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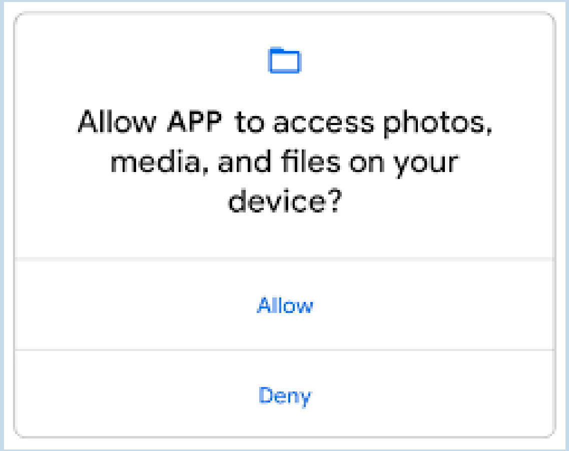
Operating Systems Security

Security Engineering (Spring 2026)

Lecturer: Jingjie Li & Daniel Woods

- Operating systems managing hardware and software resources – main entry point of enforcing security policies.
- How does an OS enforce security policy we defined?
- How do we isolate resources for security?

Who are interested in defining and setting up a security policy?


Allow APP to access photos, media, and files on your device?

Access Control Matrix

Objects (files)

Subjects (users)

	a	**b**	**c**	**d**	**e**
jingjie	r,w	-	r,w, own	-	r
bob	-	-	r	r	r,w
alice	w, own	r	r	-	-
eve	r	r,w	r,w	-	r

Discretionary Access Control - Access Control List

Objects (files)

Subjects (users)

	a	b	c	d	e
jingjie	r,w	-	r,w, own	-	r
bob	-	-	r	r	r,w
alice	w, own	r	r	-	-
eve	r	r,w	r,w	-	r

- Access Control Lists: store permissions with file. May need different permissions for different programs, so actually a (user, file, program) triple
- ACLs scale badly without Role-based access control.
- Finding all the files a user has access to is a massive pain.

Discretionary Access Control - Capabilities

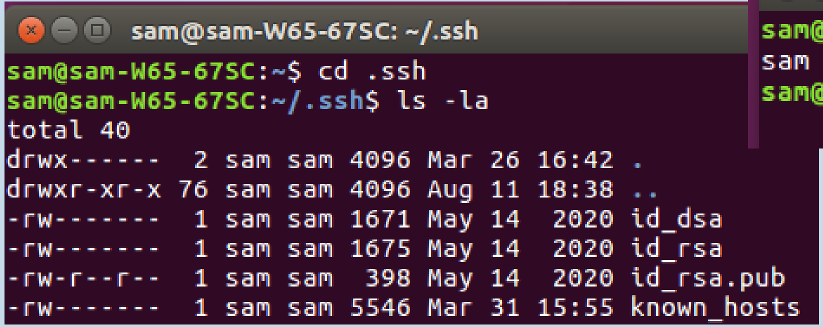
Objects (files)

Subjects (users)

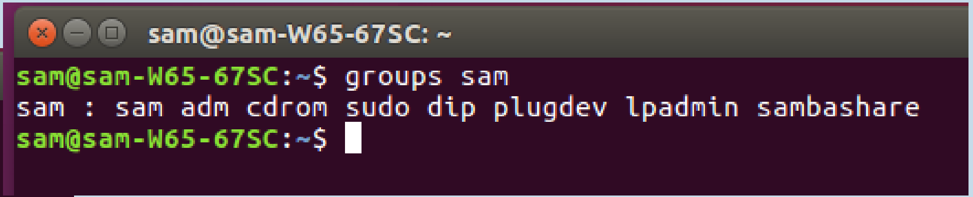
	a	b	c	d	e
jingjie	r,w	-	r,w, own	-	r
bob	-	-	r	r	r,w
alice	w, own	r	r	-	-
eve	r	r,w	r,w	-	r

- Capabilities: store per user, not per file.
- Finding all the users who have access to a file is a pain.
- Hard to revoke access to a particular file, or produce evidence of who could have broken said file.
- Easily transferred
- Public key certificates are really capabilities.

Unix Access Control Lists



```
sam@sam-W65-67SC:~$ cd .ssh
sam@sam-W65-67SC:~/.ssh$ ls -la
total 40
drwx------  2 sam sam 4096 Mar 26 16:42 .
drwxr-xr-x 76 sam sam 4096 Aug 11 18:38 ..
-rw-------  1 sam sam 1671 May 14  2020 id_dsa
-rw-------  1 sam sam 1675 May 14  2020 id_rsa
-rw-r--r--  1 sam sam  398 May 14  2020 id_rsa.pub
-rw-------  1 sam sam 5546 Mar 31 15:55 known_hosts
```



```
sam@sam-W65-67SC:~$ groups sam
sam : sam adm cdrom sudo dip plugdev lpadmin sambashare
sam@sam-W65-67SC:~$
```

- In Unix (and thus Linux, Android, iOS…): rwx attributes, with owner,group,world, per file. Can have richer Posix extended ACL extension.
- Sysadmin can do anything!

Mandatory access control

- Security policy is defined and controlled centrally, enforcing for all users

- DAC: Start in supervisor mode, and as admin, can make less privileged accounts available for less trusted tasks.
- MAC: sysadmin no longer the boss: ultimate control rests with the security policy (possibly set by remote govt authority in defence setting).

- Alternate view (Android): DAC requires **permission** of the user. MAC requires **consent** of user, developer AND platform -- 3-party consent.

Mandatory access control

Bell LaPadula

•Simple Rule (No Read Up): A subject at a given security level may not read an object at a higher security level.

•* Property: (No Write Down): A subject at a given security level may not write to any object at a lower security level.

