A tool for the

Symbolic Execution

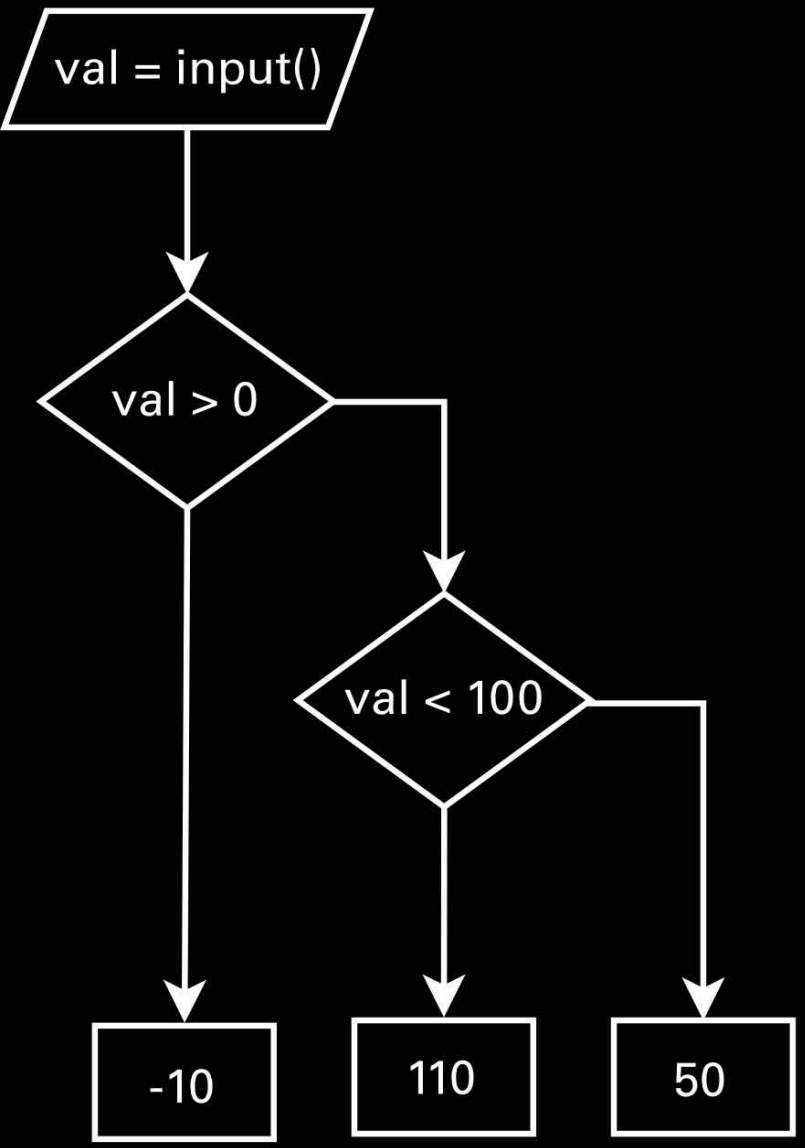
of Linux binaries

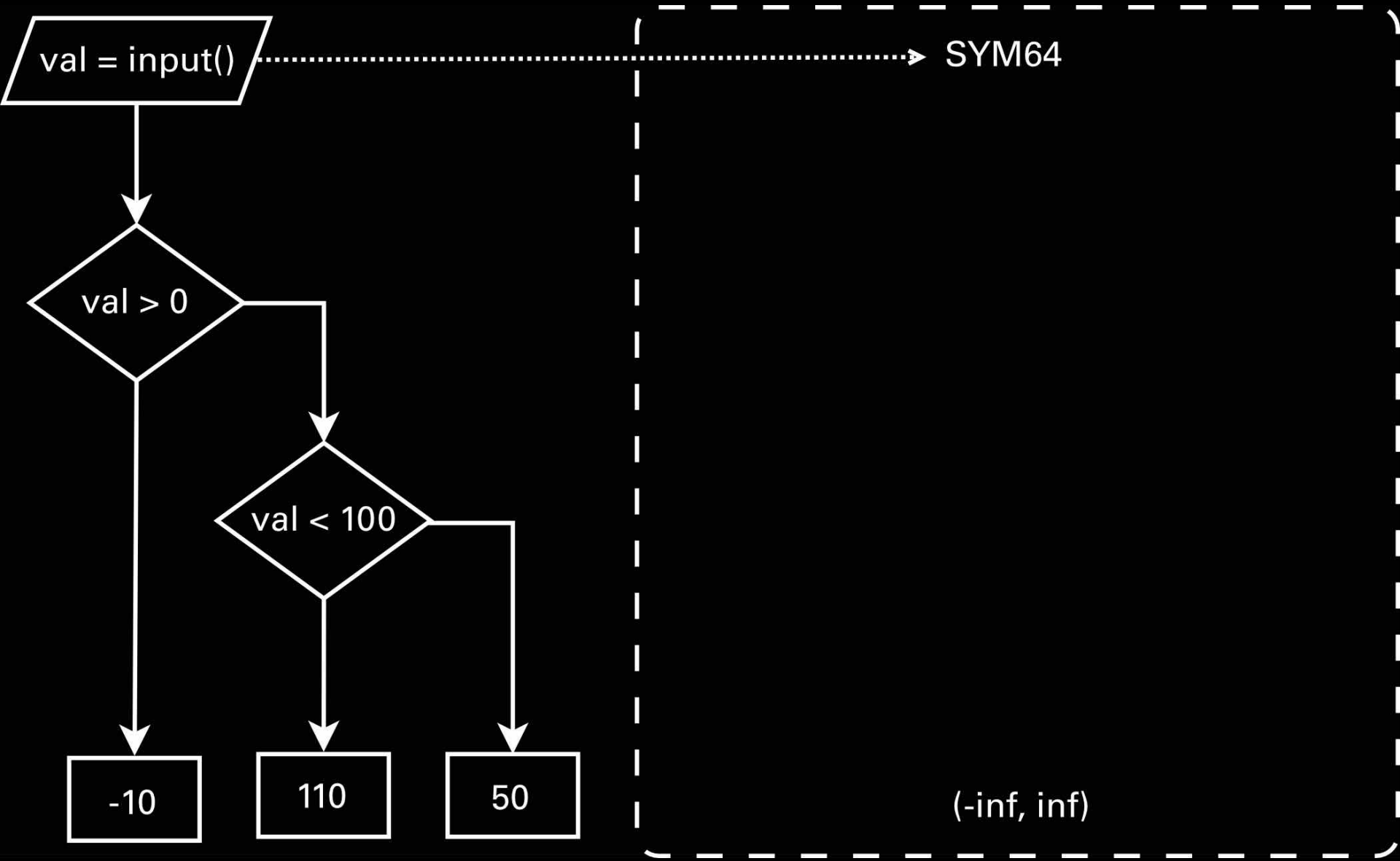
About Symbolic Execution

