Package ‘queuecomputer’

October 6, 2020

Title Computationally Efficient Queue Simulation

Version 1.0.0

Description Implementation of a computationally efficient method for
simulating queues with arbitrary arrival and service times.
Please see Ebert, Wu, Mengersen & Ruggeri (2020, <doi:10.18637/jss.v095.i05>)
for further details.

Depends R (>= 3.3)

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Encoding UTF-8

LazyData true

Imports stats, Rcpp, tidyr, dplyr, utils

RoxygenNote 7.1.0

Suggests knitr, rmarkdown, testthat, ggplot2

VignetteBuilder knitr

LinkingTo Rcpp, RcppArmadillo (>= 0.7.500.0.0)

URL https://github.com/AnthonyEbert/queuecomputer

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NeedsCompilation yes

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Date/Publication 2020-10-06 11:50:02 UTC

R topics documented:

`as.server.list` *Creates a* `"server.list"` *object from a list of times and starting availability.*

Description

Creates a `"server.list"` object from a list of times and starting availability.

Usage

```
as.server.list(times, init)
```

Arguments

`times`	list of numeric vectors giving change times for each server.
`init`	vector of 1s and 0s with equal length to `times`. It represents whether the server starts in an available `(1)` or unavailable `(0)` state.

Value

an object of class `"server.list"`, which is a list of step functions of range $\{0, 1\}$.

See Also

`as.server.stepfun`, `queue_step`

Examples

```
# Create a server.list object with the first server available anytime before time 10,
# and the second server available between time 15 and time 30.
as.server.list(list(10, c(15,30)), c(1,0))
```

`as.server.stepfun` *Create a* `server.stepfun` *object with a roster of times and number of available servers.*

Description

Create a `server.stepfun` object with a roster of times and number of available servers.

Usage

```
as.server.stepfun(x, y)
```

Arguments

`x`	numeric vector giving the times of changes in number of servers.
`y`	numeric vector one longer than `x` giving the number of servers available between x values.

Details

This function uses the analogy of a step function to specify the number of available servers throughout the day. It is used as input to the `queue_step` function. Alternatively one may use `as.server.list` to specify available servers as a list, however `queue_step` is much faster when `as.server.stepfun` is used as input rather than `as.server.list`.

If any of the service times are large compared to any element of `diff(x)` then the `as.server.list` function should be used.

Value

A `list` and `server.stepfun` object with x and y as elements.

See Also

`as.server.list`, `queue_step`, `stepfun`.

Examples

```
servers <- as.server.stepfun(c(15,30,50), c(0, 1, 3, 2))
servers
```

average_queue — *Compute time average queue length*

Description

Compute time average queue length

Usage

```
average_queue(times, queuelength)
```

Arguments

times	numeric vector of times
queuelength	numeric vector of queue lengths

Examples

```
n <- 1e3
arrivals <- cumsum(rexp(n))
service <- rexp(n)
departures <- queue(arrivals, service, 1)

queuedata <- queue_lengths(arrivals, service, departures)
average_queue(queuedata$times, queuedata$queuelength)
```

depart — *get departure times from* queue_list *object*

Description

get departure times from queue_list object

Usage

```
depart(x)
```

Arguments

x	an queue_list object

Value

departure times

Examples

```
arrivals <- cumsum(rexp(10))
service <- rexp(10)
queue_obj <- queue_step(arrivals, service)

depart(queue_obj)
queue_obj$departures_df$departures
```

---

lag_step *Add lag to vector of arrival times.*

Description

Add lag to vector of arrival times.

Usage

```
lag_step(arrivals, service)
```

Arguments

arrivals	Either a numeric vector or an object of class queue_list. It represents the arrival times.
service	A vector of service times with the same ordering as arrivals

Value

A vector of response times for the input of arrival times and service times.

See Also

wait_step, queue_step.

Examples

```
# Create arrival times
arrivals <- rlnorm(100, meanlog = 3)

# Create service times
service <- rlnorm(100)
lag_step(arrivals = arrivals, service = service)

# lag_step is equivalent to queue_step with a large number of queues, but it's faster to compute.

cbind(queue(arrivals, service = service, servers = 100),
lag_step(arrivals = arrivals, service = service))
```

`plot.queue_list` *ggplot2 method for output from queueing model*

Description

ggplot2 method for output from queueing model

Usage

```
## S3 method for class 'queue_list'
plot(x, which = c(2:6), annotated = TRUE, ...)
```

Arguments

`x`	an object of class `queue_list`
`which`	Numeric vector of integers from 1 to 6 which represents which plots are to be created. See examples.
`annotated`	logical, if `TRUE` annotations will be added to the plot.
`...`	other parameters to be passed through to plotting functions.

