lbmech

`lbmech` is a geospatial package for `R` to calculate time- and energy-based costs-of-travel for humans and animals moving across the landscape. While providing a similar functionality to the package `gdistance`, `lbmech` stores data and performs all linear algebra using the `data.table` package allowing for in-place modification of objects greatly increasing processing speed. `lbmech` also modularizes important aspects of the cost-distance workflow allowing for computationally-intensive and otherwise prohibitively-large operations to take place. Moreover, unlike similar tools such as `package` for `R`, `lbmech` allows for the estimation of various types of energetic losses (due to kinematic locomotion, work against gravity, basal metabolic processes) instead of simply the total energetic or metabolic expenditure.

The example provided in this README provides a detailed guide employing the examples included in the individual function documentation and generating all data from scratch. For applied/real-world examples, please see the provided vignettes. For most purposes, only five or six function calls to the package are necessary. A 'quick start' guide summarizing the README example in as few function calls as possible is provided at the end of this file.

Installation

You can install the development version from GitHub with:

```
# install.packages("devtools")
devtools::install_github("andresgmejiar/lbmech")
```

Example Workflow

```
library(lbmech)
# Set random seed for reproducibility's sake
set.seed(5574741)
```

Part 1: Topographic data sources

The first step in a typical `lbmech` workflow is defining the digital elevation model (DEM) to define as the topographic data source. This may be provided in one of two ways:

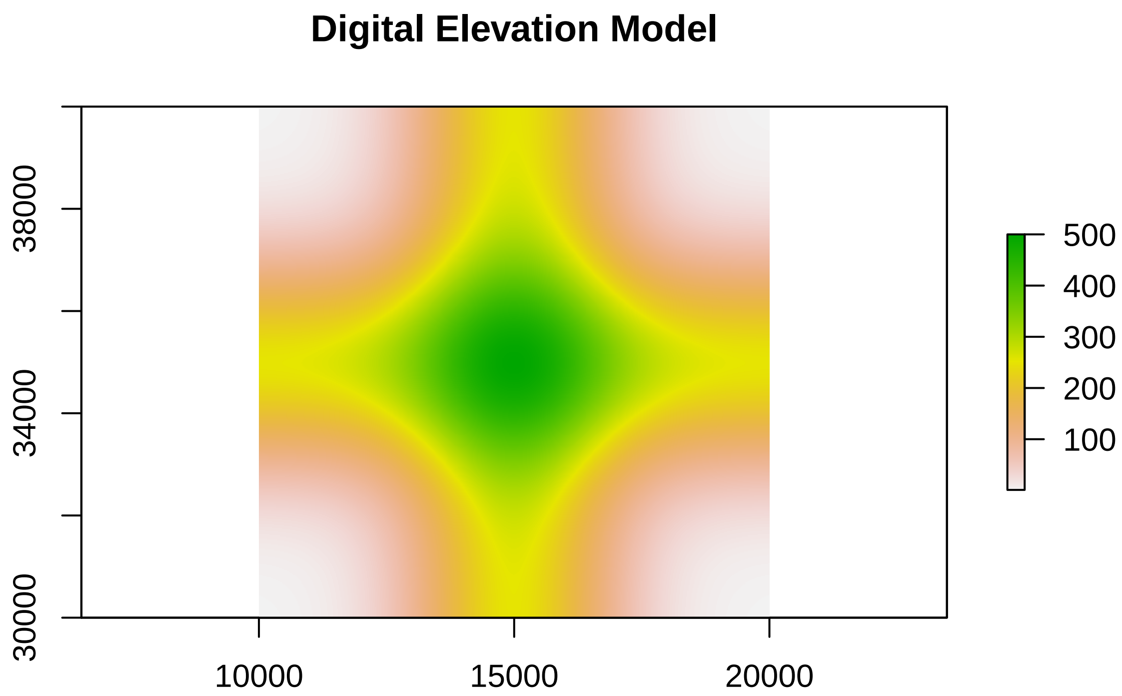
1. A RasterLayer object representing the digital elevation model for the region-of-interest
    - In order to ensure that there is a stable file path to the source DEM throughout the workflow, the raster must have been 'read in' using the `raster` function without having been further modified. If additional modifications are necessary, use the `writeRaster` function to save it to the disk first before re-reading it in using `raster`. For example:

```
# Generate a DEM
n <- 5
dem <- expand.grid(list(x = 1:(n * 100),
                        y = 1:(n * 100))) / 100
dem <- as.data.table(dem)
dem[, z := 250 * exp(-(x - n/2)^2) +
      250 * exp(-(y - n/2)^2)]
dem <- rasterFromXYZ(dem)
extent(dem) <- c(10000, 20000, 30000, 40000)
crs(dem) <- "+proj=lcc +lat_1=48 +lat_2=33 +lon_0=-100 +datum=WGS84"

# Export it so it doesn't just exist on the memory
dir <- tempdir()
writeRaster(dem, paste0(dir,"/DEM.tif"),format="GTiff",overwrite=TRUE)
```

```
# Import raster
dem <- raster(paste0(dir,"/DEM.tif"))

plot(dem, main = "Digital Elevation Model")
```

