

# Package: XOMultinom (via r-universe)

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**Type** Package

**Title** Exact Distributions of Some Functions of the Ordered Multinomial Counts

**Version** 0.8.7

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**Maintainer** Sergio Venturini <sergio.venturini@unicatt.it>

**Description** Implements exact algorithms for computing the distributions of the maximum, the minimum, the range, and the sum of the J largest order statistics of a multinomial random vector. Two complementary algorithm families are provided: the recursive tree-traversal method of Bonetti, Cirillo, and Ogay (2019) <doi:10.1098/rsos.190198>, which covers all four statistics under the equiprobable hypothesis; and the stochastic matrix method of Corrado (2011) <doi:10.1007/s11222-010-9174-3>, which handles the maximum, minimum, and range for arbitrary probability vectors. Functions for power evaluation and sample size determination for goodness-of-fit tests based on these order statistics are also provided. Computationally intensive routines are implemented in 'C++' for efficiency.

**License** GPL-3

**URL** <https://github.com/sergioventurini/XOMultinom>

**BugReports** <https://github.com/sergioventurini/XOMultinom/issues>

**Depends** R (>= 3.6.0), utils

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|                    |  |
|--------------------|--|
| XOMultinom-package | <i>XOMultinom: Exact distributions of ordered multinomial counts</i> |
|--------------------|--|

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## Description

The **XOMultinom** package provides functions for computing exact distributions of selected functions of ordered multinomial counts, including the maximum, minimum, range, and sums of order statistics.

Main functions include:

- `dmaxmultinom()`, `pmaxmultinom()`, `qmaxmultinom()`, `rmaxmultinom()`
- `dminmultinom()`, `pminmultinom()`, `qminmultinom()`, `rminmultinom()`
- `drangemultinom()`, `prangemultinom()`, `qrangemultinom()`, `rrangemultinom()`
- `dJlargemultinom()`, `pJlargemultinom()`, `qJlargemultinom()`, `rJlargemultinom()`

## Author(s)

**Maintainer:** Sergio Venturini <sergio.venturini@unicatt.it>

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- Marco Bonetti <marco.bonetti@unibocconi.it> [contributor]

## See Also

Useful links:

- <https://github.com/sergioventurini/XOMultinom>
- Report bugs at <https://github.com/sergioventurini/XOMultinom/issues>

---

```
as.data.frame.xomultinom_dist
```

*Coerce an xomultinom\_dist object to a data frame*

---

### Description

Converts the evaluation points and probability values stored in an `xomultinom_dist` object into a tidy `data.frame` suitable for further manipulation or export.

### Usage

```
## S3 method for class 'xomultinom_dist'
as.data.frame(x, ...)
```

### Arguments

`x` An object of class `xomultinom_dist`.  
`...` Further arguments passed to or from other methods (currently unused).

### Value

A `data.frame` with columns `x` (evaluation points) and either `pmf` or `cdf` (probability values). If the object was computed on the log scale the column is named `log_pmf` or `log_cdf` accordingly.

### Examples

```
k <- 5; n <- 40
obj <- dmaxmultinom(x = 0:n, size = n, prob = rep(1/k, k))
head(as.data.frame(obj))
```

---

```
as.data.frame.xomultinom_size
```

*Coerce an xomultinom\_size object to a data frame*

---

### Description

Converts the sample size results stored in an `xomultinom_size` object into a single tidy `data.frame` with columns for  $m$ , the probability perturbation, and the required sample size.

### Usage

```
## S3 method for class 'xomultinom_size'
as.data.frame(x, ...)
```

**Arguments**

`x` An object of class `xomultinom_size`.  
`...` Further arguments passed to or from other methods (currently unused).

**Value**

A `data.frame` with columns `m` (integer number of categories), `change` (probability perturbation), and `n_required` (required sample size).

**Examples**

```
sz <- maxmin_multinom_size(
  m_seq = c(5, 10), change_seq = c(0.10, 0.15, 0.20),
  power = 0.80, alpha = 0.05, type = "max"
)
as.data.frame(sz)
```

---

`autoplot.xomultinom_dist`

*ggplot2-based plot for xomultinom\_dist objects*

---

**Description**

Produces a `ggplot2` plot of the exact distribution stored in an `xomultinom_dist` object. PMFs are displayed as lollipop (spike) charts; CDFs are displayed as step functions. An optional normal approximation overlay can be added for diagnostic comparison.

**Usage**

```
## S3 method for class 'xomultinom_dist'
autoplot(
  object,
  add_approx = FALSE,
  colour = "#2166ac",
  approx_colour = "#d6604d",
  title = NULL,
  ...
)
```

**Arguments**

`object` An object of class `xomultinom_dist`.  
`add_approx` Logical; if `TRUE`, overlays the normal approximation to the distribution (mean and variance computed from the exact PMF). Defaults to `FALSE`.

|               |  |
|---------------|--|
| colour        | Character string; colour used for the exact distribution. Defaults to "#2166ac" (blue).                          |
| approx_colour | Character string; colour used for the approximation overlay when add_approx = TRUE. Defaults to "#d6604d" (red). |
| title         | Character string; plot title. If NULL (default), a descriptive title is generated automatically.                 |
| ...           | Further arguments passed to or from other methods (currently unused).  |

### Details

For multi-panel layouts use `patchwork` or `gridExtra` to combine multiple `autoplot()` outputs. For base R `par(mfrow = ...)` compatibility use `plot.xomultinom_dist` instead.

### Value

Invisibly returns the `ggplot` object.

### See Also

`plot.xomultinom_dist` for a base R alternative compatible with `par(mfrow = ...)`.

### Examples

```
k <- 5; n <- 40
obj <- dmaxmultinom(x = 0:n, size = n, prob = rep(1/k, k))
autoplot(obj)
autoplot(obj, add_approx = TRUE)
```

---

autoplot.xomultinom\_size

*ggplot2-based plot for xomultinom\_size objects*

---

### Description

Produces a `ggplot2` line chart of the required sample size as a function of the probability perturbation, with one line per value of  $m$  (number of categories).

### Usage

```
## S3 method for class 'xomultinom_size'
autoplot(object, log_scale = FALSE, title = NULL, ...)
```

**Arguments**

|           |  |
|-----------|--|
| object    | An object of class <code>xomultinom_size</code> .  |
| log_scale | Logical; if TRUE, the $y$ -axis is displayed on a $\log_{10}$ scale. Defaults to FALSE.          |
| title     | Character string; plot title. If NULL (default), a descriptive title is generated automatically. |
| ...       | Further arguments passed to or from other methods (currently unused).                            |

**Details**

For multi-panel layouts use `patchwork` or `gridExtra` to combine multiple `autoplot()` outputs. For base R `par(mfrow = ...)` compatibility use [plot.xomultinom\\_size](#) instead.

**Value**

Invisibly returns the `ggplot` object.

**See Also**

[plot.xomultinom\\_size](#) for a base R alternative compatible with `par(mfrow = ...)`.

**Examples**

```
sz_max <- maxmin_multinom_size(
  m_seq = c(5, 10, 20), change_seq = seq(0.10, 0.30, by = 0.05),
  power = 0.80, alpha = 0.05, type = "max"
)
autoplot(sz_max)
autoplot(sz_max, log_scale = TRUE)
```

---

 decr\_2\_pmin

*Utility function.*


---

**Description**

This is an auxiliary function to compute the probability values from an decrement with respect to the case of equiprobability.

**Usage**

```
decr_2_pmin(m, decr)
```

**Arguments**

|      |  |
|------|--|
| m    | An integer vector of numbers of multinomial classes.                         |
| decr | A numeric vector of decrement values for which to compute the probabilities. |

**Value**

A numeric matrix.

**Author(s)**

Sergio Venturini <sergio.venturini@unicatt.it>

**References**

Bonetti, M., Cirillo, P., Ogay, A. (2019), "Computing the exact distributions of some functions of the ordered multinomial counts: maximum, minimum, range and sums of order statistics", Royal Society Open Science, 6: 190198, doi:10.1098/rsos.190198.

**See Also**

[pmin\\_2\\_decr](#) for the opposite calculation.