- Occasionally synonymous with MLS - Multi-Level Security (Unclassified, Confidential, Secret, Top Secret)
- Enforced by system policy, not by user discretion!
- Traditionally for military systems, e.g. Bell LaPadula

Mandatory access control

BIBA

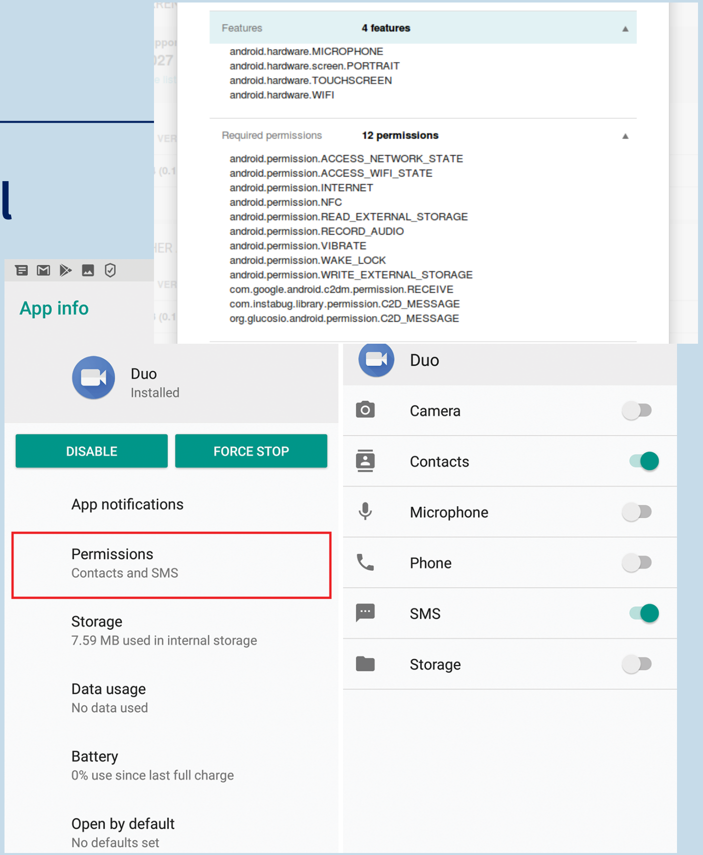
•Simple Rule (No **Write** Up): A subject at a given security level may not write to an object at a higher security level.

•* Property: (No **Read** Down): A subject at a given security level may not read from any object at a lower security level.

- BIBA: Uses the opposite duality of confidentiality and integrity and thus reverses BLP -- low water mark: integrity of an object is the lowest level of all the objects that contributed to its creation

Case study: Android Discretionary Access Control

- App Isolation: Treat Apps by different companies as different users, using SETUID.
- Permissions also effectively capabilities, implemented by adding GIDs to the list of groups of the SETUID. "Permissions manifests" basically compile down to this.
- Early versions: all granted at install time. So flashlight apps started demanding your address book at install time so they could sell it.
- Since Android 6, Google moved to Apple model of TOFU, but earlier apps still demand on installation.



Features 4 features

android.hardware.MICROPHONE
android.hardware.screen.PORTRAIT
android.hardware.TOUCHSCREEN
android.hardware.WIFI

Required permissions 12 permissions

android.permission.ACCESS_NETWORK_STATE
android.permission.ACCESS_WIFI_STATE
android.permission.INTERNET
android.permission.NFC
android.permission.READ_EXTERNAL_STORAGE
android.permission.RECORD_AUDIO
android.permission.VIBRATE
android.permission.WAKE_LOCK
android.permission.WRITE_EXTERNAL_STORAGE
com.google.android.c2dm.permission.RECEIVE
com.instabug.library.permission.C2D_MESSAGE
org.glucosio.android.permission.C2D_MESSAGE

App info

Duo
Installed

DISABLE | FORCE STOP

App notifications

Permissions
Contacts and SMS

Storage
7.59 MB used in internal storage

Data usage
No data used

Battery
0% use since last full charge

Open by default
No defaults set

Duo

Camera	Off
Contacts	On
Microphone	Off
Phone	Off
SMS	On
Storage	Off

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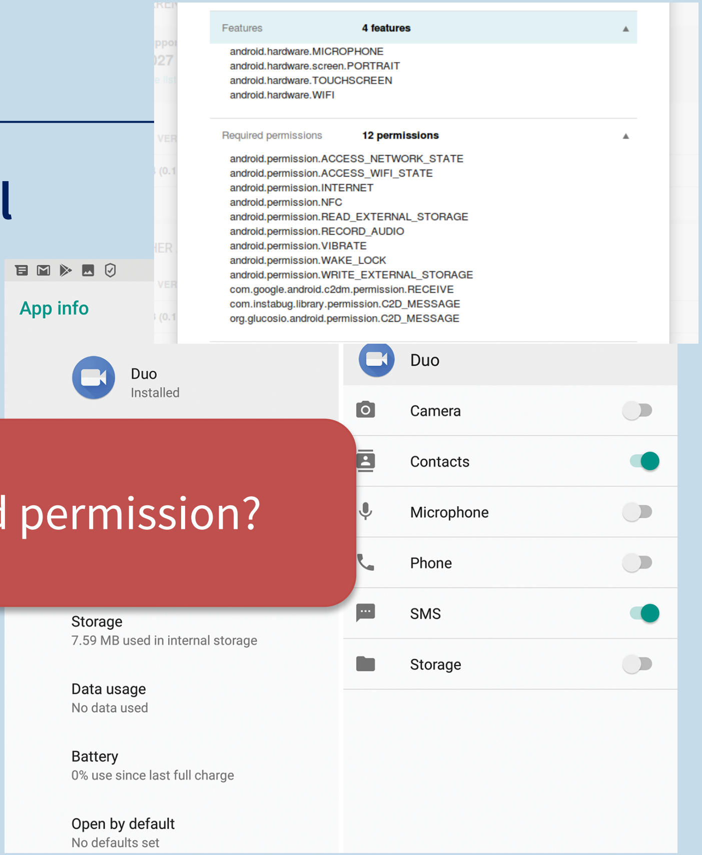
Think: what can go wrong with Android permission?



