Portfolio Management with R

Enrico Schumann

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Contents

1 Introduction

1.1 About PMwR

This manual describes how to use the PMwR package. The aim of PMwR is to provide a small set of reliable, efficient and convenient tools that help in processing and analysing trade and portfolio data. The package does not provide a complete application that could be used 'as is'; the package provides building blocks for creating such an application.

PMwR grew out of various pieces of software that I have written since 2008, first at the University of Geneva, later during my work at financial firms.

The package is currently under development and changes frequently. This is mainly because the code has been written over many years and is in need of being groomed for general use.

Consequently, this manual is only a draft, and it will change as frequently as the package.[1] I am grateful for comments and suggestions.

The latest version of the package is available from `http://enricoschumann.net/R/packages/PMwR/index.htm`. To install the package from within R, type

```
install.packages("PMwR",
                 type  = "source",
                 repos = c('http://enricoschumann.net/R',
                           getOption('repos')))
```

to download and install it. The package depends on several other packages, which are automatically obtained from the same repository and from CRAN. The source code is also pushed to a public repository at `https://github.com/enricoschumann/PMwR`.

There is currently no automatic build process for Windows. Recent versions of the package (since `0.3-4`) are pure R code and can be built without any prerequisites except an R installation; older version contained C code, so you needed to have Rtools installed. If you have problems building the package for Windows, please contact me and I will provide you with a Windows version.

1.2 Other packages

Several other packages originated from PMwR (in older versions, much of their code had been part of PMwR).

[1] The manual itself is written in Org mode. The complete tangled code is available from the website.

datetimeutils tools for handling `Date` and `POSIXct` objects

`https://github.com/enricoschumann/datetimeutils`

`http://enricoschumann.net/R/packages/datetimeutils/`

textutils string handling for reporting (plain text, HTML, LaTeX)

`https://github.com/enricoschumann/textutils`

`http://enricoschumann.net/R/packages/textutils`

tsdb terribly-simple database for time series

2 Keeping track of transactions: journals

The ultimate basis of many financial computations are lists of transactions. And so many of the tools that the PMWR package provides take lists of transactions as input.

Conceptually, you can think of such lists as dataframes, but PMWR provides an S3 class `journal` for handling them.

A `journal` is a list of atomic vectors, to which a class attribute is attached. Such a list is created through the function `journal`. Methods should not rely on this list being sorted in any particular way: components of a journal should always be retrieved by name, never by position. (In this respect a journal differs from a dataframe, for which we can meaningfully refer to the *n*-th column.) I will call these journal components, such as `amount` or `timestamp`, fields.

The simplicity of the class is intended, because it is meant for interactive analyses. The user may – and is expected to – dissect the information in a `journal` at will; such dissections include removing the class attribute.

What is actually stored in a `journal` is up to the user. A number of fields are, however, required for certain operations and so it is recommended that they be present:

`amount` The notional amount that is transacted. `amount` is, in a way, the most important property of a journal. When functions compute something from the journal (the number of transactions, say), they will look at `amount`.

`timestamp` When did the transaction take place? A numeric or character vector; should be sortable.

`price` Well, price.

`instrument` Description of the financial instrument; typically an identifier, a.k.a. ticker or symbol. That is, a string, not really a more complex object (recall that journals are lists of atomic vectors).

`id` A (possibly but not necessarily unique) transaction identifier.

`account` Description of the account.

`...` other fields. They must be named, as in `fees = c(1,2,1)`

All fields except `amount` can be missing. Such missing values will be 'added back' as `NA` with the exception of `id` and `account`, which will be `NULL`. (Note that `amount` could

be a vector with only NA values in it, but amount cannot be left out when the journal is created. This will become clearer with the examples below.) Note that when a journal has no transactions in it (which may be the case), this does not mean it has missing values. In such a case, all fields have length zero, e.g. amount would be numeric(0) and so on. Such empty journals may be created by saying journal() or by coercing a zero-row data.frame to a journal, via a call to as.journal.

Transactions in a journal can conceptually be organised in hierachies, such as *account => instrument*. (You may have traded stock XY for several different accounts, or as part of different strategies.) A simple scheme is to use specific characters or a pattern such as :: to introduce hierarchies into accounts,[1] such as pension::equities.

2.1 Creating and combining journals

The function journal creates journal objects. For details about the function and methods for journal objects, see ?journal.

At its very minimum, a journal must contain amounts of something.

```
jnl <- journal(amount = c(1, 2, -2, 3))
jnl
```

```
   amount
1       1
2       2
3      -2
4       3

4 transactions
```

Actually, that is not true. On occasion it is useful to create an empty journal, one with no entries at all. You can do this by saying journal(), without any arguments.

```
journal()
```

```
no transactions
```

To see the current balance, which is nothing more than the sum over all amounts, you can use position.

```
position(jnl)
```

```
     [,1]
[1,]    4
```

[1] This notation is inspired by the syntax of ledger files. See http://www.ledger-cli.org/ .

Only providing amounts is, admittedly, not overly useful. You can keep track of positions, true; but a journal implies chronological information, that is, flows. (As opposed to a ledger, which gives you positions, or stocks.)

When you make sure that the amounts are actually sorted in time, then you can at least track positions over time. (But nothing in the data structure that we created above could make sure that transactions really are sorted.)

Suppose you wanted to note how many bottles of milk and wine you have stored in your basement. Whenever you add to your storage, you have a positive amount; whenever you retrieve bottles, you have a negative amount. Then, by keeping track of transactions, you may not have to take stock (apart, perhaps, from occasional checking that you did not miss a transaction), as long as you keep track of what you put into your cellar and what you take out.

There may be some analyses you can do on flows alone (without any information): perhaps checking your drinking habits for patterns, such as slow accumulation of wine, followed by rapid consumption; or the other way around.

But typically, the more information you store about transactions (when, what, at what price, etc.), the better. Journals allow you to store such information. To show how they are used, let us switch to a financial example.

```
J <- journal(timestamp  = as.Date("2012-01-01") + 0:3,
             amount     = c(1, 2, -2, 5),
             instrument = c("EUR", "EUR", "CHF", "CHF"),
             comment    = c("initial balance", "",
                            "transfer", ""))
J
```

```
   instrument   timestamp  amount          comment
1         EUR  2012-01-01       1  initial balance
2         EUR  2012-01-02       2
3         CHF  2012-01-03      -2         transfer
4         CHF  2012-01-04       5

4 transactions
```

A `print` method defines how a journal is displayed. See `?print.journal` for details. (In general, you can always get help for methods for generic functions by saying `?function_name.journal`, e.g. `?print.journal` or `?as.data.frame.journal`.)

```
print(J, max.print = 2, exclude = "instrument")
```

```
    timestamp  amount          comment
1  2012-01-01       1  initial balance
2  2012-01-02       2
[ .... ]

4 transactions
```

A str method shows the fields in the journal.

```
str(J)
```

```
'journal':       4 transactions
 $ instrument: chr [1:4] "EUR" "EUR" "CHF" "CHF"
 $ timestamp : Date[1:4], format: "2012-01-01" "2012-01-02" ...
 $ amount    : num [1:4] 1 2 -2 5
 $ price     : logi [1:4] NA NA NA NA
 $ comment   : chr [1:4] "initial balance" "" "transfer" ""
```

You may notice that the output is similar to that of a data.frame or list. That is because J is a list internally, with a class attribute. Essentially, it is little more than that:

```
list(timestamp  = as.Date("2012-01-01") + 0:3,
     amount     = c(1, 2, -2, 5),
     instrument = c("EUR", "EUR", "CHF", "CHF"),
     comment    = c("initial balance", "", "transfer", ""))
```

(But note that journal silently added a price field, even though we did not specify one.)

In the example, the timestamps are of class Date. But essentially, any vector of mode character or numeric can be used, for instance POSIXct, or other classes. Here is an example that uses the nanotime package (Eddelbuettel, 2017).

```
require("nanotime")
journal(amount = 1:3,
        timestamp = nanotime(Sys.time()) + 1:3)
```

```
                              timestamp  amount
1  2017-01-23T08:10:25.404530001+00:00       1
2  2017-01-23T08:10:25.404530002+00:00       2
3  2017-01-23T08:10:25.404530003+00:00       3

3 transactions
```

Journals can be combined with c.

```
J2 <- J
J2$fees <- rep(0.1,4)
c(J, J2)
```

```
   instrument   timestamp  amount          comment  fees
1         EUR  2012-01-01       1  initial balance    NA
2         EUR  2012-01-02       2                     NA
3         CHF  2012-01-03      -2         transfer    NA
4         CHF  2012-01-04       5                     NA
```

```
5          EUR   2012-01-01        1   initial balance    0.1
6          EUR   2012-01-02        2                      0.1
7          CHF   2012-01-03       -2          transfer    0.1
8          CHF   2012-01-04        5                      0.1

8 transactions
```

But we wanted the combined journal sorted by date.

```
sort(c(J, J2))
```

```
   instrument    timestamp  amount           comment  fees
1          EUR   2012-01-01        1   initial balance    NA
2          EUR   2012-01-01        1   initial balance   0.1
3          EUR   2012-01-02        2                     NA
4          EUR   2012-01-02        2                     0.1
5          CHF   2012-01-03       -2          transfer    NA
6          CHF   2012-01-03       -2          transfer   0.1
7          CHF   2012-01-04        5                     NA
8          CHF   2012-01-04        5                     0.1

8 transactions
```

We can also sort by some other field, such as amount.

```
sort(c(J, J2), by = "amount", decreasing = TRUE)
```

```
   instrument    timestamp  amount           comment  fees
1          CHF   2012-01-04        5                     NA
2          CHF   2012-01-04        5                     0.1
3          EUR   2012-01-02        2                     NA
4          EUR   2012-01-02        2                     0.1
5          EUR   2012-01-01        1   initial balance    NA
6          EUR   2012-01-01        1   initial balance   0.1
7          CHF   2012-01-03       -2          transfer    NA
8          CHF   2012-01-03       -2          transfer   0.1

8 transactions
```

2.2 Selecting transactions

In an interactive session, you can use `subset` to select particular transactions.

```
subset(J, amount > 1)
```

```
   instrument   timestamp  amount  comment
1         EUR  2012-01-02       2
2         CHF  2012-01-04       5

2 transactions
```

With `subset`, you need not quote the expression that selects trades and you can directly access a journal's fields. Because of the way `subset` evaluates its arguments, it should not be used within functions. (See the Examples section in `?journal` for what can happen then.)

More generally, to extract or change a field, use its name, either through the `$` operator or double brackets `[[...]]`.[2]

```
J$amount
```

```
[1]  1  2 -2  5
```

You can also replace specific fields.

```
J[["amount"]] <- c(1 ,2, -2, 8)
J
```

```
   instrument   timestamp  amount          comment
1         EUR  2012-01-01       1  initial balance
2         EUR  2012-01-02       2
3         CHF  2012-01-03      -2         transfer
4         CHF  2012-01-04       8

4 transactions
```

The `` `[` `` method works with integers or logicals, returning the respective transactions.

```
J[2:3]
```

```
   instrument   timestamp  amount   comment
1         EUR  2012-01-02       2
2         CHF  2012-01-03      -2  transfer

2 transactions
```

```
J[J$amount < 0]
```

[2] The behaviour of '[[' may change in the future: it may then be used to iterate over the transactions in a journal, not the fields. This would be motivated by `https://developer.r-project.org/blosxom.cgi/R-devel/NEWS/2016/03/09` even though the commit was reversed two days later `https://developer.r-project.org/blosxom.cgi/R-devel/NEWS/2016/03/11`

```
   instrument   timestamp  amount   comment
1         CHF  2012-01-03      -2  transfer

1 transaction
```

You can also pass a string, which is then interpreted as a regular expression that is matched against all character fields in the journal.

```
J["eur"]
```

```
   instrument   timestamp  amount          comment
1         EUR  2012-01-01       1  initial balance
2         EUR  2012-01-02       2

2 transactions
```

By default, case is ignored, but you can set `ignore.case` to `FALSE`.

```
J["Transfer"]
```

```
   instrument   timestamp  amount   comment
1         CHF  2012-01-03      -2  transfer

1 transaction
```

```
J["Transfer", ignore.case = FALSE]
```

```
no transactions
```

You can also specify the fields to match the string against.

```
J["Transfer", match.against = "instrument"]
```

```
no transactions
```

2.3 Computing balances

The function `position` gives the current balance of all instruments.

```
position(J)
```

```
    2012-01-04
CHF          6
EUR          3
```

To get the position at a specific date, use the `when` argument.

```
position(J, when = as.Date("2012-01-03"))
```

```
    2012-01-03
CHF          -2
EUR           3
```

If you do not like such a tabular view, consider splitting the journal.

```
lapply(split(J, J$instrument),
       position, when = as.Date("2012-01-03"))
```

```
 $CHF
    2012-01-03
CHF          -2

$EUR
    2012-01-03
EUR           3
```

To get a time series of positions, you can use specific keywords for `when`: `all` will print the position at all timestamps in the journal.

```
position(J, when = "all")
```

```
           CHF EUR
2012-01-01   0   1
2012-01-02   0   3
2012-01-03  -2   3
2012-01-04   3   3
```

Keywords `first` and `last` give you the first and last position. (The latter is the default; so if `when` is not specified at all, the last position is computed.) `endofmonth` prints the positions at the ends of all calendar months between the first and the last timestamp.

We are not limited to the timestamps that exist in the journal.

```
position(J, when = seq(from = as.Date("2011-12-30"),
                       to = as.Date("2012-01-06"),
                       by = "1 day"))
```

```
           CHF EUR
2011-12-30   0   0
2011-12-31   0   0
2012-01-01   0   1
2012-01-02   0   3
2012-01-03  -2   3
2012-01-04   6   3
2012-01-05   6   3
2012-01-06   6   3
```

By default, position will show you all positions, even if they are zero.

```
J <- c(J, journal(instrument = "EUR",
                  amount = -3,
                  timestamp = as.Date("2012-01-05")))
position(J)
```

```
    2012-01-05
CHF          6
EUR          0
```

You can suppress such positions with drop.zero.

```
position(J, drop.zero = TRUE)
```

```
    2012-01-05
CHF          6
```

drop.zero can also be a tolerance, which is useful in cases such as this one:

```
J <- c(J, journal(instrument = "USD",
                  timestamp  = as.Date("2012-01-05"),
                  amount     = c(0.1, 0.1, 0.1, -0.3)))
position(J, drop.zero = TRUE)
```

```
    2012-01-05
CHF   6.00e+00
USD   2.78e-17
```

```
position(J, drop.zero = 1e-15)
```

```
    2012-01-05
CHF          6
```

2.4 Aggregating journal information

A straightforward strategy is to call as.data.frame on a journal and then to use aggregate on the resulting data.frame.

