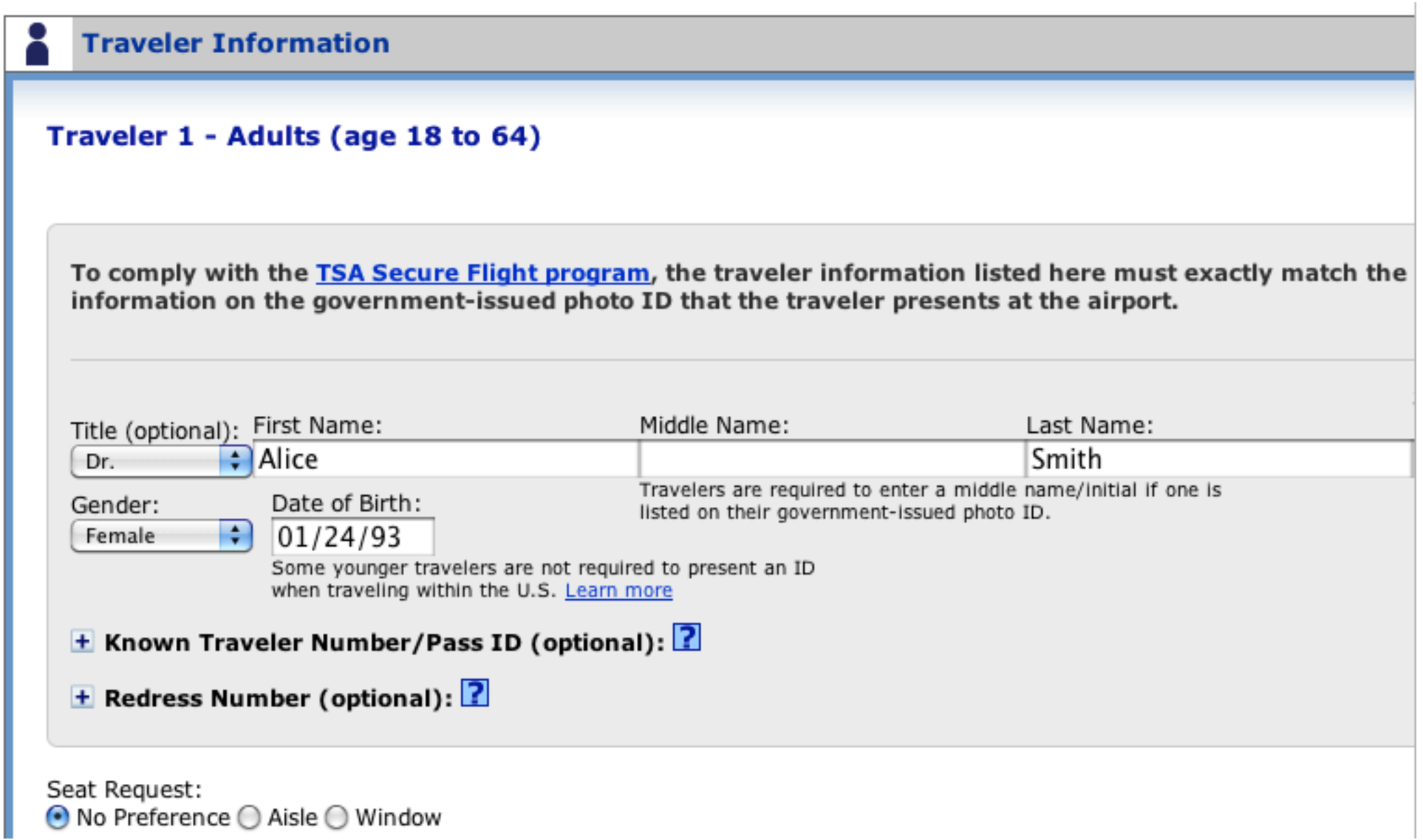
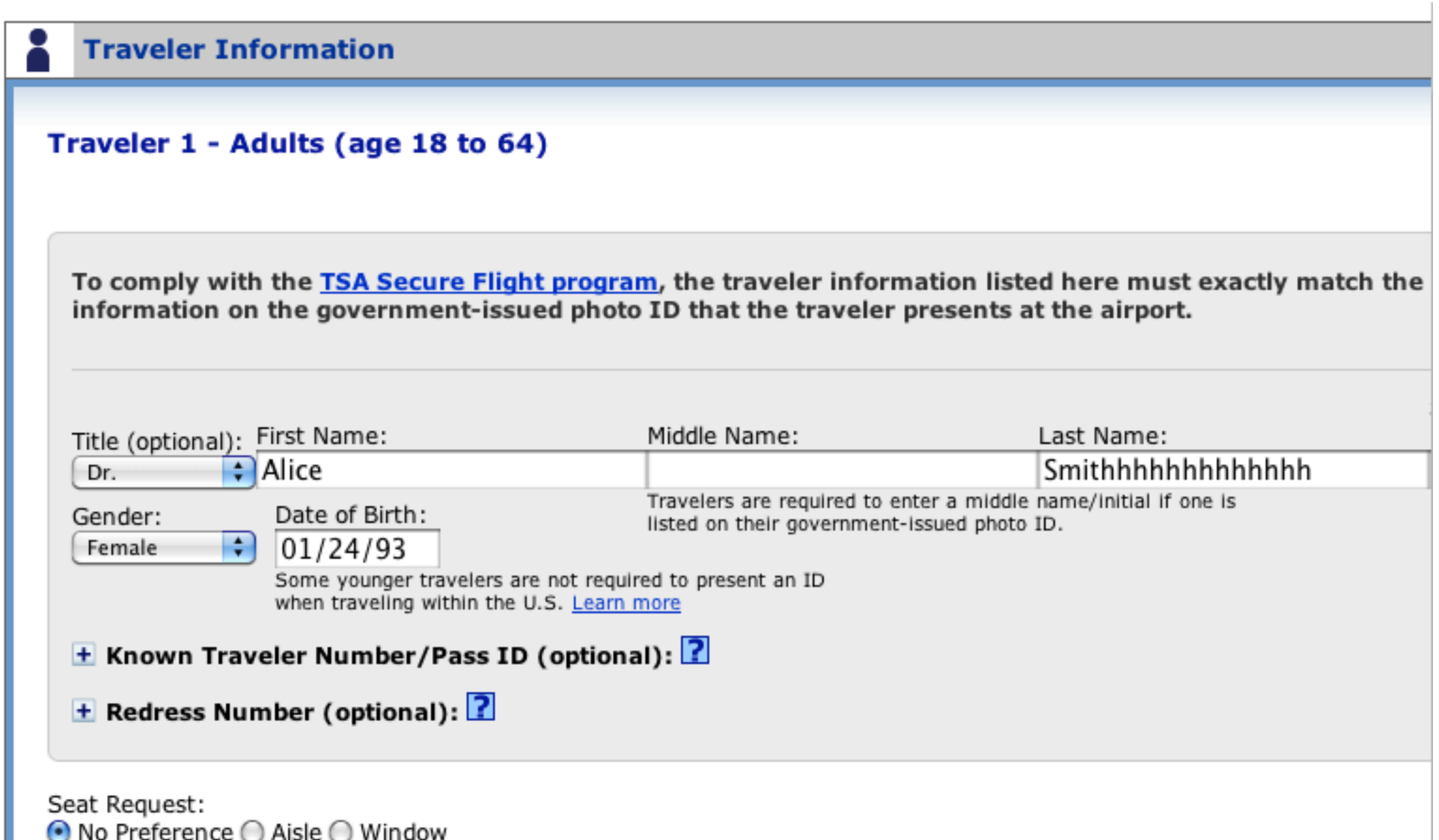
Lecture 3: Buffer Overflows

