CS 4910: Intro to Computer Security

Software Security IV:
stack-based buffer overflow - defense

Instructor: Xi Tan

Review

- Identify a buffer overflow in a program
- Exploit a buffer overflow vulnerability
  - Overwrite local variables (data-only attack)
  - Overwrite the return address (control-flow hijacking)

This class

- Stack-based buffer overflow defenses
  - Base and bound check
  - Shadow stack
  - Stack Canary/Cookie
  - Data execution prevention (DEP, NX, etc.)
  - ASLR

Attacker's Goal

Take control of the victim's machine

- Hijack the execution flow of a running program
- Execute arbitrary code

Requirements

- Inject attack code or attack parameters
- Abuse vulnerability and modify memory such that control flow is redirected

Change of control flow

- ***alter a code pointer*** (RET, function pointer, etc.)
- change memory region that should not be accessed

Overflow Types

Overflow some ***code pointer***

- Overflow memory region on the stack
  - overflow function return address
  - overflow function frame (base) pointer
  - overflow longjmp buffer
- Overflow (dynamically allocated) memory region on the heap
- Overflow function pointers
  - stack, heap

Other pointers?

Can we exploit other pointers as well?

- Memory that is used in a **value** to influence mathematical operations, conditional jumps.
- Memory that is used as a **read pointer** (or offset), allowing us to force the program to access arbitrary memory.
- Memory that is used as a **write pointer** (or offset), allowing us to force the program to overwrite arbitrary memory.
- Memory that is used as a **code pointer** (or offset), allowing us to redirect program execution!

Typically, you use one or more vulnerabilities to achieve multiple of these effects.

Defenses

- Prevent buffer overflow
  - A **direct** defense
  - Could be accurate but could be slow
  - Good in theory, but not practical in real world

- Make exploit harder
  - An **indirect** defense
  - Could be inaccurate but could be fast
  - Simple in theory, widely deployed in real world

Examples

- Base and bound check
  - Prevent buffer overflow!
  - A direct defense
- Stack Canary/Cookie
  - An indirect defense
  - Prevent overwriting return address
- Data execution prevention (DEP, NX, etc.)
  - An indirect defense
  - Prevent using of shellcode on stack

…

Defense-1:
Base and bound check

Spatial Memory Safety – Base and Bound check

char *a

- char *a_base;
- char *a_bound;

a = (char*)malloc(512)

- a_base = a;
- a_bound = a+512

Access must be between [a_base, a_bound)

- a[0], a[1], a[2], ..., and a[511] are OK
- a[512] NOT OK
- a[-1] NOT OK

Spatial Memory Safety – Base and Bound check

Propagation

- char *b = a;
  - b_base = a_base;
  - b_bound = a_bound;

- char *c = &b[2];
  - c_base = b_base;
  - c_bound = b_bound;

Overhead - Based and Bound

+2x overhead on storing a pointer

- char *a
    - char *a_base;
    - char *a_bound;

+2x overhead on assignment

- char *b = a;
    - b_base = a_base;
    - b_bound = a_bound;

+2 comparisons added on access

- c[i]
    - if(c+i >= c_base)
    - if(c+i < c_bound)

SoftBound: Highly Compatible and Complete Spatial Memory Safety for C

Santosh Nagarakatte Jianzhou Zhao Milo M. K. Martin Steve Zdancewic

Computer and Information Sciences Department, University of Pennsylvania

santoshn@cis.upenn.edu jianzhou@cis.upenn.edu milom@cis.upenn.edu stevez@cis.upenn.edu

Abstract

The serious bugs and security vulnerabilities facilitated by C/C++'s lack of bounds checking are well known, yet C and C++ remain in widespread use. Unfortunately, C's arbitrary pointer arithmetic, dress on the stack, address space randomization, non-executable stack), vulnerabilities persist. For one example, in November 2008 Adobe released a security update that fixed several serious buffer overflows [2]. Attackers have reportedly exploited these buffer-overflow vulnerabilities by using banner ads on websites to redi

PLDI 09

HardBound: Architectural Support for Spatial Safety of the C Programming Language

Joe Devietti *
University of Washington
devietti@cs.washington.edu

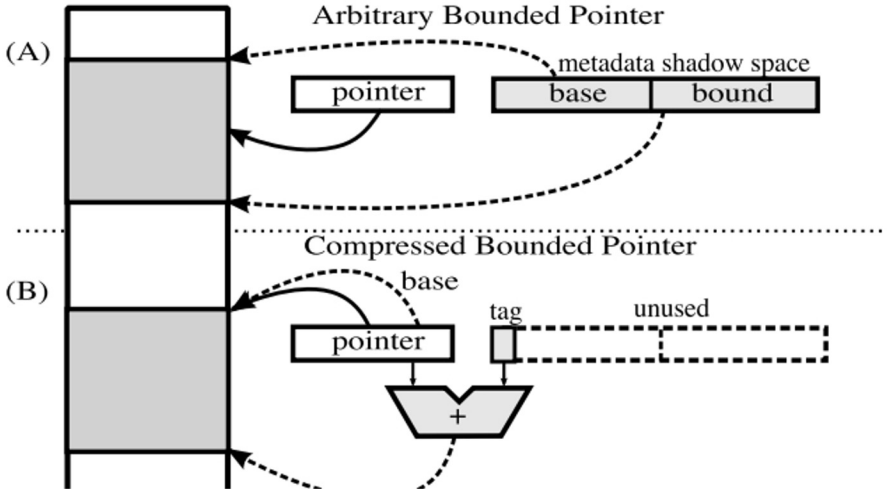
Colin Blundell
University of Pennsylvania
blundell@cis.upenn.edu

Milo M. K. Martin
University of Pennsylvania
milom@cis.upenn.edu

Steve Zdancewic
University of Pennsylvania
stevez@cis.upenn.edu

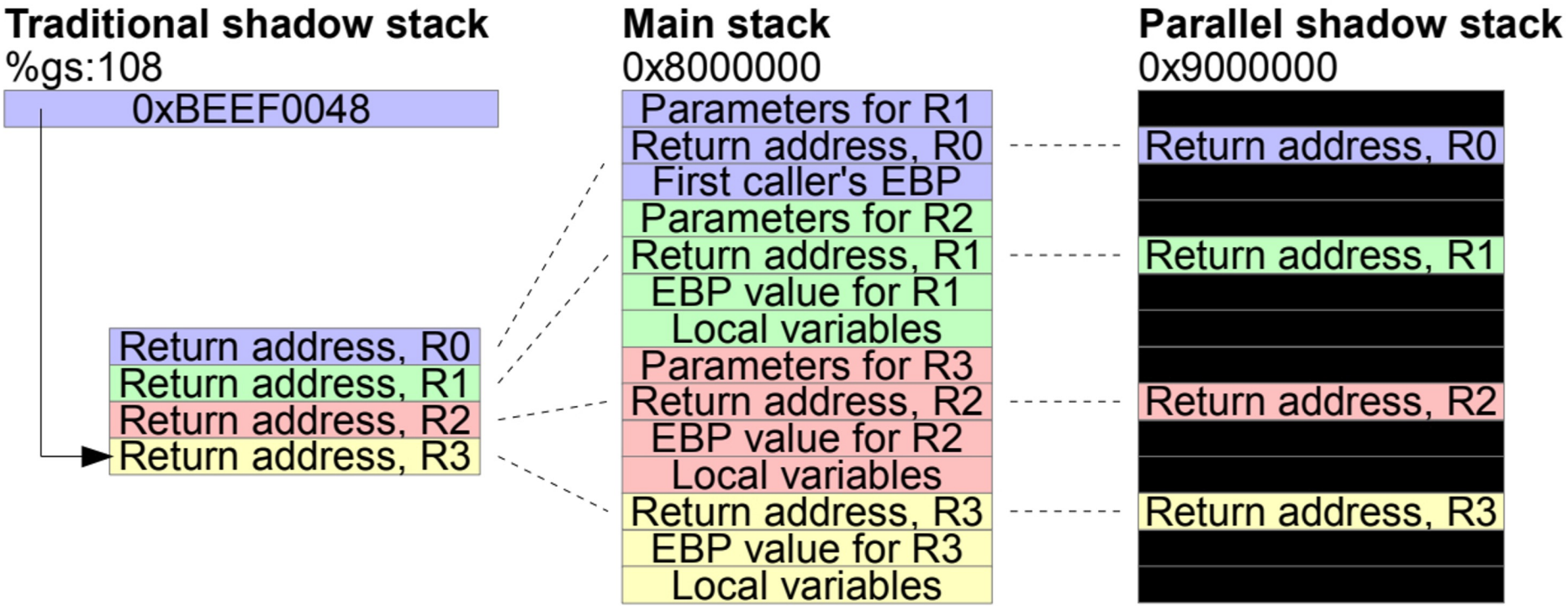
Abstract

The C programming language is at least as well known for its absence of spatial memory safety guarantees (*i.e.*, lack of bounds checking) as it is for its high performance. C's unchecked pointer arithmetic and array indexing allow simple programming mistakes to lead to erroneous executions, silent data corruption, and security vulnerabilities. Many prior proposals have tackled enforcing spatial safety in C programs by checking pointer and array accesses. However, existing software-only proposals have significant drawbacks that may prevent wide adoption, including: unacceptably high runtime overheads, lack of completeness, incompatible pointer representations, or need for non-trivial changes to existing C source code and compiler infrastructure.