The downside to this approach is that in aggregate.data.frame, you cannot address specific columns of the data.frame. So PMwR provides an aggregate.journal method that allows you to do that.

The by argument can be a list (as in the default method) or an atomic vector. The latter will be placed into a list automatically: this is useful for cases such as when by is format(j$timestamp, "%Y-%m").

FUN can either be a function or list. If it is function, it should expect to receive a journal and also evaluate to a journal. An example: given a journal jnl, compute monthly turnover (two-way).

```
aggregate(jnl,
          by  = format(jnl$timestamp, "%Y-%m"),
          FUN = function(j)
                    journal(timestamp = unique(j$timestamp),
                            amount = sum(abs(j$amount))))
```

FUN can also be list. In this case, the elements of the list should be named functions.

```
jnl <- journal(instrument = c("A", "B", "A", "B"),
               price  = c(100, 102, 105, 109),
               amount = c(  1,   1,   3,   1))
aggregate(jnl,
          by = jnl$instrument,
          FUN = list(instrument = unique,
                     price = min,
                     amount = sum))
```

```
   instrument  amount  price
1           A       4    100
2           B       2    102

2 transactions
```

Note that aggregate.journal always returns a journal, which may not be appropriate. Instead, you may also use tapply, which is more flexible.

```
tapply(jnl, jnl$instrument,
       function(x)
           data.frame(min_price = min(x$price),
                      amount_traded = sum(x$amount)))
```

```
$A
  min_price amount_traded
1       100             4

$B
  min_price amount_traded
1       102             2
```

2.4.1 Aggregate executions by day

Suppose we have the following trades, collect in a journal j.

```
    instrument   timestamp  amount  price
1            B  2013-09-02      -3    104
2            B  2013-09-03      -4    102
3            A  2013-09-02      -3    102
4            A  2013-09-03      -1    110
5            B  2013-09-02       3    106
6            B  2013-09-02      -2    104
7            A  2013-09-03       1    104
8            B  2013-09-03       3    106
9            A  2013-09-03       5    108
10           A  2013-09-03       3    107

10 transactions
```

```
by <- list(j$instrument, sign(j$amount), as.Date(j$timestamp))
fun <- function(x) {
    journal(timestamp = as.Date(x$timestamp[1]),
            amount = sum(x$amount),
            price = sum(x$amount*x$price)/sum(x$amount),
            instrument = x$instrument[1L])
}
aggregate(j, by = by, FUN = fun)
```

```
   instrument   timestamp  amount     price
1           A  2013-09-02      -3  102.0000
2           B  2013-09-02      -5  104.0000
3           B  2013-09-02       3  106.0000
4           A  2013-09-03      -1  110.0000
5           B  2013-09-03      -4  102.0000
6           A  2013-09-03       9  107.2222
7           B  2013-09-03       3  106.0000

7 transactions
```

3 Computing profit and loss

In this chapter we will deal with computing profit and loss in currency units. If you are interested in computing returns, see Computing returns.

3.1 Simple cases

We buy one unit of an asset at a price of 100 euro and we sell it for 102 euro. We have made a profit of 2 euros. This simple case is frequent enough that we should make the required computation simple as well. The PMWR package provides a function `pl`, which for this case may be called like as follows.

```
pl(price  = c(100, 102),
   amount = c(1, -1))
```

```
P/L total       2
average buy   100
average sell  102
volume          2

'P/L total' is in units of instrument;
'volume' is sum of /absolute/ amounts.
```

In principle, P/L is straightforward to compute: let x be a vector of the absolute amounts traded, and p be a vector of the prices at which we traded, then P/L is just the difference between what we gained from selling and what we paid when buying.

$$x_i^{\text{sell}} p_i^{\text{sell}} - x_i^{\text{buy}} p_i^{\text{buy}} \tag{3.1}$$

This can be simplified when we impose the convention that sold amounts are negative.

$$\begin{aligned} \text{P/L} &= -\sum_{x<0} x_i p_i - \sum_{x>0} x_i p_i && (3.2) \\ &= -\sum x_i p_i && (3.3) \end{aligned}$$

The function `pl` also follows this convention: note that in the code example above we had $x = [1, -1]'$.

There are many ways to compute PL.

```
amount <- rep(c(-100,100), 10)
price <- rep(100, length(amount))
```

```
amount %*% price
sum(amount*price)
crossprod(amount, price)
t(amount*price) %*% rep(1, length(amount))

require("rbenchmark")
benchmark(
    amount %*% price,
    sum(amount*price),
    crossprod(amount, price),
    t(amount*price) %*% rep(1, length(amount)),
    columns = c("test",    "elapsed", "relative"),
    order = "relative",
    replications = 10000)
```

You will see shortly that `pl` also accepts an argument `instrument`, in which case P/L will be split by instrument. But if you only care about total P/L, you can do it in one computation. As an example, suppose we traded shares of Adidas (ticker ADS) and Commerzbank (ticker CBK), two German companies.

```
pl(amount     = c(   50,   -50,   500,  -500),
   price      = c(  100,   102,     7,     8),
   instrument = c("ADS", "ADS", "CBK", "CBK"))
```

```
ADS
  P/L total     100
  average buy   100
  average sell  102
  volume        100

CBK
  P/L total     500
  average buy     7
  average sell    8
  volume       1000

'P/L total' is in units of instrument;
'volume' is sum of /absolute/ amounts.
```

Since the shares are denominated in the same currency (EUR) and have the same multiplier (1), total profit is the same when you leave out the tickers, though average buying and selling price become less meaningful.

```
pl(amount     = c(   50,   -50,   500,  -500),
   price      = c(  100,   102,     7,     8))
```

```
P/L total      600
average buy   15.5
```

```
average sell   16.5
volume         1100

'P/L total' is in units of instrument;
'volume' is sum of /absolute/ amounts.
```

If multipliers are not the same, you need to specify them. Suppose we have traded FGBL (German Bund futures) and FESX (EURO STOXX 50 futures).

```
jnl <- read.table(textConnection(
"instrument, price, amount
 FGBL MAR 16, 165.20,  1
 FGBL MAR 16, 165.37, -1
 FGBL JUN 16, 164.12,  1
 FGBL JUN 16, 164.13, -1
 FESX JUN 16,   2910,  5
 FESX JUN 16,   2905, -5"
), header = TRUE, stringsAsFactors = FALSE, sep = ",")

jnl <- as.journal(jnl)
jnl
```

```
     instrument  amount  price
1   FGBL MAR 16       1    165
2   FGBL MAR 16      -1    165
3   FGBL JUN 16       1    164
4   FGBL JUN 16      -1    164
5   FESX JUN 16       5   2910
6   FESX JUN 16      -5   2905

6 transactions
```

One point of the FGBL means 1000 euros; for the FESX it is 10 euros.

```
pl(jnl,
   multiplier = c("FGBL" = 1000, "FESX" = 10),
   multiplier.regexp = TRUE)
```

```
 FESX JUN 16
  P/L total     -250
  average buy   2910
  average sell  2905
  volume          10

 FGBL JUN 16
  P/L total      10
  average buy   164
  average sell  164
  volume          2
```

```
 FGBL MAR 16
  P/L total     170
  average buy   165
  average sell  165
  volume          2

'P/L total' is in units of instrument;
'volume' is sum of /absolute/ amounts.
```

In the examples above, we computed *total* P/L. As another example, suppose that a stock trader bought one share at 50, one share at 90 and sold two shares at 100. These trades resulted in a profit of 60, or an average return of more than +40% (bought at 70, sold at 100).

```
jnl <- journal(price  = c( 90, 50, 100),
               amount = c(  1,  1,  -2))
pl(jnl)
```

```
P/L total      60
average buy    70
average sell  100
volume          4

'P/L total' is in units of instrument;
'volume' is sum of /absolute/ amounts.
```

That may appear like some pretty good trading. Yet suppose that the order of the trades was

```
buy at 90  =>  buy at 50  =>  sell at 100.
```

You may have noticed that the `journal` that we created above already has the trades ordered this way. We may not know what was traded and when, but there is clearly some information in the order of the trades and the drawdown that it implies: namely a drawdown (mark-to-market loss) of at least 40 before it recovered. For situations like this, the argument `along.timestamp` can be used.

```
pl(jnl, along.timestamp = TRUE)
```

```
P/L total       0 -40  60
__ realised     0   0  60
__ unrealised   0 -40   0
average buy    70
average sell  100
volume          1   2   4

'P/L total' is in units of instrument;
'volume' is sum of /absolute/ amounts.
```

Note that we do not provide an actual timestamp, in which case the function will implicitly use integers `1`, `2`, ..., `length(amount)`. With no further arguments, as here, the function will compute the running position and evaluate it at every trade with the trade's price. This may not be totally accurate because of bid–ask spreads or other transaction costs. But it provides more information than only computing the aggregate P/L for the trades.

At this point, it may be helpful to describe how we can access these data. The function `pl` always returns a list of lists – one list for each instrument. Actually, we have not yet called `pl` for more than one instrument, so let us do that first, to have a concrete example.

```
jnl <- journal(price = c(100, 102, 5, 4),
               amount = c(1, -1,  20, -20),
               instrument = c("Equity A", "Equity A",
                              "Equity B", "Equity B"))
pl(jnl)
```

```
Equity A
  P/L total       2
  average buy   100
  average sell  102
  volume          2

Equity B
  P/L total     -20
  average buy     5
  average sell    4
  volume         40

'P/L total' is in units of instrument;
'volume' is sum of /absolute/ amounts.
```

It is often more convenient to have the data presented as a table.

```
as.data.frame(pl(jnl))
```

```
          pl buy sell volume
Equity A   2 100  102      2
Equity B -20   5    4     40
```

Or if you like ASCII tables, with `toOrg`.

```
require("orgutils")
toOrg(as.data.frame(pl(jnl)), row.names = "instrument")
```

```
| instrument |  pl | buy | sell | volume |
|------------+-----+-----+------+--------|
| Equity A   |   2 | 100 |  102 |      2 |
| Equity B   | -20 |   5 |    4 |     40 |
```

In any case, as I said, `pl` returns a list of lists.

```
str(pl(jnl))
```

```
List of 2
 $ Equity A:List of 6
  ..$ pl         : num 2
  ..$ realised   : logi NA
  ..$ unrealised: logi NA
  ..$ buy        : num 100
  ..$ sell       : num 102
  ..$ volume     : num 2
 $ Equity B:List of 6
  ..$ pl         : num -20
  ..$ realised   : logi NA
  ..$ unrealised: logi NA
  ..$ buy        : num 5
  ..$ sell       : num 4
  ..$ volume     : num 40
 - attr(*, "class")= chr "pl"
 - attr(*, "along.timestamp")= logi FALSE
 - attr(*, "instrument")= chr [1:2] "Equity A" "Equity B"
```

Each such list contains numeric vectors: 'pl', 'realised', 'unrealised', 'buy', 'sell', 'volume'. Data can be extracted by standard methods. The vectors 'realised' and 'unrealised' will be `NA` unless `along.timestamp` is `TRUE`.

```
unlist(pl(jnl)[["Equity A"]])
```

```
pl   realised unrealised        buy       sell     volume
 2         NA         NA        100        102          2
```

```
unlist(lapply(pl(jnl), `[[`, "volume"))
```

```
Equity A Equity B
       2       40
```

(You may prefer `sapply(...)` instead of `unlist(lapply(...))`.)

Back to use cases for `pl`. We can also use the function for a journal in which some positions not closed yet. The simplest example is a journal of just one trade.

```
pl(journal(amount = 1, price = 100))
```

```
P/L total       .
average buy   100
average sell    .
volume          1
```

```
'P/L total' is in units of instrument;
'volume' is sum of /absolute/ amounts.

Warning message:
In pl.default(amount, price, timestamp,
              instrument, multiplier = multiplier,  :
  'sum(amount)' is not zero: specify 'vprice' to compute p/l
```

The warning message that is thrown already tells us what to do: to close the position – only for the purpose of computing P/L; no trade really takes place –, specify `vprice`.

```
pl(journal(amount = 1, price = 100), vprice = 101)
```

```
P/L total       1
average buy   100
average sell  101
volume          1

'P/L total' is in units of instrument;
'volume' is sum of /absolute/ amounts.
```

Note that `average sell` reflects the specified valuation price. But `volume` has remained 1 since only 1 unit was actually traded.

A quite common task is to compute P/L over a specified period of time such as one trading day. Suppose yesterday, at market close, we had the following positions.

```
open_position <- c(fesx201603 = -20, fgbl201603 = 10)
prices <- c(fesx201603 = 2930, fgbl201603 = 165.23)
```

Trading just ended, and we have done the following trades.

```
jnl <- journal(amount = c(2,-3,-10),
               price = c(2910,2938,165.80),
               instrument = c("fesx201603", "fesx201603",
                              "fgbl201603"))
jnl
```

```
   instrument  amount  price
1  fesx201603       2   2910
2  fesx201603      -3   2938
3  fgbl201603     -10    166

3 transactions
```

```
pl(jnl, initial.position = open_position, initial.price = prices,
   vprice = c(fesx201603 = 2902, fgbl201603 = 165.60))
```

```
fesx201603
  P/L total      652
  average buy   2903
  average sell  2931
  volume           5

fgbl201603
  P/L total     5.7
  average buy   165
  average sell  166
  volume         10

'P/L total' is in units of instrument;
'volume' is sum of /absolute/ amounts.

Warning message:
In pl.default(amount, price, timestamp, instrument,
multiplier = multiplier,  :
all trades are closed for fgbl201603, but 'vprice' is specified
```

We could have simulated this computation by creating one journal of the initial position and another journal (with reversed `amount` signs) for the final position, merging all three journals computing P/L.

Note the warning: the final position of `fgbl201603` is zero, yet we specified an `vprice`.

3.2 More-complicated cases

Unfortunately, in real life computing P/L is often more complicated:

- One asset-price unit may not translate into one currency unit: we have multipliers or contract factors. That is easy to solve by computing effective position sizes, but it may take some thinking to come up with a reusable scheme (e.g., looking up multipliers in a table).
- Asset positions may map into cashflows in non-obvious ways. The simple case is the delay in actual payment and delivery of an asset, which is often two or three days. The more problematic cases are derivatives with daily adjustments of margins. In such cases, one may need to model (i.e. keep track of) the actual account balances.
- Assets may be denominated in various currencies.
- Currencies themselves may be assets in the portfolio. Depending on how they are traded (cash, forwards, *&c.*), computing P/L may not be straightforward.

How – or rather, to what degree – these complications are handled is, as always, up to the user. For a single instrument, computing P/L in units of the instrument is always meaningful, though perhaps not always intuitive. But *adding up* the profits and losses of several assets often will often not work because of multipliers or different currencies. A simple and transparent way is then to manipulate the journal before P/L is computed (e.g., multiply notionals by their multipliers).

