

An Introduction of Cybersecurity and Flash Memory Security Research

Josh Dafoe

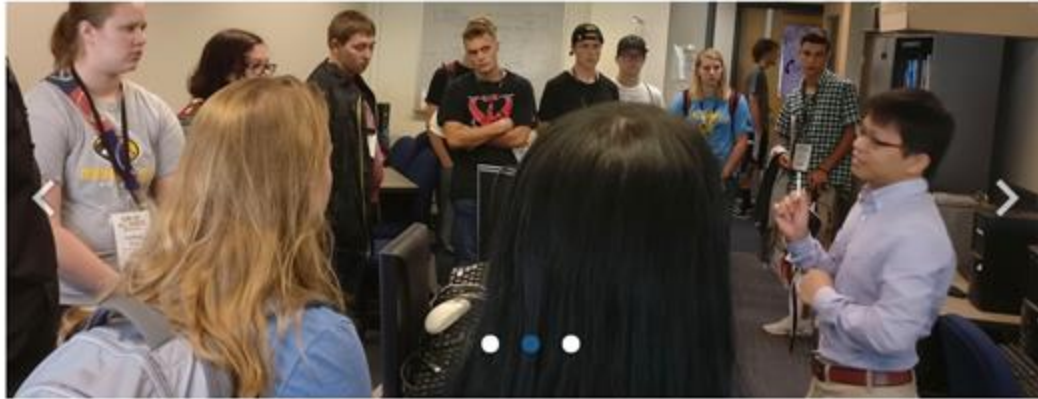
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<https://snp.cs.mtu.edu>

About MTU Security and Privacy (SnP) Lab



[Home](#) [People](#) [Research](#) [Publications](#) [Education](#) [Outreach](#) [Collaborations](#) [Contact](#)



Introduction

The Secure and Privacy (SnP) lab at Michigan Technological University was established in early 2018. The mission of SnP lab is to promote research and education of cybersecurity. For research, we aim to tackle cutting-edge security and privacy problems, protecting safety and assets of people from malicious attacks. For education, we are enthusiastic about broadcasting cybersecurity knowledge among graduate and undergraduate students. We are also dedicated to promoting cybersecurity training among underrepresented groups and future cybersecurity professionals through various outreach efforts.

People

Lab Director

[Bo Chen](#) (Associate Professor@MTU CS)

PhD Students

Josh Dafoe (2025 NSF Graduate Research Fellowship Program (GRFP)
2024, 2023 MTU Summer Undergraduate Research Fellowship)

Qiang Han

Amirmehdi Moghadamfarid

Caleb Rother (2025 MTU Outstanding Graduate Teaching Award)

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Undergraduate Students

Justin Christenson

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Lab Director



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Links of Interest

🔗 [Faculty Website](#)

🔗 [MTU Security and Privacy \(SnP\) lab](#)

Areas of Expertise

- Mobile Device Security
- Cloud Computing Security
- Internet of Things Security
- Cyber-Physical Systems Security
- Blockchain

<https://cs.mtu.edu/~bchen>

Lab director: MTU Security and Privacy (SnP) Lab

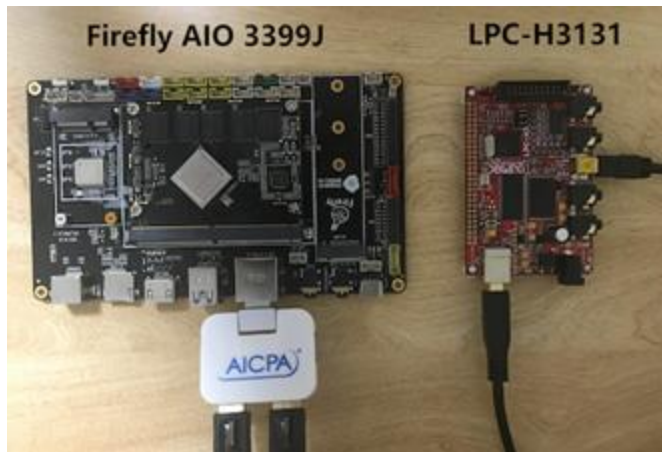


Co-advisor: MTU CS cybersecurity reading group, MTU RedTeam

Faculty coach: MTU NCL cyber competition team (our team ranked 10th out of 3916 teams across US in Fall 2021)

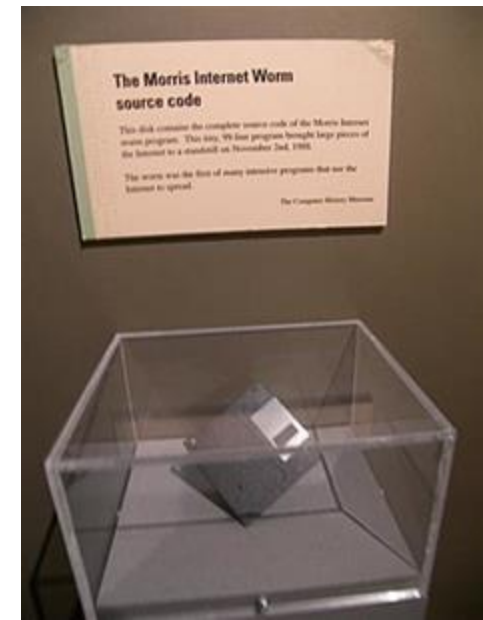
About MTU Security and Privacy (SnP) Lab

- Projects are currently funded by national science foundation, national security agency, etc.
 - Protecting sensitive data in mobile devices, IoT devices
 - Protecting critical data/infrastructures outsourced to public clouds
 - Malware detection
 - Security and privacy in connected and autonomous vehicles

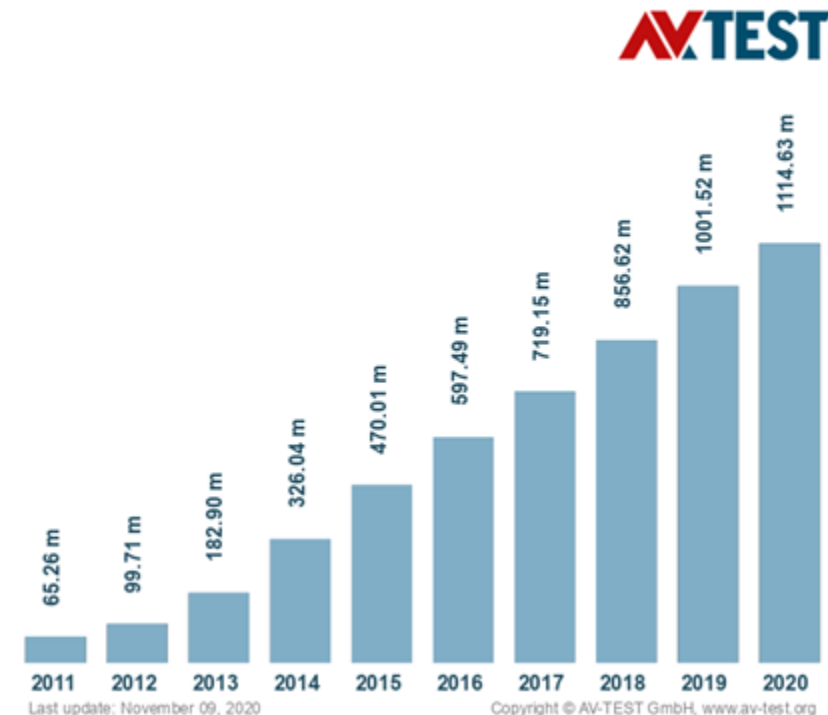


All Starts from Malware and Hacks

- On November 2, **1988**, a graduate student at Cornell University, Robert Morris, unleashed what became known as the **Morris worm**
 - Morris worm disrupted a large number of computers then on the Internet, guessed at the time to be **10%** of all those connected
- Malware and Hacks are here and there today



Total malware



How to Combat Malware and Hacks?

- The answer is cybersecurity
- Ensure our systems and networks are well protected, such that any intruders can be detected, identified, and blocked
 - Make sure the software (**code**) we build is free of vulnerabilities
 - The attackers cannot exploit the vulnerabilities to intrude into our systems and networks
 - Make sure our **data** are protected
 - Not disclosed to unauthorized parties
 - Not modified by unauthorized parties
 - Always available for use
 - Always recoverable

Outline

- Recent cybersecurity instances
- What is cybersecurity
- Why learn cybersecurity
- Mobile devices and flash memory
- Flash memory security research

Recent Cybersecurity Instances

Hacks in 2025

16 Billion Apple, Facebook, Google And Other Passwords Leaked

By [Davey Winder](#), Senior Contributor. ⓘ Davey Winder is a veteran cybersecu... ▾

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Published Jun 20, 2025, 07:07am EDT, Updated Jun 22, 2025, 06:22am EDT

If you thought that my May 23 report, confirming the leak of login data totaling an astonishing [184 million compromised credentials](#), was frightening, I hope you are sitting down now. Researchers have just confirmed what could be the largest leak ever, with an almost incredulous 16 billion login credentials, including passwords, exposed. As part of an ongoing investigation that started at the beginning of the year, the researchers have postulated that the massive password leak is the work of multiple [info stealers](#). Here's what you need to know and do.