Defense-2:
Shadow Stack

Shadow Stack



https://people.eecs.berkeley.edu/~daw/papers/shadow-asiaccs15.pdf

Traditional Shadow Stack

```
SUB $4, %gs:108    # Decrement SSP
MOV %gs:108, %eax  # Copy SSP into EAX
MOV (%esp), %ecx   # Copy ret. address into
MOV %ecx, (%eax)   #      shadow stack via ECX
```

Figure 2: Prologue for traditional shadow stack.

```
MOV %gs:108, %ecx  # Copy SSP into ECX
ADD $4, %gs:108    # Increment SSP
MOV (%ecx), %edx   # Copy ret. address from
MOV %edx, (%esp)   #      shadow stack via EDX
RET
```

Figure 3: Epilogue for traditional shadow stack (overwriting).

Traditional Shadow Stack

```
MOV %gs:108, %ecx
ADD $4, %gs:108
MOV (%ecx), %edx
CMP %edx, (%esp) # Instead of overwriting,
JNZ abort        #     we compare
RET
abort:
    HLT
```

Figure 4: Epilogue for traditional shadow stack (checking).

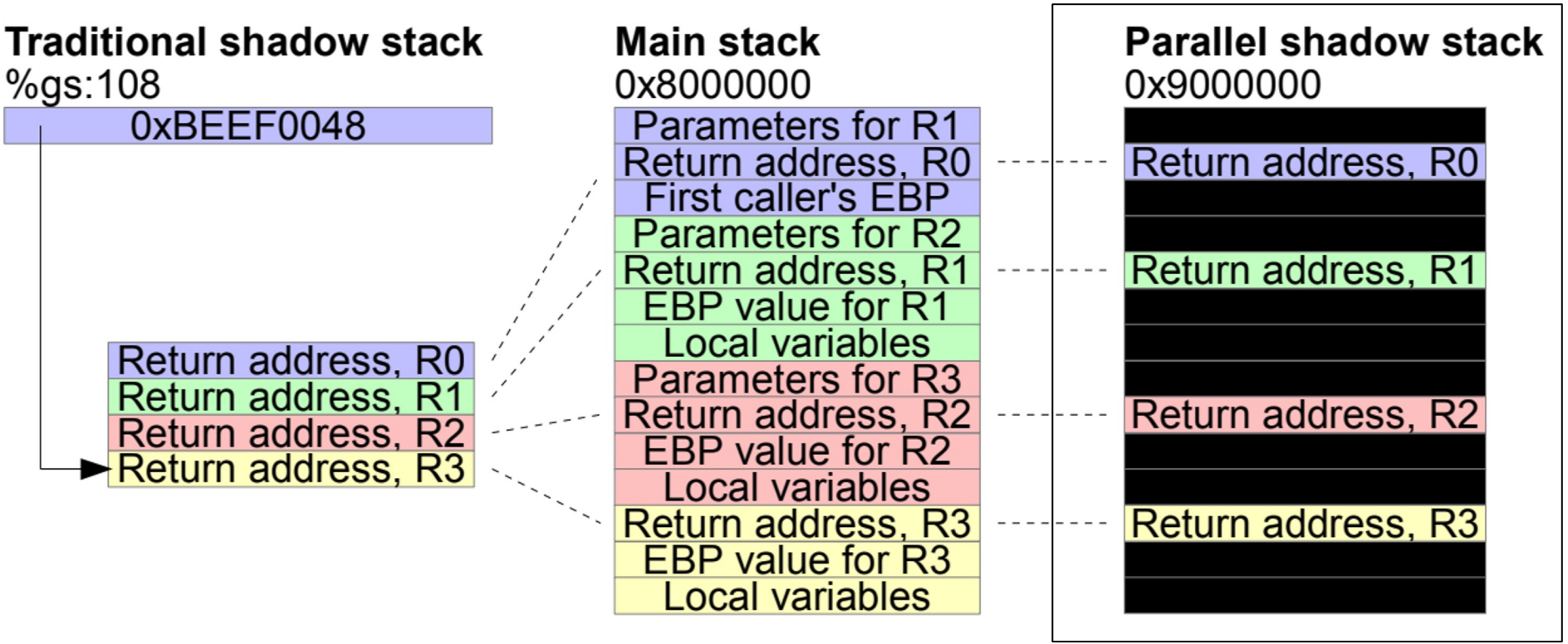
Overhead - Traditional Shadow Stack

If no attack:

- 6 more instructions
- 2 memory moves
- 1 memory compare
- 1 conditional jmp

Per function

Shadow Stack



https://people.eecs.berkeley.edu/~daw/papers/shadow-asiaccs15.pdf

Parallel Shadow Stack

```
POP 999996(%esp) # Copy ret addr to shadow stack
SUB $4, %esp # Fix up stack pointer (undo POP)
```

Figure 7: Prologue for parallel shadow stack.

```
ADD $4, %esp # Fix up stack pointer
PUSH 999996(%esp) # Copy from shadow stack
```

Figure 8: Epilogue for parallel shadow stack.

Overhead Comparison

The overhead is roughly 10% for a traditional shadow stack.

The parallel shadow stack overhead is 3.5%.

Defense-3:
Stack Cookie; Stack Canary

specific to sequential stack overflow

JANUARY 26–29, 1998 • SAN ANTONIO, TX, USA

USENIX

StackGuard: Automatic Adaptive Detection and Prevention of Buffer-Overflow Attacks

Abstract:

This paper presents a systematic solution to the persistent problem of buffer overflow attacks. Buffer overflow attacks gained notoriety in 1988 as part of the Morris Worm incident on the Internet. While it is fairly simple to fix individual buffer overflow vulnerabilities, buffer overflow attacks continue to this day. Hundreds of attacks have been discovered, and while most of the obvious vulnerabilities have now been patched, more sophisticated buffer overflow attacks continue to emerge.

We describe StackGuard: a simple compiler technique that virtually eliminates buffer overflow vulnerabilities with only modest performance penalties. Privileged programs that are recompiled with the StackGuard compiler extension no longer yield control to the attacker, but rather enter a fail-safe state. These programs require *no* source code changes at all, and are binary-compatible with existing operating systems and libraries. We describe the compiler technique (a simple patch to gcc), as well as a set of variations on the technique that trade-off between penetration resistance and performance. We present experimental results of both the penetration resistance and the performance impact of this technique.

StackGuard

A compiler technique that attempts to eliminate buffer overflow vulnerabilities

- No source code changes
- Patch for the function prologue and epilogue
  - Prologue: push an additional value into the stack (canary)
  - Epilogue: check the **canary value** hasn’t changed. If changed, exit.

