Sandboxing

logistics

CHALLENGE assignment — take-home portion of the final

next class — final exam review

CHALLENGE (1)

expect to release before Saturday; due by written final

probably complete all but two

- five of seven or four of six
- (waiting for TA feedback to callibrate difficulty)

similar format to “attack” homeworks

- create a program that produces input

you are responsible for figuringout what scenario applies

CHALLENGE (2)

some very similar to prior HWs, some not

reference solutions to OVER, ROP, FORMAT will be available

- you may modify and use these

you can ask about general strategies, but not specific challenges

- e.g. ask TAs/students to go through examples of how to do stack smashing
- e.g. ask TAs/students how to tell if pointer subterfuge would work

web page

web security summary (1)

browser as OS:

- websites are like programs

cross-site scripting

- command injection for the web
- not just stuff to display — program code for website
- problem: runs with website permissions (e.g. cookies)

web security summary (2)

isolation mechanism: same origin policy

- decision: everything on domain name is "the same"

cross-site request forgery

- consequence of statelessness
- all requests send cookie (password-equivalent)
- extra token to distinguish "user initiated" or not

on user tracking

embedding one web page in another enables tracking users across website

example: multiple webpages include `iframe` with a google ad

> your browser sends request to Google with same cookie
> Google reliably gets excerpt of web history

reason: websites cooperated with Google

users often don't like this

what can browsers do about this?

changing the cookie policy (1)

idea: no “third-party” cookies

only send cookies for URL in address bar

changing the cookie policy (1)

idea: no “third-party” cookies

only send cookies for URL in address bar

now embedded Google calendar can’t use my credentials

what about websites that use multiple domains?

changing the cookie policy (2)

current Firefox “tracking protection” approach:

manually(?) created list of sites that do tracking

...and can be ignored without breaking things

changing the cookie policy (3)

EFF Privacy Badger: heuristic apporach

create score using

- amount of info in cookies
- number of places third-party appears

block requests to third-party or filter cookies if score too high

hard-coded exceptions for common false positives/tricky caes

- 'surrogate' code to avoid breaking website by blocking
  - tracking code has callbacks to third-party
- e.g. facebook.com and fbcdn.com

tracking without cookies

websites can do tracking even with no cookies

- information in URLs — add `?sessionID` to all links
- other forms of browser storage — e.g. via Flash

websites can "fingerprint" browser and machine

- version, fonts, screen resolution, plugins, graphics features, ...
- caching of previously downloaded resources
- almost unique a surprising amount of the time

have IP addresses, too — very good hints

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Web Frameworks

tools for making writing interactive websites help

e.g. Django (Python):

default to anti-embedding HTTP header (no clickjacking)
default to HttpOnly cookies
default to requiring CSRF token for POSTs

usually provide "templates" which escape HTML properly by default

template: `<p>Name: {{name}}` (placeholder in {{...}})
if name is `<script>...` result is
`<p>Name: &lt;script&gt;...`

recall: UAF triggering code

earlier in semester: exploit in Chrome browser itself

```
// in HTML near this JavaScript:
// <video id="vid"> (video player element)
function source_opened() {
  buffer = ms.addSourceBuffer('video/webm; codecs="vorbis,vp8"');
  vid.parentNode.removeChild(vid);
  gc(); // force garbage collector to run now
  // garbage collector frees unreachable objects
  // (would be run automatically, eventually, too)
  // buffer now internally refers to delete'd player object
  buffer.timestampOffset = 42;
}
ms = new WebKitMediaSource();
ms.addEventListener('webkitsourceopen', source_opened);
vid.src = window.URL.createObjectURL(ms);
```

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browsers and exploits

browsers are in a particularly dangerous position for exploits

routinely run untrusted code (JavaScript on websites)

huge amounts of code, often written in C/C++

- WebKit (part of Chrome, Safari) has millions of lines of code

malvertising

could trick user into visiting your website

or pay for ad — embed your webpage in another!