We look at two examples: (i) computing the *pl* of ## several assets in currency units; and (ii) computing ## time-weighted returns of a portfolio of assets.

3.2.1 Example 1: P/L for lists of incomes and expenses

Suppose you keep a journal just to keep track of your personal income and expenses. An aside: it is tedious to enter journals by hand, in particular if we want to update them over time. So, for practical use, we may write transactions into files, like this:

```
|  timestamp | amount | comment          |
|------------+--------+------------------|
| 2012-01-01 |    100 | a comment        |
| 2012-01-02 |    200 | another comment  |
| 2012-01-03 |   -200 | bought something |
| 2012-02-04 |    500 | got a present    |
```

In case you use Org-mode, such tables should look familiar. The org package `http://enricoschumann.net/R/packages/org/index.htm` provides a function `readOrg` to read such tables.

```
## extract org tables from file
use warnings;
use strict;

while (<>) {
        print "$_" if /^\s*\|/;
}
```

Some of these transactions may mean a gain or loss to us, such as a dividend payment. Others are neutral, for example a transfer between bank accounts. There are several ways to deal with this.[1]

One way is to switch to double-entry accounting. A second way is to add descriptions like expense and then subset the journal by these descriptions.

And yet another approach is to use prices. Whenever we evaluate the balances of a cash account, we say that the price per unit is one. That is actually reasonable: if my account has a balance of 120.2, it actually means '120 euros and 20 cents, or 120.20 euros'. The price of one euro – no surprise here – is one euro.

[1] We could even do it in Perl. :-)

There are just two rules to remember: 1) An expense should be a negative amount; income should go with positive amounts. 2) When an entry means gain or loss to us, we make its price 0. Then, when we compute that value of a position, we make its price 1. An example:

```
J <- journal(timestamp = c("day 1", "day 2", "day 3"),
             amount    = c(100, 100, -200),
             price     = c(  1,   0,    0),
             comment   = c("neutral", "income", "expense"),
             account   = "my account")
J
```

```
   timestamp  amount  price      account  comment
1      day 1     100      1  my account  neutral
2      day 2     100      0  my account   income
3      day 3    -200      0  my account  expense

3 transactions
```

The current balance is 0.

```
position(J)
```

```
     day 3
[1,]     0
```

In terms of income and expenses we have made a loss of 100, which is exactly what the function `pl` reports.

```
pl(J, current.price = 1)
```

```
P/L total      -100
average buy     0.5
average sell      0
volume          400

'P/L total' is in units of instrument;
'volume' is sum of /absolute/ amounts.
```

3.2.2 Example 2: Futures trading and a margin account

3.2.3 Example 3: Cash equities with splits and dividends

4 Computing returns

4.1 Simple returns

The function `returns` computes returns from prices. The function computes what are often called simple returns:[1] let P_t be the prices in period t, then

$$r_t = R_t - 1 = \frac{P_t}{P_{t-1}} - 1 = \frac{P_t - P_{t-1}}{P_{t-1}} \,. \tag{4.1}$$

For computing profit/loss in currency units, see Section Computing profit and (or) loss.

Typically, we transform a whole series $P_{t_1}, P_{t_2}, P_{t_3}, \ldots$ into returns $R_{t_1}, R_{t_2}, R_{t_3}, \ldots$, which is a one-liner in R:

```
simple_returns <- function(x)
    x[-1L]/x[-length(x)] - 1
```

(You may argue that these are two lines: yet even a one-liner, if used repeatedly, should be written as a function.)

Given a vector of prices – here, the closing values of the DAX, the German stock-market index, for the first five business days of 2014, – the function computes returns.

```
P <- c(9400.04, 9435.15, 9428, 9506.2, 9497.84)
simple_returns(P)
```

```
[1]  0.003735 -0.000758  0.008294 -0.000879
```

In fact, using `returns` as provided by PMWR would have given the same result.

```
returns(P)
```

```
[1]  0.003735 -0.000758  0.008294 -0.000879
```

PMWR's `returns` offers several conveniences. For instance, it will recognise when the input argument has several columns, such as a matrix or a dataframe. In such a case, it computes returns for each column.

```
returns(cbind(P, P))
```

[1] The function never computes logarithmic returns.

```
             P          P
[1,]  0.003735  0.003735
[2,] -0.000758 -0.000758
[3,]  0.008294  0.008294
[4,] -0.000879 -0.000879
```

The argument pad determines how the initial observation is handled. The default, NULL, means that the first observation is dropped. It is often useful to use NA instead, since in this way the returns series keeps the same length as the original price series.

```
data.frame(price = P, returns = returns(P, pad = NA))
```

```
  price   returns
1  9400        NA
2  9435  0.003735
3  9428 -0.000758
4  9506  0.008294
5  9498 -0.000879
```

Setting pad to 0 can also be useful, because then it is easy to 'rebuild' the original series with cumprod. (But see Section Scaling series for a description of the function scale1, which is even more convenient.)

```
all.equal(P,
          P[[1L]] * cumprod(1 + returns(P, pad = 0)))
```

```
[1] TRUE
```

returns is a generic function, which goes along with some overhead. If you need to compute returns on simple data structures as in the examples above and need fast computation, then you may also use .returns. This function is the actual workhorse that performs the raw returns calculation.

Besides methods for numeric vectors and dataframes, the function also understands zoo objects.

```
dax <- zoo(P,
           as.Date(c("2014-01-02", "2014-01-03",
                     "2014-01-06", "2014-01-07",
                     "2014-01-08")))
returns(dax, pad = NA)
```

```
2014-01-02 2014-01-03 2014-01-06 2014-01-07 2014-01-08
        NA   0.003735  -0.000758   0.008294  -0.000879
```

Matrices work as well: We create a second series, the prices of the REXP, a German bond-market index. Then, we combine them into a two-column matrix

```
rexp <- zoo(c(440.5252, 440.7944,
              441.5456, 441.8197,
              441.7619),
            as.Date(c("2014-01-02", "2014-01-03",
                      "2014-01-06", "2014-01-07",
                      "2014-01-08")))

returns(cbind(DAX = dax, REXP = rexp))
```

```
                 DAX      REXP
2014-01-03  0.003735  0.000611
2014-01-06 -0.000758  0.001704
2014-01-07  0.008294  0.000621
2014-01-08 -0.000879 -0.000131
```

In fact, zoo objects bring another piece of information – timestamps – that returns can use.

4.2 Holding-period returns

We use two longer series for this section, included in the files PMwR_data_DAX and PMwR_data_REXP.

```
require("tsdb")
DAX <- read_ts_tables("PMwR_data_DAX",
                      start = "1970-1-1", return.class = "zoo")
colnames(DAX) <- "DAX"

REXP <- read_ts_tables("PMwR_data_REXP",
                       start = "1970-1-1", return.class = "zoo")
colnames(REXP) <- "REXP"
```

```
str(DAX)
```

```
''
zoo series from 2014-01-02 to 2015-12-30
  Data: num [1:505, 1] 9400 9435 9428 9506 9498 ...
 - attr(*, "dimnames")=List of 2
  ..$ : NULL
  ..$ : chr "DAX"
  Index:  Date[1:505], format: "2014-01-02" "2014-01-03"  ...
```

```
str(REXP)
```

```
'zoo' series from 2014-01-02 to 2015-12-30
  Data: num [1:502, 1] 441 441 442 442 442 ...
 - attr(*, "dimnames")=List of 2
  ..$ : NULL
  ..$ : chr "REXP"
  Index:  Date[1:502], format: "2014-01-02" "2014-01-03" "2014-01-06" ...
```

When a timestamp is available, `returns` can compute returns for specific calendar periods. As an example, we look at the daily DAX levels in 2014 and 2015.

```
returns(coredata(DAX), t = index(DAX), period = "month")
```

```
      Jan Feb  Mar  Apr  May  Jun  Jul  Aug  Sep  Oct Nov
Dec YTD
2014 -1.0 4.1 -1.4  0.5  3.5 -1.1 -4.3  0.7  0.0 -1.6 7.0 -1.8 4.3
2015  9.1 6.6  5.0 -4.3 -0.4 -4.1  3.3 -9.3 -5.8 12.3 4.9 -5.6 9.6
```

If you work with a zoo series, you can omit the timestamp `t`. (Since `xts` series inherit from zoo, you can omit timestamps, too.)

```
returns(DAX, period = "month")
```

```
      Jan Feb  Mar  Apr  May  Jun  Jul  Aug  Sep  Oct Nov
Dec YTD
2014 -1.0 4.1 -1.4  0.5  3.5 -1.1 -4.3  0.7  0.0 -1.6 7.0 -1.8 4.3
2015  9.1 6.6  5.0 -4.3 -0.4 -4.1  3.3 -9.3 -5.8 12.3 4.9 -5.6 9.6
```

The result of the function call is a numeric vector (the return numbers), with additional information added through attributes. There is also a `class` attribute, which has value `p_returns`. The advantage of this data structure is that it is 'natural' to compute with the returns, e.g. computing means, extremes or similar quantities.

```
range(returns(DAX, period = "month"))
```

```
[1] -0.0928  0.1232
```

Most useful, however, is probably the `print` method, whose results you have seen above.

You may also compute monthly returns for matrices, i.e. for more than one asset. But now the `print` method will behave differently. Suppose we combine the prices of the DAX and of the REXP. The function's assumption is that now it would be more convenient to print the returns aligned by date in a table.

```
returns(cbind(DAX, REXP), period = "month")
```

```
             DAX   REXP
2014-01-31  -1.0   1.8
2014-02-28   4.1   0.4
2014-03-31  -1.4   0.1
2014-04-30   0.5   0.3
2014-05-30   3.5   0.9
2014-06-30  -1.1   0.4
2014-07-31  -4.3   0.4
2014-08-29   0.7   1.0
2014-09-30   0.0  -0.1
2014-10-31  -1.6   0.1
2014-11-28   7.0   0.4
2014-12-30  -1.8   1.0
2015-01-30   9.1   0.3
2015-02-27   6.6   0.1
2015-03-31   5.0   0.3
2015-04-30  -4.3  -0.5
2015-05-29  -0.4  -0.2
2015-06-30  -4.1  -0.8
2015-07-31   3.3   0.7
2015-08-31  -9.3   0.0
2015-09-30  -5.8   0.4
2015-10-30  12.3   0.4
2015-11-30   4.9   0.3
2015-12-30  -5.6  -0.6
```

If you rather wanted the other, one-row-per-year display, just call the function separately for each series.

```
lapply(list(DAX = DAX, REXP = REXP),
       returns, period = "month")
```

```
$DAX
      Jan Feb  Mar  Apr  May  Jun  Jul  Aug  Sep  Oct Nov
Dec YTD
2014 -1.0 4.1 -1.4  0.5  3.5 -1.1 -4.3  0.7  0.0 -1.6 7.0 -1.8 4.3
2015  9.1 6.6  5.0 -4.3 -0.4 -4.1  3.3 -9.3 -5.8 12.3 4.9 -5.6 9.6

$REXP
     Jan Feb Mar  Apr  May  Jun Jul Aug  Sep Oct Nov  Dec YTD
2014 1.8 0.4 0.1  0.3  0.9  0.4 0.4 1.0 -0.1 0.1 0.4  1.0 7.1
2015 0.3 0.1 0.3 -0.5 -0.2 -0.8 0.7 0.0  0.4 0.4 0.3 -0.6 0.5
```

See `?print.preturns` for more display options. For instance:

```
print(returns(DAX, period = "month"),
      digits = 2, year.rows = FALSE, plus = TRUE,
      month.names = 1:12)
```

```
      2014    2015
1    -1.00   +9.06
2    +4.14   +6.61
3    -1.40   +4.95
4    +0.50   -4.28
5    +3.54   -0.35
6    -1.11   -4.11
7    -4.33   +3.33
8    +0.67   -9.28
9    +0.04   -5.84
10   -1.56  +12.32
11   +7.01   +4.90
12   -1.76   -5.62
YTD  +4.31   +9.56
```

There are methods `toLatex` and `toHTML` for monthly returns. In Sweave documents, you need to use `results = tex` and `echo = false` in the chunk options:

```
\noindent
\begin{tabular}{rrrrrrrrrrrrr}
<<results=tex,echo=false>>=
toLatex(returns(DAX, period = "month"))
\end{tabular}
```

`returns` accepts other values for `period`. For yearly returns, use `period "year"`.

```
returns(DAX, period = "year")
```

```
2014 2015
 4.3  9.6
```

```
returns(merge(DAX, REXP), period = "year")
```

```
     DAX REXP
2014 4.3  7.1
2015 9.6  0.5
```

To get annualised returns, use period ann (or actually any string that the regular expression ^ann matches; case is ignored).

```
returns(DAX, period = "ann")
```

```
6.9%  [02 Jan 2014 -- 30 Dec 2015]
```

Now let us try a shorter period.

```
returns(window(DAX, end = as.Date("2014-1-31")),
        period = "ann")
```

```
-1.0%  [02 Jan 2014 -- 31 Jan 2014;
        less than one year, not annualised]
```

The function did ***not*** annualise: it does not annualise if the time period is shorter than one year. (You can see the monthly return for January 2014 in the tables above.)

To force annualising, add a `!`. The exclamation mark serves as a mnenomic that it is now imperative to annualise.

```
returns(window(DAX, end = as.Date("2014-1-31")),
        period = "ann!")
```

```
-11.8%  [02 Jan 2014 -- 31 Jan 2014;
         less than one year, but annualised]
```

There are also several other periods, such as month-to-date (`mtd`), year-to-date (`ytd`) or inception-to-date (`itd`). The help page of `returns` lists all options.

4.3 Returns when weights are fixed

We can also compute returns from fixed weights and assumptions when the portfolio is rebalanced. For instance, we may want to see how a constant allocation $[0.1, 0.5, 0.4]'$ to three funds would have done, assuming that a portfolio is rebalanced once a month.

