Secure Architecture Principles

Slides credit: Dan Boneh

What Happens if you can’t drop privilege?

- In what example scenarios does this happen?
  - A service loop
  - E.g., ssh
- Solution?
  - Privilege separation
  - Identifying operations that need privileges
  - Separate original code into master (priviledged) and slave (unprivileged)
- Example: ssh

Privilege Separation

- Process:
  - Step 1: Identify which operations require privilege
  - Step 2: rewrite programs into 2 or more parts
- Approach:
  - Manual
    - Have been done on security-critical programs, e.g., ssh
    - Labor-intensive and may miss privileged operations
  - Automatic (e.g., Privtrans [Brumley-Song-2004])
    - Automatic inference of privileged operations using a few initial annotations
    - Automatic source-to-source rewriting
      - Privileged code move into master
      - Unprivileged code move into slave
      - Stubs for inter communication

Automatic Privilege Separation

- Step 1: automatic inference of privileged data and operations
  - Given some initial annotations of privileged data and/or operations, infer what other data/operations are privileged
  - Idea: can be viewed as a form of static taint analysis
  - Approach:
    - Define qualifier _priv_ and _unpriv_
    - Operations on _priv_ results in _priv_

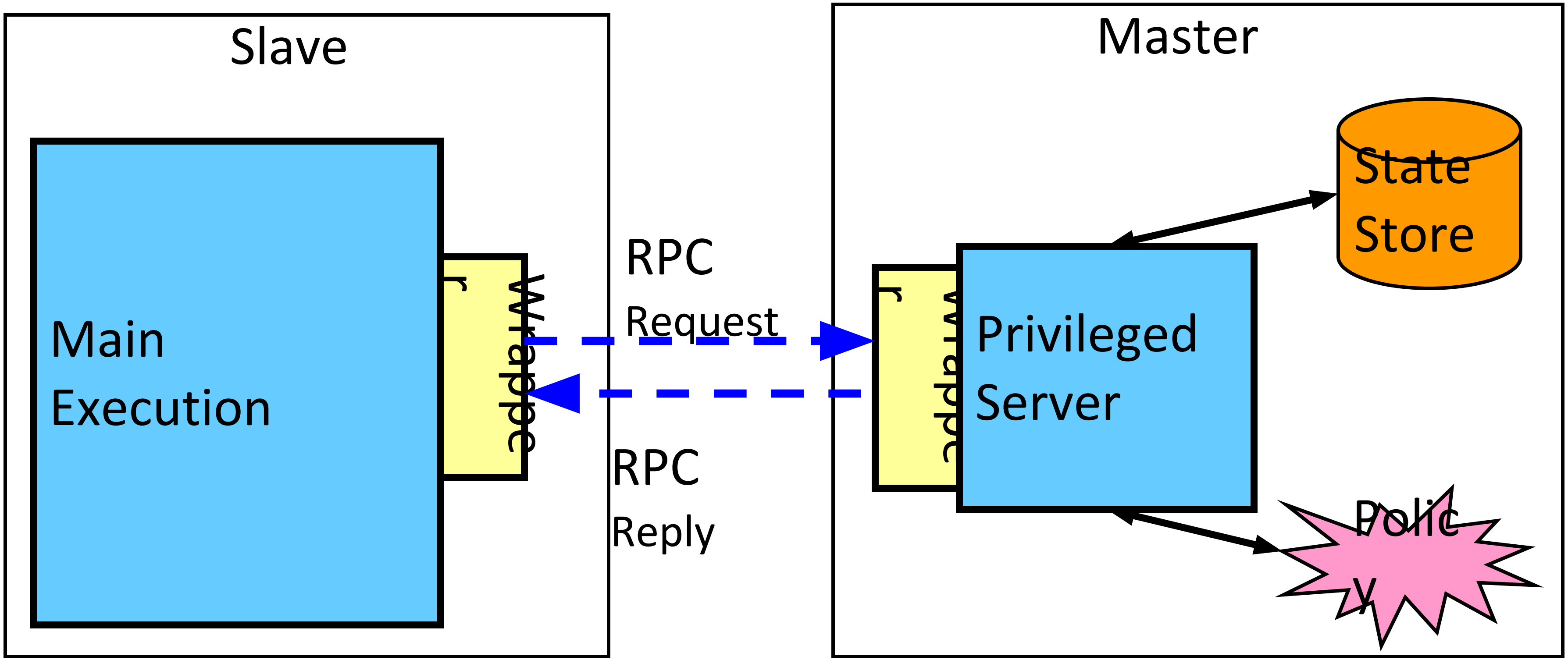
```
int _priv_ a;
Int _priv_  f();
int b = f(a);
c= c+b;
g(c);
```