- can run whatever script you like

modern advertising landscape (1)

website ads are often sold in realtime

conceptual idea: mini-auction for every ad

major concerns about fraud

- are you really showing my ad?

ad operators want to do own tracking

- get better idea what to show/bid

modern advertising landscape (2)

website operators typically don't host ads

- don't build own realtime auction infrastructure
- not trusted to report number of ad views correctly

ads often sold indirectly

- middleman handles bidding/etc.
- website operators sell to multiple ad operators

browsers and exploit mitigations

modern browsers employ many of the mitigations we talked about

- full ASLR
- write XOR execute (with exceptions for runtime-compiled code)
- stack canaries

also some other mitigations

least privilege

why can code running for a webpage install software?

never needs to do that

concept: let's run it without those permissions

multi-user OSs

```
cr4bd@labunix01:~$ cp myprogram.exe /bin/ls
cp: cannot create regular file ‘/bin/ls’ : Permission denied
```

programs have limited privileges

permission enforcement

```
struct Process {
    int user_id;
    ...
};
int handle_open_system_call(char *filename, ...) {
    Process* currentProcess = GetCurrentProcess();
    File* file = GetFileByFilename(filename);
    if (!file->UserCanAccess(currentProcess->user_id)) {
        return ERROR_PERMISSION_DENIED;
    }
    ...
}
```

multi-user OSs

```
cr4bd@labunix01:~$ cp myprogram.exe /bin/ls
cp: cannot create regular file ‘/bin/ls’ : Permission denied
```

programs have limited privileges

OS tracks "user" of running every program

result: malware I installed shouldn't be able to effect other users

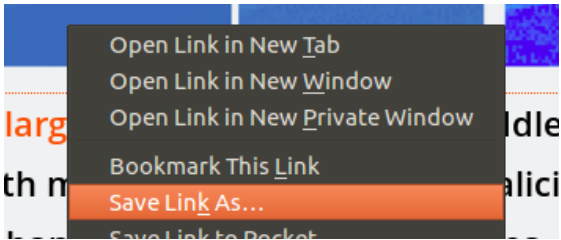
idea 1: reuse this support for web browsers

- webpage should run as "different user"
- malware should only affect web browser?

things browsers need

what things should browser be able to do?

things browsers need



save files

have your webmail password

...

the privilege separation idea

can't make whole browser run as "different user"

- still need to save files, read password, etc.

how about just the parts that are "dangerous"?

- part that runs scripts, parses HTML

simple privilege separation

simple example: want to show videos

video decoding library is tens of thousands of lines of code

- often buggy, includes hard-to-check hand-written assembly

what does video decoding library do?

- read video file as input
- output images as output

simple privilege seperation

setup: create new user

start video decoder as new user

communicate via “pipes”

- like terminal to be used by program

simple privilege seperation

```
/* dangerous video decoder to isolate */
int main() {
    /* switch to right user */
    SetUserTo("user-without-privileges"));
    while (fread(videoData, sizeof(videoData), 1, stdin) > 0) {
        doDangerousVideoDecoding(videoData, imageData);
        fwrite(imageData, sizeof(imageData), 1, stdout);
    }
}

/* code that uses it */
    FILE *fh = RunProgramAndGetFileHandle("./video-decoder");
    for (;;) {
        fwrite(getNextVideoData(), SIZE, 1, fh);
        fread(image, sizeof(image), 1, fh);
        displayImage(image);
    }
```

issues with privilege separation (1)

"other user" can still do too much

read unprotected files

- most of them?

write temporary files?

open network connections

use all your memory

...

issues with privilege separation (2)

awkward to do

switching users requires special permissions

seperate user for each video decoder, audio decoder, web page renderer?

- users can debug processes from same user

slowdown — extra copying

recall: process virtual machine

process has isolated memory + CPU

communicating outside? needs system calls

- analagous to using I/O devices

OS controls what process can do

Linux system call filtering API

privilege seperation support: system call filtering

simple API: `seccomp(SECCOMP_SET_MODE_STRICT, 0, 0)`

"The only system calls the calling thread is permitted to make are `read`, `write`, `_exit`, and `sigreturn`. Other system calls [kill the program]."

read/write only work on already open files

“sandboxing”

result of filtering called a “sandbox”

idea: attacker can play in sandbox as much as they want

can’t do anything harmful

Chrome architecture

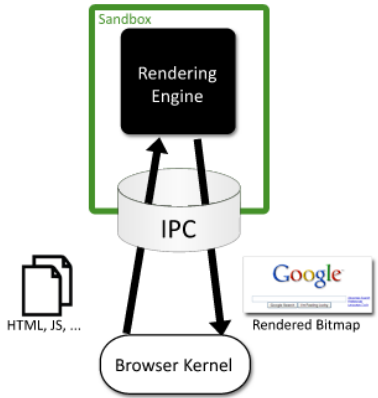


Figure 1: The browser kernel treats the rendering engine as a black box that parses web content and emits bitmaps of the rendered document.

