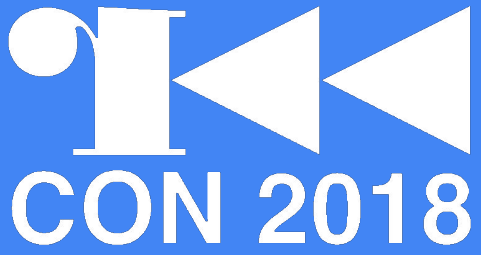


Developing Internals

by pancake & condret

Summary

- Introduction to radare2
- C Programming Language Basics
- Good coding practices
- Making tests
- How Code is Structured
- Extensibility and Plugins
- Integration with other programming languages
- How to contribute, add tests, improve stability

What We Will Learn

- Identify bugs from reproducer to implementation
- Report an issue
- Fix them in a pull request
- Good coding practices
- Understand how code is structured in r2
- Write a test
- Fuzz for more
- Learn how to write plugins

Background requirements

- C programming language
- Unix shell and libc basics

examples and exercises are here:
https://github.com/condret/r2-dev-training-exercises

POLL: Why are you here?

- Learn about r2 internals
- Make my own plugins
- Fix bugs in r2
- Find bugs in r2
- Improve radare2
- Learn about software development, maintenance and security.

Introduction to radare2

What is Radare2?

Free/libre open source reverse engineering framework written in C with unix concepts in mind.

- Supports static and dynamic analysis
- Support for debugging and emulation
- Visual mode, web interface, cli interface
- Support for scripting in various languages
- Multi platform and multi architecture

Tools

- Radare2
- Rabin2
- Rax2
- Rasm2
- Rahash2
- Rafind2
- Ragent2
- ...

Commands

- All the features exposed by the r2 libraries can be accessed not just by API and the system shell, but also, as commands inside r2.

They are known to be cryptic and may look hard to learn at first sight, but once you understand the basic logic behind each char you'll catch the rest quickly.

Command Syntax Rules

PREFIX

- . to run a command and interpret the output as commands
- ! to escape to the shell
- number to repeat a command
- # comments

Command Syntax Rules

SUFFIX

- J - output in json
- * - output in r2 commands
- = - ascii art columns
- L - long output (verbose)

Command Syntax Rules

MODIFIERS

- @ - temporal seek - see ?@? For more
- @@ - foreach operator
- | - pipe to system command
- > - redirect output to a file
- ~ internal grep

Command Implementation

- All the commands are implemented in libr/core/cmd*

There are plans to make a syntax parser and make a better parsing in a structured way… but for now we’re fine with the ugly switch/if approach.

- Autocompletion can be tweaked, changed or added at runtime with the !!! command.

Adding new commands in RCore

- You can make an RCore plugin, which basically handles only 1 call to fill in the plugin struct

Exercise: Making an RCore plugin

See libr/core/p/* or find another one in r2e with git grep RCorePlugin

How is Code Structured in r2land

API Summary

- IO
  - Descriptors and Maps
- RBin
  - Parsing binary headers
- RAsm
  - Assembler and Disassemblers
- RAnal
  - Improve jump table analysis or tweak the main loop?
  - Maybe good excuse to fix the anal.trim
- RCore
  - Show how r2pipe.native works

