The raster package

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CONTENTS

CHAPTER

ONE

THE RASTER PACKAGE

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") that can store one or more values for each of these cells. 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 raster data manipulation functions that can easily be used to develop more specific functions. For example, there are functions to read a chunk of raster values from a file or to convert cell numbers to coordinates and back. The package also implements raster algebra and most functions for raster data manipulation that are common in Geographic Information Systems (GIS). These functions are similar to those in GIS programs such as Idrisi, the raster functions of GRASS, and the "grid" module of the now defunct 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 the objects it creates from these files 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 in memory. In computations with these objects, data is 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 it. The `raster` package does not operate in isolation. For example, for vector type data it uses classes defined in the `sp` package.

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.

CHAPTER

TWO

CLASSES

The package is built around a number of "classes" of which the `RasterLayer`, `RasterBrick`, and `RasterStack` are the most important. When discussing methods that can operate on objects of all three of these classes, they are referred to as `Raster*` objects.

2.1 RasterLayer

A `RasterLayer` represents single-layer (variable) raster data. 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-layer objects. However, in many cases multi-variable raster data sets are used. The `raster` package has two classes for multi-layer 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 (functions) that apply to both `RasterStack` and `RasterBrick` objects.

CHAPTER

THREE

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)
## Loading required package: sp
# RasterLayer with the default parameters
x <- raster()
x
## class      : RasterLayer
## dimensions : 180, 360, 64800  (nrow, ncol, ncell)
## resolution : 1, 1  (x, y)
## extent     : -180, 180, -90, 90  (xmin, xmax, ymin, ymax)
## crs        : +proj=longlat +datum=WGS84 +ellps=WGS84 +towgs84=0,0,0

# With other parameters
x <- raster(ncol=36, nrow=18, xmn=-1000, xmx=1000, ymn=-100, ymx=900)
# that can be changed
res(x)
## [1] 55.55556 55.55556

# change resolution
res(x) <- 100
res(x)
## [1] 100 100
ncol(x)
## [1] 20
# change the numer of columns (affects resolution)
ncol(x) <- 18
ncol(x)
## [1] 18
res(x)
## [1] 111.1111 100.0000

# set the coordinate reference system (CRS) (define the projection)
projection(x) <- "+proj=utm +zone=48 +datum=WGS84"
x
## class      : RasterLayer
## dimensions : 10, 18, 180  (nrow, ncol, ncell)
```

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```
## resolution : 111.1111, 100  (x, y)
## extent     : -1000, 1000, -100, 900  (xmin, xmax, ymin, ymax)
## crs        : +proj=utm +zone=48 +datum=WGS84 +ellps=WGS84 +towgs84=0,0,0
```

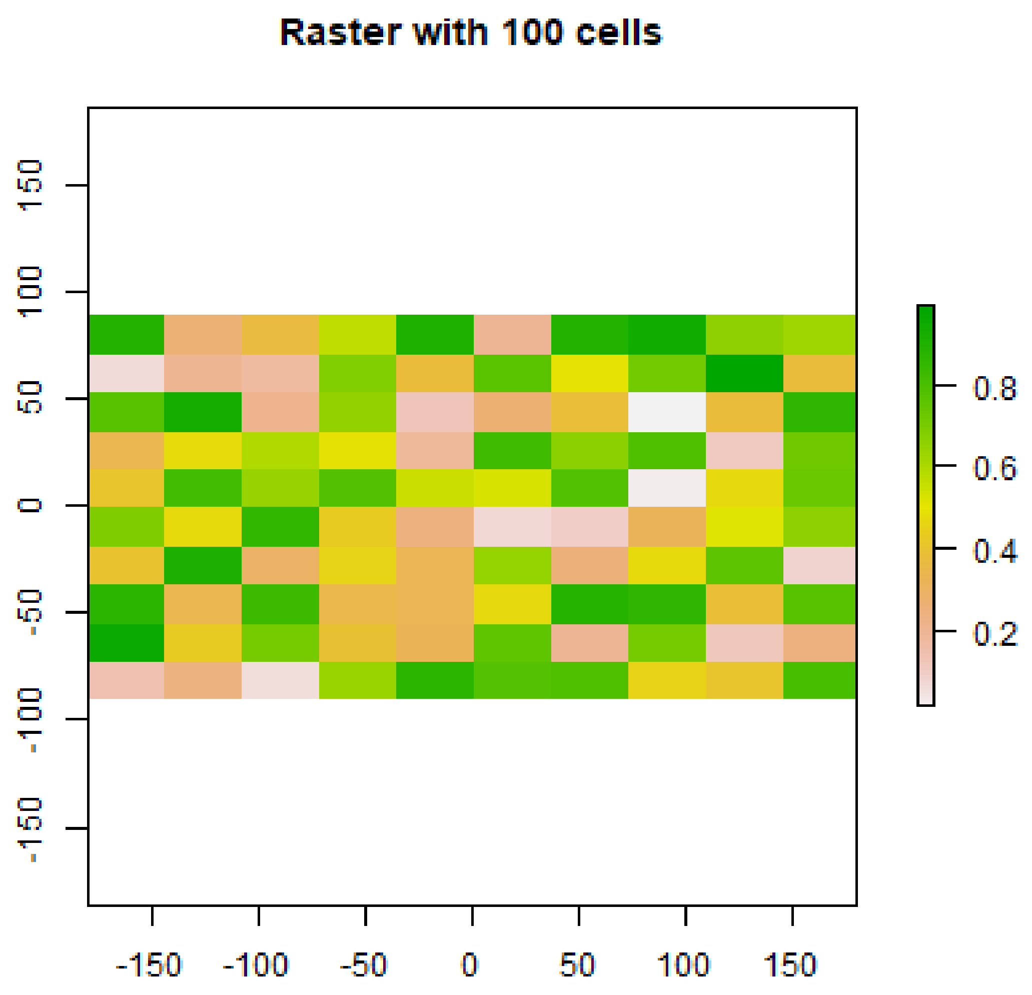
The object x created in the example above only consist of a "skeleton", that is, we have defined the number of rows and columns, and where the raster is located in geographic space, but there are no cell-values associated with it. Setting and accessing values is illustrated below.

```
r <- raster(ncol=10, nrow=10)
ncell(r)
## [1] 100
hasValues(r)
## [1] FALSE

# use the 'values' function
# e.g.,
values(r) <- 1:ncell(r)
# or
set.seed(0)
values(r) <- runif(ncell(r))

hasValues(r)
## [1] TRUE
inMemory(r)
## [1] TRUE
values(r)[1:10]
##  [1] 0.8966972 0.2655087 0.3721239 0.5728534 0.9082078 0.2016819 0.8983897
##  [8] 0.9446753 0.6607978 0.6291140

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 the extent as this change 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

# change the maximum x coordinate of the extent (bounding box) of the RasterLayer
xmax(r) <- 0

hasValues(r)
```

