CSE 484: Computer Security and Privacy

Software Security: A few more defenses and attacks

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Logistics

- Lab 1a due Wednesday
  - Lab1a writeups are individual, and are a textbox on gradescope, rather than a pdf upload.

- We do update the SSH guide and such if there are common challenges
  - Take a look at that and the lab FAQs if you run into problems first

Printf exploitation explanation not clicking?

- I’ve uploaded two short exercises for starting to write printf exploits to ed
  - Give them a try if you are a bit lost, or even if you aren’t ☺

return-to-libc

- Overwrite saved ret (IP) with address of any library routine
  - Arrange stack to look like arguments
- Does not look like a huge threat
  - …
  - We can call *any* function we want!
  - Say, exec ☺

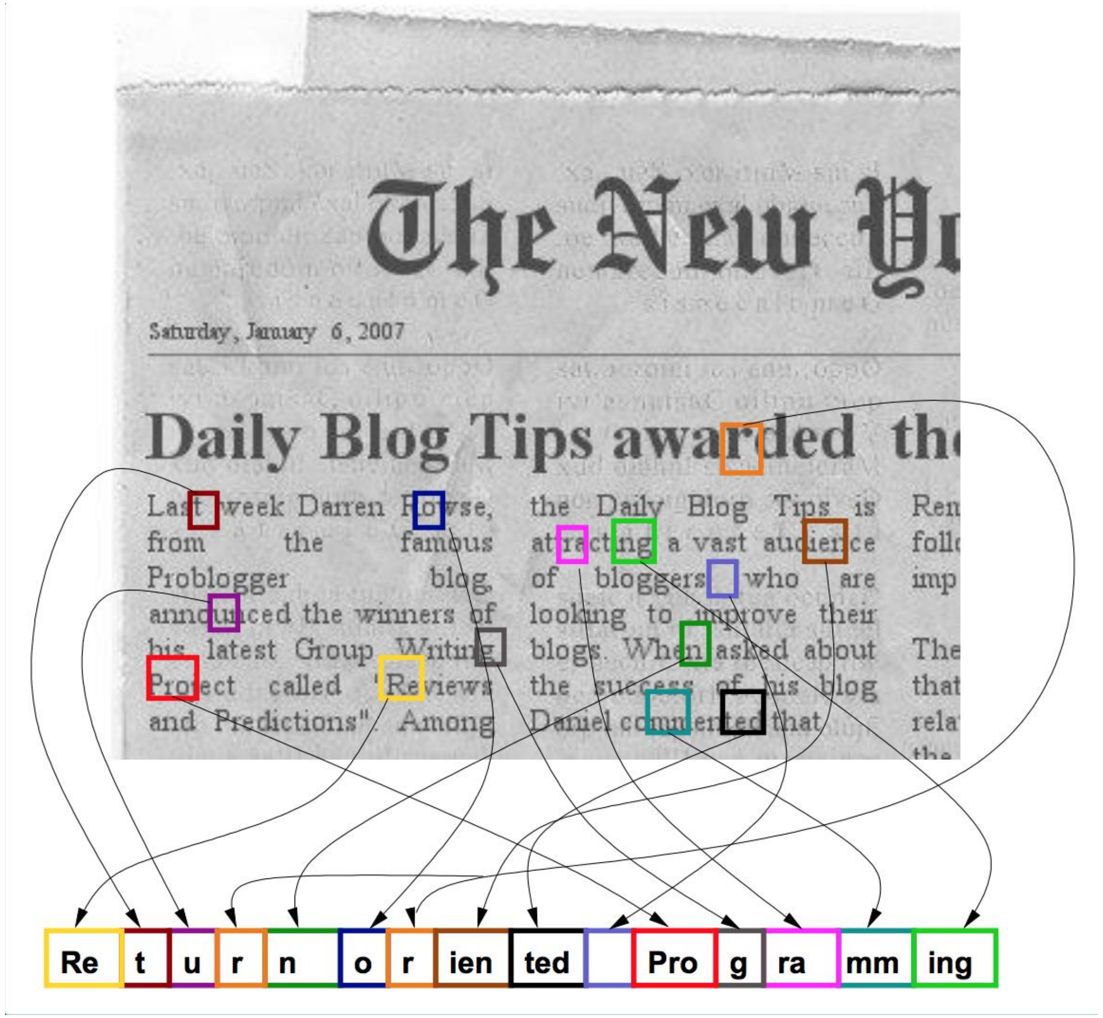
return-to-libc++

- Insight: Overwritten saved EIP need not point to the *beginning* of a library routine
- **Any** existing instruction in the code image is fine
  - Will execute the sequence starting from this instruction
- What if instruction sequence contains RET?
