

Package ‘movecost’

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Title Calculation of Slope-Dependant Accumulated Cost Surface, Least-Cost Paths, and Least-Cost Corridors Related to Human Movement Across the Landscape

Version 1.1

Description Provides the facility to calculate non-isotropic accumulated cost surface, least-cost paths, and least-cost corridors using a number of human-movement-related cost functions that can be selected by the user. It just requires a Digital Terrain Model, a start location and (optionally) destination locations. See Alberti (2019) <[doi:10.1016/j.softx.2019.100331](https://doi.org/10.1016/j.softx.2019.100331)>.

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Imports gdistance (>= 1.2-2), elevatr (>= 0.3.4), raster (>= 2.8-4), rgdal (>= 1.3-6), rgeos (>= 0.4-2), sp (>= 1.3-1), utils (>= 4.0.3)

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R topics documented:

destin.loc	2
Etna_boundary	2
Etna_end_location	3
Etna_start_location	3
movecorr	4
movecost	8
volc.loc	19

Index**20**

<code>destin.loc</code>	<i>Dataset: locations on the volcano Maunga Whau (Auckland, New Zealand)</i>
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Description

A `SpatialPointsDataFrame` representing spots on the volcano Maunga Whau (Auckland, New Zealand), to be used as destination locations for least-cost paths calculation.

Usage

```
data(destin.loc)
```

Format

```
SpatialPointsDataFrame
```

<code>Etna_boundary</code>	<i>Dataset: bounding polygon representing a study area on Mount Etna (Sicily, Italy)</i>
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Description

A `SpatialPolygonDataFrame` representing an area on Mount Etna (Sicily, Italy), to be used to download elevation data.

Usage

```
data(Etna_boundary)
```

Format

```
SpatialPolygonDataFrame
```

Etna_end_location *Dataset: locations on Mount Etna (Sicily, Italy)*

Description

A `SpatialPointsDataFrame` representing spots on Mount Etna (Sicily, Italy), to be used as destination locations for least-cost paths calculation.

Usage

```
data(Etna_end_location)
```

Format

`SpatialPointsDataFrame`

Etna_start_location *Dataset: location on Mount Etna (Sicily, Italy)*

Description

A `SpatialPointsDataFrame` representing a spot on Mount Etna, to be used as start location for least-cost paths calculation.

Usage

```
data(Etna_start_location)
```

Format

`SpatialPointsDataFrame`

`movecorr`*R function for calculating least-cost corridor between point locations*

Description

The function provides the facility to calculate the least-cost corridor between point locations. It just requires an input DTM and at least two point locations (`'SpatialPointsDataFrame'` class) representing the locations between which the corridor is calculated. Under the hood, `'movecorr'` relies on the `movecost` function and, needless to say, implements the same cost functions. See the help documentation of `movecost` for further details.

Usage

```
movecorr(  
  dtm = NULL,  
  a,  
  b,  
  lab.a = "A",  
  lab.b = "B",  
  cex.labs = 0.8,  
  studyplot = NULL,  
  funct = "t",  
  time = "h",  
  move = 16,  
  cogn.slp = FALSE,  
  sl.crit = 10,  
  W = 70,  
  L = 0,  
  N = 1,  
  V = 1.2,  
  z = 9,  
  rescale = FALSE,  
  export = FALSE  
)
```

Arguments

- | | |
|------------------|---|
| <code>dtm</code> | Digital Terrain Model (<code>RasterLayer</code> class); if not provided, elevation data will be acquired online for the area enclosed by the <code>'studyplot'</code> parameter (see <code>movecost</code>). |
| <code>a</code> | first location from which the least-cost corridor is calculated (<code>SpatialPointsDataFrame</code> class); if it contains more than two locations, see the <code>'Description'</code> section above. |
| <code>b</code> | second location from which the least-cost corridor is calculated (<code>SpatialPointsDataFrame</code> class); if parameter <code>'a'</code> stores more than two locations, this parameter is disregarded; see the <code>'Description'</code> section above. |

