Operating Systems: Design and Security

Address Space Randomization

Paul Irofti

Security and Applied Logic Master's
1st Year, 1st Semester, 2019-2020

Concepts

- buffer overflow
- NOP sled (slide)
- stack protection: NX, StackSmash
- Position Independent Code (PIC)
- Position Independent Executable (PIE)
- Return to libc attack (`ret-to-libc`)
- Address Space Layout Randomization (ASLR)

Buffer Overflow Example

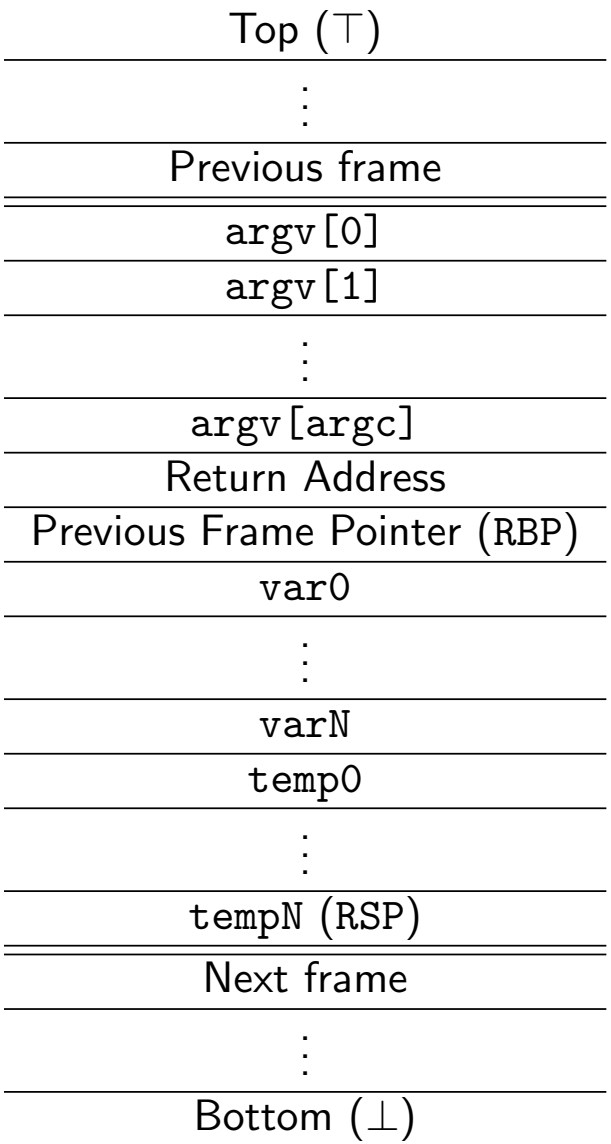
The following code produces a buffer overflow:

```
char buf[10];
i = 0;
while (i < 20) {
    buf[i] = i;
    i = i + 1;
}
```

Questions:

- How can I exploit it?
- Where is the interesting code?
- How do I get from the point of entry to the interesting code?

Stack Frame


Top (⊤)
⋮
Previous frame
argv[0]
argv[1]
⋮
argv[argc]
Return Address
Previous Frame Pointer (RBP)
var0
⋮
varN
temp0
⋮
tempN (RSP)
Next frame
⋮
Bottom (⊥)

NOP Sled

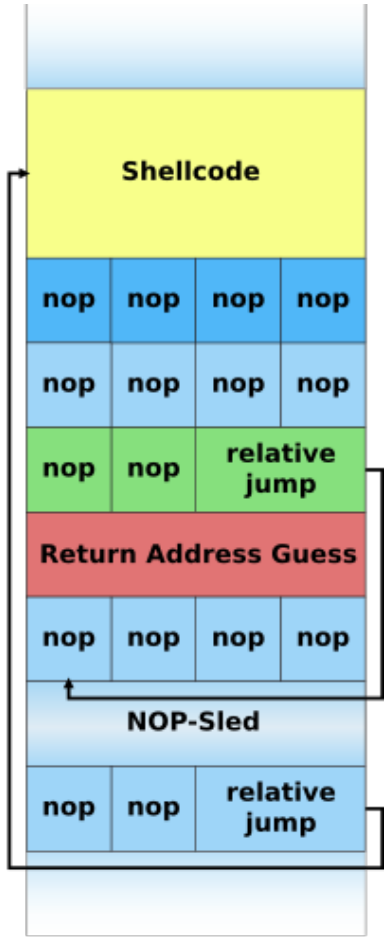


Figure: `https://en.wikipedia.org/wiki/Buffer_overflow`

Stack Protection

Solutions:

- canaries
  - terminator: enforce `RET+ NUL` to stop shellcode reads
  - random: created at load, guarded by unmapped pages
  - random `XOR`: extra layer of xor-key protection
- bounds checking: automated runtime checks
- tagging: `W^X`, non-executable (NX) bit for pages

Implementations:

- StackGuard
- ProPolice
- AddressSanitizer
- StackGhost

Supported by all compilers and operating systems. All strategies are enabled by default only on OpenBSD.

Position Independent Code (PIC)

- just like shellcode, but for program sections
- PIC code can run no matter of its absolute load address
- primary users: shared libraries
- program calls library stubs that call into the library (see past laboratory work)
- indirect data access through Global Offset Tables (GOTs)
- one GOT per compilation unit
- GOT address is fixed but unknown until link time
- extra: `ld.so` linker randomizes the GOT address

Position Independent Executable (PIE)

- executable where all sections are PIC
- recipe for address space layout randomization (ASLR)
- easy to implement for dynamic executables
- harder for static executables
- most operating systems have support, few enable it by default (OpenBSD, Mac-based, Android, and few Linux distros)

Return to libc attack (`ret-to-libc`)

- buffer overflow return address is a `libc` function (not a shellcode)
- gets around tagging, NX-bit, `W^X` protection
- avoids shellcode design issues (addresses, offsets, NOP-sleds)
- attack example:
  1. load `libc`
  2. find the address of the string `/bin/sh`
  3. find the function address for `system(3)`
  4. fill the payload (shellcode) with calls to `system("/bin/sh")`

Address Space Layout Randomization (ASLR)

- ASLR represents a suite of protection strategies
- makes it harder on the attacker to locate memory addresses of various objects (strings, functions, offsets)
- PAGEEXEC: emulates the NX-bit
- SEGMEXEC: emulates the NX-bit on 32-bit x86 through mirroring
- Restrict `mprotect(2)`: enforce `W^X` behaviour for `PROT` flags
- randomize stack base
- randomize `mmap(2)` base
- randomize `ET_EXEC` base
- KASLR is the userland equivalent for the kernel
- 2002: initial design and implementation by PaX Team as a patch for Linux
- 6 months later: OpenBSD adapted, re-implemented and enabled by default; first OS to do that
- today: still not accepted in mainline Linux, maintained by grsecurity group