CHR: DYNAMIC FUNCTIONAL CONSTRAINTS CHECKING IN R

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Abstract

Dynamic typing of R programming language may issue some quality problems in large scale data-science and machine-learning projects for which the language is used. Following our efforts on providing gradual typing library for Clojure we come with a package *chR* - a library that offers functionality of run-time type-related checks in R. The solution is not only a dynamic type checker, it also helps to systematize thinking about types in the language, at the same time offering high expressiveness and full adherence to functional programming style.

Keywords: Formal software verification, software quality, dynamic type-checking, functional programming, category theory, R

1 Introduction

Writing software in dynamically typed programming languages requires as much attention with respect to types of expressions as when using a statically and strongly typed one ([2], [1]). One popular and apparently natural approach is to use gradual typing - a process of selectively adding type checks to expressions, mostly to the critical parts of computer programs. With the approach a programmer can decide where to put checks and which parts are so “obvious”, that they do not have to be verified.

R programming language [5] has been growing in use in recent years, together with a growth of computer science and software engineering sub-domains to which it has been targeted: data science and statistical- (more broadly machine-) learning. Unfortunately, it lacks a decent type-checking solution. The great *assertthat* package [7] addresses a slightly different problem: putting generic run-time assertions into R codes. We need a package with the following properties:

- being deeply rooted in functional programming [4] and using notions from the category theory

- overall consistency with the dynamic and in a way Lispy nature of R programming language and adherence to functional programming style with purrr library [6]
- being as fast as possible, using checks that use as low-level elements of the R base (standard library) as possible
- expressiveness, ease of use, and extendability

Our previous work on dependent typing resulted in a *ch* library ([11], [12], [13]) for Clojure programming language ([8], [9]). Following that we decided to create a corresponding package for R. The package is called *chR* [10] and it is a subject of further analysis in this paper.

2 Essentials of the chR Library

The heart of our solution is *ch* procedure. In essence it executes a predicate (*pred*) on an argument *x*. If the predicate returns *false* value (or a value effectively) effectively equal to *false*, an error is raised. Otherwise *x* is returned. This behavior allows a greater composability and support for functional programming style. We may easily put any *ch(eck)* in a pipeline of data processing procedures, as will be presented further.

Procedure *ch* works also in a predicate-only mode. This mode is necessary when a *ch(eck)* is used as a sub-component of a larger one. Below we have the *ch* code together with an error generator (*errMessage*):

```
errMessage <- function(x) {
  r <- paste(capture.output(str(x)), collapse = "\n")
  paste0(" ch(eck) failed on\n", r)
}

#' Executes a ch(eck) of pred on x
#' @export
ch <- function(pred, x, asPred = FALSE) {
  r <- pred(x)
  if (asPred) return(r)
  if (!r) stop(errMessage(x))
  x
}
```

Effective use of *chR* library starts with the following procedure that takes a predicate and returns a corresponding *ch(eck)*. The returned *ch(eck)* takes an argument *x* and applies *ch* working by default in non-pred mode:

```
#' Returns a ch(eck) based on the pred
#' @export
chP <- function(pred) {
  function(x, asPred = FALSE) ch(pred, x, asPred)
}
```

For classes in R we have a *chInstance* *ch(eck)s* generator that uses a common *inherits* procedure belonging to R base:

```
## Returns a \code{inherits(., cls)} ch(eck)
## @export
chInstance <- function(class) chP(function(x)
  inherits(x, class))
```

An intrinsic property of an expressive language (including an embedded one) is composability. Our *ch(eck)s* compose. The three composition operators are logic-oriented and they reflect the most basic logical operations. We have negation:

```
## Returns a ch(eck) that is a negation of the passed ch(eck)
## @export
chNot <- function(c) chP(function(x)
  !c(x, asPred = TRUE))
```

Also, there is conjunction:

```
## Returns a ch(eck) that &s all the passed ch(eck)s
## @export
chAnd <- function(...) {
  chs <- list(...)
  chP(function(x) {
    for (c in chs) if (!c(x, asPred = TRUE)) return (FALSE)
    TRUE
  })
}
```

and alternative:

```
## Returns a ch(eck) that /s all the passed ch(eck)s
## @export
chOr <- function(...) {
  chs <- list(...)
  chP(function(x) {
    for (c in chs) if (c(x, asPred = TRUE)) return (TRUE)
    FALSE
  })
}
```

In the two latter ones we assume a non-restricted number of composed *ch(eck)s*.

