AOYAMA GAKUIN UNIVERSITY INTERNSHIP PROGRAM: DOMAIN IN PROGRAMMING

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1 Development

1.1 Introduction

In this section, I will discuss the development process of the domain project. There will be six sections, each exploring the six main features established in the requirement section, which are declaration of domains, assignment of signatures to function/methods, declaration of variables, combination of domains, implicit conversions of variables, and type checking at compile time.

1.2 Declaration of domains

The first feature I have implemented was declaration of domains. There are several methods and classes that are relevant to the code, which will be discussed one by one.

```ruby
def create_domain(compound: 0, name: "")
    if !block_given? && compound == 0
        raise ArgumentError.new "No block of rules were given.  There must be at least one rule for the domain"
    end

    cl = Class.new do
       extend DomainClass
        include DomainClass
    end

    prev = @domain_created

    @domain_created = cl

    @domain_created.compound_domain = unless compound == 0 then compound else @domain_created end
    @domain_created.rules = {}
    @domain_created.translators = {}
    @domain_created.default = nil
    @domain_created.translation_map = {}

    yield if block_given?

    @domain_created.translators.each_key do |key|
        d_in, d_out = key

        if !@domain_created.translation_map.has_key? d_in
            @domain_created.translation_map[d_in] = []
        end

        @domain_created.translation_map[d_in] << d_out
    end

    @domain_created = prev

    cl.send :generate_translators

    if not name.empty?
        if self.inspect == 'main'
            Object.const_set(name, cl)
        else
            self.const_set(name, cl)
        end
    else
        return cl
    end
end
```

Listing 1: Method for creating domains

The first of the relevant methods is create_domain. This method is simple compared to some of the TracePoint driven methods that will appear in the later codes. First, the code checks to see if there are any rules with the provided domain. This is done to prevent users from create a domain that lacks any rules. Next, the method creates an anonymous class that implements DomainClass, which is a module that contains various basic functions for domains to function, which will be shown in Figure 2. Next, an instance varialbe @domain_created is stored in prev variable. This is because the @domain_created variable is basically a global variable for the create_domain method, and if another domain was declared within the block, the value can be overridden with the new domain. To prevent this, prev store the value @domain_created was previously and return it to the original value after the domain is created. After prev has been set, the anonymous class is assigned to @domain_created and all important values such as rules and translation rules are initiated. The block is then yielded to read all the rules inside, and saved to the hashes. The lines 23 to 35 will be explained in detail in the later sections, as it is more relevant there. Finally, the anonymous class is given a name and is defined in the appropriate classes as a constant.

```ruby
module DomainClass
    include DomainErrors
    attr_accessor :rules
    attr_accessor :translators
    attr_accessor :compound_domain
    attr_accessor :default
    attr_accessor :translation_map

    def print_rules; end

    def print_translators; end

    def value?(value); end

    def check_rules(rules, value); end

    def translate(d_in, d_out, value); end

    def value=(value); end

    def value(domain=nil); end
end
```

Listing 2: Domain module

DomainClass module is the next set of codes that will be discussed. This module contains various different methods a domain should have to function properly. The implementations for each of the methods are omitted to prevent codes from taking too much space and because they are mostly self-explanatory. The most important methods are value?, value=, and value. value? method checks the value in the argument to make sure the argument follows the rules of the domain. check_rules in the module is the private helper method for the value? method. value= assigns the value to the domain for domain to use in the future, which can be read through the value method. Domain should also have ways to translate from one domain to another, which is used in implicit conversions.

```ruby
class Object
    class << self
        include Util
        def rules
            [{ self => Proc.new { |x| true } }]
        end

        def compound_domain
            self
        end

        def translators
            {}
        end
```

```ruby

        def value?(x)
            return x.is_a? self
        end

        def has_compound_domain
            self != compound_domain
        end

        def method_added(m)
            super
        end

        def singleton_method_added(m)
            super
        end

        make_compound_domain :+
        make_compound_domain :-
        make_compound_domain :&

        alias :union :+
        alias :intersect :&
        alias :difference :-
    end

    def part_of?(x)
        if x.singleton_methods.include? :value?
            x.value? self
        end

        raise TypeError.new("#{x} is not a domain.")
    end

    def value
        return self
    end
end
```

Listing 3: Monkey patching Object class

Finally, the domain adds new methods to Object class so that all class behave similarly to the domains, as type is a subset of domain in type checking sense. This allows classes that already exist, such as Integer and String class, act similarly to the domain, which allows the program to treat them like one for various benefits such as the combination of domains.