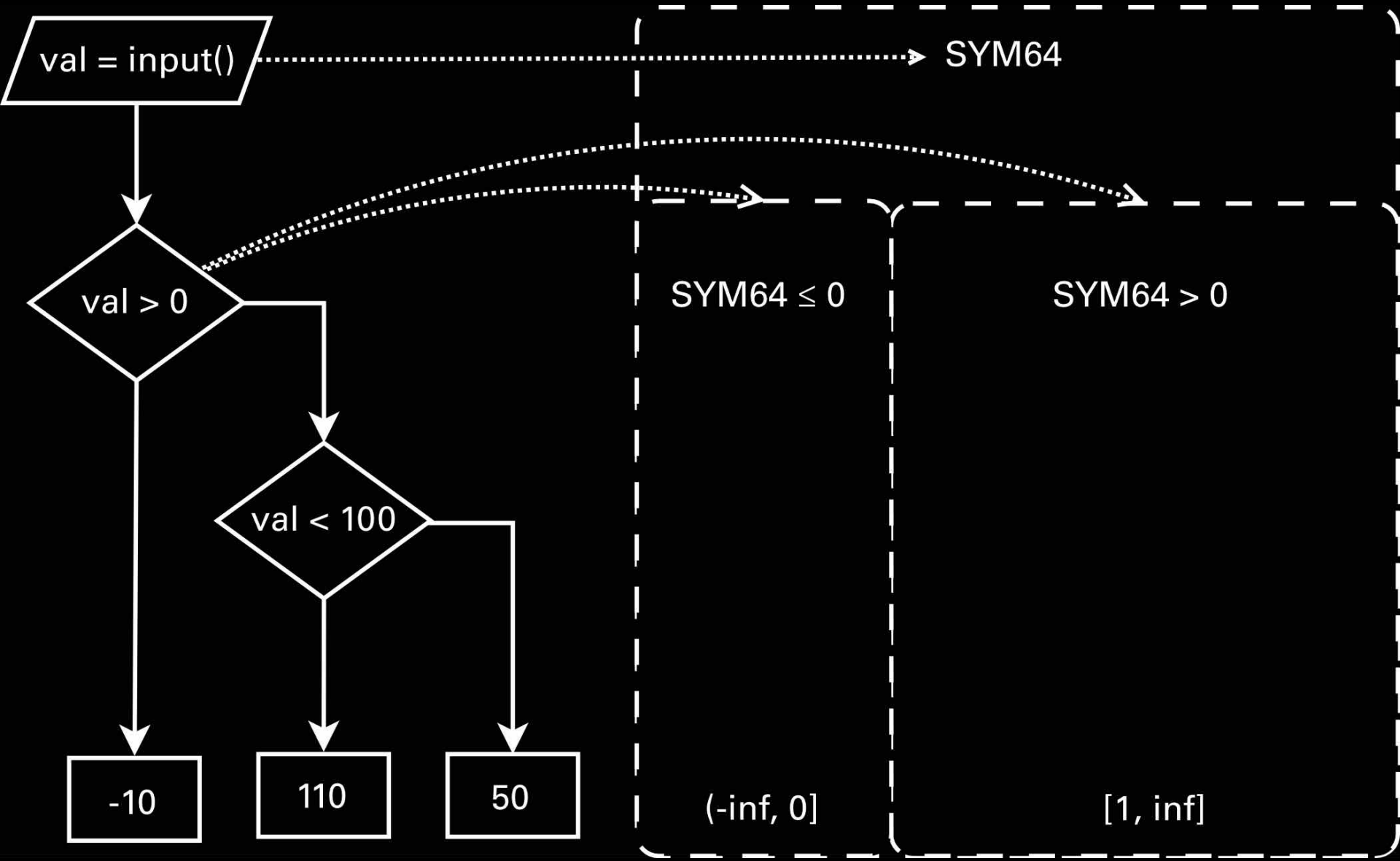
- Dynamically explore all program branches.
- Inputs are considered symbolic variables.
- Symbols remain uninstantiated and become constrained at execution time.
- At a conditional branch operating on symbolic terms, the execution is forked.
- Each feasible branch is taken, and the appropriate constraints logged.

