Safe Programming in Dynamic Languages

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Dynamic Languages

- Dynamic languages are very popular
  - C.f. Bloomberg learning to code in JavaScript!
    - Codeacademy.com
- Dynamic languages are great for rapid development
  - Time from opening editor to successful program run is small
- Dynamic languages are convenient for big data
  - Try not to "get in the programmer's way"
  - Rich libraries, flexible syntax, domain-specific support (e.g., regexps, syscalls)
    - Can often encode "little languages" inside scripting languages

Drawbacks

- Flexible syntax can make typos suddenly meaningful

```
def foo(h1, h2) ... end  # h1, h2 hash tables
foo({:a ⇒ 10}, {:b ⇒ "foo"})  # params clear

foo :a ⇒ 10, :b ⇒ "foo" # saved some typing, but oops!
```

- Dynamic typing means type errors can remain latent until run time
  - Also, no static types to serve as (rigorously checked) documentation
  - May make code evolution and maintenance harder
- Performance a challenge
  - Dynamic typing, eval, send, method_missing, etc
  - Inhibit traditional compiler optimizations (but see JavaScript!)

Types for Ruby

- Over last several years, have been working on bringing some benefits of static typing to Ruby
  - Ruby = Smalltalk + Perl
- Goal: Make types optional and useful
  - Develop a program without types (rapidly)
  - Include them (later) to provide static checking where desired
  - Find problems as *early* as possible (but not too early!)
- Plan:
  - Discuss lessons learned from this work
  - Talk about ideas for scripting and big data

Take One: Static Types for Ruby

- How do we build a static type system that accepts "reasonable" Ruby programs?
  - What idioms do Ruby programmers use?
  - Are Ruby programs even close to statically type safe?

- Goal: Keep the type system as simple as possible
  - Should be easy for programmer to understand
  - Should be predictable

- We'll illustrate our typing discipline on the core Ruby standard library
  - 185 classes, 17 modules, and 997 methods (manually) typed

Intersection Types

```
class String
  slice : (Fixnum) → Fixnum
  slice : (Range) → String
  slice : (Regexp) → String
  slice : (String) → String
  slice : (Fixnum, Fixnum) → String
  slice : (Regexp, Fixnum) → String
end
```

- Method has all the given types
  - Ex: "foo".slice(3); "foo".slice(3..42);
- Generally, if x has type A and B, then
  - x is both an A and a B, i.e., x is a subtype of A and of B
  - and thus x has both A's methods and B's methods

Union Types

```
class A def f() end end
class B def f() end end
x = ( if ... then A.new else B.new)
x.f
```

- This method invocation is always safe
  - Note: in Java, would make interface J s.t. A < J and B < J
- Here x has type A or B
  - It's either an A or a B, and we're not sure which one
  - Therefore can only invoke x.m if m is common to both A and B

Object Types

```
module Kernel
  print : (*[to_s : () → String]) → %nil
end
```

- print accepts 0 or more objects with a to_s method
  - may have other methods too
- With object types we can avoid the closed-world assumption, i.e., we don't have to write
  - print : *(C1 or C2 or ...) → %nil
    - where Ci has to_s method
- But nominal types are more terse and oftentimes more evocative, so supporting both works best

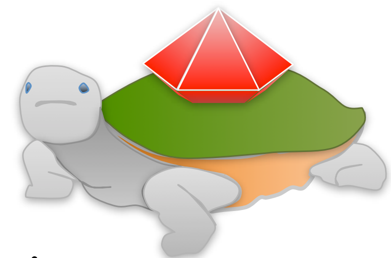
Generics: Array and Tuple Types

```
x = [ 1, 2, 3 ]
def g() [ 1, true ] end
a, b = g()                          # a = 1, b = true
```

- x : Array⟨Fixnum⟩
- g : () → Tuple⟨Fixnum, Boolean⟩
  - not () → Array⟨Fixnum or Boolean⟩
  - Tuple⟨t1, ..., tn⟩ = array where element i has type ti
- Implicit subtyping between Tuple and Array
  - Tuple⟨t1, ..., tn⟩ ≤ Array⟨t1 or ... or tn⟩

Experience (through 2010)

- We built a static inference tool for this type system
  - Diamondback Ruby (DRuby)



- Development was painstaking
  - context-sensitive parsing, surprising semantics
- Hard to support for dynamic features
  - eval, method_missing, etc.
  - Built profile-directed inference system to compensate
- Significant work to keep up to date
  - Doesn’t work with Ruby 1.9 (latest version)
- Conclusion: need lighter-weight support

Code produced at runtime

```
class Format
  ATTRS = ["bold","underscore",...]
  ATTRS.each do |attr|
    code = "def #{attr}() ... end"
    eval code
  end
end
```

```
class Format
  def bold() ... end
  def underline() end
end
```

Another Fun Example

```
config = File.read(__FILE__)
         .split(/__END__/).last
         .gsub(#\{(.*)\}/) { eval $1}
```

Another Fun Example

```
config = File.read(__FILE__)
         .split(/__END__/).last
         .gsub(#\{(.*)\}/) { eval $1}
```

Huh?

