Exploring JRuby, Truffle and Graal

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Overview

Recap

Truffle & Graal in Action

Truffle in Practice

Challenge: Optimize Keyword Arguments in JRuby

Summary

References

Recap: What is Truffle & Graal?

- Truffle and Graal is a tool chain to build fast VMs easily
    - Similar to RPython
- Truffle is an AST interpreter framework
- Graal is modified JVM
    - Comes with an aggressive JIT compiler written in Java
    - Profiles code and detects hot methods
    - Truffle can use these information for making assumptions
    - Compiles specified code segment into machine code
- Truffle uses node replacements for specific optimizations (like type specific actions)

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Demo

```ruby
def multiply(a, b)
  a * b
end

100_000.times.each do |times|
    start = Time.now
    (1..1_000_000).each do |i|
        multiply(1, 2)
    end
    end_time = Time.now
    puts "Time elapsed #{(end_time - start)*1000} ms"
end
```

Example Runtimes

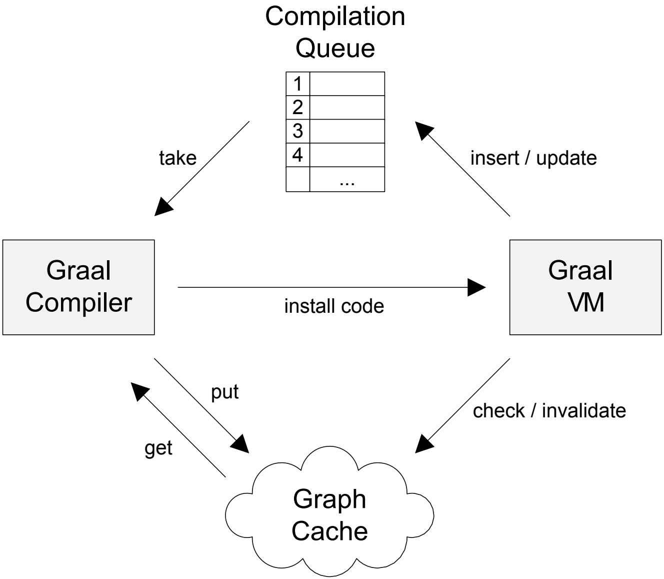
Empirical Figures

1. **MRI:** 175ms
2. **JRuby:** 80ms
3. **JRuby + Truffle:** 720ms
4. **JRuby + Graal:** 180ms and then 70ms
5. **JRuby + Truffle + Graal:** 1.5ms

Warm-Up Time

Truffle and Graal end with a very low execution time per iteration, but has large boot up time
→ Only faster if there is a large number of iterations/long overall execution time

Graal VM - System Architecture



Compilation Queue

1
2
3
4
...

