Least-Privilege Isolation: The OKWS Web Server

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Can We Prevent All Exploits?

• Many varieties of exploits
  – Stack smashing, format strings, heap smashing, return-to-libc

• As many proposed defenses
  – W⊕X, ASLR, TaintCheck, StackGuard, ...

• Exploit-specific defenses help, but ever-more vulnerabilities, and adversaries creative

• Not just a problem with C; consider SQL injection in a Python script:

```python
q = "SELECT orders FROM accounts WHERE name = " + name
db.execute(q)
```

• Programmers make errors
Can We Prevent All Exploits?

• Many varieties of exploits
  – Stack smashing, format strings, heap smashing,

  **If vulnerabilities and errors are here to stay, how can we limit the harm attackers can do when they exploit a server?**

  vulnerabilities, and adversaries creative

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  ```

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Problem: Sharing Services, But Isolating Data

- Servers often hold sensitive data
  - e.g., Amazon.com user’s credit card number
- Single server shared by distinct users, who often shouldn’t see one another’s data
  - e.g., different Amazon.com shoppers
- Subsystems on single server must cooperate
  - e.g., Amazon.com web interface and back-end order database
- Goal: prevent users from obtaining/modifying data other than their own
  - I shouldn’t be able to retrieve your order (and credit card number), even if I exploit Amazon’s web server
Approach: Compartmentalization

- Give each subsystem minimal access to system data and resources to do its job
  - If subsystem exploited, at least minimize data it can read or modify
- Define narrow interfaces between subsystems, that allow only exact operations required for application
- Design assuming exploit may occur, especially in subsystems closest to users
Idea: Principle of Least Privilege (PoLP)

• Each subsystem should only have access to read/modify data needed for its job
• Cannot be enforced within subsystem—must be enforced externally (i.e., by OS)
• Must decompose system into subsystems
  – Must reason carefully about truly minimal set of privileges needed by each subsystem
• Must be able to grant privileges in fine-grained manner
  – Else privileges granted to subsystem may be too generous...
Idea: Privilege Separation

• Determine which subsystems most exposed to attack
• Reduce privileges of most exposed subsystems
  – e.g., amazon payment page can only insert into order database, and order database doesn’t have integrated web interface with direct access to data
  – e.g., ssh login daemon code that processes network input shouldn’t run as root
OKWS: A PoLP Web Server on UNIX

• Before OKWS:
  – Apache web server process monolithic; all code runs as same user
  – Exploit Apache, and all data associated with web service becomes accessible

• How might we separate a web server into subsystems, to apply PoLP?

• Split into multiple processes, each with different, minimal privileges, running as different user IDs
  – Use UNIX isolation mechanisms to prevent subsystems from reading/modifying each other’s data
UNIX Tools for PoLP: chroot()

- **chroot()** system call: set process’s notion of file system root; thereafter, can’t change directories above that point

- So can do:
  
  ```c
  chdir(“/usr/local/alone”);
  chroot(“/usr/local/alone”);
  setuid(61100); (unprivileged user ID)
  ```

- Now process has **no access to any of filesystem but what’s in tree rooted at /usr/local/alone**
  
  - No access to the many UNIX setuid-root programs, or to sensitive data elsewhere on disk
  
  - But **must a priori set up all system files needed by process in directory**, e.g., shared libraries, &c.
UNIX Tools for PoLP: File Descriptor Passing

• Initially, parent server process privileged
• Want to run subsystem in child process, but with minimal privileges (e.g., child chroot()ed)
• Idea: privileged parent opens files needed by unprivileged child, passes child open file descriptors to these files when it fork()s child
  – Child can read these files, even if it can’t open them (i.e., because of chroot())
• Can also pass file descriptors dynamically (after fork()) with sendmsg()
  – Process that faces network can accept connection, pass socket for that connection to another process
UNIX Tools for PoLP: File Descriptor Passing

• Initially, parent server process privileged
• Want to run subsystem in child process, but with

**Powerful primitive:** means can run subsystem with minimal privilege (e.g., can’t bind to privileged port 80), but grant it **specific network connections or specific files**

  – Child can read these files, even if it can’t open them (i.e., because of chroot())

• Can also pass file descriptors **dynamically** (after fork()) with **sendmsg()**
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OKWS System Design

- okd process parses user input, holds no sensitive data
- $\text{svc}_i$ process parses user input for one service; runs in chroot()ed “jail”
- database proxy process only accepts authenticated requests for subset of narrow RPC interface; can read sensitive data
Analyzing Privilege-Separated Designs

• What data does subsystem have access to, with what permissions?
• How complex is the code in a subsystem (e.g., parsing notoriously hard to get right)?
• What input does a subsystem receive?
  – Less structured → more worrying
  – e.g., okld runs as root; should we worry about exploits of it?
Strength of Isolation vs. Performance

- One process per user gives strictest isolation, but means many, many processes → low performance
- OKWS uses one process per service for performance reasons; so compromised service may reveal one user’s data to another

“Strict” Model

OKWS Model

- $s_i$: services
- $u_j$: users
- $p_k$: processes
- $t_{ij}$: state for user $j$ in service $i$
OKWS Summary

• Shows that PoLP and privilege separation hold real promise for limiting harm exploits can do

• Programming model for services requires new style of programming
  – Can’t use the file system; services chroot()ed
  – Must define narrow, per-service interfaces to database
  – Must communicate explicitly using RPC between service and database