If more detail is necessary, then `btest` can be used; see Section Backtesting. But the simple case can be done with `returns` already. Here is an example.

```
prices <- c(100, 102, 104, 104, 104.5,
              2, 2.2, 2.4, 2.3,   2.5,
            3.5,   3, 3.1, 3.2,   3.1)

dim(prices) <- c(5, 3)
prices
```

```
     [,1] [,2] [,3]
[1,]  100  2.0  3.5
[2,]  102  2.2  3.0
[3,]  104  2.4  3.1
[4,]  104  2.3  3.2
[5,]  104  2.5  3.1
```

Now suppose we want a constant weight vector, $[0.1, 0.5, 0.4]'$, but only rebalance at times 1 and 4. (That is, we rebalance the portfolio only with the prices at timestamps 1 and 4.)

```
returns(prices,
        weights = c(10, 50, 40)/100,
        rebalance.when = c(1, 4))
```

```
[1] -0.00514  0.06376 -0.01282  0.03146

attr(,"holdings")
      [,1]  [,2]  [,3]
[1,] 0.001 0.250 0.114
[2,] 0.001 0.250 0.114
[3,] 0.001 0.250 0.114
[4,] 0.001 0.227 0.131
[5,] 0.001 0.227 0.131

attr(,"contributions")
         [,1]    [,2]    [,3]
[1,] 0.000000  0.0000  0.0000
[2,] 0.002000  0.0500 -0.0571
[3,] 0.002010  0.0503  0.0115
[4,] 0.000000 -0.0236  0.0108
[5,] 0.000481  0.0435 -0.0125
```

The result is the return series plus two additional pieces of information, stored in attributes.

holdings A matrix with the same dimensions as the price matrix we used as input. It provides the hypothetical holdings that were used to compute the returns. Note that these holdings only change at timestamps 1 and 4 in the example.

contributions Another matrix; it provides the return contributions of the single assets (in columns) in each period (in rows).

4.4 Return contribution

Let $w(t,i)$ be the weight of portfolio segment i at the beginning of period t, and let $r(t,i)$ be the return of segment i over period t. Then the portfolio return over period t, $r_{\mathrm{P}}(t)$ is a weighted sum of the N segment returns.

$$r_{\mathrm{P}}(t) = \sum_{i=1}^{N} r(t,i)w(t,i)\,. \tag{4.2}$$

When the weights sum to unity, we may also write

$$1 + r_{\mathrm{P}}(t) = \prod_{i=1}^{N} 1 + r(t,i)w(t,i) \tag{4.3}$$

or, defining $1 + r \equiv R$,

$$R_{\mathrm{P}}(t) = \prod_{i=1}^{N} R(t,i)w(t,i)\,. \tag{4.4}$$

The total return contribution of segment i over time equals

$$\sum_{t=1}^{T-1} \left(R(t,i)w(t,i) \prod_{s=t+1}^{T} R_{\mathrm{P}}(s) - 1 \right) + \underbrace{r(T,i)\,w(T,i)}_{\text{final period}}\,. \tag{4.5}$$

In this way, a segment's return contribution in on period is reinvested in the overall portfolio in succeeding periods.

The calculation is provided in the function `rc` ('return contribution').

```
weights <- rbind(c( 0.25, 0.75),  ## the assets' weights
                 c( 0.40, 0.60),  ## during three periods
                 c( 0.25, 0.75))

R <- rbind(c( 1  ,    0),         ## the assets' returns
           c( 2.5, -1.0),         ## during these periods
           c(-2  ,  0.5))/100

rc(R, weights, segment = c("equities", "bonds"))
```

```
$period_contributions
  timestamp equities    bonds    total
1         1   0.0025  0.00000  0.00250
2         2   0.0100 -0.00600  0.00400
3         3  -0.0050  0.00375 -0.00125

$total_contributions
    equities        bonds        total
 0.007494363 -0.002242500  0.005251862
```

4.5 Returns when there are external cashflows

The function `unit_prices` helps to compute time-weighted returns of a portfolio with many in- and outflows.

```
NAV <- data.frame(timestamp = seq(as.Date("2017-1-1"),
                                  as.Date("2017-1-10"),
                                  by = "1 day"),
                  NAV = c(0,101:104,205:209))

cf <- data.frame(timestamp = c(as.Date("2017-1-1"),
                               as.Date("2017-1-5")),
                 cashflow = c(100, 100))

unit_prices(NAV, cf)
```

```
    timestamp NAV   price  shares cashflow new_shares total_shares NAV_after_cf
1  2017-01-01   0 100.000 0.00000      100   1.000000
1.00000          100
2  2017-01-02 101 101.000 1.00000        0   0.000000
1.00000          101
3  2017-01-03 102 102.000 1.00000        0   0.000000
1.00000          102
```

```
4  2017-01-04 103 103.000 1.00000         0   0.000000
1.00000           103
5  2017-01-05 104 104.000 1.00000       100   0.961538
1.96154           204
6  2017-01-06 205 104.510 1.96154         0   0.000000
1.96154           205
7  2017-01-07 206 105.020 1.96154         0   0.000000
1.96154           206
8  2017-01-08 207 105.529 1.96154         0   0.000000
1.96154           207
9  2017-01-09 208 106.039 1.96154         0   0.000000
1.96154           208
10 2017-01-10 209 106.549 1.96154         0   0.000000
1.96154           209
```

5 Backtesting

This chapter explains how to test trading strategies with the `btest` function.

5.1 Decisions

At a given instant in time (in actual life, 'now'), a trader needs to answer the following questions:

1. Do I want to compute a new target portfolio, yes or no? If yes, go ahead and compute the new target portfolio.
2. Given the target portfolio and the actual portfolio, do I want to rebalance (i.e. close the gap between the actual portfolio and the target portfolio)? If yes, rebalance.

If such a decision is not just hypothetical, then the answer to the second question may lead to a number of orders sent to a broker. Note that many traders do not think in terms of ***stock*** (i.e. balances) as we did here; rather, they think in terms of ***flow*** (i.e. orders). Both approaches are equivalent, but the described one makes it easier to handle missed trades and synchronise accounts.

During a backtest, we will simulate the decisions of the trader. How precisely we simulate depends on the trading strategy. The `btest` function is meant as a helper function to simulate these decisions. The logic for the decisions described above must be coded in the functions `do.signal`, `signal` and `do.rebalance`.

Implementing `btest` required a number of decision, too: (i) what to model (i.e. how to simulate the trader), and (ii) how to code it. As an example for point (i): how precisely do we want to model the order process (e.g. use limit orders?, allow partial fills?) Example for (ii): the backbone of `btest` is a loop that runs through the data. Loops are slow in R when compared with compiled languages, so should we vectorise instead? Vectorisation is indeed often possible, namely if trading is not path-dependent. If we have already a list of trades, we can efficiently transform them into a profit-and-loss in R without relying on an explicit loop (see Section Computing profit and (or) loss). Yet, one advantage of looping is that the trade logic is more similar to actual trading; we may even be able to reuse some code in live trading.

Altogether, the aim for `btest` is to stick to the functional paradigm as much as possible. Functions receive arguments and evaluate to results; but they do not change their arguments, nor do they assign or change other variables 'outside' their environment, nor do the results depend on some variable outside the function. This creates a problem,

namely how to keep track of state. If we know what variables need to be persistent, we could pass them to the function and always have them returned. But we would like to be more flexible, so we can pass an environment; examples are below. To make that clear: functional programming should not be seen as a yes-or-no decision; it is a matter of degree. And more of the functional approach can help already.

5.2 Data structure

All computations of `btest` will be based on one or several price series of length `T`. Internally, these prices are stored in numeric matrices.

Prices are passed as argument `prices`. For a single asset, this must be a matrix of prices with four columns: open, high, low and close.

For `n` assets, you need to pass a `list` of length four: `prices[[1]]` must be a matrix with `n` columns containing the open prices for the assets; `prices[[2]]` is a matrix with the high prices, and so on. For instance, with two assets, you need four matrices with two columns each:

```
 open      high      low      close
+-+-+    +-+-+    +-+-+    +-+-+
| | |    | | |    | | |    | | |
| | |    | | |    | | |    | | |
| | |    | | |    | | |    | | |
| | |    | | |    | | |    | | |
| | |    | | |    | | |    | | |
+-+-+    +-+-+    +-+-+    +-+-+
```

If only close prices are used, then for a single asset, use either a matrix of one column or a numeric vector. For multiple assets a `list` of length one must be passed, containing a matrix of close prices. For example, with 100 close prices of 5 assets, the prices should be arranged in a matrix `p` of size 100 times 5; and `prices = list(p)`.

The `btest` function runs from `b+1` to `T`. The variable `b` is the burn-in and it needs to be a positive integer. When we take decisions that are based on past data, we will lose at least one data point. In rare cases `b` may be zero.

Here is an important default: at time `=t=`, we can use information up to time `t-1`. Suppose that `t` were 4. We may use all information up to time 3, and trade at the `open` in period 4:

```
t    time      open  high  low   close
1    HH:MM:SS                           <--\
2    HH:MM:SS                           <-- - use information
3    HH:MM:SS  _________________________  <--/
4    HH:MM:SS     X                       <- trade here
5    HH:MM:SS
```

We could also trade at the `close`:

```
t    time      open  high  low   close
1    HH:MM:SS                            <-- \
2    HH:MM:SS                            <-- - use information
3    HH:MM:SS  ________________________  <-- /
4    HH:MM:SS                      X     <-- trade here
5    HH:MM:SS
```

No, we cannot trade at the high or low. (Some people like the idea, as a robustness check, to always buy at the high, sell at the low. Robustness checks – forcing a bit of bad luck into the simulation – are a good idea, notably bad executions. High/low ranges can inform such checks, but using these ranges does not go far enough, and is more of a good story than a meaningful test.)

5.3 Function arguments

5.3.1 Available information within functions

`btest` expects as arguments a number of functions, such as `signal`; see the following section for a complete list. The default is to specify no arguments to these functions, because they can all access the following 'objects'. These objects actually are, with the exception of `Globals`, themselves functions that can access certain data. These functions can only read; there are no replacement functions. The exception is `Globals`, which is an environment, and which can explicitly be used for writing (i.e. storing data).

Open open prices

High high prices

Low low prices

Close close prices

Wealth the total wealth (cash plus positions) at a given point in time

Cash cash (in accounting currency)

Time current time (an integer)

Timestamp the `timestamp` when that is specified (i.e. when the argument `timestamp` is supplied); if not, it defaults to `Time`

Portfolio the current portfolio

SuggestedPortfolio the currently-suggested portfolio

Globals an environment (not a function)

All functions take as their first argument a `lag`, which defaults to `1`. So to get the most recent close price, say

```
Close()
```

which is the same as `Close(lag = 1)`.

The `lag` can be a vector, too: the expression

```
Close(Time():1)
```

for instance will return all available close prices. So, for instance, in period 11, you want close prices for lags 10, 9, ..., 1. Hence, to receive prices in their correct order, the lag sequence must always be in reverse order.

If you find it awkword to specify the lag in this reverse order, you may use the argument `n` instead, which specifies to retrieve the last *n* data points. So the above `Close(Time():1)` is equivalent to

```
Close(n = Time())
```

and

```
Close(n = 10)
```

returns the last ten closing prices.

5.3.2 Function arguments

`signal` The function `signal` uses information until and including `t-1` and returns the suggested portfolio (a vector) to be held at `t`. This position should be in units of the instruments; if you prefer to work with weights, then you should set `convert.weights` to `TRUE`. Then, the value returned by `signal` will be interpreted as weights and will be automatically converted to position sizes.

`do.signal` `do.signal` uses information until and including `t-1` and must return `TRUE` or `FALSE` to indicate whether a signal (i.e. new suggested position) should be computed. This is useful when the signal computation is costly and only be done at specific points in time. If the function is not specified, it defaults to `function() TRUE`. Instead of a function, this may also be

- a vector of integers, which then indicate the points in time when to compute a position, or
- a vector of logical values, which then indicate the points in time when to compute a position, or
- a vector that inherits from the class of `timestamp` (e.g. `Date`), or
- one of the keywords `firstofmonth` or `lastofmonth` (in this case, `timestamp` must inherit from `Date` or be coercible to `Date`).

`do.rebalance` just like `do.signal`, but refers to the actual trading. If the function is not specified, it defaults to `function() TRUE`. Note that rebalancing can typically not take place at a higher frequency than implied by `signal`. That is because calling `signal` leads to a position, and when this position does not change (i.e. `signal` was not called), there is actually no need to rebalance. So `do.rebalance` is normally used when rebalancing should be done less often that signal computation, e.g. when the decision whether to trade or not is conditional on something.

`print.info` The function is called at the end of an iteration. Whatever it returns will be ignored since it is called for its side effect: print information to the screen, into a file or into some other connection.

`cashflow` The function is called at the end of each iteration; its value is added to the `cash`. The function provides a clean way to, for instance, add accrued interest to or subtract fees from a strategy.

5.4 Examples: A single asset

It is best to describe the `btest` function through a number of simple examples.

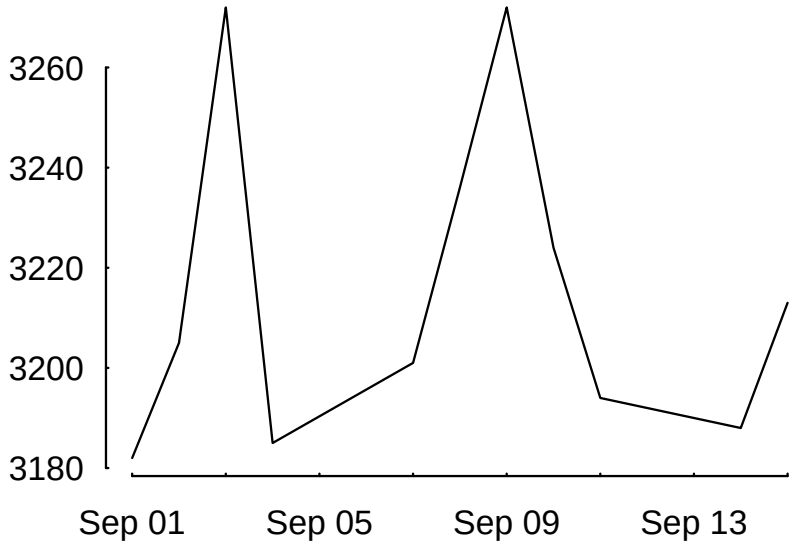
5.4.1 A useless first example

I really like simple examples. Suppose we have a single instrument, and we use only close prices. The trading rule is to buy, and then to hold forever. All we need is the time series of the prices and the signal function. As an instrument we use the EURO STOXX 50 future with expiry September 2015.

```
timestamp <- structure(c(16679L, 16680L, 16681L, 16682L,
                         16685L, 16686L, 16687L, 16688L,
                         16689L, 16692L, 16693L),
                       class = "Date")
prices <- c(3182, 3205, 3272, 3185, 3201,
            3236, 3272, 3224, 3194, 3188, 3213)
data.frame(timestamp, prices)
```

```
    timestamp prices
1  2015-09-01   3182
2  2015-09-02   3205
3  2015-09-03   3272
4  2015-09-04   3185
5  2015-09-07   3201
6  2015-09-08   3236
7  2015-09-09   3272
8  2015-09-10   3224
9  2015-09-11   3194
```

```
10 2015-09-14   3188
11 2015-09-15   3213
```



The `signal` function is very simple indeed.

```
signal <- function()
    1
```

`signal` must be written so that it returns the suggested position in units of the asset. In this first example, the suggested position always is 1 unit. It is only a *suggested* portfolio because we can specify rules whether or not to trade. Examples follow below.

