CSci 4271W
Development of Secure Software Systems
Day 15: Race Conditions and OS Protection

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Outline

- Shell code injection and related threats, cont'd
- Race conditions and related threats
- Project 1 expectations
- Secure OS interaction
- OS: protection and isolation
- More choices for isolation

Shell code injection

- The command shell is convenient to use, especially in scripts
  - In C: `system`, `popen`
- But it is bad to expose the shell's power to an attacker
- Key pitfall: assembling shell commands as strings

Shell code injection example

- Benign: `system("cp $arg1 $arg2")`, arg1 = `"file1.txt"`
- Attack: arg1 = `"a b; echo Gotcha"`
- Command: `"cp a b; echo Gotcha file2.txt"`

Different shells and multiple interpretation

- Complex Unix systems include shells at multiple levels, making these issues more complex
  - Frequent example: `scp` runs a shell on the server, so filenames with whitespace need double escaping
- Other shell-like programs also have caveats with levels of interpretation
  - Tcl before version 9 interpreted leading zeros as octal

Related local dangers

- File names might contain any character except / or the null character
- The `PATH` environment variable is user-controllable, so `cp` may not be the program you expect
- Environment variables controlling the dynamic loader cause other code to be loaded

IFS and why it was a problem

- In Unix, splitting a command line into words is the shell's job
  - String → argv array
  - `grep a b c` vs. `grep 'a b' c`
- Choice of separator characters (default space, tab, newline) is configurable
- Exploit `system("/bin/uname")`
- In modern shells, improved by not taking from environment

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Bad/missing error handling

- Under what circumstances could each system call fail?
- Careful about rolling back after an error in the middle of a complex operation
- Fail to drop privileges ⇒ run untrusted code anyway
- Update file when disk full ⇒ truncate

Race conditions

- Two actions in parallel; result depends on which happens first
- Usually attacker racing with you

1. Write secret data to file
2. Restrict read permissions on file

- Many other examples

Classic races: files in `/tmp`

- Temp filenames must already be unique
- But "unguessable" is a stronger requirement
- Unsafe design (`mktemp(3)`): function to return unused name
- Must use `O_EXCL` for real atomicity

TOCTTOU gaps

- Time-of-check (to) time-of-use races
  1. Check it's OK to write to file
  2. Write to file
- Attacker changes the file between steps 1 and 2
- Just get lucky, or use tricks to slow you down

Read It Twice (WOOT'12)

- Smart TV (running Linux) only accepts signed apps on USB sticks

1. Check signature on file
2. Install file

- Malicious USB device replaces app between steps
- TV "rooted"/"jailbroken"

TOCTTOU example

```
int safe_open_file(char *path) {
  int fd = -1;
  struct stat s;
  stat(path, &s)
  if (!S_ISREG(s.st_mode))
    error("only regular files allowed");
  else fd = open(path, O_RDONLY);
  return fd;
}
```

TOCTTOU example

```
int safe_open_file(char *path) {
  int fd = -1, res;
  struct stat s;
  res = stat(path, &s)
  if (res || !S_ISREG(s.st_mode))
    error("only regular files allowed");
  else fd = open(path, O_RDONLY);
  return fd;
}
```

TOCTTOU example

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int safe_open_file(char *path) {
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  res = stat(path, &s)
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```

Changing file references

- With symbolic links
- With hard links
- With changing parent directories

Directory traversal with ..

- Program argument specifies file, found in directory `files`
- What about `files/../../../../etc/passwd`?

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Report overall length

- 4-5 pages in US Letter (8.5 x 11in), 1 inch margins
- Double-spaced 10 point Times, Times Roman, or Computer Modern Roman
- Figures, code examples, etc., go at the end, don't count in the 4-5 pages.
- Will submit online as PDF

Threat modeling

- You should include at least one data-flow diagram
- The diagram should have enough detail to inform your threat modeling
  - E.g., `bcimgview` should not be a single component
- Threats should include, but are not limited to, the ones you'll address in the auditing

Auditing for vulnerabilities

- There are at least four bugs that are definitively problematic
  - You need to identify at least three
- Good to also include:
  - Dangerous locations that are not vulnerable in the current program
  - Dangerous locations that you're not sure if they can be attacked

Attacks

- Include three for full credit, you should be sure they work
- Include enough detail to convince me that you really did make the attack work
- For attack inputs, consider showing figure of hex dump with relevant parts highlighted

Rules reminders

- This is an individual assignment, not collaborative
  - Non-spoiler Piazza or office-hour discussions are OK
- The writing should be entirely your own
- Use of public, non-class materials is allowed, but should be acknowledged
  - No specific requirement for citation format for this project

Schedule

- First report, covering modeling, auditing, and attacks, due Friday March 25th
- Revised report with bug fixed due Friday April 8th

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Avoid special privileges

- Require users to have appropriate permissions
  - Rather than putting trust in programs
- Dangerous pattern 1: setuid/setgid program
- Dangerous pattern 2: privileged daemon
- But, sometimes unavoidable (e.g., email)

Prefer file descriptors

- Maintain references to files by keeping them open and using file descriptors, rather than by name
- References same contents despite file system changes
- Use `openat`, etc., variants to use FD instead of directory paths