https://cs161.org


Traveler Information
Traveler 1 - Adults (age 18 to 64)
To comply with the TSA Secure Flight program, the traveler information listed here must exactly match the information on the government-issued photo ID that the traveler presents at the airport.
Title (optional):
Dr.
First Name:
Alice
Middle Name:
Last Name:
Smith
Travelers are required to enter a middle name/initial if one is listed on their government-issued photo ID.
Gender:
Female
Date of Birth:
01/24/93
Some younger travelers are not required to present an ID when traveling within the U.S. Learn more
+ Known Traveler Number/Pass ID (optional):
+ Redress Number (optional):
Seat Request:
No Preference
Aisle
Window


#293 HRE-THR 850 1930
ALICE SMITH
COACH
SPECIAL INSTRUX: NONE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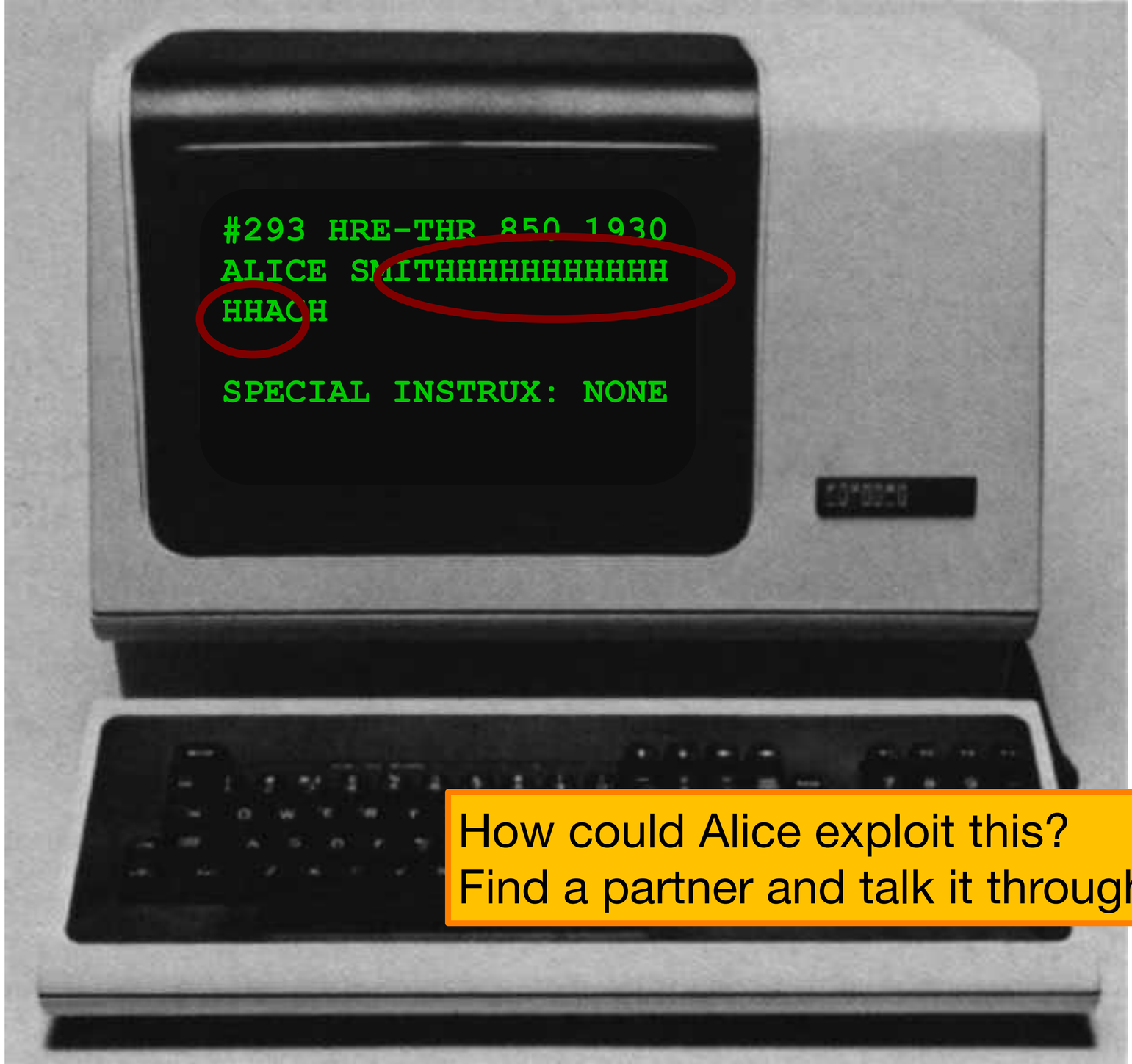
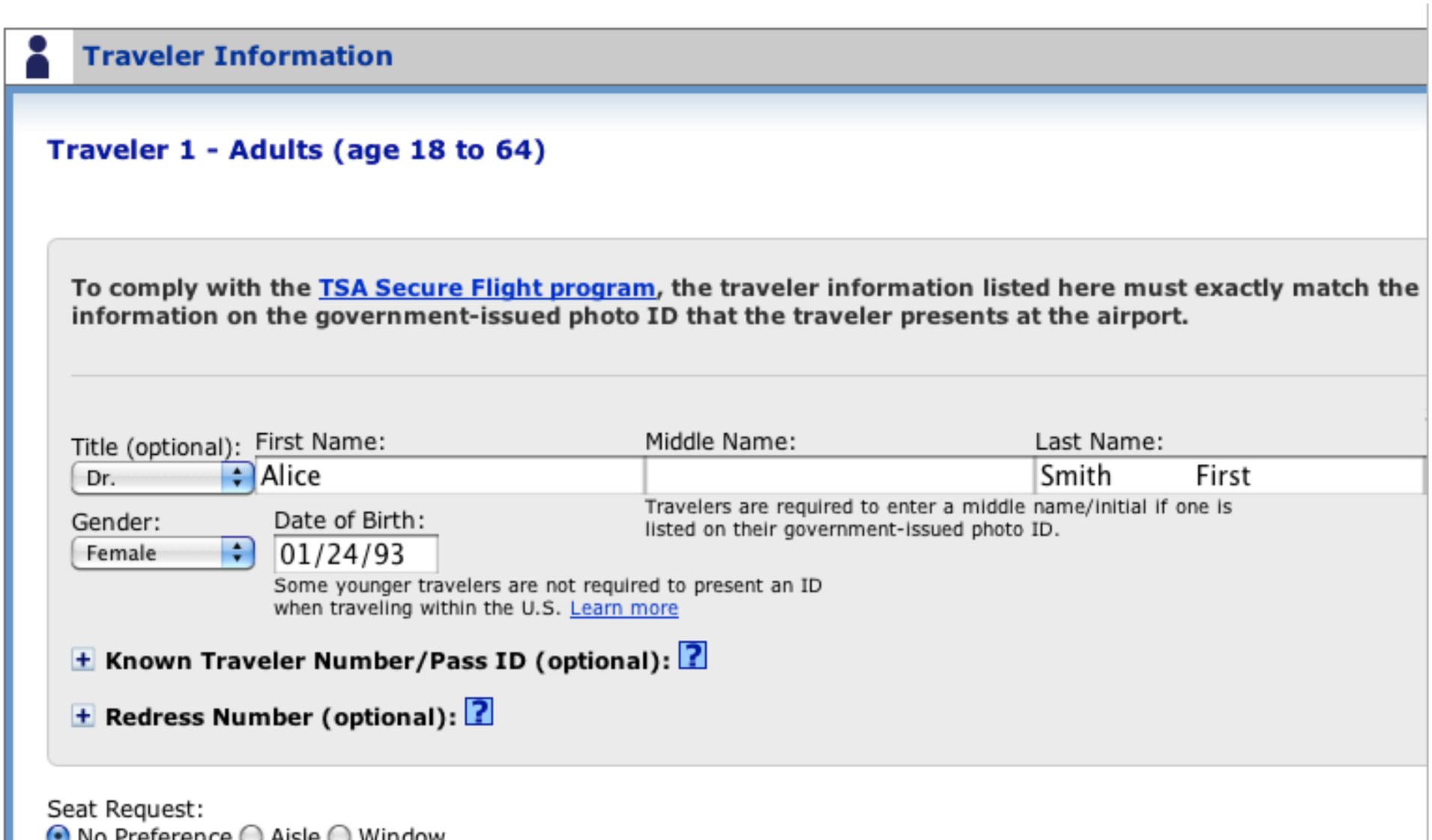


