The TruffleRuby Compilation Pipeline

Just-in-time compiling Ruby with self-specializing ASTs and partial evaluation

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TruffleRuby basics

We wanted to build a Ruby that

- Runs idiomatic Ruby code faster
- Runs Ruby code in parallel
- Executes C extensions in a managed environment
- Adds fast and low-overhead interoperability with other languages
- Provides new tooling such as debuggers and monitoring
- Has very high compatibility with the standard implementation of Ruby

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Documents — -bash — 84×15

```
$ rbenv install truffleruby-1.0.0-rc14
$ rbenv shell truffleruby-1.0.0-rc14
$ ruby -v
truffleruby 1.0.0-rc14, like ruby 2.6.2, GraalVM CE Native [x86_64-darwin]
$
```

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demo.rb

```ruby
require 'erb'

template = ERB.new(%{
  <h1>Hello world!</h1>
  <p>The time is <%= now %></p>
})

loop do
  start = Time.now

  100_000.times do
    now = Time.now
    puts template.result(binding)
  end

  $stderr.puts Time.now - start
end
```

Line 1, Column 1 Spaces: 2 Ruby

Documents — ruby perf.rb — 84×15

```
$ rbenv shell 2.6.2
$ ruby perf.rb > /dev/null
2.165717
2.134813
2.150839
2.139991
2.145957
2.17635
2.209064
2.196461
2.183587
```

Documents — ruby --jit perf.rb — 84×15

```
$ rbenv shell 2.6.2
$ ruby --jit perf.rb > /dev/null
2.404086
2.436718
2.618684
2.391098
2.47526
2.488115
2.427324
2.407296
2.503696
```

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Documents — java -Djdk.home= -

```
$ rbenv shell jruby-9.2.6.0
$ ruby perf.rb > /dev/null
4.098946
3.117474
3.164635
3.18634
3.37483
3.305855
3.40638
3.088724
3.0775989999999998
```

Documents — java -Djdk.home= -Djruby.home=/Users/chrisseaton/.rbenv/versi

```
$ rbenv shell jruby-9.2.6.0
$ ruby -Xcompile.invokedynamic=true perf.rb > /dev/null
3.8451880000000003
2.939869
3.010014
3.177851
3.1914369999999996
3.366082
2.927472
2.95315
2.990667
```

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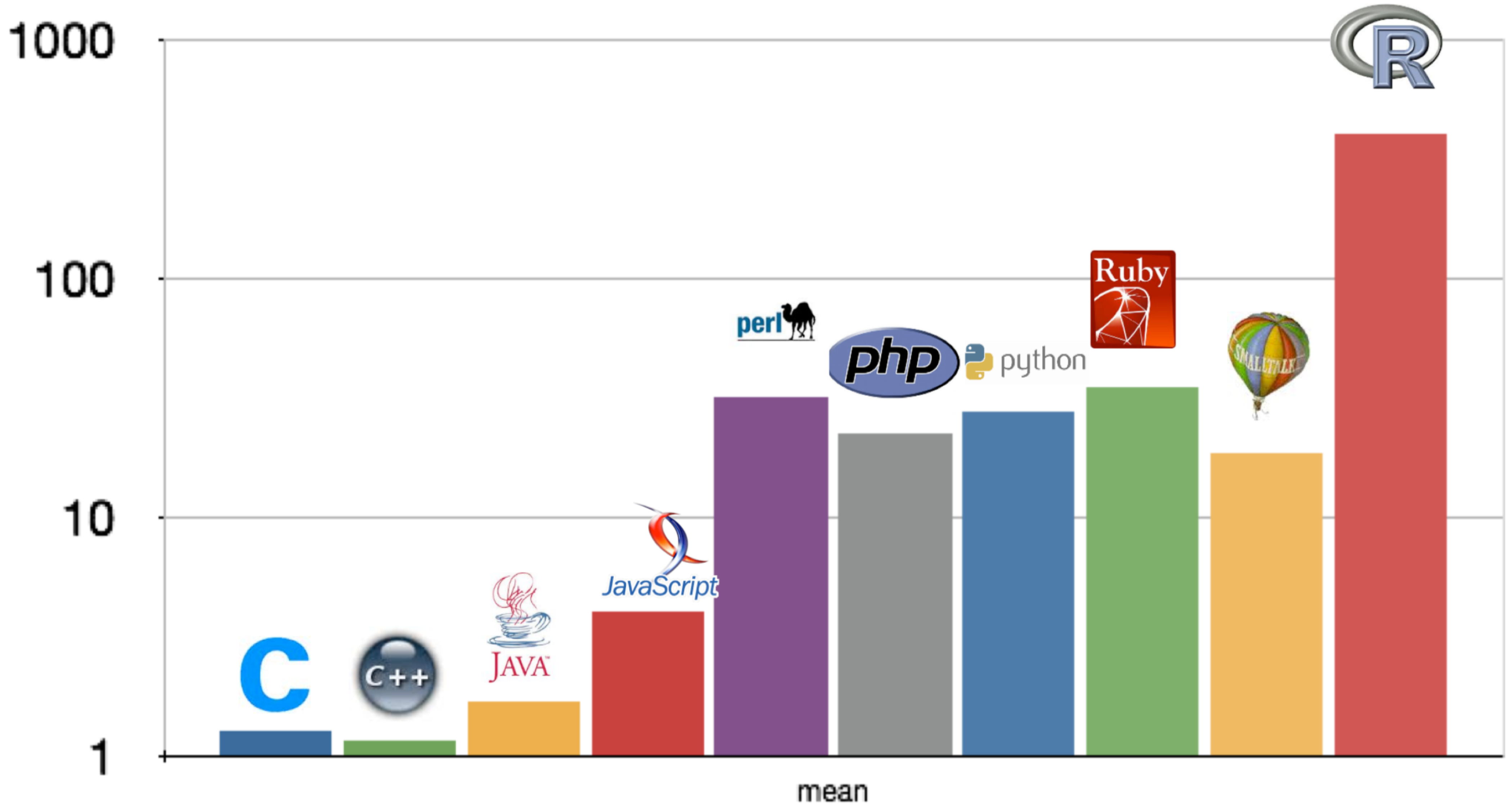
Documents — ruby perf.rb — 84×15

```
$ rbenv shell truffleruby-1.0.0-rc14
$ ruby perf.rb > /dev/null
1.577
1.912
0.781
0.464
0.465
0.6
0.465
0.47
0.461
```



1000
100
10
1
C
C++
JAVA
JavaScript
perl
php
python
Ruby
SMALLTALK
R
mean

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Current situation	How it should be

Current situation

Prototype a new language

Parser and language work to build syntax tree (AST), AST Interpreter

Write a “real” VM

In C/C++, still using AST interpreter, spend a lot of time implementing runtime system, GC, …

People start using it

People complain about performance

Define a bytecode format and write bytecode interpreter

Performance is still bad

Write a JIT compiler
Improve the garbage collector

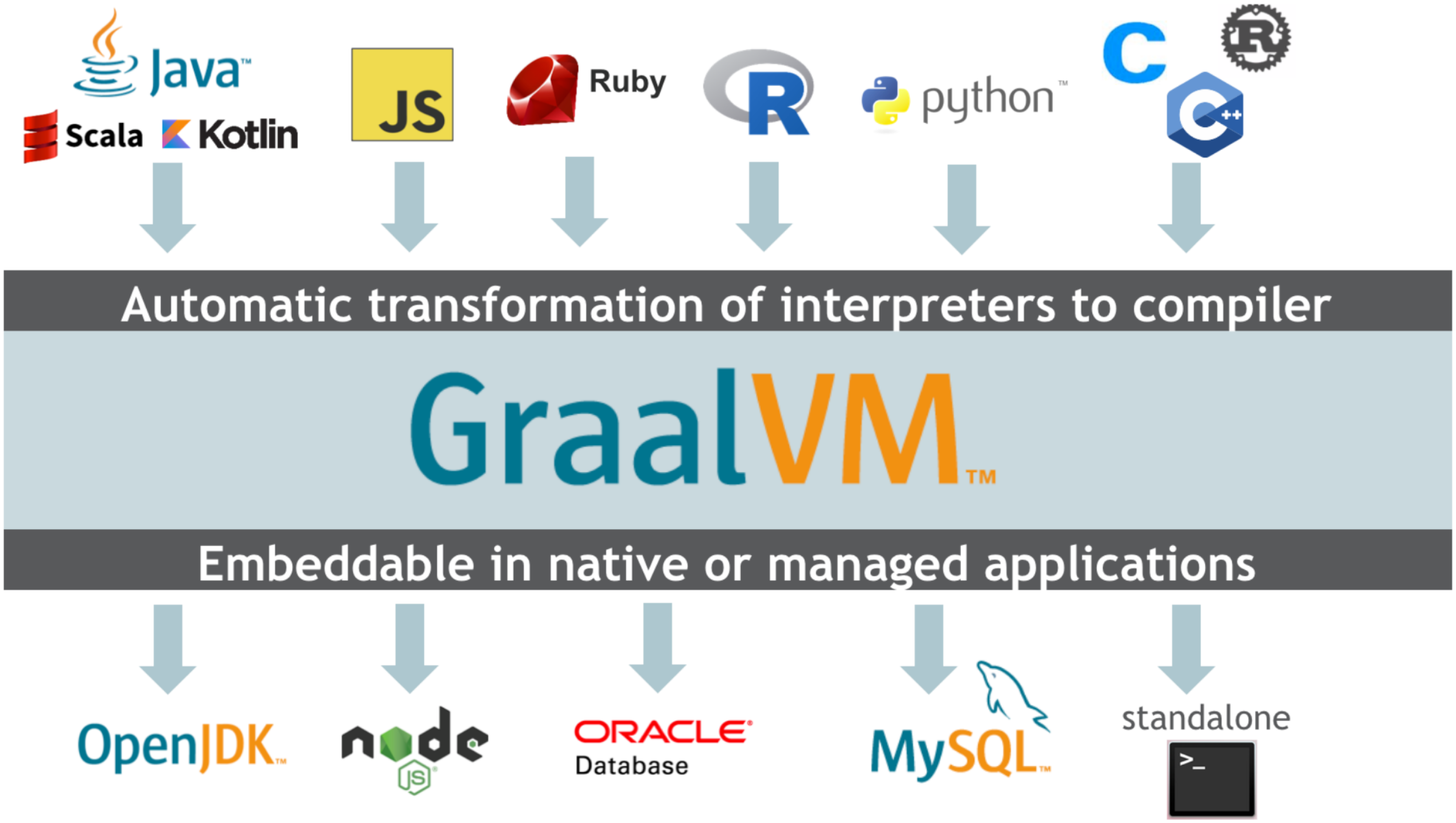
How it should be

Prototype a new language in Java

Parser and language work to build syntax tree (AST)
Execute using AST interpreter

People start using it

And it is already fast


Java
Scala
Kotlin
JS
Ruby
R
python
C
Automatic transformation of interpreters to compiler
GraalVM
Embeddable in native or managed applications
OpenJDK
node
JS
ORACLE
Database
MySQL
standalone
>_

Compilation basics

```ruby
def fib(n)
  if n <= 2
    1
  else
    fib(n - 1) + fib(n - 2)
  end
end
```

```
0x000000011a63b6e4: cmp    r10d,0x3
0x000000011a63b6e8: jl     0x000000011a63ba3f
0x000000011a63b703: sub    r13d,0x1
0x000000011a63b707: jo     0x000000011a63be54
0x000000011a63b897: call   0x000000011950bde0
0x000000011a63b8a8: sub    ebx,0x2
0x000000011a63b8ab: jo     0x000000011a63bda2
0x000000011a63b9af: call   0x000000011950bde0
0x000000011a63b9c5: add    r13d,eax
0x000000011a63b9c8: jo     0x000000011a63bd7b
0x000000011a63ba35: test   DWORD PTR [rip+0xfffffffff0e5e5cb],eax
0x000000011a63ba3e: ret
0x000000011a63ba3f: movabs rax,0x6c012dd20
0x000000011a63ba58: test   DWORD PTR [rip+0xfffffffff0e5e5a8],eax
0x000000011a63ba61: ret
```

```
def compile(ruby_source : String) : Array(UInt8)
  ...
end
```

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Compiling Ruby

blog.headius.com

Headius

Helping the JVM Into the 21st Century

Monday, October 15, 2012

So You Want To Optimize Ruby

I was recently asked for a list of "hard problems" a Ruby implementation really needs to solve before reporting benchmark numbers. You know...the sort of problems that might invalidate early perf numbers because they impact how you optimize Ruby. This post is a rework of my response...I hope you find it informative!

Fixnum to Bignum promotion

In Ruby, Fixnum math can promote to Bignum when the result is out of Fixnum's range. On implementations that use tagged pointers to represent Fixnum (MRI, Rubinius, MacRuby), the Fixnum range is somewhat less than the base CPU bits (32/64). On JRuby, Fixnum is always a straight 64-bit signed value.

This promotion is a performance concern for a couple reasons:

- Every math operation that returns a new Fixnum must be range-checked. This slows all Fixnum operations.
- It is difficult (if not impossible) to predict whether a Fixnum math operation will return a Fixnum or a Bignum. Since Bignum is always represented as a full object (not a primitive or a tagged pointer) this impacts optimizing Fixnum math call sites.

Floating-point performance

A similar concern is the performance of floating point values. Most of the native implementations have tagged values for Fixnum but only one I know of (Macruby) uses tagged values for Float. This can

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So you want to optimize Ruby?

