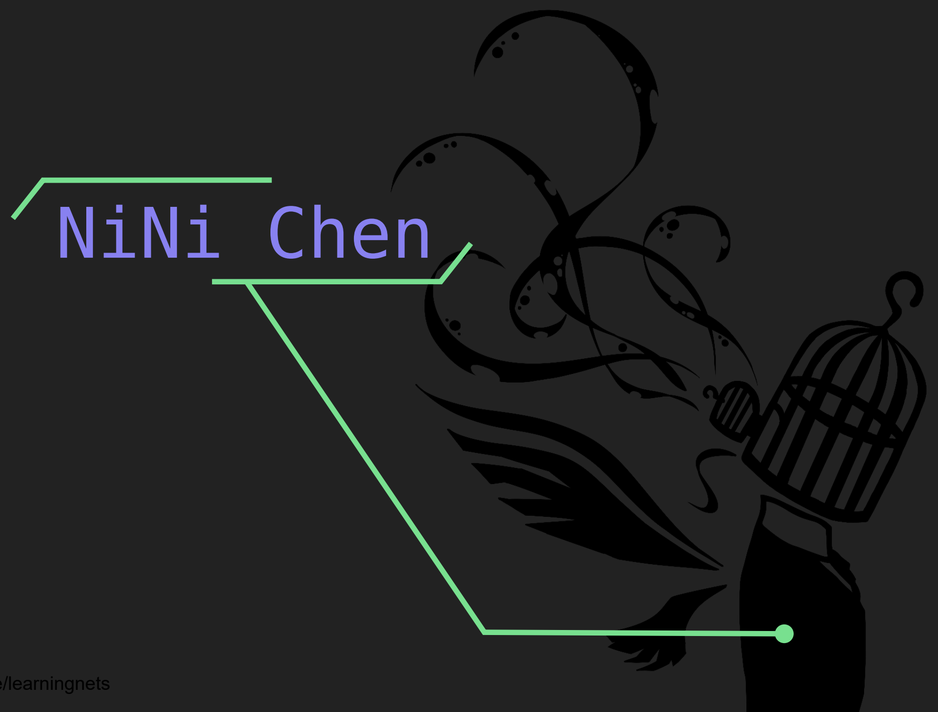
A Comprehensive Review on the Less-Traveled Road

9 Years of Overlooked MikroTik Pre-Auth RCE

NiNi Chen



NiNi Chen

- Security researcher at DEVCORE
- Member of Balsn CTF Team
- Member of UNDEFINED

 @terrynini38514

 https://blog.terrynini.tw

 nini@undefined.zip

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Why?

Target	Vector	Cash Prize	Master of Pwn Points
TP-Link AX1800 WiFi 6 Router (Archer AX21)	WAN Side	$20,000 (USD)	2
	LAN Side	$5,000 (USD)	1
NETGEAR Nighthawk WiFi6 Router (RAX30 AX2400)	WAN Side	$20,000 (USD)	2
	LAN Side	$5,000 (USD)	1
Synology RT6600ax	WAN Side	$20,000 (USD)	2
	LAN Side	$5,000 (USD)	1
Cisco Integrated Service Router C921-4P	WAN Side	$30,000 (USD)	3
	LAN Side	$15,000 (USD)	2
Mikrotik RouterBoard RB2011UiAS-IN	WAN Side	$30,000 (USD)	3
	LAN Side	$15,000 (USD)	2
Ubiquiti Networks EdgeRouter X SFP	WAN Side	$30,000 (USD)	3
	LAN Side	$15,000 (USD)	2

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Why?

Target		Point
Initial Stage	Final Stage	
TP-Link AX1800 WiFi 6 Router	Meta Portal Go	10
NETGEAR Nighthawk WiFi6 Router	Amazon Echo Show 15	
Synology RT6600ax	Google Nest Max	
Cisco Integrated Service Router C921-4P	Sonos One Speaker	
Mikrotik RouterBoard RB2011UiAS-IN	Apple HomePod mini	
Ubiquiti Networks EdgeRouter X SFP	Amazon Echo Studio	
	HP Color LaserJet Pro M479fdw	
	Lexmark MC3224i	
	Canon imageCLASS MF743Cdw	
	Synology DiskStation DS920+	
	My Cloud Pro Series PR4100 from WD	

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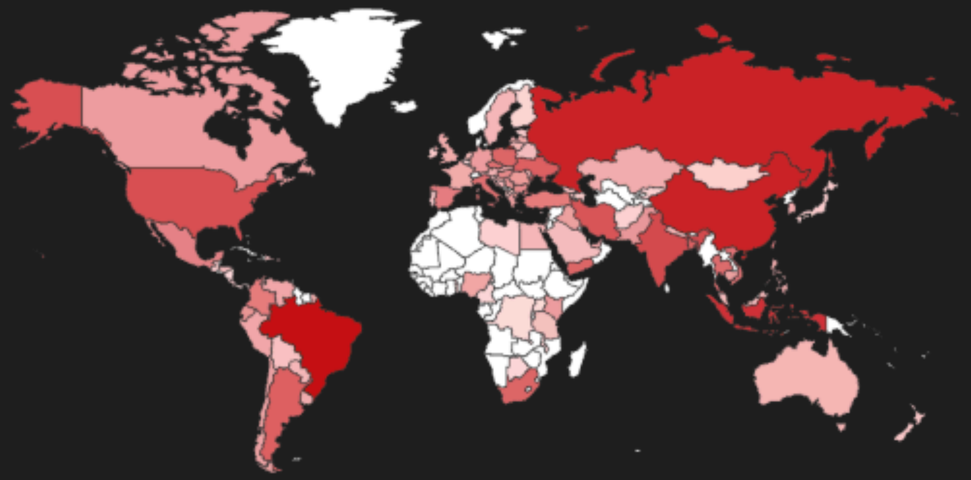
RouterOS

TOTAL RESULTS

3,032,059

TOP COUNTRIES



2023/07/03 - https://www.shodan.io/search?query=MikroTik

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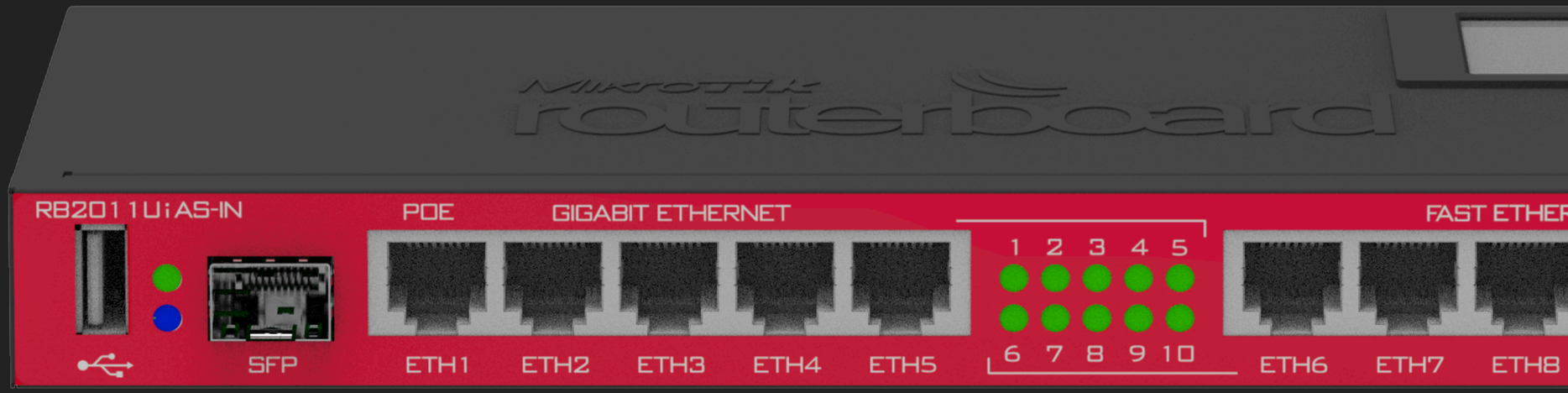
RouterOS

- A stand-alone operating system based on the Linux kernel
- Also available for virtual machines to turn a PC into a router



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RouterOS

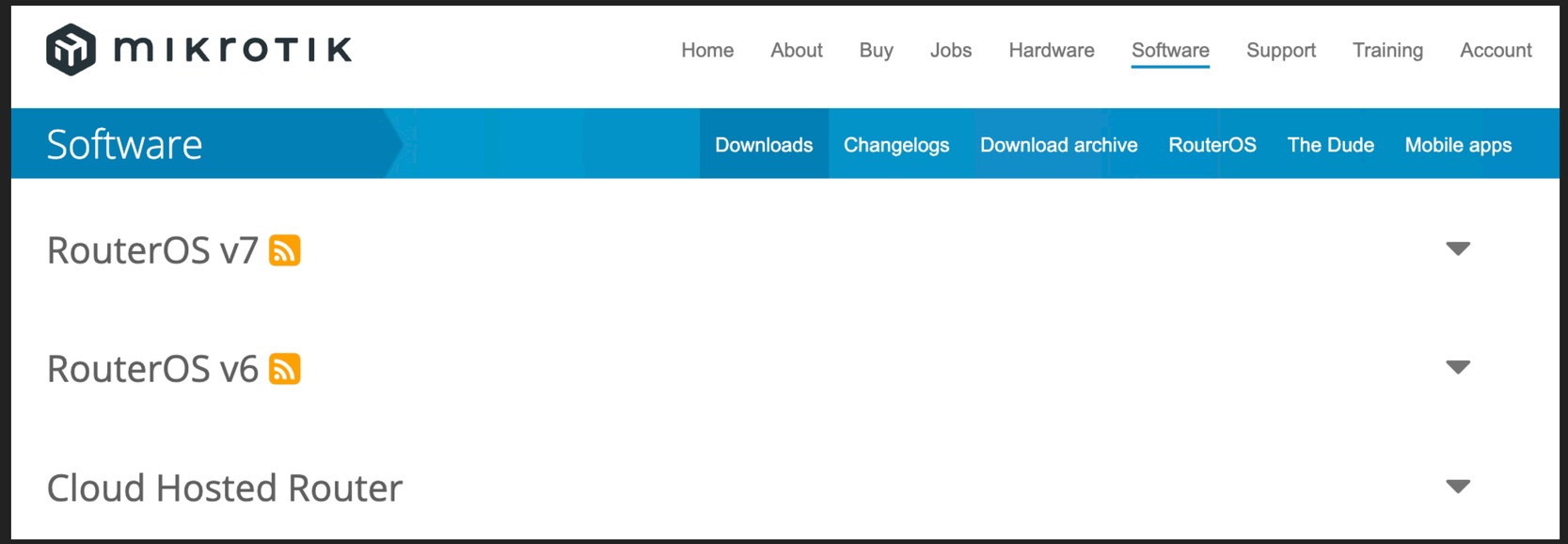
- A stand-alone operating system based on the Linux kernel
- Also available for virtual machines to turn a PC into a router
- Closed source and also a closed ecosystem.
  (It is said that you can get GPL sources used in RouterOS if you ask them)

> To get a CD with the corresponding source code for the GPL-covered programs in this distribution, wire transfer $45 to MikroTikls SIA, Ūnijas iela 2, Riga, LV-1039, Latvia. Please contact MikroTikls SIA for our current account information and wire transfer instructions. Offer valid for three years from the date of distribution of this software. This CD will only include the source code of the following programs and any non-proprietary programs distributed according to license requirements. This CD will not include MikroTikls proprietary SOFTWARE.

https://mikrotik.com/downloadterms.html

RouterOS

- RouterOS v6 and RouterOS v7 can be considered two different branches
- CHR is the RouterOS image for VM, x86_64 only



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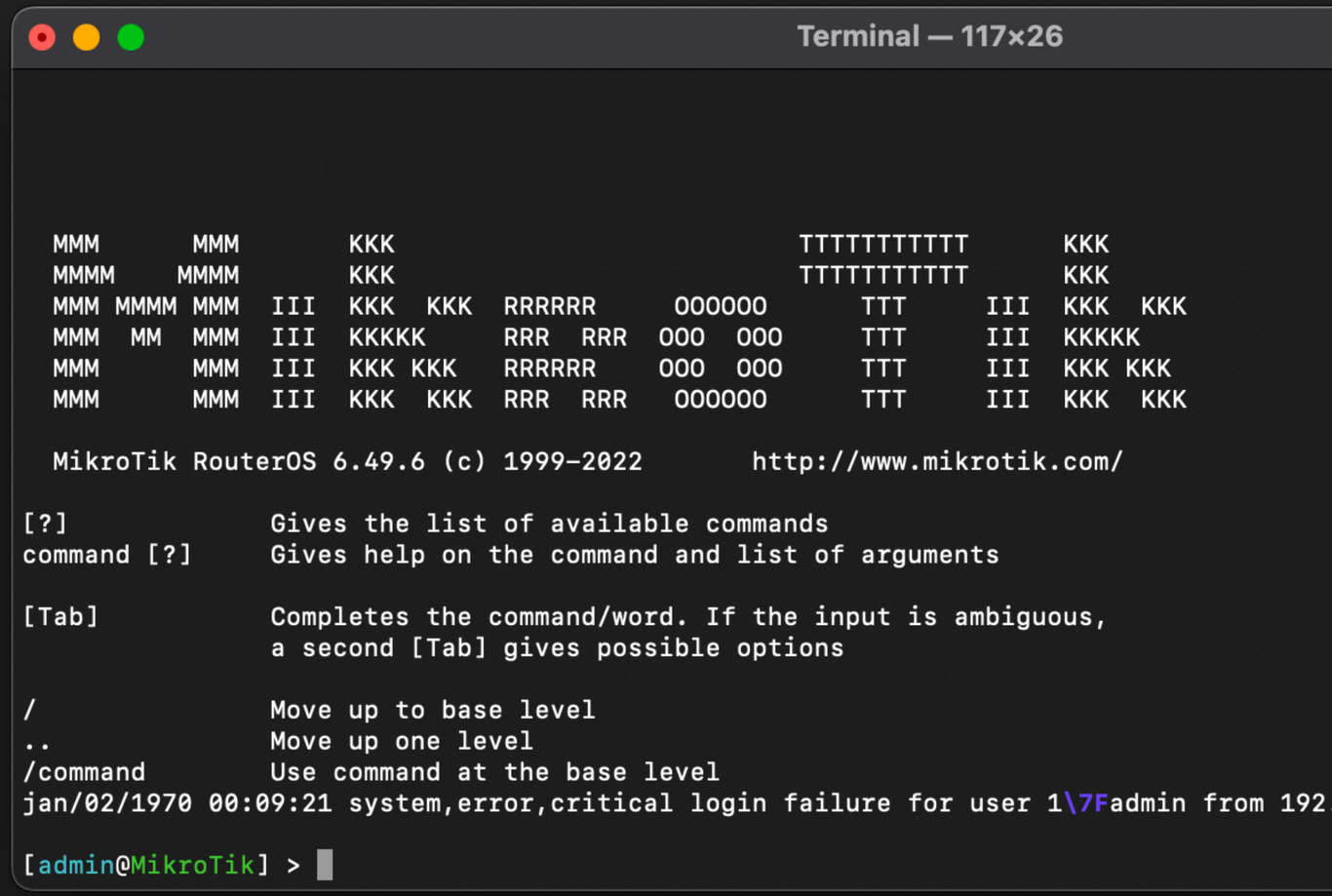
RouterOS

- Most binaries are “Nova binary”
- No official method to access the linux system.



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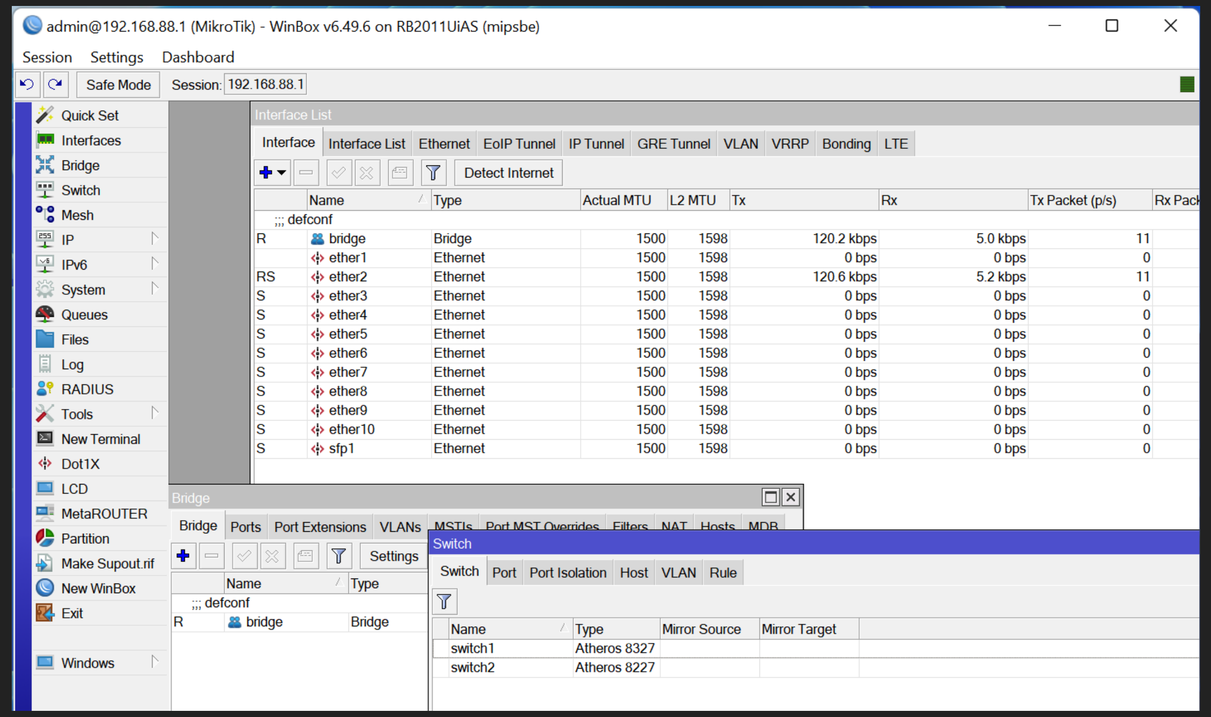
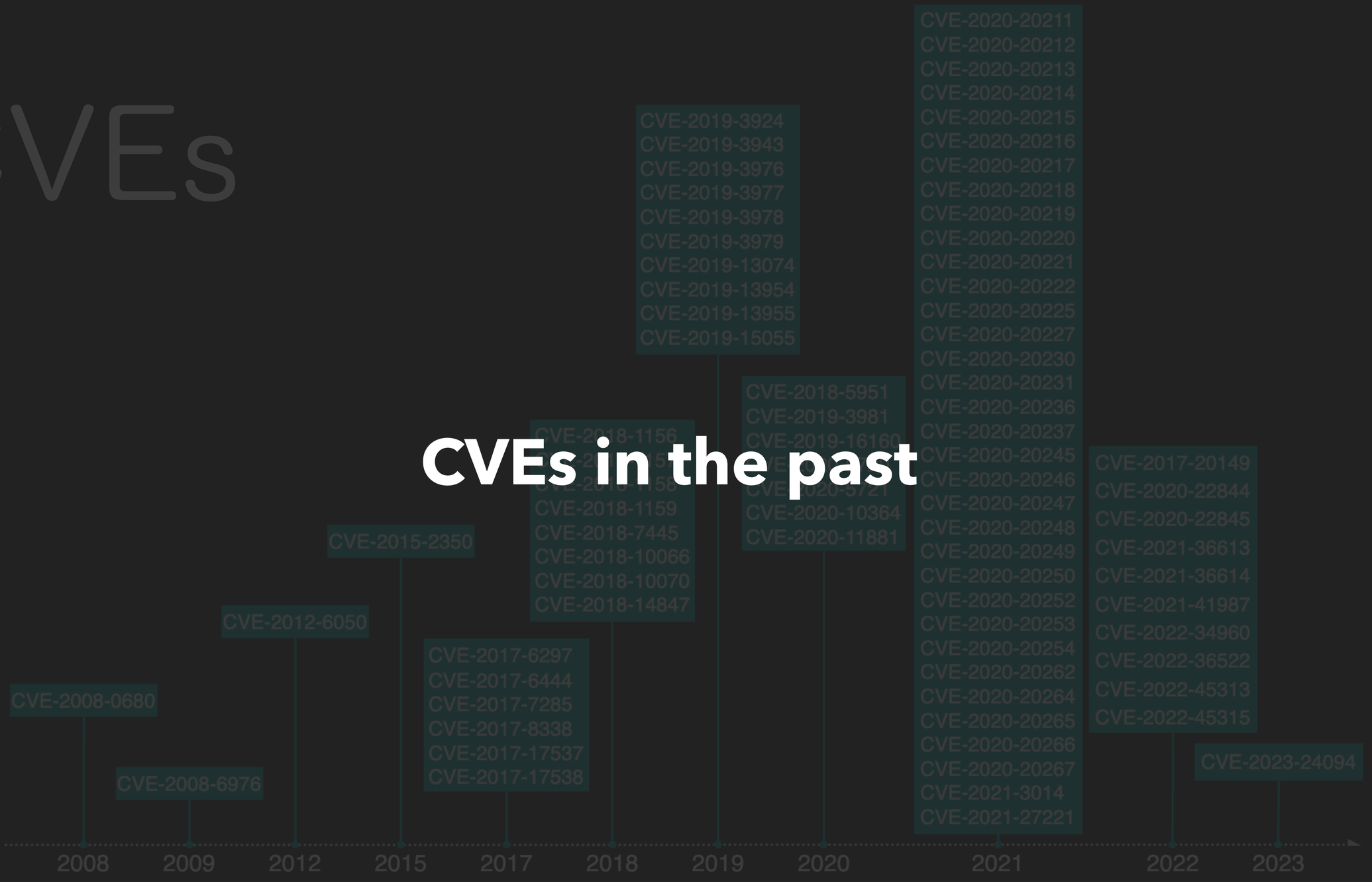
Winbox

- Winbox is a native Win32 GUI binary used for managing and configuring MikroTik routers on Windows.



CVEs



CVEs in the past

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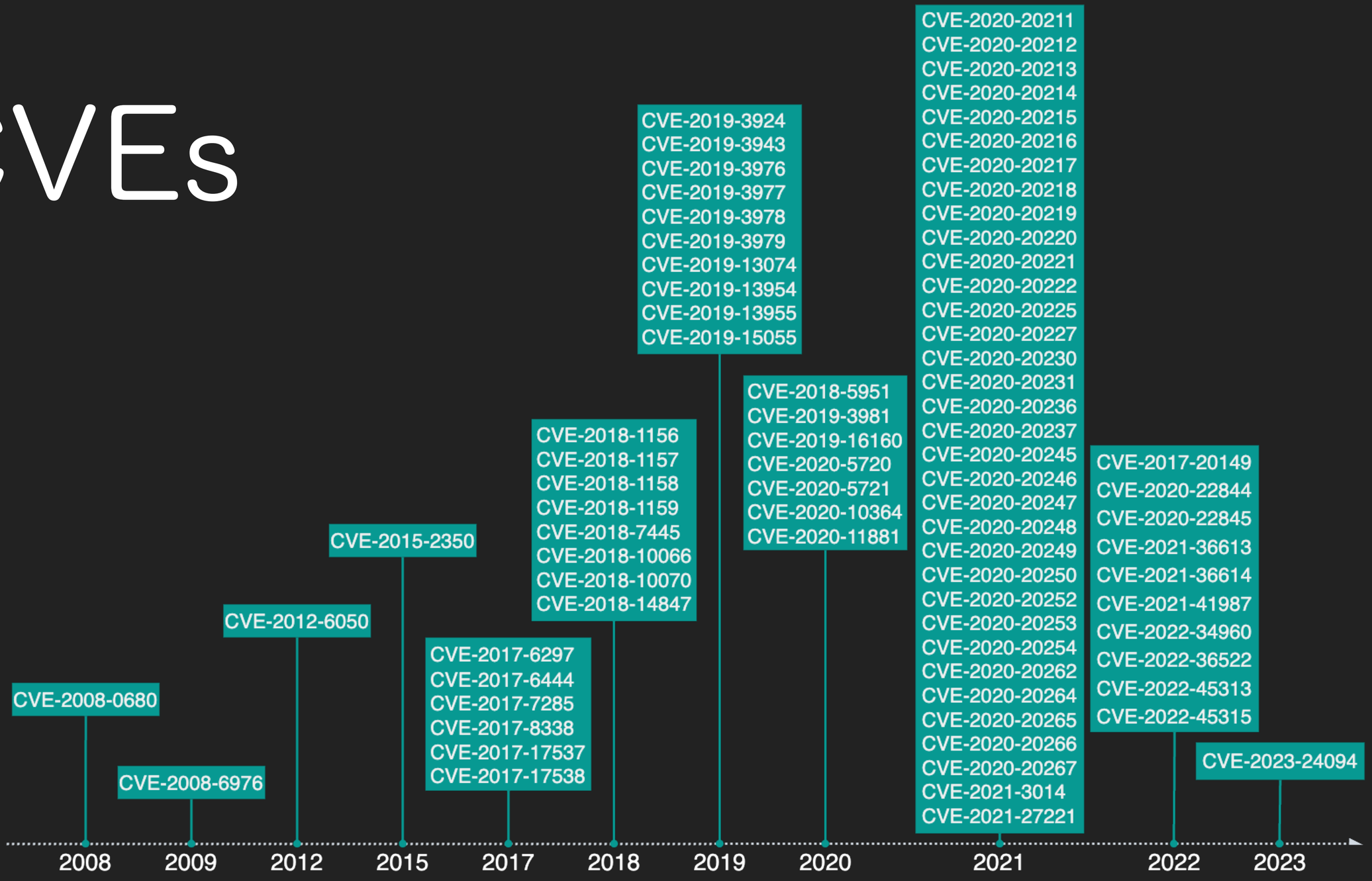
CVEs



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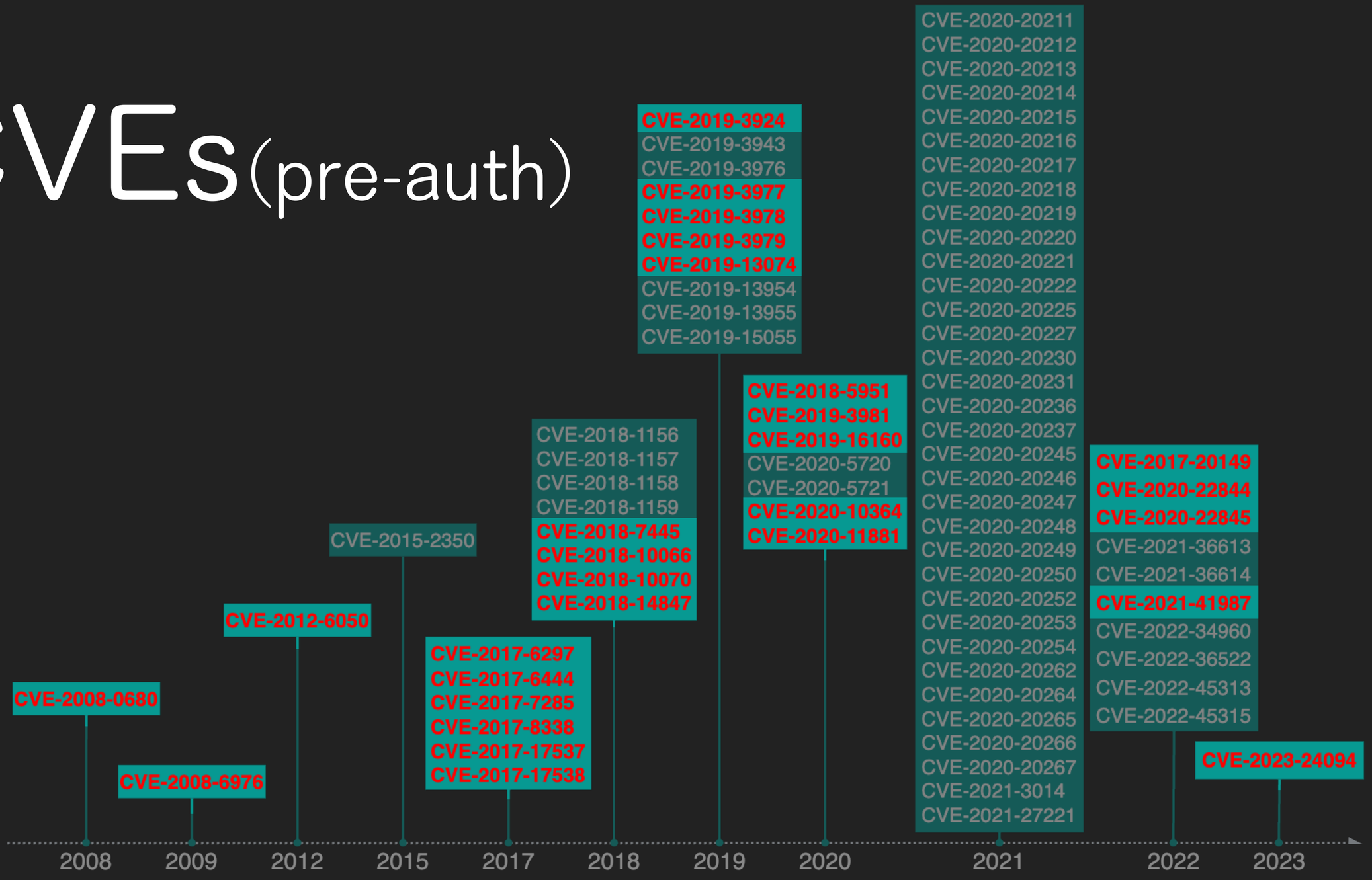
CVEs (pre-auth)



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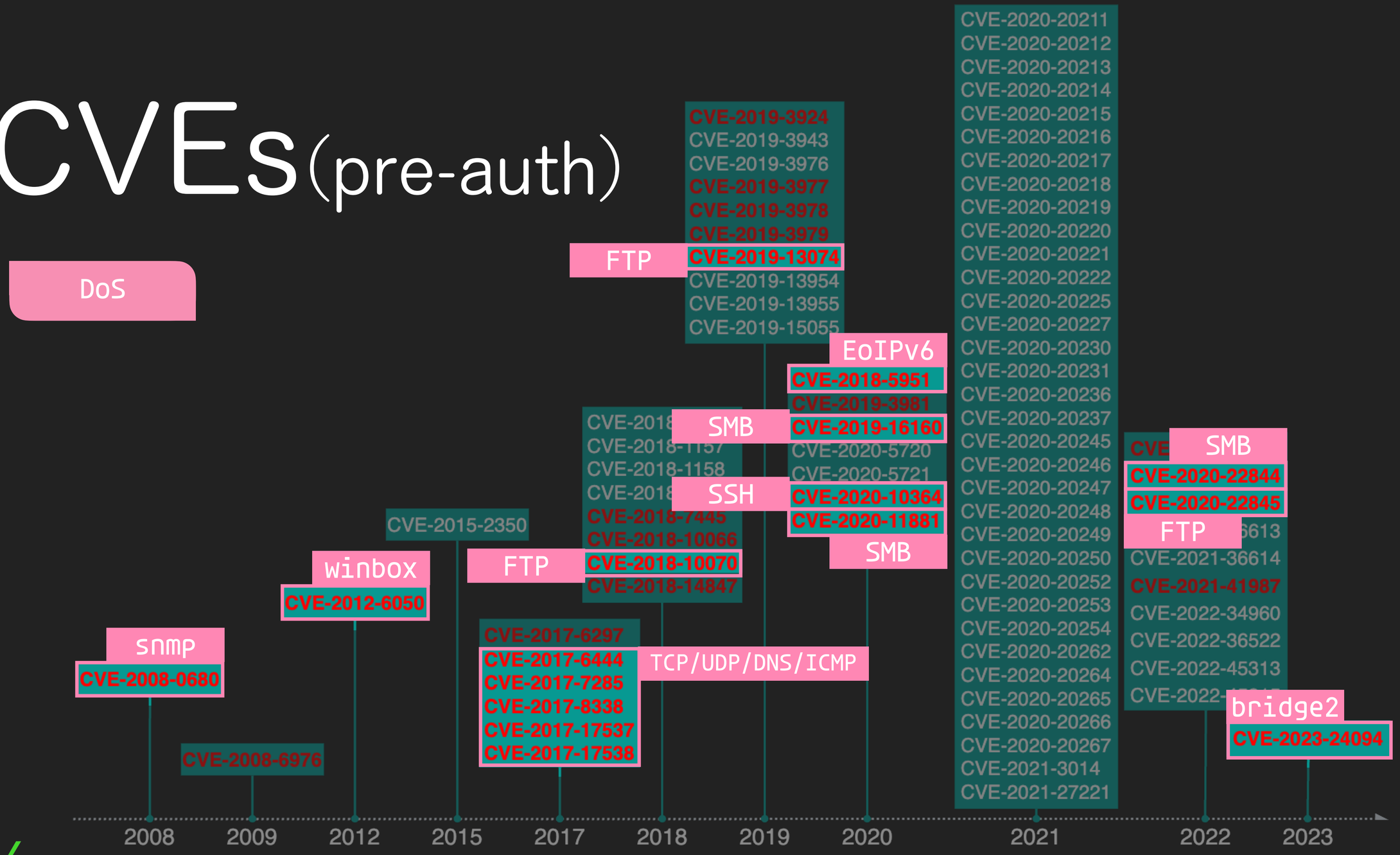
CVEs(pre-auth)



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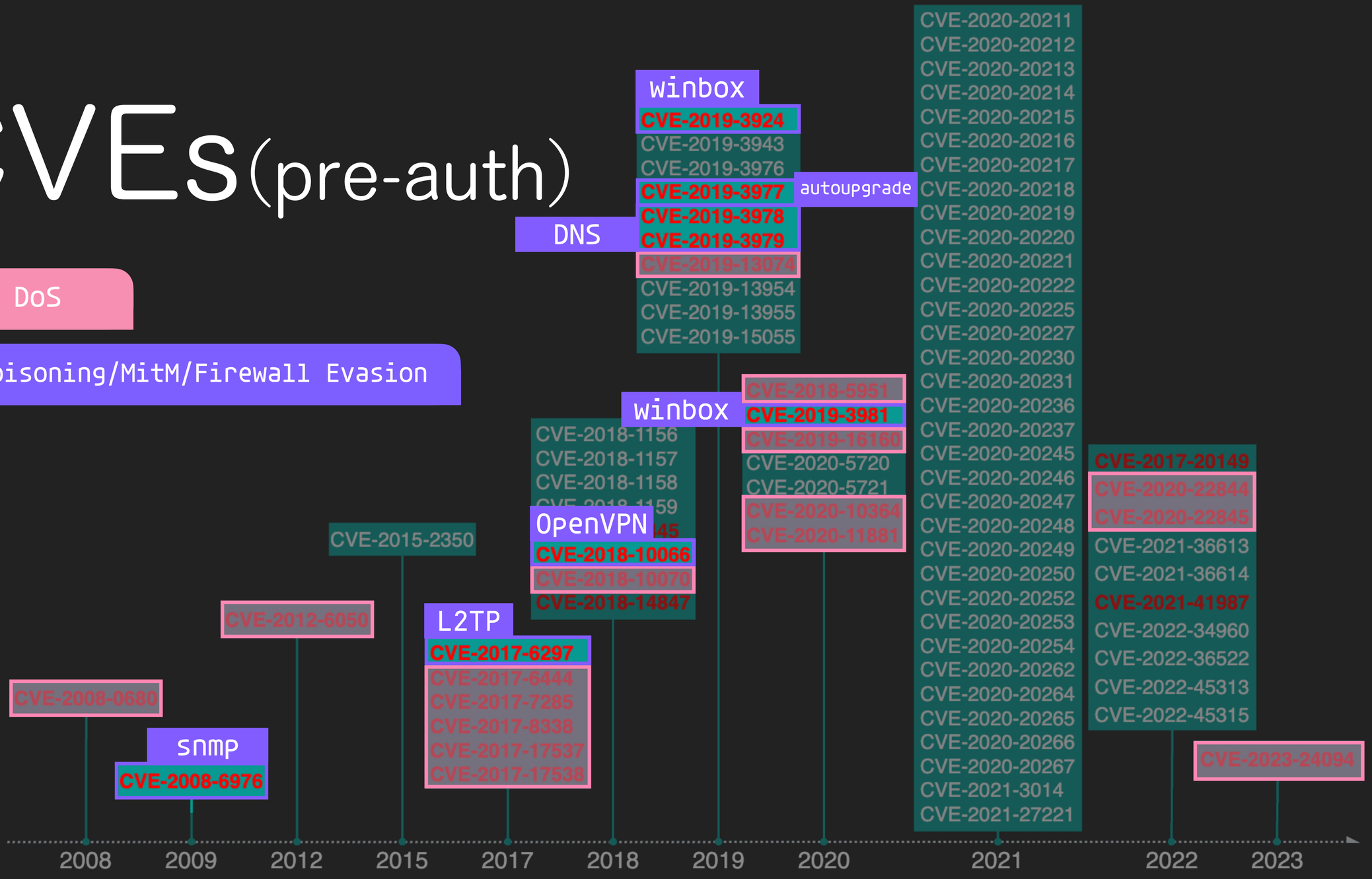
CVEs(pre-auth)

DoS

Poisoning/MitM/Firewall Evasion



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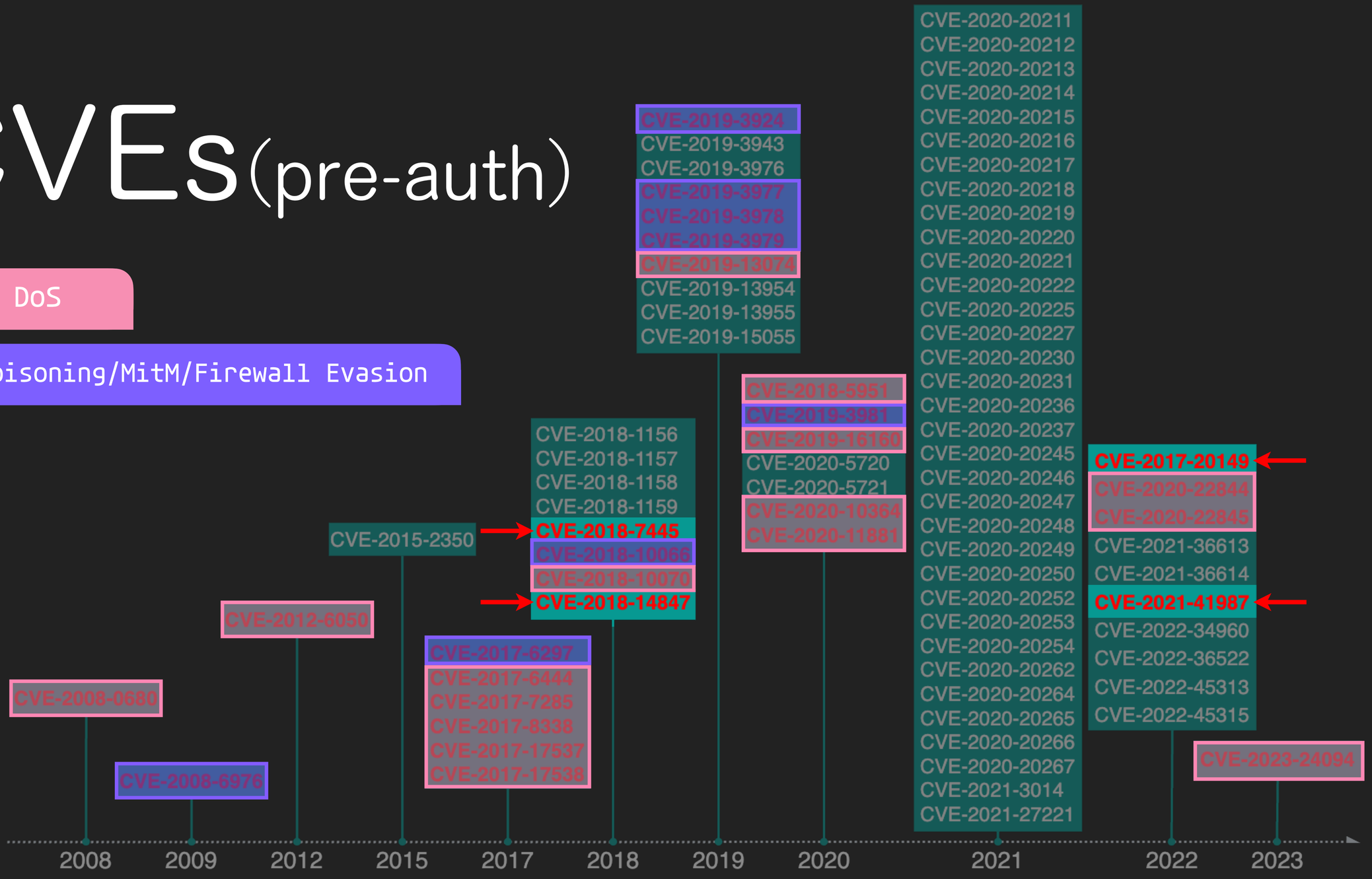
CVEs (pre-auth)

DoS

Poisoning/MitM/Firewall Evasion



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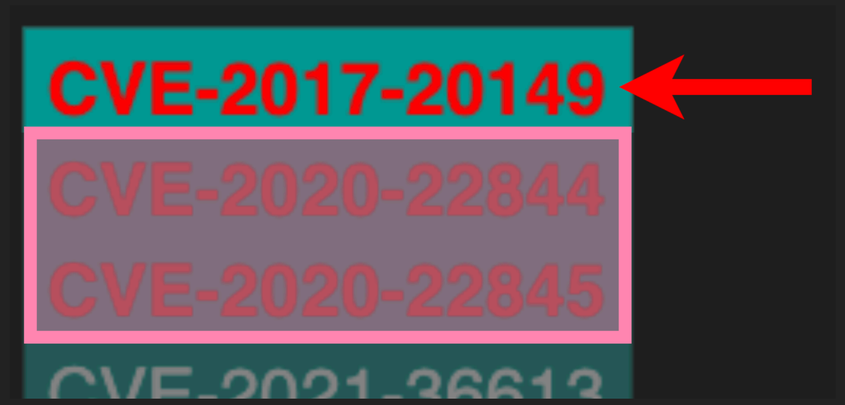
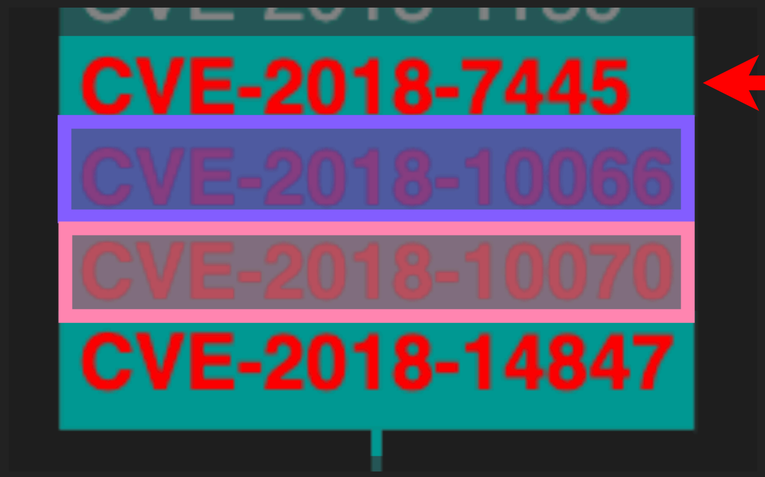
CVEs(pre-auth)



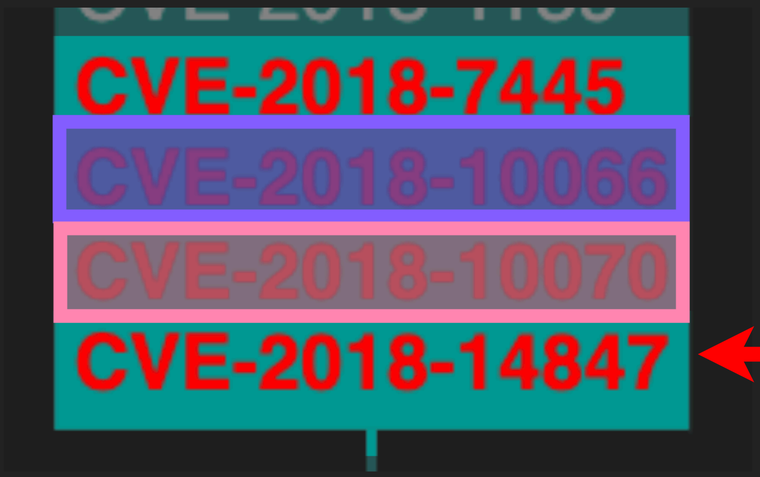
- aka Chimay-Red
- One of the exploits leaked from the CIA
- Lacking input validation on Content-Length in HTTP request cause the stack clash attack.