How could Alice exploit this?
Find a partner and talk it through.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#293 HRE-THR 850 1930
ALICE SMITH
FIRST
SPECIAL INSTRUX: NONE

```
char name[20];

void vulnerable() {
   ...
   gets(name);
   ...
}
```

```
char name[20];
char instrux[80] = "none";

void vulnerable() {
   ...
   gets(name);
   ...
}
```

```
char name[20];
int  seatinfirstclass = 0;

void vulnerable() {
   ...
   gets(name);
   ...
}
```

```
char name[20];
int  authenticated = 0;

void vulnerable() {
   ...
   gets(name);
   ...
}
```

```
char line[512];
char command[] = "/usr/bin/finger";

void main() {
   ...
   gets(line);
   ...
   execv(command, ...);
}
```

```
char name[20];
int (*fnptr)();

void vulnerable() {
   ...
   gets(name);
   ...
}
```

The CWE Top 25

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[15]	CWE-732	Incorrect Permission Assignment for Critical Resource	6.33
[16]	CWE-434	Unrestricted Upload of File with Dangerous Type	5.50
[17]	CWE-611	Improper Restriction of XML External Entity Reference	5.48
[18]	CWE-94	Improper Control of Generation of Code ('Code Injection')	5.36
[19]	CWE-798	Use of Hard-coded Credentials	5.12

```
void vulnerable() {
  char buf[64];
  ...
  gets(buf);
  ...
}
```

```
void still_vulnerable?() {
   char *buf = malloc(64);
   ...
   gets(buf);
   ...
}
```

IE's Role in the Google-China War

By Richard Adhikari
TechNewsWorld
01/15/10 12:25 PM PT

The hack attack on Google that set off the company's ongoing standoff with China appears to have come through a zero-day flaw in Microsoft's Internet Explorer browser. Microsoft has released a security advisory, and researchers are hard at work studying the exploit. The attack appears to consist of several files, each a different piece of malware.

Computer security companies are scurrying to cope with the fallout from the Internet Explorer (IE) flaw that led to cyberattacks on Google (Nasdaq: GOOG) and its corporate and individual customers.

The zero-day attack that exploited IE is part of a lethal cocktail of malware that is keeping researchers very busy.

"We're discovering things on an up-to-the-minute basis, and we've seen about a dozen files dropped on infected PCs so far," Dmitri Alperovitch, vice president of research at McAfee Labs, told TechNewsWorld.

The attacks on Google, which appeared to originate in China, have sparked a feud between the Internet giant and the nation's government over censorship, and it could result in Google pulling away from its business dealings in the country.

