CSE 484 (Winter 2010)

Software Security: Attacks, Defenses, and Design Principles

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Goals for Today

- Randomness
- Timing Attacks

- Defensive Approaches

Randomness issues

- Many applications (especially security ones) require randomness
- Explicit uses:
  - Generate secret cryptographic keys
  - Generate random initialization vectors for encryption
- Other “non-obvious” uses:
  - Generate passwords for new users
  - Shuffle the order of votes (in an electronic voting machine)
  - Shuffle cards (for an online gambling site)

C’s rand() Function

- C has a built-in random function: rand()

```
unsigned long int next = 1;
/* rand:  return pseudo-random integer on 0..32767 */
int rand(void) {
   next = next * 1103515245 + 12345;
   return (unsigned int)(next/65536) % 32768;
}
/* srand:  set seed for rand() */
void srand(unsigned int seed) {
   next = seed;
}
```

- Problem: don’t use rand() for security-critical applications!
  - Given a few sample outputs, you can predict subsequent ones

Windows/.NET

July 22, 2001

Randomness and the Netscape Browser

How secure is the World Wide Web?

Ian Goldberg and David Wagner

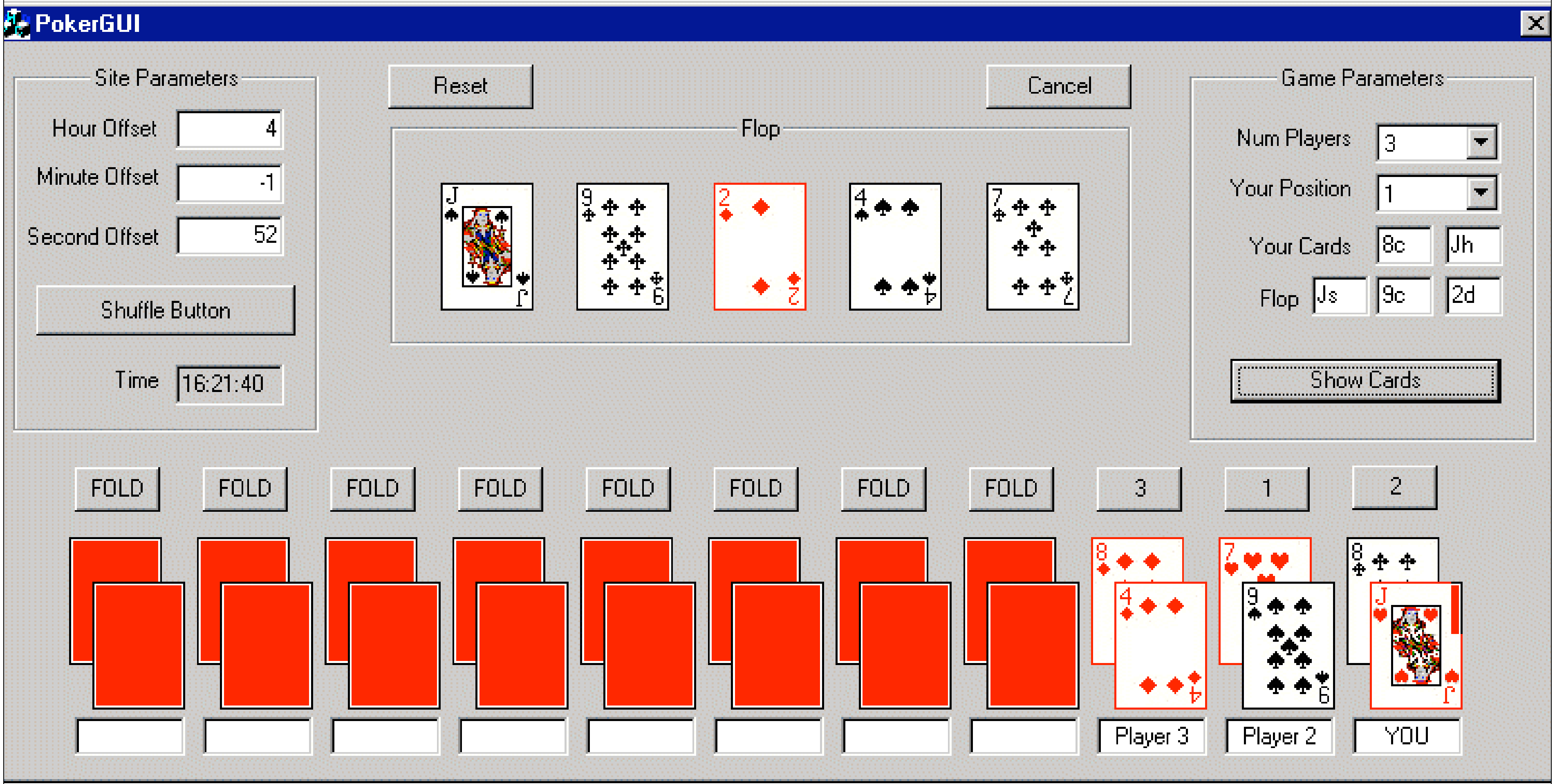
No one was more surprised than Netscape Communications when a pair of computer-science students broke the Netscape encryption scheme. Ian and David describe how they attacked the popular Web browser and what they found out.

