CSE 484 / CSE M 584 (Autumn 2011)

Software Security (cont.): Defenses, Adv. Attacks, & More

Daniel Halperin
Tadayoshi Kohno

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

Updates Oct. 7th

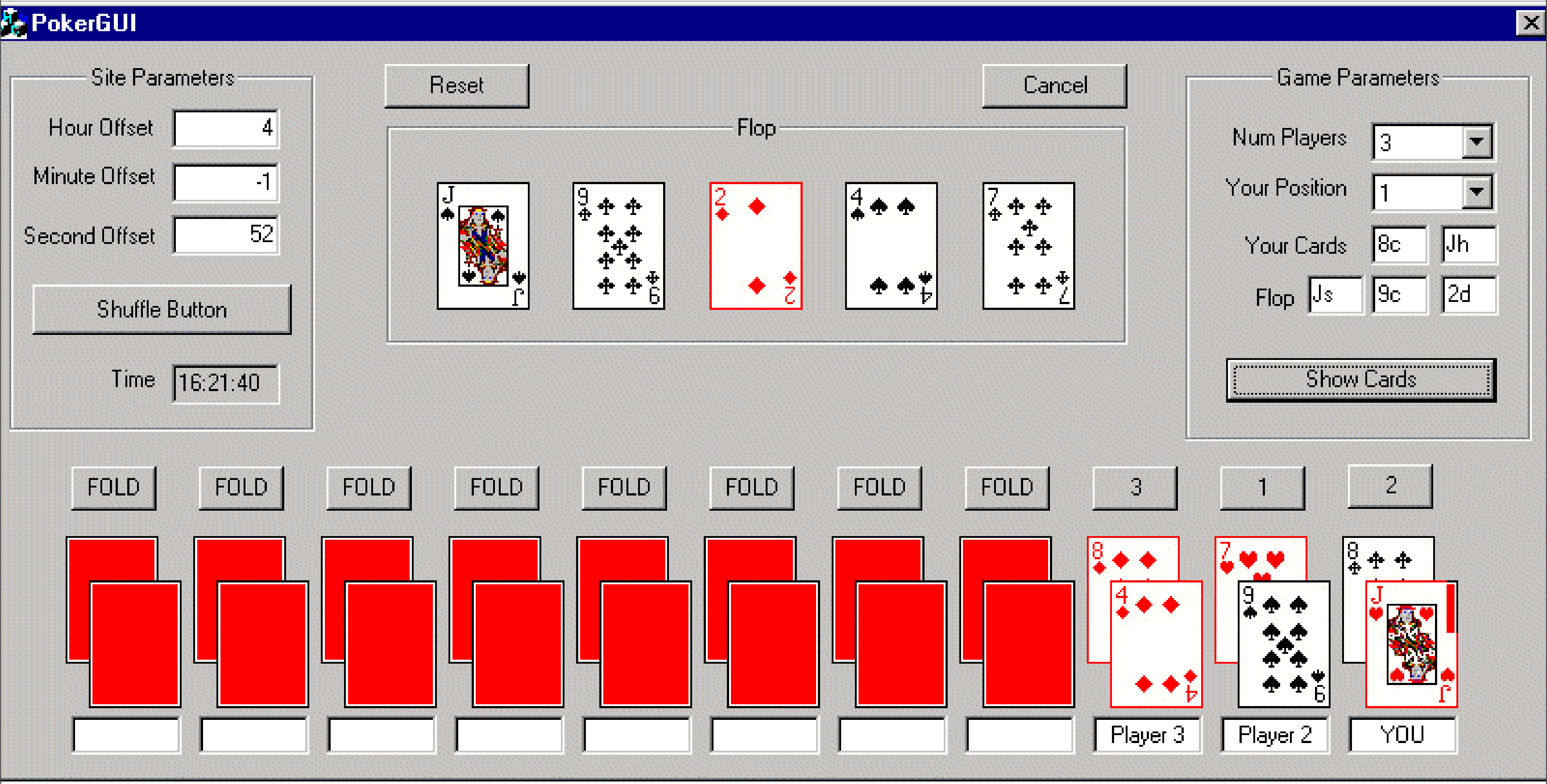
- Coffee/tea signup sheet posted (optional)
- M 584 reading for Oct. 14th posted
- Security reviews & Current events
- Lab 1

Today

- Randomness
- Software defenses
- Advanced attacks
- Advanced defense

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


DILBERT By Scott Adams
TOUR OF ACCOUNTING
OVER HERE WE HAVE OUR RANDOM NUMBER GENERATOR.
scottadams@aol.com
www.dilbert.com
NINE NINE NINE NINE NINE NINE
10/25/01 © 2001 United Feature Syndicate, Inc.
ARE YOU SURE THAT'S RANDOM?
THAT'S THE PROBLEM WITH RANDOMNESS: YOU CAN NEVER BE SURE.

