CMPSC 447
Midterm Review

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Quiz 3

- #1 - The MITRE ATT&CK framework describes the tactic of "execution" as a tactic to enable adversaries to run adversary-controlled code on a system.
  - True/False

ATT&CK Tactics

- Initial Access
- Execution
- Persistence
- Privilege Escalation
- Defense Evasion
- Credential Access
- Discovery
- Lateral Movement
- Collection
- Command and Control
- Exfiltration
- Impact
- Reconnaissance
- Resource Development

ATT&CK Tactics in Action

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- Initial Access, Discovery, and Credential access
  - Gain and learn about (via secrets) an environment
  - What was that for Stuxnet?
- Execution
  - "Execution of adversary-controlled code"
  - How Stuxnet?
- Collection and Exfiltration
  - Steal data from the domain
  - Did Stuxnet do that?

ATT&CK Tactics in Action

- Persistence and Defense Evasion
  - "to persist in the target environment" "undetected"
  - How did Stuxnet do that?
- Privilege Escalation and Lateral Movement
  - Gain more permissions in the environment and control more components of same privilege
  - How for Stuxnet?
- Command and Control
  - Method to obtain commands for malware
  - Did Stuxnet do that?

Quiz 3

- #2 - A type error can violate memory safety by allowing an adversary to cause the program to treat data values as pointer values.
  - True/False

Memory Safety

- What are the requirements for memory safety for all three categories
  - Spatial safety: All reads and writes using a pointer to a memory region must be within that memory region
    - Strings additionally require a null-terminator
  - Temporal safety: All reads and writes using a pointer must be to a live (not deallocated) memory region that is assigned to the pointer
  - Type memory safety: Semantics of all field references at the same offset must be of the same type (weaker: cannot be both data and pointer)
    - Type safety: Only pointers of one type for the memory region

Type Errors

- Type errors are possible when pointers of multiple types are used to access the same region
  - t1 *p, t2 *q; // declare pointers
  - p = (t1 *) malloc(sizeof(t1)); // allocate object and define p
  - p→field = value; // use pointer for t1
  - q = (t2 *)p; // type cast and define q
  - q→X(); // use pointer for t2
- Semantics of ”p→field” may be different than “q→X”
  - Pointer vs. data
  - Data of multiple types (formats)

Type Errors

- Downcasts – Cast to a larger type; causes overflow
  - t1 *p, t2 *q; // declare pointers
  - p = (t1 *) malloc(sizeof (t1)); // allocate t1 object, define p
  - p→field = value; // suppose this is an int field
  - q = (t2 *)p; // downcast, t2 is a larger type
  - q→extra= value2; // overflow memory of object
- E.g., t2 is a child type of t1
  - So, the size of type t2 is greater than the size of type t1
  - "extra" field is added to the type t1 to create type t2

Quiz 3

- A temporal error caused by a use-after-free vulnerability can be mitigated by which methods (may be multiple correct answers).
  - Freeing the pointer memory along with the memory region
  - Nullifying the pointer value when the assigned memory region is freed
  - Deallocating memory on function returns
  - Never freeing memory
  - Only allocating memory regions in type-specific memory pools

Use Before Initialization

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- What does ”p” reference upon use?
  - char *p; // declare pointer
  - len = snprintf(p, size, "%s", original_value); // use pointer
  - p = (char *) malloc(size); // define pointer to object
  - free(p); // deallocate object
- Called “use before initialization” (UBI)
  - Allows an adversary to use reference value defined at the location used to declare “p” (not an assignment)
  - Could be anywhere

Use After Free

- What does ”p” reference upon use?
  - char *p; // declare pointer
  - p = (char *) malloc(size); // define pointer to object
  - free(p); // deallocate object – release memory for reuse
  - len = snprintf(p, size, "%s", original_value); // use pointer
- Called “use after free” (UAF)
  - Allows an adversary to use reference to memory region that may be allocated a different object
  - Could be anywhere

Zeroing Pointers

- Yes! Set every pointer value to zero on deallocation
  - Zero pointers on deallocation from the heap
    - free(p), p = 0;
  - Trickier on the stack
    - In theory, no stack reference should outlive its assignment
    - But, hard to guarantee since deallocation is implicit
- Also, the cost of zeroing on deallocation can be worse
  - Since not done at all normally

Temporal Defense Alternatives

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- Hypothesis: memory is so cheap and abundant, we just do not need to deallocate
  - Will be some cases where this is not going to work
  - But, for others, why risk attack?
- Hypothesis: garbage collection
  - Too expensive for C
- Hypothesis: temporal safety like Rust's "safe" objects
  - Harder to program with lifetimes and ownerships
- Hypothesis: use type-specific allocation
  - All objects and fields are aligned

Quiz 3

- What are the differences between strncpy and snprintf with respect to safe string processing?
  - Only strncpy ensures a null terminator is added to the end of the string
  - Only snprintf ensures a null terminator is added to the end of the string
  - Only snprintf returns an integer for the amount of data that would have been written to detect truncation
  - Only snprintf/strncpy does bounds checking
  - Only strncpy returns a pointer to the resultant buffer memory region to detect truncation

Traditional Solution – That Works!

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- int *snprintf*(char *S, size_t N, const char *FORMAT, ...);
  - Writes output to buffer S up to N chars (bounds check)
  - Always writes '\0' at end if N>=1 (terminate)
  - Returns "length that would have been written" or negative if error (reports truncation or error)
- Thus, achieves goals of correct bounds checking
  - Enforces bounds, ensures correct C string, and reports truncation or error
    - len = snprintf(buf, buflen, "%s", original_value);
    - if (len < 0 || len >= buflen) … // handle error/truncation

Bounds Checking

- For each byte in the operation:
- If oversized option (1) – stop processing input
  - Reject and try again, or even halt program (may make DoS)
- If oversized option (2) – truncate data
  - Common approach, but has issues:
    - Terminates text "in the middle" at place of attacker's choosing
    - *Way* better to truncate than to allow easy buffer overflow attack
    - But, should report when truncation occurs for the programmer to handle the possible impacts

Quiz 3

- What kind of memory error flaw does the following code demonstrate?

```
int a;

unsigned int b;

a = adv_input;

if (a < MAX_VALUE) {   // MAX_VALUE is a constant

    b = (unsigned int)a;

    read(fd, buf, b);      // assume fd and buf are initialized

}
```

  - Integer overflow / Downcast error / Special error / Use-after-initialization / Recast error

