XDP BULK PACKET PROCESSING

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Problem statement

How can we apply batching to XDP?

Performance results

action	XDP_DROP	XDP_TX	XDP_REDIRECT
Perf boost	16%	70%	91%

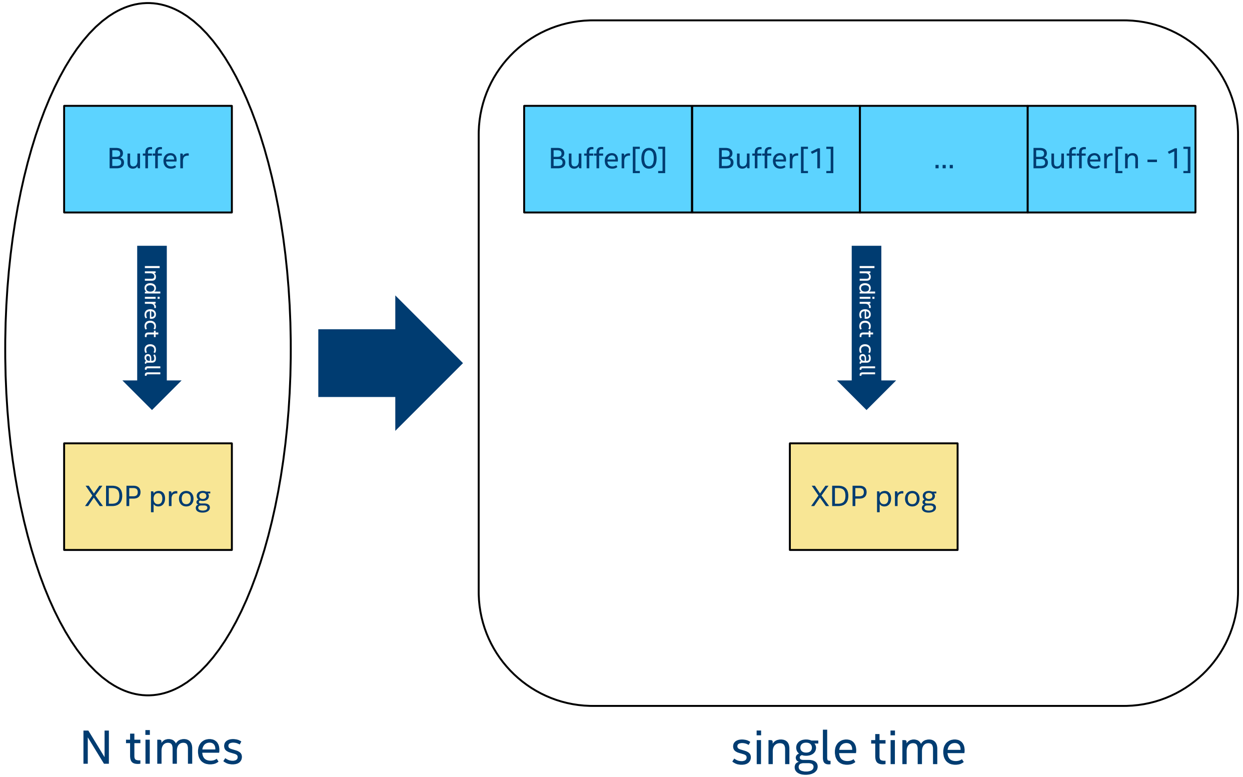
Conducted on FVL 10G, i40e driver. No fancy performance settings, just 5.3 kernel with CONFIG_RETPOLINE=y

Agenda

- Source of performance improvements
- PoC contents
  - Driver changes
  - eBPF verifier changes
- Things to be solved/questions/thoughts

Source of performance improvements

- Bulking
- Less indirect calls



DRIVER CHANGES

Storing XDP program result per XDP buffer

- Extend struct xdp_buff

```
struct xdp_buff {
     void *data;
     void *data_end;
     void *data_meta;
     void *data_hard_start;
     unsigned long handle;
     struct xdp_rxq_info *rxq;
+    unsigned int act;
 };
```

- Pass array to be filled via argument to XDP program

```
ret =
 (*(prog)->bpf_func)(ctx, (prog)->insni,
+                   results, size);
```

