

Package ‘vlad’

August 24, 2020

Type Package

Title Variable Life Adjusted Display and Other Risk-Adjusted Quality Control Charts

Version 0.2.1

Depends R (>= 2.10)

Maintainer Philipp Wittenberg <pwitten@hsu-hh.de>

URL <https://github.com/wittenberg/vlad>

BugReports <https://github.com/wittenberg/vlad/issues>

Description Contains functions to set up risk-adjusted quality control charts in health care. For the variable life adjusted display (VLAD) proposed by Lovegrove et al. (1997) <doi:10.1016/S0140-6736(97)06507-0> signaling rules derived in Wittenberg et al. (2018) <doi:10.1002/sim.7647> are implemented. Additionally, for the risk-adjusted cumulative sum chart based on log-likelihood ratio statistic introduced by Steiner et al. (2000) <doi:10.1093/biostatistics/1.4.441> average run length and control limits can be computed with fast and accurate Markov chain approximations developed in Knoth et al. (2019) <doi:10.1002/sim.8104>.

License GPL (>= 2)

NeedsCompilation yes

SystemRequirements C++11

Encoding UTF-8

LazyData true

Imports Rcpp (>= 0.12.12), checkmate, magrittr, dplyr, tidyr

Suggests ggplot2, rmarkdown, spcadjust (>= 1.1), testthat, knitr

LinkingTo BH, Rcpp, RcppArmadillo

RoxygenNote 7.1.1

Author Philipp Wittenberg [aut, cre] (<<https://orcid.org/0000-0001-7151-8243>>),
Sven Knoth [aut, ths] (<<https://orcid.org/0000-0002-9666-5554>>)

Repository CRAN

Date/Publication 2020-08-24 16:00:03 UTC

R topics documented:

vlad-package	2
bcusum_arl_sim	3
bcusum_crit_sim	3
ell	5
eocusum_ad_sim	6
eocusum_arl_sim	7
eocusum_crit_sim	10
eocusum_scores	12
llr_score	14
optimal_k	15
QQ	17
racusum_ad_sim	18
racusum_arl_mc	19
racusum_arl_sim	21
racusum_betabinomial_arl_sim	23
racusum_betabinomial_crit_sim	24
racusum_beta_arl_int	26
racusum_beta_arl_mc	27
racusum_beta_arl_sim	28
racusum_beta_crit_mc	29
racusum_beta_crit_sim	30
racusum_crit_mc	32
racusum_crit_sim	34
racusum_discretebeta_arl_sim	36
racusum_discretebeta_crit_sim	37
racusum_scores	39
search_delta	41
trafo	42
Index	44

vlad-package	<i>Variable Life Adjusted Display and Other Risk-Adjusted Quality Control Charts</i>
--------------	--

Description

Contains functions to set up risk-adjusted quality control charts in health care. For the variable life adjusted display (VLAD) proposed by Lovegrove et al. (1997) <doi:10.1016/S0140-6736(97)06507-0> signaling rules derived in Wittenberg et al. (2018) <doi:10.1002/sim.7647> are implemented. Additionally, for the risk-adjusted cumulative sum chart based on log-likelihood ratio statistic introduced by Steiner et al. (2000) <doi:10.1093/biostatistics/1.4.441> average run length and control limits can be computed with fast and accurate Markov chain approximations developed in Knoth et al. (2019) <doi:10.1002/sim.8104>.

bcusum_arl_sim	<i>Compute ARLs of the Bernoulli CUSUM control charts using simulation</i>
----------------	--

Description

Compute ARLs of the Bernoulli CUSUM control charts using simulation.

Usage

```
bcusum_arl_sim(r, h, df, R0 = 1, RA = 2)
```

Arguments

r	Integer Vector. Number of runs.
h	Double. Control Chart limit for detecting deterioration/improvement.
df	Data Frame. First column are Parsonnet Score values within a range of 0 to 100 representing the preoperative patient risk. The second column are binary (0/1) outcome values of each operation.
R0	Double. Odds ratio of death under the null hypotheses.
RA	Double. Odds ratio of death under the alternative hypotheses.

Value

Returns a single value which is the Run Length.

Author(s)

Philipp Wittenberg

bcusum_crit_sim	<i>Compute alarm threshold of Bernoulli CUSUM control charts using simulation</i>
-----------------	---

Description

Compute alarm threshold of Bernoulli cumulative sum control charts using simulation.

Usage

```
bcusum_crit_sim(
  L0,
  df,
  R0 = 1,
  RA = 2,
  m = 100,
  nc = 1,
  jmax = 4,
  verbose = FALSE
)
```

Arguments

L0	Double. Prespecified in-control Average Run Length.
df	Data Frame. First column are Parsonnet Score values within a range of 0 to 100 representing the preoperative patient risk. The second column are binary (0/1) outcome values of each operation.
R0	Double. Odds ratio of death under the null hypotheses.
RA	Double. Odds ratio of death under the alternative hypotheses. Detecting deterioration in performance with increased mortality risk by doubling the odds Ratio RA = 2. Detecting improvement in performance with decreased mortality risk by halving the odds ratio of death RA = 1/2.
m	Integer. Number of simulation runs.
nc	Integer. Number of cores.
jmax	Integer. Number of digits for grid search.
verbose	Logical. If TRUE verbose output is included, if FALSE a quiet calculation of h is done.

Details

The function `bcusum_crit_sim` determines the control limit for given in-control ARL (L_0) by applying a multi-stage search procedure which includes secant rule and the parallel version of `bcusum_arl_sim` using `mclapply`.

Value

Returns a single value which is the control limit h for a given in-control ARL.

Author(s)

Philipp Wittenberg

ell	<i>Estimated log-likelihood.</i>
-----	----------------------------------

Description

Estimated log-likelihood.

Usage

```
ell(s, y, delta)
```

Arguments

s	Integer vector. Parsonnet Score values within a range of 0 to 100 representing the preoperative patient risk.
y	Double. Binary (0/1) outcome values of each operation.
delta	Double. Box-Cox transformation parameter.

Value

Returns a single value which is estimated log-likelihood.

Author(s)

Philipp Wittenberg

Examples

```
## Not run:
## load data
data("cardiacsurgery", package = "spcadjust")

## preprocess data to 30 day mortality and subset data to
## phase I (In-control) and phase II (monitoring)
SALL <- cardiacsurgery %>% rename(s = Parsonnet) %>%
  mutate(y = ifelse(status == 1 & time <= 30, 1, 0),
         phase = factor(ifelse(date < 2*365, "I", "II")))

## subset phase I (In-control)
SI <- filter(SALL, phase == "I") %>% select(s, y)

dML <- search_delta(SI$s, SI$y, type = "ML")
ell(SI$s, SI$y, dML)

## End(Not run)
```

eocusum_ad_sim	<i>Compute steady-state ARLs of EO-CUSUM control charts using simulation</i>
----------------	--

Description

Compute steady-state ARLs of EO-CUSUM control charts using simulation.

Usage

```
eocusum_ad_sim(r, pmix, k, h, RQ = 1, side = "low", type = "cond", m = 50)
```

Arguments

r	Integer. Number of simulation runs.
pmix	Data Frame. A three column data frame. First column is the operation outcome. Second column are the predicted probabilities from the risk model. Third column can be either the predicted probabilities from the risk model or average outcome.
k	Double. Reference value of the CUSUM control chart. Either 0 or a positive value. Can be determined with function optimal_k .
h	Double. Decision interval (alarm limit, threshold) of the CUSUM control chart.
RQ	Double. Defines the true performance of a surgeon with the odds ratio ratio of death RQ. Use RQ = 1 to compute the in-control ARL and other values to compute the out-of-control ARL.
side	Character. Default is "low" to calculate ARL for the upper arm of the V-mask. If side = "up", calculate the lower arm of the V-mask.
type	Character. Default argument is "cond" for computation of conditional steady-state. Other option is the cyclical steady-state "cycl".
m	Integer. Simulated in-control observations.

Value

Returns a single value which is the Run Length.

Author(s)

Philipp Wittenberg

References

Wittenberg P, Gan FF, Knoth S (2018). A simple signaling rule for variable life-adjusted display derived from an equivalent risk-adjusted CUSUM chart. *Statistics in Medicine*, **37**(16), pp 2455–2473.

Taylor HM (1968). The Economic Design of Cumulative Sum Control Charts. *Technometrics*, **10**(3), pp. 479–488.

Crosier R (1986). A new two-sided cumulative quality control scheme. *Technometrics*, **28**(3), pp. 187–194.