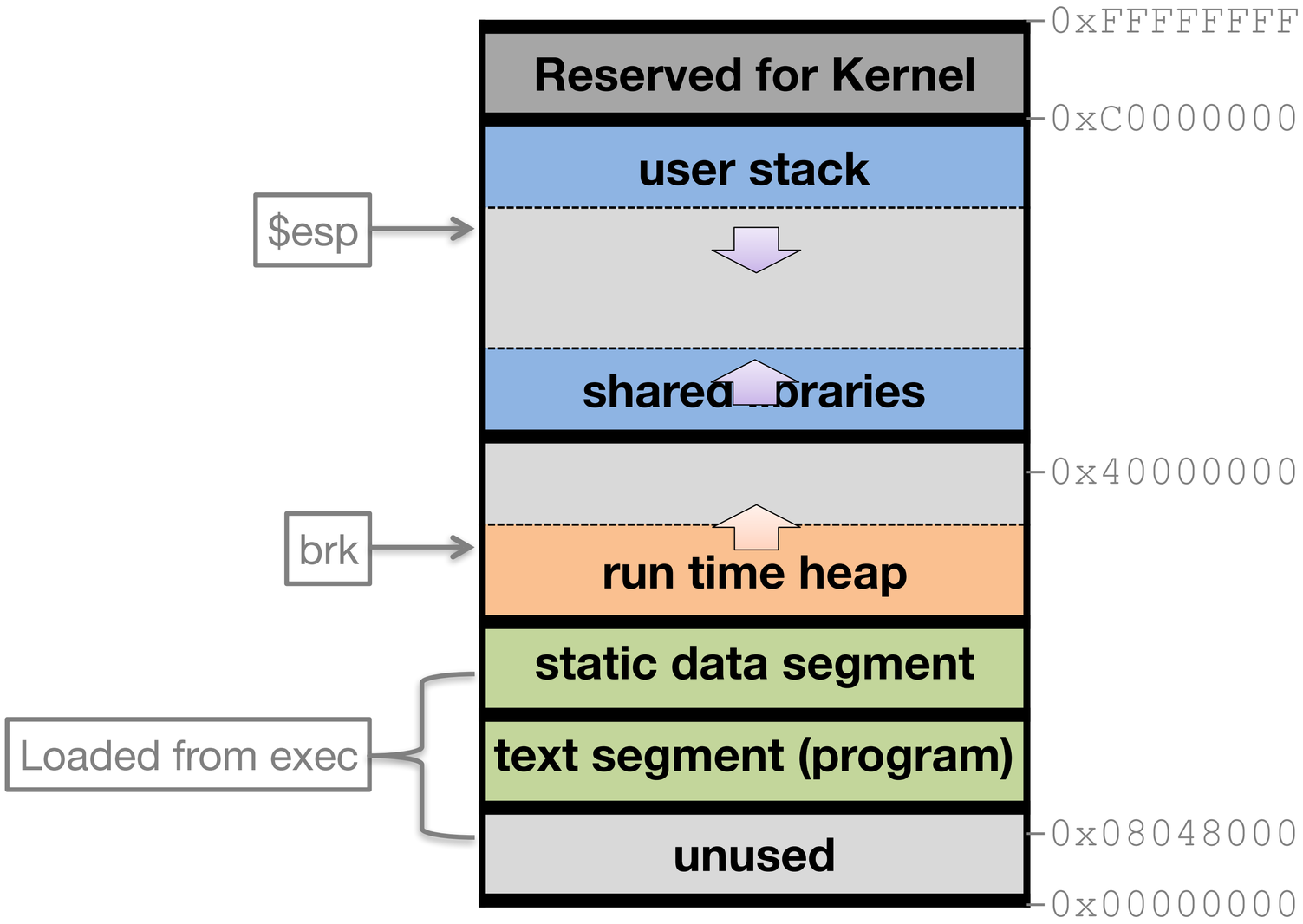
Pointing to the Flaw

The vulnerability in IE is an invalid pointer reference, Microsoft (Nasdaq: MSFT) said in security advisory 979352, which it issued on Thursday. Under certain conditions, the invalid pointer can be accessed after an object is deleted, the advisory states. In specially crafted attacks, like the ones launched against Google and its customers, IE can allow remote execution of code when the flaw is exploited.

Disclaimer: x86-32

- For this class, we are going to use 32-bit x86
  - Almost everyone in this class has access to an x86 system: Mac, Linux, Windows...
- But these attacks do apply to other microarchitectures

