Introduction to the 'raster' package (version 1.7-30)

Robert J. Hijmans

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1 Introduction

This vignette describes the R package '`raster`'. A raster is a spatial (geographic) data structure that divides a region into rectangles (called 'cells' or 'pixels') and stores one or more values for each of these rectangles. Such a data structure is also referred to as a 'grid' and is often contrasted with 'vector' data that is used to represent points, lines, and polygons.

The `raster` package has functions for creating, reading, manipulating, and writing raster data. The package provides, among other things, general low-level raster data manipulation functions that can easily be used to develop high-level functions. For example, to read a chunk of raster values from a file or to convert cell numbers to coordinates and back. It also implements raster algebra and several 'high level' functions for raster data manipulation that are common in Geographic Information Systems (GIS) programs. The types of functions in the raster package are similar to those in GIS programs such as Idrisi, the raster functions of GRASS, and the 'grid' module of ArcInfo ('workstation').

A notable feature of the `raster` package is that it can work with raster datasets that are stored on disk and are too large to be loaded into memory (RAM). The package can work with large files because it creates objects from these files that only contain information about the structure of the data, such as the number of rows and columns, the spatial extent, and the filename, but it does not attempt to read all the cell values and keep them in memory. In computations with these objects, data is read and processed in chunks. If no output filename is specified to a function, and the output raster is too large to keep in memory, the results are written to a temporary file.

To understand what is covered in this vignette, you must understand the basics of the R language. There is a multitude of on-line and other resources that can help you to get acquainted with R . The `raster` package does not operate in isolation. For example, for vector type data it uses classes defined in the `sp` package. See the vignette and help pages of that package or Bivand *et al.* (2008). Bivand *et al.*, provide an introduction to handling spatial data

in R , and to statistically oriented spatial data analysis (such as inference from spatial data, point pattern analysis, and geostatistics).

In the next section, some general aspects of the design of the 'raster' package are discussed, notably the structure of the main classes, and what they represent. The use of the package is illustrated in subsequent sections. raster has a large number of functions, not all of them are discussed here, and those that are discussed are mentioned only briefly. See the help files of the package for more information on individual functions and **help("raster-package")** for an index of functions by topic.

2 Classes

The package is built around a number of 'S4' classes of which the RasterLayer, RasterBrick , and RasterStack classes are the most important. See Chambers (2009) for a detailed discussion of the use of S4 classes in R . When discussing methods that can operate on all three of these objects, they are referred to as 'Raster*' objects.

2.1 RasterLayer

A RasterLayer object represents a single-variable raster dataset. A RasterLayer object always stores a number of fundamental parameters that describe it. These include the number of columns and rows, the coordinates of its spatial extent ('bounding box'), and the coordinate reference system (the 'map projection'). In addition, a RasterLayer can store information about the file in which the raster cell values are stored (if there is such a file). A RasterLayer can also hold the raster cell values in memory.

2.2 RasterStack and RasterBrick

It is quite common to analyze raster data using single-variable objects. However, in many cases multi-variable raster data sets are used. The raster package has two classes for multi-raster data the RasterStack and the RasterBrick. The principal difference between these two classes is that a RasterBrick can only be linked to a single (multi-layer) file. In contrast, a RasterStack can be formed from separate files and/or from a few layers ('bands') from a single file.

In fact, a RasterStack is a collection of RasterLayer objects with the same spatial extent and resolution. In essence it is a list of RasterLayer objects. A RasterStack can easily be formed form a collection of files in different locations and these can be mixed with RasterLayer objects that only exist in memory.

A RasterBrick is truly a multilayered object, and processing a RasterBrick can be more efficient than processing a RasterStack representing the same data. However, it can only refer to a single file. A typical example of such a file would be a multi-band satellite image or the output of a global climate model (with e.g., a time series of temperature values for each day of the year for each raster

cell). Methods that operate on `RasterStack` and `RasterBrick` objects typically return a `RasterBrick`.

2.3 Other classes

Below is some more detail, you do not need to read or understand this section to use the `raster` package.

The three classes described above inherit from the `Raster` class (that means they are derived from this more basic 'parent' class by adding something to that class) which itself inherits from the `BasicRaster` class. The `BasicRaster` only has a few properties (referred to as 'slots' in S4 speak): the number of columns and rows, the coordinate reference system (which itself is an object of class `CRS`, which is defined in package '`sp`') and the spatial extent, which is an object of class `Extent`.

An object of class `Extent` has four slots: xmin, xmax, ymin, and ymax. These represent the minimum and maximum x and y coordinates of the of the Raster object. These would be, for example, -180, 180, -90, and 90, for a global raster with longitude/latitude coordinates. Note that raster uses the coordinates of the extremes (corners) of the entire raster (unlike some files/programs that use the coordinates of the center of extreme cells).

`Raster` is a virtual class. This means that it cannot be instantiated (you cannot create objects from this class). It was created to allow the definition of methods for that class. These methods will be dispatched when called with a descendent of the class (i.e. when the method is called with a `RasterLayer`, `RasterBrick` or `RasterStack` object as argument). This allows for efficient code writing because many methods are the same for any of these three classes, and hence a single method for `Raster` suffices.

`RasterStackBrick` is a class union of the `RasterStack` and `RasterBrick` class. This is a also a virtual class. It allows defining methods that apply to both a `RasterStack` and to a `RasterBrick`.