Examples

```
## Not run:
data("cardiacsurgery", package = "spcadjust")
library("dplyr")

## preprocess data to 30 day mortality and subset phase I/II
cardiacsurgery <- cardiacsurgery %>% rename(s = Parsonnet) %>%
  mutate(y = ifelse(status == 1 & time <= 30, 1, 0),
         phase = factor(ifelse(date < 2*365, "I", "II")))

s5000 <- sample_n(cardiacsurgery, size = 5000, replace = TRUE)
df1 <- select(cardiacsurgery, s, y)
df2 <- select(s5000, s, y)

## estimate coefficients from logit model
coeff1 <- round(coef(glm(y ~ s, data = df1, family = "binomial")), 3)
coeff2 <- round(coef(glm(y ~ s, data = df2, family = "binomial")), 3)

## Number of simulation runs
m <- 10^3
## Number of cores
nc <- parallel::detectCores()
# steady state
RNGkind("L'Ecuyer-CMRG")
m <- 10^3
tau <- 50
kopt <- optimal_k(QA = 2, df = S2I, coeff = coeff1, yemp = FALSE)
# eocusum_arloc_h_sim(L0 = 370, df = df1, k = kopt, m = m, side = "low", coeff = coeff1,
  coeff2 = coeff2, nc = nc)
res <- sapply(0:(tau-1), function(i){
  RLS <- do.call(c, parallel::mclapply( 1:m, eocusum_ad_sim, k = kopt, QS = 2, h = 2.637854,
    df = df1, m = i, coeff = coeff1, coeff2 = coeff2, side = "low", mc.cores = nc))
  list(data.frame(cbind(ARL = mean(RLS), ARLSE = sd(RLS)/sqrt(m))))
} )
RES <- data.frame(cbind(M = 0:(tau-1), do.call(rbind, res)))
ggplot2::qplot(x = M, y = ARL, data = RES, geom = c("line", "point")) +
  ggplot2::theme_classic()

## End(Not run)
```

Description

Compute ARLs of EO-CUSUM control charts using simulation.

Usage

```
eocusum_arl_sim(r, pmix, k, h, RQ = 1, yemp = FALSE, side = "low")
```

Arguments

r	Integer. Number of simulation runs.
pmix	Data Frame. A three column data frame. First column is the operation outcome. Second column are the predicted probabilities from the risk model. Third column can be either the predicted probabilities from the risk model or average outcome.
k	Double. Reference value of the CUSUM control chart. Either 0 or a positive value. Can be determined with function optimal_k .
h	Double. Decision interval (alarm limit, threshold) of the CUSUM control chart.
RQ	Double. Defines the true performance of a surgeon with the odds ratio ratio of death RQ. Use RQ = 1 to compute the in-control ARL and other values to compute the out-of-control ARL.
yemp	Logical. If TRUE use observed outcome value, if FALSE use estimated binary logistic regression model.
side	Character. Default is "low" to calculate ARL for the upper arm of the V-mask. If side = "up", calculate the lower arm of the V-mask.

Value

Returns a single value which is the Run Length.

Author(s)

Philipp Wittenberg

References

Wittenberg P, Gan FF, Knoth S (2018). A simple signaling rule for variable life-adjusted display derived from an equivalent risk-adjusted CUSUM chart. *Statistics in Medicine*, **37**(16), pp 2455–2473.

Examples

```
## Not run:
library("dplyr")
library("tidyr")
library(ggplot2)

## Datasets
data("cardiacsurgery", package = "spcadjust")
cardiacsurgery <- cardiacsurgery %>% rename(s = Parsonnet) %>%
  mutate(y = ifelse(status == 1 & time <= 30, 1, 0))
s5000 <- sample_n(cardiacsurgery, size = 5000, replace = TRUE)
df1 <- select(cardiacsurgery, s, y)
```



```

df2 <- select(s5000, s, y)

## estimate coefficients from logit model
coeff1 <- round(coef(glm(y ~ s, data = df1, family = "binomial")), 3)
coeff2 <- round(coef(glm(y ~ s, data = df2, family = "binomial")), 3)

## set up
RNGkind("L'Ecuyer-CMRG")
m <- 10^3
kopt <- optimal_k(QA = 2, df = S2I, coeff = coeff1, yemp = FALSE)
h <- eocusum_arloc_h_sim(L0 = 370, df = df1, k = kopt, m = m, side = "low", coeff = coeff1,
                        coeff2 = coeff2, nc = 4)

## Serial simulation
RLS <- do.call(c, lapply(1:m, eocusum_arloc_sim, h = h, k = kopt, df = df1, side = "low",
                        coeff = coeff1, coeff2 = coeff2))
data.frame(cbind(ARL = mean(RLS), ARLSE = sd(RLS)/sqrt(m)))

## Parallel simulation (FORK)
RLS <- simplify2array(parallel::mclapply(1:m, eocusum_arloc_sim, h = h, k = kopt, df = df1,
                                        side = "low", coeff = coeff1, coeff2 = coeff2,
                                        mc.cores = parallel::detectCores()))
data.frame(cbind(ARL = mean(RLS), ARLSE = sd(RLS)/sqrt(m)))

## Parallel simulation (PSOCK)
no_cores <- parallel::detectCores()
cl <- parallel::makeCluster(no_cores)
side <- "low"
h_vec <- h
QS_vec <- 1
k <- kopt
parallel::clusterExport(cl, c("h_vec", "eocusum_arloc_sim", "df1", "coeff1", "coeff2",
                             "QS_vec", "side", "k"))

time <- system.time( {
  RLS <- array(NA, dim = c( length(QS_vec), length(h_vec), m))
  for (h in h_vec) {
    for (QS in QS_vec) {
      cat(h, " ", QS, "\n")
      RLS[which(QS_vec==QS), which(h==h_vec), ] <- parallel::parSapply(cl, 1:m, eocusum_arloc_sim,
                              side = side, QS = QS, h = h,
                              k = k, df = df1,
                              coeff = coeff1,
                              coeff2 = coeff2,
                              USE.NAMES = FALSE)
    }
  }
} )
ARL <- apply(RLS, c(1, 2), mean)
ARLSE <- sqrt(apply(RLS, c(1, 2), var)/m)
print(list(ARL, ARLSE, time))
parallel::stopCluster(cl)

## End(Not run)

```

eocusum_crit_sim	<i>Compute alarm threshold of EO-CUSUM control charts using simulation</i>
------------------	--

Description

Compute alarm threshold of EO-CUSUM control charts using simulation.

Usage

```
eocusum_crit_sim(
  L0,
  pmix,
  k,
  RQ = 1,
  side = "low",
  yemp = FALSE,
  m = 10000,
  nc = 1,
  hmax = 30,
  jmax = 4,
  verbose = FALSE
)
```

Arguments

L0	Double. Prespecified in-control Average Run Length.
pmix	Data Frame. A three column data frame. First column is the operation outcome. Second column are the predicted probabilities from the risk model. Third column can be either the predicted probabilities from the risk model or average outcome.
k	Double. Reference value of the CUSUM control chart. Either 0 or a positive value. Can be determined with function optimal_k .
RQ	Double. Defines the true performance of a surgeon with the odds ratio ratio of death RQ. Use RQ = 1 to compute the in-control ARL and other values to compute the out-of-control ARL.
side	Character. Default is "low" to calculate ARL for the upper arm of the V-mask. If side = "up", calculate the lower arm of the V-mask.
yemp	Logical. If TRUE use observed outcome value, if FALSE use estimated binary logistic regression model.
m	Integer. Number of simulation runs.
nc	Integer. Number of cores used for parallel processing. Value is passed to parSapply .
hmax	Integer. Maximum value of h for the grid search.

jmax	Integer. Number of digits for grid search.
verbose	Logical. If TRUE verbose output is included, if FALSE a quiet calculation of h is done.

Details

Determines the control limit ("h") for given in-control ARL ("L0") applying a grid search using [eocusum_arl_sim](#) and [parSapply](#).

Value

Returns a single value which is the control limit h for a given in-control ARL.

Author(s)

Philipp Wittenberg

References

Barnard GA (1959). Control charts and stochastic processes. *J R Stat Soc Series B Stat Methodol*, **21**(2), pp. 239–271.

Kemp KW (1961). The Average Run Length of the Cumulative Sum Chart when a V-mask is used. *J R Stat Soc Series B Stat Methodol*, **23**(1), pp. 149–153.

Wittenberg P, Gan FF, Knoth S (2018). A simple signaling rule for variable life-adjusted display derived from an equivalent risk-adjusted CUSUM chart. *Statistics in Medicine*, **37**(16), pp 2455–2473.

