



## ASSIGNMENT OF MASTER'S THESIS

**Title:** Improvements of the RIR bytecode toolchain  
**Student:** Bc. Jan Je men  
**Supervisor:** Ing. Petr Máj  
**Study Programme:** Informatics  
**Study Branch:** System Programming  
**Department:** Department of Theoretical Computer Science  
**Validity:** Until the end of winter semester 2018/19

### Instructions

Familiarize yourself with the R language, its bytecode compiler, and interpreter architecture. Familiarize yourself with RIR, an alternative bytecode format, compiler, and interpreter for the language. The R bytecode compiler assumes certain invariants (such as built-in meaning of control flow statements and certain operators) about the code to make the compiled code faster. Analyze similar assumptions that are used by RIR and extend RIR to use assumptions made by GNU-R as well. Identify and implement improvements to the RIR (compiler, bytecode format, and interpreter). Discuss your results.

### References

Will be provided by the supervisor.

doc. Ing. Jan Janoušek, Ph.D.  
Head of Department

prof. Ing. Pavel Tvrdík, CSc.  
Dean

Prague March 1, 2017



CZECH TECHNICAL UNIVERSITY IN PRAGUE

FACULTY OF INFORMATION TECHNOLOGY

DEPARTMENT OF THEORETICAL COMPUTER  
SCIENCE



Master's thesis

# Improvements of the RIR bytecode toolchain

*Bc. Jan Ječmen*

Supervisor: Ing. Petr Máj

April 25, 2017



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# Acknowledgements

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In Prague on April 25, 2017

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## **Citation of this thesis**

JEČMEN, Jan. *Improvements of the RIR bytecode toolchain*. Master's thesis. Czech Technical University in Prague, Faculty of Information Technology, 2017. Available also from WWW: [⟨https://github.com/JanJecmen/dip⟩](https://github.com/JanJecmen/dip).



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# Abstract

**[[abstract english]]** This is the second paragraph. Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like “Huardest gefburn”? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

**Keywords** **[[keywords en]]**



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## Abstrakt

**[[abstract czech]]** And after the second paragraph follows the third paragraph. Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like “Huardest gefburn”? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

**Klíčová slova** **[[keywords cz]]**



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# Introduction

[[write intro]]

[[cite: <https://www.tiobe.com/tiobe-index/> <http://pypl.github.io/PYPL.html>]]

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## INTRODUCTION

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**[[write about structure]]** And after the second paragraph follows the third paragraph. Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like “Huardest gefburn”? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

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## About GNU R

GNU R<sup>1</sup> is a programming language used mainly for statistical computations. It is an open-source dialect of S, an older statistical language created in 1976 by John Chambers at Bell Laboratories. R has been around from 1993 and was designed by Ross Ihaka and Robert Gentleman, both recognised statisticians. It is a part of the GNU software family and is still actively developed by the R Core Team today. It is a popular alternative to the other major implementation of the S language, S-PLUS, which is a commercial version shipped by TIBCO Software Inc. [\[\[cite\]\]](#)



**Figure 1.1:** R logo [\[\[license for r logo https://www.r-project.org/logo/\]\]](https://www.r-project.org/logo/)

R comes with a software environment built around it, which allows for easily manipulating data, carrying out computations and producing quality graphical outputs such as plots and figures. Although at heart R is used via a command line interface, there are also more user-friendly graphical IDEs available like RStudio. This, together with R's readable syntax and a vast collection of

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<sup>1</sup>Homepage: <https://www.r-project.org/>

extension packages available through CRAN makes it simple for new users to step in and start working quickly.

### 1.1 Language features of R

[[cite: <http://r.cs.purdue.edu/pub/ecoop12.pdf>]]

[[cite: <http://adv-r.had.co.nz/>]]

R is, as far as programming languages go, very interesting and has some quite unusual semantic features. It is an interpreted language, and is dynamically typed and garbage collected. It supports multiple programming paradigms: users can use procedural imperative style, but at the same time R provides an object system (more than one, in fact!) for object oriented programming, and is heavily influenced by functional programming languages, notably Scheme.

Functions are, in accordance with functional languages, first-class values, so they can be passed around as call arguments, returned as results and created dynamically at runtime. R uses lexical scoping (which it adopted from Scheme) and R functions are closures that capture their enclosing environment at creation time. Arguments are passed by value (although reference counting is implemented, so that deep copies are only created as needed e.g., when an object is modified). All actual arguments to a function are lazy evaluated by default. When applying a closure, parameters are wrapped in promises and these are only evaluated when the value is needed.

These features highlight the functional approach by minimizing side effects. However, R supports assignment which enables programmers to change function's local state by modifying its bindings and thus the imperative programming style. Also, the superassignment operator makes it possible to change non-local bindings and thus brings the side effects back into play.

The basic data type in R is a vector. Vectors are ordered collections of homogeneous values (i.e., a given vector can only hold objects of one particular type). R also provides a list type which is heterogeneous. Higher-dimensional types such as matrices and data frames, as well as objects, are built from vectors.

In R there are no scalar types, as scalar values, such as individual numbers and strings, are considered to be vectors of length one.

