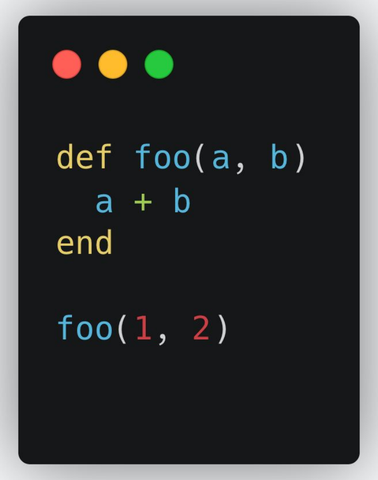
Call-Target Agnostic Keyword Arguments

Maple Ong, Chris Seaton

shopify

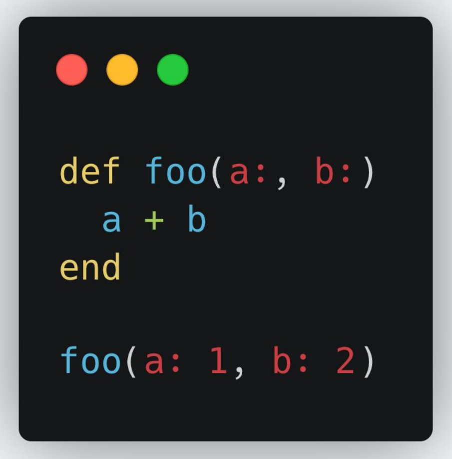
Method arguments in Ruby



```
def foo(a, b)
  a + b
end

foo(1, 2)
```

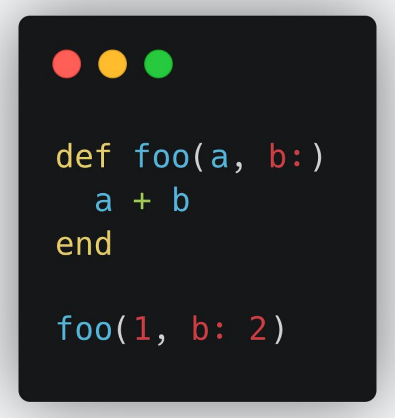
Positional arguments



```
def foo(a:, b:)
  a + b
end

foo(a: 1, b: 2)
```

Keyword arguments



```
def foo(a, b:)
  a + b
end

foo(1, b: 2)
```

Combination of both

```
def foo(**args)
  args[:a] + args[:b]
end

foo(**{a: 1, b: 2})
```

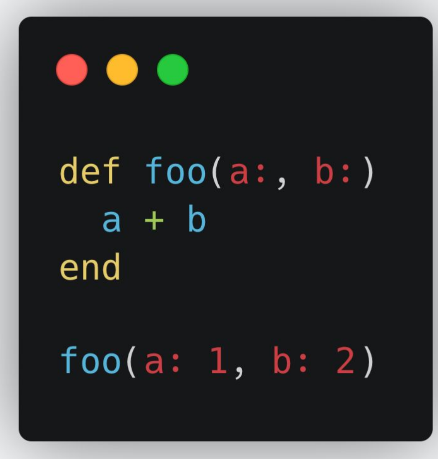
Generic keyword implementation

Generic keyword argument handling

- Keyword arguments wrapped into generic representation - a full Ruby hash object that is heap allocated
- Pushed onto the stack and receiver is looked up
- Dispatched to the call-target
- Call-target looks up each argument in the Ruby hash

Big reason why this is bad

Ruby Hash is allocated here…



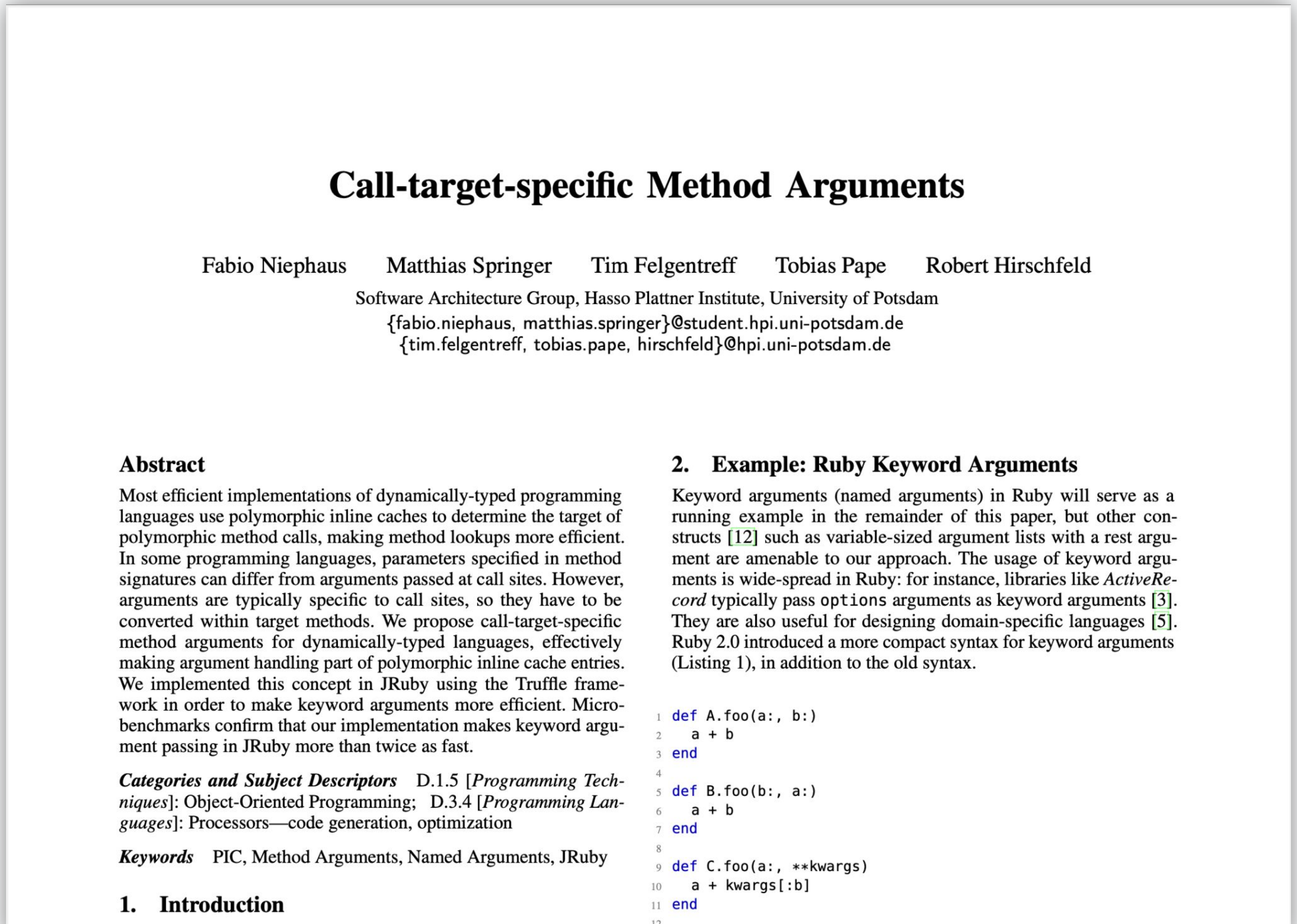
```ruby
def foo(a:, b:)
  a + b
end

foo(a: 1, b: 2)
```