- Fixnum to Bignum promotion
- Floating-point performance
- Closures
- Bindings and eval
- callcc and Continuation
- Fiber implementation
- Thread/frame/etc local $globals
- C extension support
- Ruby 1.9 encoding support
- Garbage collection and object allocation
- Concurrency / Parallelism
- Tracing/debugging
- ObjectSpace
- Method invalidation
- Constant lookup and invalidation
- Rails

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The TruffleRuby compilation pipeline

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fib.rb

```ruby
def fib(n)
  if n <= 2
    1
  else
    fib(n - 1) + fib(n - 2)
  end
end

loop do
  puts fib(30)
end

```

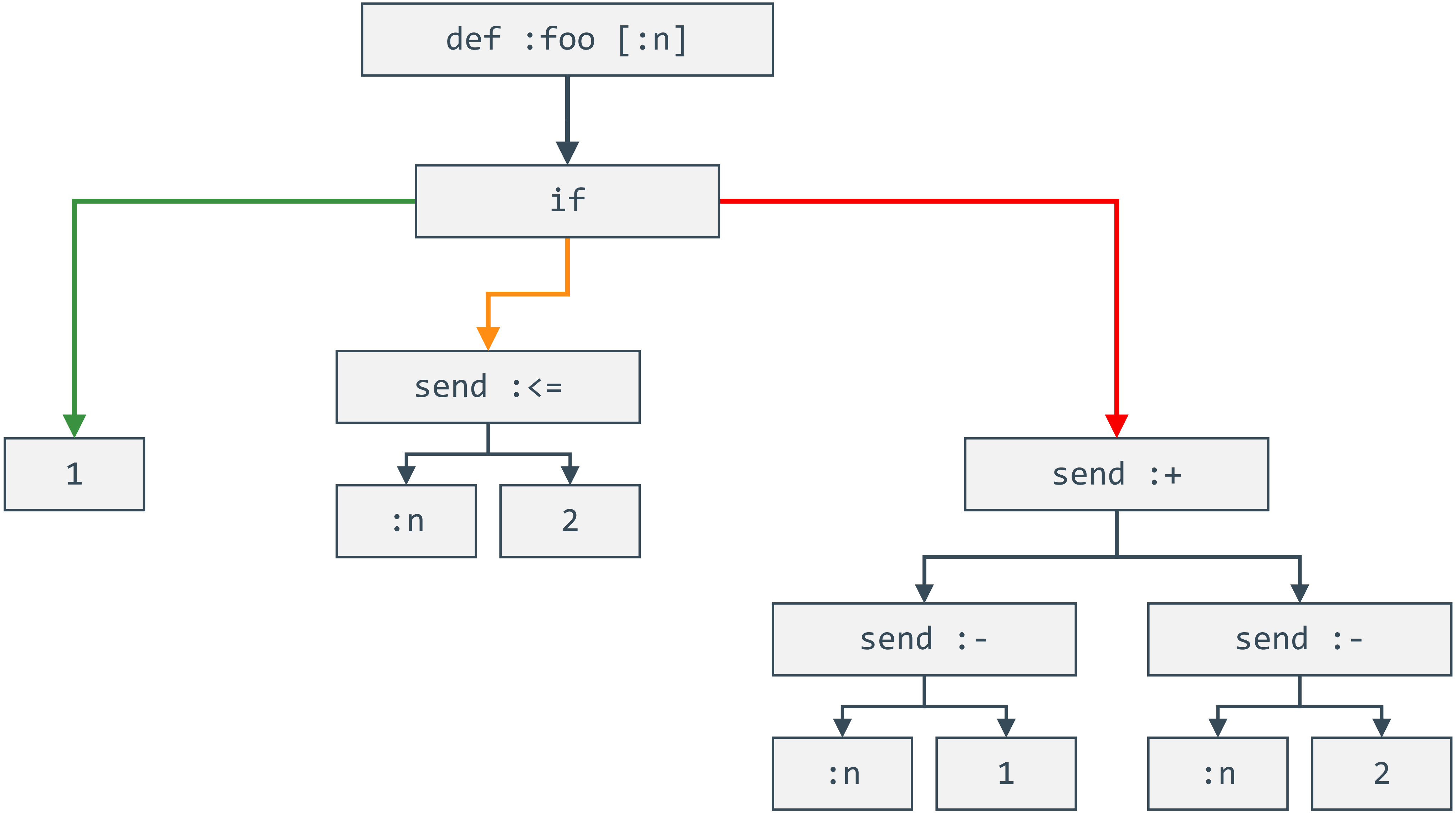
Line 1, Column 1 master Spaces: 2 Ruby

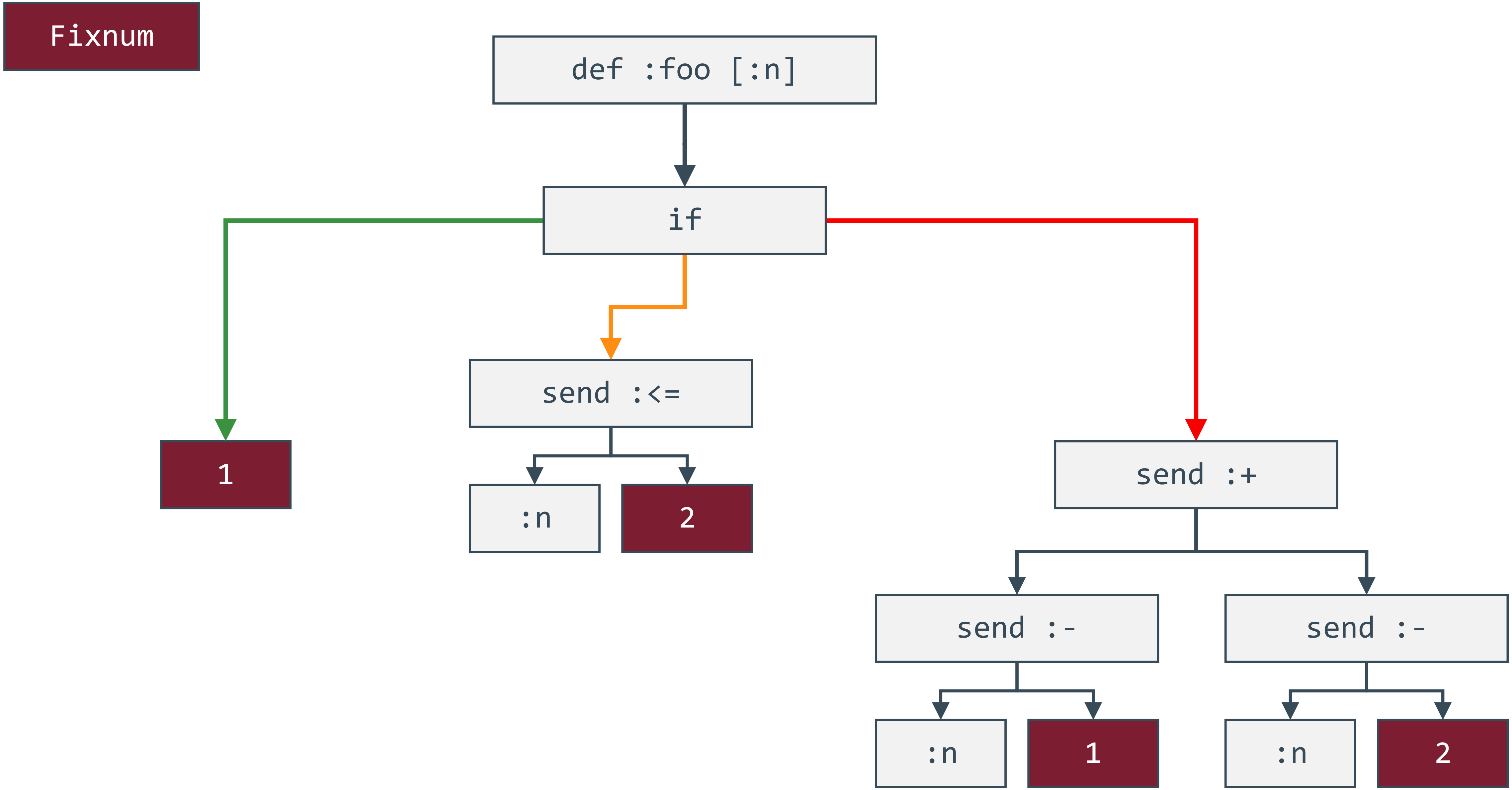
truffleruby — -bash — 110×58

```
$ rbenv shell 2.6.2
$ ruby --dump=parse fib.rb
###########################################################
## Do NOT use this node dump for any purpose other than  ##
## debug and research.  Compatibility is not guaranteed. ##
###########################################################

# @ NODE_SCOPE (line: 1, location: (1,0)-(11,3))
# +- nd_tbl: (empty)
# +- nd_args:
# |   (null node)
# +- nd_body:
#     @ NODE_BLOCK (line: 1, location: (1,0)-(11,3))
#     +- nd_head (1):
#     |   @ NODE_DEFN (line: 1, location: (1,0)-(7,3))*
```

```
#                  +- nd_args:
#                      @ NODE_ARRAY (line: 10, location: (10,7)-(10,14))
#                      +- nd_alen: 1
#                      +- nd_head:
#                      |   @ NODE_FCALL (line: 10, location: (10,7)-(10,14))
#                      |   +- nd_mid: :fib
#                      |   +- nd_args:
#                      |       @ NODE_ARRAY (line: 10, location: (10,11)-(10,13))
#                      |       +- nd_alen: 1
#                      |       +- nd_head:
#                      |       |   @ NODE_LIT (line: 10, location: (10,11)-(10,13))
#                      |       |   +- nd_lit: 30
#                      |       +- nd_next:
#                      |           (null node)
#                      +- nd_next:
#                          (null node)
$ 
```


def :foo [:n]
if
1
send :<=
:n
2
send :+
send :-
send :-
:n
1
:n
2



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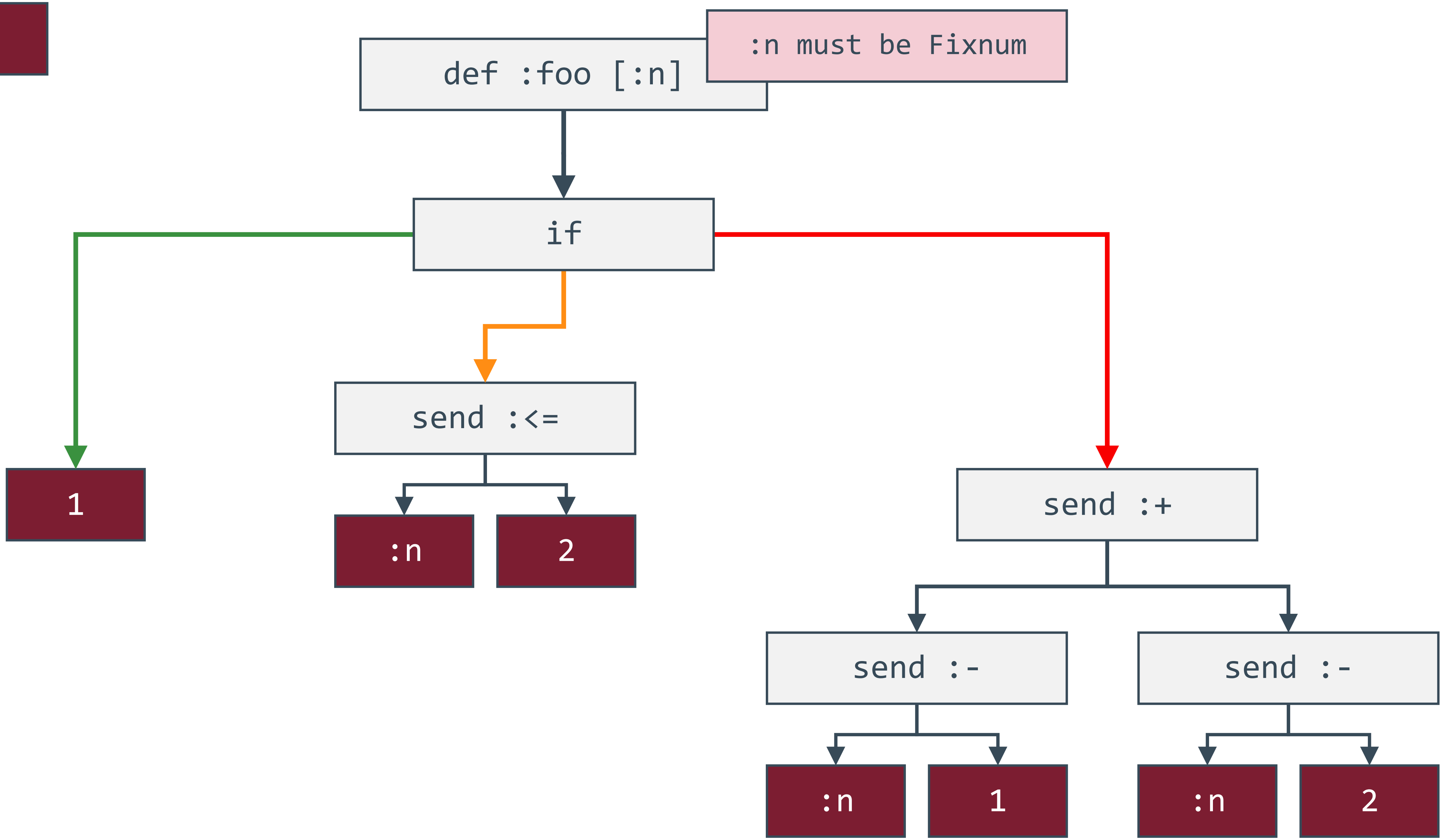
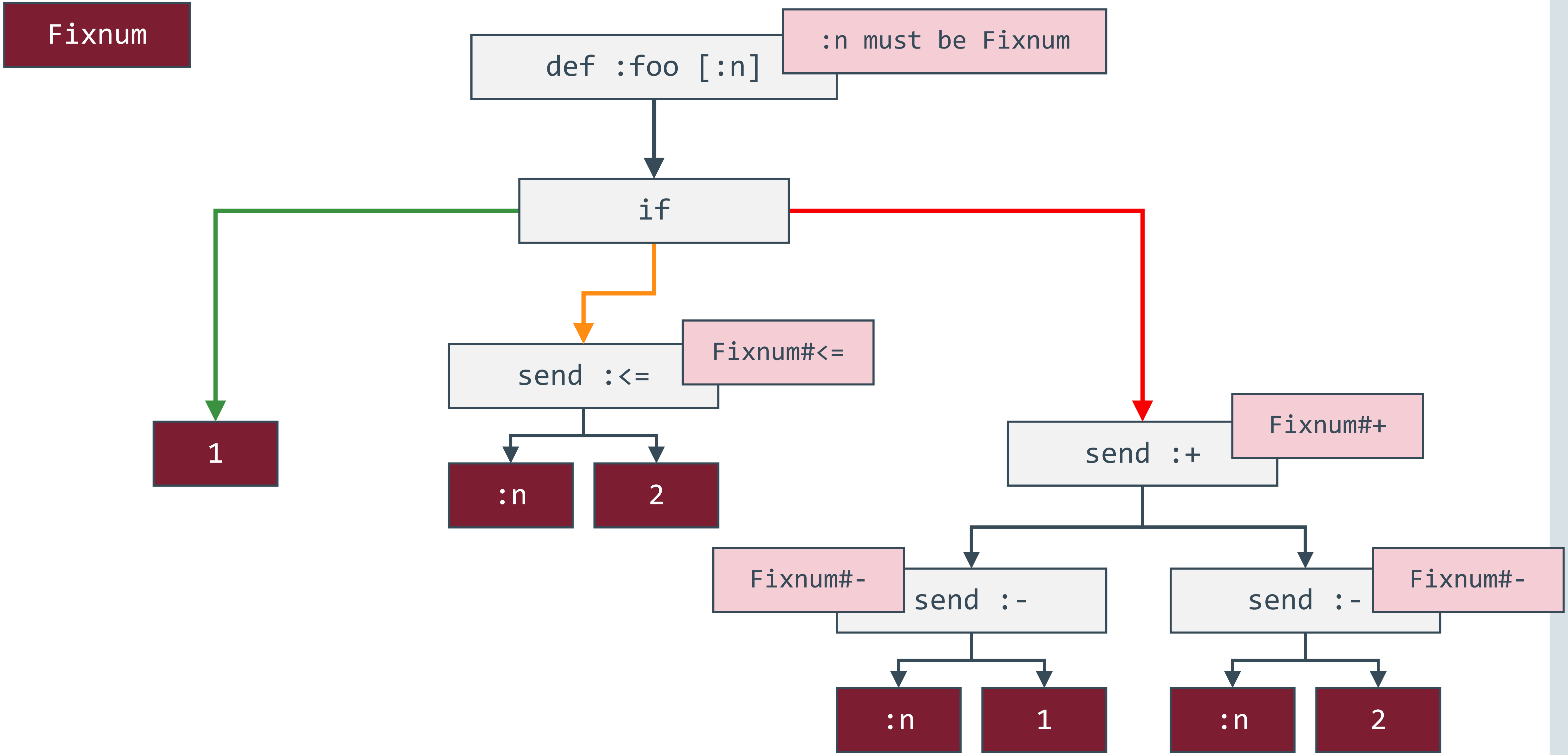
Fixnum