priv b
priv c
priv g

Automatic Privilege Separation

- Step 2: automatic source-to-source transformation
  - Move privileged data and code to Master
  - For call to privileged functions, change the call site to a wrapper function which marshals the args on slave side and sends them to Master's stub
  - Similar stubs on returns for unprivileged return values

Privilege Separation at Runtime



Summary: Privilege Separation

- Only master is privileged, usually much smaller
- Slave is unprivileged
- Bug in slave cannot harm master, cannot gain privilege
- How to protect master from a compromised slave?
  - Fault isolation: e.g., running in different processes

Setuid programming

- Be Careful with Setuid 0 !
    - Root can do anything; don’ t get tricked
    - Principle of least privilege – change EUID when root privileges no longer needed

Non-Language-Specific Vulnerabilities

```
// Part of a setuid program
if (access("file", W_OK) != 0) {
   exit(1);
}



fd = open("file", O_WRONLY);
write(fd, buffer, sizeof
   (buffer));
```

access(“file”, W_OK)	Returns 0 if the user invoking the program has write access to “file” (it checks the real uid, the actual id of the user, as opposed to the effective uid, the id associated with the process)
open(“file”, O_WRONLY)	Returns a handle to “file” to be used for writing only
write(fd, buffer …)	Writes the contents of buffer to “file”

Time-of-Check-to-Time-of-Use (TOCTTOU)

```
// Part of a setuid program
if (access("file", W_OK) != 0) {
   exit(1);
}


fd = open("file", O_WRONLY);
write(fd, buffer, sizeof
   (buffer));
```

```
// After the access check
symlink("/etc/passwd",
   "file");
// Before the open, "file"
   points to the password
   database
```

access(“file”, W_OK)	Returns 0 if the user invoking the program has write access to “file” (it checks the real uid, the actual id of the user, as opposed to the effective uid, the id associated with the process)
open(“file”, O_WRONLY)	Returns a handle to “file” to be used for writing only
write(fd, buffer …)	Writes the contents of buffer to “file”
symlink(“/etc/passwd”, “file”)	Creates a symlink from “file” to “/etc/passwd”. A symbolic link is a reference to another file, so in this case the attacker causes “file” (which they have privileges for) to point to “/etc/passwd”. The program then opens “/etc/passwd” instead of “file”.