take

insert / update

Graal Compiler

install code

Graal VM

put

get

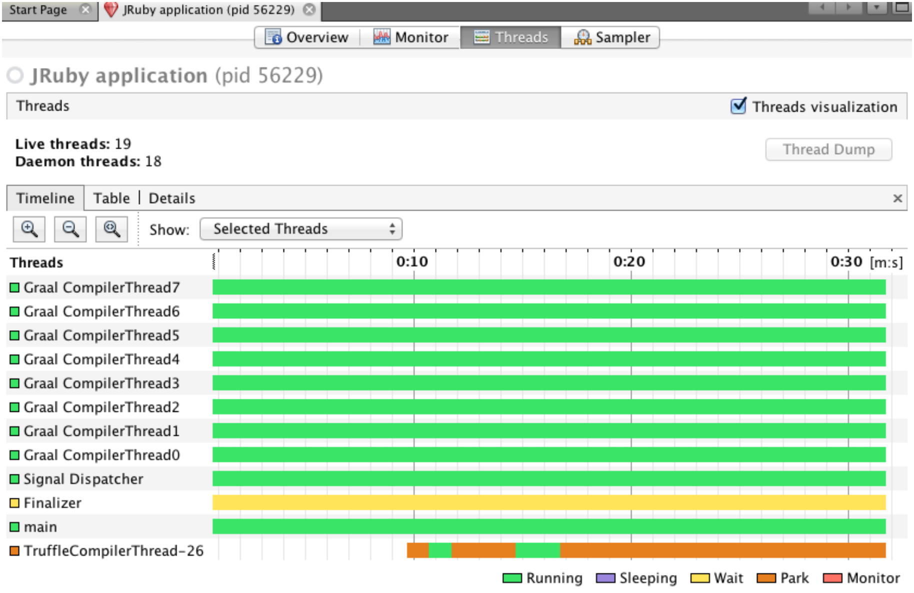
check / invalidate

Graph Cache

Handout only: Graal VM - Details

1. Graal VM detects *hot* methods
2. Graal VM adds these methods to compilation queue
3. Compiler threads compile methods with highest priorities
4. Machine code is installed into runtime's cache

JRuby, Truffle and Graal: Overview of Threads



Live threads: 19
Daemon threads: 18

Show: Selected Threads

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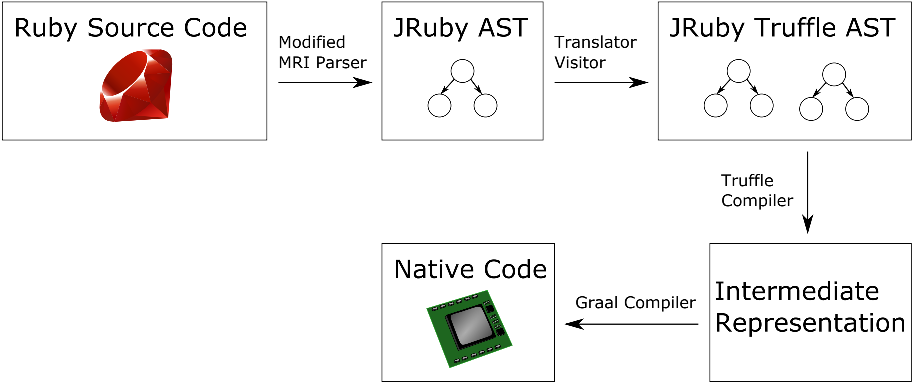
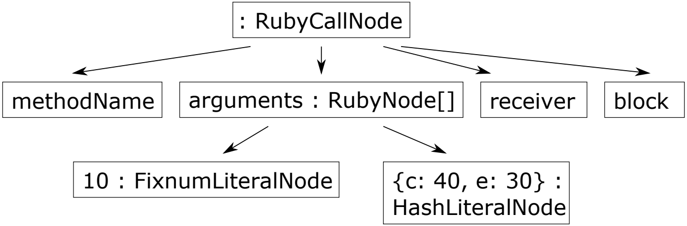
Ways to use Truffle within an existing AST Interpreter

Convert to Truffle: Translate all AST nodes to Truffle nodes

Add-On Truffle: Add an additional set of AST nodes:



Method Call Nodes in (J)Ruby



- `RubyCallNode` contains:
  - Receiver object
  - Method name (fix)
  - List of argument AST nodes
  - Block AST node
- Dynamic call → Dynamic dispatch is run on every execution

Method Callee Node in (J)Ruby

1. `RubyRootNode`
2. `Catch*Nodes` (`CatchNextNode`, `CatchRetryAsErrorNode`, `CatchReturnNode` ...)
3. `SequenceNode`
   - 3.1 `CheckArityNode`
   - 3.2 `WriteLocalVariableNode` for argument 1
   - 3.3 `WriteLocalVariableNode` for argument 2
   - 3.4 `WriteLocalVariableNode` for kwargument e
   - 3.5 `WriteLocalVariableNode` for kwargument c
   - 3.6 Statement sequence itself (wrapped in `TracingNodes`, with `CyclicAssumptions`)

Nice: Every argument has a node to create its default argument, maybe a node that throws every time a exception

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- Problem
- Solution

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Task: Keyword Arguments in Ruby 2.x

- Shortcut to call method with dictionary as last argument:

```
method(10, e: 30, c: 40)
method(10, {:e => 30, :c => 40})
```