**Examples**

```
m <- 3:50
decr <- seq(0, 1, 0.01)
pmin <- decr_2_pmin(m, decr)
summary(as.numeric(pmin))
```

---

|                 |  |
|-----------------|--|
| dJlargemultinom | <i>PMF of the sum of J largest order statistics for a multinomial distribution</i> |
|-----------------|--|

---

**Description**

Computes the probability mass function of the sum of  $J$  largest order statistics for a multinomial random vector with equal cell probabilities.

**Usage**

```
dJlargemultinom(x, size, prob, J = 2, log = FALSE, verbose = TRUE)
```

**Arguments**

|         |   |
|---------|---|
| x       | Numeric vector of values at which to evaluate the PMF.  |
| size    | Integer number of trials.   |
| prob    | Numeric vector of non-negative cell probabilities. Values are internally normalized to sum to 1. Categories with zero probability are removed before computation. |
| J       | Integer number of largest order statistics to consider. Defaults to 2.  |
| log     | Logical; if TRUE, returns log-probabilities.  |
| verbose | Logical; if TRUE, displays progress information during the computation.   |

**Details**

The function only implements the equiprobable case.

**Value**

An object of class `xomultinom_dist` with fields `x`, `values` (containing  $P(S_J = x)$ ,  $S_J = \sum_{j=1}^J N_{(j)}$ , or log-probabilities if `log = TRUE`), `stat = "J_largest"`, `type = "pmf"`, `size`, `prob`, and `log`.

**References**

Bonetti, M., Cirillo, P., Ogay, A. (2019). Computing the exact distributions of some functions of the ordered multinomial counts: maximum, minimum, range and sums of order statistics. Royal Society Open Science, 6, 190198. doi:10.1098/rsos.190198

**See Also**

[dmaxmultinom](#) for the PMF of the maximum, [dminmultinom](#) for the PMF of the minimum, and [drangemultinom](#) for the PMF of the range.

**Examples**

```
m <- 4
n <- 60
probs <- rep(1 / m, m)
J <- 3
xseq <- 0:n

pmflarge <- dJlargemultinom(x = xseq, size = n, prob = probs, J = J)
plot(pmflarge)
```

---

dmaxmultinom

*PMF of the maximum for a multinomial distribution*


---

**Description**

Computes the probability mass function of the maximum cell count of a multinomial random vector with arbitrary cell probabilities.

**Usage**

```
dmaxmultinom(x, size, prob, log = FALSE, verbose = TRUE)
```

**Arguments**

|         |   |
|---------|---|
| x       | Numeric vector of values at which to evaluate the PMF.  |
| size    | Integer number of trials.   |
| prob    | Numeric vector of non-negative cell probabilities. Values are internally normalized to sum to 1. Categories with zero probability are removed before computation. |
| log     | Logical; if TRUE, returns log-probabilities.  |
| verbose | Logical; if TRUE, displays progress information during the computation.   |

**Details**

The function first checks whether prob corresponds to the equiprobable case and then applies either the Bonetti et al. (2019) algorithm or the Corrado (2011) algorithm accordingly.

**Value**

An object of class `xomultinom_dist` with fields `x`, `values` (containing  $P(\max(N_1, \dots, N_m) = x)$ ), or log-probabilities if `log = TRUE`, `stat = "max"`, `type = "pmf"`, `size`, `prob`, and `log`.

**References**

Bonetti, M., Cirillo, P., Ogay, A. (2019). Computing the exact distributions of some functions of the ordered multinomial counts: maximum, minimum, range and sums of order statistics. *Royal Society Open Science*, 6, 190198. doi:10.1098/rsos.190198

Corrado, C.J. (2011). The exact distribution of the maximum, minimum and the range of Multinomial/Dirichlet and Multivariate Hypergeometric frequencies. *Statistical Computing*, 21, 349–359. doi:10.1007/s1122201091743

**See Also**

[pmaxmultinom](#) for the CDF of the maximum, [dminmultinom](#) for the PMF of the minimum, and [drangemultinom](#) for the PMF of the range.

**Examples**

```
m <- 4
n <- 60
probs <- rep(1 / m, m)
xseq <- 0:n

pmfmax <- dmaxmultinom(x = xseq, size = n, prob = probs)
plot(pmfmax)
```

---

|              |  |
|--------------|--|
| dminmultinom | <i>PMF of the minimum for a multinomial distribution</i> |
|--------------|--|

---

### Description

Computes the probability mass function of the minimum cell count of a multinomial random vector with arbitrary cell probabilities.

### Usage

```
dminmultinom(x, size, prob, log = FALSE, verbose = TRUE)
```

### Arguments

|                      |   |
|----------------------|---|
| <code>x</code>       | Numeric vector of values at which to evaluate the PMF.  |
| <code>size</code>    | Integer number of trials.   |
| <code>prob</code>    | Numeric vector of non-negative cell probabilities. Values are internally normalized to sum to 1. Categories with zero probability are removed before computation. |
| <code>log</code>     | Logical; if TRUE, returns log-probabilities.  |
| <code>verbose</code> | Logical; if TRUE, displays progress information during the computation.   |

### Details

The function first checks whether `prob` corresponds to the equiprobable case and then applies either the Bonetti et al. (2019) algorithm or the Corrado (2011) algorithm accordingly.

### Value

An object of class `xomultinom_dist` with fields `x`, `values` (containing  $P(\min(N_1, \dots, N_m) = x)$ , or log-probabilities if `log = TRUE`), `stat = "min"`, `type = "pmf"`, `size`, `prob`, and `log`.

### References

Bonetti, M., Cirillo, P., Ogay, A. (2019). Computing the exact distributions of some functions of the ordered multinomial counts: maximum, minimum, range and sums of order statistics. *Royal Society Open Science*, 6, 190198. doi:10.1098/rsos.190198

Corrado, C.J. (2011). The exact distribution of the maximum, minimum and the range of Multinomial/Dirichlet and Multivariate Hypergeometric frequencies. *Statistical Computing*, 21, 349–359. doi:10.1007/s1122201091743

### See Also

[pminmultinom](#) for the CDF of the minimum, [dmaxmultinom](#) for the PMF of the maximum, and [drangemultinom](#) for the PMF of the range.

**Examples**

```

m <- 4
n <- 60
probs <- rep(1 / m, m)
xseq <- 0:n

pmfmin <- dminmultinom(x = xseq, size = n, prob = probs)
plot(pmfmin)

```

---

drangemultinom

*PMF of the range for a multinomial distribution*


---

**Description**

Computes the probability mass function of the range  $R = \max(N_1, \dots, N_m) - \min(N_1, \dots, N_m)$  for a multinomial random vector with arbitrary cell probabilities.

**Usage**

```
drangemultinom(x, size, prob, log = FALSE, verbose = TRUE)
```

**Arguments**

|         |   |
|---------|---|
| x       | Numeric vector of values at which to evaluate the PMF.  |
| size    | Integer number of trials.   |
| prob    | Numeric vector of non-negative cell probabilities. Values are internally normalized to sum to 1. Categories with zero probability are removed before computation. |
| log     | Logical; if TRUE, returns log-probabilities.  |
| verbose | Logical; if TRUE, displays progress information during the computation.   |

**Details**

The function first checks whether prob corresponds to the equiprobable case and then applies either the Bonetti et al. (2019) algorithm or the Corrado (2011) algorithm accordingly.

**Value**

An object of class `xomultinom_dist` with fields `x`, `values` (containing  $P(R = x)$ ), or log-probabilities if `log = TRUE`), `stat = "range"`, `type = "pmf"`, `size`, `prob`, and `log`.

## References

Bonetti, M., Cirillo, P., Ogay, A. (2019). Computing the exact distributions of some functions of the ordered multinomial counts: maximum, minimum, range and sums of order statistics. *Royal Society Open Science*, 6, 190198. doi:10.1098/rsos.190198

Corrado, C.J. (2011). The exact distribution of the maximum, minimum and the range of Multinomial/Dirichlet and Multivariate Hypergeometric frequencies. *Statistical Computing*, 21, 349–359. doi:10.1007/s1122201091743

## See Also

[prangemultinom](#) for the CDF of the range, [dmaxmultinom](#) for the PMF of the maximum, and [dminmultinom](#) for the PMF of the minimum.