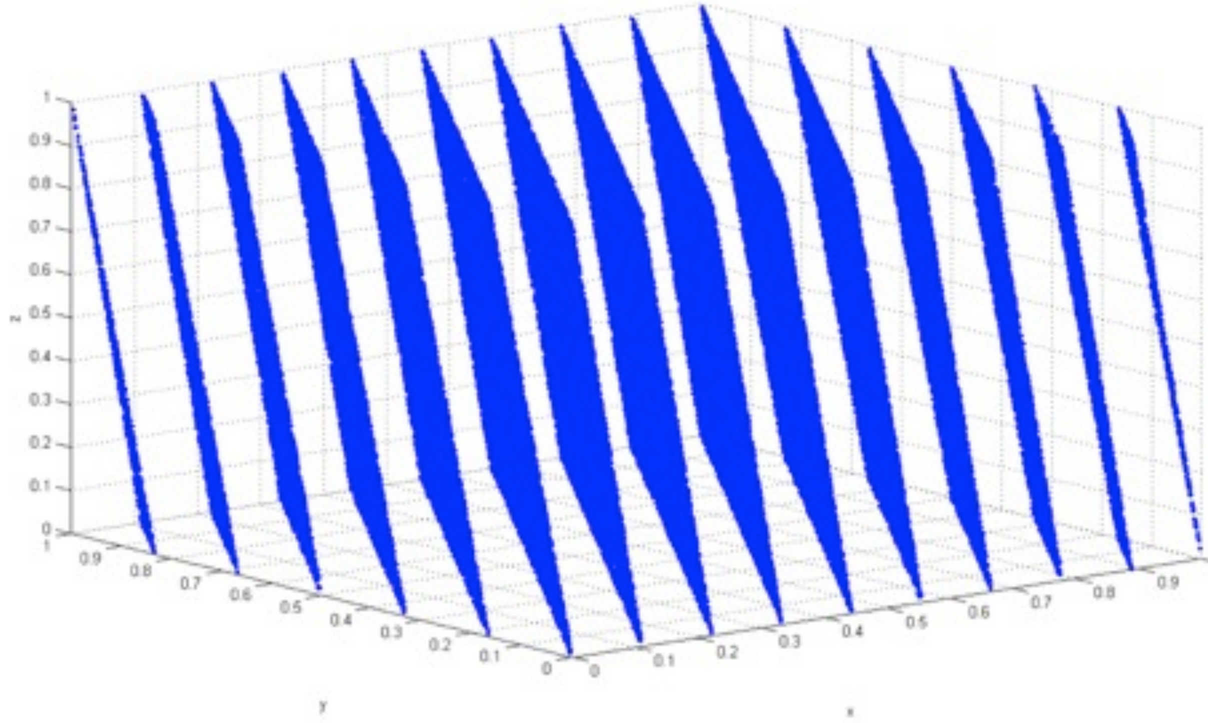
How would you test a RNG?

How would you test a RNG?

- ***Statistical tests:*** how are the output values distributed?
- ***Spectral tests:*** plot data in *n*-D, find patterns
  - Related to compressibility/summarizibility
    `A: 010101010101010101010101010101`
    `B: 110010000110000111011110111010`

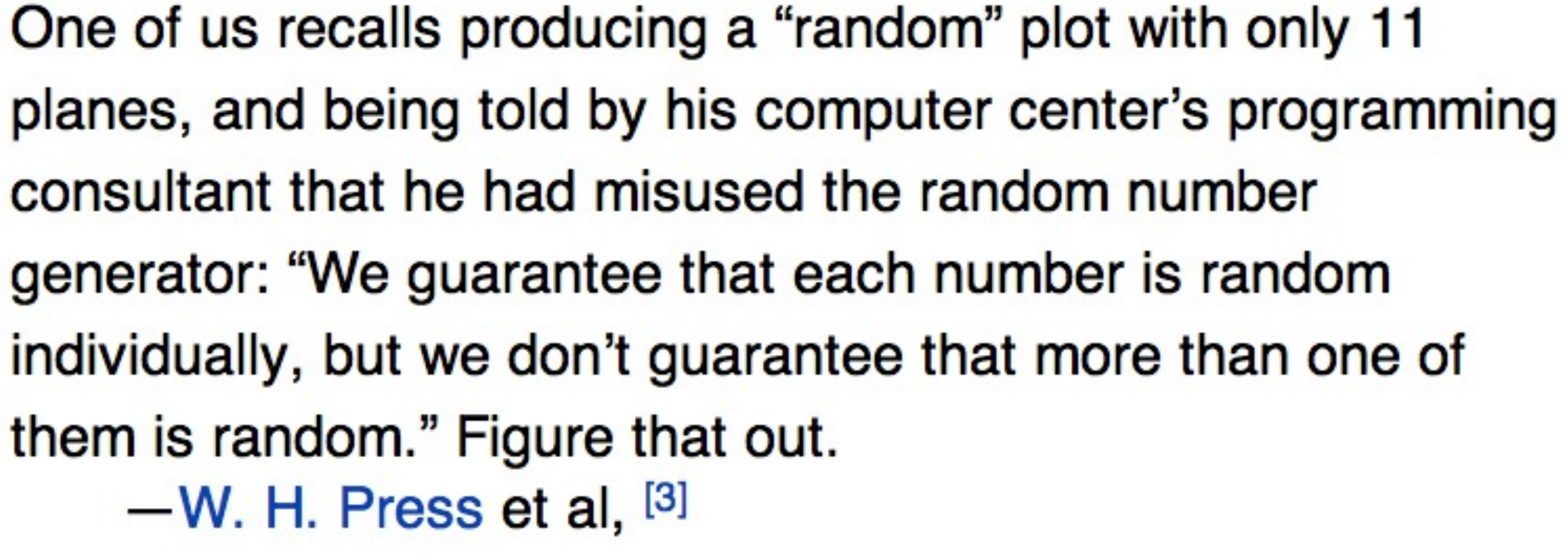
RANDU - famously bad PRNG

- X[i+1] = 65539 * X[i] (mod 2^{32})
- All X[i] are odd!



3-D plot of
RANDU output
(Wikipedia, RANDU article)

RANDU - famously bad PRNG



> One of us recalls producing a “random” plot with only 11 planes, and being told by his computer center’s programming consultant that he had misused the random number generator: “We guarantee that each number is random individually, but we don’t guarantee that more than one of them is random.” Figure that out.
>
> —W. H. Press et al, [3]

(Wikipedia, RANDU article)

Where do (good) random numbers come from?

Where do (good) random numbers come from?