- Starting with Ruby 2.0, Ruby can process this dictionary automatically (so called keyword arguments):

```
def method(a, b=3, e:, c:30)
end
```

Performance Bottlenecks

- `Hash` object creation: object is created, passed as argument, then destructed again
- Inefficient code paths (e.g., multiple scans of `Hash` object)
- Code involving `Hash` objects is harder to optimize than code involving primitive objects (Graal optimizations)
- Keyword argument nodes are not optimized by Truffle (Java `equals`, Truffle boundary for `Hash` iterator)
- Execution remains in interpreter modus

Goal: Pass keyword arguments as normal arguments

Optimizations

1. Optimize implementations (efficient hash operations)
2. Store kwargs within normal arguments array, separated by marker
3. Cache kwargs mapping within dispatch chain

→ We will now look into optimization #3

Handout only: Fully Optimized Keyword Arguments

Callee's Point of View

- `VirtualFrame` contains `arguments` array.
- Array contains `Marker` object, generated by `MarkerNode` as last element, if call is optimized.
- `CachedBoxedDispatchNode` is always optimized if keyword arguments are present (rewriting of `argumentNodes` array).
- `ReadKeywordArgumentNode` has offset (from right side) into `arguments` array as instance variable.
- `ReadKeywordArgumentNode` accesses `arguments` array at offset if call is optimized, otherwise expects a `RubyHash` (old behavior).
- `CachedBoxedDispatchNode` might generate an additional `RubyHash` if rest keyword arguments are present.

Fully Optimized Keyword Arguments

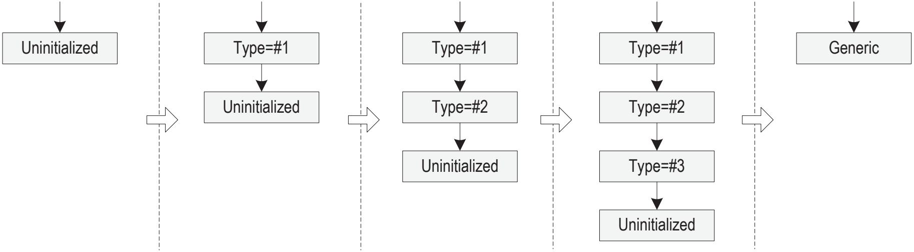
Example

```
class Cls1
    def method(a:, **kwargs)
    end
end

class Cls2
    def method(a:, b:)
    end
end

[Cls1.new, Cls2.new].each do |obj|
   obj.method(a: 1, b: 2)
end
```

Recap: Type Decision Chains

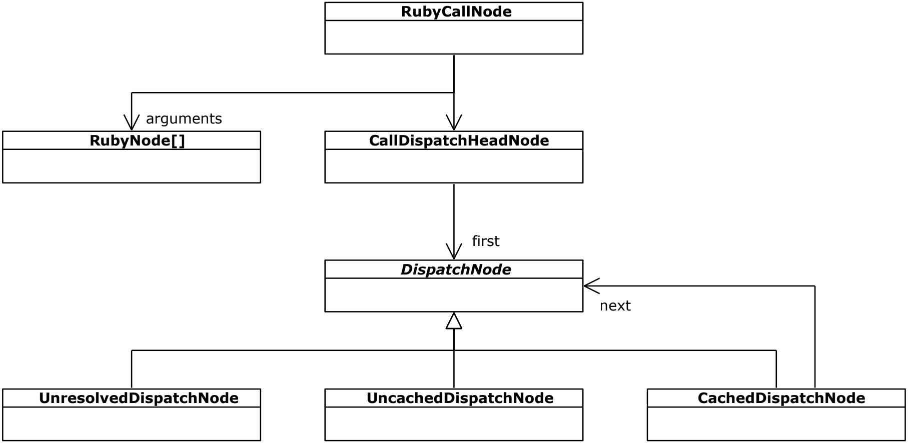


Fully Optimized Keyword Arguments

Problems

- Nodes are specific with regard to user-defined Ruby classes (cannot use Truffle DSL)
- Truffle DSL supports only specialization for language types
- Type of receiver is not known before dispatching the call