3 Creating Raster* objects

A `RasterLayer` can easily be created from scratch using the function **raster**. The default settings will create a global raster data structure with a longitude/latitude coordinate reference system and 1 by 1 degree cells. You can change these settings by providing additional arguments such as *xmin*, *nrow*, *ncol*, and/or *crs*, to the function. You can also change these parameters after creating the object. If you set the projection, this is only to properly define it, not to change it. To transform a `RasterLayer` to another coordinate reference system (projection) you can use the function **projectRaster**.

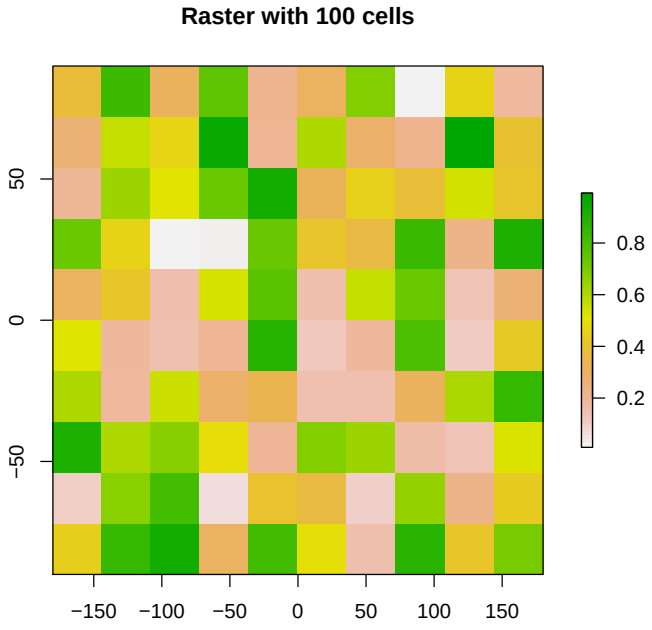
Here is an example of creating and changing a `RasterLayer` object 'r' from scratch.

```
> library(raster)
```

```
raster version 1.7-30 (21-January-2010)

> # \RasterLayer with the default parameters
> r <- raster()
> r

class       : RasterLayer
dimensions  : 180, 360, 1  (nrow, ncol, nlayers)
resolution  : 1, 1  (x, y)
extent      : -180, 180, -90, 90  (xmin, xmax, ymin, ymax)
projection  : +proj=longlat +datum=WGS84
values      : none

> # With other parameters
> r <- raster(ncol=36, nrow=18, xmn=-1000, xmx=1000, ymn=-100, ymx=900)
> # that can be changed
> res(r)

[1] 55.55556 55.55556

> res(r) <- 100
> res(r)

[1] 100 100

> ncol(r)

[1] 20

> ncol(r) <- 18
> ncol(r)

[1] 18

> res(r)

[1] 111.1111 100.0000

> projection(r) <- "+proj=utm +zone=48 +datum=WGS84"
> r

class       : RasterLayer
dimensions  : 10, 18, 1  (nrow, ncol, nlayers)
resolution  : 111.1111, 100  (x, y)
extent      : -1000, 1000, -100, 900  (xmin, xmax, ymin, ymax)
projection  : +proj=utm +zone=48 +datum=WGS84
values      : none
```

The objects 'r' created in the example above only consist of a 'skeleton', that is, we have defined the number of rows and columns, and where the raster is located in geographic space, but there are no cell-values associated with it. Setting and accessing values is illustrated below.

```
> r <- raster(ncol=10, nrow=10)
> ncell(r)

[1] 100

> hasValues(r)

[1] FALSE

> # use the 'values' function
> values(r) <- runif(ncell(r))
> hasValues(r)

[1] TRUE

> inMemory(r)

[1] TRUE

> values(r)[1:10]

 [1] 0.08856194 0.67871698 0.10421949 0.52371181 0.71437241
 [6] 0.32454192 0.43639148 0.52486218 0.03004418 0.64094468

> plot(r, main='Raster with 100 cells')
```



In some cases, for example when you change the number of columns or rows, you will lose the values associated with the `RasterLayer` if there were any (or the link to a file if there was one). The same applies, in most cases, if you change the resolution directly (as this can affect the number of rows or columns). Values are not lost when changing it via the extent as this adjusts the resolution, but does not change the number of rows or columns.

```
> hasValues(r)

[1] TRUE

> res(r)

[1] 36 18

> dim(r)

[1] 10 10  1

> xmax(r)

[1] 180

> xmax <- 0
> hasValues(r)
```

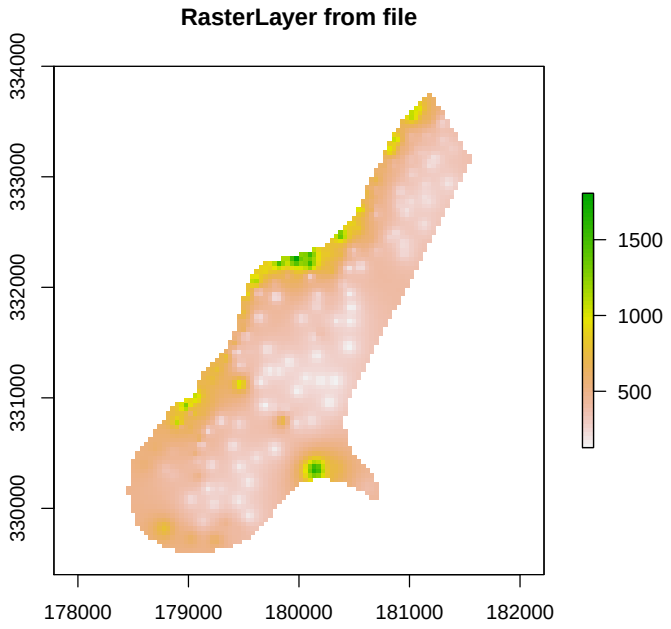
```
[1] TRUE

> res(r)

[1] 36 18

> dim(r)

[1] 10 10  1

> xmax(r)

[1] 180

> ncol(r) <- 6
> hasValues(r)

[1] FALSE

> res(r)

[1] 60 18

> dim(r)

[1] 10  6  1

> xmax(r)

[1] 180
```