Examples

```
## Not run:
library(vlad)
library(dplyr)
data("cardiacsurgery", package = "spcadjust")

## preprocess data to 30 day mortality
SALL <- cardiacsurgery %>% rename(s = Parsonnet) %>%
  mutate(y = ifelse(status == 1 & time <= 30, 1, 0),
         phase = factor(ifelse(date < 2*365, "I", "II")))
SI <- subset(SALL, phase == "I")
y <- subset(SALL, select = y)
GLM <- glm(y ~ s, data = SI, family = "binomial")
pi1 <- predict(GLM, type = "response", newdata = data.frame(s = SALL$s))
pmix <- data.frame(y, pi1, pi1)

## (Deterioration)
kopt <- optimal_k(pmix = pmix, RA = 2)
h <- eocusum_crit_sim(L0=370, pmix=pmix, k=kopt, side = "low", verbose=TRUE, nc=4)

## parameters to set up a tabular CUSUM or V-Mask (upper arm)
d <- h/kopt
```

```

theta <- atan(kopt)*180/pi
cbind(kopt, h, theta, d)

## (Improvement)
kopt <- optimal_k(pmix = pmix, RA = 1/2)
h <- eocusum_crit_sim(L0=370, pmix=pmix, k=kopt, side = "up", verbose=TRUE, nc=4)

## parameters to set up a tabular CUSUM or V-Mask (lower arm)
d <- h/kopt
theta <- atan(kopt)*180/pi
cbind(kopt, h, theta, d)

## End(Not run)

```

eocusum_scores	<i>Compute CUSUM scores based on E-O</i>
----------------	--

Description

Compute CUSUM scores based on E-O.

Usage

```
eocusum_scores(z, k1, k2, reset = FALSE, h1 = NULL, h2 = NULL)
```

Arguments

z	NumericVector. E-0 values.
k1	Double. Reference value k for detecting improvement can be determined from function optimal_k .
k2	Double. Reference value k for detecting deterioration can be determined from function optimal_k .
reset	Logical. If FALSE CUSUM statistic is not reset. If TRUE CUSUM statistic is reset to 0 after a signal is issued.
h1	Double. Upper control limit of the CUSUM chart.
h2	Double. Lower control limit of the CUSUM chart.

Value

Returns a list with two components for the CUSUM scores.

Author(s)

Philipp Wittenberg

References

Wittenberg P, Gan FF, Knoth S (2018). A simple signaling rule for variable life-adjusted display derived from an equivalent risk-adjusted CUSUM chart. *Statistics in Medicine*, **37**(16), pp 2455–2473.

Examples

```
## Not run:
library("dplyr")
library("tidyr")
library("ggplot2")
data("cardiacsurgery", package = "spcadjust")

## preprocess data to 30 day mortality and subset phase I (In-control) of surgeons 2
SALL <- cardiacsurgery %>% rename(s = Parsonnet) %>%
  mutate(y = ifelse(status == 1 & time <= 30, 1, 0),
         phase = factor(ifelse(date < 2*365, "I", "II")))

## subset phase I (In-control)
SI <- subset(SALL, phase == "I")

## estimate coefficients from logit model
GLM <- glm(y ~ s, data = SI, family = "binomial")

## set up patient mix
pi1 <- predict(GLM, type = "response", newdata = data.frame(s = SI$s))
pmix <- data.frame(SI$y, pi1, pi1)

## determine k for detecting improvement
k1opt <- optimal_k(pmix=pmix, RA = 1/2)

## determine k for detecting deterioration
k2opt <- optimal_k(pmix=pmix, RA = 2)

## subset phase II of surgeons 2
S2II <- filter(SALL, phase == "II", surgeon == 2) %>% select(s, y)
n <- nrow(S2II)
z <- predict(GLM, type = "response", newdata = data.frame(s = S2II$s))-S2II$y

## CUSUM statistic without reset
cv <- eocusum_scores(z = z, k1 = k1opt, k2 = k2opt)
s1 <- cv$s1; s1l <- cv$s1l
dm1 <- data.frame(cbind("n" = 1:length(s1), "Cup" = s1, "Clow" = s1l, "h1" = 2, "h2" = -2))

## CUSUM statistic reset after signal
cv <- eocusum_scores(z = z, k1 = k1opt, k2 = k2opt, reset = TRUE, h1 = 2, h2 = 2)
s1 <- cv$s1; s1l <- cv$s1l
dm2 <- data.frame(cbind("n" = 1:length(s1), "Cup" = s1, "Clow" = s1l, "h1" = 2, "h2" = -2))

dm3 <- bind_rows(dm1, dm2, .id = "type")
dm3$type <- recode_factor(dm3$type, `1`="No resetting", `2`="Resetting")
dm3 %>%
```

```
gather("CUSUM", value, c(-n, - type)) %>%
ggplot(aes(x = n, y = value, colour = CUSUM, group = CUSUM)) +
geom_hline(yintercept = 0, colour = "darkgreen", linetype = "dashed") +
geom_line(size = 0.5) +
facet_wrap(~ type, ncol = 1, scales = "free") +
labs(x = "Patient number n", y = "CUSUM values") + theme_classic() +
scale_y_continuous(sec.axis = dup_axis(name = NULL, labels = NULL)) +
scale_x_continuous(sec.axis = dup_axis(name = NULL, labels = NULL)) +
guides(colour = "none") +
scale_color_manual(values = c("blue", "orange", "red", "red"))

## End(Not run)
```

llr_score

Compute the log-likelihood ratio score

Description

Compute the log-likelihood ratio score.

Usage

```
llr_score(df, coeff, R0 = 1, RA = 2, yemp = TRUE)
```

Arguments

df	Data Frame. First column are Parsonnet Score values within a range of 0 to 100 representing the preoperative patient risk. The second column are binary (0/1) outcome values of each operation.
coeff	Numeric Vector. Estimated coefficients α and β from the binary logistic regression model.
R0	Double. Odds ratio of death under the null hypotheses.
RA	Double. Odds ratio of death under the alternative hypotheses. Detecting deterioration in performance with increased mortality risk by doubling the odds Ratio RA = 2. Detecting improvement in performance with decreased mortality risk by halving the odds ratio of death RA = 1/2.
yemp	Logical. If TRUE use observed outcome value, if FALSE use estimated binary logistic regression model.

Value

Returns a single value which is the log-likelihood ratio score.

Author(s)

Philipp Wittenberg

References

- Steiner SH, Cook RJ, Farewell VT and Treasure T (2000). Monitoring surgical performance using risk-adjusted cumulative sum charts. *Biostatistics*, **1**(4), pp. 441–452.
- Steiner S (2014). Risk-Adjusted Monitoring of Outcomes in Health Care. In Lawless JF (ed.), *Statistics in Action*, pp. 225–242. Informa UK Limited.
- Rigdon SE and Fricker RD (2015). Health Surveillance. In Chen DG and Wilson J (eds) *Innovative Statistical Methods for Public Health Data*, pp. 203–249. Springer, Cham.

Examples

```
## Not run:
library(vlad)
## see Steiner et al. (2000) p. 446 or Steiner (2014) p. 234
coeff <- c("(Intercept)" = -3.68, "Parsonnet" = 0.077)
## Log-likelihood ratio scores for detecting an increase in the failure rate:
## low risk patients with a Parsonnet score of zero

llr_score(df = data.frame(as.integer(0), 0), coeff = coeff, RA = 2)
llr_score(df = data.frame(as.integer(0), 1), coeff = coeff, RA = 2)

## higher risk patients with a Parsonnet score of 50
llr_score(df = data.frame(as.integer(50), 0), coeff = coeff, RA = 2)
llr_score(df = data.frame(as.integer(50), 1), coeff = coeff, RA = 2)

## see Steiner (2014) p. 234
## Log-likelihood ratio scores for detecting an decrease in the failure rate:
## low risk patients with a Parsonnet score of zero
llr_score(df = data.frame(as.integer(0), 0), coeff = coeff, RA = 1/2)
llr_score(df = data.frame(as.integer(0), 1), coeff = coeff, RA = 1/2)

## higher risk patients with a Parsonnet score of 50
llr_score(df = data.frame(as.integer(50), 0), coeff = coeff, RA = 1/2)
llr_score(df = data.frame(as.integer(50), 1), coeff = coeff, RA = 1/2)

## see Rigdon and Fricker p. 225 and 226
## detecting an increase in the failure rate:
coeff <- c("(Intercept)" = -3.67, "Parsonnet" = 0.077)
df <- data.frame(Parsonnet = c(19L, 19L, 0L, 0L), status = c(0, 1, 0, 1))
lapply(seq_along(df$Parsonnet), function(i) round(llr_score(df = df[i, ], coeff = coeff,
  RA = 2), 4))

## detecting an decrease in the failure rate:
round(llr_score(df = data.frame(19L, 0), coeff = coeff, RA = 1/2), 5)

## End(Not run)
```

Description

Compute approximate optimal k.

Usage

```
optimal_k(pmix, RA, yemp = FALSE)
```

Arguments

pmix	Data Frame. A three column data frame. First column is the operation outcome. Second column are the predicted probabilities from the risk model. Third column can be either the predicted probabilities from the risk model or average outcome.
RA	Double. Odds ratio of death under the alternative hypotheses. Detecting deterioration in performance with increased mortality risk by doubling the odds Ratio $RA = 2$. Detecting improvement in performance with decreased mortality risk by halving the odds ratio of death $RA = 1/2$. Odds ratio of death under the null hypotheses is 1.
yemp	Logical. If TRUE, use emirical outcome values, else use model.