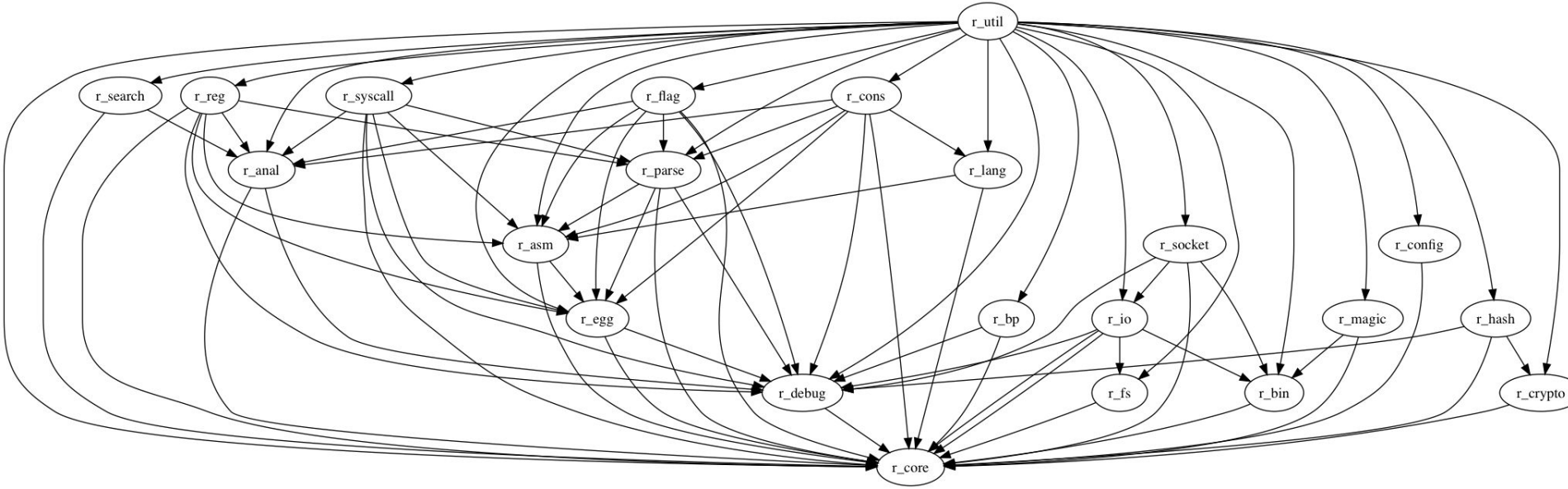
API Summary (2)

But there are more!

- bp/
- config/
- cons/
- crypto/
- debug/
- egg/
- flag/
- fs/
- hash/
- lang/
- magic/
- parse/
- reg/
- search/
- socket/
- syscall/
- util/

API Summary

- Make depgraph.png



Module Dependencies

- Dependencies are important
  - You cannot use RCore apis from RUtil.
- Forces us to find cleaner and more modular designs.
- RBind instances to solve this problem

See RBindIO, RBindCore, ...

Quizz

- Where are commands implemented in r2?
- How to show a backtrace without a debugger?
- Where are the plugins implemented?
- Which directory contains 3rd party projects?
- How many programs are shipped with r2?

Releases

Making a release

- Update version in configure.acr and rerun autogen.sh
- Commit it and add a git tag with the version number
- Github will do the tarballs but you can do make dist

All the steps are implemented in a shell-script in the radare2-release repository.

Release Schedules

Rolling releases every 6 weeks.

Bumping +1.0 after every r2con

Bumping +0.1 every 6 weeks

Building from Git

$ git clone --depth=1 https://github.com/radare/radare2

$ cd radare2

$ sys/install.sh

.. sys/rebuild.sh gdb # if you want to rebuild part of r2 to solve the problems introduced by the lack of revdeps in the makefiles for stuff in shlr/

With Meson

$ git clone --depth=1 https://github.com/radare/radare2

$ sys/meson.sh

Using Git

How to use Git

Git is the version control system we use. So it’s important to know how to operate with it in order to make branches, resolve conflicts, squash commits, etc..

- Many of those words may sounds strange to you.

So let’s go for them!

- Please install tig

Commit

A group of changes in files associated to a person and a time, and referenced to the parent commit, in order to have a hierarchy of patches.

$ git commit -a # commit all changes (see git add, rm …)

$ git commit -p # pick change one by one

$ git commit libr/ # commit only changes inside libr

Branch

Master is the default branch, but you can have other branches following different changes, a branch is a name for a specific commit which is considered HEAD for that branch.

$ git checkout -b branchname # create new branch

$ git checkout branchname # switch to it

$ git reset --hard # reset all changes in files

$ git checkout -d branchname # delete a branch

Rebase

Rebasing is moving the heading commits in a branch rebasing them on top of the changes of another branch. This is necessary to avoid doing branch merges which can introduce many issues. Rebasing is cleaner.