lab.a	string to be used to label point a on the output plot (A is the default)
lab.b	string to be used to label point b on the output plot (B is the default).
cex.labs	scaling factor for the size of the points' labels (0.8 by default)
studyplot	polygon (SpatialPolygonDataFrame class) representing the study area for which online elevation data are acquired (see movecost); NULL is default.
funct	cost function to be used (for details on each of the following, see movecost): t (default) uses the on-path Tobler's hiking function; tofp uses the off-path Tobler's hiking function; mp uses the Marquez-Perez et al.'s modified Tobler's function; icmonp uses the Irmischer-Clarke's hiking function (male, on-path); icmoffp uses the Irmischer-Clarke's hiking function (male, off-path); icfonp uses the Irmischer-Clarke's hiking function (female, on-path); icfoffp uses the Irmischer-Clarke's hiking function (female, off-path); ug uses the Uriarte Gonzalez's slope-dependant walking-time cost function; alb uses the Alberti's Tobler hiking function modified for pastoral foraging excursions; gkrs uses the Garmy, Kaddouri, Rozenblat, and Schneider's hiking function; r uses the Rees' hiking function; ree uses the relative energetic expenditure cost function; hrz uses the Herzog's metabolic cost function; wcs uses the wheeled-vehicle critical slope cost function; p uses the Pandolf et al.'s metabolic energy expenditure cost function; vl uses the Van Leusen's metabolic energy expenditure cost function; ls uses the Llobera-Sluckin's metabolic energy expenditure cost function. b uses the Bellavia's cost function.
time	time-unit expressed by the accumulated raster if Tobler's and other time-related cost functions are used; 'h' for hour, 'm' for minutes.
move	number of directions in which cells are connected: 4 (rook's case), 8 (queen's case), 16 (knight and one-cell queen moves; default).
cogn.slp	TRUE or FALSE (default) if the user wants or does not want the 'cognitive slope' to be used in place of the real slope (see movecost).
sl.crit	critical slope (in percent), typically in the range 8-16 (10 by default) (used by the wheeled-vehicle cost function; see movecost).
W	walker's body weight (in Kg; 70 by default; used by the Pandolf's and Van Leusen's cost function; see movecost).
L	carried load weight (in Kg; 0 by default; used by the Pandolf's and Van Leusen's cost function; see movecost).
N	coefficient representing ease of movement (1 by default) (see movecost).
V	speed in m/s (1.2 by default) (used by the Pandolf's and Van Leusen's cost function; see movecost).
z	zoom level for the elevation data downloaded from online sources (from 0 to 15; 9 by default) (see movecost and get_elev_raster).
rescale	TRUE or FALSE (default) if the user wants or does not want the output least-cost corridor raster to be rescaled between 0 and 1.

`export` TRUE or FALSE (default) if the user wants or does not want the output to be exported; if TRUE, the least-cost corridor, the dtm (if not provided by the user but acquired online), and the accumulated cost surface around a and b are exported as a GeoTiff file, while the two LCPs (from a to b, and from b to a) as individual shapefiles. If multiple locations are analysed, only the least-cost corridor (and the DTM if originally not provided) will be exported.

Details

If only two locations are provided (one via parameter 'a', one via parameter 'b'), the function renders a raster representing the least cost corridor (which can be optionally exported as GeoTiff) with least-cost paths superimposed. If more than 2 locations are fed into the function via the 'a' parameter, the function calculates the least-cost corridor between pairs of locations. All the pair-wise corridor rasters are returned (but not individually plotted) in a list. All those rasters will be summed, and the resulting raster will be plotted (and can be, optionally, exported as GeoTiff).

The function returns a list containing a number of components (see 'Value' below). For more details about exporting the function's outputs, see 'Arguments' below.

If the user wants to calculate the least-cost corridor between two locations only, (s)he may want to use parameter 'a' and 'b' to indicate the two locations of interest respectively. For example, using the datasets provided by this package:

```
result <- movecorr(a=Etna_start_location, b=Etna_end_location[1,], studyplot=Etna_boundary, funct="tofp")
```

The above will produce the least-cost corridor between two locations close to Mt Etna (Sicily, Italy), using the Tobler's cost function (for off-path hiking). Side note: the elevation data will be acquired online.

If the interest lies in using more than 2 locations, the user may want to feed the dataset storing all the locations into parameter 'a' (disregarding 'b'). As explained above, in this case the function calculates the least-cost corridor between pairs of locations. All the pair-wise corridor rasters are returned in a list. Those rasters will be summed, and the resulting raster will be plotted (and can be, optionally, exported as GeoTiff). For example, to calculate the least-cost corridors between every individual unique pair of the 9 locations stored in the 'destin.loc' dataset:

```
volc <- raster::raster(system.file("external/maungawhau.grd", package="gdistance"))
```

```
result <- movecorr(dtm=volc, a=destin.loc, funct="ree", rescale=TRUE)
```

Note that only parameter 'a' has been used. The function returns and plots the sum of the 36 individual corridors; the latter are not plotted, but are stored in a list. If the user wants to plot the least-cost corridor, say, n 4, and then add the two locations between which the corridor has been calculated, (s)he can first plot the corridor raster n 4:

```
raster::plot(result$corridors[[4]])
```

Then, identifying which locations are related to corridor n 4 can be easily accomplished by looking up the values stored in the 4th column of the returned matrix:

```
result$locations.matrix
```

The locations are the n 1 and n 5, so the user can add them to the plot previously produced using:

```
raster::plot(destin.loc[1,], pch=20, add=T)
raster::plot(destin.loc[5,], pch=20, add=T)
```

Note that the resulting plot can be produced (with a nicer outlook) directly by 'movecorr()' by feeding those two locations in the parameter 'a' and 'b' respectively:

```
result <- movecorr(dtm=volc, a=destin.loc[1,], b=destin.loc[5,], funct="ree")
```

Overall, what 'movecorr()' does is to calculate (via the [movecost](#) function) the accumulated cost surface around each location. Those are eventually summed to produce the least-cost corridor between locations. On the produced corridor raster, the cost of a cell is the total cost to reach it from all the analysed locations. About least-cost corridors between pairs of locations, see for instance: Mitchell A. (2012), "The ESRI Guide to GIS Analysis. Vol 3. Modelling Suitability, Movement, and Interaction", New York: Esri Press (257-259).