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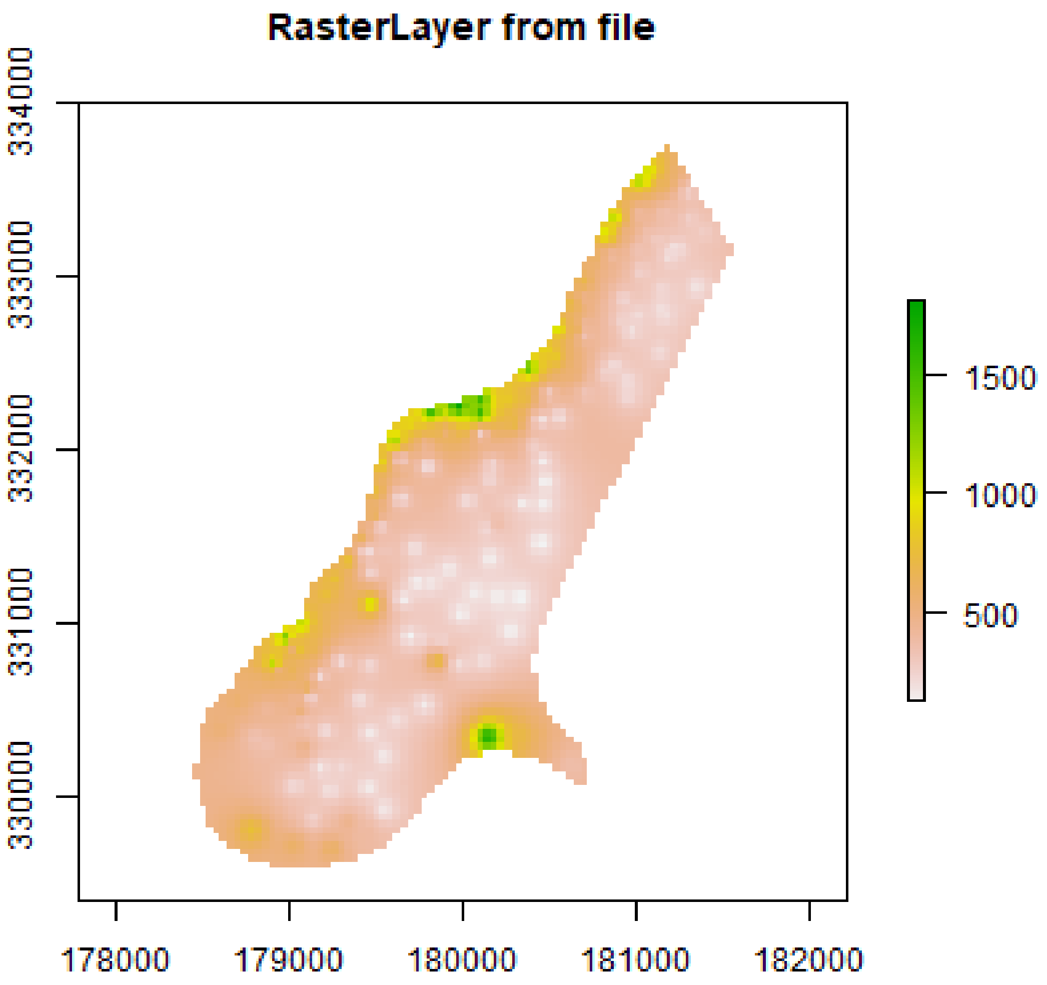
```
## [1] TRUE
res(r)
## [1] 18 18
dim(r)
## [1] 10 10  1

ncol(r) <- 6
hasValues(r)
## [1] FALSE
res(r)
## [1] 30 18
dim(r)
## [1] 10  6  1
xmax(r)
## [1] 0
```

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 GeoTIFF, ESRI, ENVI, and ERDAS. Most formats supported for reading can also be written to. 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
# do not use this construction of your own files
filename <- system.file("external/test.grd", package="raster")

filename
## [1] "C:/soft/R/R-3.6.0/library/raster/external/test.grd"
r <- raster(filename)
filename(r)
## [1] "C:\\soft\\R\\R-3.6.0\\library\\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, 100, 3  (nrow, ncol, ncell, nlayers)
## resolution : 36, 18  (x, y)
## extent     : -180, 180, -90, 90  (xmin, xmax, ymin, ymax)
## crs        : +proj=longlat +datum=WGS84 +ellps=WGS84 +towgs84=0,0,0
## names      :    layer.1,    layer.2,    layer.3
```

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```
## min values : 0.01307758, 0.02778712, 0.06380247
## max values :  0.9926841,  0.9815635,  0.9960774
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
filename <- system.file("external/rlogo.grd", package="raster")
filename
## [1] "C:/soft/R/R-3.6.0/library/raster/external/rlogo.grd"
b <- brick(filename)
b
## class      : RasterBrick
## dimensions : 77, 101, 7777, 3  (nrow, ncol, ncell, nlayers)
## resolution : 1, 1  (x, y)
## extent     : 0, 101, 0, 77  (xmin, xmax, ymin, ymax)
## crs        : +proj=merc +datum=WGS84 +ellps=WGS84 +towgs84=0,0,0
## source     : C:/soft/R/R-3.6.0/library/raster/external/rlogo.grd
## names      : red, green, blue
## 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(filename, band=2)
```

CHAPTER

FOUR

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.

```
# create an empty RasterLayer
r <- raster(ncol=10, nrow=10)
# assign values to cells
values(r) <- 1:ncell(r)
s <- r + 10
s <- sqrt(s)
s <- s * r + 5
r[] <- runif(ncell(r))
r <- round(r)
r <- r == 1
```

You can also use replacement functions:

```
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'. For example, if you multuply a 4-layer object (a1, a2, a3, a4) with a 2-layer object (b1, b2), the result is a four-layer object (a1b1, a2b2, a3b1, a3b2).