Integer Overflows

- Key question
  - What is an integer?
  - In a computer system?
- There are several different computer representations for integers
  - Size – number of bytes used to represent
  - Signedness – range of values integers can take

Quiz 3

- safe_strcpy(dest, src) is a secure string copy function. What properties should that function ensure and how could you implement that function to ensure those properties given the limitations in the arguments available?
  - Idea: Automatic memory resizing

Automatic Resizing

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- For each byte in the operation:
- If oversized – Auto-resize – move string to a new memory region, if necessary
  - This is what most languages do automatically
    - other than C
    - Must deal with "too large" data
- By default, handling auto-resize manually in C can create issues
  - More code changes/complexity in existing C code
    - But, available APIs support options to handle this for you
  - Dynamic allocation is manual in C, so adds new risks
    - Temporal errors

Quiz 3

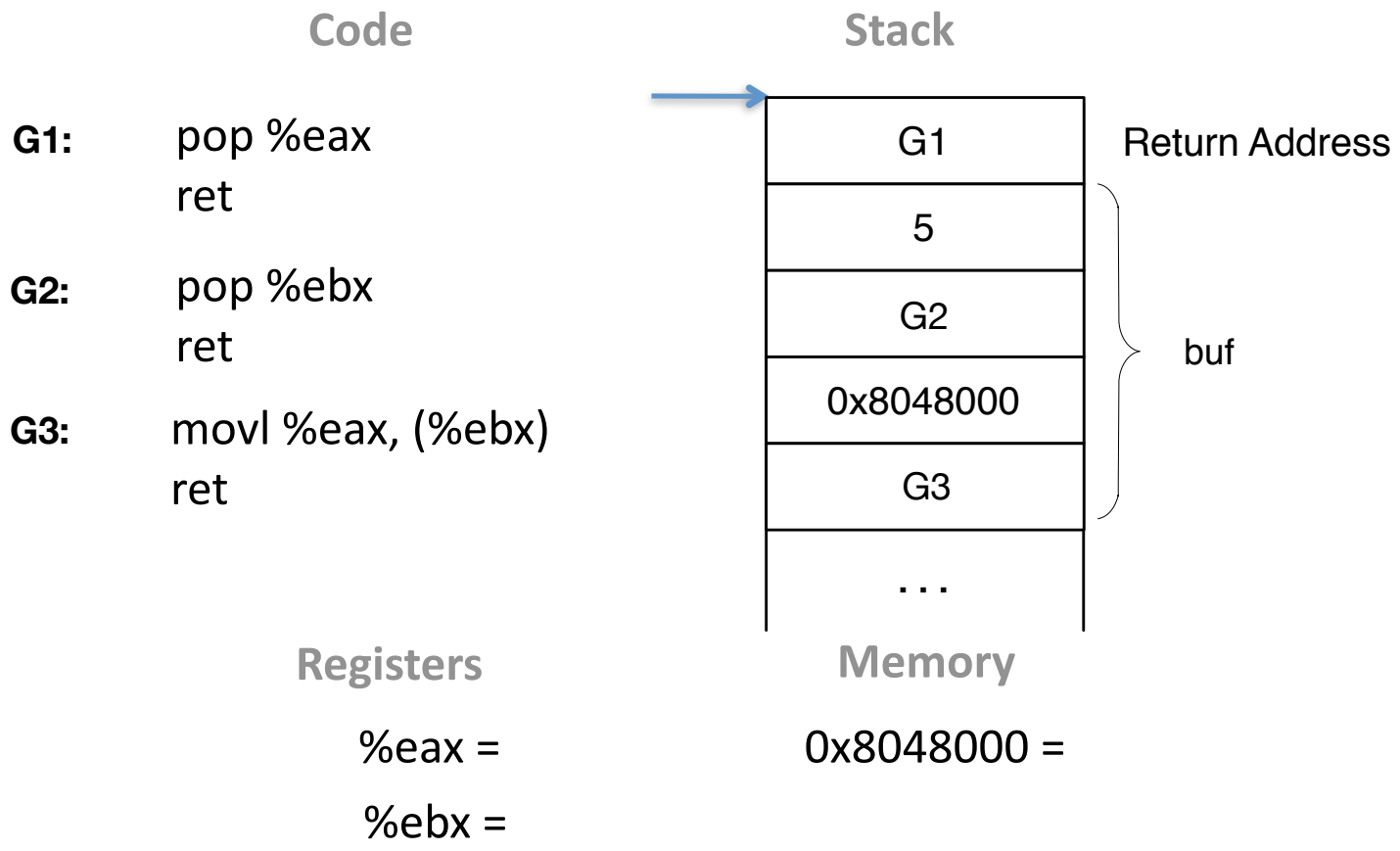
- Produce the stack layout to use the following return-oriented programming (ROP) gadgets to move a value at 0xffcd to 0x0804.

```
G1:  push %ebx; ret

G2:  push %ecx; ret

G3:  pop %ebx; ret

G4:  pop %ecx; ret

G5:  mov %ecx, (%ebx); ret // store value in %ecx to memory location (%ebx)

G6:  mov %ebx, (%ecx); ret // store value in %ebx to memory location (%ecx)

G7:  mov (%ecx), %ebx; ret // load value in %ebx from memory location (%ecx)

G8:  mov (%ebx), %ecx; ret // load value in %ecx to memory location (%ebx)
```

- G4 | 0xffcd | G7 | G4 | 0x0804 | G6

ROP Example

- Use ESP as program counter
  - E.g., Store 5 at address 0x8048000 (without introducing new code)



