CSci 4271W
Development of Secure Software Systems
Day 11: Race Conditions and Isolation

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Outline

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

Review question

Which of these is safe to assume about a filename on Linux x86-64?

A. The filename will not contain the user's password
B. A single component will not be more than 64 characters long
C. Any bytes with the high bit set will be legal UTF-8
D. An entire path will not be more than 512 characters
E. The filename will not contain the address of a global variable

Outline

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) {
  int fd = -1, res;
  struct stat s;
  res = stat(path, &s)
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    error("only regular files allowed");
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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`?

Outline

- Shell code injection and related threats (cont'd)
- Race conditions and related threats
- Secure OS interaction
- OS: protection and isolation
- More choices for isolation

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)

Whitelist 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...

- I've posted the first external reading, chapters from a web-hosted book by David A. Wheeler
- Reading questions are not ready yet, but will be due one week after they are posted on Canvas

Outline

Shell code injection and related threats (cont'd)

Race conditions and related threats

Secure OS interaction

OS: protection and isolation

More choices for 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

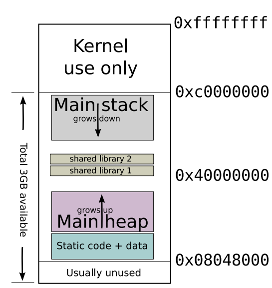
Reference monitor

- 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 32-bit 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"

Outline

Shell code injection and related threats (cont'd)

Race conditions and related threats

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OS: protection and isolation

More choices for isolation

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/`