Examples

```
if(require(ggplot2, quietly = TRUE)){

n_customers <- 50
arrival_rate <- 1.8
service_rate <- 1
arrivals <- cumsum(rexp(n_customers, arrival_rate))
service <- rexp(n_customers, service_rate)
queue_obj <- queue_step(arrivals, service, servers = 2)
plot(queue_obj)

}

## Not run:

library(ggplot2)

## density plots of arrival and departure times
plot(queue_obj, which = 1)

## histograms of arrival and departure times
plot(queue_obj, which = 2)

## density plots of waiting and system times
plot(queue_obj, which = 3)

## step function of queue length
```

```
plot(queue_obj, which = 4)

## line range plot of customer and server status
plot(queue_obj, which = 5)

## empirical distribution plot of arrival and departure times
plot(queue_obj, which = 6)


## End(Not run)
```

---

print.summary_queue_list
Print method for output of `summary.queue_list`.

Description

Print method for output of `summary.queue_list`.

Usage

```
## S3 method for class 'summary_queue_list'
print(x, ...)
```

Arguments

`x`	an object of class `summary_queue_list`, the result of a call to `summary.queue_list()`.
`...`	further arguments to be passed to or from other methods.

Value

A list of performance statistics for the queue:

"Total customers": Total customers in simulation,

"Missed customers": Customers who never saw a server,

"Mean waiting time": The mean time each customer had to wait in queue for service,

"Mean response time": The mean time that each customer spends in the system (departure time - arrival time),

"Utilization factor": The ratio of available time for all servers and time all servers were used. It can be greater than one if a customer arrives near the end of a shift and keeps a server busy,

"Mean queue length": Average queue length, and

"Mean number of customers in system": Average number of customers in queue or currently being served.

Examples

```
n <- 1e3
arrivals <- cumsum(rexp(n, 1.8))
service <- rexp(n)

queue_obj <- queue_step(arrivals, service, servers = 2)
summary(queue_obj)
```

ql_summary *Summarise queue lengths*

Description

Summarise queue lengths

Usage

```
ql_summary(times, queuelength)
```

Arguments

times	numeric vector of times
queuelength	numeric vector of queue lengths

Examples

```
n <- 1e3
arrivals <- cumsum(rexp(n))
service <- rexp(n)
departures <- queue(arrivals, service, 1)

queuedata <- queue_lengths(arrivals, service, departures)
ql_summary(queuedata$times, queuedata$queuelength)
```

queue *Compute the departure times for a set of customers in a queue from their arrival and service times.*

Description

queue is a faster version of `queue_step` but the input returned is much simpler. It is not compatible with the `summary.queue_list` method or the `plot.queue_list` method.

Usage

```
queue(arrivals, service, servers = 1, serveroutput = FALSE)
```

Arguments

`arrivals`	numeric vector of non-negative arrival times
`service`	numeric vector of non-negative service times
`servers`	a non-zero natural number, an object of class `server.stepfun` or an object of class `server.list`.
`serveroutput`	boolean whether the server used by each customer should be returned.

Details

If the arrival vector is out of order the function will reorder it. The same reordering will be applied to the service vector, this is so each customer keeps their service time. Once the queue is computed the original order is put back.

See Also

`queue_step`

Examples

```
n <- 1e2
arrivals <- cumsum(rexp(n, 1.8))
service <- rexp(n)

departures <- queue(
    arrivals, service, servers = 2)

head(departures)
curve(ecdf(departures)(x) * n,
    from = 0, to = max(departures),
    xlab = "Time", ylab = "Number of customers")
curve(ecdf(arrivals)(x) * n,
    from = 0, to = max(departures),
    col = "red", add = TRUE)
```

`queue_lengths` *Compute queue lengths from arrival, service and departure data*

Description

Compute queue lengths from arrival, service and departure data

Usage

```
queue_lengths(arrivals, service = 0, departures, epsilon = 1e-10, ...)
```

Arguments

`arrivals`	vector of arrival times
`service`	vector of service times. Leave as zero if you want to compute the number of customers in the system rather than queue length.
`departures`	vector of departure times
`epsilon`	numeric small number added to departures to prevent negative queue lengths
`...`	additional arguments - does nothing, for compatibility

