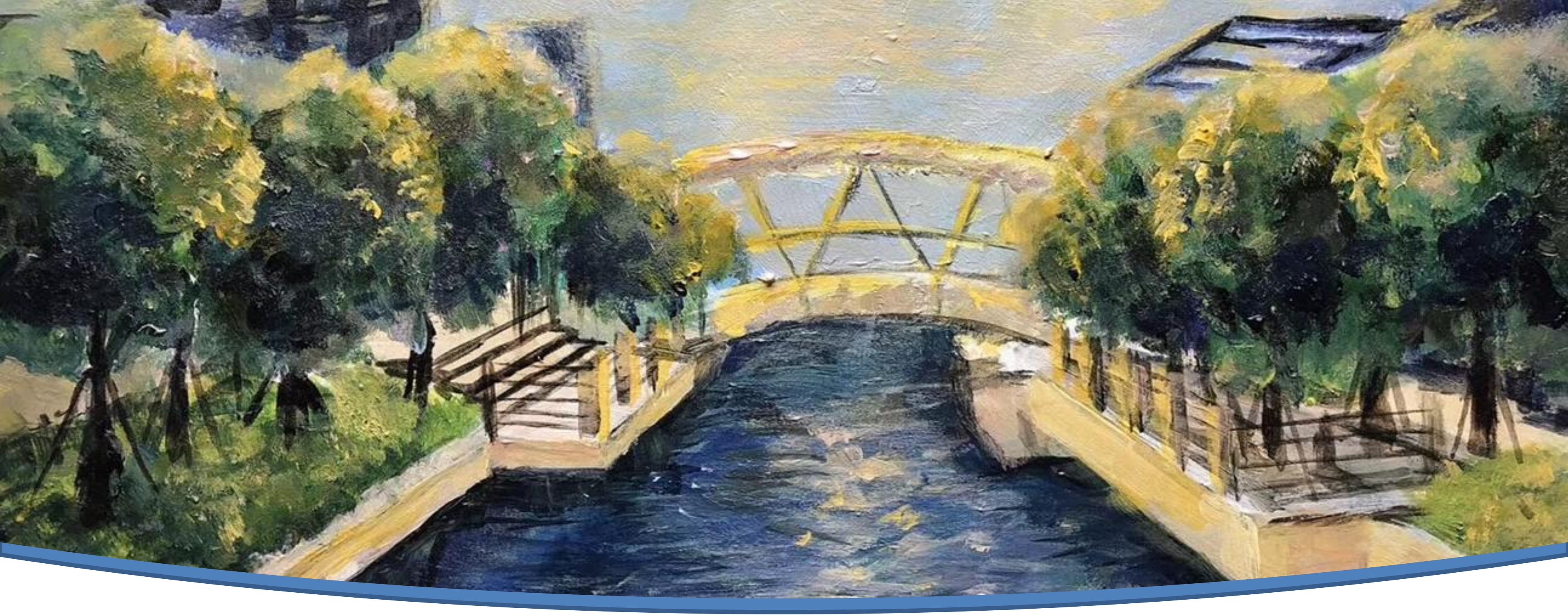


CS 253 Cyber Security
The confinement principle

ShanghaiTech University

Admin

- Project 1 ddl: 10/8 23:59

PART ONE

01

Confinement

Running untrusted code

We often need to run buggy/unstrusted code:

- programs from untrusted Internet sites:
  - mobile apps, Javascript, browser extensions
- exposed applications: browser, pdf viewer, outlook
- legacy daemons: sendmail, bind
- honeypots

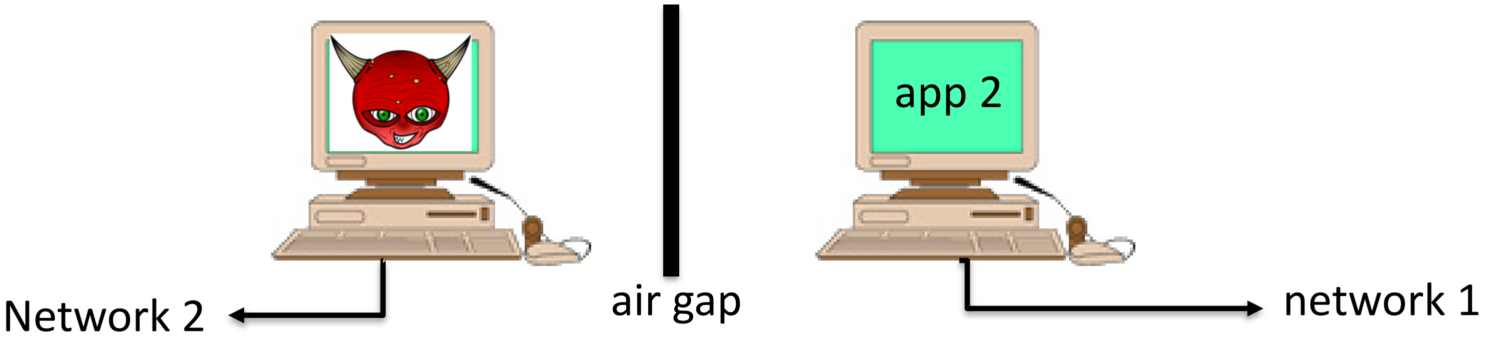
Goal: if application "misbehaves" $\Rightarrow$ kill it