Details

Formula deterioration:

$$k_{det} = \frac{RA - 1 - \log(RA)}{\log(RA)} \bar{p}, RA > 1$$

Formula improvement:

$$k_{imp} = \frac{1 - RA + \log(RA)}{\log(RA)} \bar{p}, RA < 1$$

Value

Returns a single value which is the approximate optimal k.

Author(s)

Philipp Wittenberg

References

Wittenberg P, Gan FF, Knoth S (2018). A simple signaling rule for variable life-adjusted display derived from an equivalent risk-adjusted CUSUM chart. *Statistics in Medicine*, **37**(16), pp 2455–2473.

Examples

```

## Not run:
library(vlad)
library(dplyr)
data("cardiacsurgery", package = "spcadjust")

## preprocess data to 30 day mortality
SALL <- cardiacsurgery %>% rename(s = Parsonnet) %>%
  mutate(y = ifelse(status == 1 & time <= 30, 1, 0),
         phase = factor(ifelse(date < 2*365, "I", "II")))
SI <- subset(SALL, phase == "I")
GLM <- glm(y ~ s, data = SI, family = "binomial")
pi1 <- predict(GLM, type = "response", newdata = data.frame(s = SI$s))
pmix <- data.frame(SI$y, pi1, pi1)

## (Deterioration)
optimal_k(pmix = pmix, RA = 2)

## manually find optimal k for detecting deterioration
RA <- 2
pbar <- mean(pmix$pi1)
kopt <- pbar * ( RA - 1 - log(RA) ) / log(RA)

all.equal(kopt, optimal_k(pmix = pmix, RA = 2))

## (Improvement)
optimal_k(pmix = pmix, RA = 1/2)

## manually find optimal k for detecting improvement
RA <- 1/2
pbar <- mean(pmix$pi1)
kopt <- pbar * ( 1 - RA + log(RA) ) / log(RA)

all.equal(kopt, optimal_k(pmix = pmix, RA = 1/2))

## End(Not run)

```

 QQ

Pearson measure

Description

Pearson measure.

Usage

QQ(s, y, delta)

Arguments

s	Integer vector. Parsonnet Score values within a range of 0 to 100 representing the preoperative patient risk.
y	Numeric Vector. Binary (0/1) outcome values of each operation.
delta	Double. Box-Cox transformation parameter.

Value

Returns a single value.

Author(s)

Philipp Wittenberg

Examples

```
## Not run:
## load data
data("cardiacsurgery", package = "spcadjust")

## preprocess data to 30 day mortality and subset data to
## phase I (In-control) and phase II (monitoring)
SALL <- cardiacsurgery %>% rename(s = Parsonnet) %>%
  mutate(y = ifelse(status == 1 & time <= 30, 1, 0),
         phase = factor(ifelse(date < 2*365, "I", "II")))

## subset phase I (In-control)
SI <- filter(SALL, phase == "I") %>% select(s, y)

dQQ <- search_delta(SI$s, SI$y, type = "Pearson")
QQ(SI$s, SI$y, dQQ)

## End(Not run)
```

racusum_ad_sim	<i>Compute steady-state ARLs of RA-CUSUM control charts using simulation</i>
----------------	--

Description

Compute steady-state ARLs of risk-adjusted cumulative sum control charts using simulation.

Usage

```
racusum_ad_sim(r, pmix, h, RA = 2, RQ = 1, m = 50, type = "cond")
```

Arguments

r	Integer Vector. Number of runs.
pmix	Data Frame. A three column data frame. First column is the operation outcome. Second column are the predicted probabilities from the risk model. Third column can be either the predicted probabilities from the risk model or average outcome.
h	Double. Control Chart limit for detecting deterioration/improvement.
RA	Double. Odds ratio of death under the alternative hypotheses. Detecting deterioration in performance with increased mortality risk by doubling the odds Ratio $RA = 2$. Detecting improvement in performance with decreased mortality risk by halving the odds ratio of death $RA = 1/2$. Odds ratio of death under the null hypotheses is 1.
RQ	Double. Defines the true performance of a surgeon with the odds ratio ratio of death RQ. Use $RQ = 1$ to compute the in-control ARL and other values to compute the out-of-control ARL.
m	Integer. Simulated in-control observations.
type	Character. Default argument is "cond" for computation of conditional steady-state. Other option is the cyclical steady-state "cycl".

Value

Returns a single value which is the Run Length.

Author(s)

Philipp Wittenberg

racusum_arl_mc	<i>Compute ARLs of RA-CUSUM control charts using Markov chain approximation</i>
----------------	---

Description

Computes the Average Run Length of a risk-adjusted cumulative sum control chart using Markov chain approximation.

Usage

```
racusum_arl_mc(pmix, RA, RQ, h, scaling = 600, rounding = "p", method = "Toep")
```

Arguments

pmix	Numeric Matrix. A three column matrix. First column is the risk score distribution. Second column are the predicted probabilities from the risk model. Third column can be either the predicted probabilities from the risk model or average outcome per risk score, see examples.
RA	Double. Odds ratio of death under the alternative hypotheses. Detecting deterioration in performance with increased mortality risk by doubling the odds Ratio $RA = 2$. Detecting improvement in performance with decreased mortality risk by halving the odds ratio of death $RA = 1/2$. Odds ratio of death under the null hypotheses is 1.
RQ	Double. Defines the true performance of a surgeon with the odds ratio ratio of death RQ. Use $RQ = 1$ to compute the in-control ARL and other values to compute the out-of-control ARL.
h	Double. h is the control limit (>0).
scaling	Double. The scaling parameter controls the quality of the approximation, larger values achieve higher accuracy but increase the computation burden (larger transition probability matrix).
rounding	Character. If rounding = "p" a paired rounding implementation of <i>Knoth et al. (2019)</i> is used, if rounding = "s" a simple rounding method of <i>Steiner et al. (2000)</i> is used.
method	Character. If method = "Toep" a combination of Sequential Probability Ratio Test and Toeplitz matrix structure is used to calculate the ARL. "ToepInv" computes the inverted matrix using Toeplitz matrix structure. "BE" solves a linear equation system using the classical approach of <i>Brook and Evans (1972)</i> to calculate the ARL.

Value

Returns a single value which is the Average Run Length.

Author(s)

Philipp Wittenberg

References

- Knoth S, Wittenberg P and Gan FF (2019). Risk-adjusted CUSUM charts under model error. *Statistics in Medicine*, **38**(12), pp. 2206–2218.
- Steiner SH, Cook RJ, Farewell VT and Treasure T (2000). Monitoring surgical performance using risk-adjusted cumulative sum charts. *Biostatistics*, **1**(4), pp. 441–452.
- Brook D and Evans DA (1972) An approach to the probability distribution of CUSUM run length. *Biometrika*, **59**(3), pp. 539–549
- Webster RA and Pettitt AN (2007) Stability of approximations of average run length of risk-adjusted CUSUM schemes using the Markov approach: comparing two methods of calculating transition probabilities. *Communications in Statistics - Simulation and Computation* **36**(3), pp. 471–482

Examples

```

## Not run:
library(vlad)
library(dplyr)
data("cardiacsurgery", package = "spcadjust")

## preprocess data to 30 day mortality and subset phase I (In-control) of surgeons 2
SALLI <- cardiacsurgery %>% rename(s = Parsonnet) %>%
  mutate(y = ifelse(status == 1 & time <= 30, 1, 0),
         phase = factor(ifelse(date < 2*365, "I", "II"))) %>%
  filter(phase == "I") %>% select(s, y)

## estimate risk model, get relative frequencies and probabilities
mod1 <- glm(y ~ s, data = SALLI, family = "binomial")
fi <- as.numeric(table(SALLI$s) / length(SALLI$s))
usi <- sort(unique(SALLI$s))
pi1 <- predict(mod1, newdata = data.frame(s = usi), type = "response")
pi2 <- tapply(SALLI$y, SALLI$s, mean)

## set up patient mix (risk model)
pmix1 <- data.frame(fi, pi1, pi2)

## Average Run Length for detecting deterioration RA = 2:
racusum_arl_mc(pmix = pmix1, RA = 2, RQ = 1, h = 4.5)

## Average Run Length for detecting improvement RA = 1/2:
racusum_arl_mc(pmix = pmix1, RA = 1/2, RQ = 1, h = 4)

## set up patient mix (model free)
pmix2 <- data.frame(fi, pi1, pi2)

## Average Run Length for detecting deterioration RA = 2:
racusum_arl_mc(pmix = pmix2, RA = 2, RQ = 1, h = 4.5)

## Average Run Length for detecting improvement RA = 1/2:
racusum_arl_mc(pmix = pmix2, RA = 1/2, RQ = 1, h = 4)

## compare results with R-code function 'findarl()' from Steiner et al. (2000)
source("https://bit.ly/2KC0SYD")
all.equal(findarl(pmix = pmix1, R1 = 2, R = 1, CL = 4.5, scaling = 600),
         racusum_arl_mc(pmix = pmix1, RA = 2, RQ = 1, h = 4.5, scaling = 600, rounding = "s"))

## End(Not run)

```

 racusum_arl_sim

Compute ARLs of RA-CUSUM control charts using simulation

Description

Computes the Average Run Length of a risk-adjusted cumulative sum control chart using simulation.