To test this strategy, we call `btest`. The initial cash is zero per default, so initial wealth is also zero in this case. We can change it through the argument `initial.cash`.

```
(solution <- btest(prices = prices, signal = signal))
```

```
initial wealth 0  =>  final wealth  8
```

The function returns a list with a number of components, but they are not printed. Instead, a simple print method displays some information about the results. In this case, it tells us that the total equity of the strategy increased from 0 to 8.

We arrange more details into a `data.frame`. `suggest` is the suggested position; `position` is the actual position.

```
trade_details <- function(solution, prices)
    data.frame(price    = prices,
               suggest  = solution$suggested.position,
```

```
               position = unname(solution$position),
               wealth   = solution$wealth,
               cash     = solution$cash)

trade_details(unclass(solution), prices)
```

```
   price suggest position wealth  cash
1   3182       0        0      0     0
2   3205       1        1      0 -3205
3   3272       1        1     67 -3205
4   3185       1        1    -20 -3205
5   3201       1        1     -4 -3205
6   3236       1        1     31 -3205
7   3272       1        1     67 -3205
8   3224       1        1     19 -3205
9   3194       1        1    -11 -3205
10  3188       1        1    -17 -3205
11  3213       1        1      8 -3205
```

We bought in the second period because the default setting for the burnin b is 1. Thus, we lose one observation. In this particular case here, we do not rely in any way on the past; hence, we set b to zero. With this setting, we buy at the first price and hold until the end of the data.

```
solution <- btest(prices = prices, signal = signal,
                  b = 0)
trade_details(solution, prices)
```

```
   price suggest position wealth  cash
1   3182       1        1      0 -3182
2   3205       1        1     23 -3182
3   3272       1        1     90 -3182
4   3185       1        1      3 -3182
5   3201       1        1     19 -3182
6   3236       1        1     54 -3182
7   3272       1        1     90 -3182
8   3224       1        1     42 -3182
9   3194       1        1     12 -3182
10  3188       1        1      6 -3182
11  3213       1        1     31 -3182
```

If you prefer the trades only, i.e. not the position series, the solution also contains a `journal`. (See Keeping track of transactions: journals for more on journals.)

```
journal(solution)
```

```
   instrument  timestamp  amount  price
1     asset 1          1       1   3182
```

```
1 transaction
```

To make the journal more informative, we can pass `timestamp` and `instrument` information when we call `btest`.

```
journal(btest(prices = prices, signal = signal, b = 0,
              timestamp = timestamp, ## defined above,
                                     ## together with prices
              instrument = "FESX SEP 2015"))
```

```
      instrument   timestamp  amount  price
1  FESX SEP 2015  2015-09-01       1   3182

1 transaction
```

Before we go to the next examples, a final remark, on data frequency. I have used daily data here, but any other frequency, also intraday data, is fine. `btest` will not care of what frequency your data are or whether your data are regularly spaced; it will only loop over the observations that it is given. It is your own responsibility to write `signal` (and other functions) in such a way that they encode a meaningful trade logic.

5.4.2 More-useful examples

Now we make our strategy slightly more selective. The trading rule is to have a position of 1 unit of the asset whenever the last observed price is below 3200 and to have no position when it the price is above

1. The `signal` function could look like this.

```
signal <- function() {
    if (Close() < 3200)
        1
    else
        0
}
```

If you like to write clever code, you may as well have written this:

```
signal <- function()
    Close() < 3200
```

The `logical` value of the comparison `Close() < 3200` would be converted to either 0 or 1. But the more verbose version above is clearer.[1]

We call `btest` and check the results.

[1] Remember what Brian Kernighan said: *Everyone knows that debugging is twice as hard as writing a program in the first place. So if you're as clever as you can be when you write it, how will you ever debug it?*

```
solution <- btest(prices = prices, signal = signal)
```

```
trade_details(solution, prices)
```

```
   price suggest position wealth  cash
1   3182       0        0      0     0
2   3205       1        1      0 -3205
3   3272       0        0     67    67
4   3185       0        0     67    67
5   3201       1        1     67 -3134
6   3236       0        0    102   102
7   3272       0        0    102   102
8   3224       0        0    102   102
9   3194       0        0    102   102
10  3188       1        1    102 -3086
11  3213       1        1    127 -3086
```

(Yes, this strategy works better than the simple buy-and-hold, but I hope you agree that this is only because of luck.)

The argument `initial.position` specifies the initial position; default is no position. Suppose we had already held one unit of the asset.

```
solution <- btest(prices = prices, signal = signal,
                  initial.position = 1)
```

Then the results would have looked as follows.

```
trade_details(solution, prices)
```

```
   price suggest position wealth cash
1   3182       1        1   3182    0
2   3205       1        1   3205    0
3   3272       0        0   3272 3272
4   3185       0        0   3272 3272
5   3201       1        1   3272   71
6   3236       0        0   3307 3307
7   3272       0        0   3307 3307
8   3224       0        0   3307 3307
9   3194       0        0   3307 3307
10  3188       1        1   3307  119
11  3213       1        1   3332  119
```

In the example above, we use the close price, but we do not access the data directly. A function `Close` is defined by `btest` and passed as an argument to `signal`. Note that we do not add it as a formal argument to `signal` since this is done automatically. In fact, doing it manually would trigger an error message:

```
signal <- function(Close = NULL)   ## argument name 'Close'
    1                              ## not allowed
```

```
Error in btest(prices = prices, signal = signal) :
  'Close' cannot be used as an argument name for 'signal'
```

Similarly, we have functions `Open`, `High` and `Low`; see Section 5.3 above for all functions.

Suppose we wanted to add a variable: a `threshold` that tells us when to buy. This would need to be an argument to `signal`; it would also need to be passed with the `...` argument of `btest`.

```
signal <- function(threshold) {
    if (Close() < threshold)
        1
    else
        0
}

solution <- btest(prices = prices,
                  signal = signal,
                  threshold = 3190)

trade_details(solution, prices)
```

```
   price suggest position wealth  cash
1   3182       0        0      0     0
2   3205       1        1      0 -3205
3   3272       0        0     67    67
4   3185       0        0     67    67
5   3201       1        1     67 -3134
6   3236       0        0    102   102
7   3272       0        0    102   102
8   3224       0        0    102   102
9   3194       0        0    102   102
10  3188       0        0    102   102
11  3213       1        1    102 -3111
```

So far we have treated `Close` as a function without arguments, but actually it has an argument `lag` that defaults to `1`. Suppose the rule were to buy if the last close is below the second-to-last close. `signal` could look like this.

```
signal <- function() {
    if (Close(1L) < Close(2L))
        1
    else
        0
}
```

We could also have written `(Close() < Close(2L))`. In any case, the rule uses the close prices of yesterday and of the day before yesterday, so we need to increase b.

```
trade_details(btest(prices = prices, signal = signal, b = 2),
              prices)
```

```
   price suggest position wealth  cash
1   3182       0       NA     NA     0
2   3205       0        0      0     0
3   3272       0        0      0     0
4   3185       0        0      0     0
5   3201       1        1      0 -3201
6   3236       0        0     35    35
7   3272       0        0     35    35
8   3224       0        0     35    35
9   3194       1        1     35 -3159
10  3188       1        1     29 -3159
11  3213       1        1     54 -3159
```

If we want to trade a different size, we have `signal` return the desired value.

```
signal <- function()
    if (Close() < 3200)
        2 else 0

trade_details(btest(prices = prices, signal = signal), prices)
```

```
   price suggest position wealth  cash
1   3182       0        0      0     0
2   3205       2        2      0 -6410
3   3272       0        0    134   134
4   3185       0        0    134   134
5   3201       2        2    134 -6268
6   3236       0        0    204   204
7   3272       0        0    204   204
8   3224       0        0    204   204
9   3194       0        0    204   204
10  3188       2        2    204 -6172
11  3213       2        2    254 -6172
```

A often-used way to specify a trading strategy is to map past prices into `+1`, `0` or `-1` for long, flat or short. A signal is often only given at a specified point (like in 'buy one unit now'). Example: suppose the third day is a Thursday, and our rule says 'buy after Thursday'.

```
signal <- function()
    if (Time() == 3L)
        1 else 0
```

```
trade_details(btest(prices = prices, signal = signal),
              prices)
```

```
   price suggest position wealth  cash
1   3182       0        0      0     0
2   3205       0        0      0     0
3   3272       0        0      0     0
4   3185       1        1      0 -3185
5   3201       0        0     16    16
6   3236       0        0     16    16
7   3272       0        0     16    16
8   3224       0        0     16    16
9   3194       0        0     16    16
10  3188       0        0     16    16
11  3213       0        0     16    16
```

But this is not what we wanted. If the rule is to buy and then keep the long position, we should have written it like this.

```
signal <- function()
    if (Time() == 3L)
        1 else Portfolio()
```

The function `Portfolio` evaluates to last period's portfolio. Like `Close`, its first argument sets the time `lag`, which defaults to 1.

```
trade_details(btest(prices = prices, signal = signal), prices)
```

```
   prices sp asset.1 wealth  cash
1    3182  0       0      0     0
2    3205  0       0      0     0
3    3272  0       0      0     0
4    3185  1       1      0 -3185
5    3201  1       1     16 -3185
6    3236  1       1     51 -3185
7    3272  1       1     87 -3185
8    3224  1       1     39 -3185
9    3194  1       1      9 -3185
10   3188  1       1      3 -3185
11   3213  1       1     28 -3185
```

We may also prefer to specify `signal` so that it evaluates to a weight; for instance, after a portfolio optimisation. In such a case, you need to set `convert.weights` to `TRUE`. (Make sure to have a meaningful initial wealth: 5 percent of nothing is nothing.)

```
signal <- function()
    0.05

solution <- btest(prices = prices,
```

```
                  signal = signal,
                  initial.cash = 100,
                  convert.weights = TRUE)
trade_details(solution, prices)
```

```
   prices      sp asset.1 wealth  cash
1    3182 0.00000 0.00000    100 100.0
2    3205 0.00157 0.00157    100  95.0
3    3272 0.00156 0.00156    100  95.0
4    3185 0.00153 0.00153    100  95.1
5    3201 0.00157 0.00157    100  95.0
6    3236 0.00156 0.00157    100  95.0
7    3272 0.00155 0.00155    100  95.0
8    3224 0.00153 0.00153    100  95.1
9    3194 0.00155 0.00155    100  95.0
10   3188 0.00157 0.00157    100  95.0
11   3213 0.00157 0.00157    100  95.0
```

Note that until now we – potentially – rebalanced in every period. If you do not want that, we need to specify `do.rebalance`.

```
do.rebalance <- function() {
    if (sum(abs(
        SuggestedPortfolio(0) - SuggestedPortfolio())) > 2e-5)
        TRUE
    else
        FALSE
}

solution <- btest(prices = prices,
                  signal = signal,
                  initial.cash = 100,
                  do.rebalance = do.rebalance,
                  convert.weights = TRUE)

trade_details(solution, prices)
```

```
   price suggest position wealth   cash
1   3182  0.0000   0.0000    100 100.00
2   3205  0.0000   0.0000    100 100.00
3   3272  0.0000   0.0000    100 100.00
4   3185  0.0306   0.0306    100   2.66
5   3201  0.0000   0.0000    100 100.49
6   3236  0.0000   0.0000    100 100.49
7   3272  0.0000   0.0000    100 100.49
8   3224  0.0000   0.0000    100 100.49
9   3194  0.0000   0.0000    100 100.49
10  3188  0.0000   0.0000    100 100.49
11  3213  0.0000   0.0000    100 100.49
```

`do.rebalance` is called after `signal`. Hence, the suggested position is known and the lag should be zero ('`SuggestedPortfolio(0)`').

The `tol` argument works similarly: it instructs `btest` to only rebalance when the maximum absolute suggested change in any single position is greater than `tol`. Default is 0.00001, which practically means always rebalance.

```
solution <- btest(prices = prices,
                  signal = signal,
                  initial.cash = 100,
                  tol = 2e-5,
                  convert.weights = TRUE)

trade_details(solution, prices)
```

```
   prices      sp asset.1 wealth  cash
1    3182 0.00000 0.00000    100 100.0
2    3205 0.00157 0.00157    100  95.0
3    3272 0.00156 0.00157    100  95.0
4    3185 0.00153 0.00153    100  95.1
5    3201 0.00157 0.00157    100  95.0
6    3236 0.00156 0.00157    100  95.0
7    3272 0.00155 0.00155    100  95.0
8    3224 0.00153 0.00155    100  95.0
9    3194 0.00155 0.00155    100  95.0
10   3188 0.00157 0.00155    100  95.0
11   3213 0.00157 0.00157    100  95.0
```

Passing environments

To keep information persistent, we can use environments. As an example, we store (and update) the most recent entry price.

```
notepad <- new.env()
notepad$entry <- numeric(length(prices))

signal <- function(threshold, notepad) {
    notepad$entry[Time(0L)] <- notepad$entry[Time(1L)]
    if (Close() < threshold) {
        if (Portfolio() < 1)
            notepad$entry[Time(0L)] <- Close(0L)
        1
    } else {
        0
    }
}

solution <- btest(prices = prices,
```

```
                  signal = signal,
                  threshold = 3200,
                  notepad = notepad)

cbind(trade_details(solution, prices), entry = notepad$entry)
```

```
   price suggest position wealth  cash entry
1   3182       0        0      0     0     0
2   3205       1        1      0 -3205  3205
3   3272       0        0     67    67  3205
4   3185       0        0     67    67  3205
5   3201       1        1     67 -3134  3201
6   3236       0        0    102   102  3201
7   3272       0        0    102   102  3201
8   3224       0        0    102   102  3201
9   3194       0        0    102   102  3201
10  3188       1        1    102 -3086  3188
11  3213       1        1    127 -3086  3188
```

Let us check.

```
subset(journal(solution), amount > 0)
```

btest provides an environment Globals for exactly such purposes.

```
signal <- function(threshold) {
    Globals$entry[Time(0L)] <- Globals$entry[Time(1L)]
    if (Close() < threshold) {
        if (Portfolio() < 1)
            Globals$entry[Time(0L)] <- Close(0L)
        1
    } else {
        0
    }
}

solution <- btest(prices = prices,
                  signal = signal,
                  threshold = 3200,
                  include.data = TRUE)

cbind(trade_details(solution, prices),
      entry = solution$Globals$entry)
```

```
   price suggest position wealth  cash entry
1   3182       0        0      0     0    NA
2   3205       1        1      0 -3205  3205
3   3272       0        0     67    67  3205
4   3185       0        0     67    67  3205
```

```
5    3201        1         1     67 -3134   3201
6    3236        0         0    102   102   3201
7    3272        0         0    102   102   3201
8    3224        0         0    102   102   3201
9    3194        0         0    102   102   3201
10   3188        1         1    102 -3086   3188
11   3213        1         1    127 -3086   3188
```

5.5 Examples: Several assets

It does not really make a difference whether `btest` is called with a single or with several instruments. The pattern in `signal` is still to call `Close()` and friends to obtain data, but now these functions will return matrices with more than one column. For instance, when you have 5 assets, then `Close(n = 250)` would return a matrix of size 250 times 5.