## Examples

```
m <- 4
n <- 60
probs <- rep(1 / m, m)
xseq <- 0:n

pmfrange <- drangemultinom(x = xseq, size = n, prob = probs)
plot(pmfrange)
```

---

|                 |  |
|-----------------|--|
| find_gamma_prob | <i>Randomization probability for max/min multinomial tests</i> |
|-----------------|--|

---

## Description

Computes the randomization probability  $\gamma$  associated with a critical value  $k_\alpha$  for tests based on the maximum or minimum of a multinomial random vector.

## Usage

```
find_gamma_prob(probs, n, alpha = 0.05, k_alpha, type)
```

## Arguments

|         |  |
|---------|--|
| probs   | Numeric vector of probabilities. Must correspond to the equiprobable case. |
| n       | Integer number of trials.  |
| alpha   | Significance level in (0, 1).  |
| k_alpha | Integer critical value.  |
| type    | Character string; either "max" or "min".                                   |

## Value

Numeric value representing the randomization probability. Returns NA if not defined.

---

|              |   |
|--------------|---|
| find_k_alpha | <i>Critical value for max/min multinomial tests</i> |
|--------------|---|

---

**Description**

Computes the critical value  $k_\alpha$  for hypothesis tests based on the maximum or minimum of a multinomial random vector.

**Usage**

```
find_k_alpha(probs, n, alpha = 0.05, type)
```

**Arguments**

|       |  |
|-------|--|
| probs | Numeric vector of probabilities. Must correspond to the equiprobable case. |
| n     | Integer number of trials.  |
| alpha | Significance level in (0, 1).  |
| type  | Character string; either "max" or "min".                                   |

**Value**

Integer critical value  $k_\alpha$ . Returns NA if no valid rejection region exists.

---

|              |   |
|--------------|---|
| find_k_gamma | <i>Critical value and randomization probability for max/min tests</i> |
|--------------|---|

---

**Description**

Computes the critical value  $k_\alpha$  and the corresponding randomization probability  $\gamma$  for hypothesis tests based on the maximum or minimum of a multinomial random vector under the null hypothesis of equiprobable categories.

**Usage**

```
find_k_gamma(probs, n, alpha = 0.05, type)
```

**Arguments**

|       |  |
|-------|--|
| probs | Numeric vector of probabilities. Must correspond to the equiprobable case (i.e., all equal). |
| n     | Integer number of trials.  |
| alpha | Significance level in (0, 1).  |
| type  | Character string; either "max" or "min" indicating the test statistic.                       |

**Details**

The function determines the rejection region for tests based on the maximum or minimum cell count. When the test is not exact, a randomized decision rule is constructed via  $\gamma$ .

**Value**

A list with components:

|            |                            |
|------------|----------------------------|
| k_alpha    | Critical value.            |
| gamma_prob | Randomization probability. |

---

|             |                          |
|-------------|--------------------------|
| incr_2_pmax | <i>Utility function.</i> |
|-------------|--------------------------|

---

**Description**

This is an auxiliary function to compute the probability values from an increment with respect to the case of equiprobability.

**Usage**

```
incr_2_pmax(m, incr)
```

**Arguments**

|      |  |
|------|--|
| m    | An integer vector of numbers of multinomial classes.                         |
| incr | A numeric vector of increment values for which to compute the probabilities. |

**Value**

A numeric matrix.

**Author(s)**

Sergio Venturini <sergio.venturini@unicatt.it>

**References**

Bonetti, M., Cirillo, P., Ogay, A. (2019), "Computing the exact distributions of some functions of the ordered multinomial counts: maximum, minimum, range and sums of order statistics", Royal Society Open Science, 6: 190198, [doi:10.1098/rsos.190198](https://doi.org/10.1098/rsos.190198).

**See Also**

[pmax\\_2\\_incr](#) for the opposite calculation.

### Examples

```
m <- 3:50
incr <- seq(0, 1, 0.01)
pmax <- incr_2_pmax(m, incr)
summary(as.numeric(pmax))
```

---

leukaemia

*Data: Leukaemia cases*

---

### Description

This is a well-known epidemiological dataset of diagnosed leukaemia cases over eight counties in upstate New York. These data originated from the New York State Cancer Registry, and were gathered during the 5-year period 1978-1982, with a total of 584 individuals diagnosed with leukaemia over a population of approximately 1 million people. The original data contain spatial information about registered events split into 790 census tracts.

### Usage

```
data(leukaemia)
```

### Format

A data frame with 790 observations and the following 5 variables:

- ID (int): 10 character long identification number for a cell or census district in the study area
- x (num): x-coordinate of the geographic centroid of each cell
- y (num): y-coordinate of the geographic centroid of each cell
- pop (int): 1980 U.S. Census population count for each cell
- cases (num): incident cases of leukemia (all types) occurring between 1978 and 1982 in each cell; fractional values can occur due to partially missing data

### Source

The data set has been downloaded from <https://www.stats.ox.ac.uk/pub/datasets/csb/>.

### References

Lange, N., Ryan, L., Billard, L., Brillinger, D., Conquest, L., Greenhouse, J. (1994), "Case Studies in Biometry", Hoboken, NJ: Wiley & Sons.

---

mainsail

*MAINSAIL trial: comparator-arm data with Halabi 2014 risk scores*


---

## Description

Baseline characteristics and Halabi (2014) prognostic linear predictor for the 520 patients randomised to the comparator arm (docetaxel plus prednisone) of the MAINSAIL trial (NCT00988208), a phase III study in metastatic castration-resistant prostate cancer (mCRPC). The dataset is used in [XOMultinom](#) to illustrate the sequential recalibration-alarm procedure described in Section~5.2 of the package paper.

## Usage

```
mainsail
```

## Format

A data frame with 520 rows and 21 variables:

**RPT** Character. Zero-padded patient identifier (e.g. `"00468"`).

**ENROLLDAY** Numeric. Randomisation day on the study-day scale (day 0 = study start). Ranges from  $-265$  to  $353$ ; used to derive `entry_order`.

**entry\_order** Integer. Patient's rank by ascending ENROLLDAY, from 1 (earliest randomised) to 520 (latest). Ties in ENROLLDAY are broken arbitrarily.

**ecog** Numeric. Eastern Cooperative Oncology Group (ECOG) performance status at baseline: 0 (fully active), 1 (restricted in strenuous activity), or 2 (ambulatory, capable of self-care only).

**disease\_site** Character. Halabi (2014) disease-site classification: `"ln_only"` (lymph-node involvement only,  $n = 89$ ) or `"visceral"` (any liver or lung metastasis,  $n = 350$ ). NA for 81 patients for whom disease site could not be determined from the available tumour-assessment records; all such patients have `has_bone = 0`.

**has\_ln** Integer. Binary indicator: 1 if lymph-node metastases were recorded at the screening visit, 0 otherwise.

**has\_bone** Integer. Binary indicator: 1 if bone metastases were recorded at the screening visit, 0 otherwise.

**has\_visceral** Integer. Binary indicator: 1 if visceral (liver or lung) metastases were recorded at the screening visit, 0 otherwise.

**opioid** Integer. Binary indicator: 1 if the patient was receiving opioid analgesics (ATC code N02A\*) at the time of randomisation, 0 otherwise.

**ldh** Numeric. Lactate dehydrogenase (LDH) at baseline, in U/L. Missing for 8 patients.

**ldh\_uln** Numeric. Upper limit of normal for LDH as recorded in the trial laboratory data. Constant at 250 U/L for all patients in this dataset.

**ldh\_gt\_uln** Integer. Binary indicator: 1 if `ldh > ldh_uln`, 0 otherwise. Complete for all 520 patients (missing `ldh` values were treated as not exceeding the ULN).

**albumin** Numeric. Serum albumin at baseline, in g/dL. Missing for 5 patients.

- hgb** Numeric. Haemoglobin at baseline, in g/dL. Missing for 16 patients.
- psa** Numeric. Prostate-specific antigen (PSA) at baseline, in ng/mL. Missing for 6 patients.
- alp** Numeric. Alkaline phosphatase (ALP) at baseline, in U/L. Missing for 8 patients.
- ln\_psa** Numeric. Natural logarithm of psa. Missing for the same 6 patients as psa.
- ln\_alp** Numeric. Natural logarithm of alp. Missing for the same 8 patients as alp.
- halabi2014\_lp** Numeric. Halabi (2014) linear predictor computed by strict listwise deletion: NA for any patient missing at least one of the ten model covariates (99 patients). Identical to halabi2014\_lp\_raw for the 421 complete cases.
- halabi2014\_lp\_raw** Numeric. Halabi (2014) linear predictor computed under partial listwise deletion: available for the 498 patients with complete laboratory values, regardless of disease\_site availability. For the 77 patients with missing disease\_site but complete labs, both disease\_site indicators are set to zero (equivalent to assigning the lymph-node-only reference category). NA for the 22 patients missing at least one laboratory value.
- halabi2014\_lp\_imputed** Numeric. Halabi (2014) linear predictor after single imputation: complete for all 520 patients. Continuous covariates (albumin, hgb, ln\_psa, ln\_alp) are imputed at their sample median; disease\_site is imputed at its sample mode ("visceral"). Used as the risk score in the sequential recalibration-alarm illustration of Section~5.2.

