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Turning the JVM into a Polyglot VM with Graal

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Programming languages

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Stack Overflow is a question and answer site for professional and enthusiast programmers. It's 100% free, no registration required.

Why can't there be an “ultimate” programming language?

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Why can't there be an “ultimate” programming language?

closed as not constructive by Tim, Bo Persson, Devon_C_Miller, Mark, Graviton Jan 17 at 5:58

JavaScript: **One language to rule them all** | VentureBeat

venturebeat.com/2011/.../javascript-**one-language-to-rule-them**-...

by Peter Yared - in 23 Google+ circles

Jul 29, 2011 - Why code in two different scripting languages, one on the client and one on the server? It's time for **one language to rule them all**. Peter Yared **...**

[PDF] Python: **One** Script (**Language**) **to rule them all** - Ian Darwin

www.darwinsys.com/python/python4unix.pdf

Another **Language**? ▸ Python was invented in 1991 by Guido van. Rossum. ▫ Named after the comedy troupe, not the snake. ▸ Simple. ▫ They **all** say that!

Q & Stuff: **One Language to Rule Them All - Java**

qstuff.**blogspot**.com/2005/10/**one-language-to-rule-them-all-java**.html

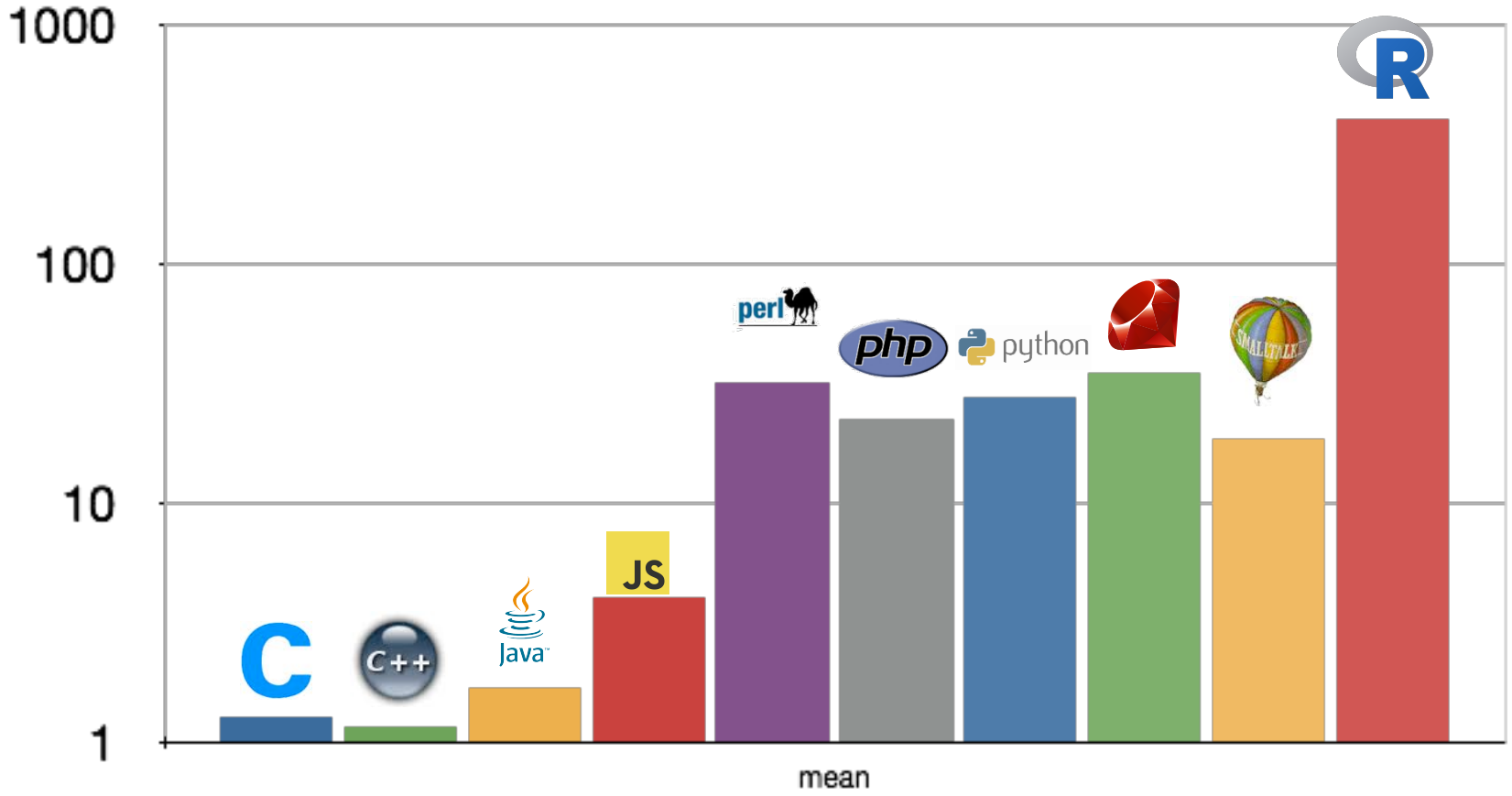
Oct 10, 2005 - **One Language to Rule Them All - Java**. For a long time I'd been hoping to add a scripting language to LibQ, to use in any of my (or other **...**

Dart : **one language to rule them all** - MixIT 2013 - Slideshare

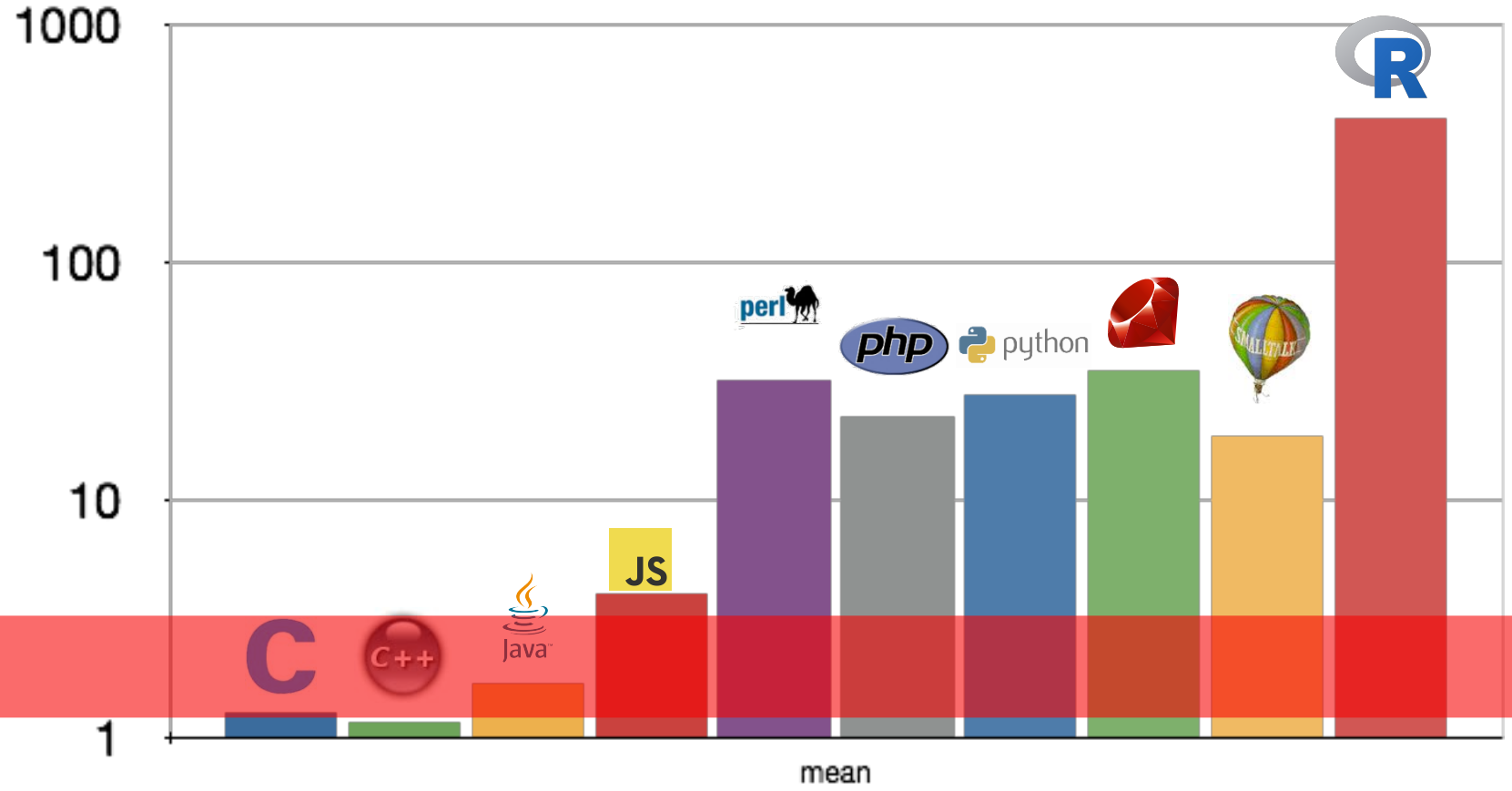
fr.slideshare.net/sdeleuze/dart-mixit2013en

DartSébastien Deleuze - @sdeleuzeMix-IT 2013One **language to rule them all** ...

Computer Language Benchmarks Game



Computer Language Benchmarks Game



Goal:

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

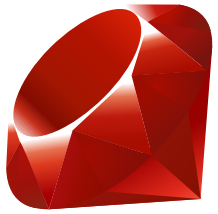
Current situation

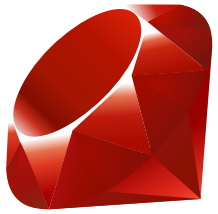
- Prototype a new language
  - Parser and language work to build syntax tree (AST), AST Interpreter
- Write a “real” VM
  - In C/C++, still using AST interpreter, spend a lot of time implementing runtime system, GC, …
- People start using it
- People complain about performance
  - Define a bytecode format and write bytecode interpreter
- Performance is still bad
  - Write a JIT compiler
  - Improve the garbage collector

How it should be

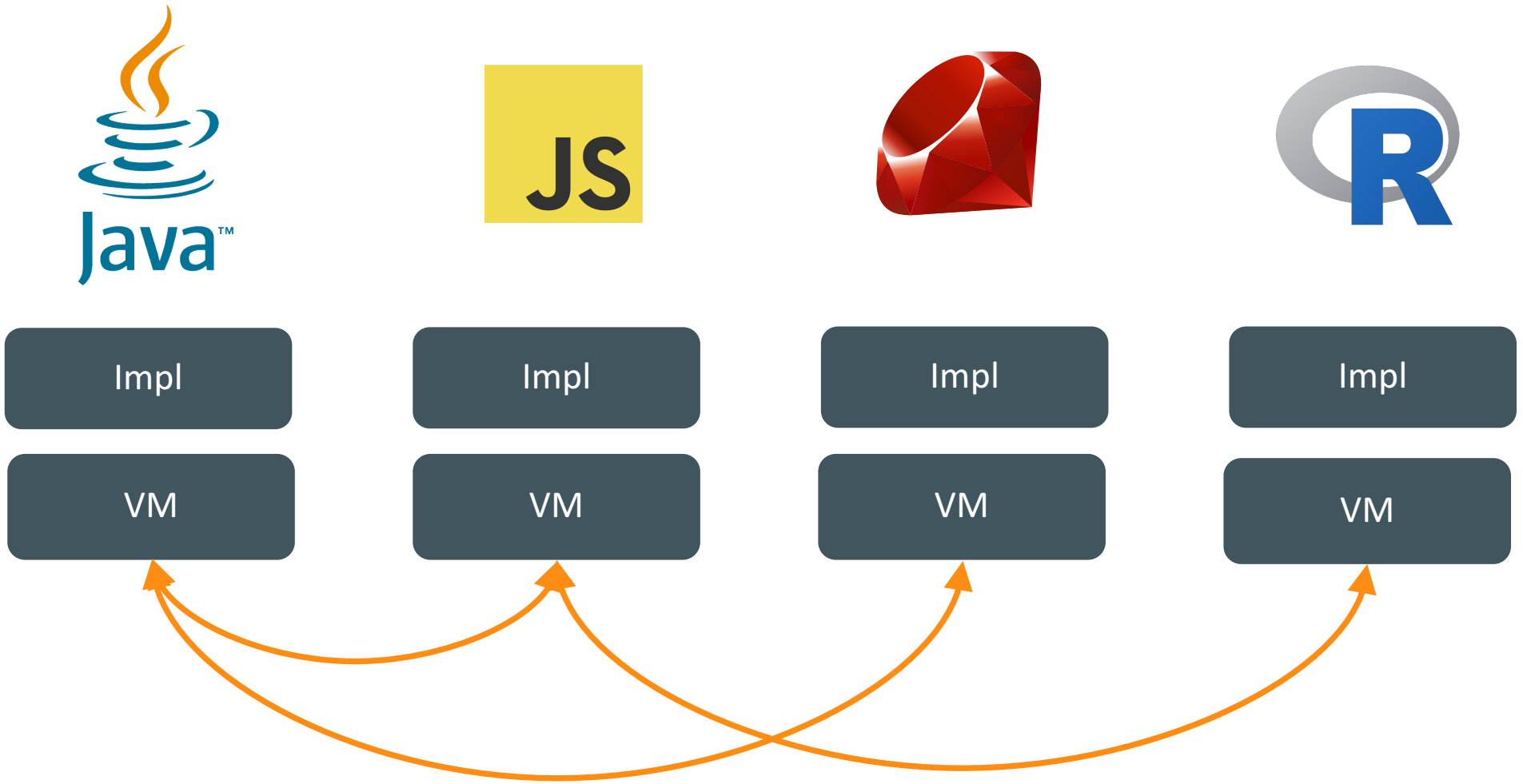
- Prototype a new language in Java
  - Parser and language work to build syntax tree (AST)
  - Execute using AST interpreter
- People start using it
  - And it is already fast