Hacks in 2024



Crafting Shields: Defending Minecraft Servers Against DDoS Attacks

Minecraft, with over 500 million registered users and 166 million monthly players, faces significant risks from distributed denial-of-service (DDoS) attacks, threatening server functionality, player experience, and the game's reputation. Despite the prevalence of DDoS attacks on the game, the majority of incidents go unreported, leaving a gap in awareness and protection. This article explains what happens to a Minecraft server during a DDoS attack and how to protect against such attacks. For an in-depth version of the article, [check out this white paper](https://thehackernews.com/2024/03/crafting-shields-defending-minecraft.html).

<https://thehackernews.com/2024/03/crafting-shields-defending-minecraft.html>

Hacks in 2023

2. Enormous Data Breach at T-Mobile

International telecoms giant T-Mobile admitted that 37 million customers had their personal and account information accessed by a malicious actor via an API attack that began on November 25, 2022. The incident was not discovered until January 5, 2023. In a separate incident, T-Mobile USA notified customers of another breach of personal and account data that occurred in February and March 2023. The breaches mean many millions of customers are vulnerable to follow-on fraud attempts.

<https://www.infosecurity-magazine.com/news-features/top-cyber-attacks-2023/>

Hacks in 2019

Entity ↕	Year ▼	Records ↕	Organization type ↕	Method ↕
Adobe Inc.	2019	7.5 million	tech	poor security
Amazon Japan G.K.	2019	unknown	web	accidentally published
2019 Bulgarian revenue agency hack	2019	over 5,000,000	government	hacked
Canva	2019	140,000,000	web	hacked
Capital One	2019	106,000,000	financial	unsecured S3 bucket
Desjardins	2019	2,900,000	financial	inside job
DoorDash	2019	4,900,000	web	hacked
Facebook	2019	540,000,000	social network	poor security
Facebook	2019	1,500,000	social network	accidentally uploaded
Facebook	2019	267,000,000	social network	poor security
First American Corporation	2019	885,000,000	financial service company	poor security
Health Sciences Authority (Singapore)	2019	808,000	healthcare	poor security
Justdial	2019	100,000,000	local search	unprotected api
LifeLabs	2019	15,000,000	healthcare	hacked
Ministry of Health (Singapore)	2019	14,200	healthcare	poor security/inside job
Mobile TeleSystems (MTS)	2019	100,000,000	telecommunications	misconfiguration/poor security
Quest Diagnostics	2019	11,900,000	Clinical Laboratory	poor security
StockX	2019	6,800,000	retail	hacked

More in Years Prior to 2018 ...

- https://en.wikipedia.org/wiki/List_of_data_breaches

Cox Communications	2016	40,000	telecoms	hacked	[90]
Democratic National Committee	2016	19,252	political		[98]
US Department of Homeland Security	2016	30,000	government	poor security	[99][100]
EyeWire	2016	unknown	tech	lost / stolen computer	[130]
Friend Finder Networks	2016	412,214,295	web	poor security / hacked	[144][145]
Funimation	2016	2,500,000	web	hacked	[146][147]
Gyft	2016	unknown	web	hacked	[164][165]
Inuvik hospital	2016	6,700	healthcare	inside job	[188]
KM.RU	2016	1,500,000	web	hacked	[196]
Nival Networks	2016	1,500,000	gaming	hacked	[241]
Ofcom	2016	unknown	telecom	inside job	[244]
Rosen Hotels	2016	unknown	hotel	hacked	[261]
Taobao	2016	20,000,000	retail	hacked	[293]
TaxSlayer.com	2016	8,800	web	hacked	[297][298][299]
University of California, Berkeley	2016	80,000	academic	hacked	[330]
University of Central Florida	2016	63,000	academic	hacked	[332]
Verizon Communications	2016	1,500,000	telecoms	hacked	[344]
Weebly	2016	43,430,316	web	hacked	[354][355]
Bell Canada	2017	1,900,000	telecoms	poor security	[46]
Defense Integrated Data Center (South Korea)	2017	235 GB	military	hacked	[95]
Deloitte	2017	350 clients emails	consulting, accounting	poor security	[96][97]
Equifax	2017	163,119,000	financial, credit reporting	poor security	[120][121]
Grozio Chirurgija	2017	25,000	healthcare	hacked	[159][160][161]
Heathrow Airport	2017	2.5GB	transport	lost / stolen media	[175][176][177]
Taringa!	2017	28,722,877	web	hacked	[294]
Uber	2017	57,000,000	transport	hacked	[320]

What is Cybersecurity?

Security 101

The Definition of Security

- Security: **freedom from, or resilience against, potential harm** (or other unwanted coercive change) from external forces (*wikipedia*) – **in physical space**
- Cybersecurity: **the protection of computer systems** from theft or damage to their hardware, software or electronic data, as well as from disruption or misdirection of the services they provide – **in cyber space**



Cybersecurity Objectives: CIA

Main security objectives:

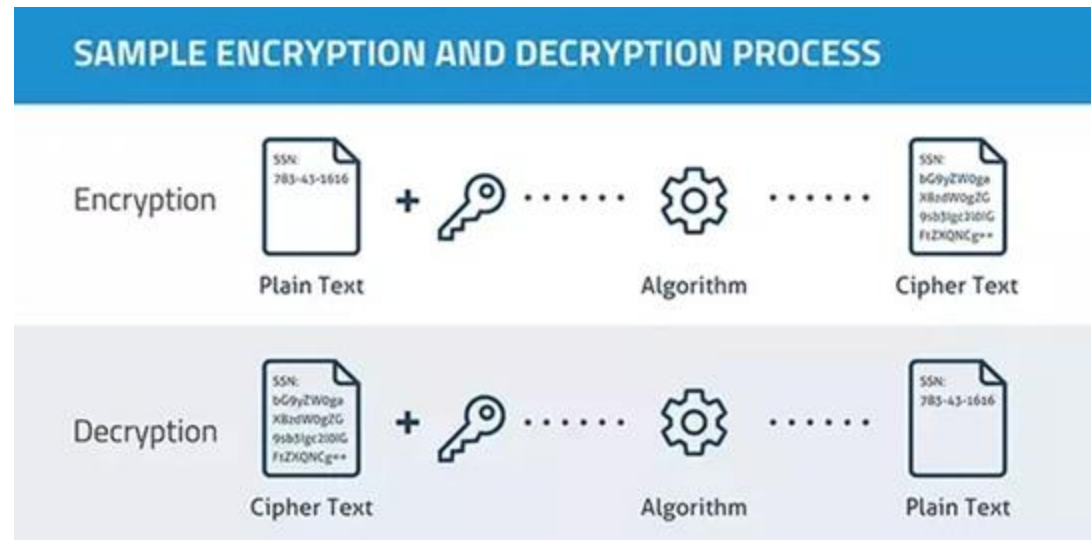
- **Confidentiality:** unauthorized users **cannot read** information
- **Integrity:** unauthorized users **cannot alter** information
- **Availability:** the information must be **available when it is needed**

Other security objectives:

- Authentication and identification
- Access control
- Anonymity
- Non-repudiation: users cannot deny actions
- Privacy
- ...

Confidentiality

- *The concealment of information or resources*
 - Information is not made available or disclosed to unauthorized individuals, entities, or processes
 - E.g., your bank accounts, private photos, etc
- How to achieve confidentiality? Encrypt the data using a secret key, and only the authorized entities can obtain the secret key to decrypt the data
 - Symmetric encryption: AES, DES, 3DES
 - Asymmetric encryption: RSA



Integrity

- Maintaining and assuring the accuracy and completeness of data over its entire lifecycle
 - Data cannot be modified in an unauthorized or undetected manner
 - E.g., your emails, your electronic homework



How to Ensure Integrity?

- Generate digest and perform integrity checking



Availability

- For any information system to serve its purpose, the **service/ information** must be available when it is needed
 - This means the computing systems used to store and process the information, the security controls used to protect it, and the communication channels used to access it must be functioning correctly
- High availability systems aim to remain available at all times
 - Preventing service disruptions due to power outages, hardware failures, and system upgrades
 - Preventing denial-of-service attacks, such as a flood of incoming messages to the target system, essentially forcing it to shut down

Authentication and Identification

- Authentication in physical world: are you **really** who you claim?
 - Confirm the identity of a person by validating his/her identity document (e.g., driver license, passport, student ID card)
- Authentication in computers:
 - Confirm whether a person is the owner of a smartphone
 - Confirm whether a person is a user of online banking
 - Confirm whether a website is authentic



How to Do Authentication?

- Four general means for authenticating user's identity

- Something the individual knows

- Passwords



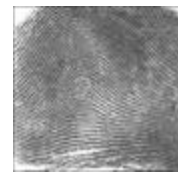
- Something the individual possesses, a *token*

- Memory card, smart card



- Something the individual is

- Fingerprint, iris, retina, face



- Something the individual does (behavior pattern)

- Typing rhythm, gait, and voice



How to Do Authentication (cont.)?