## Details

The MAINSAIL trial randomised 1059 patients with chemotherapy-naive mCRPC to docetaxel/prednisone with or without lenalidomide. Only the 520 patients on the comparator arm are included here. Patient entry order was determined by ENROLLDAY extracted from assignmt.sas7bdat in the Project Data Sphere release; all other covariates were extracted at or closest to the baseline visit. Full details of variable construction are given in Appendix~A of the package paper.

The Halabi (2014) linear predictor is defined as

$$\eta_i = \beta^\top \mathbf{x}_i,$$

where the regression coefficients  $\beta$  are the log-hazard ratios from Table~2 of Halabi et al. (2014); see vignette("recalibration", package = "XOMultinom") for the full specification.

## Source

Project Data Sphere, dataset identifier Prostat\CeIgene\\_2009\\_90 (<https://data.projectdatasphere.org/>). Access requires registration and acceptance of the Project Data Sphere terms of use.

## References

- Halabi, S., Lin, C.-Y., Kelly, W.K., Fizazi, K.S., Moul, J.W., Kaplan, E.B., Morris, M.J. and Small, E.J. (2014). Updated prognostic model for predicting overall survival in first-line chemotherapy for patients with metastatic castration-resistant prostate cancer. *Journal of Clinical Oncology*, **32**(7), 671–677. doi:10.1200/JCO.2013.52.3696
- Fizazi, K., Higano, C.S., Nelson, J.B., et al. (2013). Phase III, randomized, placebo-controlled study of docetaxel in combination with zibotentan in patients with metastatic castration-resistant prostate cancer. *Journal of Clinical Oncology*, **31**(14), 1740–1747. doi:10.1200/JCO.2012.46.4149

---

maxmin\_multinom\_size *Sample size determination for multinomial max/min tests*

---

### Description

Computes the required sample size to achieve a target power for hypothesis tests based on the maximum or minimum of a multinomial random vector under deviations from equiprobability.

### Usage

```
maxmin_multinom_size(
  m_seq,
  change_seq,
  power = 0.8,
  alpha = 0.05,
  n_max = 500,
  type,
  verbose = TRUE,
  optmethod = "uniroot",
  extendInt = "upX"
)
```

### Arguments

|            |   |
|------------|---|
| m_seq      | Integer vector of numbers of categories.                                |
| change_seq | Numeric vector of probability perturbations from the equiprobable case. |
| power      | Desired power level in (0, 1).  |
| alpha      | Significance level in (0, 1).   |
| n_max      | Maximum sample size considered in the search.                           |
| type       | Character string; either "max" or "min".                                |
| verbose    | Logical; if TRUE, progress messages are printed.                        |
| optmethod  | Character string; optimization method, either "uniroot" or "optimize".  |
| extendInt  | Passed to uniroot() when used.  |

### Details

The function evaluates the sample size needed to detect deviations from equiprobability with a given power, using tests based on either the maximum or minimum multinomial cell count.

### Value

A list where each element corresponds to a value of m\_seq and contains the required sample sizes for each value in change\_seq.

**Examples**

```

pow <- 0.8
alpha <- 0.05
m_seq <- 3:8
incr_seq <- seq(0.2, 0.8, 0.1)
res <- maxmin_multinom_size(m_seq, incr_seq, power = pow, alpha = alpha,
                           n_max = 200, type = "max",
                           verbose = TRUE, optmethod = "uniroot")

summary(res)
plot(res)

```

---

|                 |  |
|-----------------|--|
| pJlargemultinom | <i>CDF of the sum of J largest order statistics for a multinomial distribution</i> |
|-----------------|--|

---

**Description**

Computes the cumulative distribution function of the sum of  $J$  largest order statistics for a multinomial random vector with equal cell probabilities.

**Usage**

```
pJlargemultinom(x, size, prob, J = 2, log = FALSE, verbose = TRUE)
```

**Arguments**

|         |   |
|---------|---|
| x       | Numeric vector of values at which to evaluate the CDF.  |
| size    | Integer number of trials.   |
| prob    | Numeric vector of non-negative cell probabilities. Values are internally normalized to sum to 1. Categories with zero probability are removed before computation. |
| J       | Integer number of largest order statistics to consider. Defaults to 2.  |
| log     | Logical; if TRUE, returns log-probabilities.  |
| verbose | Logical; if TRUE, displays progress information during the computation.   |

**Details**

The function only implements the equiprobable case.

**Value**

An object of class `xomultinom_dist` with fields `x`, `values` (containing  $P(S_J \leq x)$ ,  $S_J = \sum_{j=1}^J N_{(j)}$ , or log-probabilities if `log = TRUE`), `stat = "J_largest"`, `type = "cdf"`, `size`, `prob`, and `log`.

## References

Bonetti, M., Cirillo, P., Ogay, A. (2019). Computing the exact distributions of some functions of the ordered multinomial counts: maximum, minimum, range and sums of order statistics. Royal Society Open Science, 6, 190198. doi:10.1098/rsos.190198

## See Also

[dJlargemultinom](#) for the PMF, [qJlargemultinom](#) for quantiles, and [rJlargemultinom](#) for random generation.

## Examples

```
m <- 4
n <- 60
probs <- rep(1 / m, m)
J <- 3
xseq <- 0:n

cdflarge <- pJlargemultinom(x = xseq, size = n, prob = probs, J = J)
plot(cdflarge)
```

---

plot.xomultinom\_dist *Plot method for xomultinom\_dist objects*

---

## Description

Produces a base R plot of the exact distribution stored in an `xomultinom_dist` object, compatible with `par(mfrow = ...)`, `layout()`, and all other base R multi-panel layout mechanisms. PMFs are displayed as spike (needle) charts; CDFs are displayed as step functions. An optional normal approximation overlay can be added for diagnostic comparison.

## Usage

```
## S3 method for class 'xomultinom_dist'
plot(
  x,
  add_approx = FALSE,
  col = "#2166ac",
  approx_col = "#d6604d",
  main = NULL,
  xlab = "x",
  ylab = NULL,
  ...
)
```

**Arguments**

|            |   |
|------------|---|
| x          | An object of class <code>xomultinom_dist</code> .   |
| add_approx | Logical; if TRUE, overlays the normal approximation to the distribution (mean and variance computed from the exact PMF). Defaults to FALSE. |
| col        | Character string; colour used for the exact distribution. Defaults to "#2166ac" (blue).   |
| approx_col | Character string; colour used for the approximation overlay when <code>add_approx = TRUE</code> . Defaults to "#d6604d" (red).              |
| main       | Character string; plot title. If NULL (default), a descriptive title is generated automatically.  |
| xlab       | Character string; x-axis label. Defaults to "x".  |
| ylab       | Character string; y-axis label. If NULL (default), an appropriate label is generated automatically.   |
| ...        | Further graphical parameters passed to the underlying base R plotting functions.  |

**Value**

Invisibly returns NULL.

**See Also**

[autoplot.xomultinom\\_dist](#) for a ggplot2-based alternative.

**Examples**

```
k <- 5; n <- 40
obj_pmf <- dmaxmultinom(x = 0:n, size = n, prob = rep(1/k, k))
obj_cdf <- pmaxmultinom(x = 0:n, size = n, prob = rep(1/k, k))

# Compatible with par(mfrow = ...)
op <- par(mfrow = c(1, 2))
plot(obj_pmf)
plot(obj_cdf)
par(op)
```

---

plot.xomultinom\_size *Plot method for xomultinom\_size objects*

---

**Description**

Produces a base R line chart of the required sample size as a function of the probability perturbation, with one line per value of  $m$  (number of categories), compatible with `par(mfrow = ...)`, `layout()`, and all other base R multi-panel layout mechanisms.