…and immediately consumed here, never to be used again…

…but the compilation boundary is in between the allocation and the use for non-inlined cases! Graal's excellent optimisations don't apply.

Call-target-specific keyword implementation



Call-target-specific Method Arguments

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Abstract

Most efficient implementations of dynamically-typed programming languages use polymorphic inline caches to determine the target of polymorphic method calls, making method lookups more efficient. In some programming languages, parameters specified in method signatures can differ from arguments passed at call sites. However, arguments are typically specific to call sites, so they have to be converted within target methods. We propose call-target-specific method arguments for dynamically-typed languages, effectively making argument handling part of polymorphic inline cache entries. We implemented this concept in JRuby using the Truffle framework in order to make keyword arguments more efficient. Micro-benchmarks confirm that our implementation makes keyword argument passing in JRuby more than twice as fast.

Categories and Subject Descriptors D.1.5 [*Programming Techniques*]: Object-Oriented Programming; D.3.4 [*Programming Languages*]: Processors—code generation, optimization

Keywords PIC, Method Arguments, Named Arguments, JRuby

1. Introduction

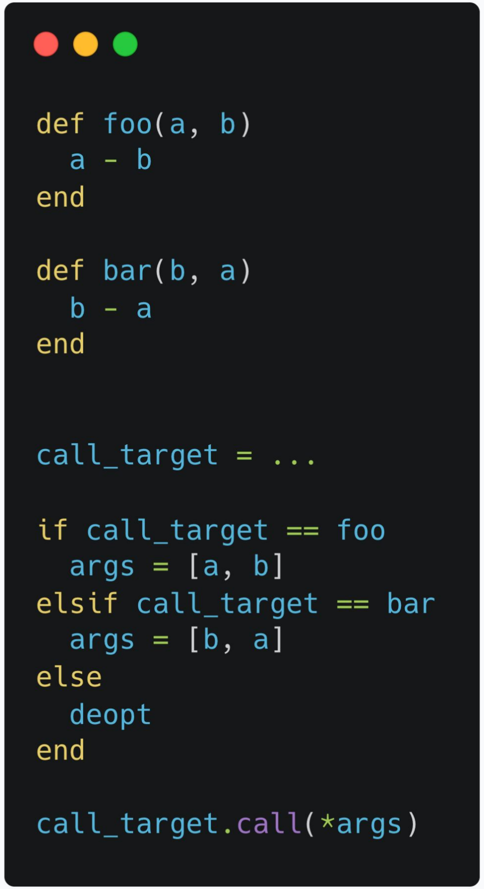
2. Example: Ruby Keyword Arguments

Keyword arguments (named arguments) in Ruby will serve as a running example in the remainder of this paper, but other constructs [12] such as variable-sized argument lists with a rest argument are amenable to our approach. The usage of keyword arguments is wide-spread in Ruby: for instance, libraries like *ActiveRecord* typically pass `options` arguments as keyword arguments [3]. They are also useful for designing domain-specific languages [5]. Ruby 2.0 introduced a more compact syntax for keyword arguments (Listing 1), in addition to the old syntax.

```ruby
def A.foo(a:, b:)
  a + b
end

def B.foo(b:, a:)
  a + b
end

def C.foo(a:, **kwargs)
  a + kwargs[:b]
end
```



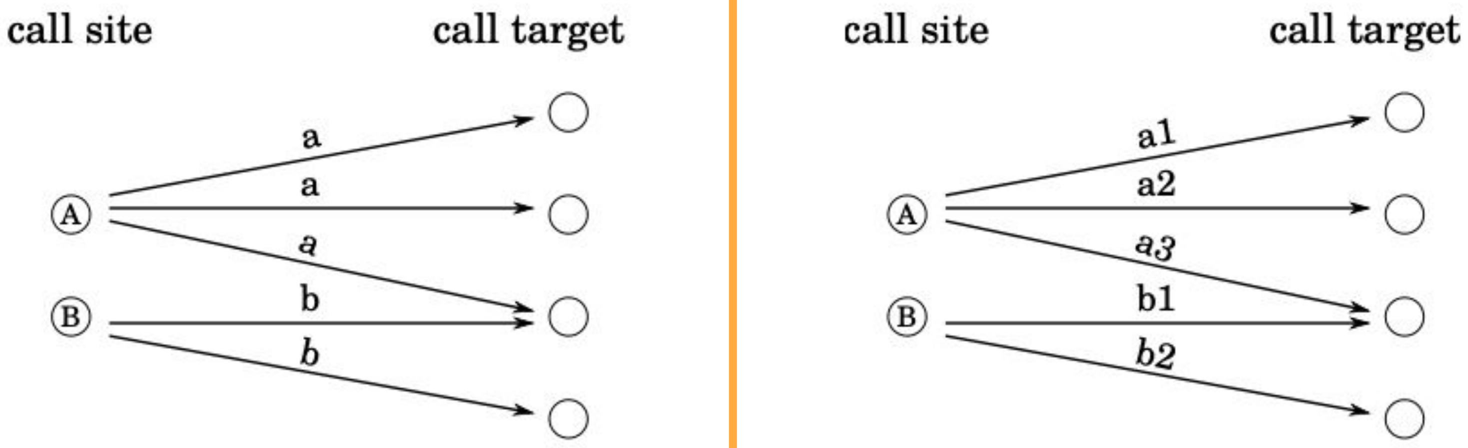
```
def foo(a, b)
  a - b
end

def bar(b, a)
  b - a
end


call_target = ...

if call_target == foo
  args = [a, b]
elsif call_target == bar
  args = [b, a]
else
  deopt
end

call_target.call(*args)
```