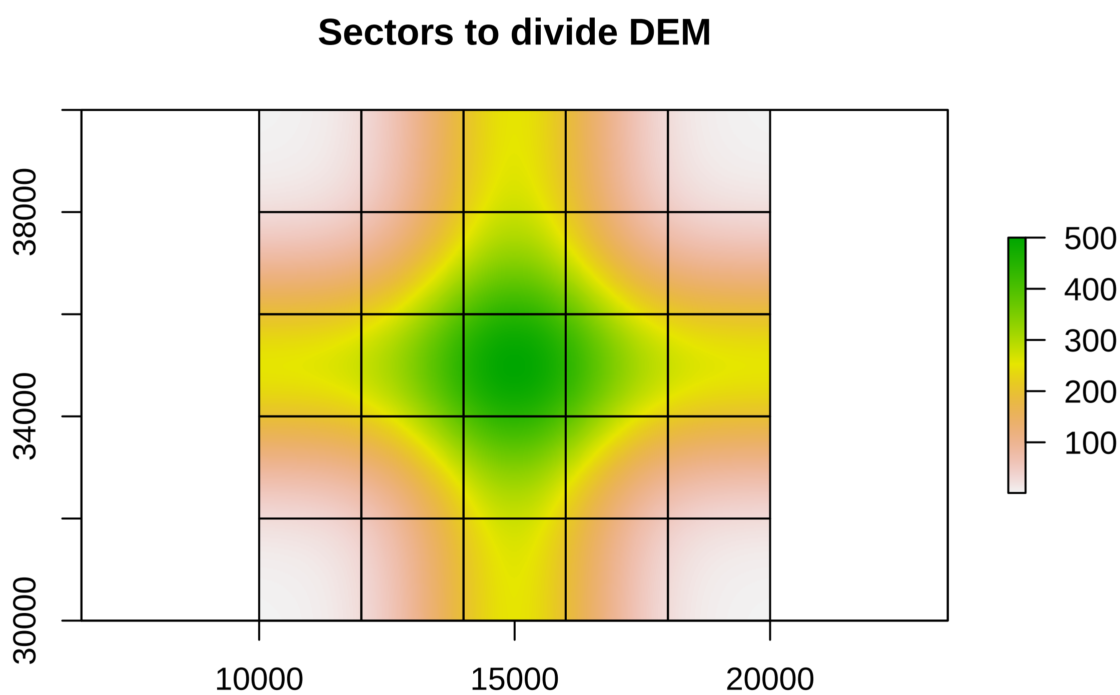


2. A SpatialPolygonsDataFrame object whose individual polygons represent sectors with unique DEM sources stored as a file path or URL in the data frame object.
   - As of the most recent version, `lbmech` supports file types readible by `rgdal` and `raster`, as well as such files compressed in `gz` and `zip` files–although the latter is likely to fail in Unix systems.

Even if you have already downloaded or imported a raster to use as a topographic data source as in case one above, most of the functions will expect a SpatialPolygonsDataFrame object in the form of case two. You can make this using the `makeGrid` function:

```
grid <- makeGrid(dem = dem, nx = n, ny = n)

plot(dem, main = "Sectors to divide DEM")
plot(grid,add=TRUE)
```



`lbmech` is specifically designed to deal with **large** regions that would be prohibitive to analyze if the data is stored exclusively within the memory. To deal with this issue, `lbmech` will crop any input raster into an `nx` by `ny` grid and save the sector in its own `gz` file for case 1. In both cases—to save memory and computational time—sectors are only cropped or downloaded on an as-needed basis. You can use the `whichTiles` and `getMap` functions to identify which tile(s) might be needed, and download or crop any such tiles that haven't been prepared:

```
# Generate five random points that fall within the grid
points <- data.table(x = runif(5, extent(dem)[1], extent(dem)[2]),
                     y = runif(5, extent(dem)[3], extent(dem)[4]))


# Run whichTiles and getMap to prepare appropriate sector files
tile_list <- whichTiles(region = points, polys = grid)
print(tile_list)
#> [1] "SECTOR_17" "SECTOR_5"  "SECTOR_1"  "SECTOR_10"

getMap(tiles = tile_list, polys = grid, dir = dir)
print(list.files(dir,recursive=TRUE, pattern = ".gz$"))
#>  [1] "Elevations/SECTOR_1.gz"      "Elevations/SECTOR_10.gz"     "Elevations/SECTOR_11.gz"
#>  [4] "Elevations/SECTOR_12.gz"     "Elevations/SECTOR_13.gz"     "Elevations/SECTOR_14.gz"
#>  [7] "Elevations/SECTOR_15.gz"     "Elevations/SECTOR_16.gz"     "Elevations/SECTOR_17.gz"
#> [10] "Elevations/SECTOR_18.gz"     "Elevations/SECTOR_19.gz"     "Elevations/SECTOR_2.gz"
#> [13] "Elevations/SECTOR_20.gz"     "Elevations/SECTOR_21.gz"     "Elevations/SECTOR_22.gz"
#> [16] "Elevations/SECTOR_23.gz"     "Elevations/SECTOR_24.gz"     "Elevations/SECTOR_25.gz"
#> [19] "Elevations/SECTOR_3.gz"      "Elevations/SECTOR_4.gz"      "Elevations/SECTOR_5.gz"
#> [22] "Elevations/SECTOR_6.gz"      "Elevations/SECTOR_7.gz"      "Elevations/SECTOR_8.gz"
```

```
#> [25] "Elevations/SECTOR_9.gz"      "Tensors/SECTOR_12_Tensor.gz" "Tensors/SECTOR_13_Tensor.gz"
#> [28] "Tensors/SECTOR_7_Tensor.gz"  "Tensors/SECTOR_8_Tensor.gz"
```