Buffer Overflow Example: overflowret4

```
int vulfoo()
{
  char buf[30];

  gets(buf);
  return 0;
}

int main(int argc, char *argv[])
{
  vulfoo();
  printf("I pity the fool!\n");
}
```

With and without Canary 32bit

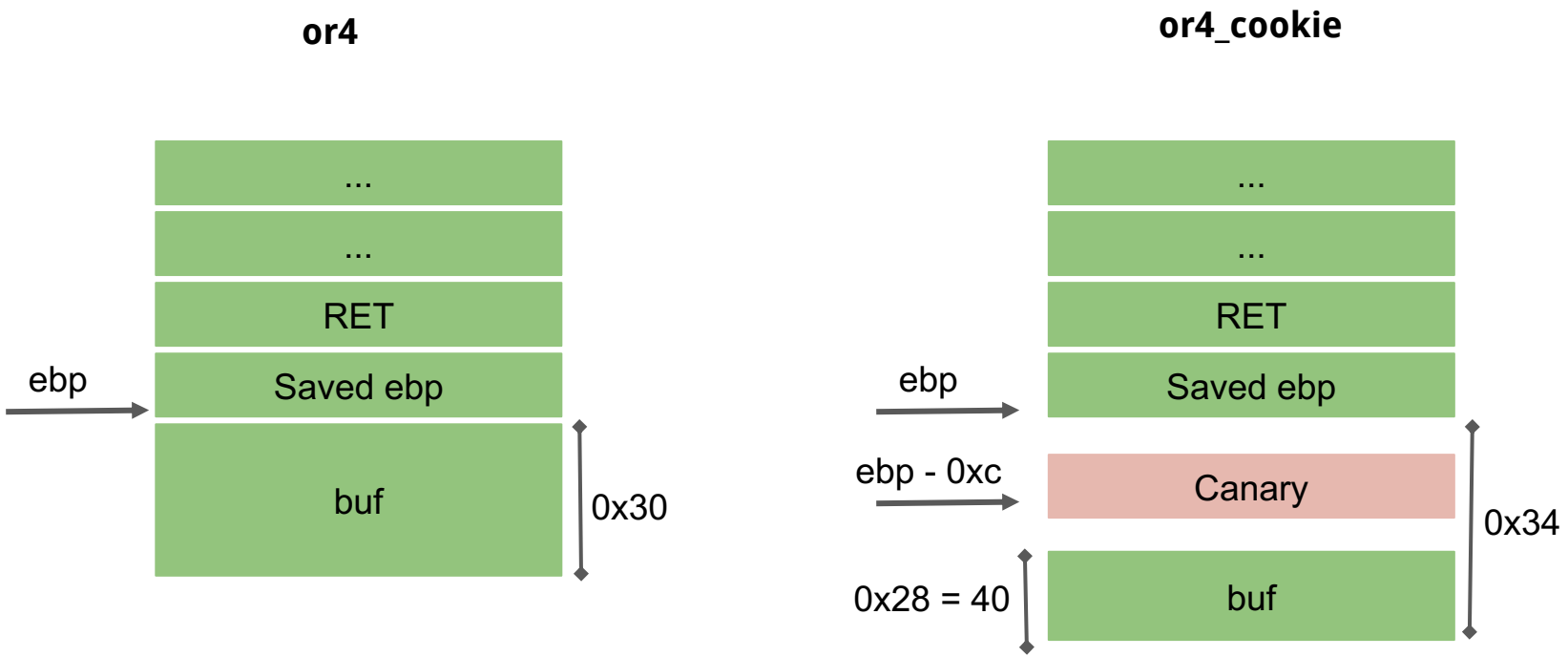
or4

```
000011ed <vulfoo>:
    11ed:       f3 0f 1e fb             endbr32
    11f1:       55                    push   ebp
    11f2:       89 e5                   mov    ebp,esp
    11f4:       83 ec 38                sub    esp,0x38
    11f7:       83 ec 0c                sub    esp,0xc
    11fa:       8d 45 d0                lea    eax,[ebp-0x30]
    11fd:       50                    push   eax
    11fe:       e8 fc ff ff ff          call   11ff <vulfoo+0x12>
    1203:       83 c4 10                add    esp,0x10
    1206:       b8 00 00 00 00          mov    eax,0x0
    120b:       c9                    leave
    120c:       c3                    ret
```

or4_cookie

```
0000120d <vulfoo>:
    120d:       f3 0f 1e fb             endbr32
    1211:       55                    push   ebp
    1212:       89 e5                   mov    ebp,esp
    1214:       53                    push   ebx
    1215:       83 ec 34                sub    esp,0x34
    1218:       e8 81 00 00 00          call   129e <__x86.get_pc_thunk.ax>
    121d:       05 b3 2d 00 00          add    eax,0x2db3
    1222:       65 8b 0d 14 00 00 00    mov    ecx,DWORD PTR gs:0x14
    1229:       89 4d f4                mov    DWORD PTR [ebp-0xc],ecx
    122c:       31 c9                   xor    ecx,ecx
    122e:       83 ec 0c                sub    esp,0xc
    1231:       8d 55 cc                lea    edx,[ebp-0x34]
    1234:       52                    push   edx
    1235:       89 c3                   mov    ebx,eax
    1237:       e8 54 fe ff ff          call   1090 <gets@plt>
    123c:       83 c4 10                add    esp,0x10
    123f:       b8 00 00 00 00          mov    eax,0x0
    1244:       8b 4d f4                mov    ecx,DWORD PTR [ebp-0xc]
    1247:       65 33 0d 14 00 00 00    xor    ecx,DWORD PTR gs:0x14
    124e:       74 05                   je     1255 <vulfoo+0x48>
    1250:       e8 db 00 00 00          call   1330 <__stack_chk_fail_local>
    1255:       8b 5d fc                mov    ebx,DWORD PTR [ebp-0x4]
    1258:       c9                    leave
    1259:       c3                    ret
```

With and without Canary



With and without Canary 64bit

or464

```
0000000000001169 <vulfoo>:
   1169:    f3 0f 1e fa          endbr64
   116d:    55                   push   rbp
   116e:    48 89 e5             mov    rbp,rsp
   1171:    48 83 ec 30          sub    rsp,0x30
   1175:    48 8d 45 d0          lea    rax,[rbp-0x30]
   1179:    48 89 c7             mov    rdi,rax
   117c:    b8 00 00 00 00       mov    eax,0x0
   1181:    e8 ea fe ff ff       call   1070 <gets@plt>
   1186:    b8 00 00 00 00       mov    eax,0x0
   118b:    c9                   leave
   118c:    c3                   ret
```

