

Raster Analysis

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Abstract

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1 Working with raster time series

Since the opening of the Landsat data archive, image time series analysis has become a real possibility. In environmental research and monitoring, methods and tools for time series analysis are becoming increasingly important. With the brick and stack object types, the raster package in R allows for certain types of raster-based time series analysis, and allows for integration with other time series packages in R.

A raster brick from a small area within the Kafa Biosphere Reserve in Southern Ethiopia can be found in the *rasta* package. Set the working directory to the packages home folder and load the raster brick from file by

```
> data(tura)
> # inspect the data
> class(tura) # the object's class
> projection(tura) # the projection
> res(tura) # the spatial resolution (x, y)
> extent(tura) # the extent of the raster brick
```

Extracting scene information

This RasterBrick was read from a .grd file. One advantage of this file format (over the GeoTIFF format, for example) is the fact that the specific names of the raster layers making up this brick have been preserved, a feature which is important for identifying raster layers, especially when doing time series analysis (where you need to know the values on the time axis). This RasterBrick was prepared from a Landsat 7 ETM+ time series, and the original scene names were inserted as layer names.

```
> names(tura) # displays the names of all layers in the tura RasterBrick
```

We can parse these names to extract information from them. The first 3 characters indicate which sensor the data come from, with 'LE7' indicating Landsat 7 ETM+ and 'LT5' or 'LT4' indicating Landsat 5 and Landsat 4 TM, respectively. The following 6 characters indicate the path and row (3 digits each), according to the WGS system. The following 7 digits represent

the date. The date is formatted in such a way that it equals the year + the julian day. For example, February 5th 2001, aka the 36th day of 2001, would be '2001036'.

```
> # display the 1st 3 characters of the layer names
> sensor <- substr(names(tura), 1, 3)
> print(sensor)
> # display the path and row as numeric vectors in the form (path,row)
> path <- as.numeric(substr(names(tura), 4, 6))
> row <- as.numeric(substr(names(tura), 7, 9))
> print(paste(path, row, sep = ","))
> # display the date
> dates <- substr(names(tura), 10, 16)
> print(dates)
> # format the date in the format yyyy-mm-dd
> as.Date(dates, format = "%Y%j")
```

There is a function in the *rasta* package, `getSceneinfo()` that will parse these names and output a `data.frame` with all of these attributes.

```
> # ?getSceneinfo
> sceneinfo <- getSceneinfo(names(tura))
> print(sceneinfo)
> # add a 'year' column to the sceneinfo dataframe and plot #scenes/year
> sceneinfo$year <- factor(substr(sceneinfo$date, 1, 4), levels = c(1984:2013))
> ggplot(data = sceneinfo, aes(x = year, fill = sensor)) +
+   geom_bar() +
+   labs(y = "number of scenes") +
+   scale_y_continuous(limits=c(0, 20)) +
+   theme_bw() +
+   theme(axis.text.x=element_text(angle = 45),
+         legend.position=c(0.9, 0.85))
```

Note that the values along the x-axis of this plot are evenly distributed, even though there are gaps in the values (e.g. between 1987 and 1994). The spacing is due to the fact that we defined `sceneinfo$year` as a vector of *factors* rather than a numeric vectors. Factors act as thematic classes and can be represented by numbers or letters. In this case, the actual values of the factors are not recognized by R. Instead, the levels defined in the `factor()` function define the hierarchy of the factors (in this case we have defined the levels from 1984 up to 2013, according to the range of acquisition dates). For more information on factors in R, check out <http://www.stat.berkeley.edu/classes/s133/factors.html>.

Try to generate the plot above with the years (x-axis) represented as a numeric vector instead of as a factor. Hint: it is not as straightforward as you might think - to convert a factor `x` to a numeric vector, try

```
x <- as.numeric(as.character(x))
```