  - Execution will be transferred… to where?
  - Read the word pointed to by stack pointer (SP)
    - Guess what? Its value is under attacker's control!
  - Use it as the new value for IP
    - Now control is transferred to an address of attacker's choice!
  - Increment SP to point to the next word on the stack

Chaining RETs

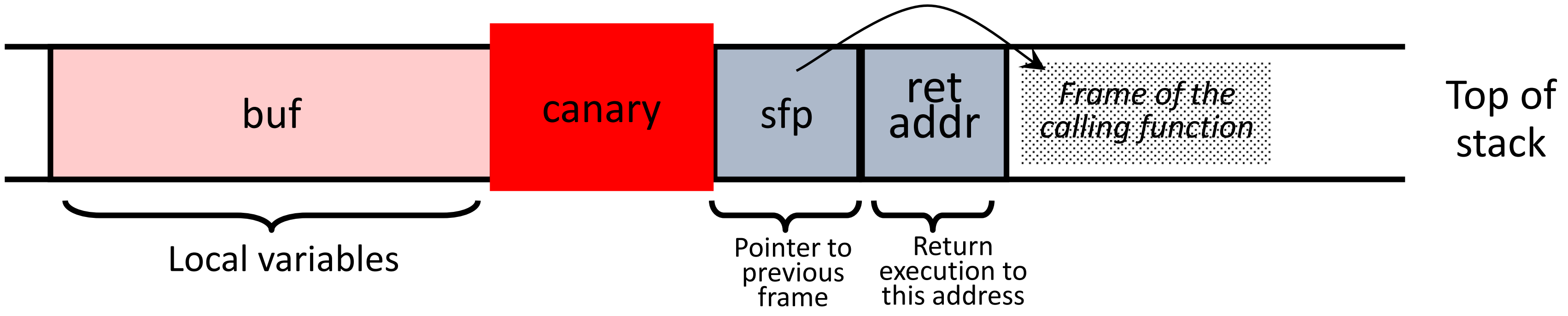
- Can chain together sequences ending in RET
  - Krahmer, "x86-64 buffer overflow exploits and the borrowed code chunks exploitation technique" (2005)
- What is this good for?
- Answer [Shacham et al.]: everything
  - Turing-complete language
  - Build "gadgets" for load-store, arithmetic, logic, control flow, system calls
  - Attack can perform arbitrary computation using no injected code at all – return-oriented programming
- Truly, a "weird machine"

Return-Oriented Programming



Defense: Run-Time Checking: StackGuard

- Embed “canaries” (stack cookies) in stack frames and verify their integrity prior to function return
  - Any overflow of local variables will damage the canary



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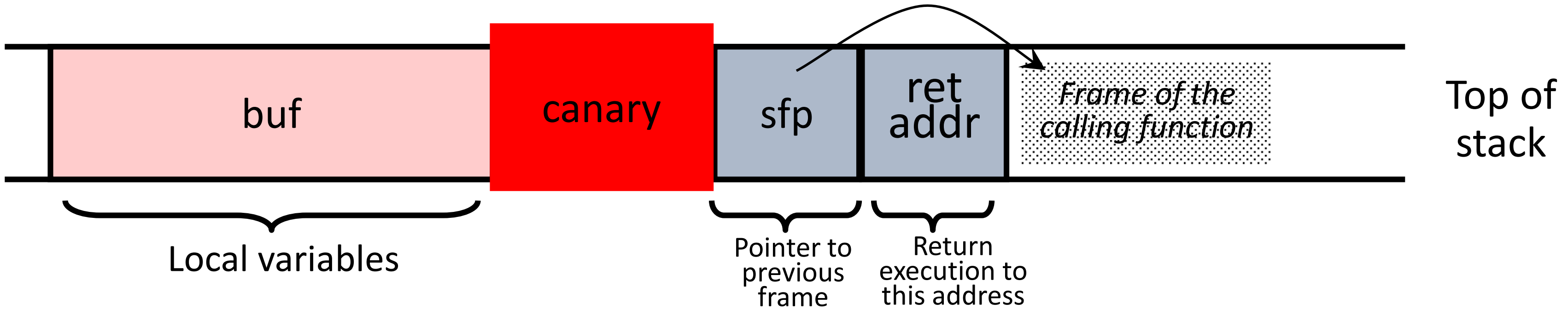