Problems in Practice

- One institution used (something like) rand() to generate passwords for new users
  - Given your password, you could predict the passwords of other users
- Kerberos (1988 - 1996)
  - Random number generator improperly seeded
  - Possible to trivially break into machines that rely upon Kerberos for authentication
- Online gambling websites
  - Random numbers to shuffle cards
  - Real money at stake
  - But what if poor choice of random numbers?

mamajoe: Hey guys, Big B is in!

Images from http://www.cigital.com/news/index.php?pg=art&artid=20



Hour Offset 4

Minute Offset -1

Second Offset 52

Time 16:21:40

Num Players 3

Your Position 1

Your Cards 8c Jh

Flop Js 9c 2d

Images from http://www.cigital.com/news/index.php?pg=art&artid=20

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Big news... CNN, etc..

Other Problems

- Live CDs, diskless clients
  - May boot up in same state every time
- Virtual Machines
  - Save state: Opportunity for attacker to inspect the pseudorandom number generator’s state
  - Restart: May use same “psuedorandom” value more than once

Obtaining Pseudorandom Numbers

- For security applications, want "cryptographically secure pseudorandom numbers"
- Libraries include:
  - OpenSSL
  - Microsoft's Crypto API
- Linux:
  - /dev/random
  - /dev/urandom
- Internally:
  - Pool from multiple sources (interrupt timers, keyboard, ...)
  - Physical sources (radioactive decay, ...)

Timing Attacks

- Assume there are no “typical” bugs in the software
  - No buffer overflow bugs
  - No format string vulnerabilities
  - Good choice of randomness
  - Good design
- The software may still be vulnerable to timing attacks
  - Software exhibits input-dependent timings
- Complex and hard to fully protect against

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]) then
            return FALSE
    return TRUE
```

- Clearly meets functional description

Attacker Model

```
PwdCheck(RealPwd, CandidatePwd)  // both 8 chars
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```

- Attacker can guess CandidatePwds through some standard interface
- Naive: Try all 256^8 = 18,446,744,073,709,551,616 possibilities

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- Attacker can guess CandidatePwds through some standard interface
- Naive: Try all 256^8 = 18,446,744,073,709,551,616 possibilities
- Better: Time how long it takes to reject a CandidatePasswd. Then try all possibilities for first character, then second, then third, ...
  - Total tries: 256*8 = 2048

Other Examples

- Plenty of other examples of timings attacks
  - AES cache misses
    - AES is the “Advanced Encryption Standard”
    - It is used in SSH, SSL, IPsec, PGP, ...
  - RSA exponentiation time
    - RSA is a famous public-key encryption scheme
    - It’s also used in many cryptographic protocols and products

Toward Preventing Buffer Overflow

- Use safe programming languages, e.g., Java
  - What about legacy C code?
- Static analysis of source code to find overflows
- Black-box testing with long strings
- Mark stack as non-executable
- Randomize stack location or encrypt return address on stack by XORing with random string
  - Attacker won't know what address to use in his or her string
- Run-time checking of array and buffer bounds
  - StackGuard, libsafe, many other tools

Non-Executable Stack

- NX bit for pages in memory
  - Modern Intel and AMD processors support
  - Modern OS support as well
- Some applications need executable stack
  - For example, LISP interpreters
- Does not defend against return-to-libc exploits
  - Overwrite return address with the address of an existing library function (can still be harmful)
- …nor against heap and function pointer overflows
- …nor changing stack internal variables (auth flag, …)