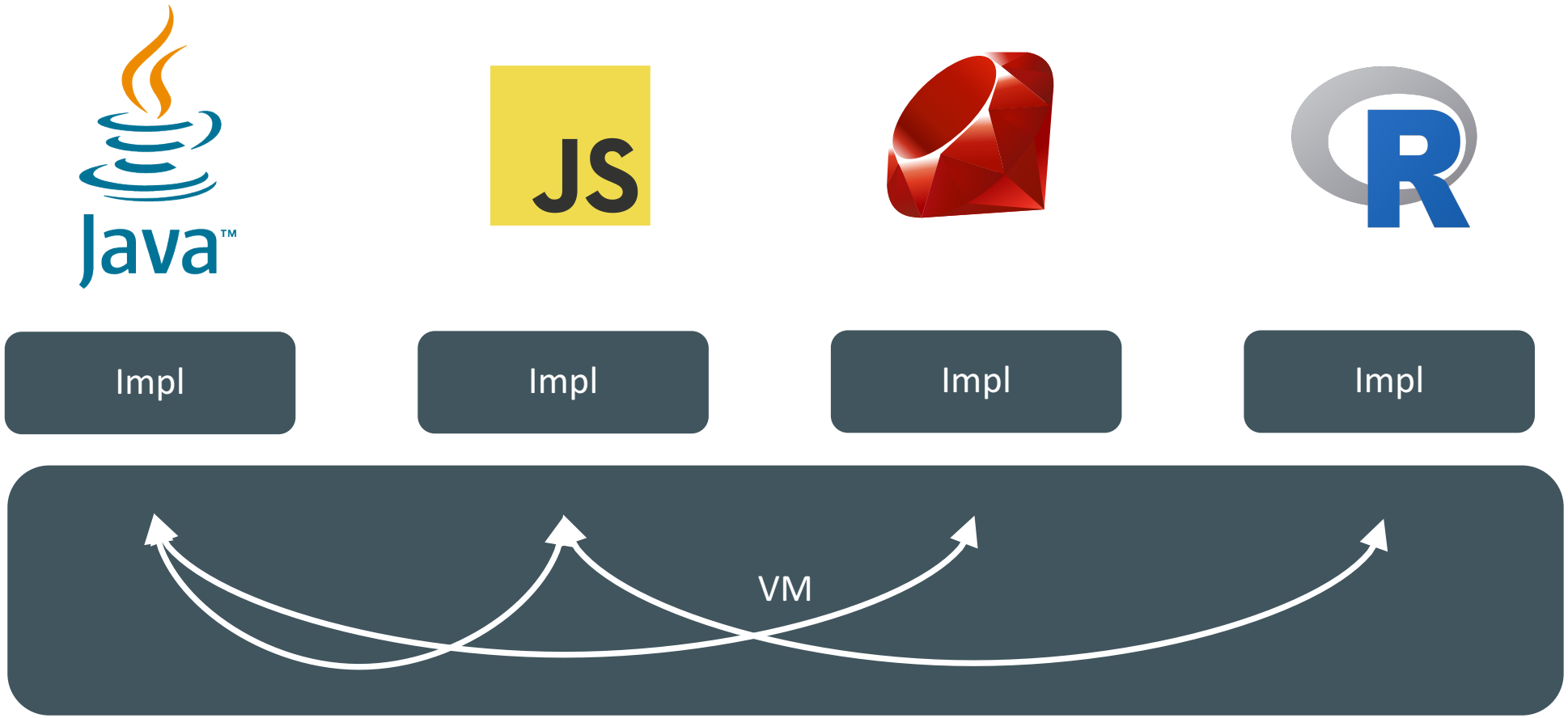
The GraalVM concept

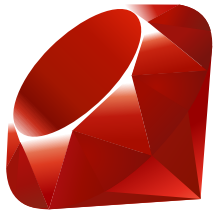


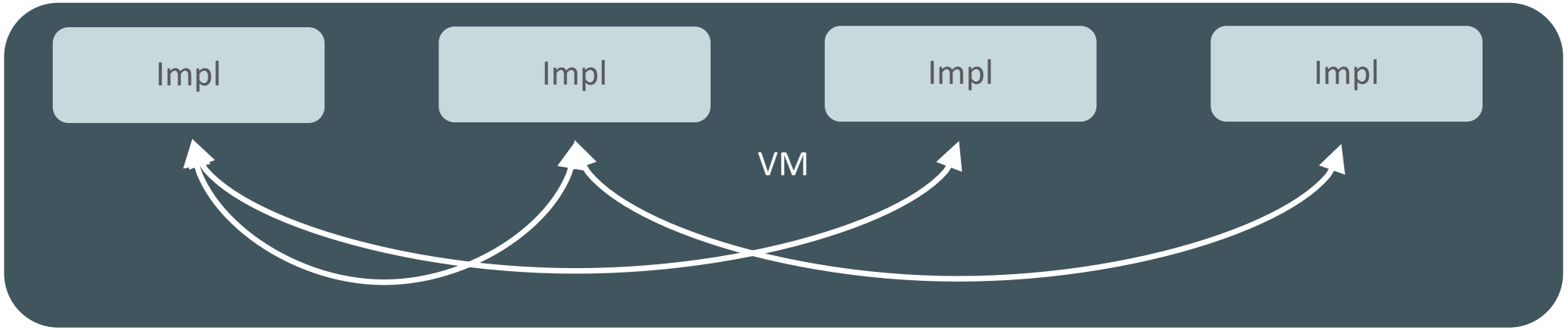


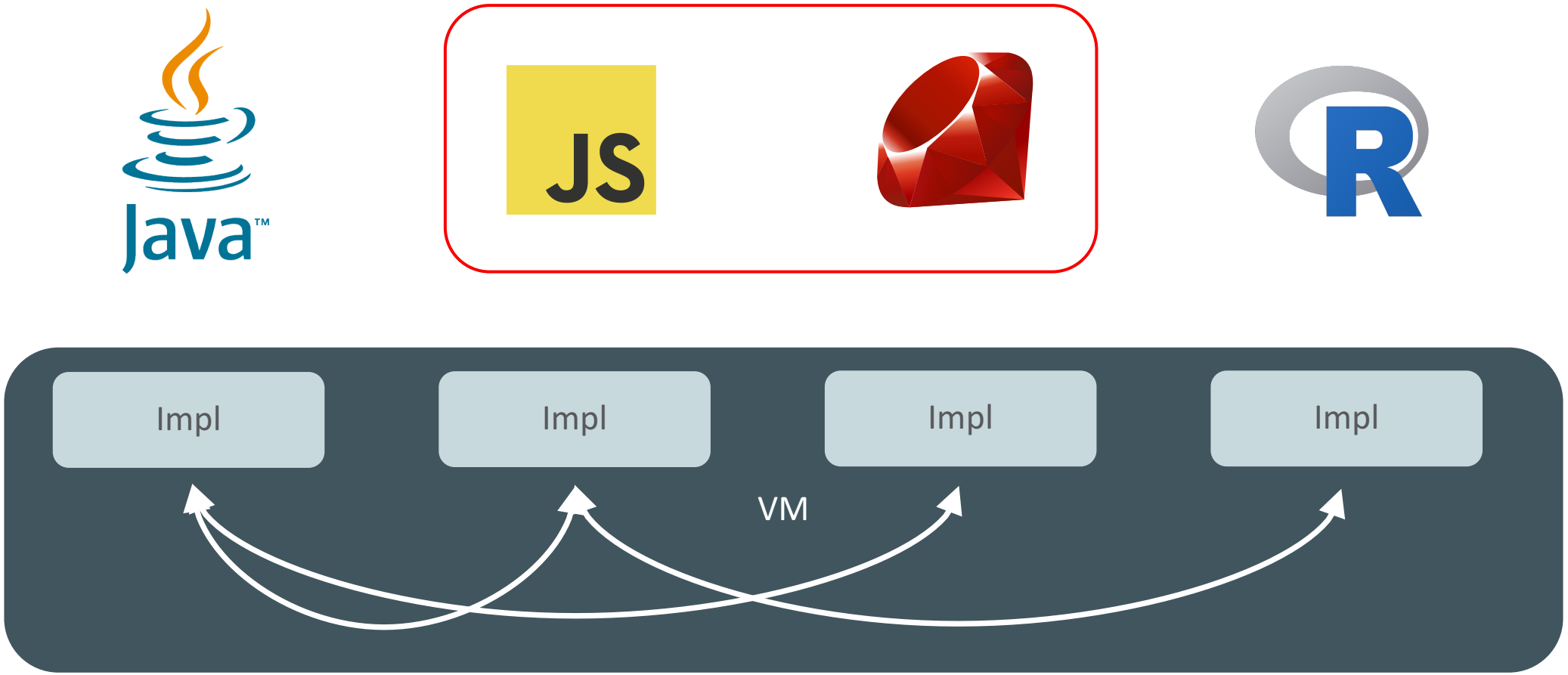
Impl	Impl	Impl	Impl
VM	VM	VM	VM











How we do polyglot in GraalVM

```
Truffle::Interop.eval('application/language', source)

value = Truffle::Interop.import(name)

Truffle::Interop.export(name)
```

```
Interop.eval('application/language', source)

value = Interop.import(name)

Interop.export(name)
```

```ruby
puts Truffle::Interop.eval('application/javascript', '14 + 2')
# 16
```

JavaScript

Ruby

```ruby
puts Truffle::Interop.eval('application/javascript', '14 + 2')
# 16
```

```
Truffle::Interop.eval('application/javascript', "
  function add(a, b) {
    return a + b;
  }

  Interop.export('add', add.bind(this));
")

add = Truffle::Interop.import('add')

puts add.call(14, 2)
# 16
```

Ruby

```
Truffle::Interop.eval('application/javascript', "
  function add(a, b) {
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JavaScript

```
function add(a, b) {
  return a + b;
}

puts add(14, 2)
# 16
```

JavaScript

```
function add(a, b) {
  return a + b;
}
```

Ruby

```
puts add(14, 2)
# 16
```

```
function Point(x, y) {
  this.x = x;
  this.y = y;
}

function random_points(n) {
  points = [];
  for (i = 0; i < n; i++) {
    points[i] = new Point(Math.random(), Math.random())
  }
  return points;
}

points = random_points(100)

point = points[0]
puts point.x, point.y
# 0.642460680339328
# 0.116305386298814
```

JS

```
function Point(x, y) {
  this.x = x;
  this.y = y;
}

function random_points(n) {
  points = [];
  for (i = 0; i < n; i++) {
    points[i] = new Point(Math.random(), Math.random())
  }
  return points;
}
```

Ruby

```
points = random_points(100)

point = points[0]
puts point.x, point.y
# 0.642460680339328
# 0.116305386298814
```

Performance

```ruby
def clamp(num, min, max)
  [min, num, max].sort[1]
end

def cmyk_to_rgb(c, m, y, k)
  Hash[{
    r: (65535 - (c * (255 - k) + (k << 8))) >> 8,
    g: (65535 - (m * (255 - k) + (k << 8))) >> 8,
    b: (65535 - (y * (255 - k) + (k << 8))) >> 8
  }.map { |k, v| [k, clamp(v, 0, 255)] }]
end

benchmark do
  cmyk_to_rgb(rand(255), rand(255), rand(255), rand(255))
end
```

```ruby
def clamp(num, min, max)
  [min, num, max].sort[1]
end

def cmyk_to_rgb(c, m, y, k)
  Hash[{
    r: (65535 - (c * (255 - k) + (k << 8))) >> 8,
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  }.map { |k, v| [k, clamp(v, 0, 255)] }]
end

benchmark do
  cmyk_to_rgb(rand(255), rand(255), rand(255), rand(255))
end
```
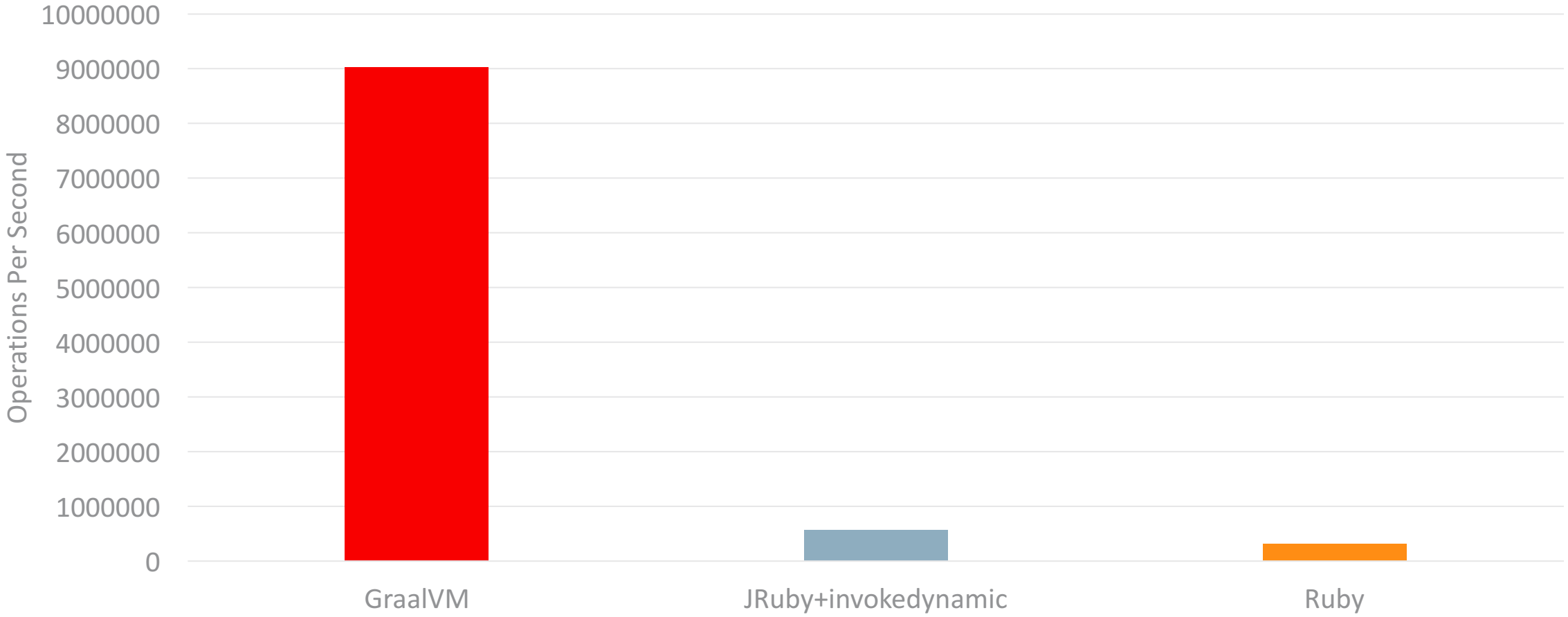
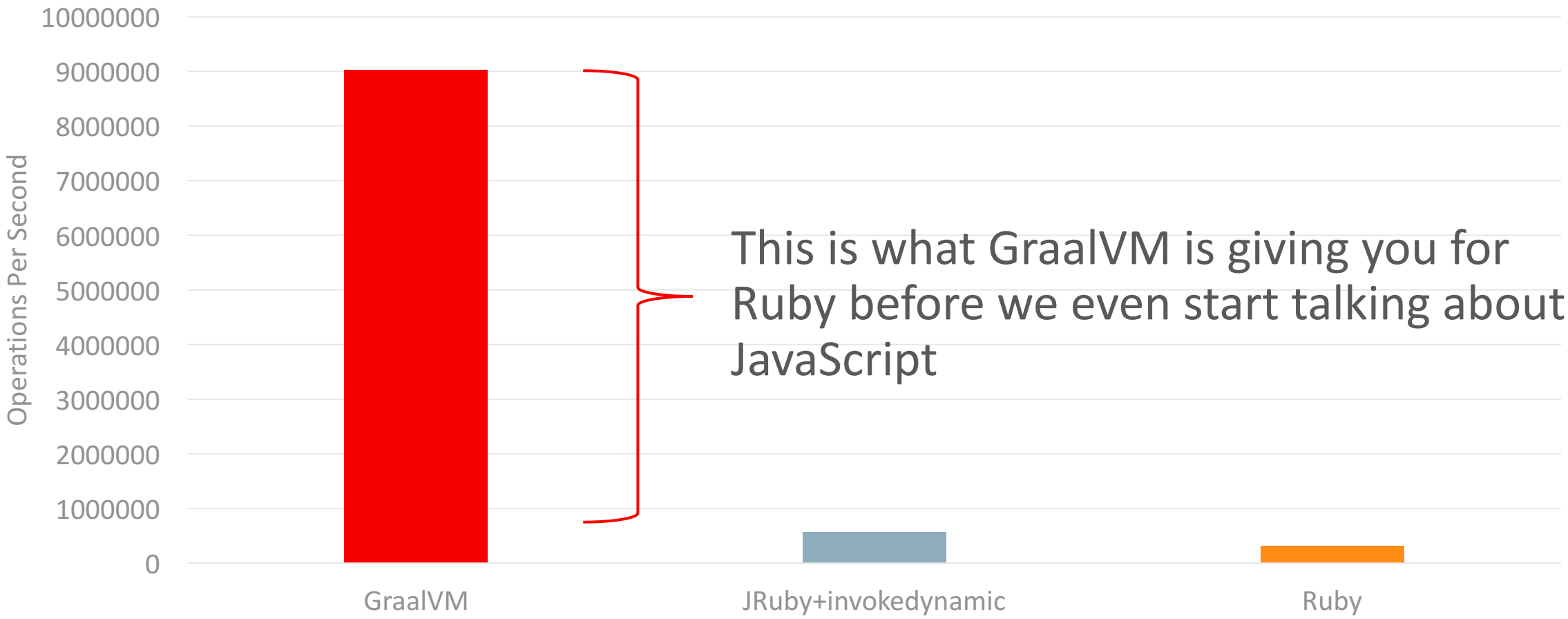

Warms up and then reports iterations per second

Random inputs stop the whole thing being totally optimised away

`clamp` in Pure Ruby



`clamp` in Pure Ruby



```ruby
require 'v8'

context = V8::Context.new

$clamp = context.eval("
  function clamp(num, min, max) {
    if (num < min) {
      return min;
    } else if (num > max) {
      return max;
    } else {
      return num;
    }
  }
  clamp;
")

def cmyk_to_rgb(c, m, y, k)
  Hash[{
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  }.map { |k, v| [k, $clamp.call(v, 0, 255)] }]
end
```

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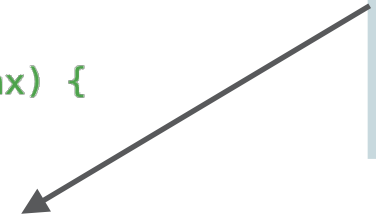
end
```

Not only have we rewritten in JavaScript, but the JavaScript code is simpler than the Ruby