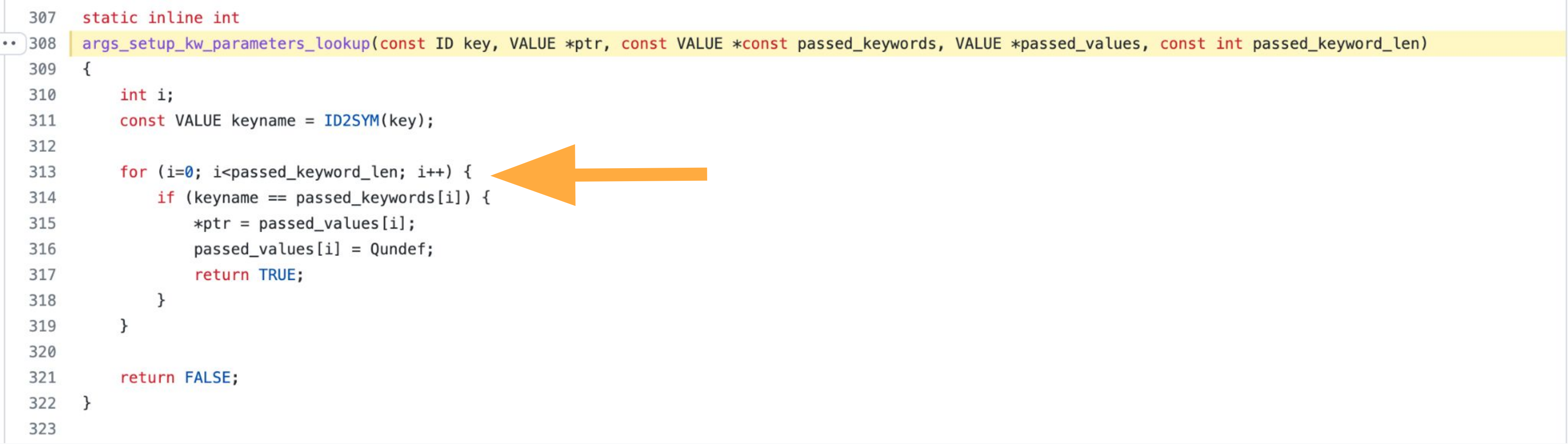


(a) Without call-target-specific arguments

(b) With call-target-specific arguments

Figure 1: Polymorphic inline cache for method dispatch.

Niephaus et al., Call-target-specific Method Arguments



```c
static inline int
args_setup_kw_parameters_lookup(const ID key, VALUE *ptr, const VALUE *const passed_keywords, VALUE *passed_values, const int passed_keyword_len)
{
    int i;
    const VALUE keyname = ID2SYM(key);

    for (i=0; i<passed_keyword_len; i++) {
        if (keyname == passed_keywords[i]) {
            *ptr = passed_values[i];
            passed_values[i] = Qundef;
            return TRUE;
        }
    }

    return FALSE;
}

```

vm_args.c

Our hypothesis

Ruby can be polymorphic

…which means call-target-specific approaches may not apply

```ruby
class A
  def foo(a, b)
    a + b
  end
end

class B
  def foo(a, b)
    a - b
  end
end

klass = rand(2) == 0 ? A.new : B.new
klass.foo(1, 2)
```

Call-target-specific implementation doesn’t work well with Ruby

- Simpler for call-target to receive arguments but more complex on the call-site
- And there are many more call-sites than call-targets
- Does not work well with polymorphism
- Does not work well with metaprogramming

Other considerations

- Ruby Hash representation of arguments will fail escape-analysis in non-inlined cases, or cases with a large number of keyword arguments
- Non-inline performance of keyword arguments has an overhead in CRuby and TruffleRuby
- Keyword arguments inherently straddle a compilation boundary
- Therefore requires more creativity to solve than conventional optimisations

What is the big idea 🧠

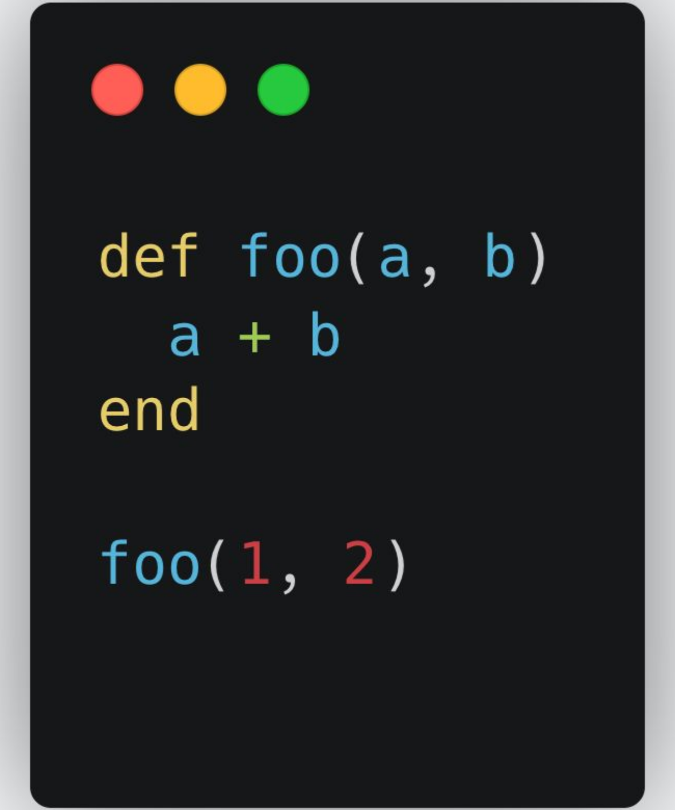
call-sites >> call-targets

Call-sites to send arguments in any format and for
call-target to dynamically adapt to the argument it receives