Value

The function returns a list storing the following components

- dtm: Digital Terrain Model ('RasterLayer' class)
- lc.corridor: raster of the least-cost corridor ('RasterLayer' class); if more than two locations are analysed, this raster is the sum of all the corridors between all the pairs of locations
- lcp_a_to_b: least-cost past from a to b ('SpatialLines' class); returned only when the corridor is calculated between two locations
- lcp_b_to_a: least-cost past from b to a ('SpatialLines' class); returned only when the corridor is calculated between two locations
- accum_cost_surf_a: accumulated cost-surface around a ('RasterLayer' class); returned only when the corridor is calculated between two locations
- accum_cost_surf_b: accumulated cost-surface around b ('RasterLayer' class); returned only when the corridor is calculated between two locations
- corridors: list of rasters ('RasterLayer' class) representing the least-cost corridor between all the unique pairs of locations; returned only when more than two locations are analysed
- locations.matrix: matrix whose columns indicate the identifiers for all the unique pairs of locations for which each corridor is calculated; returned only when more than two locations are analysed

See Also

[movecost](#)

Examples

```
# load a sample Digital Terrain Model
volc <- raster::raster(system.file("external/maungawhau.grd", package="gdistance"))

# load the sample destination locations on the above DTM
data(destin.loc)

# calculate the least-cost corridor between two locations, using the
# relative energetic expenditure cost function, and store the results
# in the 'result' object

result <- movecorr(dtm=volc, a=destin.loc[1,], b=destin.loc[3,], funct="ree", move=8)

#same as above, but using the 'cognitive slope'

# result <- movecorr(dtm=volc, a=destin.loc[1,], b=destin.loc[3,],
# funct="ree", move=8, cogn.slp=TRUE)
```

movecost

R function for calculating accumulated anisotropic slope-dependant cost of movement across the terrain and least-cost paths from a point origin

Description

The function provides the facility to calculate the anisotropic accumulated cost of movement around a starting location and to optionally calculate least-cost path(s) toward one or multiple destinations. It implements different cost estimations related to human movement across the landscape. The function takes as input a Digital Terrain Model ('RasterLayer' class) and a point feature ('SpatialPointsDataFrame' class), the latter representing the starting location, i.e. the location from which the accumulated cost is calculated.

Usage

```
movecost(
  dtm = NULL,
  origin,
  destin = NULL,
```

```

studyplot = NULL,
funct = "t",
time = "h",
outp = "r",
move = 16,
cogn.slp = FALSE,
sl.crit = 10,
W = 70,
L = 0,
N = 1,
V = 1.2,
z = 9,
return.base = FALSE,
rb.lty = 2,
breaks = NULL,
cont.lab = TRUE,
destin.lab = TRUE,
cex.breaks = 0.6,
cex.lcp.lab = 0.6,
graph.out = TRUE,
oneplot = TRUE,
export = FALSE
)

```

Arguments

dtm	Digital Terrain Model (RasterLayer class); if not provided, elevation data will be acquired online for the area enclosed by the 'studyplot' parameter (see Details).
origin	location from which the cost surface is calculated (SpatialPointsDataFrame class).
destin	location(s) to which least-cost path(s) is calculated (SpatialPointsDataFrame class).
studyplot	polygon (SpatialPolygonDataFrame class) representing the study area for which online elevation data are aquired (see Details); NULL is default.
funct	cost function to be used: t (default) uses the on-path Tobler's hiking function; tofp uses the off-path Tobler's hiking function; mp uses the Marquez-Perez et al.'s modified Tobler's function; icmonp uses the Irmischer-Clarke's hiking function (male, on-path); icmoffp uses the Irmischer-Clarke's hiking function (male, off-path); icfonp uses the Irmischer-Clarke's hiking function (female, on-path); icfoffp uses the Irmischer-Clarke's hiking function (female, off-path); ug uses the Uriarte Gonzalez's slope-dependant walking-time cost function; alb uses the Alberti's Tobler hiking function modified for pastoral foraging ex-cursions; gkrs uses the Garmy, Kaddouri, Rozenblat, and Schneider's hiking function; r uses the Rees' hiking function; ree uses the relative energetic expenditure cost function; hrz uses the Herzog's metabolic cost function;

wcs uses the wheeled-vehicle critical slope cost function;
p uses the Pandolf et al.'s metabolic energy expenditure cost function;
vl uses the Van Leusen's metabolic energy expenditure cost function;
ls uses the Llobera-Sluckin's metabolic energy expenditure cost function;
b uses the Bellavia's cost function (for all the above cost functions, see Details).

