DTrace based on BPF and tracing facilities: Challenges

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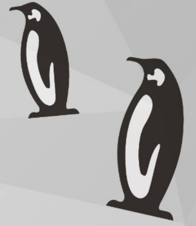
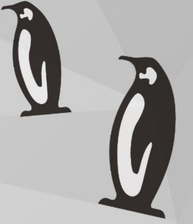
DTrace and BPF



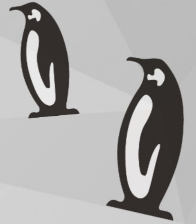
- D code compiled into BPF functions
- Dynamic generation of trampoline BPF programs
- Pre-compiled function library (C-to-BPF)
- Built-in linker to generate standalone BPF programs
- D supports local, global, and TLS variables
- D supports arrays, aggregations, dynamic variables, string functions, alloca/bcopy/...

Origins



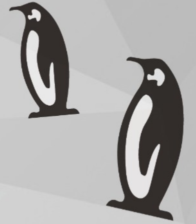
- Bleeding edge functionality is cool
- Bleeding edge functionality solves many problems
- Production systems don’t run bleeding edge kernels
- Real life use cases usually originate on production systems

We can’t...



- … tell customers to upgrade their systems
- … tell customers to wait for new features
- …
- …
- …
- … tell customers to ignore reality!

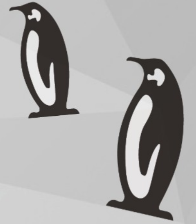
Problem: Spill register to stack



- Store constant value from reg to stack
- Load it back → constant value in reg
- Store known (bounded) value from reg to stack
- Load it back → unknown value in reg

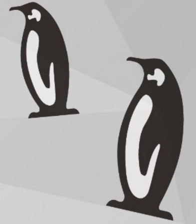
Fixed on Jul 13, 2021, first appeared in v5.14-rc4

Solution: Spill register to stack



- Store known (bounded) value from reg to stack
- Load it back → unknown value in reg
- Insert explicit bounds check(s) on the reg
  - Conditional jumps provide this info to the verifier
  - But be careful….!!!

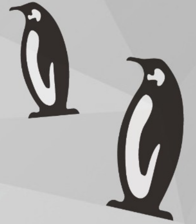
Problem: branch prediction bug



- Conditional branch comparing %rD against %rS
- %rD = bounded value, %rS = constant value
- Prediction is attempted and bounds are updated
- %rD = constant value, %rS = bounded value
- No prediction is attempted and bounds are updated incorrectly

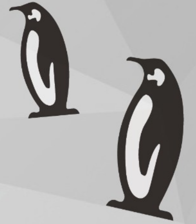
No patch for this problem in bpf-next (yet)!

Problem: branch prediction bug



```
[...]
BPF: 185: frame1: R0=invP0 R1_w=invP24 ...
R5=invP(id=0,umin_value=17,umax_value=20,var_off=(0x10; 0x7)) ...
BPF: 185: (3d) if r1 >= r5 goto pc+10
BPF:\240 frame1: R0=invP0 R1_w=invP24 ...
R5=invP(id=0,umin_value=25,umax_value=20,var_off=(0x10; 0x7)) ...
BPF: 186: frame1: R0=invP0 R1_w=invP24 ...
R5=invP(id=0,umin_value=25,umax_value=20,var_off=(0x10; 0x7)) ...
[...]
```

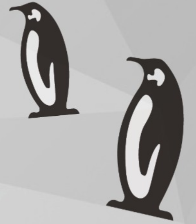
Solution: branch prediction bug



```
static int check_cond_jmp_op(struct bpf_verifier_env *env,
                              struct bpf_insn *insn, int *insn_idx)
{
 ....
        } else if (src_reg->type == SCALAR_VALUE &&
                   !is_jmp32 && tnum_is_const(src_reg->var_off)) {
                pred = is_branch_taken(dst_reg,
                                       src_reg->var_off.value,
                                       opcode,
                                       is_jmp32);
        } else if (src_reg->type == SCALAR_VALUE &&
                   !is_jmp32 && tnum_is_const(dst_reg->var_off)) {
                pred = is_branch_taken(src_reg,
                                       dst_reg->var_off.value,
                                       flip_opcode(opcode),
                                       is_jmp32);
        } ...
...
}
```

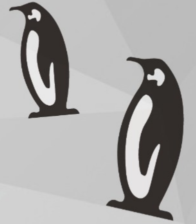
I will submit a patch for it this week.

Problem: resource limits



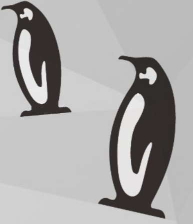
- Tracing scripts can get pretty complex
- String manipulation functions
- alloca(), bcopy()
- Associative arrays
- Dynamically allocated variables
- Need more memory than the stack provides

Problem: resource limits (cont.)



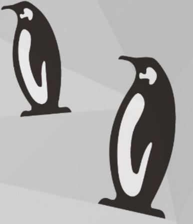
- BPF map, singleton element, large value size
- Use value as addressable memory
- Limitations:
  - Verifier cannot validate anything stored/loaded
  - Values are plain integers (can’t use as pointers)
  - Limited space (KMALLOC_MAX_SIZE)

Solution (?): resource limits



- Option 1: Allow BPF maps with larger value size
- Option 2: Use multiple map values
  - A form of paged memory (map value is like a page)
  - Cumbersome (ptr + offset + addr translation vs ptr)
- Option 3: New (per-cpu) memory resource
  - Does not need to be visible to userspace
  - Large (bounded) size – needs to be preallocated
  - Possible bpf_malloc() / bpf_free() helper support?

Other issues...



- Complex scripts and functions need loops
  - More complex invariant state detection needed
  - Invariant relations between values in registers
- Why are the CPU registers (pt_regs) not accessible from the BPF context for some program types?
- Compilers (LLVM, GCC) generating code that is valid but cannot be validated by the verifier
- Userspace validation → signed BPF programs?