Run-Time Checking: StackGuard

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

buf
Saved FP
ret/IP
Caller’s stack frame

buf
Saved FP
ret/IP
Caller’s stack frame

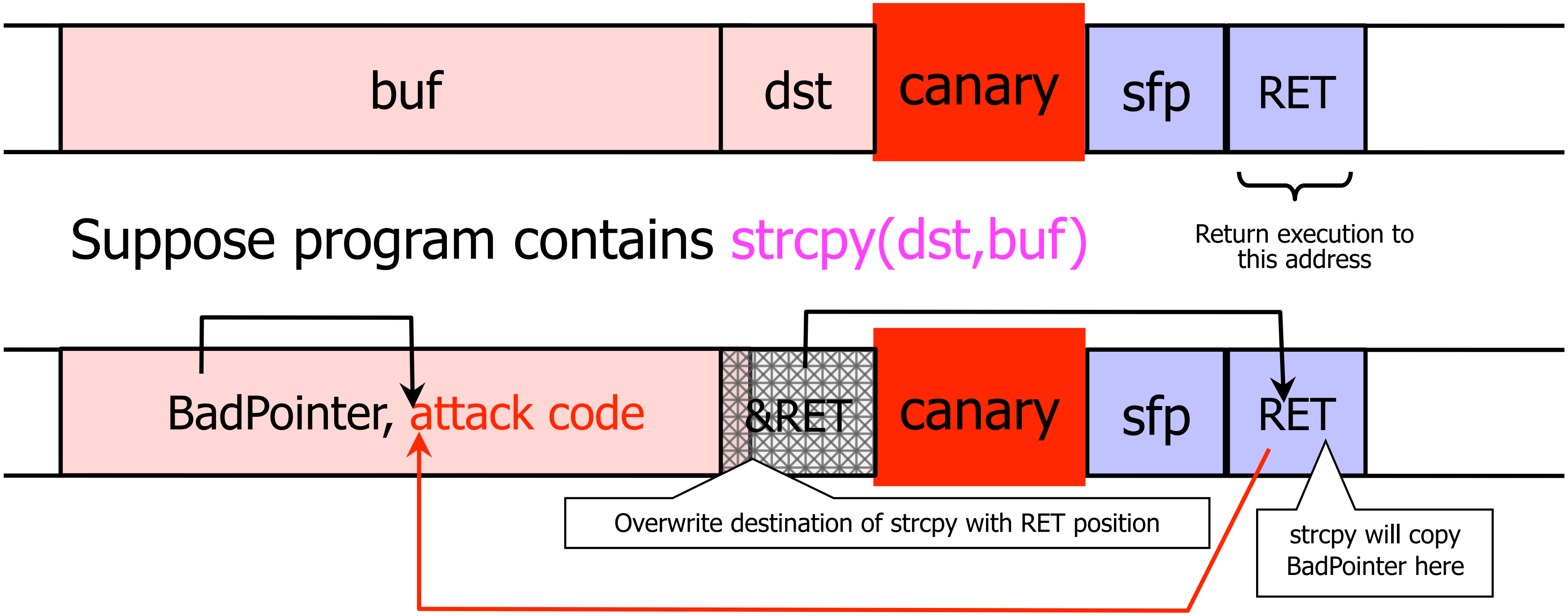
- Choose random canary string on program start
  - Attacker can’t guess what the value of canary will be
- Terminator canary: “\0”, newline, linefeed, EOF
  - String functions like strcpy won’t copy beyond “\0”

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
- PointGuard also places canaries next to function pointers and setjmp buffers
  - Worse performance penalty
- StackGuard doesn’t completely solve the problem (can be defeated)

Defeating StackGuard (Sketch)