$ git rebase master

Cherry Pick

If rebasing is not working you probably want to do this process by hand, this is done by using git cherry-pick to include a commit into your current branch.

$ git reset --hard @^^

$ git pull . master

$ git cherry-pick <hash1>

$ git cherry-pick <hash2>

Squash

Squashing is merging, aka combining N commits into one. This line will open vim and ask us what to do on each file, select all the lines, except the first one and change the first word of each line by the letter ‘s’ (for squash)

$ git rebase -i @~4

Pull Request

A pull request is a process in github where the users can publish a branch of another repository asking the owners of the repo to be able to review, comment and accept. (supports merge, rebase and squash).

Easiest way to do a pullreq is by pressing the pencil button.

Otherwise, press the fork button, clone in local, make the branch, push -f

GitHub

- pull requests
- Issues
- Commit message rules
- Branches
- How to use git

How to report issues

- Post version of r2
  - We only fix bugs that are in Git, no backports or so
- Operating System
- Architectures
- Crash log
  - Backtrace
  - Register state
  - ASAN log is preferibly
  - Valgrind logs are helpful

Building with ASAN vs Valgrind

ASAN may catch many issues at runtime and execution is nearly native, output crashlogs are really verbose and useful.

$ sys/asan.sh **or** sys/meson.py --asan

Valgrind works with asan-free builds, execution is slower, and works mainly in Linux, Mac support is sometimes not complete and Windows is not supported.

Both support debugger integration

Testing Framework

Tests

Testing is

- Boring
- Important
- Impossible to cover all cases
- Time consuming

Tests

- r2’s testsuite is in the radare2-regressions repository

We test many things:

- Commands
- Fuzzed files (loading and analyzing them)
- Assemble/disassemble instructions
- Debugger
- APIs (C)

Travis

There are many online services that can be used to build each commit of r2 and run the whole testsuite and notify in case of failure. This eases the maintenance and testing because we can be sure that the PR will not be breaking anything

- Jenkins is an opensource alternative that we used in the past but I didn't wanted to spend time with things i shouldn't care like maintaining servers, therefore using Travis is probably the best option.
- But fails randomly sometimes, as well as not being constant in time, so not usable for benchmarks.

Travis

Travis is right now running for Linux and Mac, and also enabling the ASAN build. So we can run the whole testsuite. (even the debugger tests).

Creating a test

- Clone the repository

$ git clone https://github.com/radare/radare2-regressions

- Writing tests
- Running tests
- Finding the offending commit

C Programming Language Basics

Syntax Rules

- C99?
- Space before (and around +-/*%
- DEVELOPERS.md
- See other files as examples

Space before parenthesis

Function definitions have no space before (

- Function calls need that.

This rule makes it easy to find function signatures

- Git grep ‘r_core_cmd0(‘

static

Static make things private to the object

We use 3 levels of symbol visibility

- Static (private to the object, can be safely stripped at linking time)
- Internal (can be used from inside the same module)
- Public (function names must start with r_${module_name})

R_API

It’s a define to force public visibility.

All exported functions must use this keyword.

r_types.h

All the basic types we use in r2 are redefined in this file.

This is because some types were only available in c99 and not all the compilers at the time was supporting this standard when the project started.

This is ut32 instead of uint32_t or unsigned int

etc...

Basic types

- Ut32
- St32
- Ut64
- St64
- Ut128
- Ut16
- Ut8
- ...

Bool vs Int

Split data vs errors

Indent examples

Use sys/indent.sh

Development Tricks

Development Environment

- Which is your favourite editor?
  - I don’t care, here we’ll focus in Vim.
  - But there’s people using Visual Studio or Emacs
- Compiler setup:
  - POSIX Shell && GNU Make
  - Meson + Ninja
  - Visual Studio Compiler in Docker

Development Tricks

- r_sys_backtrace();
- r_sys_breakpoint();

- Grep fcnname’ (‘
- What us R_API

Ctags

CTags, RTags ...are command line tools that can be integrated with vim and other editors in order to autocomplete function names, signatures, find references, jump to type definition, etc.