- Multi-factor authentication (MFA) – used in our own IT systems in MTU



Access Control

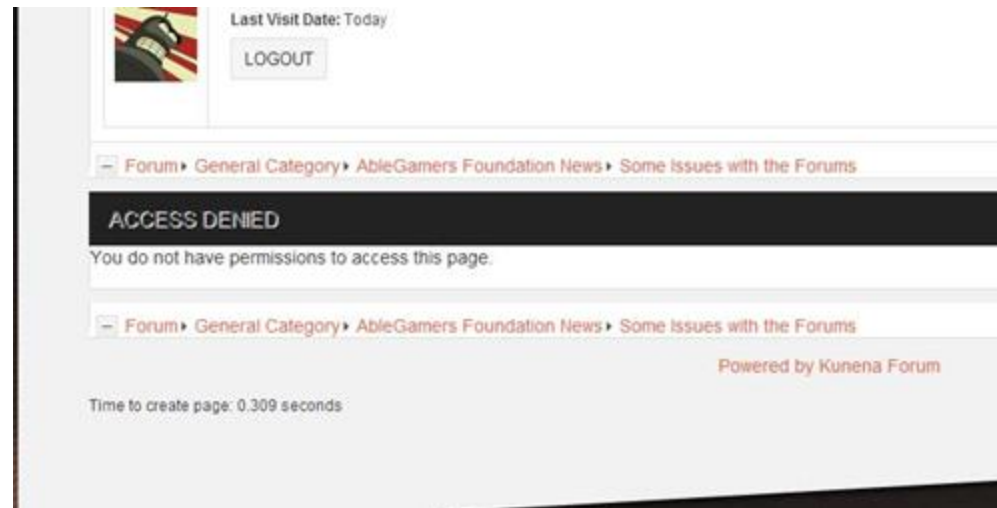
- Access control in physical world: the selective restriction of access to a place. It is a matter of **who**, **where**, and **when**.
 - Historically, this was partially accomplished through mechanical keys and locks



- Access control in computers: the selective restriction of access to computing resources (**who**, **what**, and **how**)
 - Who: users, programs, processes, etc.
 - What: computing resources like files, memory, I/O ports, etc.
 - How: how the computing resources can be “touched”

How to Do Access Control?

- Encrypting the protected computing resources using secret keys, and only disclose keys to those who are authorized
- The access control is enforced by systems (operating systems, database management systems, etc.) following permissions



```
osmc@osmc:~$ ls -al
total 37
drwxr-xr-x 7 osmc osmc 4096 Jul  4 03:11 .
drwxr-xr-x 3 root root 4096 Jan  1 1970 ..
-rw----- 1 osmc osmc  73 Jul  3 00:10 .bash_history
-rw-r--r-- 1 osmc osmc 220 Oct 18 2014 .bash_logout
-rw-r--r-- 1 osmc osmc 3515 Oct 18 2014 .bashrc
drwxr-xr-x 8 osmc osmc 4096 Jan  1 1970 .kodi
-rw-r--r-- 1 osmc osmc 675 Oct 18 2014 .profile
drwxr-xr-x 2 root root  0 Jan  1 1970 Movies
drwxrwxrwx 2 osmc osmc  64 Jul  4 00:49 Music
drwxr-xr-x 2 osmc osmc 4096 Apr 12 10:30 Pictures
drwxr-xr-x 2 osmc osmc 4096 Apr 12 10:30 TV Shows
osmc@osmc:~$ cd Music
-bash: cd: Music: Permission denied
osmc@osmc:~$
```

Why Learning Cybersecurity?

Great Job Market

Secure | <https://www.wsj.com/articles/its-a-good-time-to-find-a-cybersecurity-job-1527646081>

THE WALL STREET JOURNAL.

Home World U.S. Politics Economy **Business** Tech Markets Opinion Life & Arts Real Estate WSJ. Magazine

BUSINESS | LEADERSHIP

It's a Good Time to Find a Cybersecurity Job

There is a big gap between demand and supply. No degree required.

According to US Bureau of Labor Statistics (BLS), the cybersecurity relating job opportunity will be growing **33%** every year, which is **much faster** than the average.

bls.gov/ooh/computer-and-information-technology/information-security-analysts.htm

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Information Security Analysts

Summary What They Do Work Environment How to Become One Pay Job Outlook State & A

Summary

Quick Facts: Information Security Analysts	
2020 Median Pay ?	\$103,590 per year \$49.80 per hour
Typical Entry-Level Education ?	Bachelor's degree
Work Experience in a Related Occupation ?	Less than 5 years
On-the-job Training ?	None
Number of Jobs, 2020 ?	141,200
Job Outlook, 2020-30 ?	33% (Much faster than average)
Employment Change, 2020-30 ?	47,100

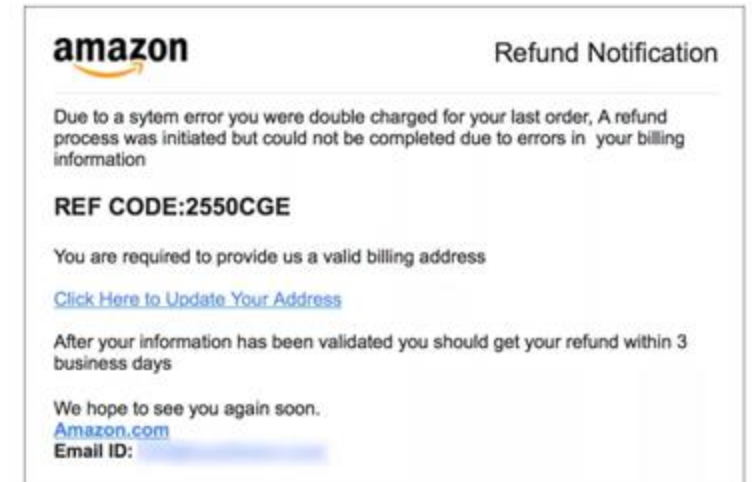
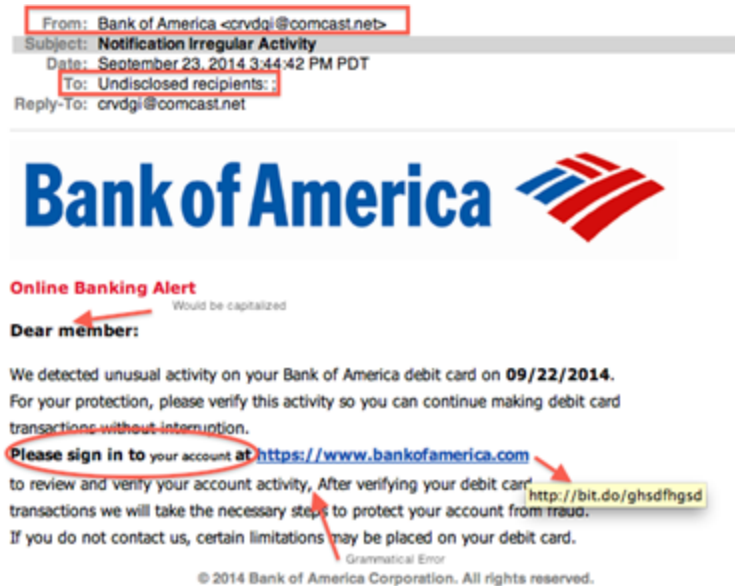
Protect Your Own Assets

- Reduce the possibility of exposure to potential hacks
 - Malicious code is here and there (malicious java scripts, applets, etc.)
 - Make sure you trust the web sites before you go there (a lot of phishing website)
 - www.google.com is fine, but www.go0gle.com may not
 - Do you want to click the link www.facebook.net, or www.b-of-America.co.cc



Protect Your Own Asset (cont.)

- Reduce the possibility of exposure to potential hacks
 - A lot of phishing emails