CVEs(pre-auth)



- Buffer overflow in SMB
- It was found by blackbox fuzzing

CVEs(pre-auth)



- One of the exploits leaked from the CIA
- A directory traversal vulnerability in the WinBox interface
- Allows unauthenticated attackers to read arbitrary files on RouterOS

CVEs (pre-auth)

CVE-2018-7445

CVE-2018-14847

$password_{db} = password_{raw}$ xor md5(username + "283i4jfkai3389")

- Allows unauthenticated attackers to read arbitrary files on RouterOS

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CVEs(pre-auth)

CVE-2021-36614

CVE-2021-41987

CVE-2022-34960

- OOB in the base64decode of the SCEP service
- The attacker must know the scep_server_name
- It was discovered on an APT's C2 server

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2017

Kirils

Rooting the MikroTik routers

focus on jailbreak

Kirils

A deeper journey into MikroTik routers

focus on jailbreak

Kirils

Tools for effortless reverse engineering of MikroTik router

focus on jailbreak

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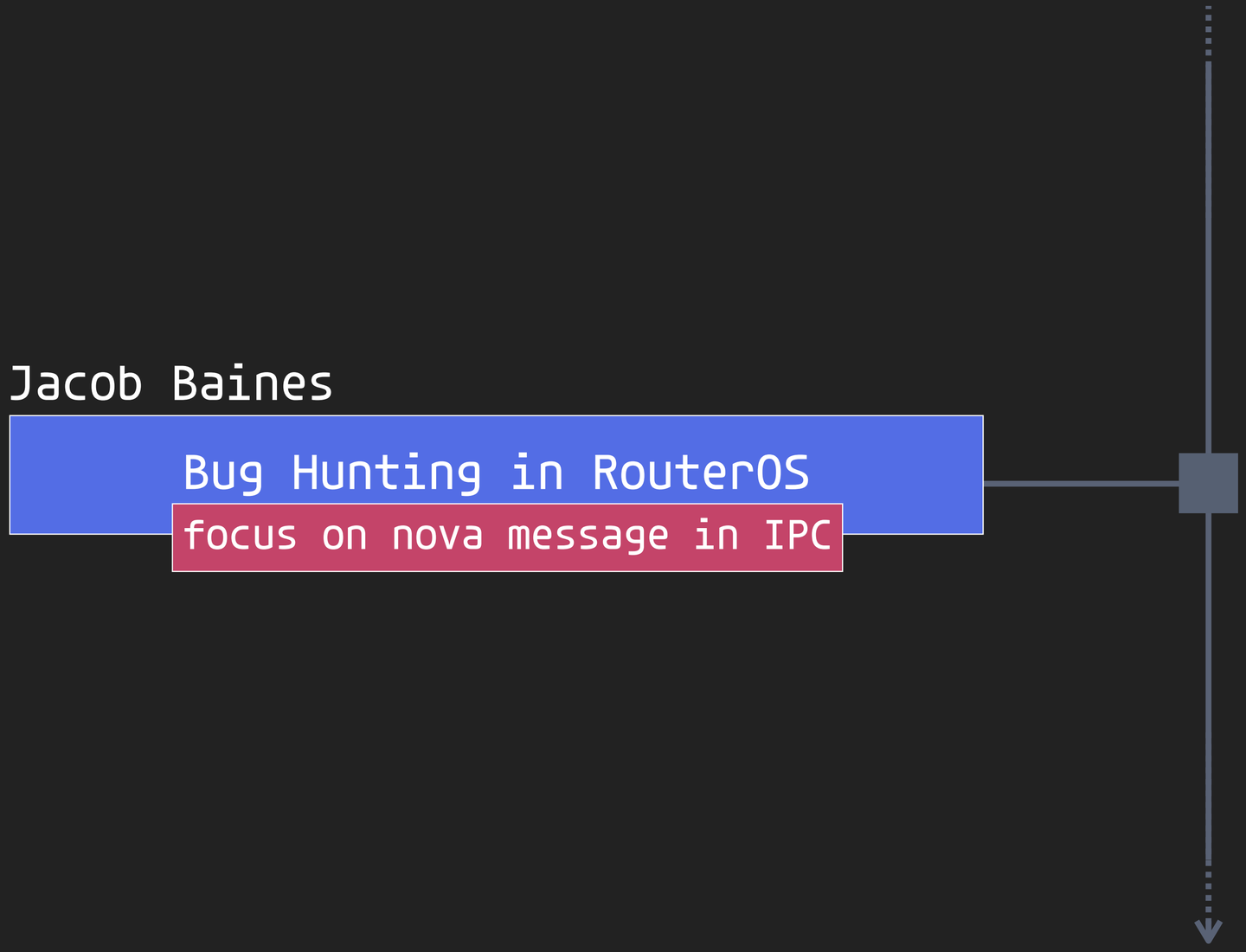
2018

Jacob Baines



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2019

Jacob Baines

Make It Rain with MikroTik

focus on nova message in IPC

Maximiliano Vidal, Juan Caillava

Finding and exploiting CVE-2018-7445

find pre-auth RCE in SMB
by blackbox fuzzing

Jacob Baines

Help Me Vulnerabilities
You're My Only Hope

focus on jailbreak

Jacob Baines

MikroTik Firewall & NAT Bypass

Firewall bypass (winbox)

Tomas Kirnak

Deep-dive:
MikroTik exploits - a security analysis

analyze the CIA exploits

Jacob Baines

RouterOS: Chain to Root

DNS poisoning (winbox)

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2022

Ian Dupont, Harrison Green

Pulling MikroTik into the Limelight

focus on nova message in IPC

We are here

????????

??????????????????????????????????

??????????????????

DEVCORE

Terminal

```
~ took 2s
[% telnet 192.168.88.1
Trying 192.168.88.1...
Connected to 192.168.88.1.
Escape character is '^]'.
lm_will: not enough room in buffer for DISPLAY
Login:
```

IPC

Terminal — 117×26

```
  MMM      MMM       KKK                          TTTTTTTTTTT      KKK
  MMMM    MMMM       KKK                          TTTTTTTTTTT      KKK
  MMM MMMM MMM  III  KKK  KKK  RRRRRR     OOOOOO      TTT     III  KKK  KKK
  MMM  MM  MMM  III  KKKKK     RRR  RRR  OOO  OOO     TTT     III  KKKKK
  MMM      MMM  III  KKK KKK   RRRRRR    OOO  OOO     TTT     III  KKK KKK
  MMM      MMM  III  KKK  KKK  RRR  RRR   OOOOOO      TTT     III  KKK  KKK

  MikroTik RouterOS 6.49.6 (c) 1999-2022       http://www.mikrotik.com/

[?]             Gives the list of available commands
command [?]     Gives help on the command and list of arguments

[Tab]           Completes the command/word. If the input is ambiguous,
                a second [Tab] gives possible options

/               Move up to base level
..              Move up one level
/command        Use command at the base level
jan/02/1970 00:09:21 system,error,critical login failure for user 1\7Fadmin from 192.168.88.200 via

[admin@MikroTik] >
```

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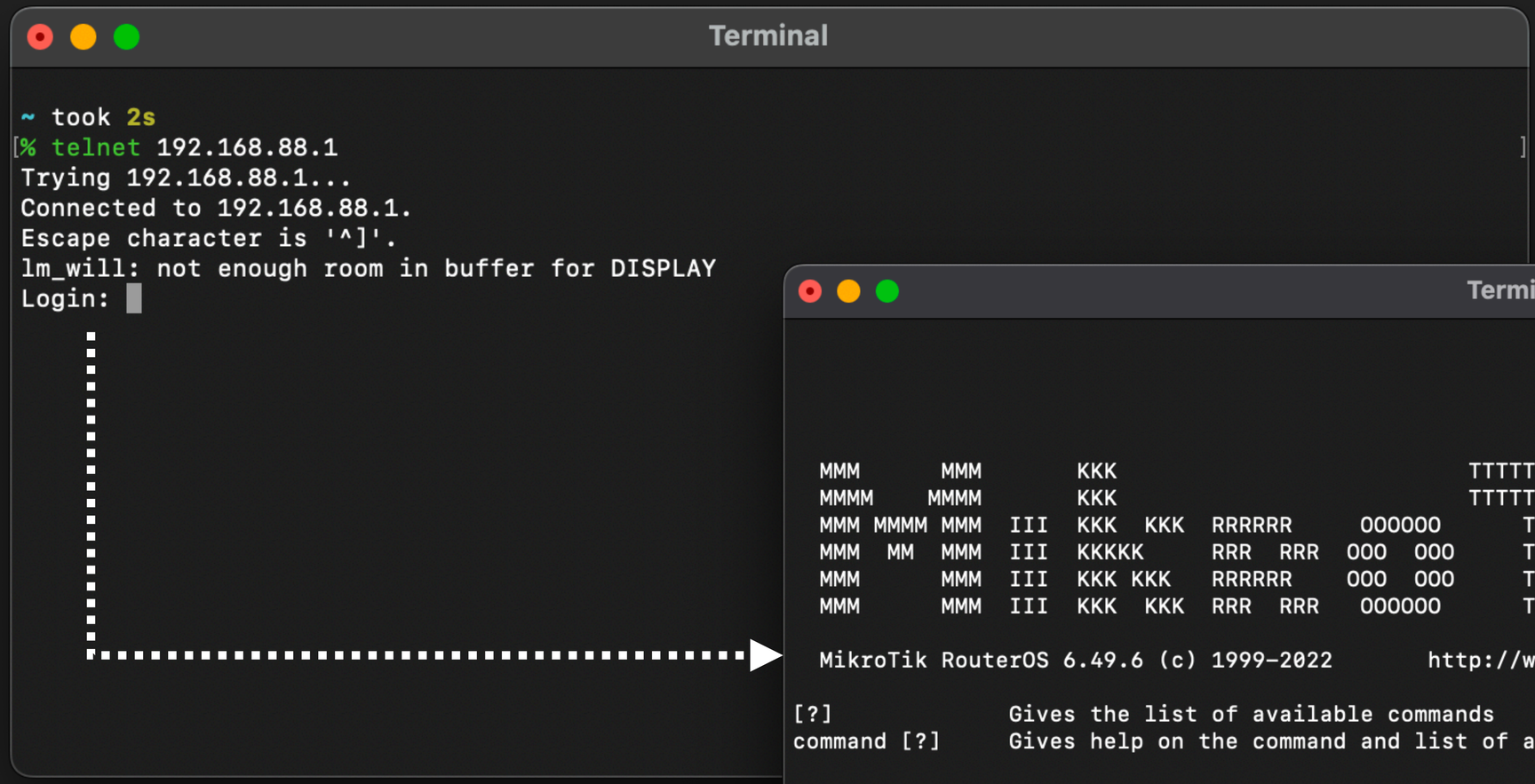
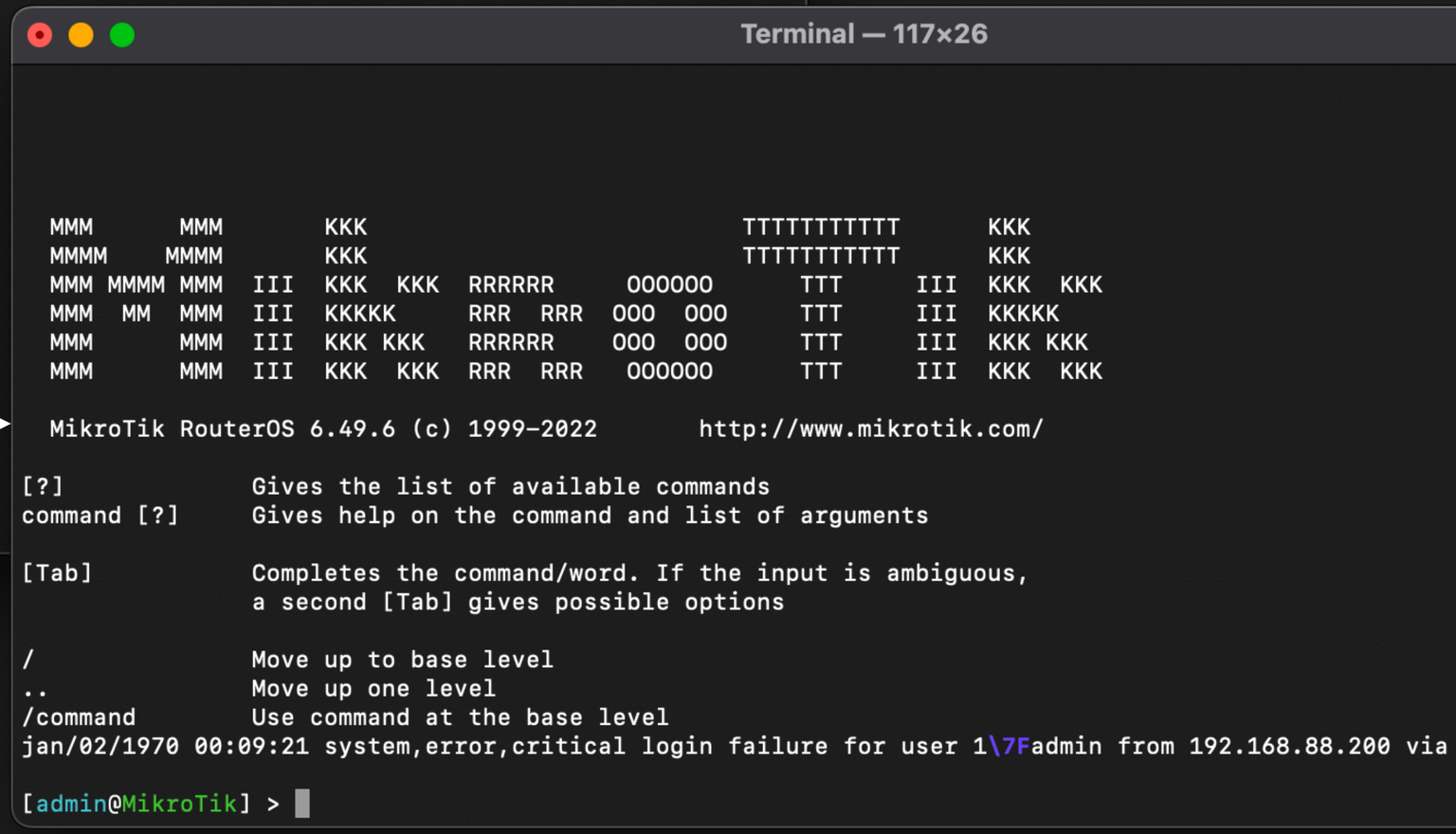
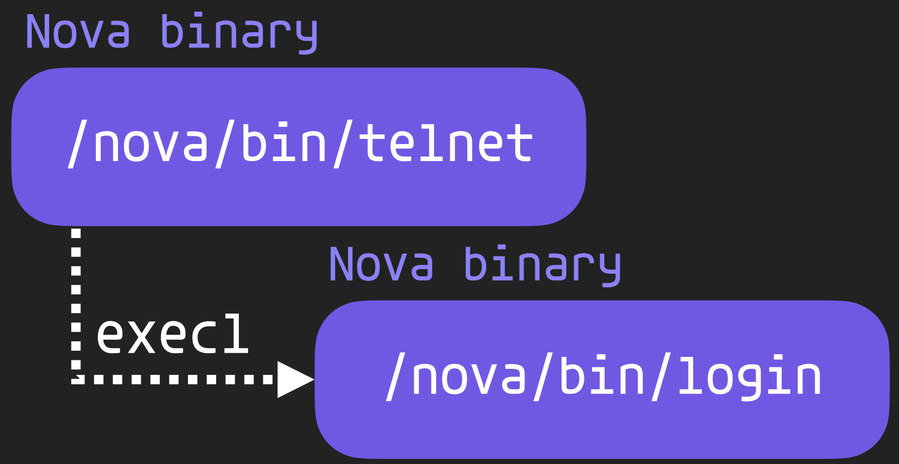


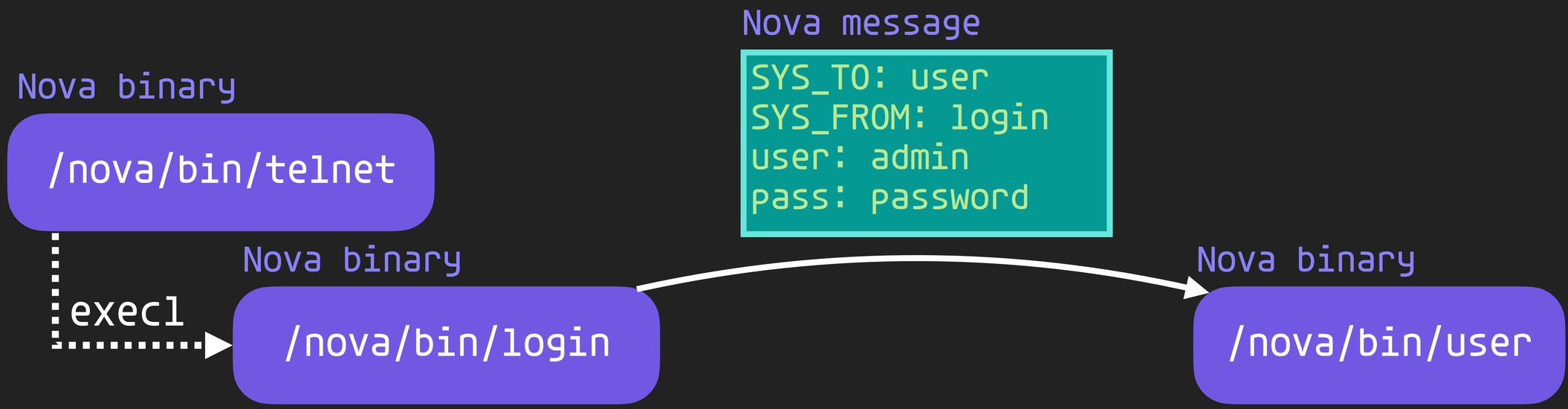


IPC



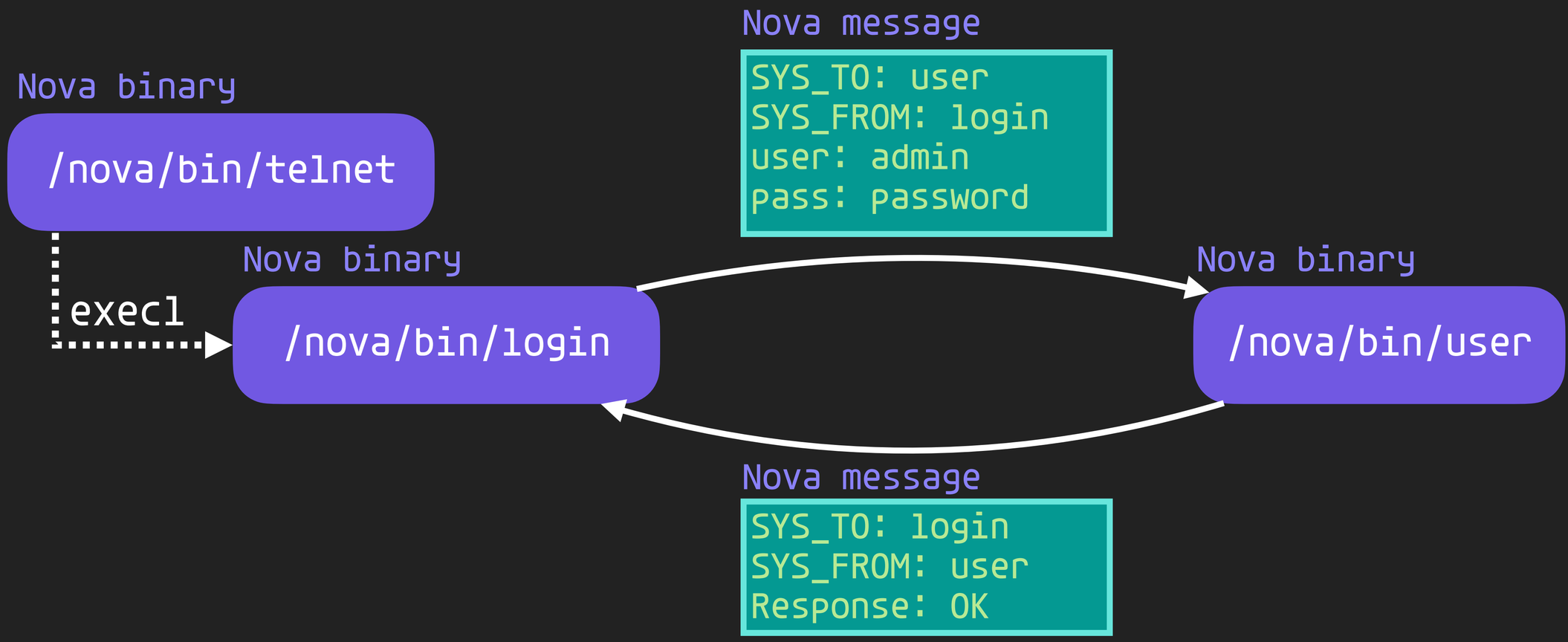
DEVCORE

IPC



DEVCORE

IPC



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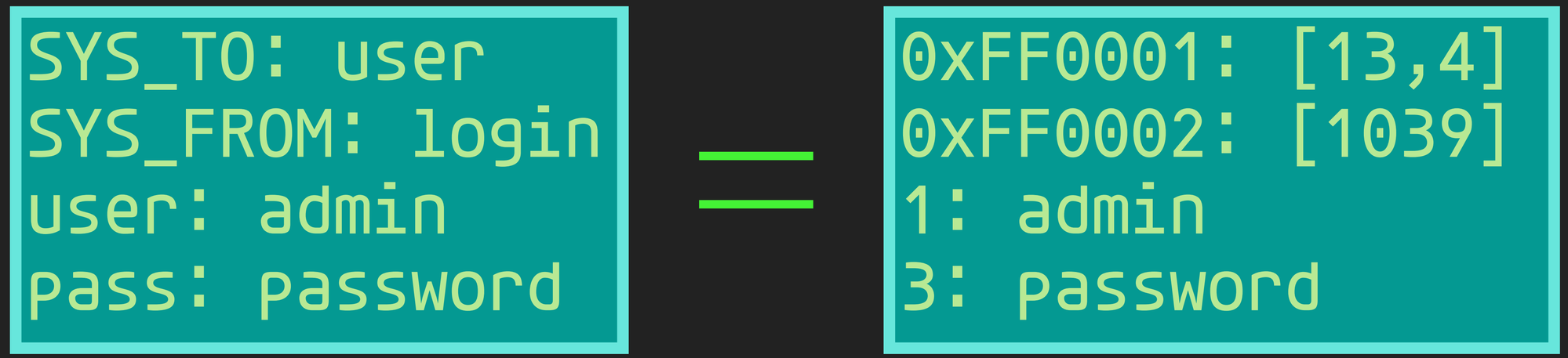
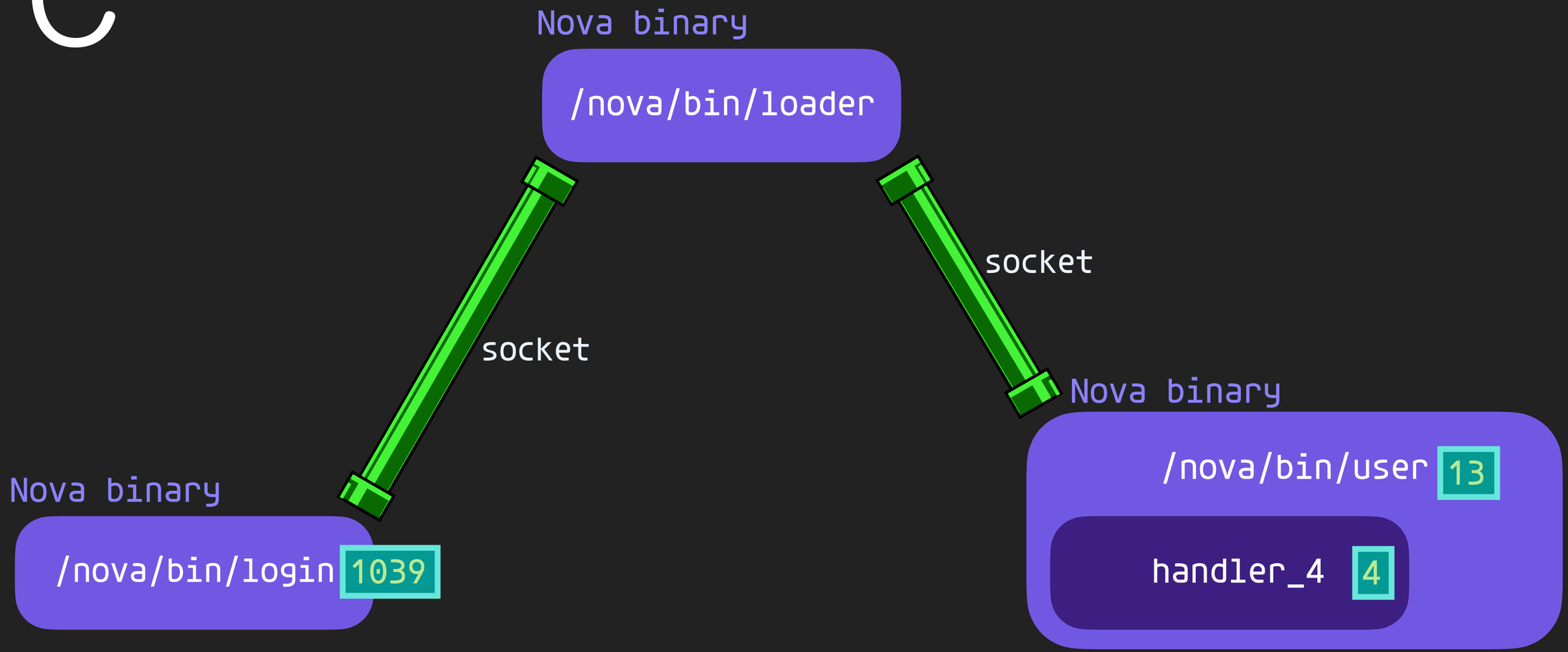
Nova Message



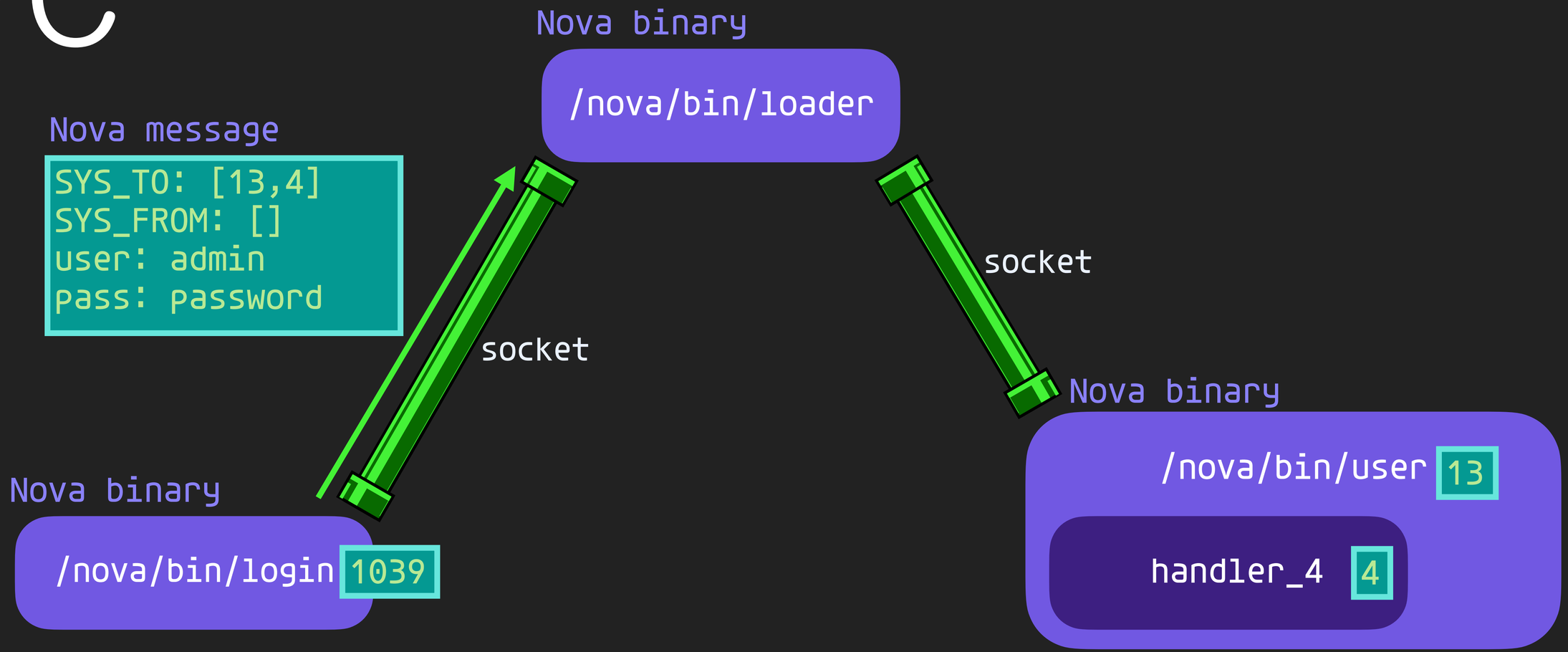
DEVCORE

IPC



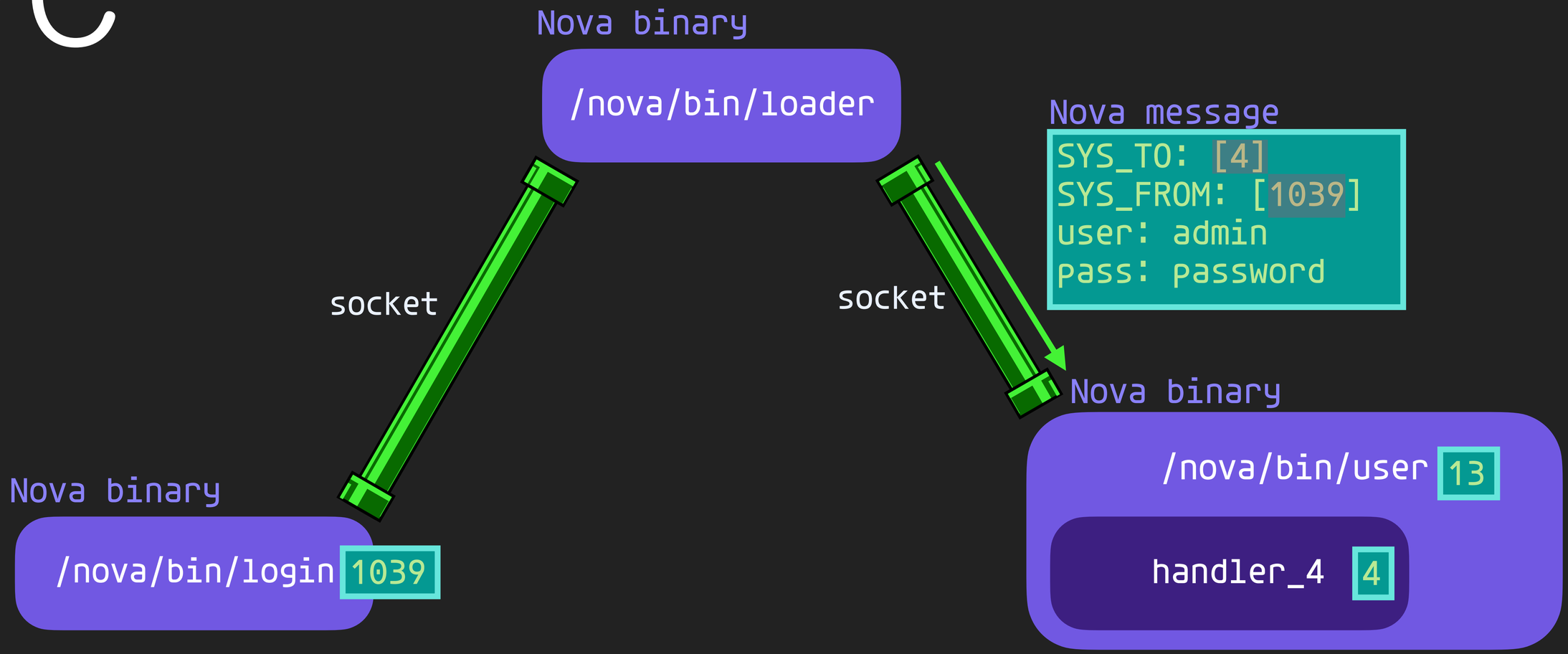
DEVCORE

IPC



DEVCORE

IPC



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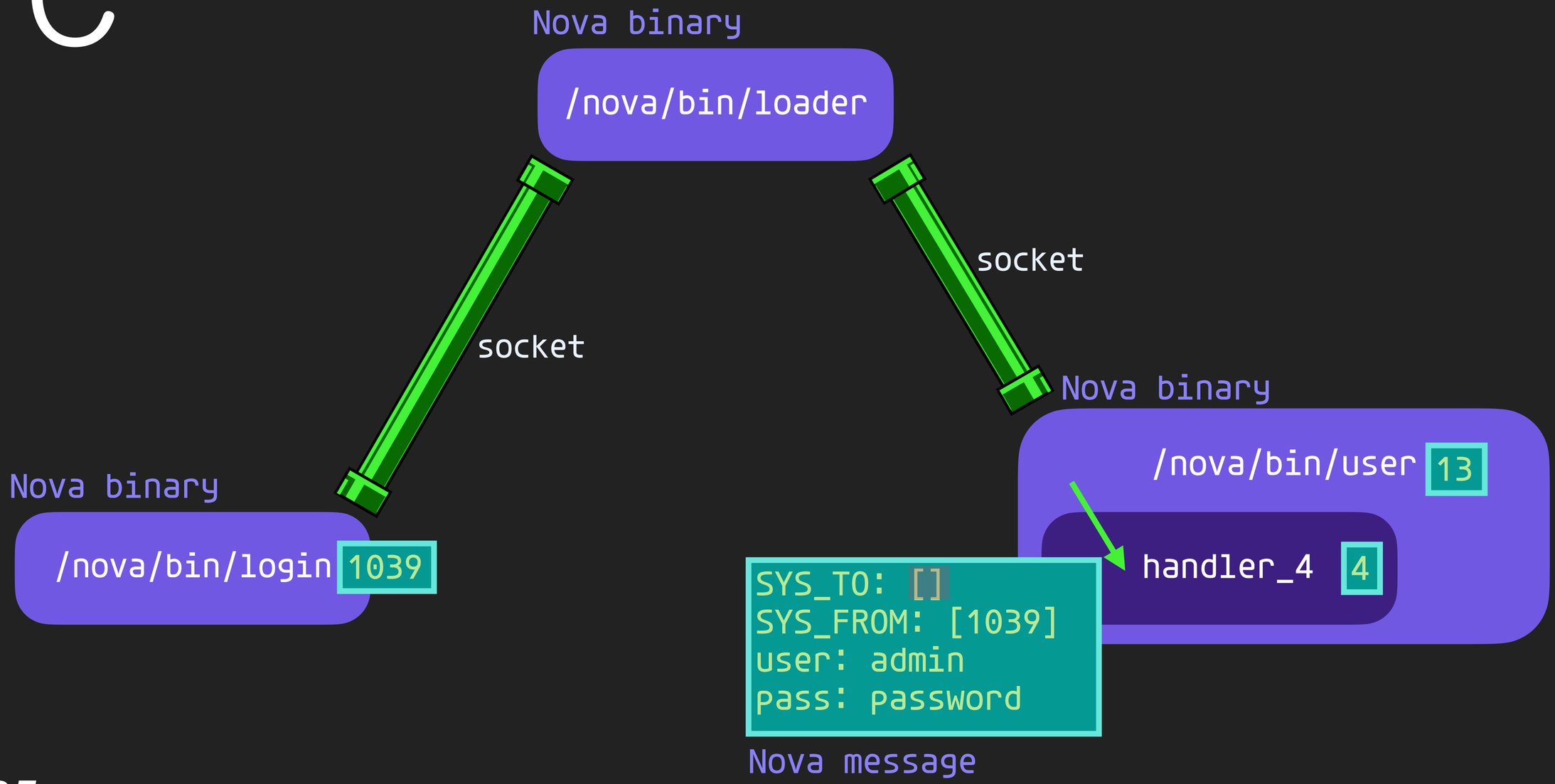
IPC



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IPC

Nova binary

/nova/bin/loader

Nova binary

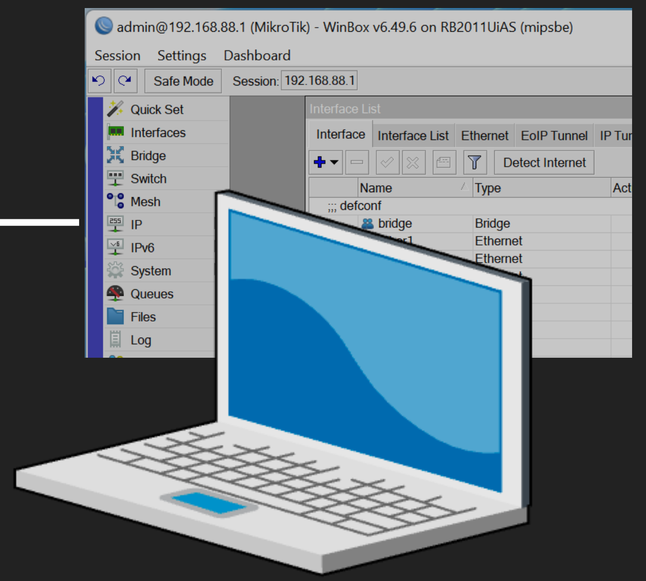
/nova/bin/sermgr

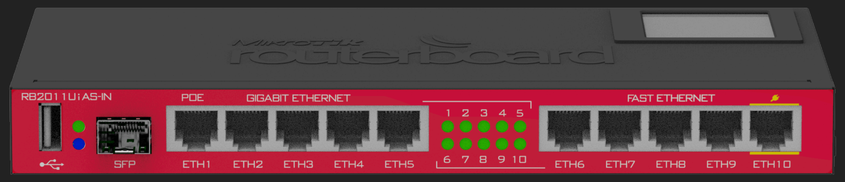
TCP

Nova message

SYS_TO: […]
SYS_FROM: […]
…

winbox





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Nova Message

- The message used in IPC is constructed by `nv::message` and relative functions
- Nova message is typed key-value mapping and can contain u32, u64, bool, string, bytes, IP, and nova message.

```
nv::message::message((nv::message *)&v121);
v87 = v82 + 4;
nv::message::insert_vector((int)&v121, 0xFF0001, 13, 4);
nv::message::insert<nv::string_id>(&v121, 1, v87);// account
nv::message::insert<nv::string_id>(&v121, 3, v75 + 4);// password
nv::message::insert<nv::u32_id>((int)&v121, 7, 9);
nv::message::insert<nv::addr6_id>(&v121, 23, *(_DWORD *)(a2 + 32) + 152);
nv::message::insert<nv::bool_id>(&v121, 8, 1);
```

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Nova Message

```
0xFF0001: [13,4]
0xFF0002: [1039]
1: admin
3: password
```

=

```
00000000: 5d00 0000 4d32 0100 ff88 0100 0400 0000  ]...M2..........
00000010: 0200 ff88 0100 0f04 0000 0500 ff01 0800  ................
00000020: 0001 0700 0009 0303 00ff 0901 0600 ff09  ................
00000030: 0007 00ff 0901 1300 ff18 0000 0000 0000  ................
00000040: 0000 0000 ffff c0a8 58c8 0300 0021 0870  ........X....!.p
00000050: 6173 7377 6f72 6401 0000 2105 6164 6d69  assword...!.admi
00000060: 6e                                       n
```