```
r <- raster(ncol=5, nrow=5)
r[] <- 1
s <- stack(r, r+1)
q <- stack(r, r+2, r+4, r+6)
x <- r + s + q
x
## class      : RasterBrick
## dimensions : 5, 5, 25, 4  (nrow, ncol, ncell, nlayers)
## resolution : 72, 36  (x, y)
## extent     : -180, 180, -90, 90  (xmin, xmax, ymin, ymax)
```

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```
## crs         : +proj=longlat +datum=WGS84 +ellps=WGS84 +towgs84=0,0,0
## source      : memory
## names       : layer.1, layer.2, layer.3, layer.4
## min values  :       3,       6,       7,      10
## max values  :       3,       6,       7,      10
```

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, 25  (nrow, ncol, ncell)
## resolution  : 72, 36  (x, y)
## extent      : -180, 180, -90, 90  (xmin, xmax, ymin, ymax)
## crs         : +proj=longlat +datum=WGS84 +ellps=WGS84 +towgs84=0,0,0
## source      : memory
## names       : layer
## values      : 11.5, 11.5  (min, max)
```

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

```
cellStats(st, 'sum')
## layer.1.1 layer.1.2 layer.2.1 layer.2.2   layer.3
##      25.0      25.0      50.0      87.5     100.0
cellStats(sst, 'sum')
## [1] 287.5
```

CHAPTER

FIVE

HIGH-LEVEL METHODS

Several 'high level' methods (functions) have been implemented for `RasterLayer` objects. 'High level' refers to methods that you would normally find in a GIS program that supports raster data. Here we briefly discuss some of these. See the help files for more detailed descriptions.

The high-level methods 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 method (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 method is to return a `raster` object that only exists in memory. However, if the method 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 to indicate whether existing files should be overwritten.

5.1 Modifying a Raster* object

There are several methods that deal with modifying the spatial extent of `Raster*` objects. The `crop` method lets you take a geographic subset of a larger `raster` object. 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 method.

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

The `merge` method 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`.

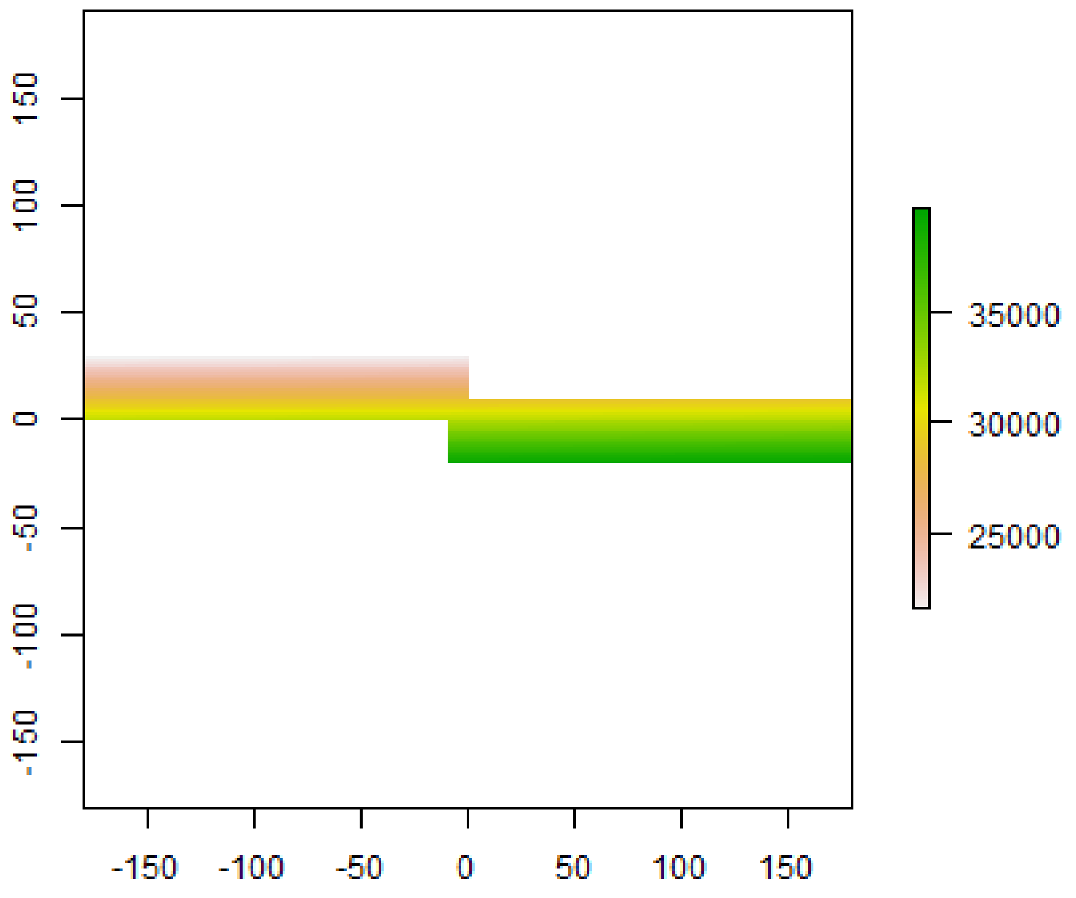
`aggregate` and `disaggregate} allow for changing the resolution (cell size) of a ```Raster*``` object. In the case of‘aggregate, you need to specify a function determining what to do with the grouped cell values (e.g.`mean`). It is possible to specify different (dis)aggregation factors in the x and y direction.` aggregate`and`disaggregate‘ are the best methods 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` method can be used. It can do either nearest neighbor assignments (for categorical data) or bilinear interpolation (for numerical data). Simple linear shifts of a Raster object can be accomplished with the `shift` method or with the `extent` method. `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` method you can transform values of `Raster*` object to a new object with a different coordinate reference system.

Here are some simple examples:

```
library(raster)
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)
```



`bf` 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. With `t` you can rotate a `Raster*` object 90 degrees.

5.2 Overlay

The overlay method can be used as an alternative to the raster algebra discussed above. Overlay, like the methods discussed in the following subsections provide either easy to use short-hand, or more efficient computation for large (file based) objects.

With overlay you can combine multiple Raster objects (e.g. multiply them). The related method 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.

5.3 Calc

The calc method 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.

5.4 Reclassify

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

```
r <- raster(ncol=3, nrow=2)
values(r) <- 1:ncell(r)
getValues(r)
## [1] 1 2 3 4 5 6
s <- calc(r, fun=function(x){ x[x < 4] <- NA; return(x)} )
as.matrix(s)
##      [,1] [,2] [,3]
## [1,]   NA   NA   NA
## [2,]    4    5    6
t <- overlay(r, s, fun=function(x, y){ x / (2 * sqrt(y)) + 5 } )
as.matrix(t)
##      [,1]     [,2]     [,3]
## [1,]   NA       NA       NA
## [2,]    6 6.118034 6.224745
u <- mask(r, t)
as.matrix(u)
##      [,1] [,2] [,3]
## [1,]   NA   NA   NA
## [2,]    4    5    6
v <- u==s
as.matrix(v)
##      [,1] [,2] [,3]
## [1,]   NA   NA   NA
## [2,] TRUE TRUE TRUE
w <- cover(t, r)
as.matrix(w)
##      [,1]     [,2]     [,3]
## [1,]    1 2.000000 3.000000
## [2,]    6 6.118034 6.224745
x <- reclassify(w, c(0,2,1,  2,5,2, 4,10,3))
as.matrix(x)
##      [,1] [,2] [,3]
## [1,]    1    1    2
```

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```
## [2,]    3    3    3
y <- subs(x, data.frame(id=c(2,3), v=c(40,50)))
as.matrix(y)
##      [,1] [,2] [,3]
## [1,]   NA   NA   40
## [2,]   50   50   50
```

5.5 Focal

The `focal` method currently only works for (single layer) RasterLayer objects. It uses values in a neighborhood of cells around a focal cell, and computes a value that is stored in the focal cell of the output RasterLayer. The neighborhood is a user-defined a matrix of weights and could approximate any shape by giving some cells zero weight. It is possible to only compute new values for cells that are `NA` in the input RasterLayer.

