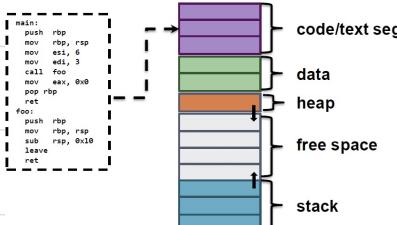
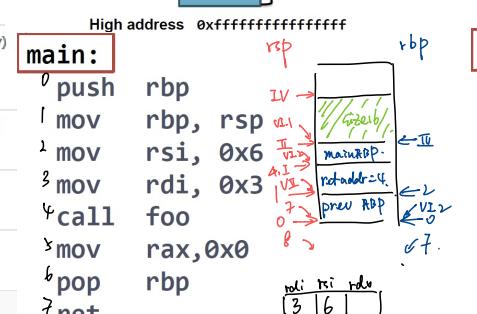
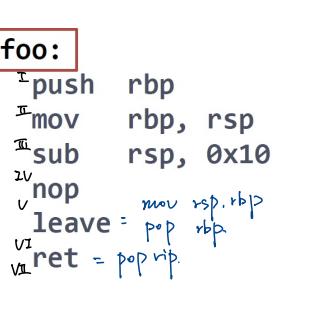


Encryption Scheme	Malleable	Length Extension	Padding Oracle	MITM Attack	Eavesdropping	Number of Keys	Authentication, access control policy, prevent impersonation attacks * Something you know (password) Something you have (2FA) Something you are (biometrics) Attack: online password guessing attack Defense: Lock after n guesses, limit attempts, CAPTCHAs, anomaly detection
Caesar Cipher	Y	N	N	Y	Y	1	As a user: <ul style="list-style-type: none">Never reuse passwords.Use a password manager and let it generate strong passwords for you whenever possible.Otherwise, \$ openssl rand -base64 15 and write it down As a developer: <ul style="list-style-type: none">Prefer outsourcing sign-on (e.g., Google/Facebook/Github OAuth) to requiring users to invent yet another password for your site.Avoid restrictive password complexity or rotation policies, which have been shown to do more harm than good.
Vigenère Cipher	Y	N	N	Y	Y	1	Attack: Password Breaches Defense: Use Password Hashes Attack: Offline Password Guessing Dictionary attack: Search corpus of previously leaked passwords and variants. Defense: Salted password hashes → Identical password have different salted hashes → Leaked database doesn't reveal passwords. Attack: Phishing attacks, spear-phishing, more sophisticated forgery methods for specific targets
One-Time Pad (OTP)	Y	N	N	Y	N (if key secure)	1 (Key length = message length)	Best Practice: Multi-Factor Authentication. ① distinct from pass Second Method must be: ② not just another pass. ③ not crackable from pass
Stream Cipher (e.g., RC4, ChaCha20)	Y	N	N	Y	N (if key secure)	1	One-time passwords counter based: OTP(c,k)=HMAC(k,c) time based: Use timestamp for c. SMS / phone calls → susceptible to phishing
ECB Mode	N	N	N	Y	N (if key secure)	1	Universal 2nd factor → cannot be phished. → limited support. PKX: return values. RBX, RCX, RDX, RDX: general use. RBP: Instruction Pointer RSP: Stack Pointer RBP: Frame/Base Ptr.
CBC Mode (MAC-then-Encrypt)	Y	N	Y	Y	N	2	Low address 0x0000000000000000
CBC Mode (Encrypt-and-MAC)	Y	N	Y	Y	N	2	
CBC Mode (Encrypt-then-MAC)	N	N	Y	N	N	2	
CTR Mode	Y	N	N	Y	N (if key secure)	1	
SHA-256 (Merkle-Damgård)	U	Y	N	U	U	0 (No key)	High address 0xffffffffffffffffff
RSA (Textbook)	Y	N	N	Y	N (if public keys verified)	2 (Public, Private)	
AES-GCM (AEAD)	N	N	N	N	N	1	
HMAC-SHA256	N	N	N	N	N	1	
Protocol/Mechanism	Stored XSS	Reflected XSS	SQL Injection	CSRF			
HTTPS	N	N	N	N			Attack: Buffer overflow. Defense: Data Execution Prevention.
CSP	Y	Y	U	U			Attack: Return to libc: return address = existing function. Defense: Extraneous function removal: remove functions not need.