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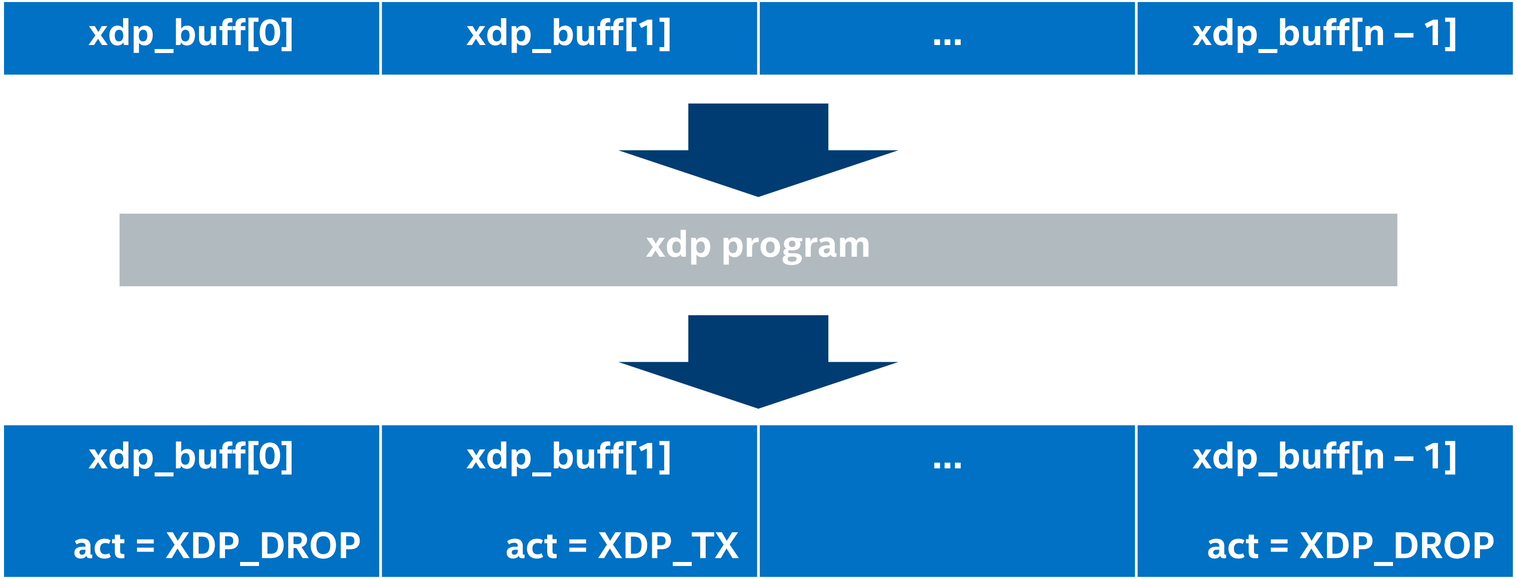
- Pass array to be filled via argument to XDP program

```
ret =
 (*(prog)->bpf_func)(ctx, (prog)->insni,
+                    results, size);
```

Bulking in driver

```
During ring alloc, for each ring:
     vsi->rx_rings[i]->xdp_buffs = (struct xdp_buff *)kcalloc(64, sizeof(struct xdp_buff),
                                                               GFP_KERNEL);
```



xdp_buff[0] | xdp_buff[1] | … | xdp_buff[n – 1]

xdp program

xdp_buff[0] act = XDP_DROP | xdp_buff[1] act = XDP_TX | … | xdp_buff[n – 1] act = XDP_DROP