Security Technology Is Money Sometimes

Bitcoin price

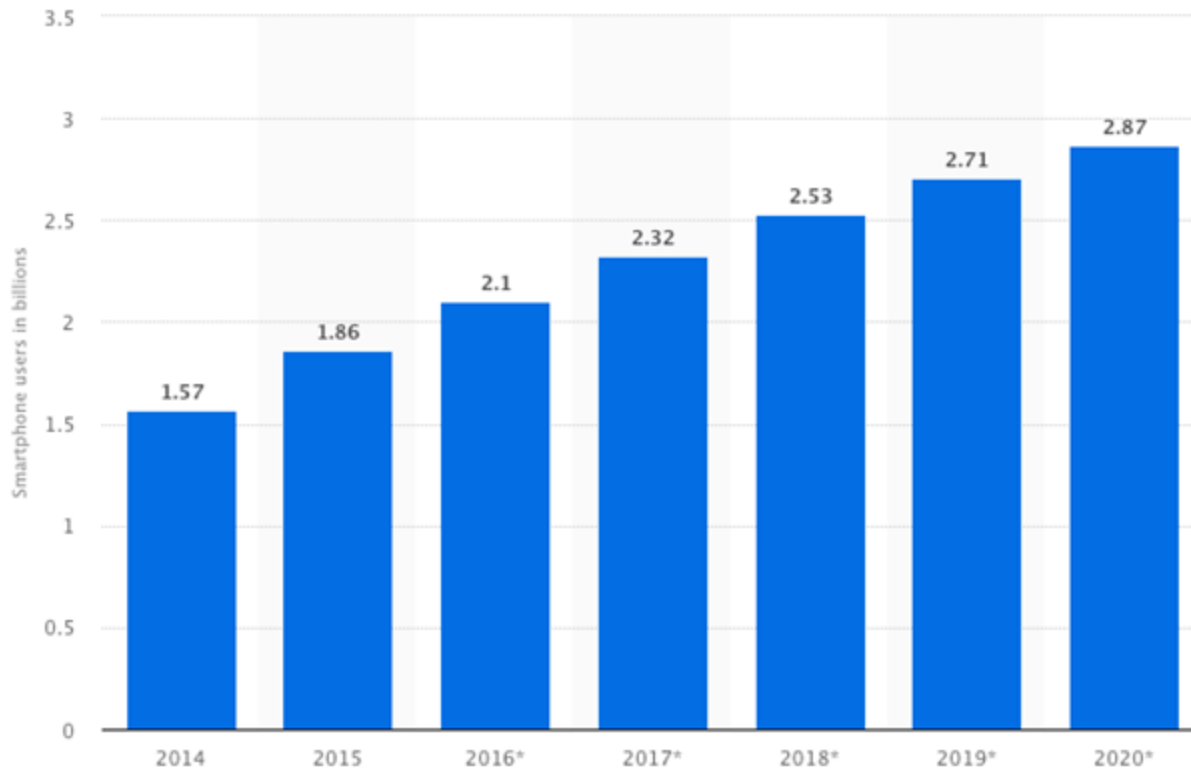


Bitcoin price

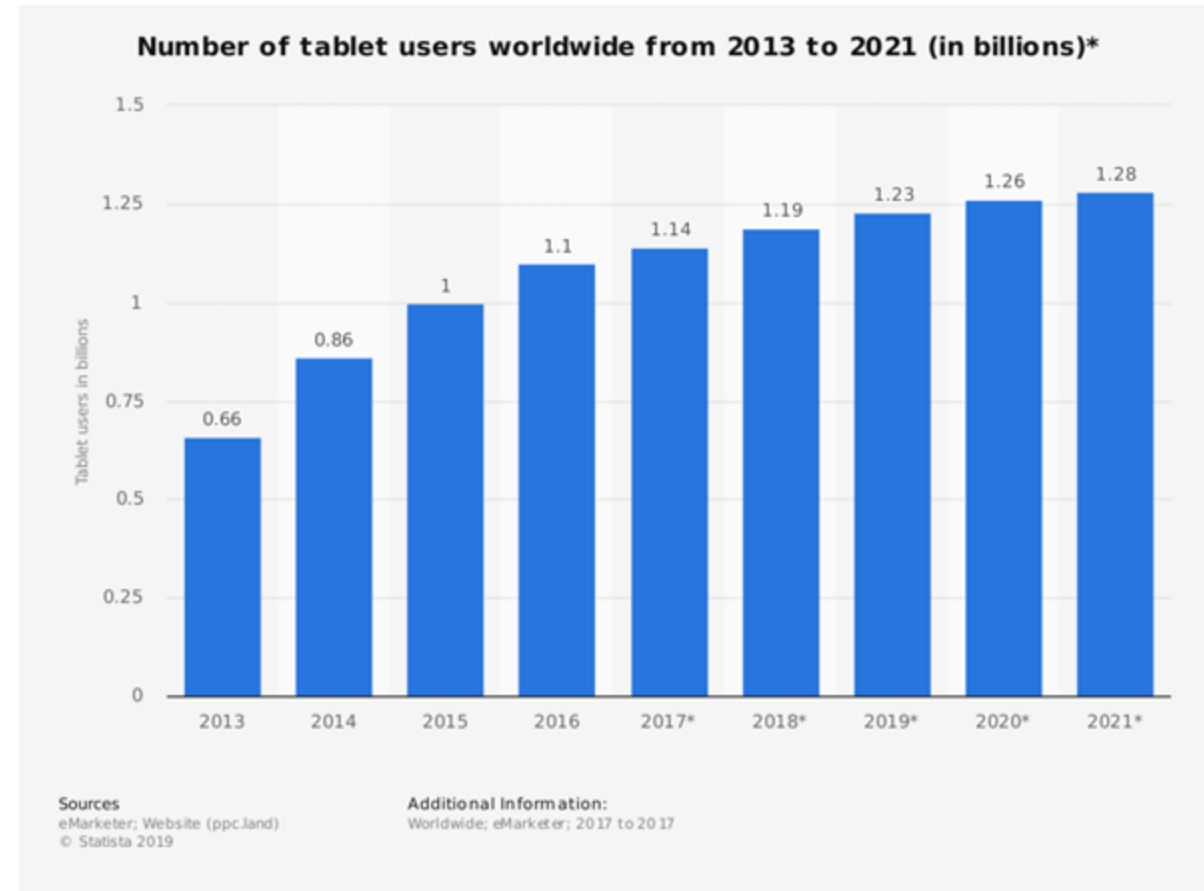


Mobile Devices and Flash Memory

Mobile Devices are Turning to Mainstream Computing Devices



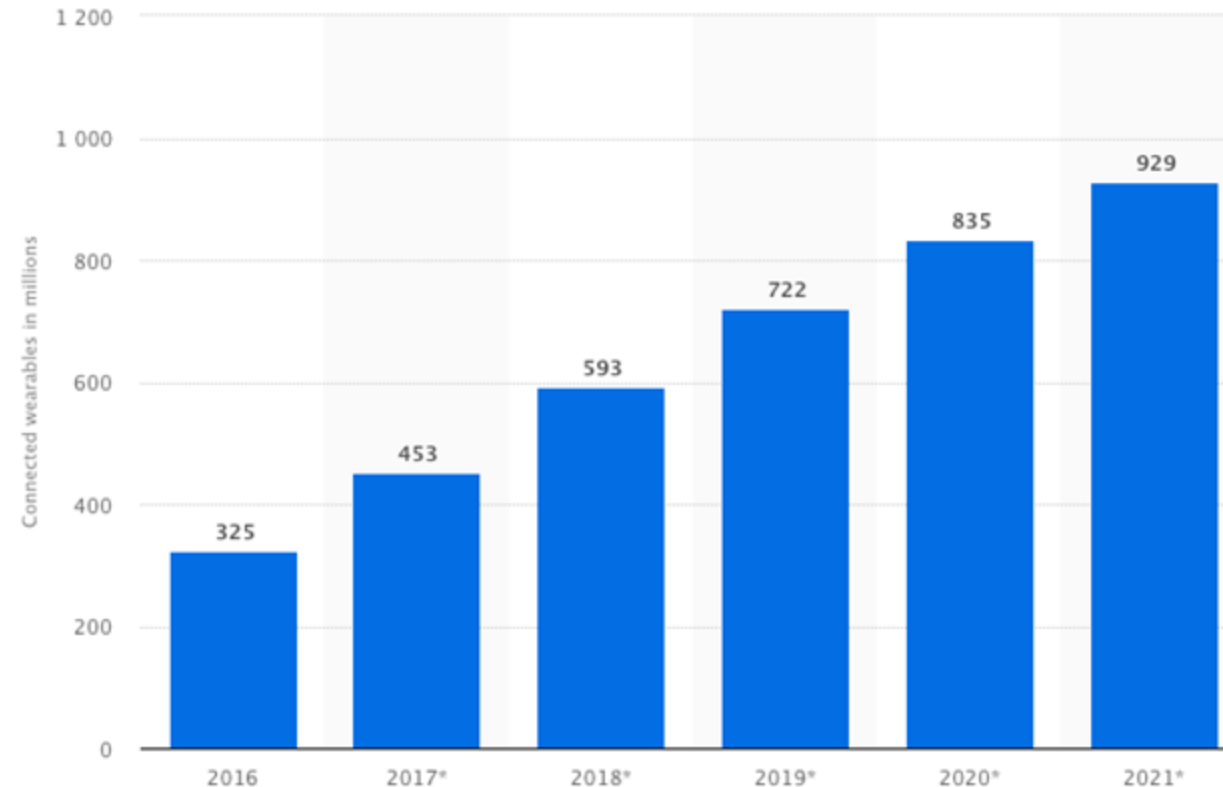
Number of smartphone users worldwide from 2014 to 2020 (in billions)



Number of tablet users worldwide from 2013 to 2021 (in billions)



Mobile Devices are Turning to Mainstream Computing Devices (cont.)