or4_cookie_64

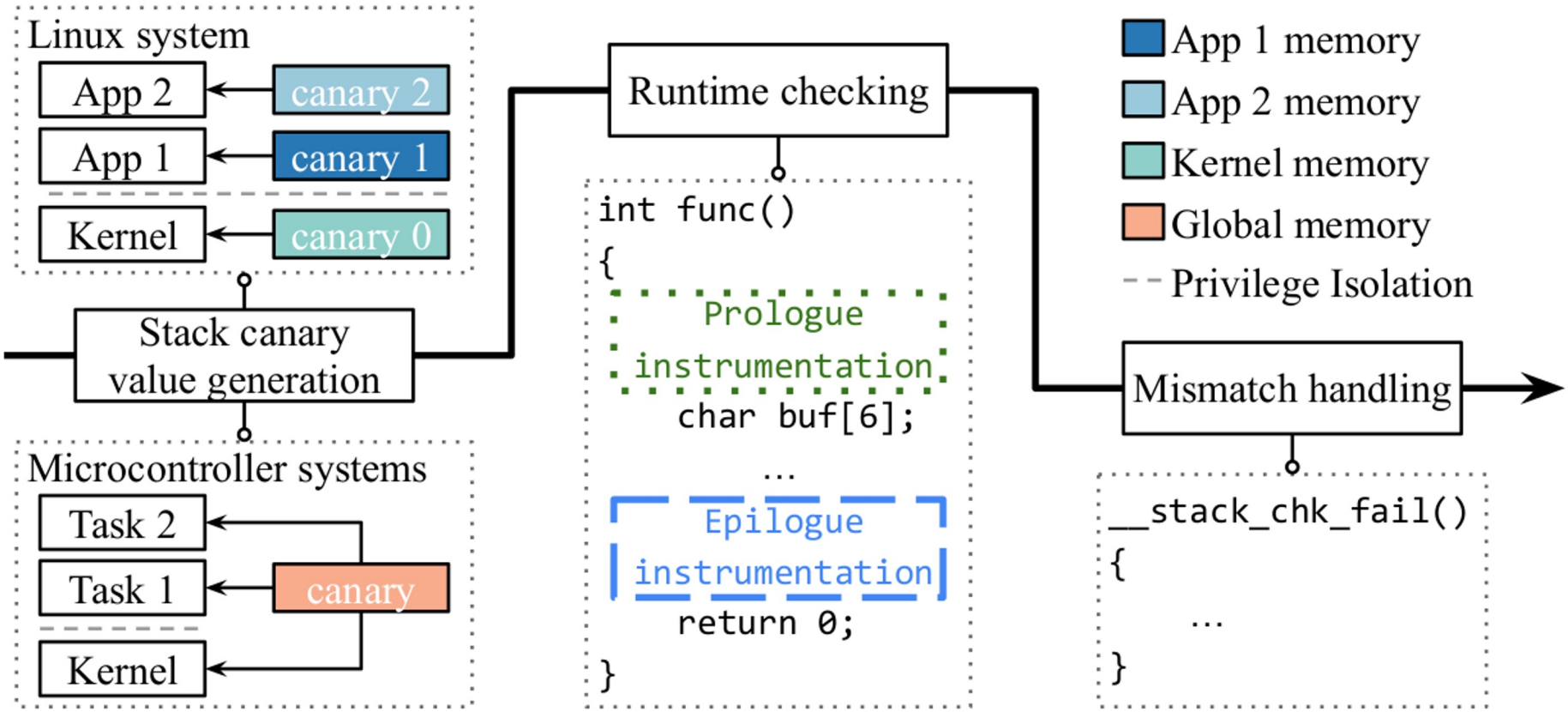
```
0000000000401176 <vulfoo>:
 401176:    f3 0f 1e fa          endbr64
 40117a:    55                   push   rbp
 40117b:    48 89 e5             mov    rbp,rsp
 40117e:    48 83 ec 30          sub    rsp,0x30
 401182:    64 48 8b 04 25 28 00 mov    rax,QWORD PTR fs:0x28
 401189:    00 00
 40118b:    48 89 45 f8          mov    QWORD PTR [rbp-0x8],rax
 40118f:    31 c0                xor    eax,eax
 401191:    48 8d 45 d0          lea    rax,[rbp-0x30]
 401195:    48 89 c7             mov    rdi,rax
 401198:    b8 00 00 00 00       mov    eax,0x0
 40119d:    e8 de fe ff ff       call   401080 <gets@plt>
 4011a2:    b8 00 00 00 00       mov    eax,0x0
 4011a7:    48 8b 55 f8          mov    rdx,QWORD PTR [rbp-0x8]
 4011ab:    64 48 33 14 25 28 00 xor    rdx,QWORD PTR fs:0x28
 4011b2:    00 00
 4011b4:    74 05                je     4011bb <vulfoo+0x45>
 4011b6:    e8 b5 fe ff ff       call   401070 <__stack_chk_fail@plt>
 4011bb:    c9                   leave
 4011bc:    c3                   ret
```

Overhead - Canary

If no attack:

6 more instructions
2 memory moves
1 memory compare
1 conditional jmp

Per function


Linux system
App 2
canary 2
App 1
canary 1
Kernel
canary 0
Stack canary value generation
Microcontroller systems
Task 2
Task 1
canary
Kernel
Runtime checking
int func()
{
Prologue instrumentation
char buf[6];
...
Epilogue instrumentation
return 0;
}
App 1 memory
App 2 memory
Kernel memory
Global memory
Privilege Isolation
Mismatch handling
__stack_chk_fail()
{
...
}

```
STATIC int
LIBC_START_MAIN (int (*main) (int, char **, char ** MAIN_AUXVEC_DECL),
                 int argc, char **argv,
#ifdef LIBC_START_MAIN_AUXVEC_ARG
                 ElfW(auxv_t) *auxvec,
#endif
                 __typeof (main) init,
                 void (*fini) (void),
                 void (*rtld_fini) (void), void *stack_end)
{
#ifndef SHARED
  char **ev = &argv[argc + 1];

  __environ = ev;

  /* Store the lowest stack address.  This is done in ld.so if this is
     the code for the DSO.  */
  __libc_stack_end = stack_end;

# ifdef HAVE_AUX_VECTOR
  /* First process the auxiliary vector since we need to find the
     program header to locate an eventually present PT_TLS entry.  */
#  ifndef LIBC_START_MAIN_AUXVEC_ARG
  ElfW(auxv_t) *auxvec;
  {
    char **evp = ev;
    while (*evp++ != NULL)
      ;
    auxvec = (ElfW(auxv_t) *) evp;
  }
#  endif
  _dl_aux_init (auxvec);
# endif

  __tunables_init (__environ);

  ARCH_INIT_CPU_FEATURES ();

  /* Do static pie self relocation after tunables and cpu features
     are setup for ifunc resolvers. Before this point relocations
     must be avoided.  */
  _dl_relocate_static_pie ();

  /* Perform IREL{,A} relocations.  */
  ARCH_SETUP_IREL ();

  /* The stack guard goes into the TCB, so initialize it early.  */
  ARCH_SETUP_TLS ();

  /* In some architectures, IREL{,A} relocations happen after TLS setup in
     order to let IFUNC resolvers benefit from TCB information, e.g. powerpc's
     hwcap and platform fields available in the TCB.  */
  ARCH_APPLY_IREL ();

  /* Set up the stack checker's canary.  */
  uintptr_t stack_chk_guard = _dl_setup_stack_chk_guard (_dl_random);
# ifdef THREAD_SET_STACK_GUARD
  THREAD_SET_STACK_GUARD (stack_chk_guard);
# else
```

https://elixir.bootlin.com/glibc/glibc-2.38/source/csu/libc-start.c#L288

Defense - 4:
Data Execution Prevention
(DEP, W⊕X, NX)

Older CPUs

Older CPUs: Read permission on a page implies execution. So all readable memory was executable.

AMD64 – introduced NX bit (No-eXecute in 2003)

Windows Supporting DEP from Windows XP SP2 (in 2004)

Linux Supporting NX since 2.6.8 (in 2004)

gcc parameter ***-z execstack*** to disable this protection

```
→  security gcc of6.c -o of6
→  security readelf -l of6

Elf file type is DYN (Position-Independent Executable file)
Entry point 0x1040
There are 13 program headers, starting at offset 64

Program Headers:
  Type           Offset             VirtAddr           PhysAddr
                 FileSiz            MemSiz              Flags  Align
  PHDR           0x0000000000000040 0x0000000000000040 0x0000000000000040
                 0x00000000000002d8 0x00000000000002d8  R      0x8
  INTERP         0x0000000000000318 0x0000000000000318 0x0000000000000318
                 0x000000000000001c 0x000000000000001c  R      0x1
      [Requesting program interpreter: /lib64/ld-linux-x86-64.so.2]
  LOAD           0x0000000000000000 0x0000000000000000 0x0000000000000000
                 0x00000000000005f0 0x00000000000005f0  R      0x1000
  LOAD           0x0000000000001000 0x0000000000001000 0x0000000000001000
                 0x0000000000000145 0x0000000000000145  R E    0x1000
  LOAD           0x0000000000002000 0x0000000000002000 0x0000000000002000
                 0x00000000000000c4 0x00000000000000c4  R      0x1000
  LOAD           0x0000000000002df0 0x0000000000003df0 0x0000000000003df0
                 0x0000000000000220 0x0000000000000228  RW     0x1000
  DYNAMIC        0x0000000000002e00 0x0000000000003e00 0x0000000000003e00
                 0x00000000000001c0 0x00000000000001c0  RW     0x8
  NOTE           0x0000000000000338 0x0000000000000338 0x0000000000000338
                 0x0000000000000030 0x0000000000000030  R      0x8
  NOTE           0x0000000000000368 0x0000000000000368 0x0000000000000368
                 0x0000000000000044 0x0000000000000044  R      0x4
  GNU_PROPERTY   0x0000000000000338 0x0000000000000338 0x0000000000000338
                 0x0000000000000030 0x0000000000000030  R      0x8
  GNU_EH_FRAME   0x0000000000002004 0x0000000000002004 0x0000000000002004
                 0x000000000000002c 0x000000000000002c  R      0x4
  GNU_STACK      0x0000000000000000 0x0000000000000000 0x0000000000000000
                 0x0000000000000000 0x0000000000000000  RW     0x10
  GNU_RELRO      0x0000000000002df0 0x0000000000003df0 0x0000000000003df0
                 0x0000000000000210 0x0000000000000210  R      0x1
```

```
→  security gcc -z execstack -o of6_exe of6.c
→  security readelf -l of6_exe

Elf file type is DYN (Position-Independent Executable file)
Entry point 0x1040
There are 13 program headers, starting at offset 64

Program Headers:
  Type           Offset             VirtAddr           PhysAddr
                 FileSiz            MemSiz              Flags  Align
  PHDR           0x0000000000000040 0x0000000000000040 0x0000000000000040
                 0x00000000000002d8 0x00000000000002d8  R      0x8
  INTERP         0x0000000000000318 0x0000000000000318 0x0000000000000318
                 0x000000000000001c 0x000000000000001c  R      0x1
      [Requesting program interpreter: /lib64/ld-linux-x86-64.so.2]
  LOAD           0x0000000000000000 0x0000000000000000 0x0000000000000000
                 0x00000000000005f0 0x00000000000005f0  R      0x1000
  LOAD           0x0000000000001000 0x0000000000001000 0x0000000000001000
                 0x0000000000000145 0x0000000000000145  R E    0x1000
  LOAD           0x0000000000002000 0x0000000000002000 0x0000000000002000
                 0x00000000000000c4 0x00000000000000c4  R      0x1000
  LOAD           0x0000000000002df0 0x0000000000003df0 0x0000000000003df0
                 0x0000000000000220 0x0000000000000228  RW     0x1000
  DYNAMIC        0x0000000000002e00 0x0000000000003e00 0x0000000000003e00
                 0x00000000000001c0 0x00000000000001c0  RW     0x8
  NOTE           0x0000000000000338 0x0000000000000338 0x0000000000000338
                 0x0000000000000030 0x0000000000000030  R      0x8
  NOTE           0x0000000000000368 0x0000000000000368 0x0000000000000368
                 0x0000000000000044 0x0000000000000044  R      0x4
  GNU_PROPERTY   0x0000000000000338 0x0000000000000338 0x0000000000000338
                 0x0000000000000030 0x0000000000000030  R      0x8
  GNU_EH_FRAME   0x0000000000002004 0x0000000000002004 0x0000000000002004
                 0x000000000000002c 0x000000000000002c  R      0x4
  GNU_STACK      0x0000000000000000 0x0000000000000000 0x0000000000000000
                 0x0000000000000000 0x0000000000000000  RWE    0x10
  GNU_RELRO      0x0000000000002df0 0x0000000000003df0 0x0000000000003df0
                 0x0000000000000210 0x0000000000000210  R      0x1
```