Bulking in driver – simplified pseudo code

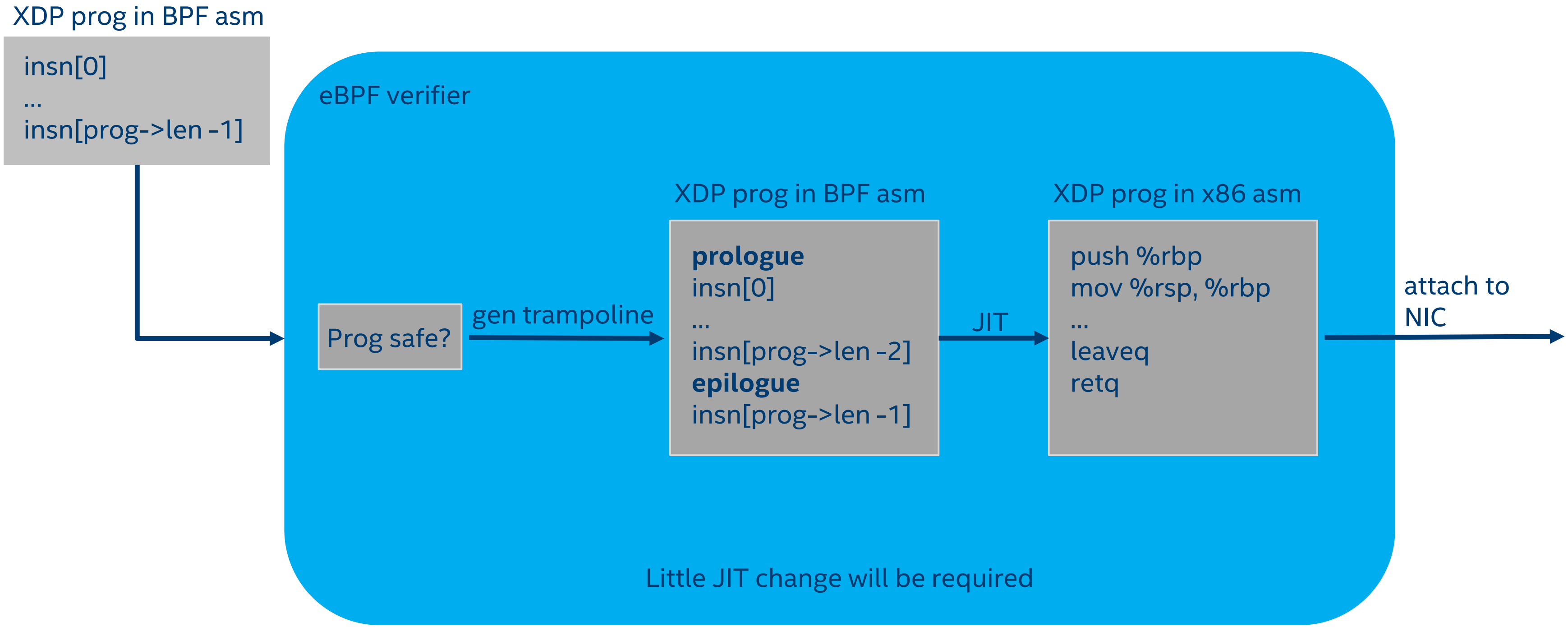
```
Clean rx interrupt:
    struct xdp_buff *xdp;
    total_rx_pkts = 0;

    while (total_rx_pkts < budget) {
        get Rx descriptor from rx_ring
        xdp = &rx_ring->xdp_buffs[total_rx_pkts];
        setup xdp_buff;
        total_rx_pkts++;
    }
```

```
    (void)bpf_prog_run_xdp(xdp_prog, rx_ring->xdp_buffs);
```

```
    for (i = 0; i < total_rx_pkts; i++) {
        xdp = &rx_ring->xdp_buffs[i];
        based on xdp->act, take appriopriate action;
    }
```

EBPF CHANGES

Trampoline patching flow



XDP prog in BPF asm

insn[0]
…
insn[prog->len -1]

eBPF verifier

Prog safe?

gen trampoline

XDP prog in BPF asm

prologue
insn[0]
…
insn[prog->len -2]
epilogue
insn[prog->len -1]