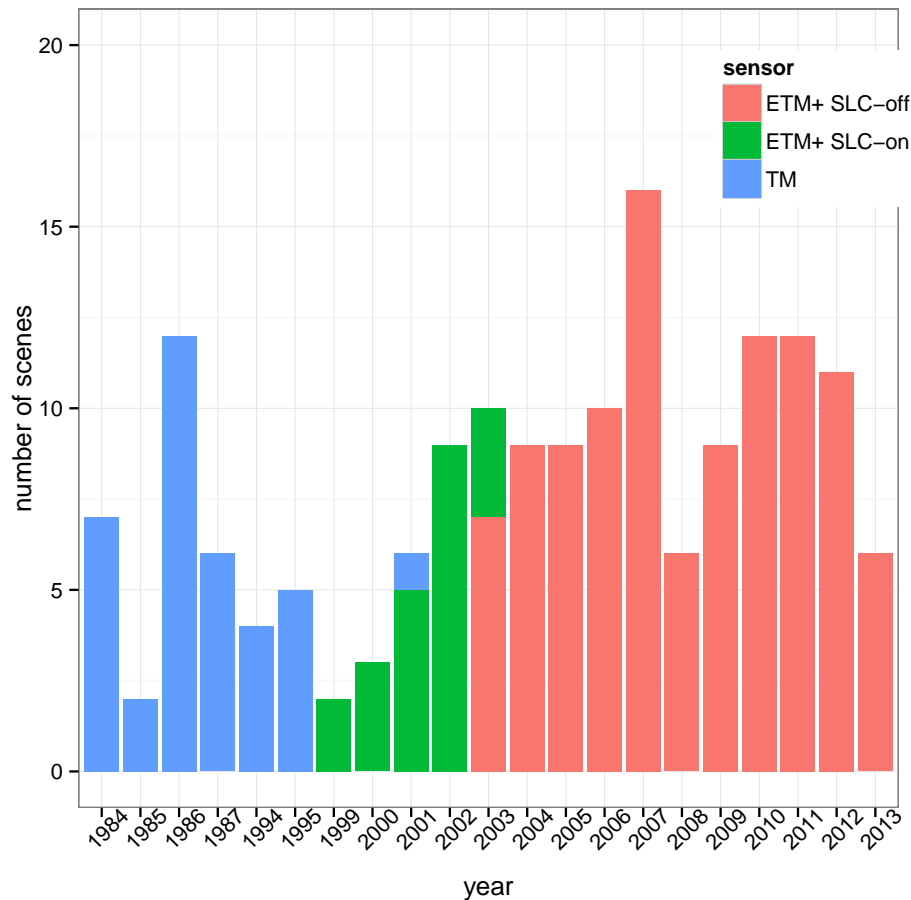


Figure 1: Number of scenes available per year in the time series.

Plotting RasterBricks

A RasterBrick can be plotted just as a RasterLayer, and the graphics device will automatically split into panels to accommodate the layers (to an extent: R will not attempt to plot 100 layers at once!). To plot the first 9 layers:

```
> plot(tura, c(1:9))
> # alternatively, you can use [[]] notation to specify layers
> plot(tura[[1:9]])
> # use the information from sceneinfo data.frame to clean up the titles
> plot(tura[[1:9]], main = sceneinfo$date[c(1:9)])
```

Unfortunately, the scale is different for each of the layers, making it impossible to make any meaningful comparison between the raster layers. This problem can be solved by specifying a breaks argument in the plot() function.

```
> # we need to define the breaks to harmonize the scales (to make the plots comparable)
> bks <- seq(0, 10000, by = 2000) # (arbitrarily) define the breaks
> # we also need to redefine the colour palette to match the breaks
```

```
> cols <- rev(terrain.colors(length(bks))) # col = rev(terrain.colors(255)) is the default
> # (opt: check out the RColorBrewer package for other colour palettes)
> # plot again with the new parameters
> plot(tura[[1:9]], main = sceneinfo$date[1:9], breaks = bks, col = cols)
```

Alternatively, the rasterVis package has some enhanced plotting functionality for raster objects, including the levelplot() function, which automatically provides a common scale for the layers.

```
> library(rasterVis)
> levelplot(tura[[1:6]])
> # NOTE:
> # for rasterVis plots we must use the [[]] notation for extracting layers
>
> # providing titles to the layers is done using
> # the 'names.attr' argument in place of 'main'
> levelplot(tura[[1:8]], names.attr = sceneinfo$date[1:8])
> # define a more logical colour scale
> library(RColorBrewer)
> # this package has a convenient tool for defining colour palettes
> # ?brewer.pal
> display.brewer.all()
> cols <- brewer.pal(11, 'PiYG')
> # to change the colour scale in levelplot(),
> # we first have to define a rasterTheme object
> # see ?rasterTheme() for more info
> rtheme <- rasterTheme(region = cols)
> levelplot(tura[[1:8]], names.attr = sceneinfo$date[1:8], par.settings = rtheme)
```

This plot gives us a common scale which allows us to compare values (and perhaps detect trends) from layer to layer. In the above plot, the layer titles do not look very nice – we will solve that problem a bit later.