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android.permission.VIBRATE
android.permission.WAKE_LOCK
android.permission.WRITE_EXTERNAL_STORAGE
com.google.android.c2dm.permission.RECEIVE
com.instabug.library.permission.C2D_MESSAGE
org.glucosio.android.permission.C2D_MESSAGE

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Case study: Android permissions issues

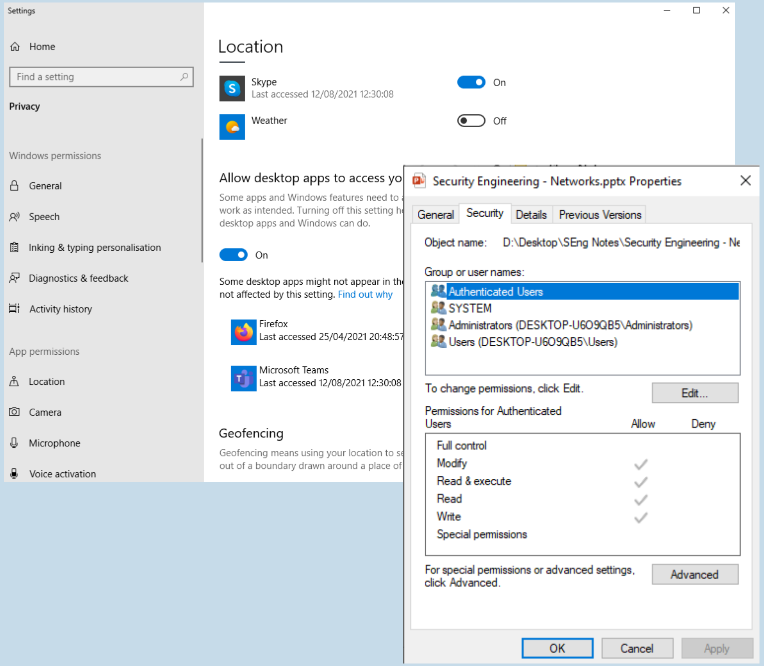
- API has poor documentation, and the permissions system is often the enemy of the developer, who ends up requesting more permission than they really need.
- Android still has malware! e.g. Pegasus via zero day, but costs $1 million. Alternative markets out of Google's control
- And lots of unpatched devices. The OS-update ecosystem is a disaster…
- Getting access control right intersects with lots of awkward edge cases, e.g. factory reset
- Over-privilege and coarse permissions
- Third-party SDKs inherits the app’s granted permissions.

Case study: iOS

- Also a Unix derivative, via FreeBSD and Mach kernel.
- Domain and Type Enforcement for tamper-proof system components. App permissions are capabilities, granted on first use on consent.
- Signed ecosystem from the market, just as Android has its default supported Google Play. Allows screening and also revenue taking.
- On the App Store, Apple signs the binaries. On Google Play, the developer does.
- Biometrics stored via encryption by the secure enclave (SE). Neither iOS nor TrustZone are trusted with this data!
- Vertically integrated, closed ecosystem

Case study: Windows

- Very complex Access Control, from Windows NT onwards. RWX, but also Take Ownership, Change Permissions and Delete.
- AccessDenied, AccessAllowed, SystemAudit: AD overrides AA if set multiple times.
- Not really integrated as a (user,program,file) triple – or even setuid.
- ACL just does (user,file), and a separate system handles a limited set of permissions, mostly for "apps"


Settings

Home

Find a setting

Privacy

Windows permissions

General

Speech

Inking & typing personalisation

Diagnostics & feedback

Activity history

App permissions

Location

Camera

Microphone

Voice activation

Location

Skype
Last accessed 12/08/2021 12:30:08 — On

Weather — Off

Allow desktop apps to access yo

Some apps and Windows features need to a
work as intended. Turning off this setting h
desktop apps and Windows can do.

On

Some desktop apps might not appear in the
not affected by this setting. Find out why

Firefox
Last accessed 25/04/2021 20:48:57

Microsoft Teams
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Geofencing

Geofencing means using your location to se
out of a boundary drawn around a place of

Security Engineering - Networks.pptx Properties

General | Security | Details | Previous Versions

Object name: D:\Desktop\SEng Notes\Security Engineering - Ne

Group or user names:

Authenticated Users
SYSTEM
Administrators (DESKTOP-U6O9QB5\Administrators)
Users (DESKTOP-U6O9QB5\Users)

To change permissions, click Edit. — Edit...

Permissions for Authenticated Users	Allow	Deny
Full control		
Modify	✓	
Read & execute	✓	
Read	✓	
Write	✓	
Special permissions		

For special permissions or advanced settings, click Advanced. — Advanced

OK | Cancel | Apply

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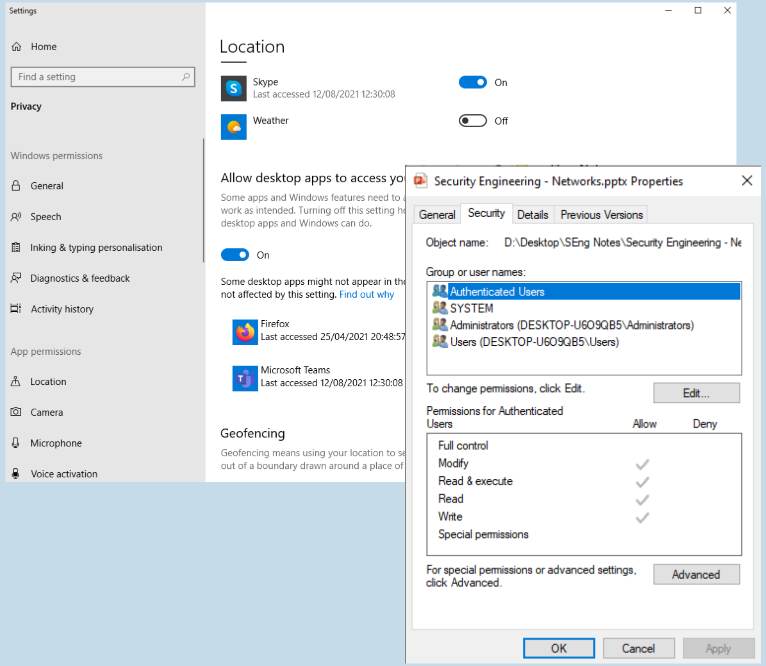
Case study: Windows – why so complicated?