JIT

XDP prog in x86 asm

push %rbp
mov %rsp, %rbp
…
leaveq
retq

attach to
NIC

Little JIT change will be required

insn – a single BPF assembly instruction

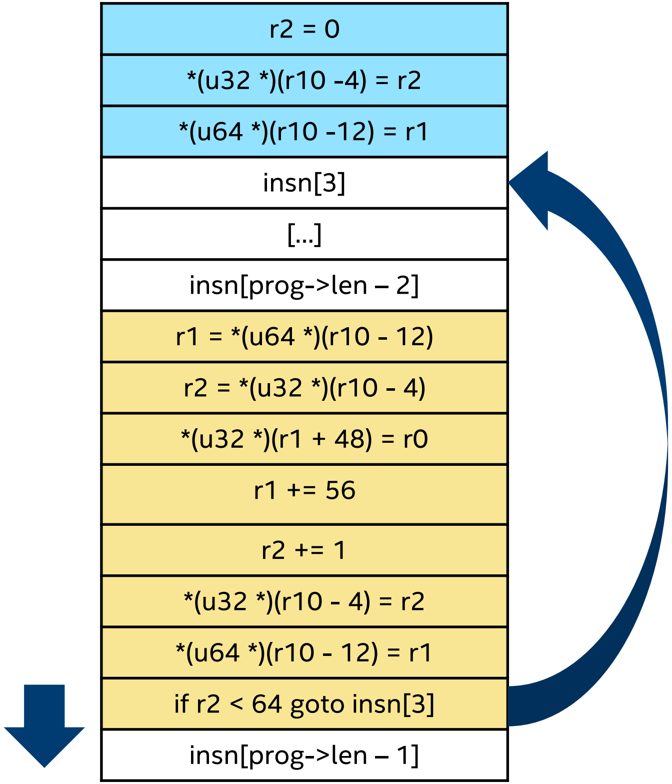
eBPF calling convention

Before we dive into eBPF, a little reminder how calling convention is defined:

- R0 - return value from in-kernel function, and exit value for eBPF program
- R1 - R5 - arguments from eBPF program to in-kernel function
- R6 - R9 - callee saved registers that in-kernel function will preserve
- R10 - read-only frame pointer to access stack

Taken from https://www.kernel.org/doc/Documentation/networking/filter.txt

eBPF program layout after generating trampoline



```
r2 = 0
*(u32 *)(r10 -4) = r2
*(u64 *)(r10 -12) = r1
insn[3]
[...]
insn[prog->len – 2]
r1 = *(u64 *)(r10 - 12)
r2 = *(u32 *)(r10 - 4)
*(u32 *)(r1 + 48) = r0
r1 += 56
r2 += 1
*(u32 *)(r10 - 4) = r2
*(u64 *)(r10 - 12) = r1
if r2 < 64 goto insn[3]
insn[prog->len – 1]
```

Prologue is executed once, whilst epilogue is executed on each loop iteration

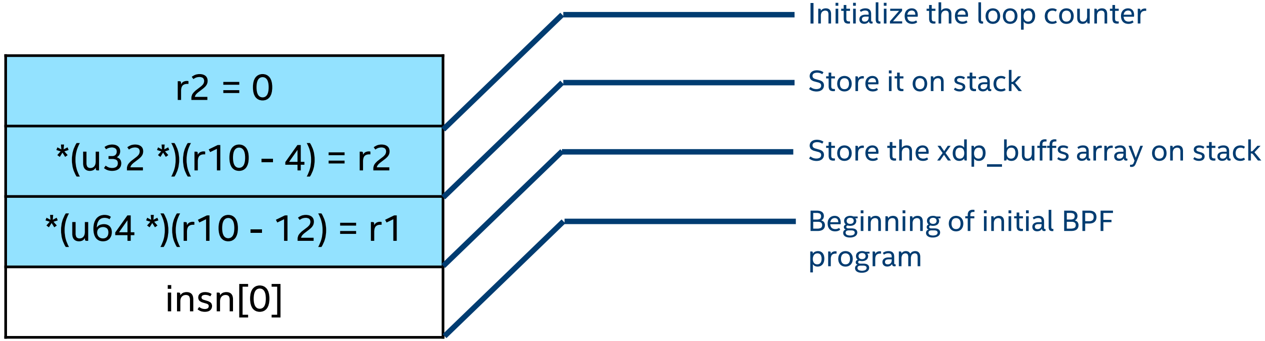
prologue

Initial program insns

epilogue

eBPF trampoline prologue section

Simple as that:



r2 = 0

*(u32 *)(r10 - 4) = r2

*(u64 *)(r10 - 12) = r1

insn[0]

Initialize the loop counter

Store it on stack

Store the xdp_buffs array on stack

Beginning of initial BPF program

At the start of a program, R1 is of a PTR_TO_CTX register type.
This means that, for XDP case, it is holding the xdp_buff pointer that was initialized by the network driver that is running the XDP program against that buffer.

eBPF trampoline prologue section, continued

Since we're consuming 12 stack bytes, we need to refresh the instructions that are making use of stack in initial program.