5.6 Distance

There are a number of distance related methods. `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 for more advanced distance calculations (cost distance, resistance distance)

5.7 Spatial configuration

The `clump` method identifies groups of cells that are connected. `boundaries` identifies edges, that is, transitions between cell values. `area` computes the size of each grid cell (for unprojected rasters), this may be useful to, e.g. compute the area covered by a certain class on a longitude/latitude raster.

```
r <- raster(nrow=45, ncol=90)
r[] <- round(runif(ncell(r))*3)
a <- area(r)
zonal(a, r, 'sum')
##      zone       sum
## [1,]    0  93604336
## [2,]    1 168894837
## [3,]    2 158110025
## [4,]    3  87822040
```

5.8 Predictions

The package has two methods 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. method `interpolate` is similar but is for models that use coordinates as predictor variables, for example in kriging and spline interpolation.

5.9 Vector to raster conversion

The raster packages supports point, line, and polygon to raster conversion with the `rasterize` method. 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 region.

It is also possible to convert the values of a `RasterLayer` to points or polygons, using `rasterToPoints` and `rasterToPolygons`. Both methods 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).

5.10 Summarize

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 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] 0.5179682
s = r
s[] <- round(runif(ncell(r)) * 5)
zonal(r, s, 'mean')
##      zone      mean
## [1,]    0 0.5144431
## [2,]    1 0.5480089
## [3,]    2 0.5249257
## [4,]    3 0.5194031
## [5,]    4 0.4853966
## [6,]    5 0.5218401
freq(s)
##      value count
## [1,]     0    54
## [2,]     1   102
## [3,]     2   139
## [4,]     3   148
## [5,]     4   133
## [6,]     5    72
freq(s, value=3)
## [1] 148
crosstab(r*3, s)
##         layer.2
## layer.1  0  1  2  3  4  5
##       0  8 13 21 16 24 10
##       1 17 31 42 56 45 24
##       2 19 31 52 54 37 27
##       3 10 27 24 22 27 11
```

CHAPTER

SIX

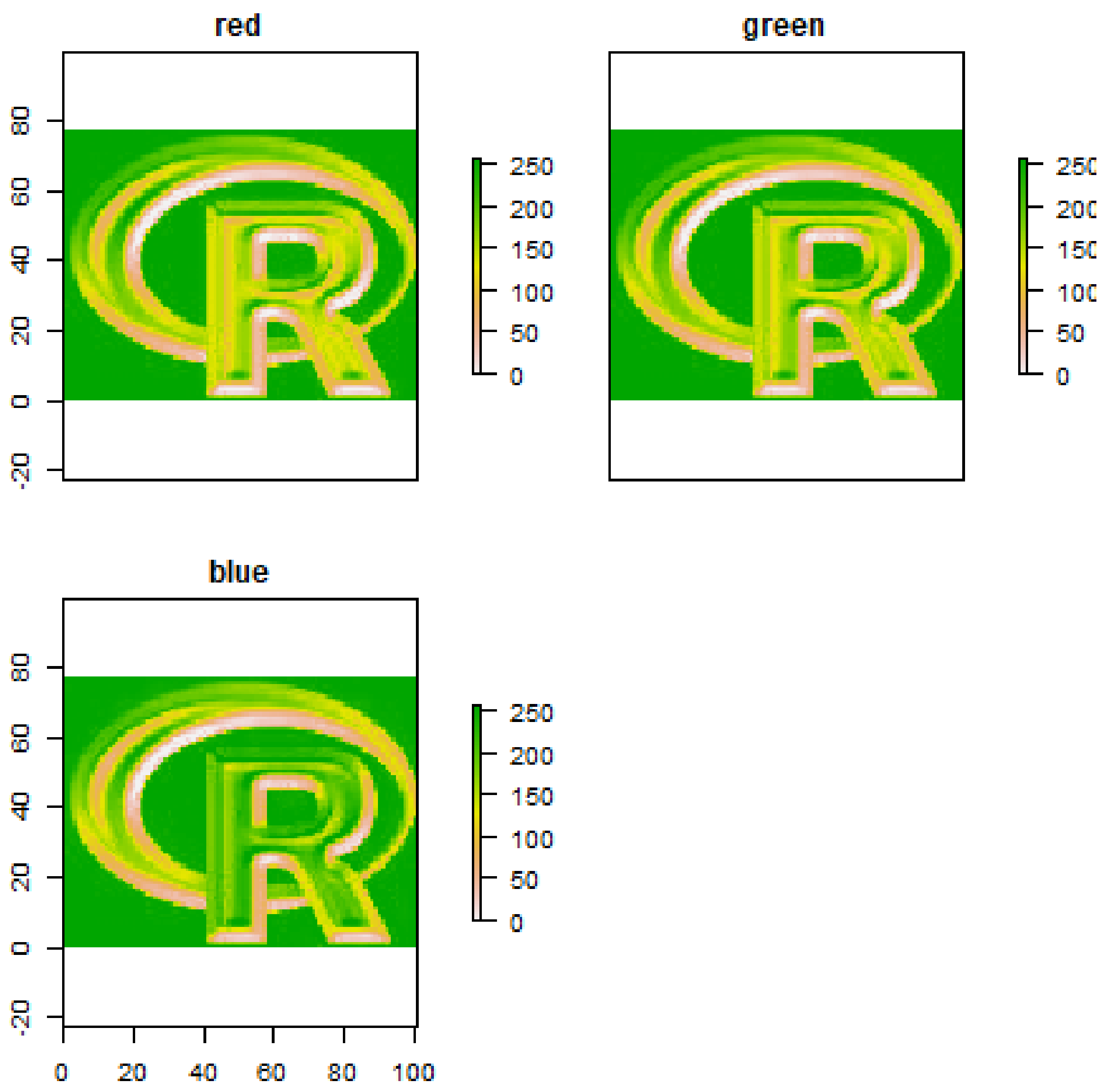
PLOTTING

Several generic functions have been implemented for Raster* objects to create maps and other plot types. Use 'plot' to create a map of a Raster* object. When plot is used with a `RasterLayer`, it calls the function 'rasterImage' (but, by default, adds a legend; using code from fields::image.plot). 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). With `click` it is possible to interactively query a Raster* object by clicking once or several times on a map plot.

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. You can also plot Raster* objects with `spplot`. The `rasterVis` package has several other `lattice` based plotting functions for Raster* objects. `rasterVis` also facilitates creating a map from a `RasterLayer` with the `ggplot2` package.

Multi-layer Raster objects can be plotted as individual layers

```
library(raster)
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 a number of other plotting functions with a `raster` object as argument, including `hist`, `persp`, `contour`, and `density`. See the help files for more info.