What DEP cannot prevent

Can still corrupt stack or function pointers or critical data on the heap

As long as RET (saved EIP) points into legit code section, W⊕X protection will not block control transfer

Defense - 5:
Address Space Layout Randomization (ASLR)

ASLR History

2001 - Linux PaX patch
2003 - OpenBSD
2005 - Linux 2.6.12 user-space
2007 - Windows Vista kernel and user-space
2011 - iOS 5 user-space
2011 - Android 4.0 ICS user-space
2012 - OS X 10.8 kernel-space
2012 - iOS 6 kernel-space
2014 - Linux 3.14 kernel-space

Not supported well in embedded devices.

Address Space Layout Randomization (ASLR)

Attackers need to know which address to control (jump/overwrite)

- Stack - shellcode
- Library - system()

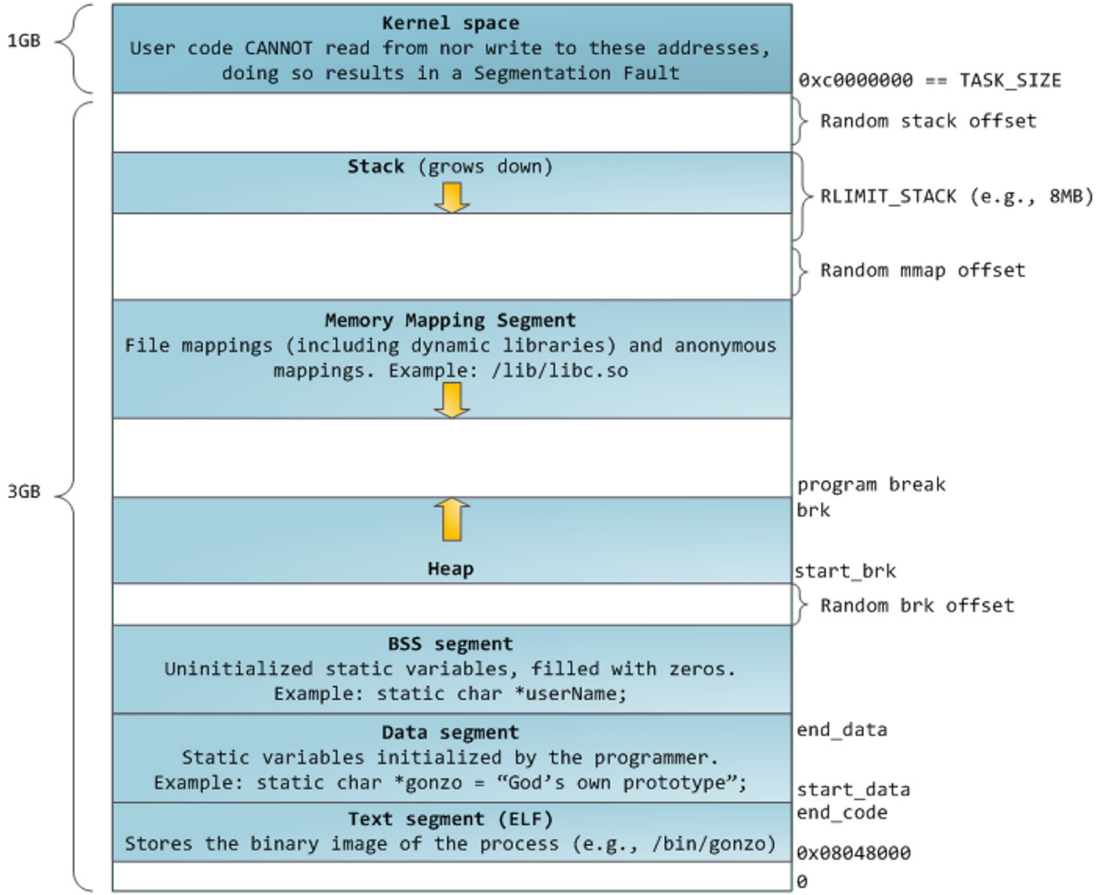
Defense: let’s randomize it!

- Attackers do not know where to jump...

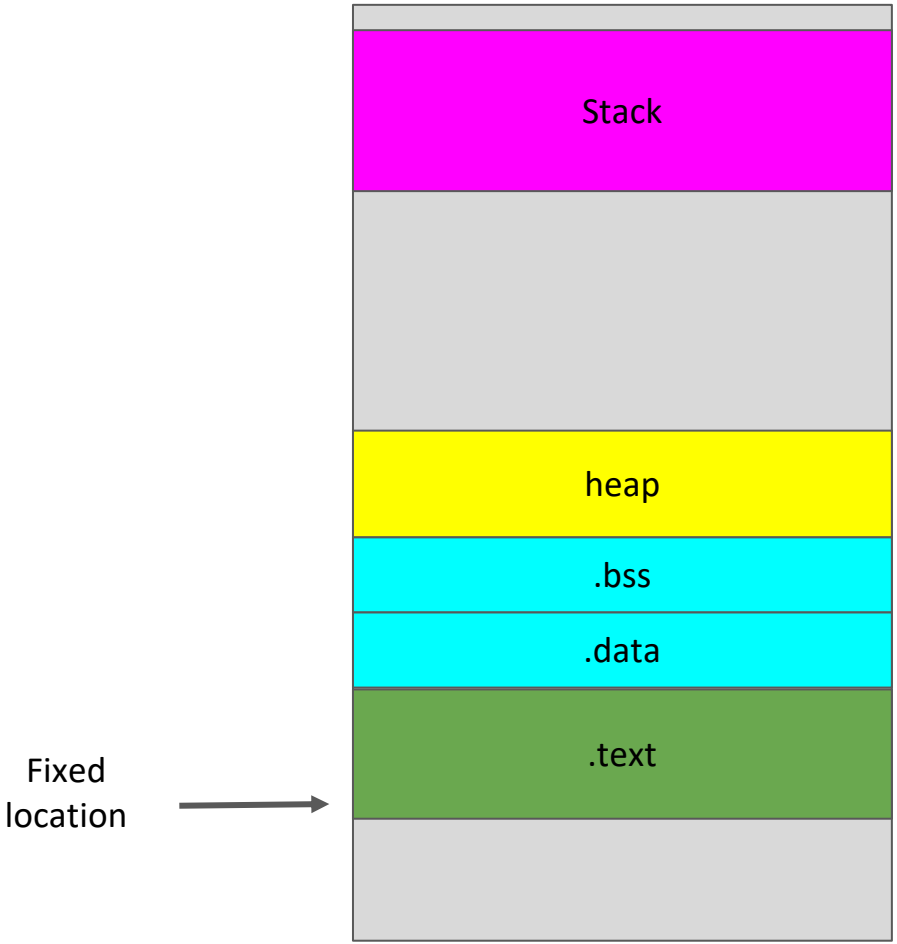
Position Independent Executable (PIE)

Position-independent code (PIC) or position-independent executable (PIE) is a body of machine code that executes properly regardless of its absolute address.

