C like DSL for Open vSwitch

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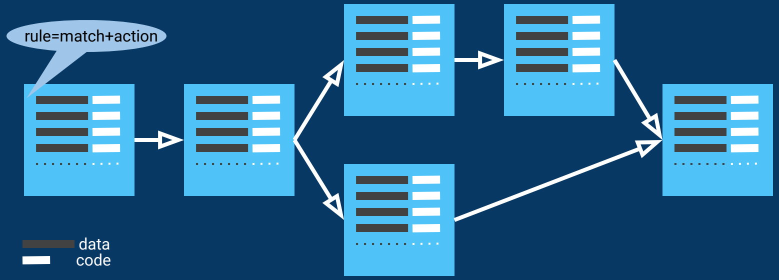
Packet Processing Pipeline

- Processing pipeline has several stages
- Each stage is a table of rules
- Each rule has “match” and “actions”
- “data”: the “match” part of a rule and the constants in the “actions” of a rule
- “code”: anything which is not “data”

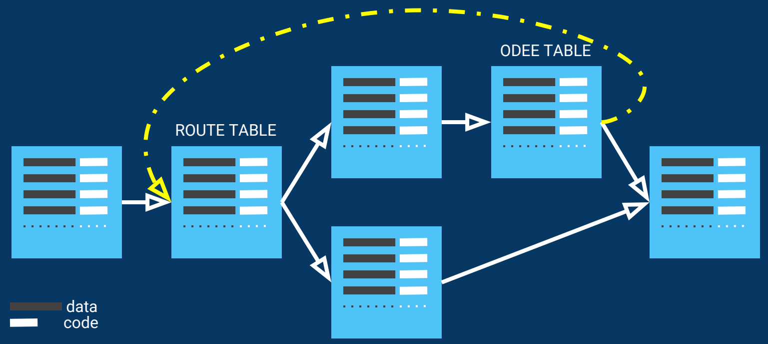


A Packet Processing Pipeline

Code mixed with Data

- Table rules have “code” and “data”
  ⇨ update of “code” can’t happen independent of “data” e.g. bug fixes need only “code” changes

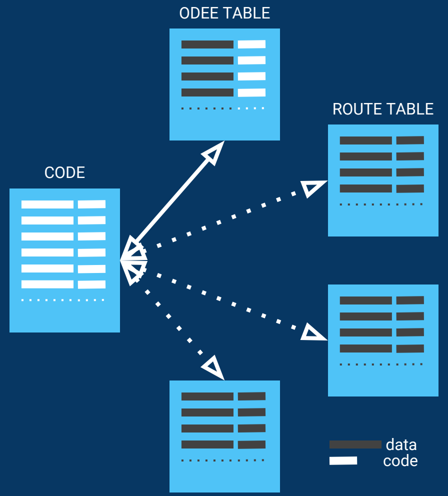
- Table modifies state (due to “code”)
  ⇨ table can’t be reused easily e.g. need for route lookup to be done on source address for RPF checks in addition to lookup done for destination address



A Packet Processing Pipeline with loops

Code separate from Data

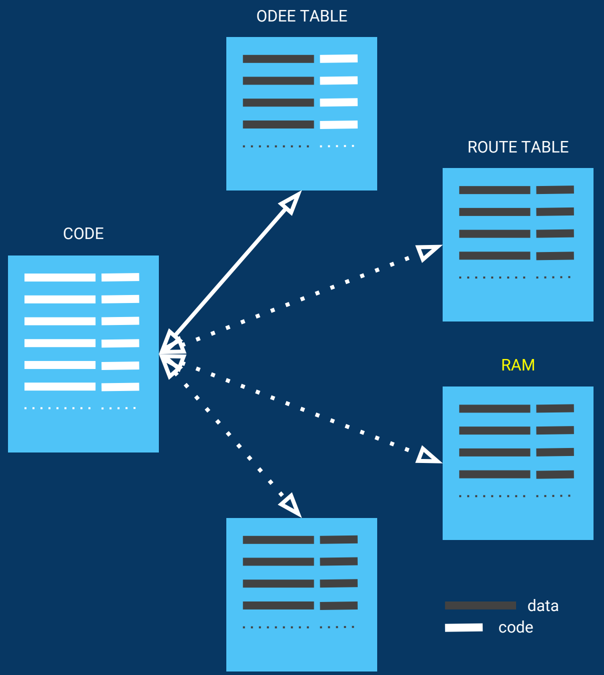
- Table that has only “code”
  ⇨ can be updated without touching forwarding state (“data”)
  ⇨ can achieve 0 downtime!
- Table that has only “data”
  ⇨ no side effects of updating state
  ⇨ table can be reused e.g. ROUTE TABLE