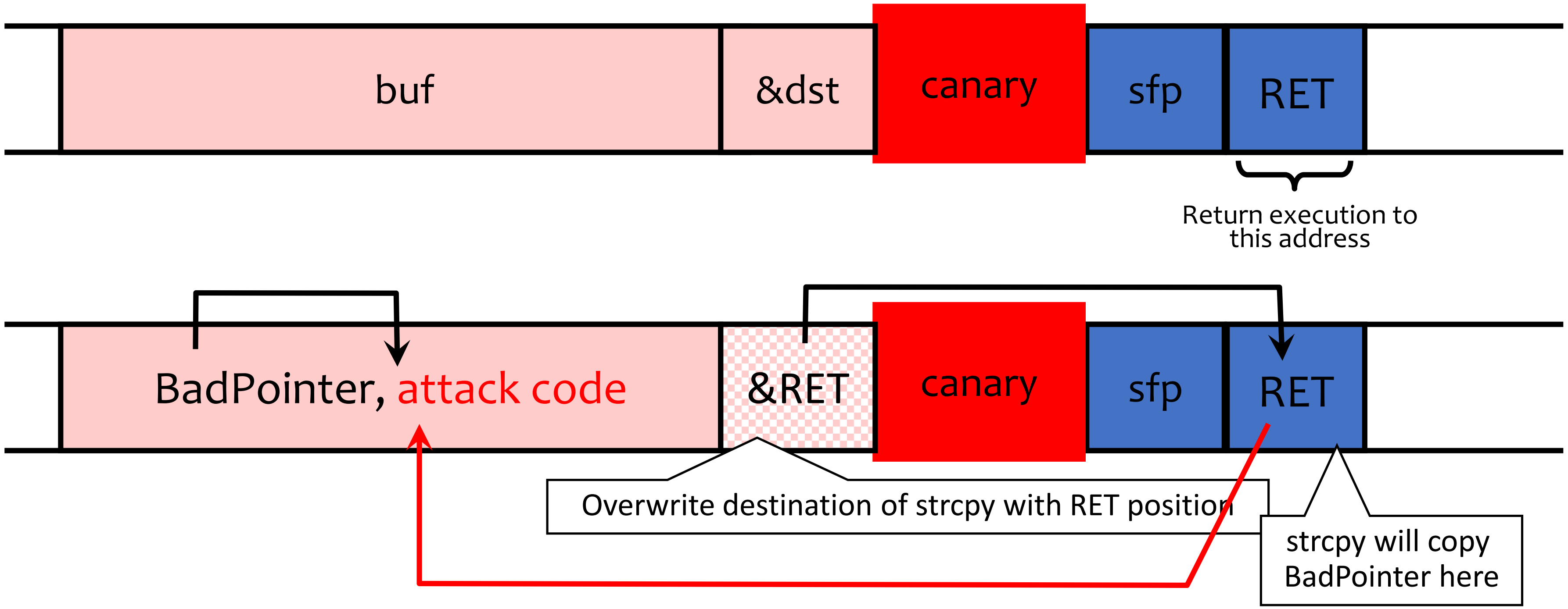
- Choose random canary string on program start
  – Attacker can't guess what the value of canary will be
- Canary contains: "\0", newline, linefeed, EOF
  – String functions like strcpy won't copy beyond "\0"

StackGuard Implementation

- StackGuard requires code recompilation
- Checking canary integrity prior to every function return causes a performance penalty
  - For example, 8% for Apache Web server at one point in time