Usage

```
racusum_arl_sim(r, pmix, h, RA = 2, RQ = 1, yemp = FALSE)
```

Arguments

r	Integer Vector. Number of runs.
pmix	Data Frame. A three column data frame. First column is the operation outcome. Second column are the predicted probabilities from the risk model. Third column can be either the predicted probabilities from the risk model or average outcome.
h	Double. Control Chart limit for detecting deterioration/improvement.
RA	Double. Odds ratio of death under the alternative hypotheses. Detecting deterioration in performance with increased mortality risk by doubling the odds Ratio $RA = 2$. Detecting improvement in performance with decreased mortality risk by halving the odds ratio of death $RA = 1/2$. Odds ratio of death under the null hypotheses is 1.
RQ	Double. Defines the true performance of a surgeon with the odds ratio ratio of death RQ. Use $RQ = 1$ to compute the in-control ARL and other values to compute the out-of-control ARL.
yemp	Logical. If TRUE use observed outcome value, if FALSE use estimated binary logistic regression model.

Value

Returns a single value which is the Run Length.

Author(s)

Philipp Wittenberg

References

Steiner SH, Cook RJ, Farewell VT and Treasure T (2000). Monitoring surgical performance using risk-adjusted cumulative sum charts. *Biostatistics*, **1**(4), pp. 441–452.

Wittenberg P, Gan FF, Knoth S (2018). A simple signaling rule for variable life-adjusted display derived from an equivalent risk-adjusted CUSUM chart. *Statistics in Medicine*, **37**(16), pp 2455–2473.

Examples

```
## Not run:
library(vlad)
library(dplyr)
data("cardiacsurgery", package = "spcadjust")

set.seed(1234)
SALLI <- cardiacsurgery %>% mutate(s = Parsonnet) %>%
  mutate(y = ifelse(status == 1 & time <= 30, 1, 0),
```

```

        phase = factor(ifecycle(date < 2*365, "I", "II")) %>%
        filter(phase == "I") %>% select(s, y)

## estimate risk model, get relative frequencies and probabilities
mod1 <- glm(y ~ s, data = SALLI, family = "binomial")
y <- SALLI$y
pi1 <- fitted.values(mod1)

## set up patient mix (risk model)
pmix <- data.frame(y, pi1, pi1)
h <- 2.75599

m <- 1e4
RLS <- sapply(1:m, racusum_arl_sim, h=h, pmix=pmix, RA=2)
data.frame(cbind(ARL=mean(RLS), ARLSE=sd(RLS)/sqrt(m), h, m))

## End(Not run)

```

racusum_betabinomial_arl_sim

Compute ARLs of RA-CUSUM control charts using simulation

Description

Compute ARLs of RA-CUSUM control charts using simulation.

Usage

```

racusum_betabinomial_arl_sim(
  r,
  shape1,
  shape2,
  coeff,
  h,
  RA = 2,
  rs = 71,
  RQ = 1
)

```

Arguments

r	Integer Vector. Number of runs.
shape1	Double. Shape parameter $\alpha > 0$ of the beta-binomial distribution.
shape2	Double. Shape parameter $\beta > 0$ of the beta-binomial distribution.
coeff	Numeric Vector. Estimated intercept and slope coefficients from a binary logistic regression model.
h	Double. Control Chart limit for detecting deterioration/improvement.

RA	Double. Odds ratio of death under the alternative hypotheses. Detecting deterioration in performance with increased mortality risk by doubling the odds Ratio RA = 2. Detecting improvement in performance with decreased mortality risk by halving the odds ratio of death RA = 1/2.
rs	Integer. Maximum risk score.
RQ	Double. Defines the performance of a surgeon with the odds ratio ratio of death Q.

Value

Returns a single value which is the Run Length.

Author(s)

Philipp Wittenberg

Examples

```
## Not run:
library(vlad)
m <- 1e3
RLS <- sapply(1:m, racusum_betabinomial_arl_sim, shape1=1, shape2=3, coeff=c(-3.6798, 0.0768),
h=4.5, RA=2, rs=71, RQ=1)
data.frame(cbind(ARL=mean(RLS), ARLSE=sd(RLS)/sqrt(m)))

## End(Not run)
```

racusum_betabinomial_crit_sim

Compute alarm threshold of RA-CUSUM control charts using simulation

Description

Compute alarm threshold of risk-adjusted cumulative sum control charts using simulation.

Usage

```
racusum_betabinomial_crit_sim(
  L0,
  shape1,
  shape2,
  coeff,
  RA = 2,
  rs = 71,
  RQ = 1,
  m = 10000,
```



```

nc = 1,
hmax = 30,
jmax = 4,
verbose = FALSE
)

```

Arguments

<code>L0</code>	Double. Prespecified in-control Average Run Length.
<code>shape1</code>	Double. Shape parameter $\alpha > 0$ of the beta-binomial distribution.
<code>shape2</code>	Double. Shape parameter $\beta > 0$ of the beta-binomial distribution.
<code>coeff</code>	Numeric Vector. Estimated intercept and slope coefficients from a binary logistic regression model.
<code>RA</code>	Double. Odds ratio of death under the alternative hypotheses. Detecting deterioration in performance with increased mortality risk by doubling the odds Ratio $RA = 2$. Detecting improvement in performance with decreased mortality risk by halving the odds ratio of death $RA = 1/2$.
<code>rs</code>	Integer. Maximum risk score.
<code>RQ</code>	Double. Defines the performance of a surgeon with the odds ratio ratio of death Q .
<code>m</code>	Integer. Number of simulation runs.
<code>nc</code>	Integer. Number of cores used for parallel processing. Value is passed to parSapply .
<code>hmax</code>	Integer. Maximum value of h for the grid search.
<code>jmax</code>	Integer. Number of digits for grid search.
<code>verbose</code>	Logical. If TRUE verbose output is included, if FALSE a quiet calculation of h is done.

Details

Determines the control limit (" h ") for given in-control ARL (" L_0 ") applying a grid search using [racusum_betabinomial_arl_sim](#) and [parSapply](#).

Value

Returns a single value which is the control limit h for a given in-control ARL.

Author(s)

Philipp Wittenberg

Examples

```
## Not run:
library(vlad)
racusum_betabinomial_crit_sim(L0=100, shape1=1, shape2=3, coeff=c(-3.6798, 0.0768), RA = 2,
rs = 71, RQ = 1, verbose=TRUE)

## End(Not run)
```

racusum_beta_arl_int *Compute ARL of RA-CUSUM control charts assuming a beta distributed patient mix with using collocation methods.*

Description

Compute ARL of RA-CUSUM control charts assuming a beta distributed patient mix with using collocation methods.

Usage

```
racusum_beta_arl_int(h, N, RA, RQ, g0, g1, shape1, shape2, pw)
```

Arguments

h	Double. h is the control limit (>0).
N	Integer. Number of quadrature nodes, dimension of the resulting linear equation system is equal to N.
RA	Double. Odds ratio of death under the alternative hypotheses. Detecting deterioration in performance with increased mortality risk by doubling the odds Ratio $RA = 2$. Detecting improvement in performance with decreased mortality risk by halving the odds ratio of death $RA = 1/2$.
RQ	Double. Defines the performance of a surgeon with the odds ratio ratio of death.
g0	Double. Estimated intercept coefficient from a binary logistic regression model.
g1	Double. Estimated slope coefficient from a binary logistic regression model.
shape1	Double. Shape parameter $\alpha > 0$ of the beta distribution.
shape2	Double. Shape parameter $\beta > 0$ of the beta distribution.
pw	Logical. If FALSE full collocation is applied. If TRUE a piece-wise collocation method is used.

Value

Returns a single value which is the Run Length.

Author(s)

Philipp Wittenberg

Examples

```
## Not run:
library(vlad)
## full colocation
racusum_beta_arl_int(h=4.5, RA=2, RQ=1, shape1=1, shape2=6, g0=-3.6798, g1=0.0768*71, N=50,
  pw=FALSE)
## piece-wise colocation
racusum_beta_arl_int(h=4.5, RA=2, RQ=1, shape1=1, shape2=6, g0=-3.6798, g1=0.0768*71, N=49,
  pw=TRUE)

## End(Not run)
```

racusum_beta_arl_mc *Compute ARL of RA-CUSUM control charts assuming patient mix with beta distribution using Markov chain approximation.*

Description

Compute ARL of risk-adjusted-CUSUM control charts assuming patient mix with beta distribution using Markov chain approximation.

