CSci 4271W
Development of Secure Software Systems
Day 13: OS Attacks and Protection

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Outline

Two kinds of privilege escalation

- Local exploit: give higher privilege to a regular user
  - E.g., caused by bug in setuid program or OS kernel
- Remote exploit: give access to an external user who doesn't even have an account
  - E.g., caused by bug in network-facing server or client

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
- Note: different from binary "shellcode"

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"`
- Not a complete solution: prohibit `';'`

The structure problem

- What went wrong here?
- Basic mistake: assuming string concatenation will respect language grammar
  - E.g., that attacker supplied "filename" will be interpreted that way

Best fix: avoiding the shell

- Avoid letting untrusted data get near a shell
- For instance, call external programs with lower-level interfaces
  - E.g., `fork` and `exec` instead of `system`
- May constitute a security/flexibility trade-off

Less reliable: text processing

- Allow-list: known-good characters are allowed, others prohibited
  - E.g., username consists only of letters
  - Safest, but potential functionality cost
- Deny-list: known-bad characters are prohibited, others allowed
  - Easy to miss some bad scenarios
- "Sanitization": transform bad characters into good
  - Same problem as deny-list, plus extra complexity

Terminology note

- Historically the most common terms for allow-list and deny-list have been "whitelist" and "blacklist" respectively
- These terms have been criticized for a problematic "white=good", "black=bad" association
- The push to avoid the terms got significant additional attention in summer 2020, but is still somewhat political and in flux

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

Outline

Shell code injection and related threats

Announcements intermission

Race conditions and related threats

Secure OS interaction

OS: protection and isolation

Assignments news

- Problem set 1 grades and comments are posted
  - Be sure to read comments both in the box and on the document
- Reading assignment about Unix/Linux OS security posted
  - Canvas quiz due date delayed to 3/14 due to spring break

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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

```
int safe_open_file(char *path) {
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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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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: protection and isolation

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

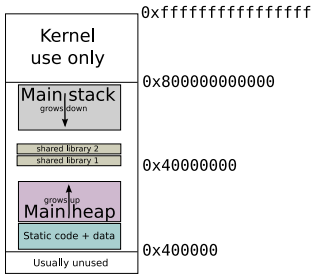
Reference monitor

- 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"