Defeating StackGuard

- StackGuard can be defeated
  - A single memory write where the attacker controls both the value and the destination is sufficient
- Suppose program contains copy(buf,attacker-input) and copy(dst,buf)
  - Example: dst is a local pointer variable
  - Attacker controls both buf and dst



Defenses so far

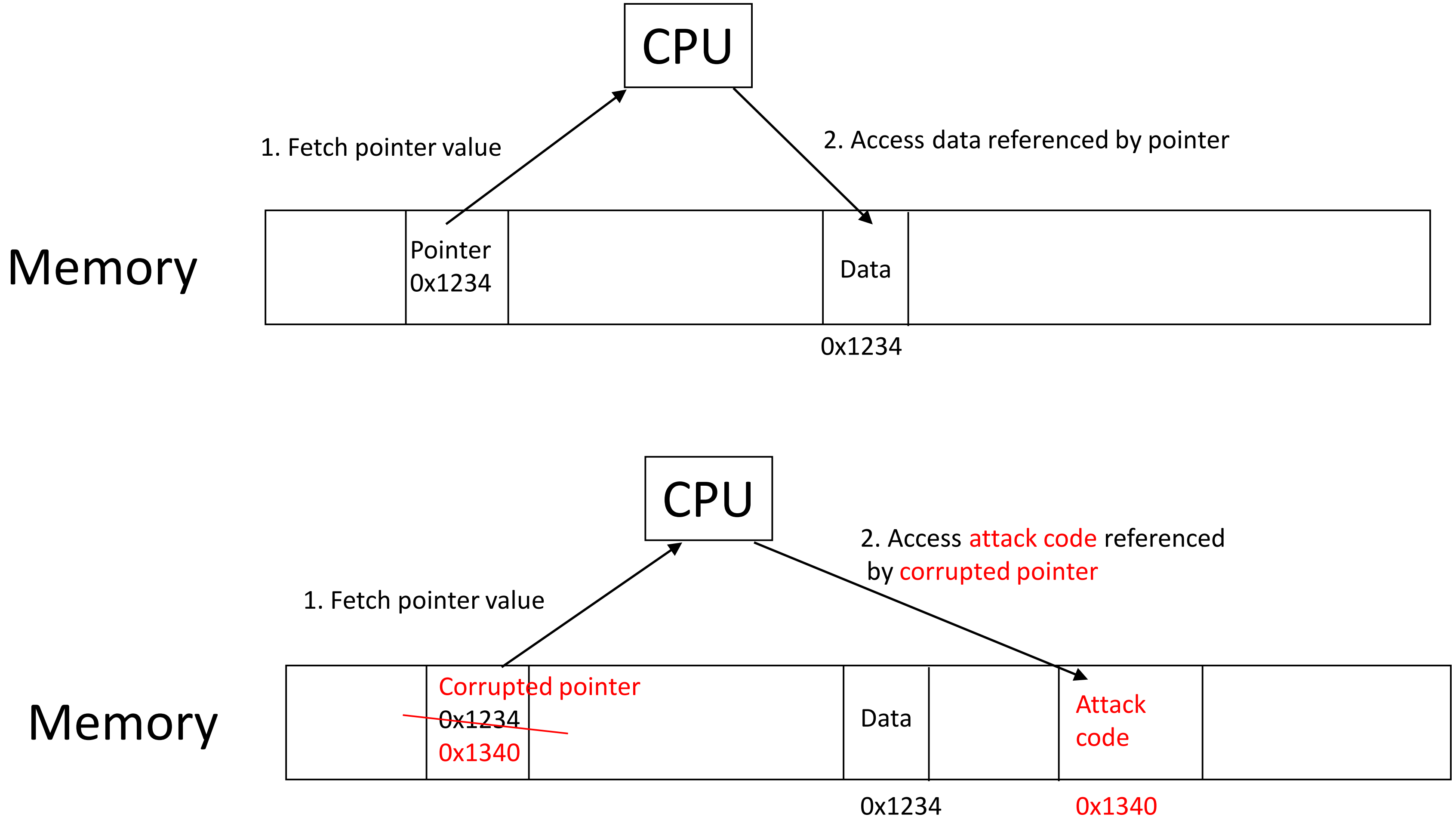
- ASLR – Randomize where the stack/heap/code starts
  - Counters: Information disclosures, sprays and sleds
- Canaries – Put a value on the stack, see if it changes
  - Counters: Arbitrary writes
- DEP – Mark sections of memory as non-executable, e.g. the stack
  - Counters: ROP, JOP, Code-reuse attacks in general

Pointer integrity protections (e.g. PointGuard, PAC, etc.)

