Applied Econometrics with R

Extension 2

Time, Date, and Time Series Classes

Time, Date, and Time Series Classes

Motivation

Motivation

Illustration: Time series computations for NASDAQ-100 series.

Infrastructure: "`zoo`" series with "`Date`" time index for daily data.

Technical details: Deferred to later sections.

More information/examples: Zeileis & Grothendieck (2005) and Shah, Zeileis, Grothendieck (2015).

Data source: The data are take from `http://finance.yahoo.com/`. In fact, this can be queried interactively using `get.hist.quote()` from **tseries**.

Motivation

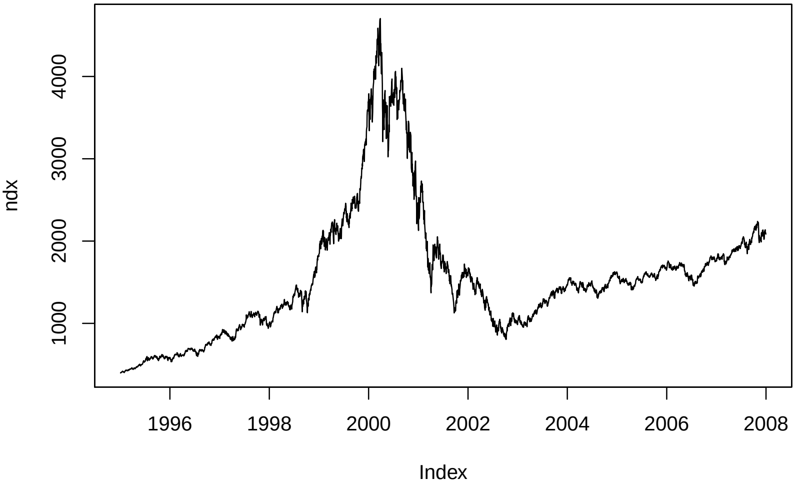
Data in external text file `ndx.txt` where each row of the file looks like this:

```
03 Jan 1995| 398.00
04 Jan 1995| 399.65
...
```

Read into "`zoo`" time series:

```
R> ndx <- read.zoo("ndx.dat", format = "%d %b %Y", sep = "|")
R> plot(ndx)
```

Motivation


ndx
4000
3000
2000
1000
1996
1998
2000
2002
2004
2006
2008
Index

Motivation

Compute log-difference returns (in percent):

```
R> rndx <- 100 * diff(log(ndx))
```

Visualize:

```
R> plot(cbind(ndx, rndx))
```

Different visualization: `xyplot()` from **lattice**.

```
R> library("lattice")
R> xyplot(cbind(ndx, rndx))
```

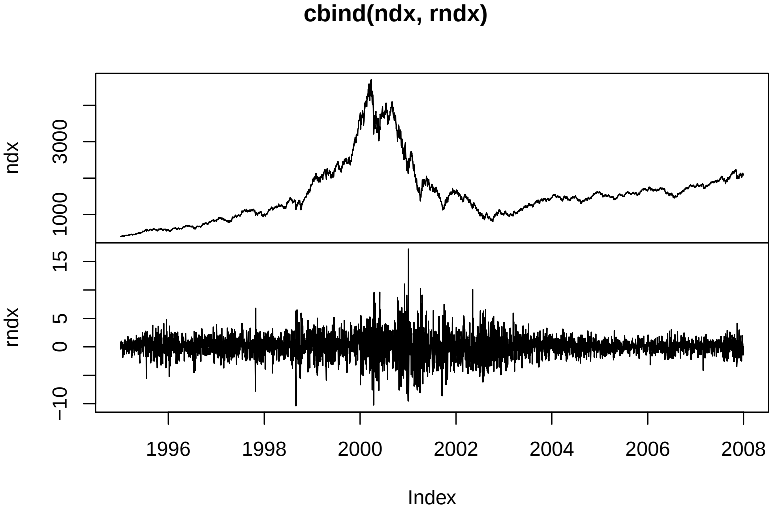
Or: `autoplot()` from **ggplot2**.

```
R> library("ggplot2")
R> autoplot(cbind(ndx, rndx)) + facet_free()
```