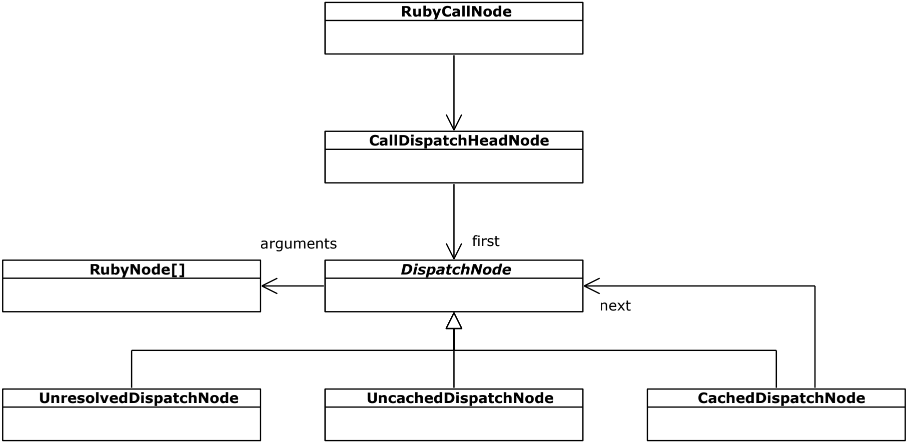
Guest Language PIC in JRuby



Handout only: Guest Language PIC in JRuby

- `UnresolvedDispatchNode`: corresponds to Truffle's *unspecified node*
- `UncachedDispatchNode`: corresponds to Truffle's *generic node*
- `CachedDispatchNode`: corresponds to Truffle's *specialized nodes*
- Node rewriting similar to Truffle but without Truffle

Argument Passing in *DispatchNode*



Handout only: Argument Passing in `DispatchNode`

- Unmodified arguments array (possible with `HashLiteralNode`) is stored in `UnresolvedDispatchNode`
- `CachedDispatchNode` contains keyword arguments mentioned in signature in array, and other keyword arguments in `HashLiteralNode`
- `ReadKeywordArgumentNode` checks if method dispatch is optimized (marker present in arguments array) and reads keyword arguments from arguments array, otherwise extracts them from `Hash` (same as before)

Evaluation

Results

Keyword arguments are as fast as position arguments
(for specific but common cases)

Handout only: Evaluation

→ Keyword arguments are as fast as position arguments

- Optimization affects only arguments passed in keyword argument syntax in method calls
- Optimization does not affect keyword arguments passed as an already existing `Hash`

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Truffle Summary

- Specific Java code cannot be translated by Graal (or it is disallowed)
- Large AST interpreters can still get unclear/distracting, knowledge is the composition of nodes, not the nodes itself
- Truffle DSL is not enough for efficient implementation of complex languages
- It is still needed to write efficient code and node implementations

Truffle and RPython - A Very Subjective Comparison

RPython
- Lightweight stack
- A little bit easier to get to work - mostly getting the correct libs in the Python path
- Difficult to debug in depth what is happening at execution

Truffle
- Heavy stack (Java, mostly multiple JDK and often maven . . .)
- If you get it working, you have the full power of (debugging) Java, even Graal itself

References

- L. Stadler, G. Duboscq, H. Mössenböck, T. Wurthinger, **Compilation Queuing and Graph Caching for Dynamic Compilers**, http://lafo.ssw.uni-linz.ac.at/papers/2012_VMIL_Graal.pdf
- T. Würthinger, C. Wimmer, A. Wöß, L. Stadler, G. Duboscq, C. Humer, G. Richards, D. Simon, M. Wolczko. **One VM to Rule Them All**, 2013, http://lafo.ssw.uni-linz.ac.at/papers/2013_Onward_OneVMToRuleThemAll.pdf
- Graal (http://hg.openjdk.java.net/graal/graal)
- JRuby (https://github.com/jruby/jruby)
- JRuby Developers (especially Chris Seaton)
- JRuby Benchmarks (https://github.com/jruby/bench9000)