Approach: confinement

Confinement: ensure misbehaving app cannot harm rest of system

Can be implemented at many levels:

- **Hardware**: run application on isolated hw (air gap)



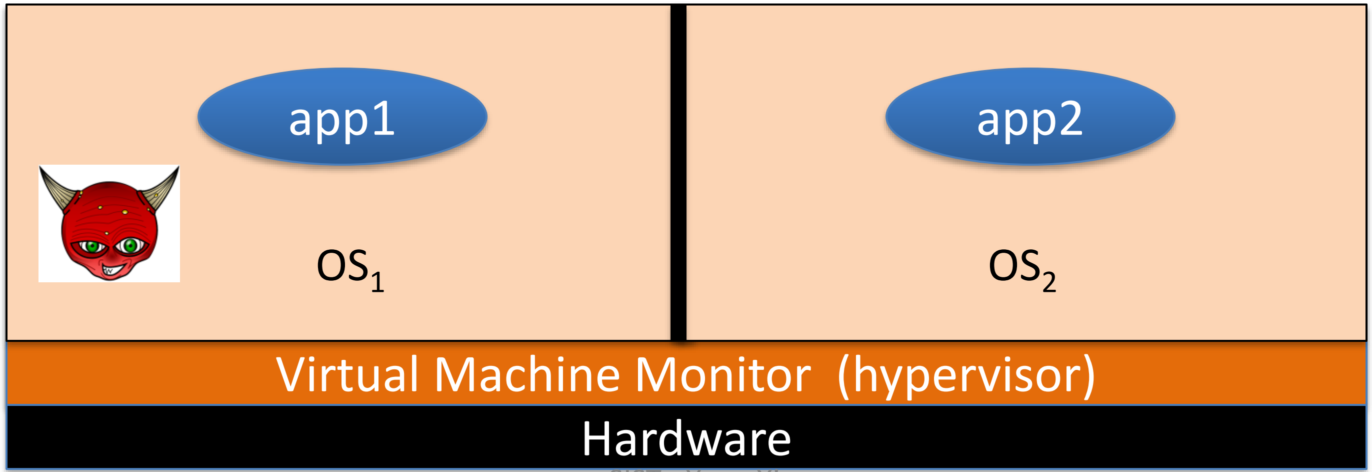
⇒ difficult to manage

Approach: confinement

Confinement: ensure misbehaving app cannot harm rest of system

Can be implemented at many levels:

– **Virtual machines**: isolate OS's on a single machine



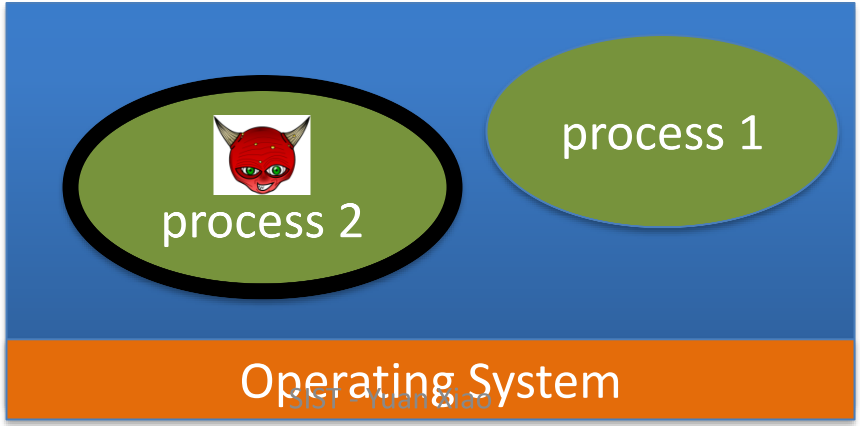
Approach: confinement

Confinement: ensure misbehaving app cannot harm rest of system

Can be implemented at many levels:

– **Process:** System Call Interposition (containers)

Isolate a process in a single operating system



Approach: confinement

Confinement: ensure misbehaving app cannot harm rest of system

Can be implemented at many levels:

- **Threads:** Software Fault Isolation (SFI)
  - Isolating threads sharing same address space

- **Application level confinement**:
  e.g. browser sandbox for Javascript and WebAssembly

