RE-Learning w/R2

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Who Am I?

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- Mobile Security Research Engineer at NowSecure
- Author and leader of the Radare project
- Free Software enthusiast and developer

Target Audience

- Newcomers to the Low Level Reigns
- Commandline cowboys
- Malware analysts
- Unix Enthusiasts

Poll

First of all, let’s understand better the audience:

- Do you know and use **radare2**?
- Can you read **assembly**?
- What about **Reverse** Engineering?
- Toolkit overview

Contents

Disclaimer

Take these slides as a reference!

- **Focus on practical examples**
- Get yourself fluent and **comfortable** in the shell

What's radare2

—

The

Libre Software

Reversing Framework

History

Back in 2006..

- I was a forensic analyst
    - And had to recover some deleted files from a mac
    - I was not allowed to use company software
- So I wrote my own thing
    - A portable unix-centric hexeditor for 64bit seeks
- 18 years after that it’s still kicking

In short

Libre RE Framework with **UNIX** philosophy in mind.

- Purely written in **C**, portability and control matters
  - Very extensible through plugins and scripts
- Added disassembler, binary parser, analyser
  - Debugger, Emulator, Scripting, GUI
- One-man project most of its lifetime

Installation

- Always from git or latest release.

```
$ git clone https://github.com/radareorg/radare2
$ radare2/sys/install.sh
```

https://rada.re

Iaito

The official GUI (but there are more)

- Runs on BSD, Haiku, Linux, macOS, Windows

Check the release page or use flatpak

https://github.com/radareorg/iaito

Exercise

Get your workshop environment ready!

- **Install radare2 from git**

Introduction To The Shell

- The Magic Of The Commandline

Commandline

Main way to interact with **radare2** is through the **shell**

- Basic posix shell commands (`ls`, `cd`, `rm`, `cat`, ..)

- Learning the commands and syntax matters!
- Subcommands just add a letter after the root one
- Useful for **scripting** and automation
- Doing things faster than using the mouse

Basic Commands

s = seek (s 0x/s..)	**a** = analysis
p = print (px / pd)	**V** = visual/panels
f = flags	**e** = eval config
i = info	**?** = help/math
w = write	**!** = system shell
q = quit	**d** = debugger

Command Operators

| = redirect to process (like in posix shell)

> = redirect to file (`$file` are internal)

~ = internal grep (indent json, xml, code, filter words)

# = comment

; = command separator

? = show command help

Command Suffixes

- `?` = help message
- `j` = json
- `*` = r2 commands
- `q` = quiet
- `,` = comma separated values
- `k` = key-value

Command Prefixes

- (`number`) = repeat a command N times
- `‘` = single quote, to avoid parsing special characters
- `?t` = calculate execution time
- `:` = io command
- `` ` ` `` = replace command output inline
- `.` = run script

Iterator Operator

Useful to run commands in different items

- Functions, flags, registers, symbols, basic blocks, ..

- `@` - temporal seek
- `@@` - repeat command on different places
- `@@@` - advanced repeat actions

See `@?` `@@?` `@@@?` for help

Useful Commands

Combine and learn new commands every day!

- Recursive Help: `?*`
- JSON indent (json path queries like jq): `~{}`
- HUD filtering: `~…`
- Analyse all symbols: `af @@ sym*`
- Set, list flags: `f`
- Comments: `CC`

Commandline Exercise

- Open a file (`/bin/ls` ;D)
- Dump bytes and disassemble
- Seek to different addresses
- Analyze code / list and count functions
- Use tab to autocomplete flags
- Enter visual mode

IO

- The lowest layer in r2, where everything becomes a file.