Fixnum
def :foo [:n]
:n must be Fixnum
if
1
send :<=
Fixnum#<=
:n
2
send :+
Fixnum#+
Fixnum#-
send :-
send :-
Fixnum#-
:n
1
:n
2
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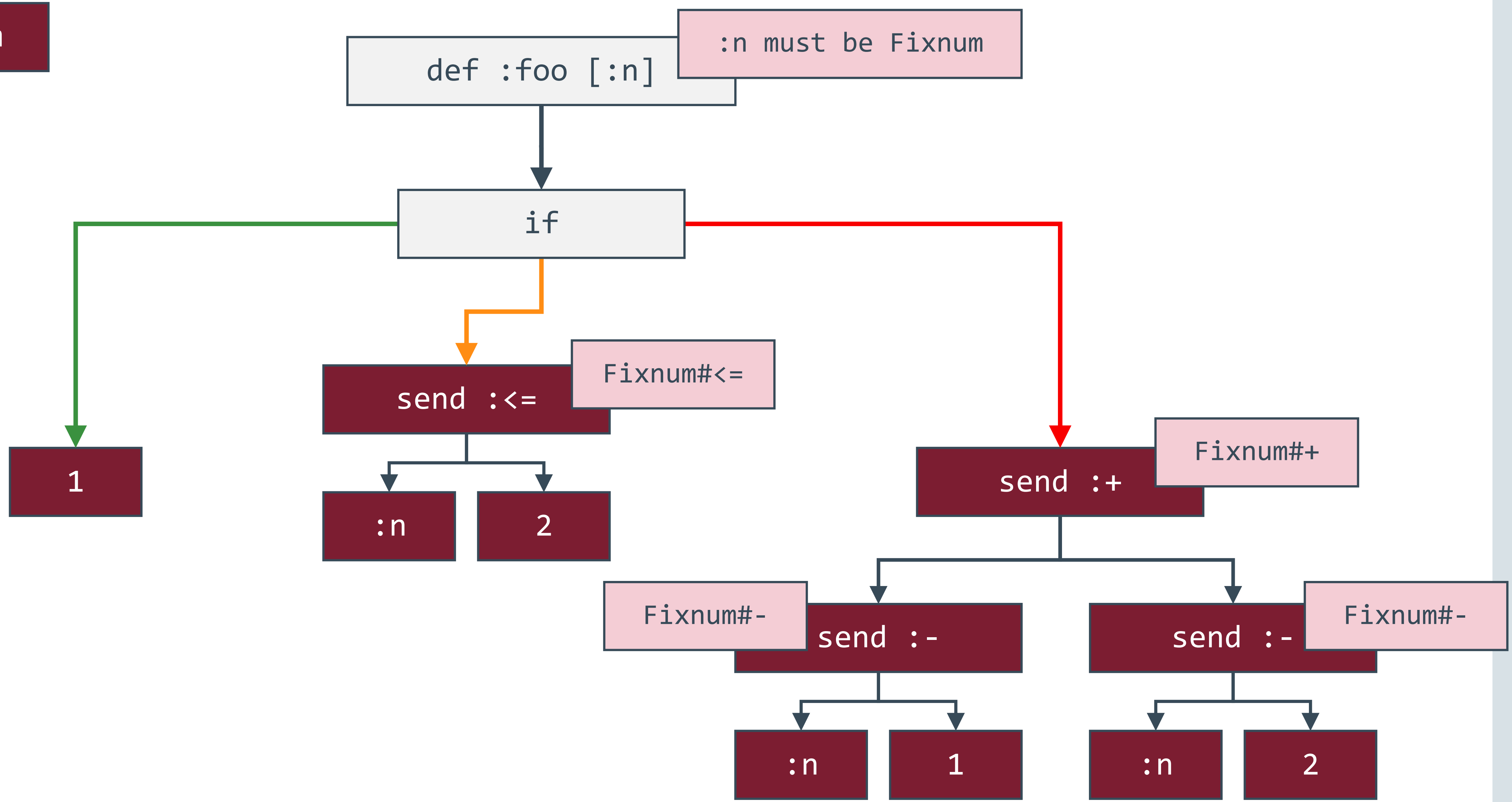
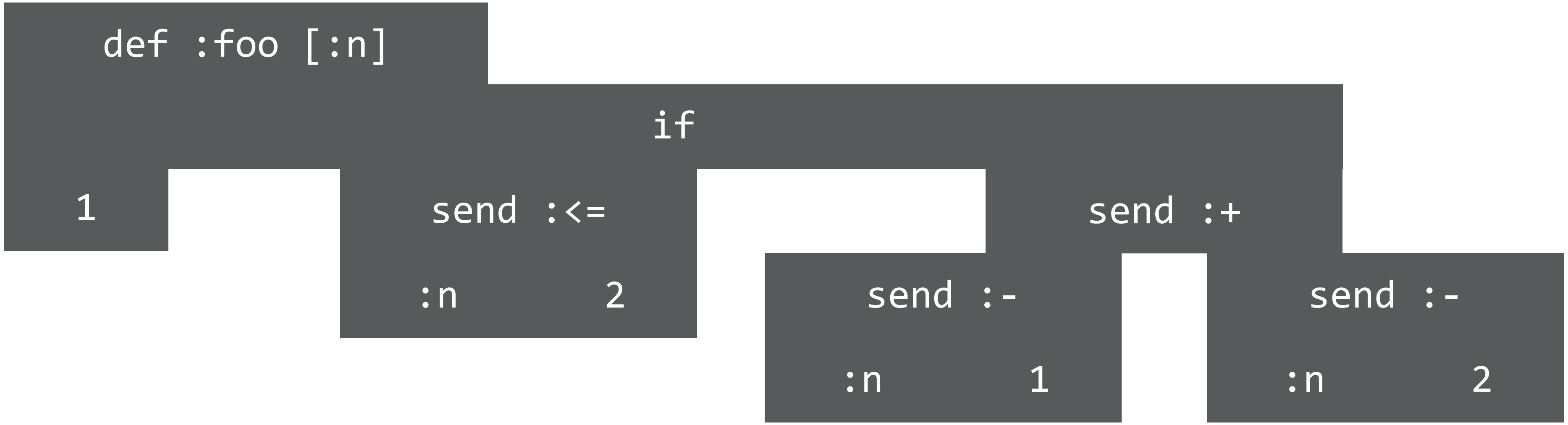
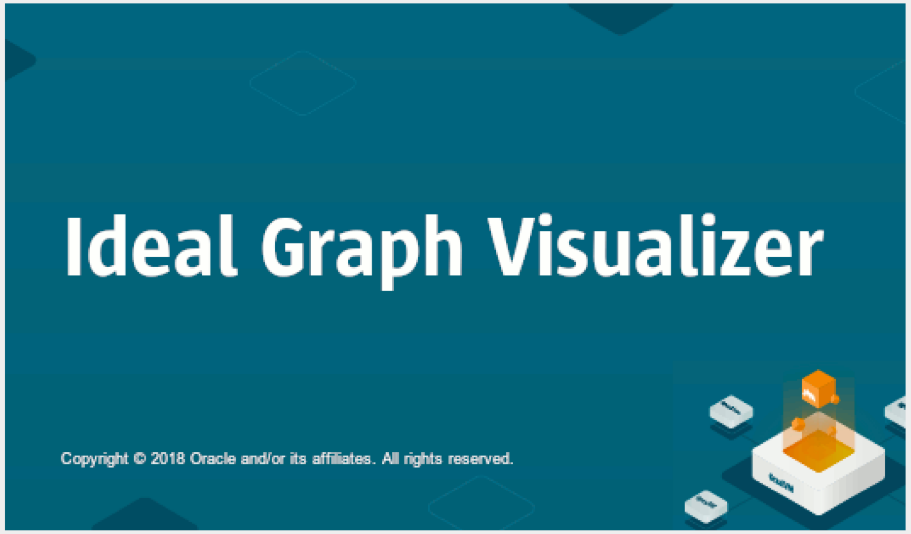
Fixnum



def :foo [:n]
:n must be Fixnum
if
send :<=
Fixnum#<=
1
:n
2
send :+
Fixnum#+
Fixnum#-
send :-
send :-
Fixnum#-
:n
1
:n
2


def :foo [:n]
if
1
send :<=
:n
2
send :+
send :-
:n
1
send :-
:n
2

About



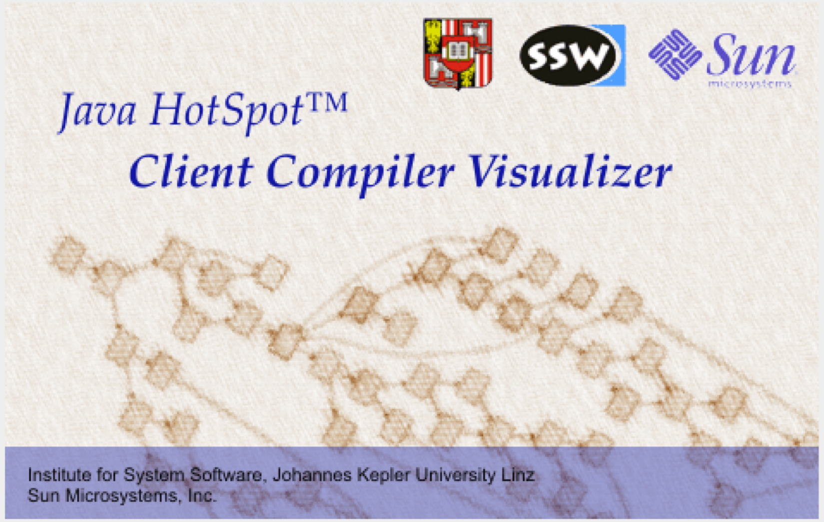
IdealGraphVisualizer, Copyright (c) 2013, 2018, Oracle and/or its affiliates.

IdealGraphVisualizer is based on Apache NetBeans from the Apache Software Foundation.

Product Version: IdealGraphVisualizer dev-19baa6a3fef1
Updates: Updates available
Java: 1.8.0_202; Java HotSpot(TM) GraalVM EE 1.0.0-rc14 25.202-b08-jvmci-0.56
Runtime: Java(TM) SE Runtime Environment 1.8.0_202-b08
System: Mac OS X version 10.14.3 running on x86_64; UTF-8; en_GB (idealgraphvisualizer)
User directory: /Users/chrisseaton/Library/Application Support/idealgraphvisualizer/0.27

Close

About



NetBeans IDE and NetBeans Platform are based on software from netbeans.org, which has been dual licensed under the Common Development and Distribution License (CDDL) and the GNU General Public License version 2 with Classpath exception. For more information, please visit www.netbeans.org.

