Package ‘errors’

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Documentation about 'errors' is provided in the paper by Ucar, Pebesma & Azcorra (2018, <doi:10.32614/RJ-2018-075>), included in this package as a vignette; see 'citation("errors")' for details.

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**errors-package**  
**errors**: Uncertainty Propagation for R Vectors

**Description**

Support for measurement errors in R vectors, matrices and arrays: automatic uncertainty propagation and reporting.

**Details**

Every measurement has an unknown error associated. Uncertainty is the acknowledgement of that error: we are aware that our representation of reality may differ from reality itself. This package provides support for measurement errors in R vectors, matrices and arrays. Uncertainty metadata is associated to quantity values (see `errors`), and this uncertainty is automatically propagated when you operate with `errors` objects (see `groupGeneric.errors`), or with `errors` and numeric objects (then numeric values are automatically coerced to `errors` objects with no uncertainty).

Correlations between measurements are also supported. In particular, any operation (e.g., `z <- x + y`) results in a correlation between output and input variables (i.e., `z` is correlated to `x` and `y`, even if there was no correlation between `x` and `y`). And in general, the user can establish correlations between any pair of variables (see `correl`).

This package treats uncertainty as coming from Gaussian and linear sources (note that, even for non-Gaussian non-linear sources, this is a reasonable assumption for averages of many measurements),
and propagates them using the first-order Taylor series method for propagation of uncertainty. Although the above assumptions are valid in a wide range of applications in science and engineering, the practitioner should evaluate whether they apply for each particular case.

Author(s)
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References

See Also
`datasets` for a description of the datasets used in the examples below.

Examples

```r
## Simultaneous resistance and reactance measurements

# Obtain mean values and uncertainty from measured values
V <- mean(set_errors(GUM.H.2$V))
I <- mean(set_errors(GUM.H.2$I))
phi <- mean(set_errors(GUM.H.2$phi))

# Set correlations between variables
correl(V, I) <- with(GUM.H.2, cor(V, I))
correl(V, phi) <- with(GUM.H.2, cor(V, phi))
correl(I, phi) <- with(GUM.H.2, cor(I, phi))

# Computation of resistance, reactance and impedance values
(R <- (V / I) * cos(phi))
(X <- (V / I) * sin(phi))
(Z <- (V / I))

# Correlations between derived quantities
correl(R, X)
correl(R, Z)
correl(X, Z)

## Calibration of a thermometer

# Least-squares fit for a reference temperature of 20 degC
fit <- lm(bk ~ I(tk - 20), data = GUM.H.3)

# Extract coefficients and set correlation using the covariance matrix
y1 <- set_errors(coef(fit)[1], sqrt(vcov(fit)[1, 1]))
y2 <- set_errors(coef(fit)[2], sqrt(vcov(fit)[2, 2]))
covar(y1, y2) <- vcov(fit)[1, 2]

# Predicted correction for 30 degC
```

as.data.frame.errors  Coerce to a Data Frame

Description
S3 method for errors objects (see as.data.frame).

Usage
## S3 method for class 'errors'
as.data.frame(x, row.names = NULL, optional = FALSE, ...)

Arguments
x any R object.
row.names NULL or a character vector giving the row names for the data frame. Missing values are not allowed.
optional logical. If TRUE, setting row names and converting column names (to syntactic names: see make.names) is optional. Note that all of R’s base package as.data.frame() methods use optional only for column names treatment, basically with the meaning of data.frame(*, check.names = !optional). See also the make.names argument of the matrix method.
...
additional arguments to be passed to or from methods.

Examples
x <- set_errors(1:3, 0.1)
y <- set_errors(4:6, 0.2)
(z <- cbind(x, y))
as.data.frame(z)

as.list.errors  Coerce to a List

Description
S3 method for errors objects (see as.list).

Usage
## S3 method for class 'errors'
as.list(x, ...)

References

See Also
as.data.frame, as.list, make.names, data.frame

Examples
cbind(x, y)
as.matrix.errors

Arguments

x argument to be coerced or tested.
...

Examples

x <- set_errors(1:3, 0.1)
as.list(x)

as.matrix.errors Coerce to a Matrix

Description

S3 method for errors objects (see as.matrix).

Usage

## S3 method for class 'errors'
as.matrix(x, ...)

Arguments

x an R object.
...