3 Fundamental Ch(eck)s

Many functional programming languages rooted in category theory ([3]), e.g. Haskell, use a unit type and unit value. Although R fully supports functional style of program-

ming, it does not unify notion of no-values. We made an arbitrary decision to treat NULL as unit value. The decision was based upon pragmatics in the technology. A corresponding `ch(eck)` follows:

```
#' \code{is.null} ch(eck)
#' @export
chUnit <- chP(is.null)

#' \code{!is.null} ch(eck)
#' @export
chSome <- chP(function(x) !is.null(x))
```

The `chSome` `ch(eck)` is an opposite to `chUnit`, as can be seen above. In R programming language we have both NULL as well as NA values. Thus, a separate `ch(eck)` for NAs is needed:

```
#' \code{is.na} ch(eck)
#' @export
chNA <- chAnd(chScalar, chP(is.na))
```

For two-element *Discriminated Union Types* we have the following `chEither` `ch(eck)`:

```
#' Either ch(eck) where the left and right types are
#' expressed by checks cl and cr
#' @export
chEither <- function(cl, cr, x, asPred = FALSE)
  chOr(cl, cr)(x, asPred)
```

that used with `chUnit` forms a *Maybe* `ch(eck)`:

```
#' Maybe ch(eck)
#' @export
chMaybe <- function(c, x, asPred = FALSE)
  chEither(chUnit, c, x, asPred)
```

Because R uses only vectorized values (and lists), we need `ch(eck)`s for scalars, hereby treated as one-element atoms (vectors):

```
#' Scalar \code{is.atomic} & \code{length == 1L}
#' value ch(eck)
#' @export
chScalar <- chP(function(x)
  is.atomic(x) && length(x) == 1L)
```

With the new `ch(eck)` we can define e.g. a `ch(eck)` for either a String vector of any length or a single String:

```

#' \code{is.character} ch(eck)
#' @export
chStrings <- chP(is.character)

#' \code{chScalar} & \code{chStrings} ch(eck)
#' @export
chString <- chAnd(chScalar, chStrings)

```

Another essential `ch(eck)` is for R functions:

```

#' \code{is.function} ch(eck)
#' @export
chFun <- chP(is.function)

```

This shortened presentation ends a section about the most common `ch(ecks)` in *chR* library. For more, please read Appendix A.

4 Registry of Ch(eck)s

Additionally the *chR* library (like its ancestor *ch* for Clojure) provides a registry of `ch(eck)s`, that helps the programmer to understand, what kind of `ch(eck)s` an object or a collection of objects fulfill. The registry is an associative container that can be used to put a relation between a `ch(eck)` symbol (name) and the `ch(eck)`:

```

CHSREG <- list()

#' Registeres the ch(eck) using an optional name
#' (ch(eck) name by default)
#' @export
chReg <- function(ch, name = NA) { # BEWARE: THREAD UNSAFE
  if (is.na(name)) name <- as.character(substitute(ch))
  CHSREG[[as.character(name)]] <- as.function(ch)
  NULL
}

```

After we register selected `ch(eck)s` like below:

```

chReg(chUnit)
chReg(chScalar)
chReg(chString)
chReg(chStrings)
chReg(chFun)

```

we can ask the library about what kinds of `ch(eck)s` a given object fulfills:

```
chR::chs(1:10)

[1] "chAtomic"    "chInts"      "chNatInts"
[4] "chNumerics" "chPosInts"   "chSome"
[7] "chVector"
```

5 Supporting C++ Codes (via Rcpp)

Some of the *ch*(eck)s are better implemented in a low-level programming language. Thankfully R supports easy extensions in C++ written in effective library Rcpp. In *chR* the following procedure is defined to allow evaluation of predicates on vectors of any (presumably numeric) types:

```
template<typename V, typename F>
static inline bool everyInVector(const V xs,
                                const F&& pred) {
    const int n = xs.size();
    for (int i = 0; i < n; i++)
        if (!pred(xs[i])) return false;

    return true;
}
```