Java: 1.8.0_201; Java HotSpot(TM) 64-Bit Server VM 25.201-b09
Runtime: Java(TM) SE Runtime Environment 1.8.0_201-b09
System: Mac OS X version 10.14.3 running on x86_64; UTF-8; en_GB (c1visualizer)
User directory: /Users/chrisseaton/Library/Application Support/c1visualizer/dev
Cache directory: /Users/chrisseaton/Library/Application Support/c1visualizer/dev/var/cache

Close

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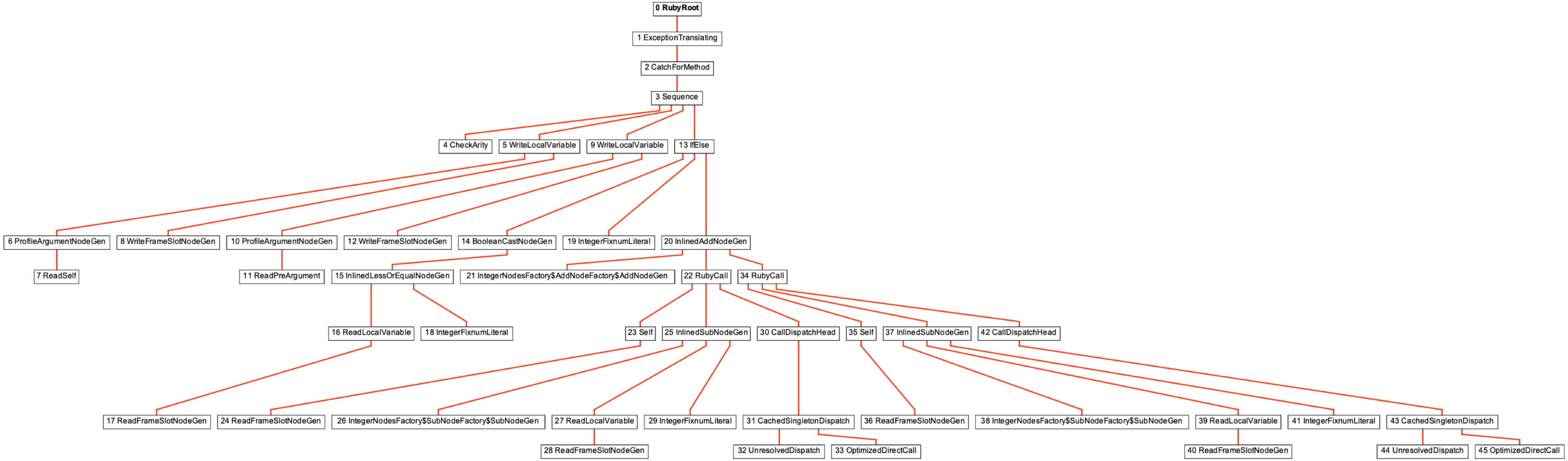
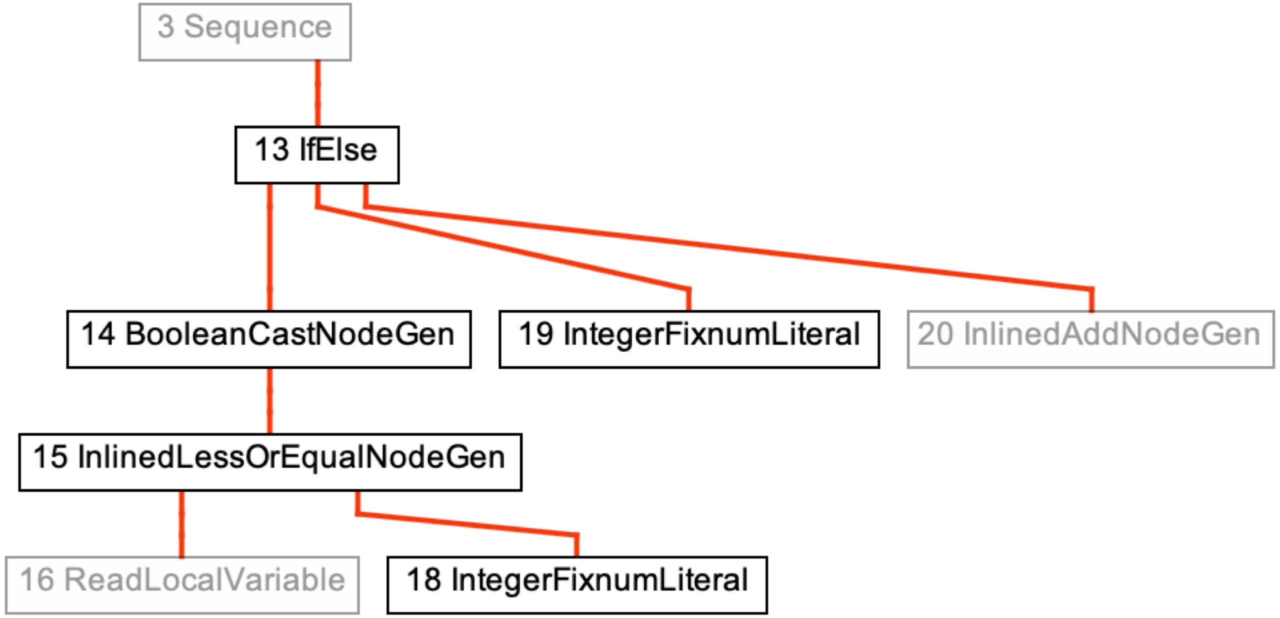

0 RubyRoot
1 ExceptionTranslating
2 CatchForMethod
3 Sequence
4 CheckArity
5 WriteLocalVariable
9 WriteLocalVariable
13 IfElse
6 ProfileArgumentNodeGen
8 WriteFrameSlotNodeGen
10 ProfileArgumentNodeGen
12 WriteFrameSlotNodeGen
14 BooleanCastNodeGen
19 IntegerFixnumLiteral
20 InlinedAddNodeGen
7 ReadSelf
11 ReadPreArgument
15 InlinedLessOrEqualNodeGen
21 IntegerNodesFactory$AddNodeFactory$AddNodeGen
22 RubyCall
34 RubyCall
16 ReadLocalVariable
18 IntegerFixnumLiteral
23 Self
25 InlinedSubNodeGen
30 CallDispatchHead
35 Self
37 InlinedSubNodeGen
42 CallDispatchHead
17 ReadFrameSlotNodeGen
24 ReadFrameSlotNodeGen
26 IntegerNodesFactory$SubNodeFactory$SubNodeGen
27 ReadLocalVariable
29 IntegerFixnumLiteral
31 CachedSingletonDispatch
36 ReadFrameSlotNodeGen
38 IntegerNodesFactory$SubNodeFactory$SubNodeGen
39 ReadLocalVariable
41 IntegerFixnumLiteral
43 CachedSingletonDispatch
28 ReadFrameSlotNodeGen
32 UnresolvedDispatch
33 OptimizedDirectCall
40 ReadFrameSlotNodeGen
44 UnresolvedDispatch
45 OptimizedDirectCall


3 Sequence
13 IfElse
14 BooleanCastNodeGen
19 IntegerFixnumLiteral
20 InlinedAddNodeGen
15 InlinedLessOrEqualNodeGen
16 ReadLocalVariable
18 IntegerFixnumLiteral

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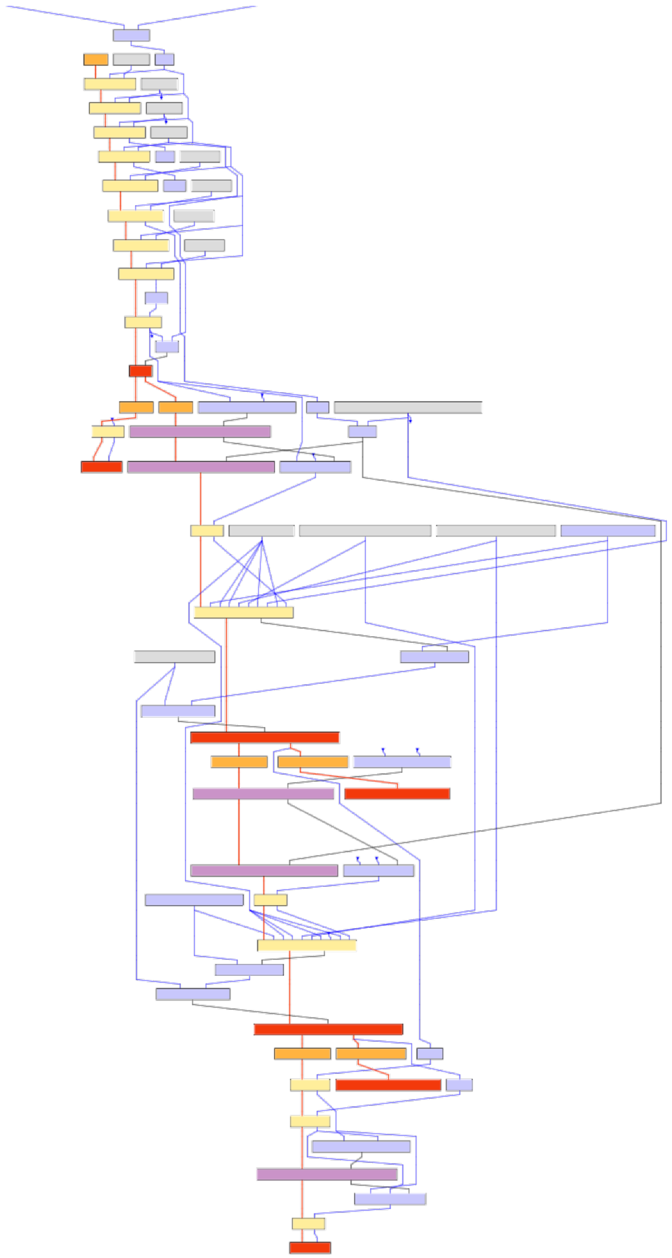