Implementing confinement

Key component: **reference monitor**

- **Mediates requests** from applications
  - Enforces confinement
  - Implements a specified protection policy
- Must **always** be invoked:
  - Every application request must be mediated
- **Tamperproof**:
  - Reference monitor cannot be killed
    … or if killed, then monitored process is killed too
- **Small** enough to be analyzed and validated

A old example: chroot

To use do: (must be root)

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

root dir "/" is now "/tmp/guest"

EUID set to "guest"

Now "/tmp/guest" is added to every file system accesses:

fopen("/etc/passwd", "r") ⇒
fopen("/tmp/guest/etc/passwd" , "r")

⇒ application (e.g., web server) cannot access files outside of jail

Escaping from jails

Early escapes: relative paths

fopen(“../../etc/passwd”, “r”) ⇒

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

---

chroot should only be executable by root.

- otherwise jailed app can do:
  - create dummy file “/aaa/etc/passwd”
  - run chroot “/aaa”
  - run su root to become root

(bug in Ultrix 4.0)

Problems with chroot and jail

Coarse policies:

- 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

PART TWO

02

System Call Interposition:

sanboxing a process

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:

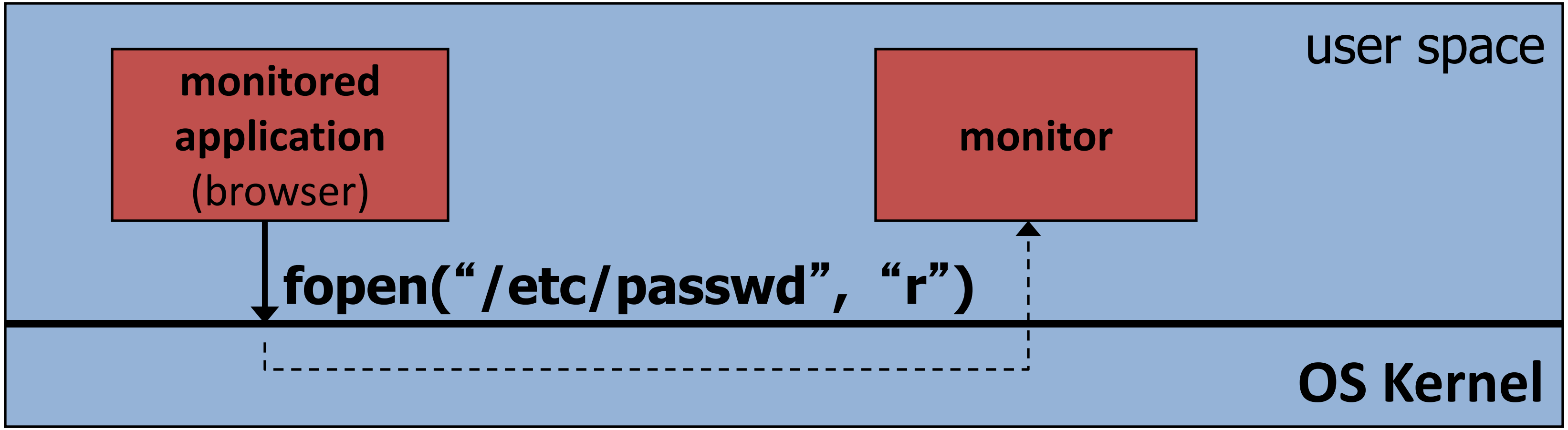
- Completely kernel space (e.g., Linux seccomp)
- Completely user space (e.g., program shepherding)
- Hybrid (e.g., Systrace)

Early 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

Example policy

Sample policy file (e.g., for PDF reader)

```
path allow  /tmp/*
path deny  /etc/passwd
network deny all
```

Manually specifying policy for an app can be difficult:

- Recommended default policies are available

… can be made more restrictive as needed.

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: me ⟶ mydata.dat

time ↓

proc 1: open("me")

monitor checks and authorizes

proc 2: me ⟶ /etc/passwd

OS executes open("me")