The procedure is used to implement the predicates on vectors of doubles, as presented below:

```
/// Returns true iff all the xs are positive
/// @param xs vector to check
/// @return true or false
/// @export
// [[Rcpp::export]]
bool arePosDoubles(const DoubleVector xs) {
    return everyInVector(xs, [](double d)
        { return d > 0; });
}

/// Returns true iff all the xs are negative
/// @param xs vector to check
/// @return true or false
/// @export
// [[Rcpp::export]]
bool areNegDoubles(const DoubleVector xs) {
    return everyInVector(xs, [](double d)
        { return d < 0; });
}
```

```
/// Returns true iff all the xs are non-negative
/// @param xs vector to check
/// @return true or false
/// @export
// [[Rcpp::export]]
bool areNonNegDoubles(const DoubleVector xs) {
    return everyInVector(xs, [](double d)
        { return d >= 0; });
}
```

Accordingly, there are the preds for *IntegerVector*:

```
/// Returns true iff all the xs are positive
/// @param xs vector to check
/// @return true or false
/// @export
// [[Rcpp::export]]
bool arePosInts(const IntegerVector xs) {
    return everyInVector(xs, [](int n)
        { return n > 0; });
}

/// Returns true iff all the xs are negative
/// @param xs vector to check
/// @return true or false
/// @export
// [[Rcpp::export]]
bool areNegInts(const IntegerVector xs) {
    return everyInVector(xs, [](int n)
        { return n < 0; });
}

/// Returns true iff all the xs are naturals (>= 0)
/// @param xs vector to check
/// @return true or false
/// @export
// [[Rcpp::export]]
bool areNatInts(const IntegerVector xs) {
    return everyInVector(xs, [](int n)
        { return n >= 0; });
}
```

What's interesting is use of C++ lambdas in the procedures above. They are no-cost and highly expressive. Their use is possible in C++11 and above. Current Rcpp implementation supports that language standard.

6 Cases of Use in Production Setting

Our library is currently used in at least three commercial products. The usefulness of `ch(eck)s` can be seen in the following procedure, whose goal is to read employees' absences information in a business intelligence project:

```
readAbsences <- function(file) chDT({
  chString(file)
  absncs <- fread(file) %>%
    assertDTcolnames (ABSENCES_PROPS)

  for (p in ABSENCES_DATE_PROPS)
    set (absncs, j = p, value =
      parseDates (parse_character (absncs[[p]])))

  absncs %>% setDTcolorder (ABSENCES_PROPS)
  setkey (absncs, "Employee Number")
  absncs
})
```

The argument *file* is intended to be a String (`chString(file)` `ch(eck)`) and the result of the procedure is a *data.table* object (`chDT({...})` `ch(eck)`). Apparently, the system of `ch(eck)s` not only increases software correctness, but also has a positive impact on readability of codes.

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A Appendix: Selected Pre-defined Ch(eck)s

```
#' \code{is.logical} ch(eck)
#' @export
chBools <- chP(is.logical)

#' \code{chScalar} & \code{chBools} ch(eck)
#' @export
chBool <- chAnd(chScalar, chBools)

#' \code{is.integer} ch(eck)
#' @export
chInts <- chP(is.integer)

#' \code{chScalar} & \code{chInts} ch(eck)
#' @export
chInt <- chAnd(chScalar, chInts)

#' \code{is.double} ch(eck)
#' @export
chDoubles <- chP(is.double)

#' \code{chScalar} & \code{chDoubles} ch(eck)
#' @export
chDouble <- chAnd(chScalar, chDoubles)

#' \code{is.complex} ch(eck)
#' @export
chComplexes <- chP(is.complex)
```

```

#' \code{chScalar} & \code{chComplexes} ch(eck)
#' @export
chComplex <- chAnd(chScalar, chComplexes)

#' \code{is.numeric} ch(eck)
#' @export
chNumerics <- chP(is.numeric)

#' \code{chScalar} & \code{chNumerics} ch(eck)
#' @export
chNumeric <- chAnd(chScalar, chNumerics)

#' \code{chInts} & > 0 ch(eck)
#' @export
chPosInts <- chAnd(chInts, chP(arePosInts))

#' \code{chInt} & > 0 ch(eck)
#' @export
chPosInt <- chAnd(chInt, chP(arePosInts))

#' \code{chDoubles} & > 0 ch(eck)
#' @export
chPosDoubles <- chAnd(chDoubles, chP(arePosDoubles))

#' \code{chDouble} & > 0 ch(eck)
#' @export
chPosDouble <- chAnd(chDouble, chP(arePosDoubles))

#' \code{chInts} & < 0 ch(eck)
#' @export
chNegInts <- chAnd(chInts, chP(areNegInts))

#' \code{chInt} & < 0 ch(eck)
#' @export
chNegInt <- chAnd(chInt, chP(areNegInts))

#' \code{chDoubles} & < 0 ch(eck)
#' @export
chNegDoubles <- chAnd(chDoubles, chP(areNegDoubles))

#' \code{chDouble} & < 0 ch(eck)
#' @export
chNegDouble <- chAnd(chDouble, chP(areNegDoubles))

#' \code{chInts} & >= 0 ch(eck)