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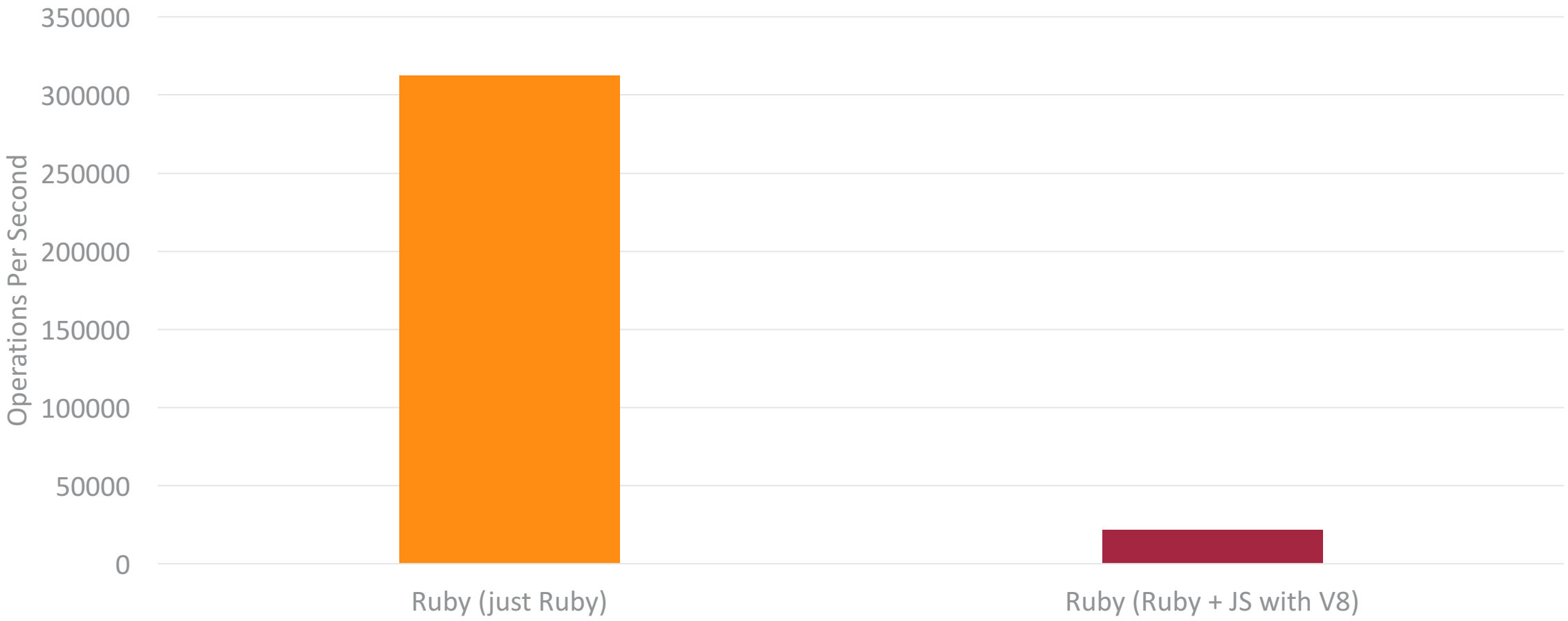
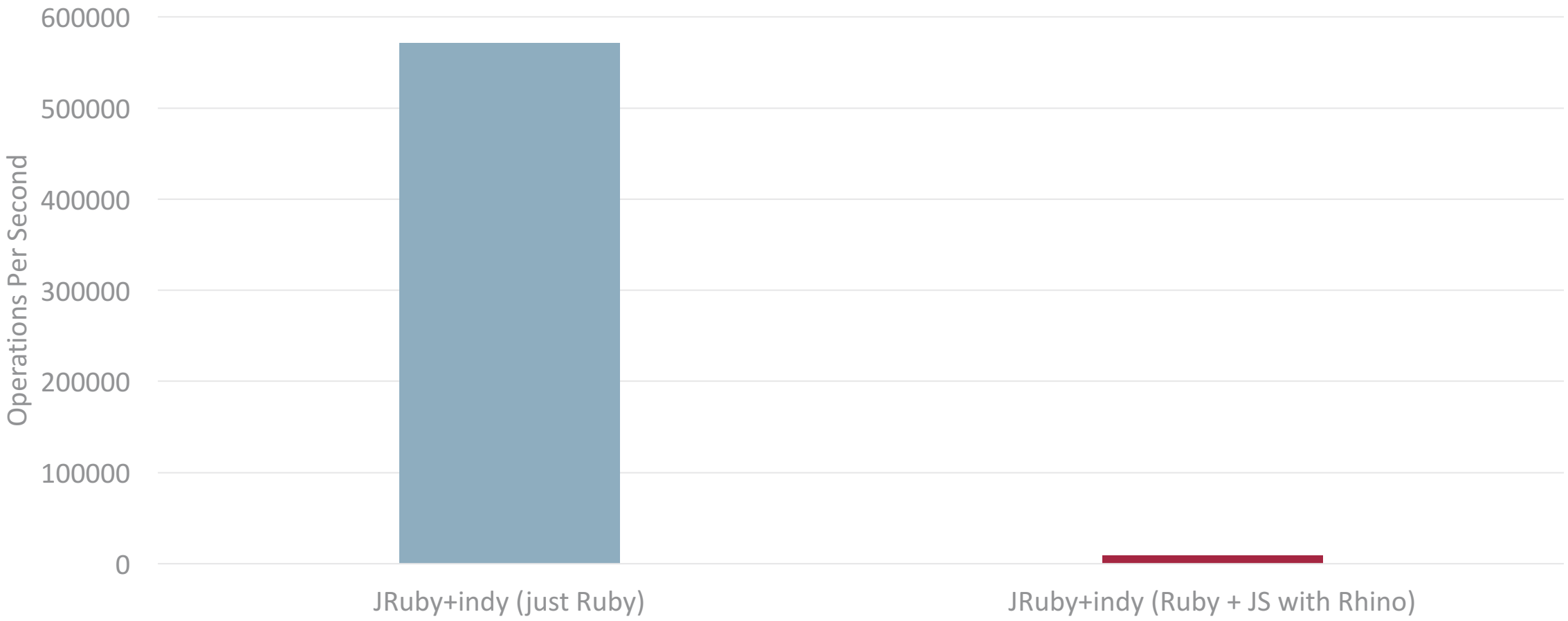
`clamp` in Ruby and JavaScript with V8



```
require 'rhino'

context = Rhino::Context.new
```

`clamp` in Ruby and JavaScript with JRuby and Rhino



```
factory = javax.script.ScriptEngineManager.new
engine = factory.getEngineByName 'nashorn'
bindings = engine.createBindings

$clamp = engine.eval("
  function clamp(num, min, max) {
    if (num < min) {
      return min;
    } else if (num > max) {
      return max;
    } else {
      return num;
    }
  }
", bindings)

def cmyk_to_rgb(c, m, y, k)
  Hash[{
    r: (65535 - (c * (255 - k) + (k << 8))) >> 8,
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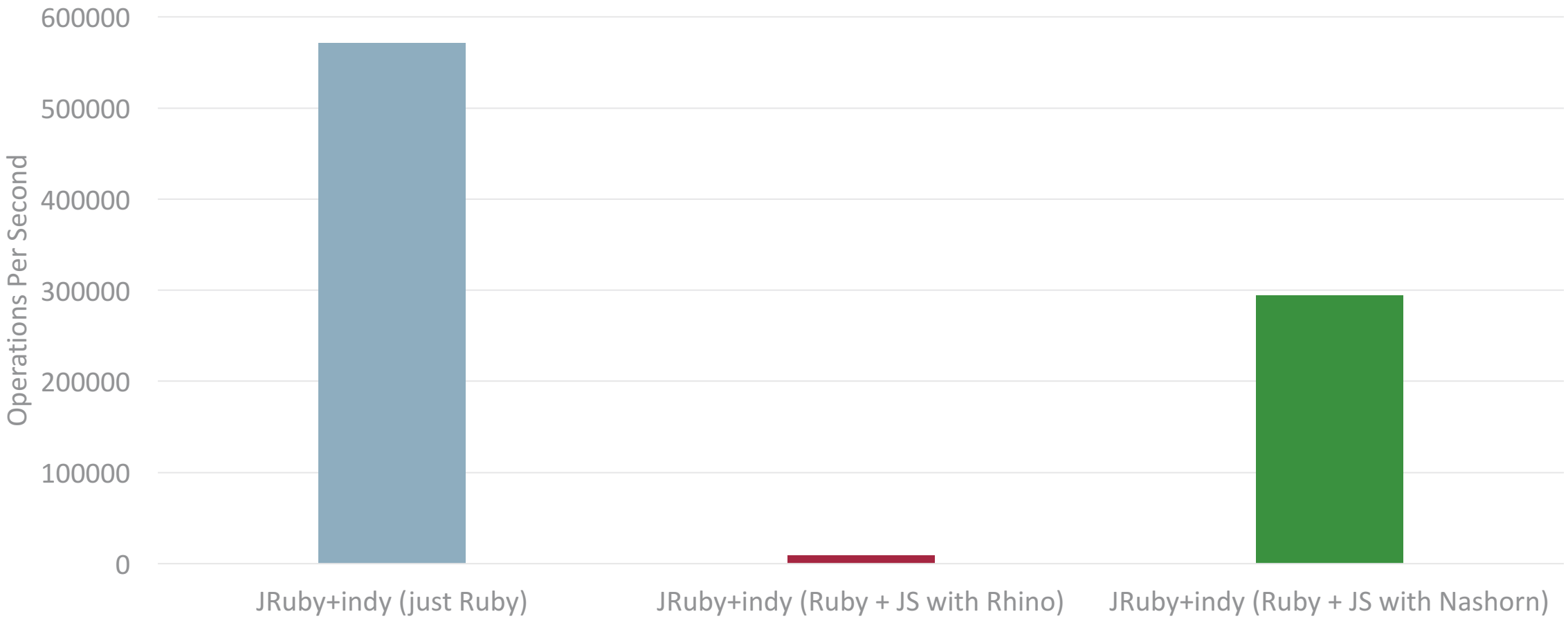
  }.map { |k, v| [k, $clamp.call(v, 0, 255)] }]
end
```