Examples

as.matrix(set_errors(1:3, 0.1))

c.errors Combine Values into a Vector or List

Description

S3 method for errors objects (see c).

Usage

## S3 method for class 'errors'
c(..., recursive = FALSE)
Arguments

\[\ldots\] objects to be concatenated. All \texttt{NULL} entries are dropped before method dispatch unless at the very beginning of the argument list.

\texttt{recursive} logical. If \texttt{recursive = TRUE}, the function recursively descends through lists (and pairlists) combining all their elements into a vector.

Examples

\[c(\text{set\_errors}(1, 0.2), \text{set\_errors}(7:9, 0.1), 3)\]

\section*{cbind.errors}

\textbf{Combine R Objects by Rows or Columns}

\section*{Description}

S3 methods for \texttt{errors} objects (see \texttt{cbind}).

\section*{Usage}

\begin{verbatim}
## S3 method for class 'errors'
cbind(\ldots, deparse.level = 1)

## S3 method for class 'errors'
rbind(\ldots, deparse.level = 1)
\end{verbatim}

\section*{Arguments}

\[\ldots\] (generalized) vectors or matrices. These can be given as named arguments. Other R objects may be coerced as appropriate, or S4 methods may be used: see sections ‘Details’ and ‘Value’. (For the ”\texttt{data.frame}” method of \texttt{cbind} these can be further arguments to \texttt{data.frame} such as \texttt{stringsAsFactors}.)

\texttt{deparse.level} integer controlling the construction of labels in the case of non-matrix-like arguments (for the default method): \texttt{deparse.level = 0} constructs no labels; the default, \texttt{deparse.level = 1} or 2 constructs labels from the argument names, see the ‘Value’ section below.

\section*{See Also}

\texttt{c.errors}
Examples

```r
x <- set_errors(1, 0.1)
y <- set_errors(1:3, 0.2)
(m <- cbind(x, y)) # the '1' (= shorter vector) is recycled
(m <- cbind(m, 8:10)[, c(1, 3, 2)]) # insert a column
cbind(y, diag(3)) # vector is subset -> warning
cbind(0, rbind(x, y))
```

---

**correl**

*Handle Correlations Between errors Objects*

**Description**

Set or retrieve correlations or covariances between errors objects. See the details section below.

**Usage**

```r
correl(x, y)
correl(x, y) <- value
set_correl(x, y, value)
covar(x, y)
covar(x, y) <- value
set_covar(x, y, value)
```

**Arguments**

- `x`: an object of class errors.
- `y`: an object of class errors.
- `value`: a numeric vector of length 1 or the same length as `x`.

**Details**

The uncertainties associated to errors objects are supposed to be independent by default. If there is some known correlation, it can be defined using these methods, and it will be used for the propagation of the uncertainty by the mathematical and arithmetic operations.

The `correl` method sets or retrieves correlations, i.e., a value (or vector of values) between -1 and 1 (see base `cor` on how to compute correlations). A covariance is just a correlation value multiplied by the standard deviations (i.e., the standard uncertainty) of both variables. It can be defined using the `covar` method (see base `cov` on how to compute covariances). These methods are equivalent; in fact, `correl` calls `covar` internally.
Every `errors` object has a unique ID, and pairwise correlations are stored in an internal hash table. All the functions or methods that modify somehow the dimensions of `errors` objects (i.e., subsets, binds, concatenations, summaries...) generate new objects with new IDs, and correlations are not, and cannot be, propagated. Only mathematical and arithmetic operations propagate correlations, where appropriate, following the Taylor series method.

**Value**

`correl` and `covar` return a vector of correlations and covariances respectively (or NULL). `set_correl` and `set_covar`, which are pipe-friendly versions of the setters, return the `x` object.

**Examples**

```r
x <- set_errors(1:5, 0.1)
y <- set_errors(1:5, 0.1)

# Self-correlation is of course 1, and cannot be changed
correl(x, x)
## Not run:
correl(x, x) <- 0.5
## End(Not run)

# Cross-correlation can be set, but must be a value between -1 and 1
correl(x, y)
## Not run:
correl(x, y) <- 1.5
## End(Not run)
correl(x, y) <- runif(length(x))
correl(x, y)
covar(x, y)
```

---

**datasets**

Datasets from the Guide to the Expression of Uncertainty in Measurement (GUM)

**Description**

Datasets found in Annex H of the GUM (see reference below).