- ***Humans:*** keyboard, mouse input
- ***Timing:*** interrupt firing, arrival of packets on the network interface
- ***Physical processes:*** unpredictable physical phenomena

SGI's LavaRand

(http://hackaday.com/2005/06/05/lava-lamp-random-number-generator/)

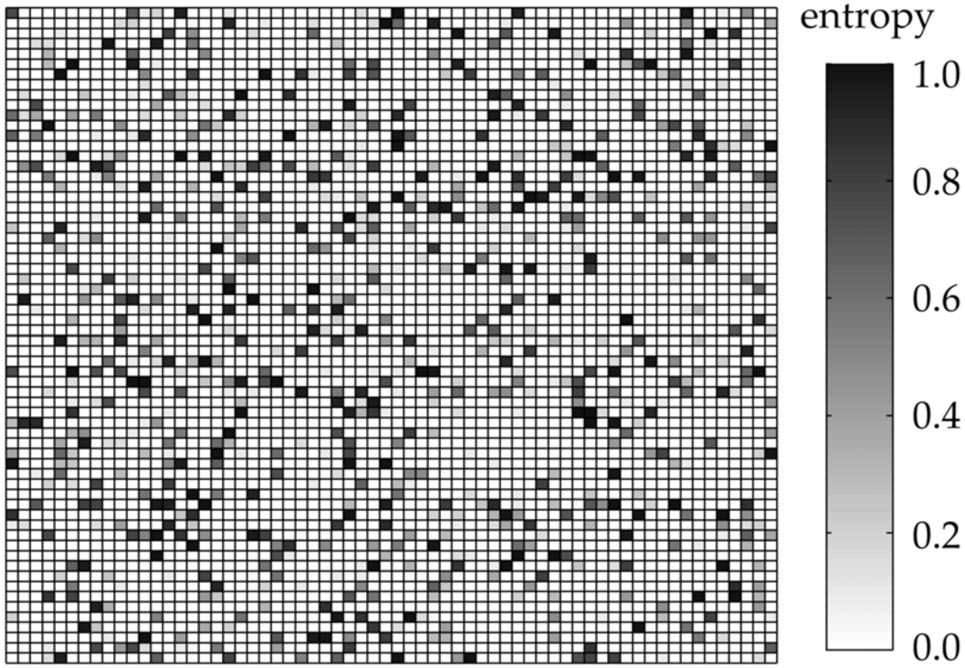
Open Source LavaRnd

- Camera CCD looking into an empty, dark, shielded can
- Measuring background radiation
  “thermal noise”
- Quantum process: randomness from Heisenberg’s Uncertain Principle

(http://www.lavarnd.org/what/process.html)

Physical RNGs in CPUs

- ***State of uninitialized memory*** when machine powers on



(Holcomb, Burleson, Fu, IEEE Trans. Comp 58(9), Sept. 2009)

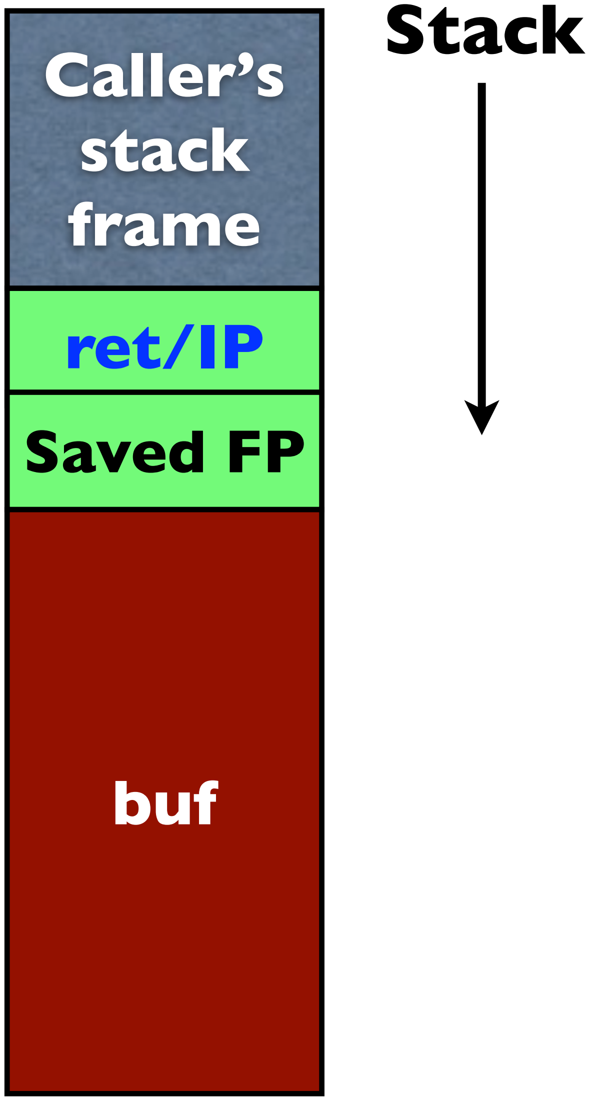
- Tiny ***variations in voltage*** over resistor

Obtaining Pseudorandom Numbers

- For security applications, want "cryptographically secure pseudorandom numbers"
- Libraries include:
  - OpenSSL
  - Microsoft's Crypto API
- Linux:
  - /dev/random
  - /dev/urandom - nonblocking, possibly less entropy
- Internally:
  - Entropy pool gathered from multiple sources
  - Physical sources

Buffer overflow attacks

```
void foo (char *argv[])
{
push    %ebp
mov     %esp,%ebp
char buf[128];
sub     $0x88,%esp
mov     0x8(%ebp),%eax
strcpy(buf, argv[1]);
add     $0x4,%eax
mov     (%eax),%eax
mov     %eax,0x4(%esp)
lea     -0x80(%ebp),%eax
mov     %eax,(%esp)
call    804838c <strcpy@plt>
}
leave
ret
```