The function **raster** also allows you to create a `RasterLayer` from another object, including another `RasterLayer`, `RasterStack` and `RasterBrick` , as well as from a SpatialPixels* and SpatialGrid* object (defined in the `sp` package), an `Extent` object, a matrix, an 'im' object (SpatStat), and 'asc' and 'kasc' objects (adehabitat).

It is more common, however, to create a `RasterLayer` object from a file. The raster package can use raster files in several formats, including some 'natively' supported formats and other formats via the `rgdal` package. Supported formats for reading include ESRI, ENVI, and ERDAS grids and geoTiff. Most formats supported for reading can also be written too. Here is an example using the 'Meuse' dataset (taken from the `sp` package), using a file in the native 'raster-file' format:

```
> #get the name of an example file installed with the package
> filename <- (system.file("external/test.grd", package="raster"))
> filename

[1] "c:/temp/RtmpPR4Qzb/Rinst69f7d7a/raster/external/test.grd"
```

```
> r <- raster(filename)
> filename(r)

[1] "c:/temp/RtmpPR4Qzb/Rinst69f7d7a/raster/external/test.grd"

> hasValues(r)

[1] TRUE

> inMemory(r)

[1] FALSE

> plot(r, main='RasterLayer from file')
```



Multi-layer objects can be created in memory (from `RasterLayer` objects) or from files.

```
> # create three identical RasterLayer objects
> r1 <- r2 <- r3 <- raster(nrow=10, ncol=10)
> # Assign random cell values
> values(r1) <- runif(ncell(r1))
> values(r2) <- runif(ncell(r2))
> values(r3) <- runif(ncell(r3))
```

```
> # combine three RasterLayer objects into a RasterStack
> s <- stack(r1, r2, r3)
> s

class       : RasterStack
dimensions  : 10, 10, 3  (nrow, ncol, nlayers)
resolution  : 36, 18  (x, y)
extent      : -180, 180, -90, 90  (xmin, xmax, ymin, ymax)
projection  : +proj=longlat +datum=WGS84
min values  : 0.0024 0.0392 0.0016
max values  : 1 1 1

> nlayers(s)

[1] 3

> # combine three RasterLayer objects into a RasterBrick
> b1 <- brick(r1, r2, r3)
> # equivalent to:
> b2 <- brick(s)
> # create a RasterBrick  from file
> b <- brick(system.file("external/rlogo.grd", package="raster"))
> b

class       : RasterBrick
dimensions  : 77, 101, 3  (nrow, ncol, nlayers)
resolution  : 1, 1  (x, y)
extent      : 0, 101, 0, 77  (xmin, xmax, ymin, ymax)
projection  : '+proj=utm +zone=1 +ellps=WGS84'
values      : c:/temp/RtmpPR4Qzb/Rinst69f7d7a/raster/external/rlogo.grd
min values  : 0 0 0
max values  : 255 255 255

> nlayers(b)

[1] 3

> # extract a single RasterLayer
> r <- raster(b, layer=2)
> # equivalent to creating it from disk
> r <- raster(system.file("external/rlogo.grd", package="raster"), band=2)
```

4 Raster algebra

Many generic functions that allow for simple and elegant raster algebra have been implemented for `Raster*` objects, including the normal algebraic operators such as +, -, *, /, logical operators such as >, >=, <, ==, ! and functions

such as **abs, round, ceiling, floor, trunc, sqrt, log, log10, exp, cos, sin, max, min, range, prod, sum, any, all**. In these functions you can mix `Raster*` objects with numbers, as long as the first argument is a `Raster*` object.

```
> r <- raster(ncol=10, nrow=10)
> r[] <- 1:ncell(r)
> s <- r + 10
> s <- sqrt(s)
> s <- s * r + 5
> r[] <- runif(ncell(r))
> r <- round(r)
> r <- r == 1
> s[r] <- -0.5
> s[!r] <- 5
> s[s == 5] <- 15
```

If you use multiple `Raster*` objects (in functions where this is relevant, such as range), these must have the same resolution and origin. The origin of a `Raster*` object is the point closest to (0, 0) that you could get if you moved from a corners of a `Raster*` object towards that point in steps of the `x` and `y` resolution. Normally these objects would also have the same extent, but if they do not, the returned object covers the spatial intersection of the objects used.