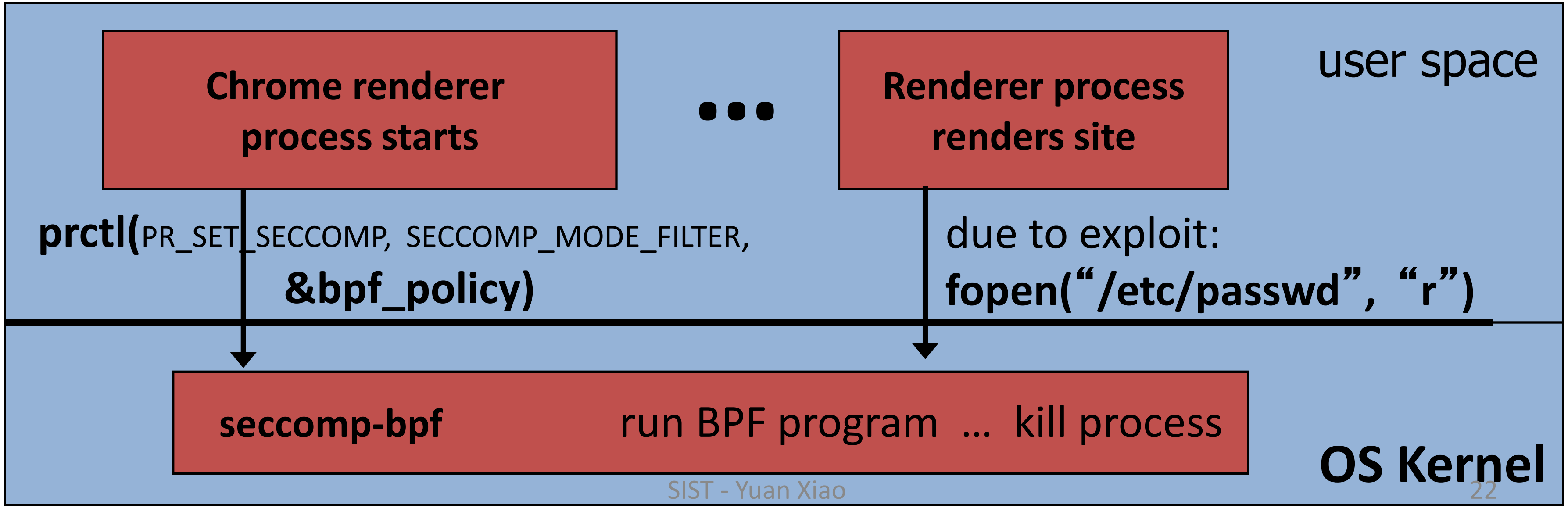
not atomic

Classic **TOCTOU bug**: time-of-check / time-of-use

SCI in Linux: seccomp-bpf

Seccomp-BPF: Linux kernel facility used to filter process sys calls

- Sys-call filter written in the BPF language (use BPFC compiler)
- Used in **Chromium, Docker containers**, …



BPF filters (policy programs)

Process can install multiple BPF filters:

- once installed, filter cannot be removed (all run on every syscall)
- if program forks, child inherits all filters
- if program calls execve, all filters are preserved

BPF filter input: syscall number, syscall args., arch. (x86 or ARM)

Filter returns one of:

- SECCOMP_RET_KILL: kill process
- SECCOMP_RET_ERRNO: return specified error to caller
- SECCOMP_RET_ALLOW: allow syscall

Installing a BPF filter

- Must be called before setting BPF filter.
- Ensures set-UID, set-GID ignored on subequent execve()
  ⇒ attacker cannot elevate privilege

```
int main (int argc , char **argv )  {
    prctl(PR_SET_NO_NEW_PRIVS , 1);
    prctl(PR_SET_SECCOMP,  SECCOMP_MODE_FILTER,  &bpf_policy)
    fopen(“file.txt",  “w”);
    printf(“… will not be printed. \n” );
}
```

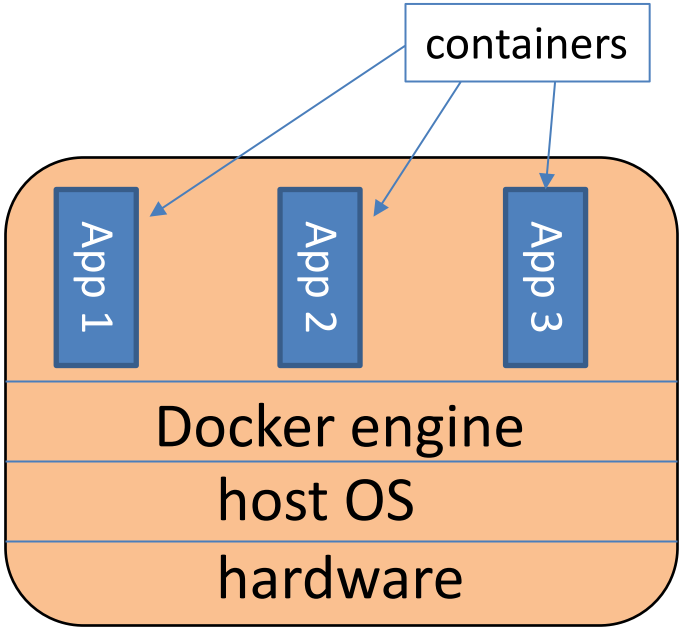
Kill if call open() for write

Docker: isolating containers using seccomp-bpf

Container: process level isolation

- Container prevented from making sys calls filtered by secomp-BPF

- Whoever starts container can specify BPF policy
  - default policy blocks many syscalls, including ptrace