Through these methods, the users of this library can create domain using syntax like this:

```ruby
def is_integer(x)
    return Integer(x) rescue false
end

domain :Int do
    rule(Integer)
    rule(String) { |x| is_integer?(x) }
end
```

Listing 4: Sample code: declaration of domains

The domain :Int do . . . end defines domain Int with two rules. The first rule states that it can accept any Integer, and the second rule states that if the object is String, domain Int can accept values that returns true for the is_integer?() method, which checks if the x is an integer. With this domain, it is possible to use both integer and string only containing integer as if they're integer, which can be a very power tool.

1.3 Assignment of signatures to function/methods

Unlike the declaration of domain, the implementation of signatures require heavy exploitation of Ruby's metaprogramming features, which can be difficult to understand. Additionally, the implementation is very long, so it requires extensive explanation on how they are implemented.

The signature is implemented in three steps. First, the signature reads the String passed in as a signature and parse and interpret the string to see if the String is a valid signature. The string is then transformed into two arrays, each indicating the rules for argument and rules for return values respectively. The arrays are then used to wrap the new method with checks that makes sure the argument and return value conforms to the rules and the original method is overridden with the new wrapped method. We will discuss each parts in detail over this section

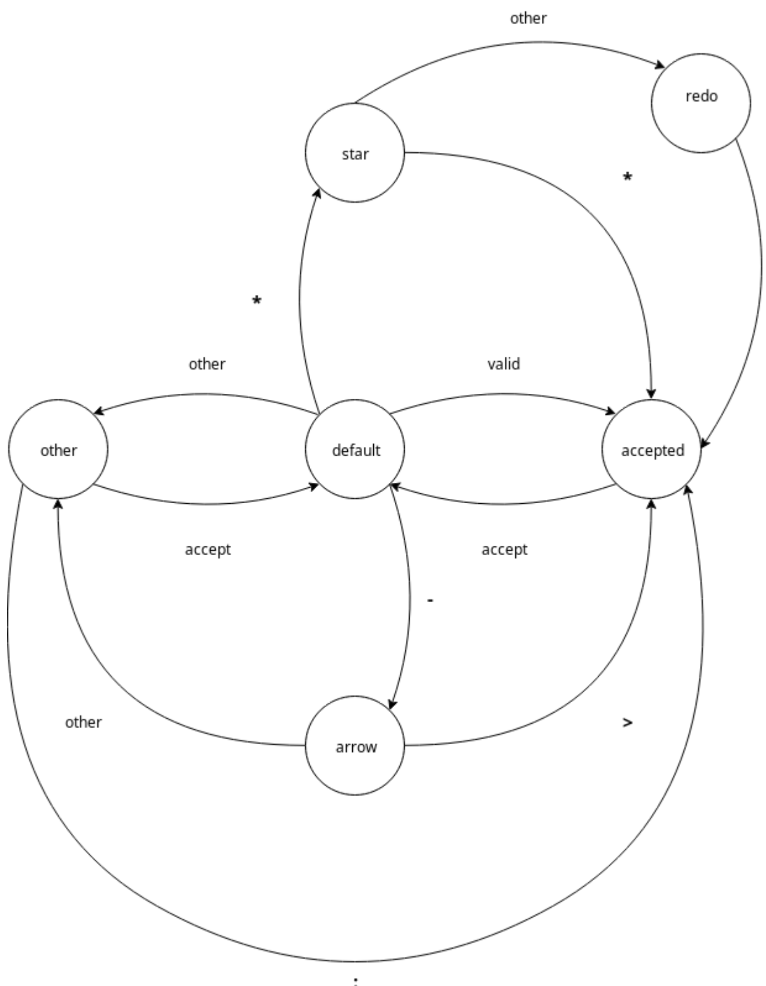
```ruby
def parse_tokens(sig)
    valid_tokens = ['(', ')', ',', '[', ']', '$', '{', '}', '&']
    sig.gsub!(/\s/, "")

    tokens = []

    other = ""
    token = ""

    state = :default
    redo_state = false

    sig.each_char do |x|
        case state
        when :default
            token += x
            case x
            when '*'
                state = :star
            when '-'
                state = :arrow
            when *valid_tokens
                state = :accepted
            else
                state = :other
            end
        when :star
            case x
            when '*'
                state = :accepted
                token += x
            else
                state = :accepted
                redo_state = true
            end
        when :arrow
            token += x
            case x
            when '>'
                state = :accepted
            else
                state = :other
            end
        end

        if state == :other
            other += token

            if token == ":" then state = :accepted else state = :default end
            token = ""
        end

