CSci 4271W
Development of Secure Software Systems
Day 21: Software Engineering and Security

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Preview question

- What's the type of the return value of `getchar`?
- Why?

Outline

Defensive programming

- Analogy to defensive driving: drive so that there won't be a crash even if other drivers are negligent
- Don't just avoid bugs, reduce risks
- Aim for security even if other code and programmers are imperfect

Modularity

- Divide software into pieces with well-defined functionality
- Isolate security-critical code
  - Minimize TCB, facilitate privilege separation
  - Improve auditability

Minimize interfaces

- Hallmark of good modularity: clean interface
- Particularly difficult:
  - Safely implementing an interface for malicious users
  - Safely using an interface with a malicious implementation

Appropriate paranoia

- Many security problems come down to missing checks
- But, it isn't possible to check everything continuously
- How do you know when to check what?

Invariant

- A fact about the state of a program that should always be maintained
- Assumed in one place to guarantee in another
- Compare: proof by induction

Pre- and postconditions

- Invariants before and after execution of a function
- Precondition: should be true before call
- Postcondition: should be true after return

Dividing responsibility

- Program must ensure nothing unsafe happens
- Pre- and postconditions help divide that responsibility without gaps

When to check

- At least once before any unsafe operation
- If the check is fast
- If you know what to do when the check fails
- If you don't trust
  - your caller to obey a precondition
  - your callee to satisfy a postcondition
  - yourself to maintain an invariant

Sometimes you can't check

- Check that `p` points to a null-terminated string
- Check that `fp` is a valid function pointer
- Check that `x` was not chosen by an attacker

Error handling

- Every error must be handled
  - I.e, program must take an appropriate response action
- Errors can indicate bugs, precondition violations, or situations in the environment

Error codes

- Commonly, return value indicates error if any
- Bad: may overlap with regular result
- Bad: goes away if ignored

Exceptions

- Separate from data, triggers jump to handler
- Good: avoid need for manual copying, not dropped
- May support: automatic cleanup (`finally`)
- Bad: non-local control flow can be surprising

Outline

Software engineering for security

Fuzz testing

Saltzer & Schroeder's principles

More secure design principles

Testing and security

- "Testing shows the presence, not the absence of bugs" – Dijkstra
- Easy versions of some bugs can be found by targeted tests:
  - Buffer overflows: long strings
  - Integer overflows: large numbers
  - Format string vulnerabilities: `%x`

Random or fuzz testing

- Random testing can also sometimes reveal bugs
- Original 'fuzz' (Miller): `program </dev/urandom`
- Even this was surprisingly effective

Mutational fuzzing

- Instead of totally random inputs, make small random changes to normal inputs
- Changes are called *mutations*
- Benign starting inputs are called *seeds*
- Good seeds help in exercising interesting/deep behavior

Grammar-based fuzzing

- Observation: it helps to know what correct inputs look like
- Grammar specifies legal patterns, run backwards with random choices to generate
- Generated inputs can again be basis for mutation
- Most commonly used for standard input formats
  - Network protocols, JavaScript, etc.

What if you don't have a grammar?

- Input format may be unknown, or buggy and limited
- Writing a grammar may be too much manual work
- Can the structure or interesting inputs be figured out automatically?

Coverage-driven fuzzing

- Instrument code to record what code is executed
- An input is interesting if it executes code that was not executed before
- Only interesting inputs are used as basis for future mutation

AFL

- Best known open-source tool, pioneered coverage-driven fuzzing
- American Fuzzy Lop, a breed of rabbits
- Stores coverage information in a compact hash table
- Compiler-based or binary-level instrumentation
- Has a number of other optimizations

Outline

A classic paper

Jerome H. Saltzer and Michael D. Schroeder, "The Protection of Information in Computer Systems." In *Proceedings of the IEEE*, Sept. 1975. (853 citations per IEEE)

Economy of mechanism

- Security mechanisms should be as simple as possible
- Good for all software, but security software needs special scrutiny

Fail-safe defaults

- When in doubt, don't give permission
- Whitelist, don't blacklist
- Obvious reason: if you must fail, fail safe
- More subtle reason: incentives

Complete mediation

- Every mode of access must be checked
  - Not just regular accesses: startup, maintenance, etc.
- Checks cannot be bypassed
  - E.g., web app must validate on server, not just client

Open design

- Security must not depend on the design being secret
- If anything is secret, a minimal key
  - Design is hard to keep secret anyway
  - Key must be easily changeable if revealed
  - Design cannot be easily changed

Open design: strong version

- "The design should not be secret"
- If the design is fixed, keeping it secret can't help attackers
- But an unscrutinized design is less likely to be secure

Separation of privilege

- Real world: two-person principle
- Direct implementation: separation of duty
- Multiple mechanisms can help if they are both required
  - Password and `wheel` group in Unix

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`

Least privilege: privilege separation

- Programs must also be divisible to avoid excess privilege
- Classic example: multi-process OpenSSH server
- N.B.: Separation of privilege $\neq$ privilege separation

Least common mechanism

- Minimize the code that all users must depend on for security
- Related term: minimize the Trusted Computing Base (TCB)
- E.g.: prefer library to system call; microkernel OS

Psychological acceptability

- A system must be easy to use, if users are to apply it correctly
- Make the system's model similar to the user's mental model to minimize mistakes

Sometimes: work factor

- Cost of circumvention should match attacker and resource protected
- E.g., length of password
- But, many attacks are easy when you know the bug

Sometimes: compromise recording

- Recording a security failure can be almost as good as preventing it
- But, few things in software can't be erased by `root`

Outline

Separate the control plane

- Keep metadata and code separate from untrusted data
- Bad: format string vulnerability
- Bad: old telephone systems

Defense in depth

- Multiple levels of protection can be better than one
- Especially if none is perfect
- But, many weak security mechanisms don't add up

Canonicalize names

- Use unique representations of objects
- E.g. in paths, remove `.`, `..`, extra slashes, symlinks
- E.g., use IP address instead of DNS name

Fail-safe / fail-stop

- If something goes wrong, behave in a way that's safe
- Often better to stop execution than continue in corrupted state
- E.g., better segfault than code injection