There are two cases that need to be handled:

-= 12

- store/load onto/from R10, e.g.:
  - `BPF_LDX_MEM(BPF_DW, BPF_REG_2, BPF_REG_10, -12),`
- ALU ops on PTR_TO_STACK register types, e.g.:
  - `BPF_MOV64_REG(BPF_REG_1, BPF_REG_10),`
  - `BPF_ALU64_IMM(BPF_ADD, BPF_REG_1, -20),`

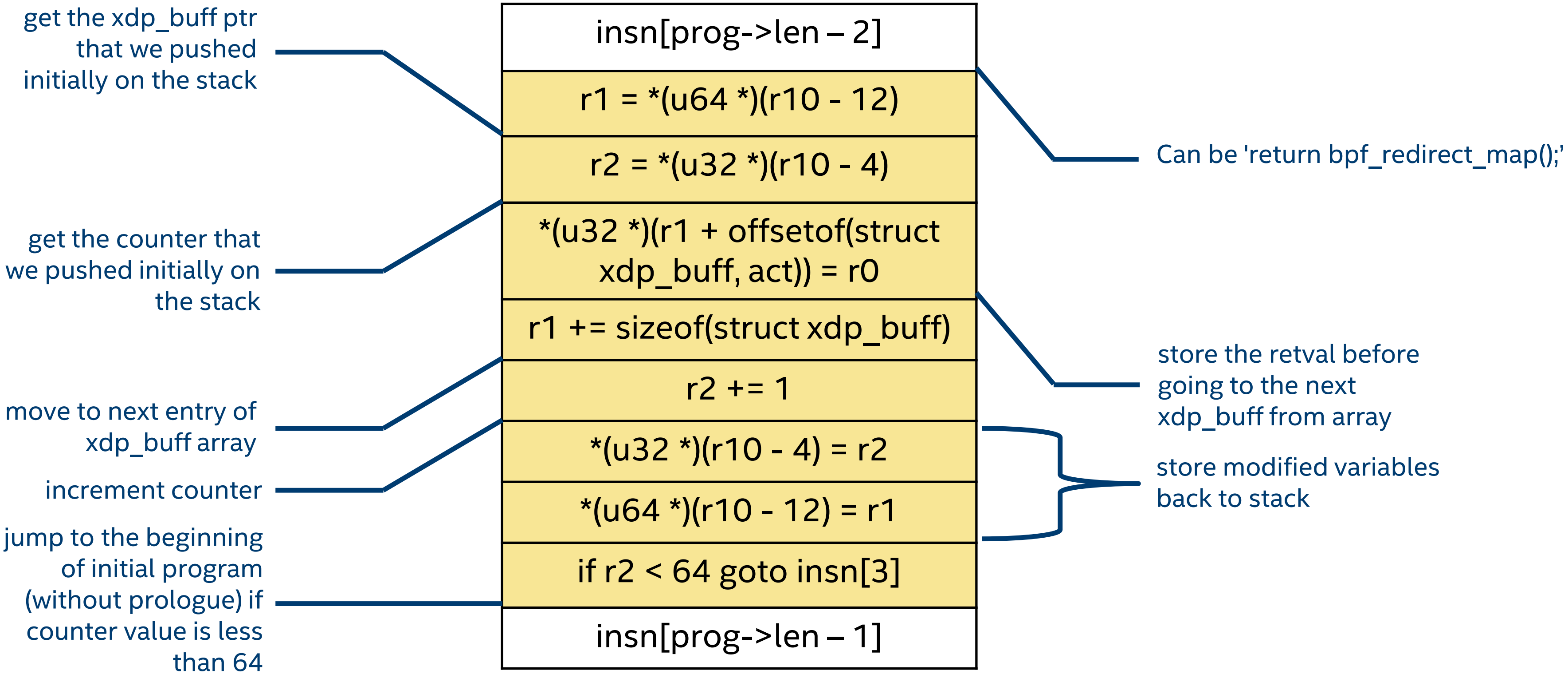
eBPF trampoline prologue section, continued

In JIT generation, the additional 12 bytes needs to be taken into account when stack depth is looked up

```
   0:    push    %rbp
   1:    mov     %rsp,%rbp
   4:    sub     $0x10,%rsp
   b:    push    %rbx
   c:    push    %r13
   e:    push    %r14
  10:    push    %r15
```