5.5.1 A simple example

```
prices1 <- c(100,98, 98, 97, 96, 98,97,98,99,101)
prices2 <- c(100,99,100,102,101,100,96,97,95,82)
prices <- cbind(A = prices1, B = prices2)

signal <- function()
    if (Close()[1L] > Close()[2L])
        c(2, 0) else c(0, 1)

(solution <- btest(prices = list(prices),
                   signal = signal,
                   b=2))
```

```
  trade_details <- function(solution, prices)
      data.frame(price    = prices,
                 suggest  = solution$suggested.position,
                 position = solution$position, ## do not unname
                 wealth   = solution$wealth,
                 cash     = solution$cash)

trade_details(solution, prices)
```

```
   price.A price.B suggest.A suggest.B position.A position.B wealth cash
1      100     100         0         0         NA         NA
NA    0
2       98      99         0         0          0
0      0    0
```

```
3        98      100          0          1          0
1       0 -100
4        97      102          0          1          0
1       2 -100
5        96      101          0          1          0
1       1 -100
6        98      100          0          1          0
1       0 -100
7        97       96          0          1          0
1      -4 -100
8        98       97          2          0          2
0      -3 -199
9        99       95          2          0          2
0      -1 -199
10      101       82          2          0          2
0       3 -199
```

```
journal(solution)
```

```
   instrument  timestamp  amount  price
1           B          3       1    100
2           A          8       2     98
3           B          8      -1     97

3 transactions
```

5.6 Common tasks

There is more than one way to accomplish a certain task.

5.6.1 Remembering an entry price

In `signal`, assign the current price (with lag 0) to `Globals`. (That is easiest because `do.rebalance` may not be defined.)

5.6.2 Delaying signals

Add a random variable to to `do.rebalance`:

```
if (runif(1) > prob_of_delay)
    TRUE else FALSE
```

If `TRUE`, rebalancing will take place.

5.6.3 Specifying when to compute a signal and trade

`btest` takes two functions, `do.signal` and `do.rebalance`, that tell the algorithm when to compute a new portfolio and when to rebalance. There are different ways to specify these dates: as a function that returns `TRUE` or `FALSE` (most general), but also as integers, logicals or actual timestamps (e.g. dates).

Supplying particular timestamps is useful when you know you want to trade on a specific calendar day, say. That is OK because you know in advance when this calendar is going to be. But be careful when you use other information to specify when to trade. The following examples are not equivalent:

```
btest(prices = prices,
      signal = signal,
      do.signal = prices > 3600)
```

```
btest(prices = prices,
      signal = signal,
      do.signal = function() Close() > 3600)
```

Loosely speaking, both variations compute a signal and trade only when `prices` is above 3600. But in the first version, there will be no time lag: if the prices exceeds 3600 at time t_i, we will trade at t_i. In the second example, `Close()` comes with a default lag of 1: if the price exceeds 3600 at t_i, we will trade at t_{i+1}, which is the more realistic case.

When `timestamp` is of a type that can be coerced to `Date`, you can also use the keywords `firstofmonth` and `lastofmonth`:

```
btest(prices = prices,
      signal = signal,
      do.signal = "firstofmonth")
```

5.6.4 Writing a log

Specify the function `print.info`. The function is called at the very end of an iteration, so it is best to use no time lag. An example

```
print.info <- function() {
    cat("Time",
        sprintf("%2d", Time(0L)), "...",
        sprintf("%3d", Wealth(0L)), "\n")
    flush.console()
}
```

And since `cat` has a `file` argument, you can have it write such information into a logfile.

5.6.5 Selecting parameters: calling `btest` recursively

Suppose you have a strategy that depends on a parameter vector θ. For a given θ, the signal for the strategy would look like this.

```
signal <- function(theta) {
    ## compute position as a function of theta
}
```

Now suppose we do not know theta. We might want to test several values, and then keep the best one. For this, we need to call btest recursively: at a point in time *t*, the strategy simulates the results for various values for theta and chooses the best theta, according to some criterion `f`.

A useful idiom is this:

```
signal <- function(theta) {
    if (not defined theta) {
        - run btest with theta_1, ... \theta_n, select best theta
        - theta = argmin_theta f(btest(theta_i))
    }

    compute position as a function of theta
}
```

`btest` will first be invoked without θ (or `NULL`). When the function calls `signal`, θ is not defined and `signal` will call `btest` with a specified θ.

Let us look at an actual example.

```
require("tseries")
require("zoo")
require("runStats")

## tmp <- get.hist.quote("^GSPC",
##                       start = "2010-01-01",
##                       end = "2013-12-31", quote = "Close")

signal <- function(Data) {

    if (is.na(Data$N)) {
        message(Timestamp(0))

        price <- Close(n = 500)
        Ns <- c(10,20)

        Data1 <- list(N = 10, hist = 200)
        res1 <- btest(price, signal, Data = Data1, b = 200)

        Data2 <- list(N = 20, hist = 200)
```

```
        res2 <- btest(price, signal, Data = Data2, b = 200)


        message("N 10 : ", round(tail(res1$wealth, 1), 2))
        message("N 20 : ", round(tail(res2$wealth, 1), 2))

        N <- if (tail(res1$wealth, 1) > tail(res2$wealth, 1))
                 10
             else
                 20
        message("N is ---> ", N, "\n")
    } else  {
        N <- Data$N
    }

    ##
    price <- Close(n = Data$hist)
    MA <- runStats("mean", price, N = N)
    pos <- 0
    if (Close() > tail(MA, 1))
        pos <- 1
    pos
}

Data <- list(N = NA, hist = 200)
res <- btest(tmp$Close, signal,
             Data = Data,
             b = 500,
             initial.cash = 100,
             convert.weights = TRUE,
             timestamp = index(tmp))

par(mfrow = c(2,1))
plot(index(tmp), res$wealth, type = "s")
plot(tmp)
```

6 Rebalancing a portfolio

The function `rebalance` computes the transactions necessary for moving from one portfolio to another.

6.1 Usage with unnamed vectors

The `current` portfolio is given in currency units; the `target` portfolio is given in weights. To compute the required order sizes, we also need the current prices of the assets. When `current`, `target` and `price` are unnamed, the assets' positions in the vectors need to match.

```
current <- c(0,0,100,100)
prices  <- c(1,1,1,1)
target  <- c(0.25, 0.25, 0.25, 0.25)
rebalance(current, target, prices, match.names = FALSE)
```

```
  price current value    %       target value    %       order
1     1       0     0  0.0           50    50 25.0
50
2     1       0     0  0.0           50    50 25.0
50
3     1     100   100 50.0           50    50 25.0
-50
4     1     100   100 50.0           50    50 25.0
-50

Notional: 200.  Amount invested: 200.  Total (2-way) turnover: 200.
```

The current portfolio may also be empty, in which case `current` can be set to 0. Then, of course, we need to specify a `notional` for the target portfolio.

```
current <- 0
rebalance(current, target, prices,
          match.names = FALSE, notional = 100)
```

```
  price current value   %       target value    %       order
1     1       0     0 0.0           25    25 25.0
25
2     1       0     0 0.0           25    25 25.0
25
```

```
3     1       0     0 0.0            25    25 25.0
25
4     1       0     0 0.0            25    25 25.0
25

Notional: 100.  Amount invested: 100.  Total (2-way) turnover: 100.
```

We may also specify the target portfolio as a single number.

```
current <- c(5, 5, 100, 100)

target <- 0    ## liquidate the portfolio
rebalance(current, target, prices, match.names = FALSE)
```

```
  price current value    %       target value   %       order
1     1       5     5  2.4            0     0 0.0
-5
2     1       5     5  2.4            0     0 0.0
-5
3     1     100   100 47.6            0     0 0.0        -100
4     1     100   100 47.6            0     0 0.0        -100

Notional: 210.  Amount invested: 0.  Total (2-way) turnover: 210.
```

```
## every assets gets a weight of 20%
target <- 0.2
rebalance(current, target, prices, match.names = FALSE, notional = 100)
```

```
  price current value     %       target value    %       order
1     1       5     5   5.0           20    20 20.0
15
2     1       5     5   5.0           20    20 20.0
15
3     1     100   100 100.0           20    20 20.0
-80
4     1     100   100 100.0           20    20 20.0
-80

Notional: 100.  Amount invested: 80.  Total (2-way) turnover: 190.
```

6.2 Usage with named vectors

More usefully, `rebalance` can also use the names of the vectors `current`, `target` and `price`. The argument `match.names` must be set to `TRUE` for this (which is the default, actually).

```
prices  <- c(1,1,1,1)
names(prices) <- letters[1:4]
current <- c(a = 0, b = 10)
target  <- c(a = 0, d = 0.5)
rebalance(current, target, prices)
```

```
  price current value     %       target value    %       order
b     1      10    10 100.0            0     0  0.0
-10
d     1       0     0   0.0            5     5 50.0
5

Notional: 10.  Amount invested: 5.  Total (2-way) turnover: 15.
```

To also show all instruments, set the argument `drop.zero` to `FALSE`.

```
print(rebalance(current, target, prices), drop.zero = FALSE)
```

```
  price current value     %       target value    %       order
a     1       0     0   0.0            0     0  0.0
0
b     1      10    10 100.0            0     0  0.0
-10
d     1       0     0   0.0            5     5 50.0
5

Notional: 10.  Amount invested: 5.  Total (2-way) turnover: 15.
```

6.3 Optimisation

Whenever you need to round positions, you may prefer to do an actual optimisation. The ideal place for this optimisation is the original objective function, not in `rebalance`. And the differences, if there are any at all, are typically small. But here is an example.

```
n <- 10
target <- runif(n)
target <- target/sum(target)
price <- sample(10:200, n, replace = TRUE)
s <- sample(c(1,5,10,100), n, replace = TRUE,
            prob = c(0.4,0.4,0.1,0.1))
data.frame(price = price, lot.size = s)
```

```
   price lot.size
1    178        5
2     37        5
```

```
3      62         5
4      93         1
5      81         5
6     111         5
7     146         5
8     154         5
9     187         1
10    138         1
```

Now suppose we have only a limited budget available.

```
budget <- 10000
x <- rebalance(0, target, notional = budget,
               price = price, match.names = FALSE)
x
```

```
   price current value   %       target value    %       order
1    178       0     0 0.0            4   712  7.1
4
2     37       0     0 0.0           40  1480 14.8
40
3     62       0     0 0.0           20  1240 12.4
20
4     93       0     0 0.0           16  1488 14.9
16
5     81       0     0 0.0           13  1053 10.5
13
6    111       0     0 0.0            6   666  6.7
6
7    146       0     0 0.0            4   584  5.8
4
8    154       0     0 0.0            6   924  9.2
6
9    187       0     0 0.0            5   935  9.3
5
10   138       0     0 0.0            7   966  9.7
7

Notional: 10000.  Amount invested: 10048.  Total (2-way) turnover: 10048.
```

Now we use `TAopt`, from the NMOF package, to find the optimal integer portfolio.

```
require("NMOF")
ediff <- function(x) {
    tmp <- x*price/budget - target
    sum(tmp*tmp)
}

neighbour <- function(x) {
```

```
    i <- sample.int(length(x), size = 1L)
    x[i] <- x[i] + if (runif(1) > 0.5) - s[i] else s[i]
    x
}

sol <- TAopt(ediff,
             algo = list(x0 = numeric(length(price)),
                         neighbour = neighbour,
                         q = 0.1,
                         nS = 1000,
                         printBar = FALSE))
```

```
Threshold Accepting.

Computing thresholds ... OK.
Estimated remaining running time: 0.23 secs.

Running Threshold Accepting...
Initial solution:  0.109341
Finished.
Best solution overall: 0.001108741
```

```
df <- data.frame(TA = sol$xbest, rounded = s*round(x$target/s))
df[apply(df, 1, function(i) any(i != 0)), ]
```

```
   TA rounded
1   5       5
2  40      40
3  20      20
4  16      16
5  15      15
6   5       5
7   5       5
8   5       5
9   5       5
10  7       7
```

The difference.

```
ediff(sol$xbest) - ediff(s*round(x$target/s))
```

```
[1] 0
```

6.4 Substituting a basket by its components

If you run tests with baskets of instruments or whole strategies, you often need to substitute the components of the basket for overall basket. PMWR provides a function

`replace_weight` that helps with this task. (It is also helpful if you have hierarchies of benchmarks or want to do a 'lookthrough' through a subportfolio within your portfolio.)