`clamp` in Ruby and JavaScript with JRuby and Nashorn



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  }
}
```

```
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  }.map { |k, v| [k, clamp(v, 0, 255)] }]
end
```
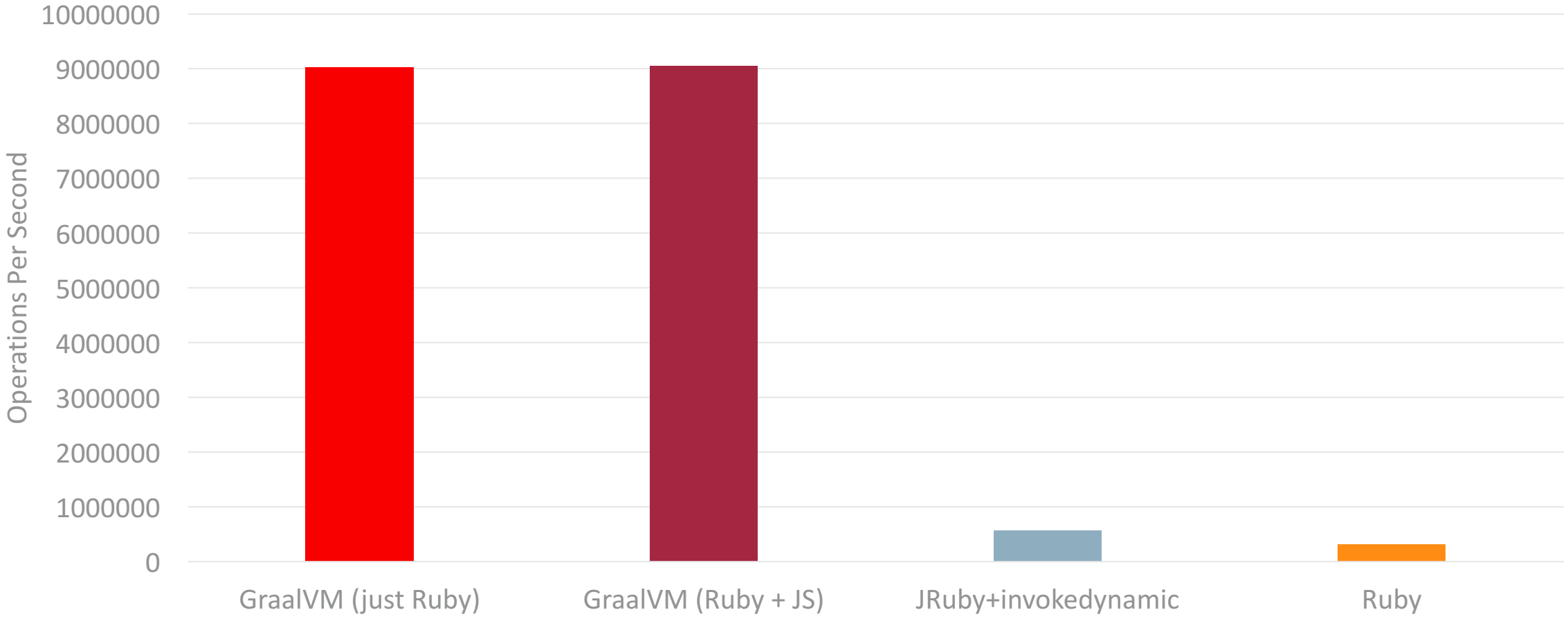
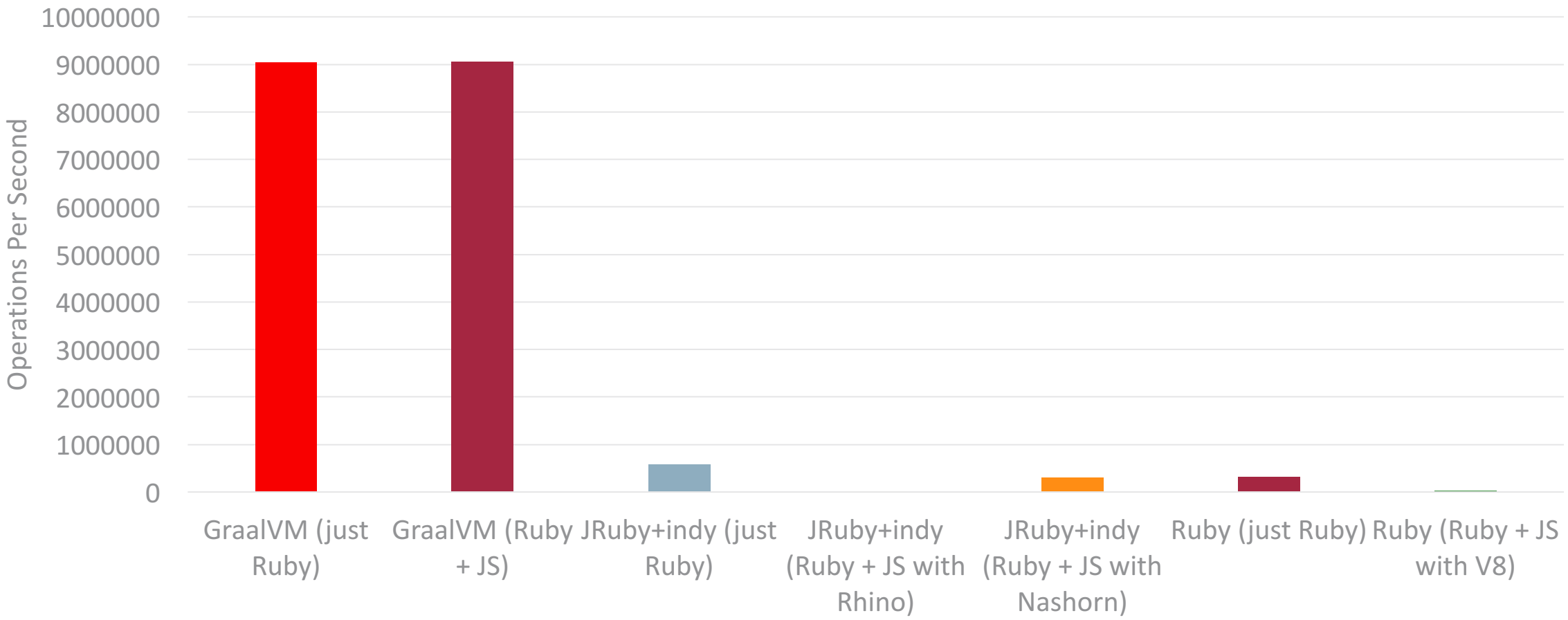
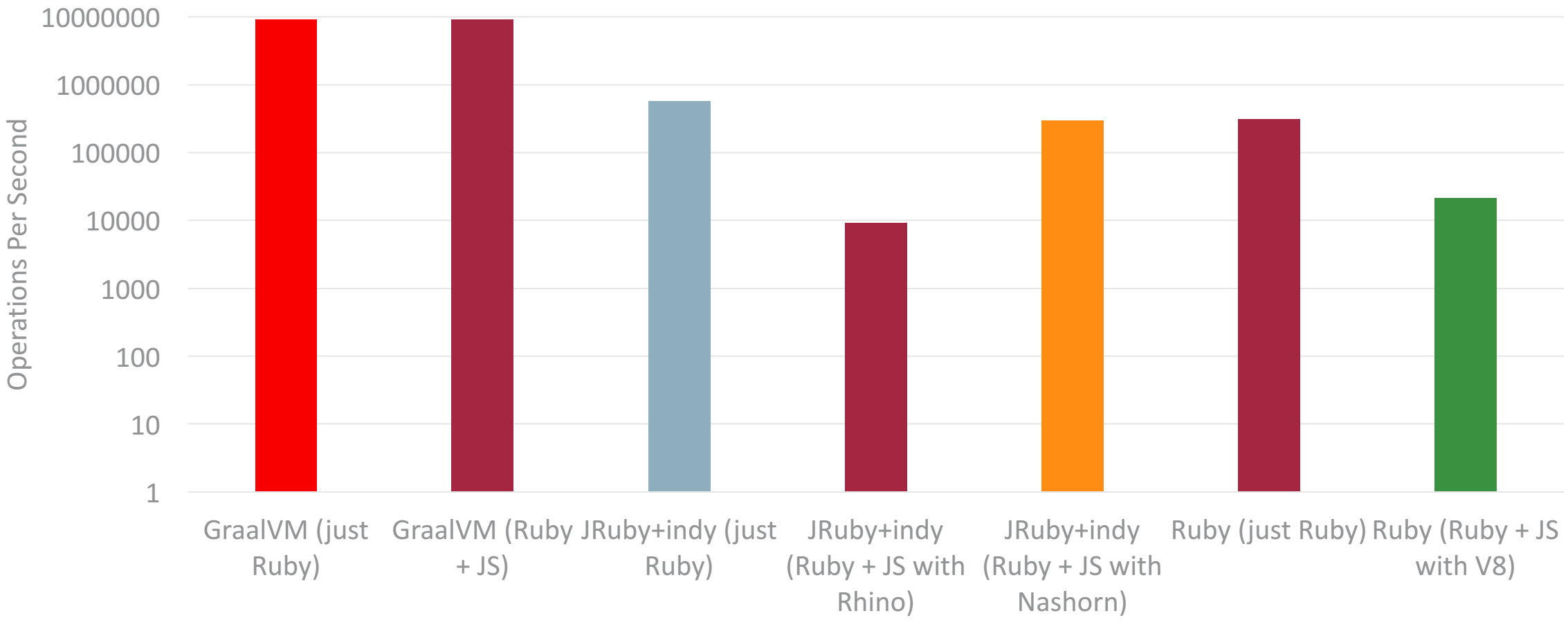

`clamp` in Ruby and JavaScript with GraalVM



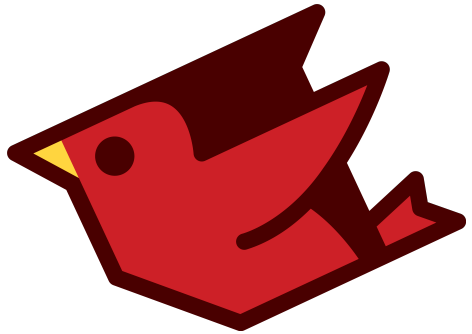
`clamp` in all configurations



`clamp` in all configurations



How Graal achieves this



Jython

renjin

Conventional JVM implementations of languages work by emitting JVM bytecode – the same thing that the Java compiler does

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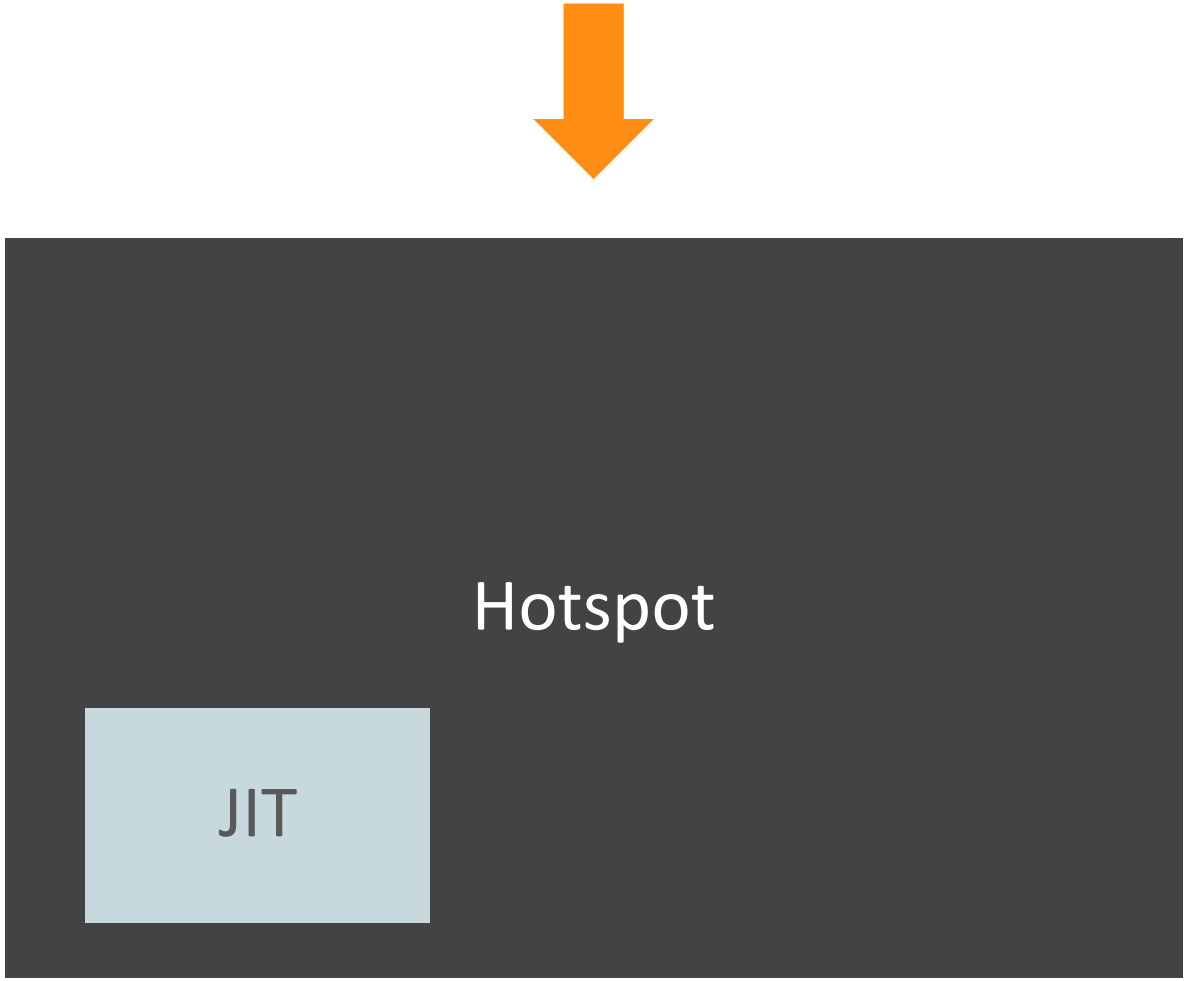
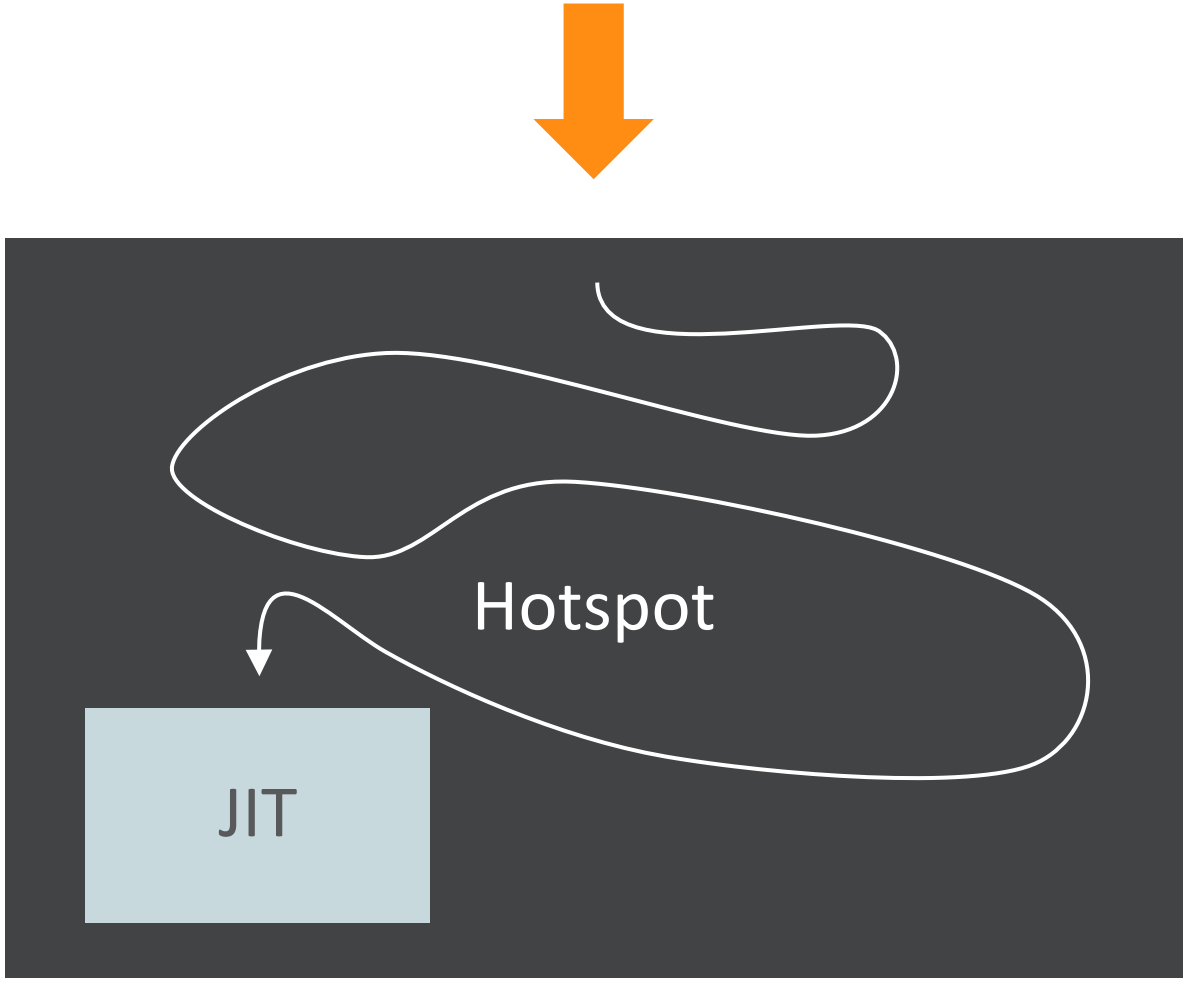
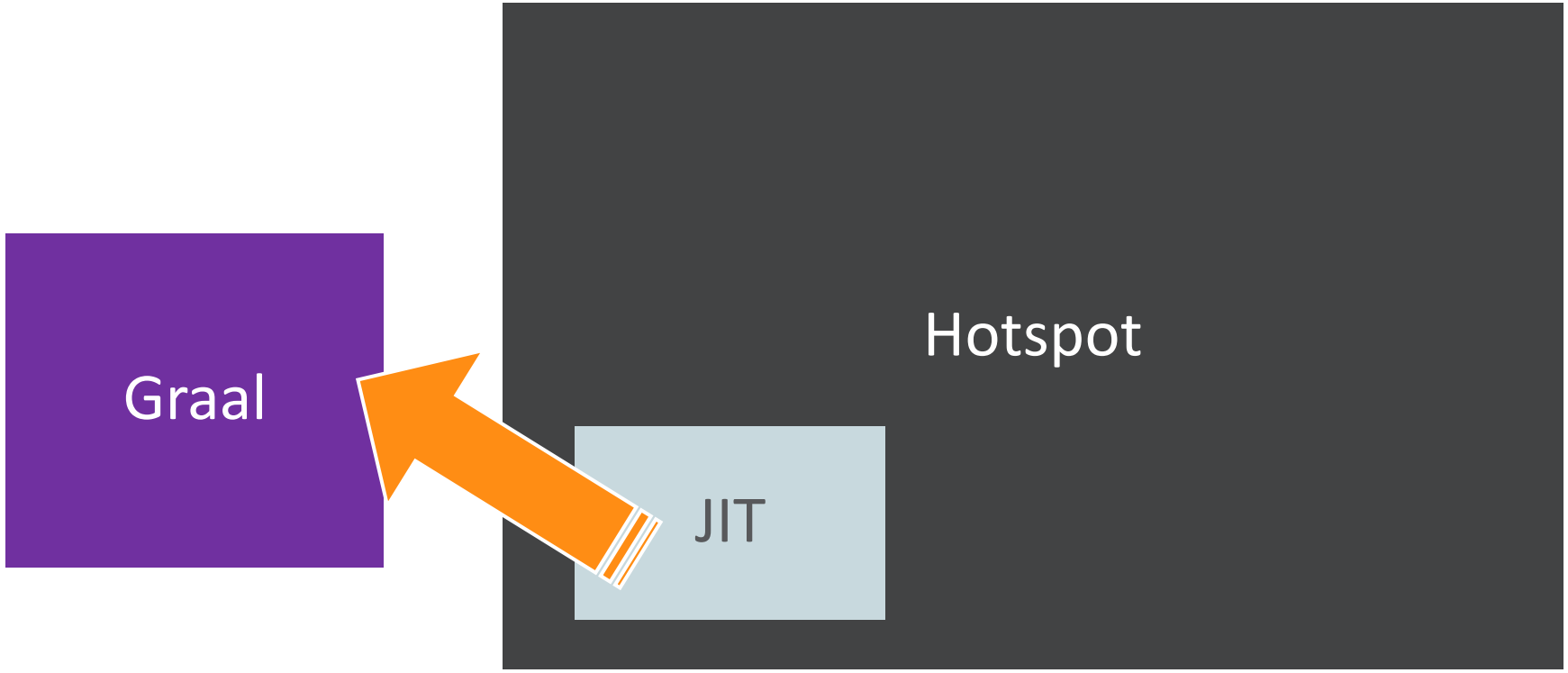
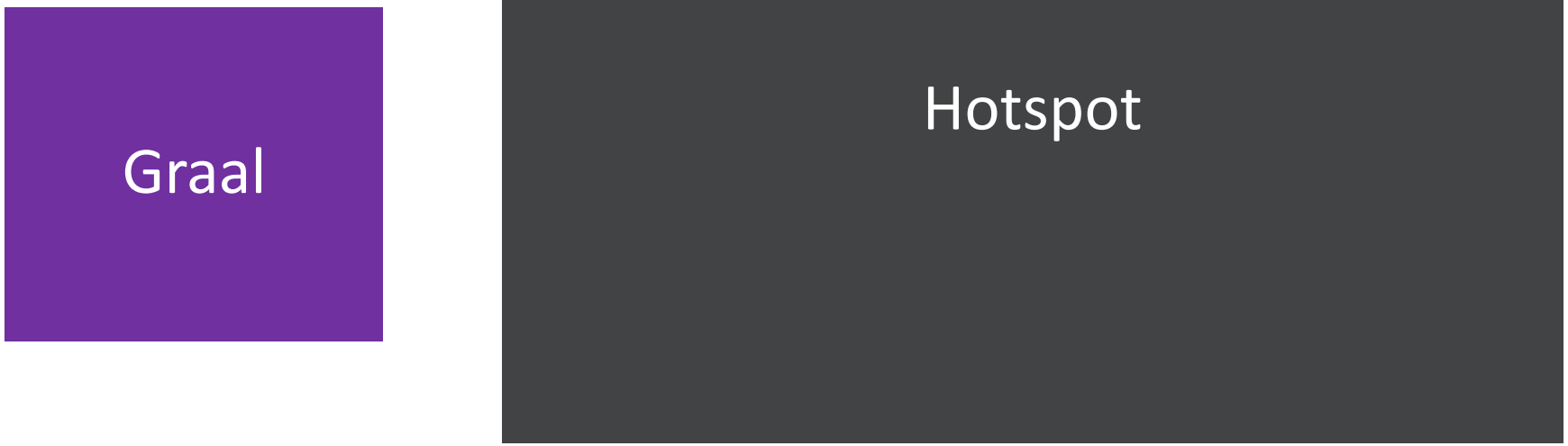
Hotspot

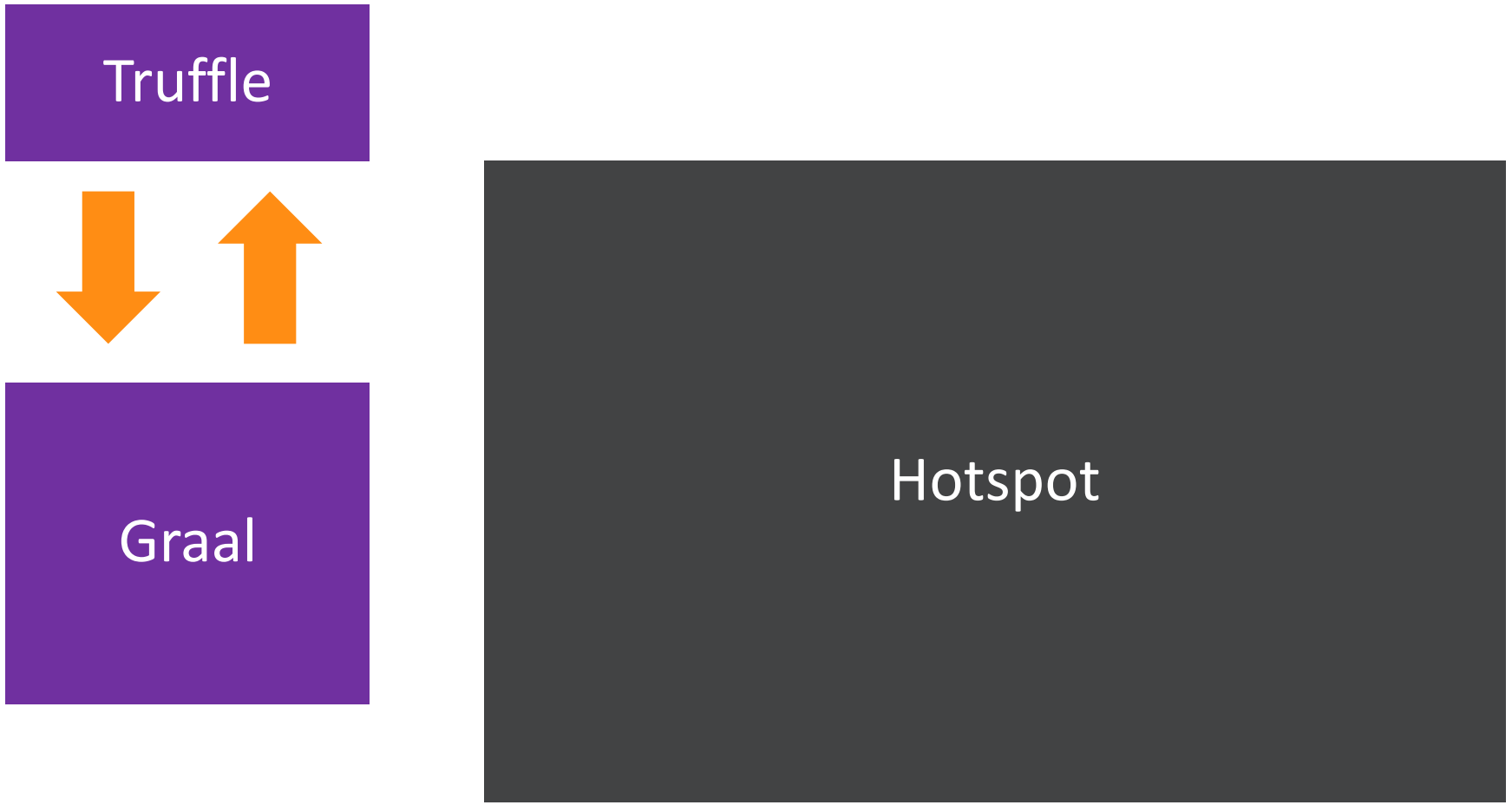
Hotspot











Slightly confusing terminology…

- Graal is a new JIT compiler for the JVM
- Graal VM is the JVM, with Graal, Truffle, and our languages bundled in it
- Truffle uses Graal on your behalf

Guest Language

Bytecode

JVM

Guest Language

Compiler internal data structures, optimisation passes, machine code, …

Graal

Guest Language

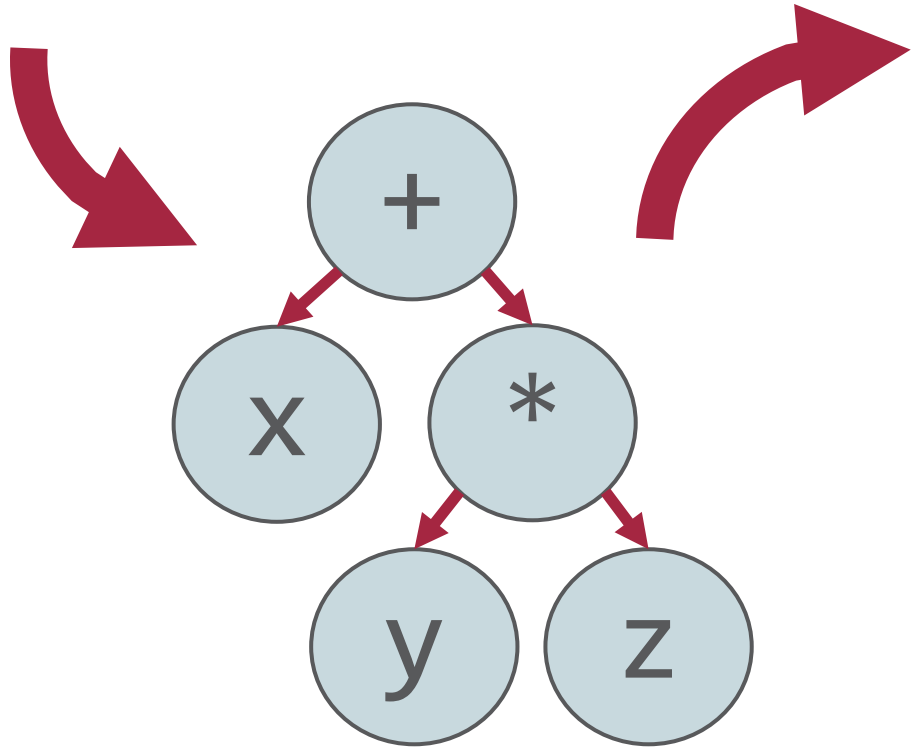
language interpreter

Truffle

Graal

The very basics of Truffle and Graal