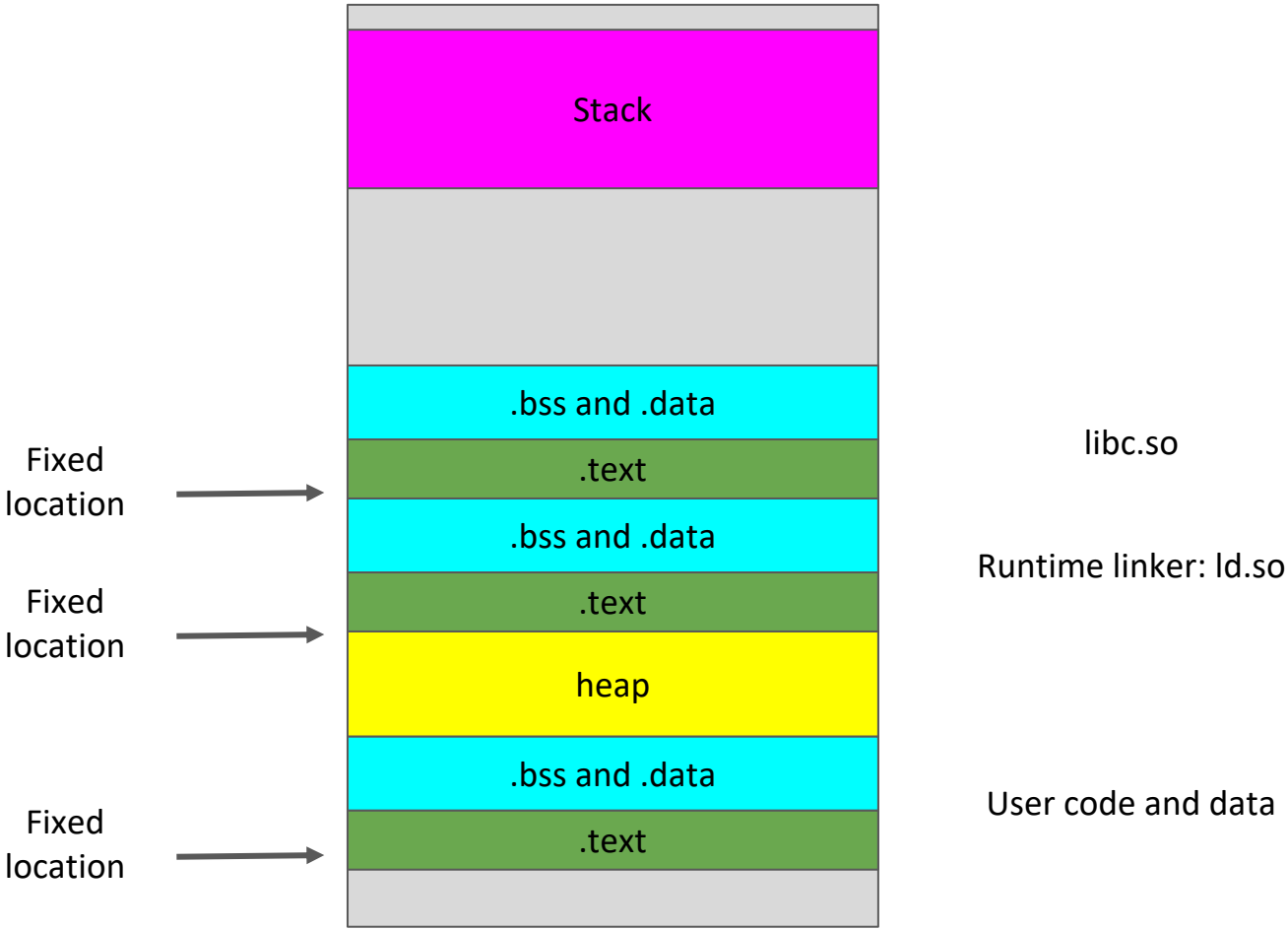
Process Address Space in General



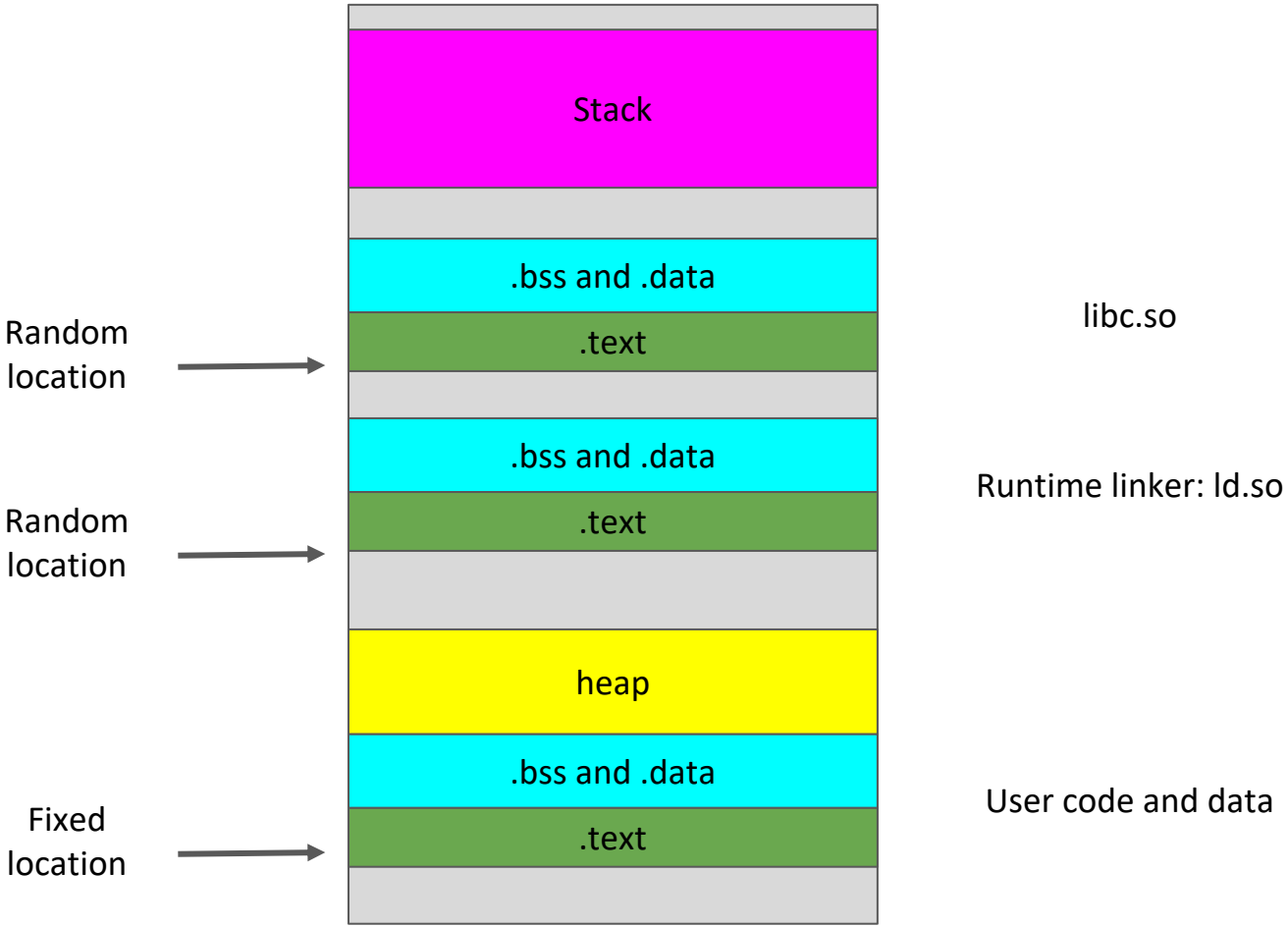
Traditional Process Address Space - Static Program