Call-target-agnostic Method Argument Handling

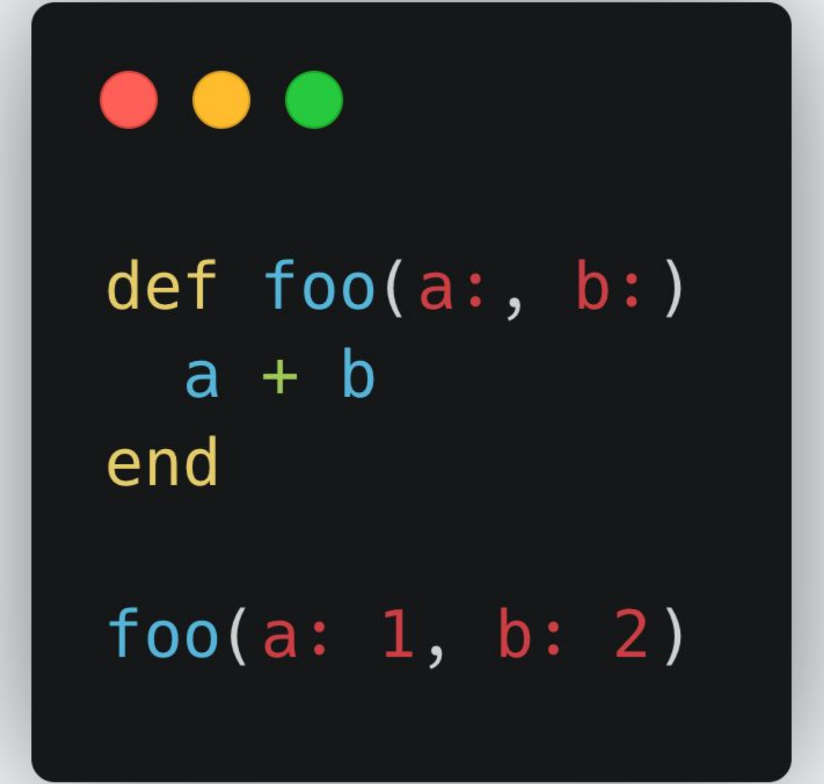
- Argument values flattened and paired with a static descriptor
- Both are pushed onto the stack and receiver is looked up
- Dispatched to the call-target
- Call-target uses the descriptor to unpack arguments based on the index

How our idea works in theory



```
def foo(a, b)
  a + b
end

foo(1, 2)
```

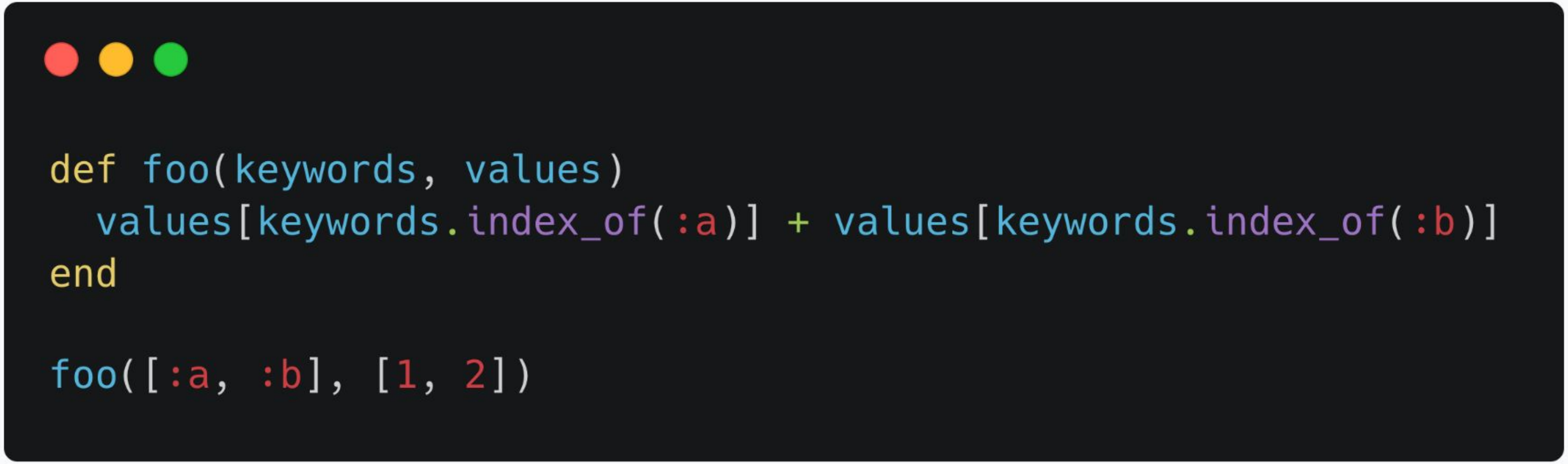


```
def foo(a:, b:)
  a + b
end

foo(a: 1, b: 2)
```

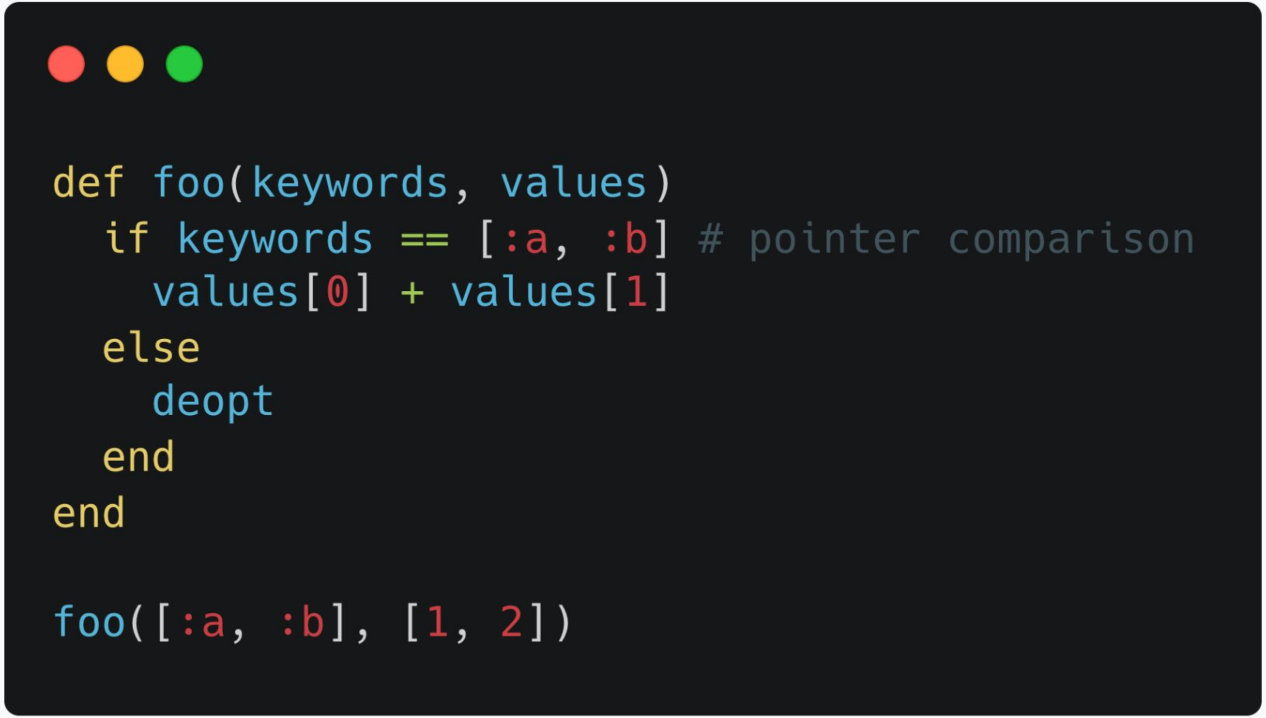
```
def foo(kwargs)
  kwargs[:a] + kwargs[:b]
end

foo({a: 1, b: 2})
```