**Usage**

```
## S3 method for class 'xomultinom_size'
plot(
  x,
  log_scale = FALSE,
  col = NULL,
  main = NULL,
  xlab = NULL,
  ylab = "Required n",
  ...
)
```

**Arguments**

|                        |  |
|------------------------|--|
| <code>x</code>         | An object of class <code>xomultinom_size</code> .  |
| <code>log_scale</code> | Logical; if TRUE, the $y$ -axis (required $n$ ) is displayed on a $\log_{10}$ scale. Useful when $n$ varies over several orders of magnitude. Defaults to FALSE. |
| <code>col</code>       | Character vector of colours, one per value of <code>m_seq</code> . If NULL (default), colours are taken from the default R palette.                              |
| <code>main</code>      | Character string; plot title. If NULL (default), a descriptive title is generated automatically.   |
| <code>xlab</code>      | Character string; x-axis label. If NULL (default), an appropriate label is generated automatically.  |
| <code>ylab</code>      | Character string; y-axis label. Defaults to "Required n".  |
| <code>...</code>       | Further graphical parameters passed to the underlying base R plotting functions.   |

**Value**

Invisibly returns NULL.

**See Also**

[autoplot.xomultinom\\_size](#) for a ggplot2-based alternative.

**Examples**

```
sz <- maxmin_multinom_size(
  m_seq = c(5, 10, 20), change_seq = seq(0.10, 0.30, by = 0.05),
  power = 0.80, alpha = 0.05, type = "max"
)

# Compatible with par(mfrow = ...)
op <- par(mfrow = c(1, 2))
plot(sz)
plot(sz, log_scale = TRUE)
par(op)
```

---

pmax\_2\_incr

*Utility function.*

---

### Description

This is an auxiliary function to compute the increment as the distance from the case of equiprobability.

### Usage

```
pmax_2_incr(m, pmax)
```

### Arguments

**m** An integer vector of numbers of multinomial classes.  
**pmax** A numeric vector of probability values for which to compute the increments.

### Value

A numeric matrix.

### Author(s)

Sergio Venturini <sergio.venturini@unicatt.it>

### References

Bonetti, M., Cirillo, P., Ogay, A. (2019), "Computing the exact distributions of some functions of the ordered multinomial counts: maximum, minimum, range and sums of order statistics", Royal Society Open Science, 6: 190198, [doi:10.1098/rsos.190198](https://doi.org/10.1098/rsos.190198).

### See Also

[incr\\_2\\_pmax](#) for the opposite calculation.

### Examples

```
m <- 3:50
pmax <- seq(0.05, 1, 0.05)
incr <- pmax_2_incr(m, pmax)
summary(as.numeric(incr))
```

---

pmaxmultinom *CDF of the maximum for a multinomial distribution*

---

### Description

Computes the cumulative distribution function of the maximum cell count of a multinomial random vector with arbitrary cell probabilities.

### Usage

```
pmaxmultinom(x, size, prob, log = FALSE, verbose = TRUE)
```

### Arguments

|         |   |
|---------|---|
| x       | Numeric vector of values at which to evaluate the CDF.  |
| size    | Integer number of trials.   |
| prob    | Numeric vector of non-negative cell probabilities. Values are internally normalized to sum to 1. Categories with zero probability are removed before computation. |
| log     | Logical; if TRUE, returns log-probabilities.  |
| verbose | Logical; if TRUE, displays progress information during the computation.   |

### Details

The function first checks whether prob corresponds to the equiprobable case and then applies either the Bonetti et al. (2019) algorithm or the Corrado (2011) algorithm accordingly.

### Value

An object of class `xomultinom_dist` with fields `x`, `values` (containing  $P(\max(N_1, \dots, N_m) \leq x)$ , or log-probabilities if `log = TRUE`), `stat = "max"`, `type = "cdf"`, `size`, `prob`, and `log`.

### References

Bonetti, M., Cirillo, P., Ogay, A. (2019). Computing the exact distributions of some functions of the ordered multinomial counts: maximum, minimum, range and sums of order statistics. *Royal Society Open Science*, 6, 190198. doi:10.1098/rsos.190198

Corrado, C.J. (2011). The exact distribution of the maximum, minimum and the range of Multinomial/Dirichlet and Multivariate Hypergeometric frequencies. *Statistical Computing*, 21, 349–359. doi:10.1007/s1122201091743

### See Also

[pminmultinom](#) for the CDF of the minimum, [dmaxmultinom](#) for the PMF of the maximum, and [dminmultinom](#) for the PMF of the minimum.

**Examples**

```
m <- 4
n <- 60
probs <- rep(1 / m, m)
xseq <- 0:n

cdfmax <- pmaxmultinom(x = xseq, size = n, prob = probs)
plot(cdfmax)
```

---

pmin\_2\_decr

*Utility function.*

---

**Description**

This is an auxiliary function to compute the decrement as the distance from the case of equiprobability.

**Usage**

```
pmin_2_decr(m, pmin)
```

**Arguments**

**m** An integer vector of numbers of multinomial classes.

**pmin** A numeric vector of probability values for which to compute the decrements.

**Value**

A numeric matrix.

**Author(s)**

Sergio Venturini <sergio.venturini@unicatt.it>

**References**

Bonetti, M., Cirillo, P., Ogay, A. (2019), "Computing the exact distributions of some functions of the ordered multinomial counts: maximum, minimum, range and sums of order statistics", Royal Society Open Science, 6: 190198, [doi:10.1098/rsos.190198](https://doi.org/10.1098/rsos.190198).

**See Also**

[decr\\_2\\_pmin](#) for the opposite calculation.

**Examples**

```
m <- 3:50
pmin <- seq(0.05, 1, 0.05)
decr <- pmin_2_decr(m, pmin)
summary(as.numeric(decr))
```

pminmultinom

*CDF of the minimum for a multinomial distribution***Description**

Computes the cumulative distribution function of the minimum cell count of a multinomial random vector with arbitrary cell probabilities.

**Usage**

```
pminmultinom(x, size, prob, log = FALSE, verbose = TRUE)
```

**Arguments**

|         |   |
|---------|---|
| x       | Numeric vector of values at which to evaluate the CDF.  |
| size    | Integer number of trials.   |
| prob    | Numeric vector of non-negative cell probabilities. Values are internally normalized to sum to 1. Categories with zero probability are removed before computation. |
| log     | Logical; if TRUE, returns log-probabilities.  |
| verbose | Logical; if TRUE, displays progress information during the computation.   |

**Details**

The function first checks whether prob corresponds to the equiprobable case and then applies either the Bonetti et al. (2019) algorithm or the Corrado (2011) algorithm accordingly.

**Value**

An object of class `xomultinom_dist` with fields `x`, `values` (containing  $P(\min(N_1, \dots, N_m) \leq x)$ , or log-probabilities if `log = TRUE`), `stat = "min"`, `type = "cdf"`, `size`, `prob`, and `log`.

**References**

Bonetti, M., Cirillo, P., Ogay, A. (2019). Computing the exact distributions of some functions of the ordered multinomial counts: maximum, minimum, range and sums of order statistics. *Royal Society Open Science*, 6, 190198. doi:10.1098/rsos.190198

Corrado, C.J. (2011). The exact distribution of the maximum, minimum and the range of Multinomial/Dirichlet and Multivariate Hypergeometric frequencies. *Statistical Computing*, 21, 349–359. doi:10.1007/s1122201091743

**See Also**

[pmaxmultinom](#) for the CDF of the maximum, [dminmultinom](#) for the PMF of the minimum, and [drangemultinom](#) for the PMF of the range.

**Examples**

```
m <- 4
n <- 60
probs <- rep(1 / m, m)
xseq <- 0:n

cdfmin <- pminmultinom(x = xseq, size = n, prob = probs)
plot(cdfmin)
```

---

|                |  |
|----------------|--|
| prangemultinom | <i>CDF of the range for a multinomial distribution</i> |
|----------------|--|

---

**Description**

Computes the cumulative distribution function of the range  $R = \max(N_1, \dots, N_m) - \min(N_1, \dots, N_m)$  for a multinomial random vector with arbitrary cell probabilities.