IO Plugins

List of uri handlers exposed by the IO plugins:

```
$ r2 -L
```

You can find more plugins if you need them

```
$ r2pm -s …
```

IO Primitives

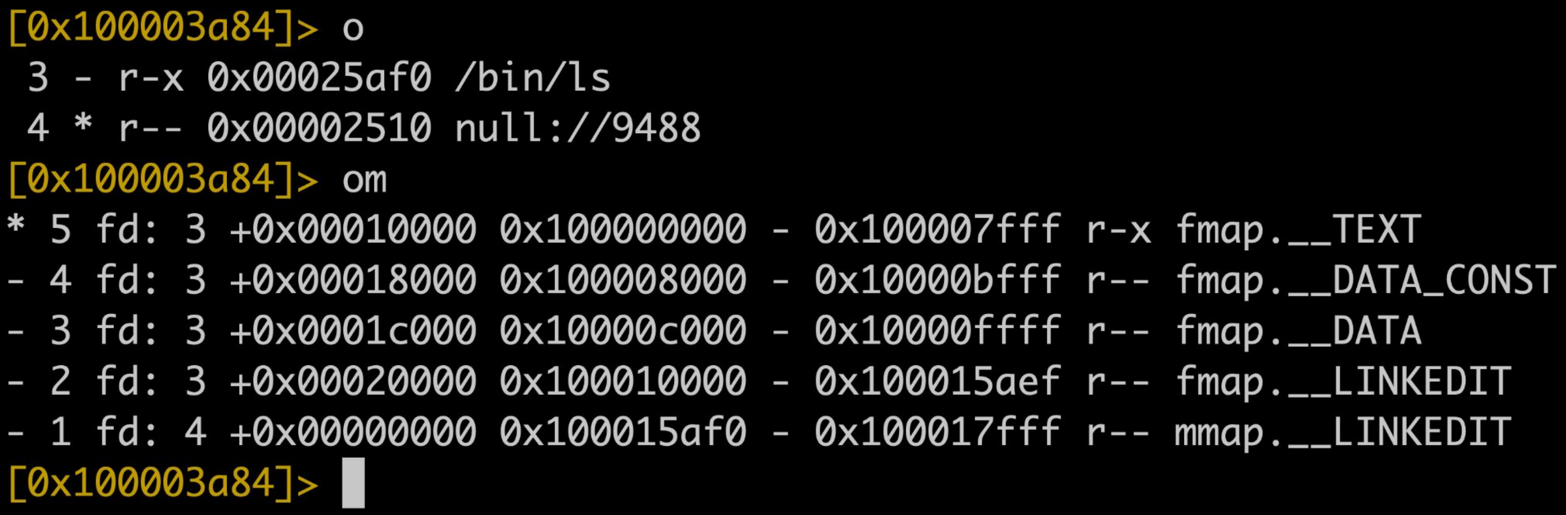
Those plugins provide the following callbacks

- Open/close = handle uri `://` to select plugin
- Seek = used to move around, 64 bit offsets, getsize
- Read/write = basic IO operations
- System = run a command return string with result

Maps and File Desriptors

Use **o** and **om** commands to list files and their maps

- Necessary to configure the memory layout



```
[0x100003a84]> o
 3 - r-x 0x00025af0 /bin/ls
 4 * r-- 0x00002510 null://9488
[0x100003a84]> om
* 5 fd: 3 +0x00010000 0x100000000 - 0x100007fff r-x fmap.__TEXT
- 4 fd: 3 +0x00018000 0x100008000 - 0x10000bfff r-- fmap.__DATA_CONST
- 3 fd: 3 +0x0001c000 0x10000c000 - 0x10000ffff r-- fmap.__DATA
- 2 fd: 3 +0x00020000 0x100010000 - 0x100015aef r-- fmap.__LINKEDIT
- 1 fd: 4 +0x00000000 0x100015af0 - 0x100017fff r-- mmap.__LINKEDIT
[0x100003a84]>
```

Run IO Commands

IO Plugins expose a callback to run commands through the `:` prefix from the core shell.

- Used to expose custom functionality
  - Filesystems
  - Debugger
  - Binary parsing
  - ..

Searching Patterns

The / command is used to search stuff

- / - text
- /x - byte patterns (with binary mask?)
- /a - assembly code
- /c - cryptographic materials
- /m - magic headers
- /z - find strings

Exercise

Create your custom configuration file in your home!

- `r2 -H R2_RCFILE`
- Select a theme with `eco`
- Change `scr.` and `asm.` options

Structured Binary Data

Files with Executable Code Structured with Headers and Metadata

Binary Formats

The list of file formats supported is very large:

```
$ rabin2 -L
```

- ELF, MACHO, PE, COFF, NE
- DYLDCACHE, KERNELCACHE
- CLASS,DEX,LUA,PYC
- GB, NES, 3DS, SMS, SMD, XBE, Z64, NSO
- ..

Parsing Headers

Executables and libraries store information needed by the operating system to load and execute them.