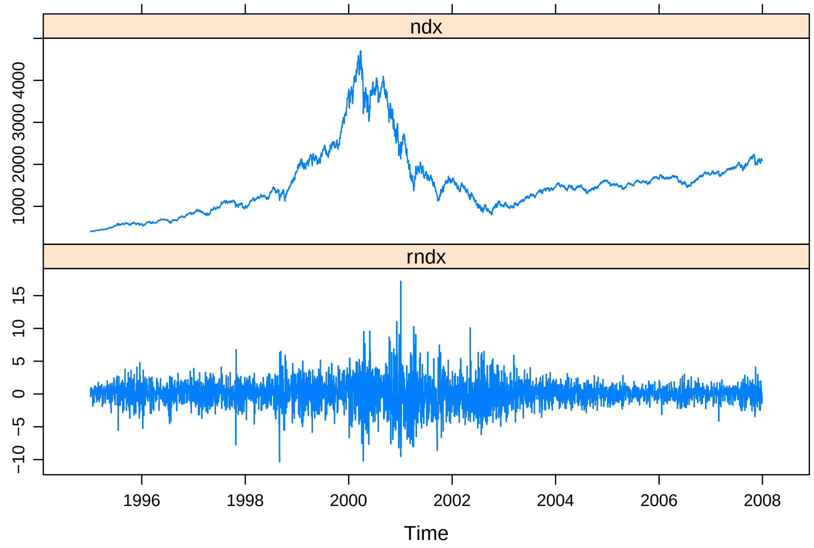
Rolling mean (adjusted to annual level):

```
R> plot(rollapply(rndx, 365, mean) * 365.25)
R> abline(h = 0, lty = 2)
```

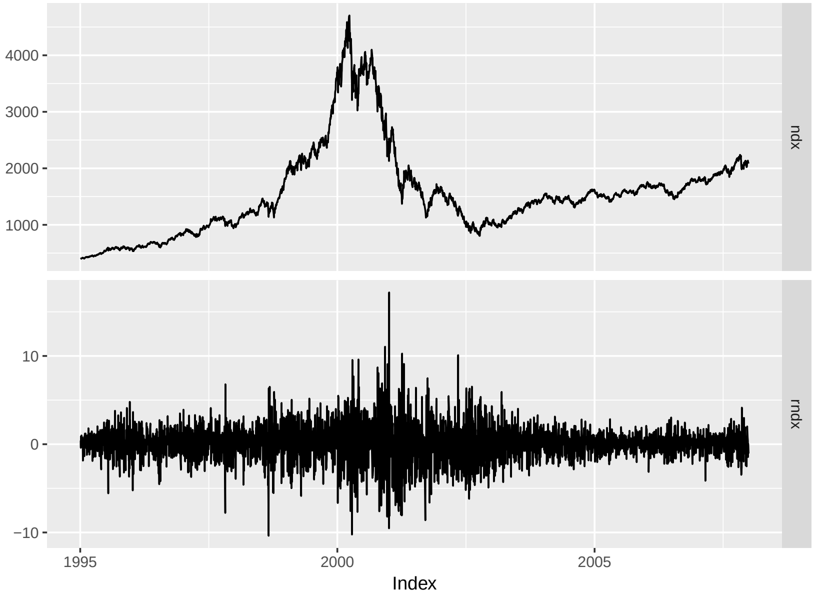
Motivation


cbind(ndx, rndx)
ndx
rndx
1000
3000
−10
0
5
15
1996
1998
2000
2002
2004
2006
2008
Index