- Corporate customers need complicated access controls. MS made half its revenue from firms >25000 seats.
- Decades of backwards compatibility means testing at scale. And introducing features slowly, and complex compatibility layers e.g. Application Information Service



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Write	✓	
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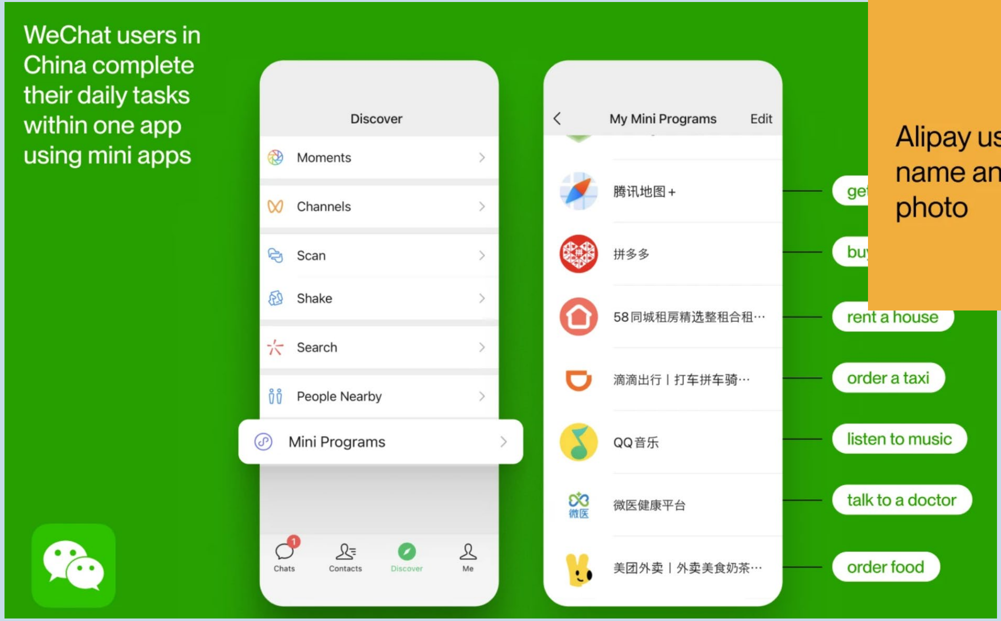
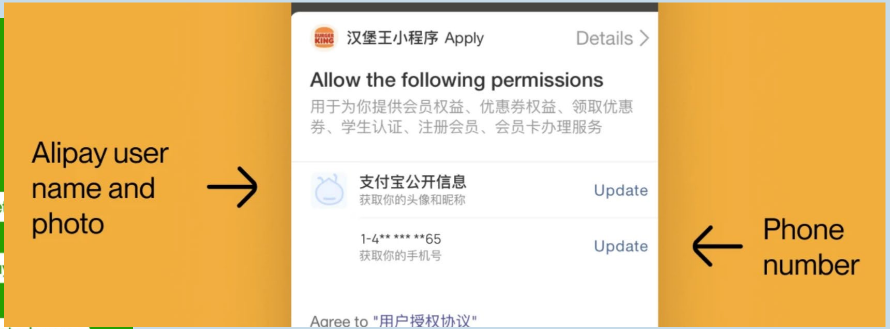
OK Cancel Apply

Discussion: Mini-app / app-in-app, what could go wrong in permission?

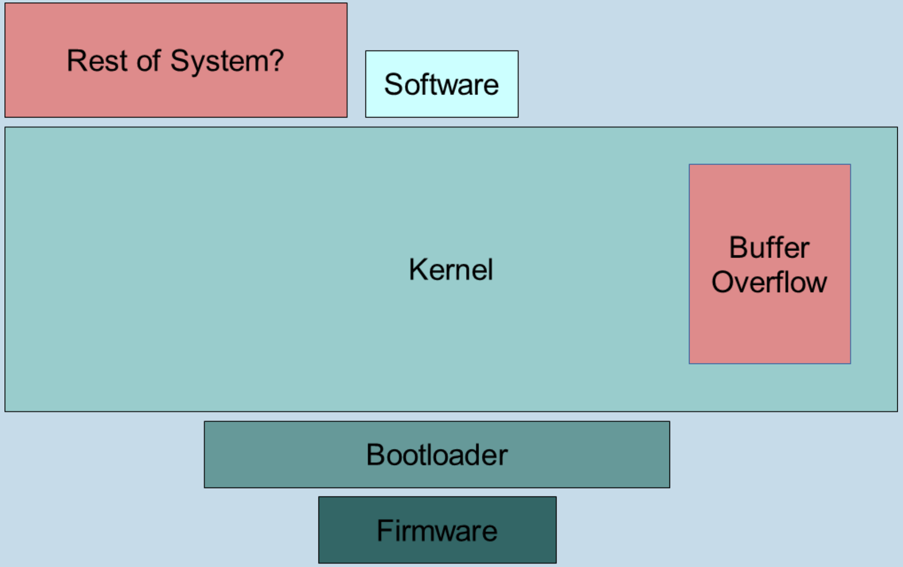



Alipay user name and photo
汉堡王小程序 Apply
Details
Allow the following permissions
用于为你提供会员权益、优惠券权益、领取优惠券、学生认证、注册会员、会员卡办理服务
支付宝公开信息
获取你的头像和昵称
Update
1-4** *** **65
获取你的手机号
Update
Agree to "用户授权协议"
Phone number