Linux (32-bit) process memory layout



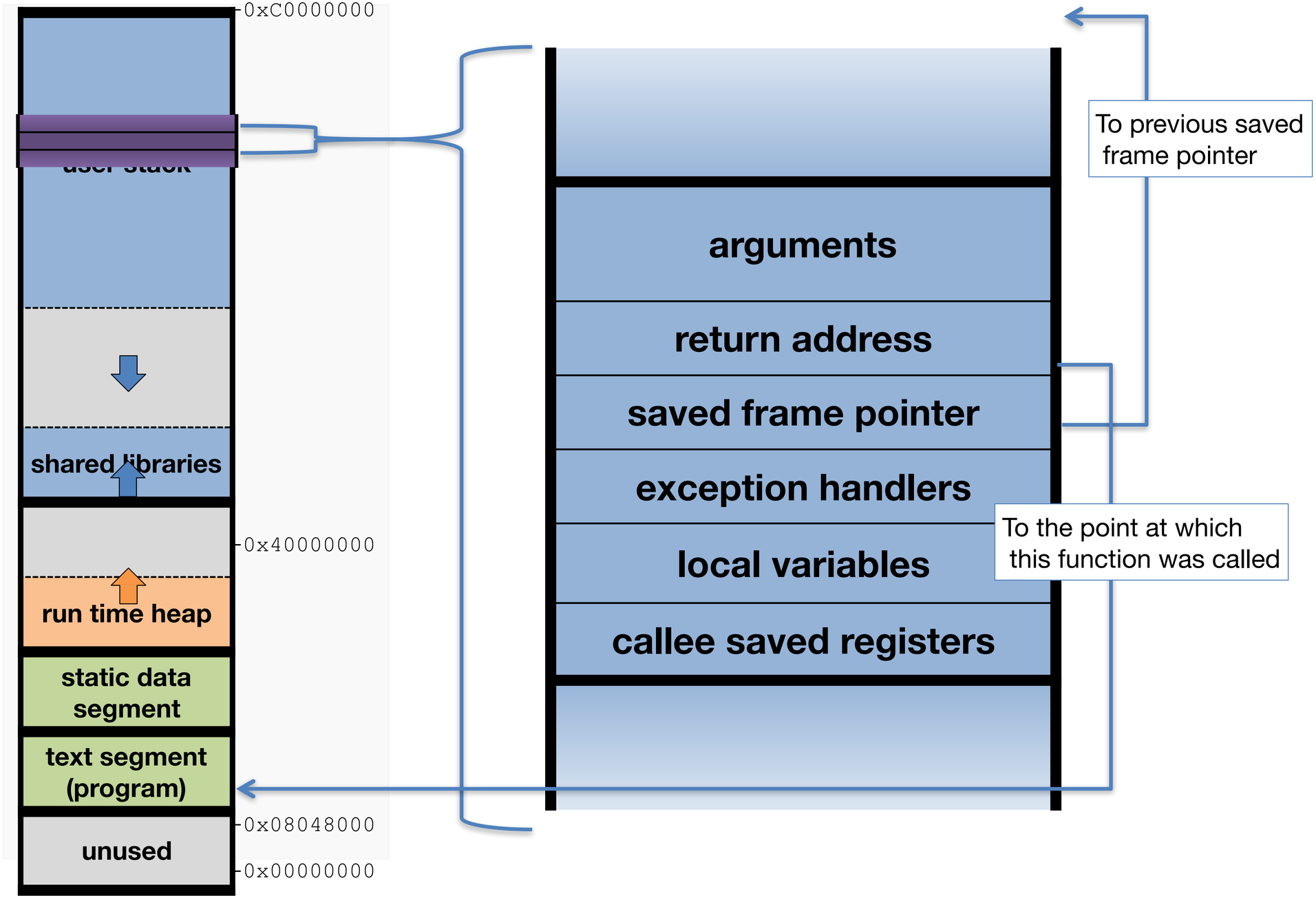
The main x86 registers…

- EAX-EDX: General purpose registers
- EBP: “Frame pointer”: points to the start of the current call frame on the stack
- ESP: “Stack pointer”: points to the current stack
  - PUSH: Decrement the stack pointer and store something there
  - POP: Load something and increment the stack pointer

x86 function calling

- Place the arguments on the stack
- CALL the function
  - Which pushes the return address onto the stack (RIP == Return Instruction Pointer)
- Function saves old EBP on the stack (SFP == Saved Frame Pointer)
- Function does its stuff
- Function restores everything
  - Reload EBP, pop ESP as necessary
- RET
  - Which jumps to the return address that is currently pointed to by ESP
  - And can optionally pop the stack a lot further…

Buffer Overflows


0xC0000000
user stack
shared libraries
0x40000000
run time heap
static data segment
text segment (program)
0x08048000
unused
0x00000000
arguments
return address
saved frame pointer
exception handlers
local variables
callee saved registers
To previous saved frame pointer
To the point at which this function was called

```
void safe() {
   char buf[64];
   ...
   fgets(buf, 64, stdin);
   ...
}
```

```
void safer() {
  char buf[64];
  ...
  fgets(buf, sizeof(buf), stdin);
  ...
}
```

Assume these are both under the control of an attacker.

```
void vulnerable(int len, char *data) {
  char buf[64];
  if (len > 64)
    return;
  memcpy(buf, data, len);
}
```

```
memcpy(void *s1, const void *s2, size_t n);
```

size_t is ***unsigned***:
What happens if len == -1?

```
void safe(size_t len, char *data) {
  char buf[64];
  if (len > 64)
    return;
  memcpy(buf, data, len);
}
```

```
void f(size_t len, char *data) {
  char *buf = malloc(len+2);
  if (buf == NULL) return;
  memcpy(buf, data, len);
  buf[len] = '\n';
  buf[len+1] = '\0';
}
```

Is it safe? Talk to your partner.

Vulnerable!
If **`len`** = **`0xffffffff`**, *allocates only 1 byte*

Broward Vote-Counting Blunder Changes Amendment Result

POSTED: 1:34 pm EST November 4, 2004

BROWARD COUNTY, Fla. -- The Broward County Elections Department has egg on its face today after a computer glitch misreported a key amendment race, according to WPLG-TV in Miami.

Amendment 4, which would allow Miami-Dade and Broward counties to hold a future election to decide if slot machines should be allowed at racetracks, was thought to be tied. But now that a computer glitch for machines counting absentee ballots has been exposed, it turns out the amendment passed.

"The software is not geared to count more than 32,000 votes in a precinct. So what happens when it gets to 32,000 is the software starts counting backward," said Broward County Mayor Ilene Lieberman.