Otherwise, caller’s (driver’s) stack variables might get overwritten.

eBPF trampoline epilogue section



```
insn[prog->len – 2]
r1 = *(u64 *)(r10 - 12)
r2 = *(u32 *)(r10 - 4)
*(u32 *)(r1 + offsetof(struct
xdp_buff, act)) = r0
r1 += sizeof(struct xdp_buff)
r2 += 1
*(u32 *)(r10 - 4) = r2
*(u64 *)(r10 - 12) = r1
if r2 < 64 goto insn[3]
insn[prog->len – 1]
```

get the xdp_buff ptr that we pushed initially on the stack

get the counter that we pushed initially on the stack

move to next entry of xdp_buff array

increment counter

jump to the beginning of initial program (without prologue) if counter value is less than 64

Can be 'return bpf_redirect_map();'

store the retval before going to the next xdp_buff from array

store modified variables back to stack

Things to be solved/questions/thoughts

1. “prefetch” instruction in BPF asssembly
2. Selftests
3. How to provide backward compatibility?
4. Sort actions?
5. How much AF_XDP would benefit from it?
6. Thought – driver changes ARE required
7. Thought – boost for Tx/Redirect speaks for itself

Q&A

BACKUP

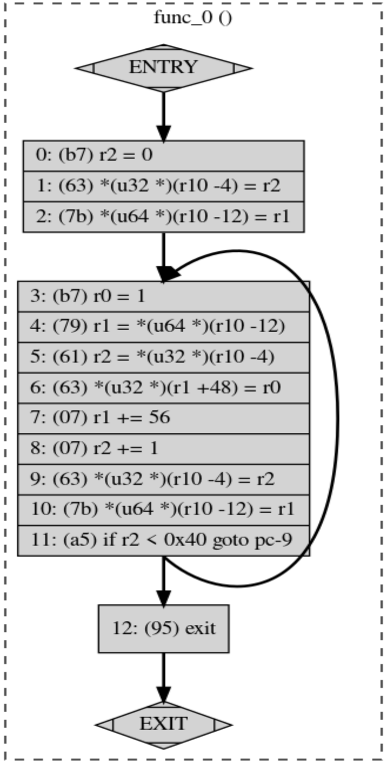
eBPF program layout after generating trampoline
putting it all together

```
#include <linux/bpf.h>

__section("prog")
int xdp_drop(struct xdp_md *ctx)
{
    return XDP_DROP;
}
```

Clang compiler

```
R0 = 1
exit
```

Generate trampoline



```
0: (b7) r2 = 0
1: (63) *(u32 *)(r10 -4) = r2
2: (7b) *(u64 *)(r10 -12) = r1
3: (b7) r0 = 1
4: (79) r1 = *(u64 *)(r10 -12)
5: (61) r2 = *(u32 *)(r10 -4)
6: (63) *(u32 *)(r1 +48) = r0
7: (07) r1 += 56
8: (07) r2 += 1
9: (63) *(u32 *)(r10 -4) = r2
10: (7b) *(u64 *)(r10 -12) = r1
11: (a5) if r2 < 0x40 goto pc-9
12: (95) exit
```

JIT

```
0xffffffffc04bea37:
   0:   push   %rbp
   1:   mov    %rsp,%rbp
   4:   sub    $0x10,%rsp
   b:   push   %rbx
   c:   push   %r13
   e:   push   %r14
  10:   push   %r15
  12:   pushq  $0x0
  14:   xor    %esi,%esi
  16:   mov    %esi,-0x4(%rbp)
  19:   mov    %rdi,-0xc(%rbp)
  1d:   mov    $0x1,%eax
  22:   mov    -0xc(%rbp),%rdi
  26:   mov    -0x4(%rbp),%esi
  29:   mov    %eax,0x30(%rdi)
  2c:   add    $0x38,%rdi
  30:   add    $0x1,%rsi
  34:   mov    %esi,-0x4(%rbp)
  37:   mov    %rdi,-0xc(%rbp)
  3b:   cmp    $0x40,%rsi
  3f:   jb     0x000000000000001d
  41:   pop    %rbx
  42:   pop    %r15
  44:   pop    %r14
  46:   pop    %r13
  48:   pop    %rbx
  49:   leaveq
  4a:   retq
```