When you use multiple multi-layer objects with different numbers or layers, the 'shorter' objects are 'recycled'.

```
> r <- raster(ncol=5, nrow=5)
> r[] <- 1
> s <- stack(r, r+1)
> q <- stack(r, r+2, r+4)
> x <- r + s + q
> x
```

```
class       : RasterBrick
dimensions  : 5, 5, 3  (nrow, ncol, nlayers)
resolution  : 72, 36  (x, y)
extent      : -180, 180, -90, 90  (xmin, xmax, ymin, ymax)
projection  : +proj=longlat +datum=WGS84
values      : in memory
min values  : 3 6 7
max values  : 3 6 7
```

Summary functions **(min, max, mean, prod, sum, Median, cv, range, any, all)** always return a `RasterLayer` object. Perhaps this is not obvious when using functions like **min, sum or mean**.

```
> a <- mean(r,s,10)
> b <- sum(r,s)
```

```
> st <- stack(r, s, a, b)
> sst <- sum(st)
> sst

class       : RasterLayer
dimensions  : 5, 5, 1  (nrow, ncol, nlayers)
resolution  : 72, 36  (x, y)
extent      : -180, 180, -90, 90  (xmin, xmax, ymin, ymax)
projection  : +proj=longlat +datum=WGS84
values      : in memory
min value   : 11.5
max value   : 11.5
```

Use **cellStats** if instead of a `RasterLayer` you want a single number summarizing the cell values of each layer.

```
> cellStats(st, 'sum')

layer_1 layer_2 layer_3 layer_4 layer_5
   25.0    25.0    50.0    87.5   100.0

> cellStats(sst, 'sum')

[1] 287.5
```

5 'High-level' functions

Several 'high level' functions have been implemented for `RasterLayer` objects. 'High level' functions refer to functions that you would normally find in a GIS program that supports raster data. Here we briefly discuss some of these functions. All these functions work for raster datasets that cannot be loaded into memory. See the help files for more detailed descriptions of each function.

The high-level functions have some arguments in common. The first argument is typically 'x' or 'object' and can be a `RasterLayer`, or, in most cases, a `RasterStack` or `RasterBrick`. It is followed by one or more arguments specific to the function (either additional `RasterLayer` objects or other arguments), followed by a filename="" and "..." arguments.

The default filename is an empty character "". If you do not specify a filename, the default action for the function is to return a `Raster*` object that only exists in memory. However, if the function deems that the `Raster*` object to be created would be too large to hold memory it is written to a temporary file instead.

The "..." argument allows for setting additional arguments that are relevant when writing values to a file: the file format, datatype (e.g. integer or real values), and a logical value indicating whether existing files should be overwritten.

5.1 Modifying the structure of a Raster* object

There are several functions that deal with modifying the structure of `Raster*` objects. The **crop** function lets you take a geographic subset of a larger `RasterLayer`. You can crop a `Raster*` by providing an extent object or another spatial object from which an extent can be extracted (objects from classes deriving from Raster and from Spatial in the sp package). An easy way to get an extent object is to plot a `RasterLayer` and then use **drawExtent** to visually determine the new extent (bounding box) to provide to the crop function.

trim crops a `RasterLayer` by removing the outer rows and columns that only contain NA values. In contrast, **expand** adds new rows and/or columns with NA values. The purpose of this could be to create a new `RasterLayer` of the same extent of another larger `RasterLayer` such that the can be used together in other functions.

The **merge** function lets you merge 2 or more `Raster*` objects into a single new object. The input objects must have the same resolution and origin (such that their cells neatly fit into a single larger raster). If this is not the case you can first adjust one of the `Raster*` objects with use **(dis)aggregate** or **resample**.

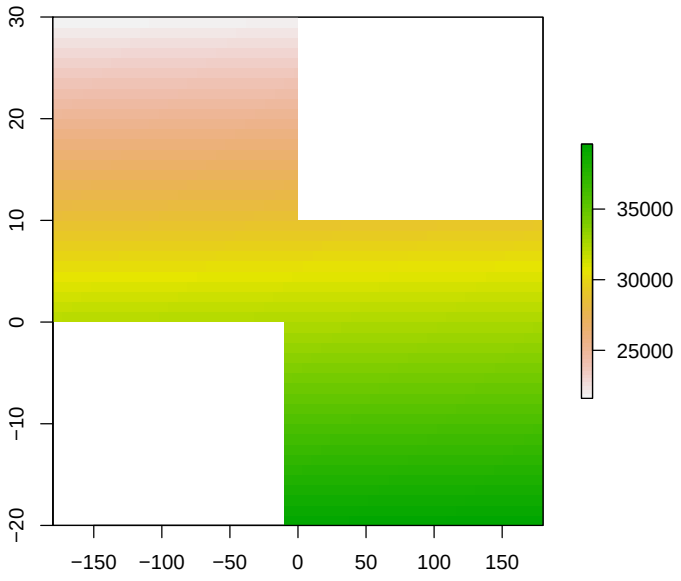
aggregate and **disaggregate** allow for changing the resolution of a `Raster*` object. In the case of **aggregate**, you need to specify a function determining what to do with the grouped cell values (e.g. **mean**). It is possible to specify different (dis)aggregation factors in the x and y direction. **aggregate** and **disaggregate** are the best functions when adjusting cells size only, with an integer step (e.g. each side 2 times smaller or larger), but in some cases that is not possible.

For example, you may need nearly the same cell size, while shifting the cell centers. In those cases, the **resample** function can be used. It can do either nearest neighbor assignments (for categorical data) or bilinear interpolation (for non-categorical data). Simple linear shifts of a Raster object can be accomplished with the **shift** function or with the **extent** function. **resample** should not be used to create a Raster* object with much larger resolution. If such adjustments need to be made then you can first use aggregate.