- Attack: overwrite a pointer (heap date, ret, function pointer, etc.)
- Idea: encrypt all pointers while in memory
  - Generate a random key when program is executed
  - Each pointer is XORed with this key when loaded from memory to registers or stored back into memory
    - Pointers cannot be overflowed while in registers
- Attacker cannot predict the target program's key
  - Even if pointer is overwritten, after XORing with key it will dereference to a "random" memory address

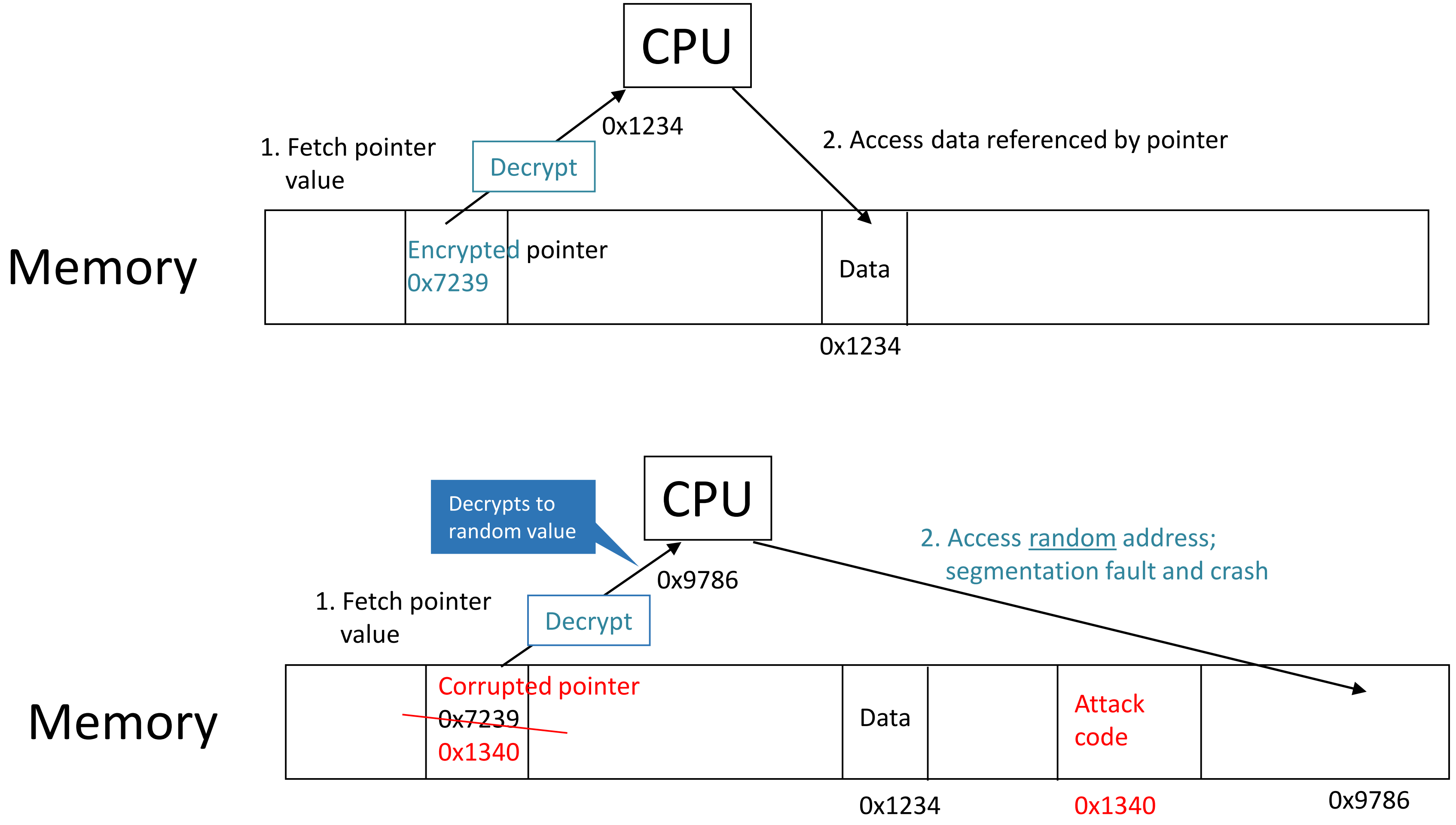
[Cowan]