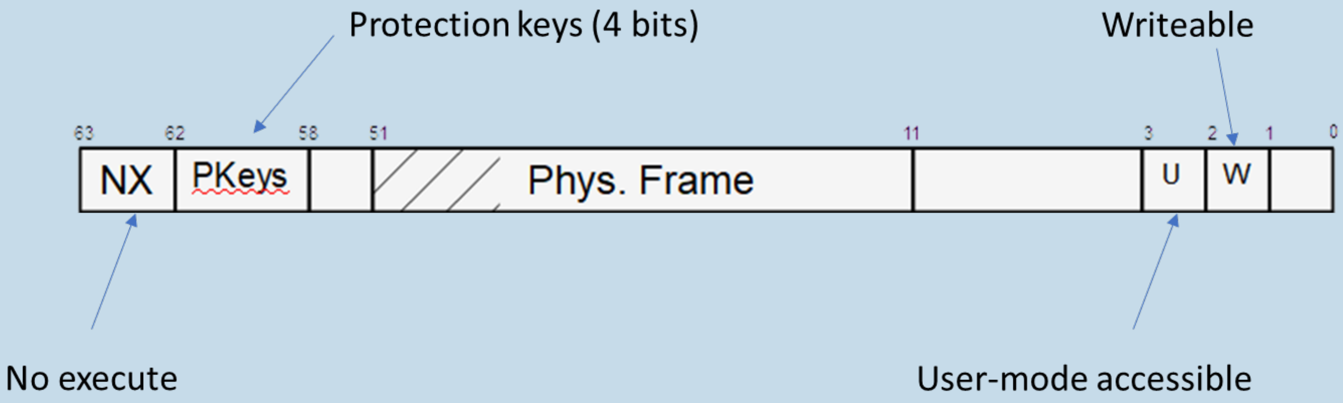
- What's the miniapp business model?
- What could go wrong in security?

Isolation

- How do you stop others, using the same system(s), from being able to read your data / hack your software?
- I mean, really stop them (side channels, bugs in trust computing base)?

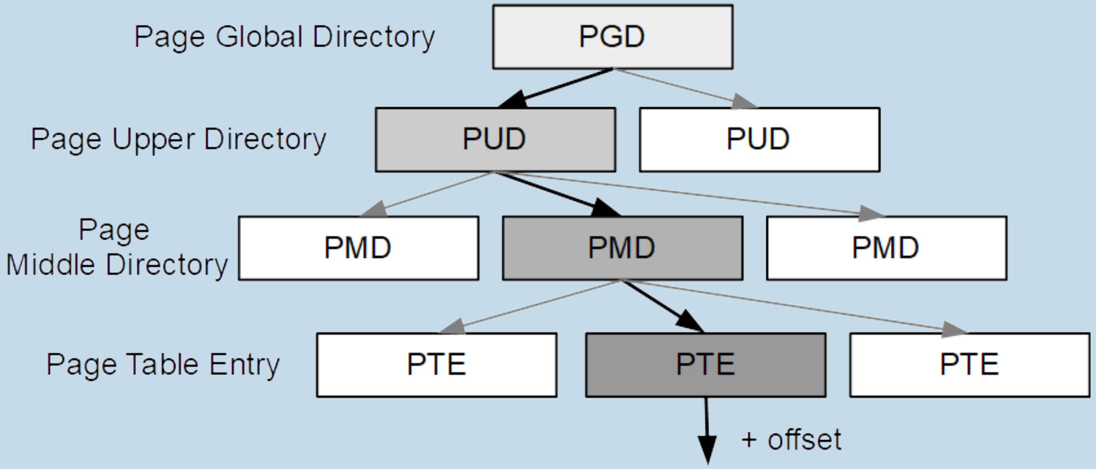


Isolation: Processes and Memory Management



You can get some isolation from individual **processes** in a single operating system. See Android last time for examples of precise **file-system** isolation, but it's also typical for OSes to support isolation within virtual memory.

Isolation: Page-Table Walk



- Up to four memory accesses, though many cached, to transform isolated virtual address to shared resource of physical frames.
- Data Execution Prevention (NX XOR W) – forces attackers to use Return-Oriented Programming.
- Address Space Layout Randomisation

Isolation granularities: Sandboxing, Virtualization and Containers

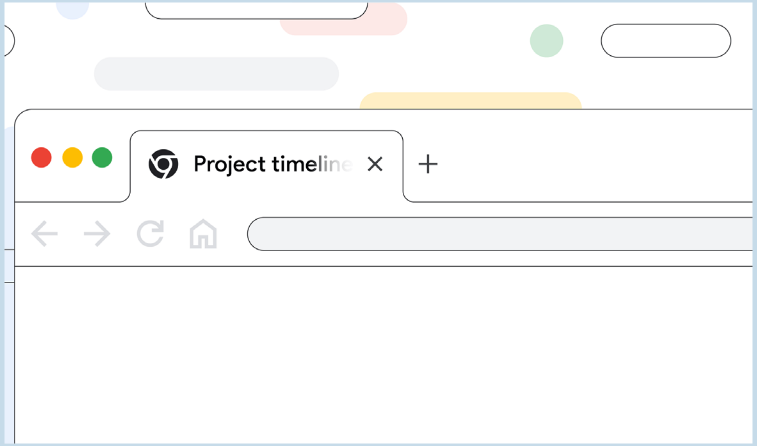
- Sandboxing e.g. Chrome, eBPF: often within-process
- Containers e.g. Docker: between-process with filtering
- Virtualization e.g. VirtualBox: whole separate “guest” OS on top of a shared “host” OS

