Package: intkrige (via r-universe)

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Type Package

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Description An interval-valued extension of ordinary and simple kriging. Optimization of the function is based on a generalized interval distance. This creates a non-differentiable cost function that requires a differentiable approximation to the absolute value function. This differentiable approximation is optimized using a Newton-Raphson algorithm with a penalty function to impose the constraints. Analyses in the package are driven by the 'intsp' and 'intgrd' classes, which are interval-valued extensions of 'SpatialPointsDataFrame' and 'SpatialPixelsDataFrame' respectively. The package includes several wrappers to functions in the 'gstat' and 'sp' packages.

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intkrige-package *INTERVAL-VALUED KRIGING MODELS IN R*

Description

An interval-valued extension of ordinary and simple kriging. Optimization of the function is based on a generalized interval distance. This creates a non-differentiable cost function that requires a differentiable approximation to the absolute value function. This differentiable approximation is optimized using a Newton-Raphson algorithm with a penalty function to impose the constraints. Analyses in the package are driven by the 'intsp' and 'intgrd' classes, which are interval-valued extensions of 'SpatialPointsDataFrame' and 'SpatialPixelsDataFrame' respectively. The package includes several wrappers to functions in the 'gstat' and 'sp' packages.

Functions

The package contains several generic functions such as `plot`, `print`, and `summary` to facilitate interval-valued analysis. In addition to these functions, the package also contains the following functions:

- `intkrige` Make predictions on interval-valued spatial data using interval-valued kriging.
- `interval<-` Create an interval-valued spatial object.
- `intvariogram` Simultaneously calculate the empirical variograms for an interval-valued spatial object.
- `fit.intvariogram` Automatically fit theoretical variograms to empirical variograms obtained from interval-valued spatial objects.
- `intvCheck` Visualize the variogram fits for interval-valued spatial objects.
- `dist_cpp` A c++ function to calculate great circle or Euclidean distances.

Data

- utsnow An interval-valued design ground snow load dataset for Utah.
- ohtemp An interval-valued 30 year mean temperature dataset for the Ohio River Basin.
- ohMap A `SpatialPolygons` shapefile for the Ohio River Basin.

Author(s)

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as.data.frame *Convert intgrd or intsp object back to a data frame*

Description

Convert intgrd or intsp object back to a data frame

Usage

```
## S4 method for signature 'intgrd'
as.data.frame(x)

## S4 method for signature 'intsp'
as.data.frame(x)
```

Arguments

x	An object of class intsp or class intgrd.

Value

An object of class data.frame.

dist_cpp *Distance matrix calculation.*

Description

Calculation of Euclidean or geographic distance. Based on an adaptation of rdist.earth in the fields package. Uses earth radius = 6378.388 km for great circle distance calculations.

Usage

```
dist_cpp(loc1, loc2, geographic)
```

Arguments

loc1	A two column matrix representing the longitude/latitude (i.e. x/y) coordinates of the first set of distances.
loc2	A two column matrix representing the longitude/latitude (i.e. x/y) coordinates of the second set of distances (for pairwise distance matrix set loc1 = loc2).
geographic	If TRUE, calculate great circle distance. If FALSE, calculate Euclidean distance.

Details

Note that while this function is still available to users. It is not actively used in the intkrige function. Instead, for user convenience, distances are calculated using distance functions in the sp package.

Value

A matrix of pairwise distances between each combination of rows from loc1 and loc2 respectively.

Examples

```
data(utsnow)
locs1 <- as.matrix(utsnow[, c("LONGITUDE", "LATITUDE")])
distMat <- dist_cpp(locs1, locs1, geographic = TRUE)
```

---

extract *Extract subset of an* intsp *or* intgrd *object*

Description

Extract subset of an intsp or intgrd object

Usage

```
## S4 method for signature 'intgrd'
x$name

## S4 replacement method for signature 'intgrd'
x$name <- value

## S4 method for signature 'intgrd,ANY,missing,missing'
x[i, j, ..., drop = TRUE]

## S4 method for signature 'intsp'
x$name

## S4 replacement method for signature 'intsp'
x$name <- value

## S4 method for signature 'intsp,ANY,missing,missing'
x[i, j, ..., drop = TRUE]

## S4 replacement method for signature 'intsp'
x$name <- value
```

Arguments

x	An object of class intsp or class intgrd from which to replace elements.
name	Character vector corresponding to the name of the column that will be extracted or replaced.
value	The new data used to replaced drop data in the desired slot.
i, j, ...	indices specifying elements to extract or replace. See generic function documentation for details.
drop	The requested column that may be reassigned.