Number of connected wearable devices worldwide from 2016 to 2021 (in millions)

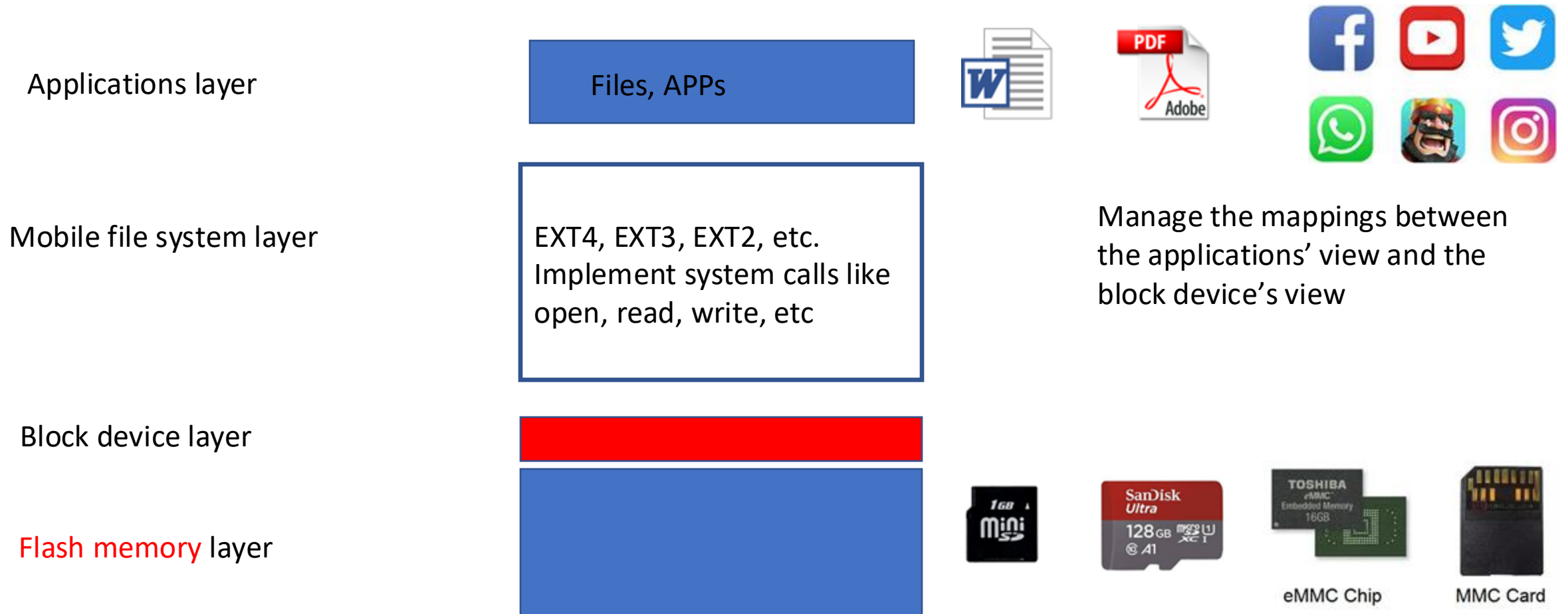


Mobile Devices are Used for Critical Applications

- Mobile devices are increasingly used to handle sensitive data
 - Online banking
 - Ecommerce
 - Cryptocurrency/stock trading
 - A human rights worker collects evidence of atrocities in a region of oppression
 - Etc.
- Security issues in mobile computing devices
 - Confidentiality
 - Integrity
 - Authentication
 - Access control
 - ...



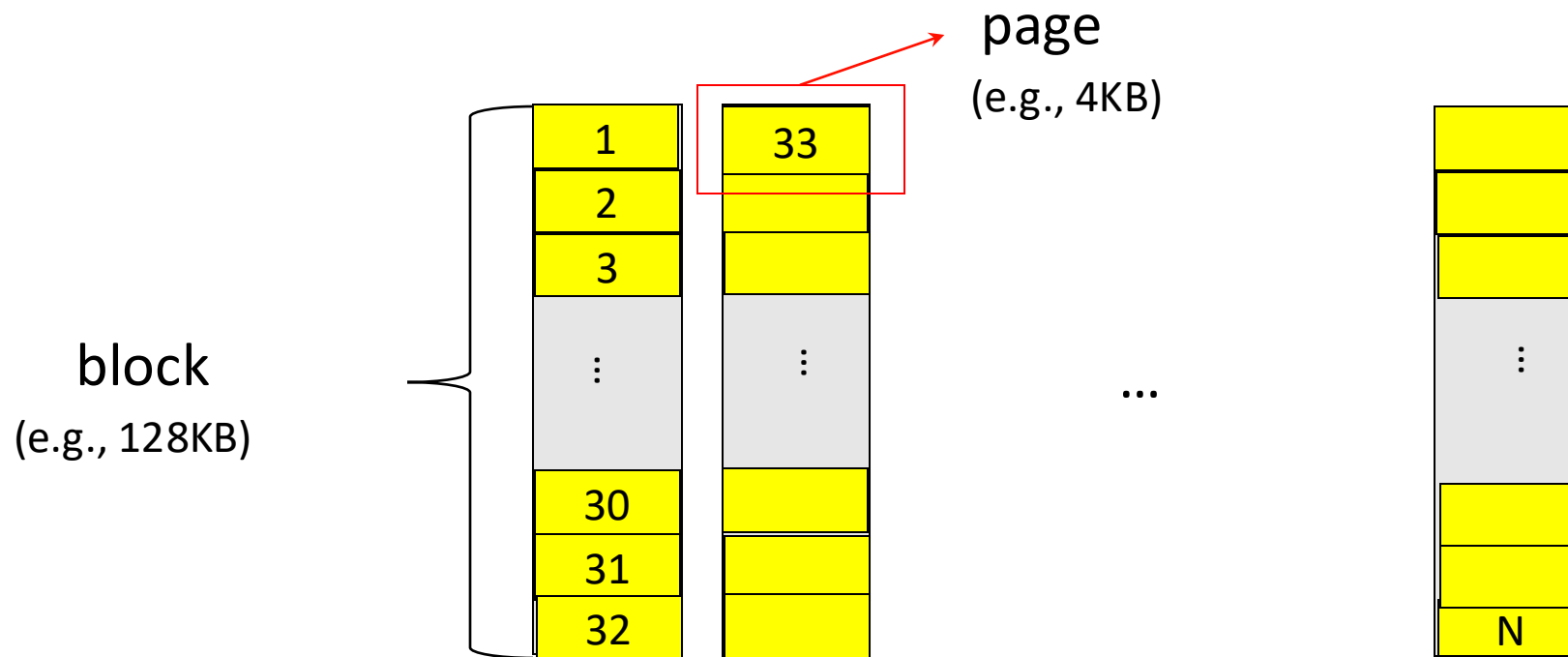
A Common Storage System of a Mobile Device



Flash Memory Security Research

NAND Flash is Usually Used as Storage Media

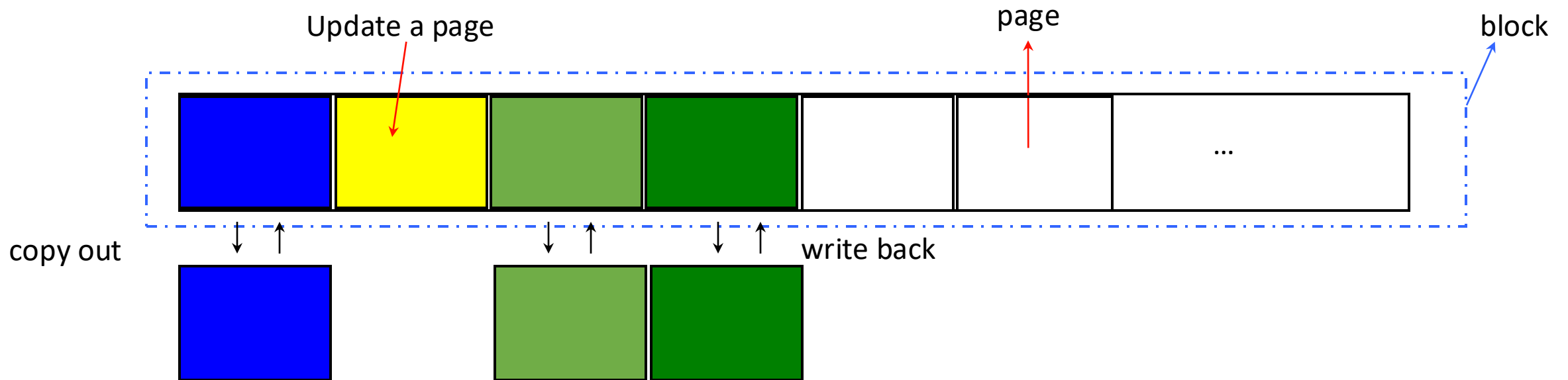
- NAND flash
 - USB sticks
 - Solid state drives (SSD)
 - SD/miniSD/microSD/eMMC



Special Characteristics of NAND Flash

- **Update unfriendly**

- Over-writing a page requires first erasing the entire block
- Write is performed in pages (e.g., 4KB), but erase is performed in blocks (e.g., 128KB)



- Over-write may cause significant **write amplification**

Special Characteristics of NAND Flash (cont.)