Suppose we have this weight vector:

```
w <- c(basket_1 = 0.3,
       basket_2 = 0.5,
       basket_3 = 0.2)
```

We also know what the first two baskets represent.

```
b1 <- c(a = 0.5, b = 0.2, c = 0.3)
b2 <- c(d = 0.1, e = 0.2, a = 0.7)
```

Now we can call `replace_weight`.

```
replace_weight(w,
               basket_1 = b1,
               basket_2 = b2)
```

```
basket_1::a basket_1::b basket_1::c
       0.15        0.06        0.09

basket_2::d basket_2::e basket_2::a
       0.05        0.10        0.35

   basket_3
       0.20
```

If the names of the baskets or of the things in the baskets have spaces or other characters that cause trouble, quote them.

```
replace_weight(c("basket 1" = 0.3,
                 "basket 2" = 0.7),
               "basket 1" = b1,
               "basket 2" = b2)
```

7 Looking at portfolio time-series

This chapter explains the function `NAVseries`.

```
24 Jun 2013 ==> 09 Jun 2016   (695 data points, 0 NAs)
         50          68.5415
```

```
summary(tmp)
```

```
------------------------------------------------------------
24 Jun 2013 ==> 09 Jun 2016   (695 data points, 0 NAs)
         50          68.5415
------------------------------------------------------------
High                    80.04  (13 Apr 2015)
Low                     50.00  (24 Jun 2013)
------------------------------------------------------------
Return (%)               11.2  (annualised)
------------------------------------------------------------
Max. drawdown (%)        23.6
_ peak                  80.04  (13 Apr 2015)
_ trough                61.18  (11 Feb 2016)
_ underwater now (%)     14.4
------------------------------------------------------------
Volatility (%)           13.1  (annualised)
_ upside                 10.9
_ downside                7.4
------------------------------------------------------------

Monthly returns

      Jan  Feb  Mar  Apr May  Jun  Jul  Aug  Sep  Oct Nov
Dec  YTD
2013                          3.9  5.3 -1.6  5.4  3.1 1.6
1.2 20.3
2014 -1.5  5.3 -1.0  0.3 2.5 -1.0 -3.1  2.4  0.8 -0.2 4.5 -0.8
8.2
2015  9.3  5.8  2.4 -1.1 1.8 -4.5  4.0 -7.7 -3.5  7.7 2.4 -3.4 12.3
2016 -5.6 -2.8  1.3 -1.1 3.7 -1.7
-6.3
```

8 Plotting irregularly-spaced series during trading hours

8.1 An example

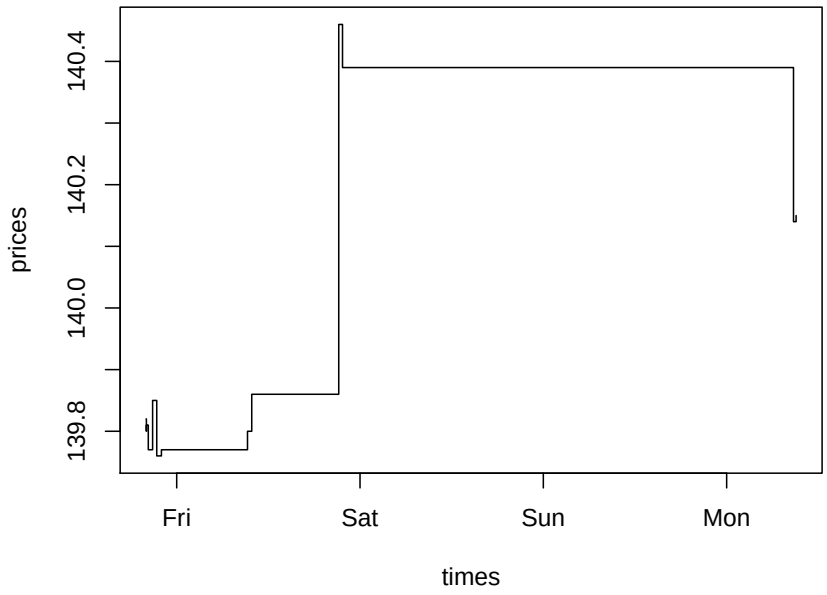
We have the following sample of prices of the Bund future contract, traded at the Eurex in Germany.

times	prices
2012-10-18 20:00:09	139.82
2012-10-18 20:01:11	139.82
2012-10-18 20:01:59	139.8
2012-10-18 20:01:29	139.81
2012-10-18 20:16:49	139.77
2012-10-18 20:50:49	139.85
2012-10-18 21:23:19	139.76
2012-10-18 21:41:39	139.76
2012-10-18 21:59:59	139.77
2012-10-19 09:16:10	139.8
2012-10-19 09:49:31	139.86
2012-10-19 21:12:49	140.46
2012-10-19 21:42:31	140.39
2012-10-22 08:45:15	140.14
2012-10-22 09:05:33	140.15

Note that I have left the time zone to the operating system. Since my computer is typically located in the time zone that the `tz database` (`http://www.iana.org/time-zones`) calls 'Europe/Berlin', the first time should be `2012-10-18 20:00:09`. If, for instance, your computer is in 'America/Chicago' instead and you run the above code, the first time would be `2012-10-18 13:00:09`. Which is right: it is the correct time, only translated into Chicago local time.

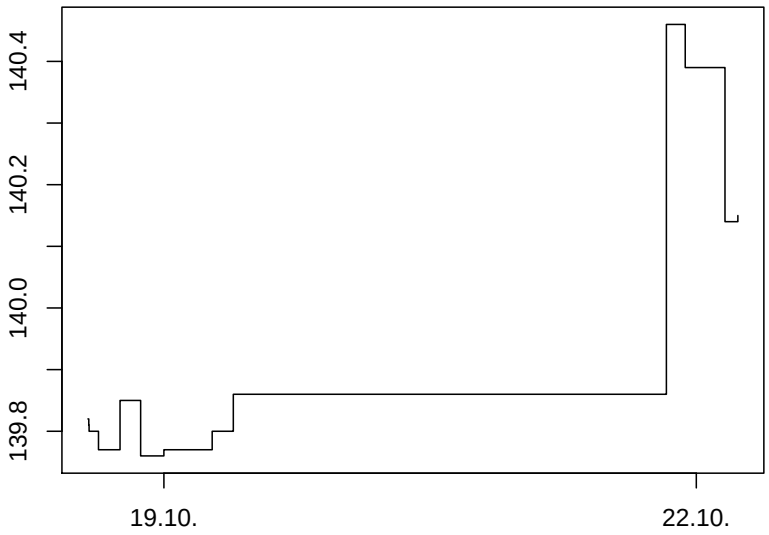
A `plot` of price against time looks like this.

```
plot(times, prices, type = "s")
```



Such a plot is fine for many purposes. But the contract for which we have prices is only traded from Monday to Friday, not on weekends, and it istraded only from 08:00 to 22:00 Europe/Berlin time. So the plot should omit those times at which no trading takes place. This is what the function `plotTradingHours` does.

```
tmp <- plotTradingHours(x = prices, t = times,
                        interval = "1 sec", labels = "day",
                        fromHHMMSS = "080000", toHHMMSS = "220000",
                        type = "s")
```



What we need for such a plot is a function that maps actual time to a point on the x-scale, while the y-scale stays unchanged. If we were talking only about days, not times, we needed something like this:

day	x-position	mapped x-position
Thursday	1	1
Friday	2	2
Saturday	3	<removed>
Sunday	4	<removed>
Monday	5	3

This mapping is what `plotTradingHours` provides. And not much more: the design goal of the function is to make it as much as possible an ordinary plot; or more specifically, to make it as similar as possible to the `plot` function. Indeed, `plotTradingHours` calls `plot` with a small number of default settings:

```
list(type = "l", xaxt = "n", xlab = "", ylab = "")
```

These settings can all be overridden through the `...` argument, which is passed to `plot`. Note that we already set `s` as the plot's `type` in the last code chunk. The only required setting is suppressing the x-axis with setting `xaxt` to 'n', because `plotTradingHours` will create its own x-axis via a call to `axis(1, ...)`. In case you wish to use your own axis specification, either set `do.plotAxis` to `FALSE` or pass settings to `axis` through the list `axis1.par`.

8.2 More examples

8.2.1 Value of `plotTradingHours`

Like `plot`, `plotTradingHours` is typically called for its side effect: creating a plot. But it also returns useful information (invisibly, unless called with `do.plot = FALSE`).

```
str(tmp)
```

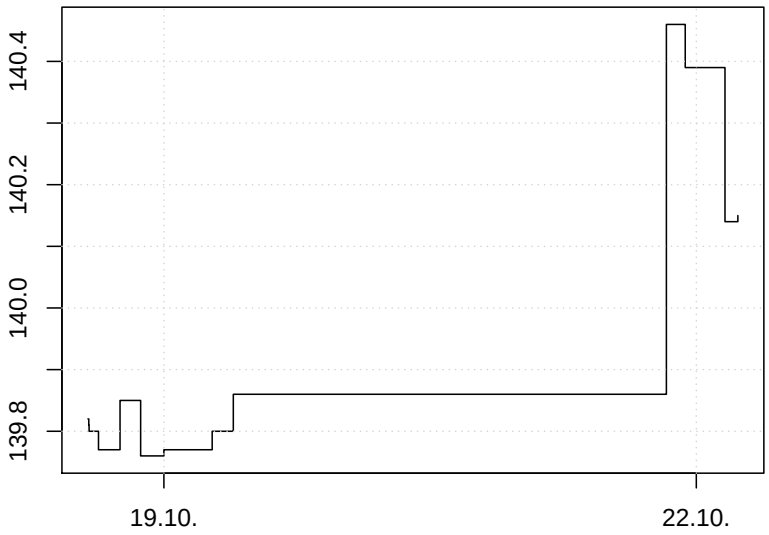
```
List of 6
 $ t          : int [1:15] 1 63 81 111 1001 3041 4991 6091 7191 11763 ...
 $ x          : num [1:15] 140 140 140 140 140 ...
 $ axis.pos   : num [1:2] 7193 57594
 $ axis.labels: chr [1:2] "19.10." "22.10."
 $ timegrid   : POSIXct[1:61527], format: "2012-10-18 20:00:09" ...
 $ map        : function (t)
```

This information can be used to add elements to plots. An example follows.

8.2.2 Adding grid lines

We can add grid lines with `abline`. The y-axis poses no special problem. The positions of the x-axis ticks are returned from `plotTradingHours`.

```
tmp <- plotTradingHours(x = prices, t = times,
                        interval = "1 sec",
                        labels = "day",
                        fromHHMMSS="080000",
                        toHHMMSS = "220000",
                        type = "s")
abline(h = axTicks(2), v = tmp$axis.pos,
       col = "lightgrey", lty = "dotted")
```



If we wan to add to a specific time, say 19 October, 13:10:23, we can use the function `map` that the call to `plotTradingHours` returns. We first create the specific time with, for example, `ISOdatetime` or `strptime`.

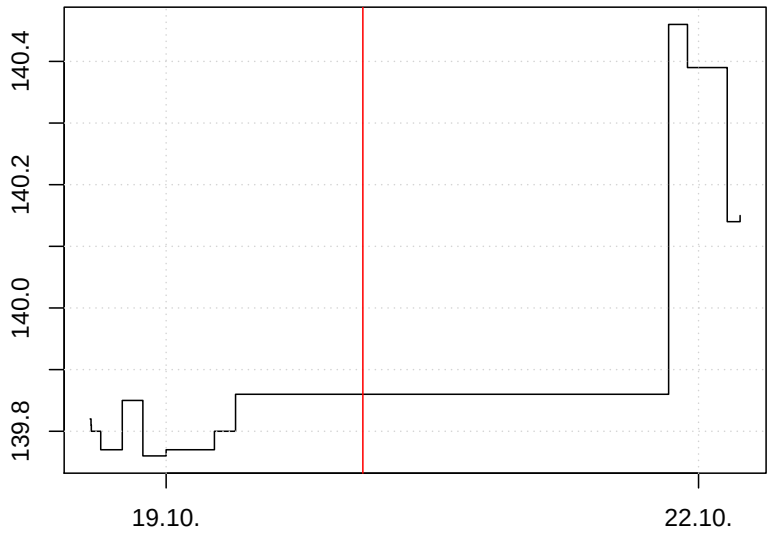
```
## Again, I do not specify a time zone since time zones
## depend on the operating system. To reproduce the
## example, you may use this representation:
##
## mytime <- structure(1350645023,
##                     class = c("POSIXct", "POSIXt"),
##                     tzone = "")

mytime <- ISOdatetime(2012, 10, 19, 13, 10, 23)
mytime
```

```
[1] "2012-10-19 13:10:23 CEST"
```

Now we use `map` to translate this time into the appropriate x-position.

```
tmp <- plotTradingHours(x = prices, t = times,
                        interval = "1 sec", labels = "day",
                        fromHHMMSS="080000",
                        toHHMMSS = "220000",
                        type = "s")
abline(h = axTicks(2), v = tmp$axis.pos,
       col = "lightgrey", lty = "dotted")
abline(v = tmp$map(mytime)$t, col = "red")
```



The function `map` returns a list with two components, `t` and `ix`.

```
tmp$map(mytime)
```

```
$t
[1] 25816

$ix
[1] 1
```

The first component is the appropriate position on the x-axis; since it is a time it is called `t`. The second component gives the subscripts to values that should actually be plotted. As an example, suppose that we wish to plot points at several prices at 21:00:00 for several days.

```
## moretimes <- structure(c(1350586800, 1350673200, 1350759600),
##                        class = c("POSIXct", "POSIXt"), tzone = "")
##

moretimes <- ISOdatetime(2012, 10, 18:20, 21, 00, 00)
values <- seq(140, 140.20, length.out = length(moretimes))
data.frame(times = moretimes,
           weekday = format(moretimes, "%A"),
           values)
```

```
                times  weekday values
1 2012-10-18 21:00:00 Thursday  140.0
```

```
2 2012-10-19 21:00:00   Friday  140.1
3 2012-10-20 21:00:00 Saturday  140.2
```

But 20 October 2012 falls on a Saturday, and so it does not appear in the plot.

```
tmp$map(moretimes)
```

```
$t
[1]  3592 53993

$ix
[1] 1 2
```

The values that should be plotted can conveniently be found by using `ix`.

```
values[tmp$map(moretimes)$ix]
```

```
[1] 140.0 140.1
```

9 Valuation

Computing the value of a position is, in principle, straightforward: multiply the prices of assets by the numbers of contracts you hold and sum the resulting values.

That immediately leads to three questions:

1. What is price?
2. What is a contract?
3. Can we really sum?

9.1 Prices

Valuing an instrument can mean using either a market price or a theoretical price. In the discussion that follows, I will assume that we already have prices (or net-present values).