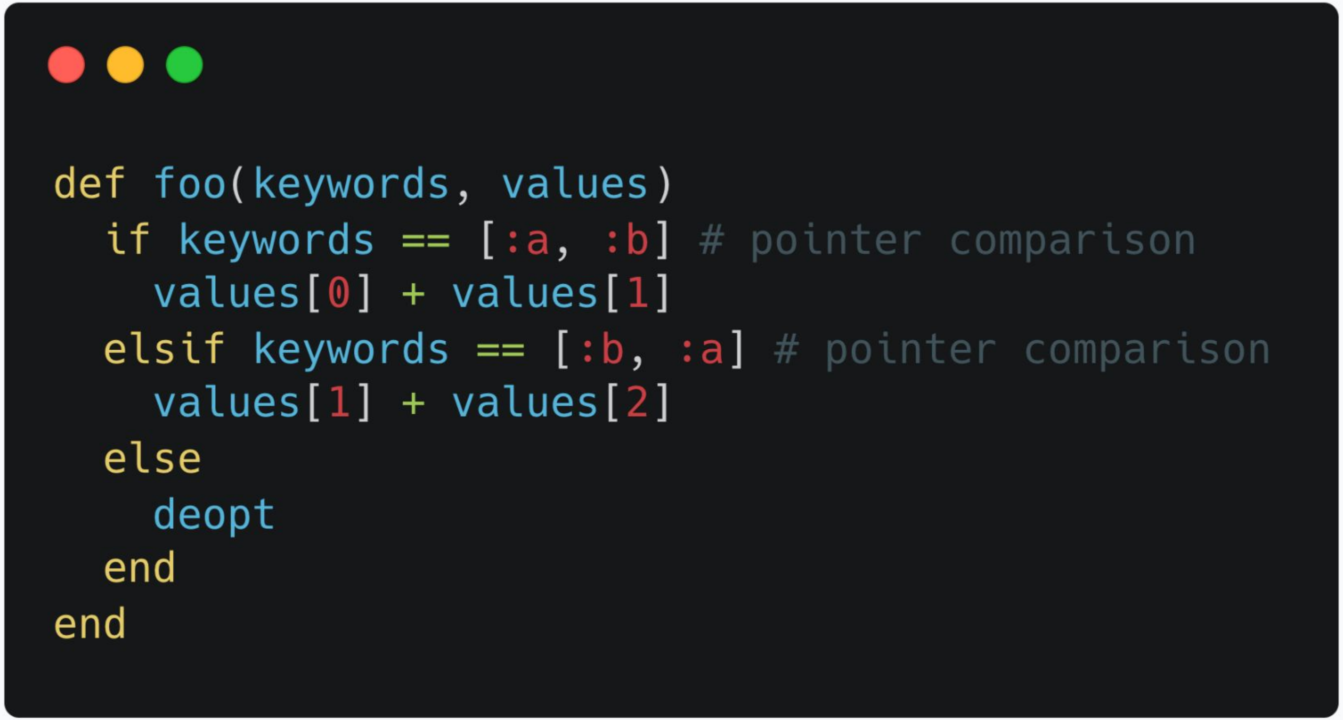
```
def foo(keywords, values)
  values[keywords.index_of(:a)] + values[keywords.index_of(:b)]
end

foo([:a, :b], [1, 2])
```

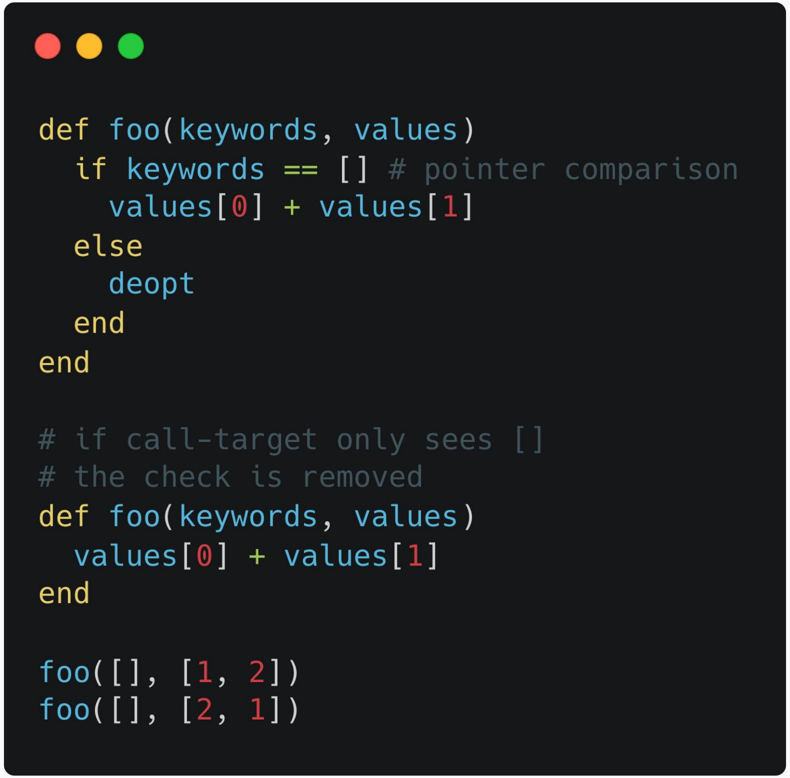


```
def foo(keywords, values)
  if keywords == [:a, :b] # pointer comparison
    values[0] + values[1]
  else
    deopt
  end
end

foo([:a, :b], [1, 2])
```



```ruby
def foo(keywords, values)
  if keywords == [:a, :b] # pointer comparison
    values[0] + values[1]
  elsif keywords == [:b, :a] # pointer comparison
    values[1] + values[2]
  else
    deopt
  end
end
```



```
def foo(keywords, values)
  if keywords == [] # pointer comparison
    values[0] + values[1]
  else
    deopt
  end
end

# if call-target only sees []
# the check is removed
def foo(keywords, values)
  values[0] + values[1]
end

foo([], [1, 2])
foo([], [2, 1])
```