Another Fun Example

```
config = File.read(__FILE__)
           .split(/__END__/).last
           .gsub(#\{(.*)\}/) { eval $1}
```

Read the current file

```
class RubyForge
  RUBYFORGE_D = File::join HOME, ".rubyforge"
  COOKIE_F    = File::join RUBYFORGE_D, "cookie.dat"
  config = ...
  ...
end
__END__
  cookie_jar : #{ COOKIE_F }
  is_private : false
  group_ids :
      codeforpeople.com : 1024
  ...
```

Another Fun Example

```
config = File.read(__FILE__)
         .split(/__END__/).last
         .gsub(#\{(.*)\}/) { eval $1}
```

```
class RubyForge
  RUBYFORGE_D = File::join HOME, ".rubyforge"
  COOKIE_F    = File::join RUBYFORGE_D, "cookie.dat"
  config = ...
  ...
end
__END__
  cookie_jar : #{ COOKIE_F }
  is_private : false
  group_ids :
      codeforpeople.com : 1024
  ...
```

Get everything after here

Another Fun Example

```
config = File.read(__FILE__)
             .split(/__END__/).last
             .gsub(#\{(.*)\}/) { eval $1}
```

```
class RubyForge
  RUBYFORGE_D = File::join HOME, ".rubyforge"
  COOKIE_F    = File::join RUBYFORGE_D, "cookie.dat"
  config = ...
  ...
end
__END__
  cookie_jar : #{ COOKIE_F }
  is_private : false
  group_ids :
      codeforpeople.com : 1024
  ...
```

Substitute this

Another Fun Example

```
config = File.read(__FILE__)
              .split(/__END__/).last
              .gsub(#\{(.*)\}/) { eval $1}
```

```
class RubyForge
  RUBYFORGE_D = File::join HOME, ".rubyforge"
  COOKIE_F    = File::join RUBYFORGE_D, "cookie.dat"
  config = ...
  ...
end
__END__
  cookie_jar : #{ COOKIE_F }
  is_private : false
  group_ids :
      codeforpeople.com : 1024
  ...
```

With this

Another Fun Example

```
config = File.read(__FILE__)
             .split(/__END__/).last
             .gsub(#\{(.*)\}/) { eval $1}
```

```
class RubyForge
  RUBYFORGE_D = File::join HOME, ".rubyforge"
  COOKIE_F    = File::join RUBYFORGE_D, "cookie.dat"
  config = ...
  ...
end
__END__
  cookie_jar : “/home/jfoster/.rubyforge/cookie.dat”
  is_private : false
  group_ids :
      codeforpeople.com : 1024
  ...
```

Eval it

Another Fun Example

```
config = File.read(__FILE__)
           .split(/__END__/).last
           .gsub(#\{(.*)\}/) { eval $1}
```

```
class RubyForge
  RUBYFORGE_D = File::join HOME, ".rubyforge"
  COOKIE_F    = File::join RUBYFORGE_D, "cookie.dat"
  config = ...
  ...
end
__END__
  cookie_jar : "/home/jfoster/.rubyforge/cookie.dat"
  is_private : false
  group_ids :
      codeforpeople.com : 1024
  ...
```

Store in config

Take Two: Rubydust and Rtc

- **Ruby D**ynamic **U**nraveling of **S**tatic **T**ypes
  - Type inference
- The **R**uby **T**ype **C**hecker
  - Type checking
- Pure Ruby libraries
  - Dynamic analysis—does not examine source code
  - Infers or checks types at run time
  - Later than pure static analysis, but...
  - Earlier than Ruby's type checks

Types are Run-time Objects

- Type information is stored in class objects

```
class Array
  rtc_annotated :t
  typesig "[] : (Range) → Array<t>"
  typesig "[] : (Fixnum, Fixnum) → Array<t>"
  typesig "[] : (Fixnum) → t"
  typesig "map<u> : () {(t)→ u}→ Array<u>"
end
```

  - If generic type is instantiated, the instantiation of the type variable is stored in the constructed object