Docker sys call filtering

Run nginx container with a specific filter called filter.json:

$ docker run --security-opt=“seccomp=filter.json” nginx

Example filter:

```
“defaultAction”:  “SCMP_ACT_ERRNO”,          //  deny by default

“syscalls”: [

        {  "names":  ["accept”],              //  sys-call name
           "action":  "SCMP_ACT_ALLOW",       //  allow (whitelist)
           "args": [ ]  } ,                   // what args to allow
              …
      ]
```

More Docker confinement flags

Specify as an unprivileged user:

$ docker run --user www nginx

Limit Linux capabilities:

$ docker run --cap-drop all --cap-add NET_BIND_SERVICE nginx

drop all capabilities

allow to bind to privileged ports

Prevent process from becoming privileged (e.g., by a setuid binary)

$ docker run --security-opt=no-new-privileges:true nginx

Limit number of restarts and resources (# open files, # processes):

$ docker run --restart=on-failure:<max-retries>

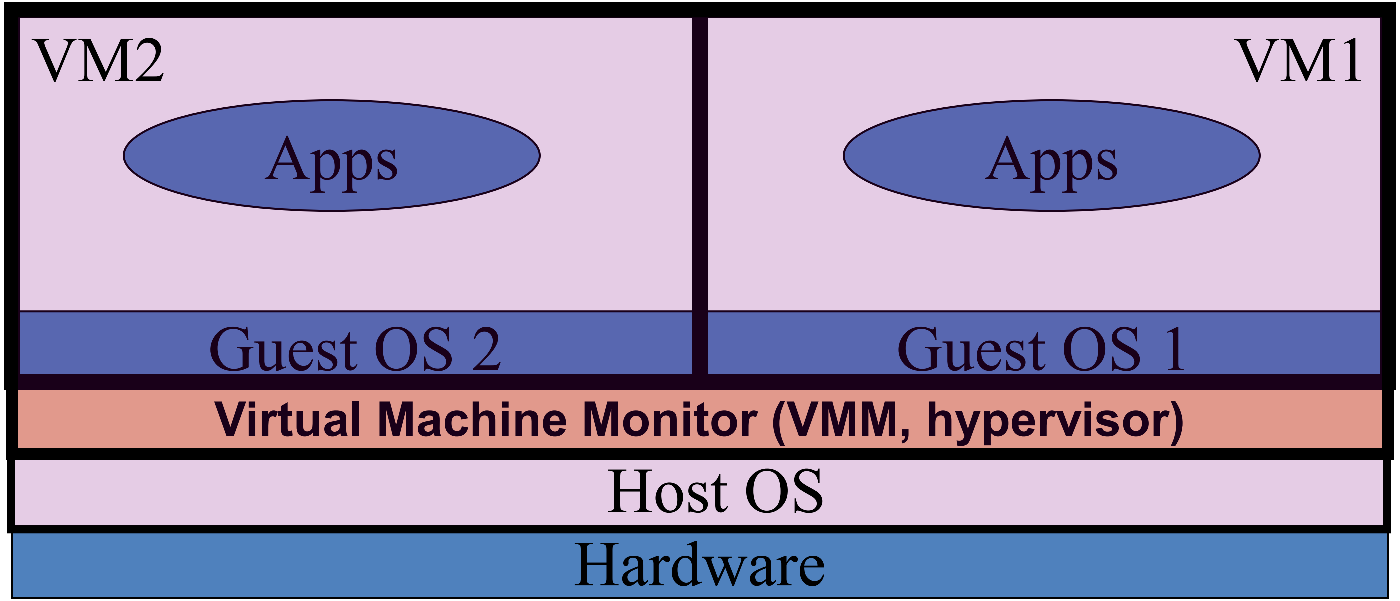
--ulimit nofile=<max-fd> --ulimit nproc=<max-proc> nginx

PART THREE

03

Confinement Via Virtual Machines

Virtual Machines



single HW platform with isolated components

Why so popular?

VMs in the 1960's:

- Few computers, lots of users
- VMs allow many users to shares a single computer

VMs 1970's – 2000: non-existent

VMs since 2000:

- Too many computers, too few users
  - Print server, Mail server, Web server, File server, Database , …
- VMs heavily used in private and public clouds

Hypervisor security assumption

Hypervisor Security assumption:

- Malware can infect guest OS and guest apps
- But malware cannot escape from the infected VM
  - Cannot infect host OS
  - Cannot infect other VMs on the same hardware