By far the most computationally intensive part of the workflow is the first transformation of the topographic data. To calculate the distances, we will need to convert the data from a a matrix of locations (a raster) with an associated attribute (elevation) to a list of possible movements between locations (all raster cells and their neighbors) and associated attribute (difference in elevation). These are stored as `gz` files in a folder named `'Tensors'` in the workspace directory and will be later read into the memory as required to avoid having to re-calculate them every time they are needed:

```
# Select all tiles that exist between x = (12000,16000) and y = (32000,36000)
tiles <- extent(c(12000,16000,32000,36000))
tiles <- as(tiles,"SpatialPolygons")
crs(tiles) <- crs(grid)
tiles <- whichTiles(region = tiles, polys = grid)

makeWorld(tiles = tiles, polys = grid, cut_slope = 0.5, z_fix = dem, dir = dir)
```

`makeWorld` internally calls `getMap` so you do not need to prepare the data beforehand. A note about the parameters. The `cut_slope` is the magnitude of the dimensionless slope beyond which movement is not possible.

`z_fix` merits special attention since its consistency will be required for most of the later functions in the workflow. `lbmech` allows for sector-defining grids pointing to DEM sources in different coordinate reference systems, spatial resolutions, and grid origins. However, the package requires a 'master' raster be designated that will define the projection, spatial resolution, and grid origin to be used in the analyses. All data will be projected to these 'fixed' parameters. If your sector-defining grid points to a single raster such as the output of the `makeGrid` function, you can simply use the original DEM as the `z_fix` parameter throughout. If the grid is custom or comes from a third party, it is useful to designate a raster from within the dataset as the master if the spatial resolution matches the desired unit of analysis. If not, you can make an appropriate `z_fix` using the `fix_z` function:

```
z_fix <- fix_z(res = res(dem)[1],       # Desired resolution
               crs = crs(dem),          # Desired projection
               dx  = origin(dem)[1],    # Desired horizontal offset
               dy  = origin(dem)[2])    # Desired vertical offset
```

Part 2: Velocity data sources

The fundamental assumption behind the least-cost calculations is that humans and animals tend to prefer to walk at predictable speeds at a given slope. The maximum speed is generally achieved at one particular slope, and speed would tend to decrease exponentially as the distance to this ideal slope increases. Mathematically, this is described by Tobler's Hiking function:

$$\frac{d\ell}{dt} = v_{\max} e^{-k|\frac{dz}{d\ell} - \alpha|},$$

where ℓ is horizontal displacement, t time, $\frac{d\ell}{dt}$ horizontal speed, $v_{\max}$ the maximum walking speed, $\frac{dz}{d\ell}$ the change in elevation versus the change in horizontal distance (dimensionless slope, or $\arctan\theta$ where θ is the slope in degrees or radians), α the ideal slope of maximum walking speed, and k a parameter controling how sensitive changes in speed are to changes in slope. Canonical applications of this function to humans set $v_{\max} = 1.5$ m/s, $k = 3.5$, and $\alpha = -0.05 = \tan(-2.83°)$.

`lbmech` provides the getVelocity function by which these parameters can be estimated from locational data for different species. Data should be structured such that there is a column with x coordinates, a column with y coordinates, a column with changes in time, and a column with a trajectory id. Note that all values must be in meters, and the 'x' and 'y' coordinates in a projected coordinate system. If those columns are named anything other than 'x', 'y', 'dt', and 'id', the column names need to be declared explicitly. Elevational data is provided as the z parameter. This can be either a column with elevations—such as those recorded by a GPS unit—a RasterLayer representing the DEM for that region, or a SpatialPolygonsDataFrame like the output of the makeGrid function:

```
# Generate dummy GPS data
# 10,000 observations falling within the extent of the generted DEM
# taken at an interval of 120 seconds between observations
# and of 10 different individuals (1000 per individual)
data <- data.table(x = runif(10000,extent(dem)[1],extent(dem)[2]),
                   y = runif(10000,extent(dem)[3],extent(dem)[4]),
                   dt = 120,
                   ID = rep(1:10,each=1000))

velocity <- getVelocity(data = data, z = grid, dir = dir)
```

So what happened? getVelocity called whichTiles and getMap to identify which tiles were needed to get the elevation for the points we generated in data. It then cropped and saved each tile in a folder named 'Elevations' in the dir. Afterwards, it extracted the elevation for each data point, and performed a nonlinear quantile regression to get the appropriate parameters.