Type Wrapping

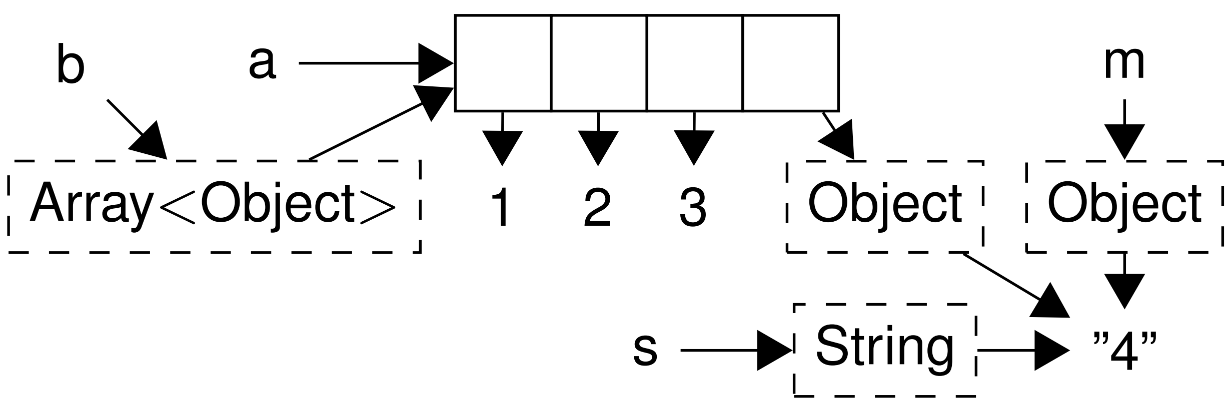
- To track type information at run-time, we wrap objects in *proxies*

```
x = 1.rtc_annotate("Fixnum")
# equivalent to...
x = Proxy.new(1,"Fixnum")
```

  - Proxied object delegates all calls to the underlying object
  - Rtc: checks types on entry and exit of method
  - Rubydust: generates type constraints on entry and exit of method
- Why is this useful:
  - Rtc: can associate a *larger* type with object than run-time type
  - Rubydust: can associate *type variable* with object

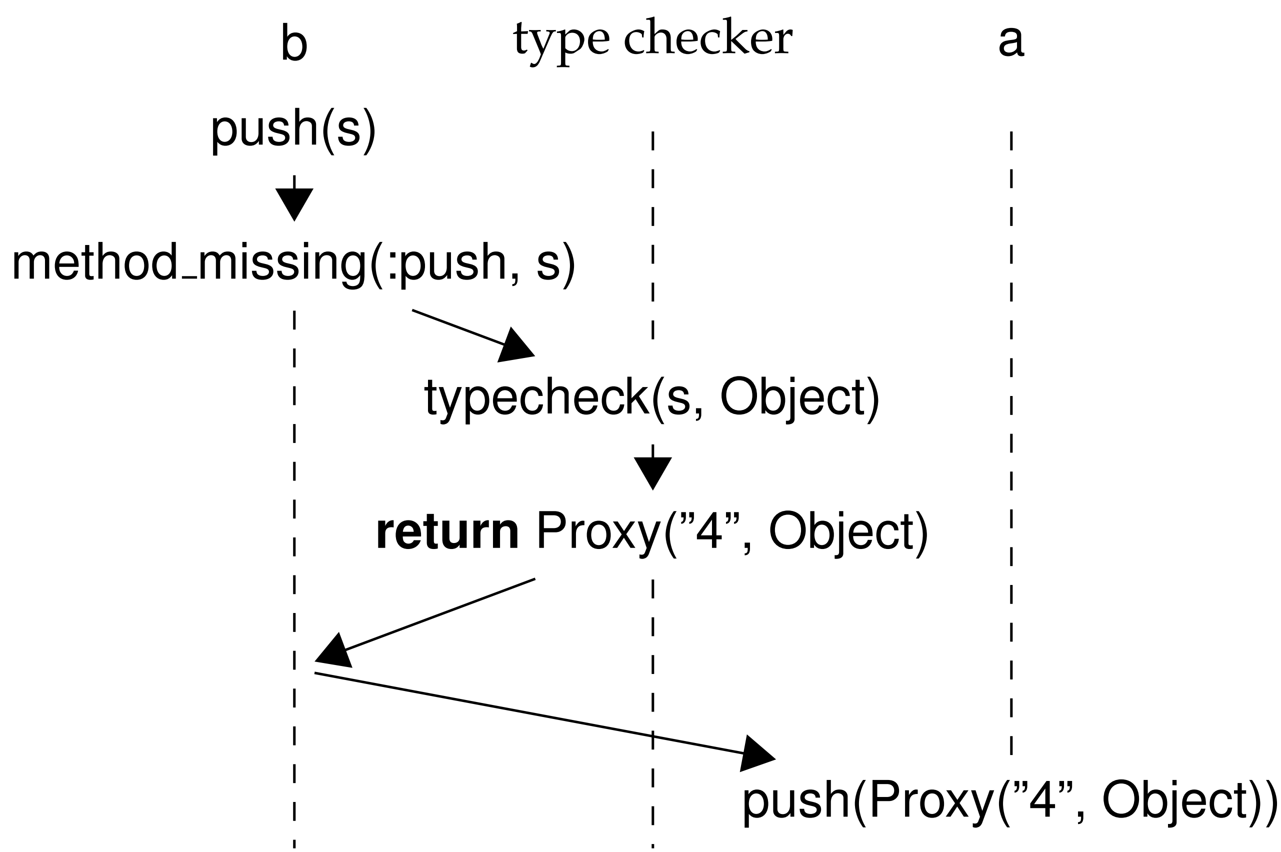
Type Wrapping Example

```
a = [1,2,3]
b = a.rtc_annotate("Array<Object>")
# Notice that b's type captures programmer intention
s = "4".rtc_annotate("String")
b.push(s)
m = b[3]
```