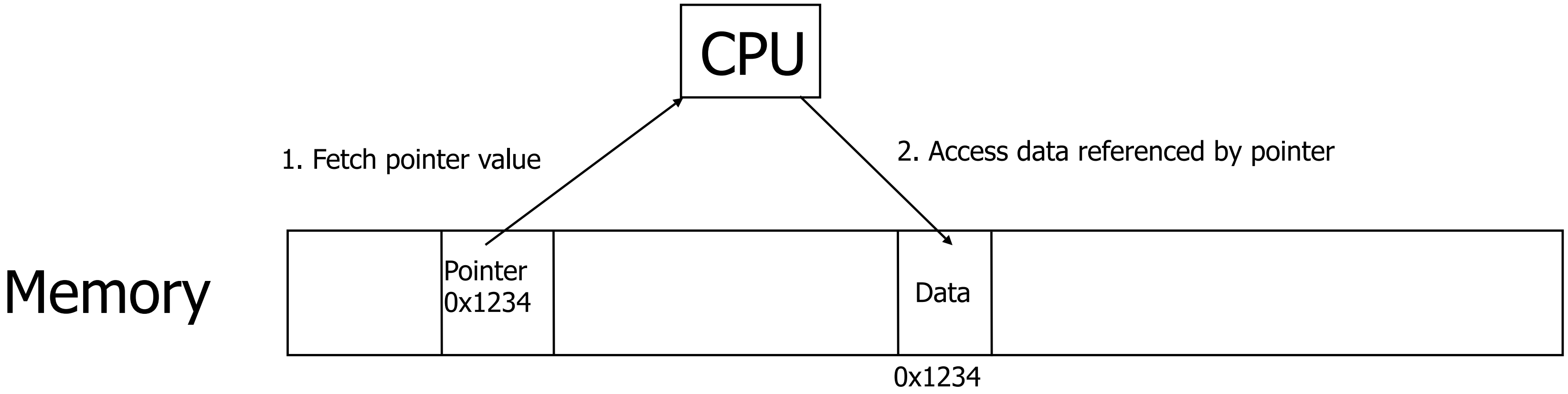
- Idea: overwrite pointer used by some strcpy and make it point to return address (RET) on stack
  - strcpy will write into RET without touching canary!



PointGuard

- Attack: overflow a function pointer so that it points to attack code
- 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 overflown 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

Normal Pointer Dereference [Cowan]



