CSE 484 (Winter 2010)

Software Security: Attacks, Defenses, and Design Principles

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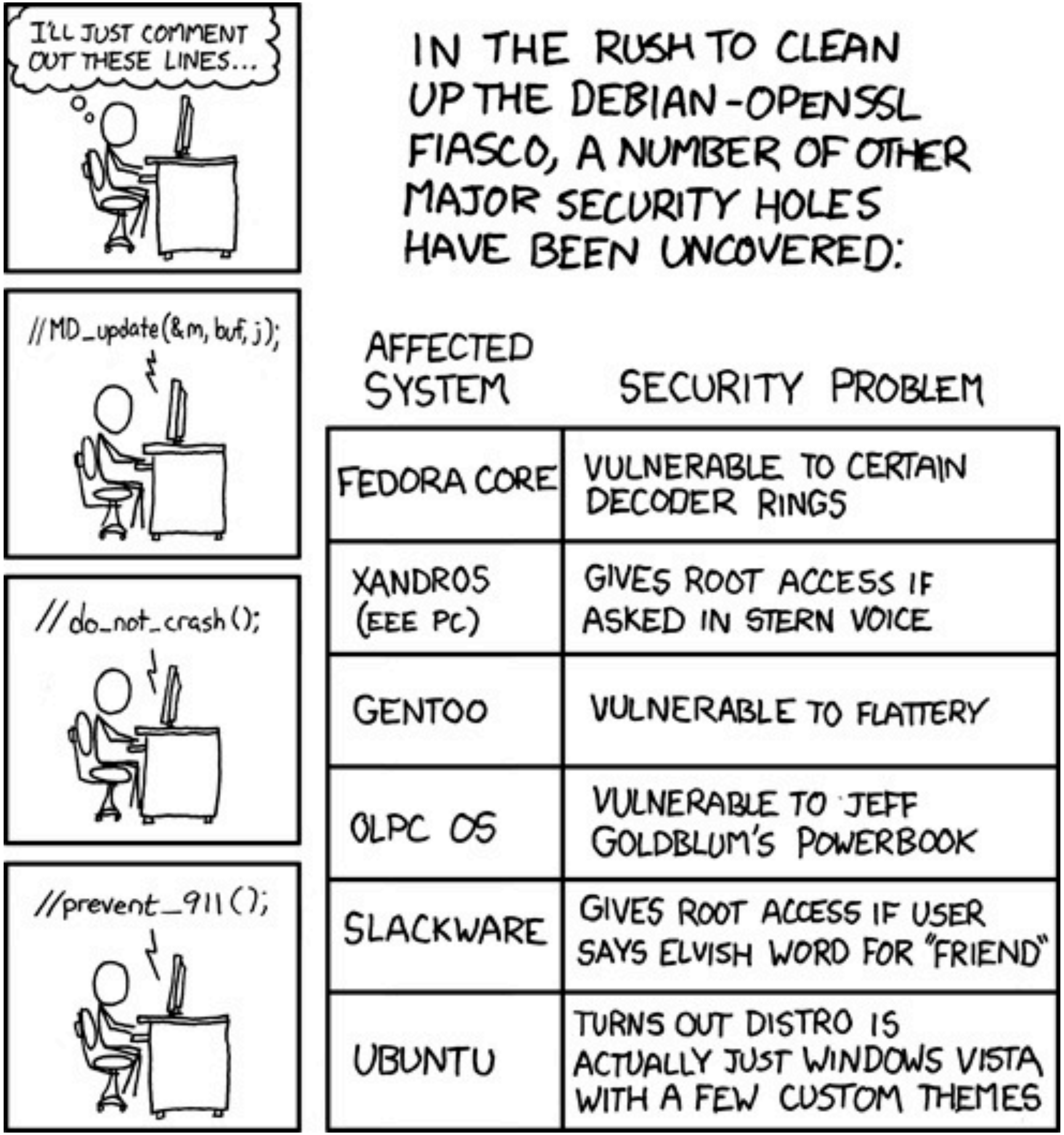
Thanks to Dan Boneh, Dieter Gollmann, John Manferdelli, John Mitchell, Vitaly Shmatikov, Bennet Yee, and many others for sample slides and materials ...