talking to the sandbox

browser kernel sends commands to sandbox

sandbox sends commands to browser kernel

idea: commands only allow necessary things

original Chrome sandbox interface

sandbox to browser "kernel"

- show this image on screen
  - (using shared memory for speed)
- make request for this URL
- download files to local FS
- upload user requested files

browser "kernel" to sandbox

- send user input

original Chrome sandbox interface

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- show this image on screen
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needs filtering — at least no `file:` (local file) URLs

browser "

- send user input

original Chrome sandbox interface

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browser "kernel" to sandbox

- send user input

can still read any website!
still sends normal cookies!

original Chrome sandbox interface

sandbox to browser “kernel”

- show this image on screen
  - (using shared memory for speed)
- make request for this URL
- download files to local FS
- upload user requ[illegible]

browser “kernel” to

- send user input

files go to download directory only
can’t choose arbitrary filenames

original Chrome sandbox interface

sandbox to browser “kernel”

- show this image on screen
  - (using shared memory for speed)
- make request for this URL
- download files to local FS
- upload user requested files

browser “kernel” to sandbox

- send user input

browser kernel displays file choser
only permits files selected by user

process per site

Chrome almost does process-per-site

idea: one sandbox process per site

with one huge exception

recall: same-origin policy

recall: operations not requiring same origin

loading images, stylesheets (CSS), video, audio

loading scripts

- but not getting syntax errors

accessing with “permission” of other website

submitting forms to other webpages

displaying other webpages (but not reading contents)

browser kernel security

the browser kernel is not simple

needs to securely implement special protocol

UI, networking code overall more complicated than before

hope: writing secure browser kernel easier than secure whole-browser

OpenSSH privilege seperation

OpenSSH uses privilege seperation for its SSH server

what runs on the lab machines when you log into them

separate network processing code from authentication code

seperate process per connection — users don't share

OpenSSH privsep protocol

sandboxed process tells “monitor” to:

perform cryptographic operations

- long-term keys never in sandboxed process
- commands to ask for cryptographic messages they need

ask to switch to user — if given user password, etc.

- monitor process verifies login information

after authentication: new process running as logged-in user

- (normally) no issues with special privileges

privilege seperation overall

large application changes

- OpenSSH: 3k lines of code for communication/etc. added
- OpenSSH: 2% of existing code (950 of 44k lines) changed
- (but most changes simple)

lots of application knowledge

- what is a meaningful separation of ‘privileged’ and ‘unprivileged’?

better application design anyways?

application confinement

confining whole browsers was hard

- we trust them to do a lot of things — e.g. write arbitrary files

but maybe we can do this for simpler applications?

idea 1: applications send system calls to OS

- limit syscalls like we limited browser kernel commands
- constructing command language "in reverse"

filtering system calls?

example: video player VLC playing a local file on my laptop

uses 73 unique system calls

opens many files that are not the video file

- libraries
- fonts
- configuration files
- translations of messages

can I limit the files my video player can read?

how do I come up with a useful filter?

OS X sandboxing

OS X (tries to) implement system call filtering

main challenge: what about files?

- user can open a file anywhere — we expect that to work

OS X sandboxing

OS X (tries to) implement system call filtering

main challenge: what about files?