time	time-unit expressed by the accumulated raster and by the isolines if Tobler's and other time-related cost functions are used; 'h' for hour, 'm' for minutes.
outp	type of output: 'raster' or 'contours' (see Details).
move	number of directions in which cells are connected: 4 (rook's case), 8 (queen's case), 16 (knight and one-cell queen moves; default).
cogn.slp	TRUE or FALSE (default) if the user wants or does not want the 'cognitive slope' to be used in place of the real slope (see Details).
sl.crit	critical slope (in percent), typically in the range 8-16 (10 by default) (used by the wheeled-vehicle cost function; see Details).
W	walker's body weight (in Kg; 70 by default; used by the Pandolf's and Van Leusen's cost function; see Details).
L	carried load weight (in Kg; 0 by default; used by the Pandolf's and Van Leusen's cost function; see Details).
N	coefficient representing ease of movement (1 by default) (see Details).
V	speed in m/s (1.2 by default) (used by the Pandolf's and Van Leusen's cost function; see Details).
z	zoom level for the elevation data downloaded from online sources (0 to 15; 9 by default) (see Details and get_elev_raster).
return.base	TRUE or FALSE (default) if the user wants or does not want the least-cost paths back to the origin to be calculated and plotted (as dashed lines).
rb.lty	Line type used to represent the least-cost paths back to the origin in the returned plot (2 by default; dashed line; see 'lty' parameter in par).
breaks	isolines interval; if no value is supplied, the interval is set by default to 1/10 of the range of values of the accumulated cost surface.
cont.lab	if set to TRUE (default) display the labels of the contours over the accumulated cost surface.
destin.lab	if set to TRUE (default) display the label(s) indicating the cost at the destination location(s).
cex.breaks	set the size of the time labels used in the isochrones plot (0.6 by default).
cex.lcp.lab	set the size of the labels used in least-cost path(s) plot (0.6 by default).
graph.out	TRUE (default) or FALSE if the user wants or does not want a graphical output to be generated.
oneplot	TRUE (default) or FALSE if the user wants or does not want the plots displayed in a single window.

`export` TRUE or FALSE (default) if the user wants or does not want the outputs to be exported; if TRUE, the DTM, the cost-surface, and the accumulated cost surface are exported as a GeoTiff file, while the isolines and the least-cost path(s) are exported as shapefile; all the exported files (excluding the DTM) will bear a suffix corresponding to the cost function selected by the user. Notice that the DTM is exported only if it was not provided by the user and downloaded by the function from online sources.

Details

If the parameter `'destin'` is fed with a dataset representing destination location(s) (`'SpatialPoints-DataFrame'` class), the function also calculates least-cost path(s) plotted on the input DTM; the length of each path is saved under the variable `'length'` stored in the `'LCPs'` dataset (`'SpatialLines'` class) returned by the function. In the produced plot, the red dot(s) representing the destination location(s) are labelled with numeric values representing the cost value at the location(s). The cost value is also appended to the updated destination locations dataset returned by the function, which stores a new variable labelled `'cost'`.

When using cost functions expressing cost in terms of time, the time unit can be selected by the user setting the `'time'` parameter to `'h'` (hour) or to `'m'` (minutes).

In general, the user can also select which type of visualization the function has to produce; this is achieved setting the `'outp'` parameter to either `'r'` (=raster) or to `'c'` (=contours). The former will produce a raster with a colour scale and contour lines representing the accumulated cost surface; the latter parameter will only produce contour lines.

The contour lines' interval is set using the parameter `'breaks'`; if no value is passed to the parameter, the interval will be set by default to 1/10 of the range of values of the accumulated cost surface.

It is worth reminding the user(s) that all the input layers (i.e., DTM, start location, and destination locations) must use the same projected coordinate system.

Cost surface calculation:

for the cost-surface and LCPs calculation, `'movecost'` builds on functions from Jacob van Etten's [gdistance](#) package. Under the hood, `'movecost'` calculates the slope as rise over run, following the procedure described by van Etten, "R Package `gdistance`: Distances and Routes on Geographical Grids" in *Journal of Statistical Software* 76(13), 2017, pp. 14-15. The number of directions in which cells are connected in the cost calculation can be set to 4 (rook's case), 8 (queen's case), or 16 (knight and one-cell queen moves) using the `'move'` parameter (see `'Arguments'`).

Acquiring online elevation data:

if a DTM is not provided, `'movecost'` will download elevation data from online sources. Elevation data will be acquired for the area enclosed by the polygon supplied by the `'studypol'` parameter (`SpatialPolygonDataFrame` class). To tap online elevation data, `'movecost'` internally builds on the [get_elev_raster](#) function from the `elevatr` package.

The zoom level of the downloaded DTM (i.e., its resolution) is controlled by the parameter 'z', which is set to 9 by default (a trade off between resolution and download time).