```

```
        if state == :accepted
            if !other.empty? then tokens << other; other = "" end
            tokens << token if !token.empty?
            token = ""
            state = :default
        end

        if redo_state
            state = :default
            redo_state = false
            redo
        end
    end

    tokens << other if !other.empty?
    tokens
end
```

Listing 5: Parser method

First, this method parses the string into list of tokens that can be used to interpret what it means. The method follows the following finite state machine to parse the string:

Figure 1: Finite State Machine



The machine begins at default, and moves to star state when it finds a * symbol, arrow state (->) when it finds the - symbol, accepted state when it finds any of the valid tokens defined in the array, and other state for any other symbols. On star state, it moves to accepted state when it finds another * symbol and redo state otherwise, which is a state that quickly moves to accepted state and re-examine the current symbol. The arrow state changes to accepted state only when it finds the >symbol which completes the arrow. The remaining other symbols move to other state. Other state simply concatenates the value to a variable, and if : was found, Other moves to accepted state to save it as a keyword. On accepted state, the tokens that has been found is stored in an array. After the entire string has been parsed, the array is returned.

```ruby
def interpret_tokens(cl, local, tokens)
    # Get tokens for arg and return separated

    k = tokens.slice_after { |x| x == '->' }.to_a
    a, r = k
    a.pop
    length = k.length

    if length != 2
        raise ArgumentError.new "Expected only one arrow (->), got #{length - 1}"
    end

    # Change the list of tokens into something more usable

    # Ignore the () if it's properly at the begnning and end
    a = a[1..-2] if a[0] == '(' && a[-1] == ')'
    r = r[1..-2] if r[0] == '(' && r[-1] == ')'

    a = retrieve_tokens(cl, local, a)
    r = retrieve_tokens(cl, local, r)[0]

    return a, r
end
```

Listing 6: Interpreter method

Now that all the tokens are in array, the next step is to store them into two arrays, one for argument and another for return values. Once the tokens are separated, it is sent to retrieve token method, which will turn all the tokens into something the wrapper can use to check the values.

```ruby
def retrieve_tokens(cl, local, tokens)
    # initialization

    tokens.each do |x|
        case state
        when :token
            case x
            when '['
                # array logic
            when '{'
                # hash logic
            when ',', ']', '}'
                # error
            when '*', '**'
                # star logic
            when '$'
                # optional logic
            when '&'
                # block logic
            else
                # non-token logic
        when :comma
            # comma logic
        end
    end
    return arg, kwarg
```

```
end
```

Listing 7: Retriever method

The retrieve_token method can be generalized through this code. After initializing important variables, the method iterates through all the tokens that are given, and performs different checks to see what the token means. There are two states in this method, which are "token" and "comma". Because the tokens alternate between valid token and comma in real code, this two states are alternated between each other to make sure all tokens separated by comma means something.

```
def wrap_method(signature)
    # initialize

    return_trace = TracePoint.new(:return) do |tp|
        # parse signature
        # initialization for the new method
        # check if the method has correct argument(s)
        # wrap the method with checks and replace it
        # add it to the correct place and with right scope
    end

    line_trace = TracePoint.trace(:line) do |tp|
        # get a binding
        # enable return_trace and disable line_trace
    end
end
```