Usage

```
racusum_beta_arl_mc(h, RA, g0, g1, shape1, shape2, r = 600, method = 1, RQ = 1)
```

Arguments

h	Double. h is the control limit (>0).
RA	Double. Odds ratio of death under the alternative hypotheses. Detecting deterioration in performance with increased mortality risk by doubling the odds Ratio $RA = 2$. Detecting improvement in performance with decreased mortality risk by halving the odds ratio of death $RA = 1/2$. Odds ratio of death under the null hypotheses is 1.
g0	Double. Estimated intercept coefficient from a binary logistic regression model.
g1	Double. Estimated slope coefficient from a binary logistic regression model.
shape1	Double. Shape parameter $\alpha > 0$ of the beta distribution.
shape2	Double. Shape parameter $\beta > 0$ of the beta distribution.
r	Double. Matrix system dimension.
method	Character. If method = "1" a combination of Sequential Probability Ratio Test and Toeplitz matrix structure is used to calculate the ARL. "2" solves a linear equation system using the classical approach of <i>Brook and Evans (1972)</i> to calculate the ARL.
RQ	Double. Defines the performance of a surgeon with the odds ratio ratio of death.

Value

Returns a single value which is the Run Length.

Author(s)

Philipp Wittenberg

Examples

```
## Not run:
library(vlad)
racusum_beta_arl_mc(h=4.5, RA=2, g0=-3.6798, g1=0.0768*71, shape1=1, shape2=6, r=1e4, method=1)

## End(Not run)
```

racusum_beta_arl_sim *Compute ARLs of RA-CUSUM control charts using simulation*

Description

Compute ARLs of RA-CUSUM control charts using simulation.

Usage

```
racusum_beta_arl_sim(r, shape1, shape2, coeff, h, RA = 2, rs = 71, RQ = 1)
```

Arguments

r	Integer Vector. Number of runs.
shape1	Double. Shape parameter $\alpha > 0$ of the beta distribution.
shape2	Double. Shape parameter $\beta > 0$ of the beta distribution.
coeff	Numeric Vector. Estimated coefficients α and β from the binary logistic regression model.
h	Double. Control Chart limit for detecting deterioration/improvement.
RA	Double. Odds ratio of death under the alternative hypotheses. Detecting deterioration in performance with increased mortality risk by doubling the odds Ratio RA = 2. Detecting improvement in performance with decreased mortality risk by halving the odds ratio of death RA = 1/2.
rs	Integer. Maximum risk score.
RQ	Double. Defines the performance of a surgeon with the odds ratio ratio of death. Q.

Value

Returns a single value which is the Run Length.

Author(s)

Philipp Wittenberg

Examples

```
## Not run:
library(vlad)
m <- 1e3
RLS <- sapply(1:m, racusum_beta_arl_sim, h=4.5, shape1=1, shape2=3, coeff=c(-3.6798, 0.0768),
RA = 2, RQ = 1)
data.frame(cbind(ARL=mean(RLS), ARLSE=sd(RLS)/sqrt(m)))

## End(Not run)
```

racusum_beta_crit_mc *Compute alarm threshold of RA-CUSUM control chart assuming patient mix with beta distribution using Markov chain approximation.*

Description

Compute alarm threshold of risk-adjusted CUSUM control chart assuming patient mix with beta distribution using Markov chain approximation.

Usage

```
racusum_beta_crit_mc(
  L0,
  RA,
  g0,
  g1,
  shape1,
  shape2,
  method = 1,
  r = 600,
  jmax = 4,
  verbose = TRUE,
  RQ = 1
)
```

Arguments

L0	Double. Prespecified Average Run Length.
RA	Double. Odds ratio of death under the alternative hypotheses. Detecting deterioration in performance with increased mortality risk by doubling the odds Ratio RA = 2. Detecting improvement in performance with decreased mortality risk by halving the odds ratio of death RA = 1/2. Odds ratio of death under the null hypotheses is 1.

g0	Double. Estimated intercept coefficient from a binary logistic regression model.
g1	Double. Estimated slope coefficient from a binary logistic regression model.
shape1	Double. Shape parameter $\alpha > 0$ of the beta distribution.
shape2	Double. Shape parameter $\beta > 0$ of the beta distribution.
method	Character. If method = "1" a combination of Sequential Probability Ratio Test and Toeplitz matrix structure is used to calculate the ARL. "2" solves a linear equation system using the classical approach of <i>Brook and Evans (1972)</i> to calculate the ARL.
r	Double. Matrix system dimension.
jmax	Integer. Number of digits for grid search.
verbose	Logical. If FALSE a quiet calculation of h is done. If TRUE verbose output of the search procedure (see details) is included.
RQ	Double. Defines the performance of a surgeon with the odds ratio ratio of death.

Details

Determines the control limit for given in-control ARL (" L_0 ") using `racusum_beta_arl_mc` by applying a grid search.

Value

Returns a single value which is the control limit h for a given In-control ARL.

Author(s)

Philipp Wittenberg

Examples

```
## Not run:
library(vlad)
racusum_beta_crit_mc(L0=7500, RA=2, g0=-3.6798, g1=0.0768*71, shape1=.61, shape2=4.09, r=1000)

## End(Not run)
```

`racusum_beta_crit_sim` *Compute alarm threshold of RA-CUSUM control charts using simulation*

Description

Compute alarm threshold of risk-adjusted cumulative sum control charts using simulation.

Usage

```

racusum_beta_crit_sim(
  L0,
  shape1,
  shape2,
  coeff,
  rs = 71,
  RA = 2,
  RQ = 1,
  nc = 1,
  hmax = 30,
  jmax = 4,
  m = 10000,
  verbose = FALSE
)

```

Arguments

L0	Double. Prespecified in-control Average Run Length.
shape1	Double. Shape parameter $\alpha > 0$ of the beta distribution.
shape2	Double. Shape parameter $\beta > 0$ of the beta distribution.
coeff	Numeric Vector. Estimated coefficients α and β from the binary logistic regression model.
rs	Integer. Maximum risk score.
RA	Double. Odds ratio of death under the alternative hypotheses. Detecting deterioration in performance with increased mortality risk by doubling the odds Ratio $RA = 2$. Detecting improvement in performance with decreased mortality risk by halving the odds ratio of death $RA = 1/2$.
RQ	Double. Defines the performance of a surgeon with the odds ratio ratio of death. Q .
nc	Integer. Number of cores used for parallel processing. Value is passed to parSapply .
hmax	Integer. Maximum value of h for the grid search.
jmax	Integer. Number of digits for grid search.
m	Integer. Number of simulation runs.
verbose	Logical. If TRUE verbose output is included, if FALSE a quiet calculation of h is done.

Details

Determines the control limit ("h") for given in-control ARL (" L_0 ") applying a grid search using [racusum_beta_arl_sim](#) and [parSapply](#).

Value

Returns a single value which is the control limit h for a given in-control ARL.

Author(s)

Philipp Wittenberg

Examples

```
## Not run:
library(vlad)
racusum_beta_crit_sim(L0=500, shape1=1, shape2=3, coeff=c(-3.6798, 0.0768), RA = 2, rs = 71,
RQ = 1, verbose=TRUE, m=1e3)

## End(Not run)
```

racusum_crit_mc	<i>Compute alarm threshold of RA-CUSUM control chart using Markov chain approximation</i>
-----------------	---

Description

Computes alarm threshold of a risk-adjusted cumulative sum control chart using Markov chain approximation.

Usage

```
racusum_crit_mc(
  pmix,
  L0,
  RA,
  RQ,
  scaling = 600,
  rounding = "p",
  method = "Toep",
  jmax = 4,
  verbose = FALSE
)
```

Arguments

pmix	Numeric Matrix. A three column matrix. First column is the risk score distribution. Second column are the predicted probabilities from the risk model. Third column can be either the predicted probabilities from the risk model or average outcome per risk score, see examples.
L0	Double. Prespecified Average Run Length.
RA	Double. Odds ratio of death under the alternative hypotheses. Detecting deterioration in performance with increased mortality risk by doubling the odds Ratio $RA = 2$. Detecting improvement in performance with decreased mortality risk by halving the odds ratio of death $RA = 1/2$. Odds ratio of death under the null hypotheses is 1.

RQ	Double. Defines the true performance of a surgeon with the odds ratio ratio of death RQ. Use RQ = 1 to compute the in-control ARL and other values to compute the out-of-control ARL.
scaling	Double. The scaling parameter controls the quality of the approximation, larger values achieve higher accuracy but increase the computation burden (larger transition probability matrix).
rounding	Character. If rounding = "p" a paired rounding implementation of <i>Knuth et al. (2019)</i> is used, if rounding = "s" a simple rounding method of <i>Steiner et al. (2000)</i> is used.
method	Character. If method = "Toep" a combination of Sequential Probability Ratio Test and Toeplitz matrix structure is used to calculate the ARL. "ToepInv" computes the inverted matrix using Toeplitz matrix structure. "BE" solves a linear equation system using the classical approach of <i>Brook and Evans (1972)</i> to calculate the ARL.
jmax	Integer. Number of digits for grid search.
verbose	Logical. If FALSE a quiet calculation of h is done. If TRUE verbose output of the search procedure is included.