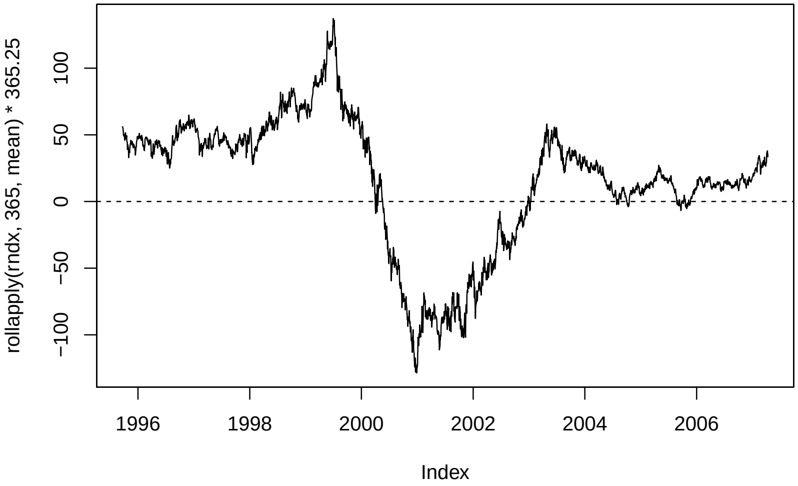
Motivation


ndx
rndx
1000
2000
3000
4000
−10
−5
0
5
10
15
1996
1998
2000
2002
2004
2006
2008
Time

Motivation



Motivation


rollapply(rndx, 365, mean) * 365.25
100
50
0
−50
−100
1996
1998
2000
2002
2004
2006
Index

Motivation

Extract subset:

```
R> ndx2 <- window(ndx,
+    start = as.Date("2000-01-01"), end = as.Date("2000-01-15"))
R> ndx2
```

```
2000-01-03 2000-01-04 2000-01-05 2000-01-06 2000-01-07
   3790.55    3546.20    3507.31    3340.81    3529.60
2000-01-10 2000-01-11 2000-01-12 2000-01-13 2000-01-14
   3717.41    3544.35    3478.14    3612.08    3704.74
```

Extract time index and data:

```
R> time(ndx2)
```

```
 [1] "2000-01-03" "2000-01-04" "2000-01-05" "2000-01-06"
 [5] "2000-01-07" "2000-01-10" "2000-01-11" "2000-01-12"
 [9] "2000-01-13" "2000-01-14"
```

```
R> coredata(ndx2)
```

```
 [1] 3790.55 3546.20 3507.31 3340.81 3529.60 3717.41 3544.35
 [8] 3478.14 3612.08 3704.74
```

Motivation

Union:

```
R> merge(ndx2, lag(ndx2, k = -1))
```

```
              ndx2 lag(ndx2, k = -1)
2000-01-03 3790.55                NA
2000-01-04 3546.20           3790.55
2000-01-05 3507.31           3546.20
2000-01-06 3340.81           3507.31
2000-01-07 3529.60           3340.81
2000-01-10 3717.41           3529.60
2000-01-11 3544.35           3717.41
2000-01-12 3478.14           3544.35
2000-01-13 3612.08           3478.14
2000-01-14 3704.74           3612.08
```

Motivation

Intersection:

```
R> merge(ndx2, lag(ndx2, k = -1), all = FALSE)
```

```
              ndx2 lag(ndx2, k = -1)
2000-01-04 3546.20           3790.55
2000-01-05 3507.31           3546.20
2000-01-06 3340.81           3507.31
2000-01-07 3529.60           3340.81
2000-01-10 3717.41           3529.60
2000-01-11 3544.35           3717.41
2000-01-12 3478.14           3544.35
2000-01-13 3612.08           3478.14
2000-01-14 3704.74           3612.08
```

Motivation

Extend along daily grid (via empty “zoo” series):

```
R> td <- seq(from = start(ndx2), to = end(ndx2), by = "day")
R> td
```

```
 [1] "2000-01-03" "2000-01-04" "2000-01-05" "2000-01-06"
 [5] "2000-01-07" "2000-01-08" "2000-01-09" "2000-01-10"
 [9] "2000-01-11" "2000-01-12" "2000-01-13" "2000-01-14"
```

```
R> ndx2 <- merge(zoo(, td), ndx2)
R> ndx2
```

```
2000-01-03 2000-01-04 2000-01-05 2000-01-06 2000-01-07
   3790.55    3546.20    3507.31    3340.81    3529.60
2000-01-08 2000-01-09 2000-01-10 2000-01-11 2000-01-12
        NA         NA    3717.41    3544.35    3478.14
2000-01-13 2000-01-14
   3612.08    3704.74
```