```
x + y * z
```




```
load_local x
load_local y
load_local z
call *
call +
```

```
pushq %rbp
movq  %rsp, %rbp
movq  %rdi, -8(%rbp)
movq  %rsi, -16(%rbp)
movq  %rdx, -24(%rbp)
movq  -16(%rbp), %rax
movl  %eax, %edx
movq  -24(%rbp), %rax
imull %edx, %eax
movq  -8(%rbp), %rdx
addl  %edx, %eax
popq  %rbp
ret
```

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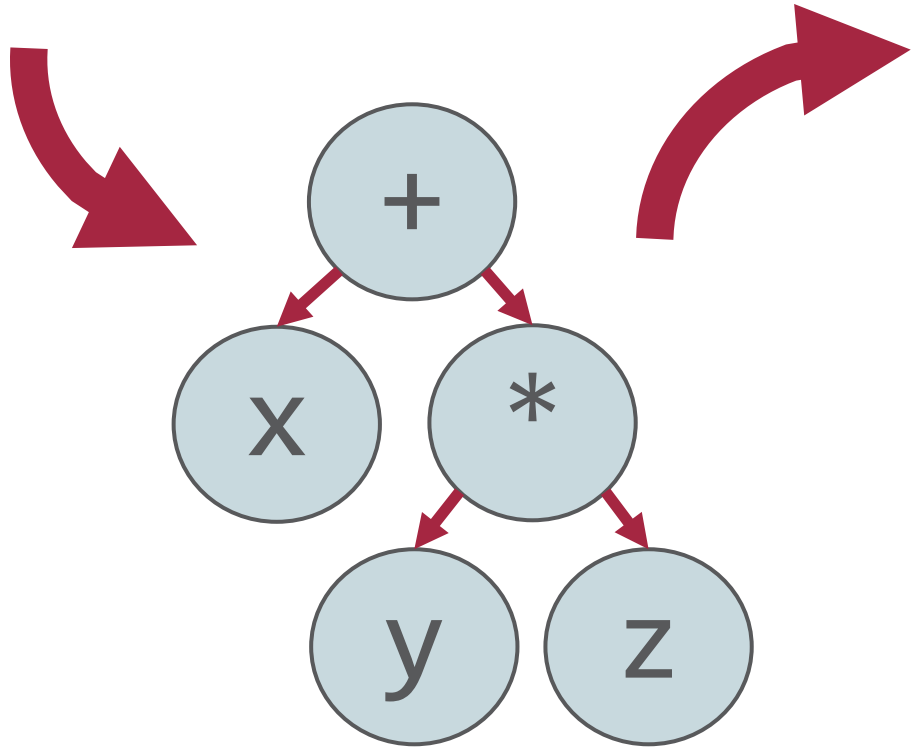
```
x + y * z
```

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movq  -24(%rbp), %rax
imull %edx, %eax
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popq  %rbp
ret
```

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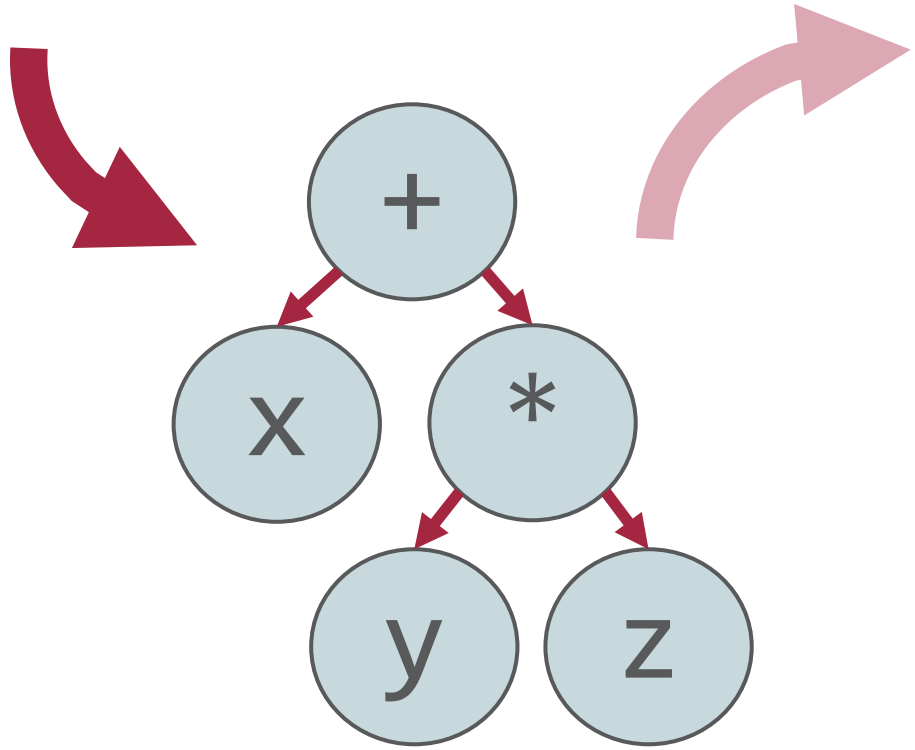
x + y * z

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```
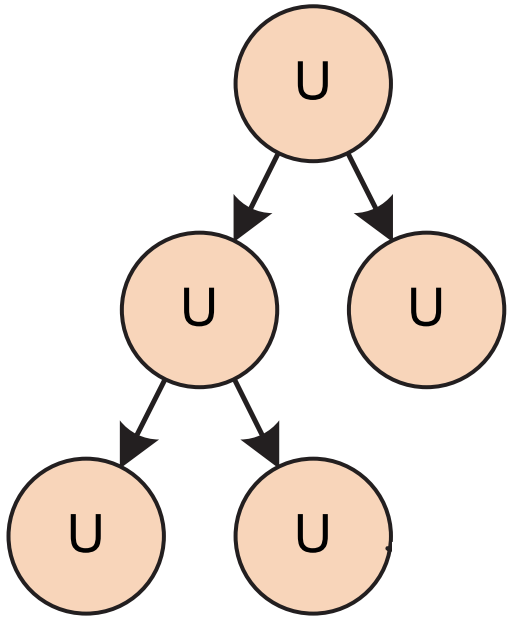
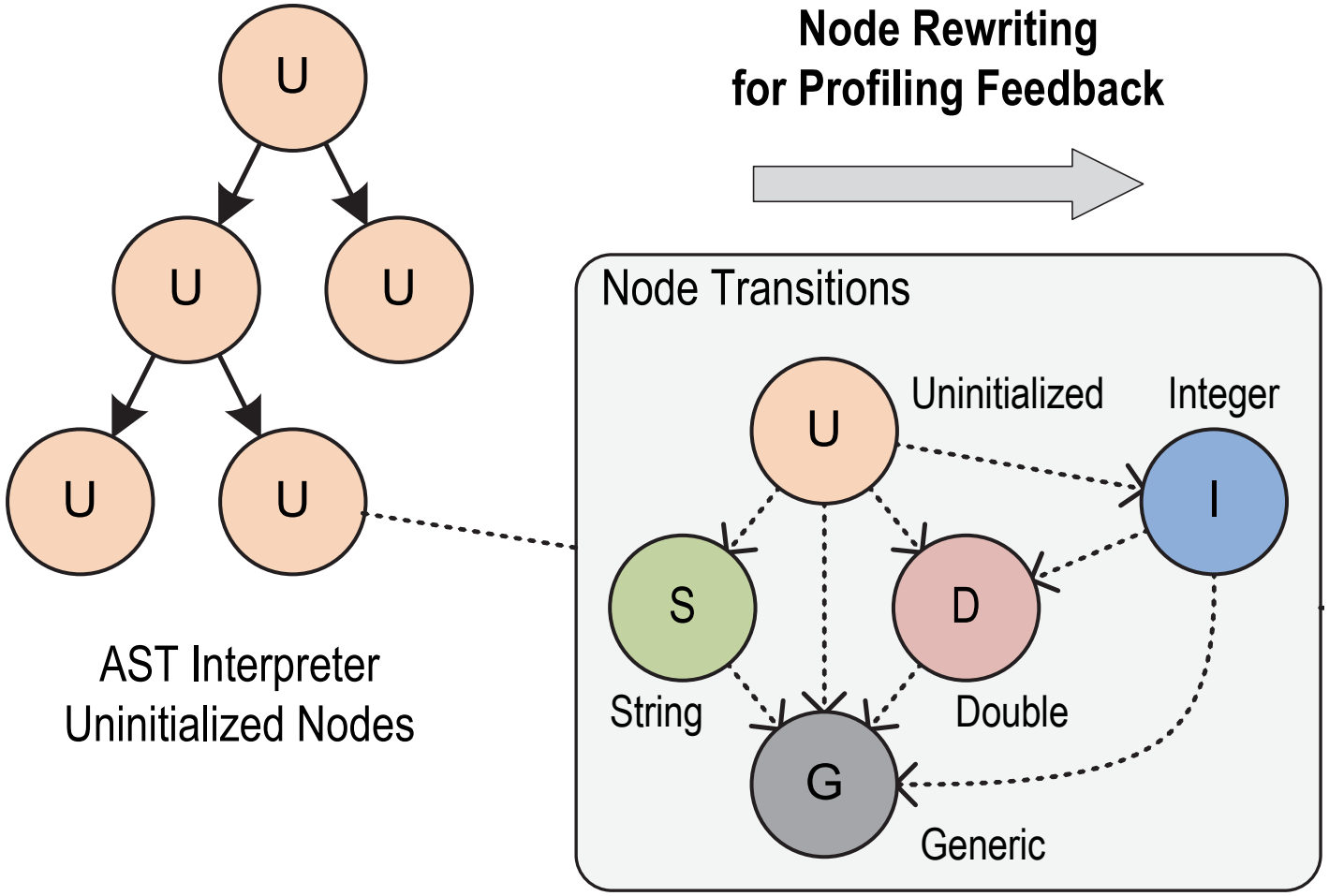



AST Interpreter
Uninitialized Nodes

T. Würthinger, C. Wimmer, A. Wöß, L. Stadler, G. Duboscq, C. Humer, G. Richards, D. Simon, and M. Wolczko. One VM to rule them all. In Proceedings of Onward!, 2013.



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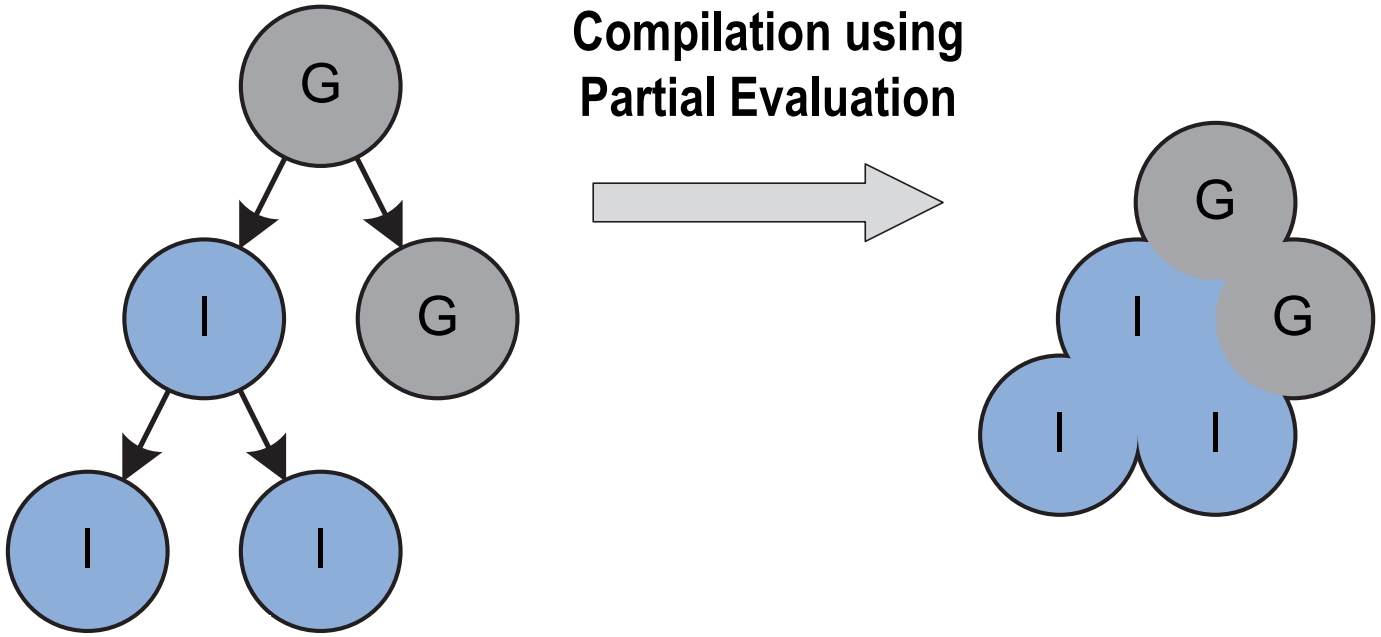
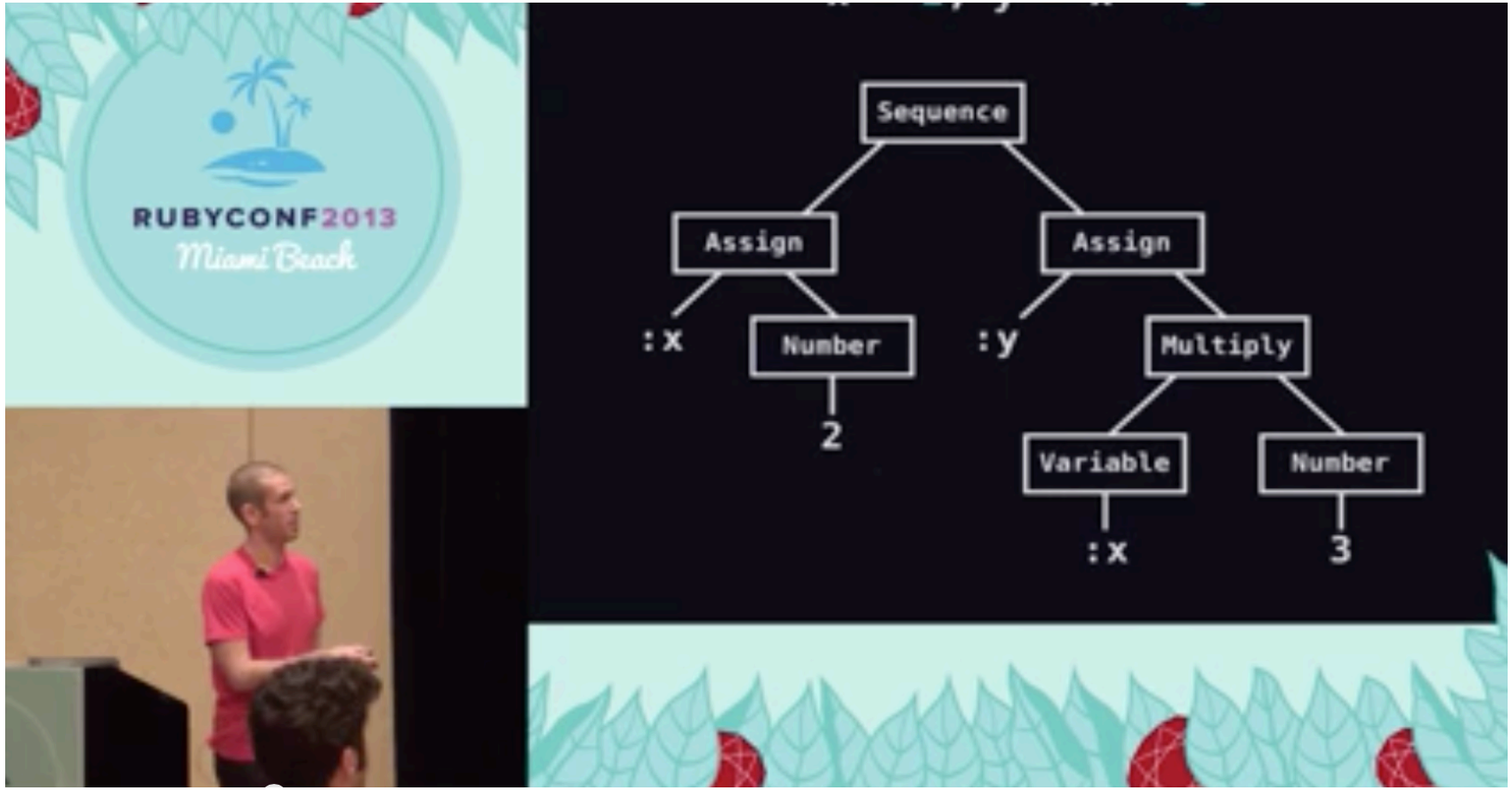
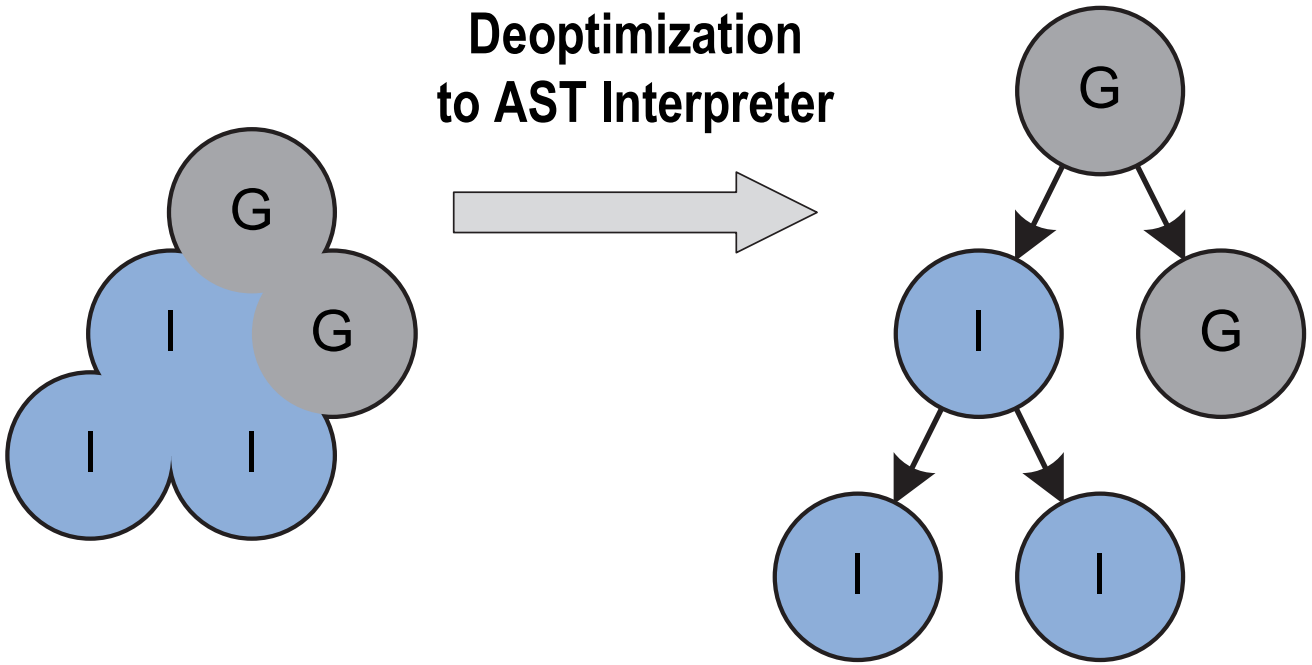


