bkcusum: Plot a BK-CUSUM
- funnelplot: Plot a funnelplot
- bercusum: Plot a Bernoulli CUSUM

Author(s)

Daniel Gomon

See Also

cgrcusum, bkcusum, bercusum, funnelplot

---

runlength *Determine run length of a CUSUM chart*

Description

This function can be used to calculate the run length of a 'cgrcusum', 'bkcusum' or 'bercusum' chart when using control limit h

Usage

```
runlength(chart, h)

## S3 method for class 'cgrcusum'
runlength(chart, h, ...)

## S3 method for class 'bkcusum'
runlength(chart, h, ...)

## S3 method for class 'bercusum'
runlength(chart, h, ...)
```

Arguments

chart	a 'cgrcusum', 'bkcusum' or 'bercusum' chart
h	control limit h to be used when determining the run length
...	other parameters

Value

The run length of the chart with the given control limit.

Methods (by class)

- cgrcusum: Determine runlength of "cgrcusum" object
- bkcusum: Determine runlength of "bkcusum" object
- bercusum: Determine runlength of "bercusum" object

Author(s)

Daniel Gomon

See Also

Other utils: calc_risk(), exp_hazards, gen_arriv_times(), gen_surv_times()

Other utils: calc_risk(), exp_hazards, gen_arriv_times(), gen_surv_times()

Other utils: calc_risk(), exp_hazards, gen_arriv_times(), gen_surv_times()

Examples

```
varsanalysis <- c("age", "sex", "BMI")
exprfitber <- as.formula(paste("(entrytime <= 365) & (censorid == 1)~",
                               paste(varsanalysis, collapse='+')))
surgerydat$instance <- surgerydat$Hosp_num
glmmodber <- glm(exprfitber, data = surgerydat, family = binomial(link = "logit"))
bercus <- bercusum(data = subset(surgerydat, Hosp_num == 14), glmmod = glmmodber,
                   followup = 100, theta = log(2))
runlength(bercus, h = 2)
```

---

summary.funnelplot *Summarizes (or elaborates on) S3 objects in this package.*

Description

Prints the (name of the) instances performing worse than expected in a "funnelplot" object at the specified confidence levels.

Usage

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

Arguments

object	S3 object to summarize
...	extra parameters

Value

A list with:

- $call The call used to obtain the input object,
- $'0.xx' The detected instances at specified confidence level.

Methods (by class)

- funnelplot: Summarize instances detected by the funnelplot object

See Also

, funnelplot

`surgerydat` *Data of surgery procedures performed at multiple hospitals (simulated)*

Description

Data about patients and their surgery procedure from 30 simulated hospitals with patient arrivals in the first 400 days after the start of the study.
Patient failure times are exponentially distributed with exponential hazard rate $h_0(t, \lambda)e^{\mu}$. Some hospitals have an increased failure rate:

- Hospitals 1-15: $e^{\mu} = 1$
- Hospitals 16-30: $e^{\mu} = 2$

which means that the hazard rate at hospitals 16-30 is twice higher than exponential(λ).
The arrival rate ψ of patients at a hospital differs. The arrival rates are:

- Hospitals 1-5 & 16-20: 0.5 patients per day
- Hospitals 6-10 & 21-25: 1 patient per day
- Hospitals 11-15 & 26-30: 1.5 patients per day

These are then respectively small, medium and large hospitals.

Usage

```
surgerydat
```

Format

A `data.frame` with 12010 rows and 9 variables:

entrytime numeric Time of entry of patient into study

survtime numeric Time from entry until failure of patient

censorid integer Censoring indicator (0 - right censored, 1 - observed)

Hosp_num integer Hospital number at which patient received treatment

expmu numeric True excess hazard used for generating patient survival

psival numeric Poisson arrival rate at hospital which the patient was at

age numeric Age of the patient

sex factor Sex of the patient

BMI numeric Body mass index of the patient

Index