Examples

```
library(dplyr)
library(queuecomputer)

set.seed(1L)
n_customers <- 100

queueoutput_df <- data.frame(
  arrivals = runif(n_customers, 0, 300),
  service = rexp(n_customers)
)

queueoutput_df <- queueoutput_df %>% mutate(
  departures = queue(arrivals, service, servers = 2)
)

queue_lengths(
  queueoutput_df$arrivals,
  queueoutput_df$service,
  queueoutput_df$departures
)

# The dplyr way
queueoutput_df %>% do(
  queue_lengths(.$arrivals, .$service, .$departures))

n_customers <- 1000

queueoutput_df <- data.frame(
  arrivals = runif(n_customers, 0, 300),
  service = rexp(n_customers),
  route = sample(c("a", "b"), n_customers, TRUE)
)

server_df <- data.frame(
  route = c("a", "b"),
  servers = c(2, 3)
)

output <- queueoutput_df %>%
  left_join(server_df) %>%
```

```
  group_by(route) %>%
  mutate(
    departures = queue(arrivals, service, servers = servers[1])
  ) %>%
  do(queue_lengths(.$arrivals, .$service, .$departures))


if(require(ggplot2, quietly = TRUE)){
    ggplot(output) +
      aes(x = times, y = queuelength) + geom_step() +
      facet_grid(~route)
}
```

`queue_step` *Compute the departure times and queue lengths for a queueing system from arrival and service times.*

Description

Compute the departure times and queue lengths for a queueing system from arrival and service times.

Usage

```
queue_step(arrivals, service, servers = 1, labels = NULL)
```

Arguments

`arrivals`	numeric vector of non-negative arrival times
`service`	numeric vector of service times with the same ordering as arrival_df.
`servers`	a non-zero natural number, an object of class `server.stepfun` or an object of class `server.list`.
`labels`	character vector of customer labels.

Value

A vector of response times for the input of arrival times and service times.

See Also

`queue`, `summary.queue_list`, `plot.queue_list`

Examples

```
# With two servers
set.seed(1)
n <- 100

arrivals <- cumsum(rexp(n, 3))
service <- rexp(n)


queue_obj <- queue_step(arrivals,
    service = service, servers = 2)


summary(queue_obj)
plot(queue_obj, which = 5)

# It seems like the customers have a long wait.
# Let's put two more servers on after time 20


server_list <- as.server.stepfun(c(20),c(2,4))

queue_obj2 <- queue_step(arrivals,
    service = service,
    servers = server_list)

summary(queue_obj2)
if(require(ggplot2, quietly = TRUE)){

    plot(queue_obj2, which = 5)

}
```

`summary.queue_list` *Summary method for queue_list object*

Description

Summary method for queue_list object

Usage

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

Arguments

object	an object of class queue_list, the result of a call to queue_step.
...	further arguments to be passed to or from other methods.

---

wait_step *Compute maximum time for each row from two vectors of arrival times.*

Description

Compute maximum time for each row from two vectors of arrival times.

Usage

```
wait_step(arrivals, service)
```

Arguments

arrivals	Either a numeric vector or an object of class queue_list. It represents the arrival times.
service	A vector of times which represent the arrival times of the second type of customers. The ordering of this vector should have the same ordering as arrivals.

Details

A good real-world example of this is finding the departure times for passengers after they pick up their bags from the baggage carousel. The time at which they leave is the maximum of the passenger and bag arrival times.

Value

The maximum time from two vectors of arrival times.

See Also

lag_step, queue_step.

Examples

```
set.seed(500)
arrivals <- rlnorm(100, meanlog = 4)
service <- rlnorm(100)

#Airport example ------------------------

# Create a number of bags for each of 100 customers
bags <- rpois(100,1)
```

```
# Create a bags dataframe, with each bag associated with one customer.
bags.df <- data.frame(BagID = 1:sum(bags),
   ID = rep(1:100, bags), times = rlnorm(sum(bags), meanlog = 2))

# Create a function which will return the maximum time from each customer's set of bags.

reduce_bags <- function(bagdataset, number_of_passengers){
   ID = NULL
   times = NULL

   zerobags <- data.frame(BagID = NA, ID = c(1:number_of_passengers), times = 0)
   reduced_df <- as.data.frame(dplyr::summarise(dplyr::group_by(
   rbind(bagdataset, zerobags), ID), n = max(times, 0)))
   ord <- order(reduced_df$ID)
   reduced_df <- reduced_df[order(ord),]
   names(reduced_df) <- c("ID", "times")
   return(reduced_df)
}


arrivals2 <- reduce_bags(bags.df, 100)$times

# Find the time when customers can leave with their bags.
wait_step(arrivals = arrivals, service = arrivals2)
```

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