Packet Processing Pipeline implemented by CODE TABLE

A different way to organize tables

- CODE table encodes forwarding logic
- A non-CODE table implements a lookup "function" e.g. ROUTE table
- Code can "call" these "function"s
- RAM table implements a function which takes in a 32b address and returns its 32b contents
- Data structures can be laid down in RAM



Programming model

```
void main (void)
{
    struct context cx = context_lkup (NXM_OF_IN_PORT[], NXM_OF_ETH_SRC[]);
    if (!cx.cx_tenant) { stats_inc (NXM_OF_IN_PORT[], E_NO_TENANT); goto done; }
    u32 tenant_id = cx.cx_tenant->te_tenant_id;
    if (!cx.cx_tenant->te_oper_state_up) { stats_inc (tenant_id, E_OPER_DOWN); goto done; }
    u32 l3_vrf_id = cx.cx_l2subnet->l2_l3vrf->l3_vrf_id;
    u8 ok = acl_lkup (l3_vrf_id); /* rest of match criteria from pkt fields */
```

CONTEXT table lookup

flow fields are “well known” global variables

RAM table lookup

- Flow fields are “well known” global variables e.g. NXM_OF_ETH_SRC[]
- Writing to a global variable updates the corresponding flow field
- Each packet goes through processing starting at “main”
- “main” may call other functions and lookup RAM
- All the writes done to global variables before returning from “main” constitutes the actions to be performed on the packet

Why another programming model?

- Use a model which has hi-fidelity with the real world so that event in the real world can be translated to the model as-is
  - forwarding code doesnt change (CODE)
  - tenant info changes at a slower rate (RAM)
  - forwarding state change at a faster rate (ROUTE)
- (all other reasons why there are several programming languages)

Why a higher level language?

- Coding at higher level of abstraction

  ⇨ no worry about register liveness, function call setup, ...

  ⇨ less lines of code

  ⇨ less things to juggle in mind

  ⇨
  - less bugs
  - higher feature velocity
  - lower barrier to entry to write forwarding code
  - (all other reasons why C is better than assembly)

Why C?

- “closer to the metal” i.e. each C statement translates to few deterministic number of instructions
- Engineers already familiar with C
- Good optimizing compiler available which can optimize use of registers
- Mature static analysis tools available which can tell worst case code path and worst case register usage

Open vSwitch can simulate a stack based processor

- Several match tables

  ⇨ table 0 for CODE, table 1 for RAM, ..
- Several registers

  ⇨ store intermediate state while executing code
- Stack

  ⇨ perform function calls
- goto_table, resubmit

  ⇨ jump to different parts of code
- Atomic transactions for grouping updates

  ⇨
  - atomically update structs in RAM (software transactional memory)
  - atomically update all of CODE and achieve 0 downtime

CODE (table 0)

```
100 void main (void)
110 {
120     struct context cx;
130     cx = context_lkup (NXM_OF_IN_PORT[],
140                         NXM_OF_ETH_SRC[]);
150     if (!cx.cx_tenant) {
160         stats_inc (NXM_OF_IN_PORT[],
170                    E_NO_TENANT);
180     }
```

```
000   priority=0, actions=
        load:130->NXM_NX_REG0[0..31],goto_table:0
130   reg0=130, priority=1, actions=
141   reg0=141, priority=1, actions=
150   reg0=150, priority=2, reg9=0, actions=
150   reg0=150, priority=1, actions=
160   reg0=160, priority=1, actions=
...   ......... .......... ........
```