Proxy Calling Sequence

- b.push(s) from previous slide



Evaluation

- Ran DRuby, Rubydust, and Rtc on a range of programs
- Found lots of interesting mistakes

- Rubydust and Rtc performance acceptable on small examples, but slow
  - Worst case: Sudoku-1.4 test suite goes from 0.04s to 7.58s (rtc)
  - Lots of wrapping/unwrapping happening
  - $\Rightarrow$ Probably need to add direct interpreter support

Dynamic Languages for Big Data

- Several interesting challenges...

Correctness

- A lot of science is done by software
  - Scripting languages are increasingly popular for this
  - How do we know that software is actually computing the right results?
    - If not, conclusions may be invalid!
    - ∃ papers that have been retracted because of software bugs

- Types are a first step in helping check correctness
  - Types are very good for "computer science" software
    - Folklore: If an OCaml program type checks, it is correct
      - (N.B.: I have disproved this myself many times...)
  - What is the equivalent folklore for scientific software?

Debugging

- Suppose one of our scripts isn't working
  - How do we figure out what's wrong and fix it?
  - Are the problems in the software? In our algorithmic idea? In our scientific hypothesis?
  - Can we do better than print statements
    - Doing better is *only* important for complex bugs
    - (Simple bugs can be found with almost any approach)

- Debugging very painful for long, complex computations
  - What if the bug only manifests 1 hour in? 24 hours in?
  - Record and replay a solution?

Notation (Domain-specific Langs)

- One really nice feature of Ruby is that it makes it easy to create nice-looking DSLs in Ruby syntax

```
every :sunday, :at => "12:30am" do
  rake "talks:send_this_week"
end
```

```
  resources :lists do
    member do
      get :subscribe
      get :feed
      get :show_subscribers
    end
  end
```

- What DSLs do we want for working with big data? With bio data?
  - Is R the answer?

Performance

- Most scripting languages have poor performance
  - Ruby is known to be slow even without proxies/wrapping
    - Improved significantly in 1.9, but still not great
  - Python is a memory hog
    - Based on our experience using Python in debugging large systems
  - Exception: Lua is quite zippy
    - But it doesn't have some of the nice features of Ruby and Python
- We need to do better to work with big data sets
  - In JavaScript, trace-based just-in-time compilation is hot
    - A key transformation: specialization based on types
      - cf. David Padua's talk yesterday—ROpt
    - Do the same ideas work in Python, Ruby, and R?

Updates

- What happens if we start a long computation running, and then halfway through we want to change it?
  - E.g., found minor bug that could be worked around
  - E.g., found performance problem we want to fix

- Dynamic software updating
  - Change code and data representations on the fly
    - Support for *state transformation* to change old state to new form
  - Research to date has focused on operating systems and on long-lived servers
  - Investigate for big data programs?

Program Synthesis

- Old idea: given a *specification*, automatically synthesize a program that satisfies the specification
  - New energy: SMT solver and other algorithmic performance improvements have made this possible, at least in the small
- Recent success stories
  - Synthesizing FFTs that out-perform hand-coded implementations
  - Synthesizing synchronization placement in high-performance code
  - Synthesizing Excel macros
- Apply to big data / bio domains?
  - Can we use synthesis to create an even higher-level way of describing big data algorithms? Can we find new algorithms this way?

Possible Topics

- Correctness
- Debugging
- Notation (DSLs)
- Performance
- Updates
- Program Synthesis