Details

Determines the control limit for given in-control ARL ("L0") using `racusum_ar1_mc` by applying a grid search.

Value

Returns a single value which is the control limit h for a given In-control ARL.

Author(s)

Philipp Wittenberg

References

- Knuth S, Wittenberg P and Gan FF (2019). Risk-adjusted CUSUM charts under model error. *Statistics in Medicine*, **38**(12), pp. 2206–2218.
- Steiner SH, Cook RJ, Farewell VT and Treasure T (2000). Monitoring surgical performance using risk-adjusted cumulative sum charts. *Biostatistics*, **1**(4), pp. 441–452.
- Brook D and Evans DA (1972) An approach to the probability distribution of CUSUM run length. *Biometrika*, **59**(3), pp. 539–549
- Webster RA and Pettitt AN (2007) Stability of approximations of average run length of risk-adjusted CUSUM schemes using the Markov approach: comparing two methods of calculating transition probabilities. *Communications in Statistics - Simulation and Computation* **36**(3), pp. 471–482

Examples

```

## Not run:
library(vlad)
library(dplyr)
data("cardiacsurgery", package = "spcadjust")

## preprocess data to 30 day mortality and subset phase I (In-control) of surgeons 2
S2I <- cardiacsurgery %>% rename(s = Parsonnet) %>%
  mutate(y = ifelse(status == 1 & time <= 30, 1, 0),
         phase = factor(ifelse(date < 2*365, "I", "II"))) %>%
  filter(phase == "I", surgeon == 2) %>% select(s, y)

## estimate risk model, get relative frequencies and probabilities
mod1 <- glm(y ~ s, data = S2I, family = "binomial")
fi <- as.numeric(table(S2I$s) / length(S2I$s))
usi <- sort(unique(S2I$s))
pi1 <- predict(mod1, newdata = data.frame(s = usi), type = "response")

## set up patient mix
pmix <- data.frame(fi, pi1, pi1)

## control limit for detecting deterioration RA = 2:
racusum_crit_mc(pmix = pmix, L0 = 740, RA = 2, RQ = 1)
## control limit for detecting improvement RA = 1/2:
racusum_crit_mc(pmix = pmix, L0 = 740, RA = 0.5, RQ = 1)

## End(Not run)

```

racusum_crit_sim	<i>Compute alarm threshold of RA-CUSUM control charts using simulation</i>
------------------	--

Description

Compute alarm threshold of risk-adjusted cumulative sum control charts using simulation.

Usage

```

racusum_crit_sim(
  L0,
  pmix,
  RA = 2,
  RQ = 1,
  yemp = FALSE,
  m = 10000,
  nc = 1,
  hmax = 30,
  jmax = 4,
  verbose = FALSE
)

```

Arguments

L0	Double. Prespecified in-control Average Run Length.
pmix	Data Frame. A three column data frame. First column is the operation outcome. Second column are the predicted probabilities from the risk model. Third column can be either the predicted probabilities from the risk model or average outcome.
RA	Double. Odds ratio of death under the alternative hypotheses. Detecting deterioration in performance with increased mortality risk by doubling the odds Ratio $RA = 2$. Detecting improvement in performance with decreased mortality risk by halving the odds ratio of death $RA = 1/2$. Odds ratio of death under the null hypotheses is 1.
RQ	Double. Defines the true performance of a surgeon with the odds ratio ratio of death RQ. Use $RQ = 1$ to compute the in-control ARL and other values to compute the out-of-control ARL.
yemp	Logical. If TRUE, use emirical outcome values, else use model.
m	Integer. Number of simulation runs.
nc	Integer. Number of cores used for parallel processing. Value is passed to parSapply .
hmax	Integer. Maximum value of h for the grid search.
jmax	Integer. Number of digits for grid search.
verbose	Logical. If TRUE verbose output is included, if FALSE a quiet calculation of h is done.

Details

Determines the control limit ("h") for given in-control ARL ("L0") applying a grid search using [racusum_arl_sim](#) and [parSapply](#).

Value

Returns a single value which is the control limit h for a given in-control ARL.

Author(s)

Philipp Wittenberg

References

Steiner SH, Cook RJ, Farewell VT and Treasure T (2000). Monitoring surgical performance using risk-adjusted cumulative sum charts. *Biostatistics*, **1**(4), pp. 441–452.

Wittenberg P, Gan FF, Knoth S (2018). A simple signaling rule for variable life-adjusted display derived from an equivalent risk-adjusted CUSUM chart. *Statistics in Medicine*, **37**(16), pp 2455–2473.

Examples

```
## Not run:
library(vlad)
library(dplyr)
data("cardiacsurgery", package = "spcadjust")

## preprocess data to 30 day mortality
SALL <- cardiacsurgery %>% rename(s = Parsonnet) %>%
  mutate(y = ifelse(status == 1 & time <= 30, 1, 0),
         phase = factor(ifelse(date < 2*365, "I", "II")))
SI <- subset(SALL, phase == "I")
y <- subset(SALL, select = y)
GLM <- glm(y ~ s, data = SI, family = "binomial")
pi1 <- predict(GLM, type = "response", newdata = data.frame(s = SALL$s))
pmix <- data.frame(y, pi1, pi1)
h <- racusum_crit_sim(pmix = pmix, L0 = 370, RA = 2, nc = 4, verbose = TRUE)

## End(Not run)
```

racusum_discretebeta_arl_sim

Compute ARLs of RA-CUSUM control charts using simulation

Description

Compute ARLs of RA-CUSUM control charts using simulation.

Usage

```
racusum_discretebeta_arl_sim(
  r,
  shape1,
  shape2,
  coeff,
  h,
  RA = 2,
  rs = 72,
  RQ = 1
)
```

Arguments

r	Integer Vector. Number of runs.
shape1	Double. Shape parameter $\alpha > 0$ of the beta distribution.
shape2	Double. Shape parameter $\beta > 0$ of the beta distribution.
coeff	Numeric Vector. Estimated intercept and slope coefficients from a binary logistic regression model.

h	Double. Control Chart limit for detecting deterioration/improvement.
RA	Double. Odds ratio of death under the alternative hypotheses. Detecting deterioration in performance with increased mortality risk by doubling the odds Ratio $RA = 2$. Detecting improvement in performance with decreased mortality risk by halving the odds ratio of death $RA = 1/2$.
rs	Integer. Number of intervals between \emptyset and the maximum risk score.
RQ	Double. Defines the performance of a surgeon with the odds ratio ratio of death. Q.

Value

Returns a single value which is the Run Length.

Author(s)

Philipp Wittenberg

Examples

```
## Not run:
library(vlad)
m <- 1e3
RLS <- sapply(1:m, racusum_discretebeta_arl_sim, shape1=1, shape2=3, coeff=c(-3.6798, 0.0768),
h=4.5, RA=2, rs=71+1, RQ=1)
data.frame(cbind(ARL=mean(RLS), ARLSE=sd(RLS)/sqrt(m)))

## End(Not run)
```

racusum_discretebeta_crit_sim

Compute alarm threshold of RA-CUSUM control charts using simulation

Description

Compute alarm threshold of risk-adjusted cumulative sum control charts using simulation.

Usage

```
racusum_discretebeta_crit_sim(
  L0,
  shape1,
  shape2,
  coeff,
  rs = 72,
  RA = 2,
```

```

RQ = 1,
nc = 1,
hmax = 30,
jmax = 4,
m = 10000,
verbose = FALSE
)

```

Arguments

L0	Double. Prespecified in-control Average Run Length.
shape1	Double. Shape parameter $\alpha > 0$ of the beta distribution.
shape2	Double. Shape parameter $\beta > 0$ of the beta distribution.
coeff	Numeric Vector. Estimated intercept and slope coefficients from a binary logistic regression model.
rs	Integer. Number of intervals between 0 and the maximum risk score.
RA	Double. Odds ratio of death under the alternative hypotheses. Detecting deterioration in performance with increased mortality risk by doubling the odds Ratio $RA = 2$. Detecting improvement in performance with decreased mortality risk by halving the odds ratio of death $RA = 1/2$.
RQ	Double. Defines the performance of a surgeon with the odds ratio ratio of death. Q.
nc	Integer. Number of cores used for parallel processing. Value is passed to parSapply .
hmax	Integer. Maximum value of h for the grid search.
jmax	Integer. Number of digits for grid search.
m	Integer. Number of simulation runs.
verbose	Logical. If TRUE verbose output is included, if FALSE a quiet calculation of h is done.

Details

Determines the control limit ("h") for given in-control ARL ("L0") applying a grid search using [racusum_discretebeta_arl_sim](#) and [parSapply](#).