- Sections and segments
- Symbols, imports and exports
- Entrypoints, constructors / destructors
- Strings, Libraries / Dependencies

```
$ rabin2 -H (ih)
```

Libraries

On linux we use to run `ldd` to see which libraries a program is using.

In r2 we can use `il`, which is portable and doesn't have code execution risks.

Sections vs Segments

Rabin2 unifies the concepts for simplicity. Other tools just have different names and commands for each file format.

`iS` vs `iSS`

- Sections are only needed for static analysis tools
- Segments is what the runtime linker needs.
- Check with `*` and `om`.

Strings

Plain text stored in the read-only sections of the binary

- Sometimes compilers put code in rw sections
- Eventually they are inside unmapped headers
- Sometimes the text is generated with code
- Or maybe it is encoded (base64, rot13, ..)

```
$ rabin2 -z /bin/ls
```

Exporting binary data as script

Using the `-r` flag to create an r2 script

- This works across all tools in r2land
- Under the r2 commands use the `*` suffix

Commands inside r2

R2 is the tool that unifies all the other tools.

- R2 uses RCore which links against RBin, RArch,..

The rabin2 functionalities are implemented under the `i` command.

```
$ rabin2 -z == iz, -zz = izz, …
```

- Check the shell

Decoding Instructions

- Analyzing program code, control flow graphs, string references, ..

Decoding

Different representations of the same

- Zeros and Ones (Machine Code)
- Bytes in Hexadecimal (octal was more readable)
- Plaintext Assembly
- Pseudo Disassembly
- Intermediate Representation (ESIL for r2)

Supported Architectures

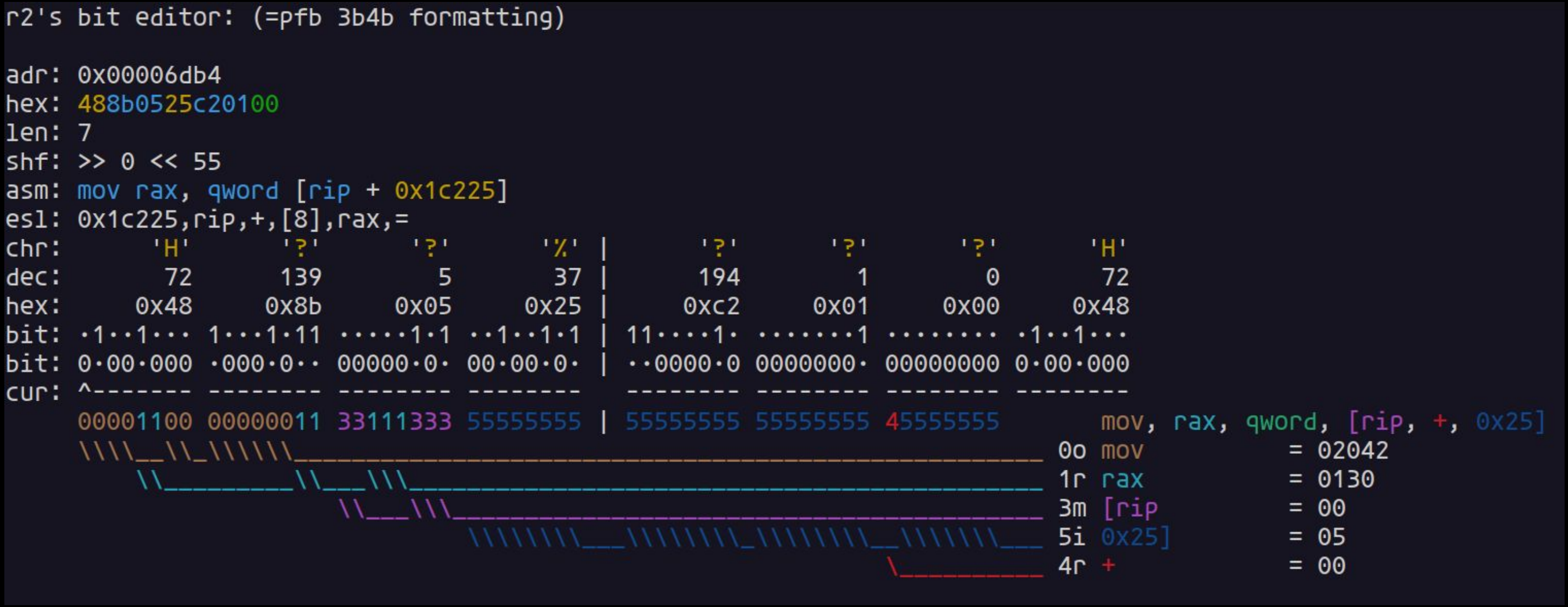
```
$ rasm2 -L
```

Note that arch plugins can optionally provide

- ESIL representation for emulation
- Encoding (assembler) support
- Different CPU models