T. Würthinger, C. Wimmer, A. Wöß, L. Stadler, G. Duboscq, C. Humer, G. Richards, D. Simon, and M. Wolczko. One VM to rule them all. In Proceedings of Onward!, 2013.



codon.com/compilers-for-free



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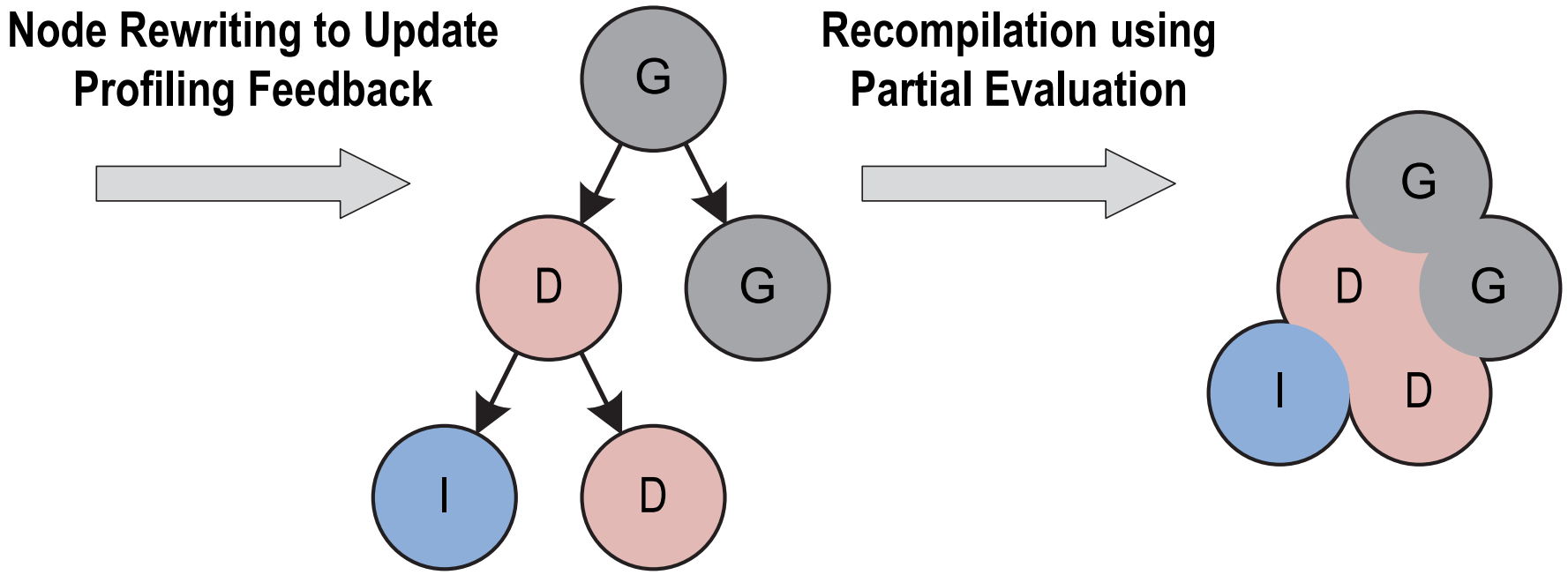

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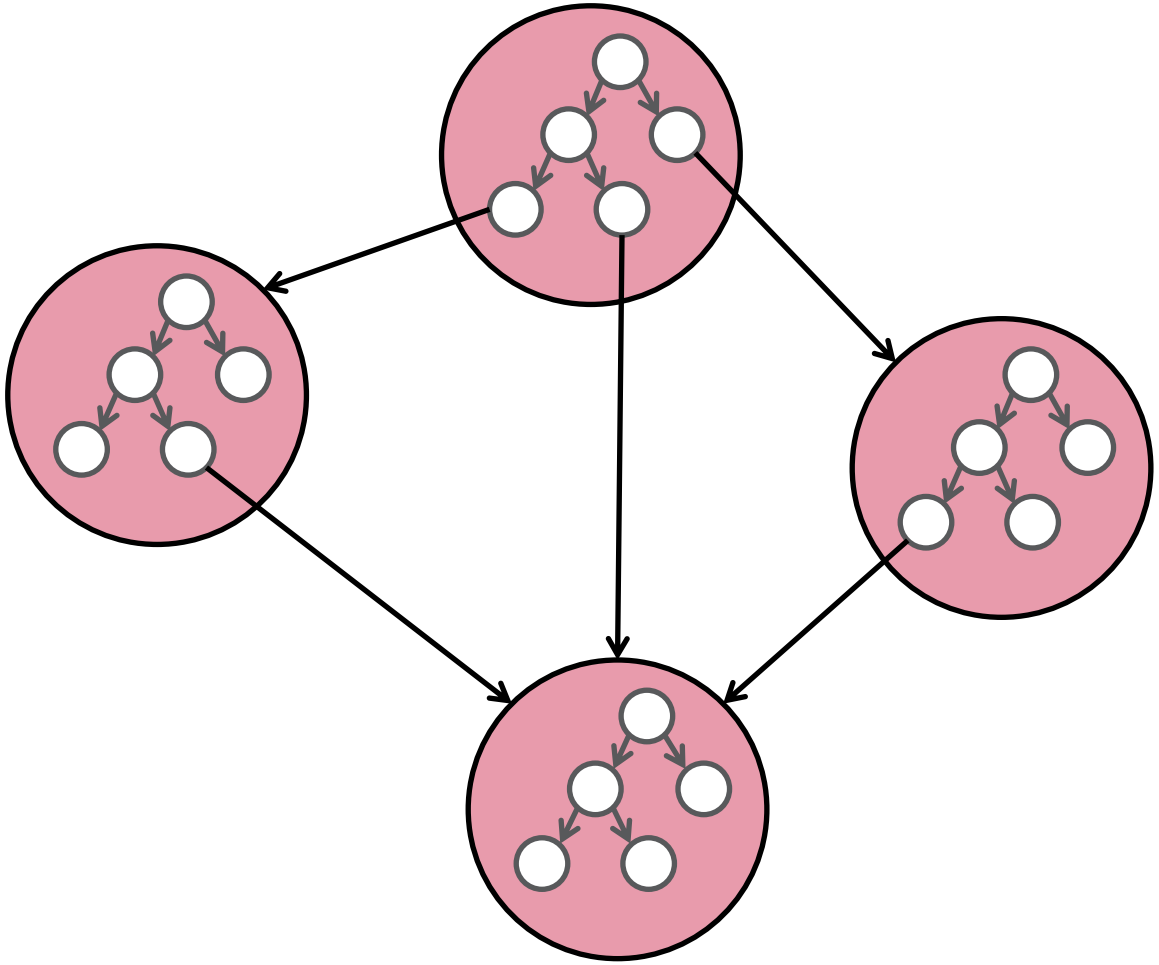