- Table 0 match criteria is only reg0 which is the “program counter”
- First rule to get executed is 000, a priority 0 rule to jump to the start of “main”
- function call uses one rule to make the call and another one to process result
- “if” uses priority 1 and 2 with same reg0 value
- All other rules are priority 1

Calling a function

```
130 cx = context_lkup (NXM_OF_IN_PORT[],
140                    NXM_OF_ETH_SRC[]);
141
150
```

- Save registers on stack
- Push return address on stack
- Load arguments in registers reg1 onwards
- Jump to table implementing the function

```
130   reg0=130, priority=1, actions=
         push:NXM_NX_REG0[0..31], push:NXM_NX_REG1[0..31], push:NXM_NX_REG2[0..31], # save regs
         push:NXM_NX_REG3[0..31], push:NXM_NX_REG4[0..31], push:NXM_NX_REG5[0..31], # ...
         push:NXM_NX_REG6[0..31], push:NXM_NX_REG7[0..31], push:NXM_NX_REG8[0..31], # ...
         push:NXM_NX_REG9[0..31],                                                   # ...
         load:141->NXM_NX_REG1[0..31], push:NXM_NX_REG1[0..31], # push return address 141
         load:NXM_OF_IN_PORT[0..31]->NXM_NX_REG1[0..31], # load IN_PORT in reg1
         load:NXM_OF_ETH_SRC[0..31]->NXM_NX_REG2[0..31], # load ETH_SRC in reg2
         load:NXM_OF_ETH_SRC[32..47]->NXM_NX_REG3[0..15], # ... and reg3
         goto_table:210                                  # jump to CONTEXT table (table 210)
```

Processing function return value

```
130 cx = context_lkup (NXM_OF_IN_PORT[],
140                    NXM_OF_ETH_SRC[]);
141
150
```

```
struct context {
    struct tenant *cx_tenant;
    struct l2subnet *cx_l2subnet;
};
```

- Pop return value into registers
- Pop saved registers
- Jump to next statement

```
141   reg0=141, priority=1, actions= # process return values from call to CONTEXT table, jump to 150
        pop:NXM_NX_REG9[0..31],                                  # pop cx.cx_tenant into reg9
        pop:NXM_NX_REG8[0..31],                                  # pop cx.cx_l2subnet into reg8
        pop, pop                                                 # pop and discard saved reg9, reg8
        pop:NXM_NX_REG7[0..31], pop:NXM_NX_REG6[0..31],          # pop and restore reg7 and reg6
        pop:NXM_NX_REG5[0..31], pop:NXM_NX_REG4[0..31],          # pop and restore reg5 and reg4
        pop:NXM_NX_REG3[0..31], pop:NXM_NX_REG2[0..31],          # pop and restore reg3 and reg2
        pop:NXM_NX_REG1[0..31], pop:NXM_NX_REG0[0..31],          # pop and restore reg1 and reg0
        load:150->NXM_NX_REG0[0..31], goto_table:0               # jump to next statement (150)
```

Function implementation

```
# <10,00:aa:bb:cc:dd:ee> -> <0x0001a004,0x0008a044>
reg1=0x10, reg2=0x00aabbcc, reg3=0xddee, actions=                # match on arguments
  pop:NXM_NX_REG0[0..31],                                        # load return address
  load:0x0001a004->NXM_NX_REG1[0..31], push NXM_NX_REG1[0..31],  # push cx.cx_l2subnet=0x0001a004
  load:0x0008a044->NXM_NX_REG1[0..31], push NXM_NX_REG1[0..31],  # push cx.cx_tenant=0x0008a044
  goto_table:0                                                   # jump back to caller

# lookup failed
priority=0, actions=
  pop:NXM_NX_REG0[0..31],                                        # load return address
  load:0x0->NXM_NX_REG1[0..31], push NXM_NX_REG1[0..31],         # push cx.cx_l2subnet=0x0
  load:0x0->NXM_NX_REG1[0..31], push NXM_NX_REG1[0..31],         # push cx.cx_tenant=0x0
  goto_table:0                                                   # jump back to caller
```

- Match on function arguments
- Pop return address from stack
- Push return value on stack, jump back to caller