Visual Instruction Decoding

- Vd1



```
r2's bit editor: (=pfb 3b4b formatting)

adr: 0x00006db4
hex: 488b0525c20100
len: 7
shf: >> 0 << 55
asm: mov rax, qword [rip + 0x1c225]
esl: 0x1c225,rip,+,[8],rax,=
chr:      'H'      '?'      '?'      '%' |      '?'      '?'      '?'      'H'
dec:       72      139        5       37 |      194        1        0       72
hex:     0x48     0x8b     0x05     0x25 |     0xc2     0x01     0x00     0x48
bit: ·1··1··· 1···1·11 ·····1·1 ··1··1·1 | 11····1· ·······1 ········ ·1··1···
bit: 0·00·000 ·000·0·· 00000·0· 00·00·0· | ··0000·0 0000000· 00000000 0·00·000
cur: ^------- -------- -------- --------   -------- -------- -------- --------
     00001100 00000011 33111333 55555555 | 55555555 55555555 45555555       mov, rax, qword, [rip, +, 0x25]
     \\\\__\\_\\\\\\____________________________________________________ 0o mov          = 02042
         \\_________\\___\\\____________________________________________ 1r rax          = 0130
                       \\___\\\_________________________________________ 3m [rip         = 00
                                \\\\\\\\___\\\\\\\\_\\\\\\\\__\\\\\\\___ 5i 0x25]        = 05
                                                             \__________ 4r +            = 00
```

ESIL

Evaluable Strings Intermediate Language

- Designed by and for radare2
- Like FORTH, but using commas instead of spaces
- Expresses the instruction behaviour
- Simple to parse, fast to execute

```
mov eax, 33 => 33,eax,:=
```

Disassembler Options

```
> e asm.
```

Enable emulation for computed references

- asm.describe
- asm.emu/emu.str

Graphs

Control Flow Graph, gives use a good overview of the function logic.

- `agf`

Formats: ascii art, graphviz, mermaid, ..

Exercise

- Open /bin/sleep with `-n` and `-w`
- Use `o` and `om` to see the differences
- Patch the entrypoint with a ret
    - Advanced: modify the default behaviour
- radiff2 to understand the patch we did
- Execute the patched program

Uplifting To High Level Languages

- Retrieving a high level representation of the underlying assembly code

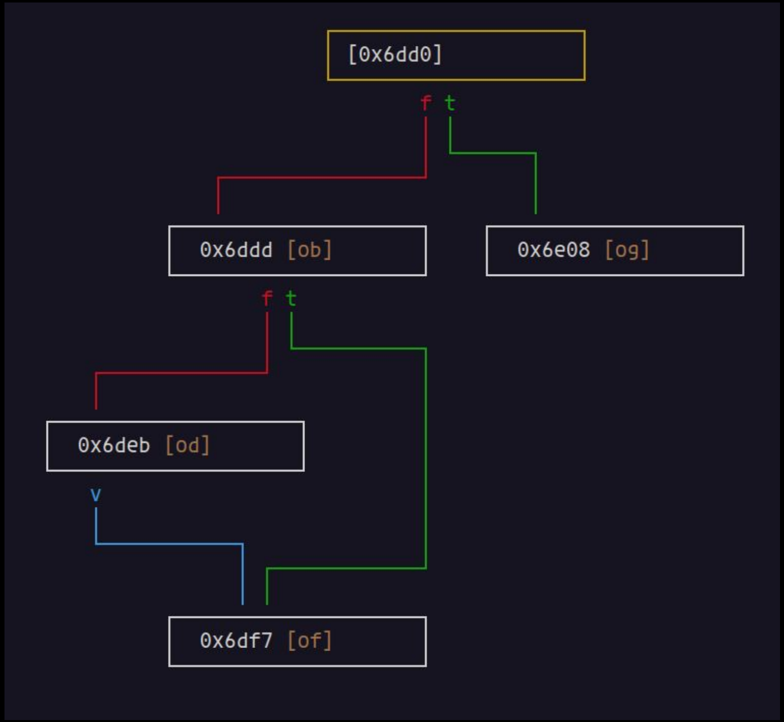
Analysis

`r2 -A = aa / r2 -AA = aaa`

- Functions / BB / Ops
  - **`afl, afb, ao`**
- Different analysis: **`aa?`**
- Options: **`e anal.`**