10 Analysing trades

10.1 Exposure

We have the following trades and times.

```
amount <- c(1,3,-3,1,-3,1)
time <- c(0,1,3,4,7,12)
```

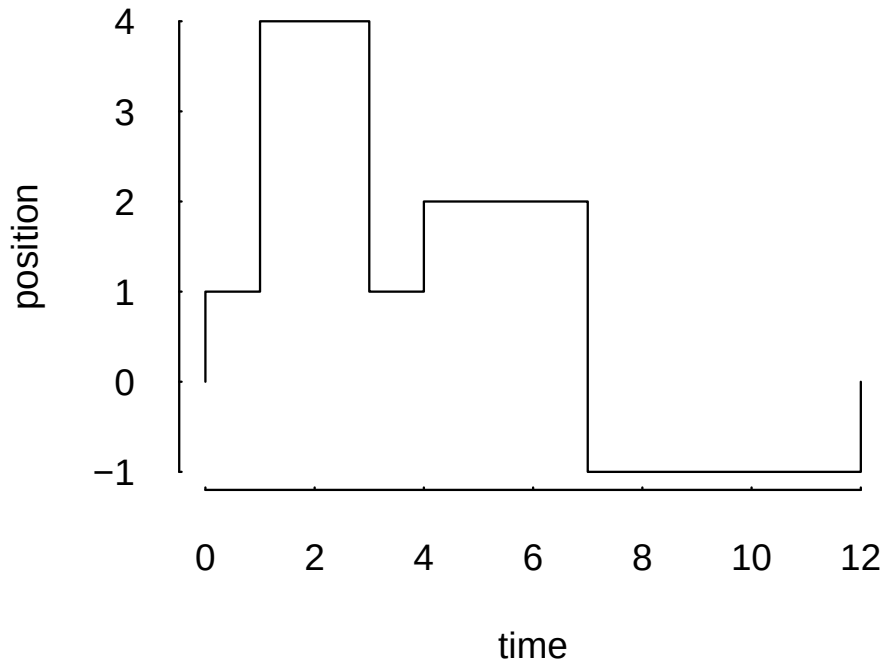
The holding period (duration) of these trades can be computed so:

```
data.frame(position = cumsum(amount)[-length(amount)],
           from = time[-length(time)],
           to   = time[-1L],
           duration = diff(time))
```

```
     position from to duration
1         1    0  1        1
2         4    1  3        2
3         1    3  4        1
4         2    4  7        3
5        -1    7 12        5
```

We can plot the exposure.

```
par(bty = "n", mar = c(4, 4, 0, 0), tck = 0.005,
    las = 1, ps = 12)
plot(c(time[1], time), cumsum(c(0, amount)),
     type = "s", xlab = "time", ylab = "position")
```



Thus, we have had a position from time zero to 12 (hours into the trading day, say), but its size varied. The function `twExposure` (time-weighted exposure) computes the average absolute exposure.

```
twExposure(amount, time)
```

```
1.75
```

To give a simple example: suppose we bought at the open of a trading day and sold at noon. The average exposure for the day is thus half a contract.

```
amount <- c(1, -1 , 0)
time   <- c(0,0.5,1)
twExposure(amount, time)
```

```
0.5
```

10.2 Splitting and rescaling

Suppose we have the following trades and impose a limit that the maximum absolute exposure for the trader should only be 2.

```
t <- 1:6
n <- c(-1,-1,-1,1,1,1)
p <- c(100,99,98,98,99,100)
limit(n, p, t, lim = 2)
```

```
$amount
[1] -1 -1  1  1

$price
[1] 100  99  99 100

$timestamp
[1] 1 2 5 6
```

Scaling the trades.

```
scaleToUnity(n)
```

```
[1] -0.333 -0.333 -0.333  0.333  0.333  0.333
```

Closing the trade at once.

```
closeOnFirst(n)
```

```
[1] -1 -1 -1  3  0  0
```

11 Scaling series

Visual comparisons of time-series are ubiquitous in finance.[1] The function `scale1` helps with scaling the levels of time-series so that is becomes easier to compare them. It is a generic function, and `PMwR` provides methods for numeric vectors/matrices, and for `zoo` and `NAVseries` objects.

11.1 Examples

To explain what the function does, we use two very short time-series: the values of the DAX, the German stock-market index, and the REXP, a German government-bond index, from 2 January and 8 January 2014 (just 5 days).

```
dax <- c(9400.04, 9435.15, 9428, 9506.2, 9497.84)
rex <-c(440.5252, 440.7944, 441.5456, 441.8197, 441.7619)
X <- cbind(dax, rex)
scale1(dax)
```

```
[1] 1.00 1.00 1.00 1.01 1.01
```

It may be more common to scale to a level of 100. We either multiply the whole series by 100, or use the `level` argument.

```
scale1(dax, level = 100)
```

```
[1] 100 100 100 101 101
```

If we give a matrix to `scale1`, the function scales each column separately.

```
scale1(X, level = 100)
```

```
     dax rex
[1,] 100 100
[2,] 100 100
[3,] 100 100
[4,] 101 100
[5,] 101 100
```

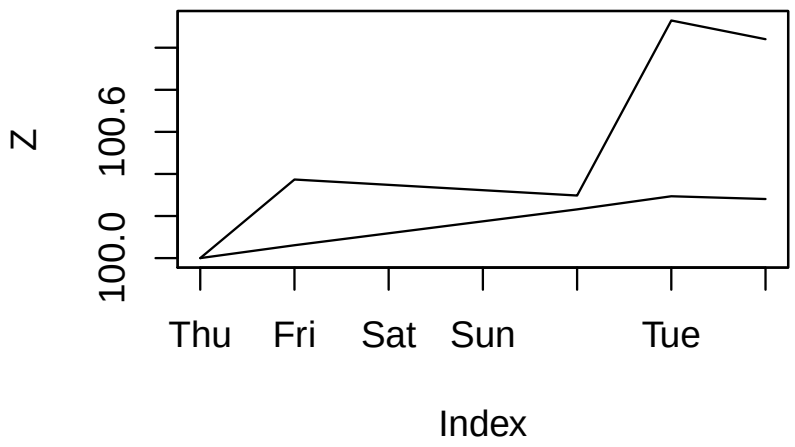
[1] Transformating or scaling data are a key element of exploratory data analysis in general. See Tukey's EDA (1977). TODO: find H. Simon reference on scaling (taking reciprocal value).

scale1 also works with zoo objects.

```
(Z <-scale1(zoo(X, as.Date(c("2014-01-02", "2014-01-03", "2014-01-06",
                             "2014-01-07", "2014-01-08"))),
            level = 100))
```

```
             dax rex
2014-01-02 100 100
2014-01-03 100 100
2014-01-06 100 100
2014-01-07 101 100
2014-01-08 101 100
```

```
plot(Z, plot.type = "single")
```



The argument when defines the origin.

```
scale1(X, when = 3, level = 100)
```

```
       dax   rex
[1,]  99.7  99.8
[2,] 100.1  99.8
[3,] 100.0 100.0
[4,] 100.8 100.1
[5,] 100.7 100.0
```

With zoo objects, when should be compatible with the class of the objects index.

```
scale1(Z, when = as.Date("2014-01-07"), level = 100)
```

```
              dax   rex
2014-01-02  98.9  99.7
2014-01-03  99.3  99.8
2014-01-06  99.2  99.9
2014-01-07 100.0 100.0
2014-01-08  99.9 100.0
```

when also understands the keyword `first.complete`, which is actually the default. That is useful when series have different lengths.

```
X[1:2, 1] <- NA
X
```

```
      dax rex
[1,]   NA 441
[2,]   NA 441
[3,] 9428 442
[4,] 9506 442
[5,] 9498 442
```

```
scale1(X, level = 100) ## 'first.complete' is the default
```

```
     dax   rex
[1,]  NA  99.8
[2,]  NA  99.8
[3,] 100 100.0
[4,] 101 100.1
[5,] 101 100.0
```

When the argument `centre` is `TRUE`, the daily mean *return* is subtracted.

```
scale1(Z, centre = TRUE)
```

```
              dax rex
2014-01-02 1.000   1
2014-01-03 1.001   1
2014-01-06 0.998   1
2014-01-07 1.003   1
2014-01-08 1.000   1
```

The argument `scale` takes a standard deviation and scales the *returns* to that standard deviation.

```
apply(returns(scale1(Z, scale = 0.02)), 2, sd)
```

```
 dax  rex
0.02 0.02
```

This may create fairer comparisons, for instance, between fund prices that exhibit very different volatilities.

```
scale1(Z, scale = 0.02)
```

```
            dax  rex
2014-01-02 1.00 1.00
2014-01-03 1.02 1.02
2014-01-06 1.01 1.06
2014-01-07 1.05 1.08
2014-01-08 1.05 1.08
```

It should be stressed that `centre` and `scale` treat ***returns***, but `scale1` expects and returns ***levels*** (not returns).

The zoo method has a further argument that affects returns: `inflate`.

```
d <- seq(from = as.Date("2015-1-1"),
         to = as.Date("2016-1-1"),
         by = "1 day")
z <- zoo(100, d)
head(z)
tail(z)
```

```
2015-01-01 2015-01-02 2015-01-03 2015-01-04 2015-01-05 2015-01-06
       100        100        100        100        100
100
2015-12-27 2015-12-28 2015-12-29 2015-12-30 2015-12-31 2016-01-01
       100        100        100        100        100
100
```

The argument should be a numeric value: the annual growth rate that is added to (or subtracted from, when negative) the time series.

```
head(scale1(z, inflate = 0.02))
tail(scale1(z, inflate = 0.02))
```

```
2015-01-01 2015-01-02 2015-01-03 2015-01-04 2015-01-05 2015-01-06
         1          1          1          1          1
1
2015-12-27 2015-12-28 2015-12-29 2015-12-30 2015-12-31 2016-01-01
      1.02       1.02       1.02       1.02       1.02
1.02
```

11.2 Scaling a series

The previous section provided examples of scaling series. In this section, we are going to see how `scale1` does its computations.

Changing **volatility** (the `scale` argument) uses the fact that multiplying a random variable X by a factor b changes its variance to b^2 times the original variance. Hence, we first divide by the actual standard deviation and then multiply by the desired one.

Changing **returns** is slightly more complicated. Suppose we want to scale the total return of the series X such that it equals r_T^*.

$$(1 + r_1)(1 + r_2)(1 + r_3) \cdots = 1 + r_T \tag{11.1}$$

There is, clearly, an infinity of possible adjustments that would do the trick. We might, for instance, change X_1 or X_T so that the desired return is achieved; but then we could go on an change two or more elements such there total contribution cancels.

But that is probably not what we want. In fact, a reasonable requirement is that the scaling touches as few of other statistical properties as possible. Adding a constant z to the return in every period does that. It has the additional advantage that it neither changes linear

$$(1 + r_1 + z)(1 + r_2 + z)(1 + r_3 + z) \cdots = 1 + r_T^* \tag{11.2}$$

12 Other Tools

12.1 Dividend adjustments

The function `div_adjust` corrects price series for dividends. It is meant as a low-level function and is implemented to work on numeric vectors. Consider a hypothetical price series `x`, which goes ex-dividend at time `3`.

```
x <- c(9.777, 10.04, 9.207, 9.406)
div <- 0.7
t <- 3
```

The default for `div_adjust` is to match the final price.

```
div_adjust(x, t, div)
```

```
[1] 9.086185 9.330603 9.207000 9.406000
```

If you prefer a correction that matches the first price, set argument `backward` to `FALSE`.

```
div_adjust(x, t, div, backward = FALSE)
```

```
[1]  9.77700 10.04000  9.90700 10.12113
```

12.2 Stocks splits

The function `split_adjust` handles stock splits. It is implemented to work on numeric vectors.

12.3 Treasuries quotes

US treasury bonds are often quoted in 1/32nds of points. For instance, the price `110'030` would mean `110+3/32`. The function `quote32` provides a way to 'pretty-print' such prices.

```
quote32(c("110-235", "110-237"))
```

```
110-23+
110-23¾
```

Internally, `quote32` will store the prices as numeric values: the fractions are only used for printing.

```
as.numeric(quote32(c("110-235", "110-237")))
```

```
[1] 110.7812 110.8125
```

13 FAQ/FRC (Frequently-required computations)

I need to compute P/L between two points in time, for instance between yesterday's evening close and now (intraday).

You need the position at t_1 and the journal of trades between t_1 and t_2. Also, you will need the valuation prices for all instruments at both points in time. Then, you can use `pl`: see arguments `initial.position` and `vprice`.

I want to compute `returns` *when a portfolio (specified as weights) is rebalanced at specific times. However, I only have returns for the assets in the portfolio, not prices.*

Compute artificial prices, and then use `returns`: see arguments `weights` and `rebalance.when`.

I have a list of trades (bought or sold what, when and at what price) and I need to compute the profit or loss.

See `pl`.

I have a list of trades in an instrument and want to plot these trades against the price of the traded instrument.

I have a signal series (`+1`, `0`, `0`, `+1`, *...) and need to transform it into a profit-and-loss series.*

I have a list of trades and need to determine the profit-and-loss between two timestamps.

Call the two timestamps `t0` and `t1`. Unless the position was zero at to and t1, we can compute the profit/loss only if we have prices for the positions at these points in time. In case the position was indeed zero, you can use `pl`; the transactions are stored in a journal `j`.

```
subset(j, timestamp >= t0 & timestamp <=t1)
```

But even the more general case is not so complicated, after all.

1. Compute the position at `t0` and make it a journal jo.
2. Take all transactions at $t > t_0$ and $t \leq t_1$ and put them into a journal J.
3. Compute the position at t_1, and make it a journal J_1, but *multiply all amounts by* -1.
4. Combine J_0, J, and J_1 and compute the PL.

I need to determine the month-to-date profit-and-loss.

1. compute position on last day of last month
2. make journal from position (add prices)
3. combine with journal since month start
4. use average (avg) on all instruments

`btest`*: I want to print my current P/L in every period.*

Use `print.info`.

`btest`*: I invest in assets that pay accrued interest.*

Directly work with the dirty prices. If the signals depend on clean prices, pass them as extra information and access them with `clean_price[Time()]`. Alternatively, work with the clean prices, and use `cashflow` to add the accrued interest to the cash account.

14 Appendix: R/package versions used

```
R version 3.4.0 (2017-04-21)
Platform: x86_64-pc-linux-gnu (64-bit)
Running under: Ubuntu 16.10

Matrix products: default
BLAS: /usr/lib/libblas/libblas.so.3.6.1
LAPACK: /usr/lib/lapack/liblapack.so.3.6.1

locale:
 [1] LC_CTYPE=en_US.UTF-8       LC_NUMERIC=C
 [3] LC_TIME=en_GB.UTF-8        LC_COLLATE=en_US.UTF-8
 [5] LC_MONETARY=en_GB.UTF-8    LC_MESSAGES=en_US.UTF-8
 [7] LC_PAPER=en_GB.UTF-8       LC_NAME=C
 [9] LC_ADDRESS=C               LC_TELEPHONE=C
[11] LC_MEASUREMENT=en_GB.UTF-8 LC_IDENTIFICATION=C

attached base packages:
[1] stats     graphics  grDevices utils     datasets  methods
base

other attached packages:
[1] zoo_1.7-14 PMwR_0.4-3 tsdb_0.4-3

loaded via a namespace (and not attached):
 [1] datetimeutils_0.1-5 compiler_3.4.0      parallel_3.4.0
 [4] tools_3.4.0         DBI_0.6             crayon_1.3.2
 [7] fastmatch_1.1-0     NMOF_1.1-0          grid_3.4.0
[10] orgutils_0.4-1      textutils_0.1-7     lattice_0.20-35
```

Bibliography

[1] Dirk Eddelbuettel. *nanotime: Nanosecond-Resolution Time for R*. R package version 0.1.0. 2017. URL: https://CRAN.R-project.org/package=nanotime.

[2] Manfred Gilli, Dietmar Maringer, and Enrico Schumann. *Numerical Methods and Optimization in Finance*. Elsevier/Academic Press, 2011. URL: http://nmof.net.

[3] Enrico Schumann. *Numerical Methods and Optimization in Finance (NMOF) – Manual (Package version 1.1-0)*. 2011–2017. URL: http://enricoschumann.net/NMOF.htm#NMOFmanual.

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