To test this facility, the user may want to try the following code, that will generate a least-cost surface and least-cost paths in an area close the Mount Etna (Sicily, Italy), whose elevation data are acquired online; the start and end locations, and the polygon defining the study area, are provided in this same package:

```
result <- movecost(origin=Etna_start_location, destin=Etna_end_location, studyplot=Etna_boundary)
```

The LCPs back to the origin can be calculated and plotted setting the parameter 'return.base' to TRUE:

```
result <- movecost(origin=Etna_start_location, destin=Etna_end_location, studyplot=Etna_boundary,
return.base=TRUE)
```

To know more about what elevation data are tapped from online sources, visit: https://cran.r-project.org/web/packages/elevatr/vignettes/introduction_to_elevatr.html.

For more information about the elevation data resolution per zoom level, visit <https://github.com/tilezen/joerd/blob/master/docs/sources.md#what-is-the-ground-resolution>.

To know what is sourced at what zoom level, visit <https://github.com/tilezen/joerd/blob/master/docs/data-sources.md#what-is-sourced-at-what-zooms>.

Terrain slope and cognitive slope:

when it comes to the terrain slope, the function provides the facility to use the so-called 'cognitive slope', following Pingel TJ (2013), Modeling Slope as a Contributor to Route Selection in Mountainous Areas, in Cartography and Geographic Information Science, 37(2), 137-148. According to Pingel, "Humans tend to overestimate geographic slopes by a surprisingly high margin...This analysis indicates downhill slopes are overestimated at approximately 2.3 times the vertical, while uphill slopes are overestimated at 2 times the vertical.". As a result, if the parameter 'cogn.slp' is set to TRUE, positive slope values are preliminarily multiplied by 1.99, while negative slope values are multiplied by 2.31.

Terrain factor (N):

virtually all the implemented cost functions (with few exceptions) can take into account a 'terrain factor' (N parameter; 1 by default), which represents the easiness/difficulty of moving on different terrain types. According to the type of terrain, the energy spent when walking increases. The same holds true for time, which increases because on a loose terrain (for instance) the walking speed decreases. While a terrain factor is 'natively' part of the Van Leusen's, Pandolf et al.'s, and Bellavia's cost function, it has been integrated into the other cost functions as well (when/if relevant).

Note that the terrain factor has NOT been implemented in the Alberti's, Tobler's off-path, and Irmischer-Clarke's off-path cost function. As for the latter two, they already natively feature a terrain factor. Therefore, it has been implemented only in their on-path version. Needless to say, if

we use a terrain factor of 1.67 with the Tobler's (on-path) hiking function, the results will be equal to those obtained using the Tobler's off-path function (the reciprocal of 1.67, i.e. 0.60, is in fact natively used by the Tobler's function for off-path hiking). In fact, compare the results of the following two runs of 'movecost()' (first some data are loaded):

```
volc <- raster::raster(system.file("external/maungawhau.grd", package="gdistance"))
data(volc.loc)
data(destin.loc)
```

```
result1 <- movecost(dtm=volc, origin=volc.loc, destin=destin.loc, breaks=0.05, funct="t", N=1.67)
result2 <- movecost(dtm=volc, origin=volc.loc, destin=destin.loc, breaks=0.05, funct="tofp")
```

The user may want to refer to the following list of terrain factors, which is based on the data collected in Herzog, I. (2020). *Spatial Analysis Based on Cost Functions*. In Gillings M, Haciguzeller P, Lock G (eds), "Archaeological Spatial Analysis. A Methodological Guide.", Routledge: New York, 340 (with previous references). The list is divided into two sections (a and b), the first reporting the terrain factors to be used for cost functions measuring time, the second for functions measuring cost other than time:

(a)

- Blacktop roads, improved dirt paths, cement = 1.00
- Lawn grass = 1.03
- Loose beach sand = 1.19
- Disturbed ground (former stone quarry) = 1.24
- Horse riding path, flat trails and meadows = 1.25
- Tall grassland (with thistle and nettles) = 1.35
- Open space above the treeline (i.e., 2000 m asl) = 1.50
- Bad trails, stony outcrops and river beds = 1.67
- Off-paths = 1.67
- Bog = 1.79
- Off-path areas below the treeline (pastures, forests, heathland) = 2.00
- Rock = 2.50
- Swamp, water course = 5.00

(b)

- Asphalt/blacktop = 1.00
- Dirt road or grass = 1.10
- Hard-surface road = 1.20
- Light brush = 1.20

- Ploughed field = 1.30 or 1.50
- Heavy brush = 1.50
- Hard-packed snow = 1.60
- Swampy bog = 1.80
- Sand dunes = 1.80
- Loose sand = 2.10

Besides citing this package, you may want to refer to the following journal article: **Alberti (2019)** <doi:10.1016/j.softx.2019.100331>.

The following cost functions are implemented (**x[adj]** stands for slope as rise/run calculated for adjacent cells):

Tobler's hiking function (on-path) (speed in kmh):

$$6 * \exp(-3.5 * \text{abs}(x[\text{adj}] + 0.05))$$

Tobler's hiking function (off-path) (speed in kmh):

$$(6 * \exp(-3.5 * \text{abs}(x[\text{adj}] + 0.05))) * 0.6$$

as per Tobler's indication, the off-path walking speed is reduced by 0.6.