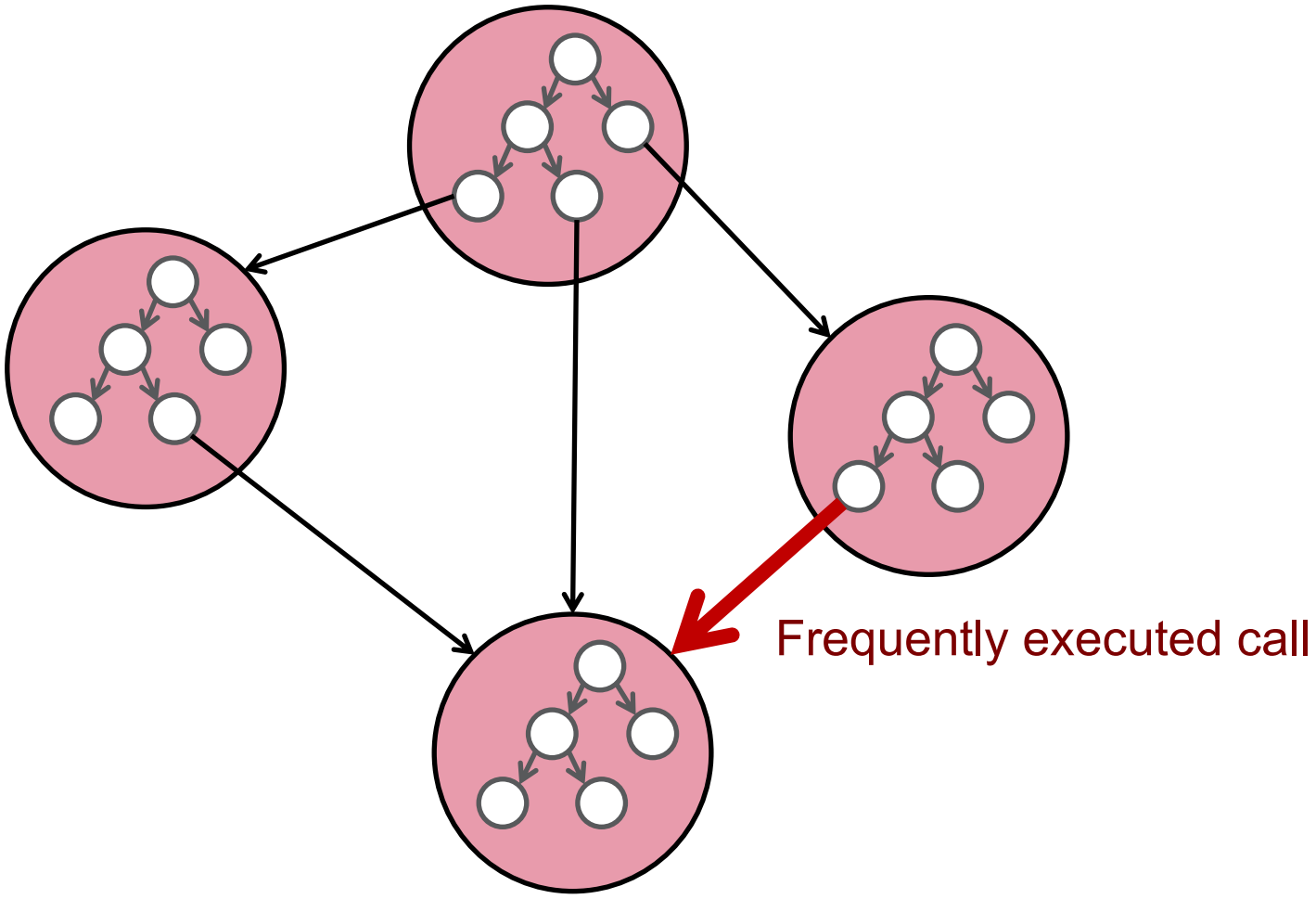

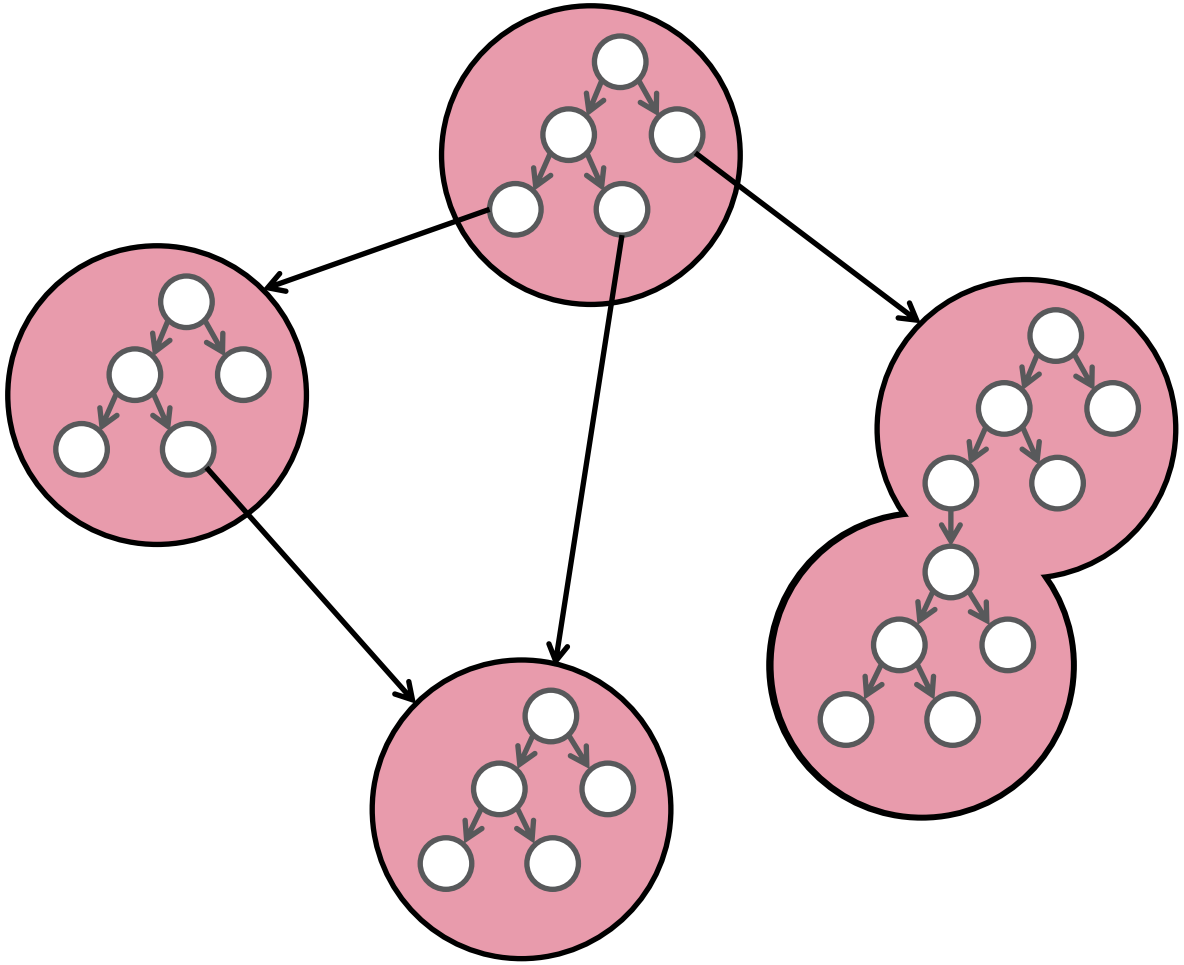

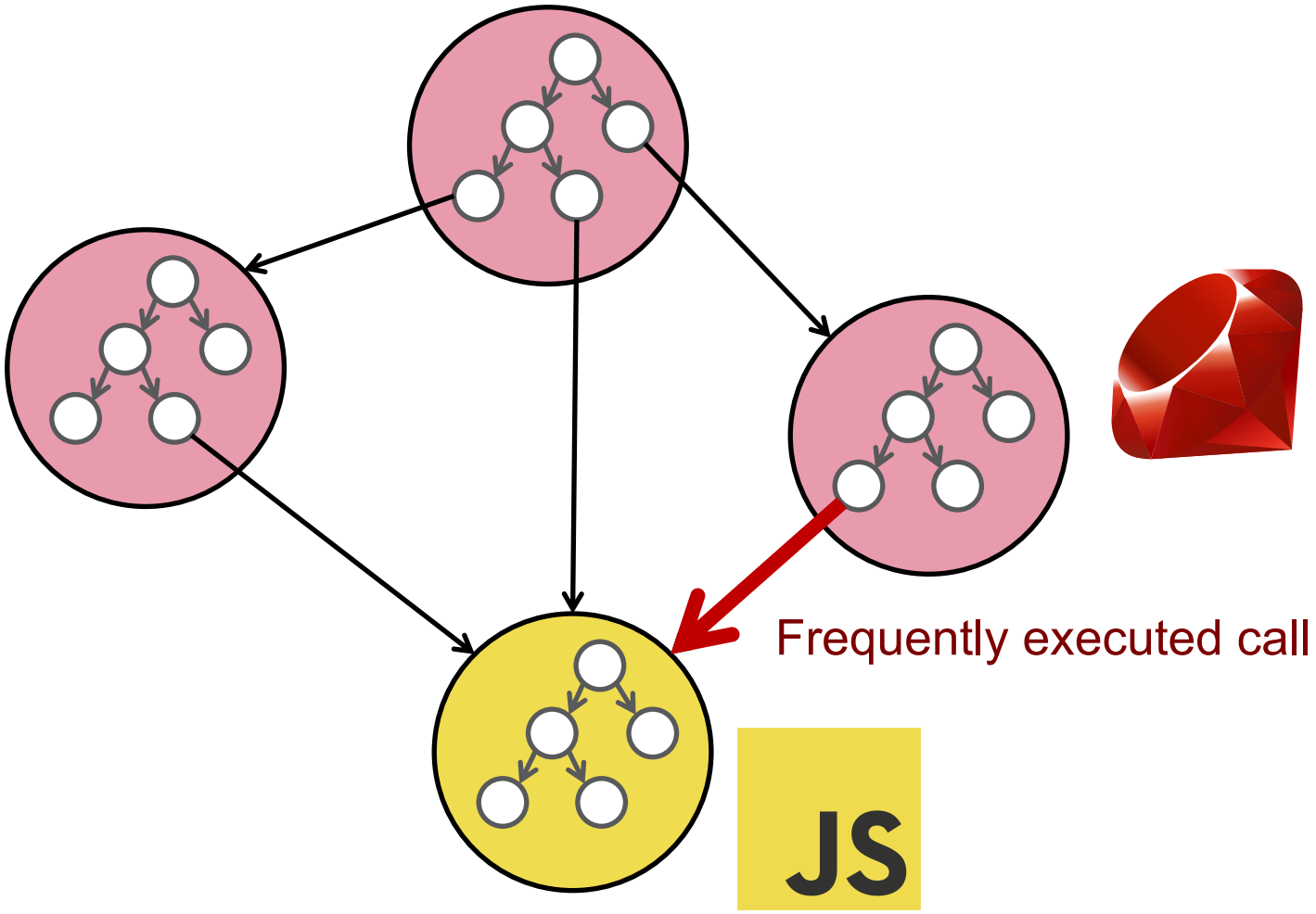

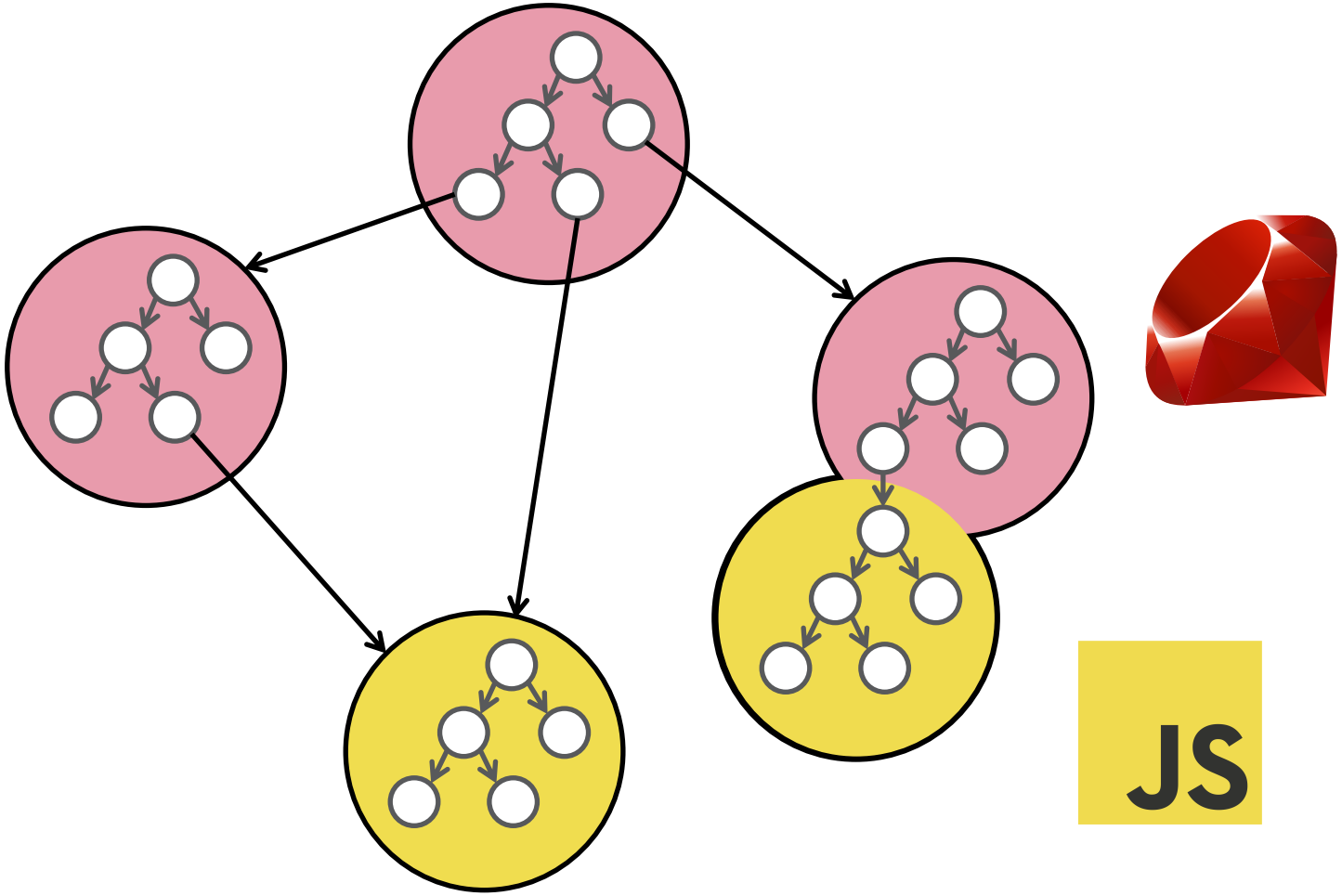

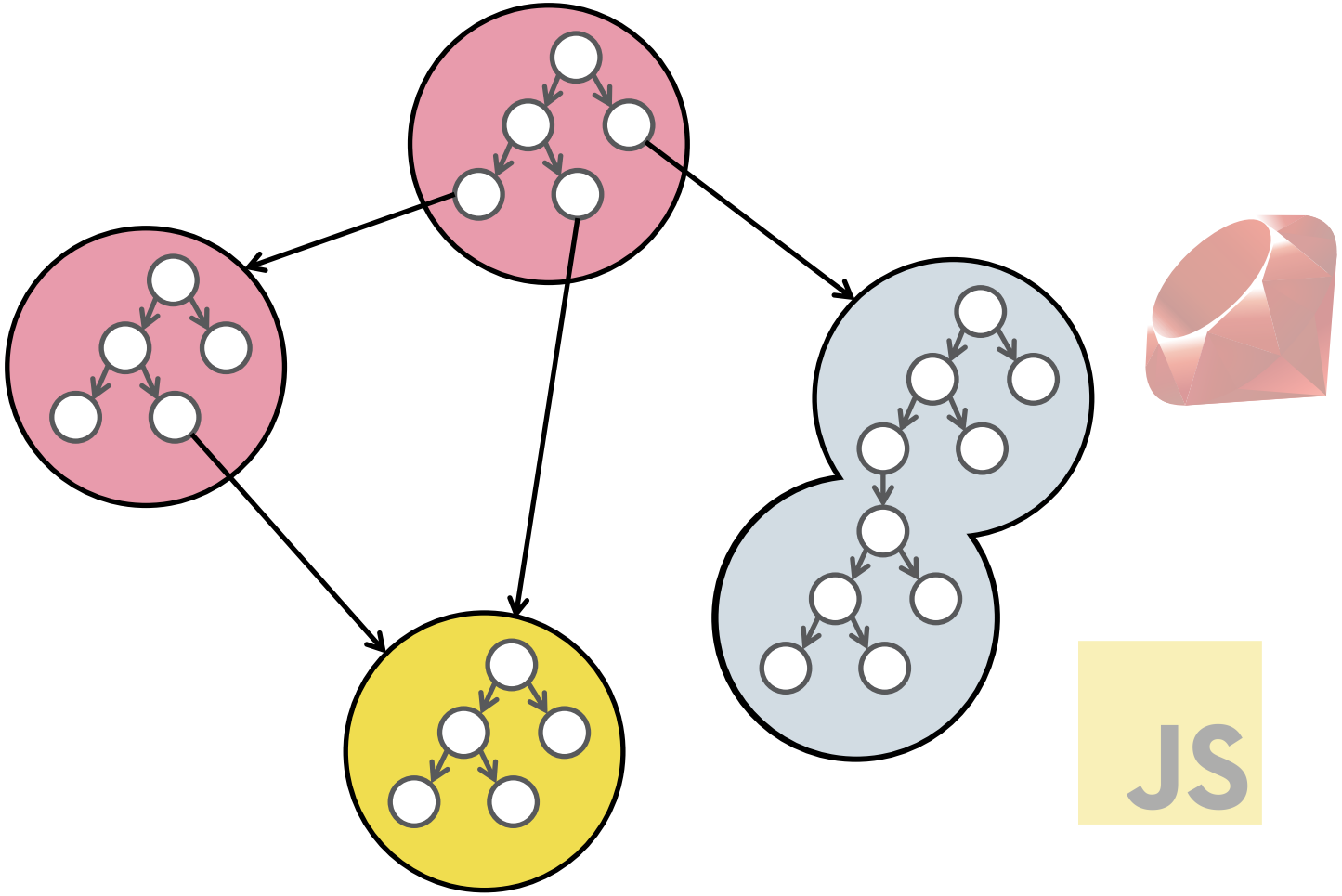

How effective is this in the extreme?

```ruby
def sum(n)
  i = 0
  a = 0
  while i < n
    i += 1
    a += n
  end
  a
end

values = (1..100).to_a

loop do
  values.each do |v|
    sum(v)
  end
end
```

```javascript
function sum(n) {
  var i = 0;
  var a = 0;
  while (i < n) {
    i += 1;
    a += n;
  }
  return a;
}

values = (1..100).to_a

loop do
  values.each do |v|
    sum(v)
  end
end
```

```ruby
def sum(n)
  i = 0
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    a += n
  end
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end

values = (1..100).to_a

loop do
  values.each do |v|
    sum(v)
  end
end
```

Looking at these loops here

```javascript
function sum(n) {
  var i = 0;
  var a = 0;
  while (i < n) {
    i += 1;
    a += n;
  }
  return a;
}

values = (1..100).to_a

loop do
  values.each do |v|
    sum(v)
  end
end
```

ORACLE

```ruby
def sum(n)
  i = 0
  a = 0
  while i < n
    i += 1
```

```
0x00000001118dfa30: mov    esi,edi
0x00000001118dfa32: add    esi,r9d
0x00000001118dfa35: jo     0x00000001118dfb62
0x00000001118dfa3b: inc    ecx
0x00000001118dfa3d: mov    edi,esi
0x00000001118dfa3f: cmp    r9d,ecx
0x00000001118dfa42: jg     0x00000001118dfa30
```

```ruby
loop do
  values.each do |v|
    sum(v)
  end
end
```

```javascript
function sum(n) {
  var i = 0;
  var a = 0;
  while (i < n) {
    i += 1;
```

```
0x000000010ca4ad90: mov    eax,r11d
0x000000010ca4ad93: add    eax,r14d
0x000000010ca4ad96: jo     0x000000010ca4ae68
0x000000010ca4ad9c: inc    r10d
0x000000010ca4ad9f: mov    r11d,eax
0x000000010ca4ada2: cmp    r14d,r10d
0x000000010ca4ada5: jg     0x000000010ca4ad90
```

```ruby
loop do
  values.each do |v|
    sum(v)
  end
end
```

ORACLE

```ruby
def add(a, b)
  a + b
end

def sum(n)
  i = 0
  a = 0
  while i < n
    i += 1
    a = add(a, n)
  end
  a
end
```

```javascript
function add(a, b) {
  return a + b;
}

def sum(n)
  i = 0
  a = 0
  while i < n
    i += 1
    a = add(a, n)
  end
  a
end
```

```ruby
def add(a, b)
  a + b
end
```

```
0x0000000103a7dc70: mov    esi,edi
0x0000000103a7dc72: add    esi,r9d
0x0000000103a7dc75: jo     0x0000000103a7dda2
0x0000000103a7dc7b: inc    ecx
0x0000000103a7dc7d: mov    edi,esi
0x0000000103a7dc7f: cmp    r9d,ecx
0x0000000103a7dc82: jg     0x0000000103a7dc70
```

```ruby
    i += 1
    a = add(a, n)
  end
  a
end
```

```javascript
function add(a, b) {
  return a + b;
}
```

```
0x00000010aadb1f0: mov    esi,edi
0x00000010aadb1f2: add    esi,r9d
0x00000010aadb1f5: jo     0x00000010aadb322
0x00000010aadb1fb: inc    ecx
0x00000010aadb1fd: mov    edi,esi
0x00000010aadb1ff: cmp    r9d,ecx
0x00000010aadb202: jg     0x00000010aadb1f0
```

```ruby
    i += 1
    a = add(a, n)
  end
  a
end
```

```
0x0000000103a7dc70: mov    esi,edi
0x0000000103a7dc72: add    esi,r9d
0x0000000103a7dc75: jo     0x0000000103a7dda2
0x0000000103a7dc7b: inc    ecx
0x0000000103a7dc7d: mov    edi,esi
0x0000000103a7dc7f: cmp    r9d,ecx
0x0000000103a7dc82: jg     0x0000000103a7dc70
```

```
0x0000000103a7dc70: mov    esi,edi
0x0000000103a7dc72: add    esi,r9d
0x0000000103a7dc75: jo     0x0000000103a7dda2
0x0000000103a7dc7b: inc    ecx
0x0000000103a7dc7d: mov    edi,esi
0x0000000103a7dc7f: cmp    r9d,ecx
0x0000000103a7dc82: jg     0x0000000103a7dc70
```

What is this for?

- We’re not really suggesting that people routinely write alternate methods in different languages

- We’re not really suggesting that people routinely write alternate methods in different languages
- More about removing the consideration of performance from the decision if you do want to combine languages

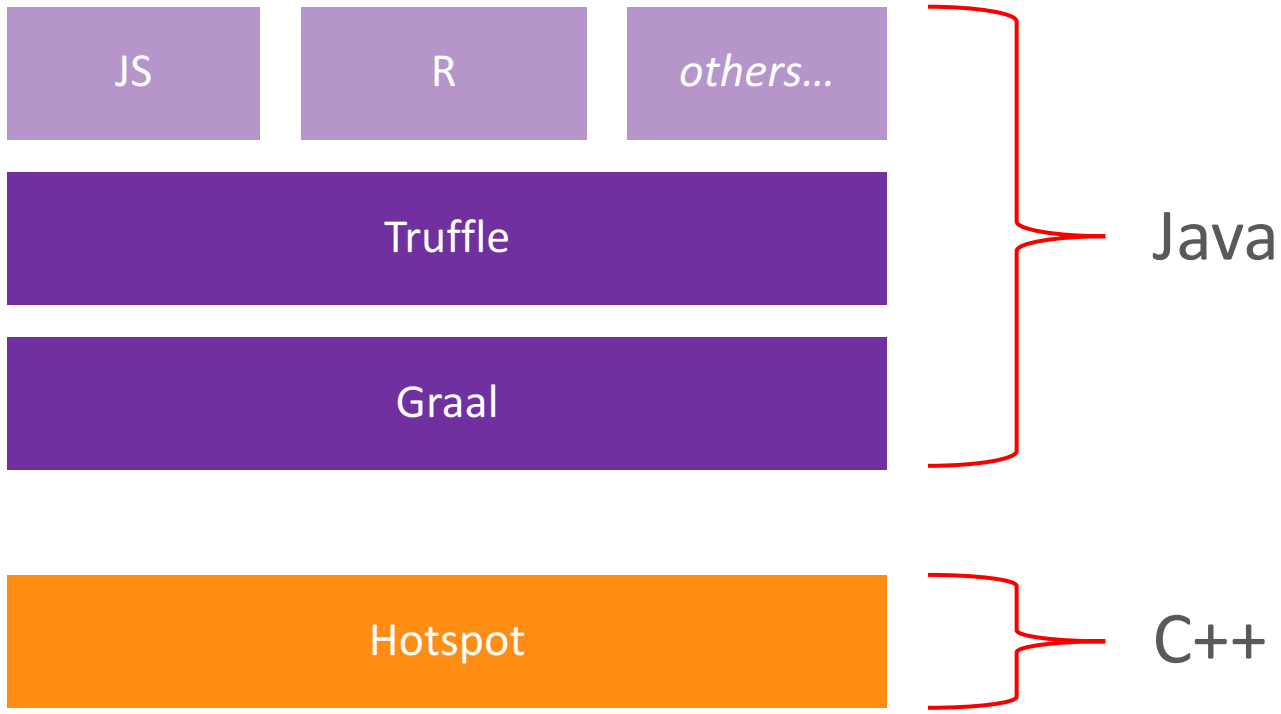
- Could make all library ecosystems available to all applications
- May be useful for unifying a front-end and back-end
- May be useful in handling legacy applications and incremental changes in implementation language