Motivation

Various strategies for dealing with NAs: linear interpolation, last observation carried forward.

```
R> merge(ndx2, na.approx(ndx2), na.locf(ndx2))
```

```
              ndx2 na.approx(ndx2) na.locf(ndx2)
2000-01-03 3790.55         3790.55       3790.55
2000-01-04 3546.20         3546.20       3546.20
2000-01-05 3507.31         3507.31       3507.31
2000-01-06 3340.81         3340.81       3340.81
2000-01-07 3529.60         3529.60       3529.60
2000-01-08      NA         3592.20       3529.60
2000-01-09      NA         3654.81       3529.60
2000-01-10 3717.41         3717.41       3717.41
2000-01-11 3544.35         3544.35       3544.35
2000-01-12 3478.14         3478.14       3478.14
2000-01-13 3612.08         3612.08       3612.08
2000-01-14 3704.74         3704.74       3704.74
```

Furthermore: `na.omit()`.

Motivation

Compress to weekly data:

```
R> to_monday <- function(x)
+    7 * ceiling(as.numeric(x - 3)/7) + as.Date(-3)
R> ndx_d <- aggregate(ndx, to_monday, tail, 1)
R> head(ndx_d, 10)
```

```
1995-01-02 1995-01-09 1995-01-16 1995-01-23 1995-01-30
    401.59     410.48     410.13     407.22     416.14
1995-02-06 1995-02-13 1995-02-20 1995-02-27 1995-03-06
    430.77     425.66     428.42     436.68     441.76
```

This exploits that the origin (1970-01-01, `as.Date(0)`) is a Thursday.

Compress to monthly data:

```
R> ndx_m <- aggregate(ndx, as.yearmon, mean)
R> head(ndx_m, 10)
```

```
Jan 1995 Feb 1995 Mar 1995 Apr 1995 May 1995 Jun 1995 Jul 1995
 408.007  425.107  444.035  453.099  484.352  517.553  567.712
Aug 1995 Sep 1995 Oct 1995
 575.515  594.547  579.728
```

Time, Date, and Time Series Classes

Times and Dates

Times and dates

In finance, business and economics, time-annotated data is ubiquitous. Therefore, a fundamental building block for more complex structures in finance/business/economics are times and dates.

In (macro-)economics, the most important types of times are/were years, quarters and months.

In finance, required times are more often at daily or intra-day level.

Times and dates: Data structures

Base R as well as various packages provide

Classes: Implementations of time/date objects that capture all necessary information of underlying conceptual entities.

Methods: Computations and extraction of relevant information.

Note: In principle, use of documented methods is preferred but sometimes knowledge about the internal structure is very useful.

Times and dates: Data structures

Typical actions and operations:

- set up time from numeric or character input,
- extract underlying numeric scale,
- produce character label,

- use for plotting,
- sequences of times with given spacing,
- time differences,
- move forward/backward on time scale,
- comparison (less/greater).

Times and dates: Data structures

Typical actions and operations (and R functions/generics):

- set up time from numeric or character input: class constructors,
- extract underlying numeric scale: `as.numeric()` method,
- produce character label:
  `format()` and `as.character()` method,
- use for plotting: input for `plot()`, e.g., `Axis()` method,
- sequences of times with given spacing: `seq()` method,
- time differences: group generic functions or `difftime()`,
- move forward/backward on time scale: group generic functions,
- comparison (less/greater): group generic functions.

Time: Years

Example: 1997, 1998, 2002, 2004, . . .

Class: "`numeric`" or (even better) "`integer`"

```
R> ty <- c(1997, 1998, 2002, 2004)
R> ty

[1] 1997 1998 2002 2004

R> as.character(ty)

[1] "1997" "1998" "2002" "2004"

R> ty[2] - ty[1]

[1] 1

R> ty + 1

[1] 1998 1999 2003 2005
```

Time: Quarters

Example: 2000 Q1, 2001 Q3, 2002 Q2, 2002 Q3, ...