CHAPTER

SEVEN

WRITING FILES

7.1 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 (http://www.diva-gis.org/){[}DIVA-GIS]. See the help file for function `writeRaster` or the "Description of the rasterfile format" vignette.

CHAPTER

EIGHT

CELL-LEVEL FUNCTIONS

8.1 Introduction

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)
## [1] 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
```

8.2 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"))
v <- getValues(r, 50)
v[35:39]
## [1] 456.878 485.538 550.788 580.339 590.029
```

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```
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% area covered" threshold, or compute an area-weighted average.

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, or to replace values (assign new values to cells) in a `raster` object. If you replace a value in a `raster` object 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:\\soft\\R\\R-3.6.0\\library\\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. As for *R* matrices, the first index represents the row number, the second the column number.

```
r[1]
## [1] NA
r[2,2]
## [1] NA
```

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```
r[1,]
##  [1] NA 10 10 NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA
## [24] NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA
## [47] NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA
## [70] NA NA NA NA NA NA NA NA NA NA NA
r[,2]
##   [1]  10.000       NA       NA       NA       NA       NA       NA       NA
##   [9]       NA       NA       NA       NA       NA       NA       NA       NA
##  [17]       NA       NA       NA       NA       NA       NA       NA       NA
##  [25]       NA       NA       NA       NA       NA       NA       NA       NA
##  [33]       NA       NA       NA       NA       NA       NA       NA       NA
##  [41]       NA       NA       NA       NA       NA       NA       NA       NA
##  [49]       NA       NA       NA       NA       NA       NA       NA       NA
##  [57]       NA       NA       NA       NA       NA       NA       NA       NA
##  [65]       NA       NA       NA       NA       NA       NA       NA       NA
##  [73]       NA       NA       NA       NA       NA       NA       NA       NA
##  [81]       NA       NA       NA       NA       NA       NA       NA       NA
##  [89]       NA       NA       NA       NA       NA       NA       NA 473.833
##  [97] 471.573       NA       NA       NA       NA       NA       NA       NA
## [105]       NA       NA       NA       NA       NA       NA       NA       NA
## [113]       NA       NA       NA
r[1:3,1:3]
## [1] NA 10 10 NA NA NA NA NA NA

# keep the matrix structure
r[1:3,1:3, drop=FALSE]
## class      : RasterLayer
## dimensions : 3, 3, 9  (nrow, ncol, ncell)
## resolution : 40, 40  (x, y)
## extent     : 178400, 178520, 333880, 334000  (xmin, xmax, ymin, ymax)
## crs        : +proj=sterea +lat_0=52.15616055555555 +lon_0=5.38763888888889 +k=0.
↪9999079 +x_0=155000 +y_0=463000 +ellps=bessel +units=m +towgs84=565.237,50.0087,465.
↪658,-0.406857,0.350733,-1.87035,4.0812 +no_defs
## source     : memory
## names      : layer
## values     : 10, 10  (min, max)
```

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

CHAPTER

NINE

MISCELLANEOUS

9.1 Session options

There is a number of session options that influence reading and writing files. These can be set in a session, with `rasterOptions`, and saved to make them persistent in between sessions. But you probably should not change the default values unless you have pressing need to do so. You can, for example, set the directory where temporary files are written, and set your preferred default file format and data type. Some of these settings can be overwritten by arguments to functions where they apply (with arguments like filename, datatype, format). 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. The options chunksize and maxmemory determine 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.

```
library(raster)
rasterOptions()
## format        : raster
## datatype      : FLT4S
## overwrite     : FALSE
## progress      : none
## timer         : FALSE
## chunksize     : 1e+08
## maxmemory     : 5e+09
## memfrac       : 0.6
## tmpdir        : c:\temp\RtmpMVsfe0/raster/
## tmptime       : 168
## setfileext    : TRUE
## tolerance     : 0.1
## standardnames : TRUE
## warn depracat.: TRUE
## header        : none
```

9.2 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
values(r1) <- runif(ncell(r1))
values(r2) <- runif(ncell(r1))
s <- stack(r1, r2)
sgdf <- as(s, 'SpatialGridDataFrame')
newr2 <- raster(sgdf, 2)
news <- stack(sgdf)
```

9.3 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 = ''
    )
)

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'
values(m) <- 1:ncell(m)
```

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

m
## class       : myRaster
## dimensions : 10, 10, 100  (nrow, ncol, ncell)
## resolution : 36, 18  (x, y)
## extent      : -180, 180, -90, 90  (xmin, xmax, ymin, ymax)
## crs         : +proj=longlat +datum=WGS84 +ellps=WGS84 +towgs84=0,0,0
## source      : memory
## names       : layer
## values      : 1, 100  (min, max)
##
## essential: my own slot
## important information:
```

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```
##    id     value
## 1   1 0.9608613
## 2   2 0.3111691
## 3   3 0.8612748
## 4   4 0.8352472
## 5   5 0.8221431
## 6   6 0.5390177
## 7   7 0.6969546
## 8   8 0.3095380
## 9   9 0.1058503
## 10 10 0.6639418
```

CHAPTER

TEN

APPENDIX I. WRITING FUNCTIONS FOR LARGE RASTER FILES

10.1 Introduction

The `raster` package has a number of 'low-level' functions (e.g. to read and write files) that allow you to write your own 'high-level' functions. Here I explain how to use these low-level functions in developing 'memory-safe' high-level functions. With 'memory-safe' I refer to function that can process raster files that are too large to be loaded into memory. To understand the material discussed in this vignette you should be already somewhat familiar with the raster package. It is also helpful to have some general knowledge of S4 classes and methods.

I should also note that if you are not sure, you probably do not need to read this vignette, or use the functions described herein. That is, the high-level functions in the raster package are already based on these techniques, and they are very flexible. It is likely that you can accomplish your goals with the functions already available in 'raster' and that you do not need to write your own.

10.2 How not to do it

Let's start with two simple example functions, f1 and f2, that are NOT memory safe. The purpose of these simple example functions is to add a numerical constant 'a' to all values of RasterLayer 'x'.

To test the functions, we create a RasterLayer with 100 cells and values 1 to 100.