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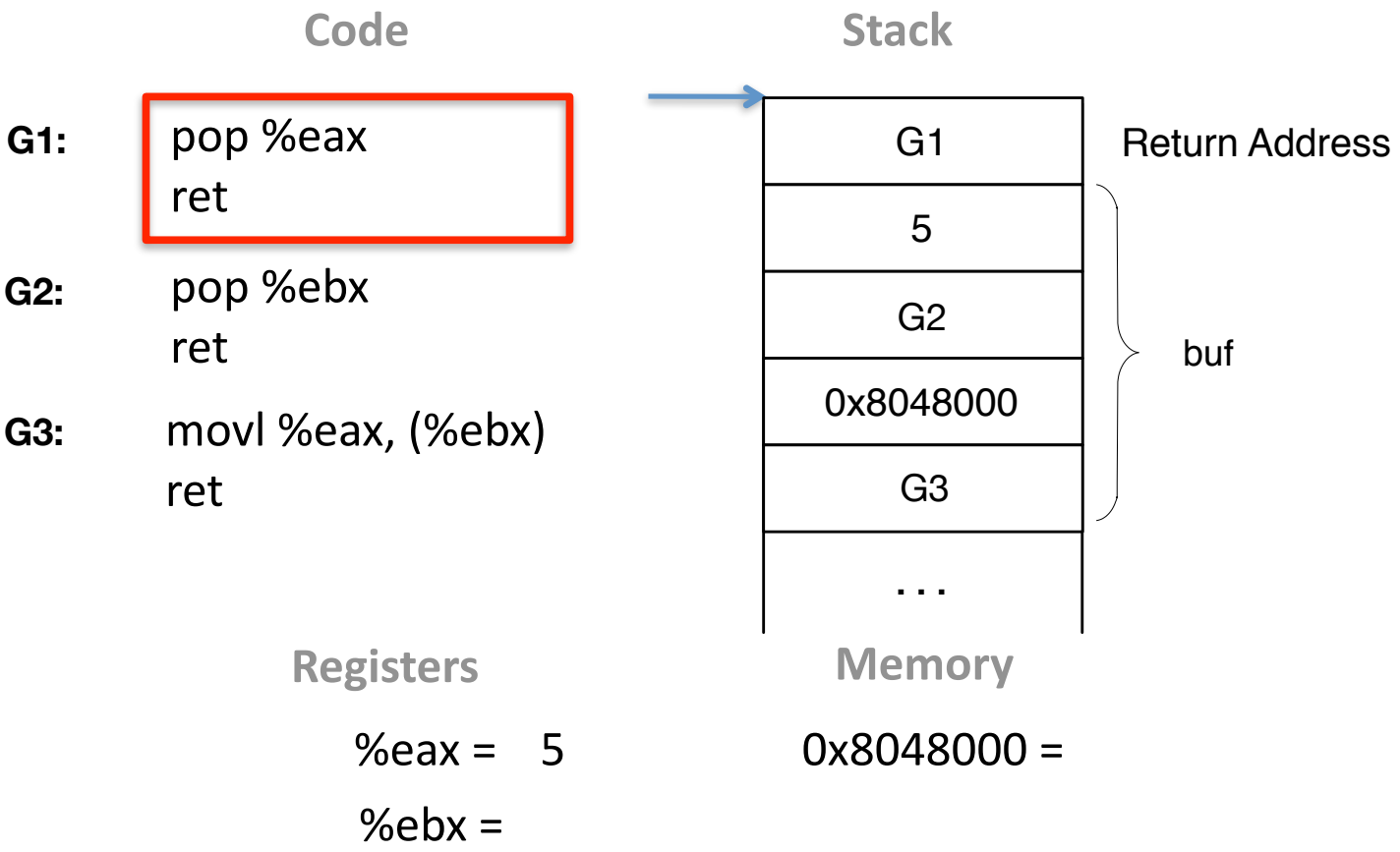

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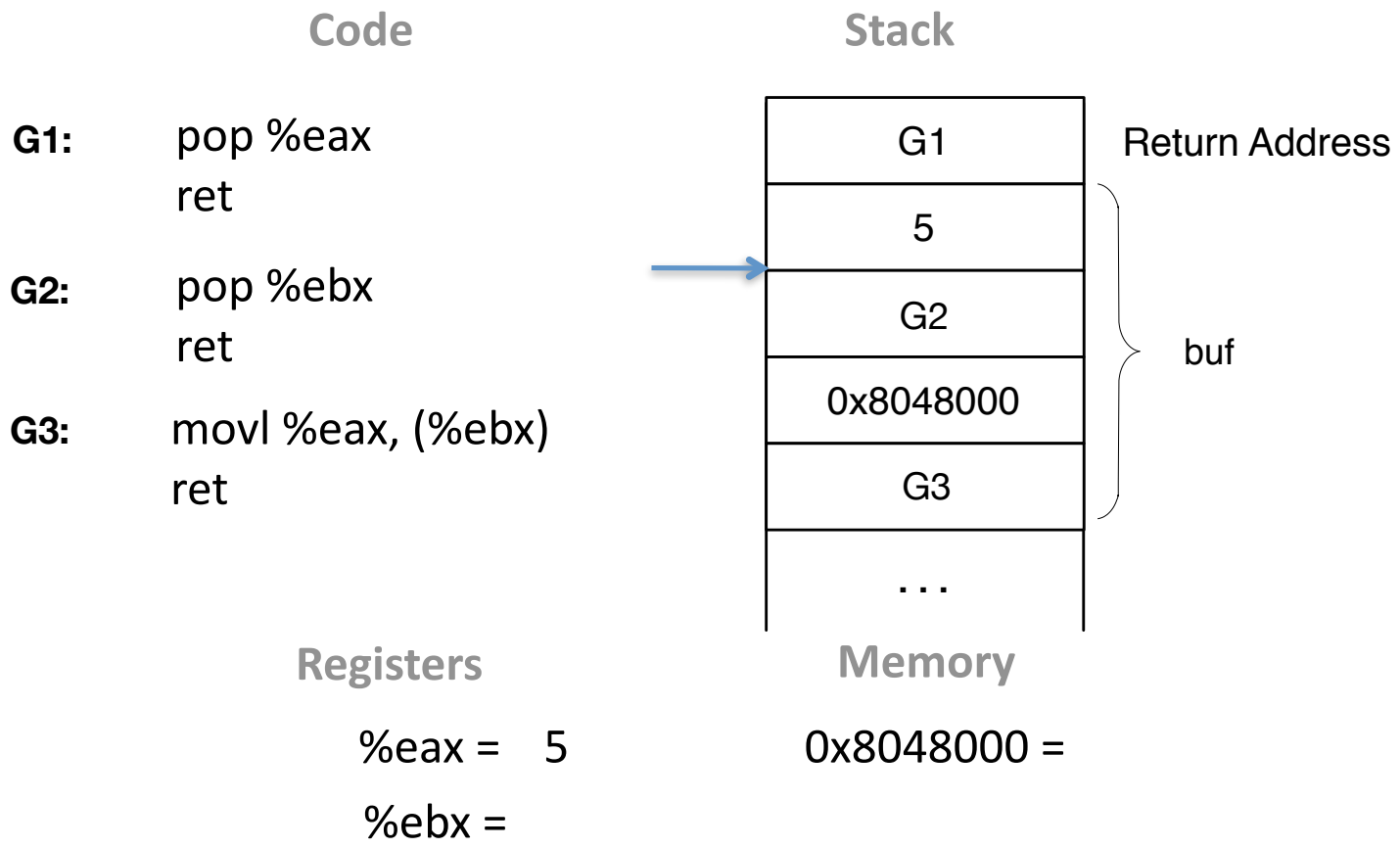