- But I personally just use grep. In fact git grep.

$ ctags -R .

nnoremap <leader>. :CtrlPTag<cr>

Compiler basics

- No warnings allowed
  - Gcc is pretty good at it
- Good code practices
  - Give some recommendations

Data Structures

Data Structures in r2land

- Double Linked Lists (SdbList, RList)
  - Can be used as stacks and queues
- Hashtables (SdbHt, RHashtable)
- Vectors (Arrays of structs)
- OIDStorage - filedescriptors
- SDB - key=value database
- RBTree
- ...

RList

- double linked list
- can be used as a stack

Operations:

split, merge, sort, iterate and join

Example: RList

(tiny example here, that puts n strings in a rlist)

Exercise: RList

Modify example0:

- use r_list_newf instead of r_list_new
- use r_list_foreach instead of while-loop

Exercise: RList

extend previous exercise:

- sort the strings in alphabetical order
  - Use r_list_sort

Exercise: RList

modify previous exercise:

- iterate over list and remove elements from it, if their strlen is odd
  - use r_list_delete_iter and r_list_foreach_safe
- store elements with odd strlen in another list
  - Print that list too

Exercise: RList

modify previous exercise:

- create a free()-wrapper and use it via r_list_newf
  - print the string
  - free it

RQueue

Operations:

enqueue and dequeue

RStack

Operations:

push and pop

RHashTable / SdbHt

Sdb

SDB it is a simple key=value database that can only store strings and works in memory or disk.

It is used inside r2 in different places, but not everywhere, because it doesn’t fits for some use cases and the payload of strings processing and hashtable sometimes is too heavy and sometimes pays off.

- Accessible using the `k` command in r2.

What is stored in Sdb inside r2?

- Syscalls database
- Xrefs
- Metadata
- Headers information
- ROP gadgets
- Zignatures
- Analysis Hints
- Call Conventions
- ...

How to operate with a keyvalue database?

- Everything can be simplified to k=v
- Several data structures and encodings can be implemented on top of a string hashtable. Linked lists, binary containers, formatted structures, etc.
- Schema-free, initialization, translation must be handled by hand.
- Non-relational database, this must be done in code.
- Easy to map from disk to memory
- Requires duplication of data for multiple column lookups
- We can set a timeout on each key.
- See sdb.h

Why use it?

- It’s simple
- It’s fast
- Can be nested into namespace and inspectable from the shell at runtime
- Easy to dump and restore from disk
- Supports arrays, numbers, booleans and structs as string frontends.

RIDStorage

- RIDPool
  - counter
  - RQueue
- dynamic array

Operations:

add, set, get, delete, take and foreach

What is stored inside RIDStorage in r2?

Used to store RIODesc (filehandle):

```
R_API RIODesc* r_io_desc_get(RIO* io, int fd) {
        if (!io || !io->files) {
                return NULL;
        }
        return (RIODesc*) r_id_storage_get (io->files, fd);
}
```

Why use RIDStorage?

- Faster than SDB
- ids can be considered as safer pointers
  - also work for scripting

ROIDStorage

- RIDStorage
- counter
- dynamic array

Operations:

add, set, get, delete, take, insert, sort, find, to_rear, to_front, first, last and foreach

Exercise: ROIDStorage

Implement a sort callback, to sort the strings in alphabetical order

Strings

- Rstrbuf
- Rstr api
- ...

Other

- vectors
- Rbtree
- ...

RNum

RNum

Rax2

Do some base number conversions

Practice with rahash2 and rax2

- Convert from
- Encode in base64
-

ESIL

What is ESIL

- Intermediate language
- Intended for emulation and detailed analysis
  - Every code analysis is abstract emulation (halting problem)
- Extendable

How does ESIL work?