Marquez-Perez et al.'s modified Tobler hiking function (speed in kmh):

$$4.8 * \exp(-5.3 * \text{abs}((x[\text{adj}] * 0.7) + 0.03))$$

modified version of the Tobler's hiking function as proposed by Joaquin Marquez-Perez, Ismael Vallejo-Villalta & Jose I. Alvarez-Francoso (2017), "Estimated travel time for walking trails in natural areas", *Geografisk Tidsskrift-Danish Journal of Geography*, 117:1, 53-62, DOI: 10.1080/00167223.2017.1316212.

Irmischer-Clarke's modified Tobler hiking function (male, on-path):

$$(0.11 + \exp(-(\text{abs}(x[\text{adj}]) * 100 + 5)^2 / (2 * 30)^2)) * 3.6$$

modified version of the Tobler's function as proposed for (male) on-path hiking by Irmischer, I. J., & Clarke, K. C. (2018). Measuring and modeling the speed of human navigation. *Cartography and Geographic Information Science*, 45(2), 177-186. <https://doi.org/10.1080/15230406.2017.1292150>. **Note:** all the all the Irmischer-Clarke's functions originally express speed in m/s; they have been reshaped (multiplied by 3.6) to turn m/s into km/h for consistency with the other Tobler-related cost functions; slope is in percent.

Irmischer-Clarke's modified Tobler hiking function (male, off-path):

$$(0.11 + 0.67 * \exp(-(abs(x[adj]) * 100 + 2)^2 / (2 * 30^2))) * 3.6$$

Irmischer-Clarke's modified Tobler hiking function (female, on-path):

$$(0.95 * (0.11 + \exp(-(abs(x[adj]) * 100 + 5)^2 / (2 * 30^2)))) * 3.6$$

Irmischer-Clarke's modified Tobler hiking function (female, off-path):

$$(0.95 * (0.11 + 0.67 * \exp(-(abs(x[adj]) * 100 + 2)^2 / (2 * 30^2)))) * 3.6$$

Uriarte Gonzalez's slope-dependant walking-time cost function:

$$1 / (0.0277 * (abs(x[adj]) * 100) + 0.6115)$$

proposed by Uriarte Gonzalez; **see:** Chapa Brunet, T., Garcia, J., Mayoral Herrera, V., & Uriarte Gonzalez, A. (2008). GIS landscape models for the study of preindustrial settlement patterns in Mediterranean areas. In *Geoinformation Technologies for Geo-Cultural Landscapes* (pp. 255-273). CRC Press. <https://doi.org/10.1201/9780203881613.ch12>.

The cost function is originally expressed in seconds; for the purpose of its implementation in this function, it is the reciprocal of time (1/T) that is used in order to eventually get T/1. Unlike the original cost function, here the pixel resolution is not taken into account since 'gdistance' takes care of the cells' dimension when calculating accumulated costs.

Alberti's Tobler hiking function modified for pastoral foraging excursions (speed in kmh):

$$(6 * \exp(-3.5 * abs(x[adj] + 0.05))) * 0.25$$

proposed by Gianmarco Alberti; **see:** [Locating potential pastoral foraging routes in Malta through the use of a Geographic Information System](#). The Tobler's function has been rescaled to fit animal walking speed during foraging excursions. The distribution of the latter, as empirical data show, turns out to be right-skewed and to vary along a continuum. It ranges from very low speed values (corresponding to slow grazing activities grazing while walking) to comparatively higher values (up to about 4.0 km/h) corresponding to travels without grazing (directional travel toward feeding stations). The function consider 1.5 km/h as the average flock speed, which roughly corresponds to the average speed recorded in some studies, and can be considered the typical speed of flocks during excursions in which grazing takes place while walking (typical form of grazing in most situations). Tobler's hiking function has been rescaled by a factor of 0.25 to represent the walking pace of a flock instead of humans. The factor corresponds to the ratio between the flock average speed (1.5 km/h) and the maximum human walking speed (about 6.0 km/h) on a favourable slope.

Garmy, Kaddouri, Rozenblat, and Schneider's hiking function (speed in kmh):

$$4 * \exp(-0.008 * ((atan(abs(x[adj])) * 180/pi)^2))$$

slope in degrees; **see:** Herzog, I. (2020). Spatial Analysis Based on Cost Functions. In Gillings M, Haciguzeller P, Lock G (eds), "Archaeological Spatial Analysis. A Methodological Guide.",

Routledge: New York, 333-358 (with previous references).

Rees' hiking function (speed in kmh):

$$(1/(0.75 + 0.09 * \text{abs}(x[\text{adj}]) + 14.6 * (\text{abs}(x[\text{adj}]))^2)) * 3.6$$

Rees' slope-dependant cost function; it is originally expressed in terms of time ($1/v$ in Rees' publication); here it is the reciprocal of time (i.e. speed) that is used in order to eventually get the reciprocal of speed (i.e. time). Slope is dealt with here as originally expressed in Rees' publication (i.e. rise over run). The speed, which is originally expressed in m/s, has been here transposed to kmh (i.e., multiplied by 3.6) for consistency with other hiking functions.