The output object is a list. Since this was calculated based on random data, the calculated parameters here are meaningless but let's have a look at the structure anyways:

```
print(velocity)
#> $model
#> Nonlinear quantile regression
#>    model:  dl_dt ~ v_max * exp(-k * abs(dz_dl - alpha))
#>     data:  data
#>      tau:  0.995
#> deviance:  428573.2
#>          k      alpha
#>  0.7260741 50.2094994
#>
#> $vmax
#> [1] 90.81751
#>
#> $alpha
#> [1] 50.2095
#>
#> $k
#> [1] 0.7260741
#>
#> $tau_vmax
#> [1] 0.995
#>
#> $tau_nlrq
#> [1] 0.95
#>
#> $data
#>        ID        x        y         z  dt         dx         dy         dz       dl    dl_dt
#>     1:  1 14184.43 37082.75 296.04593 120         NA         NA         NA       NA       NA
#>     2:  1 13726.24 35062.09 417.70062 120  -458.1817 -2020.6651  121.65469 2071.960 17.26633  0.0587
#>     3:  1 11211.38 31641.73  22.39640 120 -2514.8615 -3420.3624 -395.30422 4245.398 35.37832 -0.0931
```

```
#>     4:  1 16539.87 30648.36 140.43419 120  5328.4904  -993.3627  118.03779 5420.293 45.16911  0.0217
#>     5:  1 19063.24 34536.91 241.01436 120  2523.3705  3888.5521  100.58017 4635.541 38.62950  0.0216
#>    ---
#>  9996: 10 16832.04 33654.95 266.82159 120  4605.6630 -4322.2371  202.44404 6316.159 52.63466  0.0320
#>  9997: 10 13210.97 38417.22 126.65144 120 -3621.0667  4762.2646 -140.17016 5982.582 49.85485 -0.0234
#>  9998: 10 18523.71 37188.86  85.44712 120  5312.7413 -1228.3575  -41.20432 5452.897 45.44081 -0.0075
#>  9999: 10 16082.61 34620.62 426.77194 120 -2441.1016 -2568.2359  341.32482 3543.277 29.52731  0.0963
#> 10000: 10 11045.88 38322.00  20.53027 120 -5036.7365  3701.3801 -406.24168 6250.514 52.08762 -0.0649
```

The velocity list contains seven entries:

1. `$model`, containing an object of class `nlrq` with the output model from the nonlinear quantile regression (nlrq) structured in the form of Tobler's function. You can treat this as any other statistical model object such as `lm`.

2. `$vmax`, containing the identified maximum velocity, calculated as the `tau_max` fraction of all observed velocities.

3. `$alpha`, containing the identified angle of maximum velocity, and calculated from the nlrq of Tobler's function

4. `$k`, containing the identified topographic sensitivity factor, and calculated from the nlrq of Tobler's function.

5. `$tau_max`, containing the employed `tau_max`.

6. `$tau_nlrq`, containing the employed `tau_nlrq`.

7. `$data`, containing a data.table with the original data in a standardized format

Part 3: Preparing the World

You'll have noticed that `makeWorld` simply made the `gz` files in the working directory for each sector that's required. To import them into the memory, use the `importWorld` function. It first runs `makeWorld` (which in turn calls `getMap`) to make sure each necessary sector has been prepared, and then imports ONLY the possible movements falling within a given `region` and excluding those falling within a given `banned` area:

```
# Import the data lying between x = (12000,16000) and y = (32000,36000)...
region <- extent(c(12000,16000,32000,36000))
region <- as(region,"SpatialPolygons")
crs(region) <- crs(grid)

world <- importWorld(region = region, polys = grid, banned = NULL,
                     cut_slope = 0.5, z_fix = dem, dir = dir)
```

Let's have a look at what the `world` data.table looks like:

```
head(world)
#>           from          to         dz
#> 1: 12010,34130 12030,34130  0.8184357
#> 2: 12010,34130 12010,34110 -1.7999878
#> 3: 12010,34130 12030,34110 -0.9815521
#> 4: 12010,34130 12050,34110 -0.1442108
#> 5: 12010,34130 12030,34090 -2.8067932
#> 6: 12030,34130 12010,34130 -0.8184357
```

There are three columns. `$from` and `$to` contain the x and y coordinates for the start and stop of each possible movement/transition. These are stored as character strings, with a precision of up to two decimal points depending on the resolution and origin. `$dz` contains the change in elevation encountered when traveling from the `$from` cell to the `$to` cell.

The next step is calculating the cost in terms of time, work, and energy for every possible transition. The `calculateCosts` function takes the changes in elevation and using the velocity information from the previous section, models of biomechanical work expediture, and physical limitations calculates the expected costs. There are currently three available models, run `?calculateCosts` for more information on each model and what parameters are required. This is for a 60 kg human with a maximum walking speed of 1.5 m/s, a leg length of 80 cm, a stride length of 1.6 m, a BMR of 93 J/s, and canonical values for Tobler's hiking function:

```
world <- calculateCosts(world = world, method = 'kuo', m = 60, v_max = 1.5,
                        BMR = 93, k = 3, alpha = -0.05, l_s = 1.6, L = 0.8)
```

Note that we could simply have done `v_max = velocity$vmax, alpha = velocity$alpha, k = velocity$k`, but the current `velocity` object was generated with random data and thus the parameters are nonsensical. Taking a look at the `world` object now shows an additional nine columns:

```
head(world)
#>             from          to          dz   x_i   y_i       dl     dl_t       dt     dU_l      dK_l
#> 1: 12010,34130 12030,34130  0.8184357 12010 34130 20.00000 1.141907 17.51456 481.7312  977.9639  729
#> 2: 12010,34130 12010,34110 -1.7999878 12010 34130 20.00000 1.330383 15.03326   0.0000 1327.4394  663
#> 3: 12010,34130 12030,34110 -0.9815521 12010 34130 28.28427 1.432720 19.74167   0.0000 2177.2016 1088
#> 4: 12010,34130 12050,34110 -0.1442108 12010 34130 44.72136 1.303612 34.30572   0.0000 2849.9886 1424
#> 5: 12010,34130 12030,34090 -2.8067932 12010 34130 44.72136 1.443657 30.97782   0.0000 3495.2198 1747
#> 6: 12030,34130 12010,34130 -0.8184357 12030 34130 20.00000 1.459699 13.70145   0.0000 1598.0415  799
```