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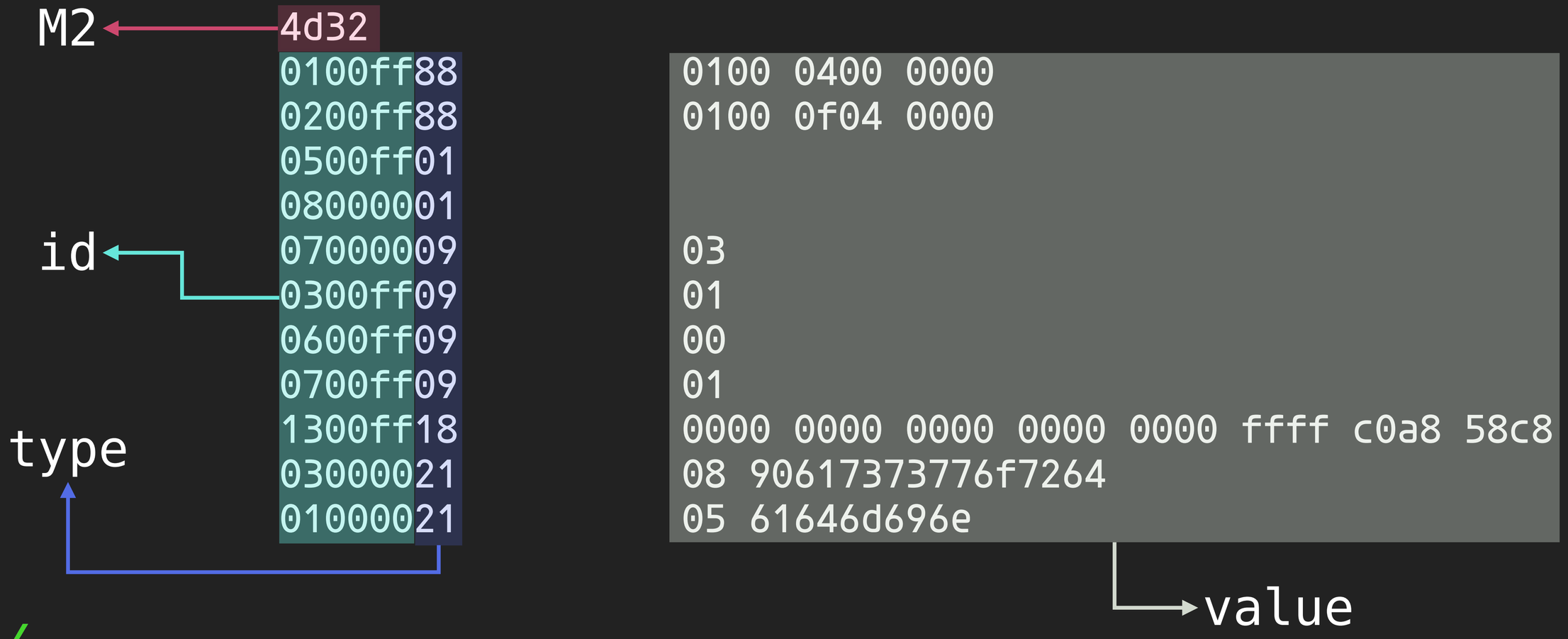
Nova Message



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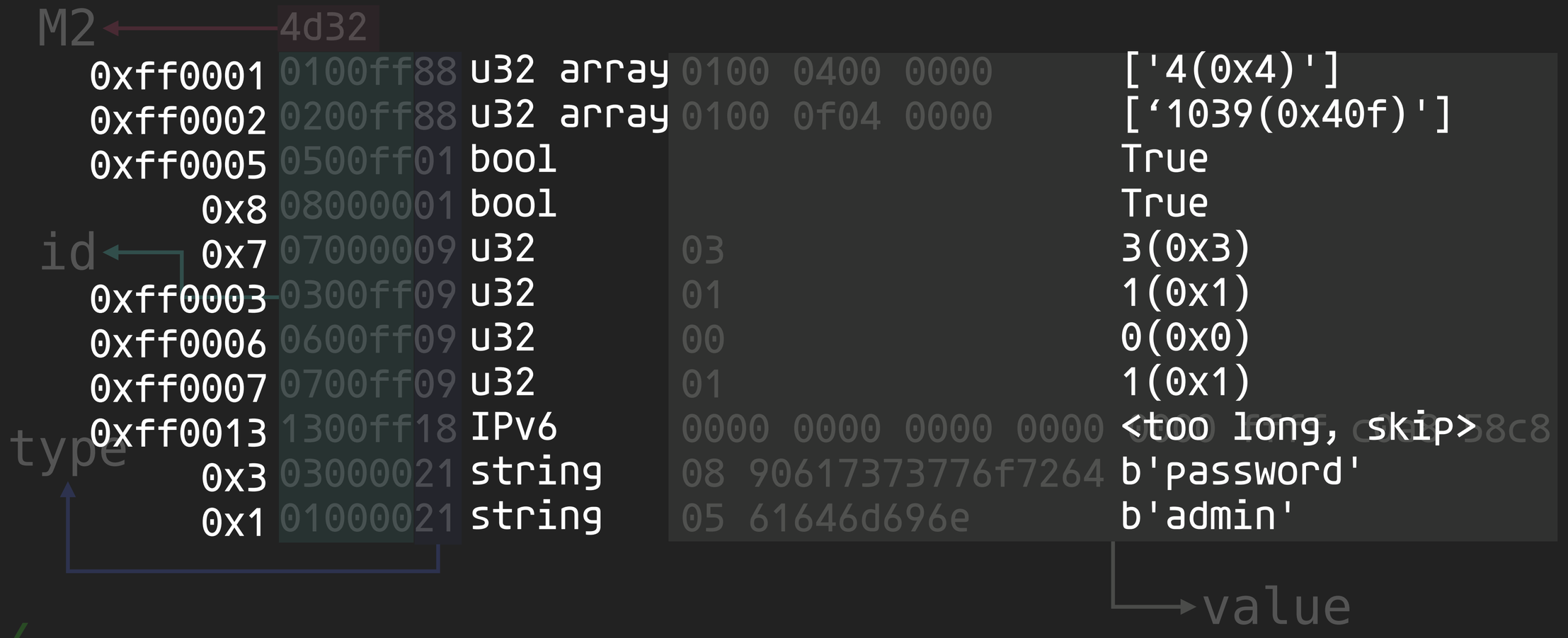
Nova Message



Nova Message

- To understand which binary corresponds to the id in the SYS_FROM or SYS_TO of the nova message, we need to parse the *.x3 file under the /nova/etc/loader/system.x3

```
<33>
  <30 (7)=b'/nova/bin/log' (4)=i32 3 (153)=b'\x01' (173)=b'\x01'
  <30 (7)=b'/nova/bin/radius' (4)=i32 5/>
  <30 (7)=b'/nova/bin/moduler' (4)=i32 6 (153)=b'\x01' (173)=b'\
  <30 (7)=b'/nova/bin/user' (4)=i32 13 (204)=b'\x01'/>
  <30 (7)=b'/nova/bin/resolver' (4)=i32 14 (173)=b'\x01'/>
  <30 (7)=b'/nova/bin/mactel' (4)=i32 15 (173)=b'\x01'/>
  <30 (7)=b'/nova/bin/undo' (4)=i32 17/>
```

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Nova Message

- If the binary was introduced by installing a package, its id is in the /ram/pckg/<package_name>/nova/etc/loader/<package_name>.x3

```
<33>
  <30 (7)=b'/nova/bin/ippool6' (4)=i32 30 (153)=b'\x01'/>
  <30 (7)=b'/nova/bin/radvd' (4)=i32 31 (153)=b'\x01'/>
</33>%
```

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Nova Message

- If the binary was introduced by install a packet, it's id is in the /ram/pckg/<package_name>/nova/etc/loader/<package_name>.x

```
<33>
  <30 (7)=b'/no                                    0 (153)=b'\x01'/>
  <30 (7)=b'/no                                   (153)=b'\x01'/>
</33>%
```

```
SYS_TO: [13, 4]
SYS_FROM: [1039]
user: admin
pass: password
```

Nova Message

- Other binaries also have their .x3 files for different purposes.

```
<169 (2)=b'www'>
  <154 (38)=b'index' (7)=b'/' (40)=b'\x01'/>
  <154 (38)=b'jsproxy' (7)=b'/jsproxy'/>
  <154 (38)=b'dir' (7)=b'/img/' (28)=b'/home/web/img'/>
  <154 (38)=b'dir' (7)=b'/doc/' (28)=b'/home/web/doc'/>
  <154 (38)=b'dir' (7)=b'/help/' (28)=b'/home/web/help'/>
  <154 (38)=b'dir' (7)=b'/webfig/list' (28)=b'/home/web/webfig/list'/>
  <154 (38)=b'dir' (7)=b'/webfig/' (28)=b'/home/web/webfig' (283)=b'\x01'/>
  <154 (38)=b'winbox' (7)=b'/winbox' (40)=b'\x01'/>
  <154 (38)=b'webgraph' (7)=b'/graphs'/>
  <154 (38)=b'kidcontrol' (7)=b'/kid-control' (40)=b'\x01'/>
  <154 (38)=b'dir' (7)=b'/winbox/' (28)=b'/home/web/winbox'/>
  <154 (38)=b'traflog' (7)=b'/accounting/ip.cgi' (40)=b'\x01'/>
  <154 (38)=b'dir' (7)=b'/' (28)=b'/home/web'/>
  <154 (38)=b'dir' (7)=b'/crl' (28)=b'/var/cm/ca_crl'/>
  <154 (38)=b'scep' (7)=b'/scep'/>
</169>
```

Nova Message

- It seems like it’s a good target for fuzzing.
- But we can’t just fuzz it and expect we can get a pre-auth RCE after two months.

```
00000000: 5d00 0000 4d32 0100 ff88 0100 0400 0000  ]...M2..........
00000010: 0200 ff88 0100 0f04 0000 0500 ff01 0800  ................
00000020: 0001 0700 0009 0303 00ff 0901 0600 ff09  ................
00000030: 0007 00ff 0901 1300 ff18 0000 0000 0000  ................
00000040: 0000 0000 ffff c0a8 58c8 0300 0021 0870  ........X....!.p
00000050: 6173 7377 6f72 6401 0000 2105 6164 6d69  assword...!.admi
00000060: 6e                                       n
```

DEVCORE

2022

Spoiler!Spoiler!Spoiler!

Spoiler!Spoiler!

Spoiler!Spoiler!Spoiler!

2022

Ian Dupont, Harrison Green

Pulling MikroTik into the Limelight

focus on nova message in IPC

We are here

Qian Chen

MikroTik RouterOS Security:
The Forgotten IPC Message

fuzzing nova message in IPC

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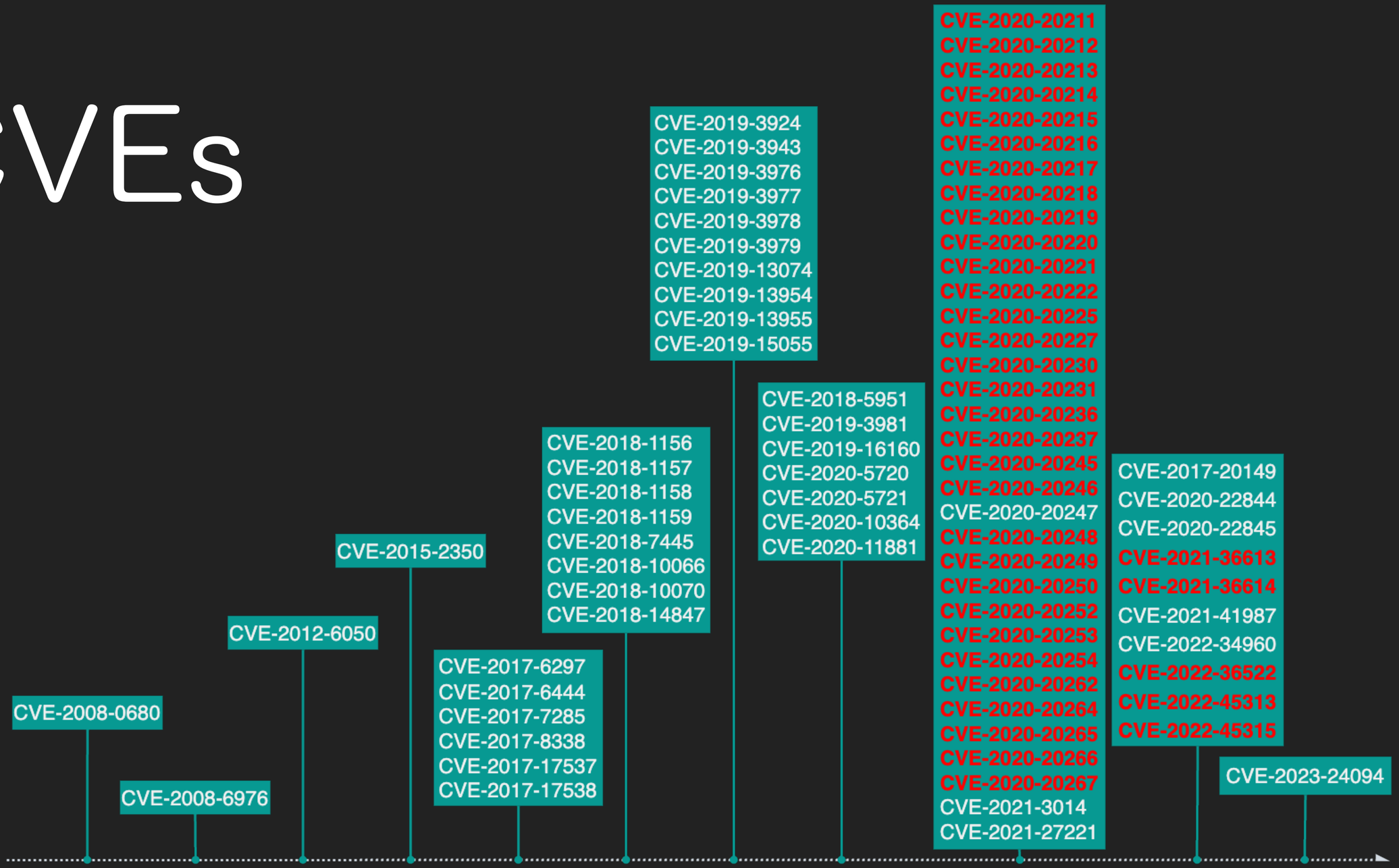
CVEs



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Is RouterOS now impervious to hacking?

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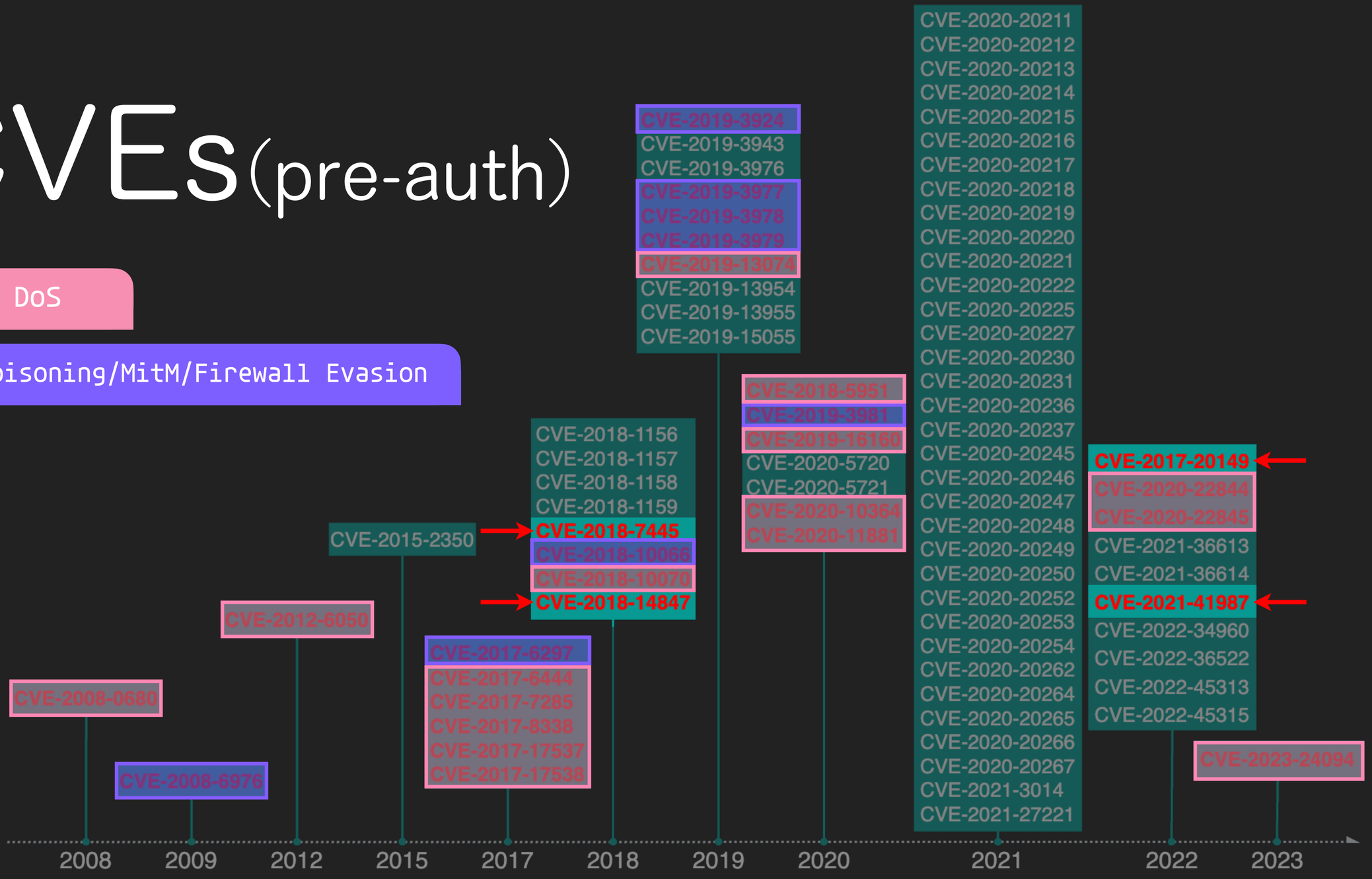
CVEs (pre-auth)

DoS

Poisoning/MitM/Firewall Evasion



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Observation

- Most researches are about
  - Jailbreaking
  - Analyzing the ITW exploits
  - Nova message in IPC

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Brief Summary

No one with sanity
would like to dive into the details of Nova Binary

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Where to start ?

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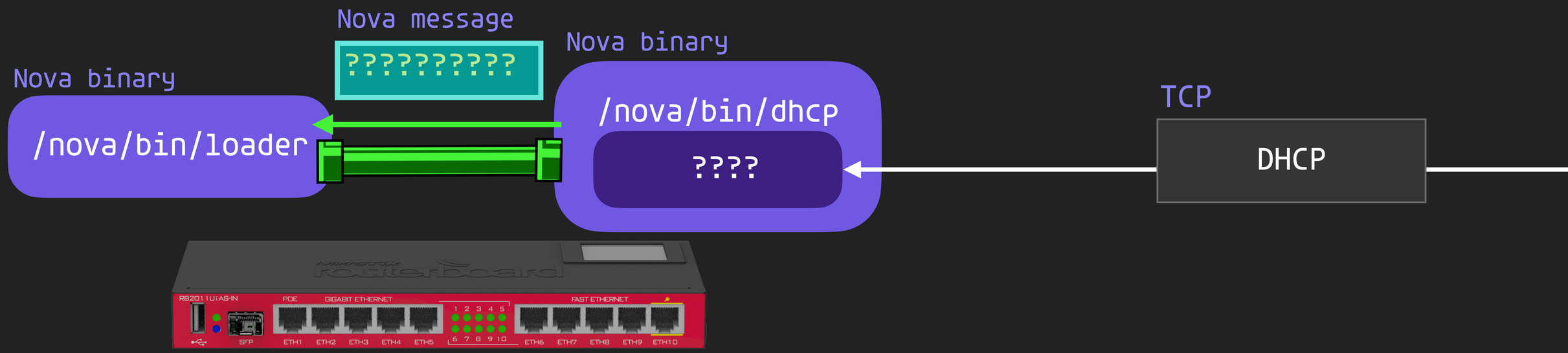
Where to start ?

- Where are the entry points to the customize IPC ?



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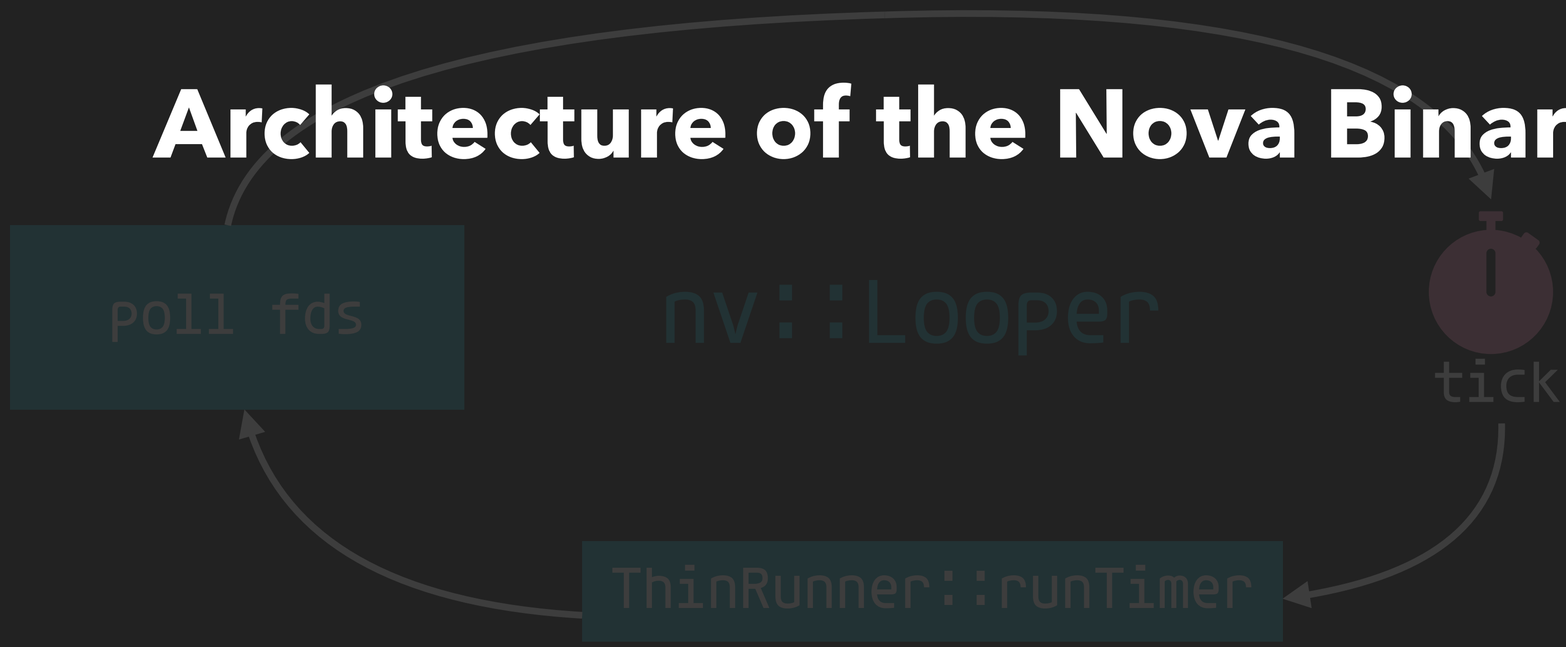
Nova Binary

- Every Nova binary has a Looper or MultifiberLooper.

Architecture of the Nova Binary



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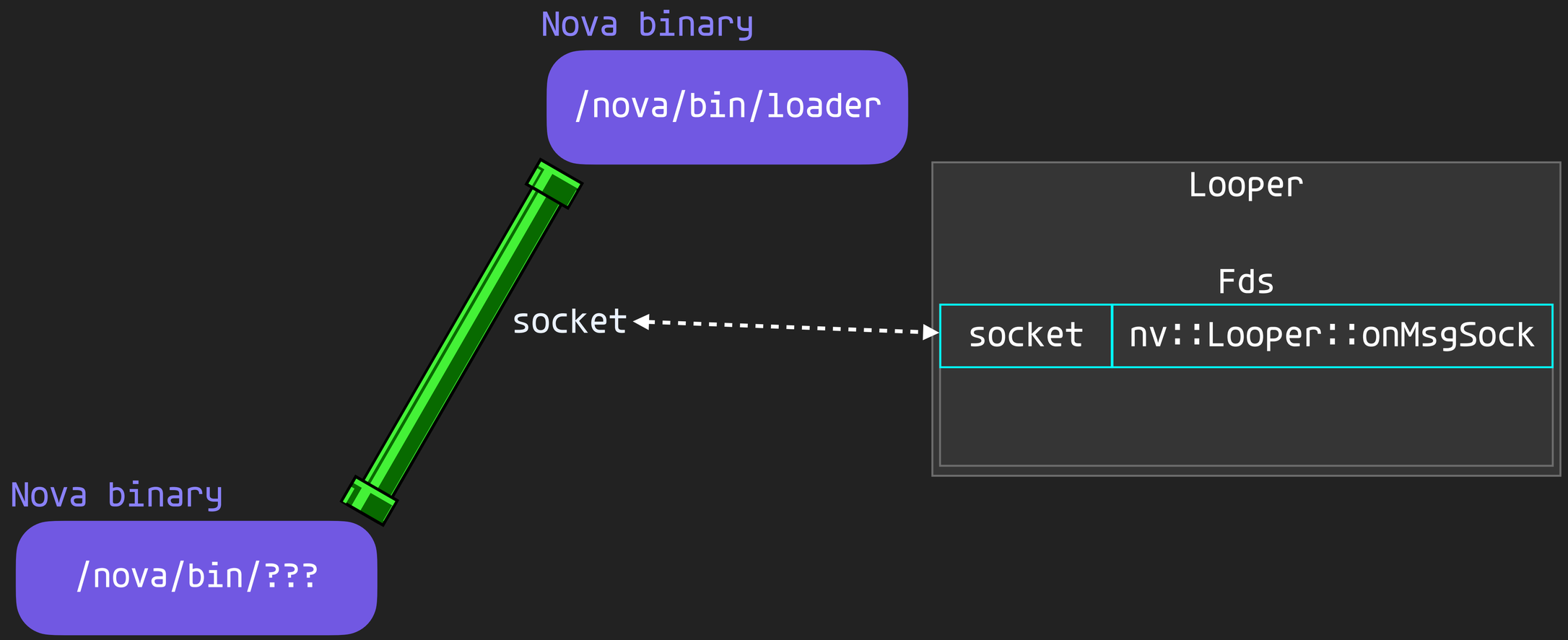
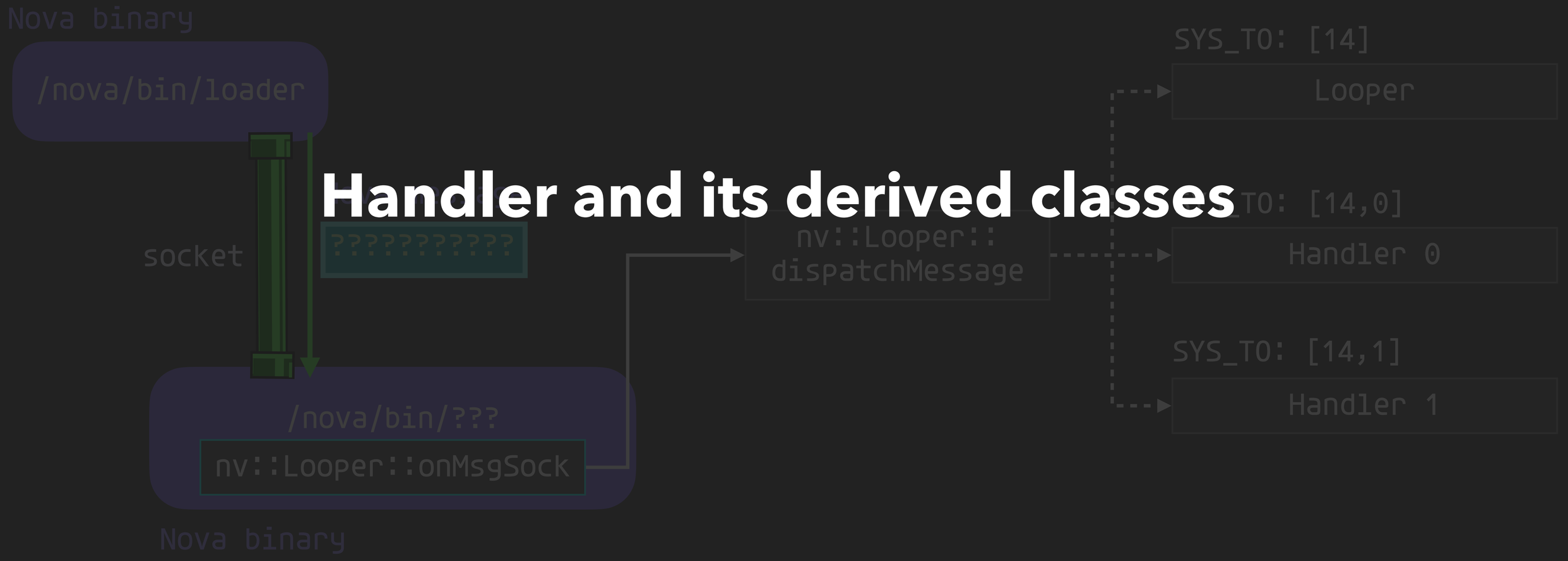
Nova Binary

- Every Nova binary has a Looper or a MultifiberLooper.

Nova Binary

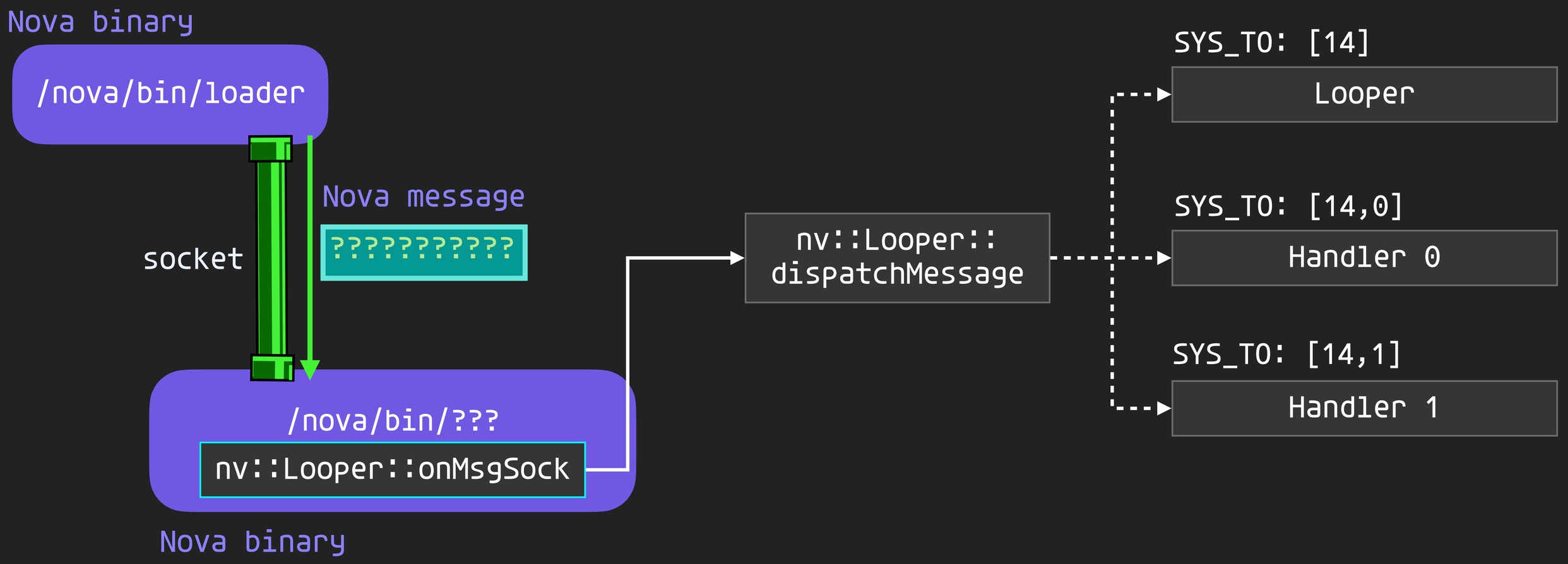


Nova Binary



Handler and its derived classes

Nova Binary



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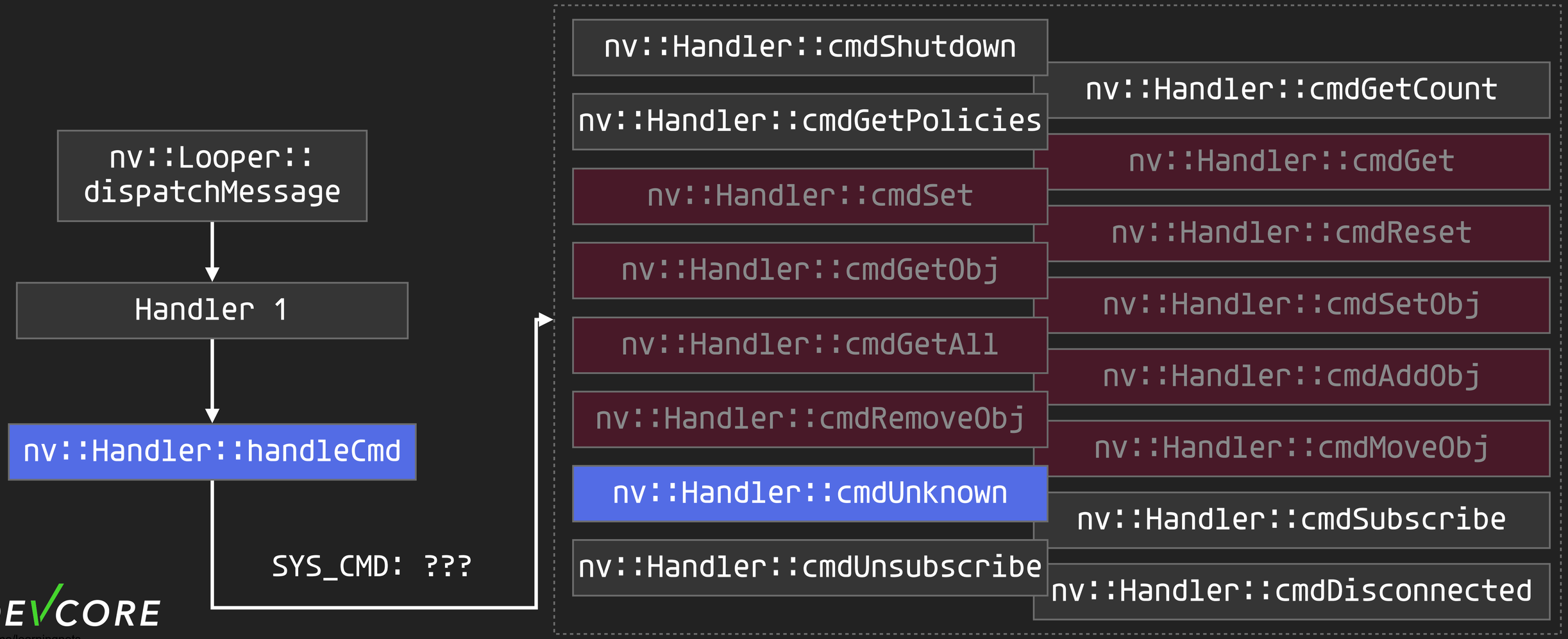
Nova Binary



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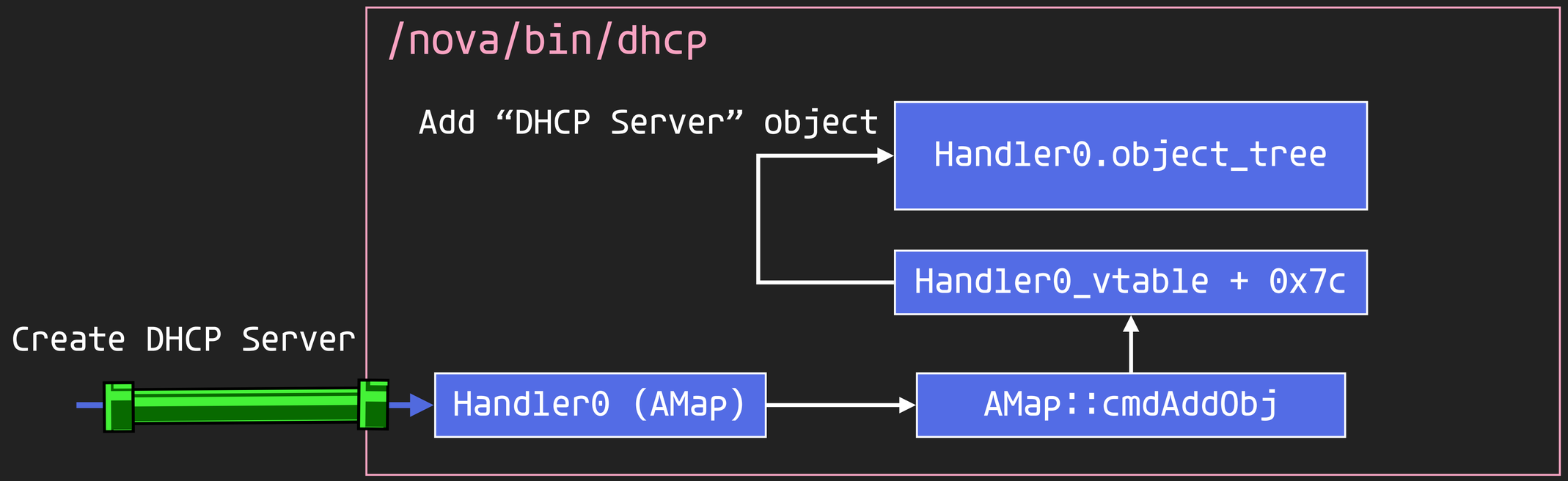
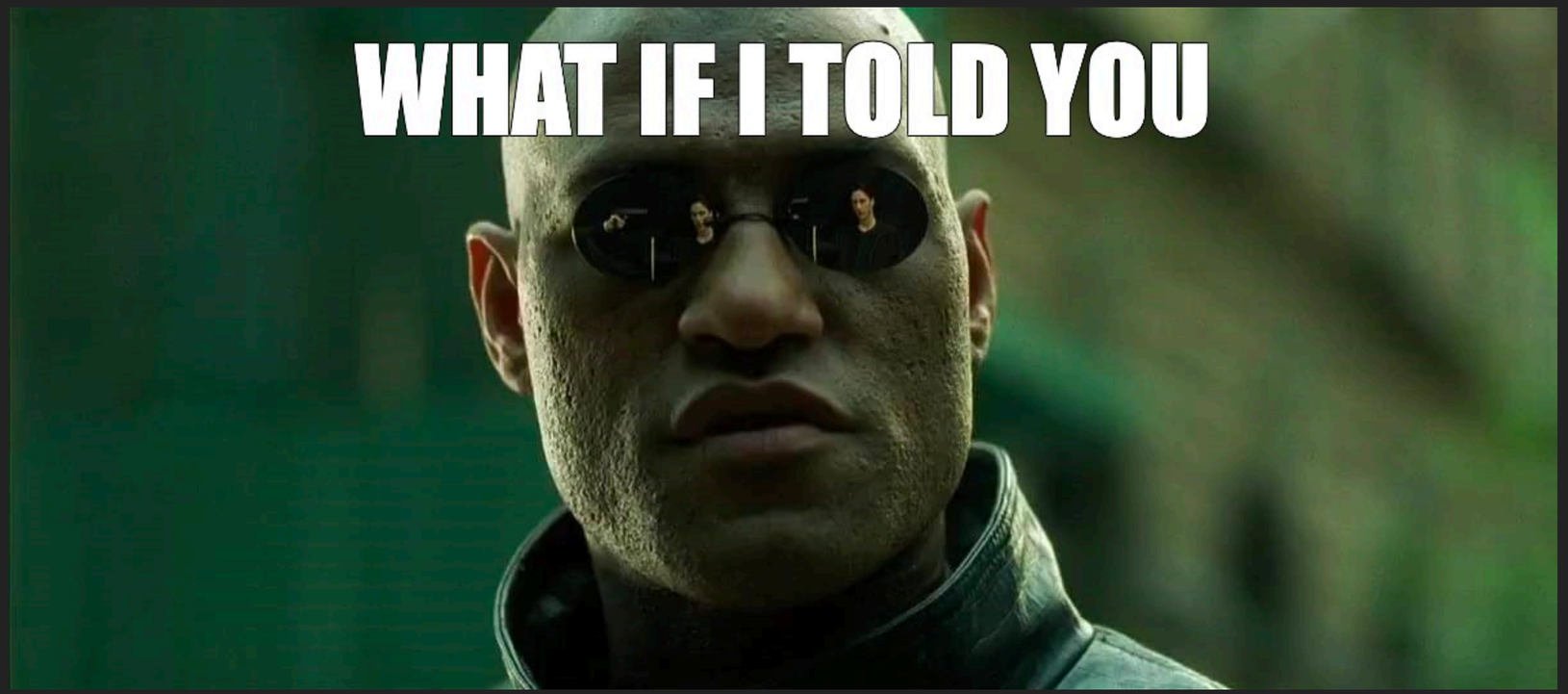
Nova Binary