Value

An object of class intsp or intgrd.

---

fit.intvariogram *Function to create a variogram object for interval-valued data.*

Description

Function to create a variogram object for interval-valued data.

Usage

```
fit.intvariogram(x, models = gstat::vgm(rep("Sph", 3)), ...)
```

Arguments

x	An object of class intvariogram.
models	an object of class variogramModelList. The user must specify at least two variogram models to fit (for center and radius). If less than three models are specified then the method does not fit a variogram for the center/radius interaction.
...	Additional arguments for fit.variogram.

Value

A list of variograms objects from the gstat package.

head.intgrd *Print the head of an intgrd object.*

Description

This function extends print.sp by including a display and summary of the interval slot for the object.

Usage

```
## S3 method for class 'intgrd'
head(x, n = 6, ..., digits = getOption("digits"))
```

Arguments

x	An object of class intgrd.
n	Number of rows to print to the screen.
...	Additional arguments to print.
digits	Determines how numeric values are printed to the screen (default from sp package).

Value

Prints a subset of the object observations to the screen, identical to SpatialPoints-class, as well as summary statistics for the interval slot.

head.intsp *Print the head of an* intsp *object.*

Description

This function extends printing methods in the sp package by including a display and summary of the head of the interval slot for the object.

Usage

```
## S3 method for class 'intsp'
head(x, n = 6, ..., digits = getOption("digits"))
```

Arguments

x	An object of class intsp.
n	The number of rows to print to the screen.
...	Additional arguments to print.
digits	Determines how values are printed to the screen (default taken from sp package).

Value

Prints a subset of the object to the screen, identical to SpatialPoints-class, as well as summary statistics for the interval slot.

`interval` *Function to extract the interval of an intsp or intgrd object*

Description

Function to extract the interval of an intsp or intgrd object

Usage

```
interval(x)

## S4 method for signature 'intgrd'
interval(x)

## S4 method for signature 'intsp'
interval(x)
```

Arguments

x	An object of class intsp or intgrd.

Value

A matrix containing the interval data.

`interval<-` *Function to reassign the contents of the interval slot*

Description

Function to reassign the contents of the interval slot

Usage

```
interval(x) <- value

## S4 replacement method for signature 'intgrd'
interval(x) <- value

## S4 replacement method for signature 'SpatialPixelsDataFrame'
interval(x) <- value
```

```
## S4 replacement method for signature 'intsp'
interval(x) <- value

## S4 replacement method for signature 'SpatialPointsDataFrame'
interval(x) <- value
```

Arguments

x	An object of class intsp or intgrd.
value	Either a character vector of length two specifying the column names which will occupy the interval slot. Or, a matrix of two columns to fill the slot.

---

intgrd-class *An interval extension of a SpatialPixelsDataFrame*

Description

An interval extension of a SpatialPixelsDataFrame

Slots

`interval` A matrix of two columns representing the lower and upper endpoints of an interval.

---

intkrige *Algorithmic implementation of interval valued kriging.*

Description

Function to implement the interval valued extension of ordinary and simple kriging. Includes all necessary input checks and error handling. Essentially acts as a switch function between the R and c++ versions of the algorithm.

Usage

```
intkrige(
  locations,
  newdata,
  models,
  centerFormula = center ~ 1,
  eta = 0.75,
  A = c(1, 1, 0),
  trend = NULL,
  thresh = 100,
  tolq = 0.001,
```

```
  maxq = 100,
  tolp = 0.001,
  maxp = 100,
  r = 1,
  useR = TRUE,
  fast = FALSE,
  weights = FALSE,
  cores = 1,
  progress = FALSE
)
```