`$x_i` and `$y_i` give the numeric x and y coordinates of the first part of the movement/transition. `$dl` gives the distance, `$dl_t` the predicted speed, `$dt` the predicted amount of time spent making that movement, `$dU_l` the work performed against gravity, `$dK_l` the kinematic work performed, `$dW_l` the net mechanical work performed, and `$dE_l` the total energetic/metabolic expenditure.

Part 4: Getting Costs, Paths, and Corridors

The final part of the workflow involves calculating the minimum cost and/or least-cost path between two sets of points. Generally the first step in this process is running the `getCosts` function, with the parameters set based on your needs:

1. If you simply desire the distance between two sets of points (cases 1 and 2), provide entries for `from` and `to` (or just `from` if the interest is in all distances between locations in that object). Output is a distance matrix. The computational time for this operation is comparable to generating a raster for the distance to all cells in the world (unless all of the locations in the object are close to each other). So unless the operation is to be done multiple times, it is highly recommended to generate the raster as below and extract values:

```
# Generate five random points that fall within the region
points <- data.table(ID = 1:5,
                     x = runif(5, extent(region)[1], extent(region)[2]),
                     y = runif(5, extent(region)[3], extent(region)[4]))

# Get the cost for travel between all combination of points
costMatrix <- getCosts(world = world, from = points, z_fix = dem,
                       costs ='all', direction = 'out', dir = dir)
```

The output will be a list of cost matrices, with elements named after the type of costand direction of travel:

```
print(costMatrix)
#> $time_out
#>        To_ID
```

```
#> From_ID         1         2         3         4         5
#>       1    0.0000 1275.3205 2026.1966  698.3684  549.8334
#>       2  944.7807    0.0000  857.4839 1629.1968  970.7801
#>       3 1541.9772  674.4063    0.0000 2239.9352 1621.3863
#>       4  942.6987 2199.1856 2968.3413    0.0000 1107.1418
#>       5  576.2873 1310.4161 2133.3876  824.7255    0.0000
#>
#> $work_out
#>        To_ID
#> From_ID         1         2         3         4         5
#>       1       0.0  564923.4  888643.2  278409.9  243956.8
#>       2  397404.3       0.0  363276.2  665565.0  401934.1
#>       3  665752.3  345912.1       0.0  938435.0  724089.3
#>       4  420245.4  977938.6 1308495.0       0.0  479852.0
#>       5  239375.0  582084.8  932552.8  394436.7       0.0
#>
#> $energy_out
#>        To_ID
#> From_ID         1         2         3         4         5
#>       1       0.0  683528.2 1077079.5  344808.0  295194.1
#>       2  486843.6       0.0  443022.2  818557.5  492216.7
#>       3  809887.9  408814.7       0.0 1153919.3  874878.2
#>       4  507916.4 1182462.8 1584550.7       0.0  582816.2
#>       5  292969.8  703953.5 1130957.8  478083.3       0.0
```

2. If you wish to generate a RasterStack of costs from and/or to all nodes in the from object, set the `output = 'object'` and `destination = 'all'`.

3. You may also save the rasters as a series of `tif` files in the same workspace directory as the transition `gz` tensor files and the cropped/downloaded DEMs. This allows us to use `getCosts` within a loop for large numbers of origin nodes without running into random access memory limitations. Do this by setting `output = 'file'` and `destination = 'all'`.

4. You may perform (2) and (3) simultaneously by setting `output = c('file','object')` and `destination = 'all'`.

```r
# Calculate the cost rasters to travel to and from a set of points
costRasters <- getCosts(world = world, from = points, z_fix = dem,
                        destination = 'all', costs = 'all',
                        output = c("object","file"), dir = dir)
```