The rasterVis package has integrated plot types from other packages with the raster package to allow for enhanced visualization of raster data.

```
> # histograms of the first 6 layers
> histogram(tura[[1:6]])
> # box and whisker plot of the first 9 layers
> bwplot(tura[[1:9]])
```

More examples from the rasterVis package can be found @ <http://oscarperpinan.github.io/rasterVis/>

Calculating data loss

In this RasterBrick, the layers have all been individually preprocessed from the raw data format into NDVI values. Part of this process was to remove all pixels obscured by clouds or SLC-off gaps (for any ETM+ data acquired after March 2003). For this reason, it may be

useful to know how much of the data has been lost to cloud cover and SLC gaps. First, we will calculate the percentage of no-data pixels in each of the layers using the `freq()` function. `freq()` returns a table (matrix) of counts for each value in the raster layer. It may be easier to represent this as a `data.frame` to access column values.

```
> # try for one layer first
> y <- freq(tura[[1]]) # this is a matrix
> y <- as.data.frame(y)
> print(y)
> # how many NA's are there in this table?
> y$count[is.na(y$value)]
> # alternatively, using the with() function:
> with(y, count[is.na(value)])
> # as a %
> with(y, count[is.na(value)] / ncell(tura[[1]]) * 100)
> # We can compute this more efficiently
> # by using the 'value' argument in freq()
> y <- freq(tura[[1]], value=NA)
> print(y)
> # apply over all layers of the rasterBrick
> y <- freq(tura, value=NA)
> print(y)
> # convert this to % pixels per scene
> y <- freq(tura, value=NA) / ncell(tura) * 100
> # add this vector as a column in the sceneinfo data.frame
> #(rounded to 2 decimal places)
> sceneinfo$nodata <- round(y, 2)
> # plot these values
> ggplot(data = sceneinfo, aes(x = date, y = nodata, shape = sensor)) +
+   geom_point(size = 2) +
+   labs(y = "% nodata") +
+   theme_bw()
>
```

We have now derived some highly valuable information about our time series. For example, we may want to select an image from our time series with relatively little cloud cover to perform a classification. For further time series analysis, the layers with 100% data loss will be of no use to us, so it may make sense to get rid of these layers.

```
> # which layers have 100% data loss?
> which(sceneinfo$nodata == 100)
> # supply these indices to the dropLayer() command to get rid of these layers
> tura <- dropLayer(tura, which(sceneinfo$nodata == 100))
> # redefine our sceneinfo data.frame as well
> sceneinfo <- sceneinfo[which(sceneinfo$nodata != 100), ]
> # optional: remake the previous ggplots with this new dataframe
```