**Usage**

- GUM.H.2
- GUM.H.3
**Format**

GUM.H.2, from Section 2 of Annex H (Table H.2), provides simultaneous resistance and reactance measurements. It is a data frame with 5 rows and 3 variables:

- **V** Voltage amplitude, in Volts.
- **I** Current amplitude, in Amperes.
- **phi** Phase-shift angle of the voltage relative to the current, in radians.

GUM.H.3, from Section 3 of Annex H (Table H.6), provides thermometer readings and observed corrections to obtain a linear calibration curve for some reference temperature. It is a data frame with 11 rows and 2 variables:

- **tk** Thermometer reading, in Celsius degrees.
- **bk** Observed correction, in Celsius degrees.

An object of class `data.frame` with 11 rows and 2 columns.

**Source**


**See Also**

See `errors-package` for examples.

---

### diff.errors

<table>
<thead>
<tr>
<th>diff.errors</th>
<th>Lagged Differences</th>
</tr>
</thead>
</table>

**Description**

S3 method for `errors` objects (see `diff`).

**Usage**

```r
## S3 method for class 'errors'
diff(x, lag = 1L, differences = 1L, ...)
```

**Arguments**

- **x** a numeric vector or matrix containing the values to be differenced.
- **lag** an integer indicating which lag to use.
- **differences** an integer indicating the order of the difference.
- **...** further arguments to be passed to or from methods.
Examples

```r
diff(set_errors(1:10, 0.1), 2)
diff(set_errors(1:10, 0.1), 2, 2)
x <- cumsum(cumsum(set_errors(1:10, 0.1)))
diff(x, lag = 2)
diff(x, differences = 2)
```

---

### drop_errors

**Drop Uncertainty**

**Description**

Drop Uncertainty

**Usage**

```r
drop_errors(x)
```

```r
## S3 method for class 'data.frame'
drop_errors(x)
```

**Arguments**

- `x` an `errors` object.

**Value**

the numeric without any `errors` attributes, while preserving other attributes like dimensions or other classes.

**Note**

Equivalent to `errors(x) <- NULL` or `set_errors(x, NULL)`.

---

### errors

**Handle Uncertainty on a Numeric Vector**

**Description**

Set or retrieve uncertainty to/from numeric vectors.
Usage

errors(x)
errors_max(x)
errors_min(x)
errors(x) <- value
set_errors(x, value = 0)
as.errors(x, value = 0)

Arguments

x a numeric object, or object of class errors.
value a numeric vector of length 1 or the same length as x.

Details

`errors<-` sets the uncertainty values (and converts x into an object of class errors). `set_errors` is a pipe-friendly version of `errors<-` and returns an object of class errors. `as.errors` is an alias for `set_errors`.

See `correl` on how to handle correlations between pairs of variables.

Value

`errors` returns a vector of uncertainty. `errors_max` (errors_min) returns the values plus (minus) the uncertainty.

See Also

groupGeneric.errors, mean.errors, Extract.errors, c, rep, cbind.errors, format.errors, print.errors, plot.errors, as.data.frame.errors, as.matrix.errors, t.

Examples

```r
x = 1:3
class(x)
x
errors(x) <- 0.1
class(x)
x

(x <- set_errors(x, seq(0.1, 0.3, 0.1)))
errors_max(x)
errors_min(x)
```
Extract.errors  Extract or Replace Parts of an Object

Description
S3 operators to extract or replace parts of errors objects.

Usage
```r
## S3 method for class 'errors'
x[...]  
## S3 method for class 'errors'
x[[...]]
## S3 replacement method for class 'errors'
x[...] <- value
## S3 replacement method for class 'errors'
x[[...]] <- value
```

Arguments
- **x**: object from which to extract element(s) or in which to replace element(s).
- **...**: additional arguments to be passed to base methods (see `Extract`).
- **value**: typically an array-like R object of a similar class as `x`.

Examples
```r
x <- set_errors(1:3, 0.1)
y <- set_errors(4:6, 0.2)
(z <- rbind(x, y))
z[2, 2]
z[2, 2] <- -1
errors(z[[1, 2]]) <- 0.8
z[, 2]
```

format.errors  Encode errors

Description
Encode errors.