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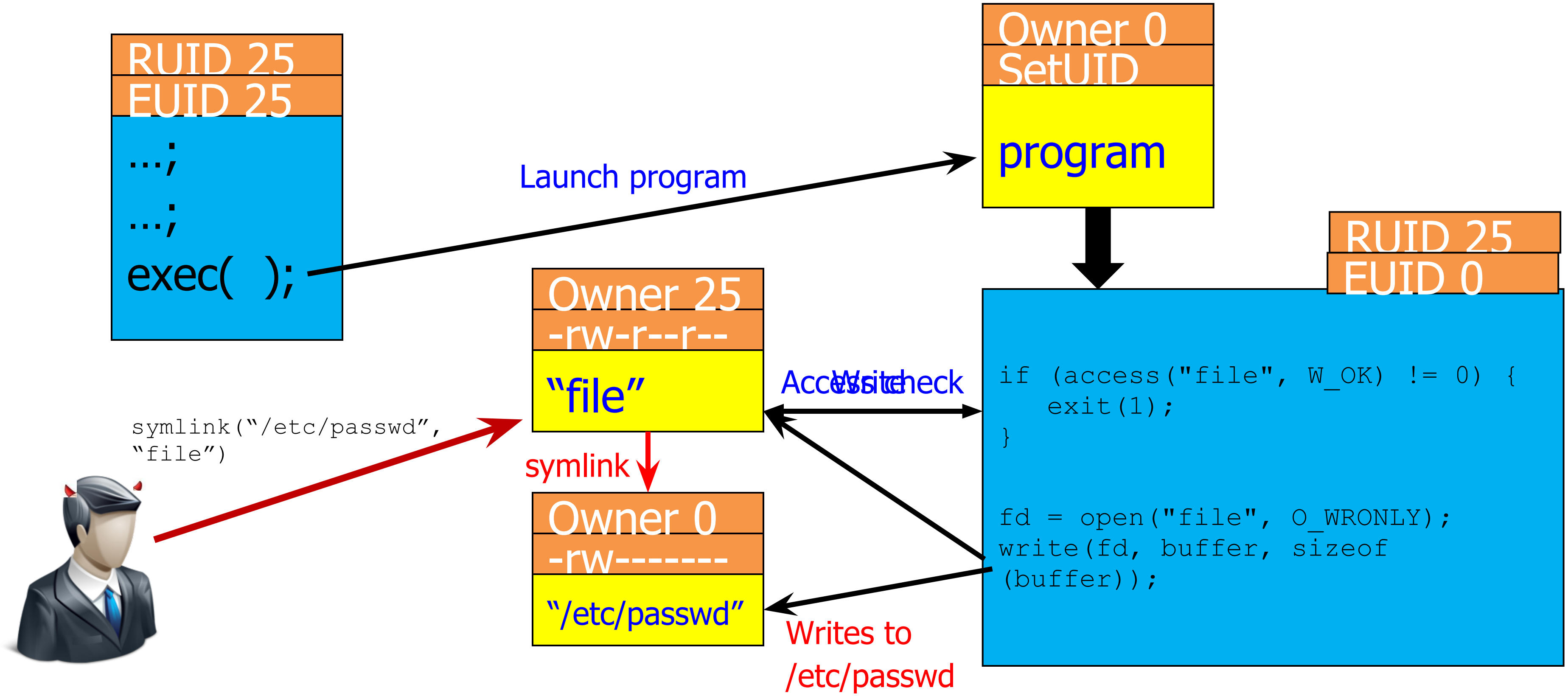
TOCTTOU



RUID 25
EUID 25

…;
…;
exec( );

Launch program

Owner 0
SetUID

program

RUID 25
EUID 0

```
if (access("file", W_OK) != 0) {
   exit(1);
}

fd = open("file", O_WRONLY);
write(fd, buffer, sizeof
(buffer));
```

Owner 25
-rw-r--r--

"file"

Access check

Write

symlink

Owner 0
-rw-------

"/etc/passwd"

Writes to /etc/passwd

`symlink("/etc/passwd", "file")`

The Flaw?

- Code assumes FS is unchanged between `access()` and `open()` calls – Never assume anything…
- An attacker could change file referred to by “`file`” in between `access()` and `open()`
  - Eg. `symlink(“/etc/passwd”, “file”)`
  - Bypasses the check in the code!
  - Although the user does not have write privileges for `/etc/passwd`, the program does (and the attacker has privileges for `file`, so they are allowed to create the symbolic link)

TOCTTOU Vulnerability

- In Unix, often occurs with file system calls because system calls are not atomic
- But, TOCTTOU vulnerabilities can arise anywhere there is mutable state shared between two or more entities
  - Example: multi-threaded Java servlets and applications are at risk for TOCTTOU