```
library(raster)
r <- raster(ncol=10, nrow=10)
r[] <- 1:100
r
## class      : RasterLayer
## dimensions : 10, 10, 100  (nrow, ncol, ncell)
## resolution : 36, 18  (x, y)
## extent     : -180, 180, -90, 90  (xmin, xmax, ymin, ymax)
## crs        : +proj=longlat +datum=WGS84 +ellps=WGS84 +towgs84=0,0,0
## source     : memory
## names      : layer
## values     : 1, 100  (min, max)
```

Below is a simple function, f1, that we use to add 5 to all cell values of 'r'

```
f1 <- function(x, a) {
    x@data@values <- x@data@values + a
    return(x)
}
s <- f1(r, 5)
s
## class      : RasterLayer
```

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```
## dimensions : 10, 10, 100  (nrow, ncol, ncell)
## resolution : 36, 18  (x, y)
## extent     : -180, 180, -90, 90  (xmin, xmax, ymin, ymax)
## crs        : +proj=longlat +datum=WGS84 +ellps=WGS84 +towgs84=0,0,0
## source     : memory
## names      : layer
## values     : 1, 100  (min, max)
```

f1 is a really bad example. It looks efficient but it has several problems. First of all, the slot `x@data@values` may be empty, which is typically the case when a raster object is derived from a file on disk. But even if all values are in memory the returned object will be invalid. This is because the values of a multiple slots need to be adjusted when changing values. For example, the returned 'x' may still point to a file (now incorrectly, because the values no longer correspond to it). And the slots with the minimum and maximum cell values have not been updated. While it can be OK (but normally not necessary) to directly read values of slots, you should not set them directly. The raster package has functions that set values of slots. This is illustrated in the next example.

```
f2 <- function(x, a) {
    v <- getValues(x)
    v <- v + a
    x <- setValues(x, v)
    return(x)
}
s <- f2(r, 5)
s
## class      : RasterLayer
## dimensions : 10, 10, 100  (nrow, ncol, ncell)
## resolution : 36, 18  (x, y)
## extent     : -180, 180, -90, 90  (xmin, xmax, ymin, ymax)
## crs        : +proj=longlat +datum=WGS84 +ellps=WGS84 +towgs84=0,0,0
## source     : memory
## names      : layer
## values     : 6, 105  (min, max)
```

f2 is much better than f1. Function `getValues` gets the cell values whether they are on disk or in memory (and will return NA values if neither is the case). `setValues` sets the values to the RasterLayer object assuring that other slots are updated as well.

However, this function could fail when used with very large raster files, depending on the amount of RAM your computer has and that *R* can access, because all values are read into memory at once. Processing data in chunks circumvents this problem.

10.3 Row by row processing

The next example shows how you can read, process, and write values row by row.

```
f3 <- function(x, a, filename) {
    out <- raster(x)
    out <- writeStart(out, filename, overwrite=TRUE)
    for (r in 1:nrow(out)) {
        v <- getValues(x, r)
        v <- v + a
        out <- writeValues(out, v, r)
    }
    out <- writeStop(out)
    return(out)
```

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```
}
s <- f3(r, 5, filename='test')
s
## class      : RasterLayer
## dimensions : 10, 10, 100  (nrow, ncol, ncell)
## resolution : 36, 18  (x, y)
## extent     : -180, 180, -90, 90  (xmin, xmax, ymin, ymax)
## crs        : +proj=longlat +datum=WGS84 +ellps=WGS84 +towgs84=0,0,0
## source     : c:/github/rspatial/rspatial-web/source/raster/_R/test.grd
## names      : layer
## values     : 6, 105  (min, max)
```

Note how, in the above example, first a new empty RasterLayer, 'out' is created using the {bf raster} function. 'out' has the same extent and resolution as 'x', but it does not have the values of 'x'.

10.4 Processing multiple rows at once

Row by row processing is easy to do but it can be a bit inefficient because there is some overhead associated with each read and write operation. An alternative is to read, calculate, and write by block; here defined as a number of rows (1 or more). The function `blockSize` is a helper function to determine appropriate block size (number of rows).

```
f4 <- function(x, a, filename) {
    out <- raster(x)
    bs <- blockSize(out)
    out <- writeStart(out, filename, overwrite=TRUE)
    for (i in 1:bs$n) {
        v <- getValues(x, row=bs$row[i], nrows=bs$nrows[i] )
        v <- v + a
        out <- writeValues(out, v, bs$row[i])
    }
    out <- writeStop(out)
    return(out)
}
s <- f4(r, 5, filename='test.grd')
blockSize(s)
## $row
## [1]  1  4  7 10
##
## $nrows
## [1] 3 3 3 1
##
## $n
## [1] 4
```

10.5 Filename optional

In the above examples (functions f3 and f4) you must supply a filename. However, in the raster package that is never the case, it is always optional. If a filename is provided, values are written to disk. If no filename is provided the values are only written to disk if they cannot be stored in RAM. To determine whether the output needs to be written to disk, the function `canProcessInMemory` is used. This function uses the size of the output raster to determine the total memory size needed. Multiple copies of the values are often made when doing computations. And perhaps you are combining values from several RasterLayer objects in which case you need to be able to use much more memory than for the output RasterLayer object alone. To account for this you can supply an additional parameter, indicating the total number of copies needed. In the examples below we use ‘3’, indicating that we would need RAM to hold three times the size of the output RasterLayer. That seems reasonably safe in this case.

First an example for row by row processing:

```
f5 <- function(x, a, filename='') {
    out <- raster(x)
    small <- canProcessInMemory(out, 3)
    filename <- trim(filename)

    if (!small & filename == '') {
        filename <- rasterTmpFile()
    }

    todisk <- FALSE
    if (filename != '') {
        out <- writeStart(out, filename, overwrite=TRUE)
        todisk <- TRUE
    } else {
        vv <- matrix(ncol=nrow(out), nrow=ncol(out))
    }

    for (r in 1:nrow(out)) {
        v <- getValues(x, r)
        v <- v + a
        if (todisk) {
            out <- writeValues(out, v, r)
        } else {
            vv[,r] <- v
        }
    }
    if (todisk) {
        out <- writeStop(out)
    } else {
        out <- setValues(out, as.vector(vv))
    }
    return(out)
}
s <- f5(r, 5)
```

Now, the same function, but looping over blocks of multiple rows, instead of a single row at a time (which can make a function very slow).