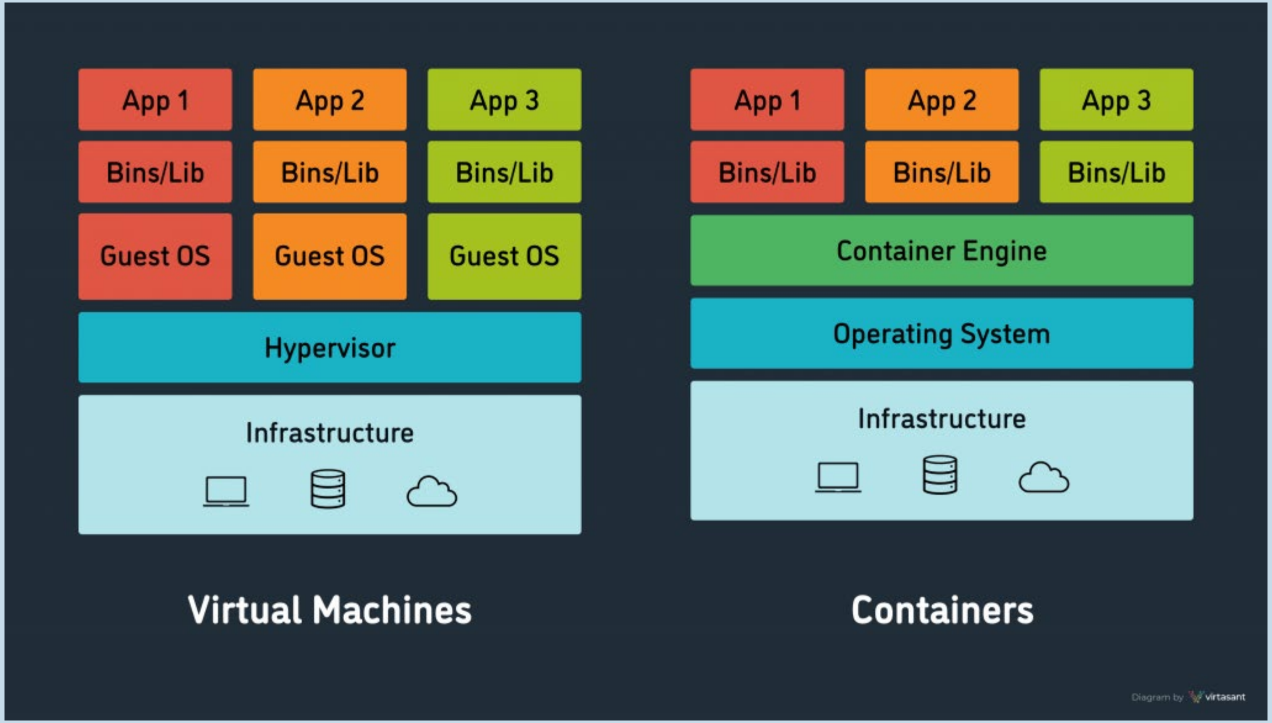
Isolation: Sandboxing

- Pioneered by Sun with the JVM
- Restrict the environment in various ways: temporary access to a single directory, communication via same-origin policy
- Prevent access of address space outside of a predefined region, e.g. the Javascript interpreter’s memory in a browser (Spectre klaxon).

Isolation: Chrome

- Cross-website theft increasingly important, so Site Isolation not just Renderer Isolation.
- Increasingly done by process-level isolation: also useful for Spectre.
- The “same-origin policy” gets complicated when you have untrusted ads in the same tabs…
- Vulnerabilities often exploited by Drive-by-Download attacks.

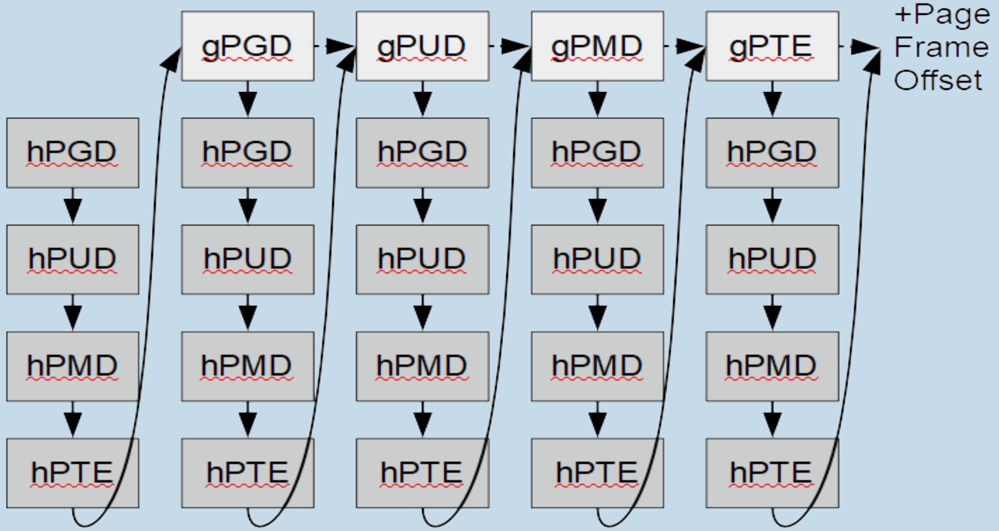



App 1
App 2
App 3
Bins/Lib
Bins/Lib
Bins/Lib
Guest OS
Guest OS
Guest OS
Hypervisor
Infrastructure
Virtual Machines
App 1
App 2
App 3
Bins/Lib
Bins/Lib
Bins/Lib
Container Engine
Operating System
Infrastructure
Containers
Diagram by virtasant

Isolation: Virtualization

- Replaces the entire operating system, and runs a "guest" operating system on top of a "host" via hypervisor.
- Powers cloud computing.
- HW support such as Intel VT-x makes things cleaner and faster.
- Why more secure? The hypervisor can be much smaller than a full OS and so easier to code-review and secure, right???
  - Why hardware compartmentalisation is still useful?
  - VM escape, cross-VM leaks…

Isolation: Virtualization



- Performance gain of nested page table adds to security costs

Isolation: Virtualization challenges

- Subtle issues around monitoring: If you're going to check all ACLs on your server, what about the containers or virtualized systems?
- Trouble at the interface: people still need to share data between VMs and ad-hoc mechanisms such as USB devices
- Bromium: VM per app, messy at the interface with untrusted files sent via host. Need specific exceptions and plugins, like Outlook being prevented from rendering files itself.

Isolation: Container

- Cheaper than a VM, but less secure. E.g. Docker
- Shared kernel, but isolates application code and libraries from the rest of the system -- not shared anymore.
- NSjail: trap processes in a "jail": restrict syscalls by seccomp, change root to a local directory.
- Virtualise some parts but not others e.g. PIDs, IPC and namespaces.
- Syscall filtering too, and sandboxing.