SOP	N	N	U	U			Attack: Return Oriented Programming: use instructions (gadgets). Defense: ASLR: move around where code lives Defense: Stack Canaries: Protect the return address
SameSite Cookies	U	U	U	U			Attack: Buffer overflow (stack smashing)
CSRF Tokens	U	U	U	U			Attack: Integer Trapping: Integer overflow. Defense: Use stronger, signed/checked. Attack More: Find large enough n, signed/unsigned cast
Input Validation	Y	Y	Y	Y			* Vulnerabilities are hard to find by hand → automated testing Memory Analysis tool: Memory Leak!
Output Escaping	Y	Y	U	U			Static Analyzer tool: Dangerous patterns and practices Taint Analyzer tool: Trace values through the code Fuzzers: Brute force fuzzer Malware (malicious software)
Parameterized Queries	U	U	Y	U			is any software intentionally designed to surreptitiously run on client devices, servers, or networks and cause harm.
Protocol	Attack Type	Defense Capabilities	TCP	SYN Flooding	N		Spyware is malware that provides remote access to data and sensors available from the device.
IP (Internet Protocol)	Spoofing	N	TCP (with SYN Cookies)	SYN Flooding	Y		Adware is unwanted software that displays paid advertisements.
IP (Internet Protocol)	Plaintext Transmission	N	TLS	Eavesdropping	Y		Ransomware encrypts files on the device and demands payment to decrypt them.
IP (Internet Protocol)	Fragmentation and Reassembly Attacks	N	TLS	Data Modification (MITM)	Y		Cryptojacking malware uses the user's device to mine for cryptocurrency.
Ethernet (Link Layer)	Eavesdropping	N	UDP	Packet Injection	N		void vulnerable(char *filename)
Ethernet (Link Layer)	ARP Spoofing	N	BGP	BGP Hijacking	N		{
			RPKI	BGP Hijacking	Y		char buf[100];
WiFi (Physical Layer)	Eavesdropping	N	Firewall	Port Scanning	Y		read_input(buf, filename);
WiFi (Physical Layer)	Jammer	N	Firewall	Denial of Service	U		start_of_buffer = 0x7fffffff6df00
DNS	DNS Cache Poisoning	N	VPN	Eavesdropping	Y		int _main(int argc, char start_of_return_address =
DNS	DNS Hijacking	N	VPN	Data Modification (MITM)	Y		*argv[])
DNSSEC	DNS Cache Poisoning	Y	Zero Trust Security	Internal Network Breach	Y		{
DNSSEC	DNS Hijacking	Y	IDS/IPS	Signature-Based Attacks	Y		vulnerable(argv[1]);
DNS-over-TLS/HTTP	Eavesdropping	Y	IDS/IPS	Anomaly-Based Attacks	Y		return 0;
DNS-over-TLS/HTTP	DNS Cache Poisoning	N	IDS/IPS				payload += b"A" *

Principle of Complete Mediation

Every access to every object must be checked

for authority by a mediator.

- Primary underpinning of access control protection systems.
- Implies that a foolproof method of identifying the source of every request must be devised.
- Be careful of caching checks!
If change in authority occurs, cached results must be updated.
- Time-of-check, time-of-use vulnerabilities.