Format an errors object for pretty printing.
Usage

```r
## S3 method for class 'errors'
format(x, digits = NULL, scientific = FALSE,
       notation = getOption("errors.notation", "parenthesis"), ...)  
```

Arguments

- **x**: an `errors` object.
- **digits**: how many significant digits are to be used for uncertainties. The default, NULL, uses `getOption("errors.digits", 1)`.
- **scientific**: logical specifying whether the elements should be encoded in scientific format.
- **notation**: error notation; "parenthesis" and "plus-minus" are supported through the "errors.notation" option.
- **...**: ignored.

Examples

```r
x <- set_errors(1:3*100, 1:3*100 * 0.05)
format(x)
format(x, digits=2)
format(x, scientific=TRUE)
format(x, notation="plus-minus")
```

---

**geom_errors**

*Errorbars for errors objects*

**Description**

Automatic errorbars for variables with uncertainty.

**Usage**

```r
geom_errors(mapping = NULL, data = NULL, stat = "identity",
            position = "identity", ..., na.rm = FALSE, orientation = NA,
            show.legend = NA, inherit.aes = TRUE)
```

**Arguments**

- **mapping**: Set of aesthetic mappings created by `aes()`. If specified and `inherit.aes = TRUE` (the default), it is combined with the default mapping at the top level of the plot. You must supply `mapping` if there is no plot mapping.
geom_errors

data
The data to be displayed in this layer. There are three options:
If NULL, the default, the data is inherited from the plot data as specified in the
call to ggplot().
A data.frame, or other object, will override the plot data. All objects will be
fortified to produce a data frame. See fortify() for which variables will be
created.
A function will be called with a single argument, the plot data. The return
value must be a data.frame, and will be used as the layer data. A function
can be created from a formula (e.g. ~ head(.x, 10)).

stat
The statistical transformation to use on the data for this layer, either as a ggproto
Geom subclass or as a string naming the stat stripped of the stat_ prefix (e.g.
"count" rather than "stat_count")

position
Position adjustment, either as a string naming the adjustment (e.g. "jitter" to
use position_jitter), or the result of a call to a position adjustment function.
Use the latter if you need to change the settings of the adjustment.

... Other arguments passed on to layer(). These are often aesthetics, used to set
an aesthetic to a fixed value, like colour = "red" or size = 3. They may also
be parameters to the paired geom/stat.

na.rm If FALSE, the default, missing values are removed with a warning. If TRUE, missing values are silently removed.

orientation The orientation of the layer. The default (NA) automatically determines the ori-
entation from the aesthetic mapping. In the rare event that this fails it can be
given explicitly by setting orientation to either "x" or "y". See the Orientation
section for more detail.

show.legend logical. Should this layer be included in the legends? NA, the default, includes if
any aesthetics are mapped. FALSE never includes, and TRUE always includes. It
can also be a named logical vector to finely select the aesthetics to display.

inherit.aes If FALSE, overrides the default aesthetics, rather than combining with them.
This is most useful for helper functions that define both data and aesthetics and
shouldn’t inherit behaviour from the default plot specification, e.g. borders().

Examples

if (requireNamespace("ggplot2", quietly=TRUE)) {

  iris.e <- iris
  iris.e[1:4] <- lapply(iris.e[1:4], function(x) set_errors(x, x*0.02))

  library(ggplot2)

  ggplot(iris.e) + aes(Sepal.Length, Sepal.Width, color=Species) +
  geom_point() + geom_errors()

  ggplot(iris.e) + aes(Sepal.Length, Sepal.Width, color=Species) +
  geom_point() + geom_errors(width=0.05, height=0.05, size=0.2)
}


**Description**

Math, Ops and Summary group generic methods for errors objects with support for automatic uncertainty propagation (see `groupGeneric` for a comprehensive list of available methods).

**Usage**

```r
## S3 method for class 'errors'
Math(x, ...)

## S3 method for class 'errors'
Ops(e1, e2)

## S3 method for class 'errors'
Summary(..., na.rm = FALSE)
```

**Arguments**

- `x, e1, e2` objects.
- `...` further arguments passed to methods.
- `na.rm` logical: should missing values be removed?