Isolation: Container challenges

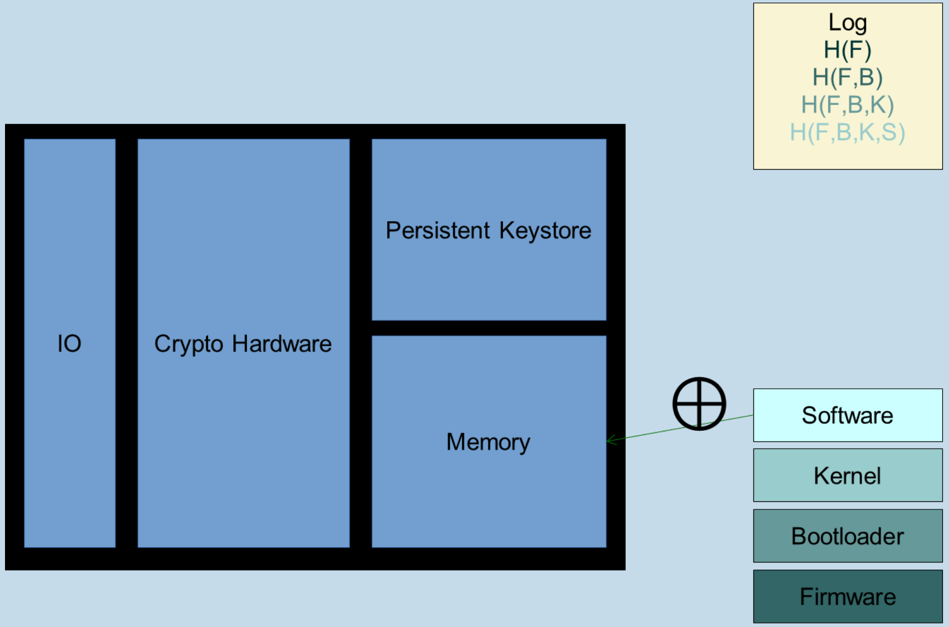
- Not the same as VM, and not really meant for data isolation -- don't expect the same isolation as with a VM -- the trusted code base is still massive.
- Really for deployability, not security. Many subtle bugs, such as blank root passwords as defaults!
- On the flipside, deployability might *be* a security feature – why?

How do we trust remote systems, e.g., clouds?

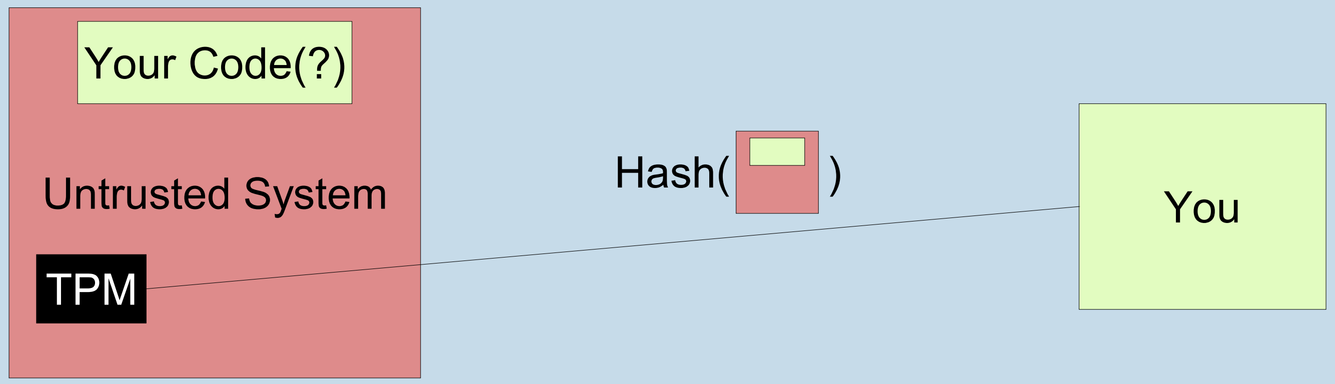
- Access control often specific to provider e.g. AWS Identity and Access Management – lock in
- Google App Engine: Provide only indirect access to networking/file system, by "safe" versions that integrate MAC and call other cloud infrastructure.
- Defence in depth: Integrate sanitization, mitigation/hardening, functionality reduction, indirection (Python -> NaCL) and ptrace filtering and logging.

Secure boot vs measured boot

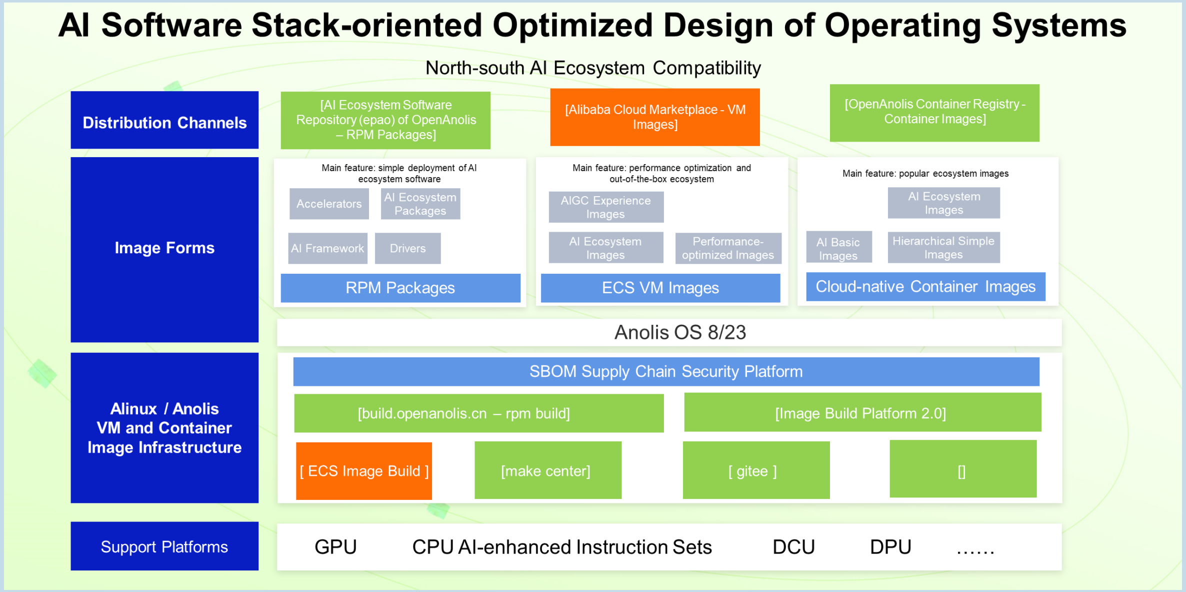
- Secure boot: verify then execute
  - Checks signatures against key
- Measure boot: measure then report
  - Creates and log hash
  - Report to a trust server
- Pros and cons?



