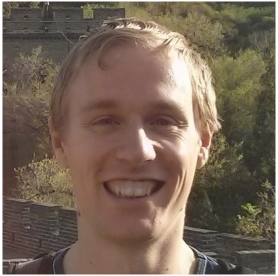
ORACLE

Just-in-Time Compiling Ruby Regexps on TruffleRuby

Benoit Daloze and Josef Haider

Presenters



Benoit Daloze

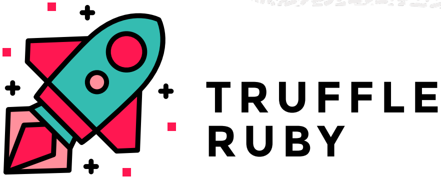
TruffleRuby lead
Twitter: @eregontp
GitHub: @eregon

Josef Haider

TRegex creator and maintainer
GitHub: @djoooooe

GraalVM™

TruffleRuby

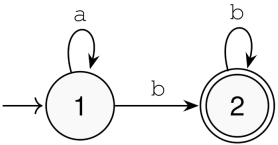


- A high-performance Ruby implementation
- Uses the GraalVM™ JIT Compiler
- Targets full compatibility with CRuby 2.7, including C extensions
- GitHub: oracle/truffleruby, Twitter: @TruffleRuby, website: graalvm.org/ruby

Background: Regexp Engines in TruffleRuby

- CRuby uses Onigmo (Oniguruma), backtracking regexp engine supporting 30 encodings
- TruffleRuby initially used Joni, which is a port of Onigmo to Java by JRuby developers
- Similar performance to Onigmo in CRuby
- TruffleRuby already JIT compiles "small languages of Ruby" like `array.pack("C*")` and `"%f" % pi`, but not yet Regexps
- It would be great if TruffleRuby would also run Regexps faster!

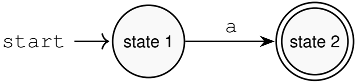
A Wild TRegex Appeared!



Wild TRegex
appeared!

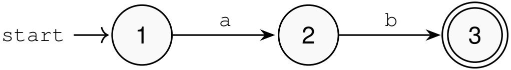
TRegex

- Regular expression engine based on state machines, more specifically "deterministic finite automata" (DFA)
- states have transitions to successor states
- every transition has a set of accepted symbols/characters



Regular Expressions and Finite State Machines

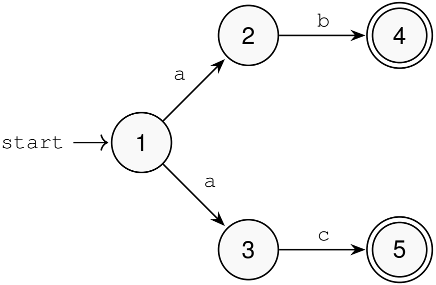
- Regular expressions used to be perfectly representable as state machines, but were extended later
- Basic concepts can still be mapped to state machines directly
- Concatenation: `/ab/`



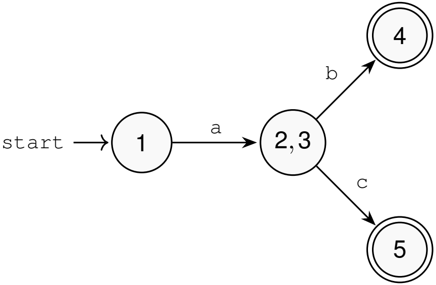
Automaton model of `/ab/`

Regular Expressions and Finite State Machines

- Disjunction: `/ab|ac/`



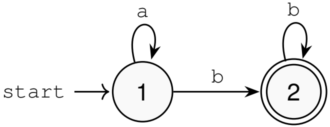
(a) NFA model of `/ab|ac/`



(b) DFA model of `/ab|ac/`

Regular Expressions and Finite State Machines

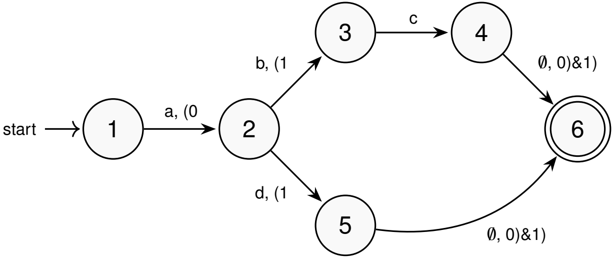
- Quantifiers: `/a*b+/`



Automaton model of `/a*b+/`

Regular Expressions and Finite State Machines

- Capture groups: annotated transitions.