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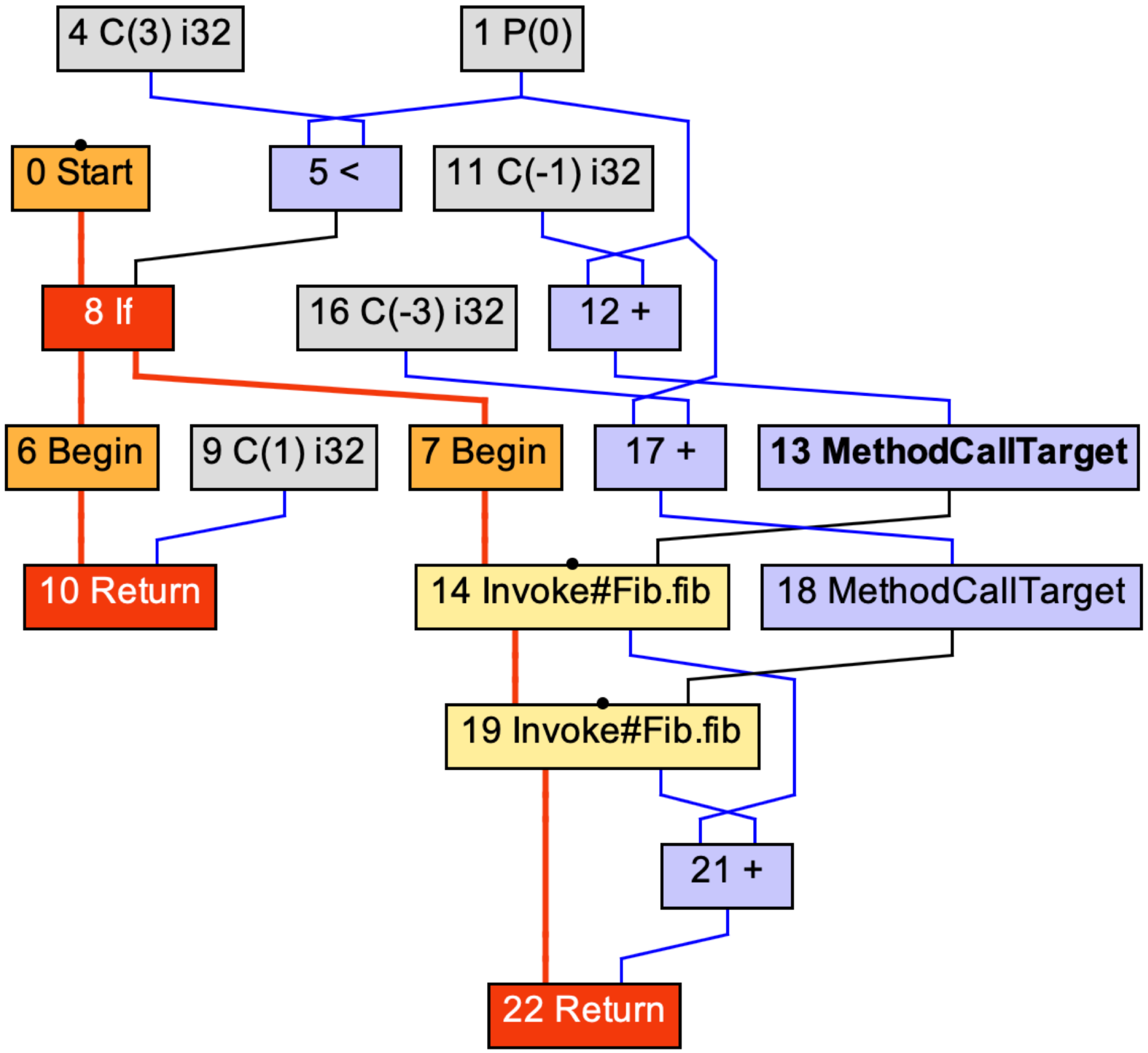
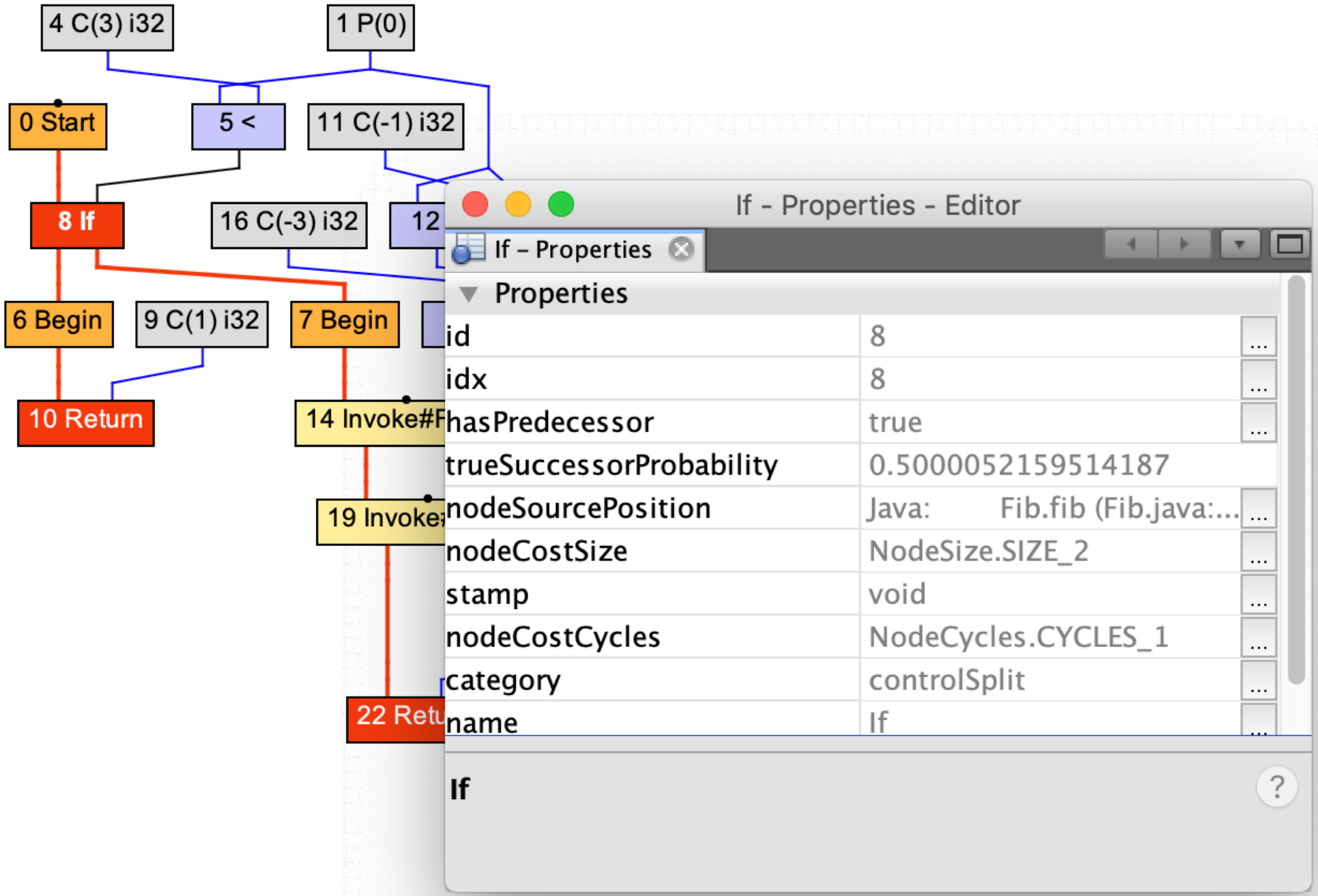
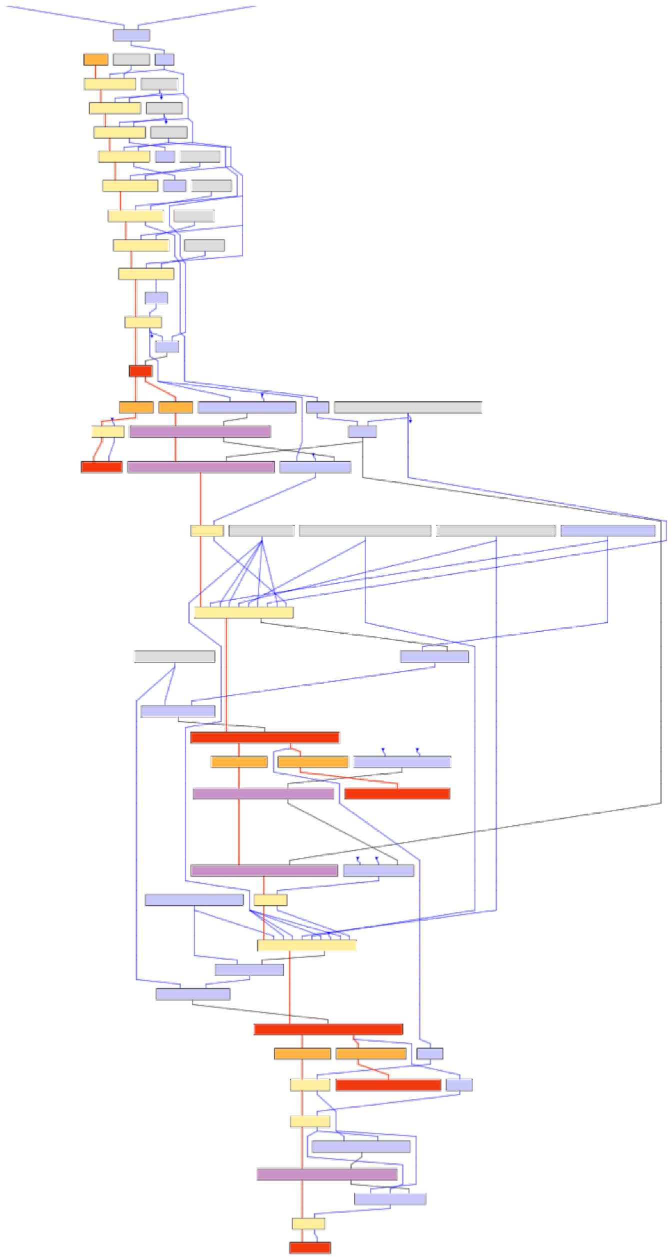
Fib.java

```java
class Fib {

  private static int fib(int n) {
    if (n <= 2) {
      return 1;
    } else {
      return fib(n - 1) + fib(n - 3);
    }
  }

  public static void main(String[] args) {
    while (true) {
      System.out.println(fib(30));
    }
  }

}
```

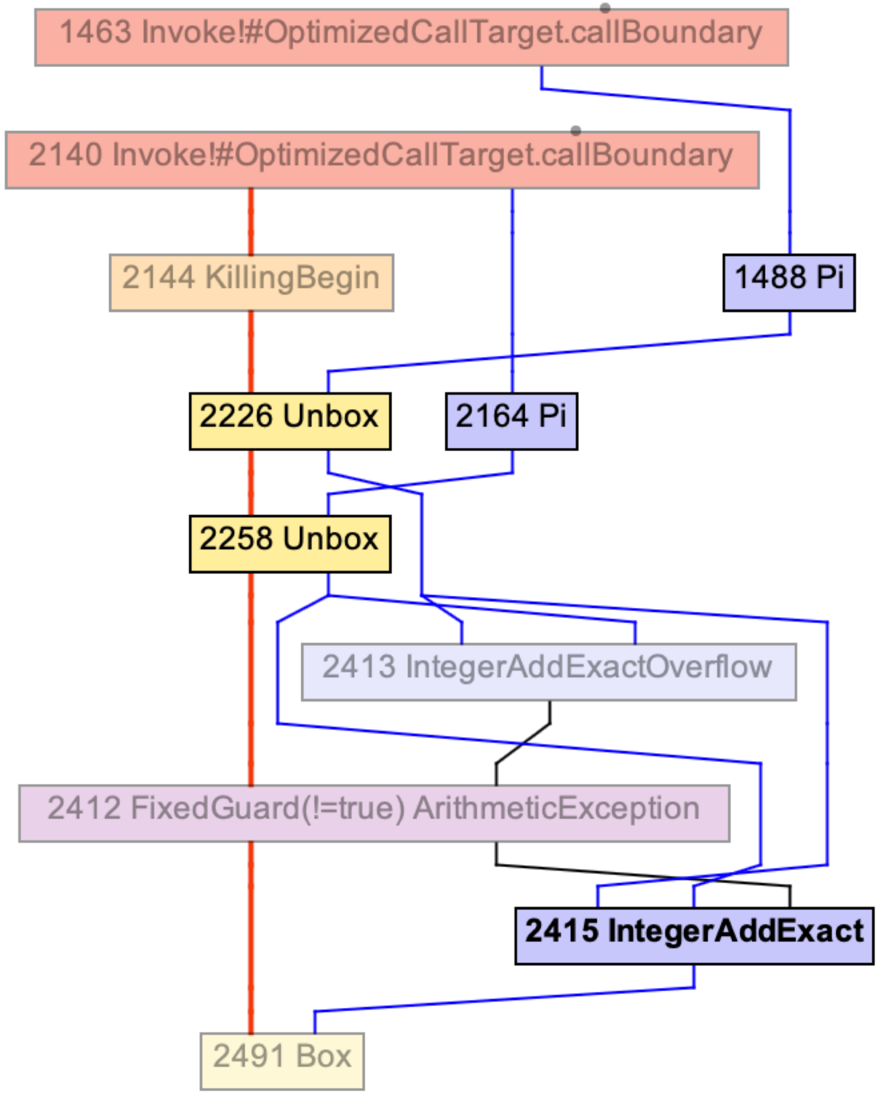
Line 1, Column 1 master 9 Spaces: 2 Java


4 C(3) i32
1 P(0)
0 Start
5 <
11 C(-1) i32
8 If
16 C(-3) i32
12 +
6 Begin
9 C(1) i32
7 Begin
17 +
13 MethodCallTarget
10 Return
14 Invoke#Fib.fib
18 MethodCallTarget
19 Invoke#Fib.fib
21 +
22 Return

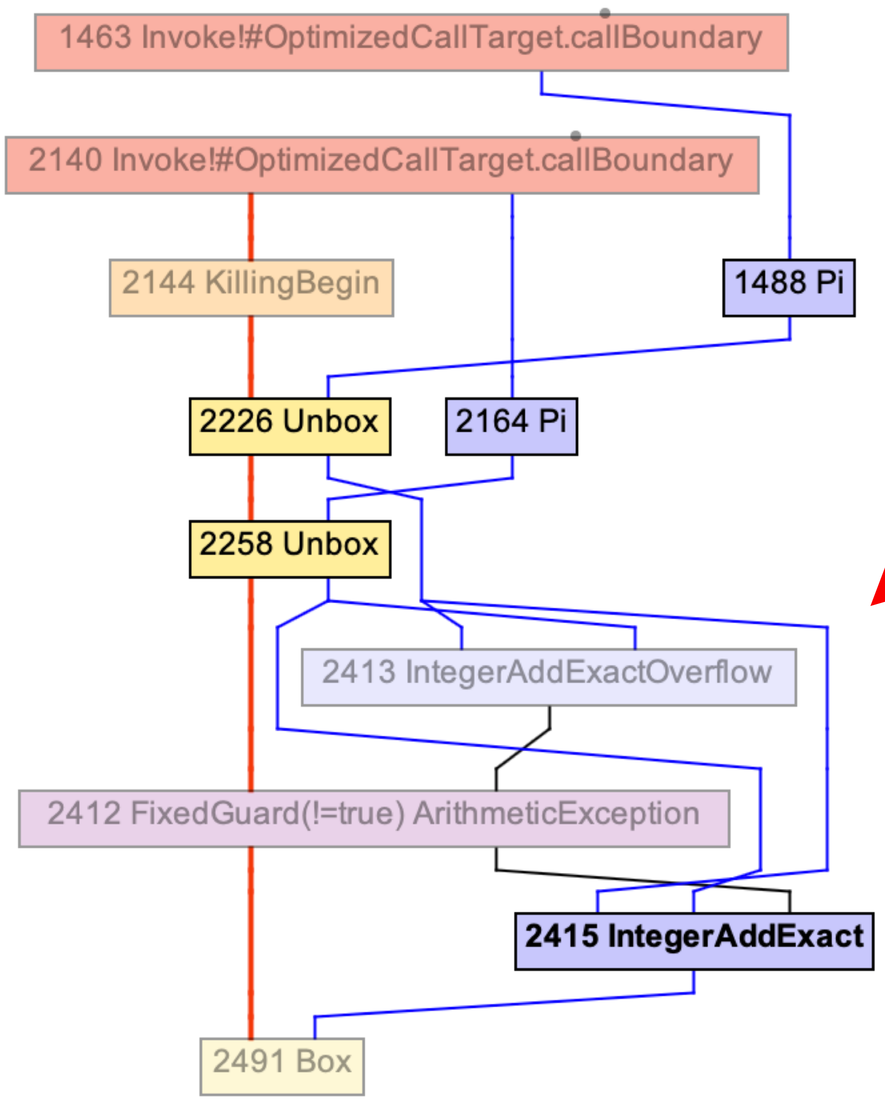

4 C(3) i32
1 P(0)
0 Start
5 <
11 C(-1) i32
8 If
16 C(-3) i32
12
6 Begin
9 C(1) i32
7 Begin
10 Return
14 Invoke#F
19 Invoke
22 Retu
If - Properties - Editor
If – Properties
Properties
id
8
idx
8
hasPredecessor
true
trueSuccessorProbability
0.5000052159514187
nodeSourcePosition
Java: Fib.fib (Fib.java:...
nodeCostSize
NodeSize.SIZE_2
stamp
void
nodeCostCycles
NodeCycles.CYCLES_1
category
controlSplit
name
If
If