How to defend against this?

```
void foo (char *argv[])
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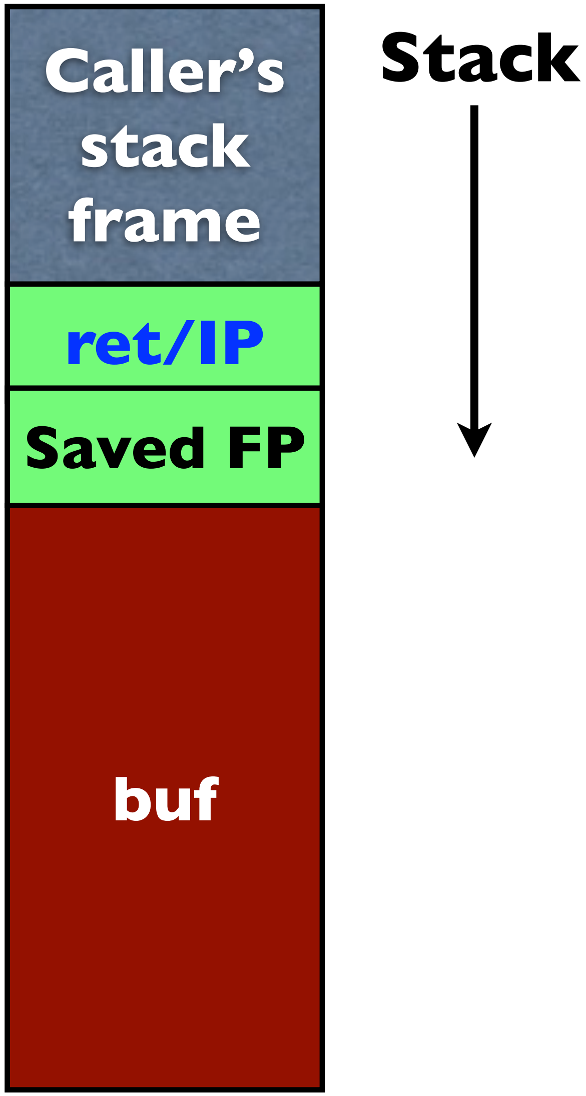
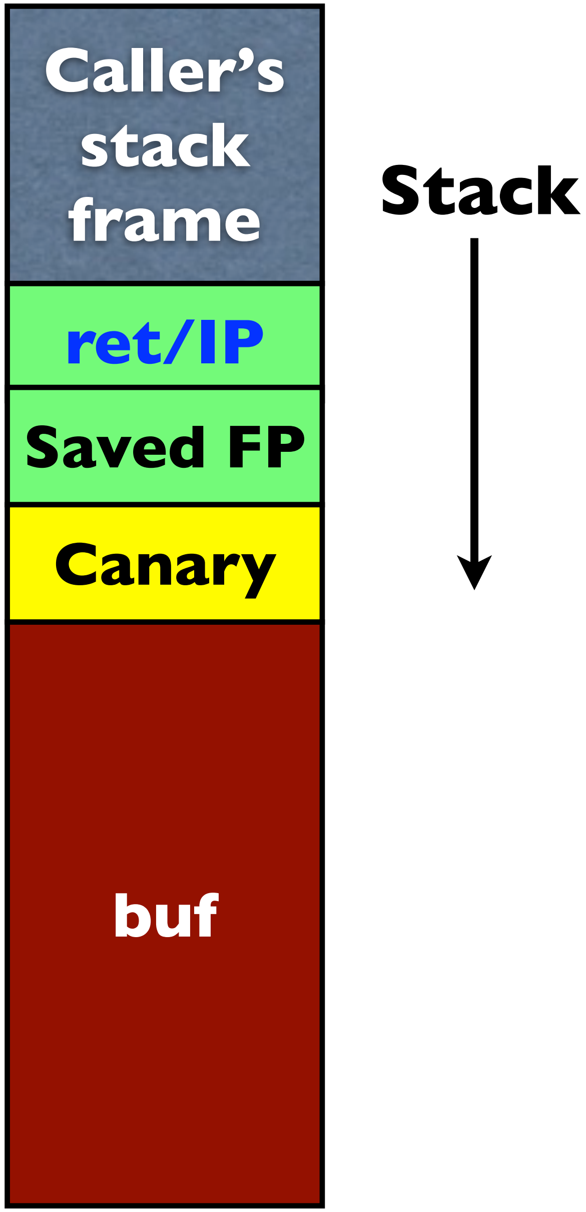


Stack Canary