- Support **a finite number of program-erase (P/E) cycles**
 - Each flash block can only be programmed/erased for a limited number of times (e.g., 10K)
 - Data should be placed evenly across flash (**wear leveling**)

How to Manage NAND Flash

- Flash-specific file systems, which can handle the special characteristics of NAND flash
 - YAFFS/YAFFS2, UBIFS, F2FS, JFFS/JFFS2
 - Less popular

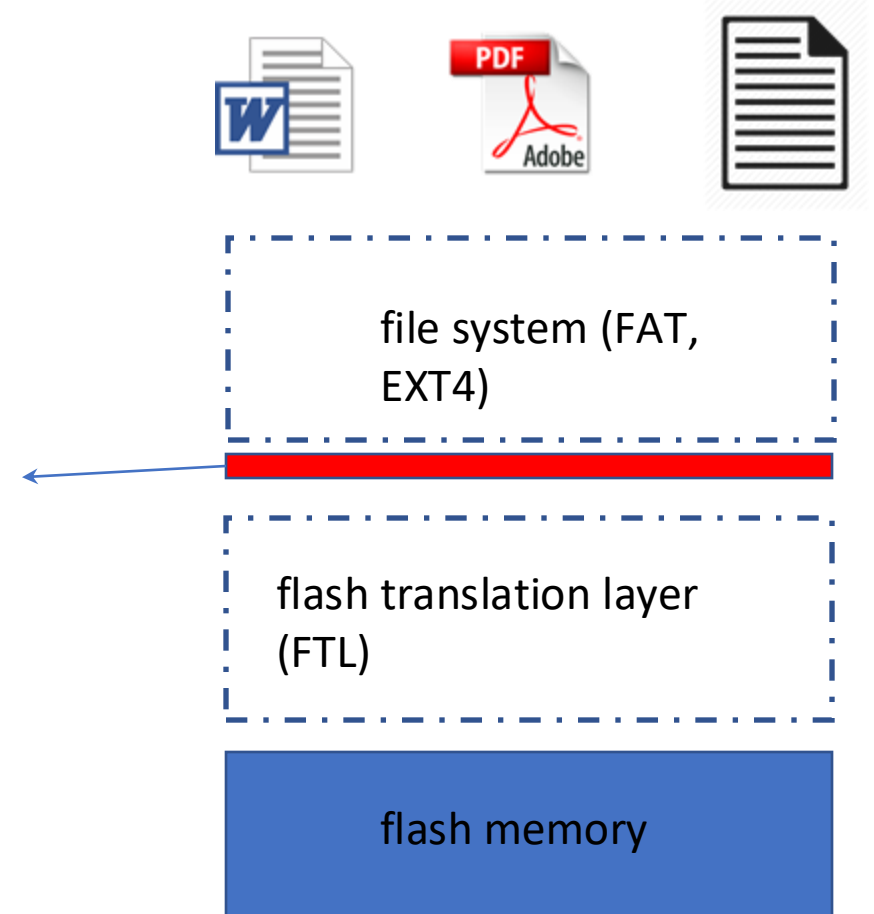


How to Manage NAND Flash (cont.)

- Flash translation layer (FTL) – a piece of flash firmware embedded into the flash storage device, which can handle the special characteristics of NAND flash and emulate the flash storage as a regular block device (**most popular**)
 - SSD
 - USB
 - SD

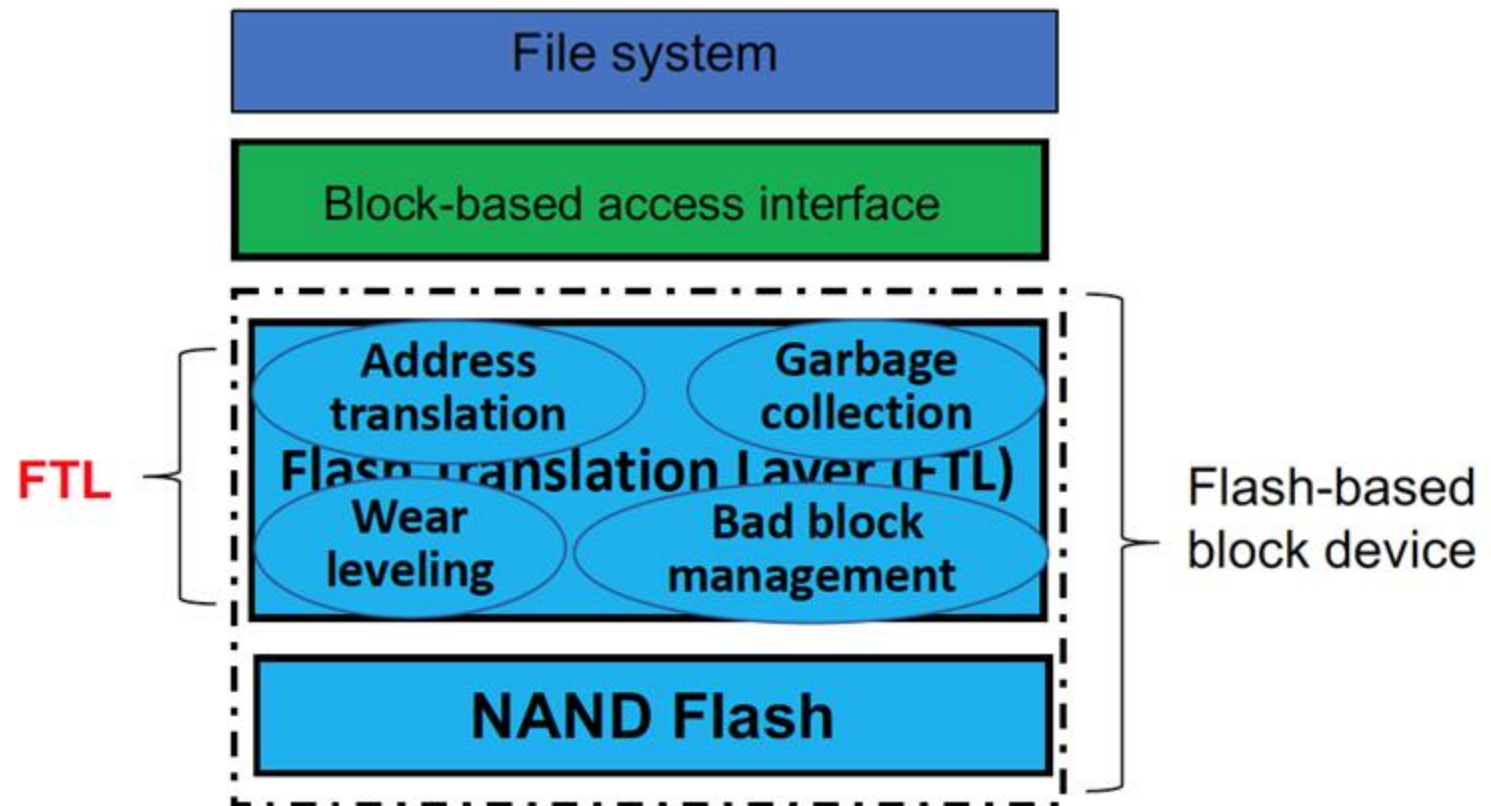


block device
interface:



Flash Translation Layer (FTL)

- FTL usually provides the following functionality:
 - Address translation
 - Garbage collection
 - Wear leveling
 - Bad block management

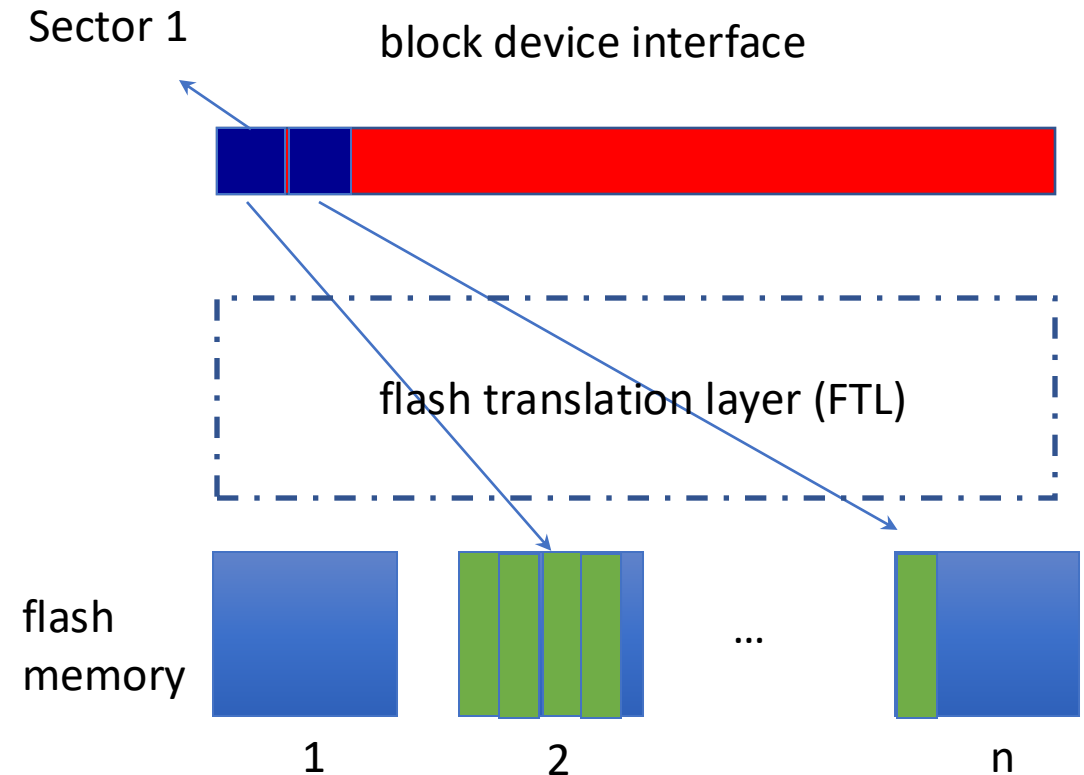


Flash Translation Layer (cont.)