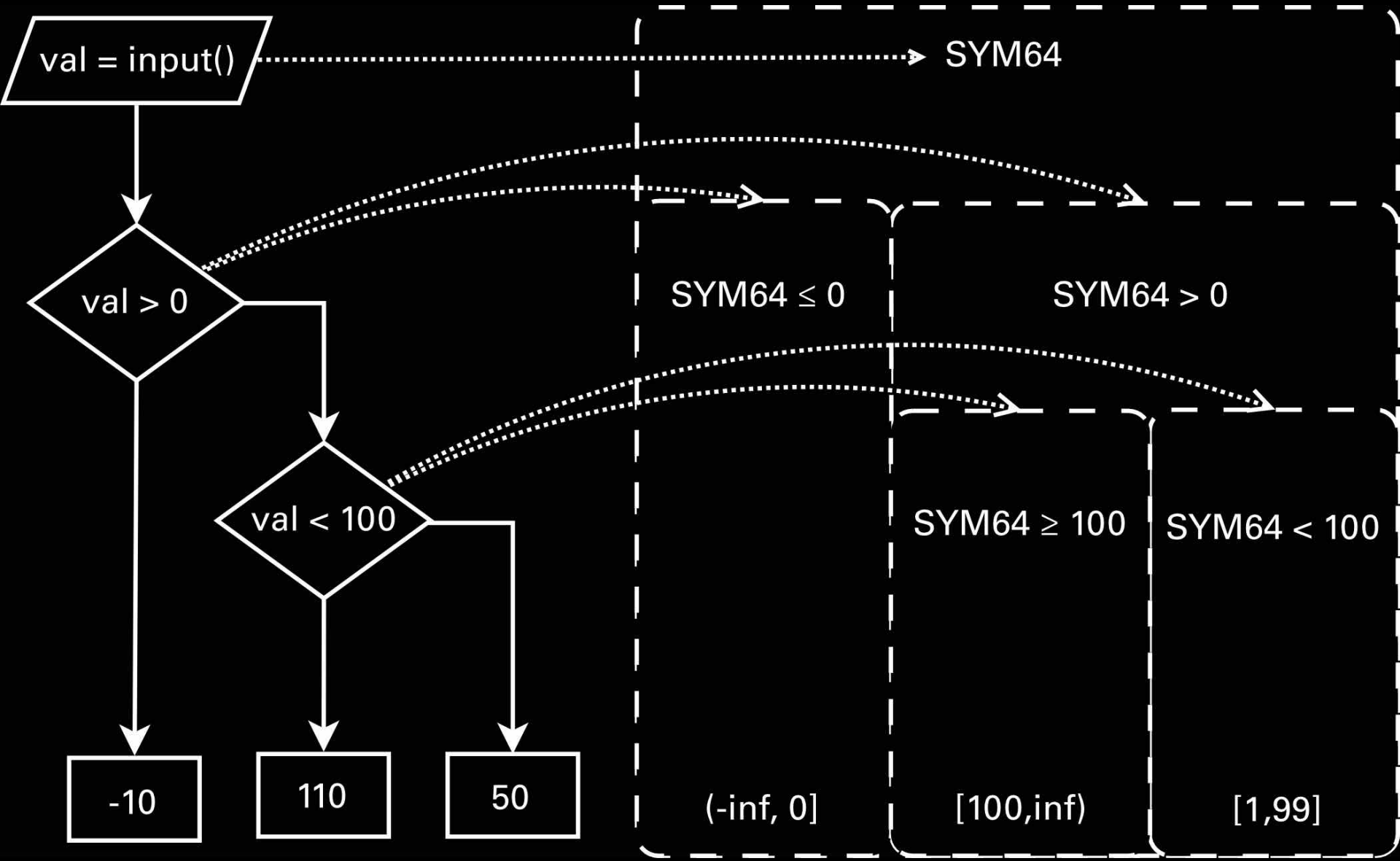
Input space >> Number of paths

```
int main( ) {
        int val;
        read(STDIN, &val, sizeof(val) );
        if ( val > 0 )
                if ( val < 100 )
                 do_something( );
             else
                 do_something_else( );
}
```


val = input()
val > 0
val < 100
-10
110
50


val = input()
SYM64
val > 0
val < 100
-10
110
50
(-inf, inf)


val = input()
SYM64
val > 0
SYM64 ≤ 0
SYM64 > 0
val < 100
-10
110
50
(-inf, 0]
[1, inf]


val = input()
SYM64
val > 0
SYM64 ≤ 0
SYM64 > 0
val < 100
SYM64 ≥ 100
SYM64 < 100
-10
110
50
(-inf, 0]
[100,inf)
[1,99]

This is used for:

- Test generation and bug hunting.
- Reason about reachability.
- Worst-Case Execution Time Analysis.
- Comparing different versions of a func.
- Deobfuscation, malware analisys.
- AEG: Automatic Exploit Generation. Whaat?!