RAM (table 1)

```
reg1=0x00010000, actions=load:0xabcdabcd->NXM_NX_REG1[0..31] # address 0x00010000 => 0xabcdabcd
reg1=0x00010004, actions=load:0xfefefefe->NXM_NX_REG1[0..31] # address 0x00010004 => 0xfefefefe
...
priority=0, actions=exit # address not found => exception
```

- Match on 32b address, load 32b contents of address
- Accessing uninitialized memory causes exit
- Complex data structures can be laid down in memory
- Bundle transactions can be used to update multiple addresses atomically ⇨ explicit synchronization between reader (forwarding code) and writer (controller) not needed - aka “software transactional memory”
- There is no explicit jumping back to caller because caller uses “resubmit” instead of “goto_table”

Pointers

```
200 u32 tenant_id;
210 tenant_id = cx.cx_tenant->te_tenant_id;
```

```
struct tenant {
    u8 te_oper_state_up :1;
    u32 te_tenant_id;
};
```

- If struct starts at 1K boundary and is at most 1K in size, address of a struct member is address of struct with the bottom 10b set as the offset of the member

```
210   reg0=210, priority=1, actions=
        load:NXM_NX_REG9[0..31]->NXM_NX_REG1[0..31], # load cx.cx_tenant in reg1
        load:4->NXM_NX_REG1[0..10],      # load offsetof (struct tenant, te_tenant_id) in bottom 10b
        resubmit (,1)                    # get cx.cx_tenant->te_tenant_id in reg1 by RAM lookup
        load:NXM_NX_REG1[0..31]->NXM_NX_REG8[0..31],   # tenant_id = cx.cx_tenant->te_tenant_id
        load:220->NXM_NX_REG0[0..31], goto_table:0     # jump to next statement (statement 220)
```

“if”

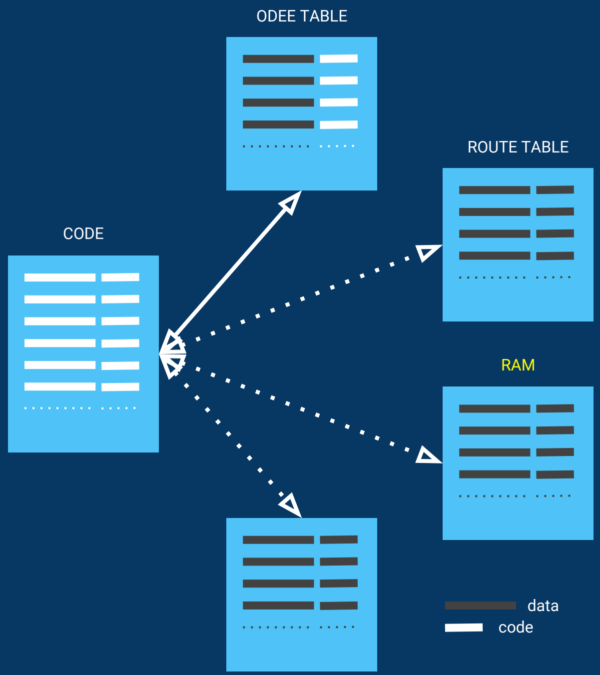
```
150 if (!cx.cx_tenant) {
160       stats_inc (NXM_OF_IN_PORT[],
170                  E_NO_TENANT);
180 }
```

- Two rules with same reg0 value but different priorities
- Higher priority rules matches on the condition being 0 or false
- The two rules jump to different locations

```
150   reg0=150, priority=2, reg9=0,actions=         # if cx.cx_tenant is NULL, jump to 160
         load:160->NXM_NX_REG0[0..31], goto_table:0
150   reg0=150, priority=1,        actions=         # if non NULL, jump to 210
         load:210->NXM_NX_REG0[0..31], goto_table:0
```

Next steps

- Make Open vSwitch a LLVM backend, so that clang C compiler can be used
- Can "asm" can be used to embed OVS instructions in the DSL
- Can service insertion be simulated as a context switch where all state is saved and packet is sent out, state is restored when packet comes back and processing continues from where it had left off



Thank you

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