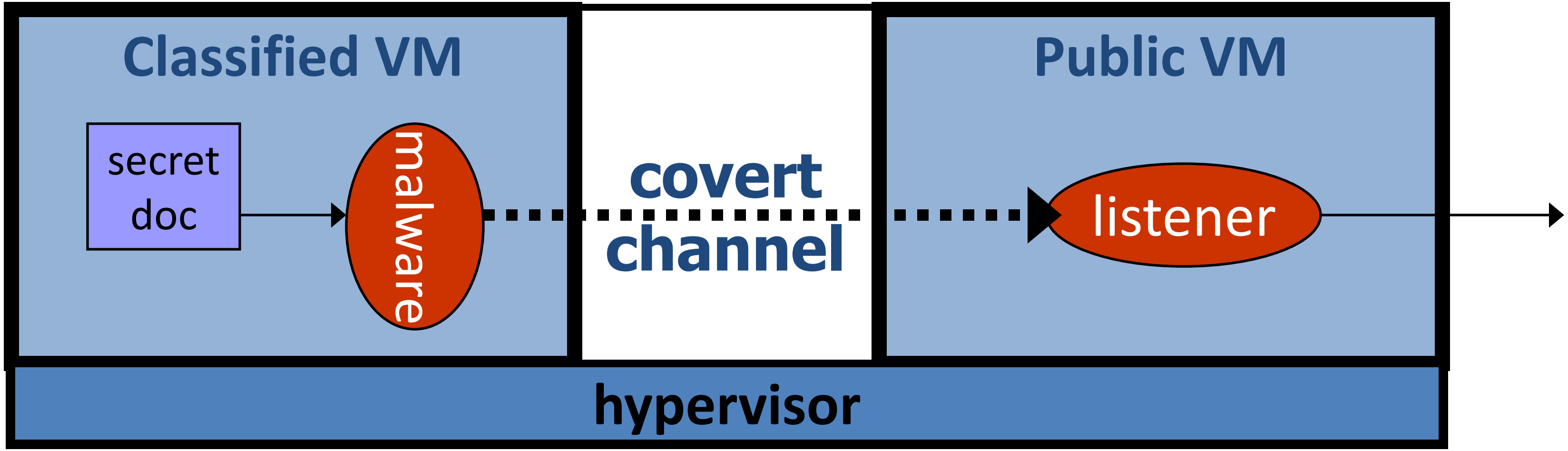
Requires that hypervisor protect itself and is not buggy

- (some) hypervisors are much simpler than a full OS

Problem: covert channels

Covert channel: unintended communication channel between isolated components

- Can leak classified data from secure component to public component



An example covert channel

Both VMs use the same underlying hardware

To send a bit $b \in \{0,1\}$ malware does:

- b= 1: at 1:00am do CPU intensive calculation
- b= 0: at 1:00am do nothing

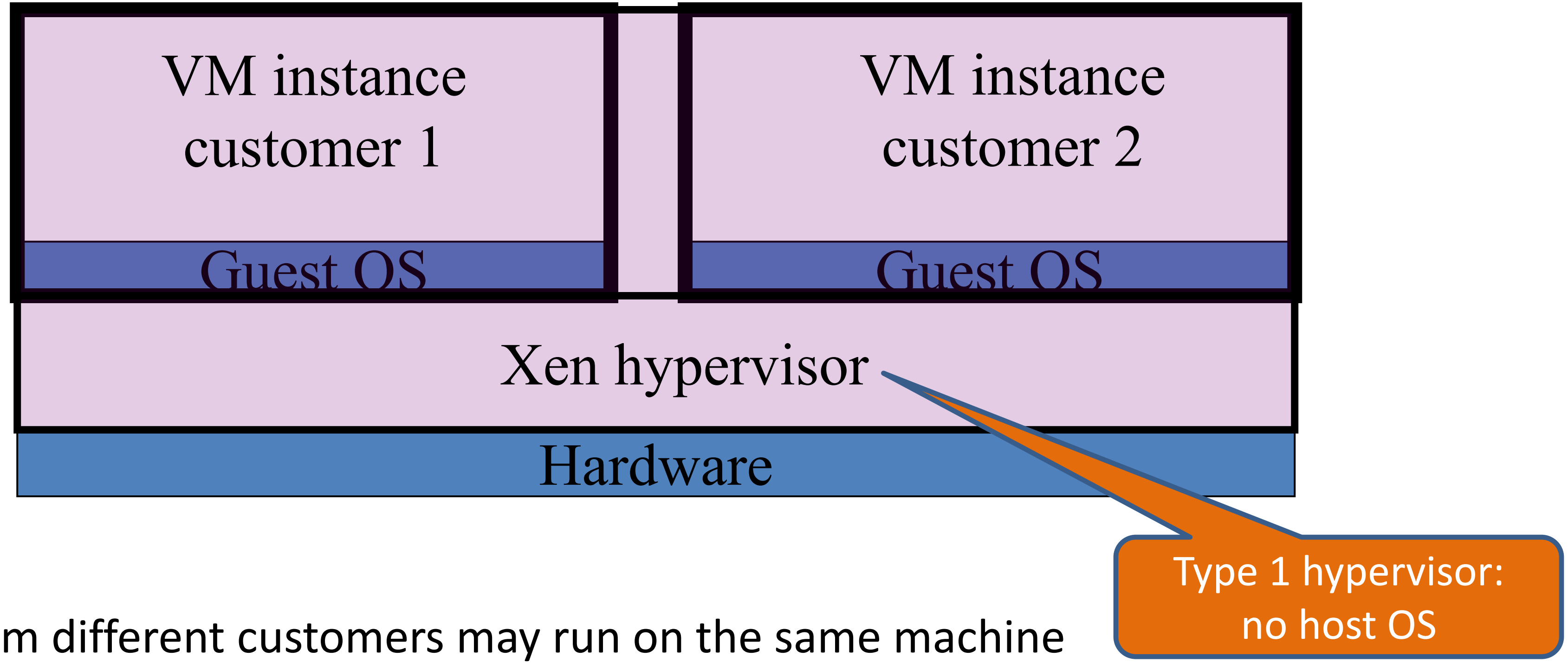
At 1:00am listener does CPU intensive calc. and measures completion time