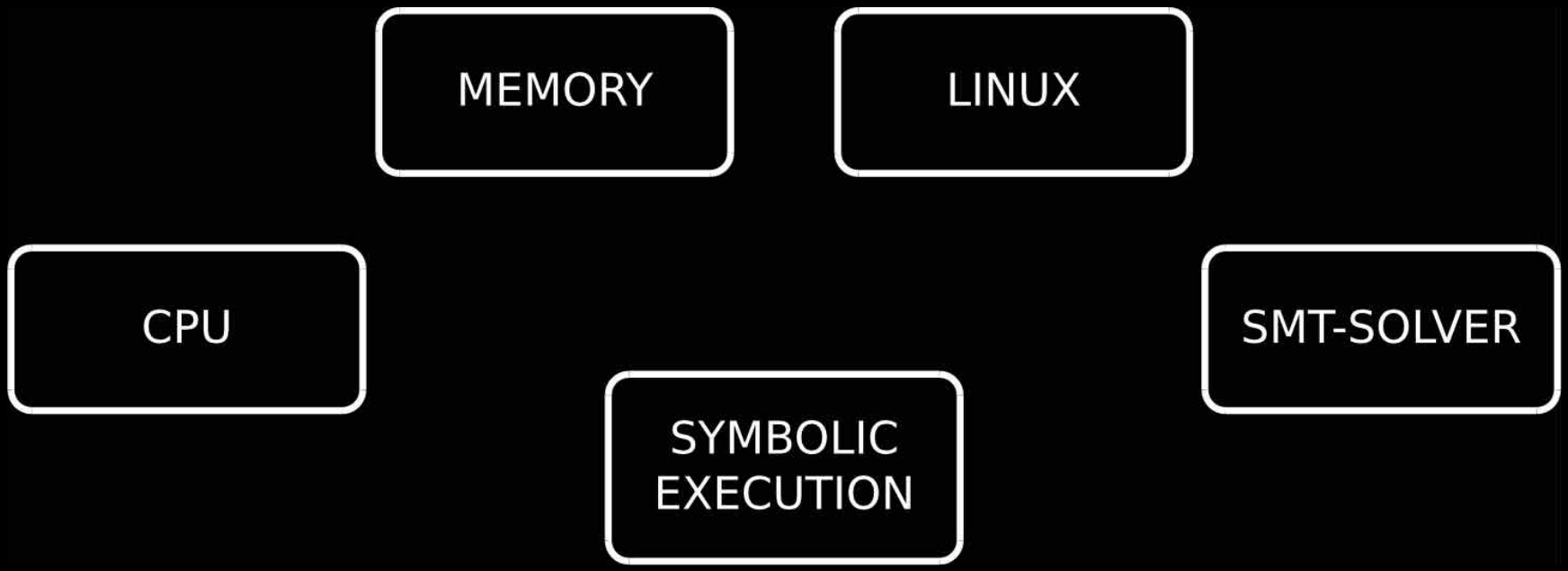
State of the art

- Lots of academic papers:
  - 2008-12-OSDI-KLEE
  - Unleashing MAYHEM on Binary
- Several implementations:
  - SymDroid, Cloud9, Pex, jCUTE, Java PathFinder, KLEE, s2e, fuzzball, mayhem, cbass
- Only a few work on binary :
  - libVEX / IL based
  - quemu based