How to use GraalVM

GraalVM – everything in one package today

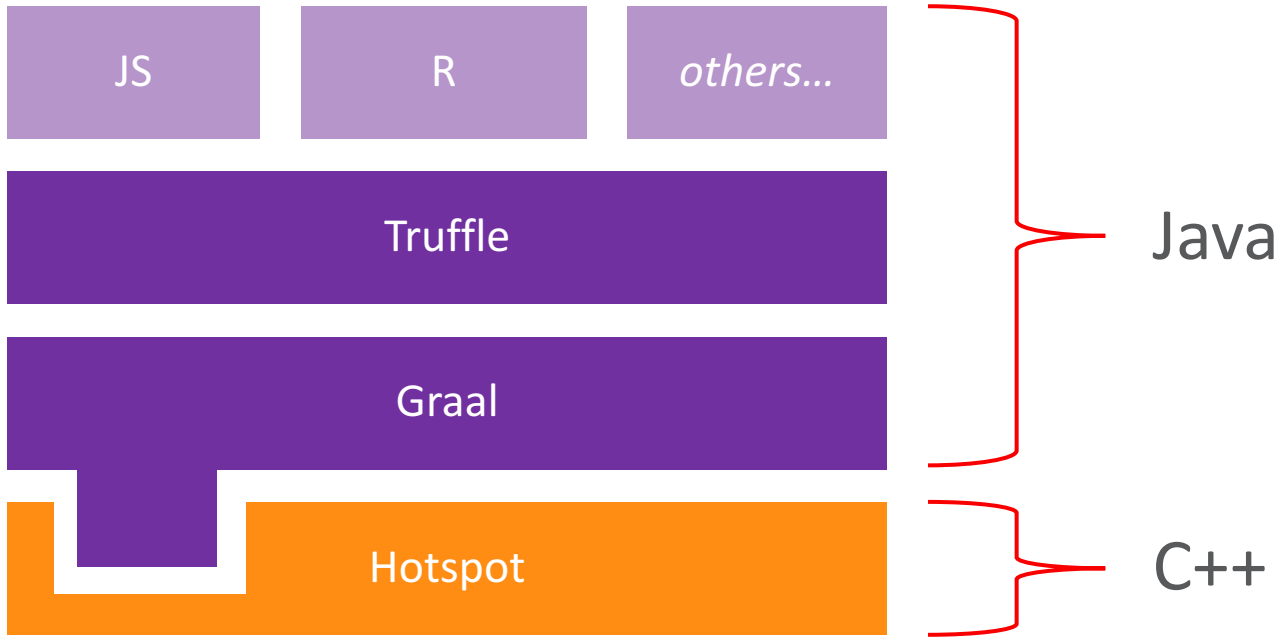
- Includes:
  - JVM (RE or DK)
  - Java
  - JavaScript
  - Ruby
  - R
  - More in the future
- Binary tarball release
- Mac or Linux

Java 9 – runs on an unmodified JVM

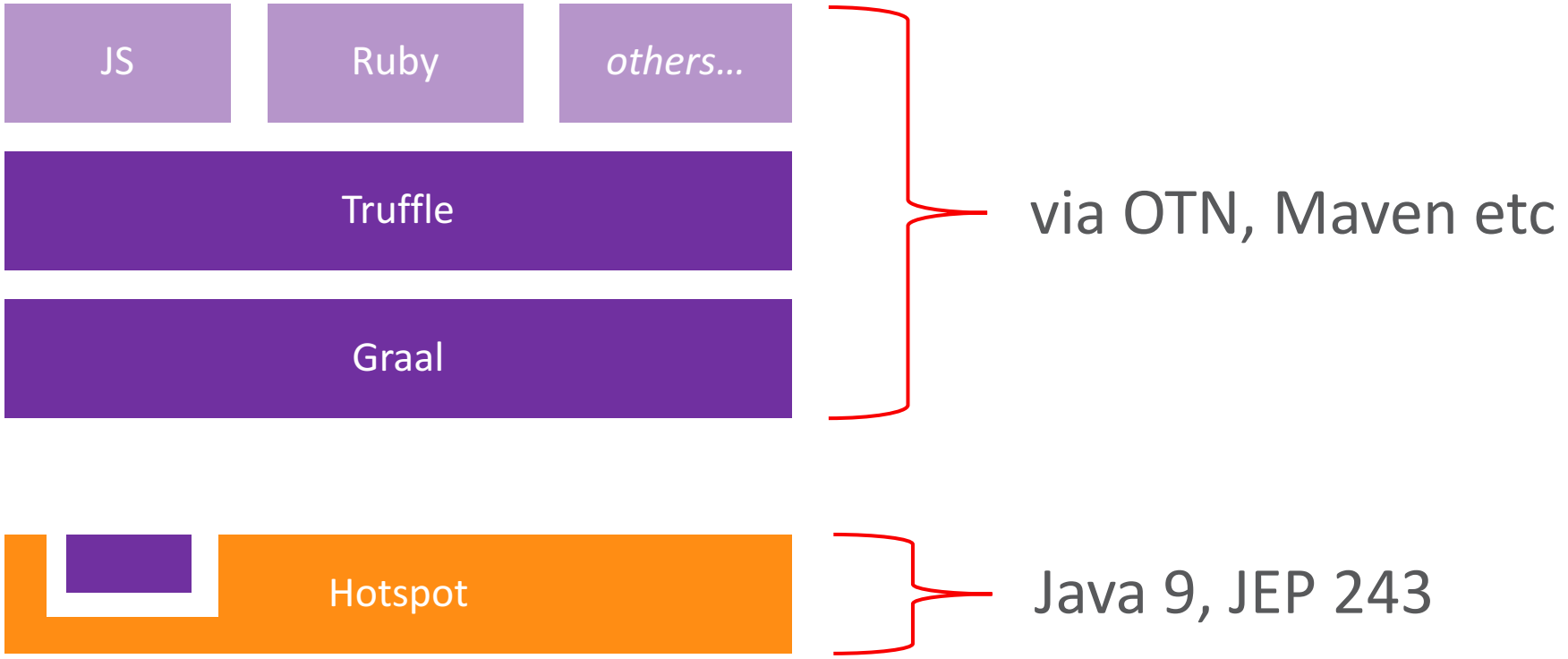


Java 9 – runs on an unmodified JVM

JVMCI
(JVM Compiler Interface)



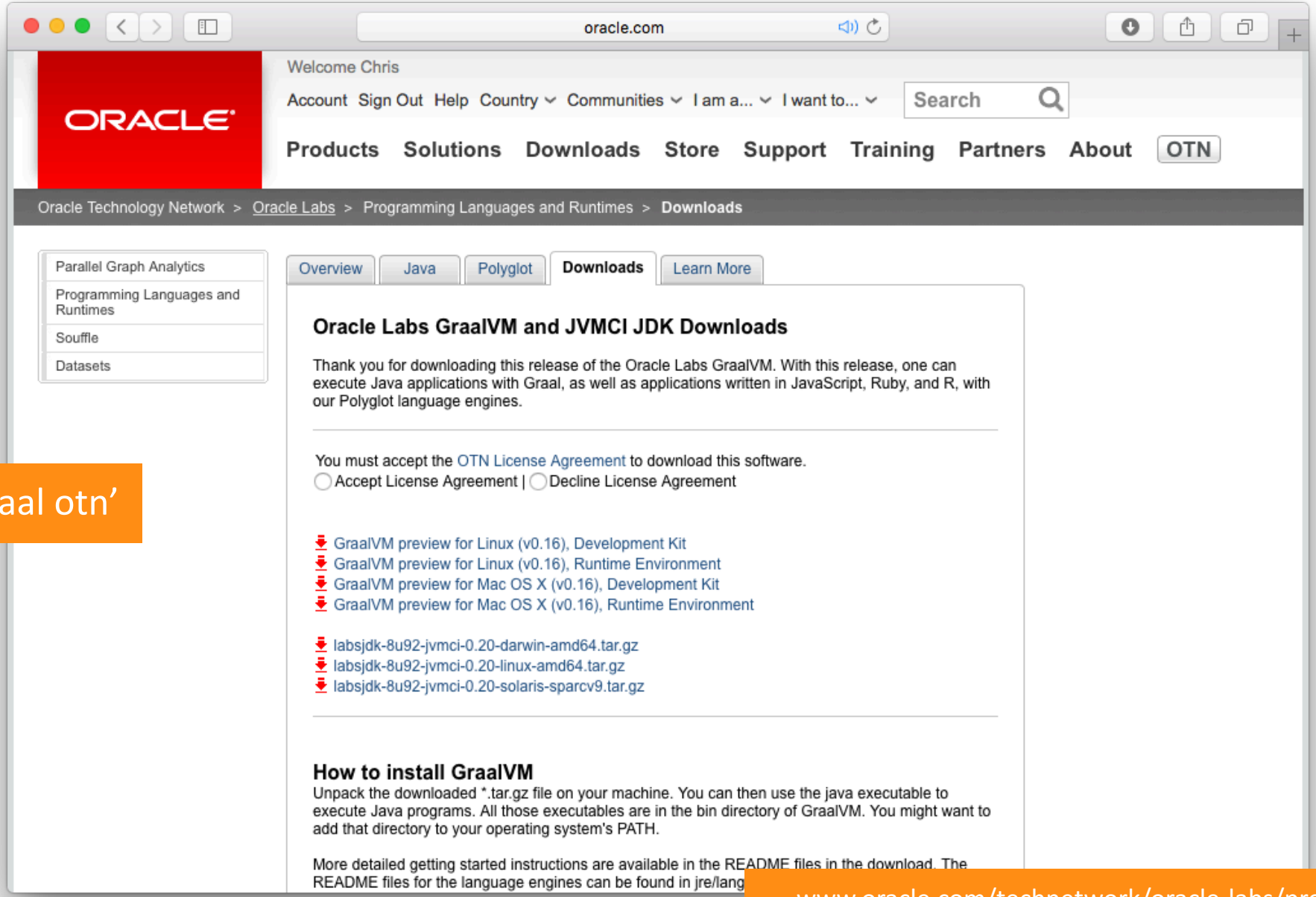
Java 9 – runs on an unmodified JVM



Takeaways

- Oracle Labs is building Graal VM to support polyglot programs and programmers
- Extremely high performance for the languages on their own
- Completely unprecedented high performance for language interoperability
- Will work on an unmodified Java 9 JVM, or available as a bundle today
- Still at the research stage, but moving towards being something more than that

Where to find more information



Search for ‘graal otn’

www.oracle.com/technetwork/oracle-labs/program-languages

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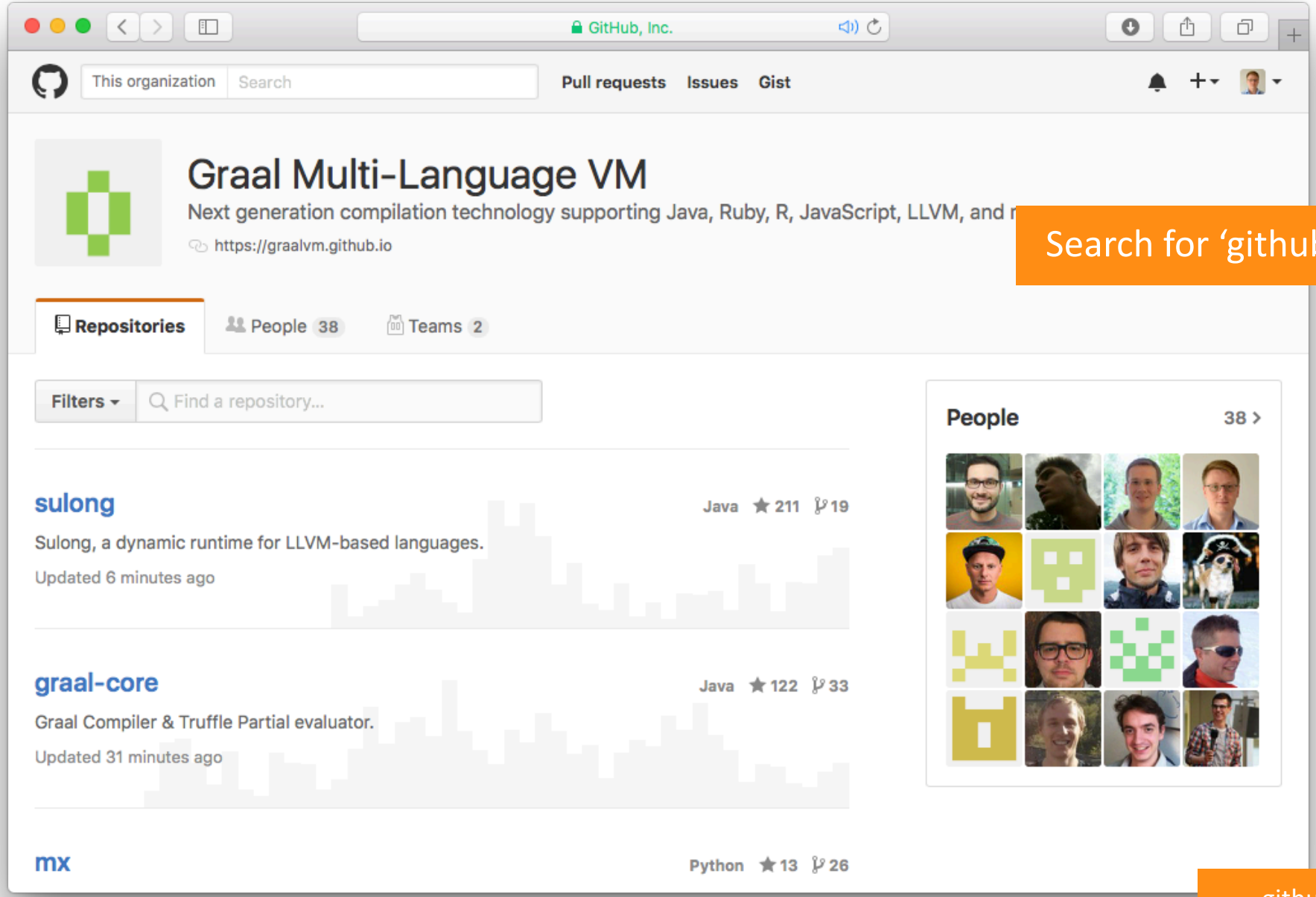


Search for ‘github graalvm’

github.com/graalvm

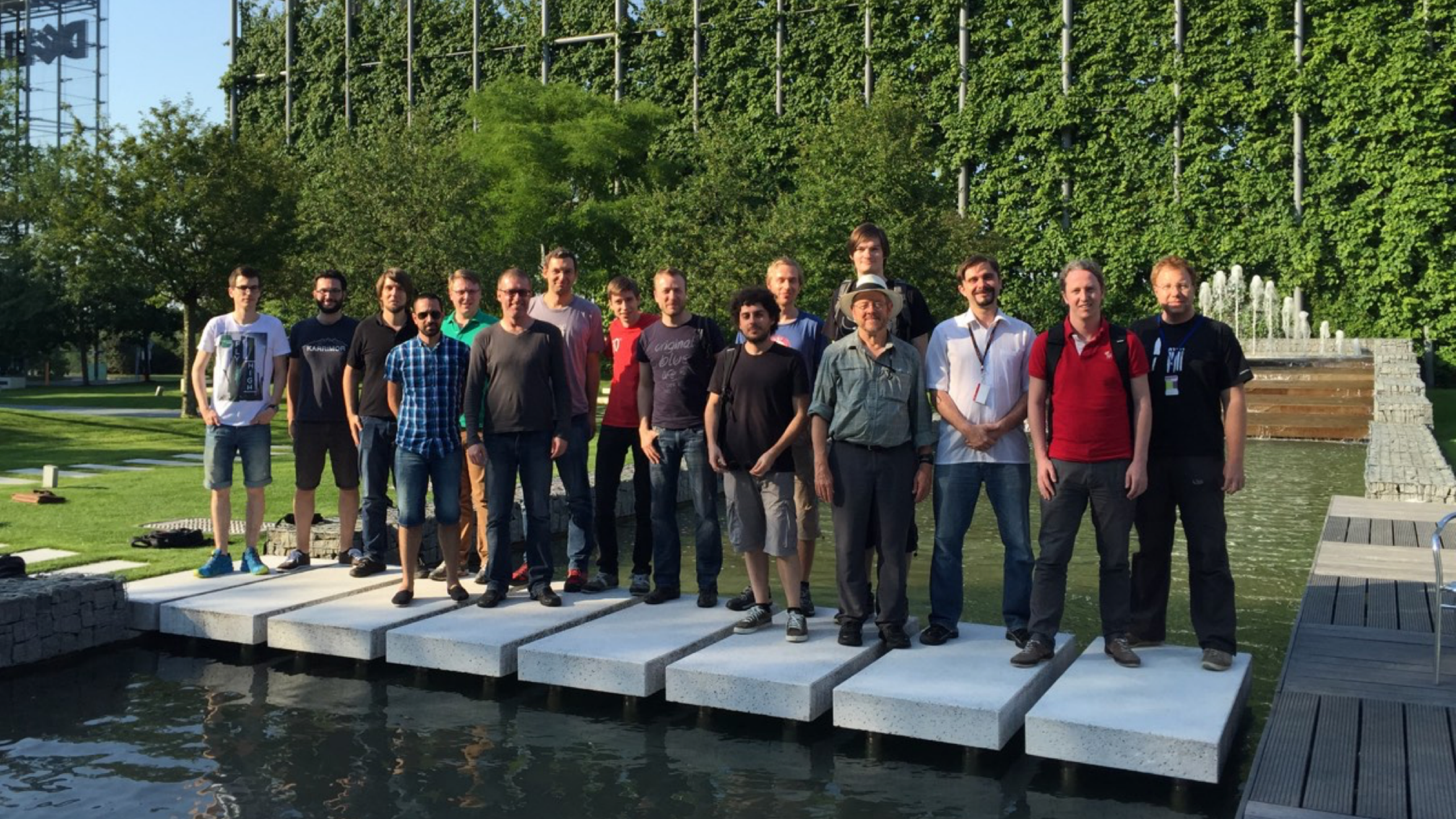
ORACLE

@chrisgseaton

github.com/graalvm

gitter.im/graalvm/graal-core

Search ‘otn graalvm’



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