Normal Pointer Dereference



[Cowan]

PointGuard Dereference



PointGuard Issues

- Must be very fast
  - Pointer dereferences are very common
- Compiler issues
  - Must encrypt and decrypt <u>only</u> pointers
  - If compiler “spills” registers, unencrypted pointer values end up in memory and can be overwritten there
- Attacker should not be able to modify the key
  - Store key in its own non-writable memory page
- PG’d code doesn’t mix well with normal code
  - What if PG’d code needs to pass a pointer to OS kernel?

Defense: Shadow stacks

- Idea: don't store return addresses on the stack!

- Store them on… a different stack!
  - A *hidden* stack

- On function call/return
  - Store/retrieve the return address from shadow stack

- Or store on both main stack and shadow stack, and compare for equality at function return

- 2020/2021 Hardware Support emerges (e.g., Intel Tiger Lake, AMD Ryzen PRO 5000)

Challenges With Shadow Stacks

- Where do we put the shadow stack?
  - Can the attacker figure out where it is? Can they access it?
- How fast is it to store/retrieve from the shadow stack?
- How *big* is the shadow stack?
- Is this compatible with all software?
- (Still need to consider data corruption attacks, even if attacker can't influence control flow.)

What does a modern program do?

```
(Mostly normal x86_32)
080491f6 <foo>:
 80491f6:  f3 0f 1e fb           endbr32
 80491fa:  55                    push   %ebp
 80491fb:  89 e5                 mov    %esp,%ebp
 80491fd:  81 ec c0 01 00 00     sub    $0x1c0,%esp
 8049203:  8b 45 08              mov    0x8(%ebp),%eax
 8049206:  89 85 40 fe ff ff     mov    %eax,-0x1c0(%ebp)
 804920c:  65 a1 14 00 00 00     mov    %gs:0x14,%eax
 8049212:  89 45 fc              mov    %eax,-0x4(%ebp)
 8049215:  31 c0                 xor    %eax,%eax
 8049217:  8b 85 40 fe ff ff     mov    -0x1c0(%ebp),%eax
 804921d:  83 c0 04              add    $0x4,%eax
 8049220:  8b 00                 mov    (%eax),%eax
 8049222:  50                    push   %eax
 8049223:  8d 85 44 fe ff ff     lea    -0x1bc(%ebp),%eax
 8049229:  50                    push   %eax
 804922a:  e8 81 fe ff ff        call   80490b0 <strcpy@plt>
 804922f:  83 c4 08              add    $0x8,%esp
 8049232:  90                    nop
 8049233:  8b 55 fc              mov    -0x4(%ebp),%edx
 8049236:  65 33 15 14 00 00 00  xor    %gs:0x14,%edx
 804923d:  74 05                 je     8049244 <foo+0x4e>
 804923f:  e8 4c fe ff ff        call   8049090 <__stack_chk_fail@plt>
 8049244:  c9                    leave
 8049245:  c3                    ret
```

```
(Lab 1 version)
08049196 <foo>:
 8049196:  55                    push   %ebp
 8049197:  89 e5                 mov    %esp,%ebp
 8049199:  81 ec b8 01 00 00     sub    $0x1b8,%esp
 804919f:  8b 45 08              mov    0x8(%ebp),%eax
 80491a2:  83 c0 04              add    $0x4,%eax
 80491a5:  8b 00                 mov    (%eax),%eax
 80491a7:  50                    push   %eax
 80491a8:  8d 85 48 fe ff ff     lea    -0x1b8(%ebp),%eax
 80491ae:  50                    push   %eax
 80491af:  e8 9c fe ff ff        call   8049050 <strcpy@plt>
 80491b4:  83 c4 08              add    $0x8,%esp
 80491b7:  90                    nop
 80491b8:  c9                    leave
 80491b9:  c3                    ret
```