Arguments

locations	An object of class intsp, specifying the prediction locations with an interval-valued response.
newdata	An object of class SpatialPointsDataFrame or SpatialPixelsDataFrame specifying the locations at which to predict intervals.
models	A list of variogram models of class vgm (see vgm) When specified, the third model represents the center/radius interaction.
centerFormula	The formula describing the relationship between the radius center and any number of explanatory variables. Must have "center" as the lone dependent variable. Note that there is no option to fit an external trend to the radius.
eta	A growth/shrink parameter for penalty term. For simple kriging: eta > 1. For ordinary kriging: eta < 1.
A	vector of length three representing the weights of the generalized L2 distance: the vector of three contains the weights for the center, radius, and center/radius respectively. A = c(1, 1, 0) assumes the regular L2 distance calculation for intervals.
trend	If null, use ordinary kriging. When specified, represents the known mean of the stationary process and is an indication to use simple kriging.
thresh	Let n = length(locations). When abs(lam_i) < 1/(n*thresh), this lambda value is set to 0.
tolq	For a set penalty term, convergence is satisfied if max(abs(lamUp-lam)) < tolq.
maxq	For a set penalty term, the max number of iterations allowed for convergence.
tolp	When abs(sum(abs(lam)) - 1) < tolp, consider the constraints satisfied.
maxp	Maximum number of allowed iterations to satisfy equation constraints.
r	The starting value of the penalty term. Must be relatively large to ensure that the initial solution stays within the feasible region.
useR	If TRUE, use the R version of the algorithm. If FALSE, use the rcppArmadillo version.
fast	(Simple kriging only). If TRUE, allows lambdas to converge to 0 and subsets matrices accordingly. When FALSE, runs simple kriging using a barrier penalty at 0. Fast = TRUE is orders of magnitude faster than the full implementation. However, it is not recommended when input measurements are sparse as it is known to have convergence issues in these cases.

weights	If TRUE, return the vector kriging weights for each prediction. If false, simply return the predicted output.
cores	An integer (for parallel computing): specify the number of cores that will be devoted to the computation. Note that the argument 'all' will use all available cores minus one. Parallel processing is only relevant if you are predicting for more than one location. Note there is no parallel option when useR = FALSE.
progress	(Not valid when useR=FALSE or in parallel): Print a progress bar showing the progress of the predictions at the new locations.

Details

The centerFormula argument allows for an external trend to be fit to the interval centers. No option is provided to scale the interval radii. This means that any transformations should be applied to the entire interval prior to input into interval-valued kriging. This ensures that input into the interval-valued kriging algorithm are well-defined intervals with properly ordered upper and lower endpoints.

Value

A matrix with 4 columns where rows correspond to the prediction locations and columns correspond to:

- center prediction

- radius predictions

- kriging prediction variance

- warning column for non-convergent optimization problem (0 - no warning, 1 - warning)

Examples

```
# First, define the location and elevation of interest.
# (In this case we pick coordinates of Utah State University)
tproj <- sp::CRS(SRS_string = "EPSG:4326")
templocs <- data.frame(lat = 41.745, long = -111.810, ELEVATION = 1456)
sp::coordinates(templocs) <- c("long", "lat")
sp::proj4string(templocs) <- tproj

# Load the Utah Snow Load Data
data(utsnow)
utsnow.sp <- utsnow

# Convert to an 'intsp' object that inherits a SpatialPointsDataFrame
sp::coordinates(utsnow.sp) <- c("LONGITUDE", "LATITUDE")
sp::proj4string(utsnow.sp) <- tproj
interval(utsnow.sp) <- c("minDL", "maxDL")
# Define the formulas we will use to define the intervals.
temp_formula <- center ~ ELEVATION

# Define, fit and check the variogram fits.
varios <- intvariogram(utsnow.sp,
                       centerFormula = temp_formula)
```

```
varioFit <- fit.intvariogram(varios, models = gstat::vgm(c("Sph", "Sph", "Gau")))
preds <- intkrige::intkrige(locations = utsnow.sp,
newdata = templocs,
models = varioFit,
centerFormula = temp_formula)
```

`intsp-class` *An interval extension of a SpatialPointsDataFrame*

Description

An interval extension of a SpatialPointsDataFrame

Slots

`interval` A matrix of two columns representing the lower and upper endpoints of an interval.