Prefer absolute paths

- Use full paths (starting with /) for programs and files
- `$PATH` under local user control
- Initial working directory under local user control
  - But FD-like, so can be used in place of `openat` if missing

Prefer fully trusted paths

- Each directory component in a path must be write protected
- Read-only file in read-only directory can be changed if a parent directory is modified

Don't separate check from use

- Avoid pattern of e.g., `access` then `open`
- Instead, just handle failure of open
  - You have to do this anyway
- Multiple references allow races
  - And `access` also has a history of bugs

Be careful with temporary files

- Create files exclusively with tight permissions and never reopen them
  - See detailed recommendations in Wheeler (q.v.)
- Not quite good enough: reopen and check matching device and inode
  - Fails with sufficiently patient attack

Give up privileges

- Using appropriate combinations of `set*id` functions
  - Alas, details differ between Unix variants
- Best: give up permanently
- Second best: give up temporarily
- Detailed recommendations: Setuid Demystified (USENIX'02)

Allow-list environment variables

- Can change the behavior of called program in unexpected ways
- Decide which ones are necessary
  - As few as possible
- Save these, remove any others

For more details...

- The first external reading is chapters from a web-hosted book by David A. Wheeler
- Reading questions will be due one week after they are posted on Canvas

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OS security topics

- Resource protection
- Process isolation
- User authentication (will cover later)
- Access control (already covered)

Protection and isolation

- Resource protection: prevent processes from accessing hardware
- Process isolation: prevent processes from interfering with each other
- Design: by default processes can do neither
- Must request access from operating system

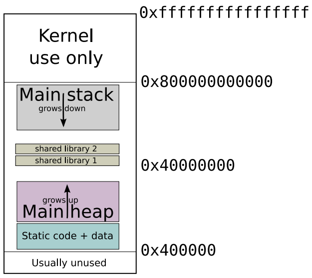
Reference monitor

- Complete mediation: all accesses are checked
- Tamperproof: the monitor is itself protected from modification
- Small enough to be thoroughly verified

Hardware basis: memory protection

- Historic: segments
- Modern: paging and page protection
  - Memory divided into pages (e.g. 4k)
  - Every process has own virtual to physical page table
  - Pages also have R/W/X permissions

Linux example



Hardware basis: supervisor bit

- Supervisor (kernel) mode: all instructions available
- User mode: no hardware or VM control instructions
- Only way to switch to kernel mode is specified entry point
- Also generalizes to multiple "rings"

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Ideal: least privilege

- Programs and users should have the most limited set of powers needed to do their job
- Presupposes that privileges are suitably divisible
  - Contrast: Unix `root`

"Trusted", TCB

- In security, "trusted" is a bad word
- X is trusted: X can break your security
- "Untrusted" = okay if it's evil
- Trusted Computing Base (TCB): minimize

Restricted languages

- Main application: code provided by untrusted parties
- Packet filters in the kernel
- JavaScript in web browsers
  - Also Java, Flash ActionScript, etc.

SFI

- Software-based Fault Isolation
- Instruction-level rewriting
  - Analogous to but predates control-flow integrity
- Limit memory stores and sometimes loads
- Can't jump out except to designated points
- E.g., Google Native Client

Separate processes

- OS (and hardware) isolate one process from another
- Pay overhead for creation and communication
- System call interface allows many possibilities for mischief

System-call interposition

- Trusted process examines syscalls made by untrusted
- Implement via `ptrace` (like strace, gdb) or via kernel change
- Easy policy: deny

Interposition challenges

- Argument values can change in memory (TOCTTOU)
- OS objects can change (TOCTTOU)
- How to get canonical object identifiers?
- Interposer must accurately model kernel behavior
- Details: Garfinkel (NDSS'03)

Separate users

- Reuse OS facilities for access control
- Unit of trust: program or application
- Older example: qmail
- Newer example: Android
- Limitation: lots of things available to any user

`chroot`

- Unix system call to change root directory
- Restrict/virtualize file system access
- Only available to root
- Does not isolate other namespaces

OS-enabled containers

- One kernel, but virtualizes all namespaces
- FreeBSD jails, Linux LXC, Solaris zones, etc.
- Quite robust, but the full, fixed, kernel is in the TCB

(System) virtual machines

- Presents hardware-like interface to an untrusted kernel
- Strong isolation, full administrative complexity
- I/O interface looks like a network, etc.

Virtual machine designs

- (Type 1) hypervisor: 'superkernel' underneath VMs
- Hosted: regular OS underneath VMs
- Paravirtualizaion: modify kernels in VMs for ease of virtualization

Virtual machine technologies

- Hardware based: fastest, now common
- Partial translation: e.g., original VMware
- Full emulation: e.g. QEMU proper
  - Slowest, but can be a different CPU architecture

Modern example: Chrom(ium)

- Separates "browser kernel" from less-trusted "rendering engine"
  - Pragmatic, keeps high-risk components together
- Experimented with various Windows and Linux sandboxing techniques
- Blocked 70% of historic vulnerabilities, not all new ones
- `http://seclab.stanford.edu/websec/chromium/`