General isolation concept: Confinement

Key component: reference monitor

- Mediates requests from applications
Implements protection policy
Enforces isolation and confinement
- 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

Approach: UNIX chroot system call

chroot "jails": Simple isolation mechanism provided by UNIX kernel
Early use included guest accounts on FTP sites

To use: (must be root)

```
root@:/ # chroot /tmp/guest
root@:/# su guest
guest@:/ $ ./myapp
```

In this example, myapp is confined such that it can only access files within /tmp/guest for which guest has permission
open("/etc/passwd", "+r") actually opens /tmp/guest/etc/passwd

Application cannot access files outside of jail because it cannot even name them!

Approach: 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., SE Linux)
- Completely user space (e.g., program shepherding)
- Hybrid (e.g., Systrace)

Virtual Machine Security

VMM 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 VMM protect itself and is not buggy

- VMM is much simpler than full OS
... but device drivers run in Host OS

Approach: Physical Air Gap

Confinement: ensure misbehaving app cannot harm rest of system

Can be implemented at many levels:

Hardware: run application on isolated hardware (air gap)



Integrity

The outcome matches voter intent.

Votes are cast as intended.

Votes are counted as cast.

Ballot Secrecy

Weak form:

Nobody can figure out how you voted.

Strong form:

...even if you try to prove it to them.

Voter Authentication

Only authorized voters can cast votes,

and

each voter can only vote up to the permitted number of times.

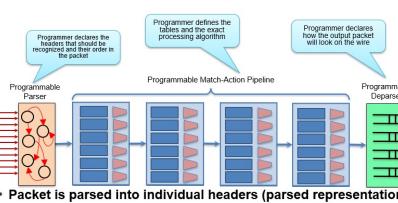
Enfranchisement

All authorized voters have the

opportunity to vote.

Network Security

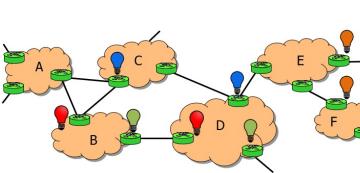
Programming Protocol-independent Packet Processors



- Packet is parsed into individual headers (parsed representation)
- Headers and intermediate results can be used for matching and actions
- Headers can be modified, added or removed
- Packet is deposed (serialized)

- Per-packet visibility
 - Can detect needle-in-a-haystack attacks
- Per-packet dynamicity
 - Can respond as fast as dynamic changing attack
- Scale-free defense
 - Naturally scales with network size and speed

Roadmap: The network as a defense fleet



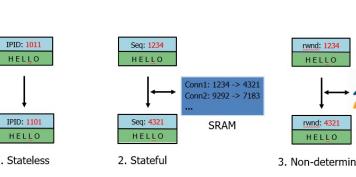
- Architect a wide range of defenses into network path
 - Networks mitigate attacks as they route traffic
 - Progress so far: Link flooding attacks (USENIX Sec'21)

Roadmap: The switch as a defense platform



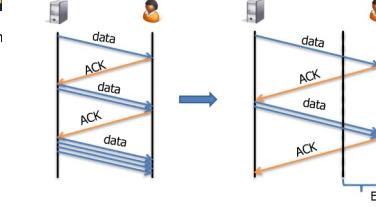
- Step 1: Design a range of switch-based security defenses
 - Switches dynamically activate the needed defenses
 - Progress so far:
 - Data exfiltration via covert channels (USENIX Sec'20)
 - Access control, RDMA security (USENIX Sec'20+22)..

Per-packet defense



- The P4 data plane performs per-packet defenses
 - Stateless: IPID, TTL, ...
 - Stateful: TCP sequence number, ACK, ...
 - Non-deterministic: receive window, timing channels..

Manipulating TCP congestion control

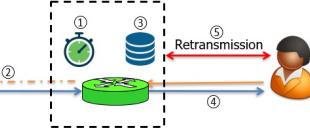


Consider the timing channel defense:

- Adding delay to packets disrupts TCP throughput
- ACK boosters:

- Optimistically ACK packets from the switch
- Create the illusion of the same RTT for the sender

ACK boosters



Creates the illusion of the same RTT despite extra delay

- (1) Measures (actual) RTT in data plane
- (2) Generates ACK optimistically to trigger more data
- (3) Caches extra packets for reliability
- (4)-(5) Serves the client from the cache

Similar as a "performance-enhancing TCP proxy"

- But accelerated in P4 hardware

Digital forensics is the process of preserving, identifying, extracting, documenting, and interpreting data in order to investigate past actions or obtain legal evidences. Used to investigate crimes, recover from attacks.