$$b = 1 \quad \Rightarrow \quad \text{completion-time} > \text{threshold}$$

Many covert channels exist in running system:

- File lock status, cache contents, interrupts, …
- Difficult to eliminate all

VM isolation in practice: cloud



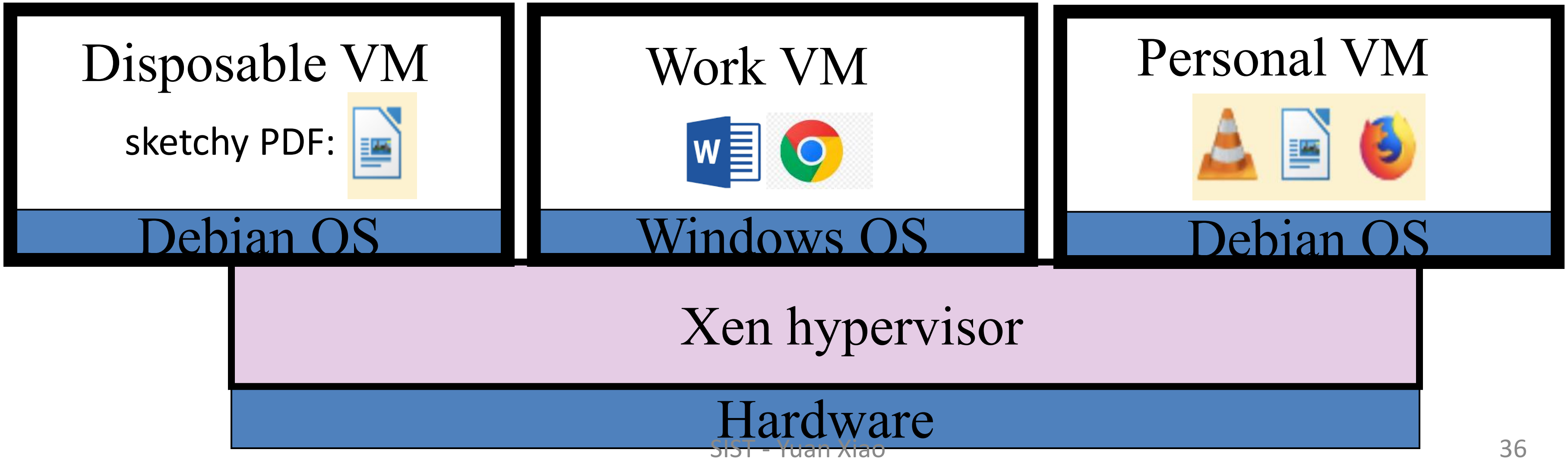
VMs from different customers may run on the same machine

- Hypervisor must isolate VMs … but some info leaks

VM isolation in practice: end-user

Qubes OS: a desktop/laptop OS where everything is a VM

- Runs on top of the Xen hypervisor
- Access to peripherals (mic, camera, usb, …) controlled by VMs