```
void foo (char *argv[])
{
int canary = <random>;
char buf[128];
strcpy(buf, argv[1]);
assert(canary unchanged);
}
```



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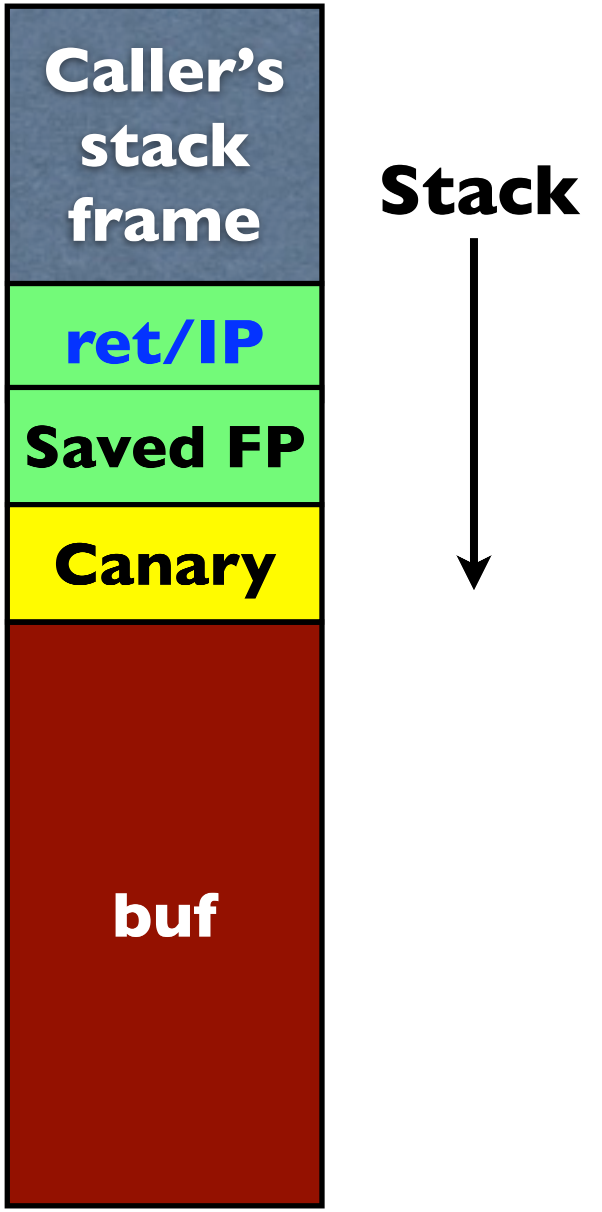

Any Canary Advice?

Stack Canary

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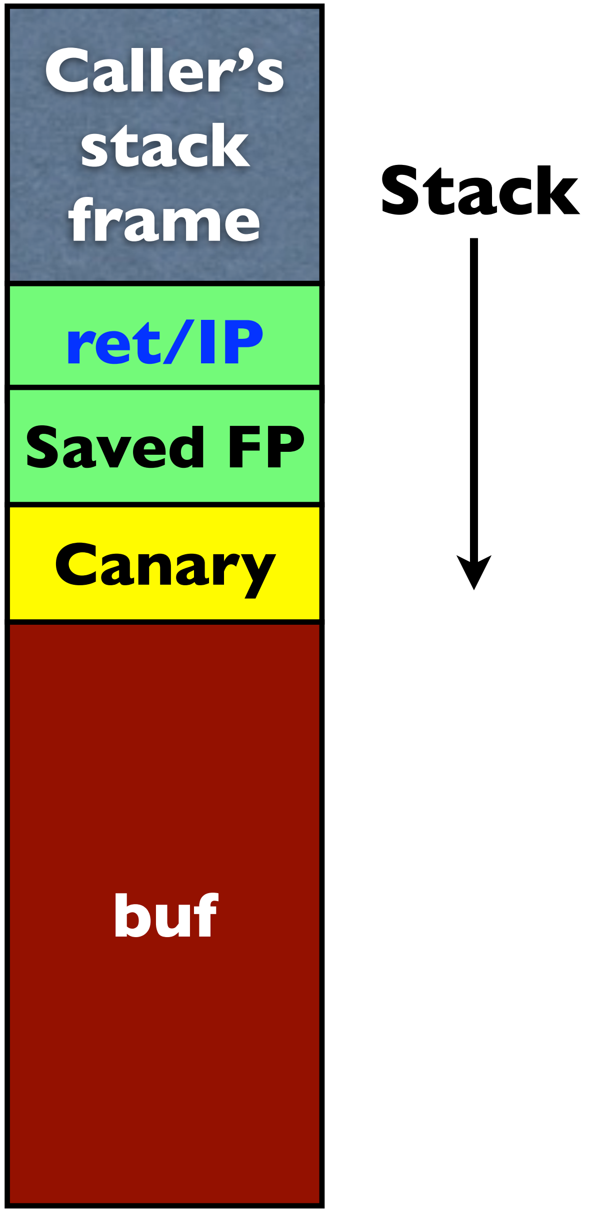


Caller's stack frame

ret/IP

Saved FP

Canary

buf

Stack

Any Canary Advice?

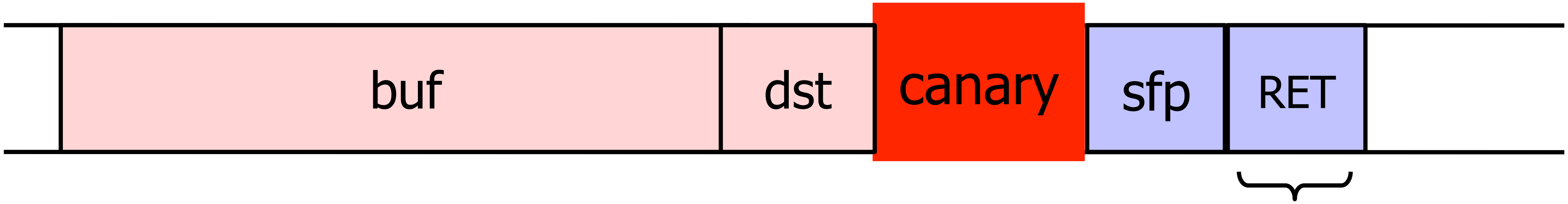
- Null byte stops strcpy() bugs
- CR-LF stops gets() bugs
- EOF stops fread() bugs

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!



Suppose program contains strcpy(dst,buf)

Return execution to this address