Use them wisely

- Default is not always the best



Decompilation

The art of creating high level representations of the assembly code, aka, the inverse step of compilation.

- Assumptions to fill the gaps with the info we miss

Pseudo Decompilation with pdc

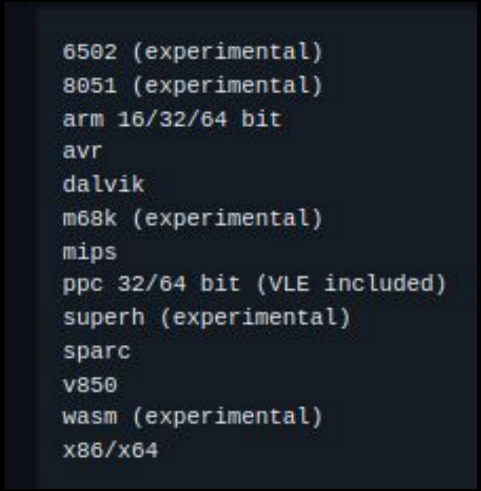
Native to r2, works on all archs

- Enables `asm.pseudo`
- Prints each basic block with labels and gotos
- Uses ESIL to reference ALL strings
- Very verbose, but useful when others fail
- Very fast, perfect for grepping around

r2dec

Decompiler for r2 written in Javascript

- Quite correct, few optimization passes
- Supports most common archs
- Actively maintained and developed
- Available in the **pdd** command
- By @wargio/deroad



```
6502 (experimental)
8051 (experimental)
arm 16/32/64 bit
avr
dalvik
m68k (experimental)
mips
ppc 32/64 bit (VLE included)
superh (experimental)
sparc
v850
wasm (experimental)
x86/x64
```

r2ghidra

Native plugin linking to the ghidra-native fork of ghidra’s decompiler (only c++ code, no java).

- Not aligned with r2 analysis
- Good results sometimes, but misses lot of info
- Looking for maintainers

decai

Decompiler based on R2AI:

- Takes N decompilations as input
- Generates better output combining them
- Guess variable names and arguments
- Best local: granite, mistral and llama
- Best remote: Claude

Exercise

- Install r2dec, r2ghidra, decai
- Try them on different functions of different binaries
- Understand the differences

Debugging And Tracing

- Manipulating program execution at runtime

Low Level Debugging

R2 is a tool for reversing, not for developers

- No plan to replace gdb/lldb
- It’s not a source debugger.

But it’s great when you don’t have the source

- Easy to script and automate

```
$ r2 -d [program|pid]
```

Backends

The native backend works on all major platforms!

- Linux, macOS, iOS, Android, Windows, *BSD, !!

But sometimes we need to do remote debugging

- Over TCP / JTAG, use the gdb:// protocol

Windbg / gdbio / qemu / bochs support..

Registers

Showing and changing register values

```
> dr, dr=, dr 32, dr rax
```

- Telescoping with `drr`

We can also telescope memory with `pxr@r:SP`

- Register profiles with **`drp`**

Breakpoints

Use the **db** command for that..

No need to use a temporal breakpoint. You can continue until address with dcu

With some archs sometimes you may need to use:

- `e dbg.hwbp`

Memory Maps

At runtime, the address space is not fully mapped

- Use **`dm`** and **`dmm`** to understand the layout

Identify regions by permissions and name

- Where’s the stack, inspect it with **`pxr`**

Heap Structures

Heap memory is structured in a way that can be parsed and detect corruptions, which is useful for analyzing and exploiting buffer overflow vulnerabilities.

- Check the `dmh` command

Exercise

Start debugging a program, change control flow by changing the program counter.