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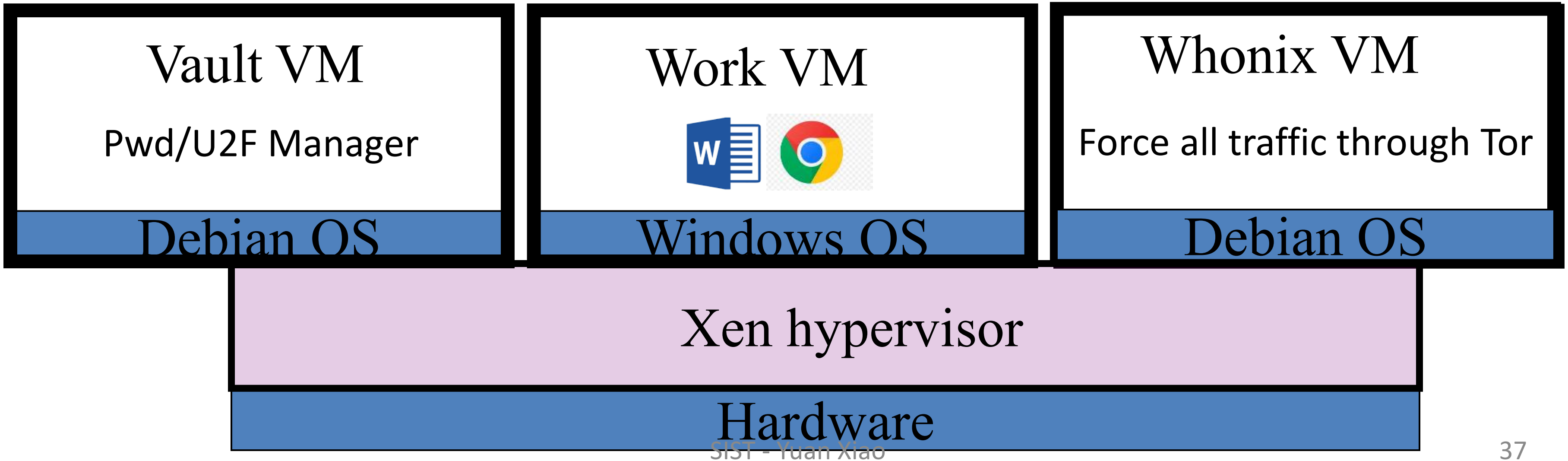
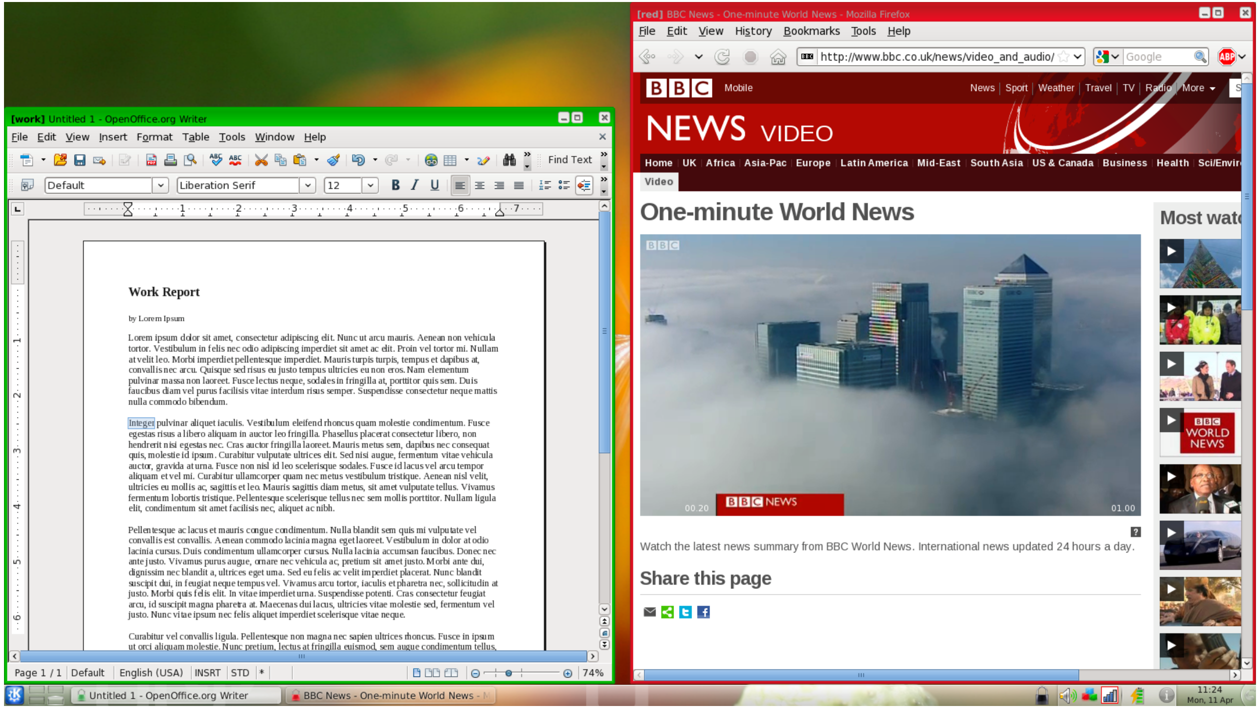


Every window frame identifies VM source



GUI VM ensures frames are drawn correctly

THE END