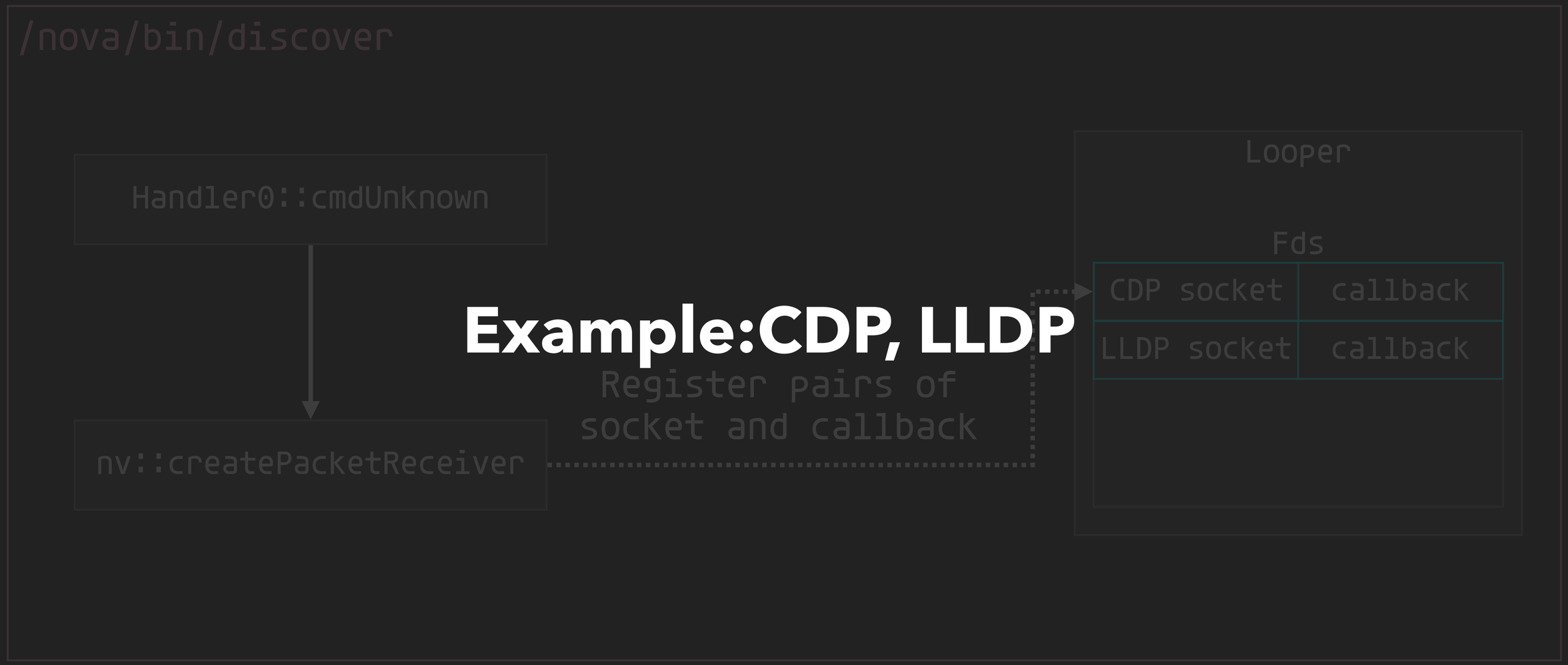
- Base class: Handler
- Derived classes: AMap, AHolder, ASecMap, AOmap, etc



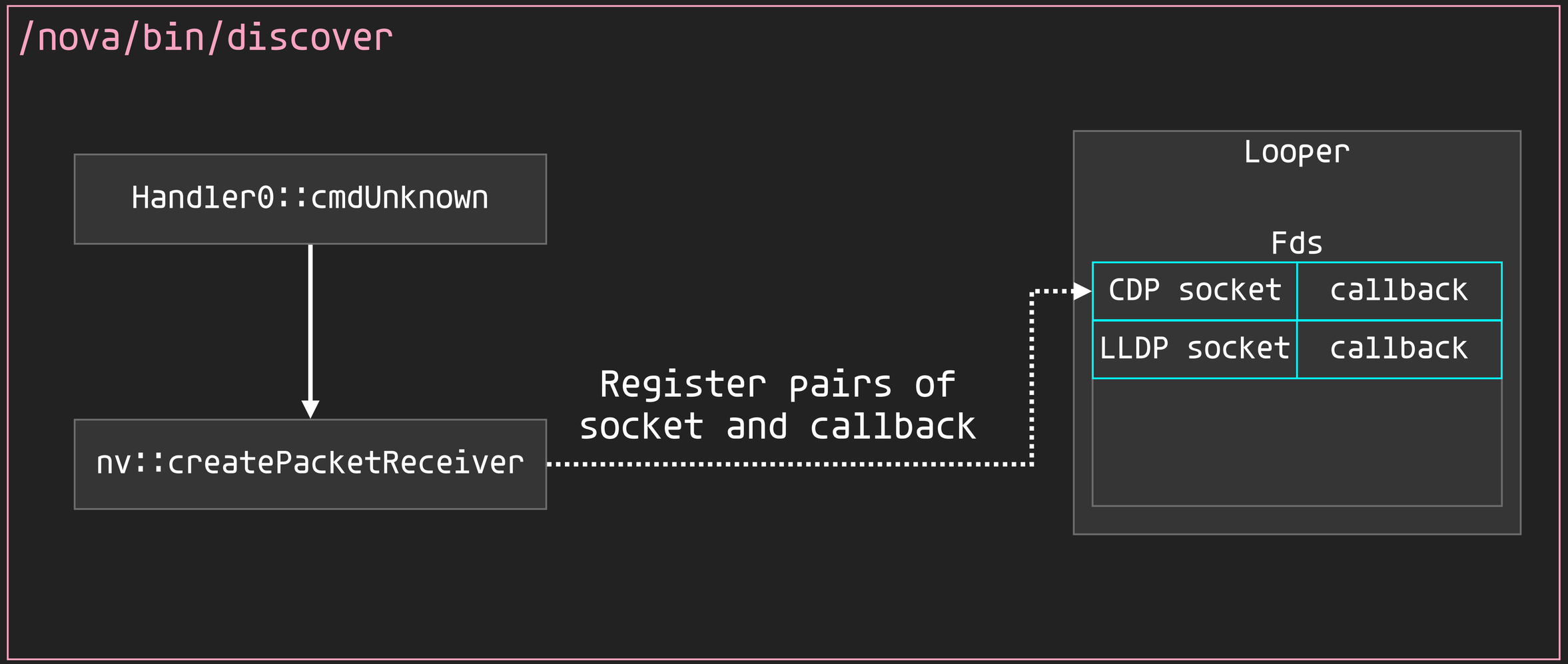
Nova Message

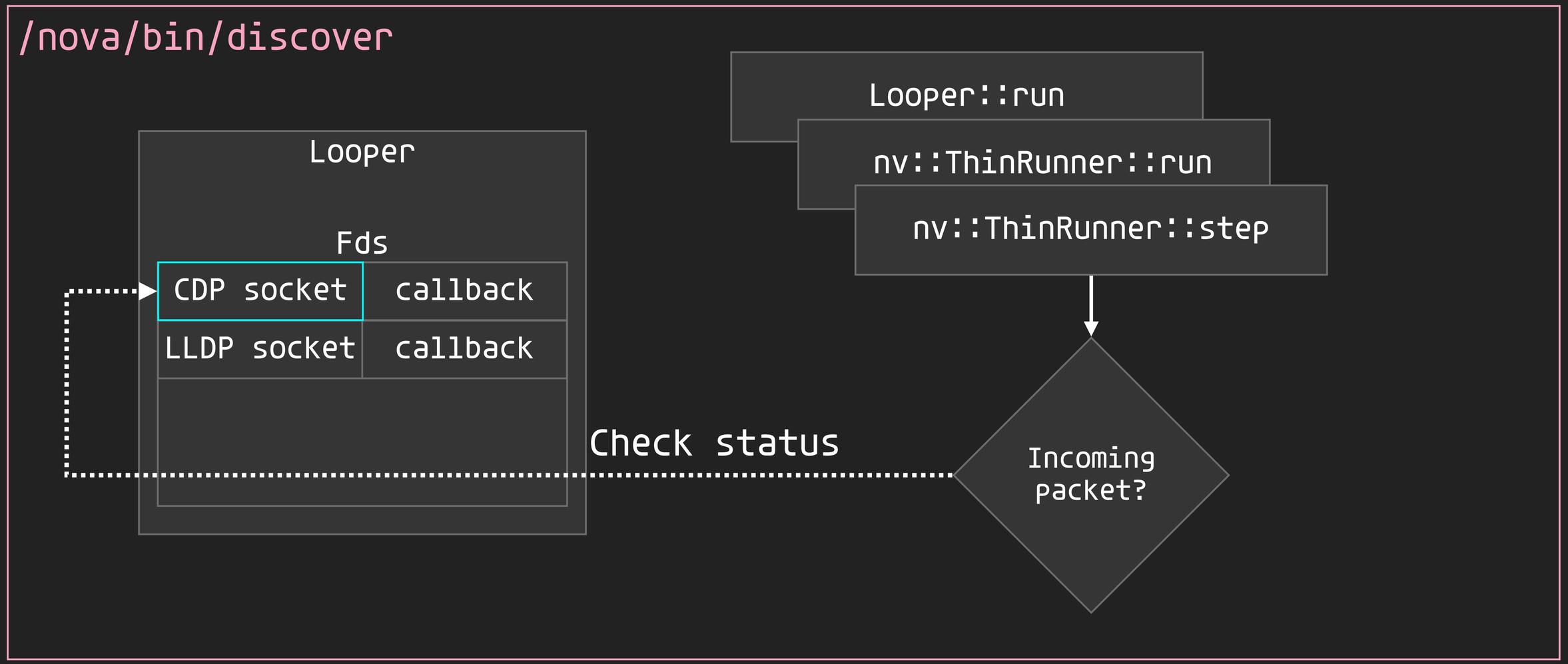
- Some functionalities don’t even use the Nova message.

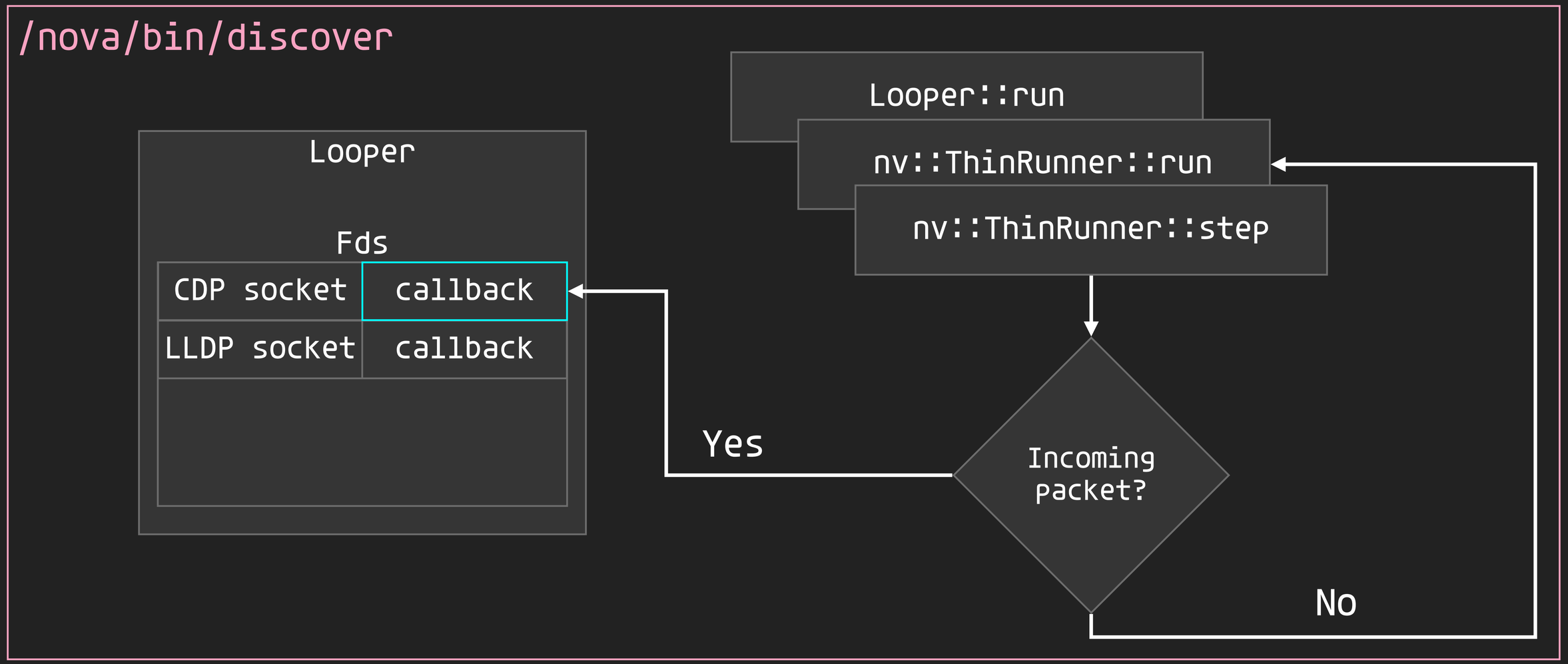


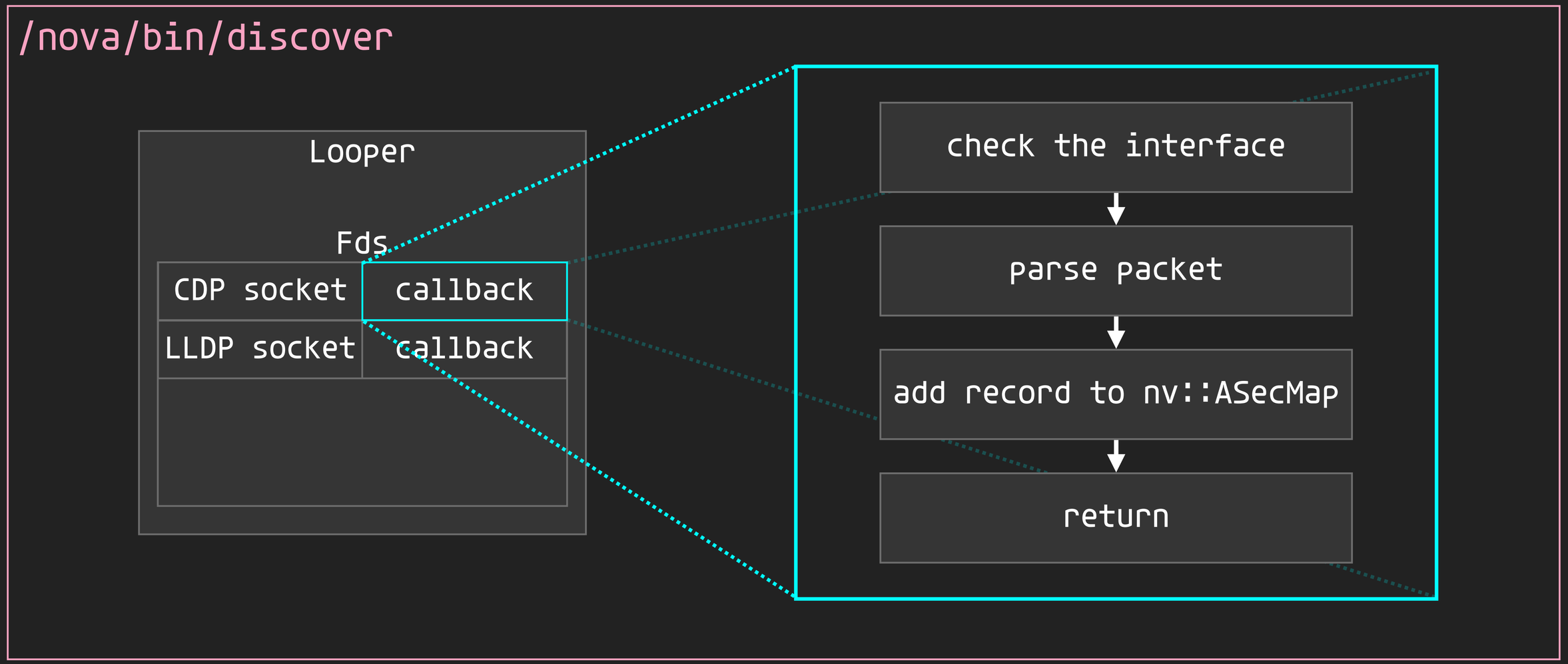


Example:CDP, LLDP









The pre-auth RCE

DEVCORE

The pre-auth RCE

- Some random crashes of radvd occur while we plugging and unplugging cables on RouterBoard

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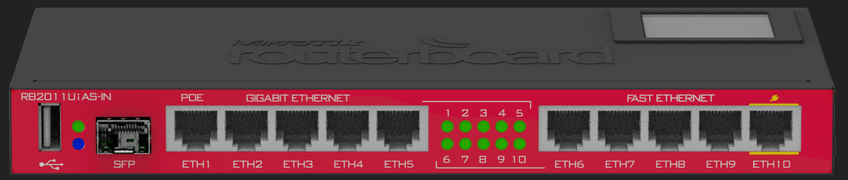
IPv6 SLAAC

ICMPv6

Router Solicitation (RS)



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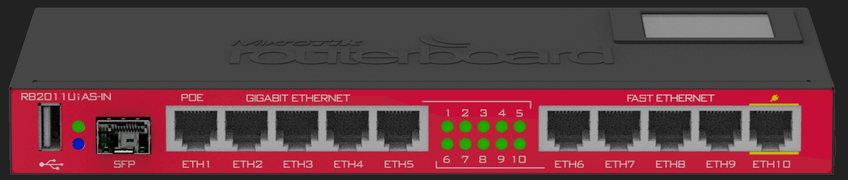
IPv6 SLAAC

ICMPv6

Router Solicitation (RS)



ICMPv6

Router Advertisement (RA)

prefix: 2001:db8::/64

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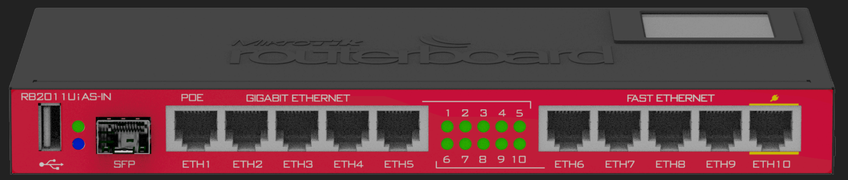
IPv6 SLAAC

IPv6 = prefix + EUI-64

ICMPv6

Router Solicitation (RS)



ICMPv6

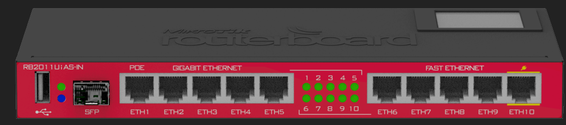
Router Advertisement (RA)

prefix: 2001:db8::/64

DEVCORE

IPv6 SLAAC

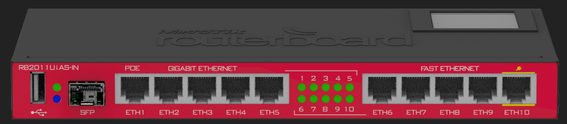
Router A



Route 2001:db8:1::/48
To ?????

link prefix

Router B



routed prefix

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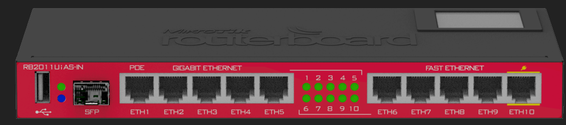
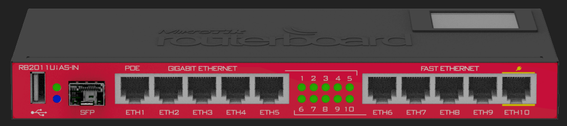
IPv6 SLAAC

Router A



Route 2001:db8:1::/48
To ?????

Router B



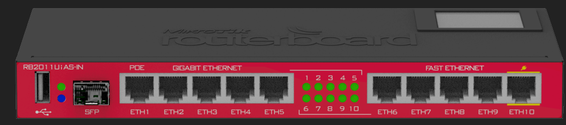
RA

prefix: 2001:db8::/64
(link prefix)

DEVCORE

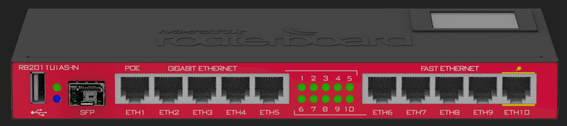
IPv6 SLAAC

Router A



Route 2001:db8:1::/48
To 2001:db8::1

Router B



2001:db8::1

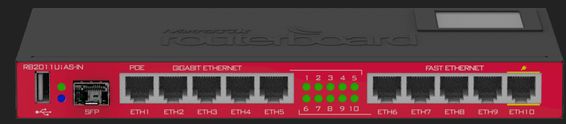
RA

prefix: 2001:db8::/64
(link prefix)

DEVCORE

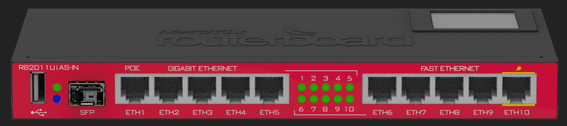
IPv6 SLAAC

Router A



Route 2001:db8:1::/48
To 2001:db8::1

Router B



2001:db8::1

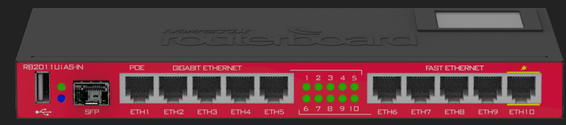
RA

prefix: 2001:db8:1::/48
(routed prefix)

DEVCORE

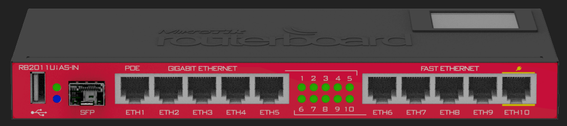
IPv6 SLAAC

Router A



Route 2001:db8:1::/48
To 2001:db8::1

Router B



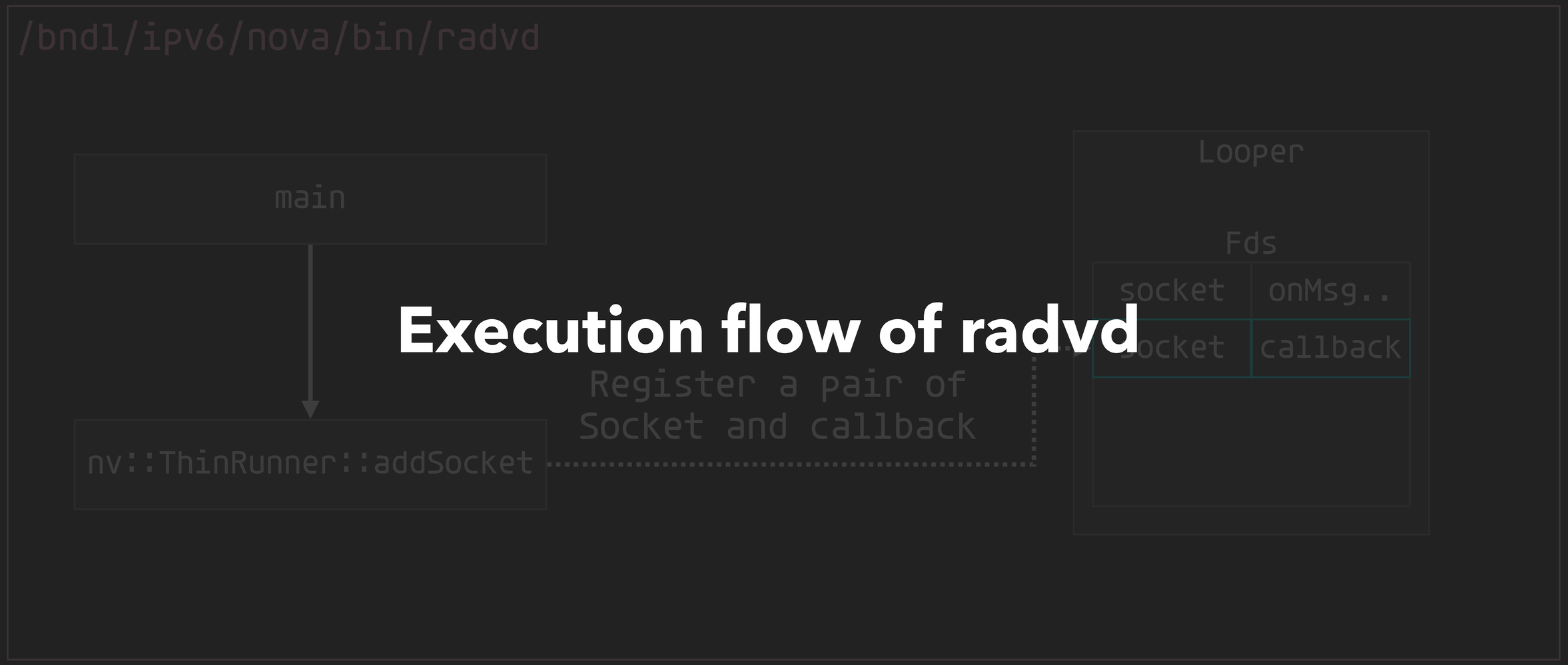
2001:db8::1

RA

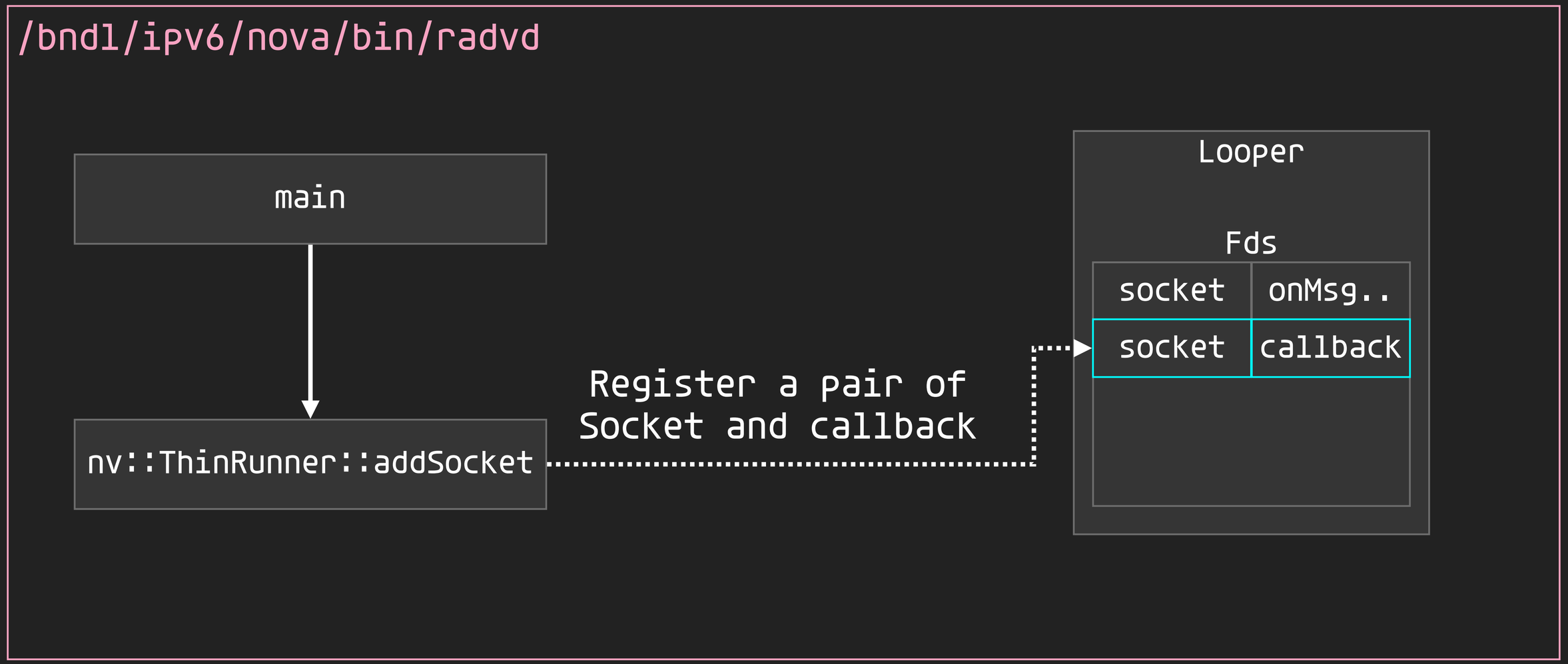
prefix: 2001:db8:1::/48
(routed prefix)

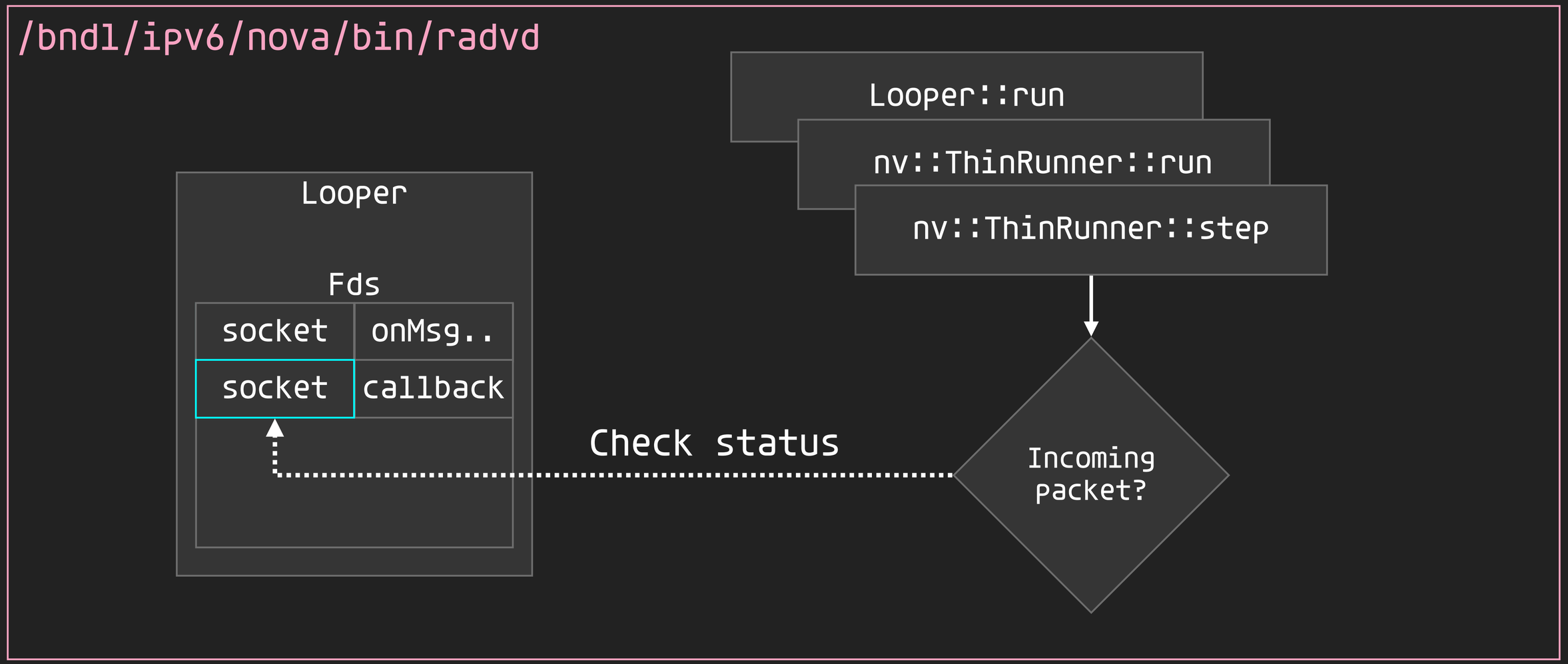
2001:db8:1::1

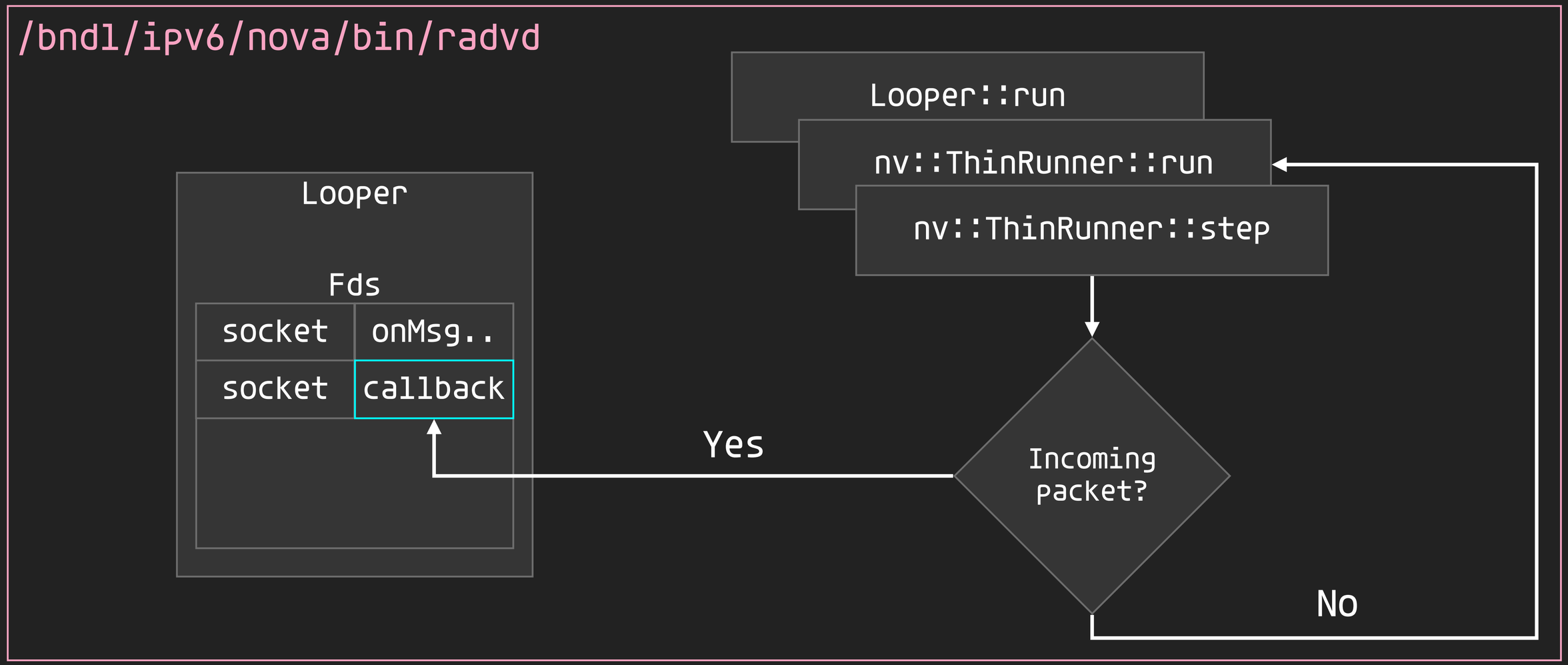
DEVCORE



Execution flow of radvd



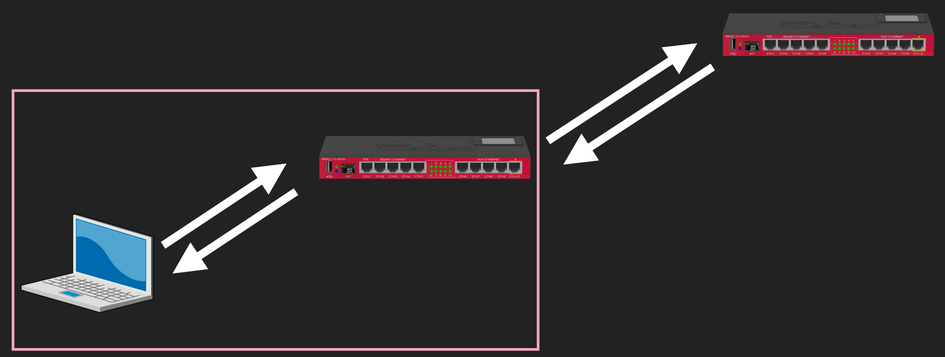




RADVD

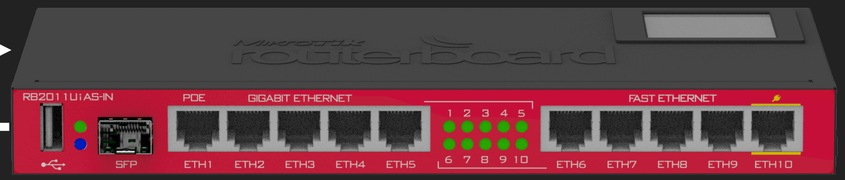
- In callback:
  - Check if the packet is a valid RA or a valid RS
  - If it is RA
    - Store information in handler 1 (AMap)
  - If it is RS
    - Multicast RA

IPv6 SLAAC



ICMPv6

Router Solicitation



ICMPv6

Router Advertisement

ICMPv6

Router Advertisement

RADVD

- In callback:
  - Check if the packet is a valid RA or a valid RS
  - If it is an RA
    - Store information in handler 1 (AMap)
  - If it is an RS
    - Multicast RA

RADVD

- Where does the radvd construct RA?
  - radvd sends RA right after it receives an RS

```
Jiffies_now = nv::getJiffies();
jiffies_start = a1->jiffies_start;
if ( jiffies_start && Jiffies_now - jiffies_start >= (unsigned int)(100 * a1->ndsetting->RADelay_d3) )
{
  sendRA_407810(a1);
  addNextTimer_407308(a1);
  return 0;
}
```

What we really care

DEVCORE

RADVD

- Where does the radvd construct RA?
  - The handler 1 registers a timer to send RA periodically

```
if ( handler_1->ndsetting )
{
  notify(handler_1, 1);
  p_Runner64 = &nv::getLooper()->Runner64;
  callback.function_ptr = RAroutine;
  callback.arg = handler_1;
  if ( ((unsigned __int8)handler_1 & 1) != 0 )
    abort();
  nv::ThinRunner::addTimer(&timer_, p_Runner64, 0x32u, (int *)&callback);
  timer = timer_;
  clean_callback(&callback);
  handler_1->timer = timer;
}
```

```
1 void __fastcall RAroutine_407F00(interface *a1)
2 {
3   a1->timer = 0;
4   sendRA_407810(a1);
5   addNextTimer_407308(a1);
6 }
```

What we really care

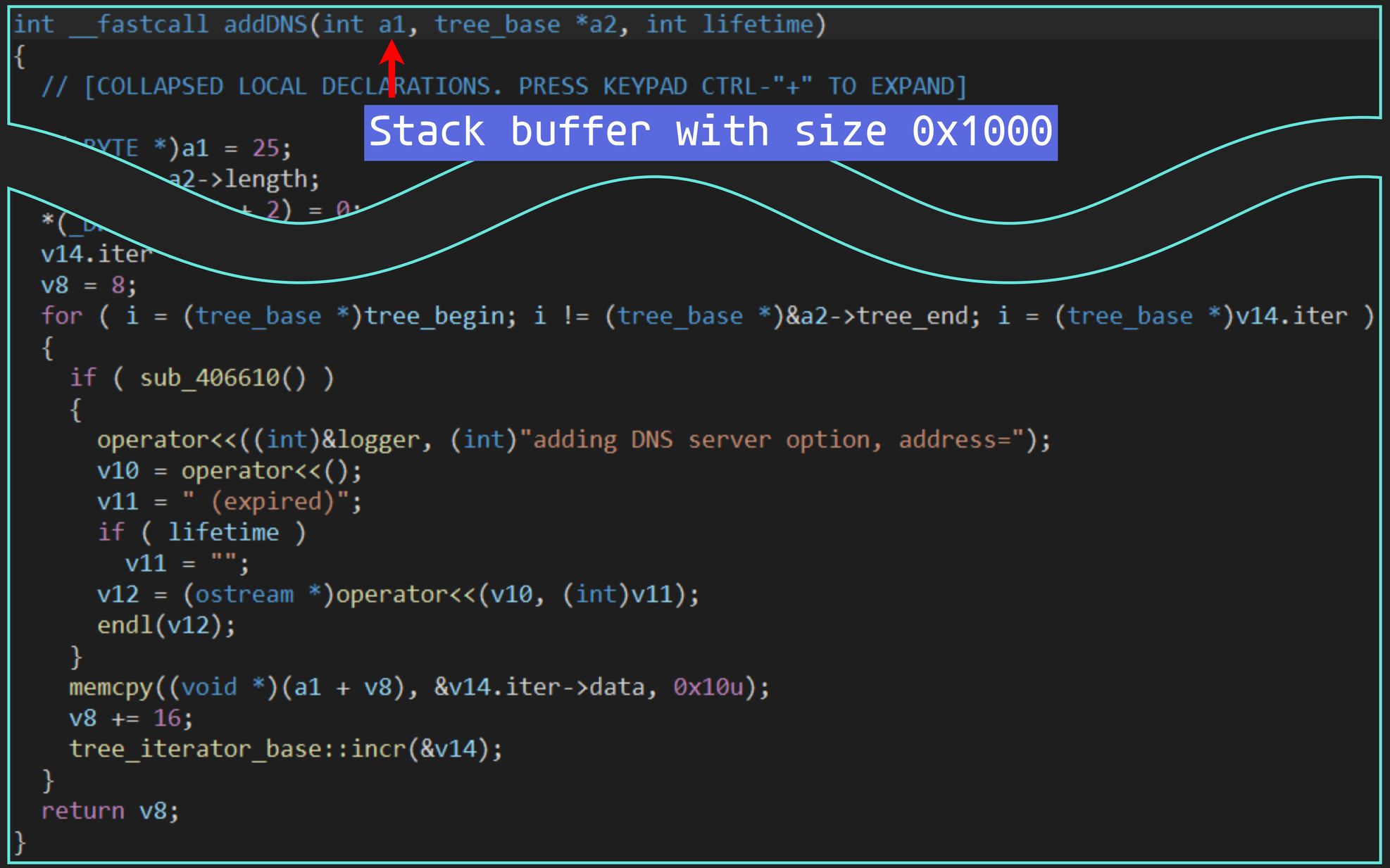
DEVCORE

RADVD

```
if ( v23->enable_advisory )
{
  lifetime = v23->lifetime;
  length = handler_1->DNS_tree.length;
  if ( length )
    length = addDNS((int)&RA_raw[pos], &handler_1->DNS_tree, (lifetime >> 1) + lifetime);
  expire_pos = length + pos;
  v32 = handler_1->expired_DNS_tree.length;
  if ( v32 )
    v32 = addDNS((int)&RA_raw[expire_pos], &handler_1->expired_DNS_tree, 0);
  pos = v32 + expire_pos;
  tree_begin = a1->prefix_tree.tree_begin;
}
else
```

Stack buffer with size 0x1000

DEVCORE



```
int __fastcall addDNS(int a1, tree_base *a2, int lifetime)
{
  // [COLLAPSED LOCAL DECLARATIONS. PRESS KEYPAD CTRL-"+" TO EXPAND]

  *(_BYTE *)a1 = 25;
  *(_WORD *)(a1 + 1) = a2->length;
  *(_BYTE *)(a1 + 2) = 0;
  *(_DWORD *)(a1 + 3) = 0;
  v14.iter = (tree_node *)a2->tree_begin.iter;
  v8 = 8;
  for ( i = (tree_base *)tree_begin; i != (tree_base *)&a2->tree_end; i = (tree_base *)v14.iter )
  {
    if ( sub_406610() )
    {
      operator<<((int)&logger, (int)"adding DNS server option, address=");
      v10 = operator<<();
      v11 = " (expired)";
      if ( lifetime )
        v11 = "";
      v12 = (ostream *)operator<<(v10, (int)v11);
      endl(v12);
    }
    memcpy((void *)(a1 + v8), &v14.iter->data, 0x10u);
    v8 += 16;
    tree_iterator_base::incr(&v14);
  }
  return v8;
}
```

Stack buffer with size 0x1000

No boundary check,

overflow if the tree is big enough

5.1. Recursive DNS Server Option

The RDNSS option contains one or more IPv6 addresses of RDNSSes. All of the addresses share the same Lifetime value. If it is desirable to have different Lifetime values, multiple RDNSS options can be used. Figure 1 shows the format of the RDNSS option.