How our idea works in practice

```java
@Specialization
protected void empty(EmptyKeywordDescriptor descriptor, Object[] values) {
  // no keyword arguments
}

@ExplodeLoop
@Specialization(guards = "descriptor == cachedDescriptor")
protected void cached(EmptyKeywordDescriptor descriptor, Object[] values,
        @Cached("descriptor") NonEmptyKeywordDescriptor cachedDescriptor,
        @Cached(value = "getSlots(cachedDescriptor)") WriteFrameSlotNode[] descriptorSlots) {
  for (int n = 0; n < cachedDescriptor.getLength(); n++) {
      final WriteFrameSlotNode frameSlot = descriptorSlots[n];
      frameSlot.write(values[n]);
  }
}
```

An Object Storage Model for the Truffle Language Implementation Framework

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Abstract

Truffle is a Java-based framework for developing high-performance language runtimes. Language implementers aiming at developing new runtimes have to design all the runtime mechanisms for managing dynamically typed objects from scratch. This not only leads to potential code duplication, but also impacts the actual time needed to develop a fully-fledged runtime.

In this paper we address this issue by introducing a common object storage model (OSM) for Truffle that can be used by language implementers to develop new runtimes. The OSM is generic, language-agnostic, and portable, as it can be used to implement a great variety of dynamic languages. It is extensible, featuring built-in support for custom extension mechanisms. It is also high-performance, as it is designed to benefit from the optimizing compiler in the Truffle framework. Our initial evaluation indicates that the Truffle OSM can be used to implement high-performance language runtimes, with no performance overhead when compared to language-specific solutions.

Categories and Subject Descriptors D.3.4 [*Programming Languages*]: Processors—Run-time environments, Optimization

General Terms Algorithms, Languages, Performance

Keywords Dynamic languages, virtual machine, language implementation, optimization, Java, JavaScript, Ruby, Truffle

1. Introduction

eral Truffle-based implementations for dynamic languages exist, including JavaScript, Ruby, Python, Smalltalk, and R. All of the existing implementations offer very competitive performance when compared to other state-of-the-art implementations, and have the notable characteristics of being developed in pure Java (in contrast to native runtimes that are usually written in C/C++).

To further sustain and widen the adoption of Truffle as a common Java-based platform for language implementation, Truffle offers a number of shared APIs that language implementers can use to optimize the AST interpreter in order to produce even more optimized machine code. In order to obtain high performance, however, there has still been one core component that the Truffle platform did not offer to language implementers, and that had to be implemented manually. This core component is the object storage model, that is, the runtime support for implementing dynamic objects. Indeed, language implementers relying on the Truffle platform have to implement their own language-specific model for representing objects, and then have to optimize the language runtime accordingly in order to optimize the AST interpreter for the characteristics of a certain language's object model. Requiring language implementers to develop the object storage model of their new language *from scratch* is not only a waste of resources, but could also lead to questionable software engineering practices such as code duplication and non-modular design.

With the goal of solving the above limitation of the Truffle framework and with the aim of supporting language developers with a richer shared infrastructure, this paper introduces a new, language-independent, object storage model (OSM) for Truf-

```
arguments = {a: 1, b: 2, c: 3}

static_descriptor = [:a, :b, :c]

dynamic_data = [1, 2, 3]
```

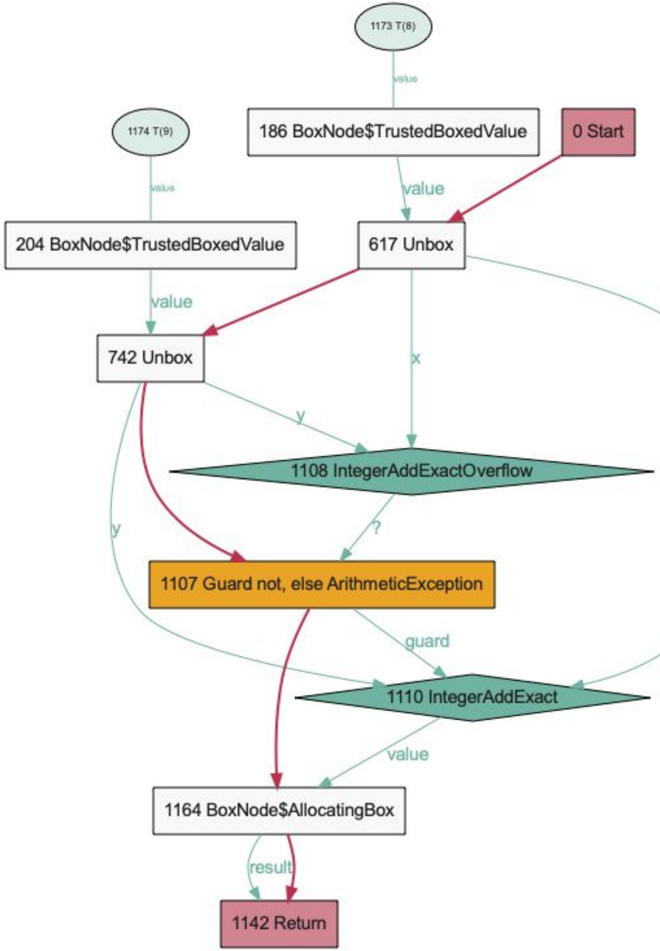
Why this is an interesting design space?