- Parser
- Operations
- Internal Vars

ESIL: Parser

Parser works like a pushdown automaton/stack machine

ESIL: Parser

Wikikpedia:

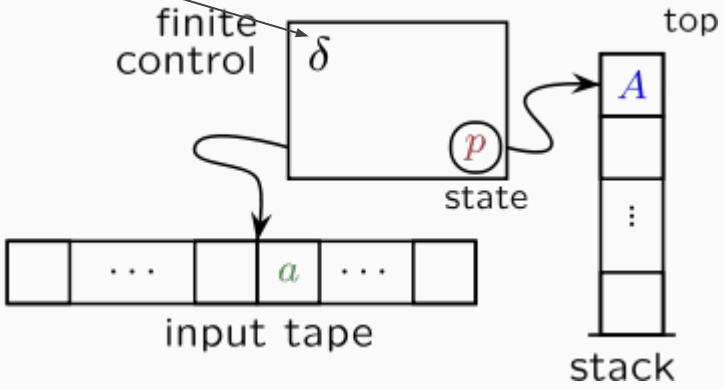
A PDA is formally defined as a 7-tuple:

$M = (Q, \Sigma, \Gamma, \delta, q_0, Z, F)$ where

- Q is a finite set of *states*
- Σ is a finite set which is called the *input alphabet*
- Γ is a finite set which is called the *stack alphabet*
- δ is a finite subset of $Q \times (\Sigma \cup \{\varepsilon\}) \times \Gamma \times Q \times \Gamma^*$, the *transition relation*
- $q_0 \in Q$ is the *start state*
- $Z \in \Gamma$ is the *initial stack symbol*
- $F \subseteq Q$ is the set of *accepting states*

How does ESIL work?

ESIL operations



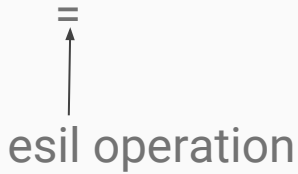
ESIL: Parser

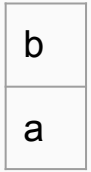
```
while not at end of esil_string {
        cur = get_next_element()
        If cur is esil_operation {
                op = get_esil_operation(cur)
                op ()
        } else {
                push (cur)
}}
```

ESIL: Parser

ESIL: Parser

ESIL: Parser





ESIL: Operations (just a few basic ones)

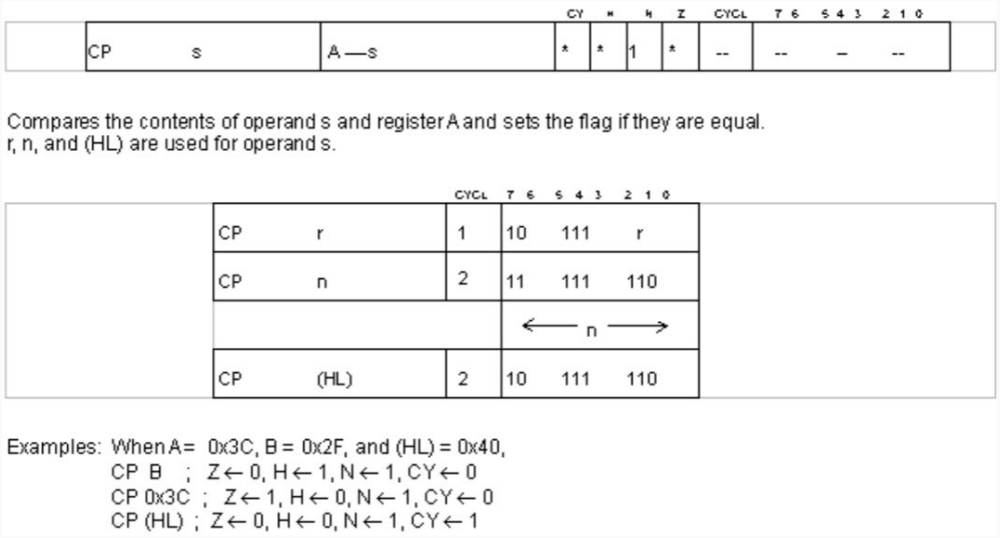
• =	• }{
• +	• &
• -	• |
• *	• ^
• /	• !
• ==	• <<
• []	• >>
• =[]	• GOTO
• ?{	• DUP
• }	• NUM

anal-plugins can and should add their own custom operations, if needed

ESIL: Internal vars

- $ is prefix for access
- calculate flags
- updated on every operation, that sets something (==)
    - comparing old and new value of the destination

ESIL: Internal vars



		CY	H	N	Z	CYCL	7 6	5 4 3	2 1 0
CP	s	A—s	*	*	1	*	--	--	–	--

Compares the contents of operand s and register A and sets the flag if they are equal.
r, n, and (HL) are used for operand s.