```
f6 <- function(x, a, filename='') {
    out <- raster(x)
    small <- canProcessInMemory(out, 3)
    filename <- trim(filename)

    if (! small & filename == '') {
        filename <- rasterTmpFile()
    }
    if (filename != '') {
        out <- writeStart(out, filename, overwrite=TRUE)
        todisk <- TRUE
    } else {
        vv <- matrix(ncol=nrow(out), nrow=ncol(out))
        todisk <- FALSE
    }
```

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```
    bs <- blockSize(r)
    for (i in 1:bs$n) {
        v <- getValues(x, row=bs$row[i], nrows=bs$nrows[i] )
        v <- v + a
        if (todisk) {
            out <- writeValues(out, v, bs$row[i])
        } else {
            cols <- bs$row[i]:(bs$row[i]+bs$nrows[i]-1)
            vv[,cols] <- matrix(v, nrow=ncol(out))
        }
    }
    if (todisk) {
        out <- writeStop(out)
    } else {
        out <- setValues(out, as.vector(vv))
    }
    return(out)
}

s <- f6(r, 5)
```

The next example is an alternative implementation that you might prefer if you wanted to optimize speed when values can be processed in memory. Optimizing for that situation is generally not that important as it tends to be relatively fast in any case. Moreover, while the below example is fine, this may not be an ideal approach for more complex functions as you would have to implement some parts of your algorithm twice. If you are not careful, your function might then give different results depending on whether the output must be written to disk or not. In other words, debugging and code maintenance can become more difficult. Having said that, there certainly are cases where processing chuck by chunk is inefficient, and where avoiding it can be worth the effort.

```
f7 <- function(x, a, filename='') {

    out <- raster(x)
    filename <- trim(filename)

    if (canProcessInMemory(out, 3)) {
        v <- getValues(x) + a
        out <- setValues(out, v)
        if (filename != '') {
            out <- writeRaster(out, filename, overwrite=TRUE)
        }
    } else {
        if (filename == '') {
            filename <- rasterTmpFile()
        }
        out <- writeStart(out, filename)

        bs <- blockSize(r)
        for (i in 1:bs$n) {
            v <- getValues(x, row=bs$row[i], nrows=bs$nrows[i] )
            v <- v + a
            out <- writeValues(out, v, bs$row[i])
        }
        out <- writeStop(out)
    }
    return(out)
```

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```
}

s <- f7(r, 5)
```

10.6 A complete function

Finally, let's add some useful bells and whistles. For example, you may want to specify a file format and data type, be able to overwrite an existing file, and use a progress bar. So far, default values have been used. If you use the below function, the dots '. . . ' allow you to change these by providing additional arguments 'overwrite', 'format', and 'datatype'. (In all cases you can also set default values with the `rasterOptions` function).

```
f8 <- function(x, a, filename='', ...) {
    out <- raster(x)
    big <- ! canProcessInMemory(out, 3)
    filename <- trim(filename)
    if (big & filename == '') {
        filename <- rasterTmpFile()
    }
    if (filename != '') {
        out <- writeStart(out, filename, ...)
        todisk <- TRUE
    } else {
        vv <- matrix(ncol=nrow(out), nrow=ncol(out))
        todisk <- FALSE
    }

    bs <- blockSize(x)
    pb <- pbCreate(bs$n, ...)

    if (todisk) {
        for (i in 1:bs$n) {
            v <- getValues(x, row=bs$row[i], nrows=bs$nrows[i] )
            v <- v + a
            out <- writeValues(out, v, bs$row[i])
            pbStep(pb, i)
        }
        out <- writeStop(out)
    } else {
        for (i in 1:bs$n) {
            v <- getValues(x, row=bs$row[i], nrows=bs$nrows[i] )
            v <- v + a
            cols <- bs$row[i]:(bs$row[i]+bs$nrows[i]-1)
            vv[,cols] <- matrix(v, nrow=out@ncols)
            pbStep(pb, i)
        }
        out <- setValues(out, as.vector(vv))
    }
    pbClose(pb)
    return(out)
}

s <- f8(r, 5, filename='test', overwrite=TRUE)

if(require(rgdal)) { # only if rgdal is installed
    s <- f8(r, 5, filename='test.tif', format='GTiff', overwrite=TRUE)
```

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```
}
## Loading required package: rgdal
## rgdal: version: 1.4-3, (SVN revision 828)
##  Geospatial Data Abstraction Library extensions to R successfully loaded
##  Loaded GDAL runtime: GDAL 2.2.3, released 2017/11/20
##  Path to GDAL shared files: C:/soft/R/R-3.6.0/library/rgdal/gdal
##  GDAL binary built with GEOS: TRUE
##  Loaded PROJ.4 runtime: Rel. 4.9.3, 15 August 2016, [PJ_VERSION: 493]
##  Path to PROJ.4 shared files: C:/soft/R/R-3.6.0/library/rgdal/proj
##  Linking to sp version: 1.3-1
s
## class      : RasterLayer
## dimensions : 10, 10, 100  (nrow, ncol, ncell)
## resolution : 36, 18  (x, y)
## extent     : -180, 180, -90, 90  (xmin, xmax, ymin, ymax)
## crs        : +proj=longlat +datum=WGS84 +no_defs +ellps=WGS84 +towgs84=0,0,0
## source     : c:/github/rspatial/rspatial-web/source/raster/_R/test.tif
## names      : test
## values     : 6, 105  (min, max)
```

Note that most of the additional arguments are passed on to writeStart:

`out <- writeStart(out, filename, ...)`

Only the `progress=` argument goes to `pbCreate`

10.7 Debugging

Typically functions are developed and tested with small (RasterLayer) objects. But you also need to test your functions for the case it needs to write values to disk. You can use a very large raster for that, but then you may need to wait a long time each time you run it. Depending on how you design your function you may be able to test alternate forks in your function by providing a file name. But this would not necessarily work for function f7. You can force functions of that type to treat the input as a very large raster by setting to option 'todisk' to `TRUE` as in `setOptions(todisk=TRUE)`. If that option is set, `canProcessInMemory` always returns `FALSE`. This should only be used in debugging.

10.8 Methods

The raster package is build with S4 classes and methods. If you are developing a package that builds on the raster package I would advise to also use S4 classes and methods. Thus, rather than using plain functions, define generic methods (where necessary) and implement them for a RasterLayer, as in the example below (the function does not do anything; replace 'return(x)' with something meaningful along the pattern explained above.

```
if (!isGeneric("f9")) {
    setGeneric("f9", function(x, ...)
        standardGeneric("f9"))
}
## [1] "f9"


setMethod('f9', signature(x='RasterLayer'),
    function(x, filename='', ...) {
        return(x)
    }
```

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```
)

s <- f9(r)
```

10.9 Mutli-core functions

Below is an example of an implementation of a customized raster function that can use multiple processors (cores), via the snow package. This is still very much under development, but you can try it at your own risk.

First we define a snow cluster enabled function. Below is a simple example:

```
clusfun <- function(x, filename="", ...) {

    out <- raster(x)

    cl <- getCluster()
    on.exit( returnCluster() )

    nodes <- length(cl)

    bs <- blockSize(x, minblocks=nodes*4)
    pb <- pbCreate(bs$n)