Goals for Today

- Randomness (bit more)
- Timing Attacks

- Defensive Approaches

DILBERT *By Scott Adams*


I'LL JUST COMMENT OUT THESE LINES...
//MD_update(&m, buf, j);
//do_not_crash();
//prevent_911();
IN THE RUSH TO CLEAN UP THE DEBIAN-OPENSSL FIASCO, A NUMBER OF OTHER MAJOR SECURITY HOLES HAVE BEEN UNCOVERED:
AFFECTED SYSTEM
SECURITY PROBLEM
FEDORA CORE
VULNERABLE TO CERTAIN DECODER RINGS
XANDROS (EEE PC)
GIVES ROOT ACCESS IF ASKED IN STERN VOICE
GENTOO
VULNERABLE TO FLATTERY
OLPC OS
VULNERABLE TO JEFF GOLDBLUM'S POWERBOOK
SLACKWARE
GIVES ROOT ACCESS IF USER SAYS ELVISH WORD FOR "FRIEND"
UBUNTU
TURNS OUT DISTRO IS ACTUALLY JUST WINDOWS VISTA WITH A FEW CUSTOM THEMES

Source: XKCD

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

```
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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 and signature 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
- 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, ProPolice, 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)
  - Newer: Return-oriented programming
- …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

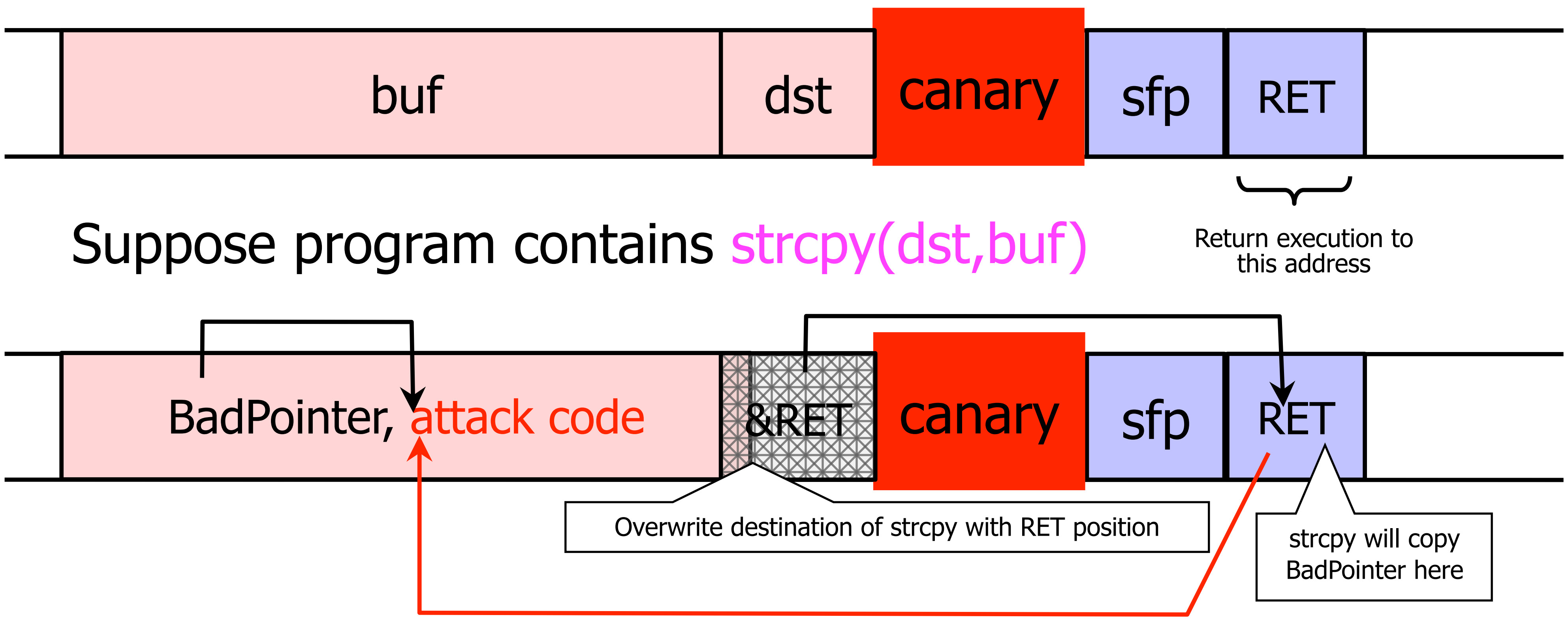
- Choose random canary string on program start
  - Attacker can't guess what the value of canary will be
- Terminator canary: "\0", newline, linefeed, EOF
  - String functions like strcpy won't copy beyond "\0"

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 (Example, Sketch)

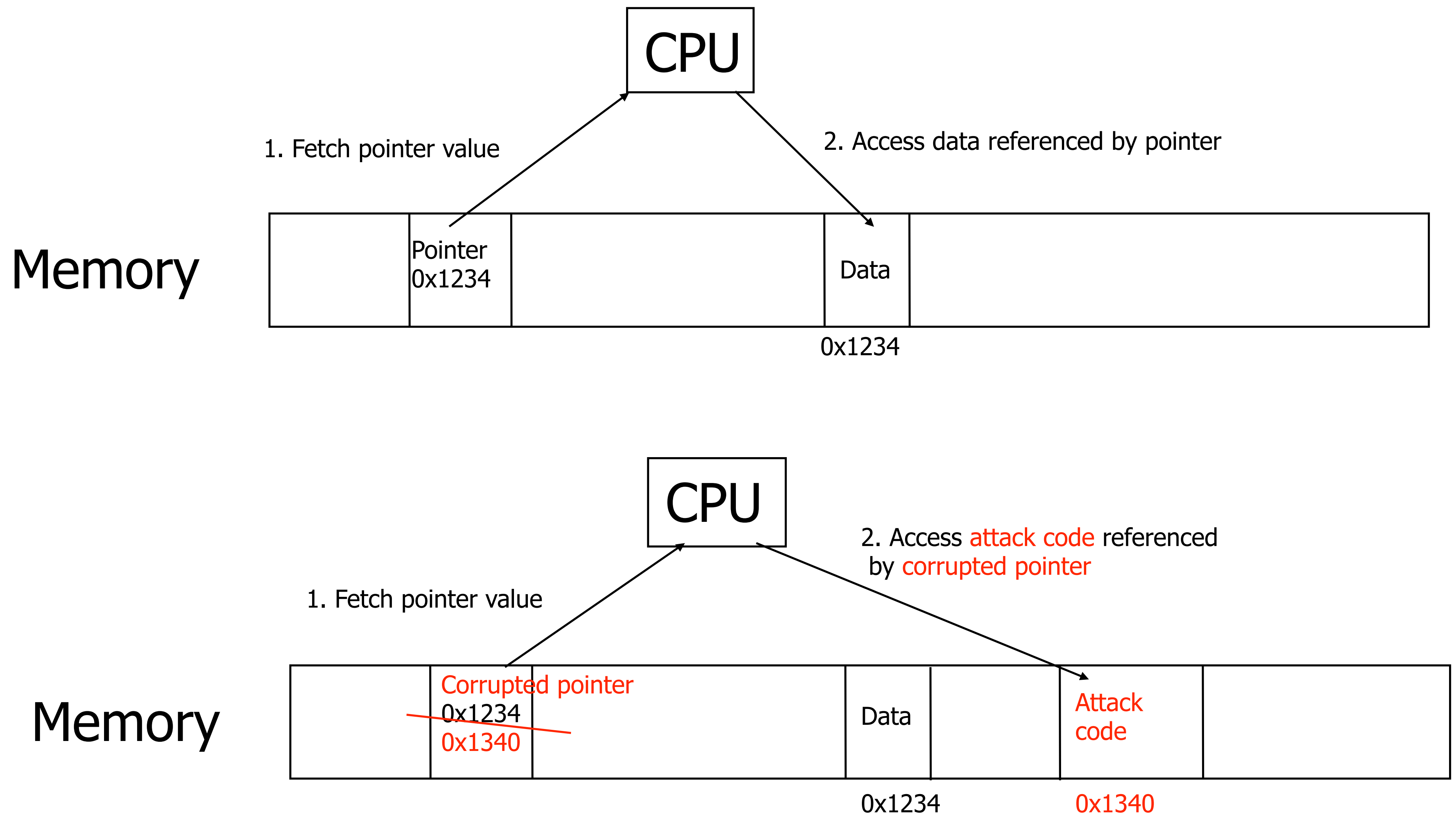
- Idea: overwrite pointer used by some strcpy and make it point to return address (RET) on stack
  - strcpy will write into RET without touching canary!



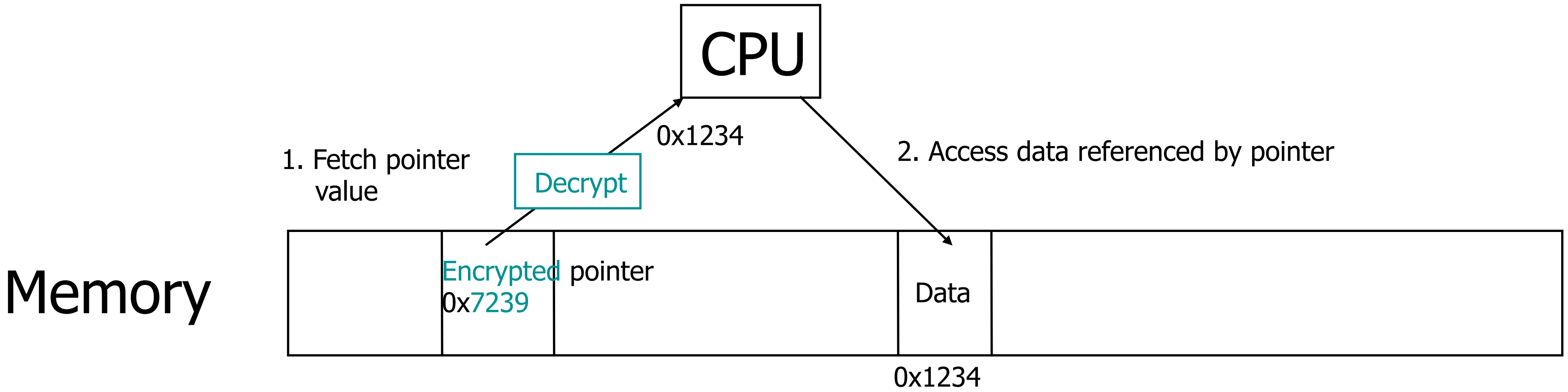
PointGuard

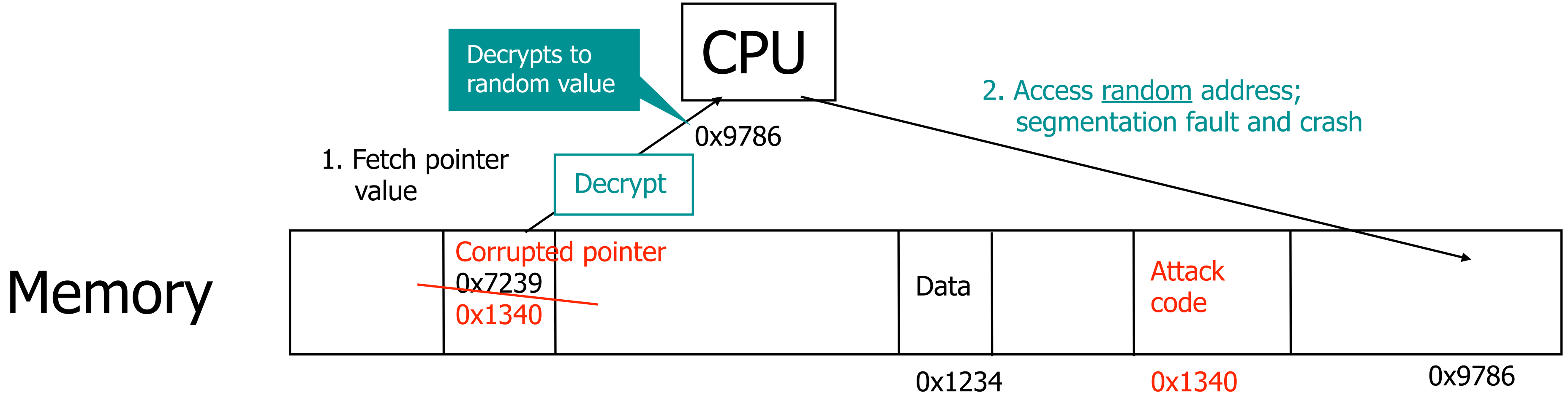
- Attack: overflow a function pointer so that it points to attack code
- Idea: encrypt all pointers while in memory
  - Generate a random key when program is executed
  - Each pointer is XORed with this key when loaded from memory to registers or stored back into memory
    - Pointers cannot be overflown 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]



PointGuard Dereference [Cowan]





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?

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

Genetic Diversity

- Problems with Monoculture

- Steps toward diversity
  - Automatic diversification of compiled code
  - Address Space Randomization

Principles

- Open design? Open source?
- Maybe...

- Linux Kernel Backdoor Attempt: http://www.freedom-to-tinker.com/?p=472

- PGP Corporation: http://www.pgp.com/developers/sourcecode/index.html