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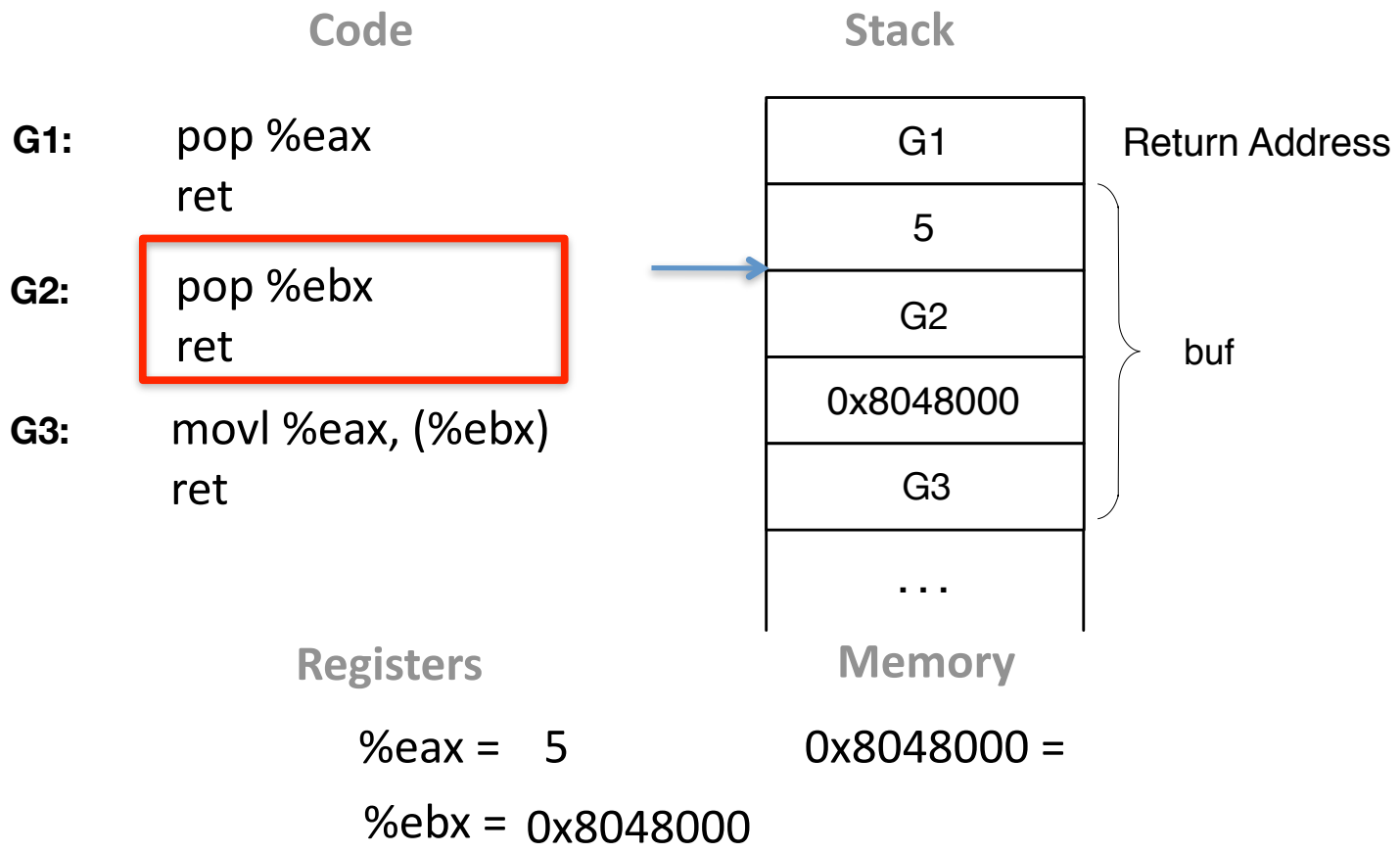

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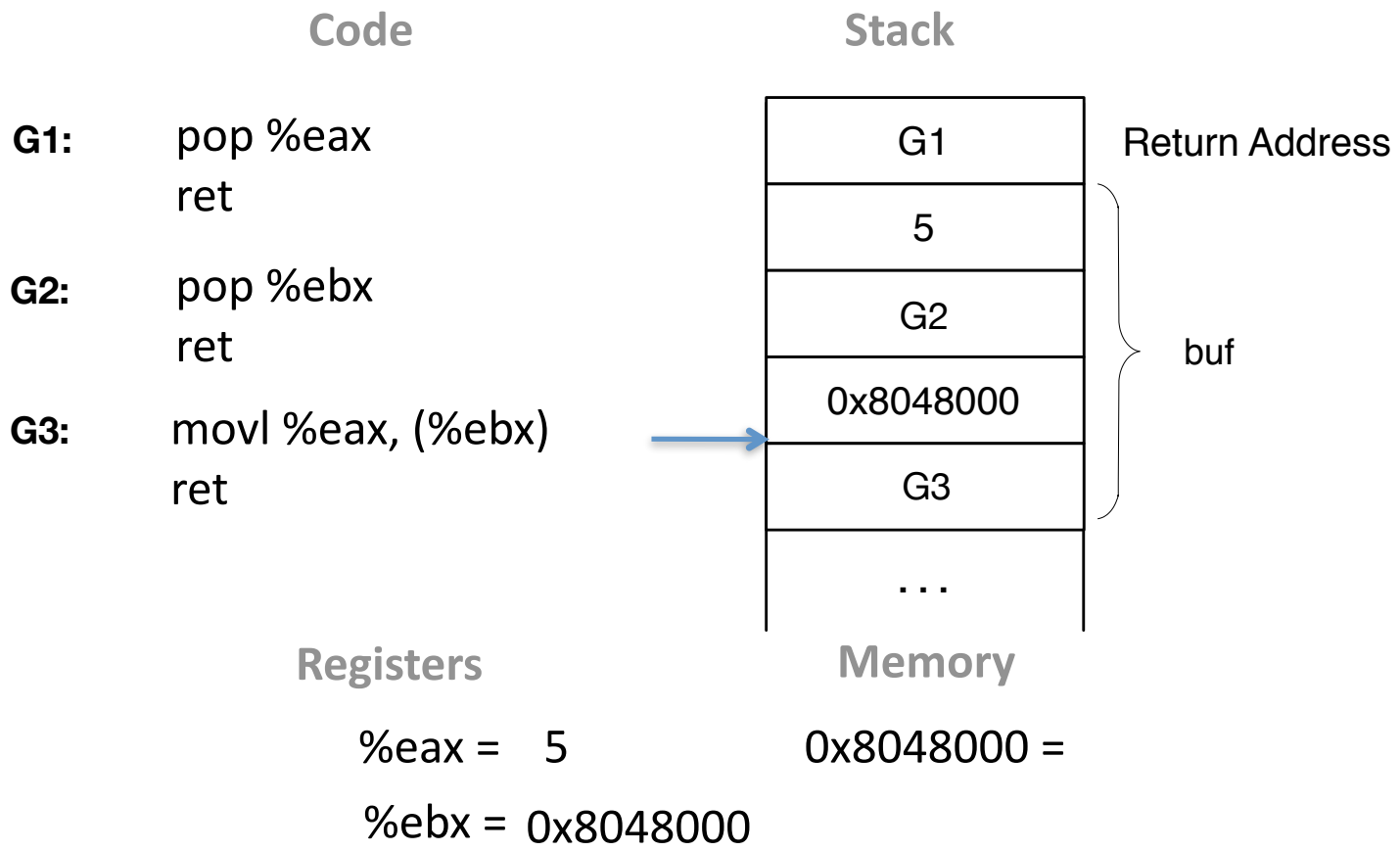