Back to Ruby…



1463 Invoke!#OptimizedCallTarget.callBoundary
2140 Invoke!#OptimizedCallTarget.callBoundary
2144 KillingBegin
1488 Pi
2226 Unbox
2164 Pi
2258 Unbox
2413 IntegerAddExactOverflow
2412 FixedGuard(!=true) ArithmeticException
2415 IntegerAddExact
2491 Box



Become registers

Become machine instructions

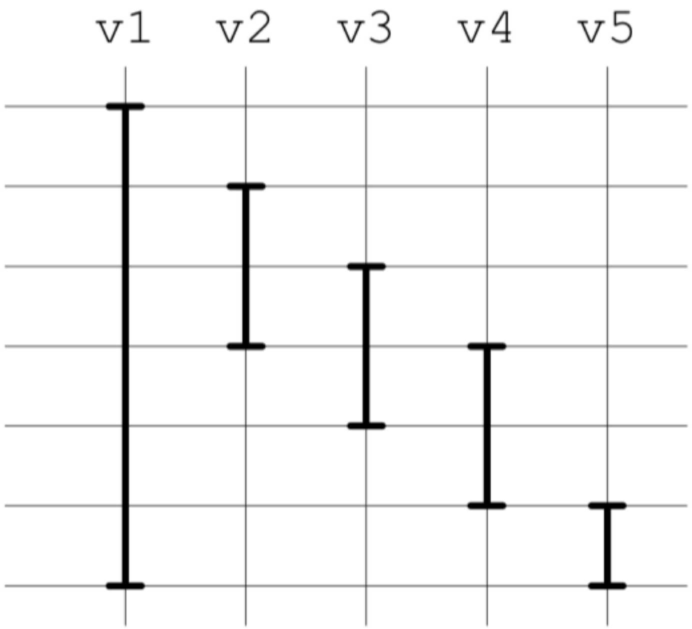
```
B0 -> B1,B2 [-1, -1]
_f__tid__d__instruction______org______________________________________________ (HIR)
 #  v0    d  StartNode stateAfter: - #next: v8
 ~  i1    d  Parameter
 ~  i4    d  Constant
 ~  v5    d  <@               .graalvm.compiler.nodes.calc.IntegerLessThanNode>@ x: i1 y: i4
 *  v8    d  If condition: v5 #trueSuccessor: v6 #falseSuccessor: v7

B1 <- B0 [-1, -1]
_f__tid__d__instruction______org______________________________________________ (HIR)
 #  v6    d  Begin #next: v10
 ~  i9    d  Constant
 *  v10   d  Return result: i9 memoryMap: -

B2 <- B0 [-1, -1]
_f__tid__d__instruction______org______________________________________________ (HIR)
 #  v7    d  Begin #next: i14
 ~  i11   d  Constant
 ~  i12   d  + x: i1 y: i11
    v23   d  HotSpotDirectCallTarget arguments: i12
    ?25   d  FrameState outerFrameState: - values: i1
 #  i14   d  Invoke stateAfter: - classInit: - callTarget: v23 stateDuring: ?25 #next: i19
 ~  i16   d  Constant
 ~  i17   d  + x: i1 y: i16
    v24   d  HotSpotDirectCallTarget arguments: i17
    ?26   d  FrameState outerFrameState: - values: - i14
 #  i19   d  Invoke stateAfter: - classInit: - callTarget: v24 stateDuring: ?26 #next: v22
 ~  i21   d  + x: i14 y: i19
 *  v22   d  Return result: i21 memoryMap: -
```

```java
@Override
public void generate(NodeLIRBuilderTool generator) {
    generator.setResult(this, generateArithmetic(generator));
    generator.emitOverflowCheckBranch(getOverflowSuccessor(), getNext(), stamp, probability(getOverflowSuccessor()));
}
```

```java
public final void jcc(ConditionFlag cc, Label l) {
    assert (0 <= cc.getValue()) && (cc.getValue() < 16) : "illegal cc";
    if (l.isBound()) {
        jcc(cc, l.position(), false);
    } else {
        // Note: could eliminate cond. jumps to this jump if condition
        // is the same however, seems to be rather unlikely case.
        // Note: use jccb() if label to be bound is very close to get
        // an 8-bit displacement
        l.addPatchAt(position());
        emitByte(0x0F);
        emitByte(0x80 | cc.getValue());
        emitInt(0);
    }

}
```

```
0x000000011a63b6e4: cmp    r10d,0x3
0x000000011a63b6e8: jl     0x000000011a63ba3f
0x000000011a63b703: sub    r13d,0x1
0x000000011a63b707: jo     0x000000011a63be54
0x000000011a63b897: call   0x000000011950bde0
0x000000011a63b8a8: sub    ebx,0x2
0x000000011a63b8ab: jo     0x000000011a63bda2
0x000000011a63b9af: call   0x000000011950bde0
0x000000011a63b9c5: add    r13d,eax
0x000000011a63b9c8: jo     0x000000011a63bd7b
0x000000011a63ba35: test   DWORD PTR [rip+0xfffffffff0e5e5cb],eax
0x000000011a63ba3e: ret
0x000000011a63ba3f: movabs rax,0x6c012dd20
0x000000011a63ba58: test   DWORD PTR [rip+0xfffffffff0e5e5a8],eax
0x000000011a63ba61: ret
```

```
(1)   v1 = 10
(2)   v2 = 20
(3)   v3 = v1 + v2
(4)   v4 = v2 + v3
(5)   v1 = v3 + v4
(6)   v5 = v4 + v1
(7)   return v1 + v5
```



Linear Scan Register Allocation for the Java HotSpot™ Client Compiler

Christian Wimmer

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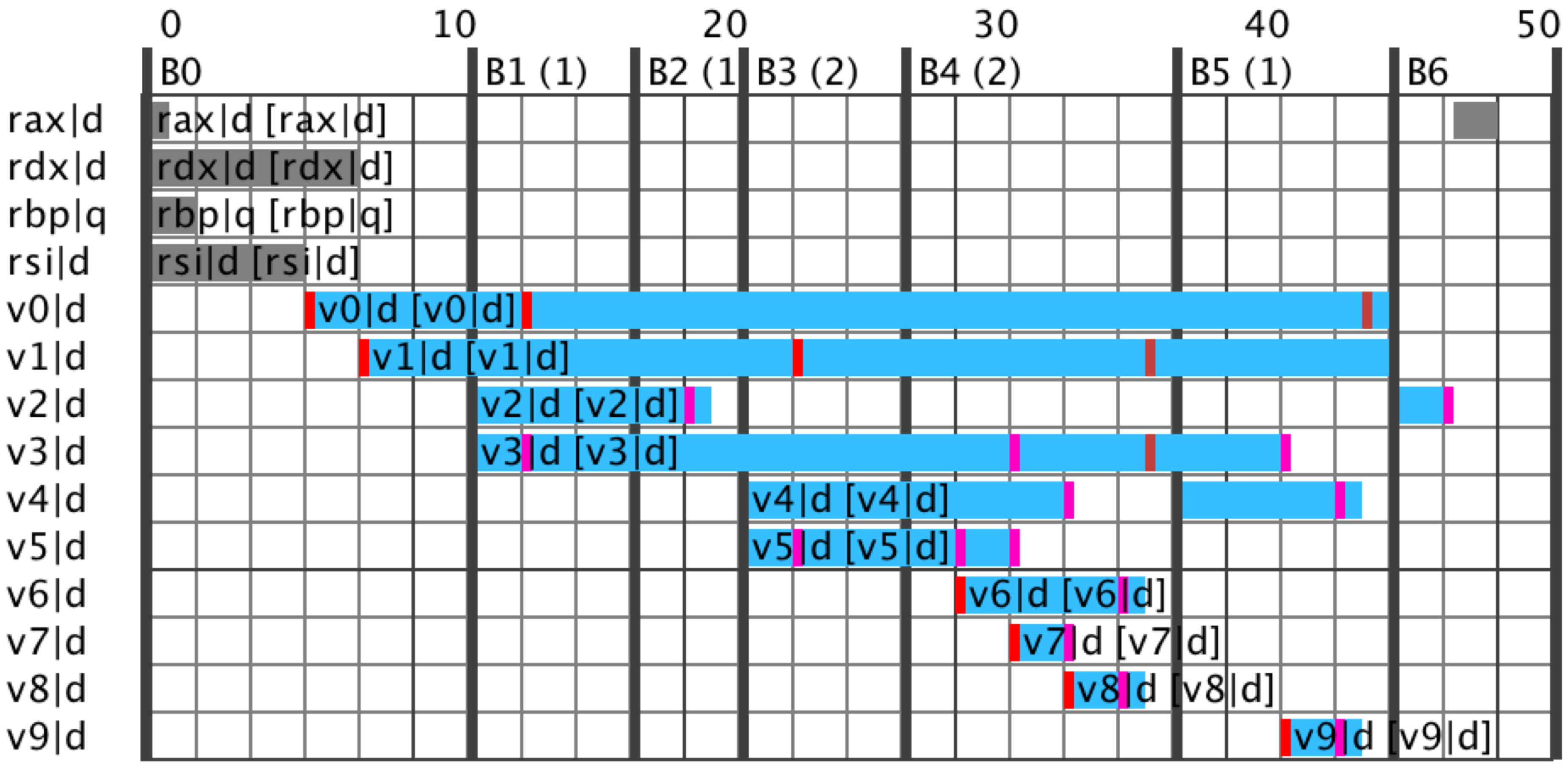
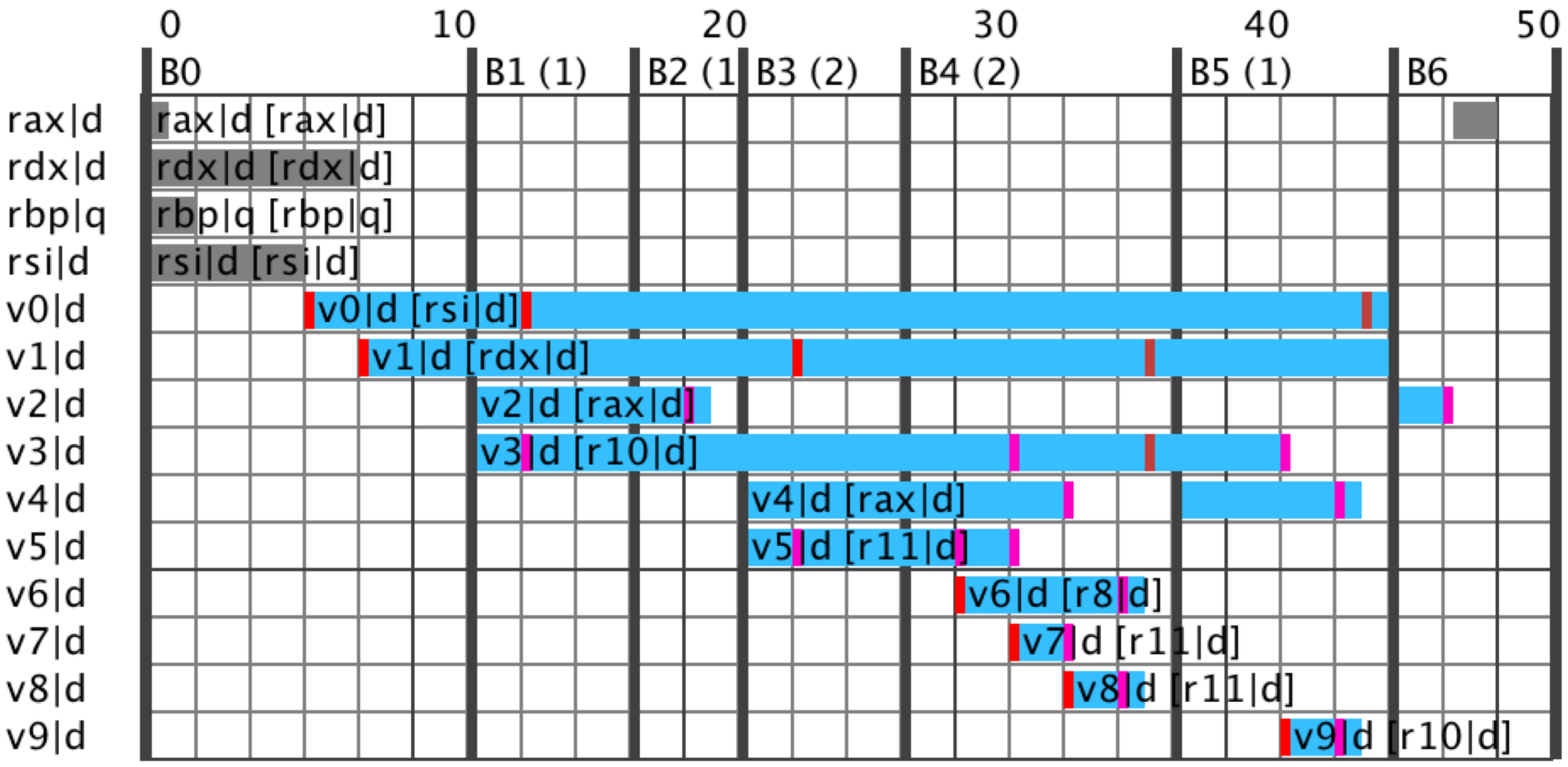
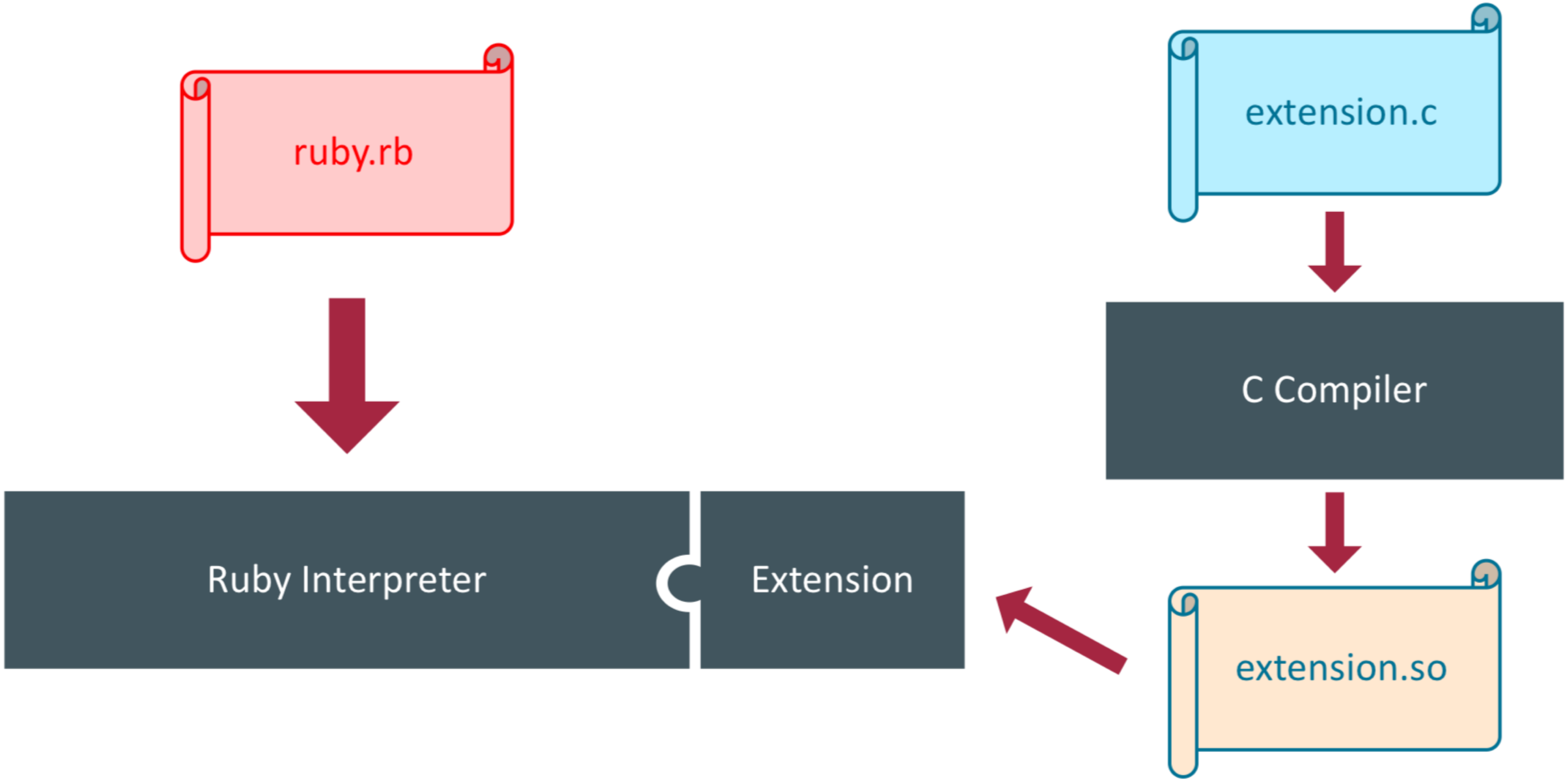
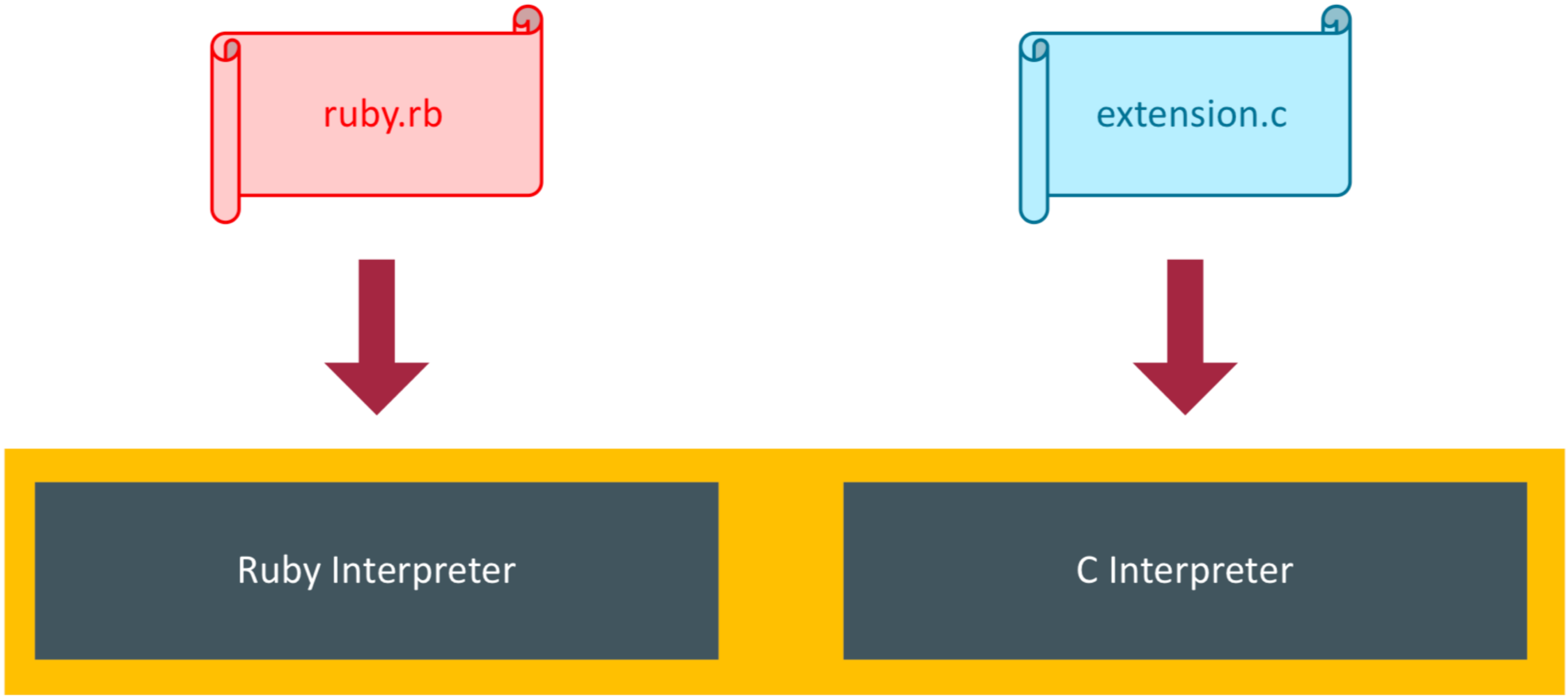