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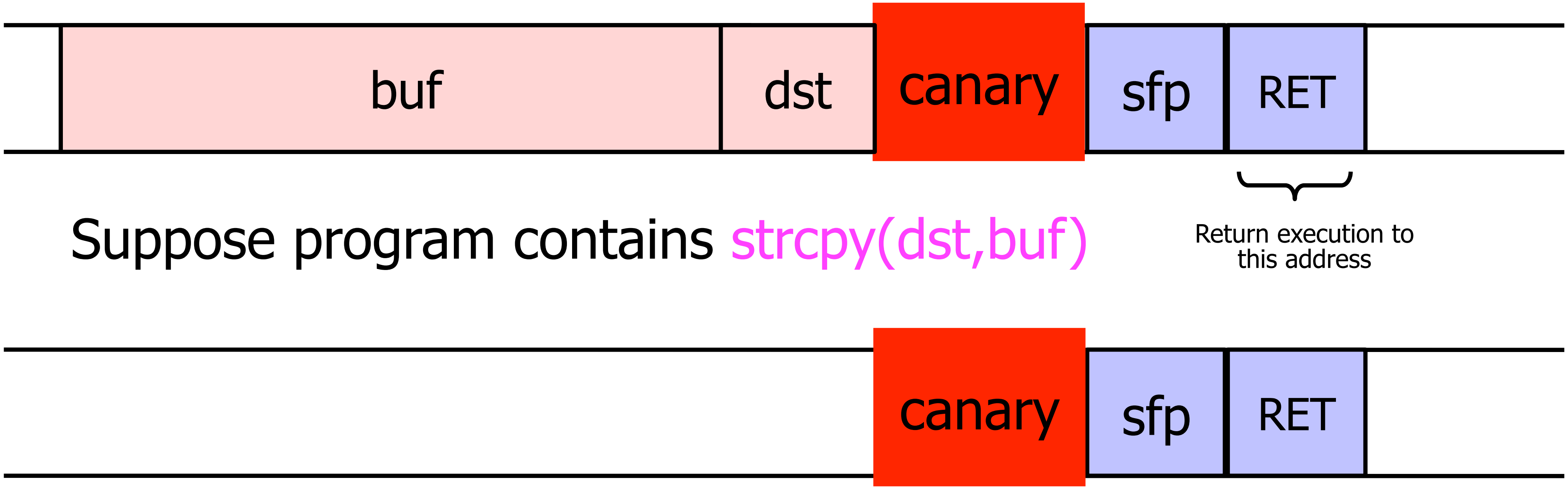

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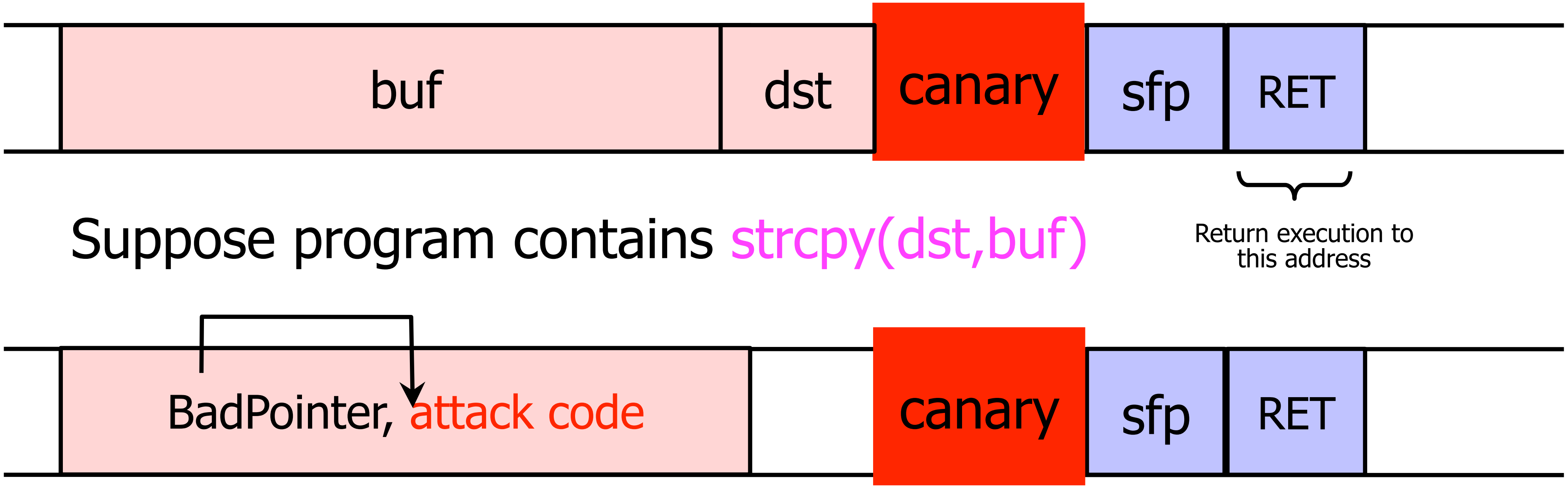

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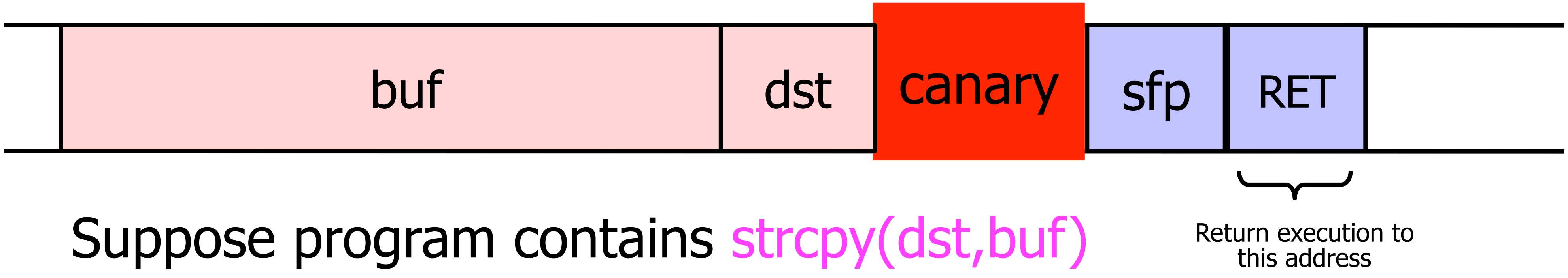

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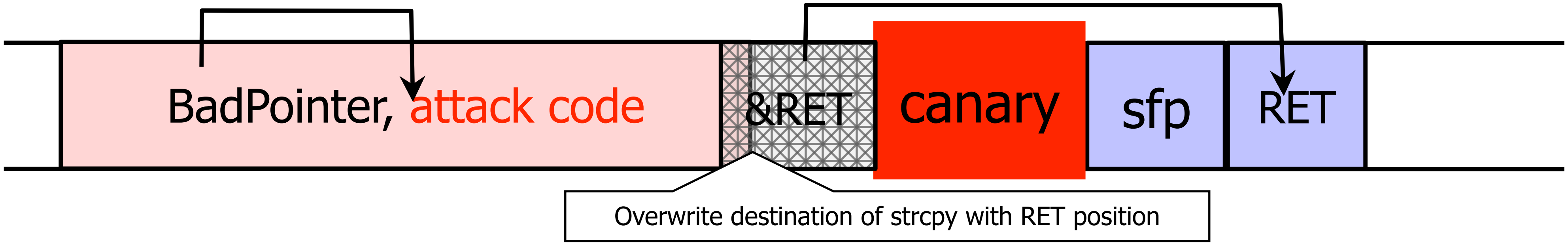
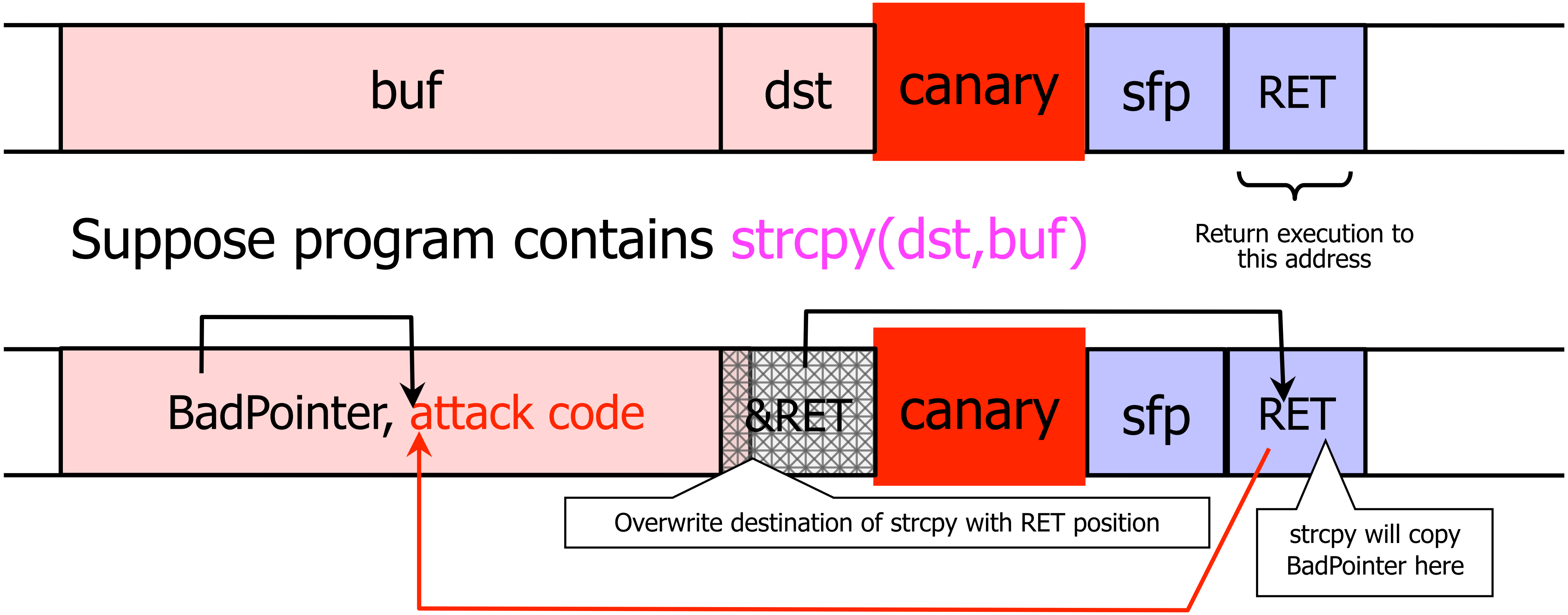


Overwrite destination of strcpy with RET position

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!



Suppose program contains strcpy(dst,buf)

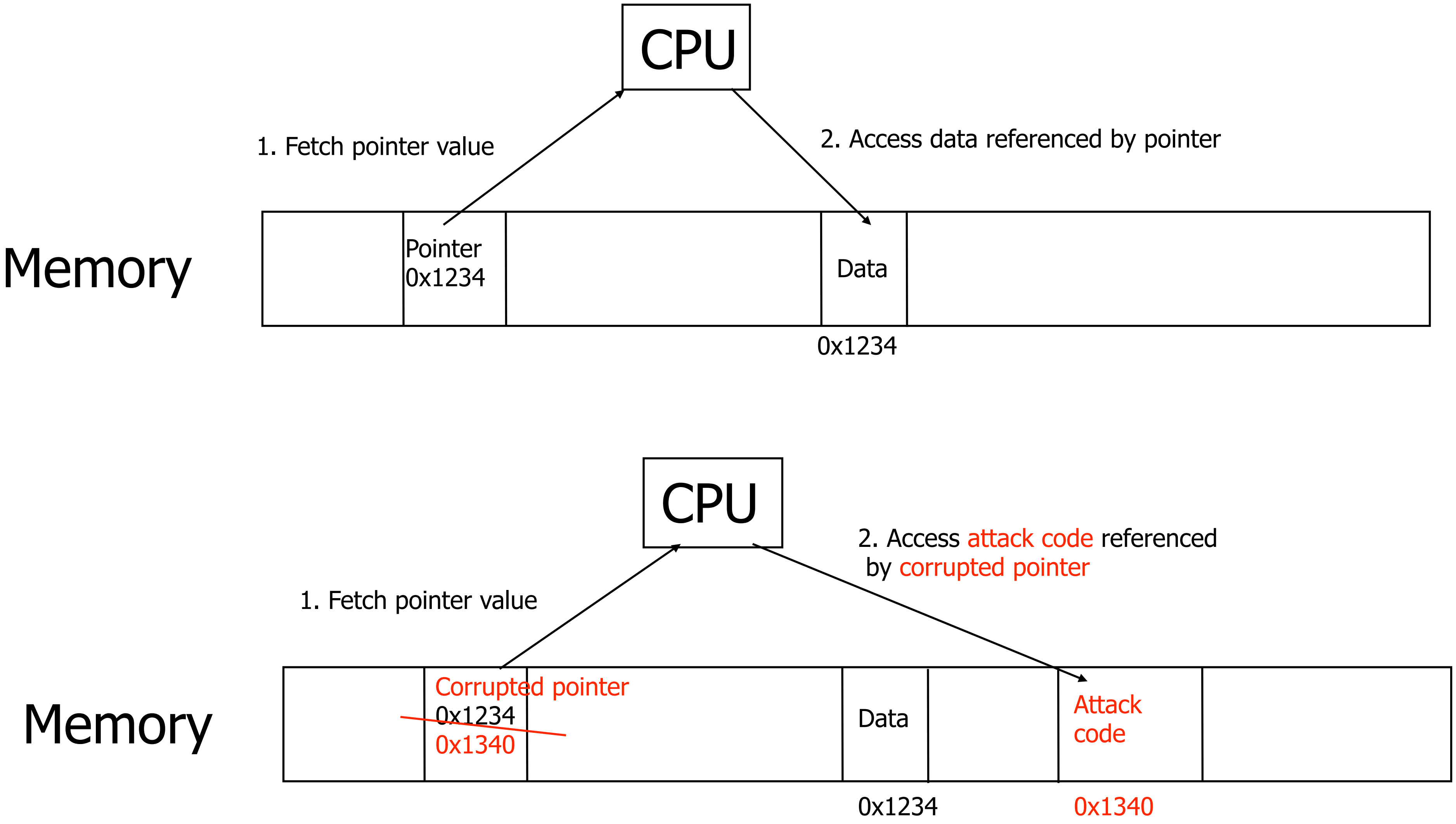
Non-Executable Stack

- 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, …)

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

2. Access attack code referenced