Four stages of forensic analysis:

1. Identification
2. Collection
3. Analysis
4. Reporting

The output of a forensic investigation is often a forensic report documenting the results of the analysis.

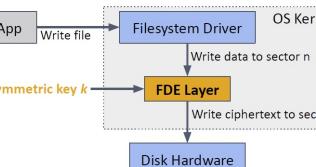
A well written report will:

- Accurately describe the details of an incident.
- Document the process the analyst followed.
- State the evidence that was uncovered.
- Draw conclusions founded on the evidence.
- State the level of confidence for each conclusion.
- Offer recommendations for further action when appropriate.
- Be understandable to decision makers.
- Be able to withstand legal scrutiny, when applicable.

Full-disk encryption (FDE)

protects data at rest by encrypting every sector of a storage partition using a secret key.

Threat model: Device is stolen or lost, attacker has physical access but **not** password/PIN.



Provided by most OSes: e.g. Windows BitLocker, MacOS FileVault, similar iOS and Android features

Complication: How to store the key?

Approach #1: Encrypt k with user-selected password or PIN p , applying a key derivation function (KDF): $E_{KDF(p)}(k)$.

Drawback: If boot partition is encrypted, OS can't start until user enters password. (GUI? Servers?)

Approach #2: Encrypt key using a trusted platform module (TPM), a tamper-resistant chip that measures boot-time code. TPM will only provide the key to OS if kernel is unmodified.

Kernel decrypts disk and boots OS, which applies user authentication and access control normally.

Drawback: Booting automatically loads key into RAM, where it's vulnerable to cold boot attacks.

Forensic Clues in Low-Level Data

Low-level filesystem layout often contain important forensic clues.

Create Blue File	I-Node Table	first data	more data			
Create Green File	I-Node Table	first data	last data	first data	last data	
Append to Blue File	I-Node Table	first data	more data	first data	last data	last data

Fragmentation shows some other data was there first.

Deleting file removes only the i-node! Residual data remains until overwritten by new files.

Delete Blue File	I-Node Table	first data	more data	first data	last data	
Create Red File	I-Node Table	data	more data	first data	last data	last data

All blocks of deleted file still fully intact.

Part of first block still recoverable in slack space.

Encryption

Encodes data so it can't be read without a key.

Obfuscation

Transforms code or binaries to conceal their purpose or mode of operation, while preserving their function.

```
if(t){var A=t.indexOf("v");o=1+A,ha=d2Q(t.substring(0,A));"click":e=Q(t,"click",p);if(t.getAttribute("type")=="checkbox"||t.getAttribute("type")=="radio")e.checked=t.checked;else p.click();}if(t){var A=t;var B=t.getAttribute("name");var C=t.getAttribute("id");var D=t.getAttribute("value");var E=t.getAttribute("label");var F=t.getAttribute("placeholder");var G=t.getAttribute("aria-label");var H=t.getAttribute("aria-labelledby");var I=t.getAttribute("aria-describedby");var J=t.getAttribute("aria-controls");var K=t.getAttribute("aria-owns");var L=t.getAttribute("aria-pressed");var M=t.getAttribute("aria-haspopup");var N=t.getAttribute("aria-expanded");var O=t.getAttribute("aria-autofocus");var P=t.getAttribute("aria-readonly");var Q=t.getAttribute("aria-multiline");var R=t.getAttribute("aria-multiline-count");var S=t.getAttribute("aria-readonly");var T=t.getAttribute("aria-integer");var U=t.getAttribute("aria-step");var V=t.getAttribute("aria-step-count");var 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