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:

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

- Programmers make errors

Can We Prevent All Exploits?

- Many varieties of exploits
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If vulnerabilities and errors are here to stay, how can we limit the harm attackers can do when they exploit a server?

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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:

```
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

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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**

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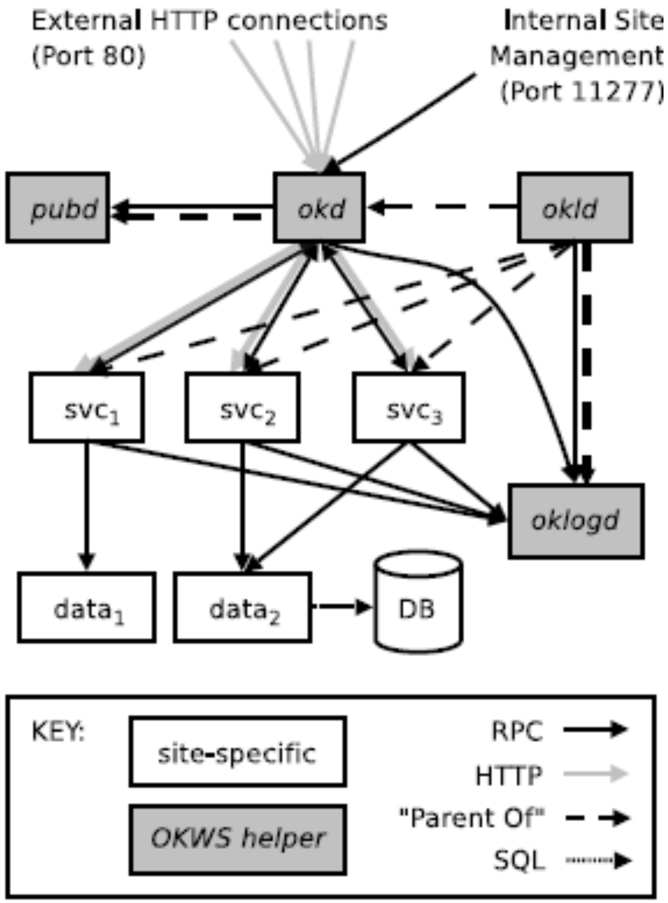
OKWS System Design

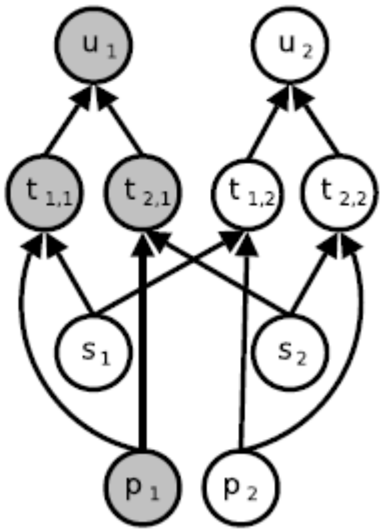
- okd process parses user input, holds no sensitive data
- svc_i process parses user input for one service; runs in chroot()ed "jail"
- database proxy process only accepts authenticated requests for subset of narrow RPC interface; can read sensitive data



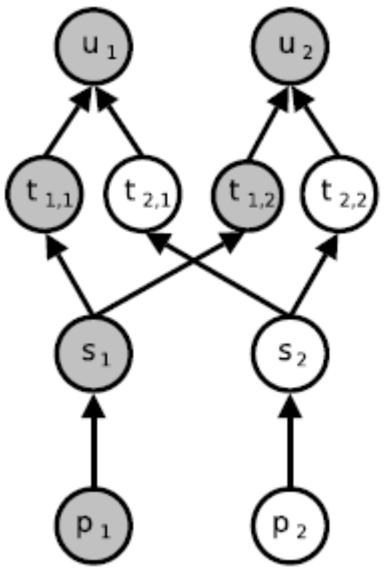
Analyzing Privilege-Separated Designs

- 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



"Strict" Model



OKWS Model

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

- 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

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