```

```

#' @export
chNatInts <- chAnd(chInts, chP(areNatInts))

#' \code{chInt} & >= 0 ch(eck)
#' @export
chNatInt <- chAnd(chInt, chP(areNatInts))

#' \code{chDoubles} & >= 0 ch(eck)
#' @export
chNonNegDoubles <- chAnd(chDoubles, chP(areNonNegDoubles))

#' \code{chDouble} & >= 0 ch(eck)
#' @export
chNonNegDouble <- chAnd(chDouble, chP(areNonNegDoubles))

#' \code{chInt} & even? check
#' @export
chEvenInt <- chAnd(chInt, chP(function (x) x %% 2L == 0L))

#' \code{chInt} & odd? check
#' @export
chOddInt <- chAnd(chInt, chP(function (x) x %% 2L != 0L))

#' \code{is.list} ch(eck)
#' @export
chList <- chP(is.list)

#' \code{is.vector} ch(eck)
#' @export
chVector <- chP(is.vector)

#' \code{is.factor} ch(eck)
#' @export
chFactor <- chP(is.factor)

#' \code{is.data.frame} ch(eck)
#' @export
chDF <- chP(is.data.frame)

#' \code{data.table::is.data.table} ch(eck)
#' @export
chDT <- chP(data.table::is.data.table)

#' Returns a check for the data.table having exactly
#' n rows

```

```

#' @export
chDTn <- function(n) {
  chNatInt(n)
  chAnd(chDT, chP(function(dt) nrow(dt) == n))
}

#' Returns a check for the data.table having exactly
#' 0 or n rows
#' @export
chDT0n <- function(n) {
  chNatInt(n)
  chAnd(chDT, chP(function(dt) {
    nr <- nrow(dt)
    nr == 0L || nr == n
  })))
}

#' Ch(eck) for a single-row data.table
#' @export
chDT1 <- NULL

#' Ch(eck) for an empty or single-row data.table
#' @export
chDT01 <- NULL

#' \code{ggplot2::is.ggplot} ch(eck)
#' @export
chGgplot <- chP(ggplot2::is.ggplot)

#' \code{tibble::is.tibble} ch(eck)
#' @export
chTibble <- chP(tibble::is.tibble)

#' \code{is.array} ch(eck)
#' @export
chArray <- chP(is.array)

#' \code{is.atomic} ch(eck)
#' @export
chAtomic <- chP(is.atomic)

#' \code{is.recursive} ch(eck)
#' @export
chRecursive <- chP(is.recursive)

```

```

#' \code{is.object} ch(eck)
#' @export
chObject <- chP(is.object)

#' \code{is.matrix} ch(eck)
#' @export
chMatrix <- chP(is.matrix)

#' \code{is.table} ch(eck)
#' @export
chTable <- chP(is.table)

#' \code{is.environment} ch(eck)
#' @export
chEnv <- chP(is.environment)

#' \code{is.call} ch(eck)
#' @export
chCall <- chP(is.call)

#' \code{is.expression} ch(eck)
#' @export
chExpr <- chP(is.expression)

#' \code{is.symbol} ch(eck)
#' @export
chSymbol <- chP(is.symbol)

#' \code{s == ""} ch(eck) for String,
#' deliberately not chReg-ed
#' @export
chEmptyString <- chAnd(chString, chP(function(s) s == ""))

#' \code{s != ""} ch(eck) for String,
#' deliberately not chReg-ed
#' @export
chNonEmptyString <- chNot(chEmptyString)

#' Blank-ness ch(eck) for String,
#' deliberately not chReg-ed
#' @export
chBlank <- chAnd(chString, chP(function(s)
  is.na(readr::parse_character(s))))

#' Non blank-ness ch(eck) for String,

```

```
#' deliberately not chReg-ed
#' @export
chNonBlank <- chNot(chBlank)

#' \code{lubridate::is.Date} ch(eck)
#' @export
chDates <- chP(lubridate::is.Date)

#' \code{chScalar} & \code{chDates} ch(eck)
#' @export
chDate <- chAnd(chScalar, chDates)
chReg(chDate)
```