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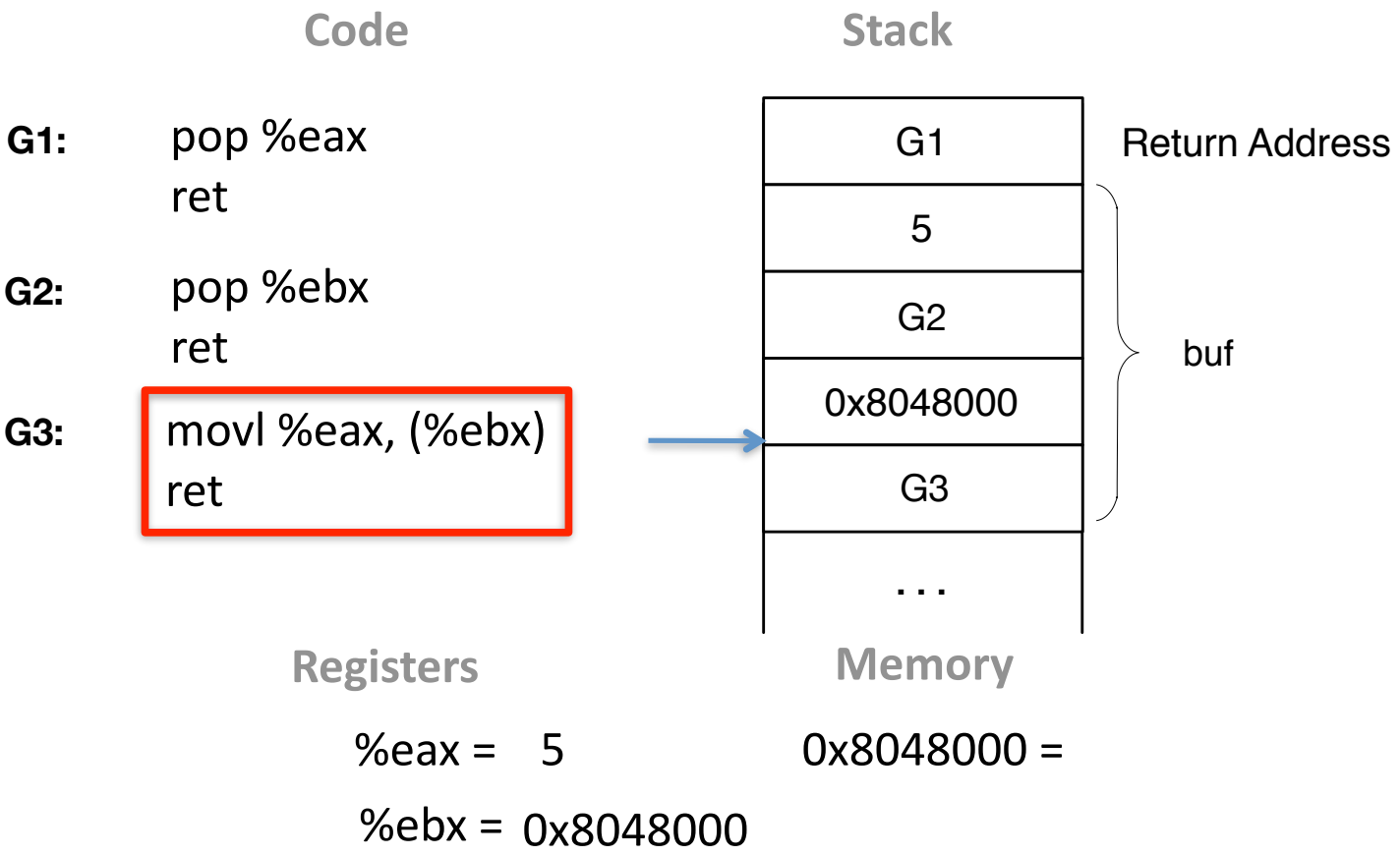