Unix summary

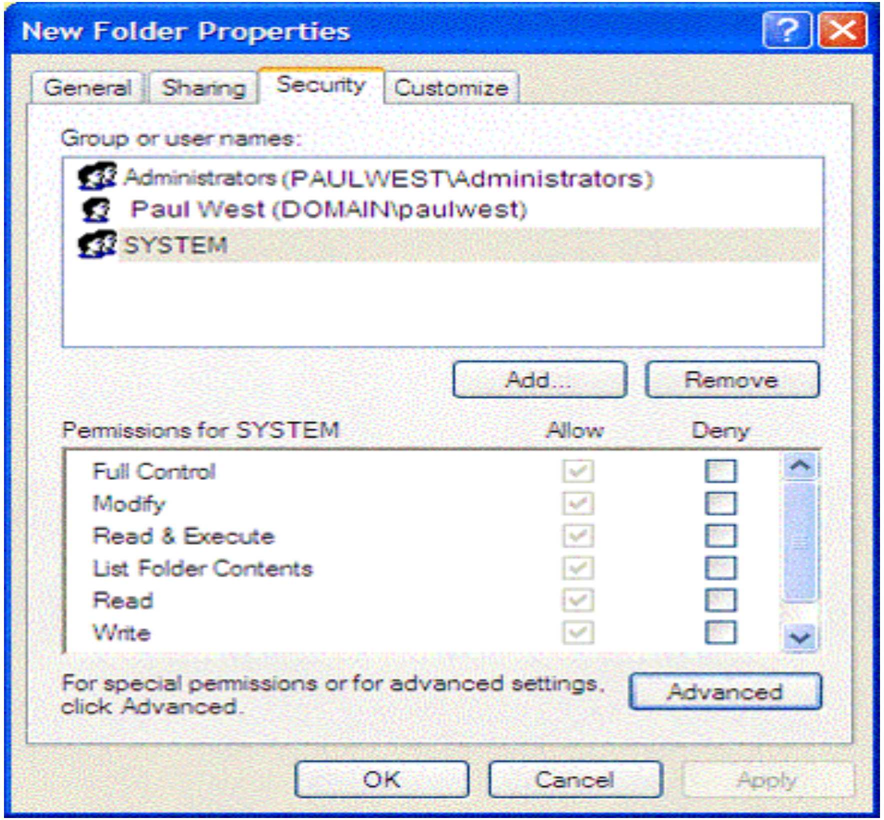
- Good things
  - Some protection from most users
  - Flexible enough to make things possible
- Main limitation
  - Too tempting to use root privileges
  - No way to assume some root privileges without all root privileges

Access control in Windows (since NTFS)

- Some basic functionality similar to Unix
  - Specify access for groups and users
    - Read, modify, change owner, delete
- Some additional concepts
  - Tokens
  - Security attributes
- Generally
  - More flexibility than Unix
    - Can define new permissions
    - Can give some but not all administrator privileges

Identify subject using SID

- Security ID (SID)
  - Identity (replaces UID)
    - SID revision number
    - 48-bit authority value
    - variable number of Relative Identifiers (RIDs), for uniqueness
  - Users, groups, computers, domains, domain members all have SIDs



New Folder Properties

Group or user names:

Administrators (PAULWEST\Administrators)
Paul West (DOMAIN\paulwest)
SYSTEM

Permissions for SYSTEM	Allow	Deny
Full Control	☑	☐
Modify	☑	☐
Read & Execute	☑	☐
List Folder Contents	☑	☐
Read	☑	☐
Write	☑	☐

For special permissions or for advanced settings, click Advanced.

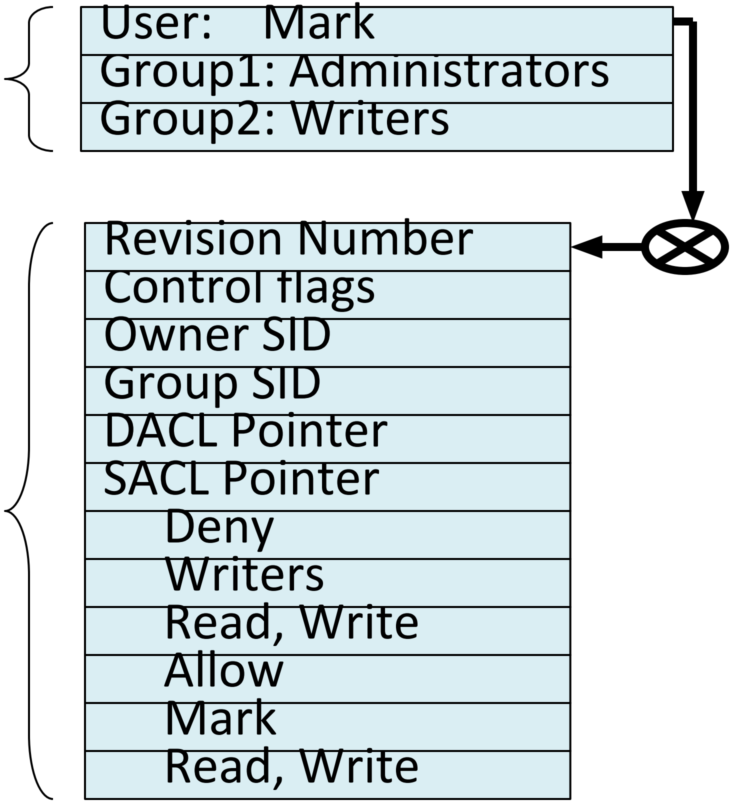
Process has set of tokens

- Security context
  - Privileges, accounts, and groups associated with the process or thread
  - Presented as set of tokens
- Security Reference Monitor
  - Uses tokens to identify the security context of a process or thread
- Impersonation token
  - Used temporarily to adopt a different security context, usually of another user