**Details**

**Math**: The sign method returns a numeric value without uncertainty. floor, ceiling, trunc, round and signif add the rounding error to the original uncertainty. lgamma, gamma, digamma and trigamma are not implemented. The rest of the methods propagate the uncertainty as expected from the first-order Taylor series method.

**Ops**: Boolean operators drop the uncertainty (showing a warning once) and operate on the numeric values. The rest of the operators propagate the uncertainty as expected from the first-order Taylor series method. Any numeric operand is automatically coerced to errors (showing a warning once) with no uncertainty.

**Summary**: The methods all and any are not supported for errors objects and fail with an informative message. min, max (and range) return the minimum or (and) maximum value minus/plus its uncertainty. sum and prod propagate the uncertainty as expected from the first-order Taylor series method.

**Examples**

```r
x <- set_errors(1:3, 0.1)
expt(x)
log(x)
```
cumsum(x)
cumprod(x)

y <- set.errors(4:6, 0.2)
x / sqrt(y) + y * sin(x)

# numeric values are automatically coerced to errors
x^2

# boolean operators drop uncertainty
y > x

c(min(x), max(x))
range(x)
sum(y)
prod(y)

**mean.errors**

*Arithmetic Mean and Median Value*

**Description**

S3 methods for errors objects.

**Usage**

```r
## S3 method for class 'errors'
mean(x, ...)

## S3 method for class 'errors'
weighted.mean(x, ...)

## S3 method for class 'errors'
median(x, ...)
```

**Arguments**

- `x` an errors object.
- `...` further arguments passed to or from other methods.

**Details**

The `mean` and `weighted.mean` methods set the uncertainty as the maximum of the standard deviation of the mean and the (weighted) mean of the uncertainty.

The `median` method sets the uncertainty as $1.253 \times \text{errors}(\text{mean}(x))$, which is derived from the asymptotic variance formula of the median. Note that this value is valid only if the sample is big enough.
plot.errors  

Scatterplot with Error Bars

Value
An errors object.

Description
S3 method for errors objects which automatically prints the error bars.

Usage
## S3 method for class 'errors'
plot(x, y, ...)

Arguments
x, y
the x and y arguments provide the x and y coordinates for the plot. Any reasonable way of defining the coordinates is acceptable. See the function xy.coords for details. If supplied separately, they must be of the same length.

...    
additional arguments (see plot).

Examples
cars <- as.matrix(cars)
cars <- as.data.frame(set_errors(cars, cars * 0.05))
plot(cars$speed)
plot(cars)

print.errors  

Print Values

Description
S3 method for errors objects.

Usage
## S3 method for class 'errors'
print(x, ...)

Arguments
x    
an errors object.

...    
further arguments passed to or from other methods.
Examples

```r
x <- set_errors(1:10, 1:10 * 0.05)
print(x)
print(x[1:3])
print(x[1])
print(x[1], digits=2)
print(x[1], notation="plus-minus")
```

---

**rep.errors**

*Replicate Elements of Vectors and Lists*

Description

S3 method for `errors` objects (see `rep`).

Usage

```r
## S3 method for class 'errors'
rep(x, ...)
```

Arguments

- `x` a vector (of any mode including a `list`) or a factor or (for `rep` only) a POSIXct or POSIXlt or Date object; or an S4 object containing such an object.
- `...` further arguments to be passed to or from other methods. For the internal default method these can include:
  - `times` an integer-valued vector giving the (non-negative) number of times to repeat each element if of length `length(x)`, or to repeat the whole vector if of length 1. Negative or NA values are an error. A double vector is accepted, other inputs being coerced to an integer or double vector.
  - `length.out` non-negative integer. The desired length of the output vector. Other inputs will be coerced to a double vector and the first element taken. Ignored if NA or invalid.
  - `each` non-negative integer. Each element of x is repeated each times. Other inputs will be coerced to an integer or double vector and the first element taken. Treated as 1 if NA or invalid.

Examples

```r
rep(set_errors(1, 0.1), 4)
```
Description

S3 method for errors objects (see t).

Usage

## S3 method for class 'errors'
t(x)

Arguments

x  
a matrix or data frame, typically.

Examples

a <- matrix(1:30, 5, 6)
errors(a) <- 1:30
t(a)
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