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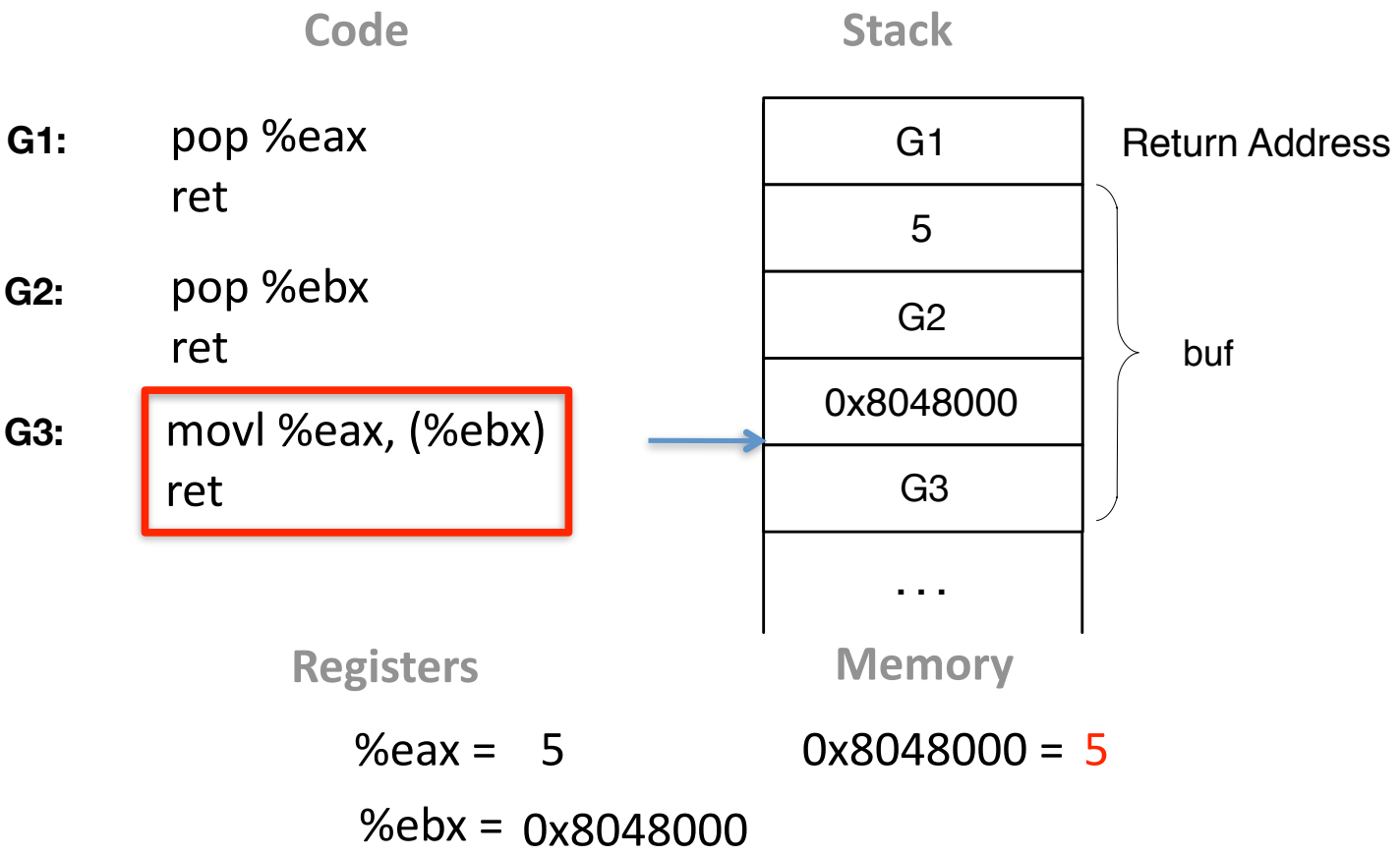


Finding Gadgets

- Snippets of code ending in "ret" are called gadgets
- How do we build a complete exploit from available code?
  - Must find the gadgets that are available in that code
- How do you think one finds all the gadgets in a code region?
  - From each byte offset in the code region, see what sequence of instructions are encoded until a "ret" is reached
    - Find "a, b, c, ret" – where a, b, and c are other instructions

Previous Quizzes (#2)

- How many filler bytes are necessary to reach the field (*fn) in the following structure if there is a buffer overflow for writing to the field "buffer" (assume 32-bit binary and 4-byte ints)?

```
struct X {
        int index;
        char buffer[12];
        char other[8];
        int answer;
        int (*fn) ( int y );
};
```

- 24 bytes

Hijack Control Flow

- Let's create a payload to hijack control by overwriting the return address
  - To print a string from the binary
- To create the payload
  - Insert filler to reach the return address
  - Add the new return address (printf@plt) at 0x10a0
    - Note: changed the from the prior figure where printf@plt at 0x1080
  - And the reference to a string at 0x342 "__libc_start_main"

Hijack Control Flow

- Create the payload
  - Actually, code is loaded at an offset
- So, need to account for the offset in the payload
  - Add the new return address (printf@plt) at offset 0x1080 → 0x56555000 + 0x10a0 = 0x565560a0
    - Little endian \xa0\x60\x55\x56
  - And the reference to the format string at offset 0x342 → 0x56555000 + 0x342 = 0x56555342
    - Little endian \x42\x53\x55\x56 or "BSUV" in ascii

Previous Quizzes (#1)

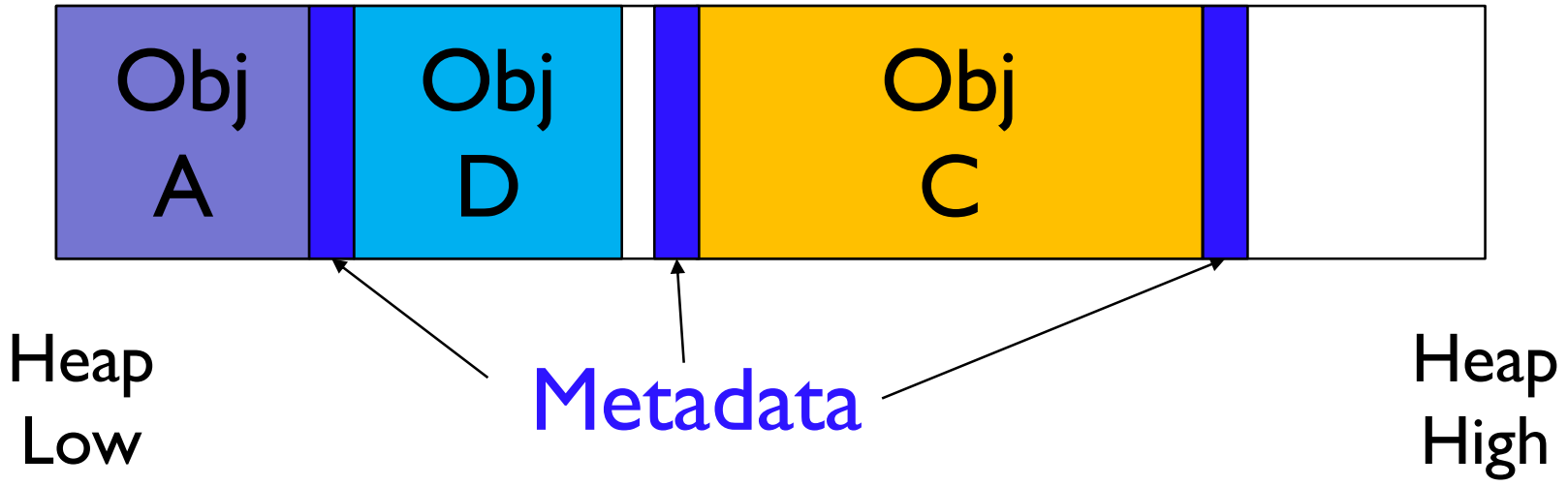
- Specify a payload to a buffer overflow vulnerability for writing a buffer of size 10 that overwrites the return address that is eight bytes above the buffer with the address 0x080432f0.
  - Payload
    - Fill buffer (10 bytes)
    - Fill rest of space to the return address (8 bytes)
    - Set the return address to 0x800432f0