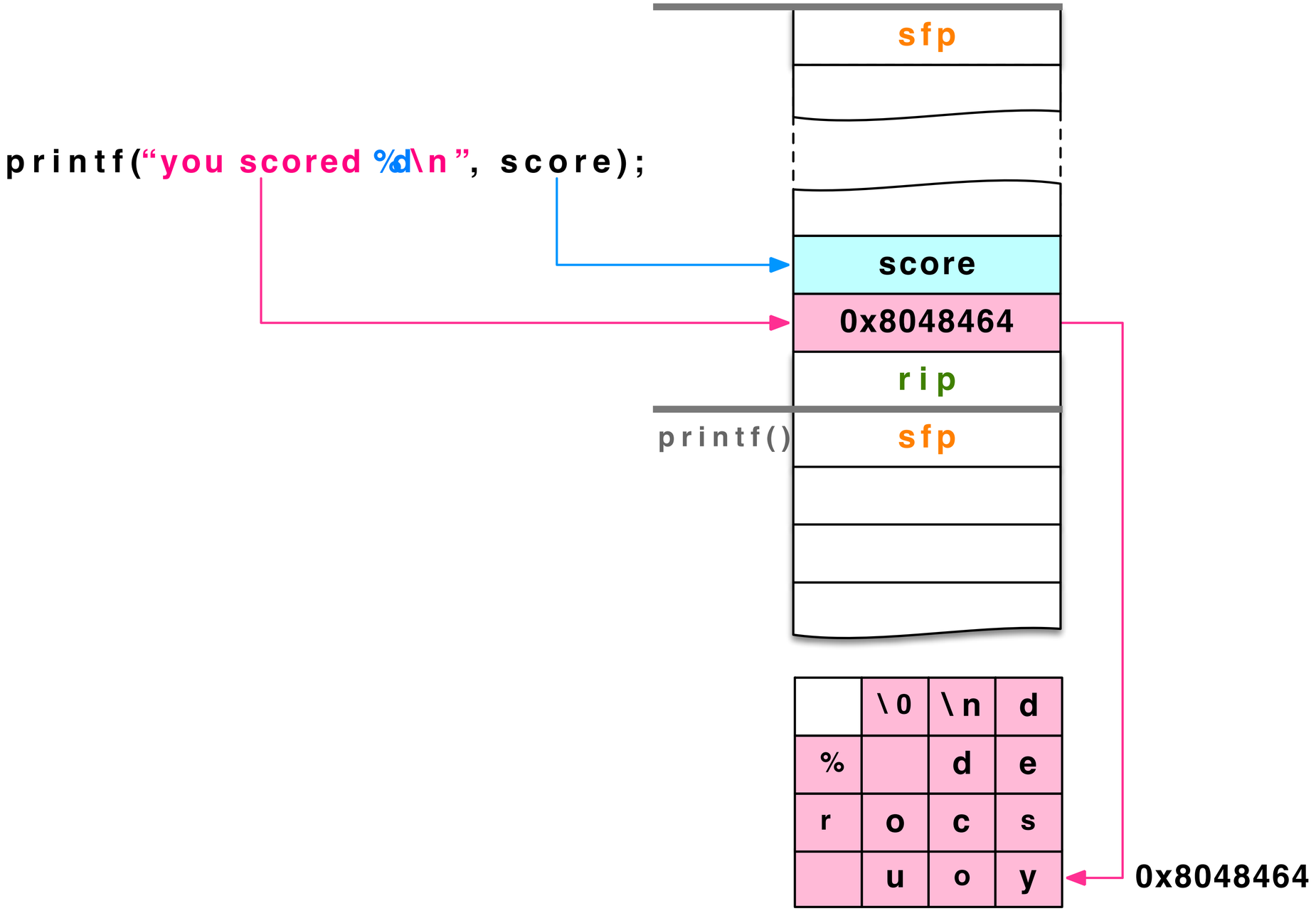
Broward County Mayor Ilene Lieberman says voting counting error is an "embarrassing mistake."

That means that Amendment 4 passed in Broward County by more than 240,000 votes rather than the 166,000-vote margin reported Wednesday night. That increase changes the overall statewide results in what had been a neck-and-neck race, one for which recounts had been going on today. But with news of Broward's error, it's clear amendment 4 passed.

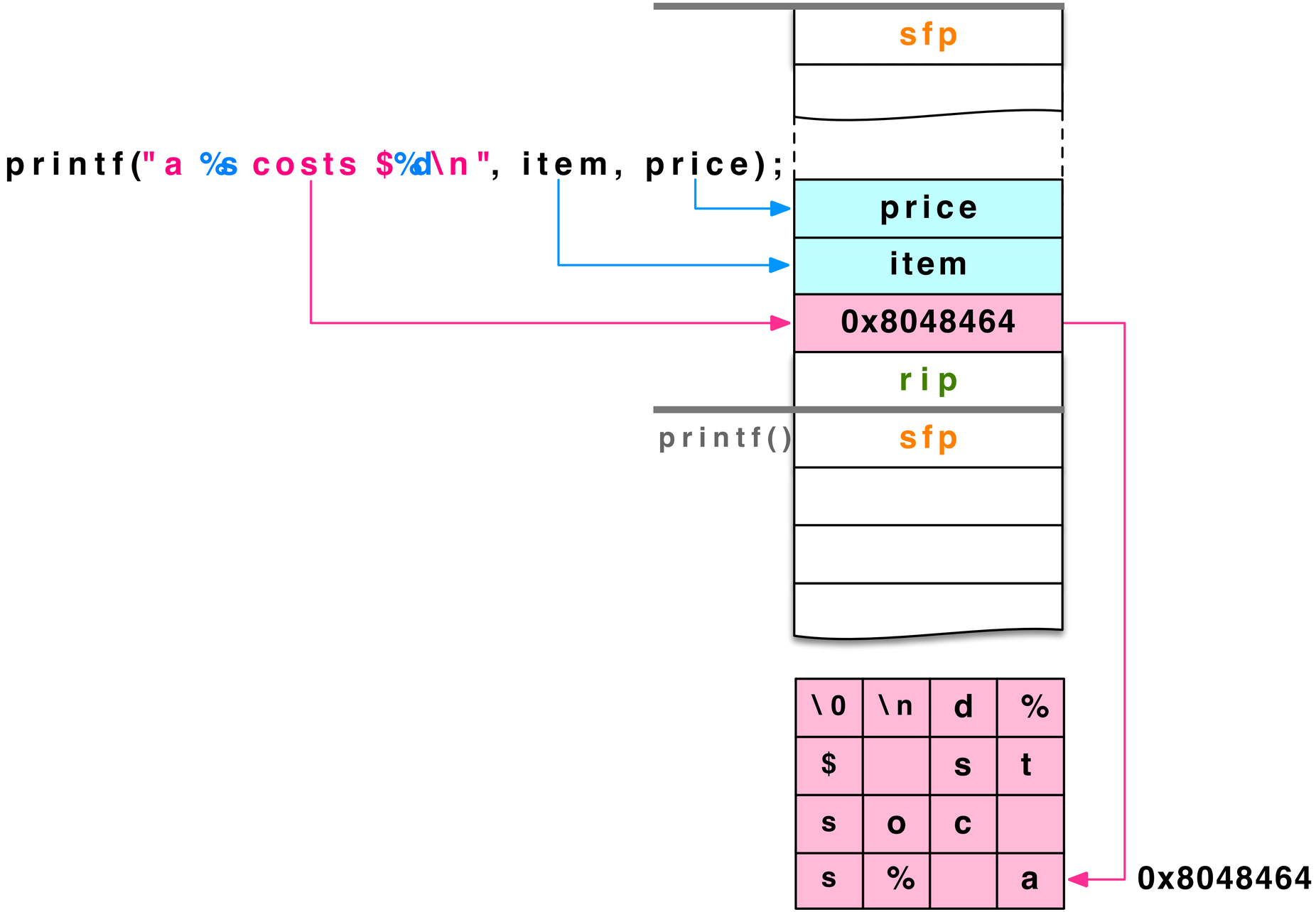
Memory Safety

```
void vulnerable() {
  char buf[64];
  if (fgets(buf, 64, stdin) == NULL)
    return;
  printf(buf);
}
```

```
printf("you scored %d\n", score);
```


printf("you scored %d\n", score);
sfp
score
0x8048464
rip
printf()
sfp
\0
\n
d
%
d
e
r
o
c
s
u
o
y
0x8048464