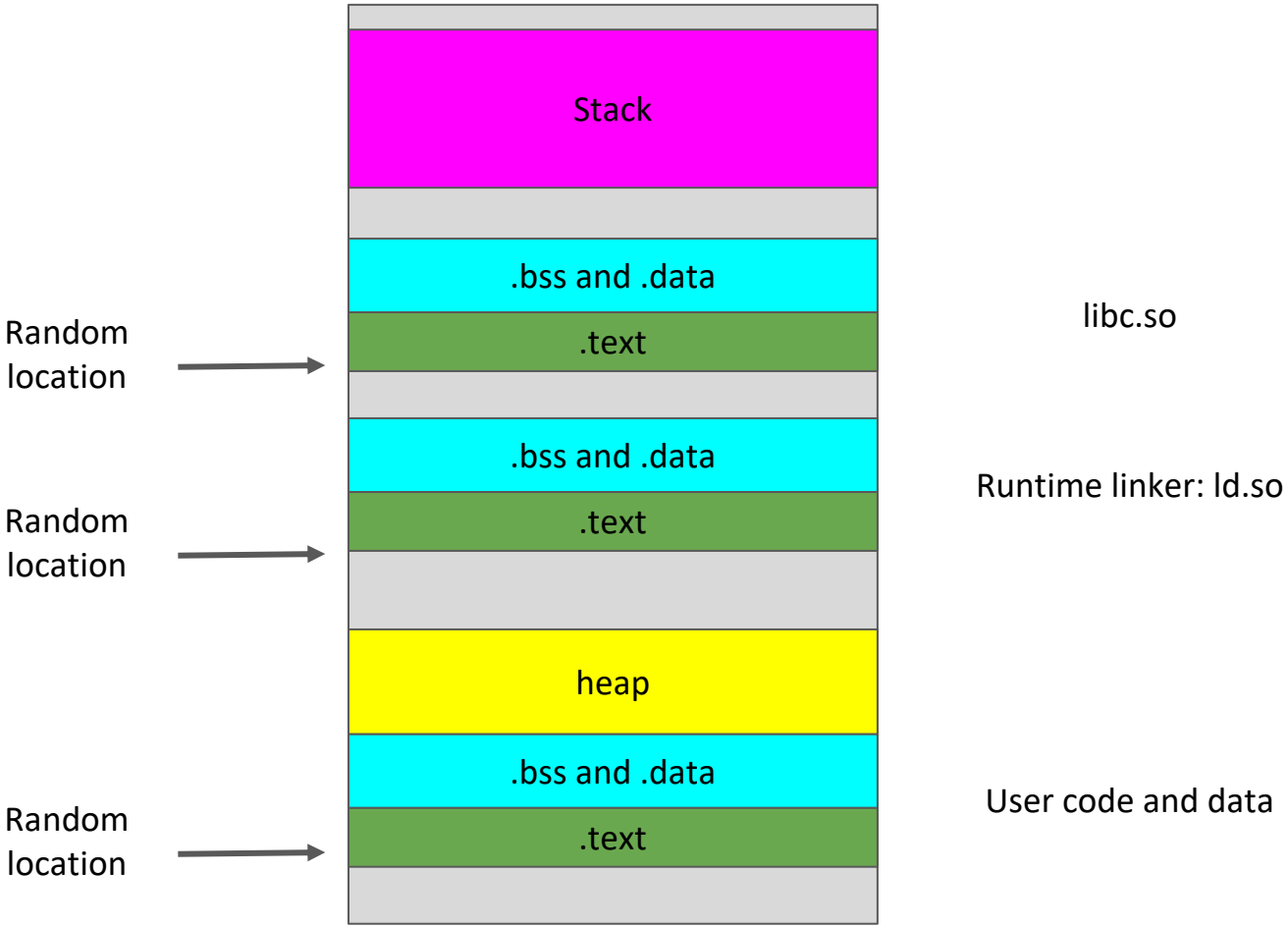
Traditional Process Address Space - Static Program w/shared Libs



ASLR Process Address Space - w/o PIE



ASLR Process Address Space - PIE



code/aslr1

```
int k = 50;
int l;
char *p = "hello world";

int add(int a, int b)
{
   int i = 10;
   i = a + b;
   printf("The address of i is %p\n", &i);

   return i;
}

int sub(int d, int c)
{
   int j = 20;
   j = d - c;
   printf("The address of j is %p\n", &j);

   return j;
}

int compute(int a, int b, int c)
{
   return sub(add(a, b), c) * k;
}
```

```
int main(int argc, char *argv[])
{
   printf("===== Libc function addresses =====\n");
   printf("The address of printf is %p\n", printf);
   printf("The address of memcpy is %p\n", memcpy);
   printf("The distance between printf and memcpy is %x\n", (int)printf - (int)memcpy);
   printf("The address of system is %p\n", system);
   printf("The distance between printf and system is %x\n", (int)printf - (int)system);
   printf("===== Module function addresses =====\n");
   printf("The address of main is %p\n", main);
   printf("The address of add is %p\n", add);
   printf("The distance between main and add is %x\n", (int)main - (int)add);
   printf("The address of sub is %p\n", sub);
   printf("The distance between main and sub is %x\n", (int)main - (int)sub);
   printf("The address of compute is %p\n", compute);
   printf("The distance between main and compute is %x\n", (int)main - (int)compute);

   printf("===== Global initialized variable addresses =====\n");
   printf("The address of k is %p\n", &k);
   printf("The address of p is %p\n", p);
   printf("The distance between k and p is %x\n", (int)&k - (int)p);

   printf("===== Global uninitialized variable addresses =====\n");
   printf("The address of l is %p\n", &l);
   printf("The distance between k and l is %x\n", (int)&k - (int)l);

   printf("===== Local variable addresses =====\n");
   return compute(9, 6, 4);
}
```

Check the symbols

nm | sort

```
00001000 t _init
000010c0 T _start
00001100 T __x86.get_pc_thunk.bx
00001110 t deregister_tm_clones
00001150 t register_tm_clones
000011a0 t __do_global_dtors_aux
000011f0 t frame_dummy
000011f9 T __x86.get_pc_thunk.dx
000011fd T add
00001261 T sub
000012c3 T compute
00001307 T main
0000158d T __x86.get_pc_thunk.ax
000015a0 T __libc_csu_init
00001610 T __libc_csu_fini
00001615 T __x86.get_pc_thunk.bp
00001620 T __stack_chk_fail_local
00001638 T _fini
00002000 R _fp_hw
00002004 R _IO_stdin_used
00002358 r __GNU_EH_FRAME_HDR
0000258c r __FRAME_END__
00003ec8 d __frame_dummy_init_array_entry
00003ec8 d __init_array_start
00003ecc d __do_global_dtors_aux_fini_array_entry
00003ecc d __init_array_end
00003ed0 d _DYNAMIC
00003fc8 d _GLOBAL_OFFSET_TABLE_
00004000 D __data_start
00004000 W data_start
00004004 D __dso_handle
00004008 D k
0000400c D p
00004010 B __bss_start
00004010 b completed.7621
00004010 D _edata
00004010 D __TMC_END__
00004014 B l
00004018 B _end
         U __libc_start_main@@GLIBC_2.0
         U memcpy@@GLIBC_2.0
         U printf@@GLIBC_2.0
         U puts@@GLIBC_2.0
         U __stack_chk_fail@@GLIBC_2.4
         U system@@GLIBC_2.0
         w __cxa_finalize@@GLIBC_2.1.3
         w __gmon_start__
         w _ITM_deregisterTMCloneTable
         w _ITM_registerTMCloneTable
```

```
0000000000001000 t _init
0000000000001090 T _start
00000000000010c0 t deregister_tm_clones
00000000000010f0 t register_tm_clones
0000000000001130 t __do_global_dtors_aux
0000000000001170 t frame_dummy
0000000000001179 T add
00000000000011dd T sub
000000000000123f T compute
000000000000127c T main
00000000000014f0 T __libc_csu_init
0000000000001560 T __libc_csu_fini
0000000000001568 T _fini
0000000000002000 R _IO_stdin_used
0000000000002378 r __GNU_EH_FRAME_HDR
000000000000253c r __FRAME_END__
0000000000003d98 d __frame_dummy_init_array_entry
0000000000003d98 d __init_array_start
0000000000003da0 d __do_global_dtors_aux_fini_array_entry
0000000000003da0 d __init_array_end
0000000000003da8 d _DYNAMIC
0000000000003f98 d _GLOBAL_OFFSET_TABLE_
0000000000004000 D __data_start
0000000000004000 W data_start
0000000000004008 D __dso_handle
0000000000004010 D k
0000000000004018 D p
0000000000004020 B __bss_start
0000000000004020 b completed.8059
0000000000004020 D _edata
0000000000004020 D __TMC_END__
0000000000004024 B l
0000000000004028 B _end
                 U __libc_start_main@@GLIBC_2.2.5
                 U memcpy@@GLIBC_2.14
                 U printf@@GLIBC_2.2.5
                 U puts@@GLIBC_2.2.5
                 U __stack_chk_fail@@GLIBC_2.4
                 U system@@GLIBC_2.2.5
                 w __cxa_finalize@@GLIBC_2.2.5
                 w __gmon_start__
                 w _ITM_deregisterTMCloneTable
                 w _ITM_registerTMCloneTable
```