Object has security descriptor

- Security descriptor associated with an object
  - Specifies who can perform what actions on the object
- Several fields
  - Header
    - Descriptor revision number
    - Control flags, attributes of the descriptor
      - E.g., memory layout of the descriptor
  - SID of the object's owner
  - SID of the primary group of the object
  - Two attached optional lists:
    - Discretionary Access Control List (DACL) – users, groups, …
    - System Access Control List (SACL) – system logs, ..

Example access request



Access token

User: Mark
Group1: Administrators
Group2: Writers

Security descriptor

Revision Number
Control flags
Owner SID
Group SID
DACL Pointer
SACL Pointer
Deny
Writers
Read, Write
Allow
Mark
Read, Write

Access request: write
Action: denied

- User Mark requests write permission
- Descriptor denies permission to group
- Reference Monitor denies request

(DACL for access, SACL for audit and logging)

Priority:
Explicit Deny
Explicit Allow
Inherited Deny
Inherited Allow

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Impersonation Tokens (compare to setuid)

- Process adopts security attributes of another
  - Client passes impersonation token to server
- Client specifies impersonation level of server
  - Anonymous
    - Token has no information about the client
  - Identification
    - server obtain the SIDs of client and client's privileges, but server cannot impersonate the client
  - Impersonation
    - server identify and impersonate the client
  - Delegation
    - lets server impersonate client on local, remote systems

Creating Jail

Creating Jail: chroot

- “Change root”- changes the root directory of current process
- Example (within a process):

```
chroot /tmp/guest
su guest
```

- The root directory for this process (“/”) is now resolved to “/tmp/guest”, and the EUID is set to “guest” (handled by the operating system)

Creating Jail: chroot

- If done properly, the process can no longer access files outside of "/tmp/guest"
- Eg: `open("/etc/passwd", "r")` ⇒
  - `open("/tmp/guest/etc/passwd" , "r")`

- Must consider other processes which it may need to invoke (eg. from /usr/bin)- these must be provided for the environment

Escaping from jails

Early escapes: relative paths

`open( “../../etc/passwd”, “r”)` ⇒

`open(“/tmp/guest/../../etc/passwd”, “r”)`

Many ways to escape jail as root

- Create device that lets you access raw disk
- Send signals to non chrooted process
- Reboot system
- Bind to privileged ports