Listing 8: Wrapper method: overview

Next, the wrapper method uses the established parser in order to wrap the method correctly. The wrapper method uses tracepoints and other metaprogramming techniques, which makes this method difficult to understand at glance, so we will examine each part separately.

```
return_trace = TracePoint.new(:return) do |tp|
    # ...
    # Check for validity of the method by getting its arity and aligning it with
    the length of arguments in signature
    method = tp.self.instance_method(method_name) if tp.method_id == :method_added
    method = tp.self.method(method_name) if tp.method_id == :
    singleton_method_added

    # Check if the parameters should have star variable (*arg) or double star
    variable (**arg)
    has_star = false
    has_dstar = false

    args.each do |x|
        has_star = true if is_star?(x) && x.star == '*'
        has_dstar = true if is_star?(x) && x.star == '**'
    end

    has_dstar = !kwargs.empty? unless has_dstar

    # Get all the parameters for the method
    param = method.parameters

    # initialization
    optional_arg = []
    optional_kwarg = []
    expected_length_arg = 0
    expected_length_kwarg = 0

    # args is nil, so there should not be any parameters except for the blocks
    if args.length == 1 && args[0].nil? && param.reject{ |x| x[0] == :block }.
    length == 0
```

```ruby
        next
    else
        # Then see if the variables are structured properly, such as making sure that star variable is a 3rd variable if the signature also have star variable for 3rd
        param_arg = param.reject { |x| x[0] != :req && x[0] != :opt && x[0] != :rest }
        if param_arg.length != args.length
            raise SignatureViolationError.new "Wrong number of total arguments: Expected #{args.length}, found #{param_arg.length}"
        end
        # Iterate every rules
        args.zip(param).each_with_index do |x, i|
            ar, par = x

            # Check if the parameter is what we expected
            case
            when ar.class == Class
                if par[0] != :req
                    raise SignatureViolationError.new "Expected a required variable for #{par[1]}, found #{par[0]}"
                end
                expected_length_arg += 1
            when is_star?(ar)
                if par[0] != :rest
                    raise SignatureViolationError.new "Expected a * variable for #{par[1]}, found #{par[0]}"
                end
            when is_optional?(ar)
                optional_arg << i
                if par[0] != :opt
                    raise SignatureViolationError.new "Expected an optional variable for #{par[1]}, found #{par[0]}"
                end
                expected_length_arg += 1
            end
        end

        # Do the same thing for the keyword section
        key_matched =  []

        param_kwarg = param.reject { |x| x[0] != :keyreq && x[0] != :key}
        if param_kwarg.length != kwargs.length
            raise SignatureViolationError.new "Wrong number of keyword arguments: Expected #{kwargs.length}, found #{param_kwarg.length}"
        end

        param.each do |par|
            if kwargs.has_key?(par[1])
                key_matched << par[1]
                if is_optional?(kwargs[par[1]])
                    optional_kwarg << par[1]
                end
            end
        end

        missing = kwargs.keys - key_matched
        missing = [] if has_dstar

        if !missing.empty?
            raise SignatureViolationError.new "The following keywords are not in the argument: #{missing}"
        end
    end
```

```
end
```

Listing 9: Wrapper method: check if the method has correct argument(s)

The second step in wrapping method is to determine if the method given has the right argument at the right area:

```
# error, first argument should be required, and second should be optional
domain 'String, $String -> nil'
def f(x = 5, y)
end

# no error
domain 'String, $String -> nil'
def f(x, y = 5)
end
```

Listing 10: Example: wrapper method

As evident by this example, the first method f does not follow the rules provided. The signature stated that the first argument is required while second argument is optional, yet the f provides the opposite. Additionally, there can be too much or too little arguments on f that would break the rule. To prevent this type of rule breaking, this part of wrapper goes through all the parameters of the method and the rules for the argument and check if they match.

1.4 Declaration of variables

```
def create_initializer(a, domain)
    line = 0

    tp = TracePoint.trace(:line) do |x|
        line += 1

        if line == 2
            bind = x.binding

            if x.self.inspect != "main"
                x.self.class_eval do
                    DomainCreate::define_initializer a, domain
                end
            else
                Object.class_eval do
                    DomainCreate::define_initializer a, domain
                end
            end

            x.disable
        end
    end
end
```

Listing 11: Method for calling define initializer correctly

```
def define_initializer(a, domain)
    define_method a do |sym|
        layer = 1
        bind = nil
        obj_id = 8
        line_checked = 0
        path_checked = 0

        line_trace = TracePoint.trace(:line) do |x|
            if bind != nil
                new_obj_id = 0
```

```
                value = bind.local_variable_get(sym) if bind.local_variable_defined?(sym)
                new_obj_id = value.object_id if bind.local_variable_defined?(sym)

                if new_obj_id != obj_id && line_checked != 0 && path_checked != 0
                    if !domain.value? value
                        raise ValueOutOfBoundsError.new "from #{path_checked}:#{line_checked}: '#{value}' assigned to variable '#{sym}', which is out of bounds from '#{domain.name}'"
                    end

                    val = domain.new
                    val.value = value

                    bind.local_variable_set(sym, val)
                end

                obj_id = new_obj_id

                path_checked = x.path
                line_checked = x.lineno
            else
                next
            end
        end

        call_trace = TracePoint.trace(:call) do |x|
            line_trace.disable if line_trace.enabled?

            layer += 1
        end


        return_trace = TracePoint.trace(:return) do |x|
            layer -= 1

            if layer == 0
                line_trace.enable
            end

            if layer == -1
                line_trace.disable
                x.disable
                call_trace.disable
            end
        end

        bind_trace = TracePoint.trace(:line) do |x|
            bind = x.binding
            bind_trace.disable
        end
    end
end
```

Listing 12: Method for defining the initializer method

1.5 Combination of domains

1.6 Implicit conversion of variables

1.7 Type Checking at Compile Time