FTL should maintain a mapping table

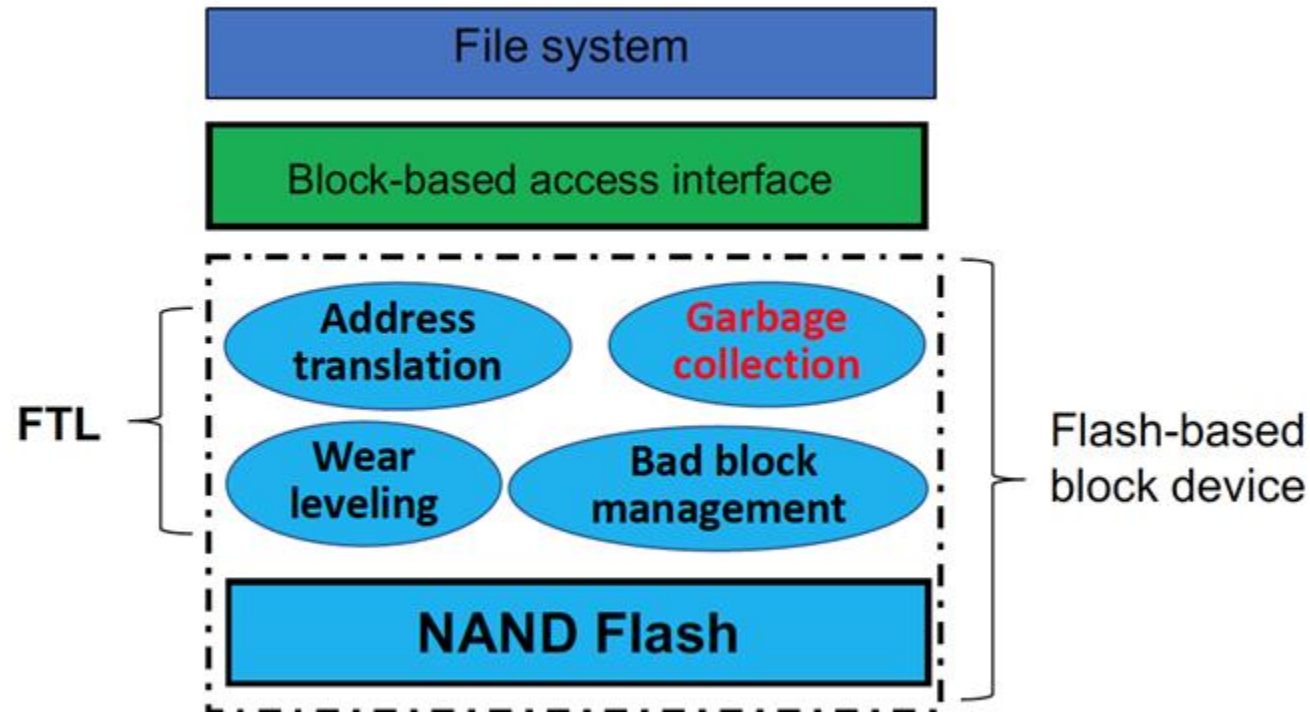
Block device location	Flash location
Sector 1	(2,3)
Sector 2	(n,1)

- Address translation
 - Translate address between block addresses and flash memory addresses
 - Need to keep track of mappings between Logical Block Address (LBA) and Physical Block Address (PBA)



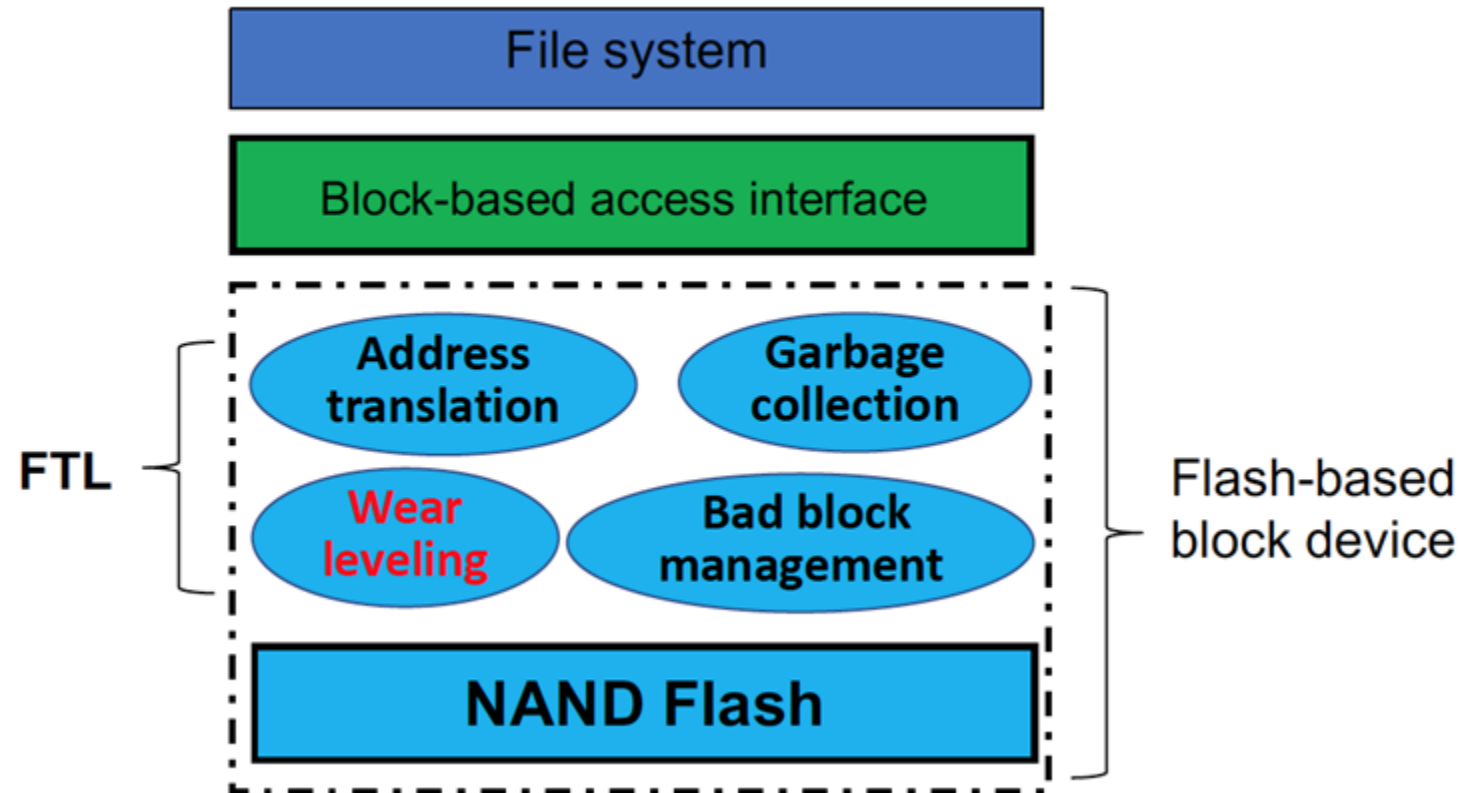
Flash Translation Layer (cont.)

- Garbage collection
 - Flash memory is update unfriendly
 - Not prefer in-place update, but prefer out-of-place update
 - The blocks storing obsolete data should be reclaimed periodically by garbage collection



