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#####  
# CS:APP Buffer Lab  
# Directions to Instructors  
#  
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#  
#####
```

This directory contains the files that you will use to build and run the CS:APP Buffer Lab.

The purpose of the Buffer Lab is to help students develop a detailed understanding of the stack discipline on IA32 processors. It involves applying a series of buffer overflow attacks on an executable file.

This version of the lab has been specially modified to defeat the stack randomization techniques used by newer versions of Linux. It works by using mmap() and an assembly language insert to move the stack pointed at by %esp to an unused part of the heap.

```
*****  
1. Overview  
*****
```

```
----  
1.1. Buffer Bombs  
----
```

A "buffer bomb" is an executable bomb, called "./bufbomb", that is solved using a buffer overflow attack (exploit). In this lab, students are asked to alter the behavior of a buffer bomb (called bufbomb) via five increasingly difficult levels of exploits.

The levels are called smoke (level 0), fizz (level 1), bang (level 2), boom (level 3), and kaboom (level 4), with smoke being the simplest and kaboom being the most difficult.

```
----  
1.2. Solving Buffer Bombs  
----
```

Each exploit involves reading a sequence of bytes from standard input into a buffer stored on the stack. Students encode each exploit string as a sequence of hex digit pairs separated by whitespace, where each hex digit pair represents a byte in the exploit string. The program "hex2raw" converts these strings into a sequence of raw bytes, which can then be fed to the buffer bomb:

```
unix> cat exploit.txt | ./hex2raw | ./bufbomb -u <userid>
```

Each student works on an identical buffer bomb, but the solution to the individual phases is a function of each student's userid. Thus, students must develop the solution on their own and cannot use the solutions from other students.

The solution to each phase is unique for each student because it typically involves the manipulation on the runtime stack of a unique "cookie" computed from the userid by the "makecookie" program:

```
unix> ./makecookie bovik  
0x1005b2b7
```

The lab writeup has extensive details on each phase and solution techniques.

1.3. Autograding Service

We have provided the same stand-alone user-level autograding service used by the Bomb Lab to handle all aspects of the Buffer Lab for you. Students download their buffer bombs from a server. As the students work on their bombs, they can submit successful exploit strings to the server by running the buffer bomb with "-s" argument:

```
unix> cat exploit.txt | ./hex2raw | ./bufbomb -u <userid> -s
```

The current results for each bomb are displayed on a Web "scoreboard." As with the Bomb Lab there are no explicit handins and the lab is self-grading.

The autograding service consists of four user-level programs that run in the main ./buflab directory:

- Request Server. Students download their bombs and display the scoreboard by pointing a browser at a simple HTTP server called the "request server."
- Result Server. Each time a student submits an exploit string the buffer bomb sends a short HTTP message, called an "autoresult string," to an HTTP "result server," which simply appends the autoresult string to a "scoreboard log file."
- Report Daemon. The "report daemon" periodically scans the scoreboard log file. The report daemon finds the most recent exploit string submitted by each student for each phase, and validates these strings by applying them to a local copy of the buffer bomb (unlike the Bomb Lab, each student works on the same buffer bomb). It then updates the HTML scoreboard that summarizes phases that have been successfully solved for each bomb (identified by cookie to protect the student privacy), rank ordered by the number of solved levels.

To avoid infinite loops during validation, the Report Daemon calls each bufbomb in autograding mode, using the -g flag. This causes the bomb to timeout after 5 seconds.

- Main daemon. The "main daemon" starts and nannies the request server, result server, and report daemon, ensuring that exactly one of

these processes (and itself) is running at any point in time. If one of these processes dies for some reason, the main daemon detects this and automatically restarts it. The main daemon is the only program you actually need to run.

2. Files

The ./buflab directory contains the following files:

Makefile	- For starting/stopping the lab and cleaning files
buflab-handout/	- Contains the files handed out to each student
buflab.pl*	- Main daemon that nannies the other servers & daemons
Buflab.pm	- Buflab configuration file
buflab-reportd.pl*	- Report daemon that continuously updates scoreboard
buflab-requestd.pl*	- Request server that serves bombs to students
buflab-resultd.pl*	- Result server that gets autoresult strings from bombs
buflab-scoreboard.html	- Real-time Web scoreboard
buflab-update.pl*	- Helper to buflab-reportd.pl that updates scoreboard
handin/	- Most recent exploits from each student and each level
log-status.txt	- Status log with msgs from various servers and daemons
log.txt	- Scoreboard log of autoresults received from bombs
makebomb.pl*	- Program that builds a buffer bomb
scores.txt	- Summarizes current scoreboard scores for each student
src/	- The buffer bomb source files, including a master <ul style="list-style-type: none">- solver in ./src/solve the automatically generates- a solution string for any userid and level.
writeup/	- Sample Latex Buffer Lab writeup

3. Buffer Bomb Terminology

Notifying Bomb: A buffer bomb can be compiled with a NOTIFY option that allows the student to submit successful exploit strings to the autograding service. Such bombs are called "notifying bombs."

Quiet Bomb: A buffer bomb that is not a notifying bomb is called a "quiet bomb."

Cookie: Unlike the Bomb Lab, each student works on the same binary. However, the solution to each phase is different for each student because the exploit string typically must contain a 32-bit "cookie" that is computed from the student's userid.

4. Offering the Buffer Lab

As with the Bomb Lab, there are two basic flavors of the Buffer Lab: In the "online" version, the instructor uses the autograding service to handout buffer bombs to each student on demand (each student gets the same bomb program), and to automatically track their progress on the realtime scoreboard. In the "offline" version, the instructor builds, hands out, and grades the student bombs manually, without

using the autograding service.

While both versions give the students a rich experience, we recommend the online version. It is clearly the most compelling and fun for the students, and the easiest for the instructor to grade. However, it requires that you keep the autograding service running non-stop, because handouts, grading, and reporting occur continuously for the duration of the lab. We've made it very easy to run the service, but some instructors may be uncomfortable with this requirement and will opt instead for the offline version.

Here are the directions for offering both versions of the lab.

4.1. Create a Buffer Lab Directory

Identify the generic Linux machine (\$SERVER_NAME) where you will create the Buffer Lab directory (./buflab) and, if you are offering the online version, run the autograding service. You'll only need a user account on this machine. You don't need root access. Any desktop with an internet connection will do.

Each offering of the Buffer Lab starts with a clean new ./buflab directory on \$SERVER_NAME. For example:

```
linux> tar xvf buflab.tar
linux> cd buflab
linux> make cleanallfiles
```

4.2 Configure the Buffer Lab

Configure the Buffer Lab by editing the following file:

./Buflab.pm - This is the main configuration file. You will only need to modify or inspect a few variables in Section 1 of this file. Each variable is preceded by a descriptive comment. If you are offering the offline version, you can ignore all of these settings.

If you are offering the online version, you will also need to edit the following file:

./src/config.h - This file lists the domain names of the hosts that notifying bombs are allowed to submit results from. Make sure you update this correctly, else you and your students won't be able to submit their results. You should include \$SERVER_NAME in this list, along with any machines that your students will be submitting from.

4.3. Update the Lab Writeup

Once you have updated the configuration files, modify the Latex lab writeup in ./writeup/buflab.tex for your environment. Then type the

following in the ./writeup directory:

```
unix> make clean
unix> make
```

This will create ps and pdf versions of the writeup

--- 4.4. Running the Online Buffer Lab ---

----- 4.4.1. Short Version -----

From the ./buflab directory:

(1) Reset the Buffer Lab from scratch by typing

```
linux> make cleanallfiles
```

(2) Start the autograding service by typing

```
linux> make start
```

(3) Stop the autograding service by typing

```
linux> make stop
```

You can start and stop the autograding service as often as you like without losing any information. When in doubt "make stop; make start" will get everything in a stable state.

However, resetting the lab ("make cleanallfiles") deletes all handin strings, status logs, and the scoreboard log. Do this only during debugging, or the very first time you start the lab for your students.

The ./src/solve directory contains a master solver script called ./solve.pl that you can use to automatically generate a nicely commented solution exploit string for any userid and phase. See ./src/solve/README for details.

The ./handin directory contains the most recent exploit string received from each userid and each phase

```
<userid>-<level>-exploit.txt
```

as well as a report showing the result from the validation

```
<userid>-<level>-report.txt
```

Students request bombs by pointing their browsers at
[http://\\$SERVER_NAME:\\$REQUESTD_PORT/](http://$SERVER_NAME:$REQUESTD_PORT/)

Students submit their successful exploit strings to the grading service by calling the bufbomb with the -s option:

```
linux> cat exploit_string | ./hex2raw | ./bufbomb -u bovik -s
```

Students view the scoreboard by pointing their browsers at
`http://$SERVER_NAME:$REQUESTD_PORT/scoreboard`

4.4.2. Long Version

(1) Resetting the Buffer Lab. "make cleanallfiles" resets the lab from scratch, deleting all data specific to a particular instance of the lab, such as the status log, the scoreboard log, and the handin file. Do this when you're ready for the lab to go "live" to the students.

Resetting is also useful while you're preparing the lab. Before the lab goes live, you'll want to request a few bombs for yourself, run them, defuse a few phases, explode a few phases, and make sure that the results are displayed properly on the scoreboard. If there is a problem (say because you forgot to update the list of machines the bombs are allowed to run in `src/config.h`) you can fix the configuration, reset the lab, and then request and run more test bombs.

CAUTION: If you reset the lab after it's live, you'll lose all your records of the students handins. You'll have to ask them to submit their results again.

(2) Starting the Buffer Lab. "make start" runs `buflab.pl`, the main daemon that starts and nannies the other programs in the service, checking their status every few seconds and restarting them if necessary:

(3) Stopping the Buffer Lab. "make stop" kills all of the running servers. You can start and stop the autograding service as often as you like without losing any information. When in doubt "make stop; make start" will get everything in a stable state.

Request Server: The request server is a simple special-purpose HTTP server that (1) builds and delivers buffer bombs to student browsers on demand, and (2) displays the current state of the real-time scoreboard.

A student requests a bomb from the request daemon by pointing their favorite browser at

`http://$SERVER_NAME:$REQUESTD_PORT/`

The request server makes the `buflab-handout` directory (if necessary), tars it up, and delivers the tar file to the browser. The student then saves the tar file to disk. When the student untars this file, it creates a directory (`./buflab-handout`) with the following three binary files:

`bufbomb*` Notifying custom bomb executable

hex2raw* Converts a hex-encoded exploit string to a byte stream
makecookie* Computes the cookie associated with a userid.

The request server also makes sure that there are bufbomb, hex2raw, and makecookie binaries in the ./buflab/src directory.

Result Server: Each time a student submits an exploit string, the buffer bomb sends an HTTP "autoresult string" to the result server, which then appends the message to the scoreboard log. Each autoresult string contains the userid, level, and exploit string.

Report Daemon: The report daemon periodically scans the scoreboard log (log.txt) and updates the scoreboard (buflab-scoreboard.txt). For each userid, it validates the most recently received exploit string, and updates the scoreboard. The update frequency is a configuration variable in Buflab.pm.

Instructors and students view the scoreboard by pointing their browsers at:

`http://$SERVER_NAME:$REQUESTD_PORT/scoreboard`

----- 4.4.3. Grading the Online Buffer Lab -----

The online Buffer Lab is self-grading. At any point in time, the tab-delimited file "./buflab/scores.txt" contains the most recent scores for each student. This file is created by the report daemon each time it generates a new scoreboard.

The autograding service also updates the ./buflab/handin directory, which contains information that will be very helpful to you when students have questions about their submissions, especially when they submit solutions that passed their bufbomb but failed when evaluated by the grading server (common for the nitro phase).

For each student (userid), it keeps the last exploit string they submitted for each phase (0-4) in a file called

`<userid>-<level>-exploit.txt`

along with a report file called

`<userid>-<level>-report.txt`

that shows the output from the buffer bomb on the corresponding string.

Section 5 describes how to generate solutions for arbitrary userids and levels.

----- 4.4.4. Additional Notes on the Online Buffer Lab -----

* If you want to build your own notifying bomb and hand it out manually to your students (rather than having them use the request server), then you should use the `./makebomb.pl` script:

```
unix> ./makebomb.pl -n
```

This creates the three binaries, `./src/bufbomb`, `./src/hex2raw`, and `./src/makecookie`, and copies them to `./buflab-handout/`, which you can then tar up and hand out to students.

* All of the servers and daemons are stateless, so you can stop ("make stop") and start ("make start") the lab as many times as you like without any ill effects. If you accidentally kill one of the daemons, or you modify a daemon, or the daemon dies for some reason, then use "make stop" to clean up, and then restart with "make start". If your Linux box crashes or reboots, simply restart the daemons with "make start".

* Information and error messages from the servers are appended to the status log in `buflab/log-status.txt`. Servers run quietly, so they can be started from `initrc` scripts at boot time.

* Before going live with the students, we like to check everything out by running some tests. We do this by typing

```
linux> make cleanallfiles  
linux> make start
```

Then we request a buffer bomb for ourselves by pointing a Web browser at

```
http://$SERVER_NAME:$REQUESTD_PORT
```

After saving our bomb to disk, we untar it, copy it to a host in the approved list in `src/config.h`, and then solve and submit different phases for different fake userids to make sure that they are properly recorded on the scoreboard, which we check at

```
http://$SERVER_NAME:$REQUESTD_PORT/scoreboard
```

Once we're satisfied that everything is OK, we stop the lab

```
linux> make stop
```

and then go live:

```
linux> make cleanallfiles  
linux> make start
```

Once we go live, we type "make stop" and "make start" as often as we need to, but we are careful never to type "make cleanallfiles" again.

4.5. Running the Offline Buffer Lab

In this version of the lab, you build your own quiet buffer bombs manually and then hand them out to the students. The students work on solving their bombs offline (i.e., independently of any autograding service) and then handin their exploit strings for each phase to you, which you then grade manually.

Use the `./makebomb.pl` script to build the quiet buffer bomb:

```
unix> ./makebomb.pl
```

This creates the three binaries `./src/bufbomb`, `./src/hex2raw`, and `./src/makecookie`, and copies them to the `./buflab-handout/` directory, which you can then tar up and hand out to students.

The students will handin their solution files, which you can validate manually by feeding to the bomb:

```
unix> cd src
unix> cat <userid>-<level>.txt | ./hex2raw | ./bufbomb
```