- Manipulate register values: `dr`, `dr=`
- Identify location with maps: `dm`
- Continue execution: `db`, `db-*`, `ds`, `dc`

Scripting

Automate actions,
Solve boring tasks
Quickly

The Basics

We know how to use the shell.

- `r2 -i` or the `.` command.

What about running a command and capturing the output displayed in return?

- That’s called r2pipe

We can also use bindings to the native API (rlang)

Supported Languages

For r2pipe you can literally use ANY language

- Python, JavaScript, Ruby, Nim, Scheme, ...

Even native!

- C, Vala, Rust, Swift, Zig, D, ...

Why Javascript

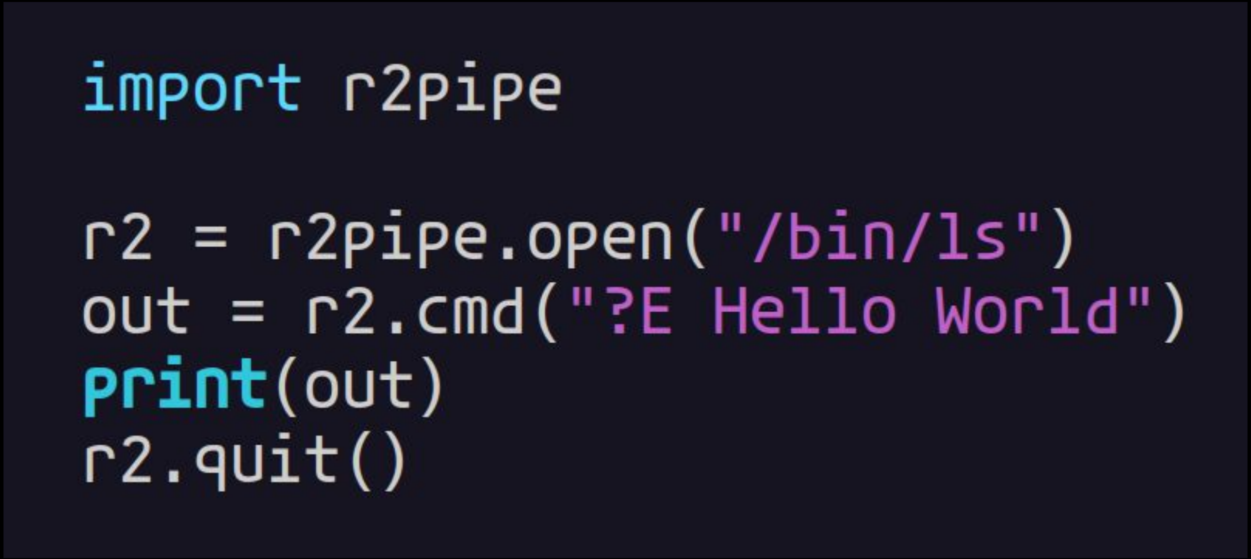
Is the only scripting language that is widely available, uses no setjmp and it’s very easy to use and many languages have it as a target for transpilation.

- Nim, TypeScript, V, Scala, Dart, LUA, Scheme,...

We ship quickjs, scripts must be named `.r2.js`

R2Pipe

Example using the basic r2pipe api



```python
import r2pipe

r2 = r2pipe.open("/bin/ls")
out = r2.cmd("?E Hello World")
print(out)
r2.quit()
```

R2Pipe Backends

R2Pipe can be used in different environments:

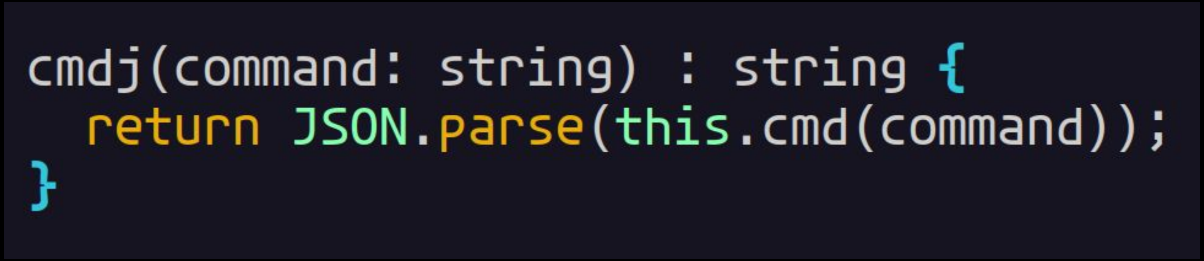
- Spawn + pipes
- Spawn + stdio
- Fork current session + pipes (#!pipe)
- Talking to an HTTP websever /cmd
- Dlopen RCore API

R2Pipe JSON (cmdj)

Appending `j` to any command in r2 shows JSON.