Our aim

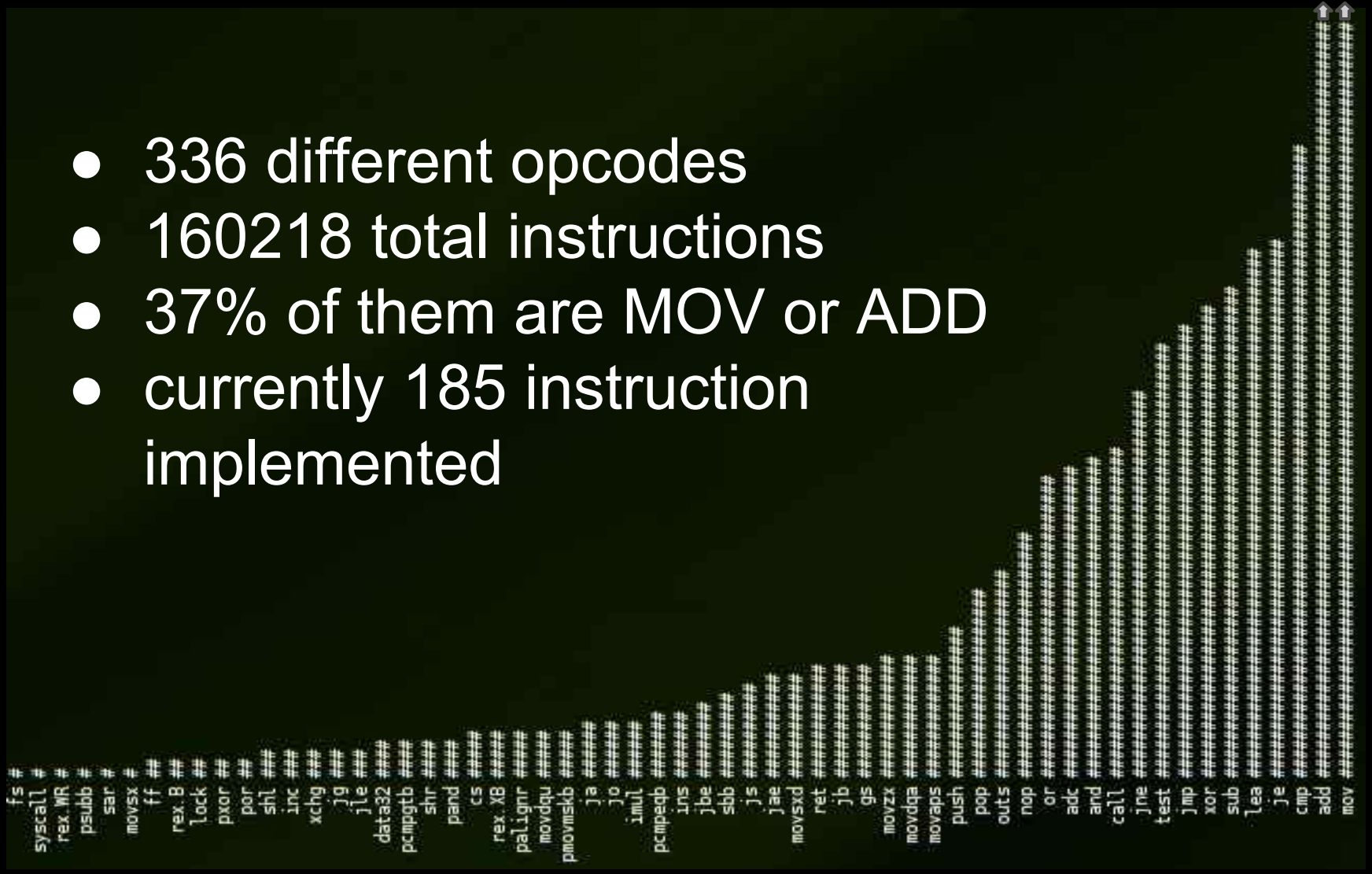
- Emulate x86-64 machine code symbolically.
- Load ELF executables.
- Synthesize any process state as starting point.
- The final code should be readable and easy to extend.
- Use as few dependencies as possible:
  - *pyelftools, distorm3* and *z3*
- Analysis state can be saved and restored.
- Workload can be distributed (dispy)

Basic architecture



Instructions Frequency in GNU LIBC

- 336 different opcodes
- 160218 total instructions
- 37% of them are MOV or ADD
- currently 185 instruction implemented