Automaton model of `/a(bc|d)/`

What is supported?

- Concatenation “`ab`”
- Disjunction “`|`”
- Infinite Quantifiers “`*`”, ”`+`”
- Capture Groups “`()`”, “`(?<name>)`”
- Character Classes “`[]`”, “`\p{}`”
- Counted Quantifiers “`?`”, “`{n,m}`” (partially)
- Anchors “`^`”, “`$`”, “`\A`”, “`\Z`”, “`\b`”, “`\B`”
- Lookahead Assertions “`(?=)`”
- Lookbehind Assertions “`(?<=)`” (partially)

What is not supported yet?

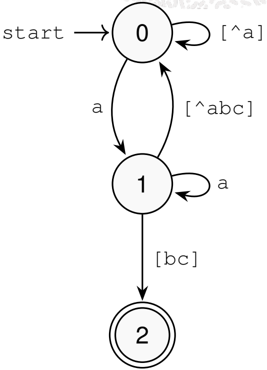
- Back-References “`\1, \k<name>`” in the Regexp (not in replacement strings: #gsub)
- Negative Lookahead “`(?!)`”
- Negative Lookbehind “`(?<!)`”
- Recursive Subexpression Calls “`\g<name>`” like “`(?<sqbr>[\g<sqbr>*])`”
- Possessive Quantifiers “`*+`”, “`++`”, “`?+`”, “`{n,m}+`”
- Atomic Groups “`(?>)`”
- Conditionals “`(?(group))`”
- Absent Expressions “`(?~)`”

Just-In-Time-Compiling regular expressions

```
@ExplodeLoop(MERGE_EXPLODE)
def execute(input, index = 0)
  result = -1
  ip = 0
outer:
  loop do
    current_state = STATES[ip]
    result = index if current_state.final_state?
    return result if index >= input.size
    c = input[index]
    index += 1
    current_state.each_transition do |transition|
      if transition.match?(c)
        ip = transition.target_ip
        goto :outer
      end
    end
    return result
  end
end
```

Just-In-Time-Compiling regular expressions

```
def execute(input, index = 0) # /a+(b|c)/
state0:
  return -1 if index >= input.size
  c = input[index]
  index += 1
  if c == 'a' then goto :state1
  else goto :state0
  end
state1:
  return -1 if index >= input.size
  c = input[index]
  index += 1
  if c == 'a' then goto :state1
  elsif c == 'b' || c == 'c' then goto :state2
  else goto :state0
  end
state2:
  return index
end
```

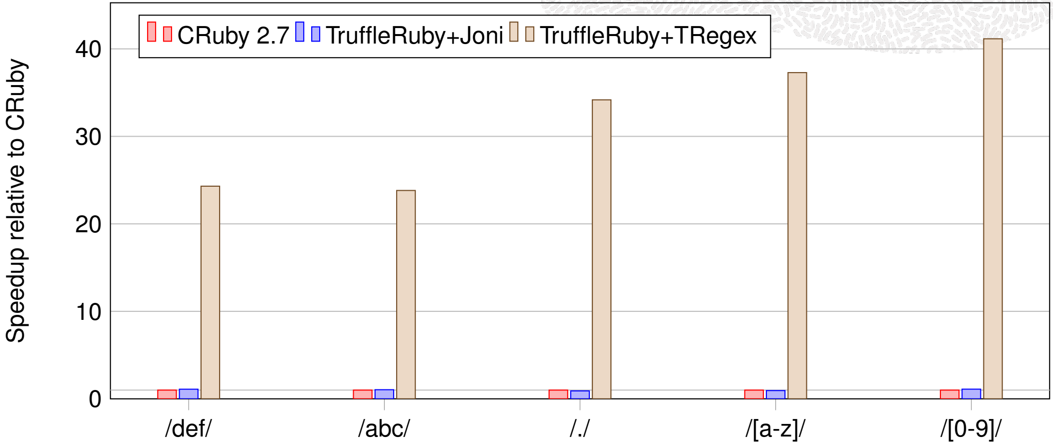


Performance Results

We use the `benchmark-ips` gem to measure peak performance and compare:

- TruffleRuby+TRegex on GraalVM JVM CE
- TruffleRuby+Joni on GraalVM JVM CE
- CRuby 2.7

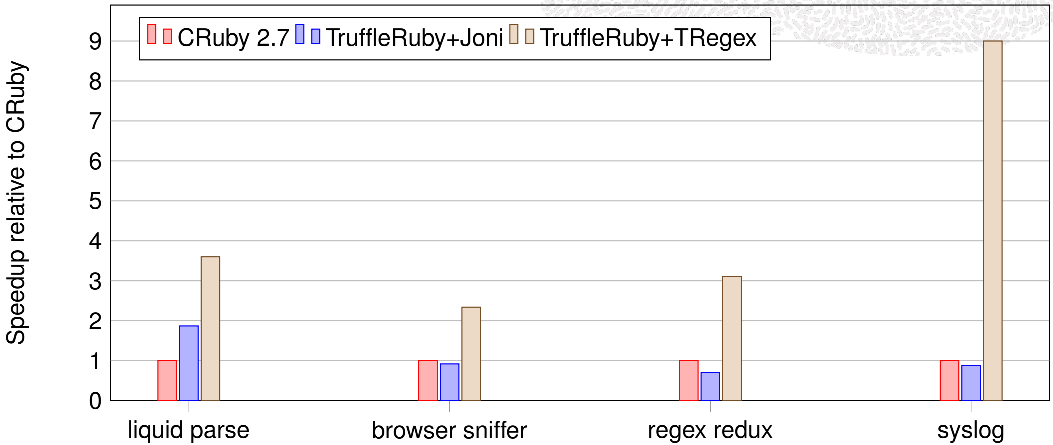
Micro-Benchmarks for "abc".match?(Regexp)



Larger Regexp Benchmarks

- liquid parse: `Liquid::Template.new.parse(cart_template)`, so the parsing part of the Liquid template language, and that parser uses Regexps heavily
- browser sniffer: from `Shopify/browser_sniffer`, a gem to detect which browser, OS, versions, etc are used from the user agent using Regexps
- regex redux (no IO): a benchmark from the Computer Language Benchmarks Game which reads 50MB of DNA/RNA sequences and transforms them using regexps (gsub!, scan)
- syslog: a benchmark parsing a single log line according to the BSD syslog Protocol (RFC 3164)

Larger Regexp Benchmarks



ReDoS and Catastrophic Backtracking

- ReDoS in Rails in 2021:
  CVE-2021-22880 Feb 10, CVE-2021-22902 and CVE-2021-22904 May 5 (2/4).

- TRegex always matches in linear time, no risk of ReDoS with TRegex!

- When falling back to Joni / backtracking, TruffleRuby can emit warnings (`--warn-slow-regex`):

```
file.rb: warning: Regexp /(?!...)/ requires backtracking
and might not match in linear time
```

Atomic Groups

- Atomic groups cannot be easily supported by finite-state machines regex engines
- Most usages of atomic groups seem workarounds for excessive backtracking.
  In that case, it is safe to ignore such groups for TRegex.
- Atomic groups can also be used for semantics (seems rare):

  ```
  /"(?>.*)"/ =~ '"Quote"' # => nil
  ```

- Approach: be optimistic and assume atomic groups are used for performance, not for semantics. TruffleRuby has an option to disable this behavior.

Conclusion

- Using finite-state machines for Regexp matching is faster than backtracking and safer
- TruffleRuby and TRegex can compile Ruby Regexps to machine code and inline them together with Ruby code
- On the presented benchmarks, TruffleRuby+TRegex is faster than CRuby by 24x-41x for regexp micro-benchmarks and 2.3x-9x for larger regexp benchmarks
- TruffleRuby can warn when Regexps are at risk of catastrophic backtracking (ReDoS)

Acknowledgments

- Jirka Maršík (@jirkamarsik) for adding support for the many features of Ruby Regexps in TRegex, and most of the integration of TRegex in TruffleRuby
- Duncan MacGregor (@aardvark179) for various optimizations related to Regexp matching (StringScanner, gsub, accessing `$~` in the C API, etc)
- Kevin Menard (@nirvdrum) for further optimizations, notably to enable splitting and inlining of regexps