		CYCL	7 6	5 4 3	2 1 0
CP	r	1	10	111	r
CP	n	2	11	111	110
			← n →		
CP	(HL)	2	10	111	110

Examples: When A = 0x3C, B = 0x2F, and (HL) = 0x40,
CP B ; Z ← 0, H ← 1, N ← 1, CY ← 0
CP 0x3C ; Z ← 1, H ← 0, N ← 1, CY ← 0
CP (HL) ; Z ← 0, H ← 0, N ← 1, CY ← 1

cp b:
b,a,==,$z,Z,=,$b4,H,=,$b8,C,=,1,N,=

cp 0x3c:
60,a,==,$z,Z,=,$b4,H,=,$b8,C,=,1,N,=

cp [hl]:
hl,[1],a,==,$z,Z,=,$b4,H,=,$b8,C,=,1,N,=

Where it is used?

- Emulation
- Search

Testing ESIL expressions

Test for functionality, not strcmp

How to improve or fix

- Try not to add new operations to the starndart set of operations
  - If really needed, create custom operations for the plugin
- Modify the code generation of it

Register profiles

Bug Finding

Compiler Warnings

We should know that when a compiler spits a warning is because there’s something wrong.

- Maybe unexpected behaviour
- Or undefined values
- Integer overflows

Static source analysis tools

- Coverity
- Clang analyzer
- ...

Github issues

-

CVEs

-

Backporting bug fixes policies

- We only fix bug in master, no backporting
- People should be aware of that because distros never handle CVEs or patches properly.

- So we just go forward

Fuzzing

Watch a training about fuzzers

Bug Fixing

Understanding a crash

r2pipe

R2Pipe

R2pipe is the simplest interface to automate r2, this is, taking a command, running it and getting the results.

As a bonus, as long as many commands support JSON output it allows to get a parsed native object.

```
> import r2pipe

> r2 = r2pipe.open("/bin/ls")

> print(r2.cmd("?V"))
```

R2Pipe

There are many backends we can use with r2pipe, some of them are local, others remote, some requires native code to be executed, .. we should choose when we need some performance boost.

- Tcp
- Http
- Native
- Popen
- Socket File
- ...

EXERCISE

Write an r2pipe script and compare times of execution.

Extensibility and Plugins

Plugins

...

Scripts

...

#!pipe

...

Plugins in !C

Using C as scripting

The #!c command will compile as shared lib the given .c, load it in memory and run the constructor. This allows us to load code at runtime, which runs fast and requires no bindings.

Building code that links to r2

Using pkg-config

RIO

What does RIO do?

- abstraction for filehandling (malloc, zip, ptrace ...)
- remapping in virtual address-space
- 2 layers of caches
- masking

How IO works

Well, magic (out of scope for this training) :P

RIO

- fd api
  - no need to use desc api
  - see example
- highlevel api
  - In most cases you only need r_io_read_at

RAsm/RAnal

Writing disassembler/analysis plugins

Using pkg-config

Write an asm/anal plugin

What about using the Via C3 risc processor?

I think plugin for crvm should be fine for this

RBin

RBin

Packages

What is r2pm

A package manager that is shipped with radare2.

Uses git and shellscript files to define the packages

- Handle dependencies
- Installs in home by default
- Focus on ease of use
- Most packages are r2 plugins

Making it available in r2pm

Future

- There’s a WIP re-implementation in Go
- We can’t depend on posix shell for the packages if we aim to be portable and dependency-free.
  - For windows
-

Questions