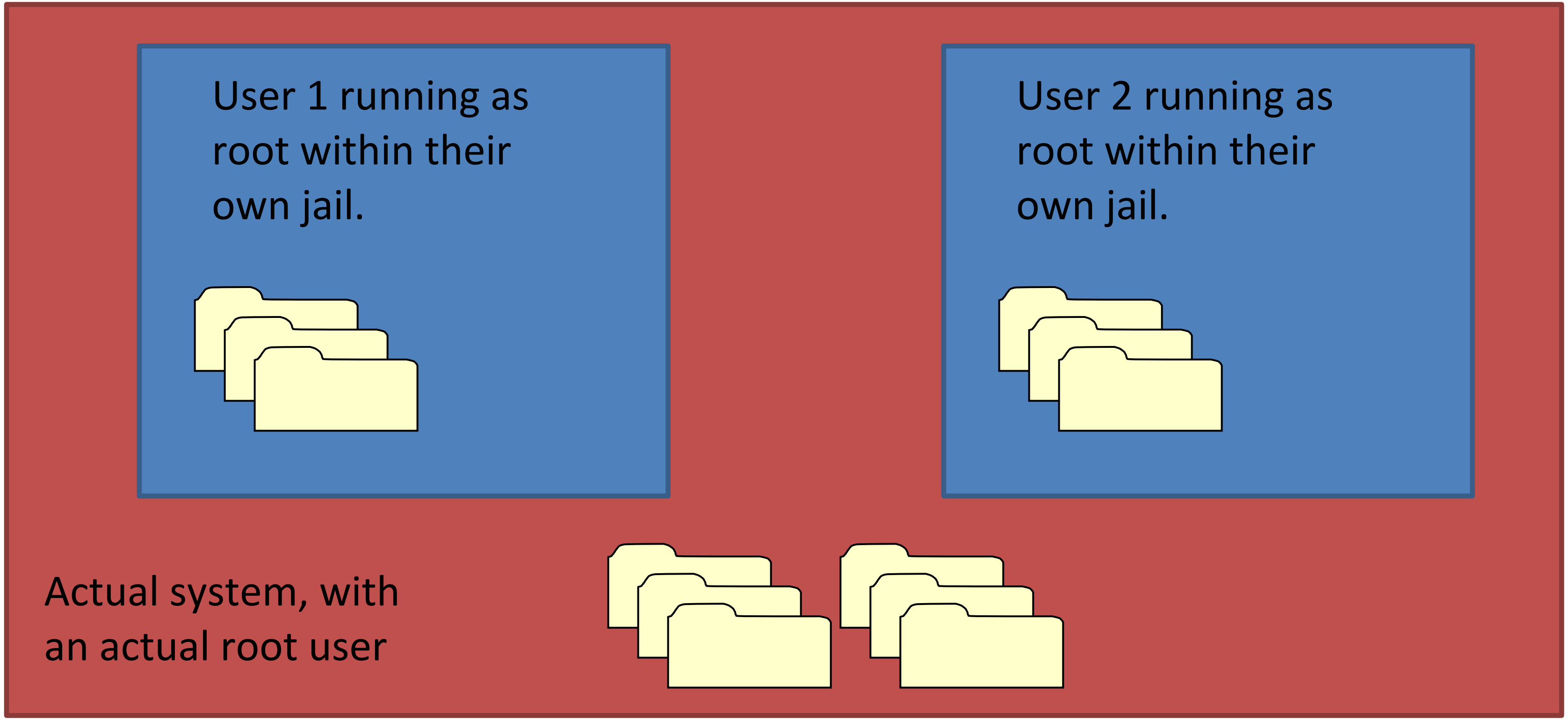
FreeBSD jail

Stronger mechanism than simple chroot

To run: **jail jail-path hostname IP-addr cmd**

- calls hardened chroot (no "../../" escape)
- can only bind to sockets with specified IP address and authorized ports
- can only communicate with processes inside jail
- root is limited, e.g. cannot load kernel modules

FreeBSD jail



User 1 running as root within their own jail.

User 2 running as root within their own jail.

Actual system, with an actual root user

Problems with chroot and jail

<u>Coarse policies</u>:

- All or nothing access to parts of file system
- Inappropriate for apps like a web browser
  - Needs read access to files outside jail
    (e.g. for sending attachments in Gmail)

Does not prevent malicious apps from:

- Accessing network and messing with other machines
- Trying to crash host OS

System Call Interposition

System call interposition

Observation: to damage host system (e.g. persistent changes) app must make system calls:

- To delete/overwrite files: unlink, open, write
- To do network attacks: socket, bind, connect, send

Idea: monitor app's system calls and block unauthorized calls

Implementation options

- Completely kernel space (e.g. GSWTK)
- Completely user space (e.g. program shepherding)
- Hybrid (e.g. Systrace)

ptrace

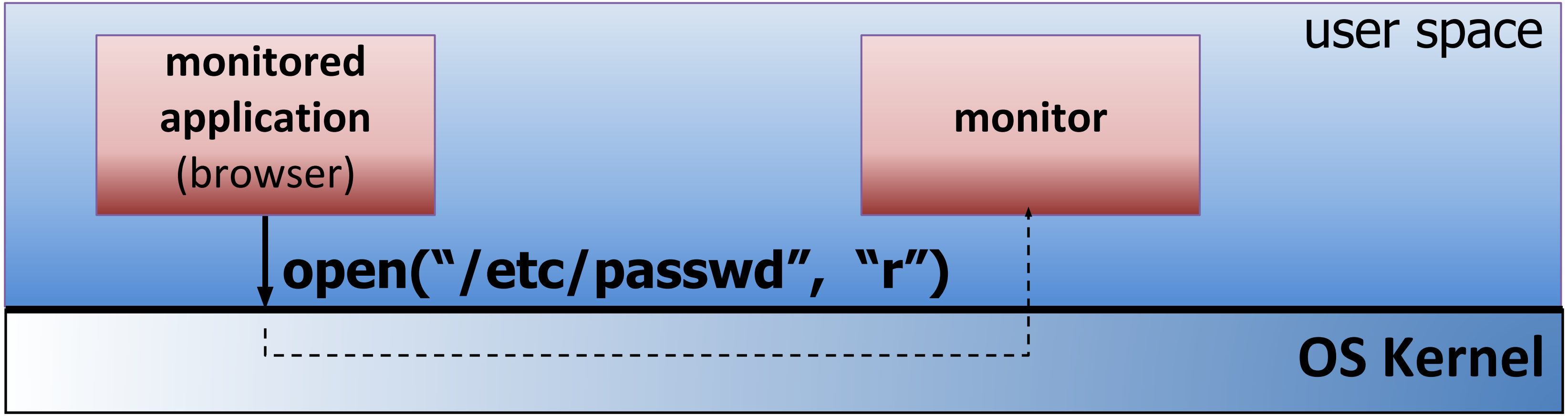
- ptrace (process trace) allows one process to
  - monitor signals sent to and from the controlled process, as well as state in registers, file descriptors, and memory
  - control another process by altering its internal state