Using the `cmdj` methods returns an object.

We can autogenerate object schemas and have autocompletion in our favourite editor!



```
cmdj(command: string) : string {
  return JSON.parse(this.cmd(command));
}
```

R2Pipe cmd vs call

Running a command implies too much internal work sometimes that we can bypass with .call()

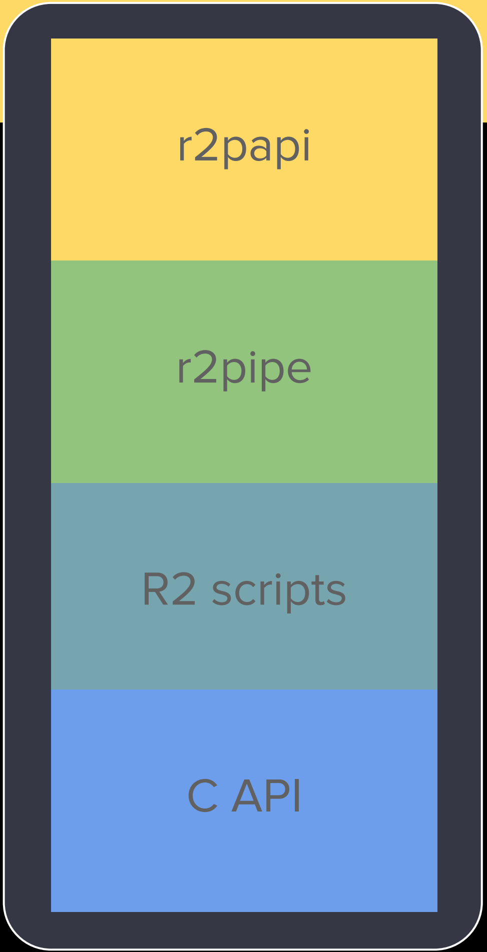
- Don't parse special characters
- Avoid command injection
- Support temporal seek .callAt()
- Faster execution for large scripts

Performance

Who said speed?

Sometimes we don’t need the output

- Use `cmd0` or `call0` commands



R2Pipe2

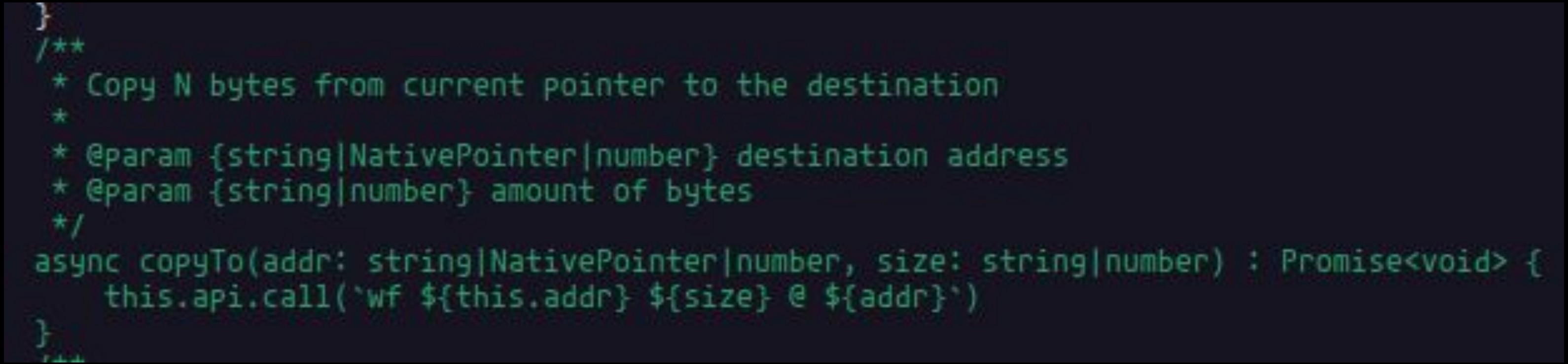
Introduced in r2-5.9.x, still under development and not fully handled; needs more testing, feedback and contributions.