**Usage**

```
prangemultinom(x, size, prob, log = FALSE, verbose = TRUE)
```

**Arguments**

|         |   |
|---------|---|
| x       | Numeric vector of values at which to evaluate the CDF.  |
| size    | Integer number of trials.   |
| prob    | Numeric vector of non-negative cell probabilities. Values are internally normalized to sum to 1. Categories with zero probability are removed before computation. |
| log     | Logical; if TRUE, returns log-probabilities.  |
| verbose | Logical; if TRUE, displays progress information during the computation.   |

**Details**

The function first checks whether prob corresponds to the equiprobable case and then applies either the Bonetti et al. (2019) algorithm or the Corrado (2011) algorithm accordingly.

**Value**

An object of class `xomultinom_dist` with fields `x`, `values` (containing  $P(R \leq x)$ ), or log-probabilities if `log = TRUE`), `stat = "range"`, `type = "cdf"`, `size`, `prob`, and `log`.

## References

Bonetti, M., Cirillo, P., Ogay, A. (2019). Computing the exact distributions of some functions of the ordered multinomial counts: maximum, minimum, range and sums of order statistics. *Royal Society Open Science*, 6, 190198. doi:10.1098/rsos.190198

Corrado, C.J. (2011). The exact distribution of the maximum, minimum and the range of Multinomial/Dirichlet and Multivariate Hypergeometric frequencies. *Statistical Computing*, 21, 349–359. doi:10.1007/s1122201091743

## See Also

[drangemultinom](#) for the PMF of the range, [pmaxmultinom](#) for the CDF of the maximum, and [pminmultinom](#) for the CDF of the minimum.

## Examples

```
m <- 4
n <- 60
probs <- rep(1 / m, m)
xseq <- 0:n

cdfrange <- prangemultinom(x = xseq, size = n, prob = probs)
plot(cdfrange)
```

---

print.xomultinom\_dist *Print method for xomultinom\_dist objects*

---

## Description

Displays a compact, human-readable table of evaluation points and the corresponding exact probabilities (or log-probabilities) stored in an xomultinom\_dist object.

## Usage

```
## S3 method for class 'xomultinom_dist'
print(x, digits = 4, max_rows = 20, ...)
```

## Arguments

|          |   |
|----------|---|
| x        | An object of class xomultinom_dist.   |
| digits   | Integer number of significant digits for probabilities. Defaults to 4.  |
| max_rows | Maximum number of rows to display when the support is large. If the number of evaluation points exceeds max_rows, the first and last max_rows / 2 rows are shown with an ellipsis in between. Defaults to 20. |
| ...      | Further arguments passed to or from other methods (currently unused).   |

**Value**

Invisibly returns x.

**Examples**

```
k <- 5; n <- 40
obj <- dmaxmultinom(x = 0:n, size = n, prob = rep(1/k, k))
print(obj)
```

---

print.xomultinom\_size *Print method for xomultinom\_size objects*

---

**Description**

Displays the required sample sizes as a formatted table, one block per number of categories  $m$ .

**Usage**

```
## S3 method for class 'xomultinom_size'
print(x, digits = 4, ...)
```

**Arguments**

|        |  |
|--------|--|
| x      | An object of class xomultinom_size.                                      |
| digits | Integer number of decimal places for probability columns. Defaults to 4. |
| ...    | Further arguments passed to or from other methods (currently unused).    |

**Value**

Invisibly returns x.

**Examples**

```
sz <- maxmin_multinom_size(
  m_seq = c(5, 10), change_seq = c(0.10, 0.15, 0.20),
  power = 0.80, alpha = 0.05, type = "max"
)
print(sz)
```

---

|                 |   |
|-----------------|---|
| qJlargemultinom | <i>Quantile function of the sum of <math>J</math> largest order statistics for a multinomial distribution</i> |
|-----------------|---|

---

### Description

Computes exact quantiles of the distribution of the sum of the  $J$  largest order statistics  $S_J = \sum_{j=1}^J N_{(j)}$  of a multinomial random vector with equal cell probabilities, by inverting the exact CDF obtained from [pJlargemultinom](#).

### Usage

```
qJlargemultinom(p, size, prob, J = 2, lower.tail = TRUE, log.p = FALSE)
```

### Arguments

|            |  |
|------------|--|
| p          | Numeric vector of probabilities (or log-probabilities if <code>log.p = TRUE</code> ) at which to evaluate the quantile function.   |
| size       | Integer number of trials.  |
| prob       | Numeric vector of non-negative, equal cell probabilities. Only the equiprobable case is supported; a non-equiprobable prob will raise an error (propagated from <a href="#">pJlargemultinom</a> ). |
| J          | Integer number of largest order statistics to sum. Defaults to 2.  |
| lower.tail | Logical; if TRUE (default), $Q(p) = \min\{x : F(x) \geq p\}$ ; if FALSE, $Q(p) = \min\{x : F(x) \geq 1 - p\}$ .  |
| log.p      | Logical; if TRUE, p is taken to be on the log scale. Defaults to FALSE.  |

### Details

The function obtains the exact CDF over the full support  $\{0, 1, \dots, n\}$  via a single vectorised call to [pJlargemultinom](#). The quantile is then located as the smallest support point whose CDF value meets or exceeds p. Only the equiprobable case is supported, consistent with [pJlargemultinom](#).

### Value

Integer vector of the same length as p containing the corresponding exact quantiles of  $S_J$ .

### References

Bonetti, M., Cirillo, P., Ogay, A. (2019). Computing the exact distributions of some functions of the ordered multinomial counts: maximum, minimum, range and sums of order statistics. Royal Society Open Science, 6, 190198. [doi:10.1098/rsos.190198](https://doi.org/10.1098/rsos.190198)

### See Also

[pJlargemultinom](#) for the CDF, [dJlargemultinom](#) for the PMF, [rJlargemultinom](#) for random generation.

**Examples**

```

m <- 4
n <- 60
probs <- rep(1 / m, m)

# Median and 95th percentile of S_3
qJlargemultinom(c(0.5, 0.95), size = n, prob = probs, J = 3)

# Upper tail
qJlargemultinom(0.05, size = n, prob = probs, J = 3, lower.tail = FALSE)

```

---

qmaxmultinom

*Quantile function of the maximum for a multinomial distribution*


---

**Description**

Computes exact quantiles of the distribution of the maximum cell count of a multinomial random vector with arbitrary cell probabilities, by inverting the exact CDF obtained from [pmaxmultinom](#).

**Usage**

```
qmaxmultinom(p, size, prob, lower.tail = TRUE, log.p = FALSE)
```

**Arguments**

|            |   |
|------------|---|
| p          | Numeric vector of probabilities (or log-probabilities if <code>log.p = TRUE</code> ) at which to evaluate the quantile function.                                  |
| size       | Integer number of trials.   |
| prob       | Numeric vector of non-negative cell probabilities. Values are internally normalized to sum to 1. Categories with zero probability are removed before computation. |
| lower.tail | Logical; if TRUE (default), $Q(p) = \min\{x : F(x) \geq p\}$ ; if FALSE, $Q(p) = \min\{x : F(x) \geq 1 - p\}$ .   |
| log.p      | Logical; if TRUE, p is taken to be on the log scale. Defaults to FALSE.   |

**Details**

The function obtains the exact CDF over the full support  $\{0, 1, \dots, n\}$  via a single vectorised call to [pmaxmultinom](#), which dispatches internally to the Bonetti et al. (2019) algorithm for equiprobable prob and to the Corrado (2011) algorithm otherwise. The quantile is then located as the smallest support point whose CDF value meets or exceeds p, an  $O(n)$  lookup requiring no root-finding or approximation.

**Value**

Integer vector of the same length as p containing the corresponding exact quantiles of the multinomial maximum.

## References

Bonetti, M., Cirillo, P., Ogay, A. (2019). Computing the exact distributions of some functions of the ordered multinomial counts: maximum, minimum, range and sums of order statistics. *Royal Society Open Science*, 6, 190198. doi:10.1098/rsos.190198

Corrado, C.J. (2011). The exact distribution of the maximum, minimum and the range of Multinomial/Dirichlet and Multivariate Hypergeometric frequencies. *Statistical Computing*, 21, 349–359. doi:10.1007/s1122201091743

## See Also

[pmaxmultinom](#) for the CDF, [dmaxmultinom](#) for the PMF, [rmaxmultinom](#) for random generation.