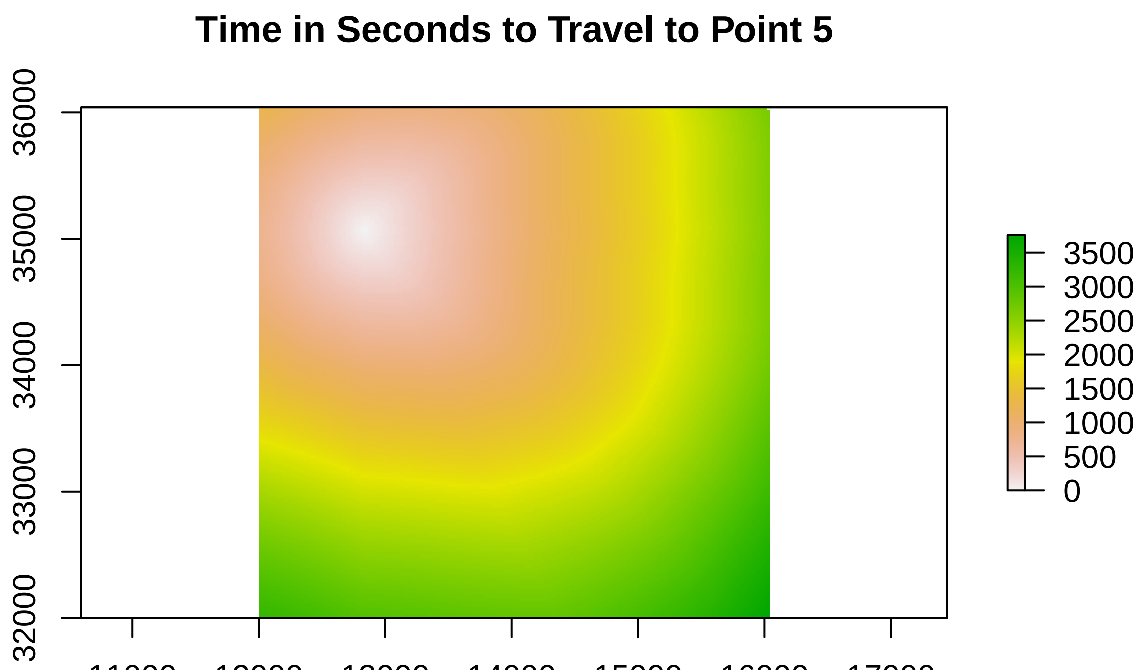
Let's take a look at the structure of the costRasters:

```r
structure(costRasters)
#> $time_in
#> class      : RasterStack
#> dimensions : 202, 202, 40804, 5  (nrow, ncol, ncell, nlayers)
#> resolution : 20, 20  (x, y)
#> extent     : 12000, 16040, 32000, 36040  (xmin, xmax, ymin, ymax)
#> crs        : +proj=lcc +lat_0=0 +lon_0=-100 +lat_1=48 +lat_2=33 +x_0=0 +y_0=0 +datum=WGS84 +units=m
#> names      :     To_4,     To_5,     To_1,     To_2,     To_3
#> min values :        0,        0,        0,        0,        0
#> max values : 3444.914, 3758.710, 3259.500, 4047.210, 4562.430
#>
#>
#> $time_out
```

```
#> class      : RasterStack
#> dimensions : 202, 202, 40804, 5  (nrow, ncol, ncell, nlayers)
#> resolution : 20, 20  (x, y)
#> extent     : 12000, 16040, 32000, 36040  (xmin, xmax, ymin, ymax)
#> crs        : +proj=lcc +lat_0=0 +lon_0=-100 +lat_1=48 +lat_2=33 +x_0=0 +y_0=0 +datum=WGS84 +units=m
#> names      :   From_4,   From_5,   From_1,   From_2,   From_3
#> min values :        0,        0,        0,        0,        0
#> max values : 3876.413, 3400.299, 2956.157, 2998.247, 3432.596
#>
#>
#> $work_in
#> class      : RasterStack
#> dimensions : 202, 202, 40804, 5  (nrow, ncol, ncell, nlayers)
#> resolution : 20, 20  (x, y)
#> extent     : 12000, 16040, 32000, 36040  (xmin, xmax, ymin, ymax)
#> crs        : +proj=lcc +lat_0=0 +lon_0=-100 +lat_1=48 +lat_2=33 +x_0=0 +y_0=0 +datum=WGS84 +units=m
#> names      :    To_4,    To_5,    To_1,    To_2,    To_3
#> min values :       0,       0,       0,       0,       0
#> max values : 1527516, 1613303, 1372397, 1812929, 2050753
#>
#>
#> $work_out
#> class      : RasterStack
#> dimensions : 202, 202, 40804, 5  (nrow, ncol, ncell, nlayers)
#> resolution : 20, 20  (x, y)
#> extent     : 12000, 16040, 32000, 36040  (xmin, xmax, ymin, ymax)
#> crs        : +proj=lcc +lat_0=0 +lon_0=-100 +lat_1=48 +lat_2=33 +x_0=0 +y_0=0 +datum=WGS84 +units=m
#> names      :  From_4,  From_5,  From_1,  From_2,  From_3
#> min values :       0,       0,       0,       0,       0
#> max values : 1700369, 1508594, 1289124, 1226222, 1279139
#>
#>
#> $energy_in
#> class      : RasterStack
#> dimensions : 202, 202, 40804, 5  (nrow, ncol, ncell, nlayers)
#> resolution : 20, 20  (x, y)
#> extent     : 12000, 16040, 32000, 36040  (xmin, xmax, ymin, ymax)
#> crs        : +proj=lcc +lat_0=0 +lon_0=-100 +lat_1=48 +lat_2=33 +x_0=0 +y_0=0 +datum=WGS84 +units=m
#> names      :    To_4,    To_5,    To_1,    To_2,    To_3
#> min values :       0,       0,       0,       0,       0
#> max values : 1867313, 1971370, 1677907, 2189321, 2475059
#>
#>
#> $energy_out
#> class      : RasterStack
#> dimensions : 202, 202, 40804, 5  (nrow, ncol, ncell, nlayers)
#> resolution : 20, 20  (x, y)
#> extent     : 12000, 16040, 32000, 36040  (xmin, xmax, ymin, ymax)
#> crs        : +proj=lcc +lat_0=0 +lon_0=-100 +lat_1=48 +lat_2=33 +x_0=0 +y_0=0 +datum=WGS84 +units=m
#> names      :  From_4,  From_5,  From_1,  From_2,  From_3
#> min values :       0,       0,       0,       0,       0
#> max values : 2068809, 1834816, 1570855, 1502340, 1598683
```