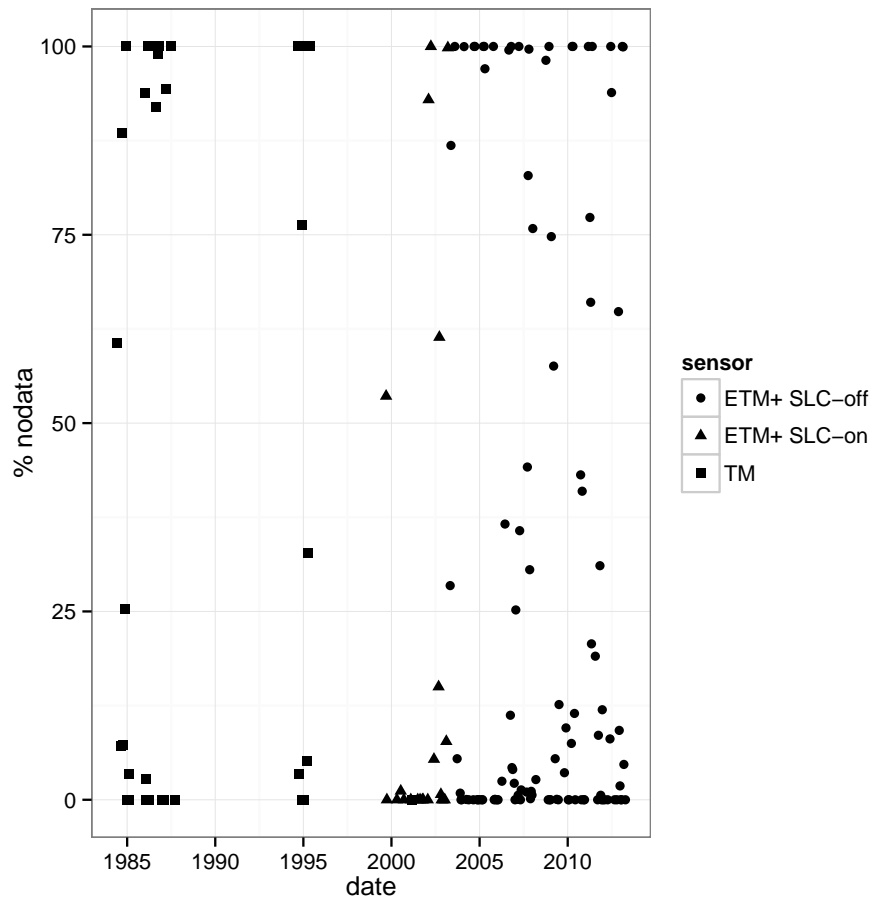


Figure 2: % NAs found in each scene of a Landsat time series.

With some analyses, it may also be desirable to apply a no-data threshold per scene, in which case layer indices would be selected by:

```
> which(sceneinfo$nodata > some_threshold)
```

In some cases, there may be parts of the study area with more significant data loss due to persistent cloud cover or higher incidence of SLC-off gaps. To map the spatial distribution of data loss, we need to calculate the % of NA in the time series for each *pixel* (ie. looking 'through' the pixel along the time axis). To do this, it is convenient to use the `calc()` function and supply a special function which will count the number of NA's for each pixel along the time axis, divide it by the total number of data in the pixel time series, and output a percentage. `calc()` will output a raster with a percentage no-data value for each pixel.

```
> # calc() will apply a function over each pixel
> # in this case, each pixel represents a time series of NDVI values
> # e.g. extract all values of the 53rd pixel in the raster grid
> y <- as.numeric(tura[53])
> print(y) # integer vector from time series values
```

```

[1] 7403 8746 7174 8003 8468 7512 8281 8652 8254 8431 7126 NA 8437 8572 NA
[16] 8407 8123 7589 7867 7474 NA NA NA 8407 8057 8293 8059 NA 6895 7526
[31] 8227 8382 8487 7737 6304 7664 NA 8264 8312 8286 7702 7758 7919 7138 NA
[46] 7948 8769 8200 8293 8275 8614 8227 7510 6730 8277 8446 8527 8687 NA NA
[61] NA 8311 8221 7801 NA 7394 NA 8295 8026 7907 7796 7572 6462 8071 8407
[76] NA 7687 8007 7865 7982 7637 7664 7939 8226 8127 7429 8324 8253 NA NA
[91] 6638 NA 8154 8365 7370 7920 8181 8260 7983 7649 8265 7652 NA 8479 8325
[106] 7194 7939 8329 7805 7858 NA 6796 8047 7438 7142 7904 8104 3645 7681 7361
[121] 6037 6363 6483 6831 7500 8029 7582 NA NA 7844 7249 6918 5954 NA 7673
[136] 8278 8144 NA 6710 7332 8237 7461

```

```

> # how many of these values have been masked (NA)?
> length(y[is.na(y)])

```

```

[1] 23

```

```

> # as a %
> length(y[is.na(y)]) / length(y) * 100

```

```

[1] 16.19718

```

```

> # now wrap this in a calc() to apply over all pixels of the RasterBrick
> nodata <- calc(tura, fun = function(x) length(x[is.na(x)]) / length(x) * 100)
> # sometimes it's more readable to define the function first
> percNA <- function(x){
+   y <- length(x[is.na(x)]) / length(x) * 100
+   return(y)
+ }
> nodata <- calc(tura, fun=function(x) percNA(x))