by corrupted pointer

1. Fetch pointer value

Memory

Corrupted pointer
~~0x1234~~
0x1340

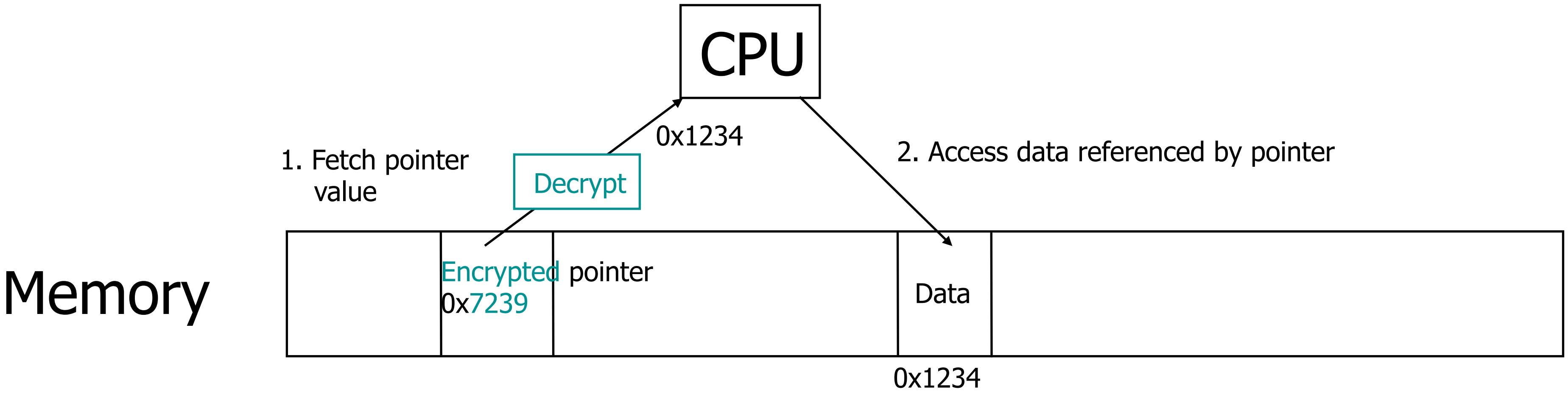
Data

Attack
code

0x1234

0x1340

PointGuard Dereference [Cowan]



CPU

1. Fetch pointer value

Decrypt

0x1234

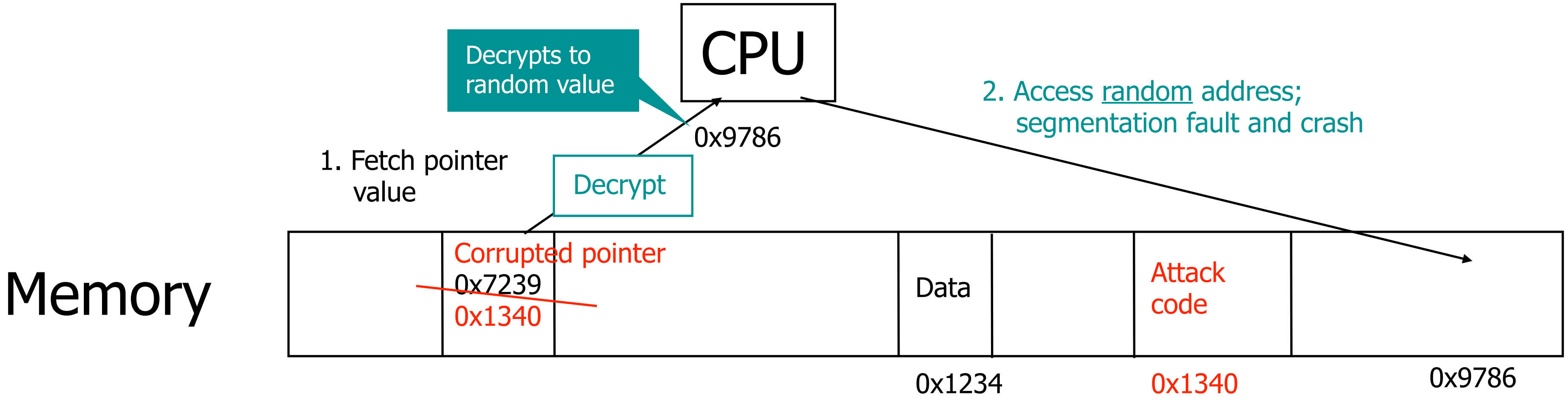
2. Access data referenced by pointer

Memory

Encrypted pointer 0x7239

Data

0x1234



Decrypts to random value

CPU

0x9786

2. Access random address; segmentation fault and crash

1. Fetch pointer value

Decrypt

Memory

Corrupted pointer ~~0x7239~~ 0x1340

Data

Attack code

0x1234

0x1340

0x9786

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?

Other solutions

- Use safe programming languages, e.g., Java
  - What about legacy C code?
- Static analysis of source code to find overflows
- 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

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
    for i = 1 to 8 do
        if (RealPwd[i] != CandidatePwd[i]) then
            return FALSE
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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

Attacker Model

```
PwdCheck(RealPwd, CandidatePwd)  // both 8 chars
    for i = 1 to 8 do
        sleep for 1 second
        if (RealPwd[i] != CandidatePwd[i]) then
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Attacker Model

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```

- 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