## Examples

```
m <- 4
n <- 60
probs <- rep(1 / m, m)

# Median and 95th percentile
qmaxmultinom(c(0.5, 0.95), size = n, prob = probs)

# Upper tail
qmaxmultinom(0.05, size = n, prob = probs, lower.tail = FALSE)
```

---

qminmultinom

*Quantile function of the minimum for a multinomial distribution*

---

## Description

Computes exact quantiles of the distribution of the minimum cell count of a multinomial random vector with arbitrary cell probabilities, by inverting the exact CDF obtained from [pminmultinom](#).

## Usage

```
qminmultinom(p, size, prob, lower.tail = TRUE, log.p = FALSE)
```

## Arguments

|            |   |
|------------|---|
| p          | Numeric vector of probabilities (or log-probabilities if <code>log.p = TRUE</code> ) at which to evaluate the quantile function.                                  |
| size       | Integer number of trials.   |
| prob       | Numeric vector of non-negative cell probabilities. Values are internally normalized to sum to 1. Categories with zero probability are removed before computation. |
| lower.tail | Logical; if TRUE (default), $Q(p) = \min\{x : F(x) \geq p\}$ ; if FALSE, $Q(p) = \min\{x : F(x) \geq 1 - p\}$ .   |
| log.p      | Logical; if TRUE, p is taken to be on the log scale. Defaults to FALSE.   |

**Details**

The function obtains the exact CDF over the full support  $\{0, 1, \dots, n\}$  via a single vectorised call to `pminmultinom`, which dispatches internally to the Bonetti et al. (2019) algorithm for equiprobable prob and to the Corrado (2011) algorithm otherwise. The quantile is then located as the smallest support point whose CDF value meets or exceeds  $p$ , an  $O(n)$  lookup requiring no root-finding or approximation.

**Value**

Integer vector of the same length as  $p$  containing the corresponding exact quantiles of the multinomial minimum.

**References**

Bonetti, M., Cirillo, P., Ogay, A. (2019). Computing the exact distributions of some functions of the ordered multinomial counts: maximum, minimum, range and sums of order statistics. *Royal Society Open Science*, 6, 190198. doi:10.1098/rsos.190198

Corrado, C.J. (2011). The exact distribution of the maximum, minimum and the range of Multinomial/Dirichlet and Multivariate Hypergeometric frequencies. *Statistical Computing*, 21, 349–359. doi:10.1007/s1122201091743

**See Also**

`pminmultinom` for the CDF, `dminmultinom` for the PMF, `rminmultinom` for random generation.

**Examples**

```
m <- 4
n <- 60
probs <- rep(1 / m, m)

# Median and 95th percentile
qminmultinom(c(0.5, 0.95), size = n, prob = probs)

# Upper tail
qminmultinom(0.05, size = n, prob = probs, lower.tail = FALSE)
```

---

qrangemultinom

*Quantile function of the range for a multinomial distribution*


---

**Description**

Computes exact quantiles of the distribution of the range  $R = \max(N_1, \dots, N_m) - \min(N_1, \dots, N_m)$  of a multinomial random vector with arbitrary cell probabilities, by inverting the exact CDF obtained from `prangemultinom`.

**Usage**

```
qrangemultinom(p, size, prob, lower.tail = TRUE, log.p = FALSE)
```

**Arguments**

|                         |   |
|-------------------------|---|
| <code>p</code>          | Numeric vector of probabilities (or log-probabilities if <code>log.p = TRUE</code> ) at which to evaluate the quantile function.                                  |
| <code>size</code>       | Integer number of trials.   |
| <code>prob</code>       | Numeric vector of non-negative cell probabilities. Values are internally normalized to sum to 1. Categories with zero probability are removed before computation. |
| <code>lower.tail</code> | Logical; if TRUE (default), $Q(p) = \min\{x : F(x) \geq p\}$ ; if FALSE, $Q(p) = \min\{x : F(x) \geq 1 - p\}$ .   |
| <code>log.p</code>      | Logical; if TRUE, <code>p</code> is taken to be on the log scale. Defaults to FALSE.  |

**Details**

The function obtains the exact CDF over the full support  $\{0, 1, \dots, n\}$  via a single vectorised call to [prangemultinom](#), which dispatches internally to the Bonetti et al. (2019) algorithm for equiprobable `prob` and to the Corrado (2011) algorithm otherwise. The quantile is then located as the smallest support point whose CDF value meets or exceeds `p`, an  $O(n)$  lookup requiring no root-finding or approximation.

**Value**

Integer vector of the same length as `p` containing the corresponding exact quantiles of the multinomial range.

**References**

Bonetti, M., Cirillo, P., Ogay, A. (2019). Computing the exact distributions of some functions of the ordered multinomial counts: maximum, minimum, range and sums of order statistics. Royal Society Open Science, 6, 190198. [doi:10.1098/rsos.190198](https://doi.org/10.1098/rsos.190198)

Corrado, C.J. (2011). The exact distribution of the maximum, minimum and the range of Multinomial/Dirichlet and Multivariate Hypergeometric frequencies. Statistical Computing, 21, 349–359. [doi:10.1007/s1122201091743](https://doi.org/10.1007/s1122201091743)

**See Also**

[prangemultinom](#) for the CDF, [drangemultinom](#) for the PMF, [rrangemultinom](#) for random generation.

**Examples**

```
m <- 4
n <- 60
probs <- rep(1 / m, m)
```

```
# Median and 95th percentile
qrangemultinom(c(0.5, 0.95), size = n, prob = probs)

# Upper tail
qrangemultinom(0.05, size = n, prob = probs, lower.tail = FALSE)
```

---

rdirichlet

*Random generation from a Dirichlet distribution*

---

### Description

Generates random samples from a Dirichlet distribution using gamma variates.

### Usage

```
rdirichlet(n, alpha)
```

### Arguments

|       |  |
|-------|--|
| n     | Integer number of observations to generate.                    |
| alpha | Numeric vector or matrix of positive concentration parameters. |

### Details

Each sample is obtained by drawing independent gamma random variables and normalizing them to sum to one. If alpha is a vector, it is recycled across rows.

### Value

A numeric matrix with n rows, where each row is a sample from the Dirichlet distribution and sums to 1.

### Examples

```
rdirichlet(5, c(1, 1, 1))
rdirichlet(3, c(2, 5, 3))
```

---

|                 |   |
|-----------------|---|
| rJlargemultinom | <i>Random generation from the distribution of the sum of <math>J</math> largest order statistics for a multinomial distribution</i> |
|-----------------|---|

---

### Description

Draws independent random samples from the exact distribution of  $S_J = \sum_{j=1}^J N_{(j)}$  for a multinomial random vector with equal cell probabilities.

### Usage

```
rJlargemultinom(n, size, prob, J = 2)
```

### Arguments

|      |  |
|------|--|
| n    | Integer number of random samples to draw.  |
| size | Integer number of trials in each multinomial experiment.   |
| prob | Numeric vector of non-negative, equal cell probabilities. Only the equiprobable case is supported; a non-equiprobable prob will raise an error (propagated from <a href="#">dJlargemultinom</a> ). |
| J    | Integer number of largest order statistics to sum. Defaults to 2.  |

### Details

The exact PMF over the support  $\{0, 1, \dots, \text{size}\}$  is computed once using [dJlargemultinom](#), and  $n$  independent draws are then obtained via [sample](#) with those probabilities as weights. Only the equiprobable case is supported, consistent with [dJlargemultinom](#).

### Value

Integer vector of length  $n$  containing independent draws from the distribution of  $S_J$ .

### References

Bonetti, M., Cirillo, P., Ogay, A. (2019). Computing the exact distributions of some functions of the ordered multinomial counts: maximum, minimum, range and sums of order statistics. Royal Society Open Science, 6, 190198. [doi:10.1098/rsos.190198](https://doi.org/10.1098/rsos.190198)

### See Also

[dJlargemultinom](#) for the PMF, [pJlargemultinom](#) for the CDF, [qJlargemultinom](#) for quantiles.

**Examples**

```

m <- 4; n <- 60
probs <- rep(1 / m, m)

set.seed(42)
sims <- rJlargemultinom(n = 1000, size = n, prob = probs, J = 3)
hist(sims, breaks = 20, main = "Simulated sums of 3 largest order statistics")

```

---

rmaxmultinom

*Random generation from the distribution of the multinomial maximum*


---

**Description**

Draws independent random samples from the exact distribution of the maximum cell count of a multinomial random vector with arbitrary cell probabilities.