CPU

1. Fetch pointer value

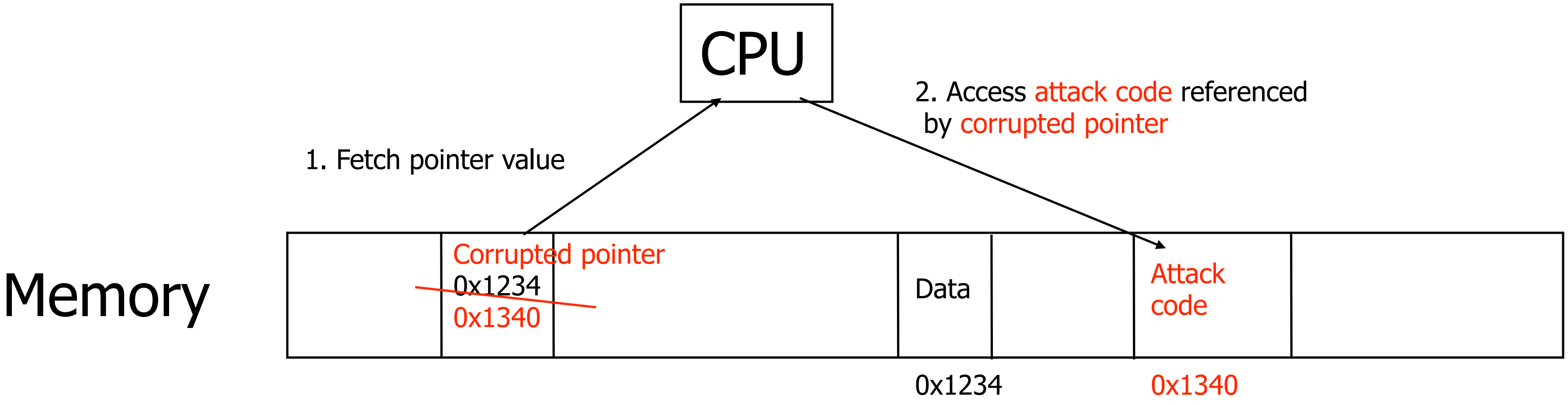
2. Access data referenced by pointer

Memory

Pointer
0x1234

Data

0x1234



CPU

1. Fetch pointer value

2. Access attack code referenced
by corrupted pointer

Memory

Corrupted pointer
~~0x1234~~
0x1340

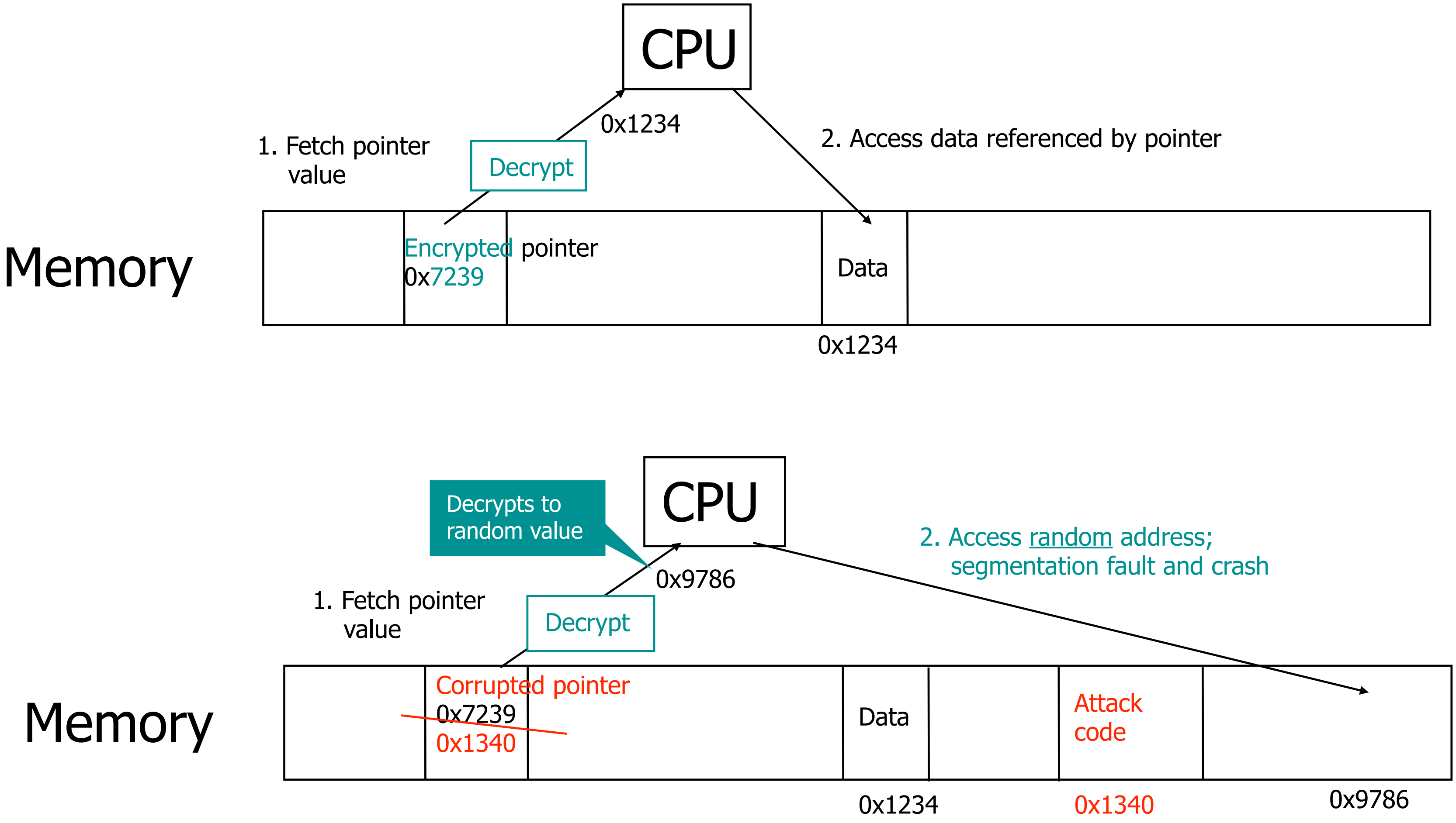
Data

Attack
code

0x1234

0x1340

PointGuard Dereference [Cowan]



CPU

1. Fetch pointer value

Decrypt

0x1234

2. Access data referenced by pointer

Memory

Encrypted pointer 0x7239

Data

0x1234

CPU

Decrypts to random value

0x9786

1. Fetch pointer value

Decrypt

2. Access random address; segmentation fault and crash

Memory

Corrupted pointer ~~0x7239~~ 0x1340

Data

Attack code

0x1234

0x1340

0x9786

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