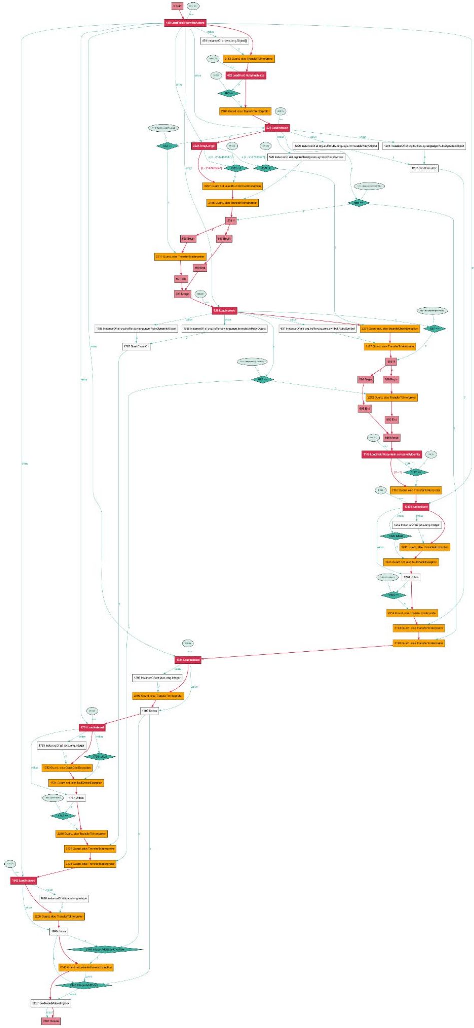
- Method arguments handling will fundamentally straddle a compilation unit, unless the call-site is inlined
- Therefore, Graal’s typical optimizations does not apply

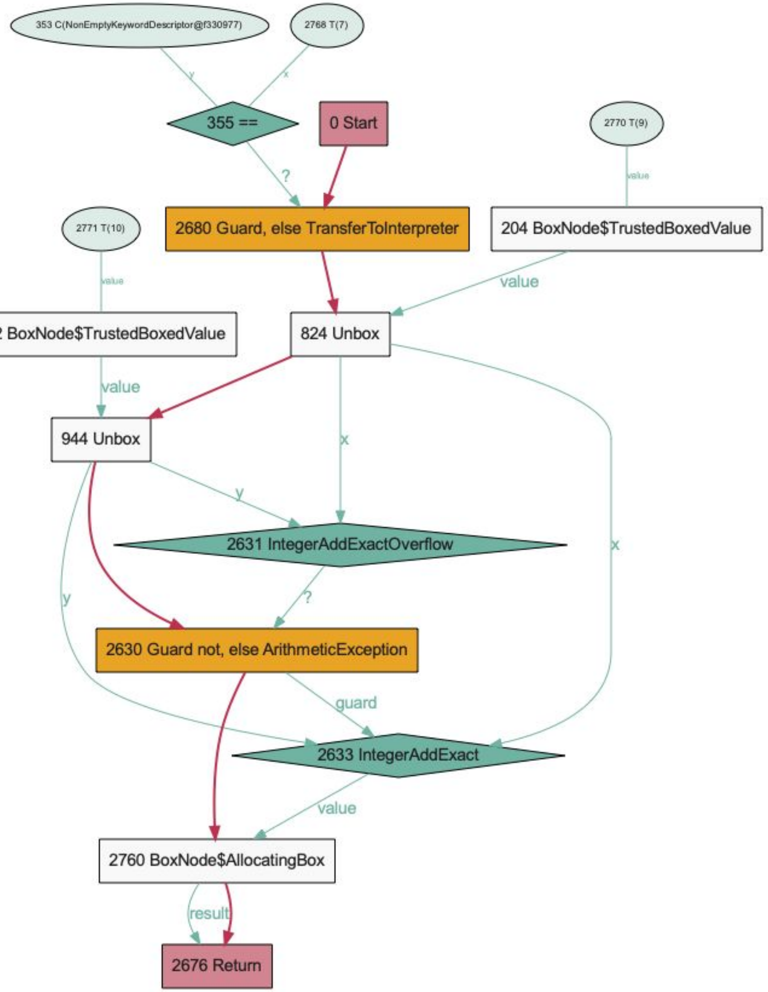
Still Playing to Graal's Strength

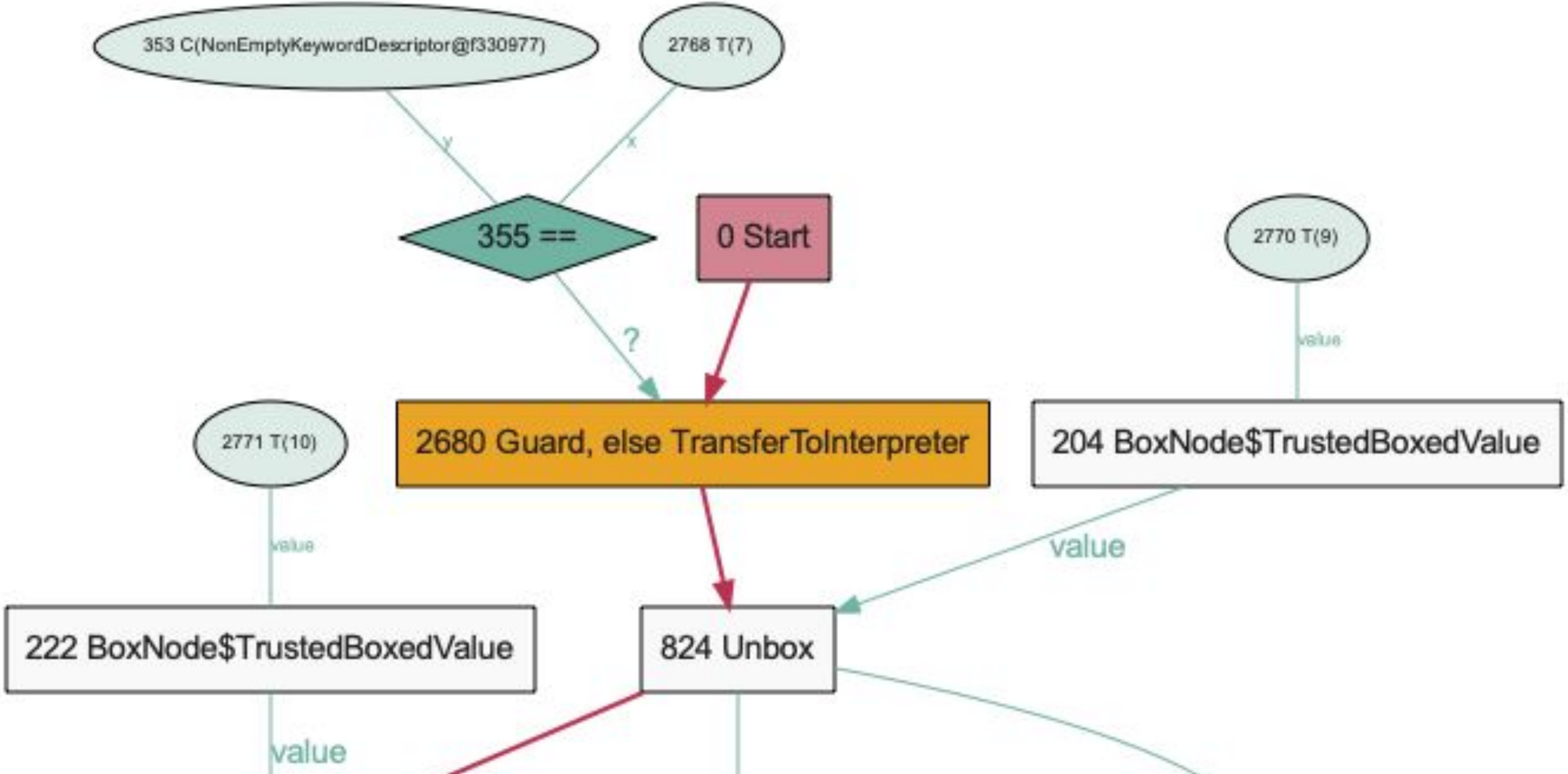
- Relies on Graal and Truffle's ability to create efficient inline caches on arbitrary guards
- Dynamic optimization results in specialized, compact code
- Fallbacks are handled by interpreter