`intvariogram` *Function to fit empirical variograms for an interval-valued spatial object*

Description

Function to fit empirical variograms for an interval-valued spatial object

Usage

```
intvariogram(x, centerFormula = center ~ 1, ...)

## S4 method for signature 'intgrd'
intvariogram(x, centerFormula = center ~ 1, ...)

## S4 method for signature 'intsp'
intvariogram(x, centerFormula = center ~ 1, ...)
```

Arguments

`x`	An object of class intsp or intgrd.
`centerFormula`	A formula specifying any external trends for the interval centers.
`...`	Additional arguments for sp::variogram().

Value

An object of class 'intvariogram' containing empirical variograms for the center, radius, and center/radius interaction.

intvCheck — *Function to visualize the three variograms from an interval valued spatial data frame.*

Description

Function to visualize the three variograms from an interval valued spatial data frame.

Usage

```
intvCheck(x, models, ...)
```

Arguments

x	An object of class intvariogram.
models	A list of fitted variogram models, typically an output of fit.intvariogram.
...	Additional arguments to plot.gstatVariogram.

ohMap — *Ohio River Basin map*

Description

Ohio River Basin map

Usage

```
ohMap
```

Format

A SpatialPolygons objects with the boundaries of the Ohio river basin. Shapefile obtained from the U.S. Geological Survey National Watershed Boundary Dataset.

ohtemp *30 year trimmed mean daily maximum and minimum temperatures for the Ohio river basin.*

Description

Intervals are defined by the mean daily maximum and minimum temperatures for the Ohio river basin from January 1, 1988 - December 31, 2018. The 116 observations in this dataset all had at least 300 daily observations of temperature in at least 30 of the 31 considered years. The mean was calculated after trimming 10 influence of potential outliers.

Usage

```
ohtemp
```

Format

A data frame with 161 rows and 8 variables:

ID The global historical climatological network (GHCN) station identifier

NAME The GHCN station name

STATE The two-digit designation for the state in which each station resides

LATITUDE Latitude coordinate position

LONGITUDE Longitude coordinate position

ELEVATION Elevation of the measurement location (meters)

minm The 30 year mean daily minimum temperature (tenths of degrees Celsius)

maxm The 30 year mean daily maximum temperature (tenths of degrees Celsius)

plot,intgrd,missing-method *Create an interval plot for spatial grid.*

Description

Calls spplot to plot the locations, centers, and radii of an intgrd object in a single figure.

Usage

```
## S4 method for signature 'intgrd,missing'
plot(x, beside = TRUE, circleCol = "black", minRad = 0.25, ...)
```

Arguments

x	An object of class intgrd.
beside	Tf true, center and radius plotted side by side if false, center and radius are plotted in a single figure with the center plotted using color and the radius plotted using circles circumscribed within each grid cell.
circleCol	If beside=TRUE, the color of the circles that will be circumscribed within each grid cell.
minRad	The minimum value of the radius in the circles drawn to represent the interval radii. Must be a number between 0 and 1 where approaching 0 results in a point being drawn in the center of the grid, while approaching 1 results in every circle being circumscribed in their respective grid cell (which is not very interesting).
...	Additional arguments to spplot.

---

plot,intsp,missing-method

Create an interval plot for spatial points.

Description

Calls spplot to plot the locations, centers, and radii of an interval-valued spatial data frame in a single figure.

Usage

```
## S4 method for signature 'intsp,missing'
plot(
  x,
  locationsOnly = FALSE,
  legend.positions = c("left", "right"),
  cuts = c(5, 5),
  radSize = c(0.1, 3),
  pch = 16,
  alpha = 0.5,
  ...
)
```

Arguments

x	An object of class intsp.
locationsOnly	If TRUE, simply plots geographic locations.
legend.positions	The positions of the center and radius legend relative to the plotting window.
cuts	The number of ranges of values to print in the center and radius legend respectively.

radSize	A vector of length 2 indicating the range of point sizes to plot to visualize radii magnitudes.
pch	The shape of the points (see plot).
alpha	The transparency of the points.
...	Additional arguments to spplot.

---

print.intgrd *Print the contents of an intgrd object*

Description

This function extends print.sp by including a display and summary of the interval slot for the object.