- user can open a file anywhere — we expect that to work

OS X solution: OS service displays file-open dialog

- OS knows user really choose a file

application can ask to remember file was chosen previously

not chosen/remembered — can't access

- requires changes to how applications open files

another sandboxing OS: Qubes

Qubes: heavily sandboxed OS

runs seperate VMs instead of filtering syscalls

UI that clearly shows what VM each window is from

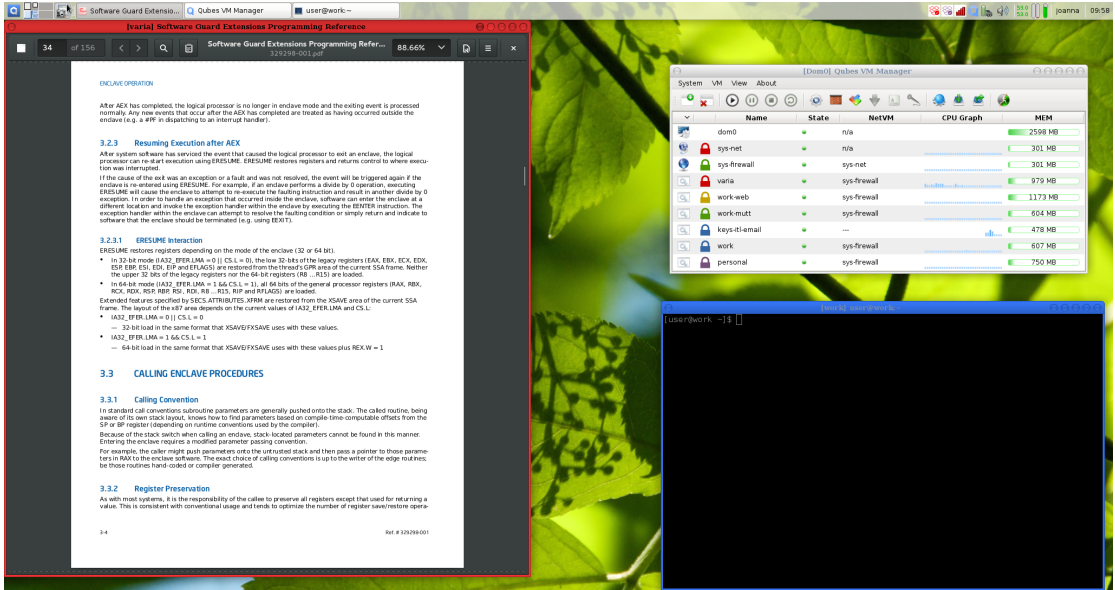
advantage: easier to gaurentee isolation

- many, many more bugs in system call filtering than VMs

disadvantage: harder to share between VMs

disadvantage: much more runtime overhead

Qubes screenshot



quick review

part 1: malware and anti-malware

part 2: (memory) vulnerabilities and exploits and mitigations

part 3: bug-finding/prevention and misc. vulnerabilities and exploits

malware — evil software

tricks itself onto victim machines

- e.g. masquarde as useful software
- e.g. embed in legitimate software (viruses)
- e.g. attack vulnerabilities in software to spread
- e.g. arrange to run automatically on disk insert

cat-and-mouse game — antivirus software to detect malware

- patterns, heuristics to detect
- tricks to appear like normal software

memory vulnerabilities and exploits

buffer overflow/underflow — program writes outside of array

- if "important" data, attacker can gain control
- usual goal: overwrite pointer to code

use-after-free — program uses data as wrong type

- attacker controls data as one type
- ideally, misinterpreted (via dangling pointer) to contain pointer to code

memory exploit mitigations

bounds-checking — don't allow outside-of-array writes

- doesn't solve use-after-free
- single object with array and pointers?

stack canaries — detect writes next to return addresses

ASLR — make it so program can't make up useful pointers?

- problem: memory bugs can print out pointers

W xor X — make it so attacker can't write new code

- problem: attack can reuse existing code (return-oriented programming)

bug-finding

systematic testing — find crashes ($\approx$ vulnerability)

- fuzz testing — generate random tests
- coverage-guided fuzz-testing — random tests, weighted by what runs
- symbolic execution — solve for input to reach each possibility

static analysis — look for dangerous patterns

- usually false positives and/or negatives
- typically examine potential paths through program

bug-prevention

ownership — enforceable rule to prevent use-after-free

- never free while object is owned
- one writer (could be changing internal pointers) or many readers
- readers and writers can borrow from owner
- language (e.g. Rust) can track borrowing lifetimes to make safe

alternate safe policies — reference counting, etc.

- have runtime overhead, but can be used only when needed

escape hatch — only check small amount of unsafe code

- ideally implements policies that make sense
- at least limits the code one needs to check

command injection/web security

command injection — type confusion problems

- try to embed constant/etc., end up embedding commands
- lots of languages to embed in — command line, SQL, HTML, ...

web security

- same origin policy (SOP) — isolate by domain name (mostly)
- XSS — command injection for the web
- trusting client inputs — the attacker controls their browser
- CSRF — innocent browser submits bad request (w/ cookies) for attacker
- clickjacking — "steal" user's click to make request

next time

final exam review: bring questions