For this cost function **see**: Rees, WG (2004). Least-cost paths in mountainous terrain. *Computers & Geosciences*, 30(3), 203–209. **See also**: Campbell MJ, Dennison PE, Butler BW, Page WG (2019). Using crowdsourced fitness tracker data to model the relationship between slope and travel rates. *Applied Geography* 106, 93-107 (with previous references).

Relative energetic expenditure cost function:

$$1/(\tan((\text{atan}(\text{abs}(x[\text{adj}])) * 180/\pi) * \pi/180)/\tan(1 * \pi/180))$$

slope-based cost function expressing change in potential energy expenditure; **see** Conolly, J., & Lake, M. (2006). *Geographic Information Systems in Archaeology*. Cambridge: Cambridge University Press, p. 220; **see also** Newhard, J. M. L., Levine, N. S., & Phebus, A. D. (2014). The development of integrated terrestrial and marine pathways in the Argo-Saronic region, Greece. *Cartography and Geographic Information Science*, 41(4), 379-390, with references to studies that use this function; **see also** ten Bruggencate, R. E., Stup, J. P., Milne, S. B., Stenton, D. R., Park, R. W., & Fayek, M. (2016). A human-centered GIS approach to modeling mobility on southern Baffin Island, Nunavut, Canada. *Journal of Field Archaeology*, 41(6), 684-698. <https://doi.org/10.1080/00934690.2016.1234897>.

Herzog's metabolic cost function in J/(kg*m):

$$1/((1337.8 * \text{abs}(x[\text{adj}]))^6 + (278.19 * \text{abs}(x[\text{adj}]))^5 - (517.39 * \text{abs}(x[\text{adj}]))^4 - (78.199 * \text{abs}(x[\text{adj}]))^3 + (93.419 * \text{abs}(x[\text{adj}]))^2 + (19.825 * \text{abs}(x[\text{adj}])) + 1.64)$$

see Herzog, I. (2016). Potential and Limits of Optimal Path Analysis. In A. Bevan & M. Lake (Eds.), *Computational Approaches to Archaeological Spaces* (pp. 179-211). New York: Routledge.

Wheeled-vehicle critical slope cost function:

$$1/(1 + ((\text{abs}(x[\text{adj}]) * 100)/\text{sl.crit})^2)$$

where *sl.crit* (=critical slope, in percent) is "the transition where switchbacks become more effective than direct uphill or downhill paths" and typically is in the range 8-16; **see** Herzog, I. (2016).

Potential and Limits of Optimal Path Analysis. In A. Bevan & M. Lake (Eds.), *Computational Approaches to Archaeological Spaces* (pp. 179-211). New York: Routledge.

Pandolf et al.'s metabolic energy expenditure cost function (in Watts):

$$1/(1.5 * W + 2.0 * (W + L) * (L/W)^2 + N * (W + L) * (1.5 * V^2 + 0.35 * V * (abs(x[adj]) * 100)))$$

where W is the walker's body weight (Kg), L is the carried load (in Kg), V is the velocity in m/s, N is a coefficient representing ease of movement on the terrain (see below).

For this cost function, see Pandolf, K. B., Givoni, B., & Goldman, R. F. (1977). Predicting energy expenditure with loads while standing or walking very slowly. *Journal of Applied Physiology*, 43(4), 577-581. <https://doi.org/10.1152/jappl.1977.43.4.577>.

For the use of this cost function in a case study, see Rademaker, K., Reid, D. A., & Bromley, G. R. M. (2012). Connecting the Dots: Least Cost Analysis, Paleogeography, and the Search for Paleoindian Sites in Southern Highland Peru. In D. A. White & S. L. Surface-Evans (Eds.), *Least Cost Analysis of Social Landscapes. Archaeological Case Studies* (pp. 32-45). University of Utah Press; see also Herzog, I. (2013). Least-cost Paths - Some Methodological Issues, *Internet Archaeology* 36 (<http://intarch.ac.uk/journal/issue36/index.html>) with references.

Note: in the returned charts, the cost is transposed from Watts to Megawatts (see, e.g., Rademaker et al 2012 cited above).

Van Leusen's metabolic energy expenditure cost function (in Watts):

$$1/(1.5 * W + 2.0 * (W + L) * (L/W)^2 + N * (W + L) * (1.5 * V^2 + 0.35 * V * abs(x[adj]) * 100) + 10)$$

which modifies the Pandolf et al.'s equation; see Van Leusen, P. M. (2002). Pattern to process: methodological investigations into the formation and interpretation of spatial patterns in archaeological landscapes. University of Groningen.