Usage

```
## S3 method for class 'intgrd'
print(x, ..., digits = getOption("digits"))
```

Arguments

x	An object of class intgrd.
...	Additional arguments to print.
digits	Determines how numeric values are printed to the screen (default from sp package).

Value

Prints object to the screen, identical to SpatialPoints-class, as well as summary statistics for the interval slot.

---

print.intsp *Print the contents of an* intsp *object*

Description

This function extends printing methods in the sp package by including a display and summary of the interval slot for the object.

Usage

```
## S3 method for class 'intsp'
print(x, digits = getOption("digits"), ...)
```

Arguments

x	An object of class intsp.
digits	Determines how numbers are displayed on the screen. Default option taken from sp package.
...	Additional arguments to print.

Value

Prints object to the screen, identical to SpatialPoints-class, as well as summary statistics for the interval slot.

---

print.summary.intgrd *Print the object summary to the screen.*

Description

Print the object summary to the screen.

Usage

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

Arguments

x	An object of class intgrd.
...	Additional arguments to print.

Value

Prints a subset of the object observations to the screen, identical to SpatialPoints-class, as well as summary statistics for the interval slot.

---

print.summary.intsp *Print the object summary to the screen.*

Description

Print the object summary to the screen.

Usage

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

Arguments

x	An object an object of class intsp.
...	Additional arguments to print.

Value

Prints a series of summaries to the screen, identical to SpatialPoints-class, as well as summary statistics for the interval slot.

---

show,intgrd-method *Extension of the show function for intgrd objects*

Description

Extension of the show function for intgrd objects

Usage

```
## S4 method for signature 'intgrd'
show(object)
```

Arguments

object	and object of class intgrd

---

show,intsp-method *Extension of the show function for intgrd objects*

Description

Extension of the show function for intgrd objects

Usage

```
## S4 method for signature 'intsp'
show(object)
```

Arguments

object	An object of class intsp.

summary.intgrd *Summarize the contents of an* intgrd *object, including special summaries for the interval slot.*

Description

Summarize the contents of an intgrd object, including special summaries for the interval slot.

Usage

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

Arguments

object	An object of class intgrd.
...	Additional arguments to summary.

Value

Prints a summary of the object observations to the screen, identical to SpatialPoints-class, as well as summary statistics for the interval slot.

summary.intsp *Summarize the contents of an* intsp *object, including special summaries for the interval slot.*

Description

Summarize the contents of an intsp object, including special summaries for the interval slot.

Usage

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

Arguments

object	An object of class intsp.
...	Additional arguments to summary.

Value

Prints a series of summaries to the screen, identical to SpatialPoints-class, as well as summary statistics for the interval slot.

tail.intgrd *Print the tail of an intgrd object.*

Description

This function extends print.sp by including a display and summary of the interval slot for the object.

Usage

```
## S3 method for class 'intgrd'
tail(x, n = 6, ..., digits = getOption("digits"))
```

Arguments

x	An object of class intgrd.
n	The number of rows to print to the screen.
...	Additional arguments to tail.
digits	Determines how numbers are displayed to the screen (default taken from package sp).

Value

Prints a subset of the object observations to the screen, identical to SpatialPoints-class, as well as summary statistics for the interval slot.

tail.intsp *Print the tail of an intsp object.*

Description

This function extends print.sp by including a display and summary of the interval slot for the object.

Usage

```
## S3 method for class 'intsp'
tail(x, n = 6, ..., digits = getOption("digits"))
```

Arguments

x	An object of class intsp.
n	The number of rows to print to the screen.
...	Additional arguments to tail.
digits	Determines how numbers are displayed (default taken from sp package).

Value

Prints a subset of the object to the screen, identical to SpatialPoints-class, as well as summary statistics for the interval slot.

---

utsnow *An interval-valued design ground snow load dataset for Utah.*

Description

A dataset containing the interval-valued data used in the analysis of Bean et. at (2019). The 415 measurement locations included in the dataset are taken from Bean et. al. (2018).