0
10
20
30
40
50
B0
B1 (1)
B2 (1
B3 (2)
B4 (2)
B5 (1)
B6
rax|d
rdx|d
rbp|q
rsi|d
v0|d
v1|d
v2|d
v3|d
v4|d
v5|d
v6|d
v7|d
v8|d
v9|d
rax|d [rax|d]
rdx|d [rdx|d]
rbp|q [rbp|q]
rsi|d [rsi|d]
v0|d [v0|d]
v1|d [v1|d]
v2|d [v2|d]
v3|d [v3|d]
v4|d [v4|d]
v5|d [v5|d]
v6|d [v6|d]
v7|d [v7|d]
v8|d [v8|d]
v9|d [v9|d]

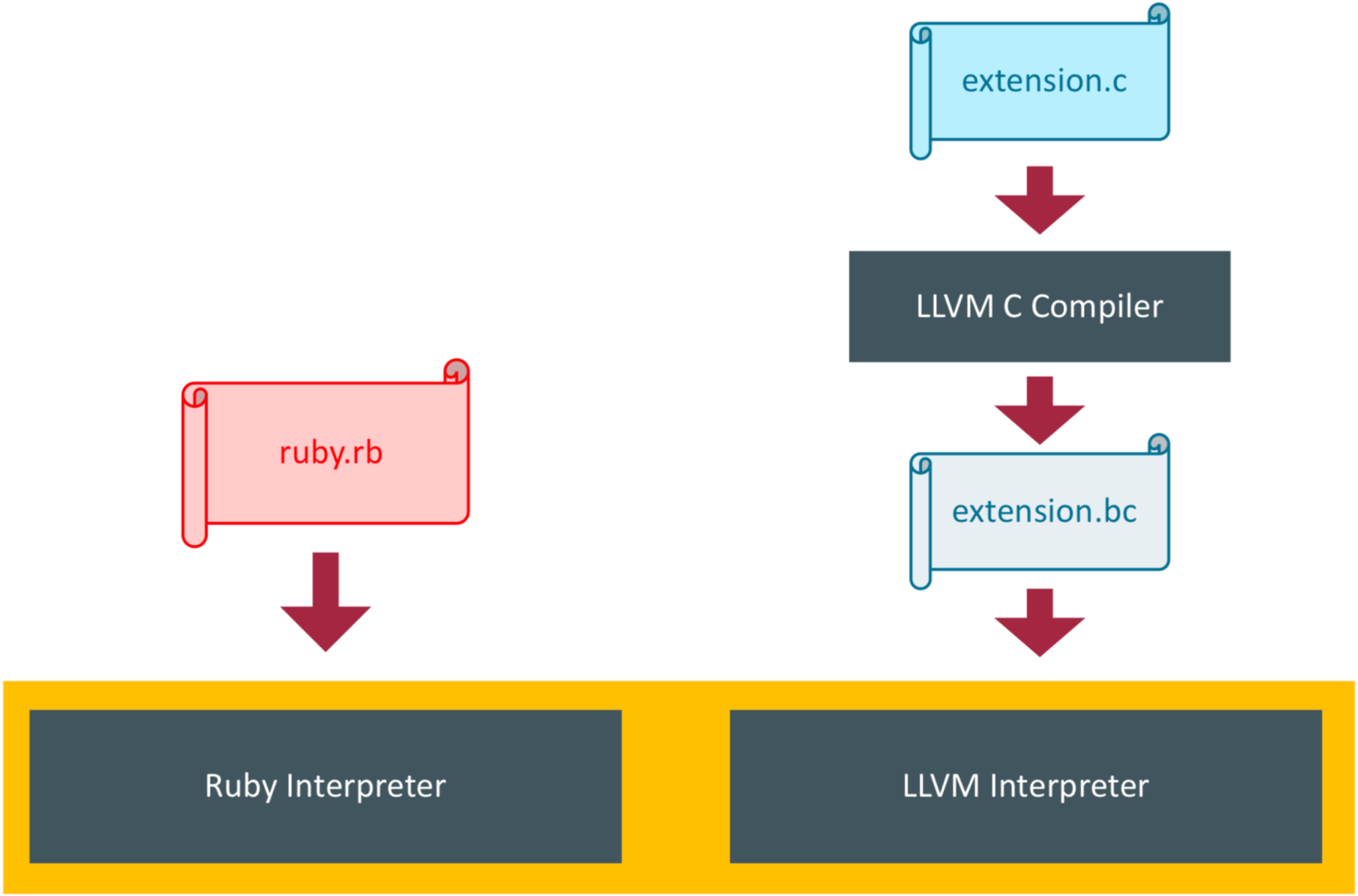

0
10
20
30
40
50
B0
B1 (1)
B2 (1
B3 (2)
B4 (2)
B5 (1)
B6
rax|d
rdx|d
rbp|q
rsi|d
v0|d
v1|d
v2|d
v3|d
v4|d
v5|d
v6|d
v7|d
v8|d
v9|d
rax|d [rax|d]
rdx|d [rdx|d]
rbp|q [rbp|q]
rsi|d [rsi|d]
v0|d [rsi|d]
v1|d [rdx|d]
v2|d [rax|d]
v3|d [r10|d]
v4|d [rax|d]
v5|d [r11|d]
v6|d [r8|d]
v7|d [r11|d]
v8|d [r11|d]
v9|d [r10|d]