```

There is an easy way to interactively extract data from a single pixel using the raster package. First, a raster plot should be made from which to identify the pixel of interest. Then, the `click()` function allows for extraction of the data contained within that pixel. Simply calling `click()` with no further arguments will only return the (x, y) coordinates of that point as a 1-row matrix.

```

> plot(tura, 101)
> click()
      x      y
[1,] 819695.2 830544.3

```

We can extract more meaningful information by passing the name of the object (in this case, a RasterBrick) as the first argument, followed by the argument 'n=1' (or the number of desired points to identify).

```

> plot(tura, 101)
> x <- click(tura, n=1)
> # returns a matrix

```

```

> class(x)
> # convert it to an integer vector
> x <- x[1,]
> # or....
> x <- as.numeric(x)
> # note that the 2nd method removes the names of the vector!

```

In this case, all data from that pixel are extracted. These time series could then easily be coerced (or inserted) into a data.frame to plot the data and further analyze them. Let's take a look at the time series of a few different pixels. Instead of using the interactive click() function to extract these data, suppose that we know the (x, y) coordinates of a land cover type (or other points of interest, from a field campaign or ground truth dataset, for example).

```

> # several pixel coordinate pairs expressed as separate 1-row matrices
> forest <- matrix(data=c(819935, 832004), nrow=1,
+                  dimnames=list(NULL, c('x', 'y')))
> cropland <- matrix(data=c(819440, 829346), nrow=1,
+                   dimnames=list(NULL, c('x', 'y')))
> wetland <- matrix(data = c(822432, 832076), nrow=1,
+                  dimnames=list(NULL, c('x', 'y')))
> # recall that we can extract pixel data if we know the cell #
> # we can easily convert from xy matrix to cell number with cellFromXY()
> cellFromXY(tura, forest)
> tura[cellFromXY(tura, forest)] # returns a 1-row matrix with all ts values

```

Now we are able to extract the time series data given a set of (x, y) coordinates. Let's put the data from these three points into a data.frame to facilitate plotting of the data.

```

> # prepare the data.frame
> ts <- data.frame(sensor = getSceneinfo(names(tura))$sensor,
+                 date = getSceneinfo(names(tura))$date,
+                 forest = t(tura[cellFromXY(tura, forest)]),
+                 cropland = t(tura[cellFromXY(tura, cropland)]),
+                 wetland = t(tura[cellFromXY(tura, wetland)])
+                 )
> print(ts)
> # simple plot of forest time series
> plot(ts$date, ts$forest)
> # same thing but using with()
> with(ts, plot(date, forest))

```

Note the two large gaps in the time series during the 1990's, during which time there are no Landsat data available from the USGS. While we could still use these data to understand historical trends, we will only look at time series data from the ETM+ sensor (ie. data acquired after 1999) for the following exercises.

```

> # remove all data from the TM sensor and plot again
> ts <- ts[which(ts$sensor != "TM"), ]
> with(ts, plot(date, forest))

```


A more informative plot would show these time series side by side with the same scale or on the same plot. These are possible with either the base `plot()` function or using `ggplot2`. Either way, there is some preparation needed, and in the case of `ggplot2`, this may not be immediately obvious. In the following example, we are going to make a `facet_wrap` plot. In order to do so, we need to merge the time series columns to make a `data.frame` with many rows indeed. An additional column will be used to identify the class (forest, cropland or wetland) of each data point, and this class will be used to 'split' the data into 3 facets. The `reshape` package has a convenient function, `melt()`, which will 'automatically' reshape the `data.frame` to make it passable to the `ggplot` framework.

```
> library(reshape)
> # convert dates to characters, otherwise melt() returns an error
> ts$date <- as.character(ts$date)
> tsmelt <- melt(ts)
> head(tsmelt)
> names(tsmelt) <- c('sensor', 'date', 'class', 'value')
> # convert tsplot$date back to Date class to enable formatting of the plot
> tsmelt$date <- as.Date(tsmelt$date)
> ggplot(data = tsmelt, aes(x = date, y = value / 10000)) +
+   geom_point() +
+   scale_x_date() +
+   labs(y = "NDVI") +
+   facet_wrap(~ class, nrow = 3) +
+   theme_bw()
```

2 Exercise

- example 1: produce a figure with maximum/minimum/median/mean NDVI per year; figure should have a common scale and be properly labelled
- example 2: compute a time series metric over an entire RasterBrick using the `calc()` function

