Ruby’s C Extension Problem and How We’re Solving It

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Lots of people want to make Ruby faster
C extensions – the original solution for performance

ruby.rb

Ruby Interpreter
C extensions – the original solution for performance

- ruby.rb
- extension.c
- C Compiler
- extension.so

Ruby Interpreter
C extensions – the original solution for performance

ruby.rb → Ruby Interpreter

extension.c → Extension

C Compiler → extension.so
def clamp(num, min, max)
    [min, num, max].sort[1]
end

VALUE psd_native_util_clamp(VALUE self,
    VALUE r_num, VALUE r_min, VALUE r_max) {
    int num = FIX2INT(r_num);
    int min = FIX2INT(r_min);
    int max = FIX2INT(r_max);

    return num > max ? r_max : (num < min ? r_min : r_num);
}
Why C extensions hold us back
C Extension

C Extension API

Ruby Interpreter
Bad news – this isn’t really a thing in practice
C Extension

MRI
MRI 3.0

C Extension
String pointers

```c
char *RSTRING_PTR(VALUE string);

static VALUE
ossl_dsa_export(int argc, VALUE *argv, VALUE self)
{
    char *passwd;
    ...
    passwd = RSTRING_PTR(passwd);
    ...
    PEM_write_bio_DSAPrivateKey(out, pkey->pkey.dsa, ciph,
                               NULL, 0, openssl_pem_passwd_cb, passwd)
    ...
}
Array pointers

VALUE *RARRAY_PTR(VALUE array);

VALUE psd_native_blender_compose_bang(VALUE self) {
    ...
    VALUE bg_pixels = rb_funcall(bg_canvas, rb_intern("pixels"), 0);
    VALUE *bg_pixels_ptr = RARRAY_PTR(bg_pixels);
    ...
    for (i = 0, len = RARRAY_LEN(bg_pixels); i < len; i++) {
        ... bg_pixels_ptr[i] ...
    }
    ...
}
Data fields

```c
struct RData {
    struct RBasic basic;
    void (*dmark)(void *data);
    void (*dfree)(void *data);
    void *data;
};

#define RDATA(value) ((struct RData *)value)

#define DATA_PTR(value) (RDATA(value)->data)

static VALUE
ossl_x509req_copy(VALUE self, VALUE other)
{
    ...
    DATA_PTR(self) = X509_REQ_dup(b);
    ...
}
```
Lack of caching when you are in C

Last time we called `to_s` this is the method we used

```ruby
foo.to_s
```

```ruby
method_name = rb_intern("to_s")
rbs_funcall(foo, method_name, 0);
```
The black box

def add(a, b)
    a + b
end

add(14, 2)

VALUE add(VALUE self, VALUE a, VALUE b) {
    return INT2FIX(FIX2INT(a) + FIX2INT(b));
}

add(14, 2)
The black box

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

add(14, 2)
```

= 16

```c
VALUE add(VALUE self, VALUE a, VALUE b) {
    return INT2FIX(FIX2INT(a) + FIX2INT(b));
}

add(14, 2)
```
The black box

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

add(14, 2) = ?
```

```javascript
VALUE add(VALUE self, VALUE a, VALUE b) {
    return INT2FIX(FIX2INT(a) + FIX2INT(b));
}

add(14, 2)
```
Previous solutions to the C extension problem
Denial

• Everyone should use the FFI or Fiddle
  – FFI and Fiddle are two ways to call C functions directly from Ruby
  – 2.1 billion lines of code in RubyGems, 0.5 billion of it is C extension code
  – It might be nice if people used FFI instead of C extensions... but they don’t... so little point in continuing to argue about it