With the **projectRaster** function you can transform values of `Raster*` object to a new object with a different coordinate reference system.

Here are some simple examples:

```
> r <- raster()
> r[] <- 1:ncell(r)
> ra <- aggregate(r, 10)
> r1 <- crop(r, extent(-180,0,0,30))
> r2 <- crop(r, extent(-10,180,-20,10))
> m <- merge(r1, r2, filename='test.grd', overwrite=TRUE)
> plot(m)
```



flip lets you flip the data (reverse order) in horizontal or vertical direction – typically to correct for a 'communication problem' between different R packages or a misinterpreted file. **rotate** lets you rotate longitude/latitude rasters that have longitudes from 0 to 360 degrees (often used by climatologists) to the standard -180 to 180 degrees system.

5.2 Overlay

As an alternative to the raster algebra discussed above, the following functions are available to accomplish similar things: **overlay**, **calc**, **reclass**, **cut**, **subs**, **cover** and **mask**. These functions provide either easy to use short-hand, or more efficient computation for large (file based) objects.

calc allows you to do a computation for a single `Raster` object by providing a function. If you supply a `RasterLayer`, another `RasterLayer` is returned. If you provide a multi-layer object you get a (single layer) `RasterLayer` if you use a summary type function (e.g. **sum**) but a `RasterBrick` if multiple layers are returned. **stackApply** computes summary type layers for subsets of a `RasterStack` or `RasterBrick`.

With **overlay** you can combine multiple Raster objects (e.g. multiply them). Function **mask** removes all values from one layer that are NA in another layer, and **cover** combines two layers by taking the values of the first layer except where these are NA .

You can use **cut** or **reclass** to replace ranges of values with single values, or **subs** to substitute (replace) single values with other values.

```
> r <- raster(ncol=5, nrow=1)
> r[] <- 1:ncell(r)
> getValues(r)

[1] 1 2 3 4 5

> s <- calc(r, fun=function(x){ x[x < 4] <- NA; return(x)} )
> as.matrix(s)

     [,1] [,2] [,3] [,4] [,5]
[1,]   NA   NA   NA    4    5

> t <- overlay(r, s, fun=function(x, y){ x / (2 * sqrt(y)) + 5 } )
> as.matrix(t)

     [,1] [,2] [,3] [,4]     [,5]
[1,]   NA   NA   NA    6 6.118034

> u <- mask(r, t)
> as.matrix(u)

     [,1] [,2] [,3] [,4] [,5]
[1,]   NA   NA   NA    4    5

> v = u==s
> as.matrix(v)

     [,1] [,2] [,3] [,4] [,5]
[1,]   NA   NA   NA TRUE TRUE

> w <- cover(t, r)
> as.matrix(w)

     [,1] [,2] [,3] [,4]     [,5]
[1,]    1    2    3    6 6.118034

> x <- reclass(w, c(0,2,1,  2,5,2, 4,10,3))
> as.matrix(x)

     [,1] [,2] [,3] [,4] [,5]
[1,]    1    2    2    3    3

> y <- subs(x, data.frame(id=c(2,3), v=c(40,50)))
> as.matrix(y)

     [,1] [,2] [,3] [,4] [,5]
[1,]   NA   40   40   50   50
```

5.3 Focal functions

There are three focal (neighorhood) functions: **focal**, **focalFilter**, **focalNA**. These functions currently only work for RasterLayer objects. They make a computation using values in a neighborhood of cells around a focal cell, and putting the result in the focal cell of the output RasterLayer. With **focal**, the neighborhood can only be a rectangle. With **focalFilter**, the neighborhood is a user-defined a matrix of weights and could approximate any shape by giving some cells zero weight. The **focalNA** function only computes new values for cells that are NA in the input RasterLayer.

5.4 Distance

There are a number of distance related functions. **distance** computes the shortest distance to cells that are not NA . **pointDistance** computes the shortest distance to any point in a set of points. **gridDistance** computes the distance when following grid cells that can be traversed (e.g. excluding water bodies). **direction** computes the direction towards (or from) the nearest cell that is not NA . **adjacency** determines which cells are adjacent to other cells, and **pointDistance** computes distance between points. See the gdistance package (on R-Forge) for more advanced distance calculations (cost distance, resistance distance)

5.5 Spatial configuration

Function **clump** identifies groups of cells that are connected. **edge** identifies edges, that is, transitions between cell values. **area** computes the size of each grid cell (for unprojected rasters)

5.6 Predictions

The package has two functions to make model predictions to (potentially very large) rasters. **predict** takes a multilayer raster and a fitted model as arguments. Fitted models can be of various classes, including glm, gam, randomforest, and brt. Function **interpolate** is similar but is for models that use coordinates as predictor variables, for example in kriging and spline interpolation.

5.7 Vector to raster conversion

The raster packages supports point, line, and polygon to raster conversion with the **rasterize** function. For vector type data (points, lines, polygons), objects of Spatial* classes defined in the `sp` package are used; but points can also be represented by a two-column matrix (x and y).

Point to raster conversion is often done with the purpose to analyze the point data. For example to count the number of distinct species (represented by point observations) that occur in each raster cell. **rasterize** takes a `Raster*`

object to set the spatial extent and resolution, and a function to determine how to summarize the points (or an attribute of each point) by cell.