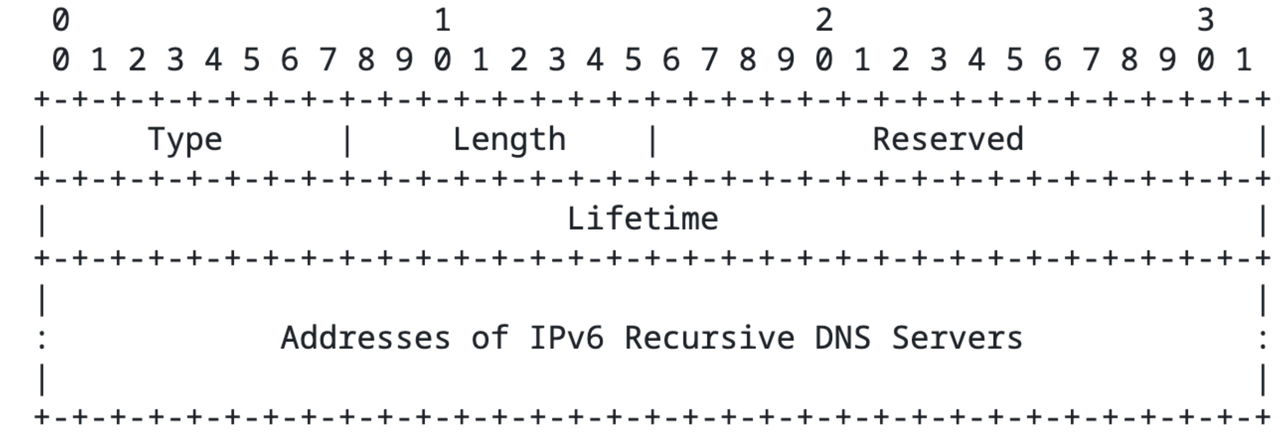


Figure 1: RDNSS Option Format

Fields:

Type 8-bit identifier of the RDNSS option type as assigned by IANA: 25

Length 8-bit unsigned integer. The length of the option (including the Type and Length fields) is in units of 8 octets. The minimum value is 3 if one IPv6 address is contained in the option. Every additional RDNSS address increases the length by 2. The Length field is used by the receiver to determine the number of IPv6 addresses in the option.

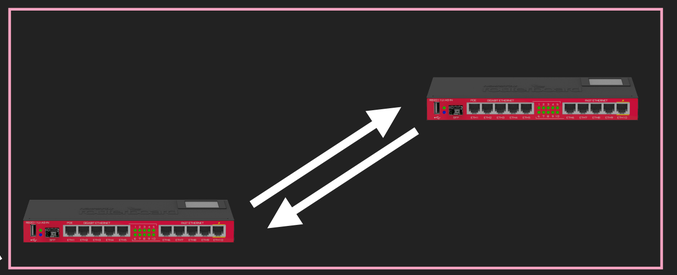
RADVD

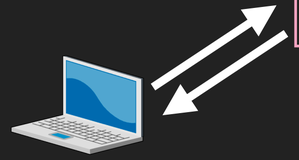
```
if ( v23->enable_advisory )
{
  lifetime = v23->lifetime;
  length = handler_1->DNS_tree.length;
  if ( length )
    length = addDNS((int)&RA_raw[pos], &handler_1->DNS_tree, (lifetime >> 1) + lifetime);
  expire_pos = length + pos;
  v32 = handler_1->expired_DNS_tree.length;
  if ( v32 )
    v32 = addDNS((int)&RA_raw[expire_pos], &handler_1->expired_DNS_tree, 0);
  pos = v32 + expire_pos;
  tree_begin = a1->prefix_tree.tree_begin;
}
else
```

Stack buffer with size 0x1000

DEVCORE

IPv6 SLAAC

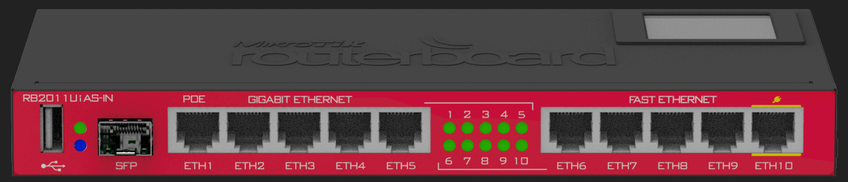


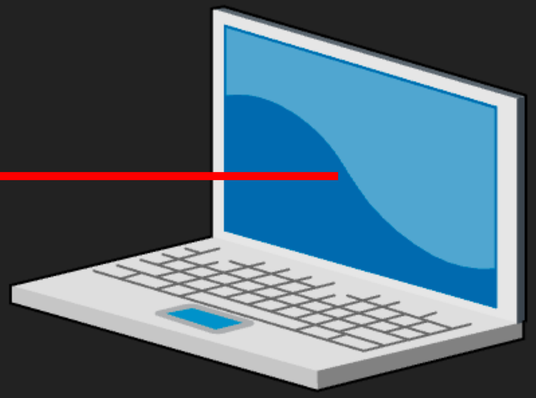


ICMPv6

Router Advertisement (RA)

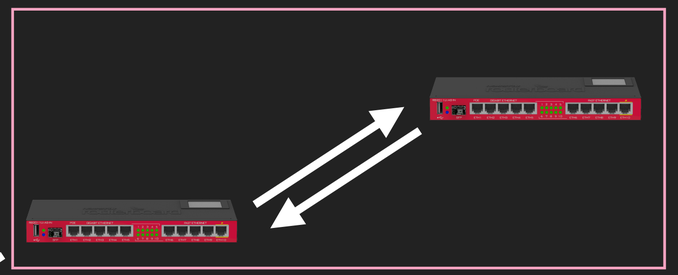
RDNSS: <a big list>





DEVCORE

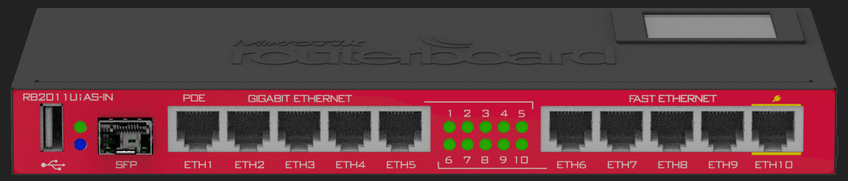
IPv6 SLAAC

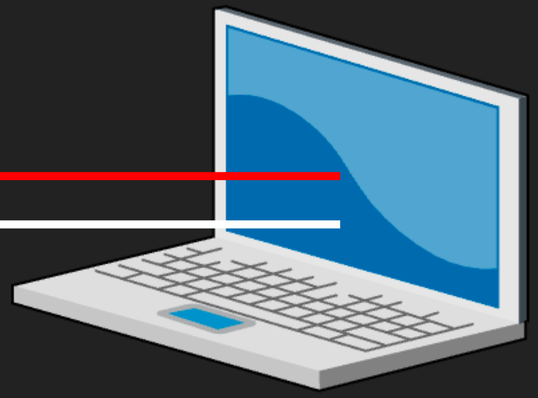


ICMPv6

```
Router Advertisement (RA)
```

RDNSS: <a big list>



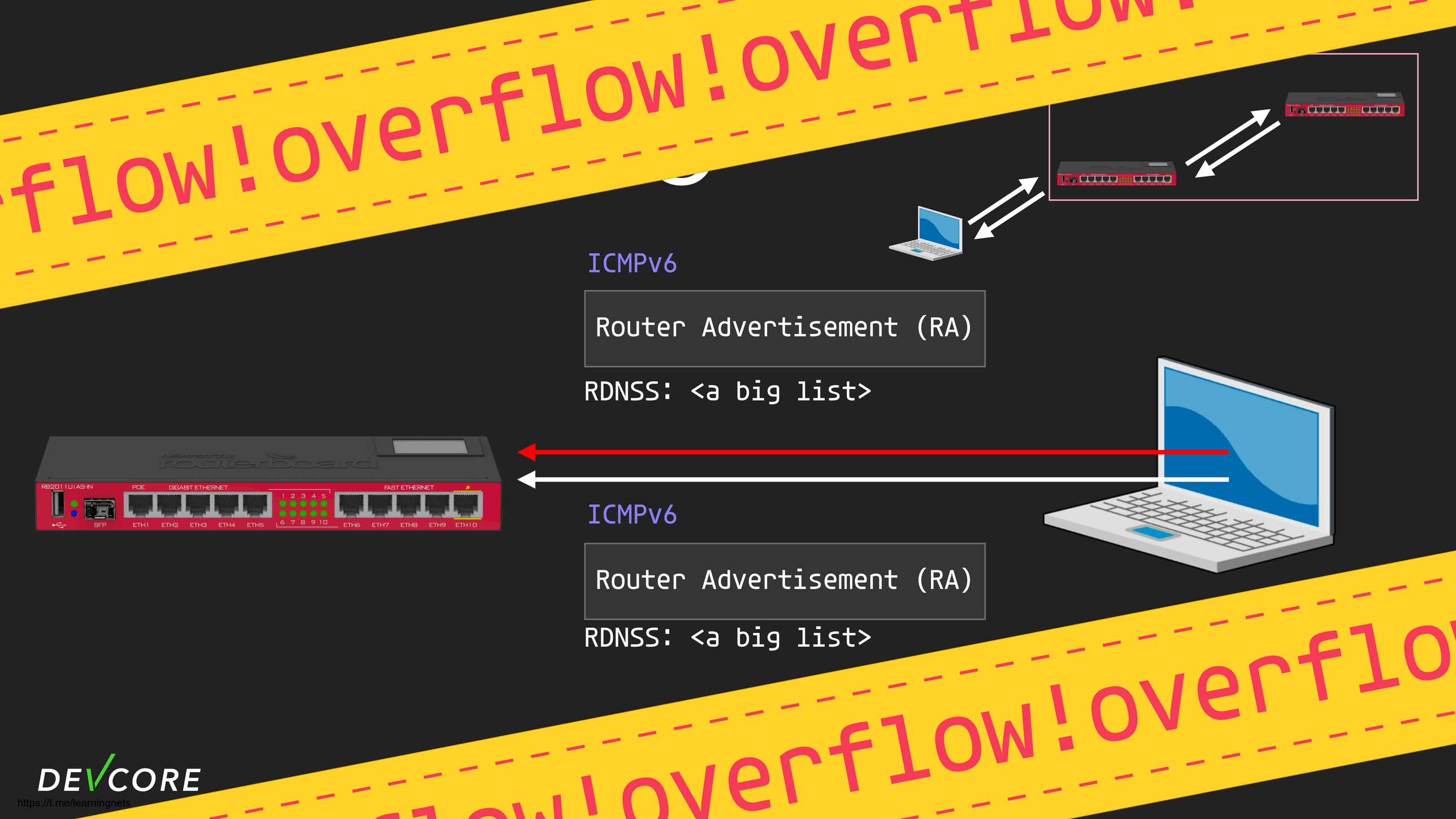


ICMPv6

```
Router Advertisement (RA)
```

RDNSS: <a big list>

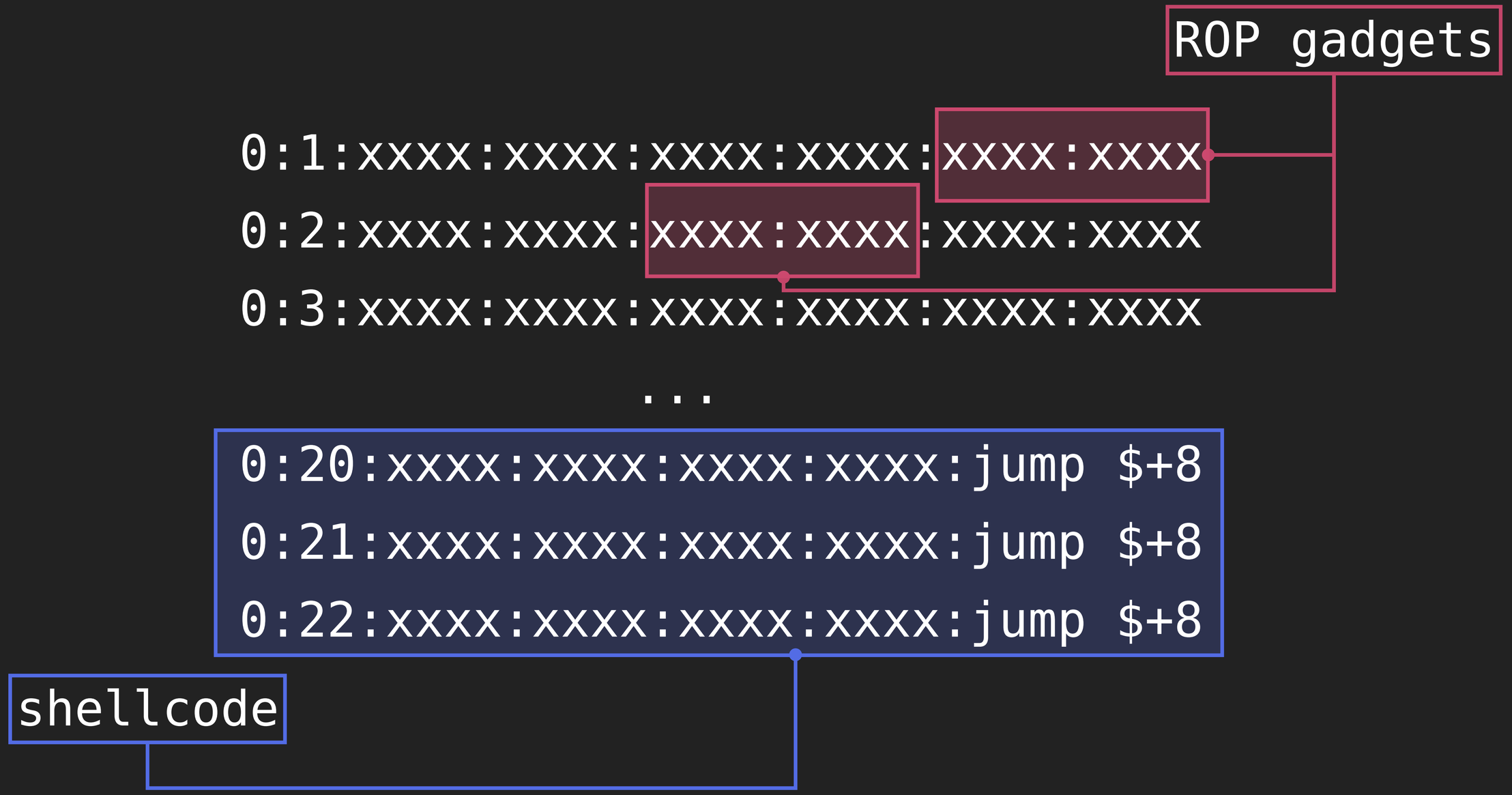
DEVCORE

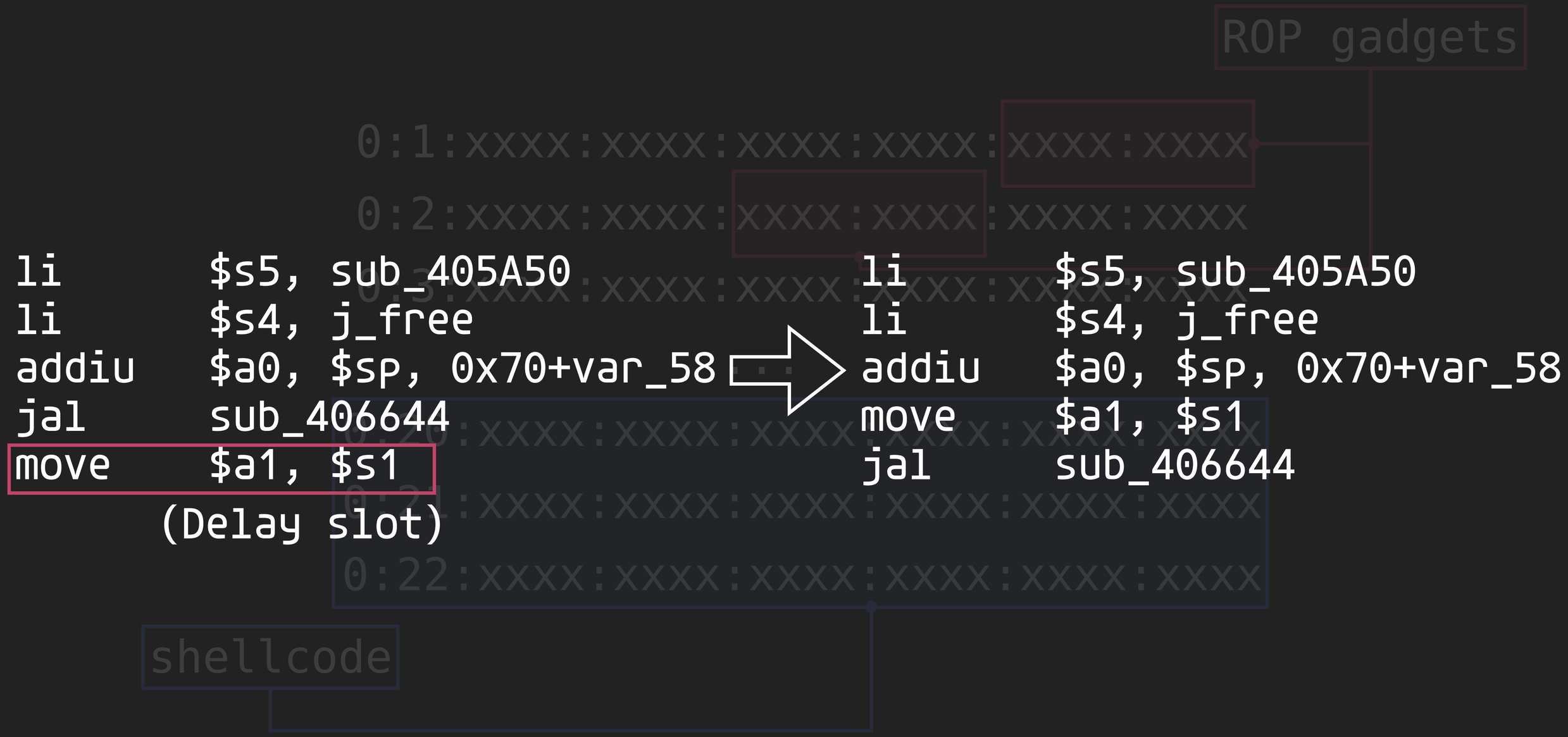

flow!overflow!overflow
ICMPv6
Router Advertisement (RA)
RDNSS: <a big list>
ICMPv6
Router Advertisement (RA)
RDNSS: <a big list>
flow!overflow!overflow
DEVCORE
https://t.me/learningnets

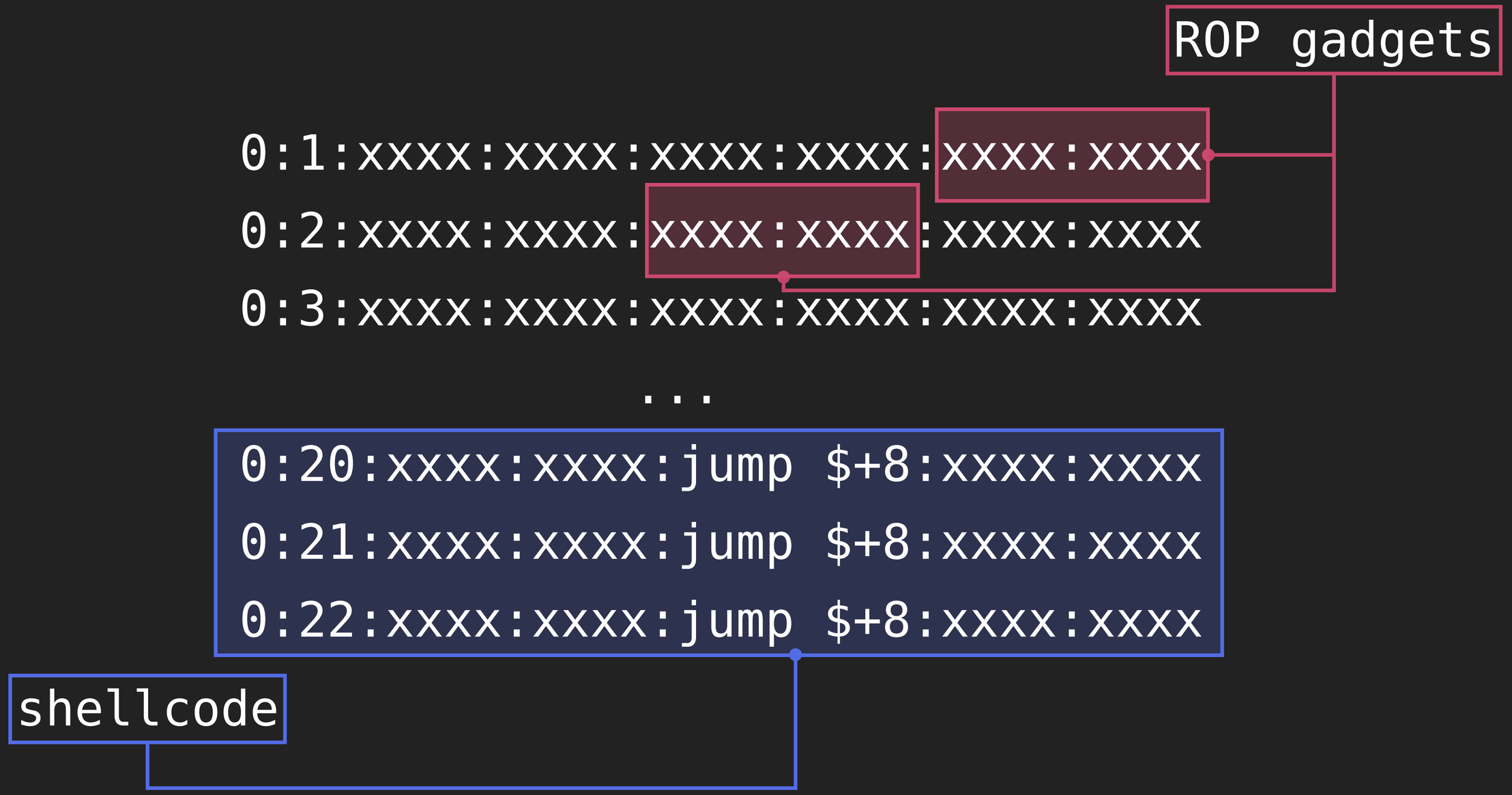
```
[*] '/tmp/radvd'
    Arch:     mips-32-big
    RELRO:    No RELRO
    Stack:    No canary found
    NX:       NX disabled
    PIE:      No PIE (0x400000)
    RWX:      Has RWX segments
ELF('/tmp/radvd')
```