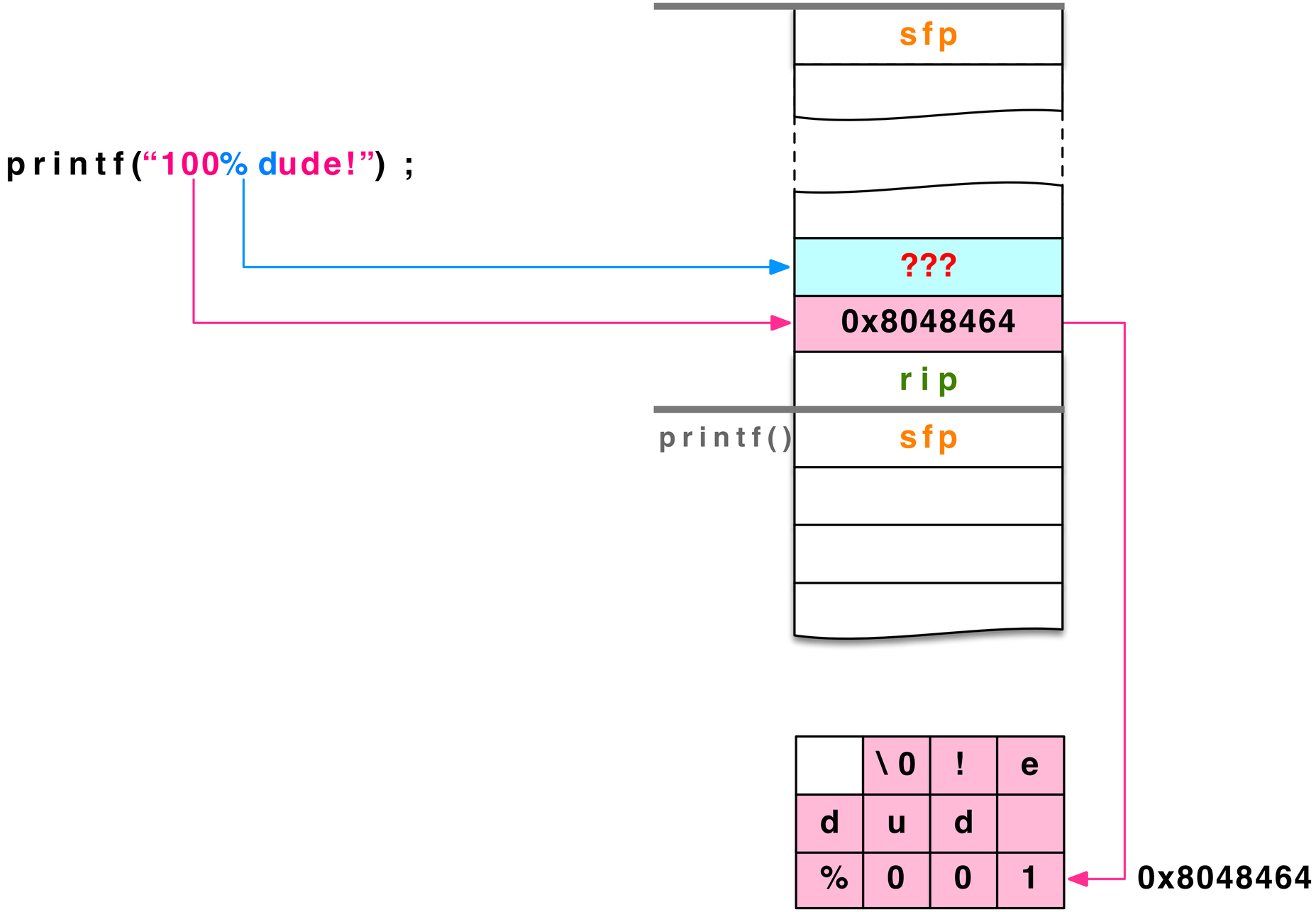
```
printf("a %s costs $%d\n", item, price);
```


printf("a %s costs $%d\n", item, price);
sfp
price
item
0x8048464
rip
printf()
sfp
\0
\n
d
%
$
s
t
s
o
c
s
%
a
0x8048464

Fun With `printf` format strings...


```
printf("100% dude!");
```

Format argument is missing!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sfp
???
0x8048464
rip
printf()
sfp
\0
!
e
d
u
d
%
0
0
1
0x8048464

More Fun With `printf` format strings...


```
printf("100% dude!");
```

⇒ *prints value 4 bytes above retaddr as integer*

```
printf("100% sir!");
```

⇒ *prints bytes pointed to by that stack entry up through first NUL*

```
printf("%d %d %d %d ...");
```

⇒ *prints series of stack entries as integers*

```
printf("%d %s");
```

⇒ *prints value 8 bytes above retaddr plus bytes pointed to by preceding stack entry*

```
printf("100% nuke'm!");
```

What does the %n format do??

%n *writes* the number of characters printed so far into the corresponding format argument.

```
int report_cost(int item_num, int price) {
  int colon_offset;
  printf("item %d:%n $%d\n", item_num,
                    &colon_offset, price);
  return colon_offset;
}
```

`report_cost(3, 22)` **prints** `"item 3: $22"`
and returns the value 7

`report_cost(987, 5)` **prints** `"item 987: $5"`
and returns the value 9

Fun With `printf` format strings...


```
printf("100% dude!");
```

⇒ *prints value 4 bytes above retaddr as integer*

```
printf("100% sir!");
```

⇒ *prints bytes pointed to by that stack entry up through first NUL*

```
printf("%d %d %d %d ...");
```

⇒ *prints series of stack entries as integers*

```
printf("%d %s");
```

⇒ *prints value 8 bytes above retaddr plus bytes pointed to by preceding stack entry*

```
printf("100% nuke'm!");
```