    # the function to be used (simple example)
    clFun <- function(i) {
        v <- getValues(x, bs$row[i], bs$nrows[i])
        for (i in 1:length(v)) {
            v[i] <- v[i] / 100
        }
        return(v)
    }

    # get all nodes going
    for (i in 1:nodes) {
        sendCall(cl[[i]], clFun, i, tag=i)
    }

    filename <- trim(filename)
    if (!canProcessInMemory(out) & filename == "") {
        filename <- rasterTmpFile()
    }

    if (filename != "") {
        out <- writeStart(out, filename=filename, ... )
    } else {
        vv <- matrix(ncol=nrow(out), nrow=ncol(out))
    }
    for (i in 1:bs$n) {
        # receive results from a node
        d <- recvOneData(cl)

        # error?
        if (! d$value$success) {
            stop('cluster error')
        }
```

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```
        # which block is this?
        b <- d$value$tag
        cat('received block: ',b,'\n'); flush.console();

        if (filename != "") {
            out <- writeValues(out, d$value$value, bs$row[b])
        } else {
            cols <- bs$row[b]:(bs$row[b] + bs$nrows[b]-1)
            vv[,cols] <- matrix(d$value$value, nrow=out@ncols)
        }

        # need to send more data?
        ni <- nodes + i
        if (ni <= bs$n) {
            sendCall(cl[[d$node]], clFun, ni, tag=ni)
        }
        pbStep(pb)
    }
    if (filename != "") {
        out <- writeStop(out)
    } else {
        out <- setValues(out, as.vector(vv))
    }
    pbClose(pb)

    return(out)
}
```

To use snow with raster, you need to set up a cluster first, with 'beginCluster' (only once during a session). After that we can run the function:

```
r <- raster()
# beginCluster()
r[] <- ncell(r):1
# x <- clusfun(r)
# endCluster()
```

CHAPTER

ELEVEN

APPENDIX II. THE “RASTERFILE” FORMAT

11.1 Introduction

The `raster` package has a default ‘native’ file format called ‘rasterfile’. This file format is used because it is simple, flexible and extensible and does not require rgdal, which may be difficult to install. The `raster` package can read and write other formats via the `rgdal` package.

The rasterfile format is highly similar to many other formats used for raster data. It consists of two files. One file with sequential binary values (filename extention is ‘.gri’), and one header file (filename extension is ‘.grd’). The main source of variation between such file formats is in the header file, and the contents of the rasterfile header file are described here.

The purpose is to standardize the format and help others to read and write files of the same format if they wish to do so. This vignette is aimed at software developers. The typical user of the `raster` package does not need to be familiar with it.

11.2 ini files

The header (‘.grd’) file is organized as an ‘.ini’ file. This is a simple database format that is subdivided in sections indicated with brackets ‘[]’. Within each section there are variables and their values seperated by the equal ‘=’ sign.

Thus, .ini files have a layout like this:

```
[section1]

var1=value

var2=value

[section2]

var3=value

var4=value
```

Variables names must be unique within a section, but the same variable name could occur in multiple sections. This is not done for raster files (variable names are unique) such that section names could be ignored. The `raster` package has a convenient function, `readIniFile`, to read .ini files.

11.3 Sections

The rasterfile ini format has four sections (general, georeference, data, legend, description) that are discussed below

11.3.1 general

This section has two variables, ‘creator’ and ‘created’. For example:

```
[general]

creator=R package 'raster'

created= 2010-03-13 17:26:34
```

These are metadata that are useful but not strictly required.

11.3.2 georeference

This section has the number of rows (nrows) and columns (ncols), and describes the spatial extent (bounding box) with four variables (xmin, xmax, ymin, ymax), and the coordinate reference system (projection). These variables are obviously required.

The number of rows and columns are integers >= 1. The extent variables are numeric with xmin < xmax and ymin < ymax. The coordinates refer to the extremes of the outer cells (not to the centers of these cells).

Resolution (cell size) is not specified (it should be derived value from the extent and the number of columns and rows).

The coordinate reference system is specified with the variable ‘projection’. Its value should be a string with the PROJ4 syntax. This value can be missing, but that is not recommended!

```
[georeference]

nrows=100

ncols=100

xmin=-180

ymin=-90

xmax=180

ymax=90

projection=+proj=longlat +datum=WGS84
```

11.3.3 data

This subsection has information about the file type as well as the cell values. Here is an example

```
[data]

datatype=FLT4S

nodatavalue=-3.4e+38

byteorder=little

nbands=3

bandorder=BIL

minvalue=1:0:5

maxvalue=255:200:255
```

`datatype` is required. Its values must be one of ‘LOG1S’, ‘INT1S’, ‘INT2S’, ‘INT4S’, ‘INT8S’, ‘INT1U’, ‘INT2U’, ‘FLT4S’, ‘FLT8S’. The first three letters indicate the type of number that is stored (logical, integer, or float). The fourth character determines how many bytes are used to store these. The last letter inidcates, if applicable, whether the values are singed or not (i.e. whether negative values are possible).

`nodatavalue` is optional (but necessary if there are nodata (NA) values). It can be any value. But in the raster package the lowest possible value is used for signed integer and float data types and the highest integer is used for unsigned integer types (this is to avoid using 0 as the nodata value).

`byteorder` is optional but recommended. It should be either 'big' or 'little'. If absent, the raster package assumes that the platform byte order is used.

`nbands` is required. It indicates the number of layers (bands) stored in the file and hence its values should be an integer >= 1. If absent, the raster package assumes it is 1.

`bandorder` is required if nbands > 1 and ignored when nbands=1. Values can be 'BIL' (band interleaved by line), 'BIP' (band interleaved by pixel) and 'BSQ' (band sequential). BIL is recommended for most cases.

`minvalue` and `maxvalue` indicate the minimum or maximum value in the each layer (excluding NA). If there are mulitple layers, the value are seperated by a colon.

If the values are integers representing a class (e.g. land cover types such as 'forest', 'urban', 'agriculture') four additional keys are required to indicate that these are categorical data and to provide three columns for a 'Raster Attribute Table'. In this case there are three variables (ID, landocver and code). ID refers to the actual cell value, the following are attributed linked to these values. rattypes describe the data type. ID and would normally be 'integer'. Other values allowed are 'character' and 'numerical'. 'ratvalues' gives the actual values. For example:

```
categorical=TRUE

ratnames=ID:landcover:code

rattypes=integer:character:numeric

ratvalues=1:2:3:Pine:Oak:Meadow:12:25:30
```

11.3.4 description

This section only has the layer names. As above, these are separated by colons. Therefore, colons are not allowed in the layer names. If they occur, they could be replaced with at dot '.'.

```
[description]

layername=red:green:blue
```