Initial implementation (Janus) [GWTB'96]

Linux **ptrace**: process tracing

process calls: **ptrace (… , pid_t pid , …)**

and wakes up when **pid** makes sys call.



Monitor kills application if request is disallowed

Complications

```
cd("/tmp")
open("passwd", "r")


cd("/etc")
open("passwd", "r")
```

- If app forks, monitor must also fork
  - forked monitor monitors forked app
- If monitor crashes, app must be killed
- Monitor must maintain all OS state associated with app
  - current-working-dir (**CWD**), **UID**, **EUID**, **GID**
  - When app does "cd path" monitor must update its CWD
    - otherwise: relative path requests interpreted incorrectly

Problems with ptrace

Ptrace is not well suited for this application:

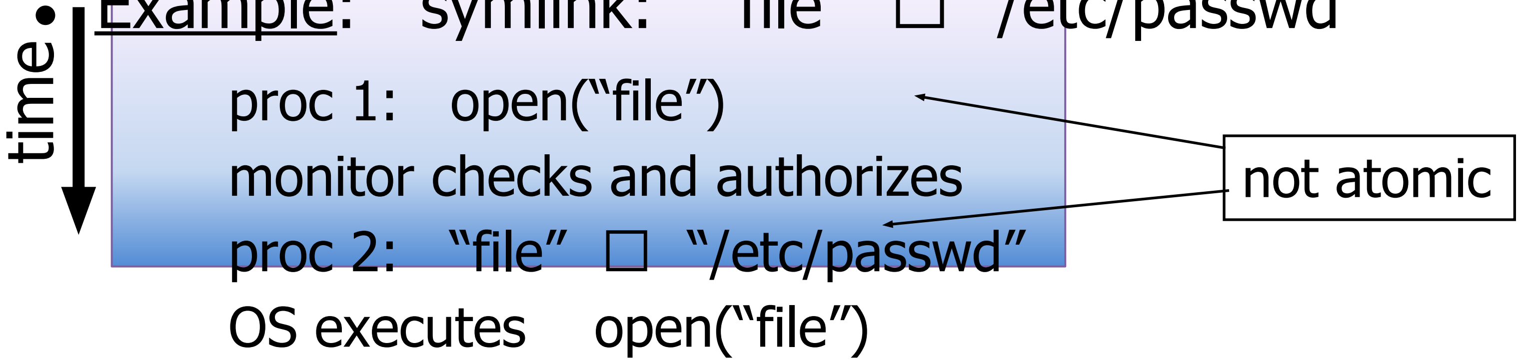
- Trace all system calls or none

  inefficient: no need to trace “close” system call

- Monitor cannot abort sys-call without killing app

Security problems: **race conditions**

- Example: symlink: “file” ☐ “/etc/passwd”



proc 1: open(“file”)

monitor checks and authorizes

proc 2: “file” ☐ “/etc/passwd”

OS executes open(“file”)

Which of the following sequence of events is a TOCTOU exploit?

P1: open(“temp”, “w”)
P2: temp □ “important.txt”
monitor checks P1’s write request
OS opens “temp” (if monitor approves)

P2: temp □ “important.txt”
P1: open(“temp”, “w”)
monitor checks P1’s write request
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