It's a list of RasterStacks, each in a slot named after the type of cost (time, work, or energy) and the direction of travel (out from a node, or in to a node). Each RasterStack has one layer for each node, with the value at each point in the RasterLayer representing the absolute minimum cost necessary to travel between that given node to/from that given point.

```
plot(costRasters$time_in[['To_5']],main='Time in Seconds to Travel to Point 5')
```



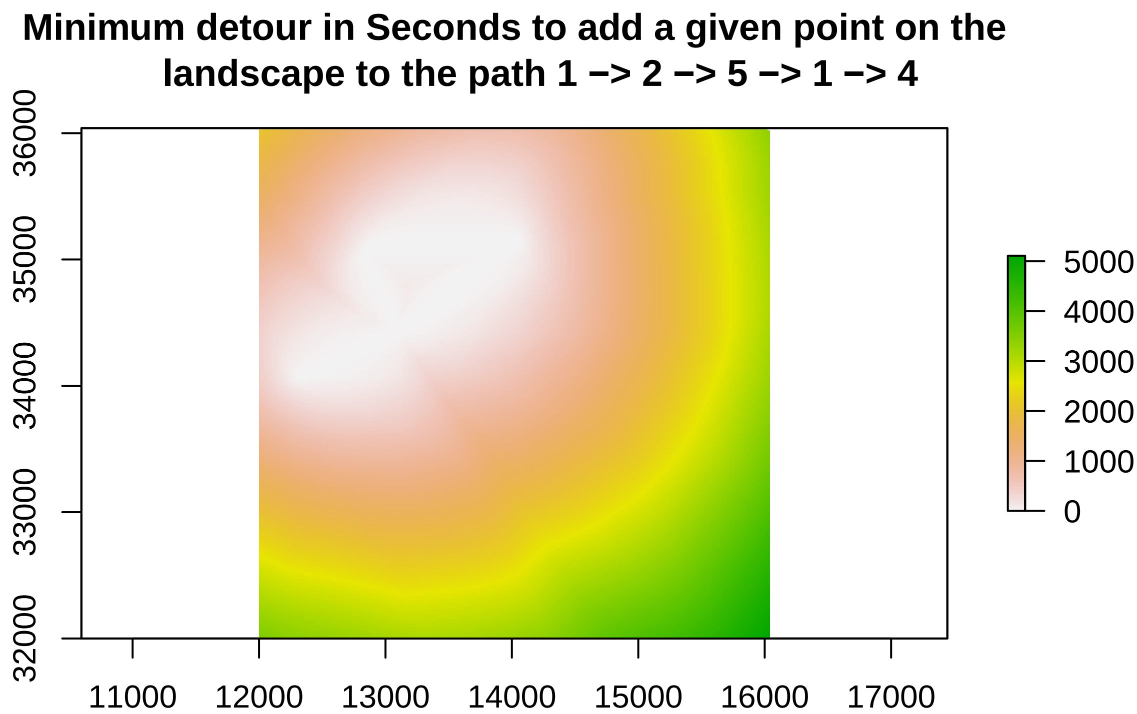
Since `'file'` was also listed in the `output` parameter for `getCosts`, the raster files were also exported to a `'CostRasters'` folder in `dir`.

```
list.files(normalizePath(paste0(dir,"/CostRasters")))
#>  [1] "Energy_From_1.tif" "Energy_From_2.tif" "Energy_From_3.tif" "Energy_From_4.tif" "Energy_From_5.
#>  [6] "Energy_To_1.tif"   "Energy_To_2.tif"   "Energy_To_3.tif"   "Energy_To_4.tif"   "Energy_To_5.ti
#> [11] "Time_From_1.tif"   "Time_From_2.tif"   "Time_From_3.tif"   "Time_From_4.tif"   "Time_From_5.ti
#> [16] "Time_To_1.tif"     "Time_To_2.tif"     "Time_To_3.tif"     "Time_To_4.tif"     "Time_To_5.tif"
#> [21] "Work_From_1.tif"   "Work_From_2.tif"   "Work_From_3.tif"   "Work_From_4.tif"   "Work_From_5.ti
#> [26] "Work_To_1.tif"     "Work_To_2.tif"     "Work_To_3.tif"     "Work_To_4.tif"     "Work_To_5.tif"
```

These rasters—be they stored as an object on the memory with `'object' %in% output` or on the hard drive with `'file' %in% object'` are required to compute cost corridors. For a given series of origins and destinations (e.g. A -> B -> C) a cost raster gives the absolute minimum expectedtotal cost that would be required to route the path through any given point on the landscape. The cells with the lowest value correspond to the least-cost path, while the value of all other cells minus the lowest value represents the cost to perform a SINGLE detour to any given location from the least-cost path. These rasters can be generated with the `makeCorridor` function:

```
# Calculating the corridors from a list of RasterStacks,
# with path 1 -> 2 -> 4 -> 1 -> 5
pathOrder <- c(1,2,5,1,4)
corridors <- makeCorridor(rasters = dir, order = pathOrder)
```