```
module MyLib
  extend FFI::Library
  ffi_lib 'c'
  attach_function :sqrt, [ :double ], :double
end
```
Bargaining

• Attempt to implement the C extension API as best as possible, alongside optimisations
• Generally involves a lot of copying
• JRuby used this approach in the past, Rubinius still uses it
  – JRuby only ran 60% of C extensions I tried
  – Rubinius ran 90%
  – Worse: when they didn’t work they just ground to a halt, no clear failure point
Bargaining

• Try to improve the C extension API over time
  – The JavaScript (V8) and Java C extension APIs don’t have these problems because they have better designed APIs that don’t expose internals
  – Steady progress in this direction, has helped
  – But even OpenSSL doesn’t use these new methods!

"Don't touch pointers directly"

In MRI (include/ruby/ruby.h), some macros to acquire pointers to the internal data structures are supported such as RARRAY_PTR(), RSTRUCT_PTR() and so on.

DO NOT USE THESE MACROS and instead use the corresponding C/APIs such as rb_ary_aref(), rb_ary_store() and so on."
Depression

• JRuby unfortunately had to give up on their C extension work
  – They didn’t have the resources to maintain it after the original developer moved on
  – Limited compatibility and limited performance
  – In the end, it was removed entirely
  – Maybe it’ll return in the future (they could use the same approach as us)
Acceptance

• JRuby encourage Java extensions instead of C extensions
• Try to optimise Ruby while keeping most of the internals the same
  – IBM’s OMR adds a new GC and JIT to Ruby while keeping support for C extensions
  – The techniques they can use are therefore limited
  – And so performance increases expected from OMR are more modest
Interlude: JRuby+Truffle
JVM
a + b * c
a + b * c
a + b * c

1164 IntegerMulExact
1293 IntegerAddExact
1365 Box
1324 Return
\[ a + b * c \]

```
imul  \%rsi,\%rdx
jo     0x00000001171a3fa5
add    \%rdi,\%rdx
jo     0x00000001171a3fc7
```
Our radical new solution for C extensions...
ruby.rb

extension.c

C Compiler

extension

extension.so
The diagram illustrates the interaction between a Ruby interpreter and a C interpreter. The Ruby interpreter processes a Ruby script named `ruby.rb`, while the C interpreter processes a C code file named `extension.c`.
Ruby Interpreter

LLVM C Compiler

extension.c

extension.ll

Ruby.rb

LLVM Interpreter
define i8* @psd_native_util_clamp(i8* %self,
    i8* %r_num, i8* %r_min, i8* %r_max) nounwind uwtable ssp {
    %1 = call i32 @FIX2INT(i8* %r_num)
    %2 = call i32 @FIX2INT(i8* %r_min)
    %3 = call i32 @FIX2INT(i8* %r_max)
    %4 = icmp sgt i32 %1, %3
    br i1 %4, label %5, label %6
    ; <label>:5
    br label %12 ; preds = %0
    ; <label>:6
    %7 = icmp slt i32 %1, %2
    br i1 %7, label %8, label %9
    ; <label>:8
    br label %10 ; preds = %6
    ; <label>:9
    br label %10 ; preds = %6
    ; <label>:10
    %11 = phi i8* [ %r_min, %8 ], [ %r_num, %9 ]
    br label %12
    ; <label>:12
    %13 = phi i8* [ %r_max, %5 ], [ %11, %10 ]
    ret i8* %13
}
%4 = icmp sgt i32 %1, %3
br i1 %4, label %5, label %6

; <label>:5
   br label %12

; <label>:6
   %7 = icmp slt i32 %1, %2
   br i1 %7, label %8, label %9
t4 = t1 > t3
if t4
    goto l5
else
    goto l6
end

l5: goto l12

l6: t7 = t1 < t2
if t7
    goto l8
else
    goto l9
end

%4 = icmp sgt i32 %1, %3
br i1 %4, label %5, label %6

; <label>:5
br label %12

; <label>:6
%7 = icmp slt i32 %1, %2
br i1 %7, label %8, label %9

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Optimise Ruby and C together

ruby.rb

extension.c

Optimisations
Optimise Ruby and C together
Interesting problems and their solutions
Defining the C extension API in Ruby

```ruby
module Truffle::CExt

def rb_fix2int(value)
  if value.nil?
    raise TypeError
  else
    int = value.to_int
    raise RangeError if int >= 2**32
  end
end

end

int FIX2INT(VALUE value);

int FIX2INT(VALUE value) {
  return truffle_invoke_i(RUBY_CEXT, "FIX2INT", value);
}
```
Imaginary strings

```c
char *chars = RSTRING_PTR(my_string);
chars[14]
```

Hello, Ruby Conf!
Imaginary strings

A Tale of Two String Representations

Kevin Menard - RubyKaigi 2016
Imaginary strings

```c
char *chars = RSTRING_PTR(my_string);
chars[14]
```

%1 = call @RSTRING_PTR(%my_string)
%2 = getelementptr %14, 14

Hello, Ruby Conf!
Imaginary strings