⇒ ***writes the value 3 to the address pointed to by stack entry***

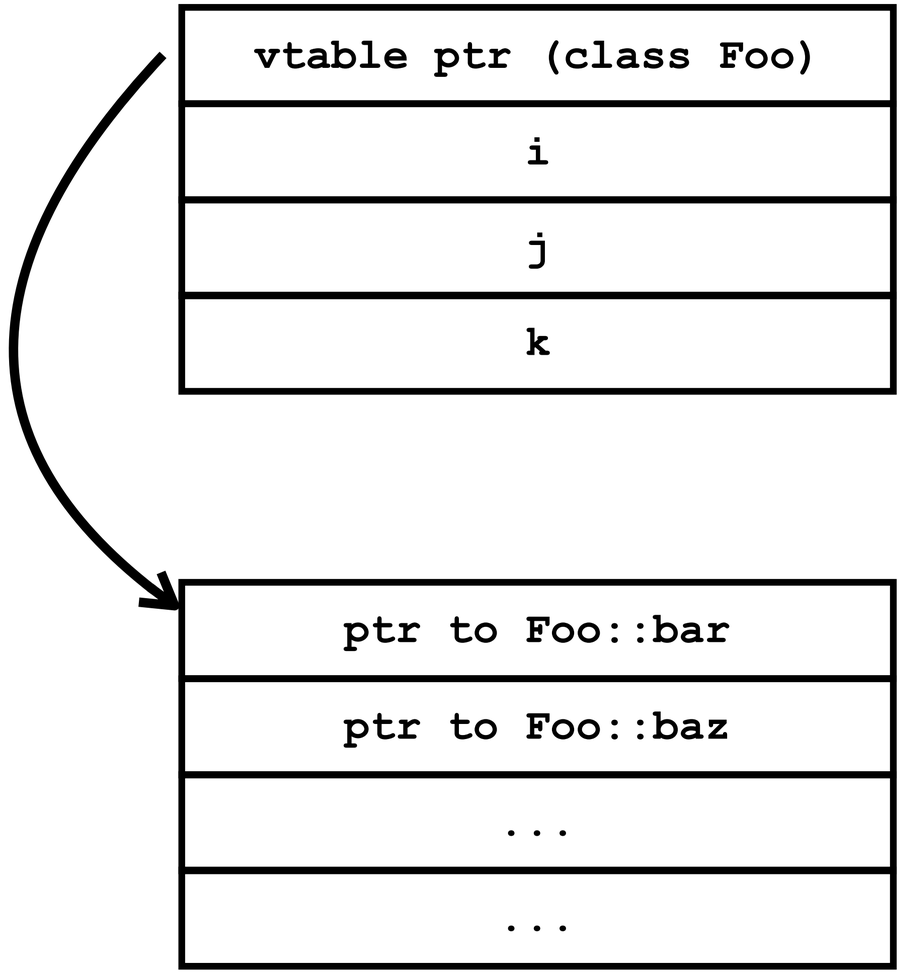
```
void safe() {
  char buf[64];
  if (fgets(buf, 64, stdin) == NULL)
    return;
  printf("%s", buf);
}
```

It isn't just the stack...

- Control flow attacks require that the attacker overwrite a piece of memory that contains a pointer for future code execution
  - The return address on the stack is just the easiest target
- You can cause plenty of mayhem overwriting memory in the heap...
  - And it is made easier when targeting C++
- Allows alternate ways to hijack control flow of the program

Compiler Operation: Compiling Object Oriented Code


```
class Foo {
    int i, j, k;
    public virtual void bar(){ ... }
    public virtual void baz(){ ... }
....
```



A Few Exploit Techniques

- If you can overwrite a vtable pointer…
  - It is effectively the same as overwriting the return address pointer on the stack:
    When the function gets invoked the control flow is hijacked to point to the attacker's code
    - The only difference is that instead of overwriting with a pointer you overwrite it with a pointer to a table of pointers...
- Heap Overflow:
  - A buffer in the heap is not checked:
    Attacker writes beyond and overwrites the vtable pointer of the next object in memory
- Use-after-free:
  - An object is deallocated too early:
    Attacker writes new data in a newly reallocated block that overwrites the vtable pointer
  - Object is then invoked

Magic Numbers & Exploitation…

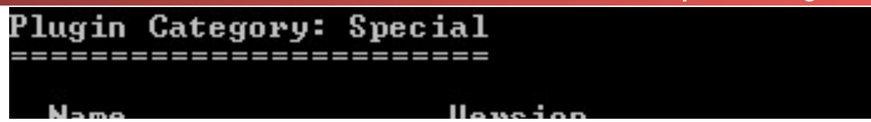
- Exploits can often be ***very*** brittle
  - You see this on your Project 1: Your ./egg will not work
    VM because the memory layout is different
- Making an exploit robust is an art unto itse
  - EXTRABACON is an NSA exploit for Cisco ASA "Adapt
    Appliances"
  - It had an exploitable stack-overflow vulnerability in the
  - But actual exploitation required two steps:
    Query for the particular version (with an SMTP read)
    Select the proper set of magic numbers for that versior

A hack that helps: NOOP sled...

- Don't just overwrite the pointer and then provide the code you want to execute...
- Instead, write a large number of NOOP operations
  - Instructions that do nothing
- Now if you are a ***little*** off, it doesn't matter
  - Since if you are close enough, control flow will land in the sled and start running...

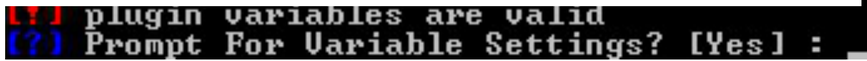
ETERNALBLUE

- ETERNALBLUE is another NSA exploit
  - Stolen by the same group ("ShadowBrokers") v
  - Remote exploit for Windows through SMBv1 (V
- Eventually it was very robust...
  - But initially it was jokingly called ETERNALBLU crash Windows computers more reliably than e



Current and former officials defended the agency's handling of EternalBlue, saying that the NSA must use such volatile tools to fulfill its mission of gathering foreign intelligence. In the case of EternalBlue, the intelligence haul was "unreal," said one

The NSA also made upgrades to EternalBlue to address its penchant for crashing targeted computers — a problem that earned it the nickname "EternalBlueScreen" in reference to the eerie blue screen often displayed by computers in distress.



Memory Safety

- Memory Safety: No accesses to undefined memory
  - "Undefined" is with respect to the semantics of the programming language
  - Read Access: attacker can read memory that he isn't supposed to
  - Write Access: attacker can write memory that she isn't supposed to
  - Execute Access: transfer control flow to memory they aren’t supposed to
- Spatial safety: No access out of bounds
- Temporal safety: No access before or after lifetime of object

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