**Usage**

```
rmaxmultinom(n, size, prob)
```

**Arguments**

|      |   |
|------|---|
| n    | Integer number of random samples to draw.   |
| size | Integer number of trials in each multinomial experiment.  |
| prob | Numeric vector of non-negative cell probabilities. Values are internally normalized to sum to 1. Categories with zero probability are removed before computation. |

**Details**

The exact PMF over the support  $\{0, 1, \dots, \text{size}\}$  is computed once using `dmaxmultinom`, and  $n$  independent draws are then obtained via `sample` with those probabilities as weights. The cost is therefore dominated by the single PMF evaluation and is independent of  $n$ .

**Value**

Integer vector of length  $n$  containing independent draws from the distribution of  $\max(N_1, \dots, N_m)$ .

**References**

Bonetti, M., Cirillo, P., Ogay, A. (2019). Computing the exact distributions of some functions of the ordered multinomial counts: maximum, minimum, range and sums of order statistics. *Royal Society Open Science*, 6, 190198. doi:10.1098/rsos.190198

Corrado, C.J. (2011). The exact distribution of the maximum, minimum and the range of Multinomial/Dirichlet and Multivariate Hypergeometric frequencies. *Statistical Computing*, 21, 349–359. doi:10.1007/s1122201091743

**See Also**

[dmaxmultinom](#) for the PMF, [pmaxmultinom](#) for the CDF, [qmaxmultinom](#) for quantiles.

**Examples**

```
m <- 4; n <- 60
probs <- rep(1 / m, m)

set.seed(42)
sims <- rmaxmultinom(n = 1000, size = n, prob = probs)
hist(sims, breaks = 20, main = "Simulated multinomial maxima")

# Check against exact mean
mean(sims)
summary(dmaxmultinom(x = 0:n, size = n, prob = probs))$mean
```

---

rminmultinom

*Random generation from the distribution of the multinomial minimum*


---

**Description**

Draws independent random samples from the exact distribution of the minimum cell count of a multinomial random vector with arbitrary cell probabilities.

**Usage**

```
rminmultinom(n, size, prob)
```

**Arguments**

|      |   |
|------|---|
| n    | Integer number of random samples to draw.   |
| size | Integer number of trials in each multinomial experiment.  |
| prob | Numeric vector of non-negative cell probabilities. Values are internally normalized to sum to 1. Categories with zero probability are removed before computation. |

**Details**

The exact PMF over the support  $\{0, 1, \dots, \text{size}\}$  is computed once using [dminmultinom](#), and  $n$  independent draws are then obtained via [sample](#) with those probabilities as weights. The cost is therefore dominated by the single PMF evaluation and is independent of  $n$ .

**Value**

Integer vector of length  $n$  containing independent draws from the distribution of  $\min(N_1, \dots, N_m)$ .

## References

Bonetti, M., Cirillo, P., Ogay, A. (2019). Computing the exact distributions of some functions of the ordered multinomial counts: maximum, minimum, range and sums of order statistics. *Royal Society Open Science*, 6, 190198. doi:10.1098/rsos.190198

Corrado, C.J. (2011). The exact distribution of the maximum, minimum and the range of Multinomial/Dirichlet and Multivariate Hypergeometric frequencies. *Statistical Computing*, 21, 349–359. doi:10.1007/s1122201091743

## See Also

[dminmultinom](#) for the PMF, [pminmultinom](#) for the CDF, [qminmultinom](#) for quantiles.

## Examples

```
m <- 4; n <- 60
probs <- rep(1 / m, m)

set.seed(42)
sims <- rminmultinom(n = 1000, size = n, prob = probs)
hist(sims, breaks = 20, main = "Simulated multinomial minima")
```

---

|             |                                 |
|-------------|---------------------------------|
| round_exact | <i>Stable rounding function</i> |
|-------------|---------------------------------|

---

## Description

Rounds numeric values while avoiding floating-point artifacts by applying a small offset before rounding.

## Usage

```
round_exact(x, digits = 0)
```

## Arguments

|        |   |
|--------|---|
| x      | Numeric vector.                               |
| digits | Integer number of decimal places to round to. |

## Details

A small perturbation proportional to the sign of x is added before rounding to mitigate issues due to floating-point representation.

## Value

Numeric vector of rounded values.

**Examples**

```
round_exact(0.145, 2)
round_exact(c(1.005, -1.005), 2)
```

---

rrangemultinom

*Random generation from the distribution of the multinomial range*


---

**Description**

Draws independent random samples from the exact distribution of the range  $R = \max(N_1, \dots, N_m) - \min(N_1, \dots, N_m)$  of a multinomial random vector with arbitrary cell probabilities.

**Usage**

```
rrangemultinom(n, size, prob)
```

**Arguments**

|      |   |
|------|---|
| n    | Integer number of random samples to draw.   |
| size | Integer number of trials in each multinomial experiment.  |
| prob | Numeric vector of non-negative cell probabilities. Values are internally normalized to sum to 1. Categories with zero probability are removed before computation. |

**Details**

The exact PMF over the support  $\{0, 1, \dots, \text{size}\}$  is computed once using [drangemultinom](#), and  $n$  independent draws are then obtained via [sample](#) with those probabilities as weights. The cost is therefore dominated by the single PMF evaluation and is independent of  $n$ .

**Value**

Integer vector of length  $n$  containing independent draws from the distribution of  $R$ .

**References**

Bonetti, M., Cirillo, P., Ogay, A. (2019). Computing the exact distributions of some functions of the ordered multinomial counts: maximum, minimum, range and sums of order statistics. Royal Society Open Science, 6, 190198. [doi:10.1098/rsos.190198](https://doi.org/10.1098/rsos.190198)

Corrado, C.J. (2011). The exact distribution of the maximum, minimum and the range of Multinomial/Dirichlet and Multivariate Hypergeometric frequencies. Statistical Computing, 21, 349–359. [doi:10.1007/s1122201091743](https://doi.org/10.1007/s1122201091743)

**See Also**

[drangemultinom](#) for the PMF, [prangemultinom](#) for the CDF, [qrangemultinom](#) for quantiles.

## Examples

```
m <- 4; n <- 60
probs <- rep(1 / m, m)

set.seed(42)
sims <- rrangemultinom(n = 1000, size = n, prob = probs)
hist(sims, breaks = 20, main = "Simulated multinomial ranges")
```

---

summary.xomultinom\_dist

*Summary method for xomultinom\_dist objects*

---

## Description

Computes and displays descriptive statistics of the exact distribution stored in an `xomultinom_dist` object, including the mean, median, mode, standard deviation, effective support, and a central 95% interval.

## Usage

```
## S3 method for class 'xomultinom_dist'
summary(object, digits = 4, ...)
```

## Arguments

|                     |   |
|---------------------|---|
| <code>object</code> | An object of class <code>xomultinom_dist</code> .                     |
| <code>digits</code> | Integer number of significant digits. Defaults to 4.                  |
| <code>...</code>    | Further arguments passed to or from other methods (currently unused). |

## Value

Invisibly returns a named list with components `mean`, `median`, `mode`, `sd`, `var`, `support`, `q025`, and `q975`.

## Examples

```
k <- 5; n <- 40
obj <- pmaxmultinom(x = 0:n, size = n, prob = rep(1/k, k))
summary(obj)
```

---

`summary.xomultinom_size`*Summary method for xomultinom\_size objects*

---

**Description**

Prints a condensed overview of the required sample sizes across all combinations of  $m$  and probability perturbations, reporting the range of  $n$  for each  $m$ .

**Usage**

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

**Arguments**

|                     |   |
|---------------------|---|
| <code>object</code> | An object of class <code>xomultinom_size</code> .                     |
| <code>...</code>    | Further arguments passed to or from other methods (currently unused). |

**Value**

Invisibly returns a named list where each element corresponds to a value of  $m$  and contains `n_min`, `n_max`, and `n_median`.

**Examples**

```
sz <- maxmin_multinom_size(  
  m_seq = c(5, 10), change_seq = c(0.10, 0.15, 0.20),  
  power = 0.80, alpha = 0.05, type = "max"  
)  
summary(sz)
```

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