Value

Returns a single value which is the control limit h for a given in-control ARL.

Author(s)

Philipp Wittenberg

Examples

```
## Not run:
library(vlad)
racusum_discretebeta_crit_sim(L0=7500, shape1=.61, shape2=4.09, rs=(71+1),
coeff=c(-3.6798, .0768), RA=2, RQ=1, nc=4, verbose=TRUE, m=1e3)

## End(Not run)
```

racusum_scores	<i>Compute CUSUM scores based on the log-likelihood ratio statistic</i>
----------------	---

Description

Compute CUSUM scores based on the log-likelihood ratio statistic.

Usage

```
racusum_scores(wt1, wt2, reset = FALSE, h1 = NULL, h2 = NULL)
```

Arguments

wt1	Double. Log-likelihood ratio scores from function llr_score for upper CUSUM.
wt2	Double. Log-likelihood ratio scores from function llr_score for lower CUSUM.
reset	Logical. If FALSE CUSUM statistic is not reset. If TRUE CUSUM statistic is reset to 0 after a signal is issued.
h1	Double. Upper control limit of the CUSUM chart.
h2	Double. Lower control limit of the CUSUM chart.

Value

Returns a list with two components for the CUSUM scores.

Author(s)

Philipp Wittenberg

References

Steiner SH, Cook RJ, Farewell VT and Treasure T (2000). Monitoring surgical performance using risk-adjusted cumulative sum charts. *Biostatistics*, **1**(4), pp. 441-452.

Parsonnet V, Dean D, Bernstein AD (1989). A method of uniform stratification of risk for evaluating the results of surgery in acquired adult heart disease. *Circulation*, **79**(6):I3-12.

Rigdon SE and Fricker RD (2015). Health Surveillance. In Chen DG and Wilson J (eds) *Innovative Statistical Methods for Public Health Data*, pp. 203–249. Springer, Cham.

Examples

```
## Not run:
# library(vlad)
# patient Cusum values with different odds ratios, see Rigdon and Fricker p. 225, 226
coeff <- c("(Intercept)" = -3.67, "Parsonnet" = 0.077)
wt1 <- round(llr_score(df = data.frame(19L, 0), coeff = coeff, R0 = 1, RA = 2), 4)
wt2 <- round(llr_score(df = data.frame(19L, 0), coeff = coeff, R0 = 1, RA = 1/2), 5)
all.equal(racusum_scores(wt1 = wt1, wt2 = wt2), list(s1 = 0, s1l = 0.05083))

library("dplyr")
library("tidyr")
library("ggplot2")
data("cardiacsurgery", package = "spcadjust")

## preprocess data to 30 day mortality and subset phase I (In-control)
SALL <- cardiacsurgery %>% rename(s = Parsonnet) %>%
  mutate(y = ifelse(status == 1 & time <= 30, 1, 0),
         phase = factor(ifelse(date < 2*365, "I", "II")))

## subset phase I (In-control)
SI <- filter(SALL, phase == "I") %>% select(s, y)

## estimate coefficients from logit model
coeff1 <- round(coef(glm(y ~ s, data = SI, family = "binomial")), 3)

## subset phase II of surgeons 2
S2II <- filter(SALL, phase == "II", surgeon == 2) %>% select(s, y)
n <- nrow(S2II)

## CUSUM statistic without reset
wt1 <- sapply(1:n, function(i) llr_score(S2II[i, c("s", "y")], coeff = coeff, RA = 2))
wt2 <- sapply(1:n, function(i) llr_score(S2II[i, c("s", "y")], coeff = coeff, RA = 1/2))
cv <- racusum_scores(wt1 = wt1, wt2 = wt2)
s1 <- cv$s1; s1l <- cv$s1l
dm1 <- data.frame(cbind("n" = 1:length(s1), "Cup" = s1, "Clow" = -s1l, "h1" = 2, "h2" = -2))

## CUSUM statistic reset after signal
cv <- racusum_scores(wt1 = wt1, wt2 = wt2, reset = TRUE, h1 = 2, h2 = 2)
s1 <- cv$s1; s1l <- cv$s1l
dm2 <- data.frame(cbind("n" = 1:length(s1), "Cup" = s1, "Clow" = -s1l, "h1" = 2, "h2" = -2))

## plot
dm3 <- bind_rows(dm1, dm2, .id = "type")
dm3$type <- recode_factor(dm3$type, `1`="No resetting", `2`="Resetting")
dm3 %>%
  gather("CUSUM", value, c(-n, - type)) %>%
  ggplot(aes(x = n, y = value, colour = CUSUM, group = CUSUM)) +
  geom_hline(yintercept = 0, colour = "darkgreen", linetype = "dashed") +
  geom_line(size = 0.5) +
  facet_wrap( ~ type, ncol = 1, scales = "free") +
  labs(x = "Patient number n", y = "CUSUM values") + theme_classic() +
  scale_y_continuous(sec.axis = dup_axis(name = NULL, labels = NULL)) +
```



```
scale_x_continuous(sec.axis = dup_axis(name = NULL, labels = NULL)) +
guides(colour = "none") +
scale_color_manual(values = c("blue", "orange", "red", "red"))

## End(Not run)
```

search_delta	<i>Search Box-Cox transformation parameter</i>
--------------	--

Description

Search Box-Cox transformation parameter.

Usage

```
search_delta(s, y, type = "ML", dmin = -2, dmax = 2)
```

Arguments

s	Integer vector. Parsonnet Score values within a range of 0 to 100 representing the preoperative patient risk.
y	Double. Binary (0/1) outcome values of each operation.
type	Character. If type = "ML" Maximum Likelihood used to search the Box-Cox transformation parameter, type = "Pearson" uses a Pearson measure.
dmin	Double. Minimum value for the grid search.
dmax	Double. Maximum value for the grid search.

Value

Returns a single value for the Box-Cox transformation parameter.

Author(s)

Philipp Wittenberg

References

Knöth S, Wittenberg P and Gan FF (2019). Risk-adjusted CUSUM charts under model error. *Statistics in Medicine*, **38**(12), pp. 2206–2218..

Examples

```
## Not run:
## load data
data("cardiacsurgery", package = "spcadjust")

## preprocess data to 30 day mortality and subset data to
## phase I (In-control) and phase II (monitoring)
SALL <- cardiacsurgery %>% rename(s = Parsonnet) %>%
  mutate(y = ifelse(status == 1 & time <= 30, 1, 0),
         phase = factor(ifelse(date < 2*365, "I", "II")))

## subset phase I (In-control)
SI <- filter(SALL, phase == "I") %>% select(s, y)

## search delta
dML <- search_delta(SI$s, SI$y, type = "ML")
dQQ <- search_delta(SI$s, SI$y, type = "Pearson")

## show Log-likelihood (ell()) and Pearson measure (QQ()) for each delta
delta <- c(-2, -1, 0, dML, dQQ, 0.5, 1, 2)
r <- sapply(delta, function(i) rbind(i, ell(SI$s, SI$y, i), QQ(SI$s, SI$y, i)))
rownames(r) <- c("d", "l", "S")
t(r)
data.frame(t(r)) %>% filter(l == max(l) | S == min(S))

## End(Not run)
```

trafo

Box-Cox transformation of data.

Description

Box-Cox transformation of data.

Usage

```
trafo(delta, x)
```

Arguments

delta	Numeric. Box-Cox transformation parameter.
x	Numeric Vector. Parsonnet Score values within a range of 0 to 100 representing the preoperative patient risk.

Value

Returns a transformed Numeric vector.

Author(s)

Philipp Wittenberg

Index

bcusum_arl_sim, [3](#), [4](#)
bcusum_crit_sim, [3](#)

ell, [5](#)
eocusum_ad_sim, [6](#)
eocusum_arl_sim, [7](#), [11](#)
eocusum_crit_sim, [10](#)
eocusum_scores, [12](#)

llr_score, [14](#), [39](#)

mclapply, [4](#)

optimal_k, [6](#), [8](#), [10](#), [12](#), [15](#)

parSapply, [10](#), [11](#), [25](#), [31](#), [35](#), [38](#)

QQ, [17](#)

racusum_ad_sim, [18](#)
racusum_arl_mc, [19](#), [33](#)
racusum_arl_sim, [21](#), [35](#)
racusum_beta_arl_int, [26](#)
racusum_beta_arl_mc, [27](#), [30](#)
racusum_beta_arl_sim, [28](#), [31](#)
racusum_beta_crit_mc, [29](#)
racusum_beta_crit_sim, [30](#)
racusum_betabinomial_arl_sim, [23](#), [25](#)
racusum_betabinomial_crit_sim, [24](#)
racusum_crit_mc, [32](#)
racusum_crit_sim, [34](#)
racusum_discretebeta_arl_sim, [36](#), [38](#)
racusum_discretebeta_crit_sim, [37](#)
racusum_scores, [39](#)

search_delta, [41](#)

trafo, [42](#)

vlad-package, [2](#)