PIE Overhead

- <1% in 64 bit

Access all strings via relative address from current rip
lea rdi, [rip+0x23423]

- ~3% in 32 bit

Cannot address using eip
Call __86.get_pc_thunk.xx functions

Temporarily enable and disable ASLR

Disable:

```
echo 0 | sudo tee /proc/sys/kernel/randomize_va_space
```

Enable:

```
echo 2 | sudo tee /proc/sys/kernel/randomize_va_space
```

ASLR Enabled; PIE; 32 bit

```
tancy@Tancy-PC:/mnt/c/Users/minta/Dropbox/sync/security$ ./aslr1_32
===== Libc function addresses =====
The address of printf is 0xf7d93520
The address of memcpy is 0xf7eb4ea0
The distance between printf and memcpy is ffede680
The address of system is 0xf7d83cd0
The distance between printf and system is f850
===== Module function addresses =====
The address of main is 0x565a12ab
The address of add is 0x565a11ad
The distance between main and add is fe
The address of sub is 0x565a120d
The distance between main and sub is 9e
The address of compute is 0x565a126b
The distance between main and compute is 40
===== Global initialized variable addresses =====
The address of k is 0x565a4008
The address of p is 0x565a2008
The distance between k and p is 2000
===== Global uninitialized variable addresses =====
The address of l is 0x565a4014
The distance between k and l is 565a4008
===== Local variable addresses =====
The address of i is 0xffb77ff8
The address of j is 0xffb77ff8
tancy@Tancy-PC:/mnt/c/Users/minta/Dropbox/sync/security$ ./aslr1_32
===== Libc function addresses =====
The address of printf is 0xf7d16520
The address of memcpy is 0xf7e37ea0
The distance between printf and memcpy is ffede680
The address of system is 0xf7d06cd0
The distance between printf and system is f850
===== Module function addresses =====
The address of main is 0x565902ab
The address of add is 0x565901ad
The distance between main and add is fe
The address of sub is 0x5659020d
The distance between main and sub is 9e
The address of compute is 0x5659026b
The distance between main and compute is 40
===== Global initialized variable addresses =====
The address of k is 0x56593008
The address of p is 0x56591008
The distance between k and p is 2000
===== Global uninitialized variable addresses =====
The address of l is 0x56593014
The distance between k and l is 56593008
===== Local variable addresses =====
The address of i is 0xffe74db8
The address of j is 0xffe74db8
```

ASLR Enabled; PIE; 64 bit

```
tancy@Tancy-PC:/mnt/c/Users/minta/Dropbox/sync/security$ ./aslr1_64
===== Libc function addresses =====
The address of printf is 0x7f23583b06f0
The address of memcpy is 0x7f23584f09c0
The distance between printf and memcpy is ffebfd30
The address of system is 0x7f23583a0d70
The distance between printf and system is f980
===== Module function addresses =====
The address of main is 0x55f613107282
The address of add is 0x55f613107179
The distance between main and add is 109
The address of sub is 0x55f6131071e0
The distance between main and sub is a2
The address of compute is 0x55f613107245
The distance between main and compute is 3d
===== Global initialized variable addresses =====
The address of k is 0x55f61310a010
The address of p is 0x55f613108008
The distance between k and p is 2008
===== Global uninitialized variable addresses =====
The address of l is 0x55f61310a024
The distance between k and l is 1310a010
===== Local variable addresses =====
The address of i is 0x7ffcd6e21c14
The address of j is 0x7ffcd6e21c14
tancy@Tancy-PC:/mnt/c/Users/minta/Dropbox/sync/security$ ./aslr1_64
===== Libc function addresses =====
The address of printf is 0x7ff7a51936f0
The address of memcpy is 0x7ff7a52d39c0
The distance between printf and memcpy is ffebfd30
The address of system is 0x7ff7a5183d70
The distance between printf and system is f980
===== Module function addresses =====
The address of main is 0x5576ea13a282
The address of add is 0x5576ea13a179
The distance between main and add is 109
The address of sub is 0x5576ea13a1e0
The distance between main and sub is a2
The address of compute is 0x5576ea13a245
The distance between main and compute is 3d
===== Global initialized variable addresses =====
The address of k is 0x5576ea13d010
The address of p is 0x5576ea13b008
The distance between k and p is 2008
===== Global uninitialized variable addresses =====
The address of l is 0x5576ea13d024
The distance between k and l is ea13d010
===== Local variable addresses =====
The address of i is 0x7ffea19634c4
The address of j is 0x7ffea19634c4
```

Bypass ASLR

- Address leak: certain vulnerabilities allow attackers to obtain the addresses required for an attack, which enables bypassing ASLR.
- Relative addressing: some vulnerabilities allow attackers to obtain access to data relative to a particular address, thus bypassing ASLR.
- Implementation weaknesses: some vulnerabilities allow attackers to guess addresses due to low entropy or faults in a particular ASLR implementation.
- Side channels of hardware operation: certain properties of processor operation may allow bypassing ASLR.

How to Make ASLR Win the Clone Wars: Runtime Re-Randomization

Kangjie Lu[†], Stefan Nürnberger[‡§], Michael Backes[‡¶], and Wenke Lee[†]
[†]Georgia Institute of Technology, [‡]CISPA, Saarland University, [§]DFKI, [¶]MPI-SWS
kjlu@gatech.edu, {nuernberger, backes}@cs.uni-saarland.de, wenke@cc.gatech.edu

***Abstract*—Existing techniques for memory randomization such as the widely explored Address Space Layout Randomization (ASLR) perform a single, per-process randomization that is applied before or at the process' load-time. The efficacy of such upfront randomizations crucially relies on the assumption that an attacker has only one chance to guess the randomized address, and that this attack succeeds only with a very low probability. Recent research results have shown that this assumption is not valid in many scenarios, e.g., daemon servers fork child processes that inherent the state – and if applicable: the randomization – of their parents, and thereby create clones with the same memory layout. This enables the so-called *clone-probing* attacks where an adversary repeatedly probes different clones in order to increase its knowledge about their shared memory layout.**

In this paper, we propose RUNTIMEASLR – the first ap-

the exact memory location of these code snippets by means of various forms of memory randomization. As a result, a variety of different memory randomization techniques have been proposed that strive to impede, or ideally to prevent, the precise localization or prediction where specific code resides [29], [22], [4], [8], [33], [49]. Address Space Layout Randomization (ASLR) [44], [43] currently stands out as the most widely adopted, efficient such kind of technique.

All existing techniques for memory randomization including ASLR are conceptually designed to perform a single, once-and-for-all randomization before or at the process' load-time. The efficacy of such upfront randomizations hence crucially relies on the assumption that an attacker has only one chance to guess the randomized address of a process to launch attack

NDSS 2016

Reference

- https://zzm7000.github.io/teaching/2023fallcse410518/index.html