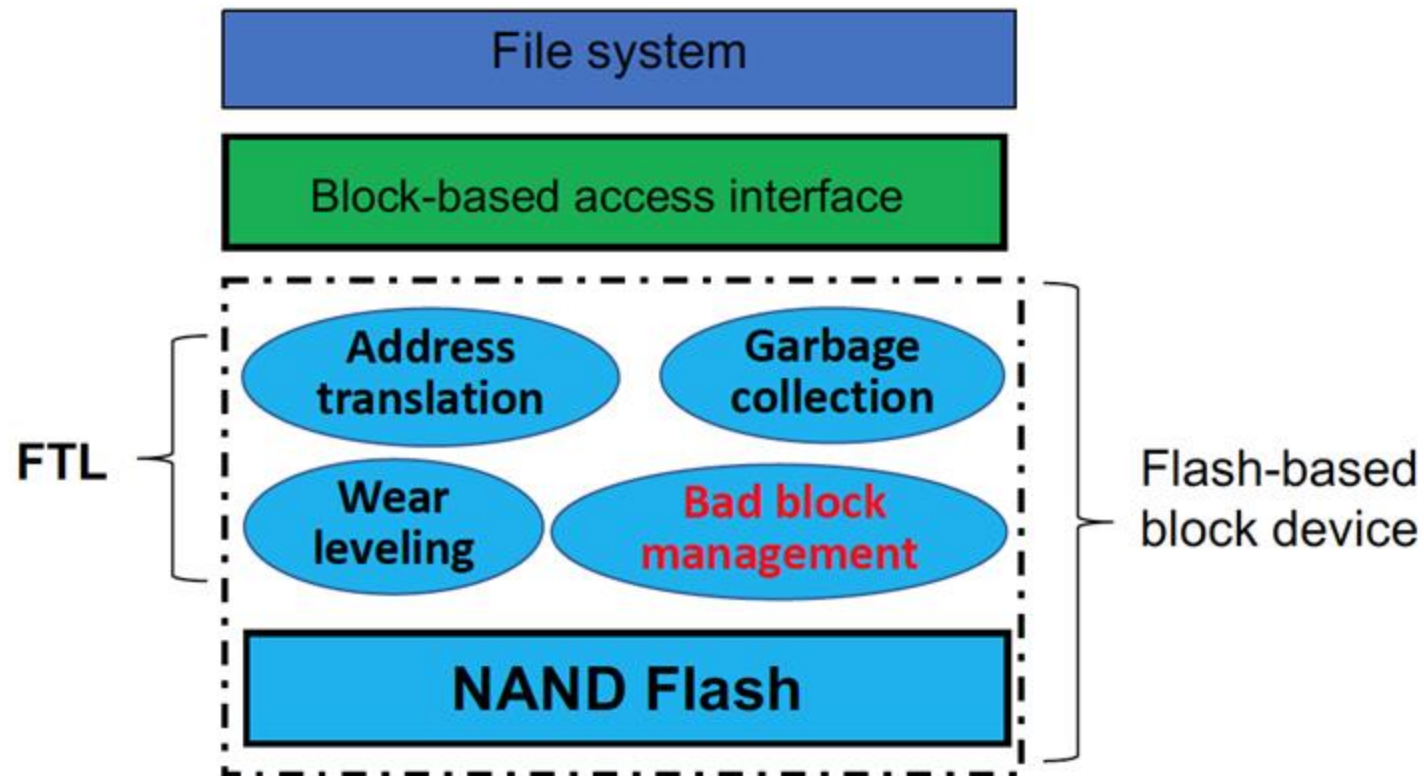
Flash Translation Layer (cont.)

- Wear leveling
 - Each flash block can be programmed/erased for a limited number of times
 - Distribute writes evenly across the flash to prolong its lifetime



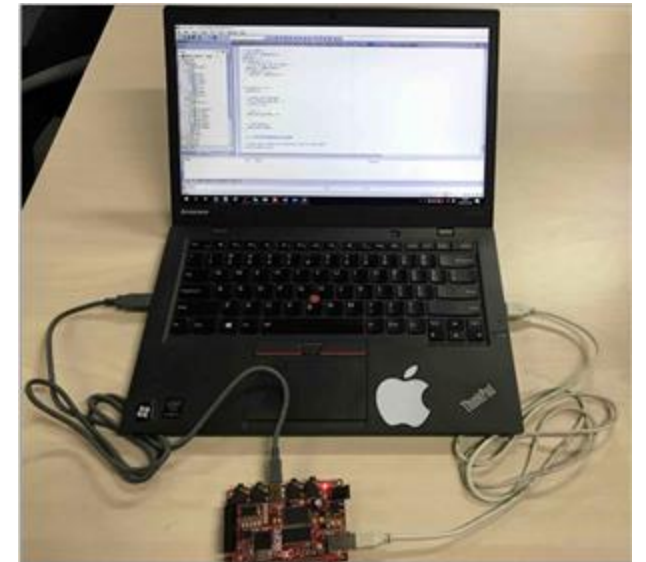
Flash Translation Layer (cont.)

- Bad block management
 - Regardless how good is the wear leveling, some flash blocks will eventually turn “bad” and cannot reliably store data
 - Bad block management is to manage these bad blocks

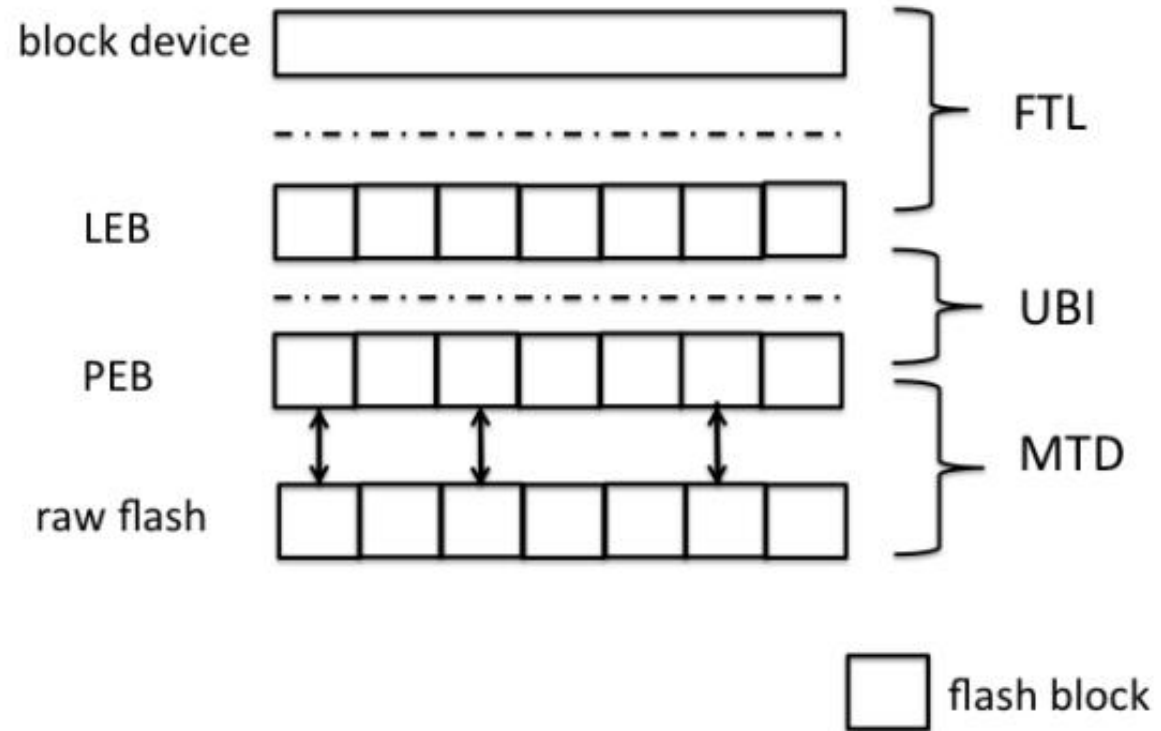


A Testbed for Flash Memory Security Research

- We have a flash memory testbed in MTU Security and Privacy (SnP) Lab. The lab is located in Rekhi 318
- The testbed includes:
 - Open-source flash firmware: OpenNFM
 - Implement flash translation layer (FTL) which is used to manage raw NAND flash, and provide a block access interface to upper layer
 - Embedded development environment: IAR Embedded Workbench
 - Electronic board: LPC-H3131



Opensource Flash Firmware OpenNFM



OpenNFM - MTD

- MTD: built on top of raw flash, and mainly provides three uniform APIs to allow the UBI to read, write and erase raw flash
 - MTD_Read(PEB index, offset, &data): read data from a PEB page identified by PEB index and offset
 - MTD_Write(PEB index, offset, data): write data to a PEB page identified by PEB index and offset
 - MTD_Erase(PEB index): erase the PEB identified by PEB index

OpenNFM - UBI

- UBI: built on top of MTD, and uses the APIs provided by MTD to read/write PEB pages or erase PEB blocks. Implement wear leveling, garbage collection, bad block management
 - UBI_Read(LEB index, offset, &data): read data from an LEB page identified by LEB index and offset
 - UBI_Write(LEB index, offset, data): write data to an LEB page identified by LEB index and offset
 - UBI_Erase(LEB index): erase an LEB identified by LEB index, which will cause an erasure over the corresponding PEB

OpenNFM - FTL

- FTL: build on top of UBI, and use the APIs provided by UBI to read/write LEB pages or erase LEBs. Implement address translation
 - FTL_Read(block_address, &data)
 - FTL_Write(block_address, data)

Hands-on Task 1 – Building A Flash Storage Device by Porting Open-source flash firmware to An Electronic Board

- Get familiar with the embedded development environment
- Play with the source code of flash firmware OpenNFM
- Port the OpenNFM to an electronic development board LPC-H3131

- Two-Three students in a group
- Each group will be provided with a desktop and an electronic development board (with cables)
- See the webpage <https://snp.cs.mtu.edu/outreach/wics2022.html> for the manual and video tutorial

Hands-on Task 2 – Integrating Disk Encryption into The Flash Translation Layer

- Conventional full disk encryption (FDE) is incorporated on the block layer to transparently ensure data confidentiality
 - BitLocker (Windows)
 - FileVault (MAC OS X)
 - Android FDE
 - TrueCrypt/VeraCrypt
- We will move the FDE from the block layer downwards to the flash memory layer (implement an symmetric encryption algorithm you like)
 - Write a flash page, encrypt it
 - Read a flash page, decrypt it using the same key
 - Encryption/Decryption is completely transparent to users
 - Test the throughput using benchmark tool fio, compare the throughput with original OpenNFM firmware