- Protocol is there
- Fully compatible with r2pipe
- Uses the `{` command from r2
- Captures stderr and return code and value

R2Papi

What about having an idiomatic and high level API on top of the r2pipe primitive?

- Similar to the Frida API (NativePointer, ..)



```
}
/**
 * Copy N bytes from current pointer to the destination
 *
 * @param {string|NativePointer|number} destination address
 * @param {string|number} amount of bytes
 */
async copyTo(addr: string|NativePointer|number, size: string|number) : Promise<void> {
    this.api.call(`wf ${this.addr} ${size} @ ${addr}`)
}
/**
```

r2skel

This project is a collection of template source codes in different languages for starting new plugins or scripts for radare2.

```
$ r2pm -ci r2skel
$ r2pm -r r2skel ..
```

Exercise

Install r2skel and write a core plugin in your language of choice to add a new command in the r2 shell.

Choose wisely!

- `C, Python, R2JS`

Plugins

- r2pm, installing plugins to extend the capabilities.

Extensibility

We are about to reach the end of this talk, but we won’t be over without having a look at all the awesome tools that can be integrated!

- Use r2pm to search and install them!

r2frida

The best way to combine dynamic instrumentation with static analysis, a powerful shell on top of the tracing capabilities of Frida.

```
$ r2 frida://0
```

r2ida

Export comments and function details from IDA to r2

- Get an r2 shell inside IDA
- Looking for contributors!
- Who uses IDA?

NOTE: r2ForGhidra

r2yara

Useful for crypto constant and malware analysis

- Create Rules with patterns
  - Integrated with r2 analysis and metadata
- Load them into memory
- Scan for patterns in memory or file

radius2

Symbolic Execution Solver (in Rust) on top of ESIL.

- Remake of esilsolver (z3py)
- Can resolve conditions that must be matched to reach a specific address
- Resolve passwords from crackmes, ..

r2poke

GNU/POKE is a programming language for describing binary files. Exposes a shell with powerful scripting capabilities.

- Integrates well with radare2
- Can run r2 commands from POKE
- Run POKE expressions in the R2 shell

r2angr

Integrate Angr decompiler with radare2

- Looking for contributors and better integration
- A bit slow the first run needs to analyze the whole binary

r2ai

Integrating language model capabilities within r2.

- Supports local ones with llama
- Remote OpenAI / Anthropic / Gemini / …

I’ll be speaking tomorrow about it!

r2sarif

The standard file format to exchange findings from different source and binary analysis tools.

- Uses JSON format
- Well structured and extensible
- Inspect vulnerabilities found by other tools

r2diaphora

A fork of the Diaphora tool from Joxean for IDA, but maintained to work with radare2.

- Designed to work on scale
- Battle tested on fuzzed and malware binaries
- Looking for contributors!
- No SQLITE backend
- Needs a GUI

Exercise

Choose your favourite plugins and install them!

```
$ r2pm -ci r2ghidra r2dec r2yara r2svd
```

Continue Learning

- Reference Books, Chats, Blogs, Videos, Conferences

Crackmes vs Projects

Do you have a project in mind?

- **Go for it!**

If you are used to other tools, make them play well with r2. It's easy and gives you lots of capabilities

Source

As I use to say, the best documentation is the source!

- Read as much code as you can, and when you are tired write more or refactor it!
- Coding plugins for r2, programming tools on top of it, or adding new commands are great ways to learn more about r2
- Fix bugs, add tests, open tickets!

r2book

Yep!

We have an official book and it’s opensource

`https://github.com/radareorg/radare2-book`

Feel free to contribute and make it better!

- It’s also available as an r2 plugin

Chats!

Join our Discord, Telegram or Matrix chats!

- We have pancakes .. i mean cookies!

The Fediverse!

Follow **`@radareorg@infosec.exchange`**

(And if you're still not in the fediverse, it's never too late!)

Exercise: Attend r2con!

Our periodic conference where r2 users, developers and hackers around the world meet in person!

- Barcelona, November 8th-9th
- Online Sunday 10th

But will be streamed and recorded!

`https://rada.re/con`

Questions?