Usage

```
utsnow
```

Format

A data frame with 415 rows and 8 variables:

STATION The global historical climatological network (GHCN) station identifier

STATION_NAME The GHCN station name

LATITUDE Latitude coordinate position

LONGITUDE Longitude coordinate position

ELEVATION Elevation of the measurement location (meters)

minDL The lower endpoint of the interval-valued design snow load as measured in kilopascals (kpa)

maxDL The upper endpoint of the design snow load interval (kpa)

pointDL The original point-valued design snow load from the 2018 Utah Snow Load Study (kpa)

Details

The interval valued kriging analysis described in Bean et. al. (2019) analyzes this dataset on a log scale after removing the effect of elevation. An example of predictions using this workflow are found in the README associated with this package.

References

Bean B, Sun Y, Maguire M (2022). "Interval-valued kriging for geostatistical mapping with imprecise inputs." *International Journal of Approximate Reasoning*, **140**, 31-51. ISSN 0888-613X, https://doi.org/10.1016/j.ijar.2021.10.003.

Bean B, Maguire M, Sun Y (2018). "The Utah Snow Load Study." https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=4591&context=cee_facpub.

`utsnow_dtl` *An interval-valued design ground snow load dataset for Utah that only considers depth to load conversions.*

Description

A dataset containing the interval-valued data used in the analysis of Bean et. at (2019). The 415 measurement locations included in the dataset are taken from Bean et. al. (2018).

Usage

```
utsnow_dtl
```

Format

A data frame with 415 rows and 8 variables:

STATION The global historical climatological network (GHCN) station identifier

STATION_NAME The GHCN station name

LATITUDE Latitude coordinate position

LONGITUDE Longitude coordinate position

ELEVATION Elevation of the measurement location (meters)

minDL The lower endpoint of the interval-valued design snow load as measured in kilopascals (kpa)

maxDL The upper endpoint of the design snow load interval (kpa)

pointDL The original point-valued design snow load from the 2018 Utah Snow Load Study (kpa)

Details

The interval valued kriging analysis described in Bean et. al. (2019) analyzes this dataset on a log scale after removing the effect of elevation. An example of predictions using this workflow are found in the README associated with this package. Note that this dataset differs from utsnow in that intervals only consider differences in depth to load conversions.

References

Bean B, Sun Y, Maguire M (2022). "Interval-valued kriging for geostatistical mapping with imprecise inputs." *International Journal of Approximate Reasoning*, **140**, 31-51. ISSN 0888-613X, https://doi.org/10.1016/j.ijar.2021.10.003.

Bean B, Maguire M, Sun Y (2018). "The Utah Snow Load Study." https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=4591&context=cee_facpub.

`utsnow_dtl2` *An interval-valued design ground snow load dataset for Utah that only considers depth to load conversions.*

Description

A dataset containing the interval-valued data used in the analysis of Bean et. at (2019). The 415 measurement locations included in the dataset are taken from Bean et. al. (2018).

Usage

```
utsnow_dtl2
```

Format

A data frame with 415 rows and 8 variables:

STATION The global historical climatological network (GHCN) station identifier

STATION_NAME The GHCN station name

LATITUDE Latitude coordinate position

LONGITUDE Longitude coordinate position

ELEVATION Elevation of the measurement location (meters)

minDL The lower endpoint of the interval-valued design snow load as measured in kilopascals (kpa)

maxDL The upper endpoint of the design snow load interval (kpa)

pointDL The original point-valued design snow load from the 2018 Utah Snow Load Study (kpa)

Details

The interval valued kriging analysis described in Bean et. al. (2019) analyzes this dataset on a log scale after removing the effect of elevation. An example of predictions using this workflow are found in the README associated with this package. Note that this dataset differs from utsnow in that intervals only consider differences in depth to load conversions. This dataset differs from utsnow_dtl in that intervals are only calculated at the final step of the analysis: after finding 50 year events using all 8 depth to load conversion techniques. utsnow_dtl rather created annual intervals, only fitting distributions to two sets of maximums (the annual lower and upper bounds), rather fitting 8 sets of maximums on all the depth-to-load conversion types.

References

Bean B, Sun Y, Maguire M (2022). "Interval-valued kriging for geostatistical mapping with imprecise inputs." *International Journal of Approximate Reasoning*, **140**, 31-51. ISSN 0888-613X, https://doi.org/10.1016/j.ijar.2021.10.003.

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