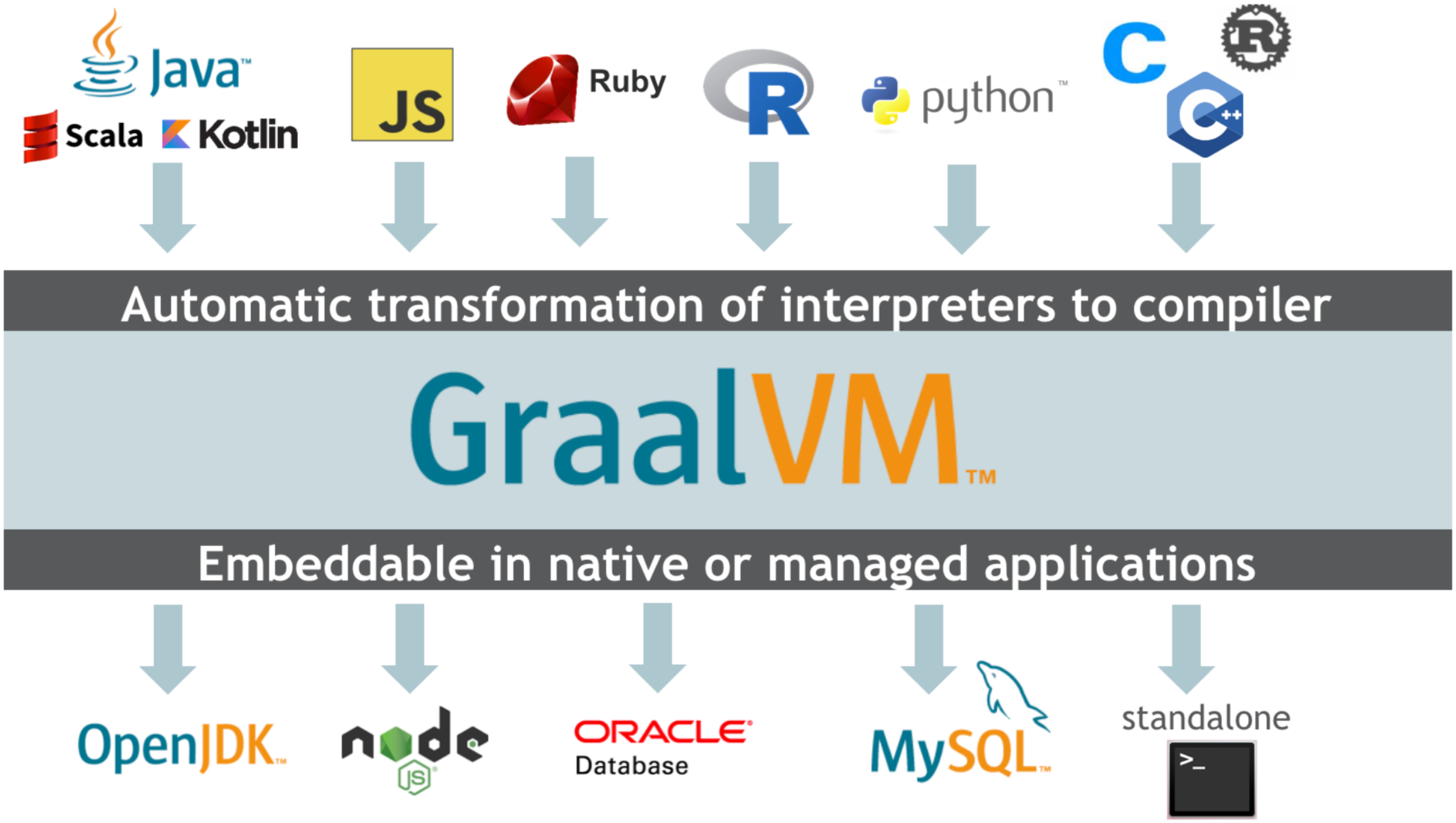
```
0x000000011a63b6e4: cmp    r10d,0x3
0x000000011a63b6e8: jl     0x000000011a63ba3f
0x000000011a63b703: sub    r13d,0x1
0x000000011a63b707: jo     0x000000011a63be54
0x000000011a63b897: call   0x000000011950bde0
0x000000011a63b8a8: sub    ebx,0x2
0x000000011a63b8ab: jo     0x000000011a63bda2
0x000000011a63b9af: call   0x000000011950bde0
0x000000011a63b9c5: add    r13d,eax
0x000000011a63b9c8: jo     0x000000011a63bd7b
0x000000011a63ba35: test   DWORD PTR [rip+0xffffffff0e5e5cb],eax
0x000000011a63ba3e: ret
0x000000011a63ba3f: movabs rax,0x6c012dd20
0x000000011a63ba58: test   DWORD PTR [rip+0xffffffff0e5e5a8],eax
0x000000011a63ba61: ret
```

There’s more to TruffleRuby


ruby.rb
extension.c
C Compiler
Ruby Interpreter
Extension
extension.so


ruby.rb
extension.c
Ruby Interpreter
C Interpreter


extension.c
LLVM C Compiler
ruby.rb
extension.bc
Ruby Interpreter
LLVM Interpreter


Java
Scala
Kotlin
JS
Ruby
R
python
C
C++
Automatic transformation of interpreters to compiler
GraalVM
Embeddable in native or managed applications
OpenJDK
node JS
ORACLE Database
MySQL
standalone
>_

Summing up

Documents — -bash — 84×15

```
$ rbenv install truffleruby-1.0.0-rc14
$ rbenv shell truffleruby-1.0.0-rc14
$ ruby -v
truffleruby 1.0.0-rc14, like ruby 2.6.2, GraalVM CE Native [x86_64-darwin]
$
```

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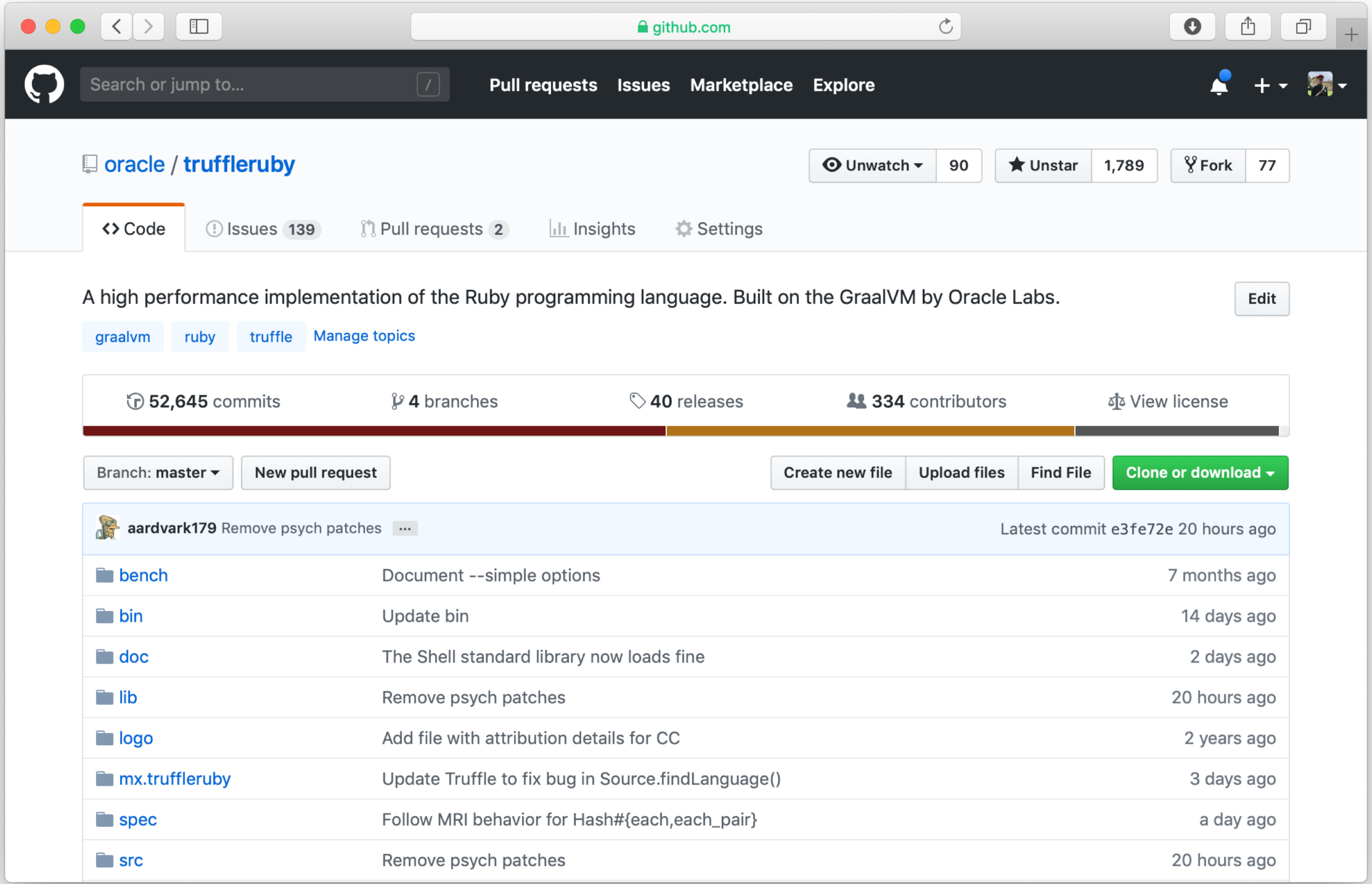
github.com
Search or jump to...
Pull requests
Issues
Marketplace
Explore
oracle / truffleruby
Unwatch 90
Unstar 1,789
Fork 77
Code
Issues 139
Pull requests 2
Insights
Settings
A high performance implementation of the Ruby programming language. Built on the GraalVM by Oracle Labs.
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truffle
Manage topics
52,645 commits
4 branches
40 releases
334 contributors
View license
Branch: master
New pull request
Create new file
Upload files
Find File
Clone or download
aardvark179 Remove psych patches
Latest commit e3fe72e 20 hours ago
bench
Document --simple options
7 months ago
bin
Update bin
14 days ago
doc
The Shell standard library now loads fine
2 days ago
lib
Remove psych patches
20 hours ago
logo
Add file with attribution details for CC
2 years ago
mx.truffleruby
Update Truffle to fix bug in Source.findLanguage()
3 days ago
spec
Follow MRI behavior for Hash#{each,each_pair}
a day ago
src
Remove psych patches
20 hours ago


graalvm.org
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8,222
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Run Programs Faster Anywhere
WHY GRAALVM
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Oracle Database
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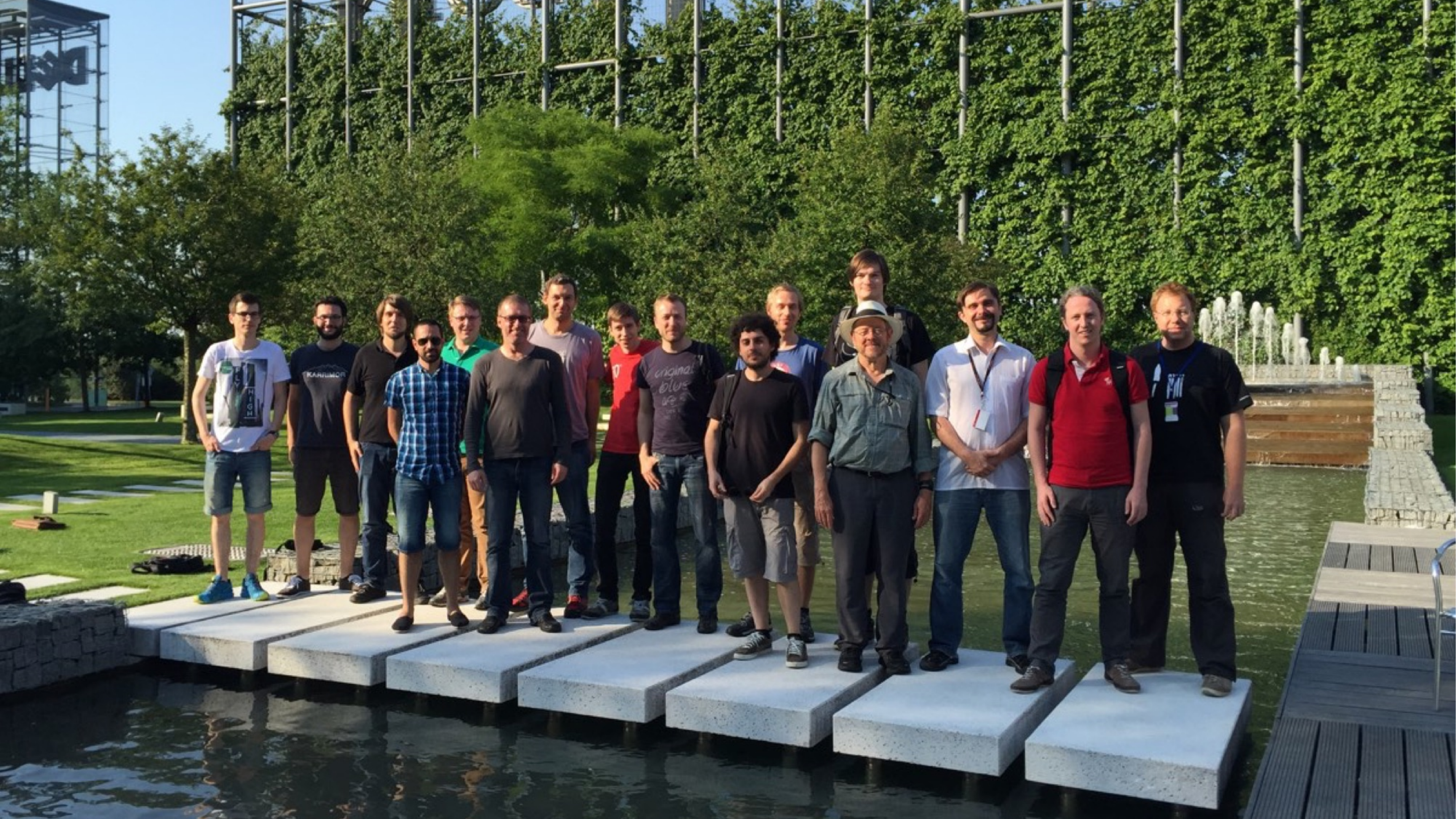
High-performance polyglot VM
GraalVM is a universal virtual machine for running applications written in JavaScript, Python, Ruby, R, JVM-based languages like Java, Scala, Kotlin, Clojure, and LLVM-based languages such as C and C++.
GraalVM removes the isolation between programming languages and enables interoperability in a shared


FLY
HIGH
KARRIMOR
original
blue

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