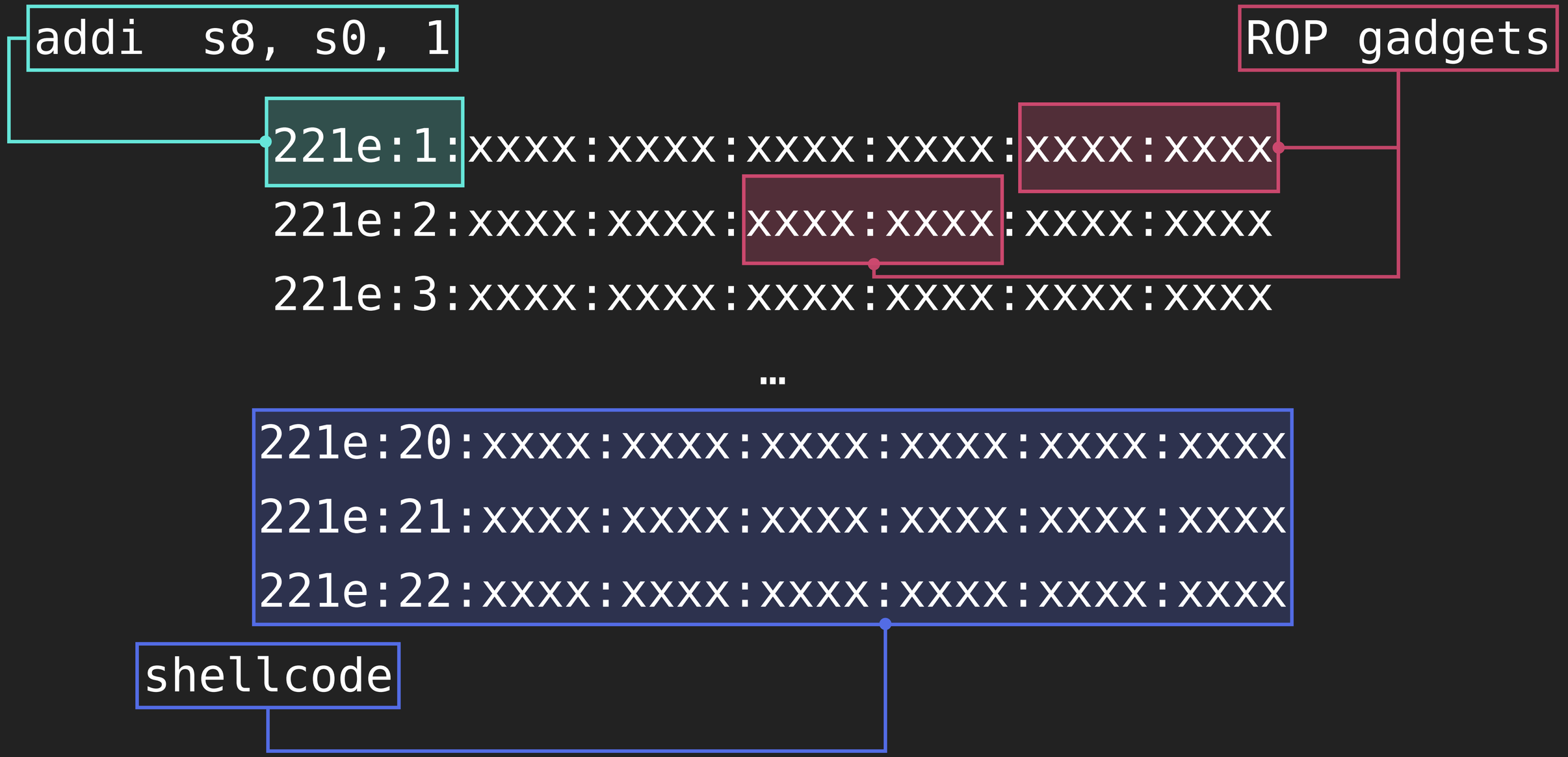
DEVCORE

Credit: @__ammar2__

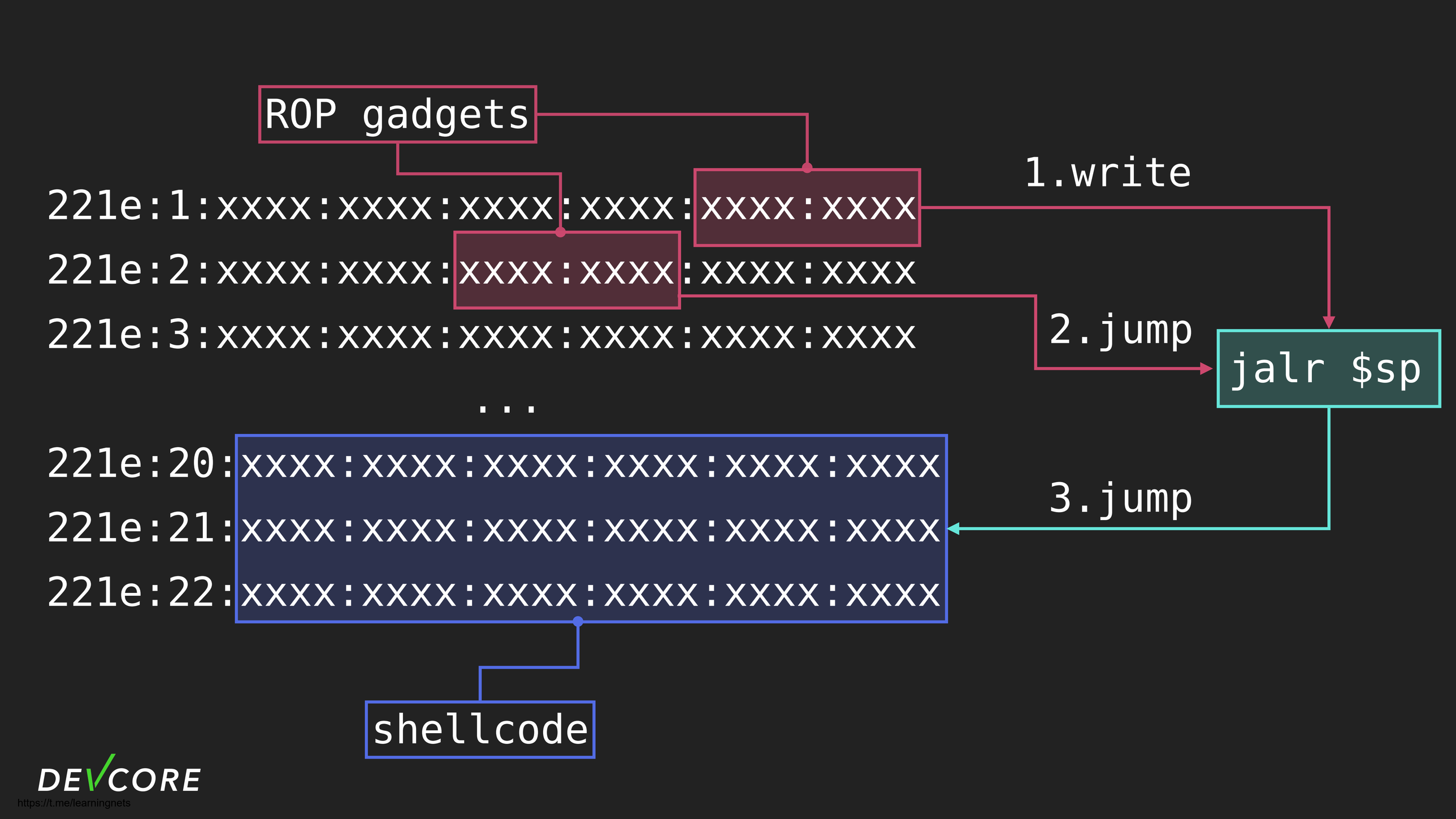


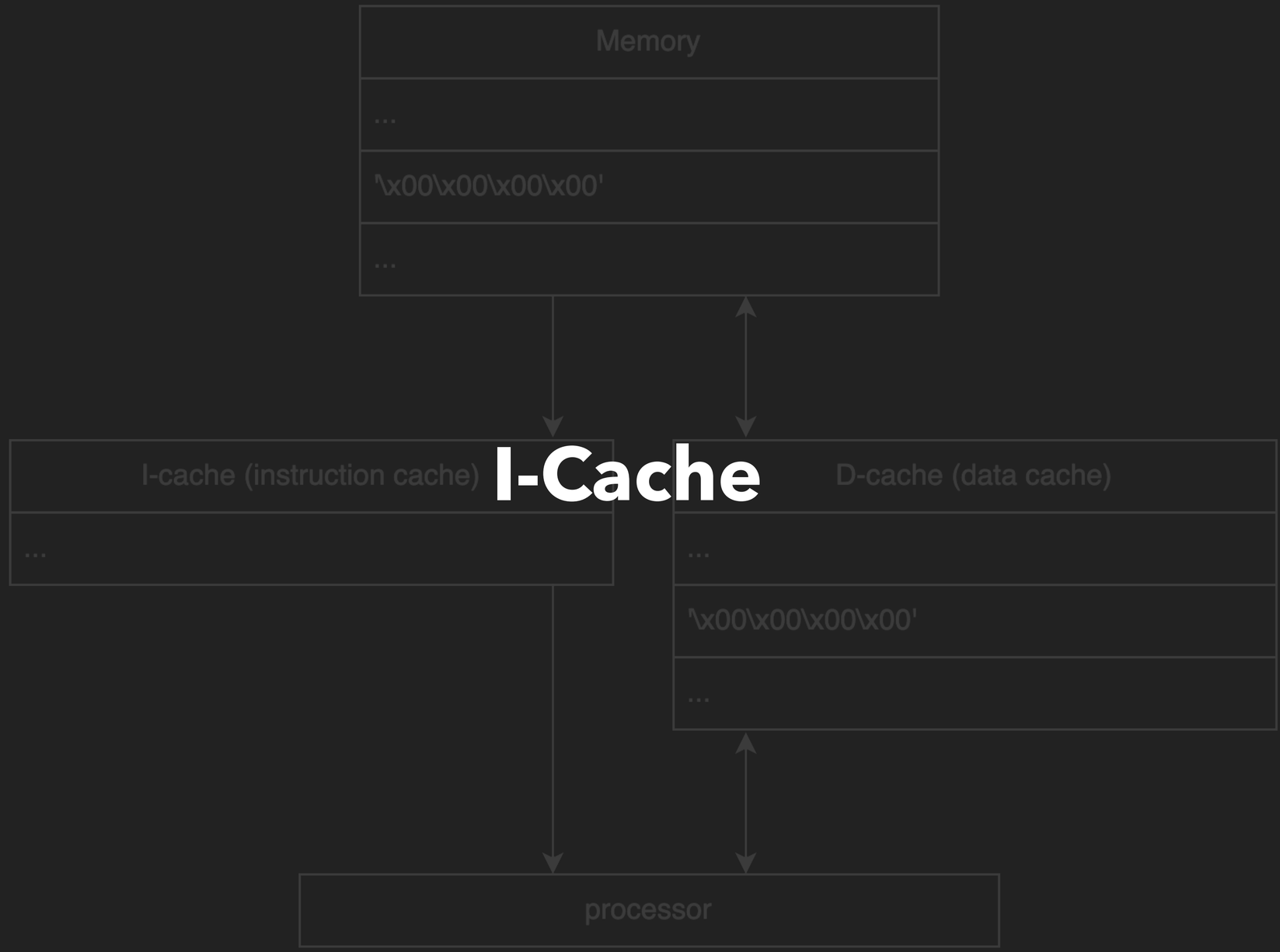




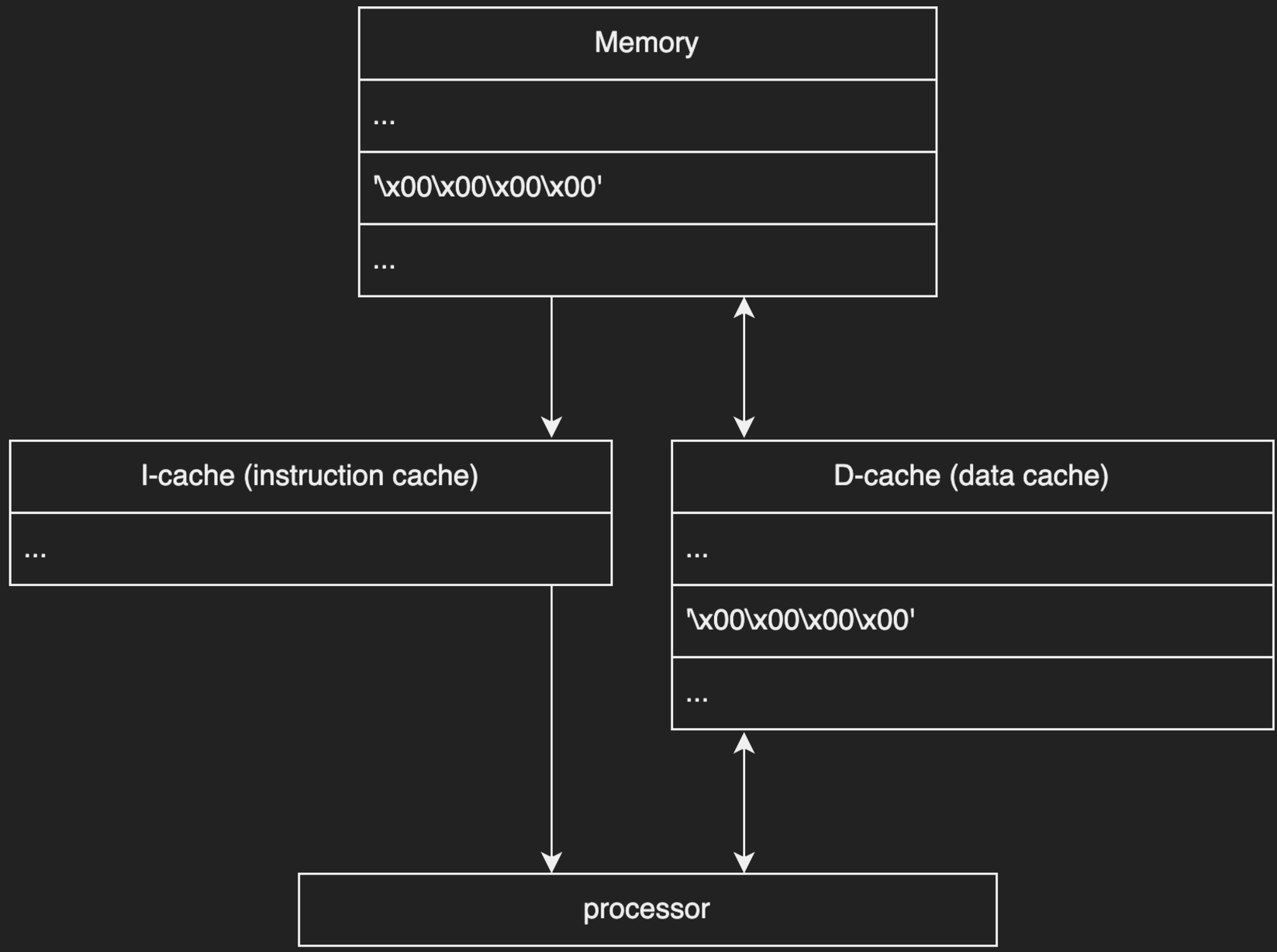


DEVCORE

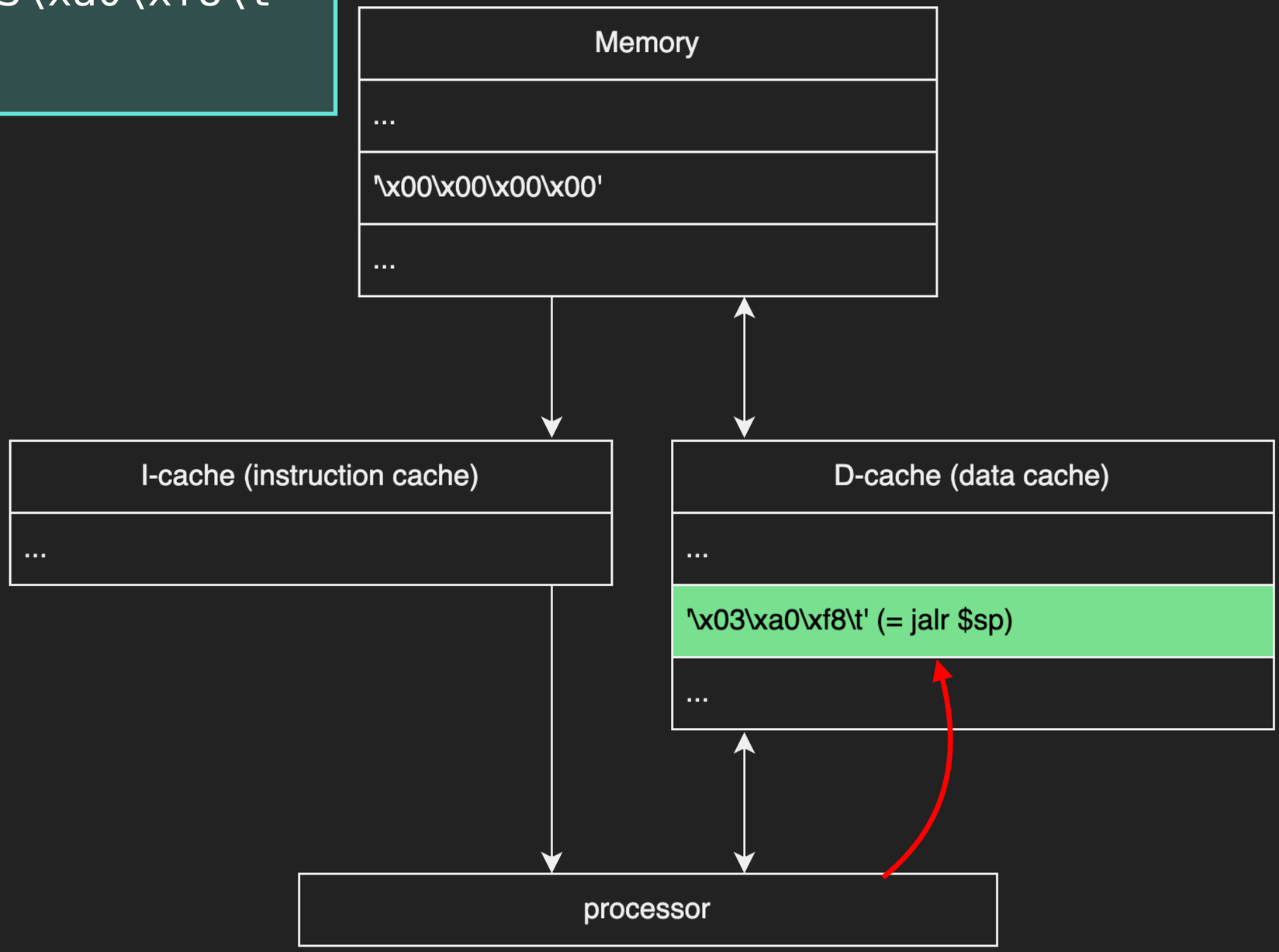




I-Cache

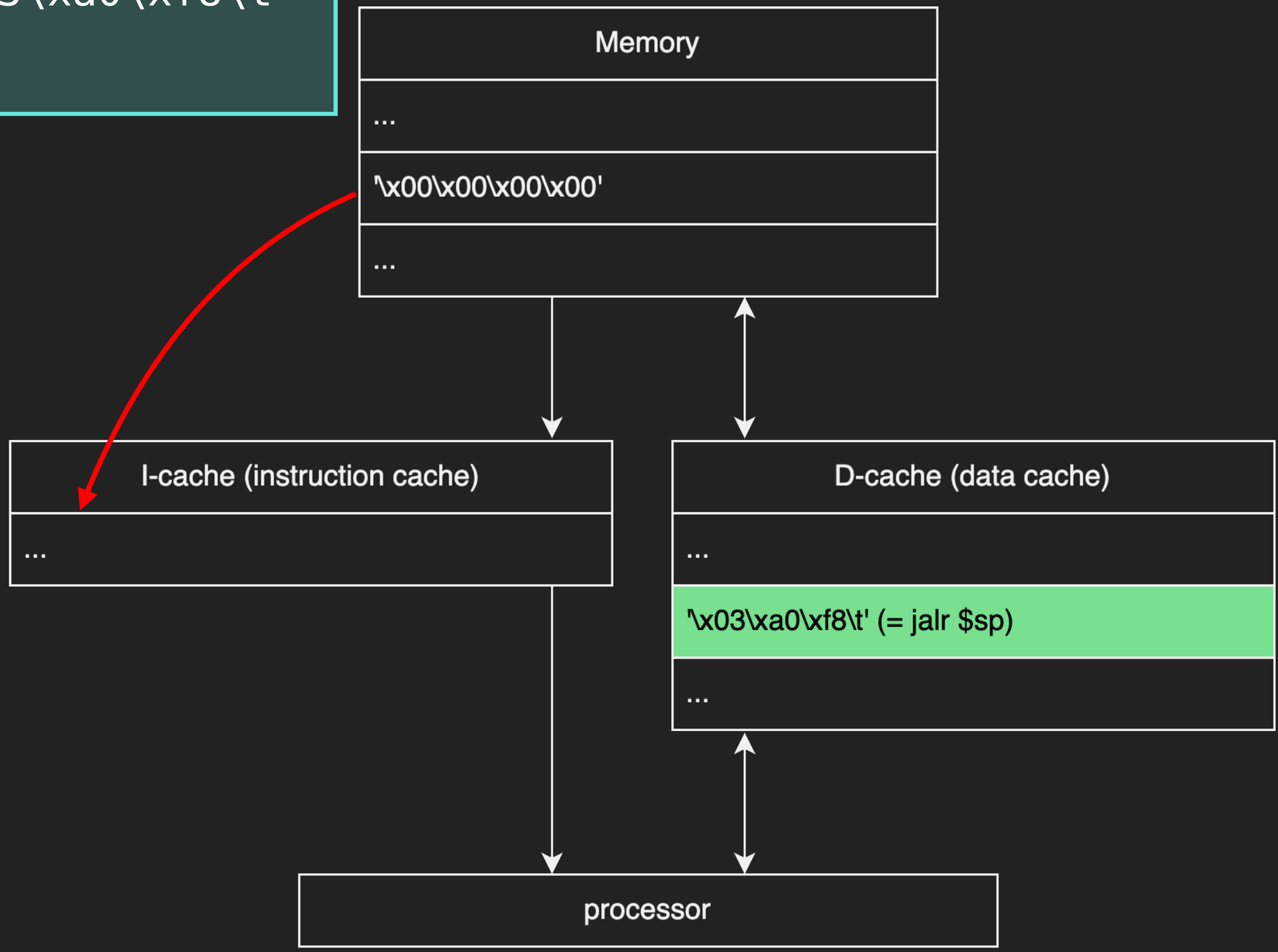


```
write adr,’\x03\xa0\xf8\t’
```



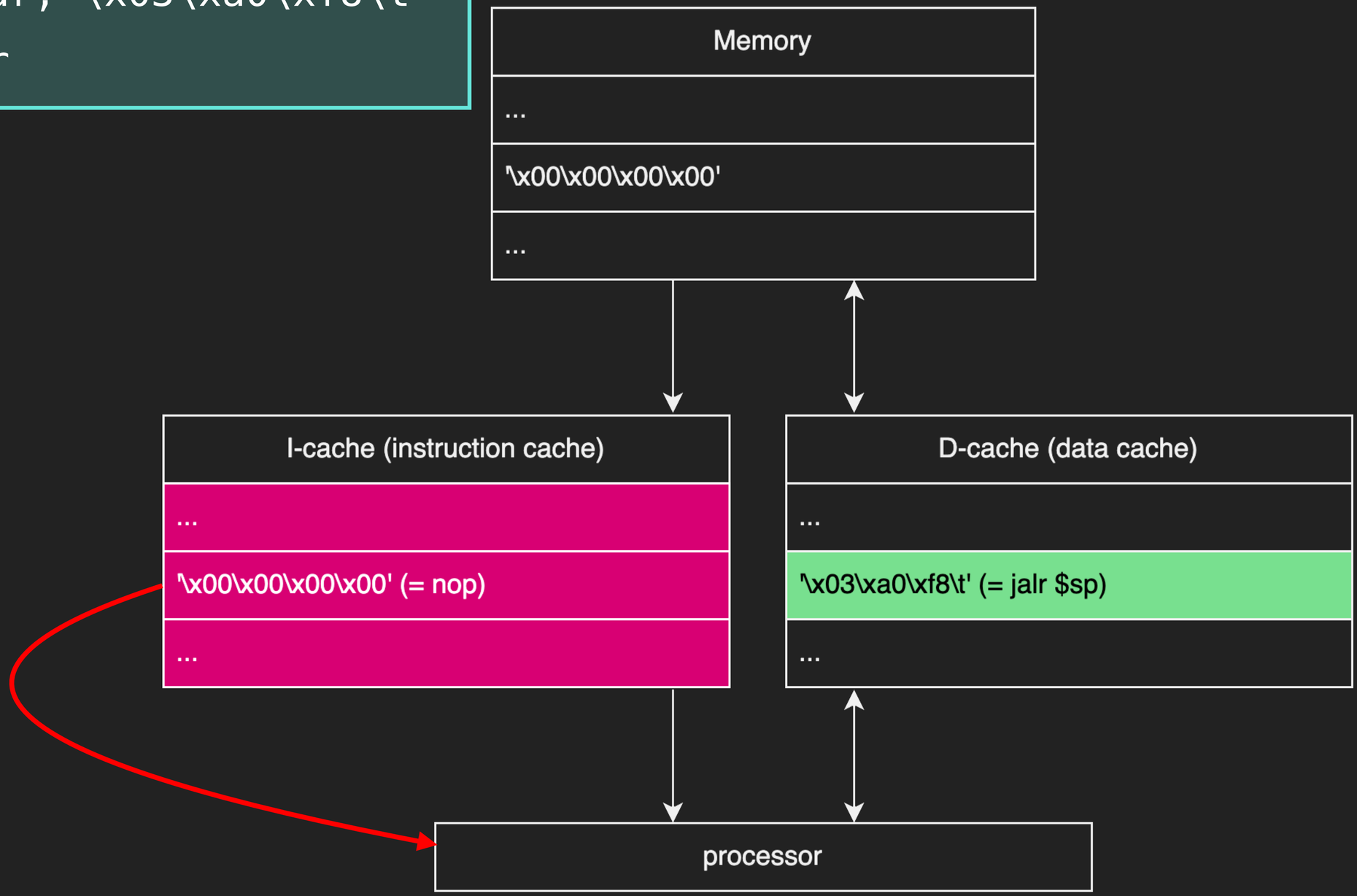
DEVCORE

```
write adr,’\x03\xa0\xf8\t’
jump adr
```

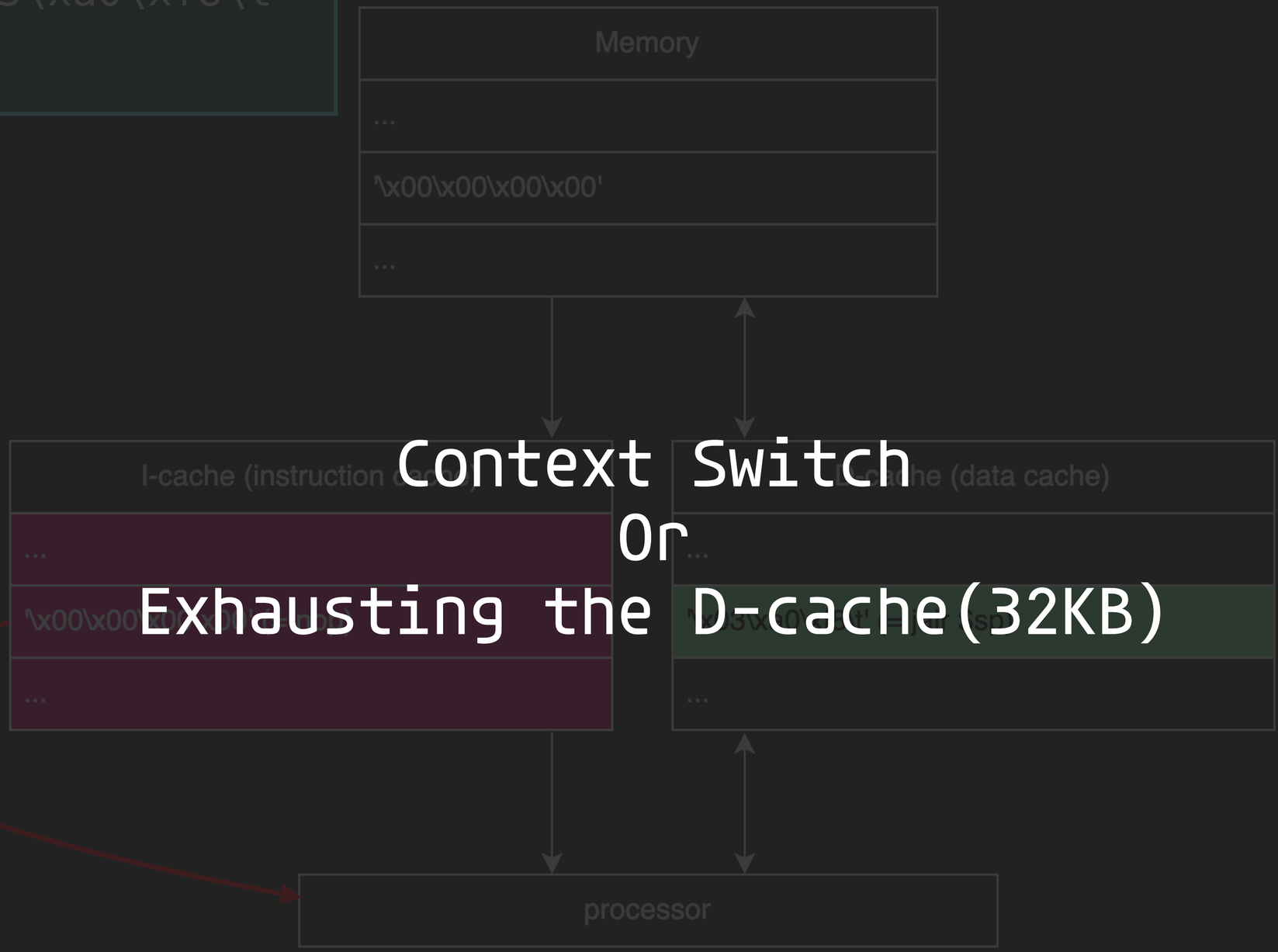


DEVCORE

```
write adr,’\x03\xa0\xf8\t’
jump adr
```



```
write adr,'\x03\xa0\xf8\t'
jump adr
```



Context Switch
Or
Exhausting the D-cache(32KB)

DEVCORE

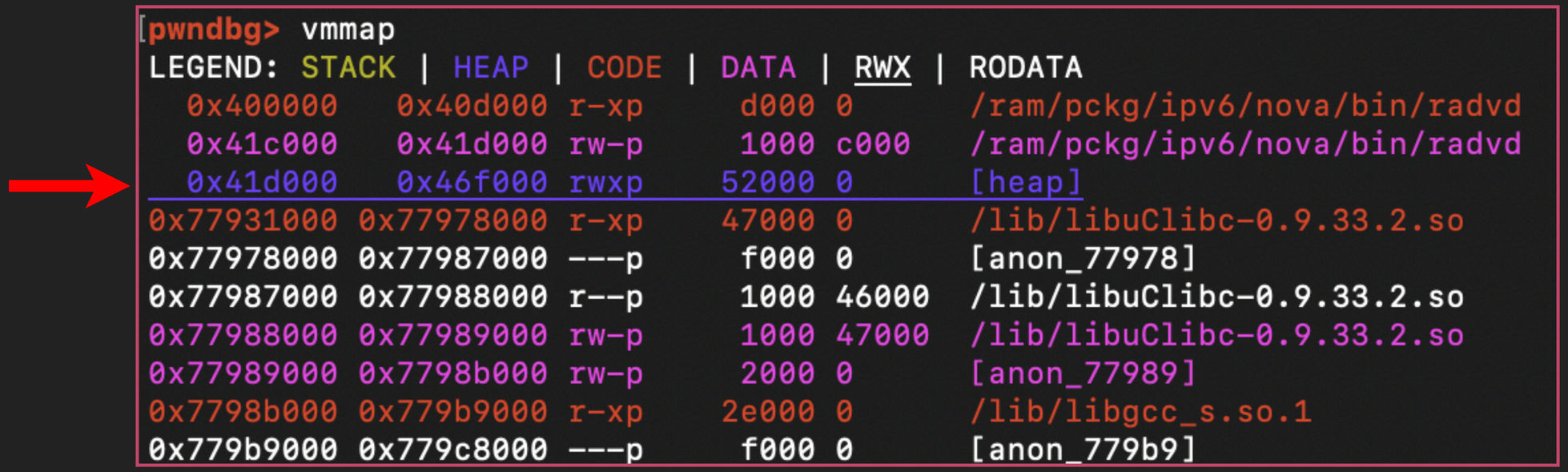
```
cat /proc/sys/kernel/randomize_va_space
1
```

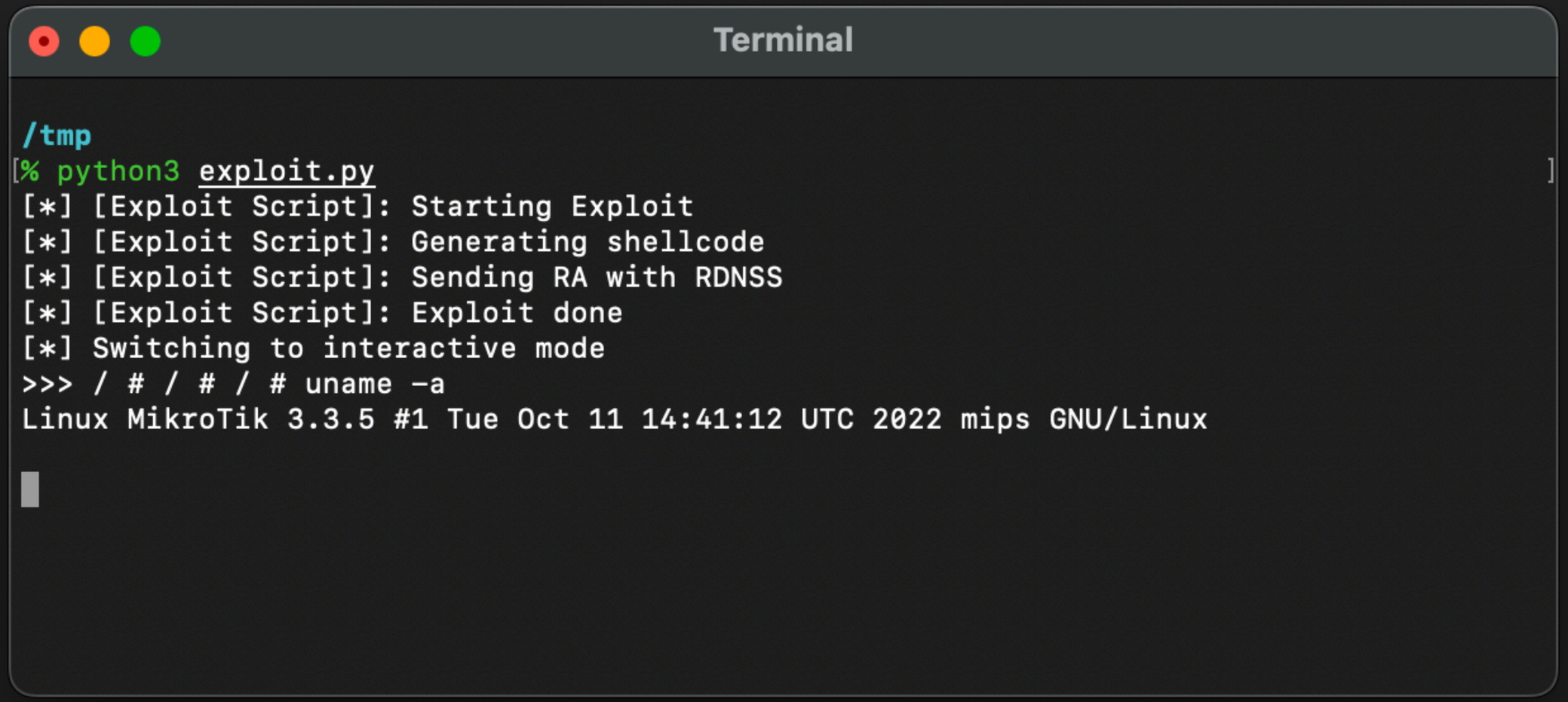
```
[pwndbg> vmmap
LEGEND: STACK | HEAP | CODE | DATA | RWX | RODATA
  0x400000   0x40d000 r-xp     d000 0      /ram/pckg/ipv6/nova/bin/radvd
  0x41c000   0x41d000 rw-p     1000 c000   /ram/pckg/ipv6/nova/bin/radvd
  0x41d000   0x427000 rwxp     a000 0      [heap]
0x77031000 0x77078000 r-xp    47000 0      /lib/libuClibc-0.9.33.2.so
0x77078000 0x77087000 ---p     f000 0      [anon_77078]
0x77087000 0x77088000 r--p     1000 46000  /lib/libuClibc-0.9.33.2.so
0x77088000 0x77089000 rw-p     1000 47000  /lib/libuClibc-0.9.33.2.so
0x77089000 0x7708b000 rw-p     2000 0      [anon_77089]
0x7708b000 0x770b9000 r-xp    2e000 0      /lib/libgcc_s.so.1
0x770b9000 0x770c8000 ---p     f000 0      [anon_770b9]
0x770c8000 0x770c9000 rw-p     1000 2d000  /lib/libgcc_s.so.1
```

RADVD

```
if ( v23->enable_advisory )
{
  lifetime = v23->lifetime;
  length = handler_1->DNS_tree.length;
  if ( length )
    length = addDNS((int)&RA_raw[pos], &handler_1->DNS_tree, (lifetime >> 1) + lifetime);
  expire_pos = length + pos;
  v32 = handler_1->expired_DNS_tree.length;
  if ( v32 )
    v32 = addDNS((int)&RA_raw[expire_pos], &handler_1->expired_DNS_tree, 0);
  pos = v32 + expire_pos;
  tree_begin = a1->prefix_tree.tree_begin;
}
else
```

DEVCORE





DEVCORE

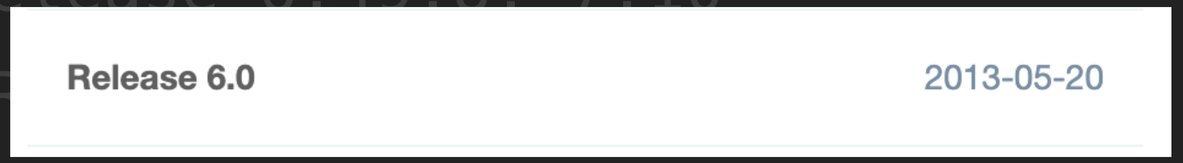
CVE-2023-32154

- Fixed at:
  - Long-term Release 6.48.7
  - Stable Release 6.49.8, 7.10
  - Testing Release 7.10rc6
- The vulnerable code has existed at least since v6.0

DEVCORE

CVE-2023-32154

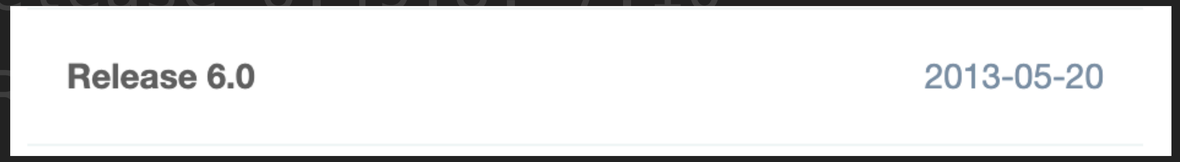
- Fixed at:
  - Long-term Release 6.48.7
  - Stable Release 6.49.8, 7.10
  - Testing R
- The vulnerable code has existed at least since v6.0



CVE-2023-32154

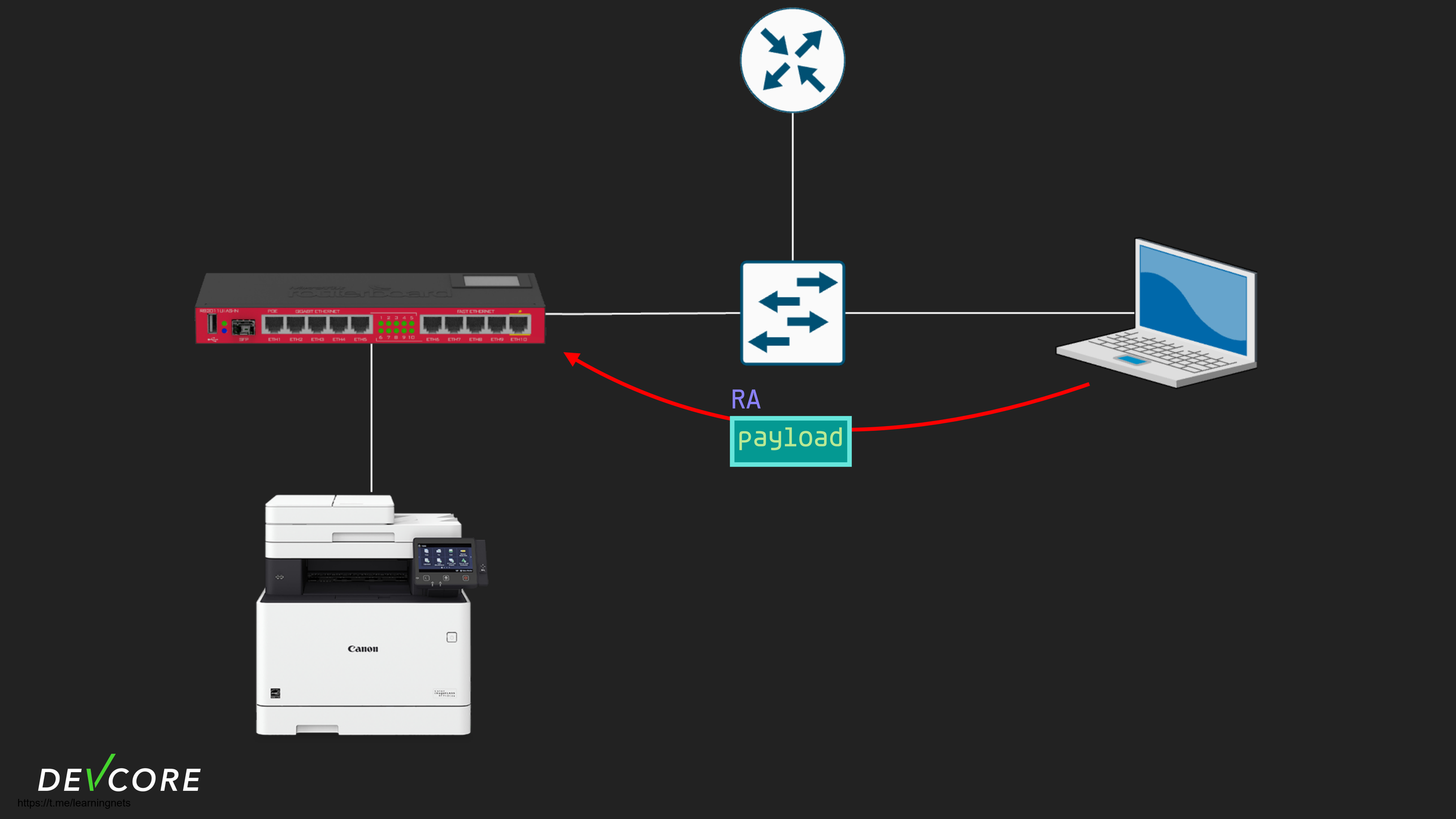
- Fixed at:
  - Long-term Release 6.48.7
  - Stable Release 6.49.8, 7.10
  - Testing R
- The vulnerable code has existed at least since v6.0

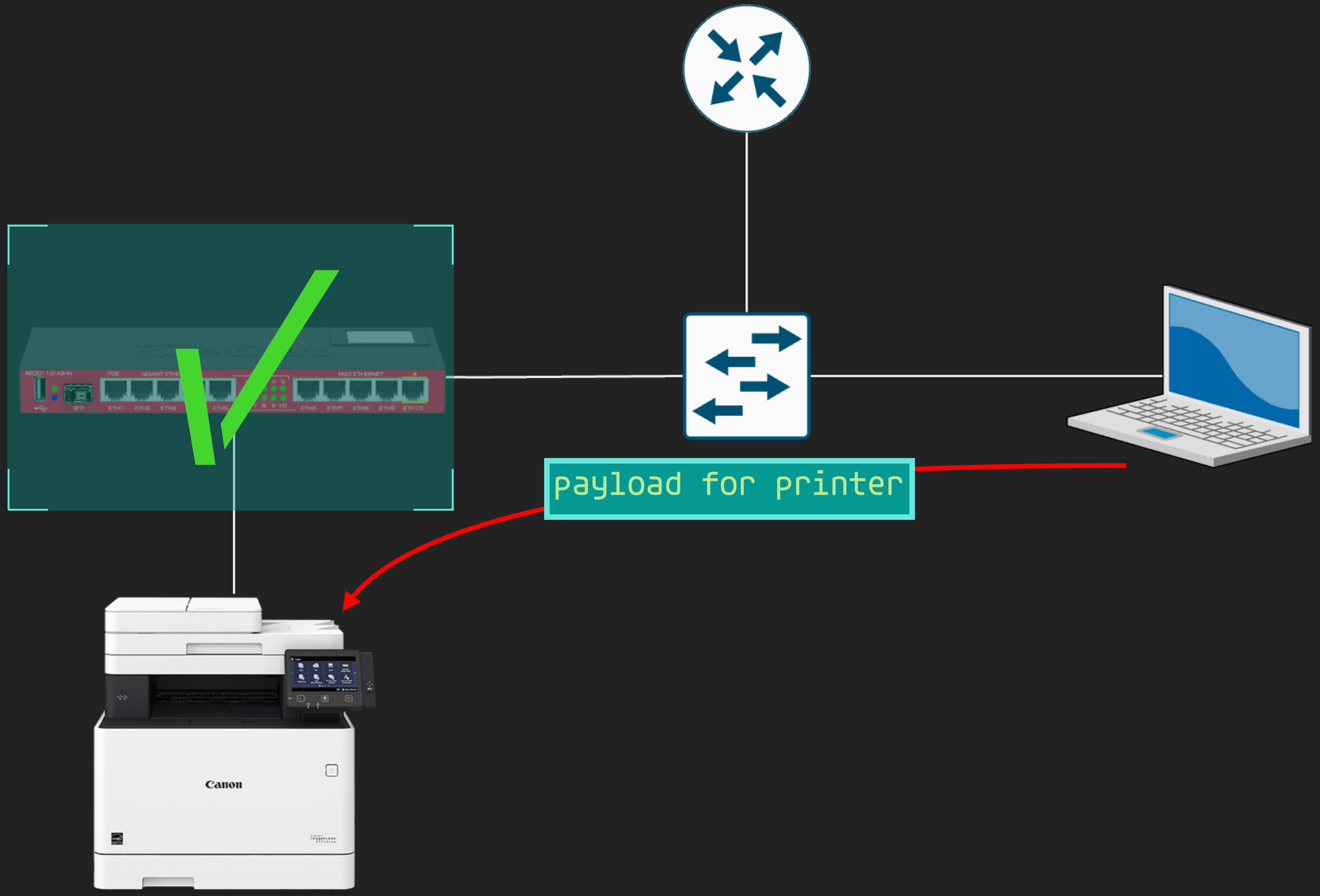
No one with sanity
would like to dive into the details of Nova Binary



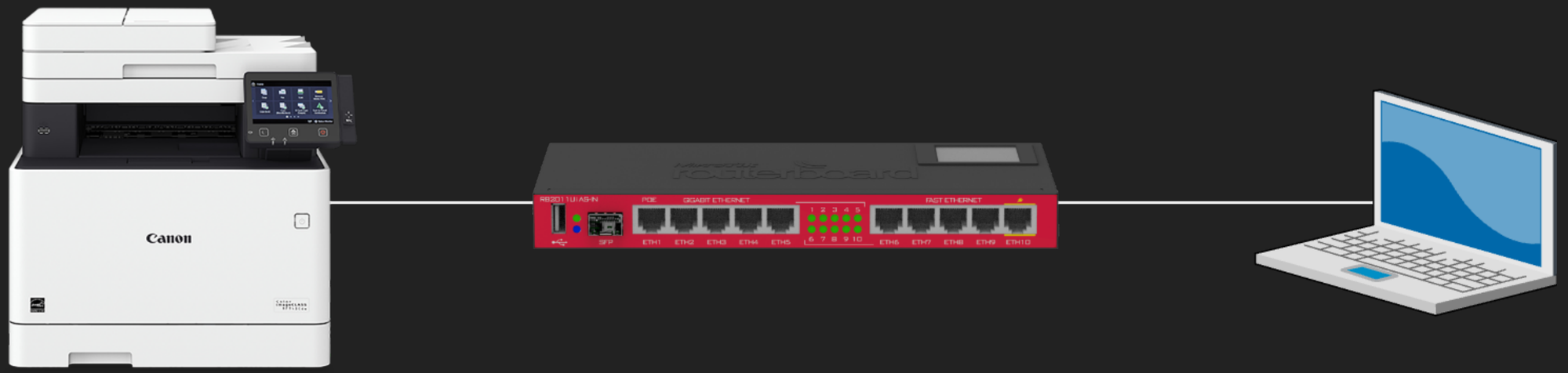
Q.E.D.

DEVCORE

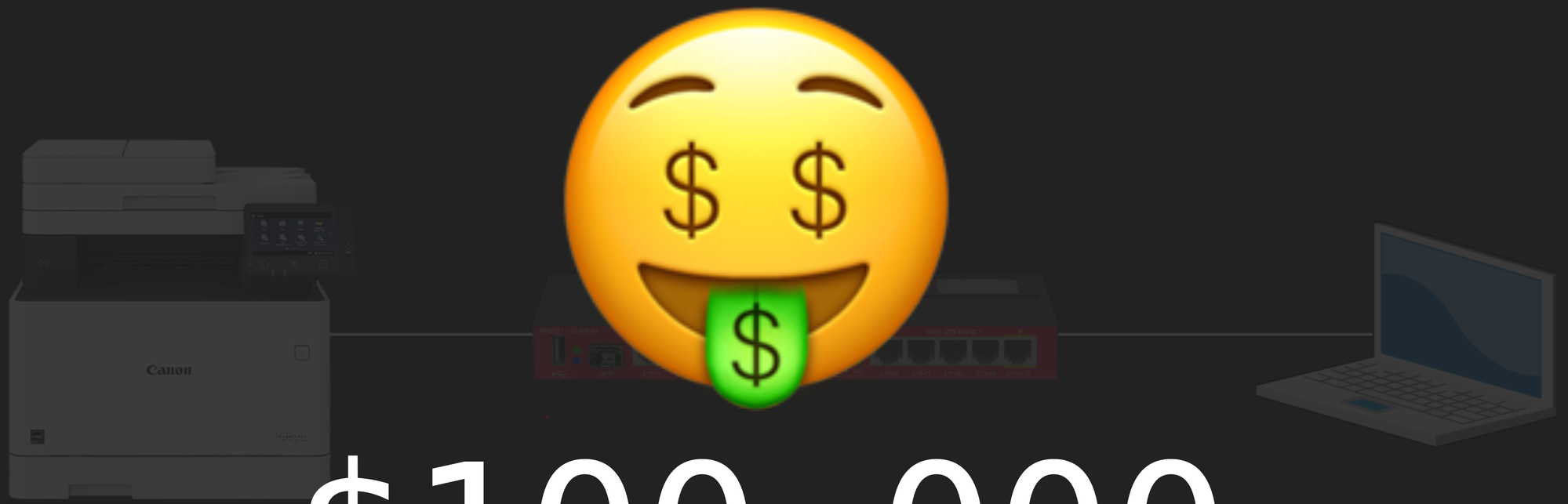




DEVCORE



DEVCORE



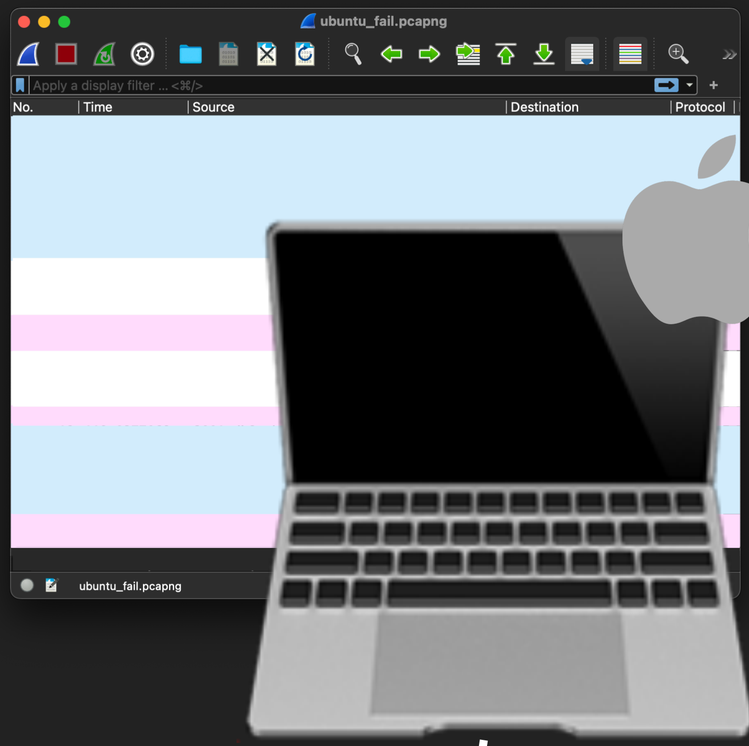
$100,000

But...

But

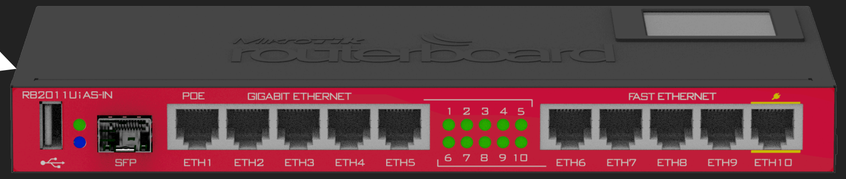
- Our exploit only worked on MacOS and failed on Ubuntu, whether it’s a VM or not.

DEVCORE

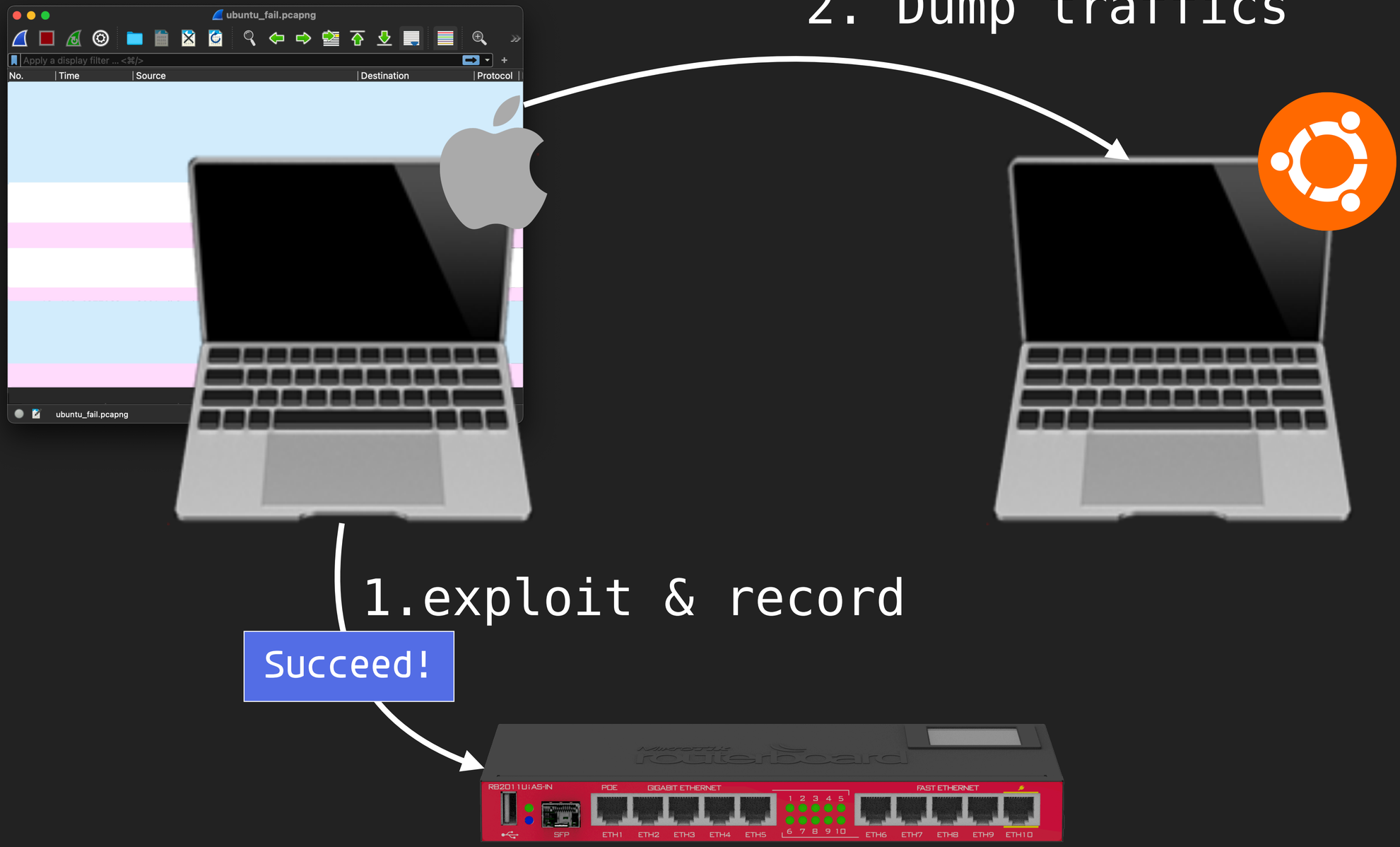


1.exploit & record

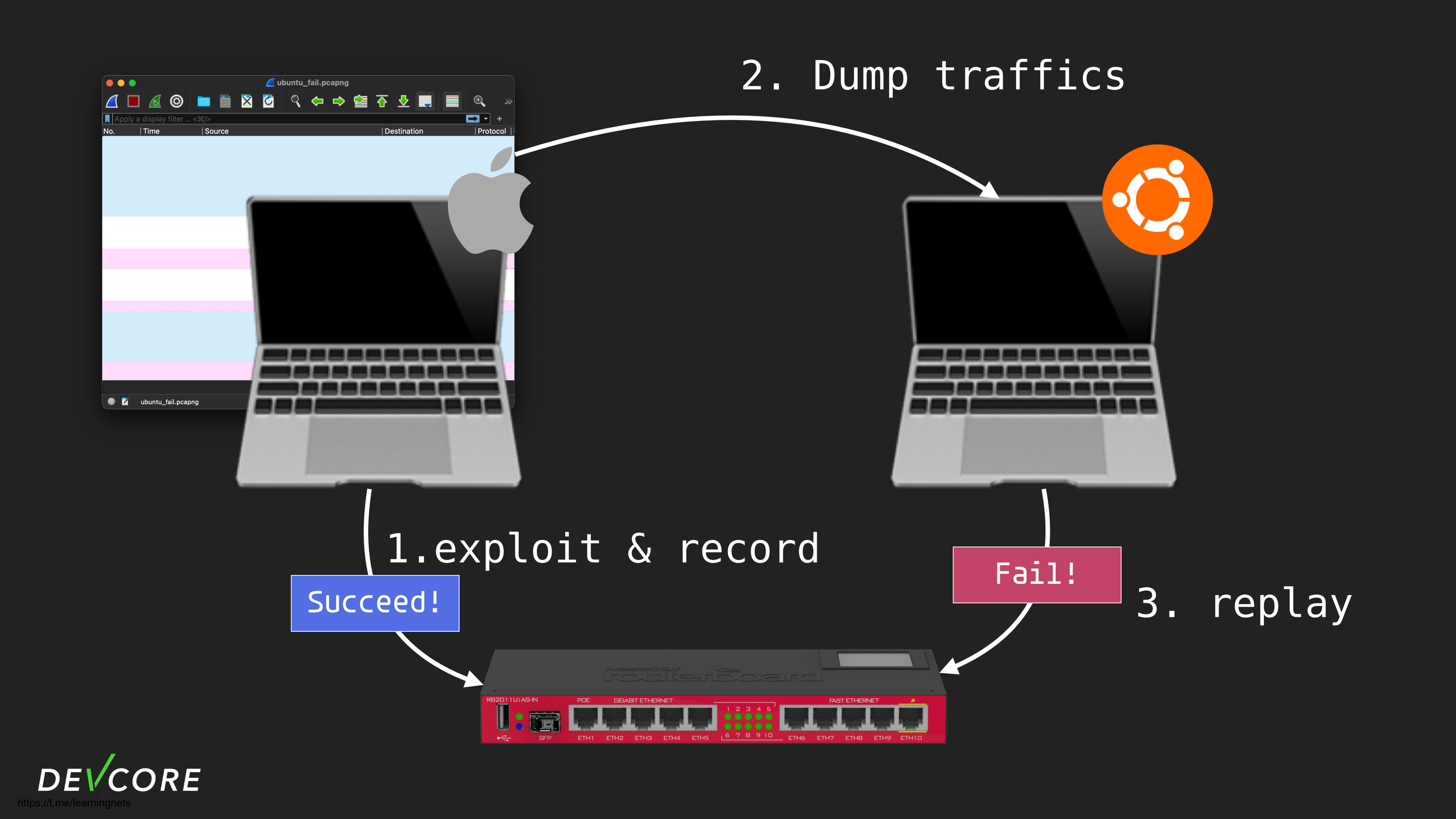
Succeed!