Polygon to raster conversion is typically done to create a `RasterLayer` that can act as a mask, i.e. to set to NA a set of cells of a `Raster` object, or to summarize values on a raster by zone. For example a country polygon is transferred to a raster that is then used to set all the cells outside that country to NA ; whereas polygons representing administrative regions such as states can be transferred to a raster to summarize raster values by state.

It is also possible to convert the values of a `RasterLayer` to points or polygons, using **rasterToPoints** and **rasterToPolygons**. Both functions only return values for cells that are not NA . Unlike **rasterToPolygons**, **rasterToPoints** is reasonably efficient and allows you to provide a function to subset the output before it is produced (which can be necessary for very large rasters as the point object is created in memory).

6 Summary functions

When used with a `Raster*` object as first argument, normal summary statistics functions such as min, max and mean return a RasterLayer. You can use cellStats if, instead, you want to obtain a summary for all cells of a single `Raster*` object. You can use **freq** to make a frequency table, or **count** to count the number of cells with a specified value. Use **zonal** to summarize a `Raster*` object using zones (areas with the same integer number) defined in a `RasterLayer` and **crosstab** to cross-tabulate two `RasterLayer` objects.

```
> r <- raster(ncol=36, nrow=18)
> r[] <- runif(ncell(r))
> cellStats(r, mean)

[1] 0.5091777

> s = r
> s[] <- round(runif(ncell(r)) * 5)
> zonal(r,s,median)

  zone    median
1    0 0.6268032
2    1 0.4760798
3    2 0.4255545
4    3 0.4713735
5    4 0.6317507
6    5 0.5518673

> freq(s)

     value count
[1,]     0    62
```

```
[2,]     1   114
[3,]     2   130
[4,]     3   151
[5,]     4   125
[6,]     5    66
```

```
> count(s, 3)
```

```
[1] 151
```

```
> crosstab(r*3, s)
```

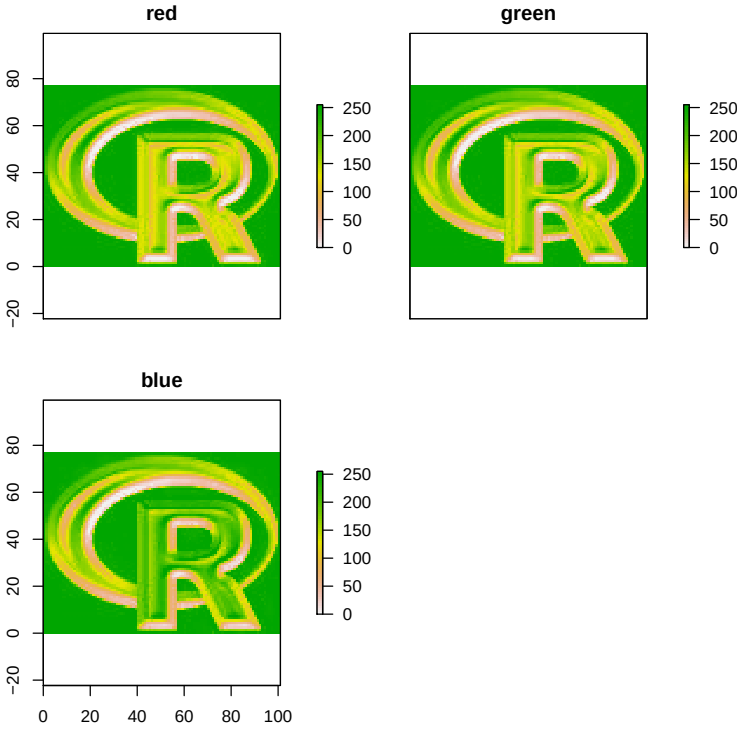
```
     second
first  0  1  2  3  4  5
    0 11 23 25 22 12  9
    1 15 36 45 62 34 21
    2 22 31 40 45 52 23
    3 14 24 20 22 27 13
```

7 Plotting

Several generic functions have been implemented for Raster* objects to create maps and other plot types. Use 'plot' to create a map of a RasterLayer. When plot is used with a `RasterLayer`, it uses code taken from the image.plot function in the fields package, which calls the function 'image' (but, by default, adds a legend). It is also possible to directly call **image**. You can zoom in using 'zoom' and clicking on the map twice (to indicate where to zoom to). After plotting a `RasterLayer` you can add vector type spatial data (points, lines, polygons). You can do this with functions points, lines, polygons if you are using the basic R data structures or plot(object, add=TRUE) if you are using Spatial* objects as defined in the sp package. When plot is used with a multi-layer Raster* object, all layers are plotted (up to 16), unless the layers desired are indicated with an additional argument.