Previous Quizzes (#2)

- In a 32-bit program, suppose the heap metadata structure only contains the fields "bk" (for referencing the previous block) and "fd" (for referencing the next block) in that order.
- And the metadata is updated using the follow code ("chunk2" is an instance of the heap metadata struct):
  - chunk2→bk→fd = chunk2→fd;
- If you want to write "0xffff" at address "0x4d78," you need to write the chunk2→fd to be 0xffff and chunk2→bk to be 0x4d74

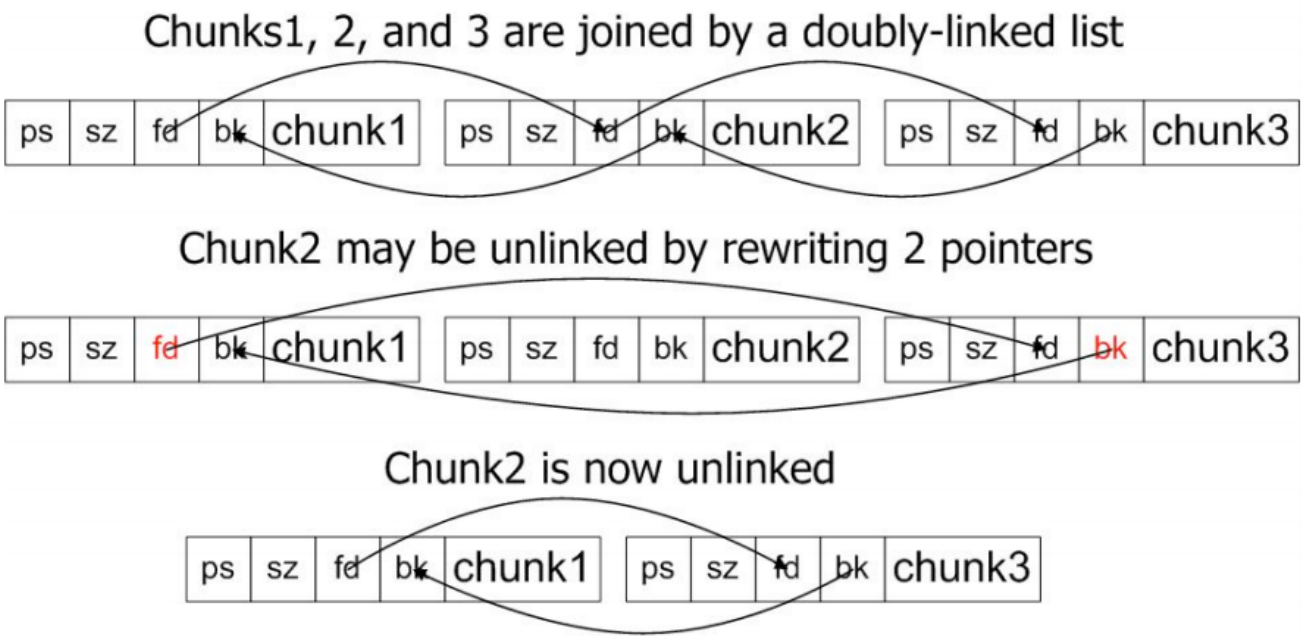
Heap Memory Layout

- The Heap Memory Layout often includes metadata
  - Depends on the heap allocator
  - Often placed between objects to store information needed to manage allocation state – e.g., sizes and status



Heap Overflows

- Heap allocators maintain a doubly-linked list of allocated and free chunks
- **`malloc`**() and **`free`**() modify this list



Previous Quizzes (#1)

- Suppose user2 has a symbolic link 'linkfile' in '/home/user2' to '/'. If a program running as root opens the file '/home/user2/linkfile/etc/foo.txt', which pathname elements does the program have to check for confused deputy attacks to detect/prevent attacks?
  - /home/user2/linkfile
  - /home/user2
    - Pathname elements modifiable by someone other than root

Common Threat (1)

- What is the threat that enables link traversal and file squatting attacks?
  - Common to both
- In both cases, the adversary has write permission to a directory that a victim uses in name resolution
  - Could be any directory used in resolution, not just the last one
  - Enables the adversary to plant links and/or files

Common Threat (2)

- What is the threat that enables directory traversal attacks?
- In this case, the victim uses adversary input to construct file names
  - Any parts of file names

Integrity (and Secrecy) Threat

- Confused Deputy
  - *Process is tricked into performing an operation on an adversary's behalf that the adversary could not perform on their own*
    - Write to (read from) a privileged file

Previous Quizzes (#1)

- Which code is guaranteed to produce a C string in the buffer defined by 'char buffer[20];'?
  - None of the answers supplied are correct
  - How would you do that now?
    - E.g., strlcpy(buffer, src, 20);
    - Check others

Traditional Solution – That Works!

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- int *snprintf*(char *S, size_t N, const char *FORMAT, ...);
  - Writes output to buffer S up to N chars (bounds check)
  - Always writes '\0' at end if N>=1 (terminate)
  - Returns "length that would have been written" or negative if error (reports truncation or error)
- Thus, achieves goals of correct bounds checking
  - Enforces bounds, ensures correct C string, and reports truncation or error
    - len = snprintf(buf, buflen, "%s", original_value);
    - if (len < 0 || len >= buflen) … // handle error/truncation

Previous Quizzes (#2)

- What properties do we expect from all secure string copy operations? Select one or more correct answers.
  - Null-terminated
  - Within memory bounds
  - Truncation reported

Previous Quizzes (#1)

- Why is it possible to execute code injected on the stack? Choose the best answer.
  - Because the page permissions of the stack memory region (all pages) include execute permission

Injecting Shell Code

- How do you invoke "execve" using injected code?