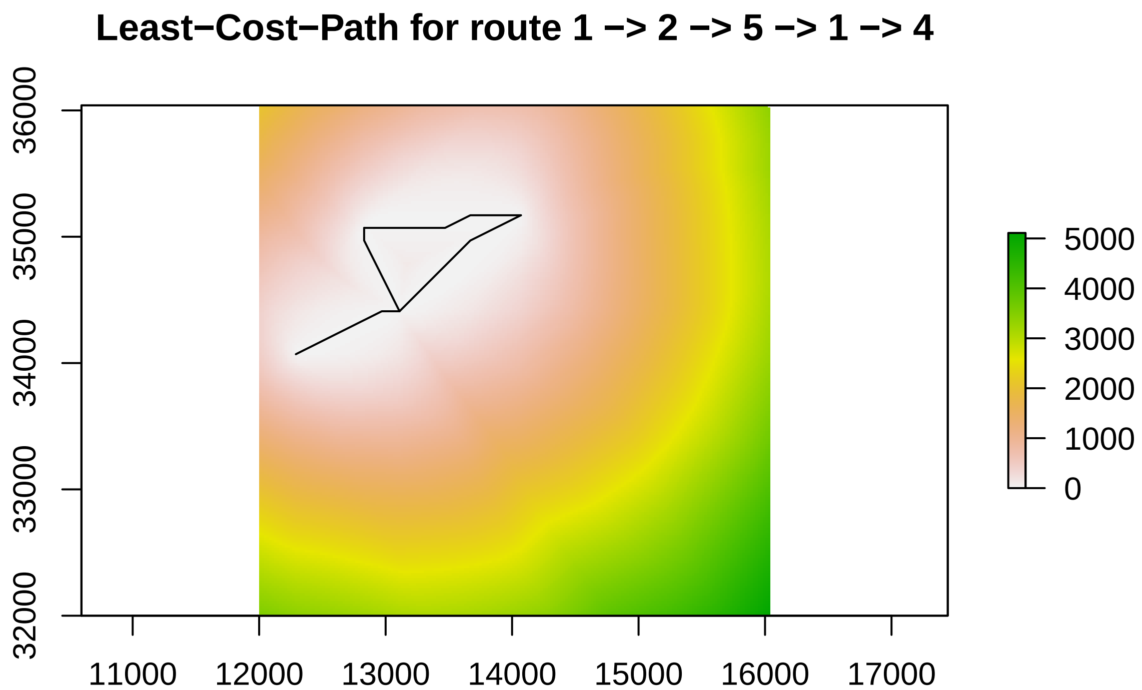
```
plot(corridors$time - minValue(corridors$time),
     main = 'Minimum detour in Seconds to add a given point on the
     landscape to the path 1 -> 2 -> 5 -> 1 -> 4')
```



We could also have used the parameter `rasters = costRasters` since `makeCorridor` accepts the object output of `getCosts` as its input. Note that the names of the nodes listed in `order` must correspond to the names of the nodes used in the `from` column of the `getCosts` function. Due to carried floats it is insufficient to simply select all values corresponding to the minimum cost to identify the least-cost path. Fortunately, the `getPaths` function can generate a list of SpatialLinesDataFrame objects corresponding to the least-cost paths:

```
paths <- getPaths(world = world, nodes = points, z_fix = dem, order = pathOrder)

# re-plot the corridors
plot(corridors$time - minValue(corridors$time),
     main = 'Least-Cost-Path for route 1 -> 2 -> 5 -> 1 -> 4')
plot(paths$time, add=TRUE)
```



Quick Start

Assuming that we have (1) generated a `dem`, (2) location `points`, (3) high-resolution locational `data` representing the XY location of an animal, and (4) a `region` of interest lying within the `dem`'s extent, the minimum required workflow to get the velocity function, cost rasters for a set of location points, a corridor between some or all of them, and the least cost path is:

```
# Start by making the grid:
n <- 5
grid <- makeGrid(dem = dem, nx = n, ny = n)
# Or you can employ a grid from an alternate source pointing to
# filepaths or URLs from which to download data


# Get the velocity function
velocity <- getVelocity(data = data, z = grid, dir = dir)

# Calculate the transitional costs to move between each allowable cells.
# Replace the v_max, alpha, and k parameters with known values if appropriate,
# and make sure all other parameters are representative for your species of interest
world <- calculateCosts(world = grid, m = 60, v_max = velocity$vmax,
                        k = velocity$k, alpha = velocity$alpha, BMR = 93,
                        l_s = 1.6, L = 0.8, region = region, z_fix = dem,
                        cut_slope = 0.5, dir = dir)

# Get the total costs for the least-cost path between any point on the landscape
```

```r
# and all of the nodes; export as rasters but don't keep the object
getCosts(world = world, from = points, z_fix = dem, destination = 'all',
         output = 'file', dir = dir)

# Calculate the corridors for the path between nodes 1 -> 2 -> 5 -> 1 -> 4
pathOrder <- c(1,2,5,1,4)
corridors <- makeCorridor(rasters = dir, order = pathOrder)

# Get that same least-cost path
paths <- getPaths(world = world, nodes = points, z_fix = dem, order = pathOrder)
```