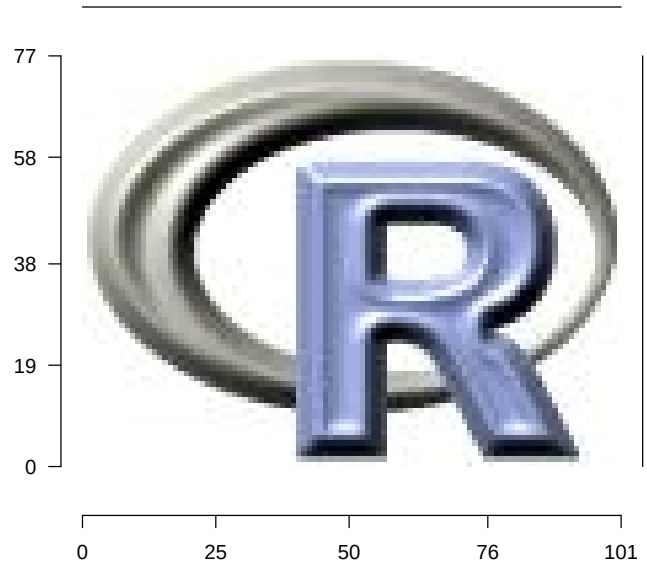
Multi-layer Raster objects can be plotted as individual layers

```
> b <- brick(system.file("external/rlogo.grd", package="raster"))
> plot(b)
```



They can also be combined into a single image, by assigning individual layers to one of the three color channels (red, green and blue):

```
> plotRGB(b, r=1, g=2, b=3)
```



You can also use the following functions with a `RasterLayer` as argument: **hist, persp, contour**, and **density**. See the help files for more info. You can use **plot3D** to create an interactive 3D plot (you need the rgl package for this).

With **click** it is possible to interactively query a Raster* object by clicking once or several times on a map plot.

8 Writing files

8.1 File format

Raster can read most, and write several raster file formats, via the `rgdal` package. However, it directly reads and writes a native 'rasterfile' format. A rasterfile consists of two files: a binary sequential data file and a text header file. The header file is of the "windows .ini" type. When reading, you do not have to specify the file format, but you do need to do that when writing (except when using the default native format). This file format is also used in DIVA-GIS (`http://www.diva-gis.org/`). See the help file for function **writeRaster**.

9 Row, column and cell numbers

The cell number is an important concept in the raster package. Raster data can be thought of as a matrix, but in a `RasterLayer` it is more commonly

treated as a vector. Cells are numbered from the upper left cell to the upper right cell and then continuing on the left side of the next row, and so on until the last cell at the lower-right side of the raster. There are several helper functions to determine the column or row number from a cell and vice versa, and to determine the cell number for x, y coordinates and vice versa.

```
> library(raster)
> r <- raster(ncol=36, nrow=18)
> ncol(r)

[1] 36

> nrow(r)

[1] 18

> ncell(r)

[1] 648

> rowFromCell(r, 100)

[1] 3

> colFromCell(r, 100)

[1] 28

> cellFromRowCol(r,5,5)

rownr
  149

> xyFromCell(r, 100)

      x  y
[1,] 95 65

> cellFromXY(r, c(0,0))

[1] 343

> colFromX(r, 0)

[1] 19

> rowFromY(r, 0)

[1] 10
```

10 Accessing cell values

Cell values can be accessed with several methods. Use **getValues** to get all values or a single row; and **getValuesBlock** to read a block (rectangle) of cell values.

```
> r <- raster(system.file("external/test.grd", package="raster"))
> getValues(r, 50)[35:39]

[1] 456.878 485.538 550.788 580.339 590.029

> getValuesBlock(r, 50, 1, 35, 5)

[1] 456.878 485.538 550.788 580.339 590.029
```

You can also read values using cell numbers or coordinates (xy) using the **extract** method.

```
> cells <- cellFromRowCol(r, 50, 35:39)
> cells

[1] 3955 3956 3957 3958 3959

> extract(r, cells)

[1] 456.878 485.538 550.788 580.339 590.029

> xy = xyFromCell(r, cells)
> xy

          x      y
[1,] 179780 332020
[2,] 179820 332020
[3,] 179860 332020
[4,] 179900 332020
[5,] 179940 332020

> extract(r, xy)

[1] 456.878 485.538 550.788 580.339 590.029
```

You can also extract values using SpatialPolygons* or SpatialLines*. The default approach for extracting raster values with polygons is that a polygon has to cover the center of a cell, for the cell to be included. However, you can use argument "weights=TRUE" in which case you get, apart from the cell values, the percentage of each cell that is covered by the polygon, so that you can apply, e.g., a 50

In the case of lines, any cell that is crossed by a line is included. For lines and points, a cell that is only 'touched' is included when it is below or to the right

(or both) of the line segment/point (except for the bottom row and right-most column).

In addition, you can use standard R indexing to access values. You can also to replace values (assign new values to cells) in a `RasterLayer`. If you replace a value in a `RasterLayer` based on a file, the connection to that file is lost (because it now is different from that file). Setting raster values for very large files will be very slow with this approach as each time a new (temporary) file, with all the values, is written to disk. If you want to overwrite values in an existing file, you can use **update** (with caution!)

```
> r[cells]

[1] 456.878 485.538 550.788 580.339 590.029

> r[1:4]

[1] NA NA NA NA

> filename(r)

[1] "c:/temp/RtmpPR4Qzb/Rinst69f7d7a/raster/external/test.grd"

> r[2:3] <- 10
> r[1:4]

[1] NA 10 10 NA

> filename(r)

[1] ""
```

Note that in the above examples values are retrieved using cell numbers. That is, a raster is represented as a (one-dimensional) vector. Values can also be inspected using a (two-dimensional) matrix notation. To do so you need to use double brackets. As in ordinary R matrices, the first index represents the row number, the second the column number.

```
> r[1]

NA

> r[2,2]

NA

> r[1,]

 [1] NA 10 10 NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA
[19] NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA
[37] NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA
[55] NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA
[73] NA NA NA NA NA NA NA NA
```

```
> r[,1]

  [1] NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA
 [19] NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA
 [37] NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA
 [55] NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA
 [73] NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA
 [91] NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA
[109] NA NA NA NA NA NA NA

> r[1:3,1:3]

[1] NA 10 10 NA NA NA NA NA NA
```

Accessing values through this type of indexing should be avoided inside functions as it is less efficient than accessing values via functions like **getValues**.