Class: "`numeric`" (first attempt)

```
R> tq <- c(2000, 2001.5, 2002.25, 2002.5)
R> tq

[1] 2000.00 2001.50 2002.25 2002.50

R> tq[2] - tq[1]

[1] 1.5

R> tq + 1/4

[1] 2000.25 2001.75 2002.50 2002.75

R> as.character(tq)

[1] "2000"    "2001.5"  "2002.25" "2002.5"
```

Time: Quarters

Example: 2000 Q1, 2001 Q3, 2002 Q2, 2002 Q3, ...

Class: “`yearqtr`” (improved)

```
R> tq <- as.yearqtr(tq)
R> as.character(tq)

[1] "2000 Q1" "2001 Q3" "2002 Q2" "2002 Q3"

R> as.numeric(tq)

[1] 2000.00 2001.50 2002.25 2002.50

R> tq[2] - tq[1]

[1] 1.5

R> tq + 1/4

[1] "2000 Q2" "2001 Q4" "2002 Q3" "2002 Q4"
```

Time: Quarters

Idea: "`numeric`" vector with class attribute that handles matching/rounding correctly and provides coercion to many other classes.

Class constructor:

```
yearqtr <- function(x)
  structure(floor(4 * x + .001)/4, class = "yearqtr")
```

provided in package **zoo**.

Time: Months

Example: Jan 2000, Oct 2001, Dec 2001, Aug 2002, ...

Class: "yearmon" (analogous to "yearqtr")

```
R> tm <- yearmon(c(2000, 2001, 2001, 2002) + c(0, 9, 11, 7)/12)
R> tm
```

```
[1] "Jan 2000" "Oct 2001" "Dec 2001" "Aug 2002"
```

```
R> as.yearmon(2000)
```

```
[1] "Jan 2000"
```

```
R> as.yearmon("2000 Jan", format = "%Y %b")
```

```
[1] "Jan 2000"
```

Time: Days

Example: 1970-01-01, 2001-07-12, 2005-03-24, ...

Class: "`Date`" (number of days since 1970-01-01)

```
R> td <- as.Date(c("1970-01-01", "2001-07-12", "2005-03-24"))
R> td
```

```
[1] "1970-01-01" "2001-07-12" "2005-03-24"
```

```
R> as.numeric(td)
```

```
[1]     0 11515 12866
```

```
R> as.character(td)
```

```
[1] "1970-01-01" "2001-07-12" "2005-03-24"
```

Time: Days

```
R> format(as.Date(td), "%B %d, %Y")
[1] "January 01, 1970" "July 12, 2001"    "March 24, 2005"
R> td[2] - td[1]
Time difference of 11515 days
R> td + 1
[1] "1970-01-02" "2001-07-13" "2005-03-25"
R> as.Date(2)
[1] "1970-01-03"
```

Time: Intra-day

Example: 1970-01-01 00:00:00, 2001-07-12 12:23:59, ...

Class: "`chron`" (days since 1970-01-01, without time zone or daylight savings time)

```
R> tc <- chron(c(0, 11515 + 12/24 + 23/1440 + 59/86400))
R> tc
```

```
[1] (01/01/70 00:00:00) (07/12/01 12:23:59)
```

```
R> as.character(tc)
```

```
[1] "(01/01/70 00:00:00)" "(07/12/01 12:23:59)"
```

```
R> as.numeric(tc)
```

```
[1]     0.0 11515.5
```

```
R> paste(format(as.Date(dates(tc))), format(times(tc)%%1))
```

```
[1] "1970-01-01 00:00:00" "2001-07-12 12:23:59"
```

```
R> tc[2] - tc[1]
```

```
Time in days:
[1] 11515.5
```

Time: Intra-day

Example: 1970-01-01 00:00:00 GMT, 2001-07-12 12:23:59 GMT, . . .