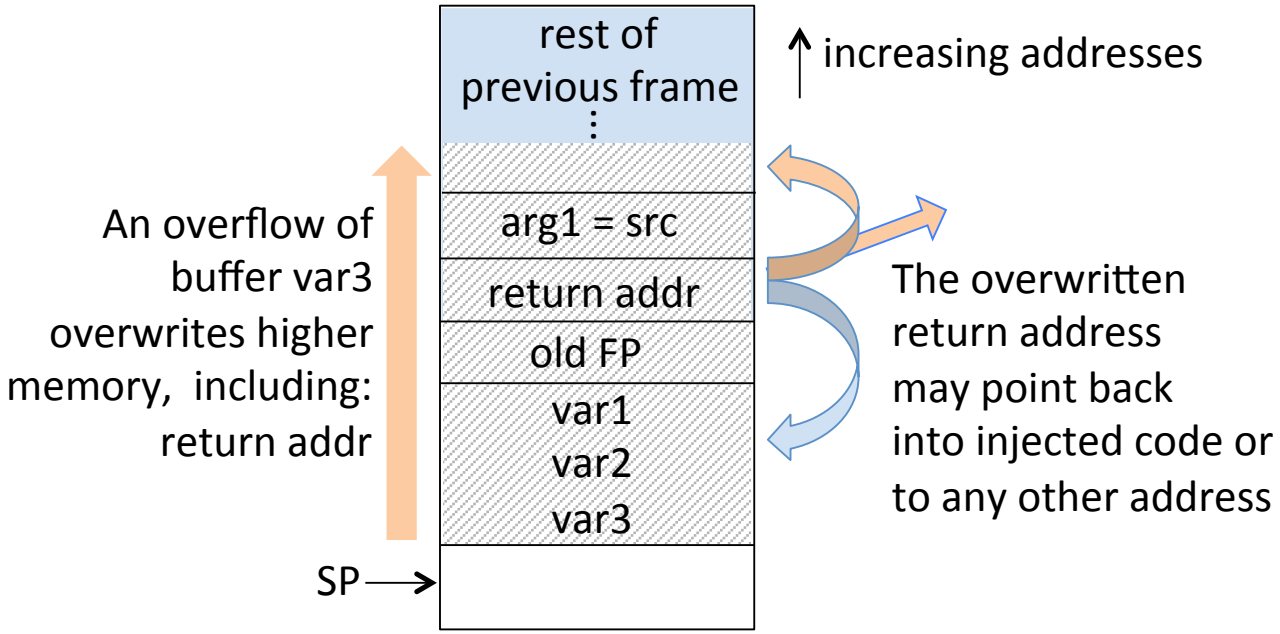

Figure 6.5: Buffer overflow of stack-based local variable.

Return-Oriented Programming

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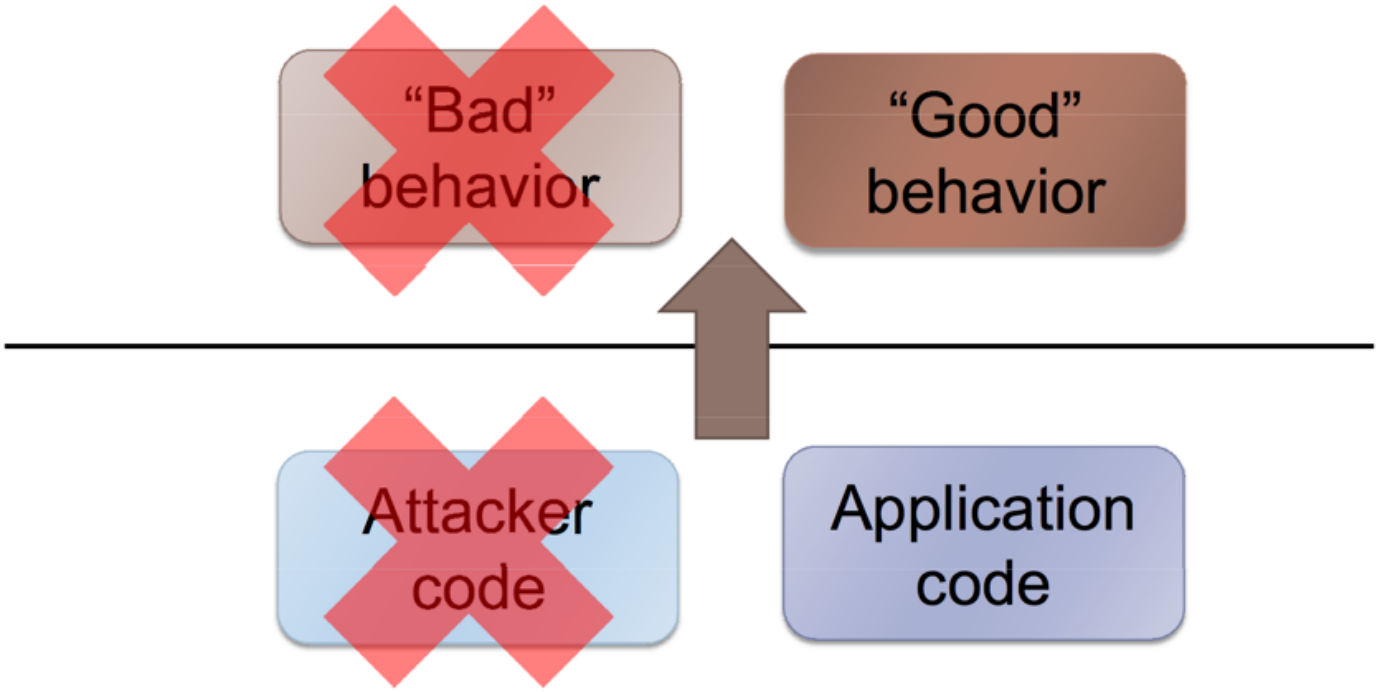
Bad code versus bad behavior



Problem: this implication is false!

Previous Quizzes (#2)

- What is one way (procedure) that the Stuxnet worm achieved tactic of "lateral movement"?
  - Infected any USB device inserted
- Compare Stuxnet behaviors to MITRE ATT&CK tactics

Stuxnet: Tactics

- Stuxnet tactics
  - Zero-day exploits (initial access)
  - Windows rootkit (persistence)
  - PLC rootkit (execution)
  - Antivirus evasion (defense evasion)
  - Peer-to-Peer updates (command and control)
  - Signed driver with a valid certificate (credentials)
- And more
  - Go through Stuxnet and map actions to tactics

Take Away

- Reviewed for midterm from the quiz questions and their answers
- Scope of exam includes these questions
  - And a little more
    - More about type and temporal attacks
  - Including more context about what we discussed, so go back to the related slide decks in the original
- Think about variants of these questions to give yourself a broader understanding
- Good luck!