11 Session options

There are a number of session options that can be set and these can be saved to make them persistent in between sessions. We would advice against changing the default values unless you have pressing need to do so. They all have to do with reading and writing files. You can set the preferred file format and data type. You can set the default value for overwrite to TRUE (be careful with that one!), and you specify a default progress-bar. All of these values can also be provided as arguments of functions where they apply. Except for generic functions like mean, '+', and sqrt. These functions may write a file when the result is too large to hold in memory and then these options can only be set through the session options. You can also set the tmpdir, the location where such files are written. The option chunksize determines the maximum size (in number of cells) of a single chunk of values that is read/written in chunk-by-chunk processing of very large files.

12 Coercion to objects of other classes

Although the raster package defines its own set of classes, it is easy to coerce objects of these classes to objects of the 'spatial' family defined in the sp package. This allows for using functions defined by sp (e.g. spplot) and for using other packages that expect spatial* objects. To create a Raster object from variable n in a SpatialGrid* x use `raster(x, n)` or `stack(x)` or `brick(x)`. Vice versa use `as( , )`

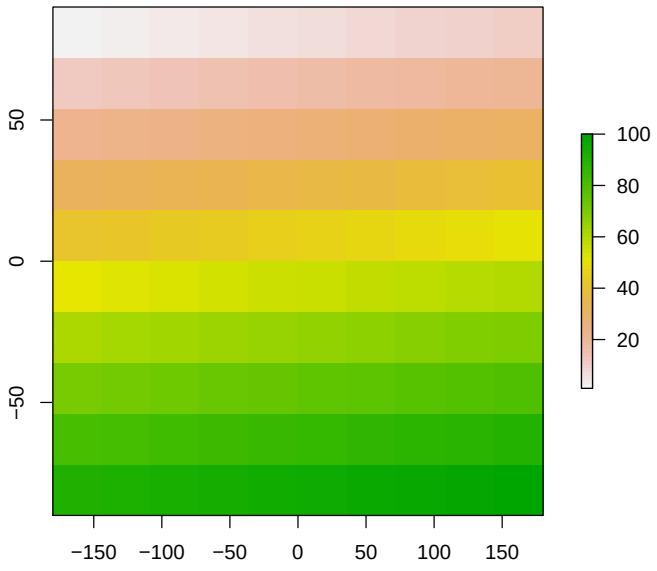
You can also convert objects of class "im" (spatstat) and "asc" (adehabitat) to a `RasterLayer` and "kasc" (adehabitat) to a `RasterStack` or Brick using the `raster(x)`, `stack(x)` or `brick(x)` function.

```
> r1 <- raster(ncol=36, nrow=18)
> r2 <- r1
> r1[] <- runif(ncell(r1))
> r2[] <- runif(ncell(r1))
> s <- stack(r1, r2)
> sgdf <- as(s, 'SpatialGridDataFrame')
> newr2 <- raster(sgdf, 2)
> news <- stack(sgdf)
```

13 Extending raster objects

It is straightforward to build on the Raster* objects using the S4 inheritance mechanism. Say you need objects that behave like a `RasterLayer`, but have some additional properties that you need to use in your own functions (S4 methods). See Chambers (2009) and the help pages of the Methods package for more info. Below is an example:

```
> setClass ('myRaster',
+         contains = 'RasterLayer',
+         representation (
+                 important = 'data.frame',
+                 essential = 'character'
+         ) ,
+         prototype (
+                 important = data.frame(),
+                 essential = ''
+         )
+ )

[1] "myRaster"

> r = raster(nrow=10, ncol=10)
> m <- as(r, 'myRaster')
> m@important <- data.frame(id=1:10, value=runif(10))
> m@essential <- 'my own slot'
> m[] <- 1:ncell(m)
> plot(m)
```




```
> setMethod ('show' , 'myRaster',
+         function(object) {
+                 callNextMethod(object) # call show(RasterLayer)
+                 cat('essential:', object@essential, '\n')
+                 cat('important information:\n')
+                 print( object@important)
+         })

[1] "show"

> m

class       : myRaster
dimensions  : 10, 10, 1  (nrow, ncol, nlayers)
resolution  : 36, 18  (x, y)
extent      : -180, 180, -90, 90  (xmin, xmax, ymin, ymax)
projection  : +proj=longlat +datum=WGS84
values      : in memory
min value   : 1
max value   : 100

essential: my own slot
important information:
```

```
   id      value
1   1 0.07584873
2   2 0.81304055
3   3 0.52341274
4   4 0.72578019
5   5 0.70214867
6   6 0.10644395
7   7 0.20819088
8   8 0.92159136
9   9 0.51595556
10 10 0.36272177
```

14 References

Bivand, R.S., E.J. Pebesma and V. Gomez-Rubio, 2008. Applied Spatial Data Analysis with R . Springer. 378p.

Chambers, J.M., 2009. Software for Data Analysis: Programming with R . Springer. 498p.