Other Big Classes of Defenses

- Use safe programming languages, e.g., Java, Rust
  - What about legacy C code?
  - (Though Java doesn't magically fix all security issues ☺)
- Static analysis of source code to find overflows
- Dynamic testing: "fuzzing"

Fuzz Testing

- Generate "random" inputs to program
  - Sometimes conforming to input structures (file formats, etc.)
- See if program crashes
  - If crashes, found a bug
  - Bug may be exploitable
- Surprisingly effective

- Now standard part of development lifecycle

Other Common Software Security Issues…

Another Class of Vulnerability: (Gradescope)

```
char buf[80];
void vulnerable() {
     long long len = get_int_from_user();
     char *p = get_string_from_user();
     int32_t buflen = sizeof buf;
     if (len > buflen) {
          error("length too large");
          return;
     }
     memcpy(buf, p, len);
}
```

Snippet 1

```
size_t len = read_int_from_network();
char *buf;
buf = malloc(len+5);
read(fd, buf, len);
```

Snippet 2

```
void *memcpy(void *dst, const void * src, size_t n);
```

```
typedef unsigned int size_t;
```

Implicit Cast

- Consider this code (x86, 32bit:

```
char buf[80];
void vulnerable() {
     long long len = read_int_from_network();
     char *p = read_string_from_network();
     int32_t buflen = sizeof buf;
     if (len > buflen) {
          error("length too large, nice try!");
          return;
     }
     memcpy(buf, p, len);
}
```

If len is negative, may copy huge amounts of input into buf.

```
void *memcpy(void *dst, const void * src, size_t n);
```

```
typedef unsigned int size_t;
```

Integer Overflow

```
size_t len = read_int_from_network();
char *buf;
buf = malloc(len+5);
read(fd, buf, len);
```

- What if len is large (e.g., len = 0xFFFFFFFF)?
- Then len + 5 = 4 (on many platforms)
- Result: Allocate a 4-byte buffer, then read a lot of data into that buffer.

(from [www-inst.eecs.berkeley.edu—implflaws.pdf]())

Another Type of Vulnerability

- Consider this code:

```
if (access("file", W_OK) != 0) {
   exit(1); // user not allowed to write to file
}

fd = open("file", O_WRONLY);
write(fd, buffer, sizeof(buffer));
```

- **Goal:** Write to file only with permission
- What can go wrong?

TOCTOU (Race Condition)

- TOCTOU = “Time of Check to Tile of Use”

```
if (access("file", W_OK) != 0) {
   exit(1); // user not allowed to write to file
}

fd = open("file", O_WRONLY);
write(fd, buffer, sizeof(buffer));
```

- **Goal:** Write to file only with permission
- Attacker (in another program) can change meaning of “file” between access and open:

```
symlink("/etc/passwd", "file");
```

Something Different: Password Checker

- Functional requirements
  - PwdCheck(RealPwd, CandidatePwd) should:
    - Return TRUE if RealPwd matches CandidatePwd
    - Return FALSE otherwise
  - RealPwd and CandidatePwd are both 8 characters long

Password Checker

- Functional requirements
  - PwdCheck(RealPwd, CandidatePwd) should:
    - Return TRUE if RealPwd matches CandidatePwd
    - Return FALSE otherwise
  - RealPwd and CandidatePwd are both 8 characters long
- Implementation (like TENEX system)

```
PwdCheck(RealPwd, CandidatePwd)  // both 8 chars
      for i = 1 to 8 do
            if (RealPwd[i] != CandidatePwd[i])
                  return FALSE
      return TRUE
```

- Clearly meets functional description

Attacker Model

```
PwdCheck(RealPwd, CandidatePwd)  // both 8 chars
      for i = 1 to 8 do
            if (RealPwd[i] != CandidatePwd[i])
                  return FALSE
      return TRUE
```

- Attacker can guess CandidatePwds through some standard interface
- Naive: Try all 256^8 = 18,446,744,073,709,551,616 possibilities
- Is it possible to derive password more quickly?

Try it

dkohlbre.com/cew