Class: “`POSIXct`” (seconds since 1970-01-01, with time zone and daylight savings time)

```
R> tp <- as.POSIXct(c(0, 994940639),
+     origin = "1970-01-01", tz = "GMT")
R> tp
```

```
[1] "1970-01-01 00:00:00 GMT" "2001-07-12 12:23:59 GMT"
```

```
R> as.numeric(tp)
```

```
[1]         0 994940639
```

```
R> as.character(tp)
```

```
[1] "1970-01-01 00:00:00" "2001-07-12 12:23:59"
```

```
R> format(tp, "%B %d, %Y (%H:%M:%S)")
```

```
[1] "January 01, 1970 (00:00:00)" "July 12, 2001 (12:23:59)"
```

```
R> tp[2] - tp[1]
```

```
Time difference of 11515.5 days
```

Times and dates: Coercion

Coercion: conversions between different time/date formats.

```
R> as.Date(tq)
[1] "2000-01-01" "2001-07-01" "2002-04-01" "2002-07-01"
R> as.yearqtr(td)
[1] "1970 Q1" "2001 Q3" "2005 Q1"
R> as.yearmon(tp)
[1] "Jan 1970" "Jul 2001"
R> as.Date(tp)
[1] "1970-01-01" "2001-07-12"
R> as.chron(tp)
[1] (01/01/70 00:00:00) (07/12/01 12:23:59)
```

Times and dates: Coercion

Note: Some care is required when time zones and daylight savings times are involved.

```
R> as.POSIXct(tq)

[1] "2000-01-01 01:00:00 CET"  "2001-07-01 02:00:00 CEST"
[3] "2002-04-01 02:00:00 CEST" "2002-07-01 02:00:00 CEST"

R> as.POSIXct(td)

[1] "1970-01-01 01:00:00 CET"  "2001-07-12 02:00:00 CEST"
[3] "2005-03-24 01:00:00 CET"

R> as.POSIXct(tc)

[1] "1970-01-01 01:00:00 CET"  "2001-07-12 14:23:58 CEST"
```

Times and dates: Coercion

Simpler: When time zones and daylight savings time are not required, all computations can be made simpler by setting the local time zone `TZ` to GMT.

```
R> Sys.setenv(TZ = "GMT")
R> as.POSIXct(tq)
```

```
[1] "2000-01-01 GMT" "2001-07-01 GMT" "2002-04-01 GMT"
[4] "2002-07-01 GMT"
```

```
R> as.POSIXct(td)
```

```
[1] "1970-01-01 GMT" "2001-07-12 GMT" "2005-03-24 GMT"
```

```
R> as.POSIXct(tc)
```

```
[1] "1970-01-01 00:00:00 GMT" "2001-07-12 12:23:58 GMT"
```

Time: Intra-day

Class: “`timeDate`” (built on “`POSIXct`”, internal computations done in GMT, deals with time zones and dayling savings times via *financial centers*)

```
R> timeDate(tp)

GMT
[1] [1970-01-01 00:00:00] [2001-07-12 12:23:59]

R> timeDate(tp, FinCenter = "Zurich")

Zurich
[1] [1970-01-01 01:00:00] [2001-07-12 14:23:59]

R> timeDate(tp, FinCenter = "NewYork")

NewYork
[1] [1969-12-31 19:00:00] [2001-07-12 08:23:59]
```

Times and dates: Summary

Classes:

- "`numeric`"/"`integer`" (**base**): annual/quarterly/monthly.
- "`yearqtr`"/"`yearmon`" (**zoo**): quarterly/monthly.
- "`Date`" (**base**): daily.
- "`chron`" (**chron**): intra-day. No time zones, daylight savings time. Slightly non-standard interface.
- "`POSIXct`" (**base**): intra-day. With time zones, daylight savings time. Computations in GMT are straightforward. Other time zones might require some more attention.
- "`timeDate`" (**timeDate**): intra-day. With time zones, daylight savings time via concept of financial centers.

Recommendation: Use time/date class that is appropriate for your data (and not more complex). See Grothendieck and Petzoldt (2004).

Time, Date, and Time Series Classes

Time Series

Time series: Structure

Time/date objects are usually not interesting as standalone objects but are used to annotate other data.

The most important application of this are *time series* where there is for each time point a vector of (typically numeric) observations.

The observations are most easily arranged in a vector (of length n) or an $n \times k$ matrix whose elements are ordered and indexed by n different times/dates.