DEVCORE

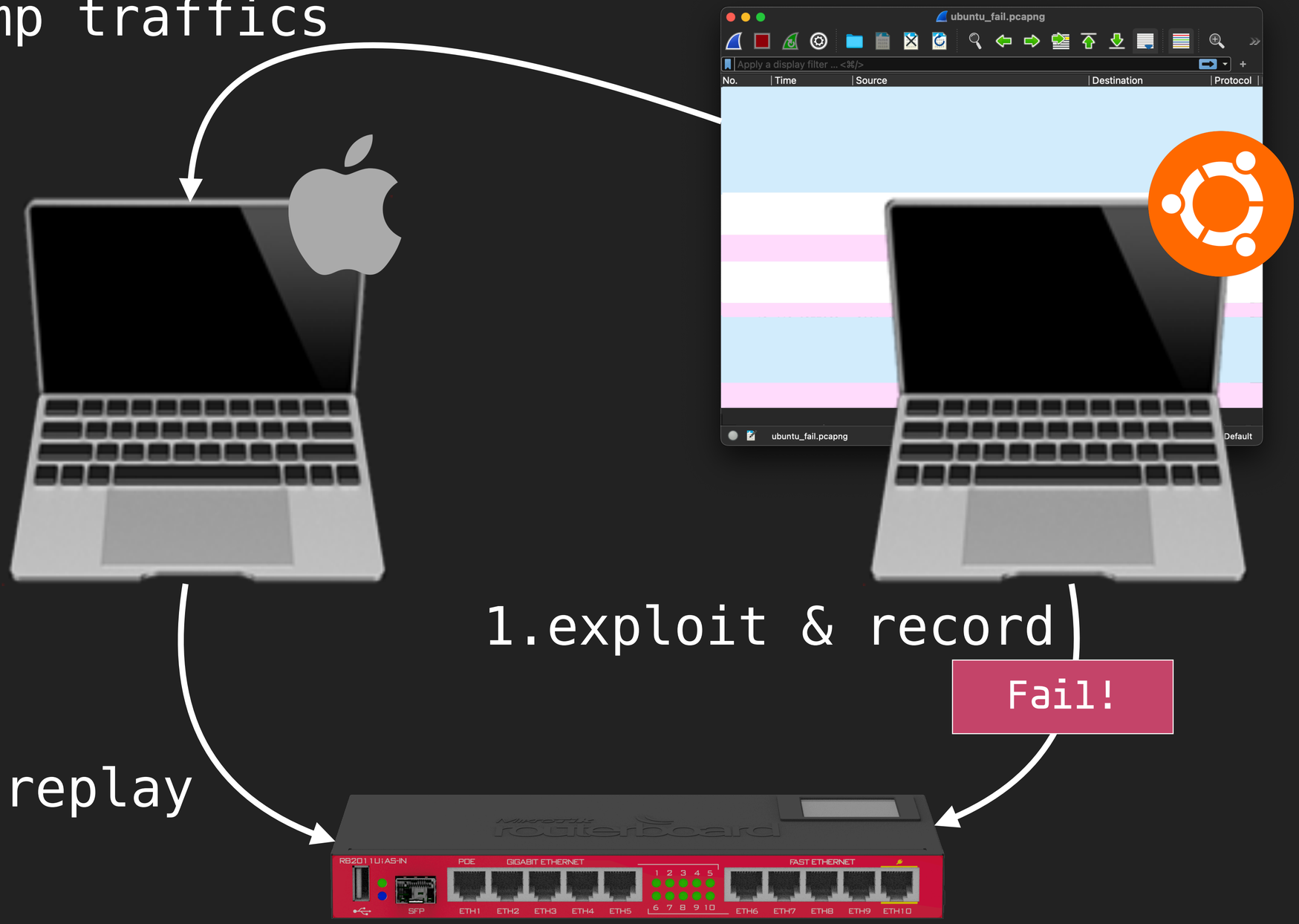


DEVCORE



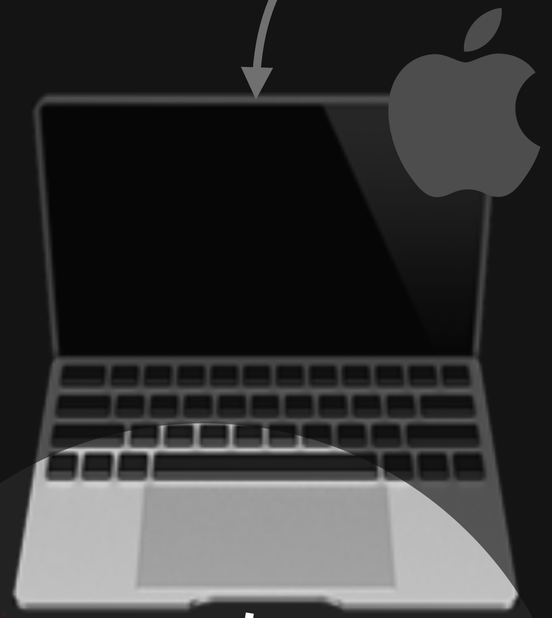
DEVCORE

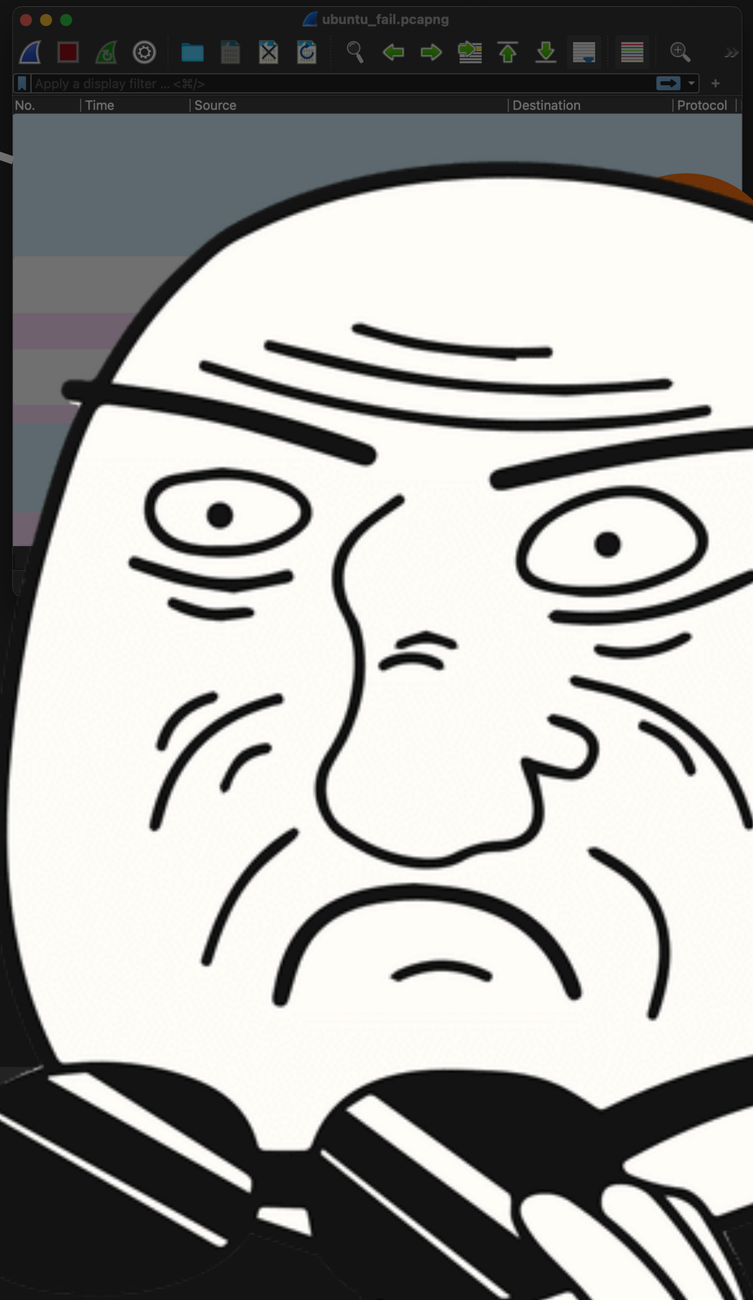
2. Dump traffics



DEVCORE

2. Dump traffics





1.explo

Succeed!

3. replay

DEVCORE

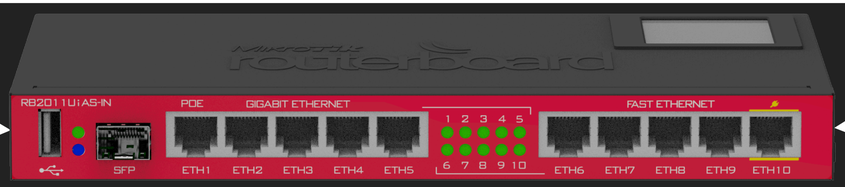
Guess:

An OS reorders the packets

exploit

exploit

```
…
int s = socket(AF_PACKET, SOCK_RAW, htons(ETH_P_IPV6)) ;
…
```

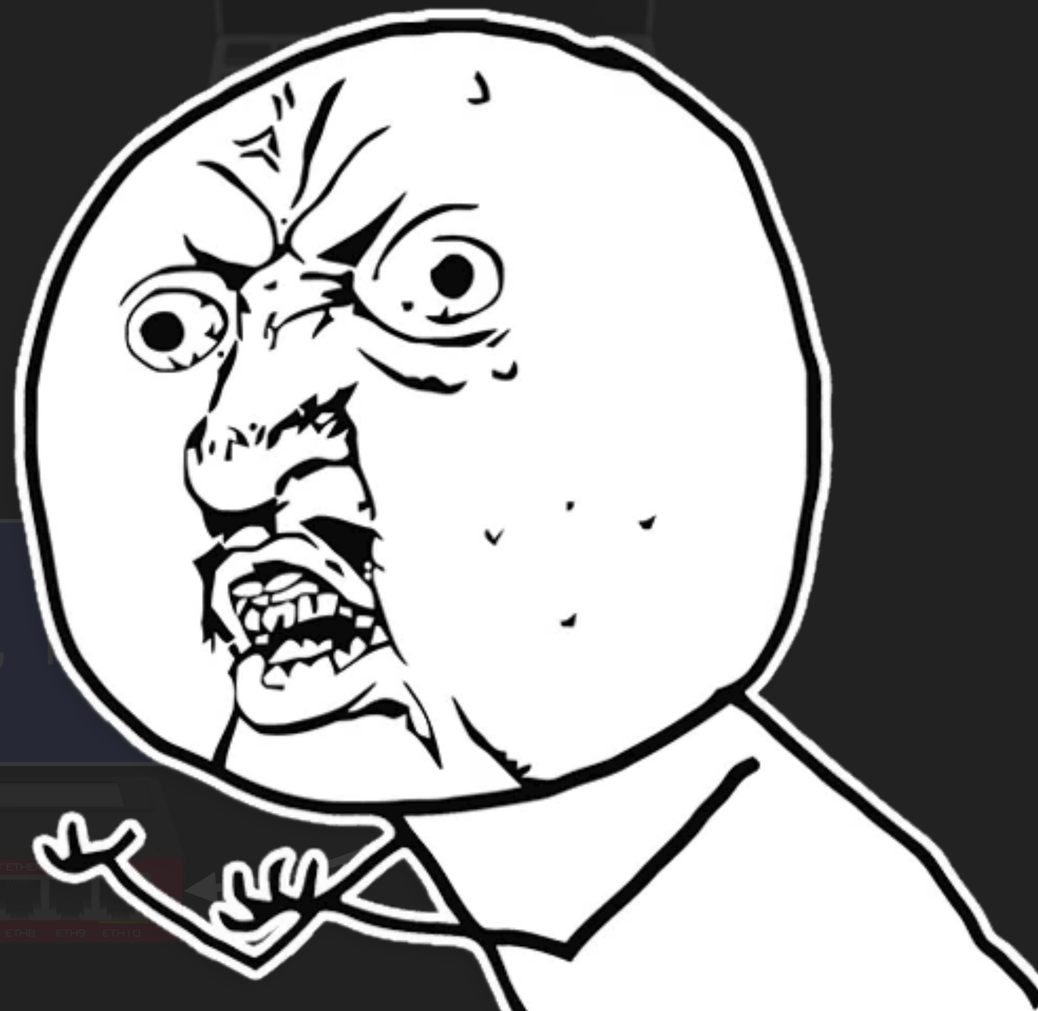


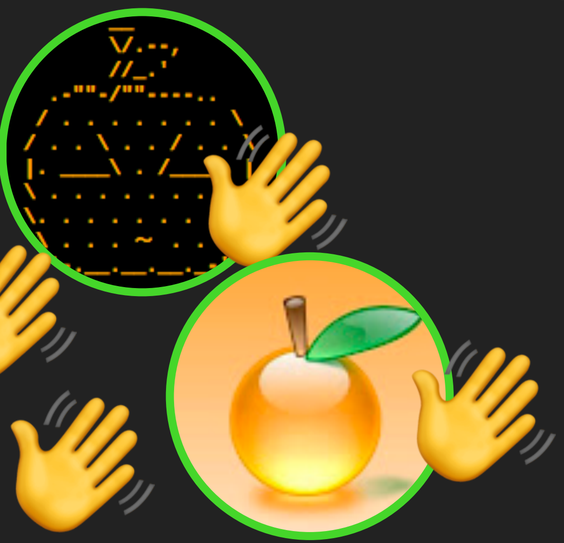
DEVCORE

exploit

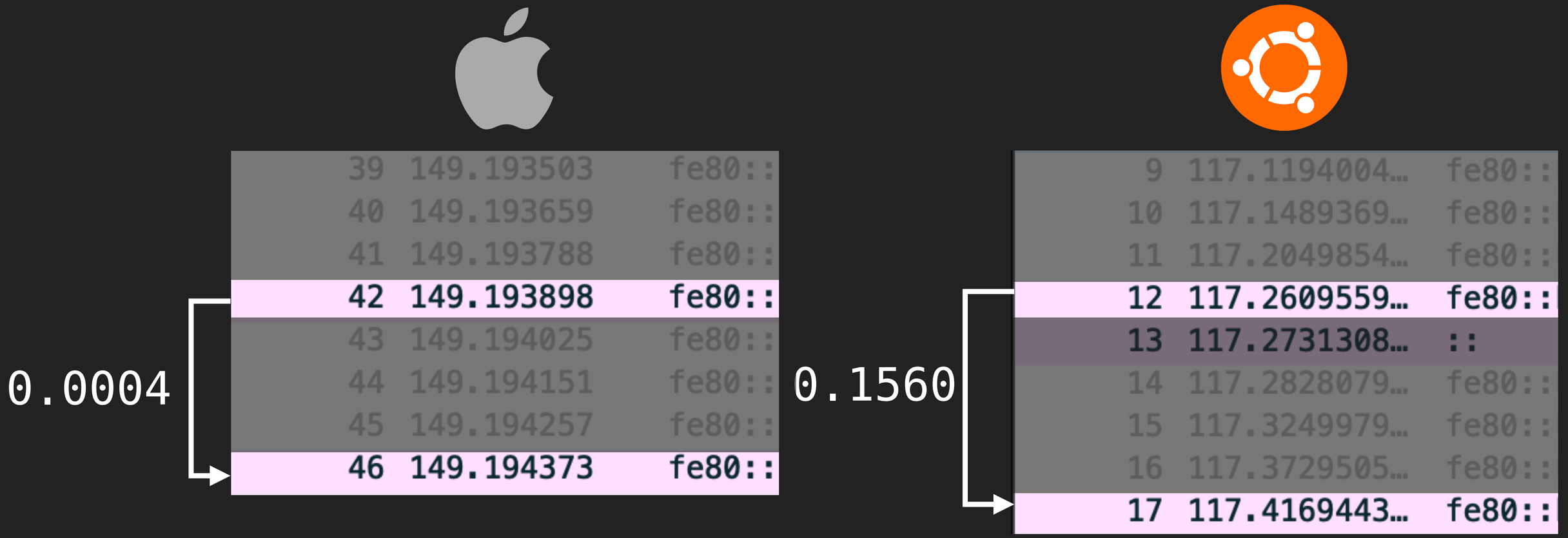
Look the same

```
...
int s = socket(AF_PACKET, SOCK_RAW,
...
```





DEVCORE



390x!!

DEVCORE

In callback function (recv RA from WAN)

```
if ( DNS_vector_now == DNS_vector_end )
{
  if ( !operator==<IPAddr6>((int *)&new_DNS_vector, (int *)&handler_1->DNS_raw) )
  {
    clean_remoteObj(handler_1);
    vector_base::swap_raw(&new_DNS_vector, &handler_1->DNS_raw);
    v163 = (void **)handler_1->DNS_raw.end;
    for ( IPAddr6 = handler_1->DNS_raw.start; IPAddr6 != v163; IPAddr6 += 4 )
    {
      *(_DWORD *)v181 = 0;
      v183[0] = 0;
      v191[0] = 0;
```

In RAroutine (send RA to LAN)

```
lifetime = ndsetting_->lifetime;
length = handler_1->DNS_treeE4.length;
if ( length )
  length = addDNS((int)&raw_packet[v18], &handler_1->DNS_treeE4, (lifetime >> 1) + lifetime);
```

DEVCORE

RADVD

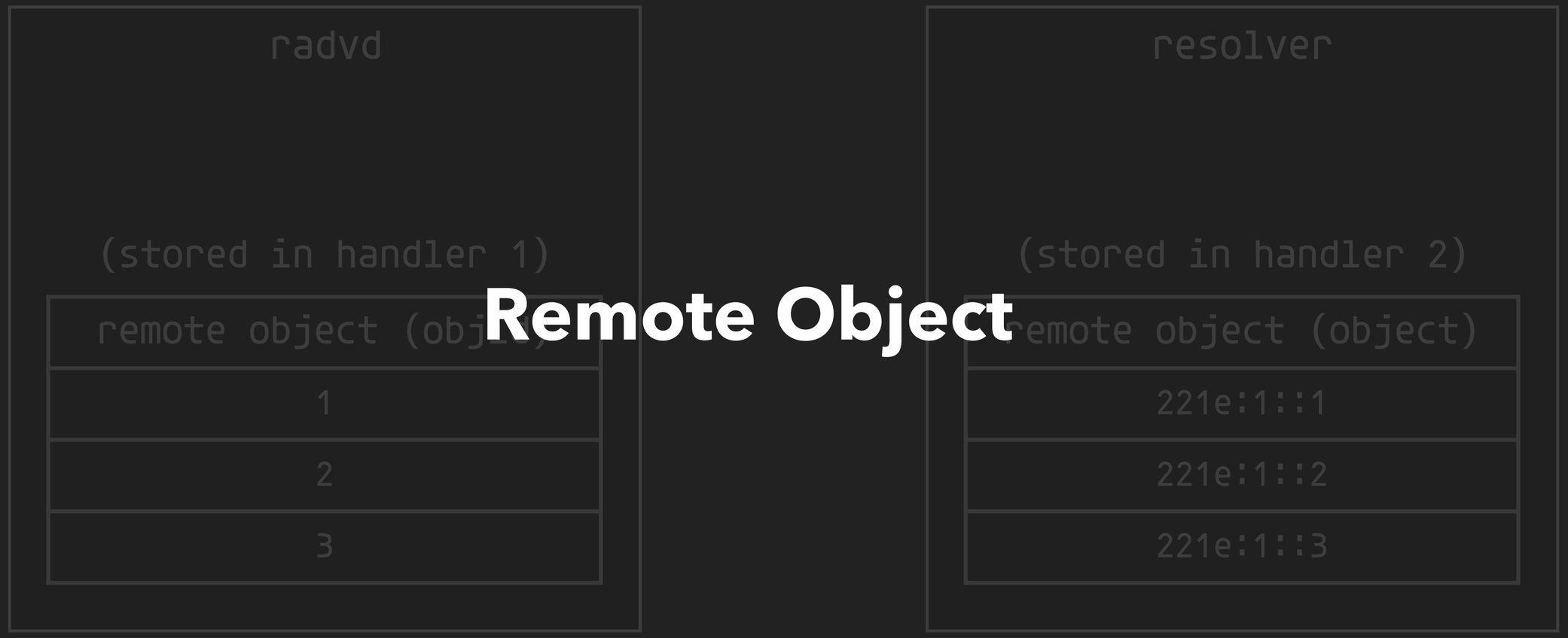
- In callback:
  - Check if the packet is a valid RA or a valid RS
  - If it is an RA
    - Store information in handler 1 (AMap)
  - If it is an RS
    - Multicast RA

In callback function (recv RA from WAN)

```
if ( DNS_vector_now == DNS_vector_end )
{
  if ( !operator==<IPAddr6>((int *)&new_DNS_vector, (int *)&handler_1->DNS_raw) )
  {
    clean_remoteObj(handler_1);
    vector_base::swap_raw(&new_DNS_vector, &handler_1->DNS_raw);
    v163 = (void **)handler_1->DNS_raw.end;
    for ( IPAddr6 = handler_1->DNS_raw.start; IPAddr6 != v163; IPAddr6 += 4 )
    {
      *(_DWORD *)v181 = 0;
      v183[0] = 0;
      v191[0] = 0;
      v191[1] = 0;
      v165 = (nv::RemoteObject *)nv::roDNS((int)IPAddr6, 0, v191);
      v166 = handler_1->DNS_remoteObject.start;
      v167 = v165;
      v168 = handler_1->DNS_remoteObject.end - (void *)v166;
      if ( v168 >> 2 == sizeOfAllocatedMem(v166) >> 2 )
```

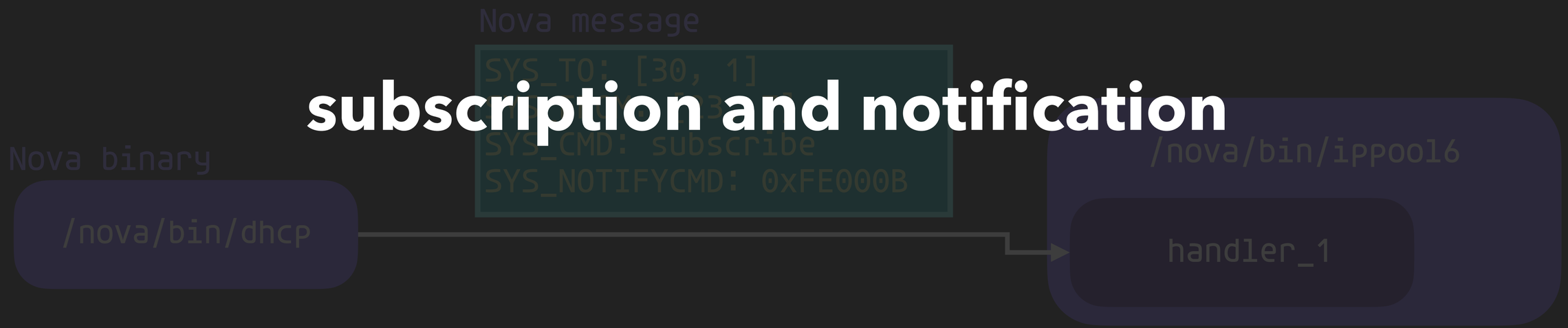
```
for obj in DNS_remoteObject:
    obj.remote_remove()
DNS_remoteObject = list(map(nv::roDNS, new_DNS_vector))
```

DEVCORE



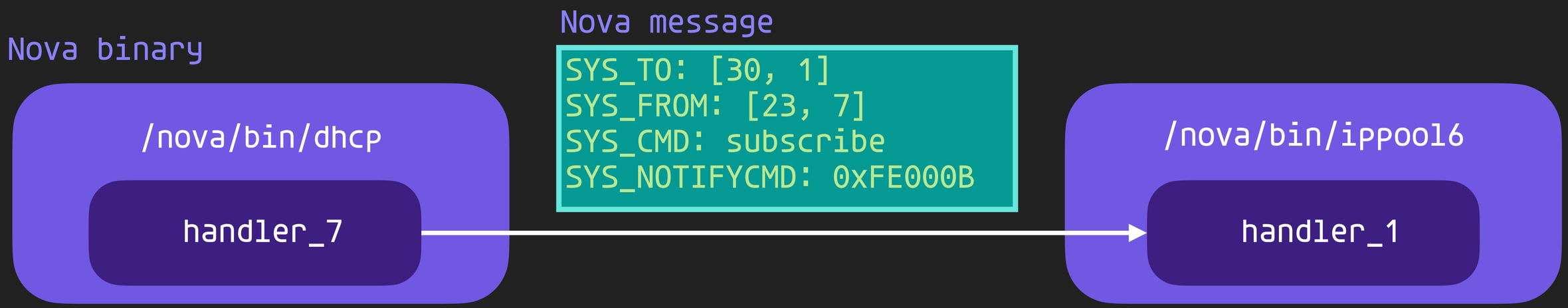
Remote Object

Subscription

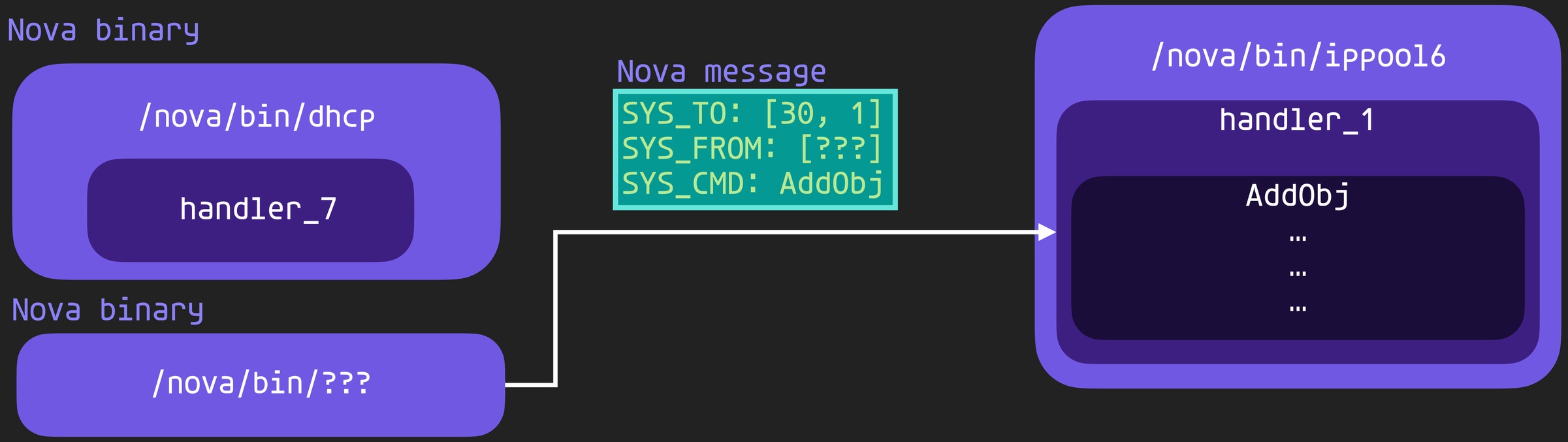


subscription and notification

Subscription

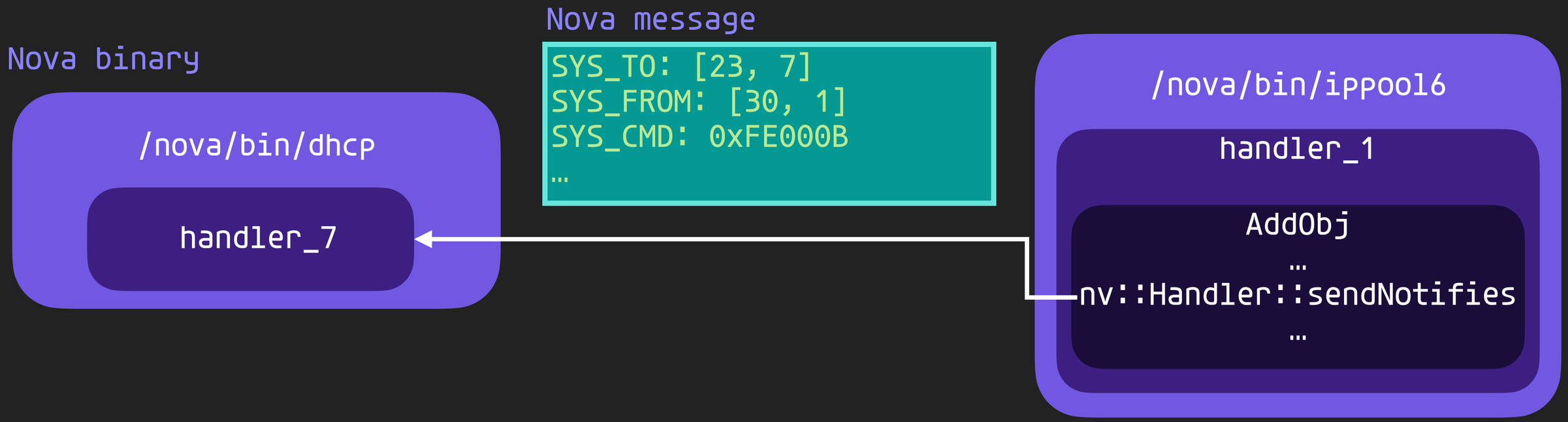


Subscription

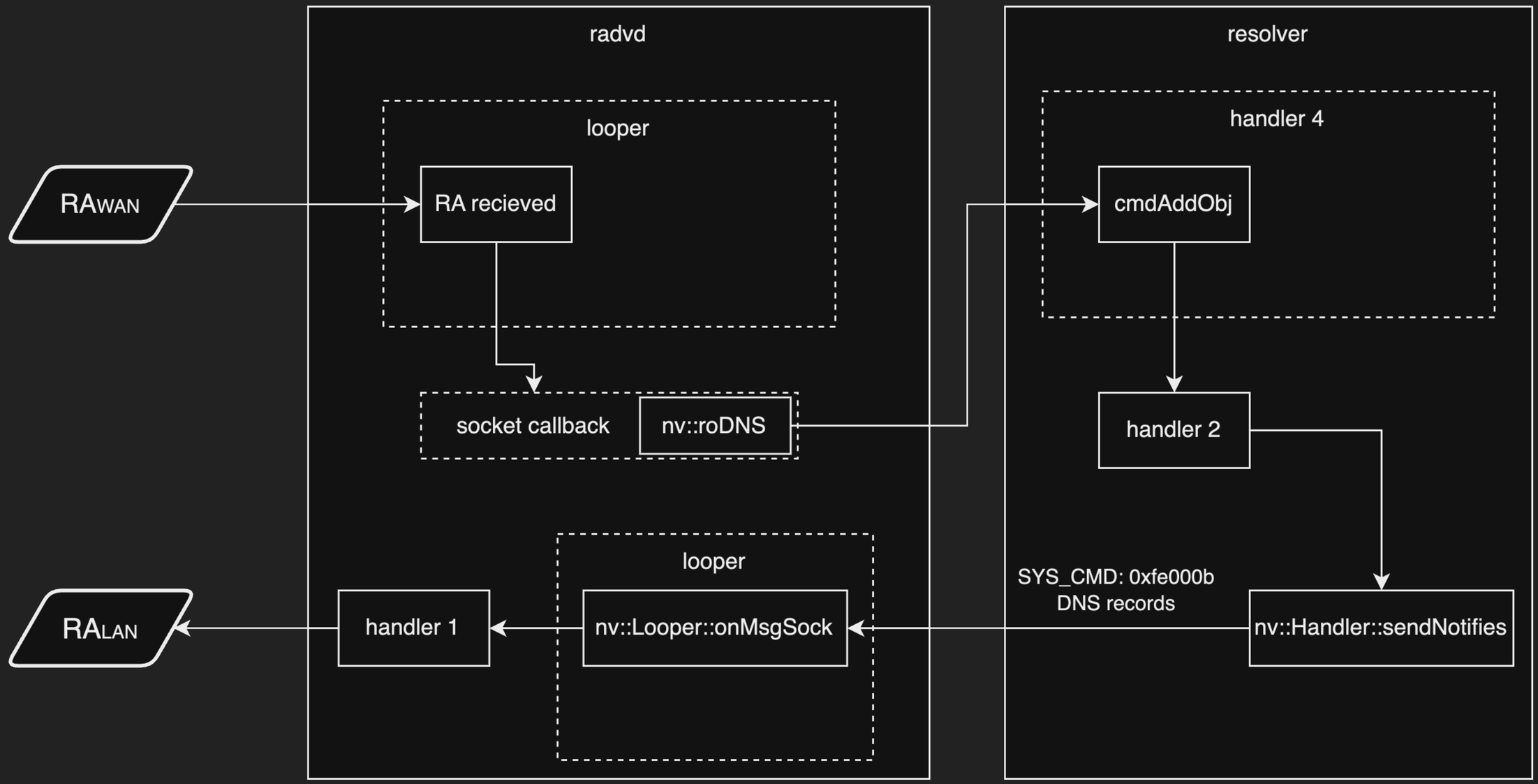


DEVCORE

Subscription



DEVCORE



In callback function (recv RA from WAN)

```
if ( DNS_vector_now == DNS_vector_end )
{
  if ( !operator==<IPAddr6>((int *)&new_DNS_vector, (int *)&handler_1->DNS_raw) )
  {
    clean_remoteObj(ha
    vector_base::swap_                                    _raw);
    v163 = (void **)handler_1->DNS_raw.end;
    for ( IPAddr6 = handler_1->DNS_raw.start; IPAddr6 != v163; IPAddr6 += 4 )
    {
      *(_DWORD *
      v183[0] = 0;
      v191[0] = 0;
      v191[1] = 0;
      v165 = (nv::RemoteObject *)nv::roDNS((int)IPAddr6, 0, v191);
      v166 = handler_1->DNS_remoteObject.start;
      v167 = v165;
      v168 = handler_1->DNS_remoteObject.end - (void *)v166;
      if ( v168 >> 2 == sizeOfAllocatedMem(v166) >> 2 )
```

nv::Handler::postMessage (Non-blocking)

nv::RemoteObjectBackend::request

```
for obj in DNS_remoteObject:
    obj.remote_remove()
DNS_remoteObject = list(map(nv::roDNS, new_DNS_vector))
```

DEVCORE

In callback function (recv RA from WAN)

```
if ( DNS_vector_now == DNS_vector_end )
{
  if ( !operator==<IPAddr6>((int *)&new_DNS_vector, (int *)&handler_1->DNS_raw) )
  {
    clean_remoteObj(handler_1);
    vector_base::swap_raw(&new_DNS_v
    v163 = (void **)handler_1->DNS_raw.end;
    for ( IPAddr6 = handler_1->DNS_raw.start; IPAddr6 != v163; IPAddr6 += 4 )
    {
      *(_DWORD *)v181
      v183[0] = 0;
      v191[0] = 0;
      v191[1] = 0;
      v165 = (nv::Rem
      v166 = handler_
      v167 = v165;
      v168 = handler_1->DNS_remoteObject.end - (void *)v166;
      if ( v168 >> 2 == sizeOfAllocatedMem(v166) >> 2 )
```

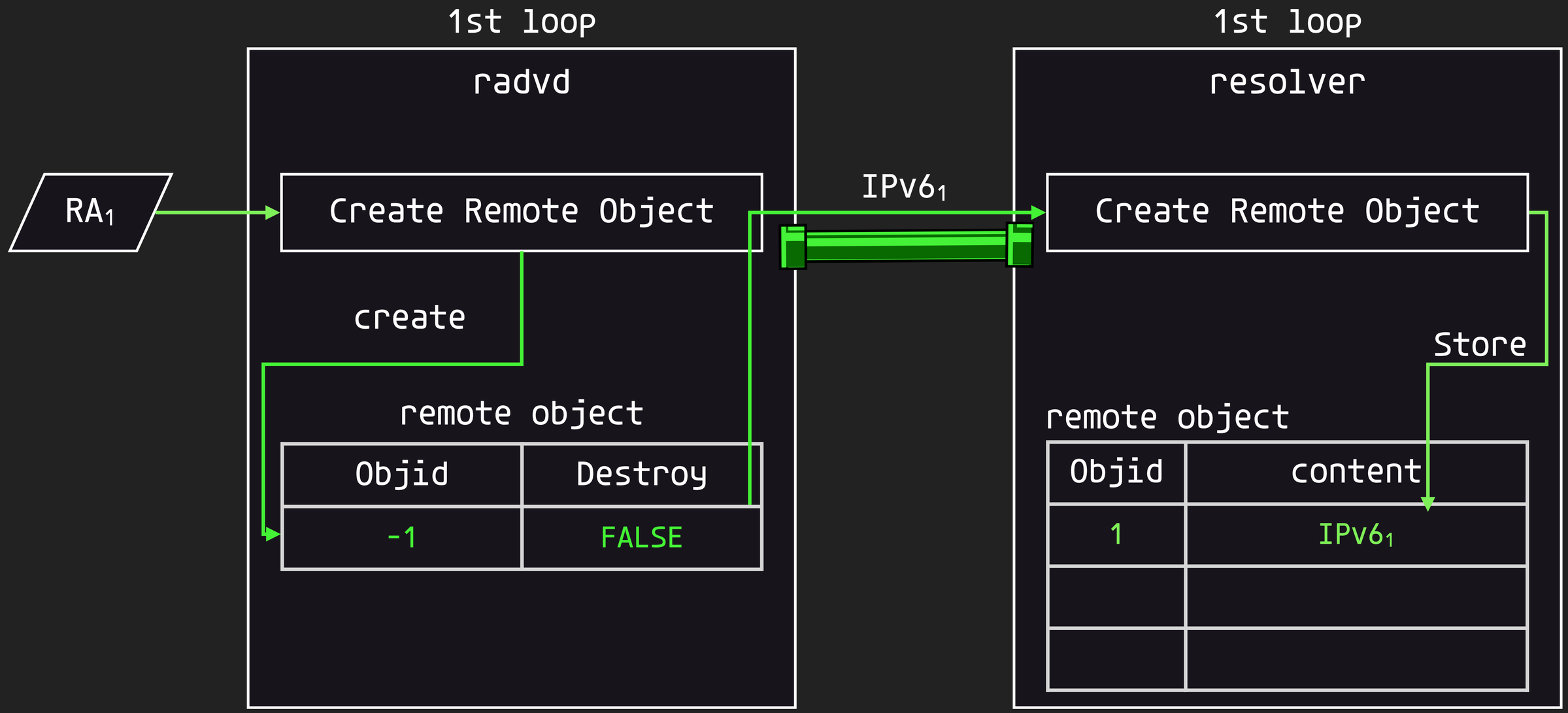
nv::RemoteObject::~RemoteObject

```
void __fastcall nv::RemoteObjectBackend::cleanup(nv::RemoteObjectBackend *this)
{
  this->destroy = 1;
  if ( this->objid != -1 )
    nv::RemoteObjectBackend::postRemove(this);
}
```

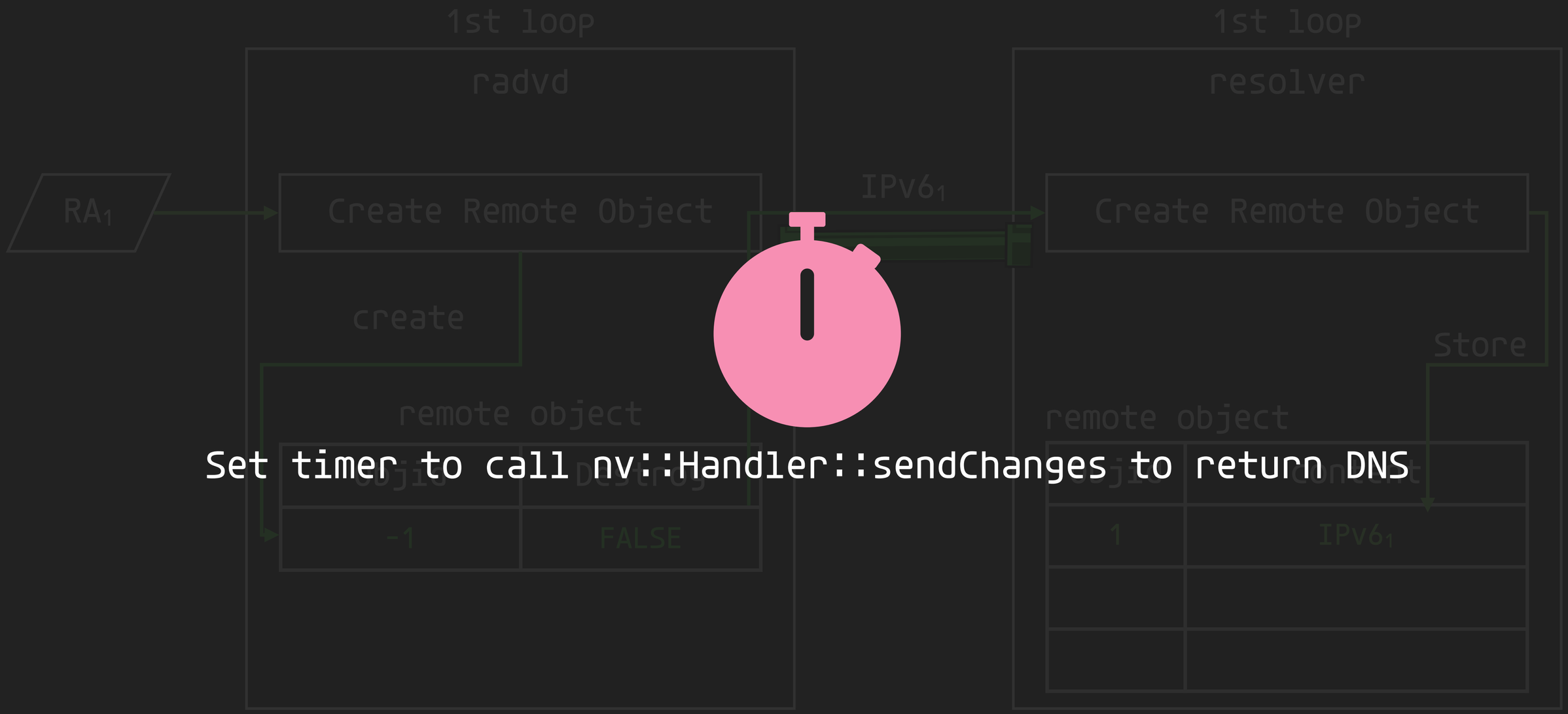
(Non-blocking)

```
for obj in DNS_remoteObject:
    obj.remote_remove()
DNS_remoteObject = list(map(nv::roDNS, new_DNS_vector))
```