Atomic vectors can have one of these six types: logical, integer, double, character, complex and raw. Since R targets data analysis, special "not available" value is available for these. R encourages vectorized operations and most of R builtin functionality works with vectors element-wise, while recycling the elements as needed (e.g., when adding vectors of different lengths).

Interestingly, everything that happens in R is in fact a function call. This goes as far as arithmetic operators being just syntactic sugar for function calls, as can be seen in listing [\[\[ref\]\]](#). In this spirit, even assigning into a variable, evaluating a block of code inside curly braces or grouping expressions with parentheses translate to calling the respective functions.

```
> typeof('+')
[1] "builtin"
> '+'
function (e1, e2) .Primitive("+")
> +(1, 2)
[1] 3
> 1 + 2
[1] 3
```

**Listing 1.1:** Arithmetic operators are function calls in R

## 1.2 Why is R hard to optimize

R is very dynamic and gives the programmer a very high degree of freedom. As was mentioned before, R

[\[\[cite: https://cran.r-project.org/doc/manuals/R-lang.html section 6 and 2\]\]](https://cran.r-project.org/doc/manuals/R-lang.html)

[\[\[ dynamic, user can do anything introspection vectorized subsetting, sub-assignment delayed evaluation two different object systems r inferno some examples\]\]](#) After this fourth paragraph, we start a new paragraph sequence. Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like "Huardest gefburn"? Kjift – not at all! A blind

## 1. ABOUT GNU R

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## 1.3 Why is R slow

**[[ vanilla r uses standard repl and ast interpreter single threaded runtime type checking, coercion memory hungry, garbage collection, everything on stack, a lot of metadata and attributes everything is function call written in c, no jit by default, no native jit compiler]]** After this fourth paragraph, we start a new paragraph sequence. Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like “Huardest gefburn”? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

### 1.3.1 AST interpreter

**[[ recursive eval heavily inspired by functional programming expressions: self evaluating / closure application]]**

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### 1.3.2 BC interpreter

**[[ from when only now as default out of the box behaviour for base compiler written in R 120sth bc instructions interoperates with the normal eval, but for bytecode evaluation uses loop with switch (or threading) bytecode encoded in vector of ints, plus per object constant pool]]** **[[disassembled bytecode listing]]** This is the second paragraph. Hello, here is some text

## 1. ABOUT GNU R

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without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like “Huardest gefburn”? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

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## About RIR

**[[Introduce RIR]]** RIR<sup>2</sup> is an alternative compiler for the R language. It comes with its own internal representation, an interpreter for its bytecode and an abstract interpretation framework which provides a way to easily implement static analyses on top of the RIR bytecode.

**[[history: research project, northeastern? grants? first appearance?]]**

RIR acts as a drop-in replacement for the GNU R bytecode compiler. It requires a patched version of GNU R that makes some slight adjustments that allow the standard GNU R expression evaluator function to interface with the RIR bytecode compiler and interpreter. RIR is written in C and C++ and is compiled as a shared library that can be dynamically loaded by R.

**[[write about rir bytecode]] [[how is rir bc different]] [[optimizations, ai framework...]]**

### 2.1 Why is RIR slow

**[[TODO]]** And after the second paragraph follows the third paragraph. Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like “Huardest gefburn”? Kjift – not at all! A blind text like this

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<sup>2</sup>Homepage: <https://github.com/reactorlabs/rir>

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**[[subsection about gnur compiler assumptions]]**

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## Improvements

**[[to compiler, to ir, to interpreter, use code snippets, describe microbenchmarks, theory (threaded code...)]]** **[[everywhere: motivation - how it helped in microbenchmarks, then how in real]]** Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like “Huardest gefburn”? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

```
f <- function() {  
  i <- 10000000L  
  while (i > 0) {  
    i <- i - 1  
  }  
}  
system.time(f())[[3]] # jit everything  
t <- c()  
for (x in 1:15) t <- c(t, system.time(f())[[3]])  
mean(t[5:15]) # only include measurments after warmup
```

**Listing 3.1:** **[[write listing caption]]** microbenchmark (run with jit enable 2)

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### 3. IMPROVEMENTS

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## Evaluation

**[[discussion of results, add figures]] [[discuss interesting point in measurements - naive nbody and threading etc.]]** Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like “Huardest gefburn”? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

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And after the second paragraph follows the third paragraph. Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really?



**Figure 4.1:** [[write title]]

Is there no information? Is there a difference between this text and some nonsense like “Huardest gefburn”? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

After this fourth paragraph, we start a new paragraph sequence. Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like “Huardest gefburn”? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

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**Figure 4.2:** `[[write title]]`

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This is the second paragraph. Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like “Huardest gefburn”? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

And after the second paragraph follows the third paragraph. Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like “Huardest gefburn”? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and

#### 4. EVALUATION

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## Conclusion

**[[conclusion, future work, related work, fails - stoke etc.]]** Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like “Huardest gefburn”? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

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## CONCLUSION

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## Acronyms

<b>API</b>	Application programming interface
<b>CLI</b>	Command Line Interface
<b>CRAN</b>	The Comprehensive R Archive Network
<b>GNU</b>	GNU's Not Unix!



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## Contents of the enclosed CD

**[[contents of cd]]** After this fourth paragraph, we start a new paragraph sequence. Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like “Huardest gefburn”? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.