Time series: Structure

Types of time series:

- *irregular* (unequally spaced),
- strictly *regular* (equally spaced),
- or have an underlying regularity, i.e., be created from a regular series by omitting some observations.

For strictly regular series: the whole time index can be reconstructed from start, end and time difference between two observations. The reciprocal value of the time difference is also called *frequency*.

For irregular series: all time indexes need to be stored in a vector of length n.

Time series: Implementations

There are many implementations for time series data in R.

Virtually all of them are focused on numeric data and fix some particular class for the time index. The most important are:

- "`ts`" (**base**): regular "`numeric`" time index (e.g., annual, quarterly, monthly),
- "`its`" (**its**): irregular time index of class "`POSIXct`",
- "`irts`" (**tseries**): irregular time index of class "`POSIXct`",
- "`timeSeries`" (**timeSeries**): irregular time index of class "`timeDate`",
- "`zoo`" (**zoo**): regular or irregular time index of arbitrary class.
- "`xts`" (**xts**): built on top of "`zoo`", with specialized infrastructure for time indexes of class "`Date`", "`POSIXct`", "`chron`", "`timeDate`", "`yearmon`", "`yearqtr`", ...

Time series: Implementations

Advantages of "`zoo`":

- Can be used with arbitrary time indexes (i.e., you could also provide your own specialized class).
- Standard interface: employs R's standard methods and introduces only few new generics.
- Talks to all other classes: coercion functions are available, e.g., `as.ts()`, `as.timeSeries()`, etc. that work if the time index is of the required class. The reverse `as.zoo()` always works.

Recommendations:

- Use "`zoo`" for storage and basic computations.
- If necessary, coerce to other classes for analysis etc.
- "`xts`" is helpful extension of "`zoo`" for date/time indexes.

Time series: Operations

Typical operations for time series:

- visualization,
- extraction of observations or associated times,

- lags and differences,
- subsets in a certain time window,
- union and intersection of several time series,
- aggregation along a coarser time grid,
- rolling computations such as means or standard deviations.

Time series: Operations

Typical operations for time series (and suitable R generics):

- visualization: `plot()`,
- extraction of observations or associated times: `time()` (and `coredata()`),
- lags and differences: `lag()` and `diff()`,
- subsets in a certain time window: `window()`,
- union and intersection of several time series: `merge()`,
- aggregation along a coarser time grid: `aggregate()`,
- rolling computations such as means or standard deviations: (`rollapply()`).

Time series: Implementations

How do arbitrary time indexes in "`zoo`" work?

To provide the desired functionality, few actions are required:

- ordering,
- matching,
- combining,
- subsetting,
- querying length *n*.

Time series: Implementations

How do arbitrary time indexes in "`zoo`" work?

To provide the desired functionality, few actions are required:

- ordering: `ORDER()` (by default calling the non-generic `order()`),
- matching: `MATCH()` (by default calling the non-generic `match()`),
- combining: `c()`,
- subsetting: `[`,
- querying length *n*: `length()`.

Time series: Implementations

If suitable methods are available for the chosen time index (including all time/date classes above), all tasks (merging, aggregating, etc.) can be performed without any knowledge about the particular time index class.

For some special operations, further methods are useful/necessary, e.g., `axis()`/`Axis()`, `as.numeric()`, `as.character()`.

If the time index is of a particular class, coercions to and from other time series classes can be easily provided.

References

Grothendieck G, Petzoldt T (2004). “R Help Desk: Date and Time Classes in R.” *R News*, **4**(1), 29–32.

Ripley BD, Hornik K (2001). “Date-Time Classes.” *R News*, **1**(2), 8–11.

Shah A, Zeileis A, Grothendieck G (2015). “**zoo** Quick Reference.” Package vignette. Version 1.7-12.

Zeileis A, Grothendieck G (2005). “**zoo**: S3 Infrastructure for Regular and Irregular Time Series.” *Journal of Statistical Software*, **14**(6), 1–27. `doi:10.18637/jss.v014.i06`. Updated version contained as vignette in **zoo** package.