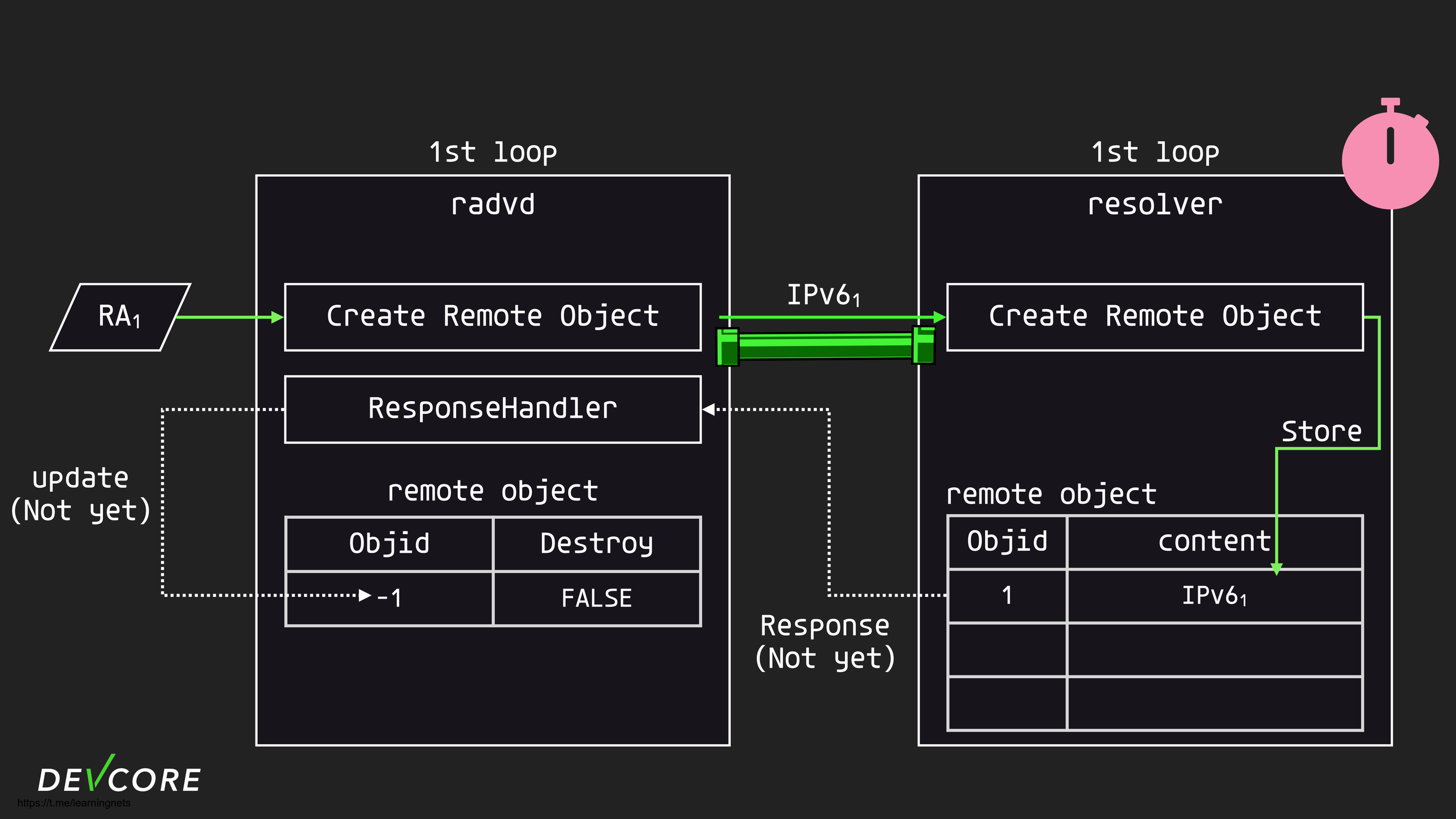
DEVCORE

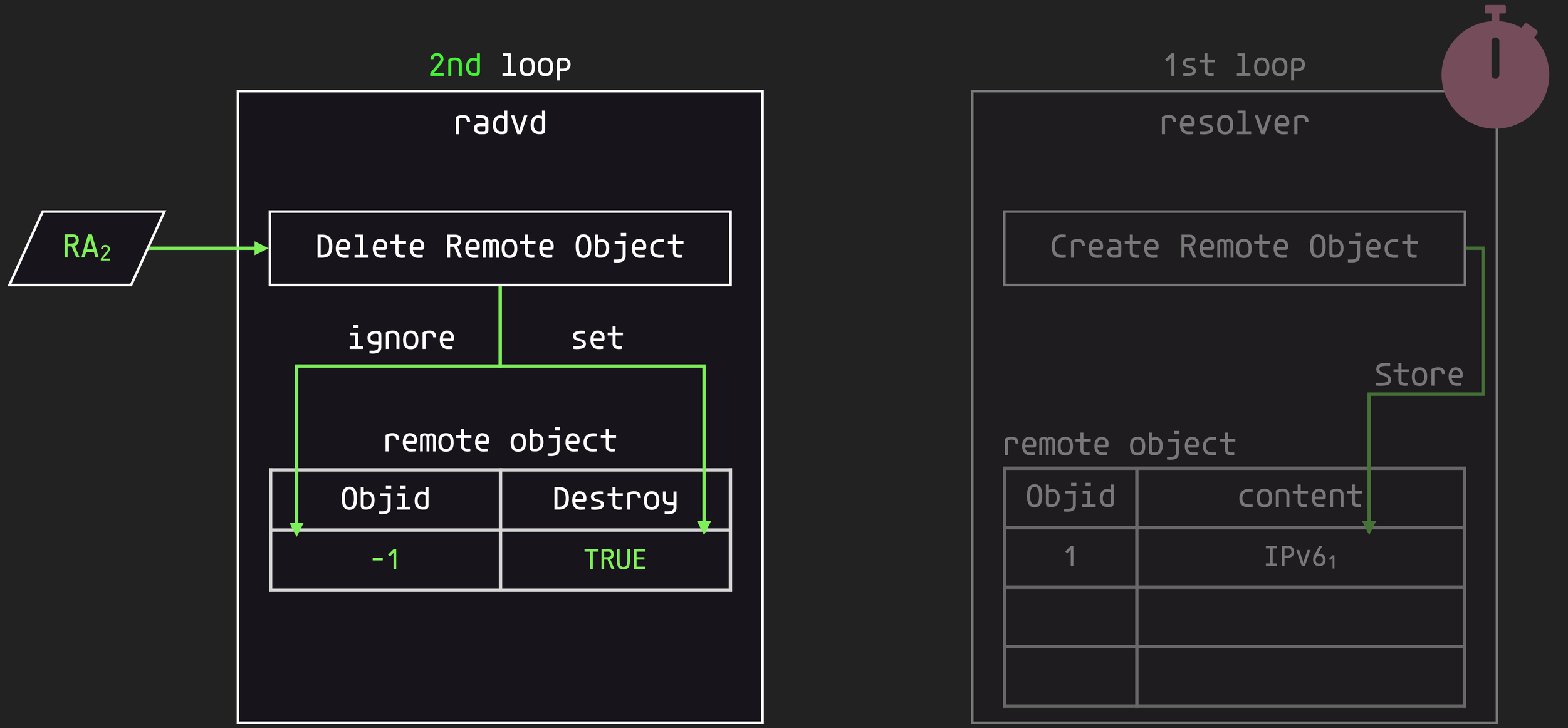


DEVCORE



Set timer to call nv::Handler::sendChanges to return DNS





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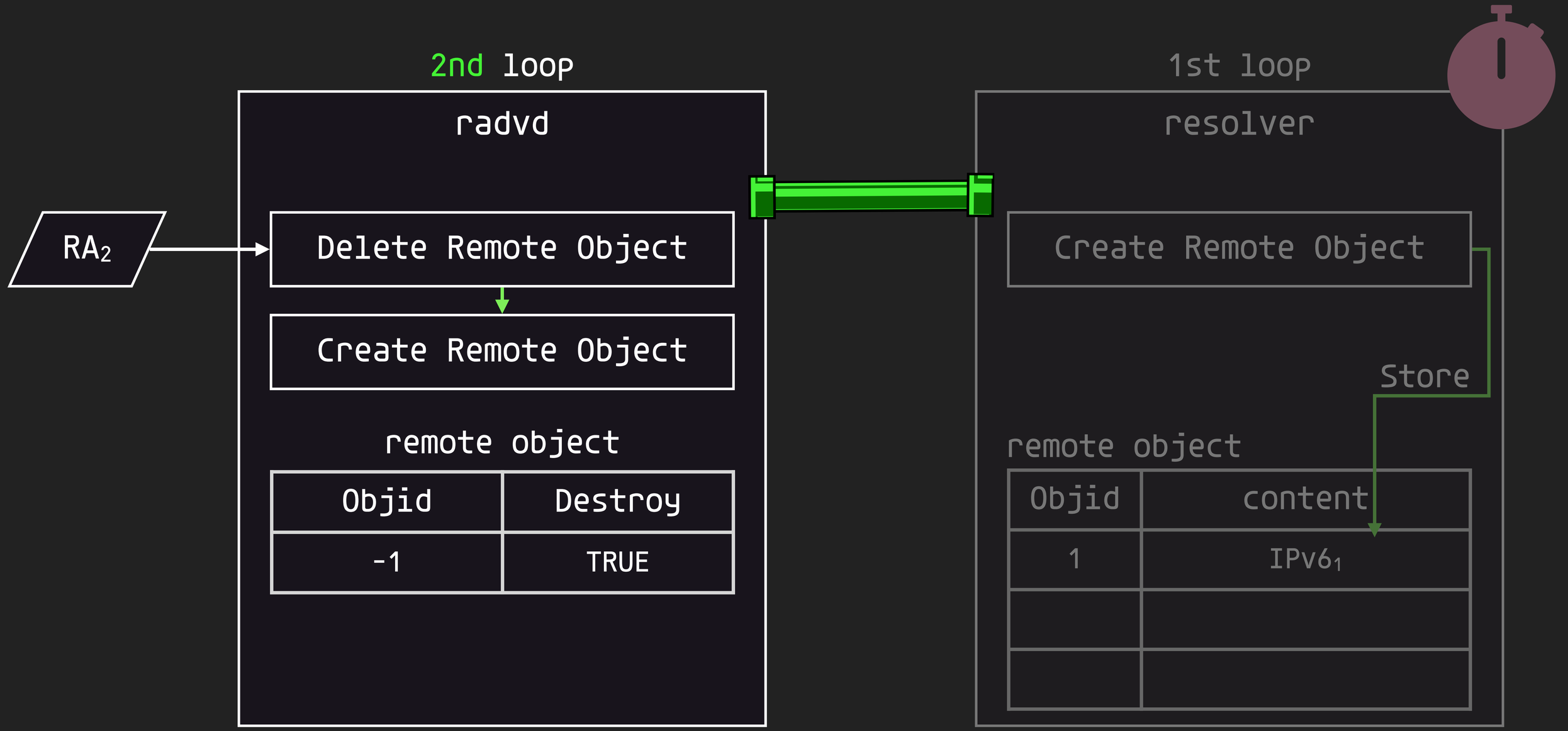

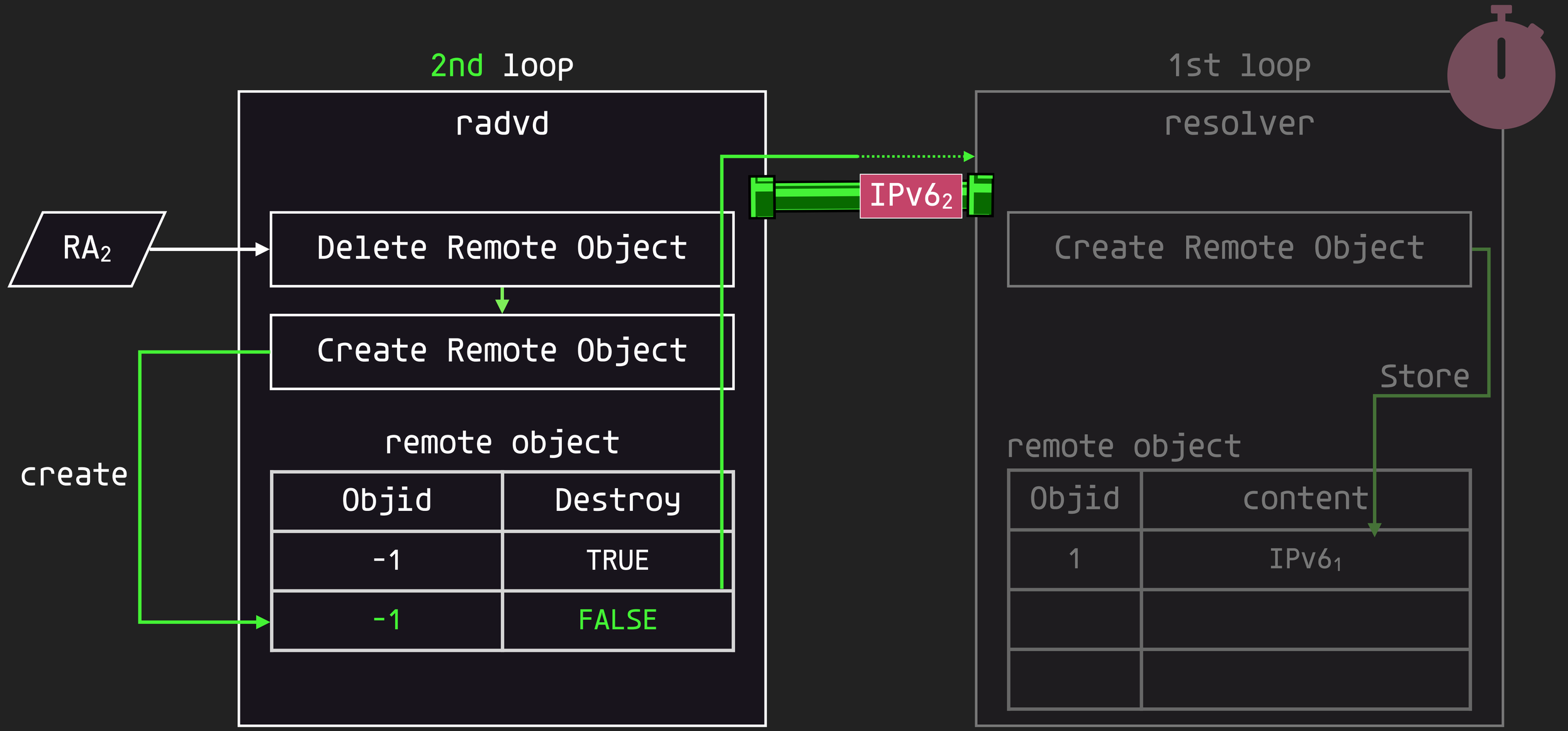

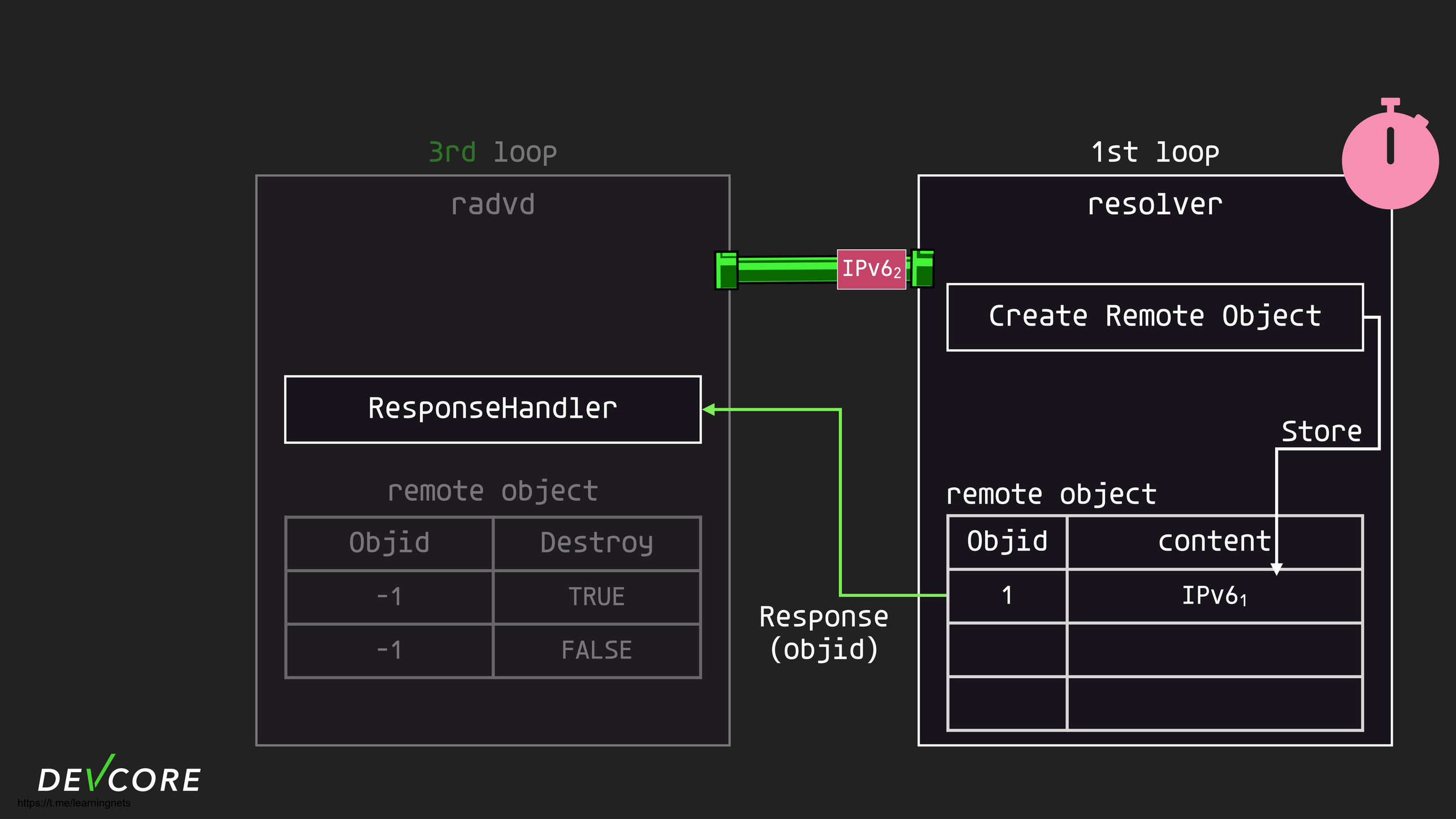

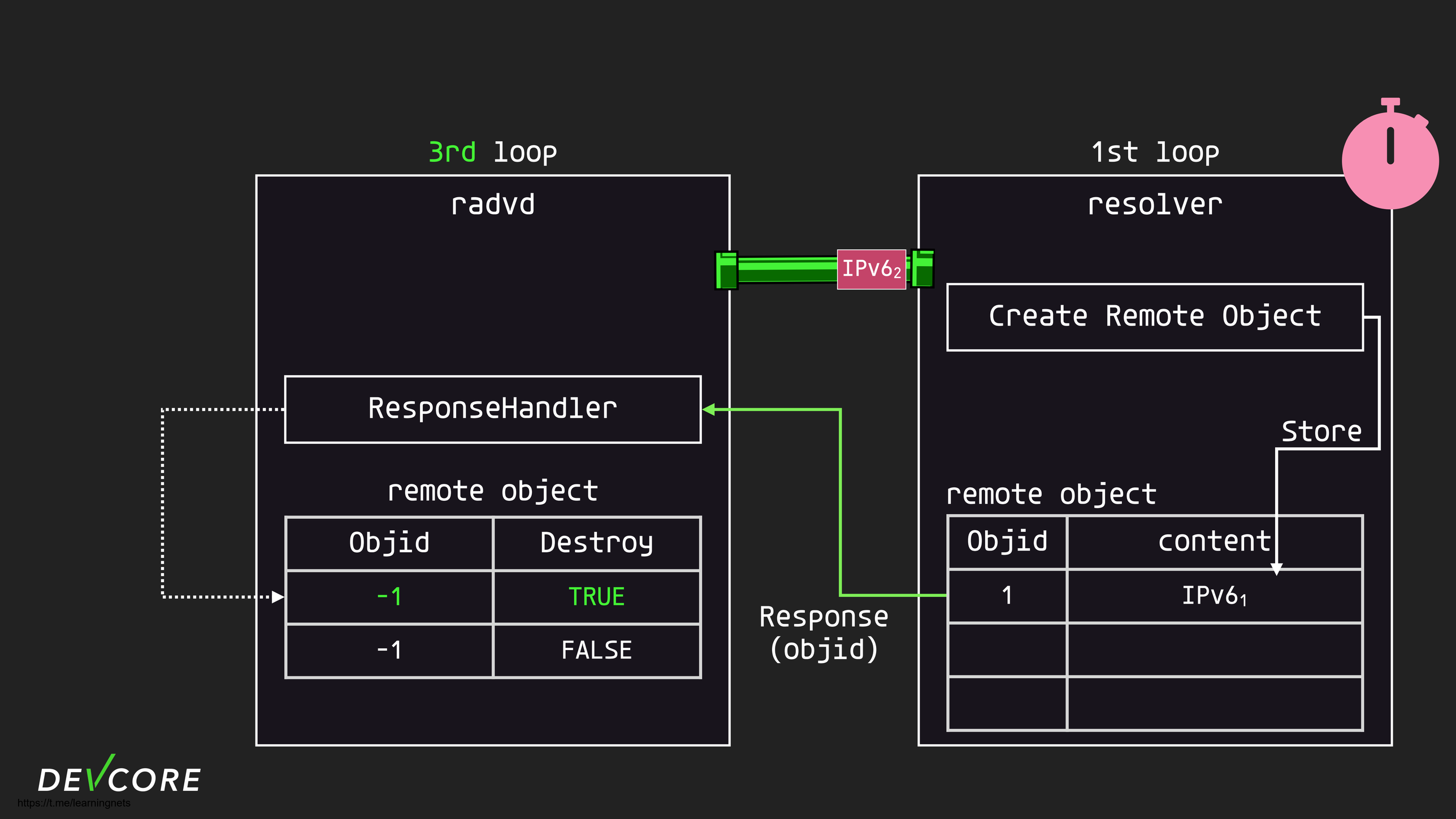

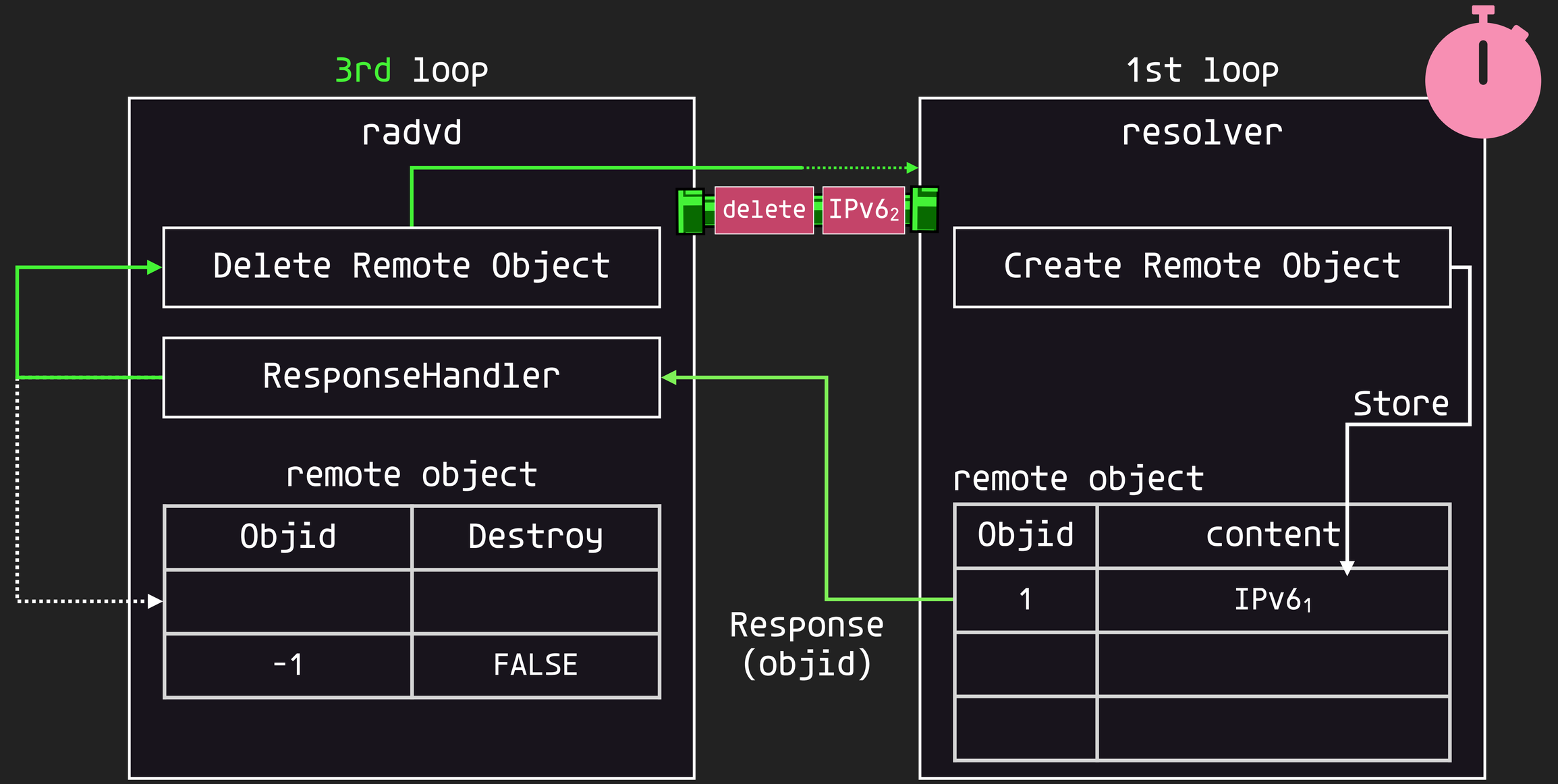

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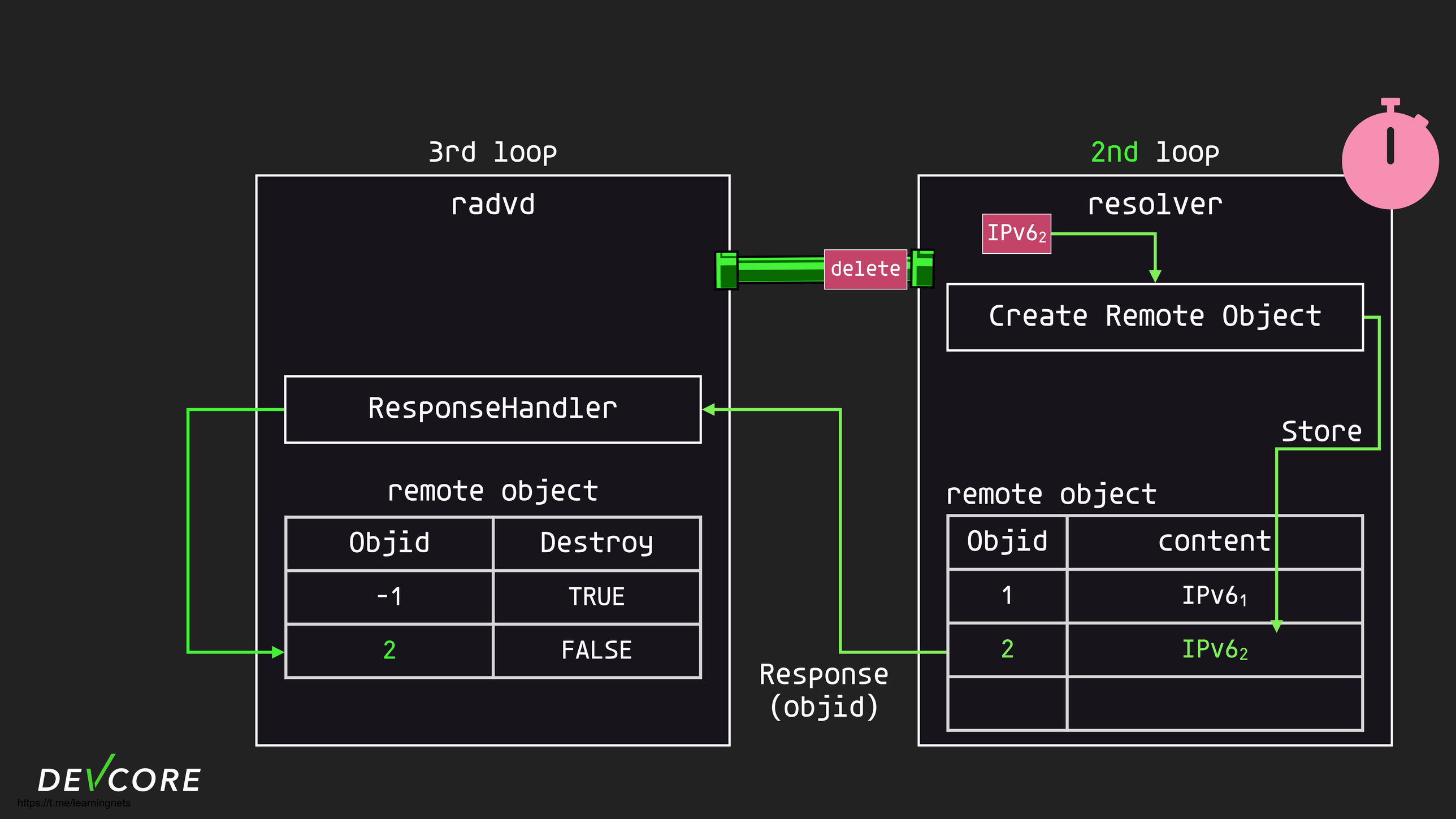
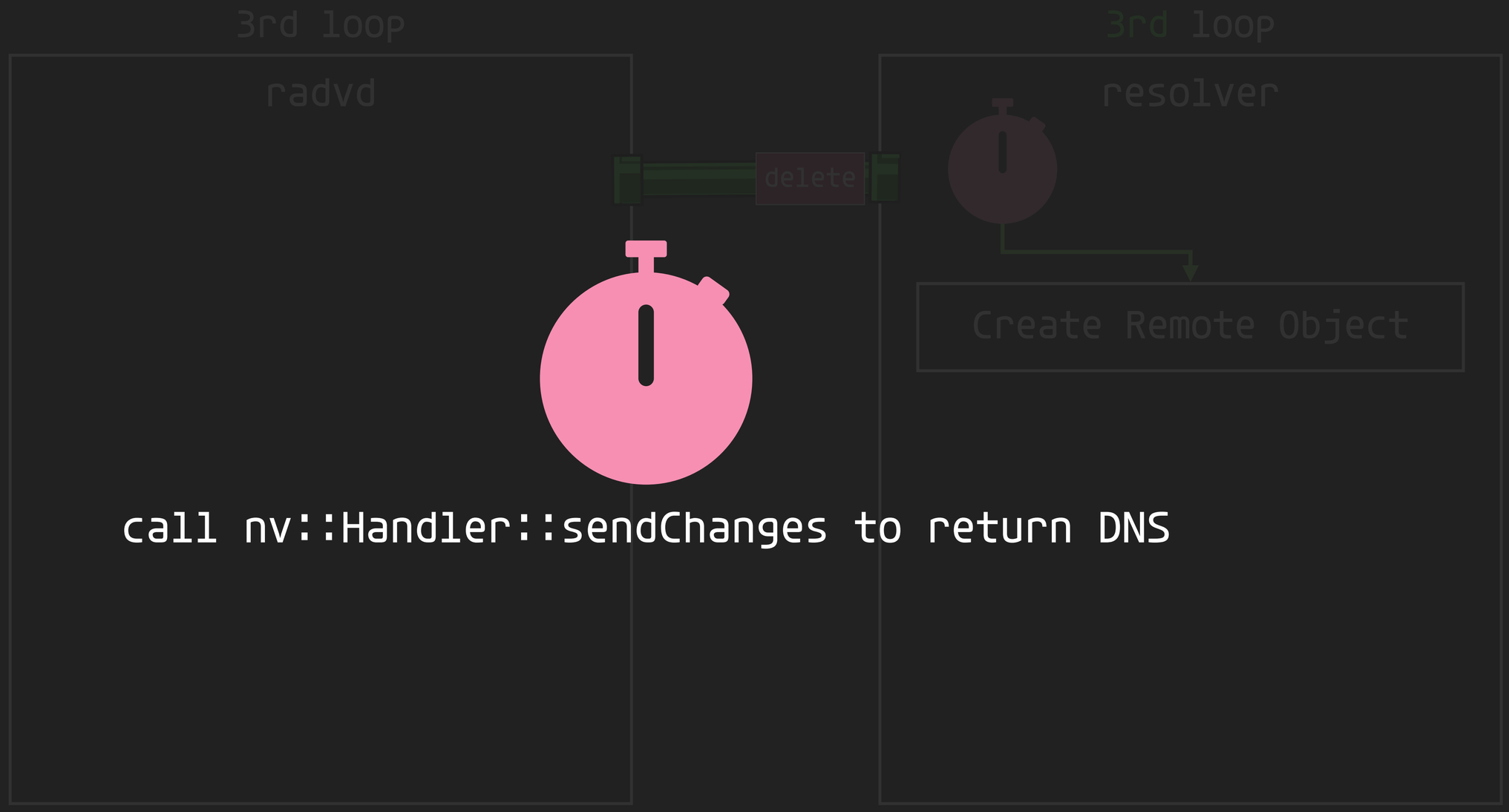
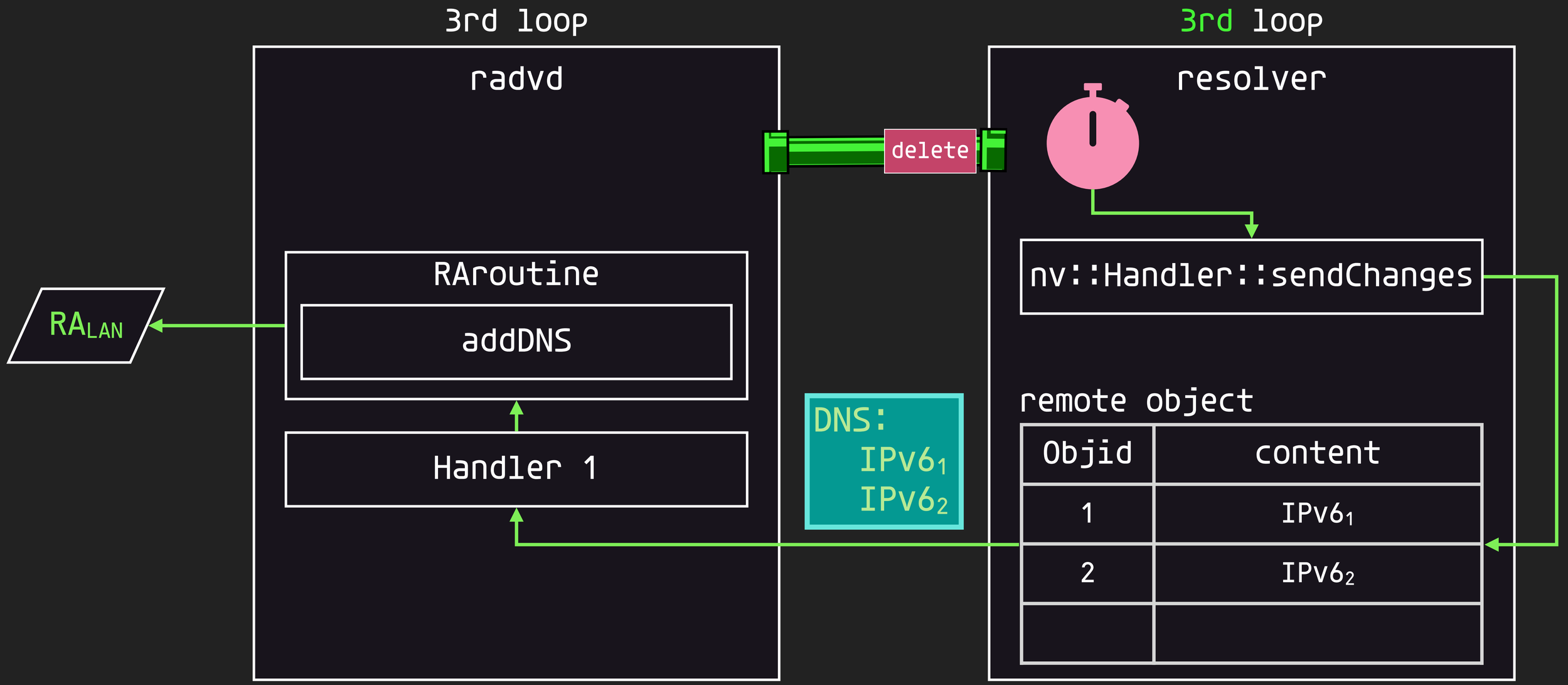




call nv::Handler::sendChanges to return DNS



Race Condition

- Pattern
  - Use non-blocking methods to create/delete the remote object
  - Subscribe to the remote object
- Impact:
  - Maybe it can be used to bypass some checks

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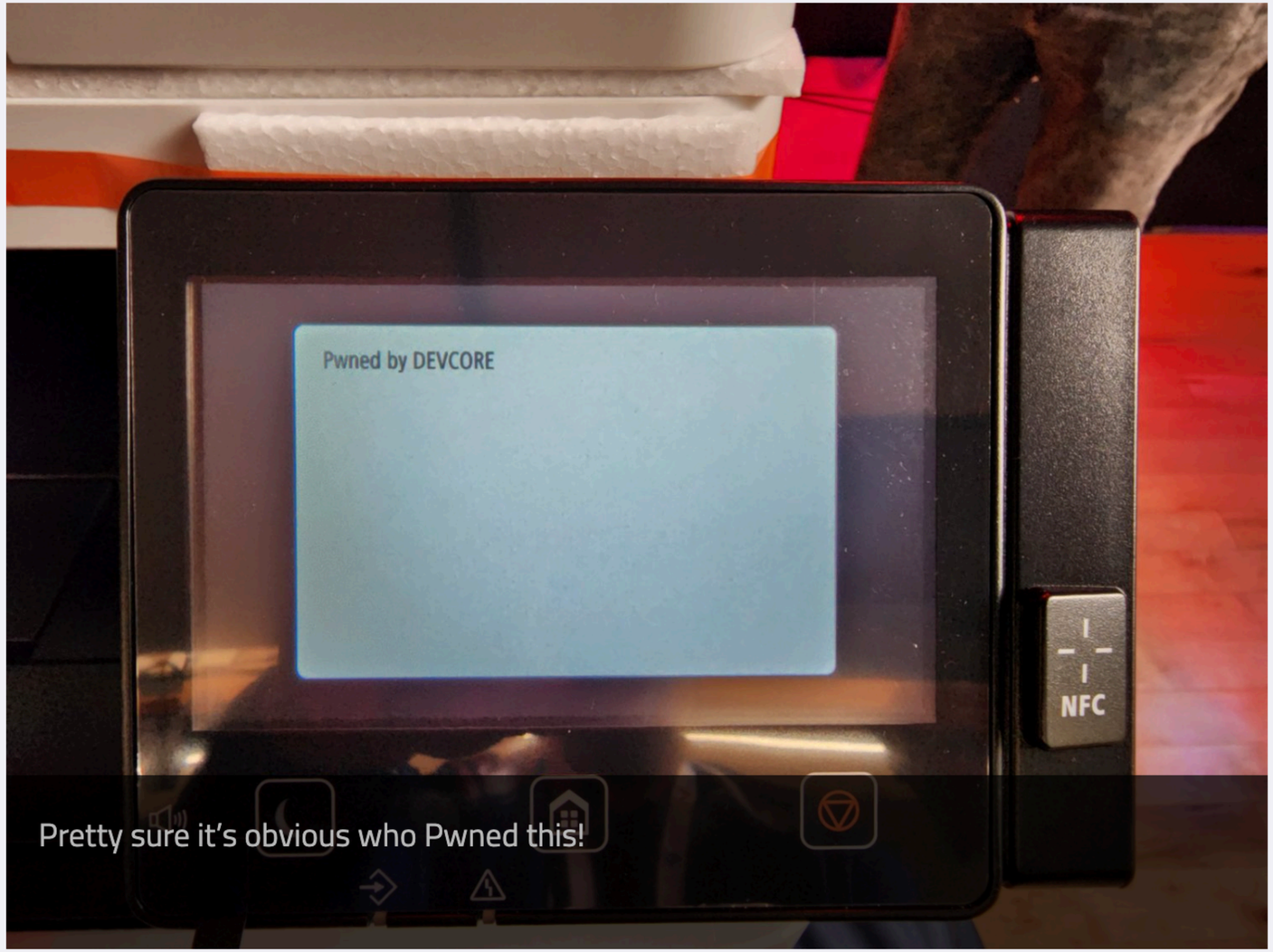
Race Condition

- Pattern
  - Use non-blocking r… …ate remote object
  - Subscribe to the …
- Impact:
  - Maybe can be used … …hecks

SUCCESS - DEVCORE becomes the first team ever to successfully execute two different Stack-based buffer overflow attacks against a Mikrotik router and a Canon printer in the brand new SOHO SMASHUP category. They earn a cool $100K cash and 10 Master of Pwn points.



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Summary

- MikroTik reimplements everything with its own designed IPC.
    - The business logic is scattered all over.
- A pre-auth RCE on WAN has existed for nine years.
- Race condition in remote objects due to non-blocking methods.
- The tools to ease reversing will be available at:
    - https://github.com/terrynini/routeros-tools

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Q&A

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