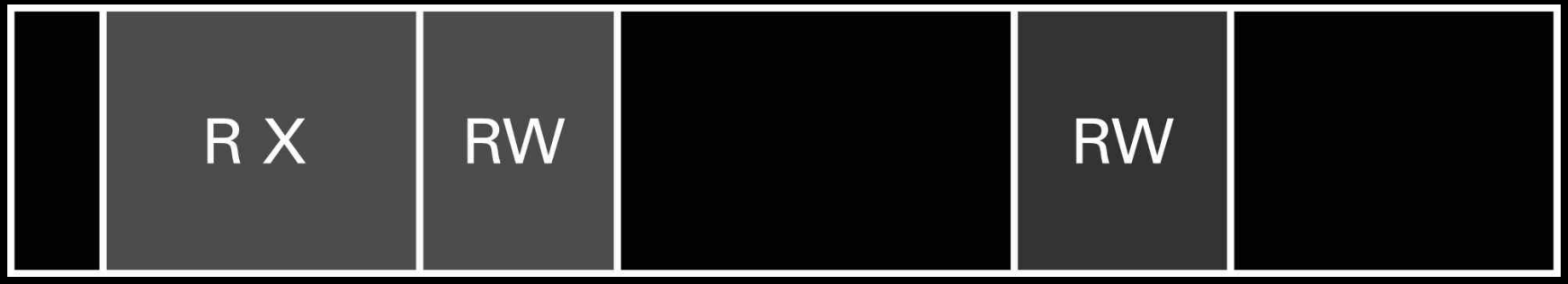


CPU

- Based on distorm3 DecomposeInterface.
- Most instructions are very simple, ex.

```
@instruction
def DEC(cpu, dest):
        res = dest.write( dest.read() - 1 )
        #Affected Flags o..szapc
        cpu.calculateFlags('DEC', dest.size, res)
```

Memory




```
class Memory:
    def mprotect(self, start, size, perms): …
    def munmap(self, start, size): …
    def mmap(self, addr, size, perms): …
    def putchar(self, addr, data): …
    def getchar(self, addr): …
```

Operating System Model (Linux)

```
class Linux:
    def exe(self, filename, argv=[], envp=[]):…
    def syscall(self, cpu):…

    def sys_open(self, cpu, buf, flags, mode):…
    def sys_read(self, cpu, fd, buf, count):…
    def sys_write(self, cpu, fd, buf, size):…
    def sys_close(self, cpu, fd):…
    def sys_brk(self, cpu, brk):…
```

Symbols and SMT solver

```
class Solver:
    def getallvalues(self, x, maxcnt = 30):
    def minmax(self, x, iters=10000):
    def check(self):
    def add(self, constraint):
#Symbols factory
    def mkArray(self, size, name ):…
    def mkBool(self, name ):…
    def mkBitVec(self, size, name ):…
```

Operation over symbols is almost transparent

```
>>> from smtlibv2 import *
>>> s = Solver()
>>> a = s.mkBitVec(32)
>>> b = s.mkBitVec(32)
>>> s.add(a + 2*b > 100)
>>> s.check()
'sat'
>>> s.getvalue(a), s.getvalue(b)
(101, 0)
```

The glue: Basic Initialization

1. Make Solver, Memory, Cpu and Linux objects.
2. Load ELF binary program in Memory, Initialize cpu registers, initialize stack.

```
solver = Solver()
mem = SMemory(solver, bits, 12 )
cpu = Cpu(mem, arch )
linux = SLinux(solver, [cpu], mem, ... )
linux.exe(“./my_test”, argv=[], env=[])
```

The glue: Basic analysis loop

```
states = [‘init.pkl’]
while len(states) > 0 :
   linux = load(state.pop())
   while linux.running:
      linux.execute()
      if isinstance( linux.cpu.PC, Symbol):
         vals = solver.getallvalues(linux.
   cpu.PC)
         -- generate states for each value --
         break
```

Micro demo

```
python system.py -h
usage: system.py [-h] [-sym SYM] [-stdin STDIN]
[-stdout STDOUT]
                 [-stderr STDERR] [-env ENV]
                 PROGRAM ...

python system.py -sym stdin  my_prog

  stdin:
     PDF-1.2++++++++++++++++++++++++++++++
```

Symbolic inputs.

We need to mark whic part of the environment is symbolic:

- STDIN: a file partially symbolic. Symbols marked with “+”
- STDOUT and STDERR are placeholders.
- ARGV and ENVP can be symbolic

A toy example

```
int main(int argc, char* argv[], char* envp[]){
    char buffer[0x100] = {0};
    read(0, buffer, 0x100);
    if (strcmp(buffer, "ZARAZA") == 0 )
        printf("Message: ZARAZA!\n");
    else
        printf("Message: Not Found!\n");
return 0;
}
```

Conclusions, future work

- Push all known optimizations: solver cache, implied values, Redundant State Elimination, constraint independence, KLEE-like cex cache, symbol simplification.
- Add more cpu instructions (fpu, simd).
- Improve Linux model, add network.
- Implement OSX loader and os model.
- https://github.com/feliam/pysymemu

Gracias.

Contacto:
feliam@binamuse.com