Note that, as per Herzog, I. (2013). Least-cost Paths - Some Methodological Issues, *Internet Archaeology* 36 (<http://intarch.ac.uk/journal/issue36/index.html>) and unlike Van Leusen (2002), in the above equation slope is expressed in percent and speed in m/s; also, in the last bit of the equation, 10 replaces the value of 6 used by Van Leusen (as per Herzog 2013).

Note: in the returned charts, the cost is transposed from Watts to Megawatts.

Llobera-Sluckin's metabolic energy expenditure cost function (in KJ/m):

$$1/(2.635 + (17.37 * abs(x[adj])) + (42.37 * abs(x[adj])^2) - (21.43 * abs(x[adj])^3) + (14.93 * abs(x[adj])^4))$$

for which see Llobera M.-Sluckin T.J. (2007). Zigzagging: Theoretical insights on climbing strategies, *Journal of Theoretical Biology* 249, 206-217.

Bellavia's cost function:

$$1/(N * ((atan(abs(x[adj])) * 180/pi) + 1))$$

proposed by G. Bellavia, it measures abstract cost. Slope in degrees; N is a terrain factor (see below). **See:** Herzog, I. (2020). Spatial Analysis Based on Cost Functions. In Gillings M, Haciguzeller P, Lock G (eds), "Archaeological Spatial Analysis. A Methodological Guide.", Routledge: New York, 333-358 (with previous references).

Note that the walking-speed-related cost functions listed above are used as they are, while the other functions are reciprocated. This is done since "gdistance works with conductivity rather than the more usual approach using costs"; therefore "we need inverse cost functions" (Nakoinz-Knitter (2016). "Modelling Human Behaviour in Landscapes". New York: Springer, p. 183). As a consequence, if we want to estimate time, we have to use the walking-speed functions as they are since the final accumulated values will correspond to the reciprocal of speed, i.e. pace. In the other cases, we have to use 1/cost-function to eventually get cost-function/1.

Value

The function returns a list storing the following components

- dtm: Digital Terrain Model ('RasterLayer' class)
- cost.surface: raster representing the cost-surface ('RasterLayer' class)
- accumulated.cost.raster: raster representing the accumulated cost ('RasterLayer' class)
- isolines: contour lines derived from the accumulated cost surface ('SpatialLinesDataFrame' class)
- LCPs: estimated least-cost paths ('SpatialLines' class)
- LCPs.back: estimated least-cost paths back to the origin ('SpatialLines' class)
- LCPs\$length: length of each least-cost path (units depend on the unit used in the input DTM)
- LCPs.back\$length: length of each least-cost path back to the origin (units depend on the unit used in the input DTM)
- dest.loc.w.cost: copy of the input destination location(s) dataset with a new variable ('cost') added

See Also

[get_elev_raster](#), [movecorr](#)

Examples

```
# load a sample Digital Terrain Model
volc <- raster::raster(system.file("external/maungawhau.grd", package="gdistance"))

# load a sample start location on the above DTM
data(volc.loc)
```

```
# load the sample destination locations on the above DTM
data(destin.loc)

# calculate walking-time isochrones based on the on-path Tobler's hiking function (default),
# setting the time unit to hours and the isochrones interval to 0.05 hour;
# also, since destination locations are provided,
# least-cost paths from the origin to the destination locations will be calculated
# and plotted; 8-directions move is used

result <- movecost(dtm=volc, origin=volc.loc, destin=destin.loc, move=8, breaks=0.05)

# same as above, but using the Irmischer-Clarke's hiking function (male, on-path)

result <- movecost(dtm=volc, origin=volc.loc, destin=destin.loc, funct="icmonp",
move=8, breaks=0.05)

# same as above, but using the 'cognitive slope'

result <- movecost(dtm=volc, origin=volc.loc, destin=destin.loc, funct="icmonp",
move=8, breaks=0.05, cogn.slp=TRUE)

# calculate accumulated cost surface and the least-cost path between the
# origin and one destination, and also calculate the LCP back to the origin

results <- movecost(dtm=volc, origin=volc.loc, destin=destin.loc[2,], move=8, return.base = TRUE)
```

volc.loc

Dataset: location on the volcano Maunga Whau (Auckland, New Zealand)

Description

A SpatialPointsDataFrame representing a spot on the volcano Maunga Whau (Auckland, New Zealand).

Usage

```
data(volc.loc)
```

Format

SpatialPointsDataFrame

Index

* **datasets**

- destin.loc, [2](#)
- Etna_boundary, [2](#)
- Etna_end_location, [3](#)
- Etna_start_location, [3](#)
- volc.loc, [19](#)

* **movecorr**

- movecorr, [4](#)

* **movecost**

- movecost, [8](#)

destin.loc, [2](#)

Etna_boundary, [2](#)

Etna_end_location, [3](#)

Etna_start_location, [3](#)

get_elev_raster, [5](#), [10](#), [11](#), [18](#)

movecorr, [4](#), [18](#)

movecost, [4](#), [5](#), [7](#), [8](#), [8](#)

par, [10](#)

volc.loc, [19](#)