What it achieves


1173 T(8)
value
1174 T(9)
186 BoxNode$TrustedBoxedValue
0 Start
value
204 BoxNode$TrustedBoxedValue
617 Unbox
value
742 Unbox
x
y
1108 IntegerAddExactOverflow
x
y
?
1107 Guard not, else ArithmeticException
guard
1110 IntegerAddExact
value
1164 BoxNode$AllocatingBox
result
1142 Return


0 Start
439 LoadField RubyHash.store
451 InstanceOf of java.lang.Object[]
2183 Guard, else TransferToInterpreter
482 LoadField RubyHash.size
485 ==
2184 Guard, else TransferToInterpreter
522 LoadIndexed
572 ==
2224 ArrayLength
x [0 - 2147483647]
[0 - 2147483647]
2225 |<|
2229 |<|
1298 InstanceOf of org.truffleruby.language.ImmutableRubyObject
1295 InstanceOf of org.truffleruby.language.RubyDynamicObject
528 InstanceOf of org.truffleruby.core.symbol.RubySymbol
1297 ShortCircuitOr
2227 Guard not, else BoundsCheckException
2185 Guard, else TransferToInterpreter
556 ==
554 If
558 Begin
553 Begin
2211 Guard, else TransferToInterpreter
598 End
591 End
586 Merge
626 LoadIndexed
1785 InstanceOf of org.truffleruby.language.RubyDynamicObject
1788 InstanceOf of org.truffleruby.language.ImmutableRubyObject
631 InstanceOf of org.truffleruby.core.symbol.RubySymbol
2231 Guard not, else BoundsCheckException
657 ==
1787 ShortCircuitOr
2187 Guard, else TransferToInterpreter
673 ==
655 If
684 Begin
659 Begin
2212 Guard, else TransferToInterpreter
689 End
690 End
686 Merge
1106 LoadField RubyHash.compareByIdentity
x [0 - 1]
[0 - 1]
1117 ==
2192 Guard, else TransferToInterpreter
1240 LoadIndexed
1242 InstanceOf of java.lang.Integer
1245 IsNull
1241 Guard, else ClassCastException
1243 Guard not, else NullCheckException
1246 Unbox
1253 ==
2214 Guard, else TransferToInterpreter
2193 Guard, else TransferToInterpreter
2196 Guard, else TransferToInterpreter
1354 LoadIndexed
1392 InstanceOf of java.lang.Integer
2199 Guard, else TransferToInterpreter
1402 Unbox
1731 LoadIndexed
1733 InstanceOf of java.lang.Integer
1736 IsNull
1732 Guard, else ClassCastException
1734 Guard not, else NullCheckException
1737 Unbox
1765 ==
2215 Guard, else TransferToInterpreter
2203 Guard, else TransferToInterpreter
2205 Guard, else TransferToInterpreter
1842 LoadIndexed
1880 InstanceOf of java.lang.Integer
2209 Guard, else TransferToInterpreter
1890 Unbox
2146 IntegerAddExactOverflow
2145 Guard not, else ArithmeticException
2148 IntegerAddExact
2257 BoxNode$AllocatingBox
2161 Return
value
array
x
y
guard


353 C(NonEmptyKeywordDescriptor@f330977)
2768 T(7)
y
x
355 ==
0 Start
?
2770 T(9)
value
2771 T(10)
2680 Guard, else TransferToInterpreter
204 BoxNode$TrustedBoxedValue
value
value
222 BoxNode$TrustedBoxedValue
824 Unbox
value
944 Unbox
x
y
2631 IntegerAddExactOverflow
x
y
?
2630 Guard not, else ArithmeticException
guard
2633 IntegerAddExact
value
2760 BoxNode$AllocatingBox
result
2676 Return


353 C(NonEmptyKeywordDescriptor@f330977)
2768 T(7)
y
x
355 ==
0 Start
?
2770 T(9)
value
2771 T(10)
2680 Guard, else TransferToInterpreter
204 BoxNode$TrustedBoxedValue
value
value
222 BoxNode$TrustedBoxedValue
824 Unbox
value

Benchmark	**Implementation**	**Compilation Time**	**AST**	**IR**	**Code size**
Long Caller	Control	1299(414+885)ms	65	147/ 1728	6994
	Call-target-agnostic	468(289+179)ms	65	120/ 230	1078
Long Callee	Control	1056(106+951)ms	137	711/ 1523	5970
	Call-target-agnostic	266(128+138)ms	72	92/ 152	570
Short Caller	Control	699(312+388)ms	28	98/ 463	1714
	Call-target-agnostic	490(281+210)ms	29	90/ 187	754
Short Callee	Control	347(142+205)ms	35	159/ 299	1158
	Call-target-agnostic	242(116+126)ms	24	44/ 98	422

Conclusion

Conclusion

- Ruby keyword arguments are logically very expensive
  - Pass a Ruby hash object of keywords and values and look up the values you want
- Previous published work tackled at the call-site this by putting arguments into a standard order for the call-target
  - But this requires knowing the call-target, and it requires extra work at the call-site
- Our hypothesis is that there are many more call-sites than call-targets, so it makes sense to put the work at the call-target
- Ruby’s idiomatic use also often means you may not know the call-target at a given call-site
- Therefore we instead have the call-site send a description of the keyword arguments, and separately their values, and have the call-target inline cache against the description

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