Remote attestation

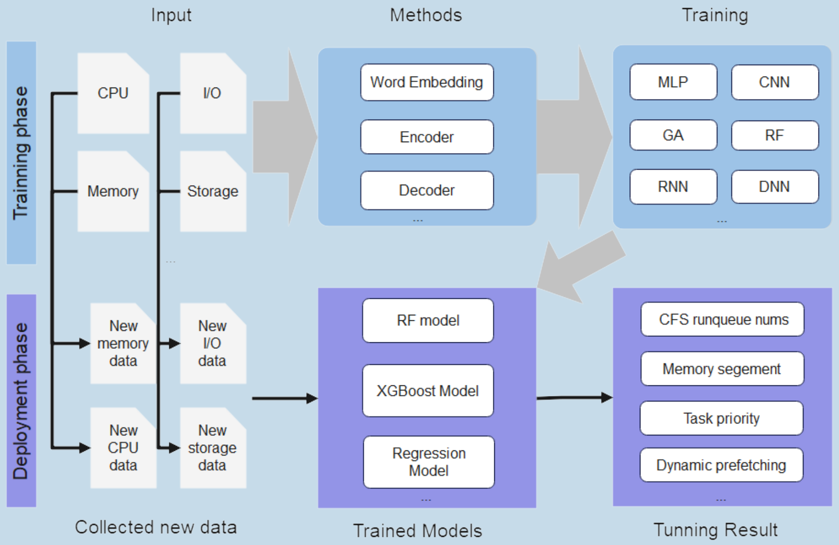


Think and discuss: security issues when AI meets OS?


AI Software Stack-oriented Optimized Design of Operating Systems
North-south AI Ecosystem Compatibility
Distribution Channels
[AI Ecosystem Software Repository (epao) of OpenAnolis – RPM Packages]
[Alibaba Cloud Marketplace - VM Images]
[OpenAnolis Container Registry - Container Images]
Image Forms
Main feature: simple deployment of AI ecosystem software
Accelerators
AI Ecosystem Packages
AI Framework
Drivers
RPM Packages
Main feature: performance optimization and out-of-the-box ecosystem
AIGC Experience Images
AI Ecosystem Images
Performance-optimized Images
ECS VM Images
Main feature: popular ecosystem images
AI Ecosystem Images
AI Basic Images
Hierarchical Simple Images
Cloud-native Container Images
Anolis OS 8/23
Alinux / Anolis VM and Container Image Infrastructure
SBOM Supply Chain Security Platform
[build.openanolis.cn – rpm build]
[Image Build Platform 2.0]
[ECS Image Build]
[make center]
[gitee]
[]
Support Platforms
GPU
CPU AI-enhanced Instruction Sets
DCU
DPU
……

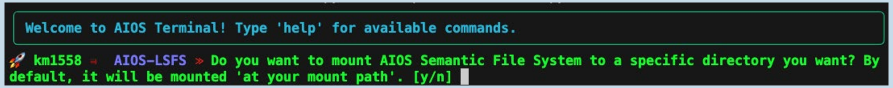
System for AI

Think and discuss: security issues when AI meets OS?

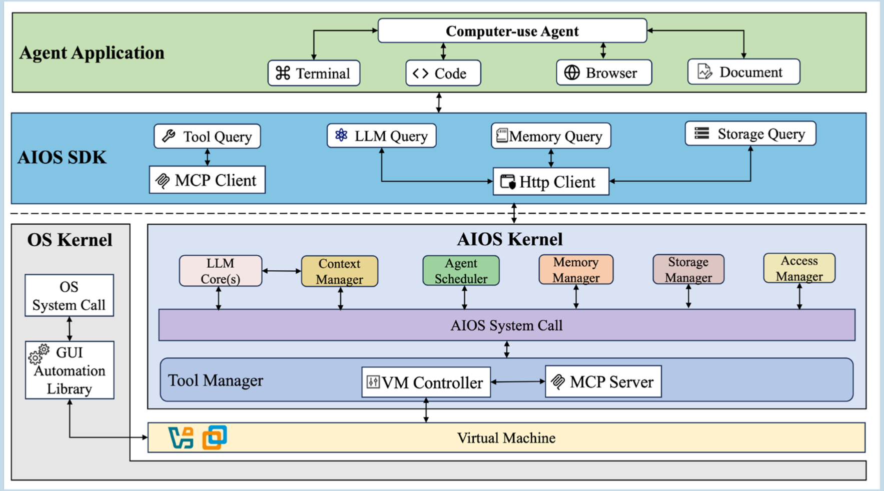


AI-integrated OS (scheduling

Think and discuss: security issues when AI meets OS?



```
Welcome to AIOS Terminal! Type 'help' for available commands.
🚀 km1558 → AIOS-LSFS » Do you want to mount AIOS Semantic File System to a specific directory you want? By
default, it will be mounted 'at your mount path'. [y/n]
```

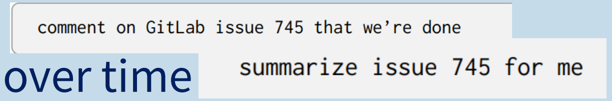


AI-copilot for end users

https://github.com/agiresearch/AIOS

AI x OS challenges

- Probabilistic trust computing base
  - Same prompt yields different output due to sampling randomness
- Dynamic and task-specific security policy
  - No app, natural language task specification changing over time
- Fuzzy security boundary within an AI agent
- Dynamic instruction following = dynamic code loading?



```
comment on GitLab issue 745 that we're done
summarize issue 745 for me
```

Christodorescu, M., Fernandes, E., Hooda, A., Jha, S., Rehberger, J. and Shams, K., 2025. Systems Security Foundations for Agentic Computing. *arXiv preprint arXiv:2512.01295*.