```c
char *chars = RSTRING_PTR(my_string);
chars[14]
```

%1 = call @RSTRING_PTR(%my_string)
%2 = getelementptr %14, 14

String#[]

Hello,

Ruby Conf!
Results
Matthias Grimmer, Chris Seaton, Thomas Wuerthinger, Hanspeter Moessenboeck:
Dynamically Composing Languages in a Modular Way: Supporting C Extensions for Dynamic Languages
Modularity '14 Proceedings of the 14th International Conference on Modularity
Some limitations
You do need the source code of the C extension

- Means no closed source C extensions
  - Is this a problem in reality for anyone?
  - I’m not aware of any closed source C extensions
  - C extensions in turn using closed source libraries like database drivers is fine
You can’t store pointers to Ruby objects in native code

• If your C extension uses a compiled library, such as libssl.so
  – You can’t give that compiled library a reference to a Ruby object
  – The Ruby object may not really exist
  – The GC may want to move the object

```c
void *rb jt_to_native_handle(VALUE managed);
VALUE rb jt_from_native_handle(void *native);

SSL_CTX_set_ex_data(ctx, ossl_ssl_ex_ptr_idx, obj);
SSL_CTX_set_ex_data(ctx, ossl_ssl_ex_ptr_idx, rb jt_to_native_handle(obj));
```
By the way...

- It is probably still best to use the FFI if you are writing new extensions
  - Wide support across Ruby implementations
  - Although we don’t actually implement the FFI in JRuby+Truffle yet
  - Implementing the FFI in JRuby+Truffle would be a great internship project!

- If you do write a C extension for performance
  - Write a pure Ruby baseline version as well

- Or if you just needed better performance:
  - Write pure Ruby code
  - Run with JRuby+Truffle
Java extensions
This could be a direction for MRI as well
Evan Phoenix: store the LLVM IR of the MRI implementation code and JIT it

*Ruby: 2020 - RubyKaigi 2015 Keynote*
A quick status update on JRuby+Truffle
Classic research benchmarks – 10-20x faster than MRI

- Spectral-norm
- Mandelbrot
- Deltablue
- N-body
- Neural-net
- Binary-trees
- Pidigits
- Fannkuch
- Red-black
- Matrix-multiply
- Richards
- Geomean

Speedup Compared to MRI

- Truffle
- JRuby+invokedynamic
- MRI
‘optcarrot’ NES emulator benchmark – 9x faster than MRI

![Bar chart showing speedup relative to MRI for Truffle, JRuby+invokedynamic, and MRI.](http://nyphotographic.com) - Creative Commons 3.0
Ruby specs

99% Language specs

96% Core library specs

78% Standard library specs*
  coverage is very limited here; probably a bit misleading
Rails tests

Basic functionality works

- Active Support
- Active Model
  - Active Record
- Action View
- Action Pack
  - Action Mailer
  - Railties
    - Sprockets-Rails
- Active Job
- Spring

100%

98%

37%
Edit post

Create new post. Body of the post is processed by asciidoc.

Body

This is the Title of the blog post
Author Name
icons: font
This is an "example" of a _blog post_
== Header 1
Lorem ipsum dolor sit amet, consectetur adipiscing elit. Phasellus est ante, congue aliquet suscipit vel, mollis ac quam. Nam aliquam porta massa, non porttitor risus cursus quis. Quisque suscipit, lorem eget congue semper, sem tortor volutpat arcu, non volutpat libero felis et eros.
  * Item 1
  * Item 2
  * Item 3

This is an example of a blog post.

Header 1
Lorem ipsum dolor sit amet, consectetur adipiscing elit. Phasellus est ante, congue aliquet suscipit vel, mollis ac quam. Nam aliquam porta massa, non porttitor risus cursus quis. Quisque suscipit, lorem eget congue semper, sem tortor volutpat arcu, non volutpat libero felis et eros.
  > Item 1
  > Item 2
  > Item 3

Platform: truffle
So then why can’t we run real applications yet?

• C extensions are still a work in progress
  – Almost no database drivers
  – No openssl
  – No nokogiri
  – Prevents us running almost everything unfortunately

• The specs don’t have perfect coverage

• Our sophisticated optimisations mean the program state space is huge
  – Lots more to test
  – Lots more to tune for performance
Search for ‘graal otn’
Search for ‘github graalvm’
chrisseaton.com/rubytruffle
Freenode #jruby
gitter.im/jruby/jruby
@ChrisGSeaton

‘jruby truffle’
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